Heating and Fuel Consumption in the Terme del Foro at Ostia

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Abstract

This study examines how the heating systems of the ancient Roman baths operated and the amount of fuel needed to run them. The Terme del Foro (Forum Baths) at Ostia Antica are used as a case study, because they are structurally well-preserved, contain both typical and unusual architectural elements in their design, and were one of the most important bathing facilities in the Roman city. By using an interdisciplinary approach that synthesizes archaeological data, ancient literary sources, comparative visual and physical evidence, modern experimental calculations, and heat transfer equations, a more complete picture of Roman baths is created. In this way, the reliability of the results is greatly expanded by minimizing unnecessary assumptions. This study also presents the archaeological history of bathing and a summary of bath research, and it provides a structural examination of the Terme del Foro.

A database program has been created to store all of the physical data collected from the site and to process measurements through heat transfer equations. In this way, simple mistakes are avoided, all calculations are performed consistently, and results are produced instantaneously. Moreover, small permutations can be made to the initial base study design to illustrate how changes in temperature, time of year, hour of the day, and structural modifications affected fuel consumption.

Once the necessary quantity of fuel for heating the Terme del Foro to the proper temperatures is determined, the greater implications of these results are examined. By computing the total weight and the total volume of space that the necessary wood

occupied, the number of trees that had to be harvested, the number of carts needed to transport the fuel to the city, the ease of moving the wood through the city, and the necessary storage space for a month's supply of fuel is ascertained. Questions of deforestation are addressed, and it is concluded that the Terme del Foro did not create a heavy burden on the neighboring forestland. Instead, the operation of the baths was efficient enough that fewer than 150 trees had to be harvested to fuel the baths for an entire year.

I would like to dedicate this dissertation to my parents, George and Licia Miliaresis, for all of their support and love. I could never have made my dreams come true without you!

Ithaka by Konstantinos Cavafis

Σὰ βγεῖς στὸν πηγαιμὸ γιὰ τὴν Ἰθάκη,
νὰ εὔχεσαι νά ῾ναι μακρὺς ὁ δρόμος,
γεμάτος περιπέτειες, γεμάτος γνώσεις.
Τοὺς Λαιστρυγόνας καὶ τοὺς Κύκλωπας,
τὸν θυμωμένο Ποσειδῶνα μὴ φοβᾶσαι,
τέτοια στὸν δρόμο σου ποτέ σου δὲν θὰ βρεις,
ἂν μέν᾽ ἡ σκέψις σου ὑψηλή, ἂν ἐκλεκτὴ
συγκίνησις τὸ πνεῦμα καὶ τὸ σῶμα σου ἀγγίζει.
Τοὺς Λαιστρυγόνας καὶ τοὺς Κύκλωπας,
τὸν ἄγριο Ποσειδῶνα δὲν θὰ συναντήσεις,
ἂν δὲν τοὺς κουβανεῖς μὲς στὴν ψυχή σου,
ἂν ἡ ψυχή σου δὲν τοὺς στήνει ἐμπρός σου.

Νὰ εὔχεσαι νά ῾ναι μακρὺς ὁ δρόμος.
Πολλὰ τὰ καλοκαιρινὰ πρωινὰ νὰ εἶναι
ποῦ μὲ τί εὐχαρίστηση, μὲ τί χαρὰ
θὰ μπαίνεις σὲ λιμένας πρωτοειδωμένους.
Νὰ σταματήσεις σ᾽ ἐμπορεῖα Φοινικικά,
καὶ τὲς καλὲς πραγμάτειες ν᾽ ἀποκτήσεις,
σεντέφια καὶ κοράλλια, κεχριμπάρια κ᾽ ἔβενους,
καὶ ἡδονικὰ μυρωδικὰ κάθε λογῆς,
ὅσο μπορεῖς πιὸ ἄφθονα ἡδονικὰ μυρωδικά.
Σὲ πόλεις Αἰγυπτιακὲς πολλὲς νὰ πᾷς,
νὰ μάθεις καὶ νὰ μάθεις ἀπ᾽ τοὺς σπουδασμένους.

Πάντα στὸ νοῦ σου νά ῾χεις τὴν Ἰθάκη.
Τὸ φθάσιμον ἐκεῖ εἶν᾽ ὁ προορισμός σου.
Ἀλλὰ μὴ βιάζεις τὸ ταξίδι διόλου.
Καλλίτερα χρόνια πολλὰ νὰ διαρκέσει.
Καὶ γέρος πιὰ ν᾽ ἀράξεις στὸ νησί,
πλούσιος μὲ ὅσα κέρδισες στὸν δρόμο,
μὴ προσδοκώντας πλούτη νὰ σὲ δώσει ἡ Ἰθάκη.

Ἡ Ἰθάκη σ᾽ ἔδωσε τ᾽ ὡραῖο ταξίδι.
Χωρὶς αὐτὴν δὲν θά ῾βγαινες στὸν δρόμο.
Ἄλλα δὲν ἔχει νὰ σὲ δώσει πιά.

Κι ἂν πτωχικὴ τὴν βρεῖς, ἡ Ἰθάκη δὲν σὲ γέλασε.
Ἔτσι σοφὸς ποὺ ἔγινες, μὲ τόση πεῖρα,
ἤδη θὰ τὸ κατάλαβες οἱ Ἰθάκες τὶ σημαίνουν.

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(All Photographs are Taken by and All Plans are Drawn
by Ismini Miliaresis, Unless Otherwise Noted)
(All Rooms Described are in the Terme del Foro, Unless Otherwise Noted)

Introduction

The public baths provide a window into many aspects the ancient Roman world. For an individual in the Roman empire a trip to the public baths was an essential element of quotidian life. Public bathing complexes were elaborate venues for cleansing, exercising, and relaxing. These baths became nuclei of Roman culture and socialization, and they stood as integral symbols of their highly advanced civilization. As such, bathing facilities left significant imprints on both the urban and the rural landscape surrounding them. Baths offer valuable insights into Roman architecture, construction practices, social stratification, and the relationship that the ancient Romans had with their environment. Many Roman baths throughout the empire are well preserved, thus all of these aspects can be examined in situ.

By focusing on one specific bathing complex, the Terme del Foro (Forum Baths) at Ostia Antica for the current study, a more in-depth understanding of each of these topics is gained. Roman baths were places of technological innovation from their outset. The system that was developed to heat them used an ingenious method of radiant heating to maintain uniform temperatures throughout even the largest structures. The goal of this study is to understand more fully Roman heating systems and engineering practices in order to illustrate the internal workings of Roman baths and to assess their impact on their surroundings. This objective is accomplished primarily through the computation of fuel volumes needed to operate a Roman bath, in particular, the Terme del Foro at Ostia. As a result of its novel approach, a technological study of unprecedented accuracy has been produced. By way of introduction, however it is important to provide some background about bathing practices in ancient Roman culture, the origins of heating technology, the city of Ostia itself, and its baths.

I. Early Roman Bathing

Public bathing on a grand scale was a practice developed by the Romans, who were likely influenced by the Greek *gymnasia*.[1] The institution became popular in the fourth or third century BC, and by the last few decades of the third century BC the use of public baths began to spread throughout the Roman world. Previously, Romans bathed with basins or buckets in a small dark room adjacent to the kitchen, called a *lavatrina*. This room, very commonly found in Roman farm villas, conveniently took advantage of the heat generated by cooking, and the stove was used to heat water for washing. As public baths were constructed, the use of the *lavatrina* gradually declined and the presence of private bathing facilities within homes became an opulence reserved for the wealthy.[2] Even those with such private conveniences often frequented the public bathing

[1] After coating their bodies with oil and dust to wrestle, box, lift weights or take part in other training activities, the athletes in the *gymnasion* scraped their bodies with a curved metal instrument called a strigil. Then, they rinsed themselves with cold water from a basin or a hip-bath. Hip-baths were half-sized tubs that an individual could sit in while splashing water over themselves. Meiggs 1973, 404; Nielsen 1990, 9; Yegül 1992, 7, 21, 24; Lawrence 1996, 198; Malacrino 2010, 176; Yegül 2010, 16, 43.

[2] Seneca (*Ep*. 86.12) makes it clear that bathing every day was not a common practice before his time. (All abbreviations of ancient sources are based on those used in the Oxford Classical Dictionary.) Romans only washed their arms and legs, as these were the parts of the body that became dirty. They bathed their full bodies only once a week. According to Giuseppina Pisani Sartorio (1999, 16), Romans in the Republican period only bathed every eight days. Meiggs 1973, 404; 1982, 257-8; Brando and Guarguaglini 1987, 66; Pasquinucci 1987a, 17; Nielsen 1990, 13; Yegül 1992, 50, 55, 377; Ling 2005, 128; Yegül 2010, 46.

establishments for social and political purposes.[3] In fact, a daily trip to the baths became a favorite past time of men and women of almost all classes of society.

With the advent of public bathing facilities, the Romans were no longer confined to rinsing in small, cold rooms. Instead, the public baths were arranged so that their patrons would be led through rooms of varying temperatures and purposes. Patrons usually began in a changing room, or *apodyterium*, which often contained niches in the walls for storing clothes and belongings. Then the warm room, or *tepidarium*, was passed through to help the body of the bather adjust. The next room approached was the hot room, or *caldarium*, where customers could sit and enjoy the heat or immerse themselves in heated pools.[4] The final room that was entered was the cold room, or *frigidarium*, where a cold plunge into a pool would close the pores of bathers and reinvigorate them.

Additional rooms were sometimes included in bathing facilities, such as the dry sauna, or *laconicum*; the steam room, or *sudatorium*; and the sunbathing room, or *heliocaminus*.[5] Larger baths were often flanked by an open area for exercising or strolling outside, called the *palestra*.[6] The *palestra* likely originated from the earlier Greek gymnasium space where athletes trained. The space was usually rectangular and

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[3] Pliny (*Ep*. 2.17.26) describes another scenario that would have made frequenting public baths desirable, even when baths in one's own home were available: when someone arrived on too short a notice or was staying for too short a time to warrant heating up the private baths. Meiggs 1982, 258; Pasquinucci 1987a, 17.

[4] Admission to the public baths was a nominal fee. Yegül 1992, 43.

[5] Inge Nielsen (1990, 3) defines a *laconicum* as a dry sweat room heated by hot stones or an open fire, and a *sudatorium* as a sweat room heated by a hypocaust.

[6] Nielsen (1990, 3) states that the presence or lack of a *palestra* is the determining factor in whether a bath should be considered a *thermae* or a *balneum*. This conclusion is far too generalizing, however, as it ignores many other factors such as size, ownership, and type of clientele frequenting the bath. *Balnea* were usually smaller facilities that were often private or reserved for particular groups, while *thermae* were usually large public complexes with many amenities and added luxuries. In fact, Yegül (1992, 43) points out that, "*Thermae* were, almost without exception, owned by the state, or the city; they occupied large areas, sometimes several city blocks, and often, as in Rome, they stood free in the middle of an open, park-like precinct."

surrounded by a peristyle.[7] Outdoor swimming pools, or *natatio*, were commonly found in this zone as well.[8]

The way in which a bather moved through a bath depended on the organization of these rooms.[9] The Terme del Foro (I.XII,6) at Ostia, the focus of the current study, is an example of a bath with an annular layout, meaning that the baths were planned in a circular fashion. Almost all the other baths at Ostia were of the single-axis row type.[10] Some baths were equipped with two separate sections, each containing roughly the same amenities and sharing the central heating systems, as recommended by Vitruvius.[11] These two wings usually had different entrances, allowing men and women to bathe at the same time without interacting.[12] None of the baths at Ostia were equipped with a configuration

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[7] The Stabian Baths at Pompeii (VII.I,8), the Suburban Baths at Herculaneum, and the Terme di Nettuno (II.IV,2) at Ostia all contain large *palestra* spaces as part of their complexes. The *palestra* of the Suburban Baths at Herculaneum is located on a terrace. Pappalardo 1999, 231.

[8] *Palestrae* with an outdoor *natatio* can be seen in the Stabian Baths at Pompeii, the Terme di Nettuno at Ostia, and the Hellenistic bath complex at Pella. Lilimpaki-Akamati 2002, 85.

[9] Some baths, the "row" type, contained rooms that were arranged in a line, and they required the bather to double back on the same path whence they came in order to exit. The Stabian Baths at Pompeii are an example of the row type. In fact, these baths may have served as the model for this kind of arrangement. The "imperial" type was essentially annular, in the sense that a bather did not have to retrace the same path, but was more complex: the structure was laid out in a symmetrical way, with identical rooms on both sides of the main bathing block. The bather could select either side to move through the chambers, but the same *tepidarium*, *frigidarium*, and *caldarium* had to be used by everyone. The large complexes at Rome, including the Baths of Titus, Trajan, and Caracalla were all of the imperial type. Krencker 1929, 177-9, 180; Menchelli 1987, 83; Nielsen 1990, 4; Yegül 1992, 3; Farrington 1995, xixx; Yegül 2010, 54.

[10] The Terme di Porta Marina (IV.X,1-2) are another example of the annular type. Yegül (1992, 81) includes both the Terme del Foro and the Terme della Porta Marina at Ostia in his "intermediary" type of bathing structures, because one portion of each facility follows the single-axis Pompeian plan (similar to the Stabian Baths), and the other follows the fully symmetrical imperial type. He mentions that these designations are not temporally based, but that they are a useful classification method. Yegül (1992, 83) also points out that these "intermediary" type of bathing complexes were very practical and more economical in highly developed urban centers. For more information on the architectural origins and layouts of the baths, see Yegül 1992. Cicerchia and Marinucci 1992, 20; Poccardi 2001, 164, 167.

[11] Examples of such divided baths include the Stabian Baths and Forum Baths (VII.V,24) at Pompeii, the Forum Baths at Herculaneum, the baths at Fregellae, and the Flavian baths at Gisacum located in Normandy. Vitr. *De Arch.* 5.10.1; Kraus 1973, 32; Menchelli 1987, 83; Yegül 1992, 74; Cantarella and Jacobelli 2003, 98; Tsiolis 2003, 94, 103; Yegül 2010, 32, 54.

[12] Some intermixing must have been taking place, since Hadrian passed a law banning men and women from bathing together. Although this law was upheld by the Antonines, Elagabalus repealed it. The law

to suggest separate bathing sectors for men and women.[13] Men and women would have either been segregated into completely distinct structures, or they would have bathed at different times.[14]

As public baths continued to grow in importance, their opulence and size reflected their popularity. New services were continuously added in the facilities, including massages, hair removal, and even dentistry.[15] Moreover, elaborate lecture halls and libraries were introduced into the space. The purpose of public baths was no longer confined to cleansing the body. Instead the baths became social centers of comfort, relaxation, networking, and entertainment. At the heart of all these elaborate bathing complexes, however, remained the heated bathing rooms.

II. Origins of Heating Technology in Baths

The origin of the heating technology used in the Roman baths has been widely debated among scholars in the past. Some of the controversy can be attributed to the fact

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banning men and women from bathing together was essentially reinstated by Alexander Severus, when he forbade the maintenance of baths that allowed the sexes to bathe together. *Hist. Aug. Hadr*. 18.10-1; *Marc. Ant*. 23.8; *Sev*. 24.2; Meiggs 1973, 406; Heinz 1983, 149; Pisani Sartorio 1999, 15-6; Yegül 2010, 33.

[13] A large number of bone *forcelline* were found in the Terme del Foro at Ostia, according to Raissa Calza and Ernest Nash (1959, 58). These implements were used by Roman matrons to tie up their hair, indicating with certainty that women used these baths. Their proximity to the forum and their opulence suggest with little doubt that men must have frequented this facility as well, and that it was not exclusive to women. Meiggs 1973, 406.

[14] The great imperial Thermae of Rome contained two symmetrical sections, but the shared spaces in these establishments makes it less likely that they could serve men and women at the same times of the day. Yegül (1992, 133) suggests, instead, that the symmetrical arrangement of these immense edifices may have allowed parts of the complex to be shut down for routine maintenance. He also posits that half of the bath could have been closed in less busy seasons to conserve fuel and funds. In fact, some ancient sources refer to "summer" and "winter" baths, suggesting some baths were even designed exclusively for certain seasons. Winter baths seem to have contained fewer pools, consuming less water. A lack of water seems to have convinced Aurelian to construct a public bath specifically for the winter in the Transtiberine region. *Hist. Aug. Aurel*. 45.2; Faventinus *Artis architectonicae privatis usibus adbreviatus liber* 16.4; Nielsen 1990, 138-40.

[15] Yegül 1992, 38-9.

that the baths and their heating systems were widely influenced by both the ancient Mediterranean and ancient north-western European civilizations.[16] The most contested topic is the hypocaust floor heating system, whose technical aspects are discussed in more detail below. This invention revolutionized the whole practice of bathing, thus understanding how it developed is valuable in forming a complete picture of the daily tradition. The debate is mostly centered on whether the original concept for the hypocaust was Greek or Roman.[17] The "true" hypocaust is described as a method of evenly spacing small pillars to support the floor of a room to be heated, allowing heated air to circulate below.

Some of the confusion fueling this origin debate was caused by Pliny the Elder. He attributed the invention of the hypocaust system to a man named Gaius Sergius Orata around 80 BC.[18] Orata was described as having formulated the idea in order to raise oysters and fish in artificial ponds for resale.[19] Although Inge Nielsen and some other scholars continue to recognize Pliny's claim, it is no longer widely accepted in the field.[20]

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[16] Yegül 1992, 48.

[17] Difficulty arises when primitive forms of the hypocaust, such as simple sub-floor channels, are included in the discussion. In fact, such channel systems were attempted throughout the Mediterranean as early as the fifth century BC, and they continued to be used in England and Central Europe into the imperial period. An early example can be seen in the baths at Gela in Sicily, dated between 310 and 280 BC, which were heated by a system of interconnected channels under the floor. A later example can be seen in the first phase of Gallo-Romanic baths at Fontaines-Salees in the Burgundy region of France, which are dated to the end of the first century AD. Yegül 1992, 48, 357, 361; 2010, 82.

[18] Plin. *NH* 9.79.

[19] He used the hypocaust to heat the oyster beds and maintain the ponds at the proper temperature. Orata's enterprise was conducted near Puteoli (Pozzuoli) and Lago Lucrino, a highly seismic area near Naples, where hot steam naturally erupts from fissures in the ground. For some time, scholars including Fritz Kretschmer (1961, 10), Ren Cagnat and Victor Chapot (1916, 219), assigned Orata credit for the invention of the hypocaust, finding it likely that he was inspired by the geothermal sources in the vicinity. Orata was also credited with dabbling in the real estate market and selling villas that were equipped with a hypocaust heating device. Cagnat and Chapot 1916, 219; Kretschmer 1961, 10; Jorio 1981-1982, 172; Brödner 1983, 23; Pasquinucci 1987a, 91; Yegül 1992, 48, 379.

[20] Nielsen (1985, 81-112) was particularly determined to disprove the theories of Hans Eschebach (1979, 38-9, 40-1) and Erika Brödner (1983, 23), and maintain that Orata was the inventor of the hypocaust. Both

In fact, evidence from the archaeological record clearly refutes the assertion.[21] Hans Eschebach determined that a "true" hypocaust system was in operation as early as the second half of the second century BC at Pompeii.[22] Moreover, according to Yegül, hypocausts were probably already widely utilized throughout Italy by the end of the first century BC when Vitruvius wrote about them.[23] In the baths at Olympia in Greece, a hypocaust was already in use from sometime around 100 BC.[24]

Determining if the system in Stabian Baths or the system at Olympia is older is problematic, particularly since the dating of the Olympia baths is somewhat contentious.[25] Furthermore, the debates on Sergius Orata and on whether Pompeii or Olympia had the older hypocaust were rendered completely irrelevant when a bath was

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Eschebach and Brödner found that the evidence in the archaeological record was enough to disprove the ancient sources. Nielsen (1990, 6) supports a fully Greek inspiration for public bathing, stating that, "The local forerunners in Italy can hardly have been of much importance." At the same time, Nielsen (1985, 89-90; 1990, 21-2) assigns all of the credit for the invention of the hypocaust system to an Italian source. She finds the dating of the Stabian Baths and the baths at Olympia problematic, saying that they are likely later than what is commonly accepted. In fact, Nielsen dates the final phase of the baths at Olympia to the second half of the first century BC. She does not mention the presence of the early hypocaust in the Stabian Baths at Pompeii, which predates Orata. Yegül (1992, 48) is opposed to such one-sided arguments, finding it more likely that the inspiration for the invention had several sources. Nielsen 1985, 81-112; Pisani Sartorio 1999, 11.

[21] Garrett G. Fagan (1999, 99) suggests that Asclepiades, who lived between the end of the second and the beginning of the first centuries BC, may have been the first person to apply the use of the hypocaust system to baths. Archaeological evidence suggests that the heating method also predated Asclepiades, however. Brödner 1983, 23; Connolly and Dodge 1998, 243.

[22] The hypocaust was being used to heat both the men's and the women's *caldaria*, and the men's *tepidarium* in the Stabian Baths. The original structure of the Stabian Baths dates to the fourth century BC, although the hypocaust is part of a later refurbishment. Some scholars, including Eschebach (1979, 38-9, 40-1), think it is possible that the Stabian Baths date as far back as the end of the 5th century BC, but other scholars, such as Yegül (1992, 48, 357, 375, 379, 434 n. 19; 2010, 84), find the evidence for this early date insufficient.

[23] The more probable scenario is that Orata adapted the hypocaust technology that he had seen in the baths (perhaps at Baiae) to suit his needs. He may have even advanced the technology in some way, although there is no way to be sure. Yegül 1992, 48; 2010, 86.

[24] This system was installed in the final phase of these baths, along with other elaborations and expansions. Yegül 1992, 357, 377, 379; 2010, 84-5.

[25] Nielsen (1990, 21-2) is adamant about an Italian origin for the hypocaust system. Lombardi and Corazza (1995, 30) state that the heating systems of the baths were a Greek invention. Yegül 1992, 467 n. 60.

excavated at Fregellae between 1996 and 2002.[26] Fregellae was a Samnite town originally founded in 328 BC along the via Latina in Latium. The inhabitants were massacred in the Samnite Wars in 320 BC, and the city was re-founded in 313 BC. The Samnites rebelled against Rome in 125 BC, and the city was definitively destroyed.[27] The history of the town is significant because it illustrates that this bath operated only between 320 and 125 BC. These dates both precede the accepted construction dates of the hypocausts of Pompeii and Olympia, and they make the baths at Fregellae "one of the earliest and technically advanced baths known to archaeology", according to Yegül.[28] The bath, located close to the forum along the Decumanus, remarkably is equipped with both a "true" hypocaust and a wall heating system in its second phase.[29] *Tubuli* were originally thought to have been invented in the first century AD; the complex at Fregellae, therefore, sets back the invention of the whole Roman bath heating system by a century.[30] The Terme del Foro at Ostia exclusively employs *tubuli* for its wall heating

[26] The bath covers an area of 48 by 22 meters (or 53 by 22 meters, according to Filippo Coarelli (2004, 73)), and it had separate sections for men and women. The southern section contains the monumental entranceway and the bathing suite, while the northern section contains the service quarters and a space adorned with columns. The presence of the bath was already attested to in 1987, when a small bone *tessera* referring to a bath was uncovered at the site. The *tessera* was probably an entrance token, according to Coarelli. Tsiolis 2003, 85-6, 88, 94; Coarelli 2004, 73; Vincenti 2008, 407.

[27] Tsiolis 2003, 86; Coarelli 2004, 73; Vincenti 2008, 407.

[28] The first phase, which Vasilis Tsiolis dates to the third century BC, has not been sufficiently excavated to understand its heating system thoroughly. One feature from the first phase that has been uncovered is a long pool in the northern sector above a conduit. The conduit was likely a channel for heated air. The polychrome pavements and other material remains illustrate that the quality was already high in the baths at this time, but a great deal of spoliation occurred for the construction of the second phase bath directly on top. The second phase of the bathing establishment is homogenous and has been dated to the first half of the second century BC by Tsiolis, and more precisely to between 185 and 150 BC by Valentina Vincenti (2008, 411). Tsiolis 2003, 88; Coarelli 2004, 74; Yegül 2010, 54.

[29] The wall heating system has been identified by Tsiolis as a series of cylindrical tubes arranged side by side against the wall in a manner very similar to *tubuli*. Tsiolis 2003, 105; Yegül 2010, 55.

[30] The pillars of the hypocaust are extant to a height of 0.35 meters, but were likely taller before the abandonment of the site. Evidence suggests that there were originally five rows of pillars on both sides. The baths also contain a large furnace with two adjacent round spaces for heating water in boilers. A service area was provided behind the furnace, and a great deal of ash and burned soil still covers the site.

system, thus knowing their origin is relevant.[31]

III. The City of Ostia

Ancient Ostia is distinctive in its level of preservation, in its proximity to Rome (approximately 15 miles southwest of Rome), and in its very close political, economic, and social relationship to the city of Rome, as Rome's harbor. The site provides insights into the relationship of Roman baths with the urban layout, both in general, and within the context of an individual Roman colony over time. In addition, Ostia provides a view of what Rome itself probably looked like, particularly in the second century AD.[32]

III.a. The Development of Ostia

As Russel Meiggs states, "Ostia is not another Pompeii; the two towns differed radically in history and character. Pompeii had already had a long life before she felt the impact of Rome." Pompeii reflects the first century AD, while Ostia largely reflects the second century AD.[33] The town was said to have been founded by Aeneas and built by Ancus Marcius, the fourth king of Rome, both as a military outpost and as an access point

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According to an onsite discussion between Vasilis Tsiolis and Fikret Yegül in 2011, a large amphora within the space may have been present to collect and store ashes. Ashes were used in the production of cleaning agents, particularly in the laundries, as described by Lombardi and Corazza (1995, 31). Connolly and Dodge 1998, 244; Tsiolis 2003, 91, 105; Coarelli 2004, 74.

[31] *Tubuli* are discussed in Chapter 2, 60-2, 64-6.

[32] Ostia is often mentioned in general urbanism studies of the ancient world, such as *Les villes romaines* by Grimal (1954, 26-7, 206-10), *Ippodamo di Mileto e l'urbanistica a pianta ortagonale* by Castagnoli (1956, 85-6), and *The City of the Landowner* by Barnow. Barnow (2002, 104) discusses the nature of Ostia's expansion and how it distinctly represented a Roman city. Packer 1971, 1, 74-5; Ward-Perkins 1974, 36.

[33] According to Carroll William Westfall (2007, 129), when the Romans took over, Pompeii was mostly a commercial center that focused on the private needs of the wealthy. Vaglieri 1912, xiii; 1914, 1-2; Meiggs 1973, 12; Kaiser 2011, 106.

to salt beds.[34] Ostia's location on the mouth of the Tiber, whence it gets its name (*os* means mouth in Latin), was initially important for strategic purposes as a naval station (fig. 0-1). The outpost grew to be an important Roman *Castrum* until the Romans were able to dominate the entire region (fig. 0-2).[35] At the time of Ostia's foundation, Rome was still developing its military power and control over Italy. Ostia was not laid out all at once or with one specific plan.[36] In fact, a new wall was constructed around the city by Sulla after the Social Wars, including an area of nearly thirty times the original size, and it was accessible from three main gates.[37]

After Rome was able to suppress its major enemies in the Mediterranean, especially the Carthaginians, the need for a large navy and defensive works was reduced. Now, the site went from being a fortified camp to being a major commercial trade

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[34] Jérôme Carcopino (1919) published an entire volume of the *Bibliothèque des Écoles françaises d'Athènes et de Rome* devoted to proving the founding legend of Ostia by using Virgil. He wrote in direct opposition to Dante Vaglieri, who was in charge of excavating the site and thought that Ostia's founding was more recent. Guido Calza and Giovanni Becatti (1987, 7) mention that there is some basis in truth for these foundation stories. Meiggs, Janet DeLaine, and Fausto Zevi (2001a, 3-5) disagree, and the lack of archaeological evidence on the site suggests that the legends were later fabrications. Meiggs (1973, 16-7) and DeLaine (2008, 99) both describe a fine marble inscription from the first half of second century AD that commemorates the story of Ostia's foundation as the first Roman colony by Ancus Marcius. The late date of the artifact suggests that the myth itself may also date to the second century. Giovannini (2001, 36-8) discusses the importance of salt to the Romans and the presence of salt beds in the area of Ostia. Vaglieri 1914; Carcopino 1919, 1; Calza 1925, 5-6; Chevallier 1986, 53.

[35] Ostia, in its earliest known form, was a Roman *Castrum*, or military camp, located approximately 250 meters from the Tiber River. The *Castrum* was rectangular (125.70 by 193.94 meters) and was accessible through four gates. There were two major streets crossing it: the Cardo, which went from north to south, and the Decumanus Maximus, which went from east to west. The fort was founded sometime between 338 and 317 BC. Paschetto 1912, 62-3; Calza 1925, 6, 7, 25; Castagnoli 1956, 85, 86; Meiggs 1973, 18, 19; Hermansen 1981, 1, 4; Chevallier 1986, 61; Calza and Becatti 1987, 7; Zevi 2001b, 10.

[36] Hermansen (1981, 6) states that it completely lacked a plan and certain areas were developed sooner than others. Frank Sear (1982, 121) also notes that the northeast area was orderly and carefully arranged, while the southern area was built in a largely haphazard manner.

[37] According to Meiggs (1973, 34-6), the Sullan walls "set a limit to expansion, marked the transformation of a naval base to a trading town, and encouraged Ostia to develop a new urban personality." Genevieve Gessert (2001, 95) claims that these new walls created a real urban space for the first time on the site. Vaglieri 1914, 12; Calza 1925, 7, 30-1; Sear 1982, 121.

center.[38] As it grew, Ostia became one of the main centers for importing many items, especially grain, into Rome.[39] Ostia was still not the main port of Rome, however. The harbor at Pozzuoli, near Naples, retained its dominance over Ostia as Rome's primary import center for a long time, mostly because the harbor of Ostia was not safe.[40]

Claudius brought the first significant changes and improvements to Ostia. Having seen the effects of hunger and discontent in Rome after the rule of Gaius (Caligula), the Emperor overrode senatorial opposition and had the construction of a new harbor begin in AD 42. His intention was to insure a steady supply of grain to the capital. The endeavor was very expensive and took twelve years to complete.[41] In fact, various coins minted in AD 64 under Nero, suggest that Claudius had already died before the inauguration of the new harbor.[42] Ostia became increasingly important to Rome thanks to

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[38] The city truly began to prosper when the Gracchi passed their grain reforms. Calza 1925, 8; Meiggs 1973, 25, 29, 32; Sear 1982, 121; Pavolini 2006, 30.

[39] It has been estimated that by 46 BC at least 320,000 inhabitants of Rome were being given free grain, creating a huge demand. Oil and wine were other important items processed through Ostia, along with wool, silk, linen, glass, Alexandrian carpets, fish from Pontus, medicinal herbs from Sicily and Africa, spices and perfumes from Arabia, pearls from the Red Sea, diamonds from India, African and Asian marble, and wood from the Atlantic coast. It is worth noting that Ostia was simply charged with processing and distributing all of these materials, not with actually producing them. Vaglieri 1914, 4; Anderson 1974, 69; Pasini 1978, 27; Vitelli 1980, 55, 56.

[40] The mouth of the river is only approximately one hundred meters in width. Many ships were wrecked and the largest grain ships could not maneuver the space. Large ships that did survive had to be unloaded at sea. Once their load had been lightened, some could continue up the Tiber to Rome. Vaglieri 1914, 3, 12; Calza 1925, 8, 9; Carcopino 1929, 9; Gessert 2001, 115, 148; Kaiser 2011, 107.

[41] Cass. Dio *Hist. Rom.* 60.11.1-26; Paschetto 1912, 68-70; Calza 1925, 9; Meiggs 1973, 54-5; Pasini 1978, 27; Kaiser 2011, 109.

[42] An example is a *sestertius*, now in the British Museum, minted in Rome (BM No. 130; Mattingly 1923, 221). The coin shows the head of a laureate Nero on the obverse and a bird's eye view of the harbor at Ostia on the reverse. The harbor is illustrated by a crescent-shaped pier with a portico and a figure sacrificing at an altar on the left side, and by a row of breakwaters on the right side. Between these two elements is a figure standing on a column, a cloaked Neptune, a dolphin, and a number of ships. Several other coins in the British Museum collection (BM No. 131-133, 135; Mattingly 1923, 221) have similar depictions on the reverse, but also include variations of an inscription: AVG VSTI S POR OSTIA. This inscription leaves no doubt that the imperial port of Ostia is being represented. Aline Abaecherli Boyce (1958, 74-5) is hesitant to assign the credit for the completion of the Ostian harbor to Nero. She suggests that Nero was only celebrating the movement of grain through such coins, and not the harbor's

this artificial port, and Francesca Pasini calls the Claudian period the most important urban moment for Ostia.[43] Even this harbor was problematical, however, and ships docked within it were still not safe from storms. As a result, Pozzuoli maintained its primary position as Rome's major harbor, forcing grain shipments to continue to be uneconomically moved across land.[44]

During Domitian's reign (AD 81-96) major changes were made to the city's urban structure, and the ground level was raised significantly.[45] Improvements were primarily needed due to the increasing populations of Rome and the subsequent increasing needs for the importation of food and other products through Ostia.[46] Ostia began to reach new levels of prosperity at this time, which soon increased dramatically under the reign of Trajan (AD 98-117).

III.b. Ostia at its Grandest

The Emperor Trajan finally addressed the problem of the Ostian harbor's lack of protection and depth for larger ships. Between AD 100 and 106 he built an enormous new harbor, in the area just above the Claudian docks, which became known as Portus.[47] The artificial port, which was larger than other such construction, contained more space and

inauguration. She points out that Casius Dio (*Hist. Rom.* 60.11.18-20) credits Claudius with this feat. Paschetto 1912, 68-70.

[43] New sets of baths, adorned with fine mosaics, began to spring up as Ostia became wealthier and more populated. Keay, et al. 2005, 11, 38; Meiggs 1973, 56, 63; Pasini 1978, 29, Vitelli 1980, 62.

[44] Claudius's primary concern was insuring that grain shipments from Sardinia, Sicily, and Africa were kept safe. According to Lynn White, the price of moving goods across land doubled every hundred miles. Meiggs 1973, 29, 56-7; Vitelli 1980, 56; White 1962, 66.

[45] By raising the ground, the city was better protected from flooding by the Tiber and possibly from a rising groundwater table, according to Gemma Jansen (2000, 90). Moreover, deeper foundations meant that taller structures could be built in the city. Jansen 2000, 90.

[46] Hermansen 1981, 9.

[47] According to Simon Keay, et al. (2005, 99) the construction of the Trajanic harbor very likely destroyed portions of the earlier Claudian harbor. Paschetto 1912, 71, 73; Calza 1925, 9-10; Keay, et al. 2008, 99.

provided greater protection for vessels than any previous arrangement.[48] *Horrea* were built all around the harbor to store the now abundant grain supply for Rome. In fact, Portus started to become a small town in its own right with a growing population and economy.[49] The new port allowed for more sea traffic than ever before, and made the second century and the beginning of the third century the most prosperous time for Ostia.[50]

During this period of its greatest flourishing, the nature of Ostia can be described as that of a bustling town with improvements constantly being made to its urban fabric, including the construction of baths, fountains, and elaborate warehouses. Ostia underwent many changes, and with the expansion of trade came larger populations living within the city.[51] A growing middle class emerged and prospered thanks to the extensive trade opportunities, which continued under Hadrian.

The city's local government was becoming increasingly stronger during the reign of Hadrian (AD 117-138), although its well-being was always dependent on Rome.[52] A great deal of attention and funds were contributed to making the colony reflect its increased status through elaborately designed buildings, carefully planned districts, and

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[48] The shape of the new construction was hexagonal, as can be seen on various Trajanic coins. This shape has been explained by Keay, who illustrates that the straight sides of the jetties would have made it much easier for boats to moor. The new port enclosed an area of 33.25 hectares. Paschetto 1912, 75; Mattingly 1926, 278 n. 471, 288 n. 631; Keay, et al. 2005, 39; 2008, 101.

[49] Paschetto 1912, 75; Keay, et al. 2005, 39.

[50] Meiggs 1973, 60; Hermansen 1981, 2; Sear 1982, 125.

[51] As at Rome, it is difficult to determine accurately what the population of Ostia was at its height. Populations soared to between 50,000 and 60,000 people, according to Ludovico Paschetto (1912, 171-2) and to Russel Meiggs's calculations (1973, 532-4), while James E. Packer (1971, 65, 70) computes a more conservative value of 27,000 inhabitants. Paschetto mentions that his population estimate not only includes the permanent residents of Ostia, but also the transient population of merchants, bankers, and individuals on vacation. In fact, Henrik Mouritsen (2001, 30) stresses that Ostia had a much larger international and temporary population than most Roman cities.

[52] DeLaine 1995, 99.

advancements to the Forum.[53] In fact, over half of the city was rebuilt, with two major sectors of the city being re-planned with an organized layout. The current archaeological remains primarily reflect this stage.[54]

III.c. Ostia's Decline

Ostia's prosperity probably began to dwindle after the death of Hadrian; focus shifted to Portus as the major trade center, and more communities began to grow around that area.[55] No more significant changes were made to the urban fabric of Ostia and only a handful of monumental constructions were undertaken. Such constructions were in the "baroque" style of the Antonines (AD 138 and 192) including the unusually-shaped Terme del Foro (I.XII,6) and the elaborately decorated "Palazzo Imperiale" in Region I.[56] The construction of these two large complexes does indicate that Ostia was still important at this time, even though the city was not significantly altered.

General decline increased under the Severans (AD 193-235) even though there are many inscriptions to Alexander Severus in Ostia.[57] Fortunately, Ostia's location not only made it an excellent port town, but also a resort, keeping the city from declining too quickly with the rest of Rome. Restorations and embellishments to existing monuments

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[53] Gessert 2001, 233.
[54] Sear 1982, 125; Pavolini 1986, 22.
[55] Meiggs 1973, 86, 88.
[56] Spurza (2000, 129) describes the Palazzo Imperiale thus, "Located in the far western part of the ancient city on the banks of the Tiber, the Palazzo in its final form comprised a double-courtyard plan with a large bath, a mithraic suite, apartments, shops and *magazzini*, having an overall length of 130 m. Its great size and rich décor apparently inspired the popular epithet of 'Palazzo' acquired by oral tradition in the 19th century during excavations by Pietro Ercole and Carlo Ludovico Visconti under Pope Pius IX." Pavolini 1986, 218.
[57] The only monumental new construction undertaken in the Severan period was the construction of the Round Temple. Meiggs (1973, 83, 90) states that the period after that of the Severans was essentially fatal to the entire empire. The brick industry collapsed with a decentralization of power, and the local governments floundered. Sear 1982, 132; Kaiser 2011, 110.

were still being made in the city.[58] In fact, the Terme del Foro were not only still operating in the fourth century, but also they were extensively refurbished at this time.

In AD 314 Constantine moved the municipal control of Ostia over to Portus, illustrating that Portus was now valued over Ostia, perhaps because of religious purposes.[59] In fact, by the beginning of the fifth century Ostia was already largely abandoned, having been sacked by the Goths in AD 410.[60] The constant silting of the Tiber, accelerated by a canal that was cut between the harbor and the Tiber, eventually largely buried the city. Malaria, especially common in this area in the summer months, kept new inhabitants from staying and building significantly on the site.[61]

III.d. Ostia's Rediscovery

Like many other ancient sites, Ostia served as a marble quarry throughout the Middle Ages. Particularly in the 15th century, building material from Ostia was used for construction in the city of Rome. The 17th century saw the site plundered for works of art that ended up in private collections across Europe. Pope Pius the VII prohibited private extractions of objects starting in 1802, and he put Giuseppe Petrini in charge of an

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[58] Paschetto 1912, 78; Vaglieri 1914, 13, 16.

[59] Constantine had just passed the Edict of Milan, legalizing Christianity, a year earlier. According to Calza (1925, 12), this shift of power from Ostia to Portus also created a religious division between the two areas. Paschetto (1912, 81) calls it a civic and religious liberation of Portus from Ostia. Christer Bruun (2002, 167) explains that except for the period during the construction of the Trajanic harbor, Ostia and Portus were always governed as two separate entities. Paschetto 1912, 81; Vaglieri 1914, 15; Calza 1925, 12; Cicerchia and Marinucci 1992, 17; Bruun 2002, 167.

[60] Carcopino 1929, 26; De Chirico 1941, 127.

[61] Paschetto (1912, 19) discusses the possibility that malaria also existed at Ostia in ancient times while the city was inhabited. Although he mentions that some thought the malaria was purposefully disseminated at the site by the Papacy to keep people away, he finds the conditions of standing water likely to have existed earlier. Perhaps the Romans dealt with the problem more efficiently by incorporating systems of drainage and through heavy cultivation of the land. Paschetto 1912, 19-21; Calza 1925, 13.

excavation in the center of town. The focus remained, however, on locating precious art and not on gaining a greater understanding of the history of Ostia.[62]

Beginning in 1855 Ostia was under the control of Pope Pius IX, and the first "modern" excavations began. The site was put under the authority of P.E. Visconti, until 1870 when it was taken over by Vaglieri and the newly formed Italian government. Vaglieri unearthed the area between the Decumanus and the Caserma dei Vigili.[63] His successor was Guido Calza who excavated about one-third of the city by 1938. Another third of the site was excavated by 1942 in time for the "Universal Exposition of Rome", which never actually took place.[64] The Claudian harbor was located in 1957 during construction of the Fiumicino International Airport.[65] Modern excavations continue at the Palazzo Imperiale, in the Forum of the Heroic Statue, in the area near the Jewish synagogue, and at the site of Portus.[66]

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[62] Alessandro Visconti excavated with Petrini. They uncovered the so-called Temple of Vulcan. Vaglieri 1914, 34; Pavolini 2006, 39.

[63] Vaglieri's careful work at Ostia led to increased interest in the site, increased funding for the site, and an increased understanding of Ostia, itself. The area of Portus was not accessible in the same way. Portus was under the control of Prince Torlonia, and many sculptures from the site became part of the private collection of the Torlonia family. Vaglieri was also responsible for the creation of the Archivio Fotografico Sociale in 1912, where negatives of excavation photographs were stored and catalogued. Vaglieri 1914, 35; Packer 1971, 1-2; Meiggs 1973, 5-6; Chevallier 1986, 56; Olivanti 2001, 56-7; 2002, 287; Pavolini 2006, 39-40.

[64] The "Universal Exposition of Rome" was intended to be Mussolini's World's Fair, where he would show everyone that he had a "sincere desire for peace", according to T. Gregory and A. Tartaro (1987, 3). The event was also set to mark the 20th anniversary of the Fascist Revolution. In reality, the event was connected to the campaign against Ethiopia, where Mussolini expected a swift and easy victory. He hoped to use the site of Ostia as an expression of his imperialist politics, according to Chevallier (1986, 57-8). Performances of both classical and modern dance were going to be held in the ancient theater at Ostia, and a new highway was constructed between Rome and Ostia. The speed of excavation to prepare for this exhibit, as well as the threat of war, led to poor techniques wherein a great deal of evidence was forever lost. In fact, the size of the excavated zone doubled in four years, bringing the area up to approximately 34 hectares. A great deal of reconstruction was also performed primarily to improve the appearance of the site. Packer 1971, 1-2; Meiggs 1973, 5-6; Chevallier 1986, 57-8; Gregory and Tartaro 1987, 3, 115; Olivanti 2001, 61; Bruschi 2004, 48-9; Pavolini 2006, 40.

[65] Chevallier 1986, 58.

[66] For the most recent discoveries at Ostia, including one of a Roman era wooden ship, see Internet Ostia Group 2011. For information on the Palazzo Imperiale, see Spurza 1999, 2000, and 2002. For information

IV. The Baths of Ostia

There were many bathing facilities at Ostia, as can be seen on the plan by Cicerchia and Marinucci (fig. 0-3).[67] In fact, Packer mentions that no location in the city was more than a five minute walk from a public bath.[68] According to Hermansen, the number of baths would have actually exceeded the needs of the permanent population.[69] As mentioned above, a large number of residents would have only been passing through the city, perhaps accounting for the substantial number of baths. Before the introduction of the aqueduct, Ostia had several small *balnea*, or private bathing facilities, that date to the late Republic or early Augustan period.[70] No physical evidence exists of any baths dated to before the Julio-Claudian era, however.[71] After the water supply was increased, and particularly in Ostia's most prosperous period, many new baths were added to the city. In fact, during this time eight new baths were built on various scales.

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on the University of Kent's work at the Forum of the Heroic Statue, see Lavan and Gering 2009. For information on the excavations of the University of Texas at Austin in the area of the synagogue, see White 2010 and Boin 2011. For information on the ongoing excavations at Portus, see Keay, et al. 2005, 2008, and 2009.

[67] Cicerchia and Marinucci 1992.

[68] Packer 1971, 74.

[69] Hermansen 1981, 8.

[70] Ostia received its aqueduct during the reign of either Tiberius (AD 14-37) or Gaius (AD 37-41). Pavolini (1986, 209) is unsure if the aqueduct was introduced during the reign of Tiberius or Gaius, but he mentions that Gaius was the earliest emperor's name found inscribed on a pipe in the city. Roberta Geremia Nucci (2001, 109) describes the inscribed pipe as 0.30 meters in diameter. Meiggs (1973, 44, 406) and Nielsen (1990, 7) both assert that the aqueduct was constructed in the time of Gaius. The water supply for the aqueduct came from the Monti di San Paolo. The majority of lead pipes in the city date to the Antonine and Severan periods, according to Bukowiecki, et al. (2008). These scholars have also identified two sections of the aqueduct of this date at Ostia. The water features may have been a part of reconstruction work done at the city. For more information on the *castellum aquae* and the distribution of water from the aqueduct in Ostia, see Bukowiecki, et al. 2008. Paschetto 1912, 249; Meiggs 1973, 44, 406; Pavolini 1986, 209; Nielsen 1990, 7.

[71] A mosaic adorned with Roman provinces marks the location of an early bath of Claudian date near the via dei Vigili. Each province was represented by an animal, such as an elephant for Africa. This establishment was probably suppressed with the construction of the Terme di Nettuno. Meiggs 1973, 406; Chevallier 1986, 75; Pavolini 1986, 212; Pellegrino 2000, 17.

The oldest extant baths from this group are the late Flavian (AD 80-90) Terme del Nuotatore (V.X,3) and the slightly later (late first century AD) Terme del Invidioso (V.V,2).[72] These bathing structures were located south of the Decumanus, and they created an interesting contrast to the new warehouses being constructed in the same area.[73] The warehouses expressed a basic human need, while the baths expressed a basic Roman social need. Moreover, the grain trade brought prosperity, which was conveyed through the elaborate bathing complexes.

Other baths added at Ostia include the Trajanic Terme di Buticosus (I.XIV,8), Terme del Faro (IV.II,I), and Terme delle Sei Colonne (IV.V,10-11); and the Hadrianic Terme dei Cisarii (II.II,3), Terme del Mitra (I.XVII,2), Terme Marittime (III.VIII,2), Terme della Trinacria (III.XVI,7), Terme dei Sette Sapienti (III.X,2), and a bath that was destroyed to enlarge the Forum.[74] The Terme del Buticosus were rather spacious and provided amenities to the western part of the city; their construction was soon followed by other enhancements to the area, including a headquarters for a guild of grain measurers and a *horrea*, or warehouse.[75] Again, the placing of a bathing facility in conjunction with a granary is observed. Perhaps the choice of location for the baths reflected the needs of the local grain workers in each area.

[72] According to Pavolini (2006, 229), the Terme del Nuotatore are the only baths to be excavated in a thoroughly stratigraphic manner, allowing all of the phases of the edifice to be preserved. They were excavated by the University of Rome between 1966 and 1975, a much later excavation date than most of the other baths at Ostia. Pavolini 2006, 229.

[73]Gessert 2001, 170.

[74] The Terme del Faro contain some rooms in *opus reticulatum*, which Italo Gismondi dates to the Augustan period. Perhaps this part of the structure served an earlier function, or perhaps the bath is earlier than generally thought. Gismondi, himself, still dates the bath to the Trajanic period. Calza, et al. 1953, 234.

[75] The name of Buticosus originates from a mosaic which likely shows the *bagnino*, or bath attendant, of this bath with his name as a label. Calza and Nash 1959, 62; Gessert 2001, 219.

Baths were meant to be convenient and accessible to many people, and sometimes to certain groups in particular.[76] Some bathing facilities, such as the Terme dei Sette Sapienti were primarily meant to service the needs of the residents of a specific *insulae*. In fact, this facility was placed in the middle of two large apartment complexes to be easily accessible to residents of both.[77]

IV.a. Imperial *Thermae*

According to Paul Zanker, the construction of elaborate bathing complexes and the "enjoyments they offered were the emperors' and patrons' guarantee of a new standard of living."[78] Ostia did not receive any such large public *thermae* until the second century AD. Three such complexes have been found in the excavated portions of Ostia, and each of them has imperial ties. Each one is in a different sector of the city to serve the inhabitants of that area; the smaller *balnea* remained in operation to supplement populations who lived too far, or for those who preferred a smaller venue.[79]

Unlike the smaller *balnea*, the *thermae* had a significant impact on the physical neighborhood in which they were placed: *thermae* took up whole city blocks, diverted

[76] The Terme dei Cisarii were located very close to the Porta Romana gate coming from Rome. A large mosaic in the *frigidarium*, or cold room, depicts men driving carts pulled by mules who have humorous names written near them. These baths may have been used particularly by traveling merchants, or even exclusively by members of a cart-driving guild. Similarly, the Suburban Baths at Herculaneum were located close to the docks, and according to Umberto Pappalardo (1999, 232), they were primarily meant to serve dock workers and sailors. Pellegrino 2000, 16.

[77] According to Chevallier (1986, 77), these elaborately decorated baths were originally Hadrianic, but were refurbished in AD 205. They contained an elaborate round mosaic that was ten meters in diameter and covered by a cupola. The mosaic shows evidence of ancient repair. Their name derives from paintings of seven famous philosophers found in the bath. Instead of adding intellectual phrases, however, the inscriptions are scatological in nature. There may have been shops on the lower floor of this complex, enforcing the possibility that non-residents may have patronized the facility. Calza and Nash 1959, 60; Pellegrino 2000, 53.

[78] Zanker 2000, 39.

[79] Pavolini 1986, 213.

water sources to the area, and contained many shops. The brick porticoes placed on the façades of the large baths enhanced the appearance of and the movement along the Decumanus as well.[80] Moreover, they housed guilds, dedications, and cult shrines, making them social and religious nuclei within the city framework.

The oldest of the three Ostian *thermae* is the Terme di Porta Marina (IV.X,1), or Baths of the Sea Gate (fig. 0-4). As the name suggests, this complex was built directly outside of the Porta Marina gate on a large terrace, and these baths served the southwestern side of town. These baths were probably built by Trajan, as evidenced by a statue of his sister Marciana that was found there.[81] An inscription describing Trajan's work in the baths was allegedly uncovered there as well.[82] Another statue located on the site has been identified as Sabina, Hadrian's wife. This discovery suggests that Hadrian may have also played a role, and that he may have been the one responsible for completing the baths.[83]

The next imperial bathing facility constructed was the Terme di Nettuno (II.IV,2), or Baths of Neptune (fig. 0-5). This bath is perhaps best known for its elaborate black and white marine mosaics and marble embellishments. The baths occupy a square block of 67 meters on each side, making them one of the largest at Ostia.[84] In fact, the bathing block

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[80] Gessert 2001, 288.

[81] The baths are sometimes referred to as the Terme di Marciana because of the discovery of this statue. Pavolini 1986, 212; Poccardi 2001, 164.

[82] This inscription was mentioned in a 1775 letter by Gavin Hamilton, a Scottish painter on the Grand Tour. Unfortunately no trace of the inscription survives today, so the imperial nature of these baths cannot be confirmed definitively beyond their lavish quality. Hamilton actually excavated these baths, and he brought back many sculptures with him. One example is a fragmentary marble copy of the Aphrodite of Knidos. Calza and Nash 1959, 56; Meiggs 1973, 407-8; Pellegrino 2000, 50; Valeri 2002, 218.

[83] Meiggs 1973, 407; Pavolini 1986, 212.

[84] The Terme di Nettuno were located on the north side of the eastern Decumanus, in a region that underwent systematic reconstruction and reorganization after their erection. DeLaine (2002, 57-64) presents a detailed study of the brickwork and brickstamps of this area. She suggests that the construction

fills almost the entire eastern half of an *insula*.[85] Hadrian paid about two million sesterces for the construction of these baths, but they were completed by funds provided by Antoninus Pius in the first year of his reign. There are also brick stamps dated to Marcus Aurelius, who is credited with the elaboration of a brick portico along the Decumanus.[86]

The third of the imperial bath complexes, and the subject of this study, is the Terme del Foro, or Forum Baths (I.XII,6), located to the east of the southern end of the Forum.[87] These baths, the largest of the three imperial bathing facilities, are thought to have been constructed in the Antonine Period (AD 138-192), although they were reconstructed and refurbished several times. The building of these baths likely began under Antoninus Pius, and they may have been finished under Marcus Aurelius.[88] An inscription found in the baths credits the construction to M. Gavius Maximus, who was the praetorian prefect of Antoninus Pius.[89] His imperial ties would have been very

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of the district may not be as homogenous as previously thought, although she says the evidence is confusing. She concludes that the whole area was likely built by the same contractor, but perhaps by different builders. Meiggs 1973, 409; Chevallier 1986, 75; Pavolini 1986, 212.

[85] These baths were among the earliest to be excavated at Ostia. The floor of the entrance room was covered with a mosaic of Neptune, who is being pulled by four marine horses. They are surrounded by tritons, nereids, dolphins, and other marine creatures. This room leads to another, which is adorned with a mosaic of Amphitrite, the bride of Neptune, reclining on a hippocampus. Amphitrite is being led towards Neptune, along with tritons and Imene; Imene has often been associated with marriage, suggesting that this is the actual wedding of Neptune and Aphitrite. The *frigidarium* is also decorated with marine mosaic pavements of Scylla and other monsters, and it contains two pools. Calza 1925, 96; Pellegrino 2000, 17.

[86] The baths were heavily damaged by fire, and they were restored by a wealthy citizen, called Lucilius Gamala the Younger. He reinforced the eastern wall of the *caldarium*, suppressed the *caldarium* with the three pools, and added pools to one of the *tepidaria*. Calza 1925, 97; Meiggs 1973, 409.

[87] This bathing complex incorporated an area of Ostia in the very center of town that had always remained public; it also included a portion of the original *pomerium* of the city. Kockel 2001, 87.

[88] Grégoire Poccardi (2001, 164) dates the baths to specifically AD 160, as does Pavolini (2006, 106). Becatti 1948, 216; Bloch 1953, 414; Meiggs 1973, 415; Poccardi 2001, 164; Pavolini 2006, 106-9.

[89] Hebert Bloch (1953, 413-6) and Meiggs (1973, 415) both present detailed discussions of the inscription and how it illustrates the likelihood that M. Gavius Maximus was their benefactor. According to Bloch (1953, 416), M. Gavius Maximus died in AD 158 or 159, however, it is possible the work was begun by him and finished after his death. The inscription has not been published in the *Corpus Inscriptionum Latinarum* (*CIL*).

important in securing the necessary materials for this luxurious baths.[90] In fact, the complex was decorated with *cipollino* columns, mosaic floors, and many statues, including those of Asclepius, Hygiea, and Fortuna.[91]

The monumentality of the imperial structure would have emphasized the importance of the edifice, its relationship to the emperor, and the setting in the Forum. The placement of the bathing complex would not only have been convenient for the daily patrons, but also it would have made a grand statement about the prosperity of the town. In fact, Pavolini states that their location made them an essential feature of the urban landscape.[92] Although standard in their northern sector, the baths were unusual in their southern sector, which had curving walls punctured by large windows to take advantage of the afternoon sun.[93] The structural remains of the Terme del Foro are described in great detail in volume 11 of the *Scavi di Ostia* series.[94] The layout, construction, and phases of the bath are also described in much more detail in the following chapter.

IV.b. Later Baths and Refurbishments

As mentioned above, few large projects were undertaken at Ostia after the second century. The Terme del Filosofo (V.II,7), were probably added around AD 200, although it is possible that they were earlier and just heavily reconstructed in AD 200.[95] The rather

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[90] Pensabene 1994, 365.
[91] The surviving statues can be seen in the small museum located at the site. Chevallier 1986, 76; Valeri 2002, 222.
[92] Pavolini 2006, 106.
[93] Meiggs 1973, 412, 414.
[94] Cicerchia and Marinucci 1992.
[95] They were frequented by a school of philosophers or by some sort of other intellectual group. Boersma 1985, 7, 197.

small Terme Bizantine (IV.IV,8) were added at the end of the second century AD.[96] Many of the baths at Ostia were refurbished in the fourth century, implying that they were still being used and that they were still important. In fact, DeLaine determines that 26 baths were still in operation in the fourth century, although this figure includes private baths as well as public ones.[97] The Terme del Mitra (I.XVII,2) became associated with a Christian cult in the fourth century; and these baths may have served as a Christian church in the fifth or sixth century, with the pools being used for baptisms.[98] The Terme del Foro remained in use until at least the fifth century, and perhaps even the sixth century.[99]

V. Methods and Goals of Heat Study

The well-preserved Terme del Foro at Ostia are an ideal case study because they contain typical heating elements found in most Roman baths, as well as some more unusual features not always seen in bathing facilities, as is mentioned above. [100] Moreover, the original urban setting of the baths – the city of Ostia – can still be observed and traversed in the same general way as a Roman would have done. Selecting this case

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[96] The Terme Bizantine were not actually a Byzantine construction as the name would suggest; the error was due to a mistake in its early excavation. Their style is similar to later Byzantine baths, however, which often contain curvilinear forms. The baths were heavily refurbished in the fourth century. DeLaine 2006, 338; Pavolini 2006, 197, 217.

[97] DeLaine 2006, 338.

[98] The Terme del Mitra are rare in their level of subterranean preservation, particularly their water systems. The remains of a *noria*, or water wheel, can also be seen here. According to Inge Nielsen and Thorkild Schioler (1980, 150), the structure ceased to be used a bath probably when it became Christianized; this is evident from the suppression of the heating system. Ownership of bathing facilities by churches for income was not uncommon at this time, although it is not clear if the bathing rooms were still functional. Nielsen and Schioler 1980, 149-50, 152; DeLaine 2006, 340.

[99] Valeri 2002, 222.

[100] According to Russell Meiggs, "The Forum Baths are first known large building to break with rectangular tradition in curving ends of their southward-facing hot rooms." Meiggs 1973, 90.

study was the critical step, after becoming as familiar as possible with the history of Roman bathing, the advancements made in their technology, a large number of extant bathing complexes, and the variations of these across the Roman empire. Baths were prevalent throughout the Roman world, and although there were certainly differences, their basic heating technology is equivalent: the floors were heated by a hypocaust constructed either of pillars or arches; and the walls were heated by forming a hollow space with *tubuli*, *tegulae mammatae*, terracotta spacer pins, terracotta spacer tubes, or a combination of these various technologies.

In order to create as accurate a heat study as possible, it was necessary to spend a great deal of time at the site, studying the structure and the heating system. For example, changes made over time to both the edifice and the heating system needed to be identified, because they would have affected the way the bath operated and potentially how much fuel was consumed. In addition, the fabric of the walls, floors, and ceilings, where available, of the Terme del Foro had to be measured in order to ascertain the quantity of heat that would have passed through each layer. To understand fully the way the heating systems worked and to determine how much energy was needed to operate them, it was necessary to examine all of the components and the properties of each individually.

All parts of the heated rooms were measured, and the materials of each element were noted. The collected data is compiled in Appendix 2. Other elements that could have affected the introduction or loss of heat, such as windows and doors, were taken into account. To make the current study as effective as possible, I took precise measurements of the bathing rooms and inserted them into modern heat transfer equations, and synthesized them with all the other variables that had to be accounted for, (e.g., properties of construction materials, solar radiation, temperatures, hours of operation, and the type of fuel utilized).

Cataloguing the data and their associated equations would have been problematic without the aid of a database. In fact, since no current software exists that can contend with the heating issues of complex ancient structures, I developed a user-friendly database both to aid in the compilation of data and to facilitate the process of computing quantities of energy and fuel for my specific case study. This program allows for any number of assessments, and it can be adjusted so that the data for any bath can be inserted and compared.

The primary goal of this study was to ascertain how much fuel was necessary to operate the Terme del Foro at Ostia under a number of different parameters, and to determine if the baths could be run efficiently. Although the idea of obtaining a specific fuel number is attractive, there is no way to be sure how accurate this value is. Therefore, the more effective way to utilize the results of this study was to compare values according to the different parameters. For example, the amount of fuel needed in each month of the year was examined to compare how different outside temperatures would have impacted the heating of the baths. Time of day was also considered to illustrate how the placement of the sun in the sky would have contributed to the heating of rooms with windows, with or without glazing in them. Types of fuel were also compared to illustrate the effectiveness of each.

By examining all these variables, both individually and in comparison to each other, larger questions are addressed. How much fuel needed to be available in the baths on a daily basis? Would transporting these volumes of fuel have affected the urban landscape surrounding the baths? How expensive would this fuel have been? How many trees needed to be cut down in order to supply the baths, and what affect did this have on the local forests?

VI. Layout of Chapters

The following study is composed of five chapters, a conclusion, and two appendices. Chapter 1 is a historiography of bath studies. The chapter begins with a description of the early role of baths – as treasure troves for artwork – and continues by demonstrating that they were important stops on the Grand Tour. Then the role of thermal baths in the Victorian Era and the beginning of systematic excavation of baths are discussed. The following sections examine the publication of baths, which initially focused on quantifying the structures and then employed the facilities as tools for understanding daily ancient life. Finally the most recent trends in bath studies are considered, including the technology of baths, and health and hygiene issues for ancient people.

Chapter 2 presents a discussion of the different elements comprising the heating system of Roman baths in general, and the presence of these features in the extant remains of the Terme del Foro are also presented briefly. The importance of sunlight, along with the presence or lack of glass in openings and windows is considered. Other factors, such as hours of operation and type of fuel, are also considered in this context because they affected the consumption of energy in Roman baths.

The structure of the Terme del Foro at Ostia is described in detail in Chapter 3, beginning with an overview of the history of excavation at the site. The Terme del Foro underwent several different phases after their construction, and each of these is explained. The way the baths were entered and how one moved through the spaces is illustrated next, followed by a description of the dimensions and features of every room in the bathing facility. Finally, the issue of the large windows in the heated rooms of the Terme del Foro is examined.

Chapter 4 contains the definitions of heat transfer and Fourier's Law, which are essential for determining how much fuel was consumed by the Terme del Foro. The different components of the structure of the bath are separated into sections, and the appropriate formulas for determining the heat lost or gained in each component is demonstrated. The process of determining the proper temperatures to be used for both the inside and the outside of the bath are discussed, as are the fuel sources that were available around Ostia. Finally, the layout and operation of the database are explained, and all of the permutations that are tested in the study are defined.

Chapter 5 presents the complete results of all of the permutations performed with the database program. Each result is examined and compared to the results of other permutations to demonstrate the effect of each on fuel consumption. The total quantity of fuel necessary to run the baths is presented and this value is compared to the values of fuel consumption obtained in studies conducted in the past. The necessary fuel volume is then examined in terms of the quantity of trees that had to be consumed, cost, transportation, and required storage space at the bath. This discussion leads to exploration of how moving fuel would have affected the urban landscape of Ostia and the fuel trade.

The greater environmental implications related to deforestation and climate change are addressed last. The chapter is followed by a section on the greater conclusions of the dissertation and future directions.

Two appendices follow the main chapters, since placing this information within the body of the text would have been too cumbersome. Appendix 1 contains all of the tables of heat transfer constants, temperatures, solar data, and fuel information that was used to compute the quantities of fuel consumed. The final appendix, Appendix 2, contains all of the raw physical data that was collected from the Terme del Foro, including all of the dimensions that were measured and the nature of the fabric of all the materials composing the structure.

To date, a study of this type has never been attempted, particularly with this level of detail. By incorporating so many different kinds of evidence into the computations, the results obtained are reliable and useful. Furthermore, fusing archaeology with engineering principles allows for a thorough understanding of how Roman baths operated. The Terme del Foro at Ostia have proved to be an excellent case study for understanding heating and fuel consumption in the Roman baths. Moreover, they are a complex and interesting structure that deserves such an in-depth examination. By focusing on this bath, greater conclusions about the impact of a Roman bathing facility on the local economy and the environment also could be made, and wider issues such a resource distribution and deforestation could be evaluated.

Chapter 1: Roman Baths: A Historiography

For a person living within the Roman empire, a trip to the local bathing establishment was a part of daily life. Throughout Italy and the provinces, individuals from all social levels frequented public baths not only for hygienic purposes, but also for socializing, exercising, and relaxing. In fact, they were one of the first facilities to be erected in military camps and in new Roman colonies, such as Exeter or Lepcis Magna, where they served both the legions of Rome and the local populations.[1] Baths stood as symbols of Romanization and "advanced civilization" throughout the empire. Later imperial baths, such as the Baths of Trajan and Caracalla became elaborate entertainment complexes, enhanced with libraries, concert halls, gardens, and museums. Their innovative forms and advanced heating technology inspired architects and engineers throughout the centuries, and today, they exist in greater number and exhibit a higher level of preservation than any other public Roman structure.

The method of excavating and studying baths has evolved greatly over time, with the focus shifting according to changes in the field of archaeology and theoretical philosophies. Originally baths served as an easy cache of artwork for plunder by popes and wealthy European individuals and as a "romantic" stop on the Grand Tour. When systematic excavation of many major bathing establishments began in the 1800s, the goal was still largely centered on finding collectible works of art like the Farnese Bull from

[1] Nielsen 1990, 1; di Vita-Évrard 1991, 35-6; Henderson 1999, 165; Rook 2002a, 5.

the Baths of Caracalla. Little attention was paid to stratigraphy, artifact collection, or structural preservation. Few plans or photographs exist to compensate for this lack of careful data recording and effective conservation methods, and many baths remain largely unpublished.[2] As scientific approaches towards the excavation of baths and archaeological sites in general became more prevalent, baths began to be viewed as sources of evidence for Roman architecture and construction practices. The focus remained primarily on describing remains and on recognizing different building phases until the 1980s when the subject of daily life began to interest scholars, propelling baths into the spotlight.

I. Early Collecting and the Baths of Caracalla

Many Roman baths continued to operate well into the fourth and fifth centuries AD, and some even experienced a revival of use during the Middle Ages, including the thermal baths at Baiae in the vicinity of Naples.[3] After many baths fell into disuse, they were plundered for both construction materials and artwork. The most prominent example is the Baths of Caracalla (fig. 1-1), which were lavishly decorated with statues and mosaics and remained largely intact through the centuries.[4] According to Miranda Marvin, the type and distribution of the statuary from the Baths of Caracalla was similar to other bathing complexes of the same period, and their spoliation is largely documented. Using the Baths of Caracalla as a model for decorative schemes is useful

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[2] Nielsen 1990, 2.
[3] Yegül 1996.
[4] Imperial baths were meant to illustrate the generosity, or *liberalitas*, of the emperor to the Roman populace. The more elaborate and luxurious the baths, the better impression he gave. Sculpture was one of the most costly embellishments in the bathing facilities. Marvin 1983, 348, 380.

because they contained “a standard repertoire of figures” that was probably present in most Roman baths throughout the empire.[5] Most of the sculptures adorning the building ended up in lime kilns, which was often the fate of Roman marble embellishments after the fall of the empire.[6]

Some objects from the Baths of Caracalla survived into the Renaissance, eventually ending up in museums. The only known *spolia* predating the Renaissance that can confidently be attributed to these particular baths, are some columns, capitals, and architrave fragments that were displayed beginning in 1139 by Pope Innocent II in Santa Maria in Trastevere.[7] Later, Alessandro Farnese, who reigned as Pope Paul III between 1534 and 1549, became particularly notorious for extracting works from these baths for his own private collection, including the famous Farnese Hercules (fig. 1-2) and Farnese Bull (fig. 1-3), uncovered in 1545.[8] After the 16th century, no more statues were reportedly found, even though Papal permits were still issued for excavations.[9]

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[5] Sculptural niches demonstrate the presence of missing statues in various Roman baths. The only regions with significant amounts of extant sculpture in their Roman baths are North Africa and Asia Minor. Use of these baths in the Christian era seems to have contributed to the longevity of their decorations. Apparently, the individuals portrayed did not conflict with Christian ideals; instead they were seen as symbols connected with bathing. Marvin 1983, 352, 377-8. For more information on sculptural works recovered from baths, see Manderscheid 1981.

[6] Although it is uncertain when the Baths Caracalla ceased to operate as a bathing complex, most of the surviving baths in Rome closed soon after the Goths seized control of the city and cut the aqueducts in AD 537. Plunder of the baths must have begun immediately after they were abandoned. Marvin 1983, 348.

[7] Marvin 1983, 348.

[8] Pope Paul III was the first pope to create a private collection instead of amassing artifacts for the Vatican. He commissioned Michelangelo to build a sculpture gallery for his artifacts in the Palazzo Farnese in Rome. Haskell and Penny 1981, 11-2; Marvin 1983, 348-9; DeLaine 1997, 21; Piranomonte 1998, 37-8; Harris 2007, 63.

[9] The mosaics from the Baths of Caracalla were kept out of private collections and in the property of the Papacy by Carlo Fea. He was the Director of Antiquities in 1824, and he prevented the pavements from being taken to Vicenza by the wealthy antiquarian, Count Girolamo Egidio di Velo. The Count allegedly had a large collection of ancient artifacts, many of them taken from other baths, but none have a recorded provenance. Marvin 1983, 349, 384.

While many works that likely came from baths completely lack provenience, at least forty-one statues and fragments from the Baths of Caracalla have been definitively identified thanks to the efforts of Ulisse Aldroandi. Aldroandi made an inventory of all the ancient sculptures visible throughout Rome in 1550, including those in the Palazzo Farnese. He also allegedly visited the house of Maccarone, the Papal agent responsible for the excavation of the Baths of Caracalla, to view his collection of uncovered works. It is quite probable that Maccarone identified works for Aldroandi within the Papal collection as well.[10]

II. The Grand Tour Era

Due to the durable nature of their vaulted structures, the remains of Roman baths often stood to considerable heights. As a result, they were often partially visible on the landscape prior to any excavation, making them popular Grand Tour destinations and subjects for artists. The Grand Tour became, according to Andrew W. Moore, "an integral part of the development of the aristocracy and of the national culture," particularly in the beginning part of the 18th century.[11] Pompeii and its baths were an especially popular stop on the Grand Tour itinerary following their discovery in 1748, and the whole area around Naples provided many interesting destinations for travelers to explore and admire.[12]

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[10] Aldroandi (referred to in some publications as Aldrovandi) published his lists in 1562. He was considered a very important naturalist. Aldroandi 1975; Marvin 1983, 354, 383; 2008, 58.

[11] British aristocrats were the most common Grand Tour adventurists, but individuals from all over Europe, including Poland, also participated in the phenomenon. Moore 1985, 12; Marvin 2008, 41.

[12] Harris 2007, 2.

Grand Tourists, usually wealthy young men from England and other parts of Europe, typically spent between one and two years abroad.[13] Throughout their adventures, these gentlemen often picked up souvenirs for their collections, while artists and architects made sketches and engravings of exposed structures.[14] Giuliano da Sangallo had already created elaborate drawings of the floor plan of the Baths of Caracalla in Rome as early as 1465. His work included details of architectural elements and relief sculptures. Andrea Palladio drew plans of the existing remains of the Baths of Nero in Rome (fig. 1-4). The famed architect, who lived between 1508 and 1580, was probably inspired by the domed bath buildings, which he recreated in his own designs. Jan Brueghel the Elder, who lived between 1568 and 1625, used the "Temple" of Diana at Baiae (fig. 1-5) as a romantic backdrop for one of his landscape drawings. Although the work is highly detailed, it does not present the structure as an important architectural section of a bath. Instead, it serves only to set the scene. Paoli and Piranesi also produced similar engravings.

Several books that focused on Roman baths were also published in these early days of bath exploration. For example, Charles Cameron published his work on his excavations of the Domus Aurea, *The Baths of the Romans Explained and Illustrated*, in 1772. Giuseppe Carletti's work, *Le Antiche Camere delle Terme di Tito e le loro pitture restituite da L. Mirri delineate, incise, dipinte,* was published in 1776.[15] Both of these works focused primarily on the decoration of the baths, rather than the baths themselves;

[13] Knight 1996, 11.
[14] Moore 1985, 9.
[15] The remains of Nero's Domus Aurea were originally thought to be the Baths of Titus, as they are referred to by both eighteenth century authors. Cameron 1772; Carletti, Mirri, and Carloni 1776; Peters and Meyboom 1982, 33.

this is in keeping with the 18^{th} century tradition of using the baths as a source of inspiration for painting and architecture, rather than as a source of information and material on Roman daily practices and technology.

III. The Victorian Era and Thermal Spas

The Last Days of Pompeii by Edward Bulwer-Lytton was published in 1834, awakening the Victorian World to the mysteries and romanticisms of Pompeii. The Anglicized Pompeii particularly drew the attention of young British men, who were fascinated by the pornographic works found on the site.[16] Establishing a connection with the grandeur of Rome also became a source of nationalistic pride in the British empire, which became very powerful between 1837 and 1901, during the reign of Victoria. Greek and Roman themes were fashionable subjects in paintings, with Pompeii providing an endless supply of inspiration to the Greco-Roman school of artists.[17] Sir Lawerence Alma-Tadema, born in Holland, was probably the best known painter of this school. He moved to Italy in 1876 to capture as much of the Roman remains as possible. He painted the Stabian Baths at Pompeii in a work entitled “In the Tepidarium” (fig. 1-6), along with many other scenes set in the Roman baths.[18] Domenico Morelli, a Neapolitan artist, painted a whimsical scene of young women bathing in the same Stabian Baths.[19]

Publications from the 1800s, focused primarily on the medicinal properties of baths, especially natural spas. Included in these are: *The Sanitary Advantages of Baths,*

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[16] Harris 2007, 192-3.
[17] Harris 2007, 194-5, 200.
[18] Alma-Tadema had a collection of 5,300 photographs of ancient architecture and artifacts, particularly Pompeii. Harris 2007, 202-4.
[19] Harris 2007, 201.

Especially the Turkish or Roman Bath, by R. Wollaston, from 1860; *The Roman or Turkish Bath: Together with Barege, Medicated, Galvanic, and Hydropathic Baths*, by J. Lawrie, from 1864; and *The Excavations of Roman Baths at Bath*, by C.E. Davis, from 1884. Thermal resorts became very popular destinations particularly in the 18th century and into the Victorian Period, for the same reasons they were popular in the ancient Roman world. According to Francesco Di Capua, the use of bathing for medicinal purposes was never prescribed or practiced as much as it was during the Roman empire.[20] The hot springs were thought to cure various ailments, including digestive issues, headaches, joint pains, skin diseases, pneumonia, breathing problems, and female disorders. In the ancient world, a trip to the baths was a common prescription given by both Asclepiades, a Greek doctor in the first century BC; and Galen, a physician in the court of Marcus Aurelius. Both drinking of the thermal water and immersion in it were recommended.[21]

Some natural hot springs have dried up, making it very difficult to locate ancient thermal spas; while other ancient Roman thermal sources remained in use in some capacity for centuries. For example, the site of Bath, England was a popular destination both for Romans and for contemporary bathers seeking health remedies and relaxation.[22] The date of the post-Roman discovery of the thermal source is difficult to pinpoint, although it must have occurred by the 12th century when the curative properties of the

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[20] Di Capua 1940, 3.

[21] The works of Asclepiades are lost but his views on bathing are discussed by Celsus (*Med.* 2.17.3) and Galen (*Nat. Fac.*1.12; 6.4, 11.10 (*Opera Omnia* 1965, X.481, X.708, X.723)). Celsus was a writer who discussed medical treatments, but he was not a doctor. Yegül 1992, 353-354; Dvorjetski 1997, 465; Fagan 1999, 11; Jackson 1999, 107, 110, 115.

[22] The ancient Roman site of Bath inspired a county in Virginia with natural hot springs to be named "Bath County". The city of Hot Springs was laid out in 1793. For more information on Bath County, see Morton 1970, 47.

waters of Bath were already well known. A drawing (fig. 1-7) by Thomas Johnson already shows the King's Bath at Bath thriving and busy in 1675. Princess Anne visited the site in 1692, and then again as queen in 1702. Following her sojourn at Bath, the thermal water complex became a trendy location for both aristocrats and commoners to take their holidays.[23] An elaborate Flavian head, once adorning a Roman statue was found at the site between 1714 and 1715, and the gilded bronze head of Sulis Minerva (fig. 1-8) was found in 1727. These discoveries sparked an interest in the earlier Roman site of Aquae Sulis.[24] The Sacred Spring and Temple courtyard were excavated at Bath between 1979 and 1983. The site also underwent excavation work during redevelopment projects between 1998 and 1999 by the Bath Archaeological Trust on the Spa Redevelopment site.[25] Bath continues to be a popular destination for tourists and for patrons seeking the curative properties of the natural thermal springs, and the wonderfully restored archaeological site is an exceptional example of a Roman bath to visit.

The baths at Hamat Gader in Israel are another example of a natural thermal spa. These and other Israeli baths were important enough to be frequented by emperors, including Vespasian, Hadrian, and Caracalla.[26] Three natural hot springs, of varying

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[23] Between AD 675 and the 18th century, the town of Bath was a Christian community of nuns and secular canons. The Pump Room opened in 1706 to take more complete advantage of the spa water. Cunliffe 1984, 7, 11, 16. For more information on Bath, see Davis 1884; Cunliffe 1984; Cunliffe and Davenport 1985; Cunliffe 1986; 1993; 2000.

[24] The major evidence for the Temple to Sulis Minerva came in 1790, with the discovery of six large pedimental blocks. The entrance to the temple precinct was discovered between 1893 and 1895 by Major C. E. Davis, the City Engineer. Cunliffe 1984, 2, 10, 16; Cunliffe and Davenport 1985, 1.

[25] The construction of a new Royal Spa building was planned with very deep foundations, necessitating archaeological work to be conducted before the eventual destruction of any extant remains. Davenport, Poole, and Jordan 2007, xi.

[26] Dvorjetski 1997, 463.

mineral contents, made the area an ideal setting for a bathing complex. Two other regular springs aided in the cooling of water.[27] Although the site's longevity does not match that of Bath, the bathing facilities remained in use perhaps until AD 749. A devastating earthquake destroyed several cities in the region in that year, and the baths were likely abandoned as a result. Hamat Gader was first visited and illustrated in the modern day by Buckingham, in 1816. He reported that the bath building was largely intact, with even upper stories surviving.[28] Sadly, the site has degraded considerably since then, although the area has recently experienced a revival as a thermal resort.

The baths at Baiae, near Puteoli, were considered the best thermal baths of the ancient world. They attracted prominent patrons like Marius, Cicero, Pompey, and Caesar, and were frequented and embellished by emperors, including Nero, Hadrian, and Severus Alexander.[29] Construction at the complex also continued over many centuries: the "Temple" of Mercury (fig. 1-9) is dated to sometime between the Republic and the Julio-Claudian period, the "Temple" of Venus is dated to the Hadrianic period, and the "Temple" of Diana is dated to the Severan period.[30] As already mentioned, these baths were often employed as backdrops in the drawings of architects and artists, and they were admired by tourists on the Grand Tour. Baiae was excavated between 1930 and 1960 by Amedeo Maiuri. The information that has been presented has usually been limited to the

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[27] In most Roman bathing establishments, a great deal of effort and expenditure went into the heating of water and chambers. In a naturally heated bath, the focus was on insuring that the thermal springs were not too hot. For the complete excavation report on the Roman baths at Hamat Gader, see Hirschfeld 1997.

[28] Hirschfeld 1997, 6, 11.

[29] Ling 1979, 33; Dvorjetski 1997, 464.

[30] Guglielmo De Angelis D'Ossat (1977, 235, 256) explains that Amedeo Mauri dates the "Temple" of Mercury to a Republican or Augustan date, while he and John Ward-Perkins and prefer a Julio-Claudian date. The bathing rooms were mislabeled temples in the Middle Ages. McKay 1989, 159; Miniero 2003, 26.

most substantial structures – the “Temples” of Mercury, Diana, and Venus. Moreover, no major publication of these three edifices or of the site exists.[31] Several articles were written about Baiae at the end of the 20th century; some of the subjects addressed include the dating of the major structures, ownership of the site, and bathers frequenting the facilities.[32] Although there are no longer any working spa facilities in the town of Baia, the general area is still renowned for its thermal waters and spa resorts.[33]

IV. Early Excavation Era

Excavations began at Herculaneum in 1738, and at Pompeii in 1748. The first bathing complex to be uncovered in Pompeii was the Forum Baths (fig. 1-10), in 1824.[34] Unfortunately an excavation monograph was never published and very few records were kept. With extensive reconstruction work having been done to the baths, both after their discovery and in recent years, it is very difficult for any scholar to deduce the original appearance of the structure. Small finds that were found *in situ*, were either disposed of or have lost their context; they can no longer provide any supporting data for understanding the site.

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[31] De Angelis D’Ossat 1977, 227-8; Ling 1979, 34.

[32] The article by De Angelis D’Ossat (1977) is largely focused on the three major “temple” structures. Dated to the same year are the articles by Paolino Mingazzini (1977), which examines questions of ownership at the site, and Italo Sgobbo (1977), which details the evidence for actual temples at Baiae. Roger Ling’s article (1979, 35) describes some history of the site, but also illustrates the extant wall paintings is three rooms. He also makes some attempts to determine the function of these three rooms, finding it likely that they were part of a bathing facility. More recently, A.G. McKay (1989, 155-6) attempted to view the baths from a more functional and everyday point of view; this is in keeping with the individualistic focus of the 1980s, which is addressed below. McKay discusses the various types of the bathers who traveled to Baiae, often to seek a cure for their afflictions. She also mentions the nature of the site before it became an extremely popular imperial resort. A later article is written by Medri, *et al.* (1999), describe the Piccole Terme. The focus on a much smaller bathing facility at the Baiae complex is also related to the individualistic focus common at that time.

[33] McKay 1989, 164.

[34] Zevi 1981, 11, 15-16; Koloski-Ostrow 2007, 231.

Archaeological techniques became more scientific in this region as the Italian kingdom became more powerful and more unified. Giuseppe Fiorelli took over the excavations at Pompeii in 1860, emphasizing preservation far more than had ever been done before and employing an organized method and the most advanced technology available at the time.[35] He ensured that not only beautiful paintings and sculptures, but also other archaeological remains were collected and recorded. The Forum Baths (fig. 1-11) at Herculaneum were also excavated in this period, between 1860 and 1875, as were the Central Baths at Pompeii (fig. 1-12), published in 1877 by Fiorelli. August Mau, whose work was published in the late 1800s, was one of the first individuals to see the baths as a potentially endless source of information, rather than just a pretty setting. He examined the baths of Pompeii in order to understand their arrangements, as well as to learn more about Roman architecture and social history.[36] Large portions of Ostia, including the Terme di Nettuno (fig. 0-5) were also excavated at this time, in 1870.[37]

V. Quantitative Analysis

The majority of the publications related to baths from the early part of the 1900s were essentially excavation monographs.[38] The focus was strictly limited to describing the extant remains of bathing complexes and attempting to determine the various phases in the life of the structure. The goal was to compile all the available data and make some vague conclusions without too much speculation. This practice came out of a tradition of

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[35] Zevi 1981, 16.
[36] Fiorelli 1877; Mau and Kelsey 1899; Koloski-Ostrow 2007, 224.
[37] Pavolini 2006, 39-40.
[38] Included in these are Taylor (1911) and Krencker, et al. (1929). One exception was the book by the German engineer, Otto Krell (1901), which explored the heating system of the Stabian Baths.

scientific analysis where the aim was not to make any concrete deductions, but to present the evidence as objectively as possible.

Large bathing complexes and their most important components were the preferred topic, which created a limited view of baths and bathing practices. For example, a book by De Angelis D'Ossat from 1943 solely describes the architecture and heating systems of typical Roman baths.[39] Giuseppe Lugli's 1968 study of the Baths of Trajan and their relationship to Nero's Domus Aurea focuses primarily on the history of the site and on the dimensions of the most important extant rooms.[40] Another illustrative example of the nature of bath publications in the early part of the 20th century is Salvatore Aurigemma's 1955 publication of the Baths of Diocletian in Rome. These baths were excavated in 1947 during the construction of the Termini train station, and they can still be seen in the vicinity of the station. Aurigemma provides only the general history of the site, the measurements of the most important sections, and the present state of the Baths as a museum and a church.[41]

VI. Daily Life

In the late 1960s interest grew in the daily aspects of Roman life throughout the field of Classical archaeology. In 1969, J.P.V.D. Balsdon published *Life and Leisure in Ancient Rome*, which described topics such as the schooling of children, and the

[39] De Angelis D'Ossat 1943.
[40] David Hemsoll (1990, 11) mentions that the Baths of Nero later became the Baths of Titus, not the Baths of Trajan. Larry F. Ball (2003, 250) recommends caution when relating the Baths of Nero to the Baths of Titus, but does suggest that they were structurally related. Lugli 1968.
[41] The majority of the structure is now the Museo Nazionale Romano, while the frigidarium of the Baths of Diocletian is now part of the church of Santa Maria degli Angeli. Aurigemma 1955, 3, 8.

entertainment of Romans through gambling, and attendance of public games.[42] This shift in concentration to the individual's quotidian experience provided a new dimension to ancient studies. As expressed by Kevin Greene, "Archaeology's unique ability to recover ordinary, everyday data can encourage an alternative approach that pays attention to appropriate technology rather than triumphalism".[43] Several other "daily life" publications followed throughout the ensuing decades and interest in the individual continued to increase.[44] In addition, the activities of lower class groups and artifacts of less "artistic" value came to the forefront.

Baths were central to this discussion since they were a part of the daily life of Romans of all social standings, increasing their popularity as a topic of interest. Even ancient sources usually discuss baths from a primarily social or moralistic standpoint.[45] For example, Seneca recounts his frustration over living above a bathing establishment:[46]

> *Supra ipsum balneum habito. Propone nunc tibi omnia genera vocum, quae in odium possunt aures adducere: cum fortiores exercentur et manus plumbo graves iactant, cum aut laborant aut laborantem imitantur, gemitus audio, quotiens retentum spiritum remiserunt, sibilos et acerbissimas respirationes; cum in aliquem inertem et hac plebeia unctione contentum incidi, audio crepitum inlisae manus umeris, quae prout plana pervenit aut concava, ita sonum mutat.*

[42] Balsdon 1969.
[43] Greene 2004, 156.
[44] For other particularly relevant works that focus on the daily life of Romans, see Etienne 1975, Pavolini 1986, Pasquinucci 1987, Zanker 1988, Wallace-Hadrill 1994, Cantarella and Jacobelli 2003, Ling 2005, Butterworth and Laurence 2006.
[45] Unfortunately, most ancient and medieval literary sources ignored the important inner workings of the bathing complexes and the technologies associated with them. Plin. *Ep.* 3.14; Sen. *Ep.* 86.6.
[46] Apartments have been found over bathing facilities, such as the Terme dell'Invidioso at Ostia. Yegül 1992, 66.

> I have lodgings right over a bathing establishment. So, picture yourself the assortment of sounds, which are strong enough to make me hate my very powers of hearing! When your strenuous gentleman, for example, is exercising himself by flourishing leaden weights; when he is working hard, or else pretends to be working hard, I can hear him grunt; and whenever he releases his imprisoned breath, I can hear him panting in wheezy and high-pitched tones. Or, perhaps, I notice some lazy fellow, content with a cheap rub-down, and hear the crack of the pummeling hand on his shoulder, varying in sound according as the hand is laid on flat or hollow.[47]

The way that baths were viewed also changed to adapt to these new theoretical applications. The spotlight shifted from the decorated walls of famous baths to the people enjoying themselves within the space. In his book on daily life habits, Balsdon discussed the moral implications of attending the baths, as well as the hours of their use; instead of dwelling on the phases of any particular bath or describing its existing chambers.[48]

The excavation of the Suburban Baths at Herculaneum (fig. 1-13) began during this period, therefore more material evidence was collected from these baths than from the other Campanian baths excavated at least a century earlier. For example, an imprint left in the ash by a marble *labrum*, or basin, which was flung across the room during the eruption, was left in situ by the archaeologists. Glass fragments from a window that was blown out by the violent seismic activity were imbedded in the ash imprint, and can still be seen there today. In 1999, Umberto Pappalardo wrote an article on the Suburban Baths of Herculaneum in which he looked beyond the structural remains and examined the spaces in terms of their use. The location immediately outside the city, the lack of

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[47] The translation by R. Grummere may contain some errors, but the general idea does not change. Sen. *Ep*. 56.1.

[48] Balsdon 1969, 27, 28-9.

separate sections for men and women, and the erotic paintings on the walls suggested to him that these baths were only used by male fisherman, dock-workers, and travelers.[49]

The Suburban Baths of Pompeii were very similar in many ways to those found in Herculaneum. The Pompeian baths were uncovered between 1985 and 1987, providing the missing link between the early Republican baths and the post-earthquake facilities of Pompeii. Since the Suburban Baths were excavated much later than most other Pompeian baths, a great deal more recording and collecting was practiced here as well, and elements such as service quarters were taken into account.[50] Although erotic paintings were also found in these extra-mural baths, John Clarke does not suggest that women were excluded from this facility. Instead, he claims that the paintings were meant to be both humorous and apotropaic.[51]

The study of Roman baths greatly expanded in the 1980s, and especially in the 1990s, when research on everyday life activities developed further. Several conferences were held, with resultant publications, examining topics such as the presence of women and slaves in baths, hygiene and health, and baths as a reflection of Roman societal

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[49] The Suburban Baths of Herculaneum are dated to the Augustan or early Julio-Claudian era. Pappalardo 1999, 231, 232.

[50] Jacobelli 1999, 221, 225.

[51] Clarke's article (2002) focuses on the Roman gaze, a topic not often taken into consideration before the 21st century. Wherever erotic images were found adorning the walls, it was assumed in the past that the chamber was part of a whorehouse. Luciana Jacobelli (1999, 225), who excavated the Suburban baths, connected the paintings with the surrounding architectural features. The location of each erotic scene above a box for personal belongings in the *apodyterium*, suggests that the images were meant as a comical way for the user to remember which spot was his. Clarke agrees with Jacobelli that the paintings had nothing to do with prostitution. The apodyterium, or changing room, would have been the first opportunity for someone's exposed body to be viewed by others and to illicit jealousy. The pornographic scenes would break the gaze of the evil eye by surprising the onlooker and causing laughter. Clarke finds it most likely that men and women of all social standings patronized this facility, perhaps at different times of the day. The paintings were actually in the process of being covered up and replaced when Vesuvius erupted. Clarke 2002, 149, 151, 155, 156, 177.

norms.[52] Two comprehensive seminal works by single authors, encompassing many aspects of Roman bathing, were also completed in the 1990s: Inge Nielsen's 1990 *Thermae et Balnea: The Architecture and Cultural History of Roman Public Baths* and Fikret Yegül's 1992 *Baths and Bathing in Classical Antiquity*.[53] Nielsen states her intention in the introduction to examine Roman baths in terms of their greater context, while encompassing many of their standard elements. She discusses issues of Hellenization, Romanization, and urbanization, in addition to the "daily life of the individual Roman".[54] Yegül also analyzes the origins of bathing and some daily life aspects, in addition to the socially inclusive nature of baths, the structural layout of bathing facilities, and the relation of baths to medicine.[55]

In 1999, Garrett Fagan published a book entitled *Bathing in Public in the Roman World*, which focuses primarily on the social aspects of bathing throughout the empire through the use of epigraphical sources. He begins the volume with evidence provided by Martial, concerning the differences between the definitions of *thermae* and *balneae*. Fagan concludes that the primary difference between *balneae* and *thermae* is that *balneae* were "rather functional, poorly lit facilities sporting stucco, rather than marble,

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[52] Included in these are: *Les Thermes Romaines: Actes de la table ronde organisée par l'Ecole française de Rome (Rome, 11-12 novembre 1988)* published in 1991, and *Roman Baths and Bathing: Proceedings of the First International Conference on Roman Baths held at Bath, England, 30 March – 4 April 1992* edited by Janet DeLaine and D. E. Johnston in 1999. Another work edited by Marinella Pasquinucci (1987), entitled *Terme Romane e vita quotidiana*, provides concise articles summarizing the different elements of bathing establishments.

[53] Yegül's study covered many aspects of ancient baths. He also focused on some specific baths, including the Greek baths at Olympia, the Roman baths of North Africa, and the naturally heated baths of Baiae. Yegül's work on the Baths of Baiae resulted in an article (1996), entitled "The Thermo-Mineral Complex at Baiae and De Balneis Puteolanis". Yegül also published a book specifically on Roman bathing in 2010. Nielsen 1990; Yegül 1992, 2010.

[54] Nielsen 1990, 1.

[55] Yegül 1992, 2.

decoration and lacking statuary and other ornate refinements."[56] Fagan then examines Martial's choice of bathing facility in order to determine which were considered more fashionable than others.[57] Another section discusses the importance of status in the baths. Stories concerning Cicero, Larcius Macedo, and Hadrian convince Fagan that there was no social segregation in the baths.[58] The work concludes with literary sources that name benefactors of the baths, as well as other texts not directly related to benefaction.

Another aspect of late 20th century bath scholarship was that many smaller and more provincial bathing establishments were both excavated and included in studies.[59] The thermal baths at Hamat Gader, mentioned above, were an early example. They were excavated between 1979 and 1982, and the excavation report was published in 1997.[60] Topics that are presented in the report include not only descriptions of architectural remains, but also studies of oil lamps and hot springs. Valesio, a small site between Brindisi and Lecce in southern Italy, was excavated between 1984 and 1987, in a region where no Roman baths had previously been found. The Hadrianic baths at Lepcis Magna, in Libya, were published in the 1990s. This work was actually one of the first archaeological publications on North Africa, perhaps due in part to the conflicts between

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[56] Yegül (1992, 43) mentions that the difference between *balneae* and *thermae* is that *balneae* were usually small privately owned and operated facilities, while *thermae* were usually large facilities owned and operated by the state. Fagan 1999, 19.
[57] Fagan (1999, 19) concludes that Martial frequented various baths according to who he was with at the time, although it seems that his favorite were the Thermulae of Etruscans. Mart. 2.48, 3.25, 3.36.5-6, 6.42, 7.34.4-5, 10.48.3-4, 11.52.4, 12.83, 14.60; Fagan 1999, 15-16, 19-20.
[58] Fagan 1999, 206-19.
[59] The provinces were also being addressed at the same time in the field of Roman painting. Boersma 1991, 161. See Liversidge 1982, for more information on Roman wall painting in the provinces.
[60] Hamat Gader was under Syrian control between 1952 and 1967. Excavations of the bath buildings did not ensue until it had been returned to Israeli authorities. Hirschfeld 1997, 2, 9.

Libya and other western countries.[61] The excavations of the Roman Baths in Lycia, in southwest Asia Minor, were also published in 1995. Although the volume discusses extant structural remains, other topics are also included, such as the bathing habits of the Lycian people and the movement of bathers through the bath building.[62]

Specific bathing complexes were also published in new ways in this time period. Although quite a number of publications focused on the Baths of Caracalla in the 1990s, Janet DeLaine's 1997 work put the baths into a completely new context – that of a Roman engineering project.[63] As both a civil engineer and an archaeologist, she was in the unique position to view the baths from both a structural and a social perspective. She examined factors such as the construction process, the design process, and the procurement of necessary materials. She also attempted to determine the overall cost of the construction venture, as any engineer would do before beginning a project.[64] Her interdisciplinary approach, factoring in engineering, archaeology, and economics, set the stage for future works, especially this study.

VII. Technology, Health, and Hygiene

The study of Roman baths declined after the 1990s, but some important research continues to be published. The focus has shifted, however, from social questions to primarily technology, health, hygiene, and medicine. The technology of Roman baths had

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[61] On North African Baths, see di Vita-Évrard 1991; Lenoir 1991; Thébert 1991; Wells and Garrison 1999; and Thébert 2003.

[62] For the complete excavation report on the baths of Roman Lycia, see Farrington 1995.

[63] For more information on the Baths of Caracalla, see Confronto 1991, Manderscheid 1991, Lombardi and Corazza 1995, DeLaine 1997, and Piranomonte 1998.

[64] DeLaine 1997, 11, 19, 45, 85, 91, 207-15.

already received some attention in the beginning of the 20th century, and analyzing the heating of the baths was the focus of several early studies. In 1903, Otto Krell's German engineering dissertation concluded that Roman baths were not heated by hypocausts or radiant wall heating, but simply by braziers. Günter Schween, another German engineer, wrote a dissertation at the Technischen Hochschule in Dresden in 1936 on the heating systems of the Stabian Baths of Pompeii. He focused on disproving the work of Krell and on determining the value of the temperature inside the hypocaust when it was in use. A more recent study was conducted by Andrea Jorio, an Italian engineer at the Istituto di Fisica Tecnica at the University of Naples, between 1978 and 1979. Jorio examined the publications of Krell and Schween, while conducting some of his own research; he found Krell's solution to be impossible and illustrated the necessity of having heated walls in the system. He also attempted a very basic fuel consumption study.[65] Each of these works was produced by engineers, who lacked a proper understanding of the cultural and social implications of baths. Even elements like construction materials or the kind of wood that was burned were not taken into account.

A non-technical analysis was attempted in 1999 by Henry Blyth. He compared a post-AD 100 inscription of a bill from a bath at Altinum in Venetia (northern Italy) to ancient documents discussing the income from wood crops, the price for individuals to bathe, and the cost to transport a cartload of wheat, in order to determine the amount of wood used in these baths each day.[66] Although this study can be seen as a good

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[65] For a closer look at these heat studies, see Krell 1901, Schween 1936, and Jorio 1981-1982.
[66] Blyth 1999.

beginning, several pitfalls are encountered when relying solely on ancient documents for evidence, as the accuracy of the written sources is often impossible to prove.

The most promising work on the topic of fuel consumption was undertaken by Tony Rook in 1978. He used the Baths at Welwyn in England, where he was the director of the excavation, to conduct a fuel consumption study. Having a background in both engineering and archaeology allowed Rook to view the problem with a wider perspective. He was forced to keep his study relatively simple, however, and he realized with later research that some of his assumptions were invalid.[67]

In the early 21st century, the study of the technology of baths has greatly expanded, incorporating an interdisciplinary method and experimental archaeology. For example, Yegül worked in collaboration with several scholars and engineers to construct a small Roman bath near the ancient site of Sardis in Turkey in 2003. After the bath was finished, the team heated it and took a bath as the Romans would have. The bath was also examined while in operation, testing the thermodynamic and heat transfer properties of the structure.[68]

Water technology and distribution is another component of Roman technology, related to the baths, which has become relevant in the 2000s. The *Handbook of Ancient Water Technology* by Ö. Wikander came out in 2000, and Christopher Ohlig published a

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[67] Insufficient structural remains did not provide information on the total height of rooms or on the placement of doors and windows. Moreover, the study preceded widespread availability of computers to aid in the computation of extensive amounts of data. After visiting a Turkish *hamam*, Rook (2002b, 17) determined that his assumed temperatures were too high. Rook continues to generate studies of this type that will certainly contribute to the field. Rook 1978, 272.

[68] The whole operation of constructing the bath, bathing in it, and testing its properties was filmed by television cameras and produced for a NOVA television program. For information and photographs from the program, see: WGBH Educational Foundation 2000. Yegül published an article with Tristan Couch in 2003 discussing the experience and the experimental results, entitled, "Building a Roman Bath for the Cameras."

highly comprehensive volume on the *Castellum Aquae* in Pompeii and the distribution of water throughout the city in 2001.[69] Ann Olga Koloski-Ostrow compiled a seminal work on Roman water use in 2001, which includes articles on water as a prestige symbol and water pipe systems. Koloski-Ostrow deals with sanitation and toilets in the 2011 volume *Roman Toilets: Their Archaeology and Cultural History*, along with Gemma C.M. Jansen and Eric M. Moormann.[70]

Health and hygiene were associated with the baths, especially the healing properties of the thermal spas, as early as ancient times. Several publications in the 1800s, as already mentioned, evaluated the regenerative abilities of the springs as well. Hygiene was also an important topic in the 1800s, with cleanliness being seen as a way to prevent rampant disease. For example, in a lecture given in 1859 to the Literary and Philosophical Institution in Cheltenham, Robert Wollaston, a medical doctor, expressed concern over the squalid state of the poor within the city. He also extolled the benefits of "Turkish" baths for curing all manners of ailments, and encouraged the city to construct such facilities at once.[71] In 1903, C.H. Shepard published, *Hygene of the Turkish Bath*, but health and hygiene have not been popular topics of study since then, until the 21st century.[72]

Domestic sanitation issues were put forth in David Eveleigh's 2002, *Bogs, Baths and Basins: The Story of Domestic Sanitation*. His chapter, entitled "Recalling Pompeii:

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[69] Wikander 2000; Ohlig 2001.
[70] Jansen, Koloski-Ostrow, and Moormann 2011.
[71] Robert Wollaston was inspired by the results of thermal baths that he witnessed while on the medical staff of the British Army stationed in Turkey. Wollaston 1865, 5, 6-7, 14.
[72] The only exceptions were studies on the history of medicinal baths at natural thermal spas. Estée Dvorjetski (1997) published such an article in the volume on the Hamat Gader excavations.

The Rise of the Bathroom", briefly mentions the Roman baths.[73] Two recent works examine purity and hygiene in close connection to bathing throughout time; these include V. Smith's *Clean: A History of Personal Hygiene and Purity*, and Katherine Ashenburg's *The Dirt on Clean: An Unsanitized History*. Ashenburg's chapter on Greek and Roman bathing, is referred to as the "The Social Bath". Both works are dated to 2007, and both examine the importance of hygiene and purity in each period, from Homer to the present. They also both examine the history of hygiene campaigns, particularly in large cities.[74]

The study of medicine in the ancient world has also become an increasingly popular topic in the 21st century. The history of baths as medical remedies had often been mentioned in conjunction with ancient physicians. Helen King published books on ancient medicine – *Greek and Roman Medicine* in 2001, and *Health in Antiquity* in 2005. The 2005 work, an edited volume, included articles on the history of medicine and disease in the Prehistoric Aegean, health and life in Herculaneum and Pompeii, and hygiene at dinner and at the symposium.[75] In 2005, P.J. Van der Eijk published a volume on classical medicine, *Medicine and Philosophy in Classical Antiquity:Doctors and Philosophers on Nature, Soul, Health and Disease*.[76] Ancient sources were the primary organizational tool of this work. Fagan also used ancient sources in his 2006 article, in order to illustrate the healthful benefits of bathing according to ancient Romans.[77]

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[73] Eveleigh 2002, 84.
[74] Ashenburg 2007; Smith 2007.
[75] King 2001; 2005.
[76] Van de Eijk 2005.
[77] Fagan 2006.

VIII. Conclusions

Roman baths had an enormous impact in ancient times and have greatly influenced the modern world. Throughout the centuries, their architectural innovations, social settings, and medicinal benefits have inspired building designs, paintings, and spas. Baths served as sources of building material since their abandonment, and they provided wealthy patrons with fantastic works of Roman art to add to their prestigious collections. Extant bath buildings, particularly those at Pompeii, were common destinations for wealthy young aristocrats to enjoy Roman ingenuity; they also served as classrooms for young architects and artists. Thermal spas were utilized in much the same way as Romans had made use of them, with many of the ancient sites becoming popular retreats in the Victorian period and beyond.

Roman baths were initially studied simply as structural remains, with an emphasis on construction techniques and phasing. Little attention was paid to what actually went on in the baths until the later part of the 20th century when the focus on daily life studies thrust the bathing facilities to the forefront. The complexes were examined as settings for patron-client relations, as evidence for social interactions and class divisions, and as lewd centers of moral corruption. The way bathers moved through the buildings and the hours that they patronized the baths were also taken into account to better understand the bathing procedure and the arrangement of the Roman day. Applications of ancient technology were more carefully examined, and modern technological advancements were applied more extensively to bathing studies in the 21st century. Historical studies of health and hygiene also took on a central role, incorporating the use of Greek and Roman bathing facilities in this context.

As archaeological and theoretical practices continue to evolve, the study and importance of Roman baths will continue to expand and develop. There are still several topics related to baths that have not been examined in very much detail thus far. For example, a comprehensive study of evidence demonstrating the presence of extra amenities in bathing complexes, including massage parlors and dental services, could provide more insight on the layout of periphery rooms and on the way baths were managed. Were there specific rooms designated for these purposes? Can these be identified? Were masseuses hired by the bath facility, or did they show up and provide services? Another topic which has received little direct attention is the safety of important individuals in the baths. Did the emperor really interact with the common plebian, or were the public baths shut down for his private use? Did he bathe with an entourage of body guards, or just use private facilities like those at Tivoli? Finally, although studies have been conducted on the heating systems of Roman baths, a more thorough and accurate evaluation is needed. How much fuel did the baths actually consume? How significant was the difference between the various types of fuel sources in efficiency and cost-effectiveness? Was it more sensible to keep the baths heated at all times rather than letting them cool at night? Some of these questions may not have easily-attainable answers and may never be fully answered, however, the questions related to heating and fuel are presented in the coming chapters.

Chapter 2: The Heating System of Roman Baths

Roman baths were hotbeds for invention and advancement in architecture and especially in technology. They employed a particularly ingenious method of radiant floor and wall heating, which made the efficient control of uniform temperatures possible. The furnace, or *praefurnium*, provided the energy both to heat the rooms of the baths and to heat the boilers used to fill pools and basins with hot water. As a result, the layout and organization of a bathing complex was often planned in order to optimize the use of these heating implements.[1] The components of this heating system are discussed in detail in the first part of this chapter below, as are heated ceiling vaults. The Terme del Foro, the focus of the current research, were heated using this type of system. The preservation of each of these features is examined briefly.

Considering other factors affecting fuel consumption in Roman baths, including sunlight, windows and openings, and heating water, is also necessary. The role of sunlight could be substantial, as is presented below, and maximizing the infiltration of solar radiation into a heated space was beneficial to the heating system. Windows could be sources of both heat gain and heat loss, which in part depended on whether or not they were glazed. Boilers and the *testudines alveolorum* system were used to heat and sustain the temperature of water in pools. The hours of operation maintained by typical bathing facilities, as well as the types of fuel used to heat the baths are important factors. A

[1] Kretzschmer 1958, 69; Yegül 1992, 356.

discussion of each of these factors, as well as their presence in the Terme del Foro at Ostia, completes the second part of this chapter.

I. The Heating Implements

The heating system of Roman baths was formed of several components working in a symbiotic way to control efficiently the temperature of several different rooms at once. The energy for each element originated in the *praefurnium*, and it moved beneath the elevated hypocaust floors of the heated rooms. The remaining heat then passed up through the hollow spaces in the walls that were formed by either *tegulae mammatae*, *tubuli*, terracotta spacer pins, or terracotta spacer tubes. Finally the remaining energy was expelled from the chimneys, and some heat was lost through the ceilings and the fabric of the bathing rooms.

I.a. The *Praefurnium*

The *praefurnium*, or furnace system, was essential for heating a Roman bath building. The hypocaust, the walls, and the water in the boilers could all be heated by the same furnace at once, ensuring that as little energy as possible was wasted (fig. 2-1). *Praefurnia* were constructed of tuff or other fire resistant brick, and they usually included a low arch that opened directly into the hollow area under the space to be heated (fig. 2-2). The opening of the furnace could also be formed by a simple stoke hole, or a small square hole with a stone lintel.[2] The fire was built in front of or under the opening.

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[2] A furnace is defined by Rehder (2000, 13) as an enclosed space where temperatures above 250 degrees Celsius are reached. Most organic materials start to char at this temperature. Enclosures reaching lower

The furnace opening was restricted occasionally by the introduction of a pair of spur walls (fig. 2-3) that projected out for a short distance, creating a sort of channel. This channel served to increase the air draft in the system, which improved the circulation of the hot gases.[3] Boilers were sometimes placed on top of the spur walls in order to take advantage of the heat.[4] Unlike most modern furnaces, Roman furnaces lacked metal grates, and the fire was built directly on the floor. Consequently, it can be deduced that the furnaces employed very slow oxidation rates and combustion levels. The openings could still be closed with metal or stone gates if necessary, in order to damp down the fire.[5]

I.b. Chimneys

Chimneys must have been used in conjunction with the furnace, although they are rarely preserved in the archaeological record. Evidence of their use can be seen through the presence of triangular or square openings found at the level of the springing of vaults. One such opening may appear at Hadrian's Villa in Tivoli (fig. 2-4). Chimneys were

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temperatures are referred to as ovens. On the effects on combustion of the size and shape of a furnace, see Rehder 2000, 15-24. Jorio 1981-1982, 172; Yegül 1992, 368-9; Lombardi and Corazza 1995, 30; Yegül 2010, 90.

[3] The amount of air that a fire receives affects the intensity of the flame and the speed at which the fuel burns. Therefore, it was important to construct the *praefurnium* and its surroundings in such a way to allow for the proper levels of air flow. Enclosing the fire as much as possible leads to a more thorough control of the natural air draft and suction created by the heated air. Rehder (2000, 9, 74) defines natural draft a "a negative pressure caused by the density of hot gas within the fuel bed being lower than that of ambient external air. Basaran and Ilken (1998, 5) estimate that 5.8884 kilograms of air were needed to burn one kilogram of wood. They do not specify what type of wood they are testing, though. Air flow could also be generated by using a blowpipe or a bellows. Yegül 1992, 368; 2010, 90.

[4] An iron cage was found in the Legionary Baths at Exeter. One interpretation, as explained by Paul T. Bidwell (1979, 31), is that this metal element was used to prevent fuel from falling into the hypocaust. He also mentions that it may have been used instead to support a pool. Brödner 1983, 20, 155; Nielsen 1990, 17; Yegül 1992, 357, 361, 368-9; Lombardi and Corazza 1995, 30-1; Rehder 2000, 30; Yegül 2010, 91.

[5] Brödner 1983, 20, 155; Nielsen 1990, 17; Yegül 1992, 357, 361, 368-9; Lombardi and Corazza 1995, 30-1; Rehder 2000, 30; Yegül 2010, 91.

sometimes as simple in form as a pipe that led from the hypocaust through the wall or through the roof to the outside. If wall heating was present, a pipe would have led to the outdoors from the top of a section of hollow wall, or from the top of a single row of *tubuli*. When discussing the construction of hollow walls, Vitruvius mentions the importance of leaving "airholes" in order to expel moisture.[6] He is most likely referring to chimneys.

Not only was the chimney necessary to expel "moisture" and spent gases, but also it was necessary to maintain the proper movement of the heated air within the system.[7] Although some movement of gases would have occurred anyway (as air cooled it descended into the hypocaust, only to rise back up into the walls as it was reheated), the chimneys facilitated this process. They created a continuous draft or suction effect, circulating the air efficiently, thanks to the extreme differentiation of the air temperature between the hypocaust and the outside.[8]

I.c. The Hypocaust

The hypocaust, which literally means "a furnace that heats from below", was central to the controlled heating of a Roman bath.[9] The hypocaust was formed by placing the floor of a room on top of short supports in the form of pillars, called *pilae* by Vitruvius.[10] Spacing the *pilae* apart at relatively even distances allowed heated air to

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[6] Vit. *De Arch.* 7.4.1-2; Nielsen 1990, 15.
[7] Yegül 1992, 357-8, 381.
[8] Yegül and Couch 2003, 170, 171.
[9] The major advantage offered by this system, according to Yegül (1992, 381), was the fact that furnaces could be kept at low temperatures with a slow burning fire, and that there was a low draft with only minor chimney loss. Jorio 1981-1982, 172; Yegül 1992, 356.
[10] Vitr. *De Arch.* 5.10.2.

circulate freely under the floor (figs. 2-5, 2-6).[11] They were usually formed with individual round or square terracotta tiles, placed one on top of the other, and secured with plaster.[12] Other shapes and materials were sometimes employed for the tiles, particularly in the eastern part of the empire.[13] In some cases *pilae* were even composed of several different forms within one hypocaust.[14]

The preservation of hypocausts and sub-floors in situ is relatively common, and sometimes these are the only parts of the baths that remain. Being built as partially subterranean helped to protect these features from damage. Often, however the *pilae* are much shorter than they were initially, and it is not always possible to determine the exact number of rows and columns in the original layout. A good test sample should have a least one *pila* that still supports a segment of floor in each heated room, illustrating the

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[11] Often the spacing between the *pilae* appears initially to be equidistant. When measured in the field, however, the separation is more haphazard. In addition, the pillars are often farther apart from north to south than from east to west, or vice versa.

[12] In the Piccole Terme at the luxurious bathing resort at Baiae, near Naples, the *pilae* were formed of singular terracotta cylinders that flared into flat elements on the ends. Similar pillars were used at the second century AD Roman bath-house at Bir el Jebbana, which is located on the western edge of Carthage. The terracotta pillars were only used in one heated room, while the other heated rooms employed regular rectangular *pilae*. The reason for this disparity is unclear. Rossiter 1998, 103, 109, 110.

[13] Round tiles forming *pilae* were more common in the eastern empire, and can be seen in the Small Baths of Phaeselis, in Turkey. In the Roman baths in Fiesole, the *pilae* were formed of octagonal terracotta tiles. In the East Baths of the Upper Gymnasium at Pergamon and in the large Roman baths of Mactar in Algeria, they were made of stone instead of terracotta. Yegül (1992, 357) describes a unique hypocaust in the Barbara Thermae at Trier in Germany, which is composed of a double-storied hypocaust. Corbels projecting from the walls were used to assist in the support of the hypocaust floor in the Legionary Baths at Exeter. Bidwell 1979, 26; Jorio 1981-1982, 172-3; Bellini delle Stelle, Mannari, and Sabelli 1984, 43; Shepard 1987, 42; Yegül 1992, 357-60, 363; 2010, 83.

[14] An example is the hypocaust in the *caldarium* of the Great Baths on the Lechaion Road at Corinth. The pillars of this heating system vary both in shape and dimension. The disparity can be attributed to numerous repairs and restorations conducted on the facility. Biers 1985, 43.

approximate original height of all of the *pilae*.[15] Vitruvius described the hypocaust system and its construction thus:

> *Suspensurae caldariorum ita sunt faciendae, ut primum sesquipedalibus tegulis solum sternatur inclinatum ad hypocausim, uti pila, cum mittatur, non possit intro resistere, sed rursus redeat ad praefurnium ipsa per se; ita flamma facilius pervagabitur sub suspensione. supraque laterculis besalibus pilae struantur ita dispositae, uti bipedales tegulae possint supra esse conlocatae; altitudinem autem pilae habeant pedes duo. eaeque struantur argilla cum capillo subacta, supraque conlocentur tegulae bipedales, quae sustineant pavimentum.*
>
> The hanging floors of the hot baths are to be made as follows: first the ground is to be paved with eighteen inch tiles sloping towards the furnace, so that when a ball is thrown in it does not rest within, but comes back to the furnace room of itself. Thus the flame will more easily spread under the floor. On this pavement, piers of eight inch bricks are to be built at such intervals that two foot tiles can be placed above. The piers are to be two feet high. They are to be laid in clay worked up with hair, and upon them two foot tiles are to be placed to take the pavement.[16]

Vitruvius's description is useful as a guide, however, the archaeological record presents much more variation. Instead of being two Roman feet high, or 0.592 meters, *pilae* most commonly ranged in height from 0.65 to 1.00 meter depending on the bathing facility. Many do not survive to such heights today.[17] The length or diameter of the individual tiles usually ranged between 0.60 and 0.80 meters on center.[18]

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[15] Some variation may have existed in the heights of the *pilae*, particularly if the landscape was somewhat sloping. The possible variation would have been minimal within a room, however, and can be ignored for the purposes of this study.
[16] Vitr. *De Arch.* 5.10.2, translated by Frank Granger, 1955.
[17] Sometimes the height of the *pilae* could reach over 1.70 m. In the South Baths at Perge in Turkey, the *pilae* are 1.50 m high. In order for this high floor to be supported, it was necessary to improve the stability of the pillars by placing arches connecting them from east to west. A similar hypocaust arrangement exists in the fifth century AD baths at Dinogetia in Dacia. The pillars in this bath are extant to a height of approximately one meter, suggesting they were originally higher. Faventinus (*Artis architectonicae privatis usibus adbreviatus liber* 16.2), a 4th century author who reworked the writings of Vitruvius, suggested 2.5

The *pilae* were usually placed on top of a sub-floor that consists of large terracotta tiles, called *bipedali*. The *bipedali* created a smooth, relatively impervious surface for the rest of the structure to be constructed over. The sub-floor was made to slope down towards the *praefurnium* to facilitate the upward flow of the hot air in the proper direction, as described by Vitruvius.[19] Only the heated gases ever came into contact with this space under the floor, but never the flames from the fire. Moreover, the hot gases did not enter the rooms, only the heat radiated to the surface through the floor.[20] The floor, itself, usually consisted of several layers. The first layer, above the *pilae*, was formed of *bipedali*. Then there was a layer of concrete or mortar 0.20 to 0.40 meters in thickness, and the top surface of the floor was sealed with marble slabs or mosaic pavements.[21]

A major benefit of the heating system used to heat Roman baths was that after heated air entered the hypocaust it was reused as much as possible, beginning with spreading beneath the whole space of the floor of the *caldarium*. A portion of the air then went up through the hollow walls, and then some of it exited through the chimney. When hollow ceiling vaults were present, the same hot air would have continued moving through them.

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feet (0.74 meters) for private baths and 3 feet (0.89 meters) for public baths. Barnea 1967, 234; Jorio 1981-1982, 173; Shepard 1987, 42; Yegül 1992, 357; Schiebold 2006, 12; Dinchev 2007, 501.

[18] Jorio 1981-1982, 173; Yegül 1992, 357.

[19] Vitr. *De Arch.* 5.10.2; Shepard 1987, 42; Lombardi and Corazza 1995, 31; Schiebold 2006, 11.

[20] Plutarch (*Quaest. conv*. 3.658E or 3.10) mentions that the darnel seed should not be thrown in the fires of the baths, as its fumes cause headaches in the bathers. He is likely referring to fires lit in braziers within the actual bathing space, though, rather than fires in the furnaces below the baths. Jorio 1981-1982, 172; Nielsen 1990, 17; Yegül 1992, 357; Yegül and Couch 2003, 169.

[21] Thin slabs of shale were used instead of *bipedali* to form the first layer of the floor in the Large South Baths at Timgad. Yegül 1992, 357.

In many baths, the hypocaust of the *caldarium* was connected to that of the *tepidarium*.[22] The hot air moved below the floors from the hot room to the warm room with the assistance of the graded sub-floor. Along the way to the *tepidarium*, some of the heat energy was lost through the floors and the walls of the room above. Even the hypocaust pillars and the sub-floor tiles absorbed some heat. The loss of the heat energy was actually a benefit in this case, however, since the hypocaust of the *tepidarium* needed to be cooler than that of the *caldarium*. In baths where all of the heated rooms had their own *praefurnia*, such as in the Terme del Foro at Ostia, lower temperatures would have had to be produced in the furnace from the beginning.

I.d. Wall Heating

The walls of the Roman baths were another essential element in heating the bathing facilities, as already alluded to. Like the floors, the walls were constructed to be hollow so that hot air could pass through the space and radiate heat into the adjoining room. The application of hollow, or double, walls in baths created a way to provide radiant heating, a way to use the remaining energy in hot gases from the hypocaust, and a way to maintain the proper temperature of rooms more easily. Yegül called this method of heating walls a major breakthrough for both technology and architecture because it allowed for a tremendous increase in the size of heated rooms in baths, without

[22] An example, described by Bidwell (1979, 26) is in the Legionary Bath House at Exeter in England, which allowed for the communication of heated air between the *caldarium* and the *tepidarium* by means of six low archways. Another example I have observed is in the bath at Dion, in northern Greece. The section of this bathing facility heated by hypocaust consists of three rooms in a row, running north to south. Heated air passed under archways between the hypocausts of the three rooms. Three archways 0.60 meters wide are extant, connecting the northern room to the middle room, and it is likely from the layout that can be observed in situ that there was a fourth archway. In addition, a *praefurnium* can be observed in the west wall of the middle room, and possibly the remains of another one in the east wall of the middle room.

compromising the temperature.[23] Since more surface area was heated and could serve as a radiator, the system could be heated to a lower temperature, thereby consuming less fuel.[24] This system also made it possible for walls to be punctured with large windows without compromising the flow of heat.

Several different methods were employed to create these cavities in the walls, including *tegulae mammatae* (figs. 2-7, 2-8), terracotta spacer pins and tubes (figs. 2-9, 2-10), and *tubuli* (figs. 2-11, 2-12).[25] Vitruvius, as well as some modern scholars, states that the purpose of the hollow space was to keep the walls of the heated rooms from becoming damp due to humidity.[26] Walls were kept warm and dry by this system, but it is more likely that they were primarily installed as part of the radiant heating process. Otherwise, it is improbable that the expense of such a system could be justified. Moreover, when tested in the experimental bath created near Sardis for the NOVA television series, it was shown that without the contribution of the heat energy from the walls, the floors would have had to be heated to 62 degrees Celsius instead of between 42

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[23] Yegül 1992, 363; 2010, 86.
[24] Yegül and Couch 2003, 169.
[25] Determining which wall heating system was invented first is very difficult, and many differing scholarly views exist. The technologies may have also developed relatively independently from each other. Before the discovery of the baths at Fregellae, it was thought that the heating technology of the *tubuli* was the latest and most advanced form. The *tegulae mammatae* were seen as a predecessor that sharply declined with the invention of *tubuli*. Yegül (1992, 363; 2010, 87) suggests that the terracotta spacer pins were an even more rudimentary form of the *tegulae mammatae*, while Kelly (2006, 243, 247) refutes the possibility that the pins were more primitive by illustrating that their dates vary widely. The pins from Quzayr ‘Amra in Israel have been dated to the eighth century AD, and the bath utilizing spacer pins at Amorium in Turkey has been dated between the sixth and ninth centuries AD. Farrington and Coulton 1990, 63, 66; Koçyiğit 2006, 113; 2007, 310.
[26] Lombardi and Corazza (1995, 31) state that reducing condensation was the major reason for installing double walls, and that the system was only used for heating in cases when chimneys were also found. As mentioned above, however, air would not have sufficiently circulated in walls without chimneys. Most chimneys are missing from the archaeological record, since most walls do not survive to sufficient heights, often making it impossible to know if they were originally present. Vit. *De Arch.* 7.4.1-2; Jorio 1981-1982, 175, Shepard 1987, 43; Yegül 1992, 363.

and 43 degrees Celsius.[27] In addition to consuming more fuel, this temperature would have been dangerous for patrons to walk on.

Tegulae mammatae can be described as large, rectangular tiles with bosses, or nipples, projecting from their corners.[28] When attached to the walls with T-clamps or nails with the bosses facing inwards, a void for hot gases was created. The earliest known use of *tegulae mammatae,* dated to the first century BC, is in the women's *caldarium* and *tepidarium*, the men's *tepidarium*, and portions of the men's *caldarium* in the Stabian Baths of Pompeii.[29] Although *tegulae mammatae* have often been viewed as an earlier or more rudimentary system, they were uncovered in the Great Baths on the Lechaion Road at Corinth, which date to either the late second century AD or the early third century AD.[30] There is no conclusive evidence for the use of *tegulae mammatae* at Ostia.[31]

Terracotta spacer pins are composed of a solid cylindrical shaft with one end formed like a spool. The spool head was made with wide grooves so that terracotta tiles, usually *bipedali*, could be secured in place by them. The other end of the pin was chiseled and secured in the fabric of the wall with mortar.[32] This system created a final product very similar to the *tegulae mammatae*.[33] The benefit of using this method of heating is

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[27] See Chapter 1, 48 for more on the NOVA bath. Yegül 2010, 89.
[28] Another form of *tegulae mammatae* was created through the reuse of roof tiles. The upturned edges of the tiles were broken off, leaving only small bits at the corners. These cheaper versions were known as *tegulae hamatae*. Nielsen 1990, 15; Yegül 1992, 363; 2010, 46.
[29] Jorio 1981-1982, 175; Shepard 1987, 43; Yegül 1992, 363, 365, 464 n. 23; 2010, 46, 87.
[30] The bath was no longer in use by the end of the sixth century AD, although repairs and restorations were made to the facility until the beginning of the sixth century. Biers 1985, 46, 61-2.
[31] According to Grégoire Poccardi (2001, 166), a rudimentary heating system similar to *tegulae mammatae* was found in the Terme dei Cisarii. He does not find that this mechanism would have worked very efficiently, however, and he does not describe the implement in detail. Only two tiles that resemble *tegulae mammatae* are found when inspecting the wall heating on site. The tiles are only 0.40 meters in length, suggesting they may have been reused elements from somewhere else or part of modern restorations.
[32] Farrington 1995; 102; Kelly 2004-2005, 611; 2006, 240.
[33] Yegül 1992, 363.

that the spacer pins could be thrown on a potter's wheel, making them very cheap and easy to produce.[34] Terracotta spacer pins have been predominantly found in the eastern part of the Roman empire, especially in Western Anatolia, Cyprus and Crete. They have also been found in North Africa and modern Israel, but not in Italy.[35]

Similar implements, identified by Yegül as terracotta spacer pins, were found at the Great Baths on the Lechaion Road at Corinth and at Amorium in Phrygia. Amanda Kelly points out, however, that there are substantial differences between these two types of artifacts. The pins found in Corinth are hollow tubes used in conjunction with metal pegs that fit inside them. The metal pegs were used to fasten the pins to the walls.[36] The spacer tubes enclosed the iron thereby protecting it from corrosion.[37] The pins and the tubes would have worked otherwise in essentially the same way, although the tubes would have been more costly since they incorporated the use of metal elements.

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[34] The manufacture of the spacer pins has been shown to be closely associated with amphora production centers, particularly on the island of Crete. Farrington and Coulton 1990, 57, 58; Kelly 2004-2005, 613, 624 fig. 9; 2006, 245.

[35] Terracotta spacer pins have been found at several sites, including Malia, Gortyna, Knossos, Chania, and Eleutherna on Crete; Balboura, Ephesus, Phaselis, and Pergamon in Turkey; Kourion in Cyprus; Mactar, Timgad, Hippo Regius, and Volubilis in North Africa; and at the site of Quzayr 'Amra in Israel. The South Baths of Perge in Turkey may have also had terracotta spacer pins, according to and Andrew Farrington (1995, 114 n. 7). Their use was originally unclear until a spacer pin was found in situ in a bath at Balboura in Lycia in 1986. They were interpreted previously at Knossos as anti-earthquake devices for vaults by J.W. Hayes, and they were often mistaken for amphora stoppers. Evidence for the use of terracotta spacer pins continues to be missing from the material record on mainland Greece, Italy, the Levant, and the north-western empire. On the other hand, they are very common in the baths of Lycia and other parts of modern Turkey, where *tubuli* are largely absent. In fact, terracotta spacer pins were being used widely in Lycia from the Flavian period (AD 69-96) to at least the sixth century, suggesting that they were a regional variation. Koçyiğit (2007, 311) suggests that the spacers may have been developed specifically in the eastern Mediterranean. Hayes 1983, 103; Karageorghis 1987, 33; Farrington and Coulton 1990, 55, 63-4; Farrington 1995, xx, xixx, 102; Kelly 2004-2005, 611, 614, 615; 2006, 240; 242-3; Schiebold 2006, 17.

[36] Biers 1985, 46, 55; Kelly 2004-2005, 616; 2006, 243-4; Koçyiğit 2006, 118, 123; 2007, 311.

[37] Such terracotta tubes were also found at the Great Baths of Dion in northern Greece from AD 200 and at the Baths of Dinogetia in Dacia from the fifth century AD. Barnea 1967, 234; Biers 1985, 46, 55; Pandermalis 1987, 39; Farrington and Coulton 1990, 65-6; Koçyiğit 2006, 114; Dinchev 2007, 501; Koçyiğit 2007, 313.

Tubuli, or box tiles, were hollow terracotta bricks that were arranged in continuous rows, permitting the movement of hot air within the walls.[38] The bricks were rectangular in shape with curved corners. They were attached to the walls and to each other with mortar, metal clamps, or both when necessary. The *tubuli* were then covered with a layer of stucco and often a layer of marble veneer.[39] *Tubuli* could also be used to create the hollow spaces for heated vaults. Their shape allowed for more flexibility than the large *tegulae mammatae*, and according to several scholars they were more efficient because they enclosed about twice as much space and they contributed to the insulation of the wall.[40] Seneca described the *tubuli* thus:

> *…ut suspensuras balneorum et inpressos parietibus tubos, per quos circumfunderetur calor, qui ima simul ac summa foveret aequaliter.*
>
> …and such as the vaulted baths, with pipes let into their walls for the purpose of diffusing the heat which maintains an even temperature in their lowest as well as in their highest spaces.[41]

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[38] The earliest use of *tubuli* was in the second phase of the bath at Fregellae. Although these elements were cylindrical, their placement and relationship to the hypocaust leaves little doubt that they had the same function as *tubuli*. The first known rectangular *tubuli* were found in the Stabian Baths of Pompeii, but they were only used in one room: the men's *caldarium*. Kretzschmer 1958, 36; Jorio 1981-1982, 174; Shepard 1987, 43; Yegül 1992, 363, 464 n. 23; 2010, 87.

[39] Sometimes the *tubuli* system heated the walls too well, creating problems when walls were shared between baths and other types of establishment; such a legal case was reported in the *Digesta*, where "a certain Hiberus, who owns the insula behind my horrea, built a bathing establishment using a party wall: he may not put hot pipes against a party-wall". Apparently *tubuli* were sometimes blamed for scorched walls. *Tubuli* could also be used to create the hollow spaces for heated vaults. Their shape allowed for more flexibility than the large *tegulae mammatae*, and according to Edwin Daisley Thatcher (1956, 190 n.66), Paul T. Bidwell (1979, 33), and Oğuz Koçyiğit (2006, 114), they were more efficient because they enclosed about twice as much space and they contributed to the insulation of the wall. Both *tegulae mammatae* and *tubuli* were used in the Suburban Baths of Pompeii. *Dig*. 8.2.13; Meiggs 1973, 417; Yegül 1992, 363; Jacobelli 1999, 227.

[40] Included in these scholars are Thatcher (1956, 190 n.66), Bidwell (1979, 33), and Koçyiğit (2006, 114). Both *tegulae mammatae* and *tubuli* were used in the Suburban Baths of Pompeii. Jacobelli 1999, 227.

[41] Sen. *Ep*. 90.25, translated by Richard Gummere, 1920.

Each type of wall heating system provided benefits and drawbacks, which may have seemed more and less appropriate in different locations or to different facility operators.[42] The actual operation of the wall heating system was likely taken into account by the Roman engineers, as well, when they were choosing which system to install. In general, each of these mechanisms worked in about the same way: the bottom ends were open to the hypocaust so that the hot air could be transferred from there directly into the walls. The top ends of the *tegulae mammatae*, the terracotta spacer pin, and the terracotta spacer tube systems would have been closed, except for a few openings that were connected to the chimneys. These three systems all allowed for a good deal of air exchange throughout the predominantly open space within the walls, since they were all formed by placing large tiles side by side to create a void. The void was only disturbed by small pegs. The relatively uninterrupted air circulation would have helped to equalize the temperature throughout the room.

The arrangement of *tubuli* did not allow for such an undivided opening inside the walls, since the sides of the bricks also filled the space.[43] A horizontal channel directly above the voids of the *tubuli* allowed them to communicate further with each other and

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[42] Farrington (1995, 102) states that the spacer pins created a more structurally stable system than the one supported by the *tegulae mammatae*. Moreover, the spacer pins broke less frequently than *tubuli* bricks. In contrast, he suggests that the use of *tubuli* may have been seen as more prestigious than the use of other heating implements, since they were expensive to produce and would have needed skilled workmen to assemble and arrange them on the walls of the baths. Terracotta spacer pins and *tegulae mammatae* would have been cheaper, which would have been useful in more provincial areas with less readily available resources. Farrington and Coulton 1990, 55, 64, 66-7; Farrington 1995, 102; Kelly 2004-2005, 614, 617; 2006, 245-6.

[43] Matching holes on the sides of the hollow bricks may have allowed the vertical rows of *tubuli* to communicate with each other to a certain degree. Such punctured *tubuli* were found in the Bath-Gymnasium complex at Sardis, and in the Roman Bath at Metropolis, both in Turkey. Kretzschmer 1961, 22; Nielsen 1990, 15; Yegül 1986, 113; 1992, 363; Basaran, et al. 2005, 4; Yegül 2010, 87.

with the chimneys, while otherwise remaining sealed.[44] The majority of the top ends of the voids, according to Yegül, were preferably closed to help contain the hot air. He determines that in this way, a lower draft and furnace activity could be maintained. In contrast, Yegül explains that leaving the tops open created a stronger draft and higher oxidation levels, radiating more heat into the room. The downside of the hotter walls was the consumption of more fuel. Evidence for both arrangements exists in the archaeological record.[45] In order to communicate with the chimneys, however, at least some of the voids had to be open on top. Moreover, an isolated wall area could have been problematic because the section of wall immediately above the *praefurnium* opening would have been very hot, while the opposite wall would have been considerably colder.

I.e. Ceilings

The ceilings of baths do not survive very often in the archaeological record. When they are preserved, or enough evidence is available to reconstruct their general structure, they are usually formed by barrel vaults or groin vaults. Even less frequent is the discovery of ceilings in the baths with double vaults. The heating of vaults was usually achieved by constructing a lining on the inside of the vault with interconnecting tubes or *tubuli*, which communicated through the hollow walls to the hypocaust.[46] Vitruvius

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[44] Heinz (1983, 189) contends that when *tubuli* were open to the outside, they only operated as chimneys. For the *tubuli* to contribute significantly to the heating of the room, he states that they needed to be mostly isolated from the outside. Yegül 1992, 365; Yegül and Couch 2003, 163.

[45] In the experimental bath constructed for the NOVA television series near Sardis, Yegül (2010, 89) and his colleagues determined that leaving the top end of only every fifth row of *tubuli* open was more efficient than leaving all of the tops of the rows open. They concluded that it reduced the consumption of wood from fifteen to six kilograms per hour. Yegül and Couch 2003, 163; Yegül 2010, 88-9.

[46] Terracotta spacer pins were also used to heat vaults as is evidenced in the North Baths at Kyaneai in Lycia, and in the Large Baths at Eleutherna on Crete. Lynne C. Lancaster (2012, 419-21) describes an

described such structures as being beneficial to the baths to prevent problems related to humidity.

> *eaeque camarae in caldariis si duplices factae fuerint, meliorem habebunt usum; non enim a vapore umor corrumpere poterit materiem contignationis, sed inter duas camaras vagabitur*.
>
> Such vaulting over hot baths will be more convenient if it is made double. For the moisture form the heat cannot attack the wood of the timbering but will be dispersed between the two vaults.[47]

Vitruvius does not suggest that the double vaults would have contributed to the heating of the room. Allowing hot air from the hypocaust or the wall heating system to pass through this hollow space would have made some contribution to the temperature of the space, particularly in terms of insulation.

Heating the vaults of the baths would have been beneficial for reducing heat loss through the roof, which has been estimated to be approximately 15 percent in most structures. Perhaps the extra expenditure was not cost effective, or perhaps a certain amount of heat loss was desired to keep heated rooms from becoming too hot. Double vaults have been found in the Suburban Baths at Herculaneum, over the pool hall at the baths at Bath in England, and in some private baths found within villas in England.[48]

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exclusively Romano-British method of heating vaults in baths, which employed hollow voussoirs and double-flue box tiles. Although the ceiling vault of the North Baths at Morgantina is constructed with hollow terracotta tubes, these tubes were not heated. On the North Baths at Morgantina, see Lucore 2009. Yegül 1992, 365; Kelly 2006, 240.

[47] Vit. *De Arch.* 5.10.3, translated by Frank Granger, 1955.

[48] Bidwell 1979, 33; Yegül 1992, 365.

I.f. The Heating Systems of the Terme del Foro at Ostia

Identifying the various heating implements presented above in the Terme del Foro at Ostia is important both for illustrating the suitability of this facility as a heat transfer case study, and for inputting the proper information into the correct heat transfer equations. Fortunately, a significant number of heating elements remain extant in the bathing facility, allowing for sufficient measurements to be taken on-site to create a more accurate representation of the heating systems in this bath.

Many of the *praefurnia* are preserved in the Terme del Foro (fig. 2-2), and in their final phase, their openings are waist-high and are large enough for a person to crouch inside them. Some furnace openings were blocked and alterations and repairs were made to others in various phases of the bath. The *caldarium*, the sauna, and the *tepidaria* all have their own *praefurnia*, but other rooms (Rooms 7, 8, 9, 10, and C) did not, and they would have recycled heat from an adjacent heated room. Reconstructions of spur walls can be seen in the *praefurnia* of the Terme del Foro, but it is difficult to tell how the structures originally looked (fig. 2-3). Although in the final phase of the bathing complex the boilers were heated separately from the bathing rooms, it is possible that boilers were originally placed above some of these spur walls. There is no evidence to support this claim, however, and the arrangement of the *praefurnium* openings would have not permitted a boiler to fit in the space and remain easily accessible.

As is usually the case for ancient structures, there are no walls that are high enough in the Terme del Foro to illustrate clear evidence of chimneys, but their presence is assumed in every heated room for the purposes of the current study. Since most of the rooms had their own furnaces, a chimney would have been needed to circulate heated air within the hollow spaces of each room. There is also no evidence of how the ceilings of the Terme del Foro looked, and if any of them were heated. The likely reconstruction for the ceiling of most of the rooms is a barrel vault, which is discussed in more detail in the following chapter.

Fortunately, the Terme del Foro retains a great deal of both its hypocaust and its subfloor systems, allowing for a more complete illustration of the heating system in this facility. All of the *pilae* are roughly square and are composed of uniform terracotta tiles. The extant *pilae* range in height from 0.57 meters to 0.75 meters, and in width from 0.20 to 0.24 meters. They are spaced between 0.30 and 0.40 meters apart.

The walls of the Terme del Foro are preserved enough to allow the complete examination of their fabric, making this bath an excellent test sample. Only evidence for *tubuli* is found on any of the walls, and they cover the majority of the walls in the heated rooms. The reason for selecting *tubuli* for the heating the walls of the Terme del Foro, rather than *tegulae mammatae* or terracotta spacer pins, is not entirely clear. Although geographic area was the most likely reason, the decision of which method to use probably depended on several factors.[49] In addition to the *tubuli*, all of the layers of mortar, *cocciopesto*, and marble can be identified in some of the heated rooms, completing the picture of the heating systems of the Terme del Foro.

II. Other Factors Affecting Fuel Consumption in Roman Baths

The arrangement of the heating elements in Roman baths impacted the quantity of fuel necessary to heat the facilities, but other factors must be taken into account as well,

[49] Kelly 2004-2005, 616; 2006, 243, 246.

including sunlight and openings, heating water, hours of operation, and type of fuel used. After a general discussion of each of these factors in Roman baths, evidence for them in the Terme del Foro at Ostia is also briefly examined, and necessary assumptions where evidence is lacking are presented.

II.a. Sunlight and Openings in Roman Baths

Sunlight was an economical way to light and heat particular rooms of Roman baths. In fact, some spaces seem to have been designated specifically for use as a *heliocaminus*, or sunning room (fig. 2-13). These rooms contained large windows, which often faced to the south. Yegül describes them specifically as, "Circular or semicircular projecting units with large, unglazed windows, oriented south or southwest."[50] Three important examples of these sunning rooms are found at Hadrian's Villa in Tivoli.

One of these rooms, in the Terme con Heliocaminus at Tivoli, is a circular chamber covered with a dome containing an oculus. The room, which is almost completely filled by a pool, is heated by a hypocaust below and *tubuli* in some portions of the walls (fig. 2-14). The sun enters through five large openings topped with arcades. The other two *heliocamini* at Tivoli lack pools, and they do not project outwards from the bathing structure. They are both round with domed roofs, and they are lit by large windows facing west.[51]

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[50] Yegül 1992, 382.

[51] Yegül (1992, 382; 2010, 18) suggests that the pool in the Terme con Heliocaminus may have been filled with sand instead of water. He also puts forth the possibility that the floors of the other two *heliocamini* at Tivoli were also covered with sand. The idea of patrons reclining on sand to sunbathe is appealing, although the only evidence provided by Yegül to support this concept is the lack of extant paving on these floors.

The strength of the sun entering the *heliocaminus* and other bath chambers varied depending on the presence or lack of glass, the angle of the entering sunlight, and the location of the window with respect to the cardinal directions. When glass was used, its thickness and opaqueness also affected the amount of sunlight that permeated the space. The presence or lack of glazing in the windows of the Roman baths is usually difficult to determine, and physical remains in the archaeological record are often missing or overlooked. As a result, many scholars conjecture that glass was either present or lacking in the bath windows based simply on assumption or logic.[52]

II.a.1. Glazed Windows in the Archaeological Record

Panes of glass for windows first came into use during the reign of Augustus, and window glass became especially popular in the high empire.[53] Glass panes were mounted in windows using either mortar or frames made of wood, stone, or metal. As is discussed below, the panes were either fixed or could be opened or closed.[54] For example, during the AD 79 eruption of Vesuvius, the windows in the *caldarium* of the Suburban Baths at Herculaneum were blown out from the impact of the volcanic flow. A *labrum* that once stood next to a window was also pushed across the room by this violent force, leaving an imprint in the ash. Fragments of double window frames and of glass that had been blown into the *labrum* were found in this ash imprint. The evidence, according to Umberto

[52] Kretzschmer 1958, 67.
[53] The advent of flat window glass coincides with the opening of the first glass factories in Italy. For more information on the manufacturing of glass, see Harden 1961. Harden 1961, 48; Gross 1977, 15; Ortiz Palomar and Paz Peralta 1997, 437-8; von Saldern 2004, 2.
[54] Although few walls survive to heights sufficient to preserve windows, and there is no extant evidence of glass in the Terme del Foro at Ostia, there is material evidence that glass was placed in the windows of some Roman baths. In Britain, according to D.B. Harden (1961, 50), almost no evidence exists to illustrate how glass was fixed in Roman windows. Briggs 1956, 416; Broise 1991, 61-2; Bachman 2008, 118.

Pappalardo, proves that this window was closed not only with glass, but also that it was closed with a double pane of glass.[55] Other bath windows were preserved by the eruption of Vesuvius, including several small round windows with glass or pieces of glass still in situ in both Herculaneum and Pompeii. The Suburban Baths of Pompeii also contained a long rectangular window, which was covered with glass, and the *caldarium* had a fenestrated apse.[56]

Windows with possible evidence for glazing exist at other several other sites as well, although in most cases the available data is inconclusive. For example, window glass was uncovered in the debris in front of the façade of the Great Bath on the Lechaion Road at the site of Corinth, in Greece. Although this implies that the windows were glazed, no indication of frames for any windows was found.[57] Room Y in the baths at Lepcis Magna, in Libya, contained five large windows with a smaller window above each. Three of these windows were oriented to the south, and all of the windows were placed in large niches. Renato Bartoccini mentions that the glass panes glazing these windows were 0.003 to 0.004 meters thick from fragments of glass recovered on the site.[58] The location of the recovered fragments and their relationship to the windows is not discussed, however.

Glass fragments were also found in the Terme Taurine, one of the biggest bathing complexes in Lazio, along with fragments of window frames. The presence of the frames makes it more likely that the glass fragments actually came from windows. The location

[55] Broise, 1991, 62-3; Pappalardo 1999, 237-8.
[56] Jacobelli 1999, 227; Bachman 2008, 121.
[57] Biers 1985, 17.
[58] Rectangular basins were found underneath each window, but these were probably later additions. Bartoccini 1929, 60-1.

of these windows, whether in heated or cold rooms, however, is not mentioned in the publication of the facility by Rita Turchetti.[59] Marble archivolts and fragments of window glass illustrate to Alexandre Lézine that the windows in the large Antonine baths at Carthage were glazed.[60] In addition, Farrington describes the Roman baths of Lycia as mostly all having very large windows that take up over half the surface area of the walls. He states that the windows usually faced west or south, but he does not specify if these windows were glazed or not.[61]

II.a.2. Window Glass and Transparency

Glass fragments in the archaeological record, such as those found in Building Z at Perge, are often iridescent, opaque, or greenish in tint. Determining whether this clouding was original or is due to oxidation over time is problematic.[62] Some scholars, such as María Esperanza Ortiz Palomar, Juan Ángel Paz Peralta, and Henri Broise definitively assert that Roman glass was not as clear as modern glass.[63] Ancient sources only partially clarify the argument. For example, Seneca when using the old-fashioned Baths of Scipio, is delighted to be bathing as his ancestors did – in the dark.[64] He expresses his disgust at the overly-opulent, excessively-bright new bathing facilities he is usually forced to patronize. He mentions that windows in the modern complexes were arranged in such a way as to admit sunlight all day, allowing one to wash and get a tan at the same time.

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[59] Turchetti 1999, 60.
[60] Carthage was a production center for specialized glass. Lézine 1968, 25.
[61] Farrington 1995, 4.
[62] Harden 1961, 52; Bachman 2008, 119.
[63] Broise (1991, 61) specifies that ancient glass was “translucide, mais non transparant,” meaning that it was generally clear but not completely transparent. Ortiz Palomar and Paz Peralta 1997, 438.
[64] Sen. *Ep*. 86.4-5, 10.

> *In hoc balneo Scipionis minimae sunt rimae magis quam fenestrae muro lapideo exsectae, ut sine iniuria munimenti lumen admitterent; at nunc blattaria vocant balnea, si qua non ita aptata sunt, ut totius diei solem fenestris amplissimis recipiant, nisi et lavantur simul et colorantur, nisi ex solio agros ac maria prospiciunt.*
>
> In this bath of Scipio's there are tiny chinks – you cannot call them windows – cut out of the stone wall in such a way as to admit light without weakening the fortifications; nowadays, however, people regard baths as fit only for moths if they have not been so arranged that they receive the sun all day long through the widest of windows, if men cannot bathe and get a coat of tan at the same time, and if they cannot look out from their bath-tubs over stretches of land and sea.[65]

Tanning the skin through these bath windows, as well as observing the countryside would have been difficult if the glass was not translucent.[66] Seneca says that Scipio was condemned by others because he did not "roast in the strong sunlight", and he also mentions that one of the new amenities in the baths was clear light that was admitted through transparent windows.[67] From Seneca's descriptions it would seem that glass in the baths he experienced was generally clear, unfortunately, it is impossible to know if his idea of transparent was the same as our modern view. Pliny also describes a scene of swimmers bathing in a pool in the private bath of a country villa. The bathers are able to see the sea through the windows from the pool, which Pliny specifically mentions is heated.[68] Umberto Pappalardo describes a large room, the *diaeta*, in the Suburban Baths at Herculaneum as having large arched windows with views of the Bay of Naples and the coastline. He conjectures that the floors were heated, since they appear to be sunken in,

[65] Sen. *Ep*. 86.8, translated by Richard Gummere, 1920.
[66] Thatcher 1956, 219.
[67] Sen. *Ep.* 86.11; 90.25.
[68] Plin. *Ep*. 2.17.11.

but does not mention if any evidence of glazing was found for these particular windows.[69]

II.a.3. To Glaze or Not to Glaze

If the conclusion that Roman glass was not very clear is accepted, then it may be deduced that it was necessary for the windows of certain rooms to be left completely open, particularly the *heliocaminus*. Otherwise, patrons would not have been able to receive enough solar radiation energy for sunbathing, and they would not have been able to view any impressive scenery. The complete lack of glass in the windows would have created several problems, however. First, heated air would have been allowed to escape, and cold breezes and rain to come in. A *heliocaminus* with unglazed windows, therefore, could only have been used on a day when the weather permitted. Second, unglazed windows with low openings would have allowed individuals outside the baths to see inside. Romans were actually quite prudish when it came to being seen nude in public, making this scenario unacceptable.[70] If instead glass was clear enough, the greenhouse effect created by glazing would have provided a warm environment less influenced by the outside weather, and these rooms could be used for a larger portion of the year.

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[69] Pappalardo 1999, 238.

[70] Yegül (1992, 34; 2010, 14, 28) explains that Romans did not exercise in the *palestrae* completely in the nude. They did not wear their street clothes, either. Instead they wore light tunics or garments similar to bikinis. He is uncertain if patrons of the baths were completely nude when actually washing in the facility, however, he finds that it is unlikely that individuals would have worn garments in the pools. Yegül (2010, 28-9, 31) also illustrates several wall paintings found in a bath in the Esquiline area in the 1860s, dated to the second century AD. These paintings show nude and seminude women bathing. One woman wears only flip-flops, while another is holding a veil-like bathing wrap in front of her. Pliny *(Ep*. 3.1.8) actually describes a man, Spurinna, taking a walk in the nude on days when there is no wind. Nielsen (1990, 140-1), citing Cicero (*Cael*. 62), Seneca (*Ep*. 122.6), Statius (*Silv*. 1.5.53), Martial (*Epig*. 1.23, 11.75), and Plutarch (*Vit*. *Cat*. *Mai*. 20.5-6), determines that ancient sources are clear on the subject: patrons of the baths almost always bathed in the nude, and according to Cicero could not wear street clothes in the baths.

Moreover, even though voyeurism would still have been possible if glass was completely translucent, a potential solution may explain the existence of glass that seems intentionally frosted on one side.[71]

Unglazed windows in rooms that were meant to be warm, but were not devoted specifically to the sun, may not have been as problematic as the *heliocaminus*. Hot rooms could have retained their usefulness if the unglazed windows were properly barricaded to prevent the outside weather from entering. As described by Martin Bachman, temporary materials could be used to block windows on days when the weather outside was less than ideal, including animal skins, vellum, sheets of heavy cloth, or thin panels of marble or other translucent stone.[72]

Some baths also had movable wooden shutters that could be opened or closed as needed. Henri Broise reconstructs such shutters outside the large windows of the second century AD South Baths at Bosra, in Syria, and the Terme di Nettuno and Terme del Invidioso at Ostia. The remains of travertine consoles with round holes in them, which would have held the metal hinges of shutters, can still be seen (figs. 2-15, 2-16).[73] In addition to controlling the effects of weather on heated rooms, wooden shutters may have helped prevent heat loss when the baths were closed, according to Leonardo Lombardi and Angelo Corazza. Furthermore, even if the windows were glazed, the wood would have helped insulate the room. Moreover, the shutters would have helped protect the

[71] The frosting was likely accomplished by rubbing the glass with sand on one side. Briggs 1956, 416; Baatz 1978, 321; von Saldern 2004, 201; Bachman 2008, 119.
[72] Bachman 2008, 118.
[73] Broise 1991, 65-72; Ring 1996; Ortiz Palomar and Paz Peralta 1997, 438.

glass from breaking due to severe weather or possible intruders.[74] The shutters would have also made the rooms dark, however, meaning the artificial light would have had to be supplied.

Another scenario for controlling the exchange of air in heated rooms was the incorporation of glazed windows that could be opened or closed. Pliny describes the windows of a cryptoporticus that could be manipulated to block the wind from particular directions on stormy days. He states that on nice days the windows were left completely open.[75] The main purpose of being able to open the windows was likely to be able to air out the spaces when necessary. Pliny does not mention if these windows were closed with glass, however, or some other material. Having the option to allow more sunlight into a room could have also been a benefit of this system. Broise finds it probable that only the bottom segments of these kinds of windows could be moved or opened, since the extant travertine consoles for hinges at Bosra are found outside the windows not only above and below, but also in the middle. Broise reconstructs a system of two sets of shutters that could be opened independently of each other, further illustrating a separation between the top and the bottom of glazed windows (fig. 2-17).[76] Windows with adjustable glass panes were found in the *apodyterium* and the *tepidarium* of the Forum Baths at Pompeii, as well as in the Suburban Baths at Herculaneum.[77]

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[74] Lombardi and Corazza (1995, 32, 33) and Basaran (2007, 205) state that the furnaces of the baths were shut down at night, which would have made retaining as much heat in them overnight as possible more important. Broise (1991, 68) mentions that the shutters in the Terme del Invidioso are outside the windows of the *frigidarium*, not a heated chamber. He conjectures that in this case, the shutters were in place solely to protect the glass.
[75] Plin. *Ep*. 2.17.16.
[76] Broise 1991, 61-2, 6-72, 72 fig. 24.
[77] Such a scenario can be imagined at the Terme del Foro at Ostia, although there is no evidence supporting this claim. Broise 1991, 61-2.

As mentioned above, the Suburban Baths at Herculaneum were also equipped with double-glazed windows, as evidenced from the extant frames.[78] Two panes of glass would have served to better insulate a space, in a manner similar to modern storm windows.[79] This insulation would have been especially important in rooms that were intended to be especially hot, or in structures that could not be properly aligned to take advantage of afternoon sunlight. For example, the windows in the *caldarium* of the Terme di Nettuno at Ostia face north because of the location of the baths on the northern side of the Decumanus. As a result, this space could not receive any direct sunlight in the afternoon hours. In order to help maintain the temperature of this room, Broise describes that the double window was actually separated by a small service corridor, 1.20 meters in width. Moreover, this space was placed over the furnace of the baths, which may have allowed hot air to circulate within the double-window.[80] If this reconstruction is correct, this double window had not only the capability to prevent heat loss through insulation, but also the capability to radiate additional heat into the space.

II.b. Heating and Draining Water

Water for the ancient Roman baths was supplied by cisterns, well, or aqueducts. Large *thermae* generally needed a connection to an aqueduct to have an abundant enough supply of water. Some aqueducts were even built with the main purpose of supplying a particular bath. For example, the Aquae Antoniniana branch of the Aqua Marcia in Rome

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[78] The windows in the Suburban Baths at Herculaneum were closed with two fixed wooden frames, set 0.10 meters apart. The frames supported 0.80 by 0.80 meter glass panes that were 0.0045 meters thick. Broise 1991, 62-3, 69; Pappalardo 1999, 237-8.
[79] Connolly and Dodge 1998, 244.
[80] Broise 1991, 64-5.

was constructed specifically to provide water to the Baths of Caracalla.[81] Water was supplied to the baths through lead pipes, which were either connected directly to the aqueduct or to a reservoir that collected water from the aqueduct.[82] Some of the pipes emptied directly into cold pools in the baths or supplied decorative fountains. Water for warm pools and for the *schola labri* was piped into metal boilers, which were usually encased in insulating masonry.[83]

II.b.1. Heating Water

Water boilers in bath structures were often connected by valves to two other tanks, one filled with tepid water and one filled with cold water. The tanks could be stacked one on top of the other, or arranged side by side. By manipulating the valves, the temperature in the boilers could be properly regulated.[84] The boilers were often placed in front of, or directly above the fire of the furnace, utilizing the same energy that heated the hypocausts.

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[81] The baths at Pompeii were originally supplied by cisterns, which collected rainwater. The construction in the Augustan period of a branch of the Serino aqueduct greatly increased the supply of fresh water to the city and to the baths; Cantarella and Jacobelli 2003, 68. See also Hodge 1995, 267 and Yegül 2010, 100.

[82] The reservoir feeding the boiler of the Roman Legionary Baths at Exeter could hold approximately 3000 gallons of water. Bidwell 1979, 40.

[83] The *schola labra* was a round marble basin set on a base and placed in an apse. Well-preserved examples can be seen in the Forum Baths and the Stabian Baths at Pompeii. Yegül (1992, 376-7) describes that in these early examples, the base of the basin was heated. The base contained a channel, which was connected to an outside furnace that provided heated air. This air helped keep the water in the basin hot. Yegül contends that once wall heating was introduced, making rooms hotter, the basins were only used to contain cold water. Bidwell 1979, 40.

[84] Bidwell (1979, 40) describes the boiler system of the baths at Exeter as more advanced than other configurations. He explains that previously water was taken from three tanks of differing temperatures, but that the baths at Exeter had a more advanced design where only one boiler was necessary. This singular boiler was supplied directly from a pipe with cold water, which was in turn heated. Biers (1985, 59) describes a set of stairs on the south side of the furnace walls in the Great Bath on the Lechaion Road at Corinth. He explains that these stairs were used for maintenance of the boiler, and for accessing the spigots that controlled the flow of water within the system. Vitr. *De Arch.* 5.10.1; Jorio 1981-1982, 179; Nielsen 1990, 16; Yegül 1992, 373, 374; 2010, 91-2.

Although such boilers were uncovered in situ in the Suburban Baths at Herculaneum, the Terme della Trinacria at Ostia, and in the small villa bath at Boscoreale (fig. 2-18), they are usually missing from the archaeological record.[85] The space reserved for the boilers, however, can often be identified.[86] For example, there is a large round space in front of the furnace of the baths at Fregellae that was reserved for a bronze boiler, according to Filippo Coarelli.[87] Another example is in the Roman Legionary Baths at Exeter, in England, where Paul T. Bidwell was able to estimate that the diameter of the boiler was 1.40 meters from the extant space, and that it could hold approximately 900 gallons of water. This boiler would have been made of lead with a bronze base-plate (fig. 2-19).[88]

A mechanism for maintaining the temperature of the water in the bathing pools was known as the *testudines alveolorum*.[89] This system was formed by a semi-cylindrical metal container with a flat bottom, which was placed above the furnace fires, often in front of the boilers. The tank had an opening directly into the pool above, which allowed water to circulate freely between the semi-cylindrical container and the pool.[90] The mechanism functioned through natural convection – hotter liquids are less dense and

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[85] Kretzschmer 1958, 34 fig. 59, 35-6; Pappalardo 1999, 234-5.
[86] Ragazzo 1999, 19; Poccardi 2001, 168 fig. 8.
[87] Coarelli 2004, 74.
[88] Bidwell 1979, 40.
[89] A more unusual method of heating pools can be seen in the Suburban Baths at Herculaneum. A bronze boiler shaped like a mushroom with a tube in the center was placed in the middle of a large pool; the pool was 7.30 meters long, 4.80 meters wide, and 1.30 meters deep. The boiler had its own furnace to heat the water contained inside. The heated water contained in the "mushroom" boiler warmed the rest of the pool. Similar implements were found in the Villa of San Marco at Stabiae and in Rome on the Via Merulana. Having a very hot object in the middle of a pool where individuals were bathing may not have been desirable, perhaps explaining why this method did not become more popular. Pappalardo 1999, 236-7.
[90] The name "*testudo*" refers to the shape, which resembles a tortoise shell. The layout of the water heating system of the Roman Legionary Baths at Exeter suggests to Bidwell (1979, 40) that the *testudo* in that facility was 2.10 meters long. Biers 1979, 59; Brödner 1983, 20; Nielsen 1990, 16; Yegül 1992, 373-4; 2010, 93-4.

move upwards, while colder liquids are denser and move downwards. More specifically, as the water in the *testudo* was heated by the furnace fire, it would rise into the space of the pool, and eventually to the surface. As the water in the pool cooled, it would move below the warmer water, descending back into the *testudo*, where it was reheated. In this way, the water in the pool was continuously kept warm.

The metal *testudo* device has almost never been found in situ, however, the semicircular imprint it left behind in the masonry on the pool wall can often be spotted.[91] In this way, it can be determined that the opening to the *testudo* was located at one end of the pool, which probably made that side hotter than the rest of the space of the pool. In the Stabian Baths at Pompeii the opening was on one of the short sides, placed below a lead pipe used to fill the pool with presumably hot water (fig. 2-20).[92] In most facilities the original location of the *testudo* opening is difficult to locate. In the Terme di Nettuno at Ostia, large portions of the wall in front of the *praefurnium* are missing even though the pools are otherwise largely intact. Determining if a *testudo* was ever present is very difficult; the damage to the walls could, in fact, be attributed to an act of looting for the metal container. Logically both the *testudo* opening, if it existed, and the pipe opening would be located on this side of the pool, closest to the furnace.

Other pipes effusing hot water may have projected from various holes in the walls of the pools, but it is often difficult to identify the purpose of these openings with certainty (fig. 2-21). Pipes emitting cold water may have also been used to keep the water

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[91] Yegül 2010, 94.

[92] The *testudo* in the women's *caldarium* of the Stabian Baths is extremely well-preserved, enough for its construction technique to be fully discernible: the device was formed by riveting several sheets of metal together. The implement was added to the pool in the *caldarium* of the women's section of the baths after the earthquake of AD 63. According to Yegül (1992, 374), it was probably never actually used.

from getting too hot and burning the patrons in the heated pools. This heat study examines briefly how the hypocaust below and the heated adjacent walls would have affected the temperature of the water in the pools. Perhaps the *testudines alveolorum* were not always a necessary element in controlling the temperature of the bathing pools after all; or maybe they could have been used in the complete absence of a boiler, as seems to be the case at Corinth.[93]

II.b.2. Draining Water

Drain outlets are a very common feature in most Roman baths. They are often found in the floors of the *frigidaria*, sometimes elaborately formed and decorated. At the site of Ostia, alone, there are many extant outlets in the cold sections of the baths. For example, a drain with four outlets resembling the horizontal petals of a daisy can be still be seen in the center of the *frigidarium* of Terme dei Sette Sapienti (III.X,2) (fig. 2-22). The drain is surrounded by a detailed mosaic showing a hunting scene with vegetal motifs. Another drain with smaller "petal" outlets in the center of an elaborate mosaic is located in the Terme dei Cisarii (II.II,3) (fig. 2-23).

The frequency with which the pools of the Roman baths were emptied, cleaned, and filled with fresh water is difficult to ascertain. Seneca in his criticism of new bathing facilities and practices mentions that in the past, baths were not so opulent and that the water was not always completely changed or very fresh. He mentions that personal comfort was not such a big concern in his earlier years, but that now things had changed,

[93] The furnace at Corinth has been dated to the sixth century AD. Biers 1979, 59.

and that patrons expected to "bathe in filtered water".[94] This statement suggests that within Seneca's lifetime it became common practice to insure that water in the bathing facilities was always fresh and clean. Whether it was actually filtered in some way is uncertain. Hubertus Mandersheid illustrates that all possibilities of cleaning pools – daily, frequently within a day, or of being refilled constantly without being emptied – are all feasible. He concludes that it is most likely that heated pools were only emptied and cleaned out once a day, while cold pools were constantly being filled with fresh water and draining continuously.[95]

The method of removing water from the pools in order to clean them is not entirely clear. Most pools in Roman baths do not contain drains at floor level. Bartoccini finds it likely that pools were purposely flooded to help clean the floors, at least at the baths in Lepcis Magna.[96] Unfortunately, he does not discuss the presence or nature of the drainage system in this facility. The regularity of this emptying process is impossible to know for sure. Maybe the heated bathing pools were only cleaned out at night, when all the customers had gone home. If the pools were completely emptied during working hours, the boilers would have had to be capable of supplying enough hot water to refill the pools in a timely fashion. Customers could not have been expected to wait for extended periods of time. Bidwell, when describing the pools of Legionary Roman Baths at Exeter, determines that the boiler would have had to be filled and heated three or four times in order replenish the water in the pools. He finds it most likely that this process

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[94] Sen. *Ep*. 86.4-11.

[95] Mandersheid's (1991, 54-5, 59) research focuses specifically on the Baths of Caracalla, but the concept can be applied to all large public baths. Marina Piranomonte (1998, 14) also states that the cool pools of the Baths of Caracalla were most likely filled constantly with aqueduct water, rather than being emptied and then refilled.

[96] Bartoccini 1929, 65.

was conducted at night.[97] If this operation did take place while the baths were closed, the furnaces had to be kept running in order to heat the water initially and to keep the water already deposited in the pools hot. The likelihood that bath furnaces were always kept running, or that they were shut down during closing hours, is a debated topic in the field and is addressed in Chapter 5.

II.c. Hours of Operation

The Roman day was composed of two twelve hour segments: the first began at sunrise and ended at sunset, and the second began at sunset and ended at sunrise. The length of each twelve hour segment varied depending on the season and the hours of sunrise and sunset. All official business was conducted in the morning hours followed by a light lunch. Roman men would retreat to the baths in the early afternoon, after they had completed the day's affairs and before going home to dine.[98] As described by Ralph Jackson, it was actually thought by the Romans that bathing helped soften the body to absorb nutrition from food better.[99] Martial proclaims that the best time for bathing is the eighth hour of the day, which corresponds to approximately two or three o'clock in the afternoon. He claims that the baths would be at their optimal temperature at this hour; earlier, particularly in the sixth hour, they would be too hot.[100] Going to the baths "late"

[97] Bidwell 1979, 41.
[98] Calza and Nash 1959, 57; Nielsen 1990, 1; Yegül 1992, 429 n. 28; 2010, 11.
[99] Jackson 1999, 107.
[100] Martial (*Epig.* 10.48) likens the excessive heat of the baths at the sixth hour to the overly heated Baths of Nero in Rome.

would have meant going in the tenth hour, or between 2:30 and 4:30 PM depending on the season.[101]

Table 2-1: Roman Hours for the Winter and Summer Seasons[102]

Hour	Winter	Summer
First	7:33-8:17	4:27-5:42
Second	8:17-9:02	5:42-6:58
Third	9:02-9:46	6:58-8:13
Fourth	9:46-10:31	8:13-9:29
Fifth	10:31-11:15	9:29-10:44
Sixth	11:15-12:00	10:44-12:00
Seventh	12:00-12:44	12:00-13:15
Eighth	12:44-13:29	13:15-14:31
Ninth	13:29-14:13	14:31-15:46
Tenth	14:13-14:58	15:46-17:02
Eleventh	14:58-15:42	17:02-18:17
Twelfth	15:42-16:27	18:17-19:33

Pliny and Martial both mention that people were called to the baths, sometimes by the ringing of a bell. Martial is startled that whoever he is playing ball with, is ignoring the bell. He is concerned to miss the baths and be forced to bathe in the Aqua Virgo.[103] The bell may have served as an indication that the baths were at an optimum temperature, or that pools that had been emptied for cleaning were again ready to receive bathers. The bell may have also been a signal that it was time for women to leave, in order to permit

[101] Pliny actually mentions that the actual time of the hour depended on the season. Martial claimed to go to the baths in the late hour in order to show how busy he was; he was trying to counter claims by Fabianus that he was being lazy by not producing a new book. He wearily followed Fabianus to the Baths of Agrippa, even though he preferred the Baths of Titus. Mart. *Epig.* 3.36.5-6, 10.70.13-4; Pliny *Ep*. 3.1.8.
[102] Modern scholars have tried to approximate the times that correspond to each hour. The ones used are estimations based on these various calculations. The values determined by Brödner (1983, 128-9) are included here.
[103] Mart. *Epig*. 14.163; Pliny *Ep*. 3.1.8; Nielsen 1990, 136.

men to occupy the baths. A contract concerning the management of a small bath from the mining town of Vipascum, in Portugal, mentions that the lessee of the baths would have to keep the facilities operating every day for two separate time segments: one for women and one for men. Women were allowed to frequent this bathing establishment between sunrise and the seventh hour (between noon and one in the afternoon); men were permitted between the eighth hour (between one and two-thirty in the afternoon) and sunset (between six-thirty and eight-thirty in the evening).[104]

Bathing after sunset was not a common practice, although there are some indications that suggest it occurred. For example, Juvenal describes a scene when a man and his guests are suffering desperately from hunger, as they wait for his wife to return from the baths. Apparently, this woman regularly frequented the baths at night – *balnea nocte subit*.[105] Evidence for artificial lighting in the form of vast quantities of oil lamps has also been found in the baths, suggesting the sun was no longer present to light the bathing rooms.[106] Alexander Severus was described as having provided oil for lighting the baths.[107] Some artificial lighting may have also been necessary before sunset on particularly cloudy or stormy days, as well as in the northern parts of the empire where the sunlight would not have been very strong.

[104] See *CIL* II, 5181 for inscription. Nielsen 1990, 135; Yegül 1992, 47; 2010, 33.
[105] Juv. *Sat.* 6.419-33.
[106] 1,500 terracotta oil lamps were discovered in the Forum Baths at Pompeii. Nielsen 1990, 136; Yegül 1992, 33; 2010, 12.
[107] *Hist. Aug Sev.* 24.6.

II.d. Fueling Roman Baths

Wood was likely the most common fuel that was used to heat Roman baths, especially in Italy, although the use of charcoal may be more common than is usually thought.[108] When wood is burned, it produces soot; the burning of charcoal, however, does not produce any soot. Pliny the Elder asserts that soot, specifically from the baths, was used for writing ink and as an additive in black paint mixtures, demonstrating that its presence in baths must have been substantial.[109] Very little soot has actually been found in baths, however, confusing the situation.[110] Ash or soil samples have been collected only rarely in the excavation of most baths, making it very difficult to determine conclusively what types of wood were used, or if charcoal was more common than generally thought.

Large spaces and service corridors for storage have often been identified in baths, enforcing that wood was the most commonly used type of fuel. For example, the Baths of Caracalla had a storage space for 2000 tons of wood, or enough to last about seven months.[111] Actual stacks of firewood, ready to be used, were found in the Suburban Baths at Herculaneum.[112] Sometimes access points for transporting wood into the area of the baths have also been identified. For example, in the Suburban Baths at Herculaneum, a

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[108] Charcoal and grain chaff were used in Egypt, while peat was often used in northern parts of the empire. Nielsen 1990, 17, 19, 20; Yegül 1992, 368.
[109] Pliny the Elder also mentions that when the soot from the baths was added to the black paint, that its high quality was reduced. He does not explain why, however. Plin. *HN* 35.41.
[110] Thatcher (1956, 191 n. 66) claims that traces of soot were found in the *tubuli* of the Terme del Foro at Ostia, and in the *tegulae mammatae* of the Terme dei Cisarii at Ostia. He also states that soot was found in all the wall heating systems of the Baths at Ostia. Nielsen 1990, 18.
[111] Nielsen 1990, 20; Pisani Sartorio 1999, 22.
[112] Included in this stack of firewood, was an entire door from a shop, illustrating that wood supplies were not always obtained directly from forests. Pappalardo 1999, 234.

paved ramp led from the beach to the baths.[113] Bringing fuel into a bath would have been more complicated in many cases, and the archaeological record often lacks particular features for facilitating this process. For example, the *caldarium* in the Roman Legionary Bathhouse at Exeter was heated by two "furnace-houses" (fig. 2-19), as was the *tepidarium*. One of the furnaces in the *tepidarium* was placed in the *palestra*, however, making it inaccessible to wheeled carts.[114]

Individual baths probably incorporated wood from a diverse selection of trees according to what was available from the supplier or what was economical at the time. Pliny describes that the forests around his villa were sufficient to supply the household with enough firewood, while all other necessities could be obtained at Ostia.[115] Indeed, it seems that the area around Ostia was well forested with good timber trees.[116] Wood could not always be derived from the local area of the bath, especially if a particular region did not have enough lumber or if the quality of the material was inadequate. Particular guilds likely existed to ensure the sufficient supply of wood for the baths. Unfortunately, ancient sources largely focus on the supply of wood for construction and ship-building, rather than as a fuel source.[117]

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[113] Paving this ramp with *bipedali* would have made it very easy to transport heavy carts of wood, which could have been unloaded directly from a ship docked nearby. Pappalardo 1999, 231.

[114] Bidwell 1979, 38.

[115] Plin. *Ep*. 2.17.26; Pisani Sartorio 1999, 22.

[116] Meiggs (1973, 269) states that the Ostian coastline was still covered by trees, even in the early part of the 19th century.

[117] Before becoming essential as a fuel source at Ostia, timber was initially important for the construction of the city and for the buildings of ships. The colony had a very important and wealthy guild, the *fabri navales*, dedicated specifically to the construction of ships. Meiggs (1973, 269) finds it likely that local sources of wood, including the coastal pine (*pinus pinea*), were usually used for this enterprise. For more information on the timber trade, see Meiggs 1982, 325-70. Hasaki 2002, 102, 125 n. 30.

Some ancient sources discuss the kinds of fuel that were used and their general benefits or drawbacks. For example, Plutarch and Macrobius both warn that olive wood can damage the structural fabric of the baths because olive wood produces a great deal of smoke and soot.[118] Archaeological evidence, however, illustrates that olive trees were sometimes used: the ashes found in the fourth century AD Baths of Gadara at Umm Qeis in Jordan are full of olive seeds.[119] Vitruvius predominantly discusses the properties of different species of wood from a construction point of view, rather than in relation to the baths or as a fuel source. Some conclusions can still be drawn from this evidence, for example, in terms of how particular woods burn. According to Vitruvius, wood from the fir tree is highly suitable for building, but it catches fire too easily and burns with a flame that is too violent.[120] Wood from the larch tree is very difficult to ignite and does not produce charcoal. When it does burn, the larch is consumed slowly.[121]

With the number of baths always increasing throughout the Roman empire, the supply of wood likely dwindled and had to be controlled more carefully.[122] The contract from Vipascum, mentioned above, states that the lessee of the baths was responsible for insuring that there was enough fuel on hand to keep the baths open every day. Moreover, the contract specifies that a thirty-day supply of wood had to be available at the baths at all times. The contract also mentions that the lessee is only permitted to sell portions of

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[118] Plut. *Quaest. conv*. 3.658E or 3.10; Macrob. *Sat*. 7.16.24; Nielsen 1990, 19.
[119] The presence of olive pits is not entirely conclusive for the burning of olive wood. It is possible that olive pits were used as a fuel after the olives themselves had been consumed. Burning olive branches with the olives still attached would have been extremely wasteful. Holm-Nielsen, et al. 1986, 220, 226.
[120] Vitr. *De Arch.* 2.9.5-6.
[121] Vitr. *De Arch.* 2.9.14.
[122] Meiggs 1973, 270.

wood that are unsuitable for burning as fuel.[123] Leaving public baths without enough funds for procuring sufficient fuel was an offense punishable by flogging: a fourth century case in Antioch recorded by Libanios describes this fate for one Hermeias.[124] A question this study hopes to answer is what was considered "sufficient fuel".

II.e. Other Factors in the Terme del Foro at Ostia

The other factors affecting fuel consumption, outlined above, must now be addressed with regard to the Terme del Foro. Windows are prevalent in the Terme del Foro, in fact, there is extant evidence of large windows in most of the heated rooms. Room 15 may even have served as a *heliocaminus* (fig. 2-13). The windows all face the southwest, whence the sun would shine directly into the rooms in the early afternoon, contributing a substantial amount of radiant solar heat to the system. The width of each of these windows was measured, and an approximate height was determined. No known glass fragments were found in the Terme del Foro. The openings and further possible evidence for glazed windows is discussed in the following chapters.

With three large heated pools in the *caldarium* of the Terme del Foro, a great deal of hot water would have been needed to fill them. Like in the Terme di Nettuno, there is no evidence of a *testudo* system, and the area where it may have been is damaged significantly. In the final phase of the facility, the space for the boilers can be seen outside of Room 20, illustrating that the boilers had their own furnaces. The

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[123] Eleni Hasaki (2002, 125 n. 30) discusses that potters took advantage of the fuel supply provided for baths for their own use. In addition to wood, potters also burned olive pits, shells from nuts, and shrubs in their kilns. See *CIL* II, 5181for inscription. Yegül 1992, 47.
[124] Lib. *Or*. 26.5-6, 27.13; Yegül 2000, 146.

configuration of these boilers and of the pipes leading out of them is unclear. The only visible evidence of a pipe in the hot pools is a segment of lead *fistula* left in situ in the middle (easternmost) pool, Pool β (fig. 2-21). Curiously enough, this opening, which has a diameter of 0.15 meters, is located in the inner step of the pool. This step is on the western side, furthest from the furnace. Since the opening is 0.06 meters up from the floor of the pool, it is not likely that it served as a drain. Instead the water pipe must wrap around the eastern and southern walls of the pool to reach this location. Perhaps this spot was chosen since emitting hot water on a different side of the pool would have helped to equalize the temperature of the water for the various patrons relaxing in the space.

There is no evidence for how the drainage of the heated pools or heated rooms in the Terme del Foro was performed. Most of the drain outlets found in Ostian baths are located in the *frigidaria* or other unheated spaces. Perhaps draining water under the floors of the heated rooms would have interfered in some way with the heating system of the baths. For example, the water may have become too hot and caused some other problem down the line. The most likely possibility remaining for emptying the heated pools is that the water was manually removed, either by buckets or some sort of siphoning system.

The *frigidarium* of this bath contains five drain openings in a row above an east-west subterranean drainage line. Each marble outlet is shaped differently: some of the outlets are composed of a single circular opening, each of a different size, while other ones are formed of several "petal" shaped openings twisting clockwise (fig. 2-24). Many of the drains still work today and continue to remove rainwater from the rooms. Both of the pools in the *frigidarium* were supplied with a large *a cappuccina* drain in the center of the inner step of the pool (fig. 2-25). These drains could have been plugged in some way or blocked by a sluice gate to prevent the loss of water from the pool. They also could have been continually refilled with a steady supply of water that replenished the volume of liquid lost down the drain. The proximity of the baths to a branch of the aqueduct would have made this latter scenario possible, albeit extravagant, and the constant effluence of cold water into the pools would have provided a very refreshing setting.

There is no way to determine what the hours of operation of the Terme del Foro were, but it can be assumed that most baths had similar hours. There is also no way to know for sure what type of fuel was used in this bath, since no charcoal or ash evidence remains in the substructures. What is clear is that the service areas are spacious enough for some wood to have been stored there. The common types of trees found in the area of Ostia and the volumes needed are discussed in the following chapters.

III. Conclusions

Romans perfected new forms of technology for use in the baths – the most significant advancement was the hypocaust system, which allowed for the temperature of rooms to be carefully regulated. When used in conjunction with heated walls, an efficient method of radiant heating was created. Sunlight from windows and openings also contributed to the heating rooms. Moreover, careful not to waste energy, the Romans used the same furnaces both to heat the hypocausts and to heat water in boilers. In this way fuel, predominantly wood, could be conserved. A great deal of physical evidence remains in the Terme del Foro, which serves to illustrate the elements of its heating system and windows. Although some assumptions have to be made (ie on chimneys and ceilings), these can be made based on data from other comparable Roman baths.

The scientific advancements made in baths were also applied to other aspects of Roman life, and they have continued to influence modern architectural and engineering practices. For example, the technology of the hypocaust system was also used by the Romans to heat domestic dwellings. Pliny describes the bedroom-wing of his country villa as having a hypocaust floor to keep it warm and to regulate the temperature.

> Adhaeret dormitorium membrum transit interiacente, qui suspensus et tubulatus conceptum vaporem salubri temperament huc illuc digerit et ministrat.
>
> Next comes the bedroom-wing on the other side of the passage which has a floor raised and fitted with pipes to receive hot steam and circulate it at a regulated temperature. [125]

At least seven houses at Ostia dated to the third century AD or later used both hypocaust and wall heating. The wall heating is often limited to either one or two walls in one room, and the *tubuli* often only cover intermittent portions of these walls.[126] The system was also incorporated into later structures in other locations, particularly Byzantine baths and the Turkish *hamam*.[127]

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[125] Plin. *Ep*. 2.17.9, translated by Betty Radice, 1972.

[126] Included in these are the Domus delle colonne (IV.III,1), the Domus dei pesci (IV.III,3), the Domus delle Gorgoni (I.VIII,6), the Domus del Decumano (III.II,3), the Domus della Fortuna Annonaria (V.II,8), and the Domus del tempio rotondo (I.XI,2-3). The heating in the Domus dei Dioscuri (III.IX,I) was actually used for the small private bathing facility that was added to the house at this time. Becatti 1987, 705.

[127] Today, implants based on the Roman hypocaust are becoming increasingly popular in modern structures, especially constructions labeled as "green" or environmentally friendly. Heat is radiated up through the floor, as in the Roman baths, in a homogenous manner that uses energy efficiently. Instead of hollow floors, however, heated coils or radiating panels are used to generate the heat. Perhaps in the future, the walls of buildings will also be used to heat modern edifices. Basaran and Ilken 1998, 1; Ragazzo 1999, 1.3; Basaran 2007, 199.

Chapter 3: The Terme del Foro at Ostia

The Terme del Foro (I.XII,6) at Ostia, the case study selected for the current study, are "largest and most sophisticated Ostian building of the second century AD, and the architectural ornament speaks of ready access to imperial resources", according to Janet DeLaine.[1] The bath presents both typical features and some unusual elements that create an interesting project. As stated by Russell Meiggs, "The Forum Baths are the first known large building to break with rectangular tradition in curving ends of their southward-facing hot rooms."[2] The elaborate decoration and the contrast between generic and unique rooms, makes this bathing complex an important example of bath architecture.[3]

Inscriptions, the sumptuous quality of the decorative scheme, and the location of the baths next to the city Forum all indicate that this facility was constructed as an important local gathering place with ties to the imperial family.[4] Today, the Terme del Foro remain one of the most impressive sites at Ostia, and one of the most interesting bathing complexes in the Roman empire. The bathing complex is generally accepted to have been constructed in the Antonine Period (AD 138-192) and to have remained in use

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[1] DeLaine 2002, 49.
[2] Meiggs 1973, 90.
[3] According to Janet DeLaine (1997, 9), even the Baths of Caracalla, which are considered one of the most important constructions of later Roman architecture, are not actually very innovative or structurally diverse.
[4] Pensabene and Lazzarini 2007, 268.

until the sixth century AD.[5] Several different phases can be detected in the extant structure.

As mentioned above, the footprint of the Terme del Foro (figs. 3-1, 3-2, 3-3) is unusual, particularly in the southern section. The bathing block consists of twenty-three rooms of various shapes and sizes; and some of the rooms contain amenities, such as pools and benches, while others are rather simple. Examining the general dimensions, the floors, the walls, the ceilings, and the additional features allows for a greater understanding of the function of each room. The numbering for Rooms 1-20 and for Room a was taken from Cicerchia and Marinucci's plan showing the final phase of the baths. The labels for Rooms a2 and 14b, and the designations for the five pools were added by me for clarity.[6] Passageways and openings are referred to as "doors" whether or not they actually supported a movable barrier, for simplicity. I labeled the doors, and also labeled all of the openings, columns, pillars, and individual walls in order to more easily be able to identify and discuss them.

I. History of the Terme del Foro

The site of Ostia, as described in the Introduction, was founded as a Roman military fort sometime between 338 and 317 BC and was largely abandoned in the fifth century AD after both Ostia and Rome were sacked by the Goths.[7] By the sixth century, the city was no longer inhabited, and it was gradually covered up by silt from the Tiber.

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[5] Thatcher 1956, 175; Meiggs 1973, 411; Cicerchia and Marinucci 1992, 22; Poccardi 2001, 161, 164; DeLaine 2002, 49; Valeri 2002, 222; Pavolini 2006, 106, 108.

[6] Cicerchia 1992, Tab. Ic.

[7] See Introduction, 9-15. Calza 1925, 6, 25; Carcopino 1929, 26; De Chirico 1941, 127; Calza and Becatti 1987, 7.

Some areas of the site, including the Terme del Foro, were not completely buried and remained partially visible in modern times. As a result, a great deal of construction material was removed for use elsewhere, and decorative elements were dispersed in various private collections and museums across Europe. Unofficial plundering of the archaeological remains ceased in 1802, when Pope Pius the VII initiated formal excavations at Ostia.[8]

Excavations of the Terme del Foro were primarily conducted in the early part of the 20th century, revealing a great deal of information about the bathing complex. Several inscriptions and brickstamps were also found, providing more extensive knowledge on the history of the facility. Scholars have concluded that the structure underwent three primary phases by examining the available evidence; and this study examines the possibility of an additional phase.

I.a. Excavation History

The Terme del Foro, originally called the "Terme Nuove" by the excavators, were first excavated between 1920 and 1941, under the direction of Guido Calza. The bathing facility appears on Calza's 1953 (fig. 3-4) reconstruction of the plan of the city, although the building footprint is not entirely accurate.[9] Work resumed after World War II between

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[8] Pavolini 2006, 39.

[9] Laser scanning conducted in 2008 and 2009 at the site of Ostia by the University of Nihon shows that the Terme del Foro were represented on Calza's plan as being further to the north and west than they actually are. The drawing by Calza was based mostly on aerial photography, and such mistakes can be attributed to the accidental tracing of shadow lines of buildings instead of the tracing of actual wall lines. Calza, et al. 1953; Pensabene and Lazzarini 2007, 268; Hanghai and Hori 2009, 2; Hori, Hanghai, and Ajioka 2010, 1.

1959 and 1980 under the direction of the Superintendancy of Ostia.[10] The site had already been significantly plundered, since some of the walls were tall enough to protrude above the level of accumulated silt and debris. Therefore, only a few of the original statues were recovered at the site, along with some of the *cipollino* columns and floor mosaics that decorated the structure. Various types of marble fragments were also uncovered, further illustrating the elaborate quality of the decorative scheme of the baths. Meiggs explains that the combination of styles and unorthodox motifs in the carvings suggests that foreign craftsman were employed in the adorning of the bathing facility.[11]

When the majority of the excavation work was undertaken, small finds were seldom collected and very little recording was done. As a result, the evidence that can be studied is primarily limited to the current structural remains. The bath complex was also restored several times, in 1928-1930, 1964, 1966, 1967, 1988, and 1994; therefore, it is necessary to understand which elements were constructed later as part of the restoration work, and which are original. Some of the early reconstructions were carried out reusing ancient materials, complicating the dating of some sections even more.

One of the first tasks to be accomplished as part of the restoration work was the re-raising of the many columns found in both the cold and hot sections of the baths. Reconstructing one particular *cipollino* column in the *frigidarium* up to the height of the trabeation was possible, thanks to well-preserved fragments recovered at the site. Missing sections of columns and bases were rebuilt using brick, allowing for a distinction to be

[10] The Superintendancy of Ostia was dissolved in 2009, and Ostia came under the direct jurisdiction of Rome. When referring to the excavation dates of the Terme del Foro, Thatcher (1956, 169) mentions that the baths were excavated only between 1928 and 1933. Johnson 1932, 143; Meiggs 1973, 109-10, 415.
[11] Patrizio Pensabene and Lorenzo Lazzarini (2007, 268) mention that the polygonal rooms in the Terme del Foro reflect a Greek-Oriental architectural style. Meiggs 1973, 415.

made with the original fabric of the structure.[12] Another significant restoration project was the capping of all of the walls with modern materials (mortar, brick fragments, and tuff blocks) after they had been cleaned. This work was done in order to prevent further destruction to the top surface of the extant walls.[13]

Although they are not numerous, preserved excavation photographs help illustrate the state of the baths when they were first uncovered. These images can help show which of the walls and other features remain in their original state, and which were rebuilt later. For example, the outer steps of Pool ε do not appear in the excavation photos at any significant height, but the niches (although damaged) are visible in the walls.[14] The southern walls of the heated rooms also are mostly missing, with only the lowest sections visible (fig. 3-5). Therefore, everything above that level must be studied with the possibility that it may be an inaccurate reconstruction.

I.b. Construction and Restoration History

The Terme del Foro at Ostia underwent many changes over the centuries, as did their ancient urban setting.[15] The dating of the various phases of the bathing complex is based on a combination of sources, especially inscriptions and brickstamps found in the facility or in the vicinity. Style and technique of the statuary and architectural elements recovered at the site provide further clues as to the dating of the structure and to later

[12] Seven out of the eighteen columns originally located in the *frigidarium* of the baths were restored. Cornice elements lacking their associated columns were not restored, even though it would have been possible to do so. Instead, they were raised two meters above the ground on iron supports in their original location. Five columns supporting the large windows in the heated section of the baths were restored in 1929. Calza 1930, 296-7.
[13] Calza 1930, 300.
[14] Calza 1930, 297 fig. 7.
[15] Meiggs 1973, 411-4; Pellegrino 2000, 32.

changes that were made. According to Pietro Cicerchia and Grégoire Poccardi, the Terme del Foro underwent three major phases, with several sub-phases: original construction in the Antonine period (AD 138-192), a structural reinforcement project in the Severan period (AD 193-235), and a restoration and refurbishment venture at the beginning of the fourth century AD.[16] Some evidence suggests that at least a portion of the baths may have been constructed before the generally accepted Antonine construction date, and this possible phase is discussed below.

The phasing of the baths is very complex, and although Cicerchia presents a great deal of valid information in the monograph on the Terme del Foro, he often contradicts himself, as is illustrated below.[17] This study provides more in-depth detail. For example, close inspection of the extant structure also reveals a number of seams and many abutting walls that Cicerchia does not mention. A more in-depth examination of these walls is needed to determine more precisely when each was constructed. At present, this research is beyond the scope of the current study, since the phasing of the bath structure will not directly affect the final fuel consumption results that focus on the final phase of the baths.

I.b.1. Phase I – Antonine (AD 138-192)

The second century AD at Ostia began with large fires in the city in both AD 115 and 120. According to Axel Gering, the new edifices that were built were based on more

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[16] Although the monograph on the Terme del Foro is authored by both Pietro Cicerchia and Alfredo Marinucci, the sections on the structure and layout of the baths is written solely by Cicerchia. Marinucci discusses the statues and decorative architectural elements that were recovered at the site. Therefore, when referring to statements made regarding the structure of the baths, only Cicerchia is mentioned as the author. Cicerchia and Marinucci 1992, 135-9; Poccardi 2001, 164.

[17] Cicerchia and Marinucci 1992.

substantial foundations, allowing them to support up to six floors for the constantly growing population of the city.[18] Hadrian had done a great deal of constructing and refurbishing in the city, particularly in the area of the Forum, prior to the Antonine period. Many houses in the area of the Semita dei cippi were refurbished during the Antonine era, and the Hadrianic bathing facility on this street was probably renovated.[19] The area between the Forum and the Semita dei cippi was cleared and designated for the building of a new bathing facility – the Terme del Foro. A portion of the original fortification walls of the *Castrum* had to be demolished along with other preexisting buildings, in order to make way for the new complex.[20]

The accepted construction date of the Terme del Foro varies within the Antonine period. The baths are usually said to have been constructed by the praetorian prefect of Antoninus Pius, Marcus Gavius Maximus, who was the prefect between AD 138 and 157 or 158. Edwin Daisley Thatcher claims that the work was conducted either in the later years of the reign of Antoninus Pius or in the earlier years of the reign of Marcus Aurelius. Carlo Pavolini dates the baths to specifically AD 160, as does Poccardi.[21] Pietro Cicerchia determines that the cistern to supply the baths with fresh water was already

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[18] Gering (2001, 207) specifies that pillars and supports were added to help reinforce buildings throughout the city of Ostia in AD 160. Earthquakes occurred relatively often, necessitating structural repairs every ten or twenty years.

[19] This Hadrianic bath was probably connected with the *Fabri Tignuarii*, the guild of construction workers, who were housed in the Caseggiato dei Triclini (I.XII,1). The size of the facility suggests that it was probably also patronized by the public, however. Calza, et al. 1953, 144; Pensabene and Lazzarini 2007, 268.

[20] The remains of these earlier structures can be seen under the baths. Calza, et al. 1953, 142; Cicerchia and Marinucci 1992, 20; Pensabene and Lazzarini 2007, 268.

[21] Gavius Maximus was an equestrian from Picenum who served in Mauretania Tingitana before becoming prefect. His unusually long service as praetorian prefect was credited to his high moral standards. Being a member of the Emperor’s inner council gave him access to an ample supply of imperial building supplies and skilled workers; but according to Edmund Thomas (2007, 76), he built the Terme del Foro with his own finances. Thatcher 1956, 175; Poccardi 2001, 161, 164; DeLaine 2002, 49; Valeri 2002, 222; Pavolini 2006, 106, 108; Pensabene and Lazzarini 2007, 268.

finished by AD 150, but that the majority of the brickstamps date to AD 157. He also mentions that the construction probably began under Antoninus Pius, but was continued under the reign of Marcus Aurelius or Commodus.[22] The Antonine date for these baths is supported by inscriptions, and the unusual shapes of the southern end of the bath are claimed by Meiggs to be stylistically Antonine architectural features, as is the "character of the brickwork" (fig. 3-6).[23] Some of these unusual shapes of the southern end are identified by Cicerchia as fourth century alterations, however, and the brickwork in the Terme del Foro presents a great deal of variation.

Epigraphic Evidence for Dating

Very little evidence remains in the ancient literary record that discusses the Terme del Foro. The *Historia Augusta* may make a mention of them when discussing a "*lavacrum Ostiense*" as one of the structures erected by Antoninus Pius, but no details are provided to confirm the identification.[24] Inscriptions found at Ostia are a more plentiful source of information: two fourth century AD fragments provide evidence related to the construction of the baths, according to Herbert Bloch. A portion of the inscription reads:

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[22] The cistern was covered with a barrel vault, and it was constructed over an area where the ground water table was especially high. Therefore, a water wheel was used to raise the water. The space that contained the water wheel is sufficiently preserved to illustrate that the wheel was approximately ten meters in diameter. The water would have reached the baths through a series of pipes, but there is not enough extant evidence to understand the exact layout of this system. Cicerchia and Marinucci 1992, 22, 38, 40, 49.

[23] Meiggs 1973, 411.

[24] Herbert Bloch (1938, 145, 147; 1953, 413) states that the bath mentioned in the list is either the Terme sul Decumano, which was demolished, or the Terme del Foro, but there is really no way to be sure. Even if this description could be definitively proven to be referring to the Terme del Foro, it would still not preclude the possibility that the baths were planned and paid for earlier than the time of Antoninus Pius, or that they were finished and inaugurated after. *Hist. Aug. Ant.* 8.2.

_ _ _MIS GAVI MA_ _ _.[25] Bloch identifies “GAVI MA_ _ _” as the genitive form of the name Gavius Maximus. He explains the presence of the name of Antoninus Pius’s prefect on a fourth century inscription by conjecturing that this was the original name of the Terme del Foro – the “Terme of Gavius Maximus”.[26] A lead pipe inscribed with the name of Gavius Maximus was found in the baths (fig. 3-7).[27] Bloch conjectures that, although Gavius Maximus died in AD 158 or 159, it is possible that the construction of the Terme del Foro began under him and were finished after his death.[28] According to this evidence it is generally accepted that Gavius Maximus was the benefactor of this facility, and therefore, a date for the construction of the baths has been assigned to the Antonine period.[29]

Brickstamps have also been found on *bipedali* in the structure of the Terme del Foro, which Bloch dates to AD 142 and to between AD 150 and 157. He has assigned a date of approximately AD 160 in accordance with these brickstamps for the construction of the baths, but he mentions that there is no direct evidence to connect the edifice to

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[25] These fragments are on display in the Terme del Foro. The entire extant inscription reads: VETVSTATIS INCVR*ia*_ _ _ _DOMINORVM NOSTrorum_ _ _ _ _ _MIS GAVI MA_ _ _ _ _ _MA FORI ET LAN_ _ _. See *CIL* XIV S I, 4716 for inscription. For further discussion, see Bloch 1953, 414-5.
[26] Bloch (1953, 415-6) explains that “_ _ _MIS” may have spelled “thermis”, although the noun should be in the accusative. Meiggs 1973, 415.
[27] The *plumbarius*, or manufacturer of the pipe was listed as Belenus Verus. His name has been found on other *fistulae* at Ostia. Cicerchia and Marinucci 1992, 22, 222.
[28] Meiggs (1973, 415, n. J) has identified a fragment of an entablature now in the Lateran, which matches the decorative scheme and dimensions of those found in the Terme del Foro at Ostia. The segment is in part inscribed with the words “MAXIMUS HAS OLIM THERM[as]”, and Meiggs interprets this to mean that Gavius Maximus was the original builder of the baths. Meiggs relates the rest of the inscription to a similar fragment on the Arch of Constantine, and he suggests that this entablature commemorated the changes made to the Terme del Foro in the Constantinian period. Restorations of the era are also reflected in the presence of brickstamps. See *ILS* 694 for inscription. For further discussion, see Bloch 1953, 416.
[29] DeLaine 2002, 49; Poccardi 2001, 161; Valeri 2002, 222.

either Antoninus Pius or Marcus Aurelius.[30] DeLaine has described the bricks used in the baths as being very diverse chromatically, while the brickstamps are "remarkably homogenous".[31] She determines that 93 percent of the 182 brickstamps recovered at the bathing site were from two specific groups: the larger group of brickstamps is associated with the brick factories on the property of Lucius Aelius Caesar, and on the property of Domitia Lucilla, the mother of Marcus Aurelius. DeLaine notes that more than half of the bricks of Domitia Lucilla were reused from some other structure. The smaller group was composed of brickstamps attributed to Asinia Quadratilla and Flavius Aper, who also had ties to Aelius Caesar. DeLaine concludes that these bricks, with a provenance so closely related to the imperial family, can logically illustrate that Marcus Gavius Maximus was responsible for the erection of the bathing facility.[32]

Artistic Evidence for Dating

The likelihood of an Antonine date for the erection of the Terme del Foro is further strengthened by decorative evidence recovered at the site. A statue of Pentelic marble from this phase was found in the baths, originally identified as Domitia Lucilla (fig. 3-8).[33] A different designation was later suggested, as Valeri explains: that the statue instead portrayed the younger sister of Marcus Aurelius, Annia Cornificia Faustina. Cornificia Faustina lived between AD 121 and 161. Valeri dates this statue to

[30] Scholars have generally adhered to Bloch's (1953, 414) claim, and they continue to date the Terme del Foro's construction to AD 160. Pellegrino 2000, 32.
[31] DeLaine 2002, 49-50.
[32] Lucius Aelius Caesar later became Lucius Verus, the adopted son of Antoninus Pius. His father is sometimes referred to by the same name. The other seven percent of recovered brickstamps were from the first century AD, and from refurbishments that were made in the Severan period and the late third century AD. Pensabene 1994, 365; DeLaine 2002, 50-2.
[33] Calza 1977, 18.

approximately AD 160 AD, regardless of which woman is being portrayed.[34] This statue illustrates that the baths were closely associated with the Antonine family, although it could have been placed in the facility at a later date than their original construction.

Structural Evidence

The current structural remains of the Terme del Foro primarily reflect the latest phase of the baths. The polygonal southern section is considered a stylistically Antonine feature, however, as can be seen by comparing the edifice to other buildings dated to the Antonine period. For example, the Antonine Baths at Carthage are mostly composed of square, semicircular, hexagonal and octagonal rooms; and the Roman baths at Thernae in Numidia are composed of curvilinear chambers. Antonine architecture, such as the Temple of Antoninus Pius at Sagalassos and the Serapeum at Ephesus, is often described as "baroque" because of its ornate quality.[35] Curved walls can also be seen in the Great Baths at Hippo Regius, in Algeria. This large bathing complex has been dated to the Severan period, illustrating that the trend of using rooms of various shapes continued.[36]

I.b.2. Phase II – Severan Period (193-235 AD)

The prosperity of Ostia had already begun to decline in the Antonine period, with very few new structures being constructed in the city, and the situation degraded rapidly under the Severans. Moreover, according to Meiggs, the marble trade probably collapsed

[34] Valeri (2002, 225) credits this new designation to Fittschen, but she does not provide a citation. She mentions that the date is chosen based on comparing this representation to two sculptures of Faustina the Younger from the same period. Valeri 2002, 225.
[35] Lézine 1968, 10, 23; Thomas 2007, 78-9, 158.
[36] Marec 1954, 89.

at some point during the third century AD.[37] Some of the only new buildings to be constructed at this time were a new bathing facility (III.VIII,2) in the southwest sector of the city, and the Round Temple (I.XI,1), which is sometimes mistakenly dated to after Constantine.[38] Little restoration work was undertaken: the capacity of the theater was increased under Commodus, and the Piazzale delle Corporazioni was refurbished (fig. 3-9). Many structures that were damaged, however, were not rebuilt at all during this period.[39] The Terme del Foro, in contrast, underwent a great deal of restructuring at this time (fig. 3-10).

Epigraphic and Artistic Evidence for Dating

As mentioned above, seven percent of the brickstamps found in the Terme del Foro have been dated to the Severan period and the late third century AD, particularly to between AD 193 and 217.[40] There are no inscriptions remaining in the bathing facility that refer to this time period.[41] There is also no extant ornamental evidence that can be securely dated to the Severan period.

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[37] The population of the city had already significantly decreased due to a drop in trade and possibly due to a plague brought to the area by the armies of Lucius Verus returning from the front. See Introduction, 14-15 for a more extensive discussion on the decline of Ostia. Meiggs 1973, 85; Sear 1982, 132; Dodge 1990, 108.

[38] Calza, et al. 1953, 151.

[39] For example, the bakery east of the House of Diana (I.III,3-4) was destroyed during a fire, and never reconstructed. Meiggs 1973, 85.

[40] Bricks dated to this time period at Ostia are characterized as red and yellow in color. Cicerchia and Marinucci 1992, 22, 137; DeLaine 2002, 50.

[41] Cicerchia and Marinucci 1992, 22.

Structural and Functional Changes

During the early Severan years, some heavy restoration was necessary in the Terme del Foro after several walls collapsed, particularly in Rooms 16, 17, 18, and 19.[42] The cause of this destruction is unclear. One possibility is that there was an earthquake that knocked down or significantly damaged some of the walls, making them no longer stable.[43] Another possibility is that the walls were not designed or constructed properly, and they failed structurally, causing a collapse or significant cracks that needed to be repaired. A final possibility is that the roofs of some rooms were changed and the walls were not thick enough to support the new ceilings. A heavier roof, or a differently shaped roof, would have required more substantial walls in order to support the increased downward forces.

As part of the repairs, the northern wall of Room 17 was heavily fortified in the northwest corner with a large pilaster (fig. 3-11), which partially blocked the passageway (Door AI) to Room 9. The southern wall of Room 17 (fig. 3-12) was completely rebuilt, and the eastern walls of Room 17 (fig. 3-13) were essentially doubled during the restoration, suggesting that they were previously too thin.[44] This wall expansion altered a passageway between Rooms 17 and 18, and a new opening (Door G) was created between Rooms 17 and 20. Some of the walls in Room 18 (Walls b, c, g, and h) and all of the walls in Room 19 were refurbished, because they were heavily damaged as well.[45]

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[42] Cicerchia and Marinucci 1992, 37, 115, 116.
[43] There is no direct evidence to confirm that an earthquake occurred in this period. Cicerchia and Marinucci 1992, 118.
[44] Another 0.74 meters was added to Wall c, and 1.15 meters was added to Wall d. Cicerchia and Marinucci 1992, 115, 137.
[45] Cicerchia and Marinucci 1992, 115, 121, 125, 137, fig. 46.

Some of the hypocausts also had to be repaired, probably due to problems created when the walls collapsed on the floor. Conserving heat may have been a more significant problem as a result of the changes to the hypocaust, and the width of Door I (between Rooms 10 and 20) was narrowed, perhaps to prevent heat loss. Some structures that had been built in the Antonine period were also demolished in the *palestra* at this time, and new ones were added.[46]

I.b.3. Phase III – Fourth Century AD

The Roman empire and the city of Ostia were already in decline for many years by the fourth century AD. With the collapse of the brick industry after the Severan period and the widespread decentralization of power, Ostia was no longer the prosperous commercial trade center it once was.[47] The situation in the city deteriorated further when the seat of municipal control was moved from Ostia to Portus. Indeed, instead of building new structures, some were refurbished and others were abandoned. The necropoleis of Ostia were also damaged and ransacked, illustrating the lack of civic control and upkeep in the Roman town.[48]

According to Giovanni Becatti, the use of public baths also decreased, with individuals preferring to frequent smaller private facilities. He describes at least thirteen houses at Ostia from this period that were equipped with hypocausts and wall heating devices, while no houses dated before the late third late century AD had similar

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[46] Cicerchia and Marinucci 1992, 22, 131, 136-7.
[47] Paschetto 1912, 78; Vaglieri 1914, 13, 16; Meiggs 1973, 83, 90.
[48] See Introduction, 14 for more on the transfer of municipal control to Portus. Paschetto 1912, 81; Vaglieri 1914, 15; Calza 1925, 12; Calza, et al. 1953, 155; Becatti 1987, 705; Bruun 2002, 167.

technology.[49] DeLaine determines that 26 baths were still in operation in the fourth century, although this figure includes private baths as well as public ones. Even with general decline, both the city and the Terme del Foro clearly remained in use and significant refurbishments were undertaken.[50] Furthermore, Meiggs illustrates that the majority of reconstruction work that was undertaken in the fourth century was on the various baths of the city.[51]

Cicerchia identifies at least five different sub-phases within this fourth century AD phase: Phase IIIa (fig. 3-14) was during the reign of Maxentius (AD 306-312); Phase IIIb was during the reign of Constantine (AD 306-337); Phase IIIc was sometime after AD 331; Phase IIId (fig. 3-15) was during the reign of Theodosian (AD 379-395); and Phase IIIe (fig. 3-16) was probably during the reign of Honorius (AD 395-423).[52]

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[49] In general, the main rooms of the dwellings, along with some nearby minor rooms were the ones to be heated. The purpose of heating these rooms, and whether or not it was related to bathing, is unclear. Becatti (1987, 726, 728) suggests the possibility that these heated rooms may have been associated with baptismal practices of the Christian cult, since the religion had become much more widespread by the fourth century. He also theorizes that perhaps the heated houses were occupied by Africans, who had a greater presence in the city in the fourth century, and who would have been used to warmer houses. The edifices described in his study are the Domus: del Tempio Rotondo (I.XI,2), delle Gorgoni (I.XIII,6), di Amore e Psiche (I.XIV,5), sul Decumano (III.II,3), del Ninfeo (III.VI,1-3), dei Dioscurri (III.IX,1), delle Colonne (IV.III,1), dei Pesci (IV.III,3), di Via della Caupona (IV.III,4), del Protiro (V.II,4-5), del Pozzo (V.III,3), della Fortuna Annonaria (V.II,8), and su Via degli Augustali (V.X,1). The heated room in the Domus della Fortuna Annonaria originally looked out onto a garden, therefore the heating may have served to keep this space usable even in colder months. The Domus dei Dioscurri was specifically converted into a private bathing facility. Becatti 1987, 679-705.

[50] Some new small baths were also constructed at this time: one on via della Foce, one near the Porta Marina, one on the Semita dei cippi (V.II,7), and several others in private houses. Many of these were probably built and maintained for private use by particular guilds. Calza, et al. 1953, 155-6; DeLaine 2006, 338.

[51] Meiggs 1973, 419.

[52] Cicerchia and Marinucci 1992, 22-3.

Epigraphic Evidence for Dating

Recovered brickstamps and inscriptions are especially abundant from the fourth century AD, and some have already been discussed above. Brickstamps have been found from both Phases IIIa and IIIb, although very little other evidence remains in testament to Phase IIIb.[53] Phase IIIc is represented by a Greek inscription in two fragments, still visible in the Terme del Foro. This inscription suggests to Meiggs that there was restoration project undertaken by another prefect of the *annona*, Flavius Octavius Victor, dating to between AD 331 and the end of the fourth century AD. Meiggs relates this to a latin inscription that reads " _nte Fl. Octavio V_", leading him to interpret this name as Flavius Octavius Victor (fig. 3-17).[54]

An inscription assigned to Phase IIId was also found on two separate fragments of a marble architrave.[55] The first architectural fragment was discovered in the entrance to the Terme del Foro, which it may have adorned, and it reads: CVRAVIT·RAGONIVS·VINCENTIVS CELSVS·.[56] The second fragment reads: [ro]MAE·ET CIVITAS·F[ecit].[57] Two *cippi* were found at Ostia with an inscription identified by Becatti as identical to the one from the Terme del Foro. One was found on the eastern end of the Forum near the baths, while the find spot for the other was not recorded. The complete inscription on these *cippi* reads:

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[53] Meiggs 1973, 415; Cicerchia and Marinucci 1992, 22, 23, 137.

[54] Becatti (1987, 722) mentions that all of the dedications made and the restoration work that was conducted at Ostia in the fourth and fifth centuries AD was carried out by various prefects of the *annona*. Flavius Octavius Victor was an Equestrian and a Senator of Rome. For inscription, see *CIL* VI 29769 and XIV 4714. See also Meiggs 1973, 415 and Cicerchia and Marinucci 1992, 22-3, 216.

[55] Cicerchia and Marinucci 1992, 22.

[56] See *CIL* XIV S I, 4718 for inscription. See also Becatti 1987, 722 and Bloch 1953, 414.

[57] The second fragment has not been included in the *CIL* or in the *ILS*. For a discussion on the inscription, see Bloch 1953, 414 and Becatti 1987, 722.

CVRAVIT·RAGONIVs
VINCENTIVS CELSVS
V C PRAEFECTUS
ANNONAE·URBIS
ROMAE ET CIVITAS
FECIT MEMORATA
DE PROPIO.[58]

Becatti and Bloch both conclude that all three of these inscribed elements were originally placed inside the Terme del Foro. The presence of multiple inscriptions referring to one restoration project illustrates both the significance of this building in the city and the extent of the financial contribution, which must have been substantial. Becatti determines that this inscription refers to refurbishments that were made to the Terme del Foro in the fourth century AD by the prefect of the *annona* Ragonius Vincentius Celsus.[59] Having the specific name of the prefect, whose years in office are known, allows for this Phase IIId restoration work done in the Terme del Foro to be precisely dated to between AD 385 and 1 September AD 389.[60]

Phase IIIe is not specifically attested to in any inscriptions, except for a possible architrave that may mention the name of Honorius in conjunction with the baths. The reading of this name is somewhat dubious, according to Cicerchia, and it may not be accurate. Several inscriptions of a late date can be seen in the facing of the walls and of the pavement of the baths. These inscriptions are reused fragments that predominantly originated in temples of non-Christian cults, which were very prevalent at Ostia at the very end of the fourth century AD. Although they were incorporated into the baths as

[58] The inscription (*CIL* XIV S I, 139; 4717), is somewhat unclear, but generally says that the building was restored in memory of Ragonius Vincentius Celsus, prefect of the *annonae* of Rome, with his or the city's funds. Bloch 1953, 414; Becatti 1987, 722.
[59] For inscription, see *CIL* XIV S I, 4718. Bloch 1953, 414; Meiggs 1973, 415; Becatti 1987, 722; Pavolini 2006, 107, 109.
[60] Bloch 1953, 415.

building material and not with any dedicatory significance, they help to date the refurbishments within the baths.[61]

Artistic Evidence for Dating

Several statues have been uncovered in the Terme del Foro dated to the fourth century AD, which are associated with the restorations made in the facility. One is a fragmentary portrait that has been identified as the Emperor Valens, who ruled between AD 364 and 378. Another portrays an older togate man, who has been associated with either the prefect Ragonius Vincentius Celsus mentioned above, or Quintus Aurelius Symmachus. Symmachus was an orator, an urban prefect of Rome in AD 384, and consul in AD 391. Raissa Calza has dated this work to approximately AD 400, and she has suggested that it was erected in honor of Symmachus after his death.[62] Two heads from statues usually attributed to the fourth century were also found in the bathing complex, although according to Claudia Valeri, the dating of the heads is rather problematic.[63]

In addition to the sculptural elements, several architectural embellishments that were added as part of a restoration also reflect features that have been found in other fourth century structures, particularly houses. Becatti points out that the two pillars and the large windows in Room 18 of the Terme del Foro recall those found in the nearby Domus della Fortuna Annonaria (V.II,8) at Ostia (fig. 3-18). The Domus della Fortuna Annonaria is one of the above-mentioned houses that was equipped with a heating system

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[61] Cicerchia and Marinucci 1992, 23.

[62] Raissa Calza published this article under the name "De Chirico". De Chirico 1941, 127-8; Valeri 2002, 226-7.

[63] Valeri 2002, 225.

in the fourth century, but it is unlikely that the heated space served any sort of bathing-related function. Becatti also illustrates that the Corinthian columns in Room 19 of the Terme del Foro very closely resemble those found in the fourth century AD elements of the Basilica of San Paolo fuori le mura (fig. 3-19), located between Rome and Ostia.[64] These comparisons help strengthen the dating of this phase.

Structural and Functional Changes

The walls of the Terme del Foro were refurbished quite extensively in the fourth century, and several repairs were made to the floors and the hypocausts of several rooms. The columns and pillars that can currently be seen in the Terme del Foro date to the fourth century, and Pavolini suggests that the extant decorative architectural featuers are contemporary in date as well, because of their eastern quality.[65]

During Phase IIIa, some significant structural modifications were made to the *tepidaria* (Rooms 17, 18, and 20), to the *caldarium* (Room 19), to the *praefurnia*, and to the *palestra* of the Terme del Foro. For example, an interior wall was added to the northern wall of Room 17, completely blocking Door AI, and an interior wall was also added to the western wall of the room.[66] Large windows were also installed in the southern walls of Rooms 17 and 18, and the architectonic order was changed. The passageway (Door G) that had been inserted between Rooms 17 and 20 was also blocked

[64] Becatti 1987, 723.
[65] Pavolini 2006, 109.
[66] 0.60 meters of wall thickness was added to Wall a, 1.13 meters was added to Wall h, and 1.14 meters was added to Wall i.

at this time.[67] The northern wall of Room 18 was significantly altered, and a passageway was created with Room 20. The eastern, western, and southern walls of Room 18 also received some attention, and the pavements and walls of Room 19 were completely re-faced. The walls of Room 20 were not significantly altered in this phase, but the access to the room was: in addition to Door G being blocked, Door M, which led to Room 14 and to the substructures, was closed.[68]

The most substantial change in Phase IIIa was the addition of the apsidal sections to the northern-most pool in the *frigidarium* (Pool δ), and to the southern-most pool in the *caldarium* (Pool γ). These additions were not for structural purposes, but were purely a stylistic choice.[69] The added round areas essentially doubled the size of both pools, providing more communal space for bathers. The apse of the Pool δ suppressed the eastern end of via della Forica by blocking the passageway and by occupying space previously held by an earlier Hadrianic bathing establishment. The apse area in Pool γ was embellished with two Corinthian columns and a very large window, and the curved

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[67] The blockage or reduction of passageways in this period suggests to Cicerchia (1992, 118) that a greater attempt was being made to conserve heat than before. He conjectures that fuel was perhaps more difficult to obtain in this period. The addition of large windows in the third phase of the baths presents a potentially contrasting idea, however, unless these windows were all glazed. Meiggs 1973, 414; Pavolini 2006, 109.

[68] Cicerchia and Marinucci 1992, 23, 37, 121, 125, 138.

[69] Apsidal pools were not uncommon in the Roman world, especially in the later empire. For example, the Great Baths at Corinth had two apsidal pools, which were not part of the original construction plan. Like in the Terme del Foro at Ostia, the curved section replaced one wall of the originally rectangular pool, and rubble and cement were used to fill the gaps. More unusual shapes can often be seen in the eastern side of the empire. For example, both *frigidaria* in the bath-gymnasium complex at Salamis, on Cyprus, are equipped with octagonal pools; and the *caldarium* in the Theater Baths at Aphrodisias, in Turkey, is equipped with a polygonal pool. Meiggs 1973, 413; Biers 1985, 38; Cicerchia and Marinucci 1992, 22, 38, 125; Erim 1996, 93; Musso 2004, 304; Pavolini 2006, 110.

walls were equipped with *tubuli* for heating the pool. The changes to this pool affected the trajectory of the substructure corridors for accessing the *praefurnia* of the baths.[70]

The area surrounding the bathing block also received a great deal of attention in this phase, according to Becatti, as part of an attempt to enhance the quality of the buildings adjacent to the Forum.[71] A monumental new entrance (fig. 3-20) was added off of via della Forica in the fourth century AD, which is normally the modern main entrance to the baths (Door T). The northern wall of Room 2 was punctured in order to create this opening, and an archway was added across via della Forica at the doorway. This more elaborate entry point would have naturally drawn individuals from the Forum by announcing the presence of an important structure.[72] The *palestra* was also embellished by a portico of columns with ionic capitals at this time, and access from Room 1 was changed.[73]

In addition, the rooms on the southern side of the *palestra* were refurbished during Phase IIIa, contributing to the overall appearance of the bathing complex.[74] Two latrines were added within the Terme del Foro complex: one was on the south side that replaced a Hadrianic shop, and another was on the west side. The triangular latrine (fig. 3-21) on the west side of the complex was easily accessible from the outside, meaning

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[70] Cicerchia and Marinucci 1992, 22, 37, 138.

[71] Improvements were also made in this period in other regions of the city. For example, several buildings were refurbished, including the Aula di Marte e Venere (II.IX,3), a building for industrial purposes (II.VIII,8), and the front portion of the Horrea di Hortensius (V.XII,1). An unusal nyphaeum (II.VI,2) was also constructed in the portico fronting the Terme di Nettuno (II.IV,2), which was adorned with five niches beginning on the ground. The floor of the monumental fountain was paved with reused marble. Calza, et al. 1953, 159; Internet Ostia Group 2011.

[72] The monumental entrance off via della Forica is currently closed to the public. Cicerchia and Marinucci 1992, 45.

[73] Cicerchia and Marinucci 1992, 23, 121, 125.

[74] Cicerchia and Marinucci 1992, 23, 121, 125.

that patrons did not necessarily have to be frequenting the baths to use them.[75] A very elaborate latrine (fig. 3-22) was also added on via della Forica, across the street from the baths, in the southeast corner of the Caseggiato dei Triclini (I.XII,1). This latrine, which replaced two earlier shops, was able to accommodate twenty individuals at once.[76]

Directly northeast of the Terme del Foro, the Hadrianic bathing complex was torn down to make way for the new Foro della Statua Eroica (I.XII,2).[77] This new area was surrounded by a portico on three sides, and it was adorned with a statue of a nude heroic man. A nymphaeum (I.II,1) embellished with five niches, alternating between rectangular and round spaces, was also built across the street. Both new constructions were placed 1.70 meters above the level of the contemporary street, making a bold statement near the Forum and along the Decumanus Maximus.[78]

An elaborate colonnaded exedra (I.XII,3) was installed between AD 385 and 389 at the intersection of the Decumanus and the Semita dei cippi, immediately to the east of the Terme del Foro, to monumentalize the central zone further. The decorative structure suppressed a bakery in the same location, and it blocked the Semita dei cippi. Obstructing passage to this street would have had significant consequences, since it would have isolated the southern sections of both Region I and Region V, suggesting to the Internet

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[75] Pellegrino 2000, 33.
[76] Internet Ostia Group 2011.
[77] This bath probably went out of use with the decline of the *Fabri Tignuarii*, in the period of Maxentius. Pensabene and Lazzarini 2007, 268.
[78] Part of the space freed by the removal of this early bath was occupied by the new apsidal section of the *frigidarium* pool in the Terme del Foro. A portion of the Hadrianic bathing facility can still be seen in the Caseggiato della Cisterna (I.XII,4); its quality suggests that the bath was large and rather luxurious. A large octagonal room is preserved in this edifice that was very likely part of the original bath structure, as are the remains of a water wheel, a cistern, and the bakery mentioned above. Pavolini (2006, 110) mentions that a secondary passageway was created in the fourth century AD in the Terme del Foro, leading from Door AA to the Foro della Statua eroica. Calza, et al. 1953, 159; Meiggs 1973, 411; Cicerchia and Marinucci 1992, 22; Internet Ostia Group 2011.

Ostia Group that goods were no longer being moved from the Tiber River to the southern section of the city.[79] This obstruction additionally would have impeded direct entry to the newly refurbished Domus della Fortuna Annonaria and Domus del Protiro (V.II,4-5), along with the late third century AD Terme del Filosofo (V.II,6-7) placed in between these two dwellings. Perhaps the residents or owners of these edifices had a hand in blocking the street: they sacrificed the convenience of easy access from the Decumanus for a quiet street without cartloads of goods shuffling down the road in the middle of the night. There is no way to determine if this was the case, unfortunately, or if the residents would have had such a strong influence on the circulation of traffic in the city.

Access to the Terme del Foro from both the Tiber and the Decumanus would have been greatly limited by the construction of the exedra during Phase IIIa. After the Semita dei cippi was obstructed, the baths must have been especially difficult to access from the eastern part of the city, particularly for the purpose of transporting fuel. The via della Forica was also blocked in the fourth century by the apse extending the *frigidarium* pool in the Terme del Foro, exacerbating the problem. Wood may have been carried from the Tiber south down the via degli Horrea Epagathiana and east along the via del Tempio Rotondo, but in the Hadrianic period two arches had been built to the south of the Temple of Roma and Augustus, limiting the traffic on the eastern end of the via del Tempio Rotondo to pedestrians.[80] Perhaps the fuel was moved by cart up to a certain point, and

[79] The exedra was formed by a semi-circular wall and a colonnade composed of columns made from granite, *portasanta* and *bigio* marble. The Semita dei cippi was the main passageway for commercial traffic to and from the porta Laurentina from the time of Tiberius. Calza, et al. 1953, 159; Cicerchia and Marinucci 1992, 20; Internet Ostia Group 2011; Kaiser 2011, 131.
[80] Internet Ostia Group 2011.

then carried by hand the rest of the way. The other option was that it was transported over land into the city from the south.

There is no structural evidence that dates definitively to either Phase IIIb or IIIc. During Phase IIId the western entrance into Room 2 from via della Forica was completely closed, and at least one new entrance was opened leading into Room 1. This room was transformed into an atrium space, and the area outside was lowered in order to match the rest of the floor level.

The pavements and the walls of the bathing rooms and of the chambers surrounding the *palestra* were also resurfaced during Phase IIId. These refurbishments are evident since the materials that were employed for the repairs were mostly reused elements from elsewhere, a practice very common at this time in Ostia.[81] For example, the floors and walls of the Terme del Foro are faced with pieces of different types and colors of marble, arranged without any set pattern. Many of the sections of marble wall veneer clearly originated from funerary inscriptions, pilasters, and cornices (fig. 3-23).[82] Even the drain covers in the *frigidarium* of the baths vary from one to another, suggesting

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[81] The reused material was primarily procured from structures in the Forum, from the necropolis, and from guild headquarters no longer in use. Included in these guilds were the *Fabri Tignuarii*, and the *Lenuncularii* of *Traiectus Luculli* and of *Traiectus Rusticeli*. The same technique was used to re-face the surfaces of many Ostian baths and other buildings, such as the Terme di Nettuno, the colonnaded exedra, and the Foro della Statua Eroica. Mosaic floors in the baths of Ostia were not repaired with great decorative precision, either. Instead, damaged areas were often filled with pieces of marble without respecting the elaborate figurative designs. Such repairs can be seen on the *frigidarium* mosaics in both the Terme dei Cisarii (II.II,3) and the Terme dei Sette Sapienti (III.X,2). Meiggs 1973, 419-20; Cicerchia and Marinucci 1992, 23; Pensabene and Lazzarini 2007, 273, 455.

[82] For example, two inscriptions commissioned by the *Fabri Tignuarii* were reused in the pavement of the baths. Pensabene and Lazzarini 2007, 423-4.

they were not installed as one unified plan with specifically designed components. Instead, they may also have been reused from other structures.[83]

Phase IIIe is characterized by the addition of arcades for supporting the aqueduct in front of the Semita dei cippi. These arcades were constructed after the water wheel, previously used to raise groundwater for the baths, went out of use. As a result, the water boilers of the Terme del Foro were moved to a service area between Rooms 19 and 20. All three heated pools in Room 19 were connected to these two tanks through *fistulae*.[84] The space between the columns of the portico in the *palestra* was also bricked up at this time.[85]

Ostia gradually declined over the centuries, along with the city of Rome. Both cities were sacked by the Goths in AD 410, during Phase IIIe, and the population of the colony significantly decreased.[86] As fewer and fewer people resided in the city, more areas were abandoned and allowed to be covered over with silt. The Terme del Foro were one of the last bathing facilities to be abandoned at Ostia, but the exact date of their final use is uncertain.[87]

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[83] The reason why so many of the floors and walls of the baths had to be replaced is unclear, and is generally not discussed by scholars referring to the Terme del Foro or other bathing complexes. Since the earlier mosaic floors in some of the rooms (for example, Rooms 2 and 14) were left intact, it is unlikely that these elements were changed as part of a new decorative scheme. The more likely scenario is that these facilities went out of use for a period, allowing some of their building material to be removed. When the baths were re-appropriated, perhaps to be used by a private guild or other group, they were re-faced with whatever luxurious material was still available in the city – marble and stone from other facilities that had been abandoned.

[84] As discussed in Chapter 2 (90-1), evidence for the *fistulae* was only uncovered in Pool β. Cicerchia and Marinucci 1992, 37, 138.

[85] Cicerchia and Marinucci 1992, 23, fig. 66b.

[86] Carcopino 1929, 26.

[87] Cicerchia and Marinucci 1992, 29.

I.b.4. Possible Earlier Phase – Hadrianic (AD 117-138)

The Terme del Foro at Ostia are generally accepted to be Antonine in their construction, as discussed above. Several pieces of evidence, however, suggest the possibility that at least part of the structure was built earlier than the rest (fig. 3-24). As Becatti states, telling the difference between a Hadrianic structure and an Antonine one with certainty is not always possible.[88] During the reign of Hadrian, the city was very prosperous and whole sections were re-planned and refurbished to improve the colony's public image. The Forum, in particular, received a great deal of attention, and it was expanded and monumentalized.[89] A logical new element in this central urban renewal would have been the construction of a new bathing complex. For example, Region II, which was heavily refurbished by Hadrian, received the imperially-funded Terme di Nettuno as part of the improvements. Although the erection of the baths began under Hadrian, they were finished by Antoninus Pius.[90] Perhaps a similar scenario occurred with the Terme del Foro, since very few new important buildings were started after the Hadrianic period.[91] The smaller Hadrianic baths built to the north of the Terme del Foro may have even provided a bathing facility while the more elaborate Terme del Foro were being constructed.

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[88] Even the presence of Hadrianic brickstamps does not necessarily signify a Hadrianic construction date. Instead, the bricks could have been stored for several years before being used for the erection of a structure. Moreover, the construction techniques used at the end of the Hadrianic period are very similar to those used at the beginning of the Antonine period. Calza, et al. 1953, 141.
[89] The current archaeological remains at the site of Ostia primarily reflect the Hadrianic period. The Capitolium at the northern end of the Forum was rebuilt in order to make it taller and to align it with the Temple of Roma and Augustus, and it was flanked with two new arches. Porticoes were also built around the Forum to make it more impressive. Paschetto 1912, 71, 73; Calza 1925, 9-10; Sear 1982, 125; Pavolini 1986, 22; DeLaine 1995, 99; Gessert 2001, 233.
[90] Calza 1925, 97; Calza, et al. 1953, 133; Meiggs 1973, 409.
[91] The Palazzo Imperiale, located in the northwestern-most corner of the excavated site of Ostia is also thought to have been constructed in the Antonine period, as was the Horrea Epagathiana (I.VIII,3). Spurza 2000, 129; Gessert 2001, 256.

Epigraphic Evidence for Dating

There is some written evidence that might support the presence of an earlier construction, although it is relatively inconclusive. An inscription mentions the construction of a certain bath complex that began under Hadrian, but was dedicated by Antoninus Pius in AD 139. Bloch initially identifies the described bath as the Terme del Foro at Ostia, but he later finds it more likely that the baths being discussed are the ones that were demolished when the Terme del Foro were constructed.[92] Determining which facility is being referred to is not possible.

DeLaine mentions that one percent of the brickstamps found on the site were from the first century AD, although she does not discuss this in any detail.[93] She also states that over half of the bricks attributed to the factories of Domitia Lucilla were reused from an earlier structure. The chart she provides in her article (fig. 3-25) specifically labels twelve percent of the brickstamps as Trajanic or Hadrianic, and she also determines that the name of Flavius Aper, who is listed with 31 percent of the brickstamps, probably refers to the consul of AD 130 – during Hadrian's reign. The brickstamps referencing Aper are all dated to the 150s, though.[94] When these bricks were actually manufactured is unclear, and their manufacture date does not necessarily determine their date of use anyway.

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[92] For the inscription, see *CIL*, XIV, 98 = *ILS* 334. For further discussion, see Bloch 1938, 147; 1953, 413.
[93] Three brickstamps were from the first century, and they were labeled thus: Adiutor Aug. Lib, Flavius Eucharis, and Plaetorius Crust(). DeLaine 2002, 50.
[94] Of the twelve percent of brickstamps attributed to the Trajanic/Hadrianic period, four brickstamps are Trajanic and associated with Rutilius Lupus, Trajan, and Caesar; twelve are Hadrianic and associated with Domitia Lucilla, T. Statilius Maximus, Domitia Domitiani, Flavia Seia Isaurica (the mother of Flavius Aper), Claudia Marcellina, and C. Statius Capito. Nineteen brickstamps are dated to the Antonine period and are associated with M. Flavius Aper, Faustina Augusta, L. Aelius Caesar, L. Aelius Caesar Commodus, Asinia Quadratilla, Domitia Lucilla, Lucilla Veri, and Iulia Saturnina. DeLaine 2002, 50, 79.

Artistic Evidence for Dating

The sculpted head of a man was found in the Terme del Foro that has been associated with a bust of a man found in the Terme della Basilica Cristiana at Ostia. Valeri dates both of the highly skilled works to the late Hadrianic period.[95] No other decorative evidence found in the baths has been dated specifically to the Hadrianic era, but early sculptural elements could have later been replaced with more current styles; and if the baths were initiated under Hadrian and finished under Antoninus Pius, these sculptural embellishments may not have been installed until after the Hadrianic period. A Hadrianic statue is not definitive evidence of a Hadrianic date, however, since it could have been placed in the baths long after it was sculpted.

Structural and Functional Evidence

The curious architectural footprint of the Terme del Foro at Ostia – highly rectangular in its northern sector and very irregular in its southern sector – suggests at least the possibility that the northern part may have existed prior to the southern part, and that the basilica-shaped edifice could have been a building with a different function all together. Cicerchia determines that Room a was Trajanic originally, and that the shape of the bathing complex was made to conform to preexisting structures and the original via pomeriale.[96] The northern and southern elements are also divided very distinctly by a

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[95] Valeri 2002, 256.
[96] Cicerchia (1992, 17) claims that none of the three imperial bathing facilities at Ostia included any preexisting structures, or that they were laid out in accordance to structures that were already present in the area. He, himself, contradicts this statement several times, however, and illustrates that the whole area where the Terme del Foro were to be built had to be demolished to make way for the new construction. Included in this were parts of the original *Castrum* fortification walls, which Cicerchia clearly states are

straight wall (fig. 3-26). B. Kenneth Johnson mentions that the original portion of the structure was built symmetrically, while the later additions were constructed asymmetrically and in a haphazard way. The result was "a strange arrangement of peculiarly shaped rooms", although movement through the bathing facility still occurred in a logical way.[97]

Several elements within the structure of the Terme del Foro are difficult to explain if the northern and southern sectors of the bath were planned at the same time. For example, both Door Y and Door AA are partially obstructed with the southern sector in place, and they would have served as very awkward entranceways to the *palestra*.[98] Otherwise, they are very accessible pathways from both sides of the baths where the changing rooms are. Moreover, eliminating the southern section of the bathing block creates a space that is much more customary for a *palestra*, and the unusual elements currently found in the *palestra* area, such as the temples, were not present in this early stage.[99]

Another unusual structural feature is observed in Room 16: seams in both Wall c and Wall e that do not extend all the way to the floor. The seam on Wall e is difficult to inspect, because of the bench that covers the wall; the seam on Wall c (fig. 3-27) can be examined fully. This seam begins 0.32 meters from the ground. Cicerchia explains that the room was constructed in two pieces, a northern piece and a southern piece, at the

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still below the Terme del Foro. Calza, et al. 1953, 134; Cicerchia and Marinucci 1992, 17, 20, 47; Pensabene and Lazzarini 2007, 268.

[97] Johnson (1932, 143-4) wrote his article immediately following the first excavation campaign, before the entire site had been uncovered or well-understood. Johnson 1932, 143.

[98] Cicerchia and Marinucci 1992, 56.

[99] The *palestrae* of the Terme di Nettuno at Ostia and the Palazzo Imperiale at Ostia are rectangular, as is the palestra in the Antonine Baths at Carthage. Lézine 1968, 11.

same time. He does not explain why the seams do not go to the floor of the room, however, or why such a construction technique would have been adopted exclusively in this room. Perhaps the room was not originally intended to be heated, or to have a roof. Instead the southern half of the room could have been open to the sky with only a short wall on the south end to delineate the space. This space may have initially been intended as some sort of elaborate entrance space from the *palestra*, and then the construction plans could have changed. Another possibility is that the room was originally meant to be an outdoor *natatio*, or swimming pool. Unfortunately these conjectures are difficult to prove, and the seams may be associated with the original construction.

The most difficult element to explain in the Terme del Foro at Ostia is the presence of a *tubuli* heating system in the walls of Rooms 7, 8, 9, and 10. The reason for heating Rooms 7 and 8 is unclear. Scholars have essentially ignored the *tubuli* in the walls, or like Meiggs, have dismissed them as being present to help "take the chill from the air".[100] Thatcher suggests that the rooms were probably *tepidaria*, but that they could also have been used as *apodyteria* (changing rooms) or *elaeothesia* (anointing rooms).[101] Cicerchia determines that the *tubuli* and hypocausts in Rooms 7 and 8 were not actually used to heat the spaces, since there is no evidence of a *praefurnium* opening connected to these rooms. Instead the voids were present to help isolate and reduce condensation from adjacent cold pool.[102] Vitruvius describes a scenario where a wall is too damp. He

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[100] Meiggs 1973, 413.
[101] Thatcher 1956, 174.
[102] Cicerchia (1992, 30, 75, 77, 81) further postulates that the *tubuli* were only placed on the east and west walls because the southern wall was mostly formed by an opening and the northern wall had windows. Openings, windows, and niches do not seem to preclude the presence of *tubuli* in the other heated rooms, however, making this statement less credible. A more likely scenario is that the rooms were not destined to be very hot, and consequently, fewer *tubuli* were needed.

suggests constructing a channel in the wall that is open to the air, but he does not suggest using *tubuli* to do so.[103] The source of the heat for these *tubuli* can no longer be determined, since modern restorations have destroyed what was left of the sub-floors.

Cicerchia states that Rooms 9 and 10 were meant to be heated, although these rooms were not equipped with *praefurnia* openings either. Instead they received recycled heated air from the adjacent heated rooms (Rooms 16 and 17, and Room 18, respectively).[104] The purpose of the hollow floors and walls in Rooms 9 and 10 may have been to keep these two rooms warm, so that heat loss would have been reduced from Rooms 16 and 20. Room 16 was already equipped with a long doorway (Door E) for preventing heat loss, however; but the facing of the wall is too damaged to tell if this passageway was heated or not. Both Rooms 9 and 10 also flank a cold pool (Pool ε), making it unlikely that their heating implements were meant to keep them very hot. Effort and additional finances were necessary to install *tubuli* and hypocaust systems in a building, however, making it likely that they had a significant purpose.

As has been shown, having four heated rooms in the *frigidarium* area is not easy to explain. Again, a possible answer can be conjectured by imagining that the southern section was not built immediately, or at least, that it was not part of the original plan. Instead, perhaps these four rooms were meant to be used as *tepidaria*. Another scenario could be that these rooms were meant to be heated spaces in the interim period before all the rooms of the southern section were completed. Unfortunately, none of these scenarios

[103] Vitr. *De Arch.* 7.4.1.
[104] Thatcher (1956, 218) states that Rooms 9 and 10 were *tepidaria*, and that they are the only two rooms that can actually be called *tepidaria*. He presents no convincing evidence for this claim. Thatcher 1956, 217; Cicerchia and Marinucci 1992, 30, 83, 87.

explains why the *tubuli* were kept in place once the whole structure was constructed. Nor do they explain why the *tubuli* used in these spaces seem to be of the same type as those used on the southern walls of Room 20, which were part of the fourth century alterations, and those found in the Domus della Fortuna Annonaria, also installed in the fourth century.[105] These *tubuli* may not have even been installed until the fourth century, according to this evidence.

A seasonal variation in the use of the bath could be another way of explaining the presence of *tubuli* in these northern rooms. Inge Nielsen presents the idea that certain baths in the Roman empire were only used seasonally, in the summer or in the winter. She also mentions that parts of larger complexes were sometimes shut down to conserve fuel.[106] Perhaps some of the larger *tepidaria* in the Terme del Foro were shut down in the wintertime, and the smaller northern rooms were fired up. If Thatcher is correct in his conjecture that all the windows in the facility were always left open, as is discussed below, closing certain rooms in the winter may have been logical. Another possibility is that some rooms in the southern sector were too hot in the summer due to the excessive solar radiation and minor heat loss, making them unpleasant.

There is no significant evidence in the Terme del Foro to suggest that seasons affected its use, however. A final possibility is that the function of some of the rooms in the Terme del Foro was altered in some ways because they became a private facility for the guild that was housed in the *palestra*, as is suggested by DeLaine.[107] The changes that

[105] Becatti 1987, 723.
[106] Nielsen 1990, 138-40.
[107] The Terme del Filosofo are thought to have been used exclusively by a private organization. Approximately sixty guilds or *collegia* have been identified within the city of Ostia, many of them

would have been made are unknown, and there is no direct evidence to deduce that such a change in use occurred.

An attempt has been made to present some evidence and hypotheses related to a possible phase of the baths that predates the Antonine period, or at least, that illustrates that the whole structure may not have been planned or constructed all at the same time. Although some ideas have been put forth, a much more in-depth study of the dating of the fabric of the structure is necessary to make more concrete statements. Moreover, a great deal of evidence has been lost or has become inaccessible due to the excavation and many restoration projects undertaken at the site. Further stipulations related to the phasing of the baths are considered beyond the scope of this study, in the hopes that a future project may provide reasons for some of the irregularities found in the Terme del Foro. The possibility that there was no earlier phase than the Antonine one is also accepted, and may even be likely. The following heat study predominantly focuses on the latest phase of the baths, which can still be studied in situ.

II. General Layout of the Baths

The Terme del Foro are the largest and most complex known bathing complex at Ostia, covering approximately 3200 square meters.[108] They are unusual in many ways, making them a very useful case study. For example, they are the only bathing establishment in the city that does not have a symmetrical plan, and the minor axis of the baths is oriented southeast-northwest rather than the more common southwest-

connected to the port facilities. They were formed of volunteers with similar religious, social, and professional objectives. DeLaine 2006, 340; Kaiser 2011, 115; Stöger 2011, 216.

[108] Cicerchia and Marinucci 1992, 29.

northeast.[109] The rooms of the baths are laid out in an annular fashion, as discussed in the Introduction, allowing bathers to move through the space without having to double-back on the same path to exit.[110] The bathing block is composed of a regular northern section that is parallel to the Decumanus Maximus, and an unusually shaped asymmetrical southern section.[111] The southern rooms are all heated, and they have large windows facing the south. Orienting the heated rooms of a bathing complex to face towards the south was a common practice, allowing the heated rooms to benefit from as much sun in the early afternoon as possible.[112] The southern rooms of the Terme del Foro are arranged in such a way as to prevent each from obstructing the other, allowing them all to be exposed to as much sunlight as possible. These baths are unique in their form – similarly shaped Roman baths are not common anywhere in the empire – and each room within the Terme del Foro is different from the other.[113]

The northern part in its current state is formed of nineteen spaces: Room a, Room a2, Rooms 1 through14, Room 14b, Pool δ, and Pool ε. The southern part is formed of

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[109] Thatcher (1956, 176) recognized that this orientation would have increased the sun exposure of the southern rooms of the baths. Thatcher 1956, 173.
[110] The Terme di Porta Marina (IV.X,1-2) at Ostia were also arranged with an annular layout. On bath layouts, see Introduction, 4. Cicerchia and Marinucci 1992, 20, 29; Poccardi 2001, 164, 167; Pensabene and Lazzarini 2007, 268.
[111] The Antonine Thermae at Carthage are an example of another bathing facility combing a curvilinear section on one side and a rectangular section on the other side. The two sides are symmetrical, unlike those of the Terme del Foro. According to Alexandre Lézine (1968, 30, 32), using polygonal shapes for heated rooms facilitated the distribution of furnaces on different sides of the rooms. The baths at Carthage were heated by 23 different furnaces, even though the three *tepidaria* were heated indirectly from a hotter room. Johnson 1932, 143; Schaal 1957, 104; Thatcher 1956, 173; Cicerchia and Marinucci 1992, 29; Yegül 1992, 194; Pavolini 2006, 109.
[112] Examples of other baths with their heated rooms oriented towards the south include the Great Hadrianic Baths at Lepcis Magna, the Baths of Maxentius in Rome, and the Large Baths at Hadrian's Villa. di Vita-Évrard 1991, 35; Yegül 1992, 86, 87.
[113] A smaller scale version with a similar arrangement, including the stepped plan, can be seen in Turkey at the South Baths of Perge. This Anatolian complex is also embellished with very large windows, providing an excellent comparison to the Terme del Foro at Ostia. Thatcher (1956, 176) mentions that stepping back each heated room of the baths helped to block northeasterly winds, in addition to improving the angle of sunlight. Thatcher 1956, 173, 218; Pavolini 2006, 109; Yegül 2010, 78.

ten spaces: Rooms 15 through 20, Room C, Pool α, Pool β, and Pool γ. The layout of the baths and the way a bather would have moved through the structure are discussed below in terms of the latest phase of the baths (fig. 3-16).[114]

II.a. Entering the Baths

Although several openings can be detected in the ruined state of the baths today, two have been specifically identified as entrances on the northern side of the baths: Door Q and Door T.[115] Door Q (fig. 3-28) is located in the northeastern-most corner of the bathing complex, and it leads through the entranceway Room 14b to Room 14, which has been identified as a vestibule. Door T leads from via della Forica to Room 2, a large open area identified as an entranceway.[116] Door Q would have been relatively difficult to access once the exedra was constructed at the intersection of the Decumanus and the Semita dei cippi in the fourth century AD, while Door T was opened and monumentalized in the same period, as mentioned above. The majority of bath patrons can therefore be assumed to have entered from Door T in this period. At some point during the third phase of the baths, however, the entrance from via della Forica was blocked due to structural reasons. New entrances on the southern end (Door AC) and on

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[114] Although an entire monograph, written by Cicerchia and Marinucci, was published on the Terme del Foro in 1992, the volume provides few dimensions and details related to the structure. For this reason, more specific details are provided here, although Cicerchia and Marinucci are referenced often.

[115] The baths were originally entered through openings on the western and southeastern sides, according to Meiggs. The openings he is referring to are unclear. Meiggs 1973, 412; Cicerchia and Marinucci 1992, 29.

[116] According to Cicerchia and Marinucci (1992, 29, 104) Rooms 2 and 14, which were the entrance areas of the baths, would have been symmetrical if the Caseggiato della Cisterna had not already been in place. They state that the presence of this structure explains why Room 14 is much shorter than Room 2.

the western end (Door AB) of Room 1 seem to have been opened as replacements. This change transformed Room 1 into a functional and integral part of the bathing block.[117]

Door AA (fig. 3-29) on the southeastern side of the baths led to what was likely a service corridor and the *palestra*. This passageway was probably not used by individuals arriving to bathe themselves in the current state of the baths, but by employees of the bathing establishment. The corridor led to a door (fig. 3-30) that may have been an earlier entrance to the baths from the Semita dei cippi. Door AA was originally wider, suggesting it may have been a principal entrance to the bathing block.

II.b. Moving Through the Baths

In the latest phase of the Terme del Foro, once inside the baths, an individual could have easily moved from either east to west or west to east depending on which opening they entered. Since Door T was monumentalized in the fourth century AD, and it was more accessible than Door Q, it can be assumed that the majority of the bath patrons entered from this side. They would have walked through the entranceway (Room 2) and removed their street clothes in a designated *apodyterium*, or changing room.[118] After Door T was blocked, the bathers would have entered through Room 1 and then passed into Room 2. Then the bather would have had several options of where to begin: option 1 – to enter the *palestra* and get some exercise;[119] option 2 – to enter the *heliocaminus* and

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[117] Cicerchia and Marinucci 1992, 29; Pensabene and Lazzarini 2007, 273.
[118] Pellegrino (2000, 32-3) has suggested that the *apodyteria* were the four rooms (Rooms 4, 5, 12, and 13) separated by the *frigidarium* space with *cipollino* columns. Rooms 1 and 14 have been labeled "vestibules" or entranceways, but they could have served as changing rooms as well. The passageway between Rooms 1 and 2 was widened in the third phase of the baths. Meiggs 1973, 412; Cicerchia and Marinucci 1992, 53.
[119] The first option would have been the most complete. There were several ways to enter the *palestra* from the bathing block. The bather would have exited the bathing rooms on the western side through Door AC

get some sun;[120] option 3 – to enter the *sudatorium/laconicum* and have a good sweat;[121] option 4 – to enter directly into the *tepidarium* and follow the basic bathing course;[122] option 5 – to remain in the *frigidarium* area and take a cold plunge;[123] or option 6 – to have some other service attended to in the northern portion of the baths.[124]

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from Room 1, and possibly Door AG, into the *palestra*. Door AG is very narrow and was not originally built, but has marble paving in its threshold suggesting it was used as a door in the final phase of the baths. Door Y, exiting from Room 2, may have also led to the *palestra*, but this door was blocked in the third phase of the baths. On the eastern side, individuals could have exited the baths through Door AA and passed down a very long corridor into the *palestra*, although this long corridor seems more likely to have been related to service functions in this phase. Once in the *palestra*, individuals could stroll or partake in other physical activities.

[120] The second option that could be chosen was to pass though Door A from Room 2 into Room 15, which has been identified as a *heliocaminus*. Patrons entering the baths from the northeastern entrance (Door Q) would have had to pass through the entire *frigidarium* in order to reach this space. Meiggs 1973, 414; Pellegrino 2000, 33.

[121] Once finished sunbathing, the bather could have moved through Door B, Room C, and Door D to reach Room 16, until this passage was blocked in the final phase. This room could also have been entered without using Room 15 by passing through Door Z, Room 9, and Door E in sequence. Meiggs (1973, 414) calls it a *sudatorium*, while Cicerchia (1992, 35-6) and Pellegrino (2000, 33) call Room 16 a *laconicum. Sudatoria* were steam baths, while *laconica* were saunas using only dry heat. From Room 16 the bather would have moved through Door F and entered Room 17, a *tepidarium*. The bather then would have had the choice to pass through either Door G or Door H in order to enter the next *tepidarium* space. Passing through Door G would have been a more circuitous way to get to Room 19 – the *caldarium*, which would have been the desired destination. An individual would have had to pass through Room 20, and then go down the long corridor of Door K to arrive into Room 19. By passing through Door H, into Room 18, instead, the patron could more easily access Room 19 through Door L.

[122] Door G and Room 20 were more likely provided for those bathers wishing to choose option 4, which bypassed both Rooms 15 and 16. Instead of passing through Door Z and Room 9, these individuals would have continued from Room 2 through Room 6, Door N, Room 10, and Door I to enter Room 20, and eventually Room 19. This pathway to the *caldarium* (Room 19) would have also been convenient for anyone entering the Terme del Foro from the northeastern entrance – Door Q. After soaking in the hot pools (Pools α, β, and γ), the bather would have gone back to the *frigidarium* through Room 20 where their body temperature could have returned to room temperature. Then they could take a cold plunge to close their pores in Pool δ or Pool ε before changing back into their clothes and departing. Pavolini 2006, 110.

[123] Option 5 would have been to ignore the heated sections of the bath and remain in the *frigidarium*. Here, the individual could have splashed about in one of the two cold pools (Pools δ and ε), or just socialized with other people in the large open area of the *frigidarium*. This option may have been preferable in the summer months.

[124] Several rooms in the northern portion of the baths had unknown functions. One can imagine that these rooms were used for such things as massages, hair depilation, or light exercise. These rooms could have been patronized before finishing the bathing process, and possibly exclusively of bathing all together.

II.c. Moving Through the Service Areas

An individual working in the baths would have moved through these spaces in a similar way to the bathers, but they would have also needed to access the service areas. The service areas can be entered on the south end of the baths down a staircase (fig. 3-31) from the *palestra* between Rooms 17 and 18, or on the east end of the baths from Room 14 or from the service corridor leading to Door AA. After descending the staircase on the southwestern side of Room 18, a bath worker could go either straight and to the left, or around the staircase and to the right: going to the left allowed them to reach the *praefurnia* of Rooms 15, 16, 17, and the western *praefurnium* of Room 18; going to the right allowed them to reach the other *praefurnia* of Room 18, as well as the southern ones of Room 19.[125] Access to the eastern end of the service corridor from this staircase was impeded with the construction of the apse of Pool γ in the fourth century AD. This section currently can be reached either through Door C from Room 14, or from the door at the end of the long corridor near Door AA. Steps lead down from both of these passageways, providing access to the eastern *praefurnia* of Rooms 19 and those of Room 20. The water boilers could also be tended from this position (fig. 3-32).

In the western end of the service passage, the corridors are narrow and there is not enough space for more than a few people to be in them at one time. There is no clearly designated area for any large quantities of fuel, either, although several small openings and abandoned furnaces exist in the walls, which could have been alcoves for storing a

[125] The dimensions of the *praefurnia* can be found in Appendix 2. Collecting more extensive measurements of the service corridors was not possible without the aid of more advanced equipment; however, the northern limits of the passageways can be assumed to generally conform to the shape and dimensions of the southern walls of the adjacent bathing rooms.

limited supply of wood. One can imagine a bath operator or slave easily walking past each of these fires, and checking them in turn. The westernmost end of the corridor, including the locations of the *praefurnia* of Rooms 15 and 16, are covered with a vault with only a few *oculi* above (fig. 3-33). Therefore, these spaces may have been too smoky to allow the fire attendants to spend more than a few minutes in these sections.

Reaching the eastern end of this southern corridor would have been tricky, since there is not very much space between the staircase southwest of Room 18 and the wall. Perhaps the modern reconstruction of these stairs restricted the space more than the original plan, but this does not seem to be the case. Once around the staircase, the bath worker passed under a vaulted space, which leads to the *praefurnia* of Room 18 and the western *praefurnium* of Room 19. A basin-shaped structure currently can be seen in this section of the corridor, and it may have been used to store water or fuel.[126] Another vaulted portion leads to the southwestern *praefurnium* of Room 19, which is contained in a small covered chamber (fig. 3-34). This space is likely a remnant of an earlier configuration of the baths, which predates the inclusion of the apse of Pool γ. There would have been very little light or air in this space. The other southern *praefurnia* of Room 19 can be found along the service corridor, which is still covered by a vault. A small drainage channel (fig. 3-35) that was once protected with a triangular stone cover can still be seen next to the southeastern *praefurnium* of Room 19.

Access to the eastern *praefurnia* of Room 19 and to the *praefurnia* of Room 20 is more spacious and airy, even though a large part of these areas are vaulted over. After

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[126] There is a hole and a spout on the bottom of the basin, which could have been used to access the water, or to remove rainwater from the fuel supply.

descending the stairs from Room 14 or from the corridor, the water boilers would have been immediately accessible. The *praefurnia* could be reached by walking south down the service passage. Although there is no specific container that seems to have been designated for fuel, enough space exists in this section to imagine that it was stacked against the walls. Otherwise fuel would have had to have been carried down the stairs from above every time it was needed.

II.d. Description of Individual Rooms

The rooms in the Terme del Foro have been described generally in Volume 11 of the *Scavi di Ostia* series, written by Cicerchia and Marinucci in 1992. The room labels assigned therein are used in this study, with new labels added where they are missing, as mentioned above. The dimensions of the rooms given by Cicerchia are for the most part just the length and width of each space, and they are not very precise. For example, a length and width of 6.00 by 9.00 meters is given for Rooms 4, 5, 12, and 13; while the precise dimensions vary and are closer to 5.75 by 9.10 meters (Room 4). For a general survey of the bathing complex, these round dimensions are sufficient; but for an accurate heat study, more precision is needed. All of the dimensions of the rooms that I measured on site can be found in Appendix 2, and only a few major dimensions of the walls and floors are mentioned below. The data was all collected between the 2009 and 2012, with the permission of the Superintendancy of Rome and Ostia. The general features of each room are also described, and any heating implements are noted. The ceilings are completely missing in most of the rooms, but the likeliest reconstruction is presented.

A feature making these baths a particularly interesting and complicated case study is the presence of extensive subterranean chambers and passageways that provide access to the furnaces and the hypocausts. The corridors were partly open on the top to allow for the circulation of air and to eliminate smoke, but most sections were vaulted over, as described above. The covered areas were adorned with a white mosaic pavement on the surface (fig. 3-36), matching that of the *palestra*.[127] Although mentioned very briefly as part of a description of extant remains in *Le Terme del Foro o di Gavio Massimo*, there is currently no complete study of the underground area as a working system.[128] In fact, hypocausts usually only serve as identifying markers for baths, but are not often studied as functional spaces. The substructures are described below as part of the description of each room, and the way an individual moved through the underground space is addressed briefly.

II.d.1. Room a

Room a (fig. 3-37) was likely used as a shop since it did not originally have direct access to the bathing block, and it is located conveniently across from the Forum.[129] The main entrance to Room a was off via della Forica, through Door AD. Door V was probably a way to enter the space from the west, but stairs would have been necessary to reach this door from the level of the Forum. Door AF begins at a higher level than the current ground level, which may be due to elevation changes in the bath. Door AH seems

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[127] Cicerchia and Marinucci 1992, 40, fig. 58.
[128] Cicerchia and Marinucci 1992, 111, 115, 121, 125, 131.
[129] On-site inspection illustrates that the walls of Room a abut those of Room a2. Cicerchia (1992, 47) dates the walls of this room to the Trajanic period, emphasizing that it was extant prior to the construction of the baths.

to be a modern opening, and it does not even appear on the drawing of the baths published by Cicerchia and Marinucci in 1992.

Rectangular in plan, Room a is approximately 11.08 meters long and 9.87 meters wide. The floor is composed of terracotta *bipedali* tiles. Many of these tiles are imprinted with brickstamps (fig. 3-38), five of which are still somewhat legible. There is neither evidence for heating systems in the floors or walls of this room, nor evidence that illustrates how the walls were faced. Determining if the room was lit by any windows is difficult, since neither the northern (Walls a, i, and j) (fig. 3-39) nor the western walls (Walls f, g, and h) (fig. 3-40) survive to a significant height.[130] Moreover, as mentioned above, Door AF is too damaged to interpret if it was originally a window.

Holes in the eastern (Walls b and c) (fig. 3-41) and southern (d and e) (fig. 3-42) walls that are located at a height of a little over two meters from the pavement suggest to Johnson that there was at least one upper story, and that these holes supported beams.[131] This upper floor was probably accessible from the staircase in Room a2 (fig. 3-43), and it may have held living quarters. Walls f through j are formed of a double wall (fig. 3-44). The inner walls have square openings starting at a height of between 0.60 and 0.75 meters from the floor. A large niche (fig. 3-41), which is almost two meters high and perhaps held a statue, is located in the room immediately to the left of Door AD (Wall b). There is a small pool or *impluvium* (fig. 3-45) in the center of the room, which measures approximately 1.98 by 1.48 meters on the outside. The pool is now approximately 0.27 meters deep. There are rather large drains both in the north corner and the south corner of

[130] The northern and western walls are extant to a height of less than 0.25 meters.
[131] Johnson (1932, pl. 44) recreates the shop with two stories above it, but it is unclear if there was enough evidence to do so.

the western wall of the shop, but it is difficult to determine the purpose of these outlets. There is no evidence available for the reconstruction of the ceiling of Room a.

II.d.2. Room a2

Room a2 (figs. 3-46, 3-47, 3-48) is a narrow space, approximately 1.96 by 10.98 meters, with a staircase (fig. 3-43) against the western wall (Wall k). The staircase and the tight, confined nature of this room suggest that it was probably only used as a passageway and possibly for storage of fuel. The space can be entered from via della Forica through Door AE (fig. 3-49), although stairs would have been necessary on the outside to reach the height of the door's threshold. The room can also be accessed from Room 2 of the bath through Door U (fig. 3-50).

There is no evidence for any heating systems in this room. The makeup of the floor is difficult to determine, since it is currently overgrown and is covered with many large broken pieces of marble. Any marble facing that may have been on the walls is no longer extant in situ, and it is possible that the walls were always left bare. A space in the wall suggests that there may have been a window on the eastern wall (Wall e) (fig. 3-51), looking into Room 2, beginning at a height of 2.20 meters from the floor. This space is entirely contained in an area reconstructed in 1964, however, making the evidence unclear. There is insufficient information for the reconstruction of the ceiling of this space.

II.d.3. Room 1

Room 1 (fig. 3-52) is a large chamber on the western end of the bathing complex, which is usually referred to as a vestibule. The room may have become an entrance area for the bathing block in the third phase, as mentioned above. Since it is inconsistent with the symmetry of the rest of the northern block of the baths, this room was probably a separate entity from the baths in the first phase.[132] The space can be entered currently from the west (fig. 3-53) through Door AB, which leads to a set of five travertine steps.[133] In its final phase Room 1 was also accessible from the south (fig. 3-54) through Doors AC and AG. Both of these openings have marble thresholds, but are not sufficiently intact to determine if the top was arched or flat. Wall k, on the western side of Door AC, is damaged, making it difficult to discern the original dimensions of the opening. Door AC also interrupts a relieving arch in this wall, suggesting that the southern wall of Room 1 was probably originally continuous, and that the opening was a later addition. Wall j, east of Door AC, is clearly built to support the door, but the entire section of wall may be a later addition. This room led to Room 2 and the rest of the bathing block through Door W (fig. 3-55).

The room is essentially rectangular, except for the southeast corner that is affected by Door AG. The longest side measures 15.24 meters, and the widest side measures 13.02 meters. There is no evidence of heating elements in the floors or the walls. The

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[132] Cicerchia and Marinucci 1992, 23, 45, 49.

[133] The opening is heavily damaged, and the original relationship between the steps and the doorway is difficult to understand. Cicerchia (1992, 49) mentions that this opening was probably originally Trajanic, when the level of the rooms was much lower than in the third phase of the baths. The steps that are in place now, are a modern reconstruction. In fact, the southern end of the steps lies behind the western wall of the room (Wall l), which would have been an illogical way to plan a staircase.

pavement of the floor (fig. 3-56) is composed of a mosaic made from large irregular tesserae (0.04 by 0.03-0.05 meters) from the third phase of the building.[134] The tesserae are made of many different types of marble, and they are laid with no particular pattern. A similar pavement can be seen in Room C (fig. 3-57), in the heated section of the baths. A small rectangular drainage canal covered with *bipedali* runs in a west-east direction at the base of the northern wall. Another drain is found outside the western end of the bath, but originating from within the facility, which is round in section and made of bricks.[135]

At its highest point, the northern wall (fig. 3-58) survives to approximately 2.30 meters; the east wall survives to approximately 2.5 meters; and the south wall survives to approximately 1.34 meters, except for the southwest corner of Wall k, which survives to 3.00 meters. Most of these walls are not sufficiently extant to determine if there were windows or other features on the walls.[136] The eastern walls show no evidence of window frames. The west wall is largely intact, reaching a height of approximately 5.05 meters to the level of the roof, and approximately 5.85 meters to the very top (fig. 3-53). Five openings of different widths, but roughly the same heights, are present in this wall beginning at 2.70 meters from the floor. Architectural elements from the Temple of Roma and Augustus were mounted in these windows and on the outside of the wall during the reconstruction work. No evidence remains in situ for interpreting how the walls were originally faced.

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[134] Cicerchia and Marinucci 1992, 45.

[135] Cicerchia (1992, 45) dates both drains as likely being from the Trajanic period, although his evidence is unclear.

[136] Windows probably existed in the western and southern sides of Room 1, according to Cicerchia (1992, 45), but there is no way to be sure. He also mentions that a wall parallel to the current eastern wall was removed in the third phase of the baths.

Wall a has been dated to the Trajanic period by Cicerchia, according to its fabric. This early date suggests to him that this wall was not originally part of the bathing block. Instead it served solely as the southern wall of Room a, which was already in place when the baths were constructed.[137] He also dates Walls b1 (which abuts Wall a) and b2 to the Trajanic period, stating that they were utilized in the first phase of the baths as part of a corridor connecting Rooms 1 and 2 and the *palestra*. This wall was later cut during Phase IIId, when the purpose of Room 1 changed.[138]

Cicerchia dates Wall c to the first phase of the bathing complex, since it is part of Room 2. The top of the wall shows signs of ancient repair during the third phase of the baths. Wall d is also dated to the first phase of the building. This wall was originally faced with marble, but it was stuccoed over at a later period when the marble veneer was no longer present. Cicerchia states that the whole southern wall of Room 1 is one homogenous construction from the end of the first phase of the baths, during the reign of Marcus Aurelius or Commodus. A brickstamp was found in Wall k associated with Lucius Verus. Cicerchia mentions that the openings were added in the third phase, breaking a relieving arch in Wall k. He does not mention the extra block formed by Walls h and i that abut Walls g and j, or the seemingly unnecessary southeast corner that is placed further north than the rest of the wall.[139]

The western wall, Wall l, is formed by two separate north-south walls (fig. 3-59) that abut each other, which were heavily restored in the modern reconstruction. The inner

[137] The western wall of Room a continues south to form Wall m in Room 1, but the relationship to Wall a in Room 1 is unclear. Before the addition of Door AB, the wall probably continued further to form the northern part of the outer Wall l in Room 1.
[138] Cicerchia and Marinucci 1992, 47.
[139] Cicerchia and Marinucci 1992, 47-48.

wall is dated to the third phase, while the southern portion of the outer wall is dated to the first phase and the northern portion is dated to the Trajanic period.[140] The outer wall is damaged by modern restorations, but a seam is still visible in the lower portion from the outside (fig. 3-60).

Two interesting features, C3 (fig. 3-61) and C4 (fig. 3-62), abut the east walls (Walls c and d, respectively). These elements flank Door W, although they are set back over a meter on each side. The short sides of both features are placed against walls c and d, and they extend 1.335 meters to the west. The overall structure is rectangular, and they each have a semicircular niche in the center. The niches face the doorway, and they begin 0.50 meters up from the ground. Perhaps they held small statues, although their shape is rather unusual.

In order to determine what the roof of Room 1 looked like, it is possible to examine the surface of Wall l. Wall l is triangular at the top (fig. 3-53), and 0.80 meters below the top of the wall there is an indentation in the form of a triangle (fig. 3-63). The peak of this triangular indentation is located in the center of the wall, 5.05 meters from the floor. The space above this indentation contains several blocked up openings that could have housed the ends of the rafters. Based on the evidence remaining on Wall l, a gabled roof is the most likely reconstruction for Room 1.

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[140] Cicerchia and Marinucci 1992, 48.

II.d.4. Room 2

Room 2 (fig. 3-64) became the main entrance hall in the fourth century AD restoration.[141] The space is accessed from via della Forica through Door T, which was monumentalized by adding an archway across via della Forica. Two steps lead up into the room from the street level. Both of the edges of the opening (Walls a and x) of Room 2 appear to extend 0.17-0.18 meters past their original limits, but the face of the wall in the opening is cut (fig. 3-65).[142] This evidence suggests that there may have originally been an opening in the northern wall, which was later blocked, and then recut to form Door T. The dating for these alterations is unclear.

Two walls (Walls y through aj and Walls ak through av) (figs. 3-66 and 3-67) that are formed of a very different construction method from the rest of the walls in this room and are dated to the third phase, protrude into the room from Door T. These walls create a channeling effect, making the passageway even more prominent (fig. 3-68).[143] A *cipollino* column (C1 and C2) (fig. 3-68) is found at the end of each of these walls (Walls ai and au), accentuating the entranceway. The columns were most likely in place long before the walls, however. The western channeling wall (Walls ag-aj) is not perpendicular to Wall x in order to align itself better between the cut of the door opening and the column, making the earlier presence of the columns likely.

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[141] Room 2 lost its significance as the main entrance hall once Door T was blocked up at the end of the third phase of the baths. Cicerchia and Marinucci 1992, 53.

[142] The door jambs are clearly cut, but appear to have been smoothed out to make the surface even.

[143] The fabric of these channeling walls is very different from the rest of the walls in this Room. The closest comparable material can be seen in the wall that is currently blocking Door Y. Cicerchia and Marinucci 1992, 53.

Once inside Room 2, an individual has several options of where to go. These options are discussed in detail above. The room is rectangular, but all of the walls are not the same thicknesses, altering the inside dimensions in some areas: the length is approximately 24.20 meters and the width is approximately 12.00 meters. The open space of the room is only interrupted by two sets of spur walls, which are separate blocks that abut the east and west walls of the room.[144] The purpose of these walls is unclear, but they probably served to create some sense of separation between the northern and southern parts of the room, and the two spur walls on the northern side echo the layout of all of the rooms in the northern sector of the baths.

The floor is composed of a white tesserae (0.01 by 0.01 meters) mosaic with a black band around it, having a width of 0.21 meters. There is no evidence for heating systems under the floors or in the walls of this room.[145] There is a large rectangular drain (D9) (fig. 3-69) on the western side (fig. 3-70) of the room (the northwest corner is 1.18 meters from Wall r and 1.44 meters from Wall s), which measures approximately 0.58 by 0.71 meters. The drain cover is modern, but the actual walls of the drainage channel are original. The drain does not seem to follow the trajectory of the main drainage channel passing through the north section of the baths, and it is larger than any other drain in this facility. Another small drain (D10) with a flower petal drain cover is located to the west of Wall i. The drain is surrounded by a marble frame and by the same white mosaic pavement as the rest of the room, but there is also a decorative black geometric pattern

[144] The spur walls that are abutting Walls g and r were added in the third phase of the complex. Cicerchia and Marinucci 1992, 53, 55.
[145] Cicerchia and Marinucci 1992, 53.

offset from the drain (fig. 3-71). The same pattern can be seen around a similar drain in Room 14 (fig. 3-72), which also retains it white mosaic pavement.[146]

The marble facing is completely missing from the archaeological record on all of the walls of this room, except for Wall k. A small section of Wall k retains a 0.025 meter thick slab of *pavonazzetto* marble, over a 0.07 meter thick layer of mortar on the wall. This evidence suggests that this entire wall was originally revetted with *pavonazzetto*. Both Walls a and x have a window looking out onto via della Forica, framing Door T.[147] Each window is approximately 3.00 meters wide and begins at a height of 1.83 meters from the floor. There is also a window in Wall r looking into Room a2, as discussed above. There is no evidence for windows remaining on any other walls.

There must have been some water features in this room in at least one of the stages of the baths, since there are indentations in the walls for pipes on Walls k and q (figs. 3-73, 3-74, 3-75). These spaces are vertical slots in the walls, which measure approximately 0.23 meters in both width and depth. The size and shape of the slots is regular throughout the bathing facility. One is found on Wall k, 1.22 meters from Wall j; another is on Wall k, at the corner with Wall l; and the final one is found on Wall q, on the corner with Wall p. Both the first and the third slots described were bricked up in the third phase of the baths.[148]

The northern wall of Room 2 is dated to the first phase of the baths, and shows few ancient alterations, except to Door T. The eastern and western walls are also dated to

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[146] The geometric mosaic around the drain is better-preserved in Room 14, where it can be observed that the drain is surrounded by a black rectangle with projecting squares on the inside.
[147] The possibility that a window also existed above Door T is suggested by Cicerchia (1992, 53).
[148] Cicerchia and Marinucci 1992, 53.

the first phase (and bond with the northern wall), with only modern restorations in the southern portion of Wall f where it meets Door X. The southern wall is also dated to the first phase, except for the wall blocking Door Y (figs. 3-76, 3-77), either completely or enough to reduce it to being a window. On the one hand it is clear that Walls o and p, which flank Door Y, are not part of the original plan and can be seen to abut Walls n and q; on the other hand Cicerchia illustrates that the walls date to the same period as those they abut. He explains this scenario by deducing that the decision was made to reduce the width of Door Y while the structure was already in process of being constructed. He suggests that the original intention may have been to create a direct connection from Door Y to Room 15, rather than to the *palestra*, but these conjectures are difficult to prove with certainty.[149] There is no evidence to definitely determine what the ceiling of Room 2 would have looked like. A barrel vault is a likely choice, though, due to the regular rectangular shape of the room.

II.d.5. Rooms 3-5

Room 3 (fig. 3-78) is entered from Room 2 and serves as a passageway and entranceway to Rooms 4 and 5. Rooms 4 (fig. 3-79) and 5 (fig. 3-80) have been identified as *apodyteria*.[150] The space between these three rooms is open except for a screen to delineate each different room, which is formed of two pairs of *cipollino* columns and

[149] The reasoning behind Cicerchia's (1992, 56) hypothesizing a connection to Room 15 is based on the fact that there was already an entrance to the *palestra* immediately to the west, and entering the *palestra* from Door Y would have been more difficult because the walls of Room 15 would have partially obstructed the view.
[150] Cicerchia and Marinucci 1992, 29, 59, 63, 67.

narrow spur walls set against the perimeter walls.[151] Room 4 has a length of approximately 5.75 meters and a width of approximately 9.10 meters. Room 5 has a length of approximately 5.92 meters and a width of approximately 9.16 meters.[152]

Rooms 4 and 5 are both paved with a white mosaic (irregular tesserae 0.01-0.02 meters on each side) with a black band (regular tesserae 0.013 meters on all sides) that is 0.13 meters wide. A 0.87 meter wide *pavonazzetto* marble strip (fig. 3-80) forms the thresholds separating both Room 4 and Room 5 from Room 3. Room 3 is paved with reused marble of many different types, including *pavonazzetto*, *giallo antico*, *verde antico*, and *rosso antico*. There is a drain (D1) (fig. 3-81) beginning 4.08 meters from the western threshold between Rooms 3 and 6.[153] This vertical drain connects to a large drainage channel that runs below the floors of Rooms 2, 3, 6, 11, and 14; drain covers can be seen in all of these rooms, illustrating the path of the conduit (fig. 3-82). There is no evidence for heating systems below the floor or in the walls of any of these rooms.[154]

Evidence of mortar and marble wall-facing remains on the lower section of many of the walls of these rooms, although the types of marble and the thicknesses of the slabs vary. Walls a, g, h, w, and x have remains of *pavonazzetto*; Walls b, c, l, m, and n have

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[151] The western spur wall between Rooms 3 and 4 is formed by a separate wall that also projects into Room 2 and abuts Walls t and x. The other spur walls between Rooms 3 and 4 and Rooms 3 and 5 bond with the adjacent walls.

[152] Cicerchia (1992, 29) lists the dimensions for Rooms 4, 5, 12, and 13 as 6.0 by 9.0 meters, however, none of the rooms are exactly the same or have these specific dimensions. The rooms are not even perfect rectangles: the eastern wall of Room 4 is 5.75 m long, while the western wall is 5.70 meters long; and the eastern wall of Room 5 is 5.92 m long, while the western wall is 5.88 meters long. Room 12 is approximately 5.75 by 8.79 meters, and Room 13 is approximately 5.86 by 8.89 meters.

[153] The drain cover, measuring 0.71 meters in length and 0.62 meters in width, is almost perfectly centered in the room: it is 4.94 meters from the Wall e and 4.92 meters from Wall j. There are four “flower petals” decorating the surface, and the circular section has a diameter of 0.36 meters.

[154] Cicerchia (1992, 30) mentions that the drainage pipe is 0.60 meters wide and runs along the whole northern section of the baths, from Room 11 to Room 2, where it turns and then connects to the main line. At least eight drain covers above vertical shafts can be found along this conduit in the northern section of the Terme del Foro. Cicerchia and Marinucci 1992, 53.

remains of *grigio* marble; and Walls e, f, r, s, and u have remains of *cipollino* marble. Determining if there was any particular pattern to this selection of different stones is very difficult, since the evidence is limited, and this marble facing may all be part of a modern reconstruction. Cicerchia considers that the veneer in Room 4 dates to the first phase of the baths, as does the mosaic pavement in both Rooms 4 and 5. Such a variety of marble, however, suggests that the wall facing may have been reconstructed at a later date. Furthermore, the marble facing of Room 5 seems eventually to have been replaced with stucco.[155]

The brick walls are all dated to the first phase of the baths, and they show little evidence of ancient structural refurbishments; although some heavy modern restoration is visible in the spur walls separating Rooms 3 and 4. Room 4 (fig. 3-83) was lit by a window divided into three parts that covered its entire northern wall, according to Cicerchia. Evidence for side and middle window frames are present in situ, but they were heavily restored after the excavation, making their original configuration difficult to surmise without a doubt.[156] The window looked out directly on via della Forica, meaning that it would have opened immediately in front of the doors of the elaborate fourth century latrine (fig. 3-22). Perhaps the revolving doors of the latrine kept foul odors from finding their way into the baths.

Cicerchia states that Room 5 was lit by a window on its southern wall, which was extant in the form of a windowsill and the left window jamb. The window would have been contained within the space of the arch of the ceiling vault, since the windowsill is at

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[155] Cicerchia and Marinucci 1992, 61, 64, 65, 68.
[156] When measured in situ, the window begins and ends almost a half meter from the edge of the wall. Cicerchia and Marinucci 1992, 30, 53, 63, 64.

the same level as the springing of the arch. The opening would have looked out over Room C, which must have been covered by a lower vault.[157] Evidence for this aperture is no longer visible in the archaeological record. The ceiling of each of these rooms is assumed to have been covered by barrel vaults, although there is no available information to reconstruct them accurately.

II.d.6. Room 6 and Pools δ and ε

Pools δ (fig. 3-84) and ε (fig. 3-85), and Rooms 7 through 10 are all accessed from Room 6 (figs. 3-86, 3-87). The presence of the large open space and two unheated pools is a clear indication that Room 6 was the *frigidarium* of the bathing complex, as well as a passageway.[158] For simplicity, Rooms 7 through 10 are dealt with in a separate section, below. Room 6 is entered through a wide opening delineated by two *cipollino* columns from either Room 3 or Room 11. *Cipollino* columns within the space of Room 6 also embellish the corners of the openings of Rooms 7 through 10 and the steps of the pools.

Room 6 is a rectangular space with a length measuring approximately 10.60 meters and a width measuring approximately 22.17 meters. The east and west ends of this room are accentuated in the pavement by a delineated strip of marble between the columns (C9, C10, C19, and C20) and the walls, clearly separating the space from Room

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[157] A similar scenario is preserved in situ in the Great Hadrianic Baths at Lepcis Magna. These windows were closed with a 0.003 to 0.004 meter wide glass panel. Bartoccini 1929, 60-1; Cicerchia and Marinucci 1992, 30.

[158] Cicerchia and Marinucci 1992, 35, 71.

3 and Room 11. Otherwise, the pavement matches that of Rooms 3 and 11: a patchwork of irregular sections of marble of differing types.

Three separate drain covers (D2, D3, and D4) can be seen on the pavement, which illustrate that the drainage canal runs down the middle of this room. D2 begins 4.43 meters from the eastern threshold between Rooms 3 and 6; D3 begins 11.03 meters from the same location; and D4 begins 16.32 meters from the same location, or 5.05 meters from the western threshold between Rooms 6 and 11. Not all of these drain covers are the same, suggesting that these elements may have also been procured from earlier structures as the marble on the floors was.[159]

Pool δ and Pool ε are located to the north and to the south, respectively, of the middle part of Room 6. The eastern end of the interior of Pool δ measures approximately 6.94 meters and the western end measures approximately 6.65 meters. The total length of the pool from the center of the apse to the inner step is approximately 10.07 meters, and the width is approximately 8.81 meters. The interior length of Pool ε is approximately 5.31 meters on the east side and 6.80 meters on the west end. The interior width is approximately 9.08 meters on the north end and approximately 8.98 on the south end.

The nature of the pavement of the pools is unclear, since it is not sufficiently preserved. Both pools have three steps (figs. 3-88, 3-89) to access them: a lower outer

[159] The drain cover of D2 measures 0.71 meters in length and 0.62 meters in width, and it is decorated with four "flower petals"; the drain cover of D3 measures 0.72 meters in length and 0.62 meters in width, and it is also decorated with four "petals", although it may be a modern reconstruction in concrete; and the drain cover of D4 measures 0.68 meters in length and 0.79 meters in width, and it is decorated with only a hole. The circular sections on each of these drain covers have a diameter of 0.37 meters, and the inner hole in D4 has a diameter of 0.105 meters. These three drain covers are also almost perfectly centered in the room: D2 is 4.97 meters from Wall 7j and 4.92 meters from Wall 9i, D3 is 5.06 meters from the step of Pool δ and 4.97 meters from the pool step of Pool ε, and D4 is 4.98 meters from Wall 8f and 4.92 meters from Wall 10m.

step, a higher middle step, and a lower inner step. The steps would have been a convenient place for bathers to sit, both inside the water, and in the space of the *frigidarium*. They are roughly 0.88 meters deep from the top step to the floor of the pool, but it is not likely that the water level went all the way up to this top step. The water was not heated, and it was probably running continuously into these pools from a connection to the aqueduct. A large *a cappuccina* drain going down from the center of the interior steps of both pools transported the wastewater into the large drainage canal mentioned above.[160]

Pool δ was equipped with a quadripartite window at its northern, apsidal end; evidence for this window can be seen in the northwestern corner of the apse. Each pool is adorned with several niches: Pool ε (figs. 3-90, 3-91) has five – one on the east wall, one on the west wall, and three on the south wall; while Pool δ (fig. 3-92, 3-93) only has two – one on the east wall and one on the west wall. Pool δ probably originally had five as well, but the three that would have been on the northern wall were removed when this partition was replaced with the semi-circular apse wall in the fourth century AD. The niches probably contained statues that may also have served as fountains, and Cicerchia mentions that there is evidence of *fistulae*, or lead pipe, imprints in the walls of Pool ε. He claims that these imprints illustrate that there was a fountain under each niche.[161] This evidence is no longer visible, but the mortar facing of the walls below the niches in Pool ε is relatively intact. The location of these imprints, therefore, is unclear and questionable. Niche m in the eastern wall of the pool has a rather significant (0.20 by

[160] Cicerchia and Marinucci 1992, 30, 71.
[161] Cicerchia and Marinucci 1992, 30, 71.

0.28 meters) hole right below it, which may have once held a pipe; along with another hole (0.15 by 0.15 meters) in the center of the niche, itself. There is currently no available evidence for how the cold water was brought to these pools. Exploratory trenches excavated under the floor of the bathing complex presented no evidence of pipes, either.[162]

The eastern and western walls of Pool δ have been dated to the first phase of the baths, while the apse has been dated to the third phase – more specifically to a period encompassing the reigns of Maxentius and Constantine. The wall facing of this pool was also changed at this time, and the two niches on the eastern and western walls were blocked up. Most of the walls of Pool ε have been dated to the first phase, and they show no signs of ancient refurbishment. An opening on the eastern wall, between the pool and Room 10, was closed in the second phase of the baths. The purpose of this opening is unclear. The pavement of Pool ε and the wall-facing was replaced in the third phase as well, according to Cicerchia.[163]

Cicerchia determines that the rectangular plan of the space and the dimensions of the rooms make it most likely that the open area was covered with a cross vault; while the pools were covered with a barrel vault, illustrated by evidence found in Pool ε.[164] The columns in this space are placed on a travertine base, and they are larger than the

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[162] Cicerchia and Marinucci 1992, 72.
[163] During modern restorations of this pool and other sections of the bath, a great deal of ancient material was reused. This practice created significant confusion in understanding the phasing of these walls. Cicerchia (1992, 72-3) was able to determine that the walls of Pool ε were not altered in ancient times by comparing and studying the mortar in the walls and by examining archival excavation photographs. Cicerchia and Marinucci 1992, 72.
[164] Cicerchia and Marinucci 1992, 29, 30; Pellegrino 2000, 33.

columns found in Rooms 3 and 11.[165] These larger columns may indicate that this part of the bath was higher than the rest of the rooms in the northern section of the baths. Cicerchia estimates the height of the room, including the vault, to have been between 15.00 and 17.00 meters.[166] Such a configuration would not be unusual in a bathing complex.[167]

II.d.7. Rooms 7-10

The purpose of Rooms 7, 8, 9, and 10 (fig. 3-86) is not entirely clear, especially Rooms 7 (fig. 3-94) and 8 (fig. 3-95). Rooms 9 (fig. 3-96) and 10 (fig. 3-97) probably served primarily as passageways to the hot rooms in the latest phase of the baths.[168] All four of these rooms are entered from Room 6. Rooms 7 and 8 do not lead anywhere, while Room 9 leads to Rooms 16 and Room 10 leads to Room 20 in the southern section of the baths. A passage between Rooms 9 and 17 (Door AI) (fig. 3-98) was closed when changes were made because of structural instability. The passage between Rooms 6 and 10 (Door N) (fig. 3-99) was narrowed in Phase II of the baths, perhaps in an attempt to

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[165] The capitals are made from Pentelic marble. They are 0.87 meters high, and they are decorated in an Oriental style according to Pensabene and Lazzarini (2007, 272). They were probably imported from Attica. Comparable capitals can be seen on the Exedra of Herod Atticus at Olympia. The Proconnesian marble trabeated sections in the Terme del Foro, instead, are decorated in a western style and seem to have their origins in a Roman workshop.

[166] Cicerchia and Marinucci 1992, 30.

[167] See DeLaine (1997, 57) for a table of proportions to determine room height.

[168] Cicerchia (1992, 31) mentions that the doorways between Rooms 9 and 16 and Rooms 10 and 20 were very narrow in order to help prevent heat from escaping. Both Door E and Door I have thresholds that are 1.80 meters wide, which is actually wider than many of the other doors in the bathing complex. Door I retains evidence that it was at least partially blocked at some point, which may be what Cicerchia is referring to. He also mentions that there was a door in the western wall of Room 10 that was blocked in the second phase of the bath. This opening would have led directly into Pool ε, which would imply that this pool was not present in the second phase. Clearly some contradictory information is being presented. Cicerchia and Marinucci 1992, 30-1, 75, 79, 83, 85, 87, 89.

improve heat retention in the room.[169] Door I was also reduced in width, but not until the third phase.[170]

According to Cicerchia, all four rooms have equal dimensions: 5.90 meters on each side.[171] When I actually measured them in the field, there were variations, and none of the dimensions actually reached 5.90 meters. In Room 7, the eastern and western walls are 5.74 meters long, and the northern wall is 5.80 meters long. In Room 8, the eastern and western walls are 5.74 meters, and the northern wall is 5.77 meters long. In Room 9, the eastern and western walls are 5.94 meters, and the southern wall is 5.77 meters long. In Room 10, the eastern and western walls are 5.88 meters, and the southern wall is 5.56 meters long.

The floor of all of these rooms is very poorly preserved, and it is predominately covered with modern concrete. In Room 7 a small portion of marble paving can be identified. *Tubuli* with outer dimensions of 0.12 by 0.08 meters can still be seen in the eastern and western walls of Room 7 (fig. 3-100), and Bloch states that there is also a hypocaust beneath the floor that is very well preserved.[172] He additionally mentions that Rooms 8, 9, and 10 were also equipped with *tubuli* in their east and west walls and a hypocaust below the floors. The only visible evidence remains in Room 8, where some

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[169] Doors E, I, and AI seem to be associated with the original construction, but both the ancient and modern refurbishments to the structure make it difficult to determine the phase of these doors conclusively.

[170] Cicerchia (1992, 31) states that the passage was between Rooms 8 and 17, but this can be assumed to be a typo, since Rooms 8 and 17 are nowhere near each other and the phrase is correctly stated on another page (1992, 83). Morever, evidence for a blocked passage between Rooms 9 and 17 is clearly visible in situ. Cicerchia and Marinucci 1992, 87, 88, 89.

[171] Cicerchia and Marinucci 1992, 30.

[172] Brickstamps related to Asinia Quadratilla, Q. Asinius Marcellus, Flavius Aprus (consul in AD 130), and Lucius Aelius (the future Lucius Verus) have been recovered in the hypocaust of Room 7. Brickstamps related to Asinia Quadratilla are considered by Bloch (1938, 141) to be from an earlier structure, and they were also found in the hypocaust under Room C. Bloch contends that these should be dated to AD 150, 151 and 153. Bloch 1938, 141.

mortar and the edge of some *tubuli* remain adhering to the wall in the southeast corner, and in Room 10 where some fragmentary *tubuli* remain in situ in the southwest corner of Wall e.[173] The possible explanations for the use of heating implements in these rooms is discussed above.

Small sections of marble veneer remain on the some of the walls, which provide a picture of what the decoration may have looked like in their final phase. Both *pavonazzetto* and *portasanta* marble slab pieces have been found, covering a layer of *cocciopesto* and mortar, in Room 7. Only *portasanta* remains were found on Wall c in Room 8; there were no visible extant remains on any of the other walls. The likeliest reconstruction of the wall-facing of these rooms, therefore, is that they were covered with a haphazard collection of reused marble elements. The possibility that all of these marble fragments were inserted as part of modern restorations is not excluded, either.

The northern wall of Room 7 is only extant to a height of 2.00 meters at its highest point, and the northern wall of Room 8 is only extant to a height of 0.50 meters. These rooms may have been equipped with windows looking out onto via della Forica, but it is impossible to know for sure, since the walls are not significantly preserved and are heavily restored.[174] Room 7 had an opening at the base of Wall a, in the northeast corner. Perhaps it was used as a drain directly onto via della Forica, or as an entry point

[173] *Tubuli* were also present in the southern wall of Room 9, according to Cicerchia (1992, 85), but the current use of this room for storing broken blocks of stone against the wall makes this statement impossible to verify in the field. Cicerchia and Marinucci 1992, 30, 75, 83, 87, 89.

[174] A window is identified on the northern walls of both Room 7 and Room 8 by Cicerchia (1992, 75, 76, 79), although it is unclear on what evidence he is basing this conclusion. He even mentions that the proof for the window in Room 7 is part of a modern reconstruction, which may not be accurate.

for a *fistulae*.[175] Another opening can be seen in the southern end of Wall b (fig. 3-101), of unknown function.

Room 9 does not retain any of the material that would have once covered the brick walls. The walls of Room 10 are also mostly bare, except for some fragments of *pavonazzetto* on Wall b. There is no evidence for windows in either room.[176] In the base of Wall c in Room 9, there is a channel made from what appear to be *tubuli* bricks laid horizontally (fig. 3-102). This section of wall was added to block Door AI, which led to Room 17, at some point during the life of the bathing complex. The channel in Wall c leads through to the base of Wall a in Room 17, but its purpose is difficult to deduce. There are also rectangular openings in Wall b (fig. 3-103), whose functions are unclear. Since Pool ε is on the other side of this wall, a logical conclusion is probably that pipes passed through these openings.[177] Another aperture in Room 9 in Wall e is large enough to have been as a door to access Room 8 (fig. 3-104). This hole is round and over a meter wide, but it appears to be a result of damage or even modern excavation, rather than a constructed ancient doorway. Furthermore, it is not even mentioned in the monograph on the baths. Openings also exist in both the northern and southern walls of Room 10, which are probably related to pipes (figs. 3-97, 3-105).[178]

The walls of Room 7 have been entirely dated to the first phase of the baths, including the *tubuli*, with no subsequent ancient restorations. Although very poorly

[175] Cicerchia and Marinucci 1992, 76.
[176] Cicerchia and Marinucci 1992, 83.
[177] The date when these opening may have housed *fistulae* is unclear. The southern opening was blocked during the first phase, suggesting that it may have been an error in construction. Cicerchia and Marinucci 1992, 83, 84.
[178] Cicerchia and Marinucci 1992, 87.

preserved, the walls of Room 8 have also been dated to the first phase, with no later structural changes.[179] Room 9 was also constructed as part of the first phase of the baths, but changes were made to the southern wall: the communication between Rooms 9 and 17 was altered in the second phase of the baths, and then it was completely blocked in the third phase. Room 10 has been dated entirely to the first phase, except for changes that were made to the doorways: Wall 10f/g was added in the second phase to reduce the width of Door N, and Wall 20j was added in the third phase to reduce the width of Door I. As mentioned above, an access to Pool ε was also closed off, forming Walls k and l.[180]

There are vertical slots in the walls outside of both Rooms 9 and 10 (figs. 3-99, 3-106), which are located next to the columns (C16 and C17). These columns flank Pool ε. The slots are similar to other recesses that were designed to hold *fistulae*, and both are between 0.21 and 0.28 meters wide. A logical reconstruction would be to place small basins or some other water feature in these locations, emphasizing the adjacent pool. Enforcing this likelihood is a rectangular depression that can be seen in the pavement directly in front of Walls i, j, and k of Room 9. Perhaps this depression was the location of a small foot bath that bathers could use before entering the pools.[181]

According to both Cicerchia and Thatcher, Rooms 7, 8, 9, and 10 were covered with cross vaults. Cicerchia states that the remains of the ceiling can be seen 2.90 meters above the floor in Rooms 9 and 10, while Thatcher says that the springing of the arch

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[179] Cicerchia and Marinucci 1992, 76-7, 81.
[180] Cicerchia and Marinucci 1992, 84-5, 87, 88, 89.
[181] The depression measures 1.38 meters in length and 1.48 meters in width. Similar shallow foot baths can be seen flanking the cold pools in the Baths of Eustolios at the site of Kourion, on Cyprus. Karageorghis 1987, 33.

begins at 3.35 meters from the floor, and that the highest point of the vault is 6.00 meters from the floor.[182]

II.d.8. Rooms 11-13

Room 11 (figs. 3-107, 3-108, 3-109) served as a passageway, while the function of Rooms 12 and 13 is unclear. Cicerchia has identified Rooms 12 and 13 as *apodyteria*.[183] The arrangement of these rooms is identical to that of Rooms 3, 4, and 5: the entranceways to Rooms 12 and 13 are composed of spur walls and columns, and the thresholds are also delineated by wide *pavonazzetto* strips. The dimensions of all of these rooms are also very similar. Room 11 is approximately 10.60 meters long and approximately 9.00 meters wide. Room 12 has a length of approximately 5.75 meters and a width of approximately 8.79 meters. Room 13 has a length of approximately 5.86 meters and a width of approximately 8.89 meters.

The pavement of Room 11 is all modern, but it can be imagined that it would have looked the same as that in Rooms 3 and 6. Like Rooms 4 and 5, Rooms 12 and 13 are paved with a white mosaic (irregular tesserae 0.015-0.018 meters on each side) with a black band (regular tesserae 0.013 meters on all sides) that is 0.13 meters wide. These mosaic floors date to the first phase of the bathing complex.[184] There is no evidence for

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[182] When measured in the field, the highest walls in Room 9 (Walls a, b, and c) measure more than 6.00 meters. This difference from Thatcher's approximation can be explained by the fact that the vault of the adjacent room was higher. Thatcher 1956, 216; Cicerchia and Marinucci 1992, 85.
[183] Cicerchia and Marinucci 1992, 29, 91, 95, 99.
[184] Cicerchia and Marinucci 1992, 95, 101.

heating systems in any of these rooms. There is a drain (D5) 4.14 meters from the eastern threshold between Rooms 6 and 11, which connects to the large drainage channel.[185]

Very little remains of the wall-facing of these three rooms, particularly that of Room 12. Walls f, g, and h, which separate Room 11 from Room 14, retain some fragments of mortar and *pavonazzetto* and *cipollino* at their bases. *Pavonazzetto* and *cipollino* fragments can also be seen at the bases of Walls m, p, q, r, s, and u. The variety of marbles and their haphazard distribution suggests that the walls were revetted with spoliated materials. In Room 12, the marble was eventually replaced with stucco that may have been painted, particularly on the eastern wall.[186]

According to Cicerchia, Room 12 was lit by a tripartite window in its northern wall, exactly as in Room 4. The northern wall of this room is only extant to approximately 2.00 meters high, implying that the presence of the window was assumed according to symmetry. The southern wall of Room 13 displays no evidence for the presence of a window, but it has been stipulated that there was probably an opening contained within the space of the arch of the ceiling vault. There is an ovoid opening at the base of wall b, in Room 12 (fig. 3-110), which communicates with Room 14b; its function is unclear, but it may have held *fistulae*.[187]

Although the walls are very poorly preserved in Rooms 11, 12, and 13 it can be concluded that they all dated to Phase I of the bathing complex, without significant later

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[185] Like the other drain covers in the northern sector of the baths, D5 is centered in the room from north to south: 5.05 meters from the northern end and 4.92 meters from the southern end. The drain cover measures 0.65 meters in length and 0.58 meters in width, and it is decorated with four “petals”. The circular section has a diameter of 0.37 meters.

[186] Cicerchia and Marinucci 1992, 96.

[187] The conclusion that there was a window in the arch of the vault of Room 13 is based on the likely presence of such a window in Room 5, and the symmetrical relationship between the two rooms. Cicerchia and Marinucci 1992, 30, 95, 99, 103.

structural changes. Wall b in Room 13 is the best preserved wall in the northern sector of the bathing block. The northern and southern walls of Room 12 were heavily restored in the modern refurbishments, as was the northern wall of Room 13.[188]

Evidence of the springing of the vault on the eastern wall of Rooms 13 (fig. 3-111) illustrates that the ceiling of this room was vaulted over. The point of springing began at 5.92 meters from the floor and enough of the arch is extant to illustrate that the vaulted section was 2.96 meters high. The total height of this room is determined to have been 8.88 meters.[189] According to symmetry, it is likely that the vaults of Rooms 4, 5, and 12 were constructed in the same way.

II.d.9. Room 14

Room 14 (fig. 3-112) has been identified as a vestibule, serving the same general function as Room 1. The room may have also acted as a passageway for accessing the service areas where the boilers and the *praefurnia* of the heated rooms were found, in addition to being one of the main entrances for the baths. These service areas could either be entered directly through Door C (fig. 3-113) from Room 14, or by first passing through Door AA and going through a door immediately to the southwest. Door AA also led from Room 14 through the long service corridor to the *palestra*. There was not enough evidence remaining in Room 14 for a complete and accurate restoration of the plan.[190] The northern wall (fig. 3-114) is not straight, but the longest dimension is

[188] Cicerchia and Marinucci 1992, 93, 96, 97, 100-1.
[189] Cicerchia and Marinucci 1992, 30.
[190] Brickstamps found in this room are Hadrianic in date and relate to an earlier structure that was demolished. Bloch 1938, 142; Cicerchia and Marinucci 1992, 53, 103, 105.

approximately 17.20 meters. The width is more regular, and it measures approximately 12.00 meters.

The threshold of Door O, between Rooms 11 and 14, consists of a band made from pieces of different types of marble. The floor of Room 14 was paved with a white mosaic (irregular tesserae 0.012 meters on each side) with a black band, similar to that described in Room 4, 5, 12, and 13. As mentioned above, a drain cover (D6) (fig. 3-72) with “flower petal” openings was surrounded by a rectangular black geometric design in the mosaic pavement. Three other drain covers can be seen (fig. 3-115) on the floor of Room 14: one is a large drain (D7), very similar to the one in Room 2, that is covered with a modern grate and located directly to the east of D6; and the other two (D8 and D11) drains are covered with a different “flower petal” motif that does not contain a circular area, and they are located to the southeast. None of these drain covers follows the straight line created by the five drain covers to the west, but their angle suggests that the drainage canal bends towards the south, as is the case in Room 2.[191]

A final feature that exists on the floor of Room 14 is a depression against wall b (figs. 3-116, 117), which was an exploratory trench opened during excavations.[192] The trench measures approximately 2.60 meters from north to south and 3.17 meters from east to west. There are two small walls beginning half a meter from the northern end with a space between them of 1.10 meters. A substantial opening in the western wall of the depression is approximately 0.13 meters wide and 0.20 meters tall. The opening is carefully constructed and continues to the west under the floor or Room 14, towards the

[191] Cicerchia and Marinucci 1992, 103.
[192] Cicerchia and Marinucci 1992, 29, 104.

large drainage canal. Perhaps this aperture functioned in conjunction with the drainage conduit. No evidence of any heating systems exists in this room.

Some of the highest extant walls in the bathing complex can be found in Room 14.[193] For example, Wall f, the western wall (fig. 3-118), is almost ten meters high. There is no evidence for any windows or openings in any of the walls. Sections of mortar continue to adhere to many of the walls in Room 14, and Wall e has a small fragment of imbedded *pavonazaetto* that is 0.02 meters thick. Small holes on the walls throughout the room suggest that all the walls were covered with marble revetment. The only extant feature on the walls is a vertical *fistulae* slot (fig. 3-119) on Wall f, which is 0.24 meters wide.[194] This slot is unusual becomes it does not originate at or below floor level. Instead it starts 1.37 meters from the floor and continues up as far as the wall is preserved. Part of the slot is filled with bricks, suggesting it was blocked up at some point.

The northern, eastern, and western walls date entirely to Phase I of the bathing facility, with no later structural interventions. The southern wall dates to the first phase as well, except for the opening leading down to the substructures. This opening dates to the third phase, but precedes the relocation of the boilers to this general area. The ceiling of this room was vaulted, and it is approximately three meters higher than that of Room 13.[195]

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[193] Walls a and b abut the walls of Caseggiato I.XII,4-5, which was originally a Hadrianic structure containing a bakery and cisterns, as discussed above. Wall b of Room 14b also abuts the western wall of Caseggiato I.XII,4. Ostia Internet Group 2011.

[194] Cicerchia and Marinucci 1992, 103.

[195] Cicerchia and Marinucci 1992, 29, 104, 105.

II.d.10. Room 14b

Room 14b is a small entrance space, connecting via della Forica through Door Q to Room 14 (figs. 3-120, 3-121). The longest dimension of this room is 6.13 meters, and the width is approximately 5.00 meters. The shape and dimensions of the room (fig. 3-122) were affected by the pre-existence of the Caseggiato della Cisterna.[196]

The floor is paved with the same white mosaic as Room 14, and the two rooms are divided by a pieced-together marble strip in the threshold of Door P. There is no evidence for any heating systems or windows in this room. Alterations were made to Door Q (fig. 3-28) in the third phase due to the construction of the Foro della Statua Eroica. Otherwise, all the walls of this room are dated to the first phase of the baths. There are two openings in this room: the opening in Wall e leads to Room 12, and it is discussed above; the opening in Wall f is 0.50 meters wide, 0.12 meters high, and leads from the base of the wall out to via della Forica.[197] The ceiling was probably covered by a barrel vault, although there is no evidence of this structure remaining.

II.d.11. Room 15

Room 15 (fig. 3-123) has been identified as an octagonal *heliocaminus*, or sun-bathing room, because it has large southwest-facing windows, and because it receives sun all day.[198] In addition, more sun enters the room in the early afternoon than any other room in the bathing complex. The space is entered primarily from Room 2 through Door

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[196] Cicerchia and Marinucci 1992, 29, 104.
[197] Cicerchia and Marinucci 1992, 99, 103, 104.
[198] Yegül (2010, 248) defines a *heliocaminus* as, "A special room for sunbathing believed to have been a part of some Roman baths. These rooms enjoyed a southern or southwestern exposure and received the sun through large, possibly unglazed, windows."

A (fig. 3-124). Room 15 could be exited in the same way, or a bather could pass through Door B (fig. 3-125), Room C, and Door D to continue through the heated rooms of the baths. As a result, this room could act almost as an independent entity.[199]

Room 15 is almost a perfect octagon, with each side measuring almost 4.90 meters in length and having an identical structural fabric.[200] The length of the room is approximately 11.81 meters and the width is approximately 12.08 meters. The floor of Room 15 was heated by a hypocaust, but there is no evidence for any wall heating apparatus. There is not even a cut in the floors against the walls, where extra space would have been necessary to accommodate any *tubuli*. Cicerchia mentions that this room was not heated by a *praefurnium*, however, a furnace opening in the substructure area below the southeast corner of the room is clearly visible (fig. 3-126). The opening proceeds under the floor of Room 15 for at least five meters, but no hypocaust pillars are visible from the outside.[201] The pavement of the floor is not visible, and it is currently covered with soil and grass.[202] The threshold of Door A, between Rooms 2 and 15, is formed by a solid marble slab. The threshold of Door B, between Rooms 15 and 16, is missing and only the yellowish terracotta tiles below, are visible.

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[199] Thatcher 1956, 196, 199, 218; Cicerchia and Marinucci 1992, 35, 107; Pavolini 2006, 109.

[200] The north side measures 4.84 meters in length; the northeast side measures 4.83 meters in length; the west, southeast, south, and northwest sides all measure 4.85 meters in length; and the southwest and west sides measure 4.88 meters in length. Cicerchia and Marinucci 1992, 29, 108.

[201] The *praefurnium* is also noted by Poccardi (2001, 169 fig. 9) in this location. Bloch (1938, 142) mentions that the hypocaust of this room was completely reconstructed after the dome of the room collapsed, alterations can be visibly noted in the archaeological record. Thatcher 1956, 195; Meiggs 1973, 414; Cicerchia and Marinucci 1992, 35, 107, 109.

[202] MacDonald and Boyle (1980, 13) mention that the pavement of the *heliocaminus* in the Piccole terme in Hadrian's Villa at Tivoli was covered with sand so that patrons could lounge on the floor. There is no evidence to support this conjecture at either Tivoli or Ostia.

As already alluded to, the space was lit by several large windows facing the south from various angles. Evidence for the windows remains in situ, at least in Walls f, h, and i (figs. 3-127, 3-128). Wall g was probably furnished with a window as well, but the wall does not survive to a sufficient height to allow for certainty.[203] The window in Wall f is 0.44 meters wide, while the ones in Walls h and i are 0.30 meters wide. Although it is unclear if the windows were glazed, Meiggs suggests it most likely that the windows in this particular room were left completely open to maximize sun exposure.[204] This possibility is enforced by the presence of heating systems in Room C. By being heated, Room C could act as a protective heat curtain between the Room 15 and the hotter Room 16, even if there were open windows in Room 15.

The walls of this room all date to Phase I of the Terme del Foro, with no evidence of later ancient alterations to their fabric.[205] There is not sufficient evidence to determine what the ceiling of this room looked like. Thatcher reconstructs a masonry dome with a springing of approximately 6.60 meters from the floor as the most likely choice.[206]

[203] Cicerchia (1992, 29, 107, 109) determines that every external wall in Room 15 was equipped with a window, although there is no longer sufficient evidence in situ to validate his claim,
[204] Most bathers would have attended the baths at the hour when the sun would have entered a room most directly from the southwest. Meiggs 1973, 414 n. 2; Cicerchia and Marinucci 1992, 35.
[205] Cicerchia and Marinucci 1992, 29, 109.
[206] Thatcher (1956, 195) uses the heights of the windows of Rooms 17, 18, and 19 to determine where the dome would have begun. Domes were often used to cover *frigidaria*, such as the one in the Gymnasium-Bath complex at Salamis. The *caldarium* was covered with a dome in the Antonine Baths at Carthage. Lézine 1968, 23; Musso 2004, 304-5.

II.d.12. Room C

Room C (fig. 3-129) functioned strictly as a heated passageway between Rooms 15 and 16, as mentioned above.[207] The small space is semicircular, with the northern wall (fig. 3-130) as the straight edge measuring 4.20 meters and the diameter of the curved wall (fig. 3-131) measuring 2.10 meters. This space is heated both by a hypocaust, and by *tubuli* that cover the whole of Wall a. The outer dimensions of these *tubuli* are 0.12 by 0.08 meters. A layer of *cocciopesto* and mortar remains on all the walls, including over the *tubuli* on Wall a, demonstrating that the other walls were not equipped with heating devices. This surface layer on the walls dates to the third phase of the baths.[208] No marble veneer remains on the walls. The hypocaust was probably heated with residual heat from the hypocaust of Room 16. The pavement (fig. 3-57) is composed of very large marble tesserae (0.04 by 0.04 meters) of various types, similar to those found in Room 1.

There is no evidence for any windows in this room, which is logical since the chamber was meant to serve as an insulating space; however, the edge of an opening can be seen in the ceiling (fig. 3-132). The walls are largely intact, reaching over 6.50 meters in height.[209] The springing of the vaults can even be seen on the top of the walls. From this evidence it can be deduced that the covering was rounded and may have resembled a tholos dome.

[207] Door D was blocked in the third phase of the bathing complex, suggesting that this room was no longer being used at that time. Cicerchia and Marinucci 1992, 29, 109.
[208] Cicerchia and Marinucci 1992, 29, 109.
[209] Cicerchia and Marinucci 1992, 29, 109.

II.d.13. Room 16

Room 16 (figs. 3-133, 3-134) has been identified as a room for sweating, either a *sudatorium* or a *laconicum*.[210] Meiggs states that that this room was the hottest in the baths, with a hypocaust (fig. 3-135), *tubuli* wall heating, possible vault heating, and a heated passage (Room C) leading to it from the west. The doors were placed at oblique angles in an attempt to reduce heat loss, according to Pavolini. Meiggs also mentions that the room may have partly been heated by sunlight.[211] The room was accessed from Room C through Door D (fig. 3-136), until the third phase of the baths when the door was blocked. Most of this blockage must have been removed sometime after 1992, since photographs in the monograph still show it in place.[212]

The longest dimension of the ellipse forming Room 16 is 14.00 meters, and the widest dimension is approximately 8.85 meters. Room 16 was heated by a hypocaust supplied through a *praefurnium* below the center of the southern end of the room. There is evidence of three other *praefurnia* at a lower level of the substructure, which appear to be abandoned in the last phase of the baths.[213] The hypocaust and the floor seem to have been raised to a higher level than before, probably also in the last phase of the baths. The

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[210] Thatcher (1956, 218) and Pellegrino (2000, 33) identify Room 16 as a *laconicum*, while Meiggs (1973, 414) and Pavolini (2006, 110) identify it as a *sudatorium*. Cicerchia (1992, 35-6, 111, 112-3) also identifies Room 16 as a dry heat *laconicum*, basing his identification on the lack of evidence for any basins, *labra*, or water systems. He also mentions that there is no trace in the room of water conduits or *fistulae*. In a contradictory statement, he describes Room 16 in its earliest phase as being almost completely filled by a pool. Yegül (2010, 6) mentions that *laconica* are usually round, but this room is elliptical, making it very unusual.

[211] Long angled doorways in the heated sections of the baths can also be seen in the Piccole terme and the Terme con Heliocaminus at Tivoli, and nine of the passageways in the Piccole terme are set at an angle, like Door E in the Terme del Foro at Ostia. Meiggs 1973, 414; MacDonald and Boyle 1980, 12; Cicerchia and Marinucci 1992, 31, 111.

[212] Cicerchia and Marinucci 1992, fig. 38.

[213] Cicerchia and Marinucci 1992, 111; Poccardi 2001, 169 fig. 9.

reason for this change is not clear.[214] Cicerchia hypothesizes that perhaps there was a pool filling this room in the first phase of the baths, which was set at a lower elevation and had stairs leading down to it.[215] However, there is no visible evidence to support this theory.

The floor is currently composed of a poorly preserved white mosaic pavement, which probably had a black band around it. The mosaic (fig. 3-137) shows signs of ancient refurbishments – the extant white tesserae that are closer to the edges of the wall are smaller than those closer to the center, suggesting the floor was repaired at some point.[216]

The wall-facing of Room 16 is very poorly preserved: most of what remains is the material that can be seen behind the marble (*grigio*) bench (fig. 3-138) that is present in the current phase of the baths. This bench would have been a useful place for patrons to sit and relax while being subjected to the high temperatures.[217] The presence of marble, mortar, and *tubuli* between the bench and the wall (fig. 3-138), suggests that the bench was not always present and that the marble was not removed when the bench was added. Cicerchia also illustrates that the bench was not introduced until the third phase of the

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[214] Bloch (1938, 142) mentions that the hypocaust of Room 16 had to be rebuilt in the Severan period because it had been heavily damaged. Cicerchia and Marinucci 1992, 35-6; Pavolini 2006, 110.

[215] This earlier hypocaust was destroyed by the restorations conducted between 1988 and 1989. Cicerchia and Marinucci 1992, 29, 112, 113 n. 1.

[216] The extant *tesserae* closer to the walls are approximately 0.010 meters on each side, while the ones further in the middle of the room are 0.015 meters on each side. The larger *tesserae* were probably put in place to repair some damage to the floor. (Or if the reconstruction of Cicerchia is correct, perhaps these larger *tesserae* filled the space where the pool once was.) Thatcher (1956, 200) states that the *tesserae* were of a pale rose, although in situ they appear to be white. He also mentions that the thickness of the floor, including the *tesserae*, was 0.406 meters. Perhaps when Thatcher wrote his article, a break in the floor was present that allowed him to examine the pavement. Cicerchia and Marinucci 1992, 29, 111.

[217] Meiggs 1973, 414; Pavolini 2006, 110.

baths.[218] The thickness of the bench makes it unlikely that the *tubuli* were placed there to heat the bench, but to heat the wall above it.

This bench goes around most of the perimeter of the room, except against the northern end (Wall a), and possibly Wall b. There is a niche in Wall a (fig. 3-136) with the base beginning at approximately 0.76 meters from the floor. The niche is 1.45 meters wide and retains large sections of white *luna* marble revetment. The veneer of the rest of Wall a can still be seen up until the height of the base of the niche.[219] The *tubuli* on Wall a have outside dimensions of 0.12 by 0.09 meters, while those on the rest of the walls of Room 16 have outside dimensions of 0.14 by 0.08 meters. The layer of mortar is also thinner on Wall a than on the other walls – 0.04 meters thick rather than 0.065 meters thick. Marble veneer of several varieties (*pavonazzetto*, *giallo antico*, and *brecia*) remains in situ on Walls c, d, and e, once again implying that the walls were patched up with spoliated material. No evidence of the wall facing or of a bench remains in situ against Wall b.

The presence of a column – C26 – on top the southern wall of Room 16 (fig. 3-134) suggests to Cicerchia that the entire southern part of the room was fenestrated with a tripartite opening.[220] He does not mention the presence or lack of glazing in this window. Thatcher approximates that the window is 4.70 meters in height, and he conjectures that glass was not used.[221] Column C25 is no longer in situ (fig. 3-134), but has been placed

[218] Cicerchia and Marinucci 1992, fig. 40, 111, 112.
[219] The marble veneer is part of the modern refurbishments, according to Cicerchia (1992, 29, 112).
[220] Photos taken after the first modern restoration work was conducted at the Terme del Foro show column C26 as a complete column. Currently, only the lowest part of the column and the base are visible. The base of the column is placed on the wall 1.66 meters from the floor. Cicerchia and Marinucci 1992, 36, fig. 41, 111.
[221] Thatcher 1956, 200.

below on the bench recently. When examining excavation photos of the southern portion of the Terme del Foro from the late 1930s, however, neither column remains in situ (fig. 3-139). The placement of this column base on top of Wall d, and the subsequent conclusion that there were windows covering the whole southern wall of this room, is therefore merely conjecture. Thatcher's claim that the window was open, if it was even present, is unconvincing, especially since a window would have made it more difficult to maintain very high temperatures in this room.

All of the walls of Room 16 have been dated to Phase I of the baths. In the current state of preservation of the baths, it has been deduced that the ceiling of the room was probably formed by a hemicycle or ellipsoid beginning at 6.60 meters from the floor. Although he admits that there is no evidence to prove it, Thatcher claims that this vault was heated.[222]

II.d.14. Room 17

Room 17 (fig. 3-140, fig. 3-141) has been identified as a *tepidarium*, with heated floors and *tubuli* in the walls. This room would have been kept at a lower temperature than the previous one, and would probably have received less direct sunlight than Room 15.[223] The room was accessible in its final phase from Room 16 through Door F, but

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[222] Thatcher 1956, 199, 201; Cicerchia and Marinucci 1992, 36.

[223] Thatcher (1956, 218) states that Room 17 can be put in a group with Rooms 15 and 16, since they each emphasized sunlight and dry heat. This statement could be true of Room 18 as well, however, he puts Room 18 in a group with Rooms 19 and 20 as having wet heat and less sunlight. Thatcher's grouping system does not seem very significant, and it is unclear why he labels Room 18 as having "wet heat". Johnson (1932, pl. 43) labels Room 17 as a *sudatorium*. The early date of this publication, prior to the complete excavation of the site, may account for his room designations. In fact, he labels Rooms 18 and 20 as "*destrictaria*", or rooms for anointing. The evidence he bases these conclusions on is not mentioned. Thatcher 1956, 218; Meiggs 1973, 414; Cicerchia and Marinucci 1992, 36, 115; Pavolini 2006, 110.

originally could have been accessed directly from Room 9 through Door AI.[224] Room 17 leads to Room 18 through Door H and to or from Room 20 through Door G.[225]

Room 17 has a hypocaust below the floor and *tubuli* in all the walls except for in the southern wall (Wall e) (fig. 3-142).[226] All the *tubuli* have an outer dimension of 0.14 by 0.11 meters. The heat originated from two separate furnaces (figs. 3-143, 3-144): one is below the southwestern end of the room, and the other is below the southern end of the room.[227] The floor is currently paved with reused marble dating from the third phase of the baths (fig. 3-23), as are the walls. The southern wall had three windows divided by two Proconnesian Corinthian columns (C27 and C28) (fig. 3-142), which were also replaced in the third phase with ones taken from another monument.[228] There is no evidence for windows or openings on any other wall of this room.

The original outer walls of Room 17 date to Phase I of the baths, but many changes were made to their structure, as discussed above. The large pilaster (fig. 3-11) constructed in the northwestern corner was added in Phase II, and then it was doubled in size in Phase III. A curve in the western wall behind the pilaster suggests that there may

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[224] Door AI was altered in the second phase of the baths, and then it was completely blocked in the third phase. Cicerchia and Marinucci 1992, 37, 115.

[225] The southern section of the wall dividing Rooms 17 and 18 was rebuilt in the late 1920s, using a system of splitting the well-preserved segments of collapsed wall and reassembling them in their (presumed) original location. Calza 1930, 298, 299-300 figs. 10 and 11.

[226] According to Bloch (1938, 142) the hypocaust of Room 17 dates to a third or fourth century refurbishment. No brickstamps were found on *bipedali* of this substructure.

[227] Cicerchia and Marinucci (1992, 37) interpret the presence of two furnaces in both Rooms 17 and 18 as an indication that these rooms were heated as much as Rooms 16 and 19, which also had two furnaces. The presence of two furnaces would have provided more temperature control, but the amount of heat generated was still dependent on the amount of fuel that was used and the air draft. The temperatures of these rooms, therefore, should not be assumed to be the same. Moreover, it is possible that all of the furnaces were not used simultaneously. Cicerchia and Marinucci 1992, 37, 115.

[228] The third phase bases and capitals of these columns are probably late Augustan in date. The bases are placed on blocks that are also reused – of *cipollino* and *luna* marble. The block below column C27 seems to have served a function related to the water systems. Meiggs 1973, 414; Cicerchia and Marinucci 1992, 37, 115; Pavolini 2006, 110; Pensabene and Lazzarini 2007, 275.

have been a decorative niche in Wall i in the first phase. The interior eastern wall was added in the second phase, while the interior western wall was added in the third phase (figs. 3-12, 3-145).[229] The southern wall was completely rebuilt in the second phase to be curved, and the large windows were added the third phase.[230] Thatcher uses the height of these windows (5.65 meters according to his calculations) to determine that the ceiling of this room would have been a barrel vault that was almost 12.50 meters to the highest point.[231]

II.d.15. Room 18

Another *tepidarium*, Room 18 (fig. 3-146) had heated floors and *tubuli* on all its walls.[232] Room 18 is accessible from Room 17 through Door H (fig. 3-145) or Room 20 through Door J (figs. 3-147, 3-148); it leads to Room 19 through Door L. The connection between Room 18 and Room 20 was not original, but was added later in the third phase. The placement of this room makes it seem redundant, but Cicerchia explains that there were *fistulae* under the floor, and he determines that these pipes probably fed either a *labrum* or a pool that was eliminated in the third phase of the complex.[233]

Room 18 was heated by a hypocaust under the floor and *tubuli* on all of the walls. The *tubuli* on the walls of Room 18 have an outside dimension of 0.14 by 0.10 meters.

[229] Cicerchia and Marinucci 1992, 115, 116, 118, 137.
[230] The southern wall of Room 17 was reconstructed in the modern restorations largely using ancient bricks, creating a great deal of confusion. In addition, both pillars that would have formed these windows are missing from the excavation photos and may have been reconstructed incorrectly. There is even the possibility that there were no windows in this wall at all. Cicerchia and Marinucci 1992, 115, 118, 137, fig. 46.
[231] Thatcher 1956, 202.
[232] Meiggs 1973, 414; Cicerchia and Marinucci 1992, 36-7, 121; Pavolini 2006, 110.
[233] Cicerchia and Marinucci 1992, 37, 38.

There are three *praefurnia* that generated the heat: one is under the western wall (fig. 3-149), in the corner formed with Room 17's western wall and the bottom of *tubuli* (fig. 3-150) can be seen rising up from the furnace area; another is under the center of the southern wall (fig. 3-151); and the final one is immediately to the west on the southern wall (fig. 3-152). A large north-south moving water pipe was also found below the floor, whose opening can be seen in the substructure area (fig. 3-153). Perhaps in an earlier phase this room was equipped with some sort of elaborate water feature.[234]

The southern wall of Room 18 (fig. 3-154) was punctured by a tripartite window, formed with two Proconnesian marble pillars that may date to the period of Maxentius. The rectangular capitals of the pillars were decorated with a marine motif. Cicerchia points out that these pillars may actually be part of a modern reconstruction with uncertain accuracy. He bases his doubts on the fact that two identical marine-motif capitals were found in the area of the *palestra*. A much more likely reconstruction would put all four of these elements in one structure.[235]

The northern wall of Room 18 (fig. 3-147) was already present in Phase I, but it was completely altered and at least partially rebuilt in the third phase. Door J was opened to provide access to Room 20. The eastern (fig. 3-155) and western walls (fig. 3-156) were also significantly changed in the second and third phases, particularly on their northern and southern end. Otherwise, they date to the first phase. The southern wall (fig. 3-148) also originally from the first phase, but was heavily altered with a tripartite

[234] Cicerchia and Marinucci 1992, 37, 121; Poccardi 2001, 169 fig. 9.
[235] Cicerchia and Marinucci 1992, 37, 38; Pensabene and Lazzarini 2007, 275.

window in the third phase.[236] Thatcher approximates the height of this window to be 5.00 meters. Using this conclusion, he estimates that the barrel vault covering this room would have had a maximum height of 12.00 meters from the floor. He also conjectures that this vault would not have been heated.[237]

II.d.16. Room 19 and Pools α, β, and γ

Room 19 (fig. 3-157) has been identified as a *caldarium* due to its many furnaces and its three heated pools: Pools α, β, and γ.[238] Pool α is located on the northeastern side of the room and is rectangular (fig. 3-158); Pool β is located on the eastern side and is rectangular except for its eastern wall, which curves (fig. 3-159); Pool γ is located on the southern side (fig. 3-160, 3-161) and was originally rectangular until the fourth century, when a large apse was added on the southern end. A very large window on the southern end of the room, above Pool γ was also added in the fourth century. The window was separated by two columns (C29 and C30) composed of *bigio* marble, topped by third century Corinthian capitals and standing on reused bases (fig. 3-162).[239] Other than the changes made to Pool γ and the few refurbishments made to the floors and to the hypocaust, the room remained largely unaltered in plan throughout the life of the bathing complex.[240]

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[236] Materials from Phase 1 were used in the reconstruction of this Wall a, creating some confusion. Cicerchia and Marinucci 1992, 121, 122.
[237] Thatcher 1956, 206-7.
[238] Thatcher 1956, 218; Meiggs 1973, 414; Cicerchia and Marinucci 1992, 221; Pavolini 2006, 110.
[239] The *bigio* marble probably originated in the quarries of Lesbos. The eastern wall of Pool β is curved to create an effect of greater depth for patrons who were entering the room from Room 18, according to Cicerchia (1992, 38). Meiggs 1973, 414; Pensabene and Lazzarini 2007, 275.
[240] Cicerchia and Marinucci 1992, 38.

Room 19, Pool α, Pool β, and Pool γ were all heated through a hypocaust under the floor, through *tubuli* on the walls, and possibly through the vault over the room, although there is no evidence to support the latter.[241] The heat originated from at least four separate *praefurnia*: one is located below the center of the northern wall of Pool α (fig. 3-163), another is located in the center of the eastern wall of Pool β (fig. 3-164), another is located below the southwest corner of the room (fig. 3-165), west of Pool γ; and the final one is located below the center of the apsidal wall of Pool γ.

There are also several access points to the hypocaust that can be seen in the substructures of the baths: one is found below the western side of the apsidal wall of Pool γ, another is found below the eastern side of the apsidal wall of Pool γ (fig. 3-166), another is found below the southeast wall of the room (fig. 3-167) and was later blocked, another is found below the southern wall of Pool β (fig. 3-168), and final one is found below the east wall of Pool α.[242] Whether these apertures were designed simply for access to the hypocaust, or if they were earlier *praefurnia* that had gone out of use by the last phase, is unclear. There were also two *praefurnia* with the sole purpose of heating two boilers that supplied the pools (fig. 3-32): one east of Pool γ, and the other north of Pool β.[243] According to Thatcher, the hypocaust heating the main part of this room was walled off and separated from the hypocausts used to heat the pools in this room. He determines that this was done because it would have been harder to maintain the

[241] Brickstamps of Fortunatus, the slave of Domitia Lucilla, were found in the *vespaio* of the pools in Room 19. These have been dated to AD 150. Bloch 1938, 142; Cicerchia and Marinucci 1992, 125.
[242] Cicerchia and Marinucci 1992, 125; Poccardi 2001, 169 fig. 9.
[243] Thatcher (1956, 213) states that all of these *praefurnia* were used at the same time, but there is no way to be sure. Meiggs 1973, 414; Cicerchia and Marinucci 1992, 40; Poccardi 2001, 169 fig. 9.

temperature of the water than that of the air in the room. The evidence he bases this conclusion on is no longer visible.[244]

The pavement and wall-facing of Room 19 are formed of reused marble slabs, dating to the third phase of the bathing complex.[245] The *tubuli* on Walls a, e, f, j, k, o, p, q, and r have exterior dimensions of 0.12 by 0.10 meters (fig. 3-169); the *tubuli* on Walls b, c, d, and l1 through nrubble have exterior dimensions of 0.13 by 0.10 meters (fig. 3-170); and the *tubuli* on Walls g, h, and i have exterior dimensions of 0.12 by 0.08 meters (fig. 3-171). Simply, the walls not associated with pools all have *tubuli* with exterior dimensions of 0.12 by 0.10 meters; the walls of Pools α and γ all have *tubuli* with exterior dimensions of 0.13 by 0.10 meters; and the walls of Pool β all have *tubuli* with exterior dimensions of 0.12 by 0.08 meters.

Openings in the walls of all three pools illustrates that the heated water passed through *fistulae* into each pool. The pipes, themselves, do not remain in the archaeological record, but the holes suggest that the water was propelled into the pool from jets. One pipe can still be seen in the western wall of Pool β, as discussed in Chapter 2, although its purpose is not entirely clear.[246] There was also originally a window in Wall n1, which was changed with the addition of the apsidal section of the pool.[247]

The walls of Room 19 mostly date to Phase I of the baths, although restorations to repair the structural damage during Phase II are visible on many, particularly the western

[244] The main evidence that Thatcher (1956, 213) employs with respect to the functioning of the hypocausts in Room 19 is a plan made by Norman Eaton in January of 1933 ("A Roman Construction." *South African Architectural Record*). This source, and even the full citation, has been impossible to locate in any research facilities.
[245] Cicerchia and Marinucci 1992, 125.
[246] Chapter 2, 90-1.
[247] Cicerchia and Marinucci 1992, 38, 40, 125, 128.

walls. Walls b and d in Pool α both date to Phase II, and the steps leading into the pool date to Phase III. Reused materials were employed to rebuild these steps. The steps of Pool β were redone in Phase III with a combination of new and reused materials, and the space was heavily restored in the modern refurbishments. The apse of pool γ, including the rubble walls connecting the curved part to the original straight walls, date to Phase IIIa.

The tripartite fenestration in the southern wall of Pool γ also dates to the third phase.[248] Thatcher reconstructs the central window as being 5.80 meters high, while the two windows flanking it were only 5.50 meters high. He deduces that the ceiling of Room 19 was composed of a barrel vault over the rectangular part, smaller barrel vaults over the rectangular pools, and a semi-circular dome over the apsidal section of Pool γ. The springing of these vaults was at 7.00 meters from the floor. He determines that a heated vault would have been preferable in this room, and that the vault would have contained an oculus that could be opened or closed to help regulate the temperature.[249] There is no evidence in situ to support any of these claims, and excavation photographs show that the evidence was not present earlier, either.

II.d.17. Room 20

Room 20 (figs. 3-172, 3-173, 3-174, 3-175) was another *tepidarium*, and it divided the northern section of the baths from the southern section. Cicerchia states that it

[248] Cicerchia and Marinucci 1992, 125, 126-8.
[249] Thatcher 1956, 210-1, 213, 214.

was the only room in the baths that had the sole purpose of being transitory.[250] The room underwent many changes within the life of the baths, and as mentioned above, access to Room 20 was altered several times. Room 20 was heated both by a hypocaust under the floor, and by *tubuli* on all of the walls except the eastern wall. The heat was generated by a *praefurnium* below the eastern wall of the room. There was also an access point to the hypocaust immediately to the south, like the ones described in Room 19.[251]

An east-west moving *fistula* remains in situ underneath the floor of this room. Both the pavement and the wall-facing in Room 20 are composed of reused marble elements from Phase III.[252] The *tubuli* on the northern and western walls had an exterior dimension of 0.14 by 0.08 meters (fig. 3-176). The *tubuli* on Walls e and f had an exterior dimension of 0.12 by 0.09 meters (fig. 3-177), and they were arranged in a very unusual way: sections of wall with *tubuli* were interspersed with sections of wall without *tubuli*. On Wall e, the three panels with heating devices were measured in the field to have lengths of 1.07, 1.10, and 1.13 meters, while those lacking heating devices were measured to have lengths of 1.39, 1.55, and 2.90 meters. On Wall f, (fig. 3-178) the panel with *tubuli* measured 0.42 meters, while the panel without measured 0.78 meters. An

[250] Thatcher (1956, 218) states that Room 20 was used as a *sudatorium*, although he does not explain how he comes to this conclusion. Cicerchia (1992, 37, 131) mentions that Room 20 divided two rooms of very different temperatures – Room 10 from Room 19. He also mentions (1992, 30) that Room 10 was heated, as discussed above, implying that the temperature between Room 10 and Room 20 would not have actually been that different.
[251] The substructure area between Rooms 19 and 20 contained brickstamps dated to AD 150 and 157. The brickstamps were associated with Flavius Aprus, Julia Saturnina, and Asinia Quadratilla. The same types of brickstamps can be seen in the central drainage canal of the baths. Imprints related to Trajan were also found in these two structures, and they must come from an earlier structure. Bloch 1938, 273; Cicerchia and Marinucci 1992, 131; Poccardi 2001, 169 fig. 9.
[252] Cicerchia and Marinucci 1992, 131.

opening, which probably served as a small window, can still be seen at the very top of Wall c (fig. 3-174). There is no evidence for any other windows in the walls of this room.

The majority of the walls in Room 20, except the southern wall, have been dated to Phase I, and they do not show significant evidence of later ancient structural restorations. In fact, the western wall was not heavily damaged during the event that largely destroyed the abutting room (Room 17). The southern wall was completely reconstructed in Phase III.[253] Thatcher reconstructs a barrel vault over this room, springing 3.35 meters from the floor, even though the height of the extant walls surpasses 4.72 meters.[254]

II.d.18. The Palestra and Surrounding Features

South of the bathing block of the Terme del Foro is an irregularly shaped open space usually identified as a *palestra*, or exercise yard (figs. 3-179, 3-180).[255] The *palestra* was excavated between 1940 and 1941, under the direction of Guido Calza.[256] The area is surrounded by a colonnade (fig. 3-181) of different marbles and granites perhaps added as part of the Maxentian or Constantinian-era refurbishments. The column capitals are Ionic and are composed of *luna* marble, and the bases are composed of Proconnesian marble.[257] The floor is paved with a mosaic formed of small white *tesserae*,

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[253] Cicerchia and Marinucci 1992, 131, 132-3.
[254] Thatcher 1956, 218.
[255] Thatcher 1956, 173; Meiggs 1973, 414.
[256] Pensabene and Lazzarini 2007, 268.
[257] Meiggs (1973, 415) states that the architect deliberately selected to use several different kinds of marbles and granites in his design, including *bigio* and *greco scritto*. This conclusion is greatly dependent on when the colonnade was erected, since a fourth century refurbishment probably indicates that the columns were *spolia* from some other monument. As discussed above, most of the marble used to adorn the baths as part of restorations in the fourth century had already been used in some other capacity. The column

however, the majority of the pavement of the *palestra* is currently covered with soil and grass, making it difficult to determine if the white *tesserae* were embellished by a black band or any other decorative feature.

On the three sides not flanking the bathing rooms, the *palestra* is surrounded by shops, by a large triangular latrine on the west side (fig. 3-22), by two small temples on the southwest side (fig. 3-181), and by what was probably the headquarters of a corporation on the south side (fig. 3-182). Patrons could enter the latrine from either the *palestra*, or the Cardo, meaning that one did not have to be attending the baths to use the facilities.[258] The proximity to the Forum would have been convenient for those in need. The larger temple was constructed of bricks, and it was adorned with decorative friezes of Vulcan, although it may have been dedicated to the imperial cult. The edifice has been dated to the Severan period, and it was probably associated with the guild housed in the baths at this time.[259] The rooms associated with this guild were adorned with a third century mosaic of Sagittarius, two *pavonazzetto* columns with spiral fluting (fig. 3-183), two *bigio* columns demarcating the *tablinum* space, and elaborate marble wall-facing. Seating was added in the fourth century AD, perhaps to provide a venue for public lectures.[260]

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variety could be explained by the possibility that there were not enough of the same type for the entire colonnade. Another possibility is that some of the colonnade is a modern restoration. In fact, at least one column was re-erected in the summer of 2010. Pellegrino (2000, 33) states that the colonnade was in *cipollino* marble, however, on-site inspection quickly demonstrates that this is not the case. Pensabene and Lazzarini 2007, 275.

[258] Meiggs 1973, 415.

[259] These friezes can now be seen in the museum at the site of Ostia. The smaller temple is very poorly preserved. Meiggs 1973, 415; Pavolini 2006, 110; Pensabene and Lazzarini 2007, 274-5.

[260] The spiral columns rested on first century AD bases, and they were topped with third century AD Corinthian capitals. Pellegrino 2000, 33; Pensabene and Lazzarini 2007, 276.

The function of the triangular space as a *palestra* in the later phase of the baths is questionable.[261] The shape is extremely unusual, there are temples within the space, and the bathing block is not very well connected.[262] In addition, although not all *palestrae* had outdoor pools, it was common for ones connected to such extensive bathing facilities to have one.[263] There is no accessible documentation that discusses the possible presence of an outdoor pool in this late phase of the baths, or in any other phase. Pensabene, Lazzarini, and Kaiser mention that the *palestra* took on a directly urban role at this time, becoming more like a public square for individuals to pass through. They stress that the area could be accessed by five separate entrances, allowing for easy passage from east to west and to the temples in the southwest corner. The plaza only allowed for pedestrian traffic, however, and carts were not permitted to enter the space.[264] One problem with the *palestra* becoming a public thoroughfare must be noted: if the windows in the southern section of the baths were completely open, bathers may have been visible to passersby.

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[261] Meiggs 1973, 415; Pavolini 1986, 216; 2006, 110.

[262] At Salamis the *palestra* and the bathing block are also rather separate entities. The *palestra* has a much more prominent position in these eastern gymnasium-bath complexes, which may account for this juxtaposition in Cyprus. Bathing rooms are otherwise usually arranged symmetrically along the axis of the *palestra*. An exception is the Severan Thermae of Zeuxippos at Constantinople, which did not have a symmetrical layout. On bath-gymnasium complexes, see Yegül 1986 and Musso 2004, 307. Yegül 2006, 201-2.

[263] Examples of large baths with outdoor pools in the *palestra* include the Stabian Baths at Pompeii, the Terme di Nettuno at Ostia, the Baths of Capito at Miletus, the bath north of the Peribolos of Apollo at Corinth, and the imperial Baths at Trier. Biers 1985, 30.

[264] Pensabene and Lazzarini 2007, 274-5; Thomas 2007, 77; Kaiser 2011, 112, 133.

II.e. The Windows of the Terme del Foro at Ostia

The heated rooms of the Terme del Foro at Ostia contain some very large windows, which were added in the fourth century AD restorations.[265] Their glazing has been the subject of several studies and articles, although none have proved conclusive. For example, Peter Connolly and Hazel Dodge contend that the windows in the Terme del Foro were not only glazed, but double-glazed. They do not present any evidence for this conjecture, however.[266] Henri Broise suggests that at least the lower parts of the windows could be opened, allowing the bathers to see out into the *palestra* space to the south. Additionally, he notes that the structures of the service corridors below were built to be as low as possible, so as to not obstruct the view.[267]

Meiggs concludes that some of the windows in the heated sections of the Terme del Foro may have been unglazed, particularly in the octagonal room (Room 15).[268] Broise also agrees that Room 15 would have had open windows if its purpose was a *heliocaminus*.[269] The presence of Room C between Room 15 and Room 16, as mentioned above, enforces the possibility that the windows in the *heliocaminus* were unglazed. If

[265] Large windows are also found in the Terme del Filosofo at Ostia. Johannes S. Boersma (1985, 127-8) states that it can be assumed that the large south-facing windows in rooms 19 and 20 of the Terme del Filosofo, the *tepidaria*, and those in room 21, the *caldarium*, were closed with glass. He does not provide any evidence or reasons for why this assumption is valid. Moreover, he mentions that these rooms were all heated by hypocausts under their floors, but that only room 21 employed any wall heating. Boersma also assumes that the windows in the *frigidarium* were glazed. For more on window types found on the houses and apartment buildings of Ostia, see Packer 1971, 24-7. Calza 1925, 97; Meiggs 1973, 414; Heinz 1983, 102.

[266] Connolly and Dodge 1998, 244.

[267] At Bulla Regia, the height of the service corridors of the Baths of Julia Memmia are too high to allow for any view out of the windows, and the windowsills of the windows are located more than two meters above the floor of the heated rooms. Broise 1991, 62.

[268] Yegül (1992, 382) mentions that the high window sills in the Terme del Foro would have protected bathers from chilly breezes that would entered through unglazed windows. Thatcher 1956, 218; Meiggs 1973, 414.

[269] Broise 1991, 76.

the two rooms were closer in temperature, heat transfer would have been minimal. Meiggs states that the elliptical room was the hottest one in the Terme del Foro, and that it may have even had a heated vault.[270] Heating the floor of the sunning room would have helped warm the room, while heating the room with *tubuli* and heated vaults may have made it too uncomfortable for individuals to enjoy the hot rays of the sun.

Broise also presents his views on the presence of glazing in the heated rooms of the Terme del Foro. He prefers not to speculate about the glazing of the windows in rooms 16 and 17, because of the poor state of conservation of the window bays. In contrast, he finds the evidence for glazing of the windows in Rooms 18 and 19 irrefutable. The double row of holes found along the interior of the pillars of Room 18, convince him that a double-glazed window was supported in this space (fig. 3-184).[271] Thatcher explains these same holes by suggesting that an ornamental grille was secured by the outer holes, while a movable frame was secured by the inner holes.[272] A problem must be noted with all of the arguments concerning the windows of Room 18: only one pillar with its capital, a second capital, part of the architrave, and the entire cornice were actually recovered at the site. The second pillar was not found (fig. 3-185). In his article from January of 1930, Calza mentions that the choice was made to restore only one of the pillars and the associated fragments of architrave and cornice. He concludes that this was the better and more scientific option than that of recreated the missing elements in

[270] Meiggs 1973, 414.
[271] A similar arrangement of holes can be seen in the large windows of the South Baths at Perge, in Turkey. Broise 1991, 76-7.
[272] Thatcher 1956, 209.

concrete.[273] A visit to the site today, however, illustrates that the second pillar *was* reconstructed at a later date (fig. 3-154). The accuracy of this reconstruction, therefore, cannot be affirmed with certainty.

According to Broise, a tripartite window was added to the *caldarium* in the fourth century AD, divided by two Corinthian columns. These columns still show evidence of a *claustra*, or window screen, in the form of adhering mortar (fig. 3-186), similar to the fourth century AD one reconstructed at Bosra.[274] As mentioned above, Seneca describes a new invention in his time, of clear light being admitted from windows "through transparent tiles."[275] Perhaps he was describing a similar system.

Thatcher wrote the most extensive article thus far, concerning the windows of the Terme del Foro at Ostia. He concludes that all of the windows in this bathing facility were unglazed. His conclusion is based on the fact that no evidence, according to him, was found in the material record for window glazing in this bathing complex. He is unable to accept that glazing could have been present without leaving some trace, thereby determining that glazing must never have existed here.[276] The lack of evidence in situ does not necessarily signify the complete lack of some element in the past, and Thatcher, who was an architect, and not an archaeologist, does not take into account the fact that the baths were excavated in the 1920s when little attention was paid to stratigraphy or small finds.

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[273] Calza 1930, 297-8, 301 fig. 13.
[274] The windows of the South Baths at Bosra, in Syria, have been reconstructed as being divided with brick pillars, measuring 0.40 by 0.40 meters. These pillars created three openings that were 0.55 meters wide, where *claustra* window screens were inserted. Metal hooks and a coating of plaster were used to secure the bricks in place within the screen. Broise 1991, 74, 76-7, 78.
[275] Sen. *Ep*. 90.25; Briggs 1956, 416; Bachman 2008, 118.
[276] Thatcher 1956, 170.

Meiggs does not contradict Thatcher outright, stating the lack of a technical background to do so. He does mention, however, that it is difficult to accept Thatcher's claim without more convincing evidence, and he states that frames for the glass panes could have been made of wood, thus leaving no record.[277] Yegül also states that he is unable sufficiently to test Thatcher's method and equations, but that he has some doubts on Thatcher's conclusions. He finds the likelihood that the octagonal room had unglazed windows to be quite high, but he does not see the logic behind applying this configuration to all of the heated rooms in the Terme del Foro.[278] Nielsen also finds fault with Thatcher's claim of unglazed windows, stating that Romans were too "thrifty" to waste such exorbitant volumes of energy to maintain high temperatures.[279] Although some of these claims may prove correct, the effects of glazing windows or leaving them open can only be understood through a proper heat study, and not through conjecture. This problem is addressed in more detail in Chapters 4 and 5.

III. Conclusions

The Terme del Foro at Ostia are an excellent case study for many reasons: they are very large and elaborate, they have both standard and unusual features, and they are well preserved. Examining a bathing facility that was probably constructed under imperial auspices allows for the better understanding of an important building where structural innovation is likely. The bath complex also survived for several centuries, with

[277] The window frames in the Antonine Baths at Carthage were made of marble. Lézine 1968, 25; Meiggs 1973, 414 n. 2.
[278] Yegül 1992, 382-3.
[279] Nielsen 1990, 17-8 n. 41.

significant changes being made often and for various reasons, providing for a multi-dimensional project. Attempting to distinguish between the various phases of the baths and conclude when they were actually constructed is a difficult task that requires an in-depth study of the fabric of the remains; however, engaging in this process demonstrates more fully how the bath facility worked.

The unique structural components found in these baths create a set of more complex parameters to be introduced into the heat study. For example, the polygonal shapes of the floors produce a different surface area than those of a rectangular room, affecting the way heat was radiated from the floor. Additionally, the presence of heating systems in rooms that are not typically thought of as heated necessitates further study in order to determine what their function was.

The excellent state of many of the floors and walls in the Terme del Foro presents a clear image of what the structure would have looked like, without relying on too much speculation. The way both bathers and bath attendants moved through the complex and the service areas can also be determined, and the effects of the modifications on the rooms of the baths can be put into the perspective of these ancient Romans. Studying the large windows extant in many of the rooms also demonstrates the effects of solar radiation. Once all of the aspects and features of the Terme del Foro were fully understood, the heat study could be effectively applied while taking all of these components into consideration.

Chapter 4: Heat Transfer and Computational Methods

The heating systems of the ancient Roman baths and the amount of fuel they consumed can only be determined through the proper application of heat transfer principles. Heat is defined as the transfer of energy between two elements of differing temperatures for the conduction mode of heat transfer, and it can be expressed using Fourier's Law. In the baths, heat was transferred from the furnaces through the floors and walls, but it was lost through the ceilings, doors and windows. The nature of each component affected the amount of heat energy that could pass through; therefore, each element of the Terme del Foro at Ostia were thoroughly examined and carefully measured. Ancient sources, comparative types of facilities, and modern experiments were used to determine the likely temperatures that were maintained in the baths, as well as the types of fuel that were used to generate the necessary energy. How significant was the effect of each structural component in the baths? What are good approximations for the temperatures used in Roman baths? What kinds of fuel burned most efficiently in the furnaces? These questions are addressed below.

Several studies related to the heating systems of the baths have been attempted in the past, but they have often focused on a single aspect of the baths.[1] Although the details

[1] Included in these are the German engineering dissertations by Otto Krell in 1901 and by Günter Schween in 1936; the study of the imperial Roman baths at Trier by Daniel M. Krencker and his colleagues in 1929; the examination of the Welwyn Baths, in England, by Tony Rook in 1978; the research conducted by the Italian engineer Andrea Jorio between 1978 and 1979; the epigraphic comparison of cartloads of wheat to wood by Henry Blyth in 1999; and finally the reconstruction of the Roman bath in Turkey by Fikret Yegül and his collaborators in 2003. The most recent work has been conducted by Robyn Veal (2012, 41-7), who

of each of these works are not fully expounded on, the advancements put forth by them are employed in the current study. Moreover, the conclusions of each are either strengthened or disproven by the results of this work.[2]

The present work differs from previous ones by employing an interdisciplinary approach, and by taking into account all aspects of both archaeology and engineering. In addition, as few assumptions are made as possible and detailed data collection prevents the need for generalizations. Finally, the incorporation of a complex database, created as part of this study, allows for many permutations of the data to be made. These multiple permutations demonstrate the impact of small changes in the system, illustrating how each altered the necessary volume of fuel for the operation of the baths. All of the data are made available in Appendix 2, allowing other scholars to test the results and use the method for other studies.

I. Fourier's Law and its Application to the Terme del Foro at Ostia

Heat transfer operates on the principle condition that systems want to be in equilibrium. In order for temperature equilibrium to be maintained, an object of higher temperature will transfer some of its heat energy to an object of lower temperature, until the two reach the same temperature.[3] For example, very hot soup will cool down as it is

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uses population figures in conjunction with estimations for per capita fuel use to determine how many hectares of forest were necessary to supply the city of Pompeii in AD 79. She uses a very simplified model to obtain general figures. Harris (2011, 120) specifically mentions that a new approach is necessary in order to compute how much fuel was consumed in the Roman baths.

[2] A short engineering study by Tahsin Basaran and Zafer Ilken from 1998 of the heating system of the Small Bath at Phaselis in Turkey also serves as an example for modeling some of the computations.

[3] Heat can be transferred through convection, conduction, or radiation. Convective heat transfer is only taken into account for the ceilings. Conduction heat transfer specifically depends on interactions of particles and is driven by the temperature difference between them; it is the result of lattice vibrations,

poured into a cold ceramic bowl; and the bowl will become warmer until the two substances are the same temperature. In a perfect vacuum, the soup and the bowl would remain at this equal state; but because the air surrounding the bowl of soup is cooler, the soup-bowl system will drop further in temperature, while the surrounding air will get warmer. This exchange of temperature will also create a draft, making it feel as though heated air is being emitted from the soup. The application of this exchange of energy from warmer to colder things, creating a movement in fluids like air and water, is the basis for the heating systems of ancient Roman bathing rooms and heated pools.

The exchange of heat energy in the Roman baths was facilitated by the temperature difference, or gradient, between the fire in the *praefurnium* and the air outside the facility. The two elements communicated through a chimney, and the hot air was passed under the floors and through the walls of the bath in the process. If the system was constructed properly, the air in the *praefurnium* was sucked into the hypocaust. This draft ensured that the air would be circulated perpetually throughout the hollow spaces. Even if a chimney was not present or properly designed, there would still be some movement of air within the walls of the baths. This phenomenon would occur because as the heated air moved up vertically in the hollow wall space, some of the heat would be lost by being radiated into the room.[4] Therefore, the temperature of this air would be cooler and less dense than the warmer air below it, causing it to move back down into the

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unbound electron flow, and molecular collisions. Conduction and radiation are the most effective methods for directly counteracting heat loss from the human body. Thatcher 1956, 171; McQuiston, et al. 2000, 124; Turns 2006, 249.

[4] Convective heat transfer would also occur between the walls and the room.

hypocaust.[5] The *testudines alveolorum*, used to maintain the temperature of the water in the pools of the baths, worked in the same way. As the water on the surface of the pool cooled, it would drop back into the boiler, while the hotter water would rise to the surface. This system is described in Chapter 2.[6]

In order to understand how heat is moving in a system, and to determine how much heat energy is being processed, it is necessary to apply Fourier's Law. Joseph Fourier (1768-1830) was a renowned mathematician and a high official in Napoleon's government who established many theories on heat conduction. He published his important formulas in 1822, beginning his book, *Théorie analytique de la chaleur*, with what is known as Fourier's Law:[7]

$$\dot{Q}_{cond} = -kA\frac{dT}{dx}$$

Where:
$\dot{Q}_{cond}$ = rate of heat transfer during conduction in J/s (Joules per second) or W (Watts)
k = thermal conductivity of conducting medium in W/mK (Watts per meter Kelvin)
A = area perpendicular to direction of heat transfer in m^2 (square meters)
$\frac{dT}{dx}$ = temperature gradient in K/m (Kelvin per meter)

Fourier's law is an equation that can be used for steady state occurrences in one dimension, and it is especially useful for determining how heat moves through walls and

[5] Yegül and Couch 2003, 167.
[6] Chapter 2, 80-1.
[7] Fourier accompanied Napoleon in Egypt between 1798 and 1801. At the time that he published his work, it was still commonly believed that heat, or caloric, was a material substance that could be used up. The concept of caloric was put forth by Antoine-Laurent de Lavoisier (1743-1794) in 1779, who thought that heat was a physical element similar to a fluid that could be poured from one object to another. The caloric theory was disproved by Benjamin Thompson, who used experiments to show that heat could be created by friction. His work negated the possibility that heat was an element that could be neither created, nor destroyed. Nevertheless, the work done by Fourier is still valid and used in heat transfer problems today. Fourier 1822; Lienhard 1981, 9-11; McQuiston, et al. 2000, 124; Turns 2006, 224, 249.

similar structures.[8] The equation determines the amount of heat energy (Q) that passes through the surface area (A) of an object with a thickness (dx) and with a specific heat transfer coefficient (k), when there is a temperature difference (dT) between one side of the object and the other. The formula carries a negative sign because the rate of heat transfer moves in a positive direction of x when the temperature gradient is negative. Put simply, if the temperature is decreasing as it moves through the thickness of a substance, then the energy flux will be positive because it will be flowing in the same direction as the substance.[9]

In choosing an ancient Roman bath complex to study, it was necessary for the edifice to be intact enough so that the factors needed in these equations could be determined, or at least very closely approximated. Being able to identify where heat was retained through insulation, and where it was lost through openings was also very important. The Terme del Foro at Ostia match these criteria. By fully measuring the rooms, the exact surface area of the different elements were computed. The composition of each was also examined to determine the thickness and the physical composition of all the components. For example, for a floor formed of a terracotta tile, covered with mortar, and then covered with a slab of marble, the thickness of each of those layers was noted and the thermal conductivity was determined (fig. 4-1).[10] Unfortunately, the vaulted

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[8] The term "steady state" indicates that the general properties of the system will not change over time. "One dimension" means that energy is only moving in one direction: through the floors or walls in the case of the Roman baths. In reality, heat is moving more three dimensionally, which creates a very complicated situation. The losses in other directions are minute enough, thanks to the insulation created by the brick walls, that they can be neglected for the purposes of this study. Lienhard 1981, 11.
[9] Lienhard 1981, 11 ; McQuiston, et al. 2000, 124; Turns 2006, 249.
[10] See Table A1-1 in Appendix 1 for a list of relevant thermal conductivities.

ceilings of the baths are almost completely missing, making some assumptions about their configuration necessary.

Permanent furniture found in the heated spaces of the baths, such as benches and pools were also measured so that the effect of their presence on the heating systems could be illustrated. (Appendix 2 presents all the physical data that was collected from the Terme del Foro). A scale model of the plan of the baths was also created using AutoCAD software (figs. 3-6, 3-10, 3-14, 3-15, 3-16, 3-24), illustrating the multiple phases of the bath complex and making it easier to understand the relationship of the rooms of the baths to each other. The reconstruction of all of these elements clarifies the way that heat would have moved in the entire structure.

Roman baths are a complicated system because they are formed of many different materials and components. Each of these elements has its own coefficient of thermal conductivity, which is defined by Çengel as the "measure of the ability of a material to conduct heat". The coefficient designated for thermal conductivity is high for materials that conduct heat easily, and low for materials that do not. The coefficient can either be found through the use of proper equations, or it can be located on a chart.[11] Thermal conductivity is dependent on temperature, geometry, and thickness.[12] This coefficient illustrates the rate at which different materials conduct heat. For example, copper transfers heat very easily, while plaster transfers heat very reluctantly. Returning to the analogy of the soup, a wooden spoon, which has a low thermal conductivity will not feel

[11] Knowing the exact makeup of the material is not necessary, since the coefficient does not vary greatly for similar materials. For example, knowing that the material is a concrete with a heavy aggregate is sufficient; knowing the exact type of aggregate is not necessary. Tsoumis 1991, 196; Çengel 2007, 18.
[12] Çengel 2007, 18, 22.

very hot to the touch, even if it is left in the pot the whole time the soup is cooking. A metal spoon, which has a high thermal conductivity, will become hot very quickly and can burn the cook if it is left in the soup for even a few minutes.

Altering Fourier's Law, by putting the equation in terms of thermal resistance, makes it easier to compute the amount of heat that was able to pass through the various layers of the floors, walls, and ceilings of the Terme del Foro. Thermal resistance, or R', is defined as the combination of the thickness and value of thermal conductivity that impedes the transfer of heat per unit area of a material:

$$\dot{Q}_{cond} = -\frac{(t_2 - t_1)}{R'}$$

$$R' = \frac{dx}{kA}$$

$$R' = R'_1 + R'_2 + R'_3 = \frac{dx_1}{k_1 A} + \frac{dx_2}{k_2 A} + \frac{dx_3}{k_3 A}$$

Where:
$\dot{Q}_{cond}$ = rate of heat transfer during conduction in J/s or W
$(t_2 - t_1)$ = temperature difference between outside and inside of the system in K
R' = thermal resistance of conducting medium in m^2K/W (square meters Kelvin per Watts)
dx = thickness of conducting medium in m
k = thermal conductivity of conducting medium in W/mK
A = area perpendicular to direction of heat transfer in m^2

To produce the following equations for heat transfer:

$$\dot{Q}_{cond} = -\frac{(t_2 - t_1)}{\frac{dx_1}{k_1 A} + \frac{dx_2}{k_2 A} + \frac{dx_3}{k_3 A} + \cdots}$$

Where:
$\dot{Q}_{cond}$ = rate of heat transfer during conduction in J/s or W
$(t_2 - t_1)$ = temperature difference between outside and inside of the system in K
dx = thickness of conducting medium in m
k = thermal conductivity of conducting medium in W/mK
A = area perpendicular to direction of heat transfer in m^2

The heat energy is determined by summing the resistance of each separate component of the elements, such as the floors and walls of the bath, across a temperature difference. Since not all parts of these elements are constructed in the same way, they need to be broken up into separate segments. The contribution of each of these segments is then added together.[13] Each separate element is dealt with below. Temperature is the final element necessary to utilize Fourier's Law, and the most difficult to obtain. The selection of temperature is presented in more detail below, as are the hours of operation of the baths.

Once the heat energy necessary for maintaining the selected temperatures is determined for one room of the Terme del Foro, the process is repeated for all of the other heated rooms. The total heat energy is computed by summing up each of these totals (with the aid of the database developed for this study):

[13] The resistance of each component of the floor, wall, or ceiling is added in series in the same way as an electrical circuit in series would be handled. The different segments of each of these elements is also summed in the same way.

$$\dot{Q}_{cond} total = (\dot{Q}_{cond} total\ room\ 1) + (\dot{Q}_{cond} total\ room\ 2) + (\dot{Q}_{cond} total\ room\ 3) \ldots$$

Where:
$\dot{Q}_{cond}$ = rate of heat transfer during conduction in J/s or W

This result is the total amount of energy needed to run the baths (in Watts or Joules per second). Converting this value into kiloJoules per hour makes the number more manageable. The amount of combustible material needed to generate this quantity of energy is then determined using the following equation:

$$\frac{\dot{Q}_{cond} total \left(\frac{kJ}{hr}\right)}{heating\ value\ of\ fuel \left(\frac{kJ}{kg}\right)} = Total\ fuel\ in\ \frac{kg}{hr}$$

The heating value of a fuel is the amount of heating energy it produces per unit of mass, and it varies according to the fuel chosen. Wood, charcoal, and peat all have different heating values, as do different species of wood.

II. Structural Components Affecting Heat Gain and Heat Loss

Each segment of the baths, including the floors, the walls, and the ceilings, contributed to the heat loss and/or heat gain of the system according to its makeup and surface area. Each of these is dealt with in detail below. Doorways and passageways leading to the heated rooms are also examined to determine the heat lost to the unheated spaces of the baths and to the outside. These features are carefully measured and evidence for heating system systems that would have reduced heat loss was sought in each. The size and placement of windows and whether there was evidence for glazing in the openings is the final element to be explored. The benefit of sunlight entering a heated room versus the drawbacks of cold breezes coming in or warm air escaping from the room is demonstrated below.

II.a. Floors

Generally, the floors of a building contribute to the loss of heat from a room, but in the case of the Roman baths, the floors are a source of heat. Heat was radiated from the hypocaust up through the different layers of the floor, warming the space above. The floors of these rooms (Rooms 15 through 20) were all heated by a hypocaust, as were the floors of Room 7, 8, 9, and 10 in the *frigidarium* area. Many of the sub-floors and most of the floors in the Terme del Foro were not well-preserved, and they were further damaged by modern restorations. Furthermore, the substructures of Rooms 7, 8, 9, and 10 are completely inaccessible.

Enough of the hypocaust is extant under some of the rooms to determine that the *pilae* had an average height of 0.72 meters, an average length of 0.20 meters, and an average width of 0.21 meters. The basic layout of the subfloors also can be understood. The makeup of the floor is still visible enough in Rooms 17 and 18 (figs. 3-141, 3-148, 3-149) to examine and measure the various layers. These floors, starting from the bottom, were determined to be formed of a 0.03 meter-thick *bipedale* terracotta tile, a 0.03 meter-thick layer of mortar, another 0.03 meter-thick *bipedale* terracotta tile, a 0.14 meter-thick layer of mortar, a 0.04 meter-thick layer of hydraulic cement (*cocciopesto*), and a 0.02 meter layer of marble pavement. The mosaic pavements were measured to be 0.025

meters thick.[14] This configuration was used for all of the heated rooms where evidence was missing. Only the surface layer of each floor was altered, according to the current presence of a mosaic, marble pavement, or other permanent feature.

Explanation of Necessary Equation

The basic equation necessary to determine how much heat conducted through the floor is the same as the one described above:

$$\dot{Q}_{cond} = -\frac{T_2 - T_1}{\left(\frac{dx_1}{k_1 A}\right) + \left(\frac{dx_2}{k_2 A}\right) + \left(\frac{dx_3}{k_3 A}\right) + \left(\frac{dx_4}{k_4 A}\right)}$$

The floor of each room is divided into segments according to the features that were found in the space. For example, Room 18 only consists of one segment – a bare floor; while Room 19 consists of sixteen segments – a bare floor, three pool floors, and twelve different pool steps. Therefore, Q_{cond} for the floor of Room 18 only has to be computed with one equation, while the Q_{cond} for the floor of Room 19 has to be computed with sixteen. These sixteen Q_{cond} values are all added together to determine the total Q_{cond} radiated from the floor of Room 19. Once the total Q_{cond} is computed for the floor, the value is added to the rate of heat transfer of the walls, the ceilings, and the openings for an overall heat balance in each room.

[14] Thatcher (1956, 200) mentions that the thickness of the floor, including the mosaic *tesserae*, was 0.406 meters. The way he arrived at this value, is unclear.

Complications arise in these computations when determining the temperature exchange between the hypocaust and the floor. Selecting temperatures in general is discussed in more detail below, but a few comments specifically related to the floors are made here. The heat for the hypocaust originated from the *praefurnia*, that is, from one or more specific locations in each room. This configuration means that the parts of the hypocaust closest to the *praefurnia* received the most direct heat, while the parts farthest away received less heat. Understanding the way the heat moved below the floor, in between the *pilae*, is very complex and could be a topic of study in itself. The decision had to be made, therefore, to assume a constant temperature for the floors depending only on the function of the room.

II.a.1. Floors with Benches

Room 16 is the only space with an extant bench, although it is likely that other rooms contained some temporary furniture. In the area of the bench, heat would have had to pass through all the layers of the floor and the wall, and then through the layers of the bench. The bench was added to the room after all of the marble facing was in place, and this facing was not removed prior to the installation of the bench (fig. 4-2). The bench was constructed of brick and mortar, 0.40 meters thick and 0.49 meters high. The brick was covered on the exposed surfaces with a layer of mortar, 0.03 meters thick; and then faced with *grigio* marble, 0.02 meters thick (fig. 4-3). Evidence for the bench is only visible against Walls c, d, and e. The niche in Wall a and the tight angles of the doorways flanking Wall b (Doors E and F) make it unlikely that the bench existed against these walls (fig. 4-4), although it is impossible to know for sure. Assuming a configuration with the bench only covering Walls c, d, and e, its surface area on the floor is 48.16 meters squared. This area was treated as a separate component from the bare floor area, which has a surface area of 341.08 meters squared.

II.a.2. Floors with Pools

There are three pools (Pools α, β, and γ) in the heated spaces of the Terme del Foro (3-156, 3-157, 3-158), all in Room 19. In the current phase of the baths, the pool floors are covered with what seems to be reused marble veneer (fig. 3-161). Pools α and β have two outer steps, one high step, and one inner step (figs. 4-5, 4-6). Pool γ has one outer step, one high step, and two inner steps (fig. 4-7). The dimensions of these steps can be found in Appendix 2. The steps are constructed of brick, and covered with mortar, *cocciopesto*, and marble.

The pool floor and the inner steps are assumed to be covered with heated water at a temperature of 35 degrees Celsius. The water level in the pools is unknown, but a height of 0.80 meters from the pool floor is assumed in Pools α and β, and a height of 0.90 meters from the pool floor is assumed in Pool γ. This assumption is based on a level of water that would allow an average person to be submerged up to their waist while sitting on the pool steps.[15] Each of the pool floors and steps needed to be examined thermodynamically as separate components, since the properties and thicknesses of their layers vary from each other.

[15] For their study on the Smath Bath at Phaselis, Basaran and Ilken (1998, 4) assumed a water level equal to the height of a man's chest while he sits on the floor of the pool.

II.b. Walls

Like the floors, the walls of Roman baths present a very complex problem in the computation of fuel consumption. In modern standard structures, walls are a source of heat loss, and insulation is used to reduce this loss of energy (both for heating and cooling the building). Thanks to the system of hollow spaces filled with heated air, most of the walls of the Roman bathing facilities contributed to the heating of a room rather than detracting from it. Like the floors, the walls radiated heat into the baths, and although some heat was dissipated through the fabric of the walls to the outside or to adjacent rooms, most of the heat was retained by the system. In addition, the thick brick walls stored a great deal of heat in the system.

Explanation of Necessary Equation

The same adaptation of Fourier's Law explained above is used to compute the heat energy introduced into the rooms from the walls. Equivalent types of complications related to temperature distribution arose in the computations for the wall as those described above for the floors. In fact, the situation in the walls was even more complex due to the direct communication with the outside through the chimneys. Even the temperature at the outlet of the chimney was difficult to determine, since the expelled heated air would be mixing with the outside air, meaning that it would not match either of these temperatures. No evidence of chimneys is extant in the Terme del Foro, but their presence was assumed.

Another element that must be taken into account for the walls with heated voids is that some of the energy from the heated air is being radiated out into the heated room, and some of it is being radiated through the brick wall into the adjacent room. The amount of energy being directed to the adjacent room is significantly less, but still needs to be taken into consideration. Moreover, as already alluded to, some of the heat is also being lost through the chimneys. The equation is reworked to include both the heat being introduced into the target room, and the heat being expelled outside of it:

$$Qin = -\frac{(T_{air\ 1} - T_{wall})}{\left(\frac{dx_1}{k_1 * A}\right) + \left(\frac{dx_2}{k_2 * A}\right)}$$

and

$$Qout = -\frac{(T_{air\ 2} - T_{wall})}{\left(\frac{dx_1}{k_1 * A}\right) + \left(\frac{dx_2}{k_2 * A}\right)}$$

Where:
Qin = rate of heat transfer into target room in J/s or W
$Qout$ = rate of heat transfer out of target room in J/s or W
$(T_{air\ 1} - T_{wall})$ = temperature difference between air of target room and inside of wall in K
$(T_{air\ 2} - T_{wall})$ = temperature difference between air of adjacent space and inside of wall in K
dx = thickness of conducting medium in m
k = thermal conductivity of conducting medium in W/mK
A = area perpendicular to direction of heat transfer in m^2

The total energy contributed from the walls is computed thus:

$$Qwall = Qin - Qout$$

In cases where a wall separates two adjacent rooms of the same temperature, the $Qout$ is equal to zero. The total contribution of the walls in each room is determined by adding all of the values together:

$$Qwalls = Qwall\,1 + Qwall\,2 + Qwall\,3 + Qwall\,4 + \cdots$$

II.b.1. Bare Walls

In the current state of the baths, most of the walls in the heated rooms are bare of furniture or other extraneous elements. The only exceptions are Room 16, which has a bench abutting some of the walls, as described above; and Room 19, which has features related to the pools altering the structure of some of the walls. Unfortunately, it is impossible to know for sure if other rooms had permanent or temporary features placed against the walls, such as basins or wooden cupboards. The walls are generally composed of a brick-faced *opus caementicium* wall that is covered with a layer of mortar, *tubuli*, another layer of mortar, and a marble veneer (fig. 4-8). Sometimes a layer of *cocciopesto* is also present underneath the marble facing to make the walls waterproof. A detailed record of the dimensions of all the elements forming the walls, as well as observations related to them, appears in Appendix 2.

Room 15 shows no evidence of having any wall heating, while all of the other rooms in the heated section are equipped with a standard arrangement of *tubuli*, except for Room 20.[16] The *tubuli* in Room 20 are unique in their configuration: three sets of six vertical rows were placed side by side against the wall, followed by a brick wall segment with no *tubuli* (fig. 4-9). This arrangement was a later addition during the third phase of the baths.[17] The reason for this very unusual layout of *tubuli* is unclear, but it is probably related to cost or heating efficiency. Another curious element is the presence of *tubuli* on the east and west walls of Rooms 7 (fig. 3-100), 8, 9, and 10, which are located next to the pool of the *frigidarium* in the unheated section of the baths. As discussed previously, the function of these *tubuli* is difficult to discern.[18]

Another factor related to the heated walls that needed to be taken into account is the environment on the other side of each partition. This examination was necessary because the temperature in the adjacent spaces could affect the way energy circulated in the heated rooms. For example, two heated rooms next to each other would produce little effect on the wall separating them; while a heated room next to the outdoor *palestra* could have significant consequences on the dividing wall, particularly on a cold day.

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[16] The size and material composition of the *tubuli* used in the Terme del Foro varies somewhat, as can be seen in Appendix 2, but they are generally consistent in form. The variations can likely be attributed to different refurbishments, but the chronological order of the various types of *tubuli* is difficult to determine conclusively. None of the *tubuli* in the bathing facilities at Ostia show any sign of communicating holes on the sides, like those seen at Sardis. Instead, there was probably an open channel above the vertical rows of *tubuli*. Such a horizontal channel would have allowed the *tubuli* to communicate with each other and with the chimneys, while otherwise remaining sealed. Yegül (Yegül and Couch 2003, 163), maintains that by sealing the majority of the top ends of the voids, hot air was more efficiently contained. He determines that in this way, a lower draft and furnace activity could be maintained. Yegül explains that leaving the top ends open did create a stronger draft and higher oxidation levels, radiating more heat into the room, but that the downside of the hotter walls was the consumption of more fuel. Evidence for both arrangements exists in the archaeological record. Kretzschmer 1961, 22; Yegül 1986, 113; Nielsen 1990, 15; Yegül 1992, 363, 365; Yegül and Couch 2003, 163; Yegül 2010, 87.

[17] A similar way of arranging tubuli can be seen in several houses at Ostia, including the Domus della Fortuna Annonaria (V.II,8) and the Domus del Tempio Rotondo (I.XI,2). Tubuli of a similar size and composition to those found in Room 20 were added to one room in these houses in the fourth century. See Becatti (1987) for more on these and other late Roman houses at Ostia. Cicerchia and Marinucci 1992, 131, 132-3.

[18] Chapter 3, 123-4.

II.b.2. Walls with Adjacent Benches and Pools

The presence of a bench in Room 16 and three pools in Room 19 affected the amount of heat that could be transferred through the walls in the same way that it altered the heat exchange through the floors. The steps of the pools did not affect the walls, but the walls of the pool space were lined more substantially than the other walls. Specifically, the surface of the *tubuli* in the pool was covered with an extra layer of brick (fig. 4-10). A regular wall in Room 19 is composed of the brick wall, a layer of mortar, *tubuli*, a layer of mortar, a layer of *cocciopesto*, and the marble veneer. In contrast, the pool walls (Pools α and β) in Room 19 are composed of the brick wall, a layer of mortar, *tubuli*, a layer of mortar, an extra brick wall, an extra layer of mortar, a layer of *cocciopesto*, and the marble veneer.

The function of this brick wall is not entirely clear, particularly since a similar arrangement can be seen in the original portion of Pool δ in the *frigidarium* (fig. 4-11), but not in Pool γ (fig. 4-12). The same configuration can also be seen in the two heated pools of the Terme di Nettuno at Ostia (fig. 4-13). The purpose could have been structural, giving more support to the walls that would have been pushed outward by the water; or to better seal the pool from leaks. Thatcher suggests that the extra thickness on the pool walls illustrates that the *tubuli* were in place not to help heat the water, but to heat the walls above.[19]

Perhaps the *tubuli* made the walls too hot for bathers to be able to comfortably lean against the walls in the pools, making the brick wall necessary, or the *tubuli* overheated the water. Fronto mentions that he burned himself when he accidentally

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[19] Thatcher 1956, 212.

brushed his knee against the entrance to the baths, and the *Digesta* of Justinian I describes the illegal nature of placing *tubuli* on a wall that is shared with another building, because of the risk of fire.[20] Brick has a very low thermal conductivity (0.68 Watts/meter·Kelvin), which means that it would have prevented a great deal of the heat radiating from the *tubuli* from passing through. The brick would have also stored a significant amount of heat, perhaps helping the pool water stay warm for longer periods of time.

II.c. Openings

The Terme del Foro at Ostia contain many openings, doors, and large windows. Heat would have been lost through openings through a combination of transmission, ventilation, and infiltration; therefore, it was important to understand their configuration. Transmission refers to heat passing through the actual fabric of a structure, as described above, and it depends on the material. For example, the glass in a window has a particular heat transmission coefficient, which allows a certain amount of heat to pass through. Ventilation refers to air that enters or exits a space either naturally through an opening, or by being pumped in or out. Unglazed windows provide natural ventilation, while not being affected by transmission heat loss. Infiltration refers to the unintentional movement of air through cracks, improperly sealed windows, and the opening and closing of doors as individuals pass through.[21]

[20] The case from the *Digesta* involved a man named Hiberus, who was upsetting his neighbor by building a bathing facility using a party wall that they both shared. The *tubuli* placed on the party wall were apparently scorching the other side. Fronto *Ep. Ad M. Caes.* 5.44; *Dig*. 8.2.13.
[21] McQuiston and Parker 1994, 226; ASHRAE 2001, 26.1; Çengel 2007, 538-9.

The smaller openings in the lower parts of the walls of the baths can be assumed to have had some sort of specific function that meant they were filled when the baths were in use. For example, openings that housed *fistulae* would have been filled by the pipes and by the mortar used to secure them. Although there may have been small cracks, allowing for some infiltration, this heat loss would have been minimal and was considered negligible for the sake of simplicity in the current study.

Explanation of Necessary Equation

In order to determine the total energy lost through the openings in the room, the following equation is used:

$$Q_{total\ opening} = Q_t + Q_v + Q_i$$

Where:
$Q_{total\ opening}$ = rate of heat transfer in W or J/s
Q_t = rate of heat transfer through transmission in W or J/s
Q_v = rate of heat transfer through ventilation in W or J/s
Q_i = rate of heat transfer through infiltration in W or J/s

The rate of heat lost through transmission is calculated using the following equation:

$$Q_t = AU(t_i - t_o)$$

Where:
Q_t = rate of heat transfer in W or J/s
U = overall heat transmission coefficient in W/m^{2}K
A = area perpendicular to direction of heat transfer in m^2
t_i = inside air temperature in K
t_o =outside air temperature in K

The heat transmission coefficient "U" takes into account both the convection and the conduction of the materials. To calculate U:

$$U = \frac{1}{\left(\frac{1}{f_i}\right) + \left(\frac{x_1}{k_1}\right) + \left(\frac{x_2}{k_2}\right) + \cdots + \left(\frac{1}{f_0}\right)}$$

Where:
f_i = surface conductance for inside wall in W/mK
f_0 = surface conductance for outside wall in W/mK
x = thickness of material in m
k = thermal conductivity of material in W/mK

The heat transmission coefficient for specific types of doors and windows can often be found in charts. For example, for a typical wooden door in a wooden frame, the U factor is 2.61 Watts per square meter Kelvin.[22] The rate of heat lost through ventilation is calculated using the following equation:[23]

$$Q_v = c_p \rho q_v (t_i - t_o)$$

Where:
Q_v = rate of heat transfer through ventilation in W or J/s
c_p = specific heat capacity of air in J/kgK
ρ = density of air in kg/m^3
q_v= air volume flow in m^3/s
t_i = inside air temperature in K
t_o =outside air temperature in K

The rate of heat lost through infiltration is calculated using the following equation:

[22] ASHRAE 2001, 30.11.
[23] The specific heat capacity (c_p) and the density (ρ) are taken from Table A-15 in Appendix 1 of Çengel 2007, 860.

$$Q_i = c_p \rho n V (t_i - t_o)$$

Where:
Q_i = rate of heat transfer through infiltration in W or J/s
c_p = specific heat capacity of air in J/kgK
ρ = density of air in kg/m^3
n= number of air shifts, how many times air is replaced in the room per second
V = volume of room in m^3
t_i = inside air temperature in K
t_o =outside air temperature in K

The value of n depends on how often a door or window is opened or closed.[24] A value of 0.1 was used in the current study.[25]

II.c.1. Doorways and Passageways

Heat is lost through passageways by transmission and by infiltration if there is a barrier, such as a wooden door, present. Heat is only lost through ventilation if the passageway is completely open. There is no evidence in situ of door hinges or hooks that could have held coverings to illustrate if the passageways were kept open or if they could be closed at times. Several doors (Doors C, I, J, T, Z, AA, AC, and AE) have circular or rectangular depressions in their marble threshold that may point to the original presence of a movable barrier (figs. 4-14, 4-15), such as a wooden door. Unfortunately, some of the thresholds (Doors G, L, O, and P) do not fit the space exactly or are composed of several pieces (fig. 4-16), suggesting that they may have been reused from elsewhere or

[24] In modern buildings n is set at a constant 0.5 per hour for doors, although this is not always accurate. See McQuiston and Parker 1994, 227-8 and Engineering Toolbox 2012.
[25] ASHRAE 2001, 25.13.

inserted as part of the modern restorations. Many of the thresholds are also missing or too damaged to illustrate this potential feature.[26]

Door T (fig. 4-17), Door AC (fig. 4-18), and Door AE (fig. 3-49) are all entry points from the outside, making it necessary for them to be closed off at times in a secure way. If it is assumed that a wooden door was present in Door O, symmetry would suggest that such a door was also present in Door X. These passageways are a logical location to be able to close off, as well, since they would have separated the entrance/changing areas from the bathing areas where individuals would have been predominantly undressed.[27] Door Z is another reasonable location for a wooden door, since it would have helped prevent substantial heat loss from Room 9 and Room 16. The doorways in the heated sections of the baths are quite long, which also perhaps helped contain heat. There also could have been a physical door on each end of the passageway to increase insulation even more.

In order to understand how significant the loss of heat was from the door openings, and how successful the possible attempts to contain it were, several permutations are tested on the heated rooms: with wooden doors blocking all of the passages, with wooden doors blocking only passages with evidence for a movable barrier, with some of the doors closed by a somewhat permeable barrier (heavy cloth), and with all the internal doors open. The results of the permutations are presented in Chapter 5.

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[26] Umberto Pappalardo (1999, 235) describes an extant paneled wooden door in the Suburban Baths at Herculaneum, which still turns on its hinges to give access to the *tepidarium*. The existence of this feature demonstrates that wooden doors were used in this context.

[27] Nielsen 1990, 40.

II.c.2. Windows

Windows are generally expected to contribute significantly to heat loss, particularly in winter.[28] The examination of the windows in the Roman baths was approached in essentially the same way as for doors and openings, except that that solar radiation being admitted through the windows also needed to be taken into account. As already described in detail in Chapter 3, the Terme del Foro were equipped with several large windows in both the cold and the heated sections.[29] The published arguments for and against the presence of glazing in these windows has already been addressed, and the lack of conclusive evidence has been pointed out. In order to make a stronger case for one scenario or the other, the effects of open windows, glazed windows, double-glazed windows, partially open windows, and windows covered with a semi-permeable material were tested to illustrate the effects on the heated rooms of the baths.

Sunlight

The amount of sunlight that would have entered openings in rooms of the baths would have depended on the solar altitude (β), cloudiness, and the height of the adjacent buildings. Solar altitude is the angle of sunlight formed by the height of the sun and the level of the ground (fig. 4-19).[30] The level of cloudiness in the sky can change continuously on particular days, and there is no way to calculate this factor. The skies were considered completely sunny to simplify the current study. Latitude (l), date, and

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[28] Approximately one-third of the total heat loss from a typical modern house during the winter months is from the windows, particularly from infiltration through insufficient seals between the glass and the frames. Çengel 2007, 533.
[29] On windows in the Terme del Foro at Ostia, see Chapter 3, 180-83.
[30] Thatcher 1956, 184; McQuiston and Parker 1994, 192.

time of day affect the angle of the sun's rays, and need to be selected. The latitude of Ostia is 41.75 degrees North. The specific day of the year changes the declination (d) of the sun, or "the angle between a line connecting the center of the sun and earth and the projection of that line on the equatorial plane."[31] The time of day affects the location of the sun in the sky, and the solar hour angle (h) is computed in degrees after the equation of time has been factored in, thus:[32]

$$h = \frac{(minutes\ from\ noon)(15)}{60}$$

The solar hour angle is the "angle between the projection of a point on the equatorial plane and the projection on that plane of a line from the center of the sun to the center of the earth."[33] The angle is highest at sunrise and sunset and is zero at local solar noon, when the sun reaches the highest location in the sky.[34] Once the latitude, solar hour angle, and declination are determined, the solar altitude is computed, thus:

[31] Declination, expressed in degrees, depends on the month and can be found in charts (Table A1-2 in Appendix 1). McQuiston and Parker 1994, 191-2.
[32] The equation of time must be used to account for the fact that the earth's orbit is not symmetrical, meaning that the time on a clock does not exactly reflect the position of the sun. The equation of time depends on the month, and it can be obtained from a chart (Table A1-2 in Appendix 1). The Local Solar Time is obtained by adding the equation of time to the time on the clock. This value is then subtracted from noon to determine how minutes away from noon it is, in order to compute the solar hour angle. McQuiston and Parker 1994, 190-1; ASHRAE 2001, 30.13.
[33] McQuiston and Parker 1994, 191.
[34] McQuiston and Parker 1994, 191-2.

$$sin\beta = \cos(l)\cos(h)\cos(d) + \sin(l)\sin(d)$$

Where:
β = solar altitude in degrees
l = latitude in degrees
h = solar hour angle in degrees
d= declination in degrees

Other solar angles that need to be computed are the solar azimuth angle (φ) and the angle of incidence (θ). The solar azimuth angle is measured on the horizontal plane between the projection of the rays of the sun and the south, and depends on latitude and declination (fig. 4-20):[35]

$$\cos\varphi = (\sin(\beta)sin\,(\,l) - \sin(d))/(\cos(\beta)cos(l))$$

Where:
φ = solar azimuth angle in degrees
β = solar altitude in degrees
l = latitude in degrees
d= declination in degrees

The angle of incidence is the angle formed by rays of the sun and the normal to the surface. For a horizontal surface:[36]

$$\cos\theta_H = sin\beta$$

Where:
θ_H = horizontal angle of incidence in degrees
β = solar altitude in degrees

[35] McQuiston and Parker 1994, 193; ASHRAE 2001, 30.15-6.
[36] In order to compute the angle of incidence ($\cos\theta = (\cos(\beta)\cos(\varphi)\,sin\,(\,\alpha) + \sin(\beta)cos(\alpha))$), the angle of tilt ($\alpha$) must also be computed. For a vertical surface the angle of tilt is ninety degrees, and for a horizontal surface the angle of tilt is zero degrees. McQuiston and Parker 1994, 194.

For a vertical surface:

$$\cos\theta_V = cos\beta cos\varphi$$

Where:
θ_V = vertical angle of incidence in degrees
β = solar altitude in degrees
φ = solar azimuth angle in degrees

Radiation from the sun is received on the earth in three forms: as direct irradiance from the sun, as diffuse irradiance from the sky, and as reflected irradiance from the ground (fig. 2-21).[37] Normal direct radiation (G_{ND}) is the portion of the radiation emitted by the sun that reaches the surface of the earth in a straight path without being absorbed or scattered by the atmosphere. The scattered portion is called diffuse radiation (G_d), and the reflected portion if called reflected radiation (G_R).[38] Total solar radiation (G_t) includes all of these portions:

$$G_t = G_{ND} + G_d + G_R$$

Where:
G_t = total solar radiation in W/m^2
G_{ND} = normal direct radiation in W/m^2
G_d = diffuse radiation in W/m^2
G_R = reflected radiation in W/m^2

[37] The normal incidence of direct irradiance outside of the earth's atmosphere is 1367 Watts per meter squared according to McQuiston and Parker (1994, 195) and 1373 Watts per meter squared according to Çengel (2007, 693). This value varies somewhat depending on the time of year, being at its maximum on January 3, and its minimum on July 4. McQuiston and Parker 1994, 187; Çengel 2007, 693.
[38] Solar radiation is scattered by air molecules, dust particles, smog particles, and water droplets found in the atmosphere. McQuiston and Parker 1994, 196-7, 199, 202; ASHRAE 2001, 30.14, 30.16; Çengel 2007, 689, 693.

$$G_{ND} = \frac{A}{\exp(\frac{B}{\sin(\beta)})}$$

Where:
G_{ND} = normal direct radiation in W/m^2
A = apparent solar irradiation at air mass equal zero in W/m^2 (Table A1-3 in Appendix 1)
B = atmospheric extinction coefficient (Table A1-3 in Appendix 1)
β = solar altitude in degrees

$$G_{dH} = (C)(G_{ND})$$

Where:
G_{dH} = horizontal diffuse radiation in W/m^2
C = ratio of diffuse to direct normal irradiation on a horizontal surface (Table A1-3 in Appendix 1)
G_{ND} = normal direct radiation in W/m^2

The amount of reflected radiation is dependent on the inclination of the surface being examined, which affects the direct radiation.[39] For a horizontal surface, the direct radiation and total horizontal radiation are computed, thus:

$$G_{DH} = G_{ND} cos\theta_H$$

Where:
G_{DH} = direct horizontal radiation in W/m^2
G_{ND} = normal direct radiation in W/m^2
θ_H = horizontal angle of incidence in degrees

$$G_{tH} = G_{DH} + G_{dH}$$

Where:
G_{tH} = total horizontal solar radiation in W/m^2
G_{DH} = direct horizontal radiation in W/m^2
G_{dH} = diffuse horizontal radiation in W/m^2

[39] Çengel 2007, 690.

The reflected horizontal radiation is therefore:

$$G_{RH} = G_{tH}\rho_g F_{wg}$$

Where:
G_{RH} = reflected horizontal radiation in W/m^2
G_{tH} = total horizontal solar radiation in W/m^2
ρ_g = reflectance of ground or horizontal surface
F_{wg} = fraction of radiation leaving wall that strikes ground or horizontal surface directly

$$F_{wg} = \frac{(1 - cos\Sigma)}{2}$$

Where:
F_{wg} = fraction of radiation leaving wall that strikes ground or horizontal surface directly
Σ = 90 – angle of tilt (90 degrees for a horizontal surface)

Logically, if the surface is horizontal, the reflected radiation is zero. The total vertical radiation is computed in a similar manner:

$$G_{DV} = G_{ND}\theta_V$$

Where:
G_{DV} = direct vertical radiation in W/m^2
G_{ND} = normal direct radiation in W/m^2
θ_V = vertical angle of incidence in degrees

$$G_{dV} = G_{dH}n$$

Where:
G_{dV} = vertical diffuse radiation in W/m^2
G_{dH} = horizontal diffuse radiation in W/m^2
n = corresponding number for $cos\theta_V$ (Table A1-4 in Appendix 1)

$$G_{RV} = G_{tH}\rho_g F_{wg}$$

Where:
G_{RV} = reflected vertical radiation in W/m^2
G_{tH} = total horizontal solar radiation in W/m^2
ρ_g = reflectance of ground or horizontal surface
F_{wg} = fraction of radiation leaving wall that strikes ground or horizontal surface directly

$$F_{wg} = \frac{(1 - cos\Sigma)}{2}$$

Where:
F_{wg} = fraction of radiation leaving wall that strikes ground or horizontal surface directly
Σ = 90 – angle of tilt

Once obtained, the total solar radiation is multiplied by the area of the opening to determine the total solar heat energy actually entering the room. For a completely unobstructed window or opening, all of the solar heat energy would have entered and warmed the space. For partially or completely obstructed windows, the solar transmission coefficient for the obstructing material, such as glass, must be multiplied by the total solar heat energy to account for energy that is blocked. The coefficient is dependent on the thickness and the opaqueness of the material, and can be obtained in charts.

Open Windows

Having completely open windows in the Roman baths would have contributed to the heating of rooms by allowing the maximum amount of solar radiation to enter and warm the space. The open windows additionally would have permitted an unobstructed view of the outdoor scenery, enhancing the experience of the bather. In contrast, unglazed windows allowed cold breezes to come in and heated air to escape, significantly reducing the overall temperature of a room in colder months.[40] In some cases, such as in Room 15, the desire for unfiltered sunlight may have superseded the need to keep the room very hot.[41] Having some cool air enter the space, to prevent sunbathers from feeling too hot, may have even been preferable.

Open windows contribute to heat loss in a room through ventilation. The quantity of energy lost primarily depends on the difference in temperature between the room and the outside.[42] The volume of air flow through the opening is calculated first, using the following equation:[43]

$$q_v = (0.019)\left[\frac{g(t_o - t_i)}{(273 + t_o)}\right]^{0.4} (h)^{1.2}$$

Where:
q_v = air flow volume in m^3/s per meter surface width
g = acceleration of gravity in m/s^2 = 9.81 m/s^2
t_o = outside air temperature in degrees Celsius
t_i = inside air temperature in degrees Celsius
h = height of opening in m

Glazed and Double-Glazed Windows

Glazed windows, or windows with glass in them, allow some sunlight to enter a space, while impeding cold air from entering or excessive amounts of heated air from

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[40] Thatcher (1956, 173) claims that the radiant heat projected from the walls and floors of the baths would have been enough to keep a bather comfortable, even if there were open windows admitting cool air.
[41] Meiggs 1973, 414; Broise 1991, 76; Yegül 1992, 382-3.
[42] Wind and building height are other factors that contribute to the heat exchange through an open window. For simplicity, they was not factored into this study. McQuiston and Parker 1994, 228-9; ASHRAE 2001, 26.10.
[43] Engineering Toolbox 2012.

escaping.[44] The amount of solar radiation that passes into a space is less than that for open windows, and depends on how translucent and on how thick the glass is. As already mentioned, determining how clear Roman glass was is somewhat difficult, and its scarcity in the collected archaeological remains of most sites makes the other properties of the glass somewhat subject to conjecture.[45]

More heat would have been lost through glass by transmission than through a closed wall, illustrating that windows always had an effect on heat loss. According to Fritz Kretzschmer, a glass window loses 50 times as much heat as a wall of the same thickness.[46] This factor increases exponentially when considering that most of the walls in the Terme del Foro were almost a meter in thickness, while fragments of window glass recovered at other sites usually range between 0.003 and 0.005 meters in thickness.[47] The glass used in the Terme del Foro was assumed to have been clear, and a value of 0.003 meters was used for the default thickness. Other thicknesses and levels of opaqueness were tested to examine how significant the effect of various glass types was.

Heat loss also occurs in windows if they are not sealed properly. Since the glass is missing in the Terme del Foro windows, it is impossible to know how well the window panes were secured. Without the availability of rubber sealants, however, it can be assumed that a fair amount of heat was lost. Double-glazed windows were sometimes

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[44] Examples of baths with glazed windows in their heated sections include the Suburban Baths at Pompeii and the South Baths at Perge. Jacobelli 1999, 227; Bachman 2008, 121.
[45] Ancient glass is generally opaque when it is recovered from archaeological sites, but its initial clarity is impossible to deduce.
[46] No brick wall would be as thin as a window, however. Kretzschmer 1961, 23.
[47] The fragments of window panes from the Suburban Baths at Herculaneum were 0.0045 meters thick. Those from Room Y in the baths at Lepcis Magna, measured between 0.003 and 0.004 meters in thickness. Bartoccini 1929, 60-1; Broise 1991, 62-3, 69; Pappalardo 1999, 237-8.

used by the Romans, as is attested in the material record.[48] These double-glazed windows would have functioned to increase insulation, in a very similar way as modern storm windows do.[49] Broise finds it likely that the windows in Room 18 were double-glazed, because of the two rows of holes found on the pillars (fig. 3-184).[50] One of the pillars is a reconstruction, however, making the evidence less certain. Less radiation energy would have been able to pass through a double-glazed window, reducing the benefits of the sun, but heat loss through transmission and infiltration would have both been significantly reduced. Double-glazed windows were tested to determine their effectiveness in the Roman baths, and results are presented in the following chapter.

Partially Open and Permeable Windows

Windows partially closed with glass, with some other permeable medium, or with moveable wooden shutters also existed in the ancient Roman world; and they are tested in this study. Broise thinks that at least the lower parts of the windows in the Terme del Foro could be opened to allow for an outdoor view and for ventilation.[51] In fact, glass panes that could be opened and closed according to the weather and the desires of the

[48] The windows in the Suburban Baths at Herculaneum were closed with two fixed wooden frames, set 0.10 m apart. Evidence of double-glazed windows in heated rooms can be seen in the *caldarium* of the Suburban Baths at Herculaneum. Double-glazed windows separated by a heated space of 1.20 meters have also been reconstructed in the Terme di Nettuno at Ostia. Broise 1991, 62-3, 64-5, 69; Pappalardo 1999, 237-8.

[49] Having a layer of air between two panes of glass significantly reduces the amount of heat lost through transmission. According to Çengel (2007, 534-5) a stratum of air that is 0.01 meters thick is the equivalent of having a stratum of glass that is 0.30 meters thick. Increasing the space between the panes of glass reduces the transmission heat loss even more. Connolly and Dodge 1998, 244.

[50] Thatcher (1956, 209) does not agree that the second row of holes held glass. Instead he thinks they were used to support an ornamental grille that could be manipulated, as mentioned previously. Broise 1991, 76-7.

[51] Broise 1991, 62.

bathers would have been ideal. Unfortunately, no evidence exists in situ to support such a reconstruction at the Terme del Foro.[52]

Windows with no permanent coverings could have been secured with heavy tarps or sheets of cloth on days of excessive weather conditions at Ostia.[53] Such a system would have allowed for windows to be kept open generally, but it is unclear how permanent the structures for covering the windows were and how effective the system was. Another solution, which could have been applied both to unglazed and glazed windows, was the use of moveable shutters that could be opened or closed as necessary.[54] The shutters would have not only helped to reduce heat loss on cold or blustery days through unglazed windows, but also they would have also helped to protect the glass from being broken at night or on very windy days. Another benefit of the wooden shutters is that they would have reduced the amount of heat lost from a room through the glass by transmission.[55]

II.d. Ceilings

Understanding the nature of the ceilings in the Roman baths is often very difficult due to their poor preservation, as is the case in the Terme del Foro. Some conjectures

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[52] Broise (1991, 61-2, 6-72, 72 fig. 24) claims to have identified movable glass panes in the baths at Bosra, in the *apodyterium* and the *tepidarium* of the Forum Baths at Pompeii, and in the Suburban Baths at Herculaneum.

[53] Other materials that could have been used to cover the windows, include sheets of vellum or animal skins and very thin sheets of translucent stone. Bachman 2008, 118.

[54] Examples of windows covered with wooden shutters have been reconstructed according to the presence of stone consoles outside of windows, which would have held the hinges for the shutters. The can be seen at Bosra, and at Ostia in the Terme di Nettuno and the Terme del Invidioso. Broise 1991, 65-72; Ring 1996; Ortiz Palomar and Paz Peralta 1997, 438.

[55] The shutters would have been especially useful in the hours when the baths were closed, preventing unwanted intruders from being able to enter. Broise 1991, 68; Lombardi and Corazza 1995, 32, 33.

have been made on their appearance, as discussed previously, and on their contribution to the heating of the rooms. For simplicity in computing the surface area of the ceilings, all were assumed to be basic barrel vaults, except for those in Rooms 15 and C, whose footprints make a dome more likely. The ceiling in Room C also presents evidence of a small opening, similar to those seen in the ceiling of the substructure (fig. 3-132). Openings such as these were probably used for ventilation. Other rooms of the baths may have had similar apertures, as Thatcher suggests, but there is no way to be sure.[56] The ceiling of Room 16 is assumed to be an ellipsoid.

The composition of the ceilings was based on comparative evidence from the vaults of the Terme dei Sette Sapienti at Ostia and the Stabian Baths at Pompeii. A segment of the vault of the Terme dei Sette Sapienti is preserved at the site, although it is on the ground (fig. 4-22). The chunk of groin vault is approximately 0.70 meters in thickness, with a layer of painted stucco approximately 0.05 meters in thickness.[57] The concrete vaults of the Stabian Baths are between 0.40 and 0.50 meters thick, and they have a layer of painted stucco covering them that is between 0.06 and 0.09 meters thick. The value used for the Terme del Foro at Ostia was 0.70 meters of concrete thickness, and 0.05 meters of painted stucco thickness. The heat loss through the ceiling of each room was computed both with a small ventilation opening in the ceiling, measuring 0.30 by 0.30 meters, and with an oculus as described by Thatcher.

[56] Thatcher (1956, 190) suggests that the openings were formed as oculi with diameters of 1.83 meters, like those in the Terme dei Sette Sapienti, and that they could be opened or closed.
[57] The barrel vaults in the Roman bath at Metropolis, in Turkey, were also 0.70 meters thick: 0.50 meters of brick, 0.10 meters of outer mortar, and 0.10 meters of inner mortar. Basaran, et al. 2005, 4.

Explanation of Necessary Equation

Most of the heat that was lost from the rooms of the Terme del Foro was lost through the ceilings, as is the case in most standard structures. In modern buildings, a heat loss factor of fifteen percent is automatically added to account for the additional loss of energy that is radiated to space.[58]

$$\dot{Q}_{cond} = -CAU(T_i - T_o)$$

Where:
$\dot{Q}_{cond}$ = rate of heat transfer during conduction in J/s or W
C = heat loss factor added to account for added radiation to space = usually 1.15
A = Area perpendicular to direction of heat transfer in m^2
U = overall heat transmission coefficient in W/mK
T_i = inside air temperature in K
T_o = outside air temperature in K

The heat transmission coefficient "U" takes into account both the convection and the conduction of the materials, which is necessary for computations related to ceilings. To calculate U:

$$U = \frac{1}{\left(\frac{1}{f_i}\right) + \left(\frac{x_1}{k_1}\right) + \left(\frac{x_2}{k_2}\right) + \cdots + \left(\frac{1}{f_0}\right)}$$

Where:
f_i = surface conductance for inside wall in W/mK
f_0 = surface conductance for outside wall in W/mK
x = thickness of material in m
k = thermal conductivity of material in W/mK

[58] Engineering Toolbox 2012.

The inverse of the surface conductance for the inside wall (f_i) is a constant of 0.13 W/m^{2}K, while the inverse of the surface conductance for the outside wall (f_0) is a constant of 0.04 W/m^{2}K.[59] Openings in the ceiling are computed in the same way as they were for open windows, as described above.

III. Temperature Selection

Internal and external temperatures are some of the main parameters needed in order to be able to apply Fourier's Law.[60] Temperature difference is actually what drives the whole heating system in the Roman baths; therefore, temperatures in the hypocaust, in the walls, in the various rooms of the baths, and in the outside environment had to be determined. The difficulty when choosing an optimal temperature for a heated space is that the perfect temperature is not the same for everybody. Since Romans probably wore very little in the baths, clothing is not really a factor that needs to be taken into account; however, people's differing metabolic rates, activity levels, and expectations can cause them to feel temperatures differently. Humidity and air movement also affect temperature at various times.[61] These factors explain why thermostats need to be adjusted on certain days for a space to actually feel warm or cold.

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[59] Engineering Toolbox 2012.
[60] See Table A1-2 in Appendix 1 for a list of selected temperatures.
[61] Clothing creates a small amount of thermal resistance. For example, a pair of shorts has a clo unit of 0.05, while a heavy business suit has a clo unit of 1.0. One clo unit is a set value for the amount of insulation needed to keep a person comfortable at 21.1 degrees Celsius (70 degrees Fahrenheit), and it is equivalent to 0.155 m^2 °C/W. Fanger 1973, 314; Brödner 1983, 155; McQuiston and Parker 1994, 126.

III.a. Indoor Temperature Selection

Since it is impossible to know what temperatures the Romans maintained within the baths and little evidence is available from ancient authors on the topic, the value must be approximated for the study using comparative evidence and modern experiments. Even the Romans, themselves, could not have told us what temperatures they employed in the baths; thermometers were not invented until 1714, when Gabriel Fahrenheit created the first mercury device.[62]

III.a.1. Ancient Evidence

Little insight can be gained from ancient literary sources, except for the fact that the baths were considered very hot by some. Seneca emphasized the intensity of the temperatures when he said:

[62] Galileo Galilei invented a rudimentary thermometer in 1593 that was able to measure temperature variations, but was not able to measure actual temperature values. Oliver S. Tonks (1908, 421) has suggested that ancient Greek potters may have used gold or silver wire to monitor temperatures inside their kilns. Temperatures in kilns that were used to fire Attic black and red figure pottery had to be precisely regulated in order to produce the desired color effect. The melting points of both metals (1062 degrees Celsius for gold, and 961 degrees Celsius for silver), are just slightly above the temperatures that potters needed to fire these vessels. Perhaps a similar method was used to regulate the temperatures in the hypocaust. J.E. Rehder (2000, 11-12) conjectures that someone with a “practiced eye” would have been able to tell the general temperature within twenty degrees Celsius by color. A twenty degree range of error in the baths, however, would have made the difference between having bathers enjoy a hot pool or being cooked alive. See Hasaki 2002, 125-6 on the relationship of bath furnaces to kilns. Noble 1965, 75; Bellis 2012.

> *Nam hoc quoque nobilissimi aediles fungebantur officio intrandi ea loca, quae populum receptabant, exigendique munditias et utilem ac salubrem temperaturam, non hanc, quae nuper inventa est similis incendio, adeo quidem, ut convictum in aliquo scelere servum vivum lavari oporteat. Nihil mihi videtur iam interesse, ardeat balineum an calcat.*
>
> For this also used to be the duty of the nobles aediles – to enter these places to which the populace resorted, and to demand that they be cleaned and warmed to a heat required by considerations of use and health, not the heat that men have recently made fashionable, as great as a conflagration – so much so, indeed, that a slave condemned for some criminal offence now ought to be *bathed* alive! It seems to me that nowadays there is no difference between "the bath is on fire," and "the bath is warm." [63]

Pliny the Younger described the story of a man named Larcius Macedo, who was punished by his slaves for his superiority and insolence. While he was bathing in a villa in Formiae, they surrounded him, beat him, and threw him onto the "scalding" pavement of the bath.[64] Both of these descriptions may be exaggerations of the temperatures in the baths, making it difficult to make definitive deductions on the pavement temperatures from them.

There is some evidence to demonstrate that sandals were worn in certain bathing facilities, suggesting perhaps that the floors were uncomfortably hot. There is also the possibility that the use of sandals was not related to floor temperatures at all, though. Instead they could have been worn for hygienic purposes, to avoid wearing outdoor shoes in a clean space in the baths, or for comfort and easy removal. The mosaics showing bathing sandals at the baths of Kerkouane, in Tunisia, were actually placed at the entrance to the *frigidarium* and the *tepidarium*. Nielsen sees these mosaics as signs indicating that bathers were to remove their outdoor shoes and only wear bathing sandals

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[63] Sen. *Ep.* 86.10, translated by R.M. Gummere, 1920.
[64] Plin. *Ep.* 3.14.

in these areas.[65] There is no reason why sandals would be needed in the *frigidarium*, if their sole purpose was to avoid the hot floors.

III.a.2. Turkish Hamam

Roman-style baths persisted through the middle ages, and elaborate public bathing facilities can still be found in many modern countries, including Finland, Japan, and Turkey.[66] Fikret Yegül determined that modern Turkish baths employ a very similar kind of technology for heating the baths as the ancient Romans, making them a reliable source of data.[67] These facilities were probably inspired directly by Roman ones during the Byzantine period. Although the Turkish bath, or *hamam*, did not adopt the technology of wall heating, its floors were placed on a *suspensurae* system just like the Roman hypocaust (fig. 4-23).[68]

Yegül studied the *hamam* in an attempt to understand the way ancient Roman baths worked and the kinds of temperatures the ancient Romans may have maintained in these facilities. He discovered that the temperatures that are regularly maintained in the *hamam* are between 40 and 42 degrees Celsius for the floors of the warm rooms and between 34 and 35 degrees Celsius for the air. In the hot rooms, floor temperatures range between 44 and 46 degrees Celsius, while air temperatures range between 36 and 38

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[65] Similar mosaics were also found at Sabratha, Thamugadi, Antiochia, and Brixia. Nielsen 1990, 141-2, fig. 46; Yegül 1992, 381, 467 n. 70.
[66] For bathing practices in the Middle Ages in Europe, see Pontieri 1977, Yegül 1996, Arthur 1999, Clark 1999, Boisseuil 2002, and Stasolla 2002. For the development of bathing customs in Medieval China, see Schafer 1956. For bathing rituals in Russia, see Pesmen 2000. For Finnish and Japanese saunas, see Viherjuuri 1961, Grilli and Levy 1985, Tobin 1992, Clark 1994, and Pentikäinen and Jetsonen 2001. For 19th and 20th century ideas of bathing in France and in the United States, see Wilkie 1986 and Penez 2005.
[67] Yegül 1992, 381, 467 n. 70.
[68] For more information on the *hamam*, see Lawrie 1864, Wollaston 1865, Cosgrove 1869, Shepard 1903, and Pasiner 1998.

degrees. Some of these temperatures were used in the bath that was recreated and fired up near Sardis by Yegül and his colleagues (fig. 4-24).[69]

Brödner also collected some measurements in a Turkish *hamam* – in the Inçirli Hamam in Bursa. Her temperature measurements were slightly different than Yegül's. She determined the temperature of the air in the *tepidarium* to be between 23 and 25 degrees Celsius, in the *caldarium* to be between 32 and 33 degrees Celsius, and in the *sudatorium* to be 37 degrees Celsius.[70] Tony Rook published values for the temperature in the hypocaust in 1978 as part of his study on the Welwyn baths, but after a visit to the Turkish *hamam*, he decided that his conjectured values were too high.[71]

Bath shoes were also worn in the Turkish *hamam*, although they were high platform shoes rather than sandals (fig. 4-25). The space created by these platforms between the floor and the feet of the bather suggests that the floors were dangerously hot. Yegül notes, however, that it is not unbearable or even uncomfortable to walk barefoot on these floors. He further mentions that the feet of Romans would have probably grown accustomed to the high temperatures of the bath floors with daily visits.[72] More concrete evidence is presented in a painting (fig. 4-26) by Gérôme from 1885, entitled "La Grande piscine à Brusa". Two women are shown in a *hamam* wearing high-platform bathing shoes. The women walk by two other women: one who is sitting nude directly on the floor, and the other who is reclining with just a sheet or a towel between her bare skin and the floor. The high platform of the sandals may have been a stylistic or hygienic

[69] Thatcher (1956, 193) claims that floor temperatures in the hot rooms of the *hamam* could reach up to 48.9 degrees Celsius, but he presents no evidence of actually having measured these numbers on site. Yegül 1992, 381; Yegül and Couch 2003, 169.
[70] Brödner 1983, 109.
[71] Rook 2002b, 17.
[72] Yegül 1992, 381, 467 n. 70.

choice rather than a safety precaution, although the temperature of the particular room in the painting is not known.

III.a.3. Modern Experiments

Modern studies attempting to understand the ranges of temperatures that were used by the Romans have yielded various results. Some of these values were applied in this study, while others were found to be unreliable. In 1936, Günter Schween determined in his dissertation on the Stabian Baths at Pompeii that a value of 500 degrees Celsius should be used for the temperature of the air entering the *caldarium* hypocaust, and a value of 300 degrees for the temperature of the air entering the *tepidarium* hypocaust. His method of arriving at these temperatures is unclear. Andrea Jorio conducted another heat study between 1978 and 1979 on the Stabian Baths. He also determined that the average temperature inside the hypocaust of the *caldarium* was 500 degrees Celsius, but that the average temperature of the hypocaust of the *tepidarium* was 200 degrees Celsius. Unfortunately, Jorio did not explain in detail how he arrived at these values, either; he only mentioned that the temperature during the process of combustion of wood is 1000 degrees Celsius, and that some heat was dissipated before the air filled the hypocaust.[73]

In 1958 and 1961, Fritz Kretzschmer used a Roman-style bath recreated at Saalburg in Germany in 1902 and the baths at Djemila to conduct heat studies. He determined that the temperatures of the warm rooms should be set between 35 and 36 degrees Celsius, and the temperature of the hot rooms should be set at 40 degrees Celsius. These values do not vary too much from those measured for the air by Yegül in the

[73] Schween 1936, 69; Jorio 1981-1982, 187.

Turkish *hamam*. Kretzschmer selected 55 degrees as the temperature for both the *sudatorium* and the *laconicum*, even though the humidity level of the *sudatorium* was one hundred percent, while that of the *laconicum* was between twelve and fourteen percent.[74] He set the hypocaust temperature to between 60 and 80 degrees Celsius, and the temperature of the heated water to between 35 and 36 degrees.[75] His values for the hypocaust temperatures are considerably lower than those determined by Schween and Jorio.

Tahsin Basaran and Zafer Ilken used the Small Bath in Phaselis, in southwesternTurkey, to study the heating systems of ancient Roman baths. The baths were not completely excavated when they conducted their project, but it generally consisted of a *sudatorium*, a *caldarium* with an assumed heated pool, two *tepidaria*, an *apodyterium*, and a *frigidarium*. They attempted to model the variation of temperature on the floors and walls according to their proximity to the furnace. They assumed an average temperature of 48.9 degrees Celsius for the sauna, 43.3 degrees for the *caldarium*, 28 degrees for the *tepidarium*, and 125 degrees for the exit temperature of the furnace. The average temperatures they determined through their study were 46.0 degrees Celsius for the *caldarium* wall, 44.9 degrees for the *caldarium* pool wall, 29.5 degrees for the *tepidarium* wall, 58.6 degrees for the *caldarium* floor, 47.6 degrees for the *caldarium*

[74] As mentioned above, humidity had an effect on temperature regulation. For example, Janet DeLaine (1997, 45-6) has shown that in rooms with pools, such as *caldaria*, it is possible to produce perspiration in individuals at lower temperatures than at those used in a dry heated room, such as *laconica*. Kretzschmer 1958, 36.

[75] Kretzschmer 1958, 36; 1961, 12.

pool floor, 34.2 degrees for the *tepidarium* floor, and 64.0 degrees Celsius for the *sudatorium* floor.[76]

The heat study conducted by Couch for the NOVA television program differs from previous studies, because temperatures were actually measured by placing probes in various areas of the baths and within in *tubuli* of the walls when the bath was experimentally heated. Some modern elements, such as sealants, had to be utilized in the construction of these baths; therefore, the experimental results may be somewhat skewed. The average temperature results obtained by Couch were 26.5 degrees Celsius for the air in the *tepidarium*, 35.0 degrees for the air in the *caldarium*, 61.1 degrees for the air inside the wall flues of the *tepidarium*, between 57.8 and 63.6 degrees for the air inside the wall flues of the *caldarium*, and 53.5 degrees Celsius inside the *tubuli*.[77]

III.a.4. Current Study

Temperatures must have varied somewhat in different Roman baths, and bathers may have patronized particular ones according to their preference. Some, like Nero's Baths, had a reputation for being excessively hot, while some other baths were probably not considered hot enough.[78] The results of all of the data collection and modern experiments discussed above vary quite significantly, and attempts to create elaborate heat models specifically for the Terme del Foro quickly became far too complex. Too

[76] Basaran and Ilken 1998, 2, 4, 8-9.
[77] Yegül and Couch 2003, 173-4.
[78] Martial is particularly perturbed by the high temperatures maintained in Nero's Baths, but it is very likely that other bathers preferred them that way. Mart. 2.48.8; 3.25; 7.34.4-5; 10.48.1-4; 12.83.

much physical data is missing and simulating the way heat moved under the floors and through the walls proved beyond the scope of the current study.

The temperatures to be used for the purposes of this study were selected based on several factors: the general consensus of a value throughout different studies, the logical agreement between values in different types of rooms, and the level of accuracy presumed according to the methods of each study. Physical measurements and more complex computer simulations of heat movement are preferred over unexplained conjectures and assumptions. The floor temperature (45.0 degrees Celsius) used for the for the *caldarium* of the Terme del Foro was based on the measurements taken by Yegül in the modern Turkish *hamam*. The air temperature (35.0 degrees Celsius) was based on the average value measured by Couch in the recreated bath near Sardis, a value that falls directly between the measurements taken by Yegül and by Brödner in different *hamam* facilities. The temperature of the air inside the wall *tubuli* (53.5 degrees Celsius) of the *caldarium* was based on the measurements of Couch, and the hypocaust temperature of the *caldarium* (65.0 degrees Celsius) was based on an approximation using a combination of values determined by Rook and Kretzschmer.[79]

The floor temperature (34.2 degrees Celsius) used for the for the *tepidarium* of the Terme del Foro was based on an average between the measurements taken by Yegül in the *hamam* and those computed by Basaran and Ilken for the Small Bath at Phaselis. The air temperature (28 degrees Celsius) was based on both the value measured by Couch and

[79] Taylor Oetelaar (2013) uses a value of 55.0 degrees Celsius for the temperature inside the *tubuli* in the computations for his recently completed dissertation on the Baths of Caracalla. Oetelaar runs complex simulations to illustrate how heat moved through the baths. Unfortunately, his conclusions were not available in time to affect the selections made in the current study. Kretzschmer 1958, 36; Brödner 1983, 109; 1961, 12; Yegül 1992, 381; Rook 2002b, 17; Yegül and Couch 2003, 169, 173-4.

the value used by Basaran and Ilken. The temperature measured by Brödner was also very close, while the one measured by Yegül in the *hamam* was significantly higher. The temperature of the air inside the wall *tubuli* (51.4 degrees Celsius) of the *tepidarium* was based on the measurements of Couch, and the hypocaust temperature (55 degrees Celsius) was again based on an approximation using the values determined by Rook and Kretzschmer.[80]

The floor temperature (64 degrees Celsius) used for the *laconicum/sudatorium* of the Terme del Foro was based on the value used by Basaran and Ilken. The air temperature (52 degrees Celsius) was based on a combination of the values used by Kretzschmer and those used by Basaran and Ilken. The temperature of the inside of the *tubuli* in the walls (55.5 degrees Celsius) was based on an approximation from the values assumed in the *tepidarium* and *caldarium*, and the hypocaust temperature (75 degrees Celsius) was based the values of Rook and Kretzschmer.[81]

The floor temperature (30 degrees Celsius) used for the rooms with heat being recycled from other rooms, rather than having their own *praefurnium* (Rooms 7-10 and C), was based on an approximation according to the other values selected above. There is currently no study that specifically addresses the temperatures in these types of systems. The air temperature (24 degrees Celsius) was also based on an approximation, as were the temperatures of the air inside the wall *tubuli* (48 degrees Celsius) and the temperature of the hypocaust (51 degrees Celsius).

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[80] Kretzschmer 1958, 36; 1961, 12; Brödner 1983, 109; Yegül 1992, 381; Basaran and Ilken 1998, 4; Rook 2002b, 17; Yegül and Couch 2003, 169, 173-4.
[81] Kretzschmer 1958, 36; 1961, 12; Basaran and Ilken 1998, 2, 4, 8-9; Rook 2002b, 17.

III.b. Determining Outside Temperature

Selecting a temperature for the environment outside the baths was necessary since the heated rooms of the Terme del Foro communicated with the outdoors through the chimneys, and through the windows. Just as with the temperatures inside the heated rooms, there is no way to be sure exactly what the values were in ancient times.[82] Additionally, the temperature, humidity level, and wind would have varied every day and even throughout each day. The best solution determined for this project was to use the average modern temperatures at Ostia for every month, and present a separate study for each of these months.[83] The database created for this study was designed in such a way as to allow for the temperatures to be altered at any time (fig. 4-27). This feature permits the

[82] Several ancient climate studies have been conducted by various scholars in an attempt to understand the temperature and humidity levels of the ancient world, with conflicting results. Oreste Reale and Paul Dirmeyer (2000, 163) created a vegetation map of the Mediterranean region, and they ran a general circulation model (CGM) experiment. The findings are presented by Reale and Shukla (2000, 213), who conclude that the climate was wetter and colder in the past. Annamaria Ciarallo (2002, 169), uses a combination of ancient flora remains and archaeological evidence also to conclude that the ancient climate was wetter and colder by a couple of degrees in Pompeii when Vesuvius erupted. She notes (2002, 174) that this phenomenon was caused by a lower sea level (between 0.60 and 0.80 meters) in the area at this time. Sing C. Chew (2008, 14) also recounts that the climate has become wetter and colder in the past 2500 years. Other scholars state that it was warmer and drier, although results vary widely. See Jalut, et al. (2000), who tests pollen ratios from the southeast coasts of France and Spain; and Magny, et al. (2002), who examines lake and river levels. Robert Sallares (2007, 17, 19-20) states that the climate of fifth and fourth century BC Greece was the same as it is today, according to evidence from ancient sources and modern plants. He also mentions that studies on the movements of glaciers during the Holocene have demonstrated that the climate during the Roman empire was "warm", peaking in AD 150; and that evidence of olive cultivation near Sagalassos, where the temperatures are too low today, suggest that the average temperature there was two to three degrees Celsius higher in Roman times. Anderson, et al. (2007, 3) declare that temperatures are higher today than they have been since between AD 800 and 1200. Moreover, they (2007, 5) note that climate patterns have been "significantly variable" within the Holocene period (11500 BC to present). Neumann, et al. (2007, 329, 342, 344) use a botanical climatological transfer function and pollen samples to test climate change in the northern Golan Heights and determine that there has been no significant climactic change in the past 6000 years. Moe, et al. (2007, 448) also conclude that there was no substantial changes in climate patterns in the past 6000 years by performing a palaeoecological study in the Italian central Alps region. Veal (2012, 20-21) mentions that pollen studies have also proved mostly inconclusive in illustrating ancient climatic conditions, although they have illustrated the types of flora that existed in particular areas.

[83] The meteorological station on the Isola Sacra, adjacent to Ostia, measured a mean annual precipitation level of 0.793 meters for the 1980 through 2002 period. The monthly air temperature range between 1961 and 1990 was between 8.5 degrees Celsius and 23.5 degrees Celsius, with an annual mean of 15.5 degrees. Sadori, et al. 2010, 3294.

user to employ any specific temperature of choice, including a monthly or daily average.[84]

IV. Fuel

Once all of components affecting heat transfer were determined and selected, they were processed through Fourier's Law using the database computer program. In this way the total amount of heat energy transferred in each room was computed. Adding up the totals for each room gave the total heat energy transferred for the entire bathing facility:

$$Qtotal\ room\ 1 = Qfloor + Qwalls + Qceiling + Qopenings$$

$$Qtotal = Qtotal\ room\ 1 + Qtotal\ room\ 2 + \cdots + Qtotal\ room\ 20$$

With this value computed, the amount of fuel needed to account for heat that is being lost could be understood. Different fuel sources produce different amounts of combustible energy, therefore, examining diverse types of energy sources likely used in the regions around Ostia provides a more realistic and complete picture of the operation of the baths. Wood was the most common fuel that was used to heat the Roman baths, especially in Italy where forests covered a great deal of the countryside in ancient times.[85] As

[84] Thatcher (1956, 183) used temperatures recorded for 1953 at Ostia. The lowest temperature recorded during the day for that year was 0.5 degrees Celsius, on February 9th. He determined that January and February were the coldest months, on average, and that the temperatures were progressively milder in December, March, and November. The maximum recorded wind velocity was 30 kilometers an hour, although this did not occur on the coldest day. He found that winds between November and March were the strongest from the north and from the southwest.

[85] Charcoal, coal, and peat were sometimes used in parts of Northern Europe and England. Charcoal was known as a fuel source in Egypt from the third millennium BC. Oil was often the preferred fuel source in coastal Mesopotamia and the Black Sea region. Different types of fuel produce different types of ash. For

discussed previously, ancient sources have yielded little insight on the fuel supplies for the Roman baths; however, Pliny does mention that the area around Ostia was heavily forested.[86] Another way to gain some insight on the floral environment around Ostia is to conduct archaeobotanical investigations on samples taken from the archaeological record, which has not been done sufficiently.

IV.a. Fuel Sources Available around Ostia

Pollen studies can be a very useful method for understanding what types of plants and trees grew in particular areas at particular times.[87] Archeobotanical investigations have not been published extensively on Ostia, but a recent study was undertaken in 2010 at the harbor site of Portus that presents valuable information.[88] The study determined that some of the most common shrubs and trees found in ancient times near the port were the prickly and Phoenicean juniper (*Juniperus oxycedrus* and *Juniperus phoenicea*), the mastic (*Pistacia lentiscus*), the llatro (*Phillyrea latifolia*), the Italian buckthorn (*Rhamnus alaternus*), the strawberry tree (*Arbutus unedo*), the tree heath (*Erica arborea*), the hornbeam (*Carpinus betulus*), the Oriental hornbeam (*Carpinus orientalis Mill*.), the field elm (*Ulmus minor Mill*.), the white elm (*Ulmus laevis Pall*.), the maritime pine (*Pinus*

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example, elm trees and ash trees both produce ash that is very high in calcium oxide, or quicklime. Unfortunately ash samples were not collected during the excavations of the Terme del Foro at Ostia. Yegül 1992, 368; Humphrey, Oleson and Sherwood 1998, 43; Rehder 2000, 31; Malanima 2011, 5, 10, 11; Veal 2012, 19.

[86] Plin. *Ep*. 2.17.26.

[87] Veal 2012, 20-1.

[88] Two cores were drilled in the area of the Claudian harbor to recover pollen, micro-charcoal, and ostracod sediments, in order to analyze them and date them through radiocarbon dating. The goal of the project was to "identify morphological and environmental features of the Tiber delta dating back to the Roman period, and to characterize the landscape of the harbor". The bottom of the first core was dated to the second half of the first century AD, the middle-top was dated between 130 and 340 AD, and the very top was dated to the Renaissance period. The second core did not contain any first century evidence, but was otherwise dated in a similar way to the first core. Sadori, et al. 2010, 3294, 3303.

pinaster Aiton), the black alder (*Alnus glutinosa*), the willow (*Salix*), the poplar (*Populus*), the tamarix (*Tamarix africana Poir.* and *Tamarix dalmatica Baum*), the maple (*Acer monspessulanum*), the bay laurel (*Laurus nobilis*), the manna ash (*Fraxinus ornus*), and several species of oak: holm or holly oak (*Quercus ilex*), turkey oak (*Quercus cerris*), Hungarian oak (*Quercus frainetto Ten.*), English oak (*Quercus robur*), cork oak (*Quercus suber*), and the lucombe oak (*Quercus crenata Lam.*).[89] Chestnut trees (*Castanea sativa*) were also known to grow in the area of Ostia.[90]

Several archeobotanical studies have also been conducted at Pompeii. Before its destruction by Vesuvius in AD 79, Pompeii was home to many different species of trees and plants.[91] Wilhelmina Jashemski conducted extensive studies of ancient sources, paintings, and material remains in Pompeii and other nearby towns to more thoroughly understand the flora of the region and the decorative urban landscaping.[92] The carbonized fragments were identified as wood from ash, beech (*Fagus sylvatica*), chestnut, hazel (*Corylus avellana*), walnut (*Juglans regia*), elm, poplar, oak, cypress *(Cupressus sempervirens*), laurel, grapevine (*Vitis vinifera*), hawthorn (*Crataegus monogyna*), and an unidentified species called *Prunus*.[93]

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[89] The evidence for the Maritime Pine tree may not have been ancient, but the information was unclear. Sadori, et al. 2010, 3295.

[90] Meiggs 1980, 188; Sadori, et al. 2010, 3303.

[91] Cultivated areas and gardens occupy 17.7 percent of the excavated area of Pompeii. Houses, temples, *palestrae*, schools, inns, restaurants, and hotels all had accompanying gardens. Jashemski 2002a, 13, 16.

[92] Jashemski investigated the vestiges of plant life from the archaeological record by filling the ancient root cavities of trees with plaster and making casts of them, and by analyzing small fragments of carbonized wood. The process of making the plaster casts involved removing the *lapilli*, reinforcing the cavities with heavy wire, pouring cement into the openings, and leaving the cement to harden. This method, developed by Giuseppe Fiorelli, allowed for the identification of ancient tree roots by comparing the casts to living examples. Jashemski 2002a, 16.

[93] Carbonized remains of plants were only preserved in areas that were covered by the pyroclastic volcanic flow. The extreme temperatures and lack of oxygen charred the plants in a different way than how normal charcoal is produced. Carbonized fragments of ash and hazelnut trees were also found in the garden of the

A more recent study was undertaken by Robyn Veal, who used pollen analysis and charcoal fragments to determine the types of trees that existed at various elevations in the area around Pompeii: alpine or silver fir (*Abies alba*) grew above 1,000 meters in altitude; beech grew between 800 and 1000 meters; oak, evergreen oak, chestnut, ash, elm, maple, hornbeam, and hazel grew between 400 and 800 meters; and primarily olive (*Olea europea*), grapevine, and other fruit and nut trees grew below 400 meters in altitude as commercial crops. Alder, willow, and poplar grew along the river flats; and tree heather (*Erica arborea*), strawberry tree, mastic, pine, and cypress grew in the plains and coastal areas that were not cultivated, as well as in city gardens.[94] The most common species that Veal identified in the charcoal remains that she studied was beech, followed by oak, hornbeam, maple, and some fruit (plums, cherries, and figs, for example) and nut trees.[95]

IV.b. Selecting a Fuel

Determining which of these available trees were burned for fuel in the baths is difficult task, with no definitive answer. Examining the properties of the wood is the best way to interpret what the benefits and the drawbacks would have been for each potential function. The Romans primarily would have based their selection on observation of how

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House of Polybius in Pompeii, and an olive tree branch was found in the garden of the Villa of Poppaea at nearby Oplontis. Hatcher 2002, 217, 219; Jashemski 2002b, 82-3.

[94] Veal (2012, 23) tested a sample of 3,719 fragments of charcoal in her study, encompassing 177 contexts. For the purposes of her project, she defines charcoal as “the residue of burnt raw fuel wood (or wood charcoal) only”. Charcoal remains when combustion is not allowed to complete. On ancient flora, particularly of Pompeii, see: Borgongino 1993; Rehder 2000, 55; Foss, et al. 2002, 66; Ciarallo 2007; Veal 2012, 21. For more general information on the characteristics of the flora, see Pignatti 1982.

[95] Over sixty percent of the charcoal remains were from beech wood. Oak comprised the next largest category, which was less than nine percent of the total. Veal 2012, 27-8 Tab. 2, 33.

the wood burned in the furnaces, in addition to considering other potential uses for the material. For example, ash wood was known to burn well as both fresh and dry wood, with virtually no smoke.[96] Beech also burns well, but it was often used in the construction of furniture. Scraps of beech wood could still have been burned in the furnaces, though, when they were available. Beech was a very common tree on the ancient Italian peninsula, and it may have been plentiful enough for both applications.[97] Hornbeam wood burns well both as a raw fuel and once converted into charcoal, and it was otherwise used by the Romans to make agricultural tools. Oak makes “excellent” charcoal, according to Veal, and it is the wood highest in caloric value. Romans extensively used the timber as construction material and for building furniture. In addition, the leaves and acorns were used to feed livestock, and acorn flour was consumed by humans as well. Hazel trees were also more likely kept intact for the production of hazelnuts, which were consumed by both animals and people. Branches that were cut would have burned well as fuel, however. The multiple potential uses of oak trees may suggest that they were less frequently burned as fuel than other wood. Another wood commonly used for in construction and furniture making was maple. Maple was also used as a fuel, and it made “good” charcoal.[98]

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[96] A.S. Watt (1924, 195) states that beech is able to grow well on exposed slopes, while ash needs protection from the wind. In fact, ash trees often grow around beech trees, gaining refuge from them. Jashemski 2002b, 83.

[97] Beech has a dense, light pink-brown heartwood. The heartwood is the inner, darker portion of a tree, which forms the older growth rings near the pith. Particularly dark heartwood is found in pine, hemlock, cypress, and oak trees. All trees eventually form a certain amount of heartwood in them. Veal (2012, 39) mentions that beech wood rotted easily outdoors, making it less suitable for building construction than other wood types. This property may explain the propensity for the use of beech as a fuel. Tsoumis 1991, 5; Mols 2002, 227 n. 37; Veal 2012, 32.

[98] Theophrastus (*HP* 5.9.1) describes holm-oak as the best for making charcoal. Plin. *HN* 16.6.15; Pignatti 1982, vol. 2 70; Humphrey, Oleson and Sherwood 1998, 41-2; Veal 2012, 33-4.

The supply of fuel for Ostia and for each individual bath would probably have been derived from various sources, depending on the location, the season, and the demand.[99] Local species were likely to have been used most frequently, and so they were tested first in this fuel study. The local species selected for this study were ash, hornbeam, and beech. More exotic wood types, including spruce, birch, and black locust were also introduced into the calculations, in order to determine the cost benefit of importing fuel.[100] Finally, charcoal was tested to compare its fuel efficiency to that of wood. A reasonable range for the amount of consumption in the baths based on various fuel possibilities was thus created.

Explanation of Necessary Equation

The effectiveness of a type of wood for use as a fuel primarily depends on the heating value, which is the heat energy produced by combustion. The heating value is defined by Rehder as the "amount of heat energy produced from one kilogram of wood", and it is dependent on moisture content. An approximate value for each species, however,

[99] Fuel would have been needed in most Roman cities not only for firing the baths, but also for cooking, heating, industry, baking, tanning, metal-working, brick-firing, and for cremation. As populations increased, the demand for more wood and charcoal increased as well. Meiggs (1980, 187, 193) mentions that the popularity of cremations, rather than inhumations, after the death of Augustus was probably the most significant drain on Rome's fuel supply. As the number of large imperial *thermae* multiplied, however, this focus shifted to baths. Hughes 1976, 337; Sallares 2007, 22; Veal 2012, 19.

[100] The importation of wood by sea became especially common after the first half of the second century, when many new building projects were being undertaken in Rome. A great deal of trees on the Apennine hills had been cut down for use during the Punic Wars, and some importation of timber became necessary. Meiggs (1980, 186) stresses that the majority of wood that was imported into Rome by sea was strictly for construction purposes, and not for use as fuel. For more information on ancient timber use, see Thirgood 1981, Dallman 1998, Grove and Rackham 2001, 158, and Harris 2011. For heating values of wood, see Tsoumis 1991, 200.

can be found in charts (Table A1-6 in Appendix 1).[101] The weight of wood is determined by combining the wood substance itself with the moisture content.[102]

Other qualities also need to be taken into account when selecting a wood type as fuel. For example, each tree species burns at a somewhat different rate depending on resin content and on how open the vessels within the cellular structure are.[103] Heat energy is reduced in the process of combustion due to the vaporization of water and other losses. Having drier pieces of wood, therefore, allows for a more efficient use of energy.[104] The moisture content of the ancient wood cannot be known, but an average value was assumed to find the heating value of each type of wood.[105]

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[101] Heating value is determined by burning some of the material in pure oxygen using a bomb calorimeter device. Heating value of fuel is usually expressed in terms of both a higher heating value (HHV) and a lower heating value (LHV). A higher heating value assumes that water vapor is condensed in the exhaust gas, which produces latent heat. An average of the higher and lower heating values was used in this study. Erika Brödner's study (1983, 20) determined that the low ignition temperature of certain fuels – between 200 and 300 degrees Celsius for wood, and between 300 and 425 degrees Celsius for charcoal – was beneficial. The fuel burned slowly in the Roman furnaces working together with a hypocaust system. Wood with a moisture content above sixty percent will not ignite easily. Haygreen and Bowyer 1982, 426-7; Rehder 2000, 25, 26, 30.

[102] Density of wood is defined as the mass contained in a unit volume of material. Density is affected by various factors, including structure, moisture, extractives, chemical composition, and the specific part of the tree. The main determining factor is the porosity of the timber, or how many voids are present in the fabric of the wood. Each variety of wood also has a different coefficient of thermal conductivity, k, just like the materials forming the structure of the bath discussed above. This coefficient is affected by wood structure, moisture, temperature, density, and defects. Haygreen and Bowyer 1982, 196-97, 428; Tsoumis 1991, 114.

[103] Wood is composed of approximately forty-nine percent carbon, forty-four percent oxygen, and six percent hydrogen. Wood burns when subjected to high temperatures, creating a chemical reaction and producing flammable gases. As the temperature rises, different substances in the wood are affected: moisture evaporates up until 100 degrees Celsius, volatile substances evaporate between 95 and 150 degrees, flammable gases begin to be emitted as carbonization starts on a superficial level between 150 and 200 degrees Celsius, flammable gases are emitted more quickly and ignition and glow occur between 200 and 37 degrees, and flammable gases undergo fast ignition and glowing charcoal is formed between 370 and 500 degrees. Haygreen and Bowyer 1982, 426-7; Tsoumis 1991, 198-200.

[104] Haygreen and Bowyer 1982, 428.

[105] Watt 1924, 195.

$$\frac{Q_{total}\left(\frac{kJ}{hr}\right)}{heating\ value\left(\frac{kJ}{kg}\right)} = Total\,\frac{kg}{hr}\,of\ fuel$$

$$\left(Total\,\frac{kg}{hr}\,of\ fuel\right) * number\ of\ hours\ of\ operation = Total\ kg\ of\ fuel\ per\ day$$

Romans used both raw wood and charcoal as a source of fuel. The benefit of using raw wood is that it does not require any special processing; while the benefits of using charcoal are that it burns more slowly, it produces very little smoke, it burns at a higher temperature, and it requires less storage space. A large amount of wood was necessary to make charcoal, which may account for its less frequent use; but moving charcoal would have been much easier, since it only weighed about a fifth of the original wood it was made from. Determining which was used more often is difficult, although most scholars agree that wood was used more often.[106]

V. Computational Methods and Permutations

The objective of the approach of this study is to account for as many factors that were present as possible. With so many elements to take into account, mistakes could have become frequent and could have gone unnoticed. Moreover, if all of these equations were computed by hand, making a small change to a temperature or a heat transfer coefficient would have meant having to rerun every equation each time. No software currently exists that can contend with the heating issues of complex ancient structures,

[106] Wood can burn in a furnace at a maximum temperature of 1400 degrees Celsius, while charcoal can burn at a maximum temperature of 1600 degrees Celsius. Rehder 2000, 7, 173; Diosono 2008, 12; Veal 2012, 26.

therefore, I developed a user-friendly interface using Microsoft Access as a base.[107] This program was used to both aid in the compilation of data, and to facilitate the process of computing quantities of energy and fuel for this specific case study. The database allowed for any number of assessments and many small changes to be made to the data with immediate results. Mistakes could be detected more readily thanks to the organization of the program, and values could be tweaked as new information became available.

The database was designed around a “basic study” (Study 1) condition that I established according to the current state of the bathing facility and other selected values (fig. 4-27). The modern average for Ostia in each month was used for the outside temperature, and each month was tested using Study 1 as a base to illustrate how the bath would have operated according to different external temperatures. A series of permutations, discussed below, were then performed on Study 1 to demonstrate how each would have affected the amount of energy needed to run the baths. Although it is impossible to know for sure how accurate the final fuel consumption values are, demonstrating the effects of small operational differences is still significant and valuable. Each bath may have functioned slightly differently, and outside temperatures always would have varied. Demonstrating the practices that were more or less efficient elucidates the choices that would have been the most logical for the Romans to make. The results of each of these permutations are presented in table form (Table 5-1) and discussed in the following chapter.

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[107] I was assisted with the creation of the basic layout and the manipulation of formulas within the framework of the program by Kostandinos Floratos.

V.a. Basic Layout of Database

The basic layout for the database consists of a main page, and it shows the total value of heat transfer for that system (fig. 4-27). Here, the city and month used in the study is inserted. Double-clicking on the name of the study opens a new page that lists all of the rooms with heating systems, their designated temperatures, and the total rate of heat transfer ($\dot{Q}_{cond}$) computed for that room (fig. 4-28). Double-clicking on each name provides access to information on that particular room, as well as to three tabs – one for the floor, one for the ceiling, and one for the walls – that open the pages related to these specific features (fig. 4-29). Returning to a previous page is accomplished simply by closing the current one, or by clicking on the correct tab.

The first page for the floors refers to the entire floor, and this is where the temperature of the floor is selected from a pull-down menu. Double-clicking on the description leads to the next page, which allows for the division of the floor into the separate elements that form it (fig. 4-30). This division is based on grouping areas with the same material constitution, including both the fabric of each layer and its thickness. There is a box for inserting the surface area of all of the different floor types, which is needed for all the calculations. These sections can each be double-clicked, opening a page where the layers that compose it can be selected from a pull-down menu (fig. 4-31). The thermal conductivity (k) is automatically inserted according to the selected material. Once the thickness of the material is inputted manually, the thermal resistance (R') for that layer is automatically computed and added to the thermal resistances of all the layers.

The thermal heat transfer rate for both the individual element and the total system is updated each time a change is made.

The ceiling tab leads to a similar page like the one for the floor (fig. 4-32). There is a box for inputting the surface area of the ceiling, a value that can only be determined by assuming a type of ceiling configuration. As mentioned above, the ceilings were all designated as having a barrel vault configuration, except for Rooms 15 and C that were assumed to have a dome. The fabric of the ceilings was also assumed to be the same for all of the ceilings in this study, but still needs to be input for each room. There is another tab that leads to a page where the information related to the openings in the ceilings is input (fig. 4-33).

The walls tab also leads a similar page where every heated wall and every wall with a window or an opening adjacent to it is listed (fig. 4-34). Some walls, like the floors, need to be divided into two segments to account for extra layers in some areas. For example, in Room 16 the bench only covered part of the wall, meaning it should be broken into two different pieces. The heights of the walls are approximated in order to determine the surface area of each, and these are inserted in the box provided for surface area.[108] For heated walls, it is necessary to input both a temperature for the hollow space in the wall, and a temperature for the space on the other side of the wall (the adjacent room, the outside, or the opposite hollow space in the wall if it is heated). The outside temperature is dependent on the month that is being studied. No heat is lost through a wall if the temperatures on both sides are the same. Double-clicking on each wall

[108] Values for the heights of the walls were taken from Thatcher's (1956) assumptions where they were available and logical according to the archaeological remains in situ.

segment leads to the next page, which has several tabs, including “In Layers”, “Out Layers”, “Windows”, “Openings”, “Chimneys”, and “Doors” (fig. 4-35). “In Layers” refers to the layers of the wall that are between the hollow heated space in the wall and the room being examined. “Out Layers” refers to the layers that are between the hollow space in the wall and the adjacent space (fig. 4-36). Most of the heat will move into the heated space, rather than in the other direction because of the presence of the thick brick wall between the hollow space and the other side. The total heat contribution from the floors and from the hollow walls was computed to determine how much fuel was needed to heat the baths initially and how much energy would be contributed positively to the system.

Clicking on the “Windows” tab opens a page where information related to windows with barriers, such as glass, is inserted (fig. 4-37). There are individual boxes for inputting the area of the opening, the distance of the bottom of the window to the floor, and the tilt angle. The type of material and its thickness, such as clear glass, is selected from a pull down menu. In this way, the coefficients related to each material are automatically inserted into the proper equations. Both the amount of heat energy introduced from solar radiation, which is always positive, and the energy transferred through the glass or other barrier, which is often negative, is displayed and added to the total summation of heat lost from each room.

The data for windows that are completely open is inserted in the tab labeled “Openings”. Once again, there is a box for the area of the opening and the distance from the floor, and the quantity of solar heat energy is computed and displayed (fig. 4-38). For an open window, energy is transferred through ventilation rather than transmittance, and the appropriate values are computed and displayed. The next tab is for chimneys (fig. 4-39), and there are boxes for inserting the dimensions of the opening. Clicking on the "Doors" tab produces a similar page, with a box for the area of the opening (fig. 4-40). The amount of heat transferred through infiltration, for doors that can be opened or closed at will, is also computed and displayed. Doors with no barriers that are always open are examined as "Openings", but the doors of the heated rooms are only subject to ventilation since they do not open to the outside. All of these values were added to the total heat lost from the heated rooms per hour, with positive values reducing the value and negative values increasing it.

V.a.1. Study 1: Base Study

Developing the database for this study involved the need to keep track of many different elements and details. A base study (**Study 1**) was developed, therefore, to serve as a template and as a way to check for errors and invalid assumptions. Permutations were then made to this template. The base study was originally created for Room 19, and then all the other rooms were added. The structure was assumed to be in its final, current phase, with the bench in Room 16 and the semi-circular pool (Pool γ) in Room 19. The modern monthly average for May for Ostia (16.67 degrees Celsius) was used as the outside temperature, and the values discussed above were used for the other temperatures in the bathing rooms and service areas. May was chosen because it is very close to the annual average, and the average for October is the same as that for May. Room C and Rooms 16 through 20 were all set as having both heated floors and walls; and Room 15 was set as having only a heated floor. None of the ceiling vaults were designated as having been heating, but they each have an opening that is 0.30 by 0.30 meters.

Room 16 and Room 20 were set with no windows; while Rooms 17, 18 and 19 were set with glazed windows. Room 15 is studied with all open unglazed windows. Doors D and I were both blocked in the final phase of the baths, before the blockage was removed as part of the restoration efforts. Therefore, these doors were designated as blocked in **Study 1**. All of the other doors leading to or between heated rooms were set as being wooden doors that could be opened or closed. The fuel assumed was ash wood, and Rooms 7 through 10 were not included as part of the calculations for **Study 1**.

V.b. Permutations

Many different data permutations were created by altering one or more elements in **Study 1** in order to test the effects of these adjustments. Designating each permutation as a separate study file facilitated direct comparisons, making it easier to see how each change affected the amount of fuel consumption in the baths.

V.b.1. Studies 2 - 10: Months

Outside temperature was a significant factor in the calculations; therefore the average outside temperature for each month was tested as a separate study (**Studies 2 through 10**). October was not tested separately since it has the same average temperature as May. June and September also have the same average temperatures, so they were combined into one study, **Study 6**.

V.b.2. Studies 11 - 45: Hour of the Day

***S*tudy 1** evaluated the heat transfer in the Terme del Foro at 1 PM, the time when most men would begin to enter the baths. The time of day would have affected the location of the sun, and therefore, the amount of solar radiation entering the baths. Other hours of the day, from 7 AM to 6 pm were also examined to create a more complete picture of fuel consumption in an entire day. **Studies 11 through 21** were used to find the values for each of these hours, otherwise using the conditions of **Study 1**. The hour of 1 PM was not tested again in this case, since it already was represented by **Study 1**. **Studies 22 through 33** were used to test these same hours, including 1 PM, in January; and **Studies 33 through 45** were used for August. This series of studies illustrated how important solar energy was depending on the time of day and the season of the year.

V.b.3. Study 46: Rooms 7-10

Rooms 7 through 10 are located in what is generally considered to be the *frigidarium*, or cold section of the baths. Although their heating systems are not accessible, the *tubuli* that remain extant on some of their eastern and western walls illustrate that these rooms were heated, at least during some times of the year. The relationship of these rooms to the other heated rooms remains unclear. **Study 46** tested the effect of including these rooms in the overall heat exchange system to determine how much heating these rooms affected the overall fuel consumption of the baths. Since there is no evidence that these rooms had windows opening to the outside, the month that was used in the study was not relevant.

V.b.4. Studies 47 - 49: Doorways

Several studies were conducted in order to illustrate the effects of allowing doorways to be opened or closed in the baths. No doors in the heated rooms communicated with the outside, therefore, only the temperatures from **Study 1** were used. In **Study 47**, the permanent obstructions in both Doors D and I were removed and replaced with movable wooden doors. These doors must have been open in an earlier phase of the baths, but they were sealed for an unknown reason. By testing these doors as being open, this reasoning was examined. **Study 48** altered **Study 1** by leaving wooden doors only where there is currently evidence for them (discussed above). The other doors, whose thresholds are reconstructed or are too damaged to interpret, were left completely open in case they did not have moveable doors in them. **Study 49** mimics **Study 48** except that tarps made of leather were assumed to have been where evidence for wooden doors is lacking.

V.b.5. Studies 50 - 62: Windows

As discussed previously, the expansive windows in the Terme del Foro have been a significant source of debate. The best way to determine how the windows were secured was to illustrate how each scenario affected the amount of fuel consumption in the facility. Since the windows communicated with the outside, the effect of closing them or keeping them open would have varied greatly according to the season. **Study 50** assumed **Study 1** conditions, but included glazing in the large windows of Room 15 to examine how much sunlight would have been blocked and how much energy would have been saved. **Study 51** assumed **Study 1** conditions, but with all the windows unglazed. **Study**

52 examined **Study 1** conditions in January, the coldest month of the year, but with all the windows open. **Study 53** determined if there was any significant heat loss through unglazed windows in the summer months by testing **Study 1** in August.

Studies 54 and 55 explored the possibility that Room 16 had a window, as often has been assumed, with and without glass. **Studies 56 and 57** examined the same scenario in January. The effects of putting wooden shutters on the outside of the windows were tested, both with and without glass, for the month of January in **Studies 58 and 59**. **Studies 60 and 61** illustrated the effects of partially open and double-glazed windows in January. Finally, **Study 62** examined the use of permeable barriers in otherwise open windows, by assuming the presence of a leather tarp on the windows in January.

V.b.6. Study 63: Ceilings

As mentioned above, it is likely that there was some sort of opening in the ceilings of the heated bathing rooms for ventilation purposes. **Study 1** assumes an opening that is square (0.30 meters on each side). Thatcher suggests much larger circular openings with a diameter of 1.83 meters for each room.[109] **Study 63** tested Thatcher's conjecture in January to illustrate how the area of an opening in the ceiling could affect heat loss.

V.b.7. Studies 64 - 69: Fuel

Many fuel types local to the area around Ostia have rather similar properties, suggesting that the quantities needed to generate the same amount of energy in the baths

[109] Thatcher 1956, 190.

should not vary significantly. For example, the density of ash wood is 0.60 grams per cubic centimeter, while the density of beech wood is 0.64 grams per cubic centimeter.[110] Ash burns at a rate between 17,789 and 22,394 kiloJoules per kilogram, and beech burns at a rate between 18,836 and 20,384 kiloJoules per kilogram.[111] The average value for the moisture content of ash wood is 20,092 kiloJoules per kilogram, and the average value for beech wood is 19,610 kiloJoules per kilogram. It is clear from these values that there is not a great deal of difference in the capacity of heat energy generated by these two kinds of wood.

Ash wood was used in **Study 1**, and hornbeam and beech wood were examined in **Studies 64 and 65** to quantitatively demonstrate these similar attributes. More exotic woods that were not local to Ostia, including spruce, birch, and black locust wood were tested in **Studies 66 through 68** to determine how cost effective importing them would have been. Finally, charcoal was used in **Study 69** to provide information related to this fuel type as well.

VI. Conclusions

The heating systems of Roman baths were complex, and the best way to understand them is to examine them as a modern heat transfer problem. Although the basic concept of heat transfer is rather obvious and intuitive, the intricacies involved with an operation as multifaceted as that in the ancient baths require a more advanced knowledge of heat transfer and its applications. Fourier's Law had to be manipulated

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[110] Haygreen and Bowyer 1982, 196-7; Tsoumis 1991, 114.
[111] Haygreen and Bowyer 1982, 426-7; Tsoumis 1991, 198-200.

properly and adjusted for the specific scenario being tested. Components such as solar radiation and the movement of air also needed to be taken into account carefully in order to include as many factors as possible in the study that affected the consumption of fuel.

Once all the proper formulas were determined and adjusted, they were applied to a base study (**Study 1**) with specifically selected conditions. Small permutations were then made to **Study 1** in order to evaluate how each change affected fuel quantities necessary to heat the baths. The permutations were chosen based on questions that have been raised on the heating of Roman baths in the past, as well as on questions that have arisen in the course of this research. They examined issues such as how season and time of day affected energy loss, how much heat was lost through openings in ceilings, and how wooden doors and glass reduced the heat lost through passageways and windows.

A great deal of data was collected and many formulas were needed to compute the final values of fuel consumption for each of these permutations. By creating a database that specifically addressed the needs of this study, the many scenarios could be tested quickly and efficiently and minor errors could be avoided. The results of all the permutations are presented and discussed in the following chapter, and the larger implications of these findings are evaluated.

Chapter 5: Numerical Results and Greater Implications

The current study determined how much fuel was necessary to heat the Roman baths according to particular permutations, such as variations in season, time of day, or architectural features. Each of these permutations was tested after all of the collected data was inserted into the database program. The results of the calculations illustrate the effect that each change had on the operation of the baths, demonstrating the efficiency of the system and illuminating the likeliest choices made by the ancient Romans. In addition, the total value of fuel needed to heat the baths was obtained. With this total value computed, it was possible to examine the greater implications of running the baths on a daily, monthly, and annual basis. Fuel needed to be harvested, transported to the site, paid for, and stored at the site. Each of these processes had an effect on both the local urban setting and the surrounding environment. How much space was needed for fuel in the baths? Were traffic patterns in the city of Ostia altered by fuel deliveries to the baths? What was the effect of fueling the baths on the local forests? These questions are answered in the following discussion.

I. Presentation and Discussion of Results

Testing many different permutations has allowed for a wide spectrum of results to be obtained, illustrating the effects of each on the fuel consumption of the baths. By testing the baths under different conditions, a more complete picture of the operation of baths was produced and the most efficient practices were illustrated. Each permutation is presented generally and compared to similar studies, which are divided by month, hour, inclusion of Rooms 7 through 10, the layout of doors and windows, the configuration of the ceiling, and the type of fuel selected. The amount of fuel needed to heat water in the boilers and the operation of the furnaces is also addressed. Finally, the values obtained in this study are compared to those obtained in earlier studies related to the heating systems of Roman baths.

I.a. Complete Results

The result from each permutation performed on Study 1, which is the base study condition described in Chapter 4, is presented below in the form of a table (Table 5-1) in order to expedite visual comparisons of values.[1] Each permutation is described briefly; more detailed descriptions are presented in Chapter 4. Permutations diverge in some way from Study 1, as labeled, but otherwise can be assumed to follow the same conditions: the skies are cloudless, the month is May or October, the time is 1 PM, Room 15 has unglazed windows, Room 16 has no windows, Rooms 17 through 19 have glazed windows, every room has one open oculus measuring 0.30 by 0.30 meters, and the fuel used is ash wood. Rooms 7 through 10 are not included in the base study, since their operation in conjunction with the heating system is unclear.

Table 5-1, and each subsequent table, illustrates the quantities computed for each permutation. The first and second columns of the tables list the number and name of each individual study, as laid out in Chapter 4. The third and fourth columns list how much

[1] Chapter 4, 244-5.

energy (in kiloJoules per hour) and how much equivalent fuel (in kilograms) were needed to initially heat the Terme del Foro from a completely cold state. As is discussed below, it is not likely that the baths were allowed to go completely cold every night, but instead, that they were kept at relatively elevated temperatures at all times. The initial quantity of energy, therefore, only needed to be generated once. This value is the same for most of the permutations, because it is based on the physical makeup of the baths – the surface area of the floors and the walls that radiate heat. Changes are only noted with the inclusion of extra rooms (Study 46), extra doorways (Study 47), or extra windows (Studies 54 through 57) from those considered in Study 1, since these features alter the total radiating surface area. Each permutation listed as a study should be viewed as a completely separate scenario for the operation of the baths; therefore, the initial value would be needed in every case, albeit for just one time. This value should not be included, however, when only using some of the data from a permutation study (i.e. the heat losses at specific hours) for the purposes of determining the quantity of fuel needed for an entire day.

The last two columns of the tables list the amount of energy gained or lost from the system (kiloJoules per hour) for each permutation study and the amount of equivalent fuel (kilograms). Negative values denote heat lost from the system (through the ceiling, windows, etc.) that must be replaced with more fuel, while positive values denote that energy was being contributed to the system from an outside source, such as sunlight.

Table 5-1: Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
2	Base Study – January	863066	43	-43361	-2.2
3	Base Study – February	863066	43	-29014	-1.5
4	Base Study – March	863066	43	-22681	-1.2
5	Base Study – April	863066	43	-38655	-2.0
6	Base Study - June/September	863066	43	31053	1.6
7	Base Study – July	863066	43	95001	4.8
8	Base Study – August	863066	43	146839	7.4
9	Base Study – November	863066	43	39132	2.0
10	Base Study – December	863066	43	-27045	-1.4
11	Base Study, 7 AM	863066	43	-265118	-13.2
12	Base Study, 8 AM	863066	43	-190296	-9.5
13	Base Study, 9 AM	863066	43	-116925	-5.9
14	Base Study, 10 AM	863066	43	-57422	-2.9
15	Base Study, 11 AM	863066	43	-17391	-0.9
16	Base Study, Noon	863066	43	-3909	-0.2
17	Base Study, 2 PM	863066	43	-57422	-2.9
18	Base Study, 3 PM	863066	43	-116925	-5.9
19	Base Study 4 PM	863066	43	-190296	-9.5
20	Base Study, 5 PM	863066	43	-265118	-13.2
21	Base Study, 6 PM	863066	43	-319819	-16.0
22	January, 7 AM	863066	43	10815113277	538280.0
23	January, 8 AM	863066	43	-319613	-16.0
24	January, 9 AM	863066	43	-176474	-8.8
25	January, 10 AM	863066	43	-89301	-4.5
26	January, 11 AM	863066	43	-43361	-2.2
27	January, Noon	863066	43	-27071	-1.4
28	January, 1 PM	863066	43	-43361	-2.2
29	January, 2 PM	863066	43	-89301	-4.5
30	January, 3 PM	863066	43	-176474	-8.8
31	January, 4 PM	863066	43	-319613	-16.0
32	January, 5 PM	863066	43	10815113277	538280.0
33	January, 6 PM	863066	43	-87211	-4.4
34	August, 7 AM	863066	43	-116459	-5.8
35	August, 8 AM	863066	43	-33436	-1.7
36	August, 9 AM	863066	43	43944	2.2
37	August, 10 AM	863066	43	105788	5.3
38	August, 11 AM	863066	43	146839	7.4
39	August, Noon	863066	43	158774	7.9
40	August, 1 PM	863066	43	146839	7.4
41	August, 2 PM	863066	43	105788	5.3
42	August, 3 PM	863066	43	43944	2.2
43	August, 4 PM	863066	43	-33436	-1.7
44	August, 5 PM	863066	43	-116459	-5.8
45	August, 6 PM	863066	43	-178403	-8.9
46	Base Study plus Rooms 7-10	979200	49	-40184	-2.0

47	Base Study, Doors D/I Open	860801	43	-19676	-1.0
48	Open – No Door Evidence	863066	43	-23420	-1.2
49	Tarps – No Door Evidence	863066	43	-21030	-1.1
50	Base Study, Room 15 Glazed	863066	43	8607	0.5
51	Base Study, All Windows Unglazed	863066	43	-77923	-3.9
52	January, All Windows Unglazed	863066	43	-169070	-8.5
53	August, All Windows Unglazed	863066	43	139838	7.0
54	Base Study, Room 16 Glazed	862819	43	24084	1.2
55	Base Study, Room 16 Unglazed	862819	43	-107053	-5.4
56	January, Room 16 Windows Glazed	862819	43	20256	1.1
57	January, Room 16 Windows Unglazed	862819	43	-153631	-7.7
58	January, Glazed with Shutters	863066	43	-238432	-11.9
59	January, Unglazed with Shutters	863066	43	-273067	-13.6
60	January, Partial Glazing	863066	43	-92464	-4.6
61	January, Double Glazed	863066	43	-53800	-2.7
62	January, Tarp Covering	863066	43	-142707	-7.1
63	January, Base Study, Oculus	863066	43	-75505	-3.8
64	Base Study, Hornbeam Wood	863066	51	-17391	-1.1
65	Base Study, Beech Wood	863066	44	-17391	-0.9
66	Base Study, Spruce Wood	863066	45	-17391	-0.9
67	Base Study, Birch Wood	863066	42	-17391	-0.9
68	Base Study, Black Locust Wood	863066	46	-17391	-1.0
69	Base Study, Charcoal	863066	30	-17391	-0.6

I.b. Monthly Differences

Testing the amount of fuel consumed by the baths in each month, rather than basing the result on annual averages, presents a more accurate illustration of how much fuel was consumed within the span of a year.

Table 5-2: Monthly Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
2	Base Study – January	863066	43	-43361	-2.2
3	Base Study – February	863066	43	-29014	-1.5
4	Base Study – March	863066	43	-22681	-1.2
5	Base Study – April	863066	43	-38655	-2.0
6	Base Study - June/September	863066	43	31053	1.6
7	Base Study – July	863066	43	95001	4.8
8	Base Study – August	863066	43	146839	7.4
9	Base Study – November	863066	43	39132	2.0
10	Base Study – December	863066	43	-27045	-1.4

As expected and can be seen in Table 5-2, more fuel is needed to heat the baths in the winter months (2.16 kilograms per hour in January) than in the summer months (no significant heat loss from the system), since there is a marked difference in temperature between the heated rooms and the outside. This discrepancy would probably have been even more significant if inclement weather could have been taken into account. The heat loss in winter is not as substantial as was expected, however, because of the time of day that was used to test each of the months – 1 PM. At 1 PM the sun shines on the windows of the southwest-facing windows of the Terme del Foro in such a way as to contribute enough heat energy to largely offset the heat that is lost through the openings or glass in the windows. The heat loss for May and October is greater than expected, because the sun does not radiate as directly on the windows at this time of year. For the summer months, there is actually a heat gain to the system at 1 PM (146,839 kiloJoules per hour for August), since outside temperatures were so high at this time of year. Some of this extra heat would have been stored in the fabric of the walls, helping to keep the structure warm even after the sun had set.

I.c. Hourly Differences

Time of day plays an important role in heat transfer, especially in certain months of the year, and must be tested to create a more complete daily picture of the operation of the baths.[2] Hourly permutations were tested for May/October, for January, and for August to determine the total amount of fuel consumed in a day for each season of the

[2] Note that hour is particularly relevant for solar calculations related to windows and external openings, and is discussed below. Time of day would have also affected outside temperatures, but for simplicity, a daily average was used for calculations.

year. A detailed discussion of the hours that the furnaces were kept running for is presented below.

Table 5-3: Hourly Permutations for May/October

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
11	Base Study, 7 AM	863066	43	-265118	-13.2
12	Base Study, 8 AM	863066	43	-190296	-9.5
13	Base Study, 9 AM	863066	43	-116925	-5.9
14	Base Study, 10 AM	863066	43	-57422	-2.9
15	Base Study, 11 AM	863066	43	-17391	-0.9
16	Base Study, Noon	863066	43	-3909	-0.2
17	Base Study, 2 PM	863066	43	-57422	-2.9
18	Base Study, 3 PM	863066	43	-116925	-5.9
19	Base Study 4 PM	863066	43	-190296	-9.5
20	Base Study, 5 PM	863066	43	-265118	-13.2
21	Base Study, 6 PM	863066	43	-319819	-16.0

There were no times of the day when the amount of solar radiation entering the baths was enough to offset the energy lost from the heated rooms during the months of May or October. The sun rises around 4:30 AM in May at Ostia and around 6:30 AM in October, meaning that there would be daylight for all of the tested hours.[3] As the sun rose in the sky throughout the day, more heat from the sun would have entered the southern rooms, reducing the total amount of heat lost. The least overall amount of heat loss would have occurred at noon, thanks to solar radiation. As the sun began to set, the quantity of fuel needed to replace the lost heat increased. When it was night and there was no sun, 15 kilograms of wood were needed per hour to offset the heat losses in the bathing facility.

[3] For approximate hours of sunrise and sunset, see Biordi 2013.

Table 5-4: Hourly Permutations for January

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
22	January, 7 AM	863066	43	10815113277	538280.0
23	January, 8 AM	863066	43	-319613	-16.0
24	January, 9 AM	863066	43	-176474	-8.8
25	January, 10 AM	863066	43	-89301	-4.5
26	January, 11 AM	863066	43	-43361	-2.2
27	January, Noon	863066	43	-27071	-1.4
28	January, 1 PM	863066	43	-43361	-2.2
29	January, 2 PM	863066	43	-89301	-4.5
30	January, 3 PM	863066	43	-176474	-8.8
31	January, 4 PM	863066	43	-319613	-16.0
32	January, 5 PM	863066	43	10815113277	538280.0
33	January, 6 PM	863066	43	-87211	-4.4

The quantity of fuel needed to offset the heat lost from the baths in January presents some unexpected results at first glance – the amount of energy generated at both 7 AM and 5 PM is exceptionally high. If the numbers are accurate, the heat from the sun during these two hours would have been enough to fuel the baths for many days. Instead, these values actually illustrate the limitation of the database program, which always assumes that the sun is present. In January the sun does not rise until around 7:30 AM and it sets by 5 PM. If the solar heat contribution that did not actually occur at 7 AM, 5 PM, or 6 PM (10,815,591,513 kiloJoules per hour or 54 kilograms of fuel) is removed from the value computed by the database, then the amount of energy transferred at each of these hours is actually 478,237 kiloJoules lost per hour, or approximately 24 kilograms of wood needed to maintain the desired temperatures.[4] The same quantity of fuel was needed for all hours during the night in January.

[4] The positive values of heat transferred for 7 AM and 5 PM expressed in Table 5-4 (10,815,113,277 kiloJoules per hour) do not correspond to the actual quantity of heat that must be subtracted (10,815,591,514 kiloJoules per hour) to obtain the correct value, because some heat that was lost from the

Table 5-5: Hourly Permutations for August

Study	Study Name	Initial (kJ/hr)	Initial Fuel	Heat Transferred (kJ/hr)	Fuel (kg)
34	August, 7 AM	863066	43	-116459	-5.8
35	August, 8 AM	863066	43	-33436	-1.7
36	August, 9 AM	863066	43	43944	2.2
37	August, 10 AM	863066	43	105788	5.3
38	August, 11 AM	863066	43	146839	7.4
39	August, Noon	863066	43	158774	7.9
40	August, 1 PM	863066	43	146839	7.4
41	August, 2 PM	863066	43	105788	5.3
42	August, 3 PM	863066	43	43944	2.2
43	August, 4 PM	863066	43	-33436	-1.7
44	August, 5 PM	863066	43	-116459	-5.8
45	August, 6 PM	863066	43	-178403	-8.9

The heat lost per hour in August is much less significant than the previously discussed months, which is logical because outside temperatures are high in the summer, reducing overall heat transfer. Studies related to the ancient climate of the Mediterranean region are presented below. Once again, noon is the time when the most solar radiation entered the heated rooms, reducing the net amount of heat lost. Heat loss was so minimal in the month of August, that the solar contribution was enough to offset it completely in most hours of the day. Unfortunately the Romans did not have solar panels to store all of this additional energy in the hours of peak sunlight, although a great deal of heat was stored within the fabric of the structure. At night, approximately 9 kilograms of ash wood were needed to offset the amount of heat lost from the baths each hour.

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system was compensated for with the solar radiation. Put simply, 10,815,591,513.85 kiloJoules per hour was the actual amount of "false" solar contribution added incorrectly by the database program.

I.d. Rooms 7 through 10

The inclusion of Rooms 7 through 10 as heated spaces in the Terme del Foro presents an interesting scenario for the current study. Since they do not seem to be heated by their own furnaces, and they employ recycled heated air, they are not initially increasing the amount of fuel needed to heat the facility.

Table 5-6: Room Permutation

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
46	Base Study plus Rooms 7-10	979200	49	-40184	-2.0

Changing the number of heated rooms accounted for in the Terme del Foro, however, does change both the amount of energy needed to heat the baths initially, and the amount of energy lost every hour. This increase in fuel is due to the fact that more surface area must be heated initially and more opportunity exists for heat to be lost through the ceilings, the fabric of the walls, and the doorways.

I.e. Effects of Doors

The effect of doors in the heated rooms of the Terme del Foro was not as significant as expected. None of the passageways in the heated rooms communicated directly with the outside, where the temperature difference would have been more extreme during the colder months. Instead, many of the doors communicated between two rooms of the same temperature; therefore, no heat exchange occurred. There was a temperature difference across Door A (between Rooms 2 and 15), Door B (between

Rooms 15 and C), Door D (between Rooms C and 16), Door E (between Rooms 9 and 16), Door F (between Rooms 16 and 17), Door I (between Rooms 10 and 20), Door K (between Rooms 19 and 20), and Door L (between Rooms 18 and 19). In Study 1, all the passageways were set as being fitted with wooden doors that could be opened or closed at will. Some heat was still lost through the fabric of the wooden door, and some heat was lost when the doors were opened and closed.

Table 5-7: Door Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
47	Base Study, Doors D/I Open	860801	43	-19676	-1.0
48	Open – No Door Evidence	863066	43	-23420	-1.2
49	Tarps – No Door Evidence	863066	43	-21030	-1.1

The most significant heat loss was from Room 16, since it is the hottest room in the facility, with Door E losing 3,650 kiloJoules per hour and Door F losing 3,056 kiloJoules per hour. This energy was not lost from the overall system, however: the heat lost through Door E helped to heat Room 9, and the heat lost from Door F helped to heat Room 17. The heat lost through the doors of Room 19 also served to heat Rooms 18 and 20: 1,826 kiloJoules per hour were transferred from Room 19 to Room 20 through Door K, and 1,617 kiloJoules per hour were transferred from Room 19 to Room 18 through Door L. The heat lost from Room 15 through Door B (714 kiloJoules per hour) was essentially negligible since Door D is completely blocked in the base study scenario, making Room C an extension of Room 15. The energy lost from Room 15 through Door

A (1,541 kiloJoules per hour), in contrast, was a total loss to the system, since Room 2 was not meant to be used as a heated room.

As discussed previously, the evidence for movable doors is not present in all of the door thresholds of the Terme del Foro.[5] If it is to be assumed that this lack of evidence meant that there were no movable doors in some of these passageways (Doors G, E, F, H, and K), then more heat would have been lost between some of the rooms. Doors G and H are openings between rooms of the same temperature, meaning that no heat transfer occurred across them. If the wooden door was removed from Door E, then 11,017 kiloJoules were lost from Room 16 to Room 9 per hour. 8,087 kiloJoules were lost through Door F per hour if the door is removed, and 1,975 kiloJoules were lost through Door K per hour. Clearly, having a wooden door in the thresholds helped reduce the heat loss between rooms of differing temperatures. If the same passageways are assumed to not have had wooden doors, it can be imagined that some kind of temporary material could have been placed in the openings instead. Placing a heavy leather tarp in Doors E, F, and K would have reduced the amount of heat lost to 5,676 kiloJoules per hour, 4,669 kiloJoules per hour, and 2,449 kiloJoules, respectively.

Both Door D and Door I were blocked in the final phase of the baths, perhaps to minimize heat loss, and Study 1 reflects this state.[6] Removing the obstructions from the passageways and replacing them with movable wooden doors to illustrate an earlier phase of the bathing establishment would have created a loss of 465 kiloJoules per hour from

[5] On doors and thresholds, see Chapter 4, 206-7.

[6] Blocking these doors would have also altered the possible pathways for bathers: Room 15 was isolated from the rest of the heated sector of the baths, forcing patrons to return to the cold sectors and pass through several rooms before regaining access to the heated rooms; Room 20 was no longer an exit point into the cold rooms from the *caldarium*, requiring bathers to surprisingly pass back through two *tepidaria* (Rooms 18 or 20 and Room 17) and the sauna (Room 16) in order to exit.

Room 20 into Room 10, and a loss of 3,459 kiloJoules per hour from Room 16 into Room C. Both Room 10 and Room C were heated by recycled air, meaning that no loss would have been incurred by the overall heating system. The purpose of Room C may have actually been to reduce heat loss on days of inclement weather from the open windows of Room 15.[7]

I.f. Effects of Windows

Windows are an important component of the baths, because they could be a substantial source of heat loss, but could also contribute a significant amount of free energy. Maximizing the introduction of solar radiation could have greatly reduced the amount of fuel necessary to heat the rooms of the baths. The results of the heat study on windows produced a mixture of some expected as well as surprising results. Computations revealed that having clear glass instead of completely open windows only reduced the amount of solar radiation that entered a room by 14 percent. Tinted glass reduced the value by 26 percent. Roman glass was probably somewhere in between in terms of opaqueness; therefore, it was concluded that having glass in the windows did not significantly reduce the amount of solar radiation entering the room. Moreover, on a clear day, solar radiation contributed a great deal of energy to the rooms, with or without glass.

[7] Chapter 3, 164.

Table 5-8: Glazing Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
50	Base Study, Room 15 Glazed	863066	43	8607	0.5
51	Base Study, All Windows Unglazed	863066	43	-77923	-3.9
52	January, All Windows Unglazed	863066	43	-169070	-8.5
53	August, All Windows Unglazed	863066	43	139838	7.0

Glazing the windows of the baths had a positive overall effect on reducing the amount of fuel necessary to run the baths. Glazing the windows of Room 15, which are assumed to be open in Study 1, eliminated heat loss completely in this room. The heat loss from the baths with all of the windows unglazed was particularly high in January, while in August, the unglazed windows had a positive effect.

More solar radiation entered the windows of the Forum Baths at noon in January than at any other time. This effect is due to the angle of the sun with respect to the vertical windows. Calculations demonstrate that there was enough energy from the sun entering the heated rooms of the Terme del Foro at noon in January to offset the effects of ventilation through the open windows completely in Room 15 (138,586 kiloJoules per hour lost vs. 220,880 kiloJoules per hour gained), Room 17 (51,794 kiloJoules per hour lost vs. 79,565 kiloJoules per hour gained), and Room 18 (48,216 kiloJoules per hour lost vs. 75,902 kiloJoules per hour gained). In Room 19, there was still an overall loss of energy (112,444 kiloJoules per hour lost vs. 112,310 kiloJoules per hour gained), but only of 135 kiloJoules per hour, or 0.0006 kilograms of wood.

Was Thatcher right after all?[8] Could heated rooms have had large open windows without the temperature of the room dropping too much, even in winter? The answer is not that simple. The values expressed above are designed for a completely cloudless day, but it is unlikely that there were many such days in January, and some days were certainly stormy. With the amount of solar radiation dramatically reduced, the heat lost through the open windows was not offset enough, as is demonstrated below. In addition, during hours of the day with less direct sunlight, more heat would have been lost through the open windows of the Terme del Foro than the heat that would have been gained.

I.f.1. Time of Day

Time of day affected the angle of the sun according to the season, thereby affecting the amount of solar radiation entering an opening. In order to examine Thatcher's claim more closely, it is necessary to examine the balance between heat lost through open windows and heat gained from solar energy for every hour of the day. Room 18 was used as an example to simplify computations. In April or October, the radiant energy sufficed to compensate for the heat lost through the unglazed windows of Room 18 between 9 AM and 3 PM, while glazing extended the hours to between 8 AM and 4 PM. In August, the heat lost through open windows was replaced by enough solar energy between 7 AM and 5 PM, and there was no change in hours by glazing the windows in August. For January, these hours were between 9 AM and 3 PM. In all other hours of the day, more heat would have been lost through the openings in this *tepidarium*

[8] For Thatcher's conclusions, see Chapter 3, 180-3; Thatcher 1956. For a simplified heat transfer study refuting Thatcher's conjectures, see Ring 1996.

than the heat that could be recovered. Glazing the windows provided two additional hours of free energy, between 8 AM and 4 PM.

If it is conservatively assumed that half the amount of solar radiation entered the baths on a cloudy day in January, for unglazed windows the solar radiation only compensated for the heat lost between 11 AM and 1 PM. Glazed windows would have extended this time span to between 9 AM and 3 PM, for an extra four hours. These values show that there was no obvious benefit to having unglazed windows in any of the heated rooms of the Terme del Foro, except for, perhaps, the *heliocaminus* (Room 15) for sunbathing purposes. In contrast, the additional hours of fuel saved by glazing the windows makes it much more likely that the windows of the baths were in fact, glazed.

I.f.2. Shutters

Putting shutters outside of both glazed and unglazed windows that could be closed when the weather was not favorable would have reduced the heat loss by providing more insulation. This scenario would have been especially useful in January, when outdoor temperatures were the lowest. For simplicity, only the results for the month of January are discussed here, since they illustrate the most extreme conditions. Shutters would have still let some light in, while reducing the surface area of the opening.[9]

[9] Shutters also may have been beneficial in the summer months to prevent too much sunlight and too much heat from entering the spaces and getting too hot.

Table 5-9: Shutter Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
28	January, 1 PM	863066	43	-43361	-2.2
52	January, All Windows Unglazed	863066	43	-169070	-8.5
58	January, Glazed with Shutters	863066	43	-238432	-11.9
59	January, Unglazed with Shutters	863066	43	-273067	-13.6

At first glance, the values in Table 5-9 suggest that putting shutters on the windows of the baths meant that even more fuel was needed to replace the heat lost. The reason for this outcome is that shutters would have blocked out a great deal of solar radiation, particularly at 1 PM on a sunny day, the time which is represented in Table 5-9. If instead the numbers are reevaluated for a stormy day when only half of the solar radiation would have entered the bathing rooms, then 260,800 kiloJoules of energy (13 kilograms of wood) would have been lost per hour through the glazed windows with no shutters, and 404,575 kiloJoules of energy (21 kilograms of wood) would have been lost per hour through the unglazed windows with no shutters. Closing the shutters on the glazed windows on a cloudy day would have meant that 312,343 kiloJoules of energy (16 kilograms of wood) were lost per hour, once again making the shutters a detriment. Closing the shutters on the unglazed windows on a cloudy day would have meant that 351,573 kiloJoules of energy (18 kilograms of wood) were lost per hour. Clearly, putting shutters on unglazed windows on a cloudy day saved fuel (3 kilograms of wood), although some fuel (presumably oil) would have had to be burned inside the room to provide light.

Closing the wooden shutters at night would have been a way of saving fuel in the heated rooms of the Terme del Foro. Closing the shutters on the glazed windows would have saved 5 kilograms of fuel per hour, while closing the shutters on the unglazed windows would have saved 11 kilograms of fuel per hour. This difference is substantial enough to suggest that shutters may have been used at the baths, at least during the nighttime hours. Unfortunately, no tangible evidence of the use of shutters has been found at the site.[10]

I.f.3. Room 16

Room 16 was the hottest room in the Terme del Foro, therefore, heat loss through a window would have been the most significant from this chamber. As mentioned earlier, the reconstruction of the large window on the southern wall of the room is uncertain. Eliminating a window from this room completely would have reduced ventilation the most, as was assumed in Study 1, but at the same time, the benefit from the radiation from the sun could not have been gained.

Table 5-10: Room 16 Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
13	Base Study, 9 AM	863066	43	-116925	-5.9
24	January, 9 AM	863066	43	-176474	-8.8
54	Base Study, Room 16 Glazed	862819	43	24084	1.2
55	Base Study, Room 16 Unglazed	862819	43	-107053	-5.4
56	January, Room 16 Windows Glazed	862819	43	20256	1.1
57	January, Room 16 Windows Unglazed	862819	43	-153631	-7.7

[10] As mentioned in Chapter 2 (76-7), evidence for shutters covering the windows of the baths was found at the Terme del Invidioso at Ostia, as well as other sites. Shutters can also be seen on the windows of homes in paintings from the House of Publius Fannius Synistor at Boscoreale, now found in the Metropolitan Museum of Art in New York. Broise 1991, 65-72.

At 1 PM on a cloudless day in May, October, or January it is noted that more energy was gained by Room 16 with a glazed window than with no window. Leaving the window unglazed would have led to a substantial heat loss, in contrast. At 9 AM in May or October 98,656 kiloJoules (5 kilograms of wood) would have been lost with a glazed window in Room 16, and 233,570 kiloJoules (12 kilograms of wood) would have been lost with an unglazed window in Room 16. At 9 AM in January 143,892 kiloJoules (8 kilograms of wood) would have been lost with a glazed window in Room 16, and 322,830 kiloJoules (16 kilograms of wood) would have been lost with an unglazed window in Room 16. Except for in the middle of the day, having a window in Room 16 rather than a closed wall would have substantially increased the loss of heat.

I.f.4. Other Coverings and Double-Glazed Windows

The use of simple glass panes in the windows of the heated rooms of the Terme del Foro is the most likely configuration, but other arrangements are possible. Included in these are windows that could be partly opened, unglazed windows covered with a temporary material, and windows sealed with two panes of glass with an air space in between.

Table 5-11: Special Window Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
2	Base Study – January	863066	43	-43361	-2.2
52	January, All Windows Unglazed	863066	43	-169070	-8.5
60	January, Partial Glazing	863066	43	-92464	-4.6
61	January, Double Glazed	863066	43	-53800	-2.7
62	January, Tarp Covering	863066	43	-142707	-7.1

Being able to open a window part-way would have been an ideal scenario – the windows could have been closed when it was cold or stormy outside, or they could have been opened on warmer days for ventilation. If the window was always partially open, however, approximately twice the amount of energy would have been lost from the heated rooms than with fully sealed windows. In contrast, only about half the amount of energy would have been lost from a partially open window than from a completely unglazed window.

Having unglazed windows in the baths would have been pleasant in the summer months and on warm, sunny days. However, these open windows would have been problematic on rainy or stormy days conceivably forcing the facility to close to patrons. Having a system where woolen or leather tarps could have been attached over the openings would have reduced the amount of cold wind and rain entering the space. The reduction of heat lost through the windows from adding a tarp is not very significant (26,363 kiloJoules per hour or 2 kilograms of ash wood), but would have allowed the spaces to be used. If wind were considered in the calculations, this difference would be more substantial.

Double-glazing windows, much like modern storm windows or double glazing (as they are referred to in the United Kingdom), would have had the most significant effect on reducing heat loss from the heated rooms of the baths, particularly on cloudy days. The values expressed above in Table 5-11 reflect the conditions of a completely cloudless day at 1 PM, when solar energy would be very strong. Double-glazing did reduce the amount of solar energy that entered a space (for example in Room 18 the solar contribution was reduced from 62,919 kiloJoules per hour to 51,944 kiloJoules per hour), but it also reduced the amount of heat that was lost through the window (12,505 kiloJoules per hour were lost with single glazing in Room 18, while only 5,518 kiloJoules per hour were lost with double-glazing). Therefore, double-glazing the windows of the baths would have been especially helpful for conserving energy.

I.g. Effects of Ceilings

As is the case in modern buildings, a great deal of heat was lost through the ceilings of ancient Roman baths. In May/October 129,155 kiloJoules (7 kilograms of wood) per hour were lost, in January 195,211 kiloJoules (10 kilograms of wood) per hour were lost, and in August 78,139 kiloJoules (4 kilograms of wood) per hour were lost through the ceilings of the heated rooms.

Table 5-12: Ceiling Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
63	January, Base Study, Oculus	863066	43	-75505	-3.8

The heated rooms would have likely had an oculus, which was included in the Study 1 scenario. If the dimensions of the oculus were 0.30 by 0.30 meters, 619 kiloJoules (0.03 kilograms of wood) per hour would have been lost in May/October, 1,111 kiloJoules (0.06 kilograms of wood) per hour would have been lost in January, and 319 kiloJoules (0.02 kilograms of wood) would have been lost in August. Using Thatcher’s dimensions for the oculi in January shows that 227,355 kiloJoules (12 kilograms of wood) per hour were lost through the fabric of the ceiling, and 35,702 kiloJoues (2 kilograms of wood) per hour were lost through the oculus opening.[11] Clearly, a larger oculus meant that more heat was lost from the heated rooms. A larger oculus would have also allowed more wind and rain to enter, but more sunlight would have entered the space as well.

I.h. Efficiency of Fuel Type

The type of fuel that was used in the Terme del Foro depended on several factors, primarily availability. Although there is no way to be sure which type of wood would have been used most frequently, testing different types of fuel illustrated which were the most efficient.

Table 5-13: Fuel Permutations

Study	Study Name	Initial (kJ/hr)	Initial Fuel (kg)	Heat Transferred (kJ/hr)	Fuel (kg)
1	Base Study - Base - May/October	863066	43	-17391	-0.9
64	Base Study, Hornbeam Wood	863066	51	-17391	-1.1
65	Base Study, Beech Wood	863066	44	-17391	-0.9
66	Base Study, Spruce Wood	863066	45	-17391	-0.9
67	Base Study, Birch Wood	863066	42	-17391	-0.9
68	Base Study, Black Locust Wood	863066	46	-17391	-1.0
69	Base Study, Charcoal	863066	30	-17391	-0.6

According to calculations for the selected group of fuel sources, birch wood would have burned the most efficiently. Birch trees were not local to the area around Ostia, however, meaning that their wood would have had to be imported. Spruce and black locust wood burned less efficiently than ash or beech wood, therefore paying to import these woods would not have been logical. Charcoal was the most efficient of the fuels tested, but would have necessitated processing that may have been expensive or time consuming.

[11] Thatcher 1956, 190.

I.i. Furnace Operation and Total Quantities

The way that furnaces were operated had to be understood, since it affected how much fuel was needed to heat a bath on a long-term basis. The total quantity of fuel needed to heat the Terme del Foro at Ostia had to be computed according to how much was needed to heat each room initially plus how much energy was lost from each individual room, since they were all heated by separate furnaces. The amount of fuel needed to heat the water in the boilers also had to be added to this total.

I.i.1. Furnace Operation

The furnaces of the baths were essential for heating the baths and maintaining them at the desired temperatures. Scholars have debated if the bath attendants extinguished the furnaces at night, when the baths closed, or if they kept them running all the time to prevent the temperature from dropping too significantly. Lombardi and Corazza state that the furnaces were shut down during closing hours, but that the chimneys were sealed to help retain heat.[12] Chimneys were not the only source of heat loss in the baths, however, and energy would have been lost nonetheless. According to Rehder, allowing the furnace to cool completely and to be reheated a few hours later wastes much more energy than keeping the furnace running at a relatively constant temperature.[13] Nielsen concludes that it was more efficient to run the furnaces all the time, and that the fire only had to be fed two or three times a day. She also mentions that the baths took a long time to heat up, but once the proper temperature was reached, it was

[12] Nielsen (1990, 17) mentions that if necessary, the hypocaust could be shut down using a damper, such as the one found in situ in the Forum Baths at Herculaneum. Lombardi and Corazza 1995, 32.
[13] Rehder 2000, 14.

easy to maintain. Kretzschmer's experiments at Saalburg seem to prove this conjecture to be true.[14] Moreover, Pliny the Younger mentions that if he was traveling to his villa near Ostia on too short a notice or for a very brief stay, there were three baths in the next village that could be patronized rather than heating up his private bath.[15] His statement suggests that warming the baths to the proper temperature took too long, and that the effort was only worthwhile if the baths were to be frequented for several days. All of this evidence suggests that Roman baths were kept running at all times.

I.i.2. Fuel Quantities for Heating the Baths

If the baths were operated at all times, rather than being shut down at night, the initial quantity of fuel needed to heat the spaces would only have needed to be employed once, as mentioned above. For most of the permutation studies, this value was computed to be 43 kilograms, which includes the energy necessary to heat the floors and the walls from a cold state. After the initial heating of the facility, fuel would only have needed to be added to the furnaces to account for the amount of heat lost from each room every hour. In some cases, several hours could have gone by without any fuel being added to the fires, both because the solar radiation contribution was so great, and because heat was stored in the fabric of the structure.[16] For a 24-hour period in May or October, 214 kilograms of ash wood would have been needed; for a 24-hour period in January, 378 kilograms would have been needed; and for a 24-hour period in August, 98 kilograms

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[14] The bath at Saalburg, in Germany, was a modern reconstruction of a Roman bath built in 1902. Kretzschmer 1958, 33 fig. 57; Nielsen 1990, 17; Basaran 2007, 205.
[15] Plin. *Ep*. 2.17.26.
[16] The storage of heat within the fabric of the thick brick walls would have created a time lag in terms of heat loss. The result of this large quantity of thermal mass is that the analysis becomes quasi-steady state, rather than simply a steady-state analysis.

would have been needed. More energy would have been produced in Rooms 15, 17, and 18 during the month of August thanks to the effects of the sun and the minimal temperature difference between the inside and the outside of the heated rooms. Unfortunately, there was no way to use this extra energy in other rooms to reduce the overall heat loss. The energy exchange in these rooms was considered to be a zero heat loss.

I.i.3. Fuel Quantities for Heating Water

The heated pools in the Terme del Foro were assumed to have been filled only once a day for the current study, probably in the early hours of the morning before the baths opened for business. The total volume of water needed to fill the three pools in the *caldarium*, was approximately 48.86 cubic meters (48,860 kilograms of wood). In order to heat this volume of water from room temperature (20 degrees Celsius) to the temperature of the *caldarium* (35 degrees Celsius), 153 kilograms of ash wood were needed.

I.i.4. Total Quantity of Fuel

Once the total value of fuel needed to maintain the desired temperatures in the heated rooms of the Terme del Foro and the total value of fuel needed to heat the water used in the baths has been calculated, these two values are added together to produce the value for the total quantity of fuel needed to heat the baths (367 kilograms of fuel in May/October, 531 kilograms of fuel in January, and 251 kilograms in August). The fuel totals are computed for each individual room and then summed, since extra heat that is retained from one room does not automatically help to heat another room.

Table 5-14: Fuel Totals

	May/October	January	August
Room 18 Fuel (kg)	-6.27	-18.71	10.45
Room 19 Fuel (kg)	-105.10	-141.24	-67.38
Room 17 Fuel (kg)	-7.01	-18.91	9.64
Room 16 Fuel (kg)	-74.68	-89.57	-63.17
Room C Fuel (kg)	-2.57	-4.24	-1.30
Room 15 Fuel (kg)	-46.64	-126.08	27.57
Room 20 Fuel (kg)	-14.63	-22.22	-8.77
Total Room Fuel (kg)	**-256.90**	**-420.97**	**-140.62**
Initial Heating Fuel (kg)	42.96	42.96	42.96
Total with Initial (kg)	**-213.94**	**-378.01**	**-97.66**
Water Fuel (kg)	-152.55	-152.55	-152.55
Total with Water (kg)	**-366.49**	**-530.56**	**-250.21**

I.j. Comparison to Other Studies

Comparing the quantity of fuel required to heat the Terme del Foro at Ostia to the results of other studies is problematic, since most other studies do not focus on the Terme del Foro, except for Thatcher's that does not consider all the rooms of the facility. Moreover, different assumptions were made and few details are provided on these assumptions in previous studies. Nevertheless, some of these other values are presented here. In the study conducted by Andrea Jorio between 1978 and 1979 on the Stabian Baths at Pompeii, he determined that 168 kilograms of fuel were needed to heat the bath initially, and that 31,240 kilocalories of energy were needed to replace the heat lost from the men's *caldarium*. Converting kilocalories into kiloJoules produces a value of

130,795.632. Jorio does not mention what type of wood he used in his calculations, but if ash wood is assumed, then 7 kilograms were needed to heat the men's *caldarium*. He does not clarify if this value was per hour, per day, or some other segment of time. The floor area of the men's *caldarium* of the Stabian Baths is 114.00 square meters.[17]

Thatcher's study on the windows of the Terme del Foro at Ostia only examined the five southern rooms. He concludes that with all the windows left open to the air, 1,360 BTUs (British Thermal Units) were needed to heat the baths per hour.[18] Converting this value into kiloJoules produces a result of 1,435 kiloJoules per hour. Thatcher does not discuss wood, but if ash wood is assumed, then 0.07 kilograms of fuel would be needed per hour to heat these five rooms. Thatcher's method for arriving at this number is unclear, and his calculations produce a quantity of fuel that is incredibly low.

In the bath built for the NOVA television program near Sardis, as discussed previously, Tristan Couch computed that 6 kilograms of fuel needed to be burned in the furnace per hour.[19] Assuming the furnaces were kept operating all night, 144 kilograms of wood would have been needed per day. The heated rooms of the NOVA bath only cover a floor surface area of 15.00 square meters, while the heated rooms of the Terme del Foro cover a floor surface area of 787.89 square meters.

Henry Blyth compares cartloads of wood to cartloads of wheat in his study utilizing an ancient contract from Altinum, near Venice, to determine the price of fuel, as

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[17] Jorio 1981-1982, 187, 188, 189.
[18] Thatcher 1956, 256.
[19] Couch does not specify what type of fuel was burned in the experimental bath. Yegül and Couch 2003, 175.

presented previously.[20] He determines that a bath generally consumed a cartload of wood per day. He estimates that one cartload weighed approximately 0.4 tonnes (400 kilograms), therefore, a bath would have consumed 400 kilograms of wood in a day.[21] This value is comparable to the values obtained in the current study.

II. Procuring and Transporting the Necessary Fuel

Computing the total quantity of fuel needed to operate the baths is only useful if the amount is translated into more tangible terms, such as cost and volume occupied. In this way, the finances and effort involved in procuring this necessary supply of wood can be examined. To determine the physical volume occupied by the above determined number of kilograms, it was useful to procure some firewood and determine its properties (fig. 5-1) by actually placing it on a scale and weighing it and by measuring its dimensions. Based on this evaluation, 13 kilograms of hardwood is equivalent to approximately 0.025 cubic meters in volume (0.41 by 0.20 by 0.31 meters); therefore, the fuel used in one day to heat the Terme del Foro during May/October occupied approximately 0.72 cubic meters, the fuel for January occupied approximately 1.04 cubic meters, and the fuel for August occupied approximately 0.49 cubic meters.

[20] Chapter 1, 47-8.
[21] For the inscription, see *CIL* II, 5181. For further discussion, see Blyth 1999, 91.

II.a. Cost of Fuel

Determining the cost of fuel is useful in order to understand the economic impact of a bathing facility on a town or an individual operating the complex. Estimating the actual cost of fuel, however, is a very difficult task.[22]

II.a.1. Evidence for the Cost of Fuel

Blyth determines that a cartload of wood, which would be enough to fuel a bath for a day, cost between 30 and 33 HS. In trying to interpret what this means in terms of value, he notes that Columella mentions that a land owner was said to be doing well if he was able to make an annual income of 100 HS from woodland per *iugerum* (0.623 of an acre). Blyth also states that one ton of firewood would be worth the same amount as 180 liters of wheat.[23] The price of entry to the baths was the equivalent of 0.22 liters of wheat, or 0.50 percent of the monthly allowance of a slave. Blyth suggests that the fee for using the baths that was charged was enough to cover the expenses of the bath.[24]

Janet DeLaine estimates the cost of constructing the Baths of Caracalla, and she considers timber prices as part of her research. One of the main sources she relies on is the *Price Edict* passed by Diocletian in AD 301 to help regulate the cost of certain goods

[22] A future project related to this topic will involve using the estimates made here to compute the price of operating a bath on a daily basis, and this value will then be compared to known ancient admission fees. A very preliminary examination, produced with Dr. Bernard Frischer, suggests that the baths may have actually been profitable.
[23] Columella *R.R*. 3.3.3; Blyth 1999, 87, 88, 92.
[24] Yegül (1992, 45) states that the entrance fees were not enough to cover the cost of running the baths. He also mentions that women had to pay twice as much as men for admission to the baths. He bases his evidence on the contract from Portugal (*CIL* II, 5181), Cicero (*Cael*. 26.62), and Horace (Hor. *Sat*. 1.3.137). Blyth 1999, 94.

throughout the empire, including food, wine, and wood.[25] Russell Meiggs has also used the *Price Edict* to evaluate the cost of timber; unfortunately, both authors interpret the quantities in different ways.[26] This ancient document provides at least a general idea of the price of these items in that time period. The *Price Edict* lists that the price of a stack of ash wood that is fourteen cubits and forty-eight digits square costs 250 *denarii*. A stack of beech wood with the same dimensions, according to DeLaine, and with a slightly smaller overall girth, according to Meiggs, costs the same amount. In contrast, the smallest stack of fir wood mentioned in the *Edict* is about three times larger in volume (37.5 Roman feet long by 5.5 Roman feet wide), and costs 5,000 *denarii*. Fir wood was clearly a much more expensive wood, making it an unlikely choice as a fuel for an extended period, that is.[27]

II.a.2. Estimated Cost for Fueling the Terme del Foro

Using Blyth's method of calculation, the cost of fueling the Terme del Foro at Ostia for one day in May/October, January, and August is equivalent to 65.97 liters of wheat, 95.50 liters of wheat, and 45.04 liters of wheat, respectively. He illustrates that 8.738 liters of wheat cost HS 4, or one *denarius*.[28] Using this information, it is computed

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[25] The prices were supposed to be final, meaning that no additional transport fees or surcharges could be added. Scattered fragments of the *Edict* have been found in Egypt, Greece, and Asia Minor, but not in Italy. Timber is the twelfth item to be discussed in the lists. Murray 1826; Mommsen 1851; Meiggs 1982, 365; DeLaine 1997, 208, 215.

[26] Meiggs (1982, 366) and DeLaine (1997, 215) list the same tree species and the same lengths for the stacks, but they differ in some of the girths they list and in some of the prices.

[27] Roger Ulrich (2007, 242) mentions that fir wood was highly prized by ancient Romans. According to Matz (2002, xvi), a *denarius* was a silver coin that was equivalent to sixteen asses or copper coins. Meiggs 1982, 366, 368; DeLaine 1997, 215 Tab. 25.

[28] Sen. (*Ep*. 80.7) mentions that a slave would have received twenty *denarii* per month, plus five *modii* (one *modius* is equivalent to 8.736 liters) of wheat. The modern equivalent of a *denarius* is unclear. Blyth 1999, 92.

that the cost of fuel for a day in May/October was 7.55 *denarii*, for January it was 10.98 *denarii*, and for August it was 5.16 *denarii*, totaling approximately 5,191 *denarii* per year.

According to DeLaine's estimations, 12.00 cubic meters of ash wood cost 250 *denarii*.[29] Combining these calculations with the ones generated above for volume produces a daily cost of 15 *denarii* for May/October, 22 *denarii* for January, and 10 *denarii* for August. The annual cost for the Terme del Foro according to this method of calculation is 5,645 *denarii*, which does not diverge substantially from the value obtained using Blyth's method.

II.b. Storage Space for Fuel

The contract from Vipascum in Portugal, mentioned above, specifies that a month's supply of fuel had to be available at the baths at all times.[30] A month's supply of fuel would have occupied approximately 22.32 cubic meters in the spring and fall months, approximately 32.24 cubic meters in the winter months, and approximately 15.19 cubic meters in the summer months at the Terme del Foro.[31]

The location of fuel storage in the Terme del Foro is unclear, but the likely locations are in the back of Room a2 (fig. 5-2) and distributed throughout the space of the substructure area (fig. 5-3). In drier months, some wood may have been stored in the *palestra* outdoors, but there is no evidence to support this claim. If the wood was stacked

[29] DeLaine 1997, 215.
[30] For inscription, see *CIL* II, 5181.
[31] According to Pisani Sartorio (1999, 2), 2000 tons of wood (a seven-month supply for the baths) could be stored in the Baths of Caracalla at Rome. This quantity is equivalent to 259,196 kilograms of wood per month. She makes no mention of how she arrived at this estimation, therefore, its reliability is questionable.

up two meters high, the southern half of Room a2 would have been enough space (the floor area is 8.56 square meters) to store fuel for three-quarters of the month of May/October, for half of the month of January, and for the whole month of August. Storing all of the wood in this space would not have been convenient for the furnace operators on a daily basis, therefore, it is likely that some wood was stored within the space of the substructures. As can be seen in Table 5-14, the quantity of wood needed per day for Rooms C, 17, 18, and 20 was minimal and would have easily fit in the space next to the *praefurnia* of these rooms. Even the volumes needed in Rooms 15 and 16 would not have been problematic to store in the substructures. The quantity for Room 19 is more substantial, but this room was heated by six different furnaces. Dividing the amount of fuel needed to heat this room by the number of furnaces, results in a rather insignificant quantity of wood to be stored near each furnace (fig. 5-3).

II.c. Transporting Fuel

Fuel would have needed to be delivered to the Terme del Foro at least once a month, although deliveries may have been more frequent to reduce the quantities delivered each time. According to Blyth, one cart could carry 394 kilograms of wood in one trip.[32] If a whole month's supply of wood (11,362 kilograms for fall and spring months, 16,448 kilograms for winter months, and 7,757 kilograms for summer months) was considered at once, twenty-nine carts of fuel would have been needed for the fall and spring months, forty-two carts would have been needed for the winter months, and twenty carts would have been needed for the summer months. However, this number of

[32] Blyth 1999, 93.

carts would have been rather difficult to transport at once. Perhaps, a more likely scenario is that fuel was delivered once a week: eight carts in the fall and spring, eleven carts in the winter, and five carts in the summer.

II.d. Trees

In order to understand the environmental implications of consuming the required quantities of fuel, it is useful to determine how many trees would have been needed to produce the firewood. Mature ash tree species that grow in the Mediterranean area can reach heights of 25.00 meters.[33] According to the calculations made by DeLaine, ash had a girth of 0.89 meters.[34] If the diameter of the trees used is assumed to have been 0.89 meters and the height is assumed to have been 25.00 meters, then the volume of each ash tree would have been 15.55 cubic meters. At these dimensions, only two ash trees would have been needed to be cut down for the monthly fall and spring fuel supply, three trees would have been needed for the monthly winter supply, and one tree would have been needed for the monthly summer supply.

If smaller ash trees are assumed to have been used, having a height of 12.50 meters and a diameter of 0.45 meters, each tree would have produced 1.99 cubic meters of wood. Using this value, twelve trees would have been needed per month for the fall and spring months, seventeen trees would have been needed for the winter months, and eight trees would have been needed for the summer months, totaling 147 trees per year

[33] Ulrich 2007, 251.
[34] DeLaine 1997, 215.

(fig. 5-4). Clearly, the number of trees that had to be cut down to be burned in the Terme del Foro was not as large as anticipated.

III. Greater Implications of Results

With the quantities of fuel needed for heating the rooms and the water in the Terme del Foro at Ostia computed, the greater implications of these results can now be addressed. How difficult was it to maneuver the carts carrying the fuel through the city? How did the cutting down and burning of trees affect the surrounding environment? These questions are answered below.

III.a. Moving Fuel Through the Urban Landscape

A significant number of carts would have been needed to transport the necessary amount of fuel to the Terme del Foro, as is illustrated above. The difficulty with transporting wood to this bathing facility is primarily due to the fact many streets were converted into pedestrian walkways around the Forum, particularly in the fourth century. As mentioned previously, the most convenient way to deliver goods to the Forum area was to offload goods from vessels moving up the Tiber, and transport them down the via degli Horrea Epagathiana and east along the via del Tempio Rotondo (fig. 5-5).[35] Since the via del Tempio Rotondo was limited to pedestrian traffic in the Hadrianic Period, however, fuel and other goods traversing this path would have had to be carried the rest of the way by hand.[36] Fuel is heavy, thus making this pathway less desirable.

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[35] Chapter 3, 116.
[36] Internet Ostia Group 2011.

The other option was to transport the carts of fuel over land into the city from the south.[37] Doing so would have simplified the process of moving fuel through the city, but would have increased the overall cost of transport. Although the baths would have been more accessible in earlier periods, the enlarging of Pool γ in Room 19 and the expansive windows in the heated rooms were not added to the baths until the fourth century.[38] The bigger pool, in particular, would have increased the quantities of fuel needed to heat the water for the baths. These complexities illustrate that moving fuel to the baths, especially to the Terme del Foro, does not seem to have been prioritized when choosing the location for the baths. Changes also were made to the traffic patterns in the city, which further limited the transportation of fuel to the Terme del Foro, without obvious consideration for how this would have affected the provisions for the baths.

III.b. The Fuel Trade

The scarcity of dense forests in the coastal regions of Southern Europe, compared to the wealth of available timber in the highlands and in northern Europe, implies that a significant lumber trade probably existed early on in the ancient world.[39] There is mention in both the *Iliad* and the *Odyssey* of characters traveling to the high mountains to

[37] The option of moving wood overland from the south would have been particularly feasible if the fuel was being procured from the forests found in the Alban Hills, which are southeast of Ostia. Ulrich 2007, 264-5.
[38] See Chapter 3, 112-3.
[39] Horden and Purcell (2000, 185) reject the theory that viable wood sources were scarce in low lying regions, particularly in Albania. Veal (2012, 39) discusses that beech was the primary wood that was used as fuel in Pompeii, and that beech trees only grew above 800 meters of altitude. Therefore, it was necessary for the Pompeians to procure this wood from the surrounding hills, including those controlled by the Samnites. Grove and Rackham 2001, 172; Thommen 2009, 86.

procure the necessary supplies of wood.[40] The city of Athens imported wood from Torone on the northern Aegean coast in the fourth century BC, according to an inscription. Lucretius also mentions that the forests continued to be found higher in the mountains, while the lowlands were used for farming.[41] Ellen Churchill Semple and Roger Ulrich state that it was not difficult for the ancient wood suppliers, or *lignari plostrari*, to float logs down the drainage paths of the mountains and into the sea. Then the wood was transported to a port town and moved by wagon, or *plaustrum*, to the destination city (fig. 5-6). The same types of carts were used to move short pieces of wood from nearby forests.[42] Logs could also be floated down rivers from mountainous areas to their destinations, or the wood could be attached to form rafts.[43] Unfortunately, there is little detailed information on the timber trade or on the price to transport lumber in ancient textual sources and records.[44]

III.c. Deforestation

The topic of deforestation, particularly its extent and chronology, has been called "the most controversial issue in Mediterranean environmental history," by Robert Sallares. In fact, scholars seem to agree on very few aspects of the subject. Deforestation

[40] Achilles sent wood cutters to Mount Ida to obtain oak for the funeral pyre of Patroklos; Priam used the same source for the funeral pyre of Hektor (*Il.* 23.116-22, 24.659-68). The *Odyssey* (9.116, 186) indicates that Sicily was well-wooded. Caesar (*De Bello Africo* 20) also sent word to Sicily to stock up on timber, since Africa was ill-supplied for the bellicose needs. See Darby 1956, 183, 184 for further discussion.
[41] See *SEG* 43, 488 for inscription. Lucretius 5.1370-1. See Harris 2011, 123 for further discussion.
[42] The *lignari plostrari* were a rather powerful guild that declared their support for various political candidates, including one Marcellus running for aedile. Vergil *Georgics* 2.451-2; Strabo 5.2.5; Pliny *HN* 16.73, 76; Churchill Semple 1919, 18-9; Meiggs 1982, 325, 342, 364; Hughes 1983, 440; Ulrich 2007, 263-4; Diosono 2008, 76.
[43] Sallares 2007, 22; Diosono 2008, 77-8.
[44] Demosthenes (*Against Timotheus* 60-1) describes timber being imported from Macedonia.

is an issue that sometimes plagued communities in antiquity, leaving them without necessary timber and fuel supplies, and it continues to be a problem. John Perlin states that thirty-seven million acres of forests are lost each year in the world; and between 1950 and 1980, twenty-three percent of Africa's forests, forty percent of Central America's forests, and forty percent of the Himalayan watershed were destroyed. He does not specifically mention if Europe has also suffered these losses.[45] How significant of a problem was deforestation for the ancient Romans?[46] What role did baths play? Could ancient deforestation have led to changes in climate? These questions are discussed below.

III.c.1. The Forests of the Roman Empire

Today, what was the Roman empire is forested according to the various climates of the different regions that compose it. The same was probably true in Roman antiquity. For example, precipitation patterns vary a great deal throughout the area, especially increasing with elevation. In central and northern Europe there is substantial rainfall, creating forests that are dense with deciduous trees, succulent grasses, and weeds. In contrast, northern Africa is characterized by steppe and desert vegetation, such as thorny shrubs, sparse grasses, and herbs. Southern Europe is inhabited by a mixture of both

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[45] Perlin 1989, 15; Perry, Oren, and Hart 2008, 4.

[46] Harris (2011, 110-2, 116) states the deforestation is rarely defined by modern scholars (citing Perry, Oren, and Hart 2008, and Rackham 2001 as examples), and he examines the way deforestation is viewed: he mentions that modern scholars often view deforestation in a negative light as something destructive; in contrast, he mentions that ancient authors, such as Tertullian (*De Anima* 30.3), describes cutting down forests as a positive benefit in favor of cultivation. Harris determines that deforestation should imply a rapid removal of forested land in a large area with subsequent significant effects, such as soil erosion. He has no doubt that the Romans contributed to the degradation of the landscape, but he questions the extent. Taking into account demographics, he concludes that the views of Grove and Rackham were too optimistic, and that Romans did indeed contribute significantly to deforestation.

types of flora: the lush forests of northern and central Europe and the arid plants of the African north coast. Along the coastlines, where many of the most populated cities of the Roman World were located, the vegetation resembles that of an arid landscape, while at higher elevations dense forests and alpine vegetation take over.[47] According to Churchill Semple, the most typical Mediterranean Basin vegetation is found on the lowlands and near the coast. In this area there is usually little rainfall in the summer, which produces primarily sparse woodlands or savannahs.[48] The majority of the forests in the ancient Mediterranean world were found in the Alps, the Balkan Mountains, and coastal northwestern Africa.[49]

III.c.2. Ancient Sources on Fuel and Deforestation

Ancient authors were aware of the negative effects caused by deforestation. For example, Pliny mentions that water would descend uncontrollably and violently from the mountains when all the trees had been cut down, eroding away all the soil; and that the water would no longer be available to supply the local springs.[50] Trees were not haphazardly cut down for use in any random function; instead, they were carefully selected according to species, location and season.[51] Owners of forest land were also subject to particular privileges and duties. For example, at some times those that harvested timber and kept their land cleared were exempt of taxes, while at other times

[47] The dense forests on the northern edge of the Mediterranean Basin likely helped repel attacks in ancient times. Churchill Semple 1919, 14, 16; Dallman 1998, 169.
[48] The temperature of the Mediterranean Sea increases considerably during the summer, creating a more moderate climate in the adjacent areas. Churchill Semple 1919, 15-6; Dallman 1998, 176.
[49] Malanima 2011, 5.
[50] Pliny *HN* 31.30; Hughes 1976, 338; 1983, 441.
[51] Hughes 1983, 439.

taxes in the form of wood, charcoal, and burnt lime were expected as payment. These supplies were often used by the army, the fleet, public works, and public baths.[52]

Both Aristotle and Plato thought it was beneficial for cities to own nearby forests. By the 2nd century BC, according to Meiggs, the city of Rome had secured an extensive mountain forest reserve that could provide for the needs of the entire city. Other towns and colonies followed suit to ensure that they had a large enough wood supply for their increasing demand.[53] As the population of Rome and other cities increased, however, these forest reserves dwindled significantly. By AD 364 an imperial intervention was necessary to insure that a supply of timber was maintained, specifically for use in the many imperial bathing complexes of Rome. In a document sent to the provincial governor of Africa in AD 364, Valens and Valentinianus ordered that African ship operators transport logs into Rome. The co-emperors later contracted the operators that moved salt on the banks of the Tiber to transport wood, indicating the importance of fueling the baths at this time. A report by the urban prefect of Terracina illustrates that his town was also required to regularly provide fuel for the baths of the city of Rome in the fourth century.[54]

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[52] Strabo 14.6.5; DeLaine 1997, 214; Diosono 2008, 21, 85.

[53] Aristotle *Politica* 1327a; Plato *Leg*. 4.705; Meiggs 1982, 327, 329.

[54] According to Meiggs (1982, 257), the idea that the forests of Italy were depleted by the fourth century AD probably arose from modern scholarly knowledge that wood was imported from Africa under imperial decree. He finds it more likely that it was only the area directly surrounding Rome that had insufficient supplies of wood. He (1982, 379) also concludes that it is too difficult to determine when deforestation occurred in the ancient world. Harris (2011, 107, 125, 126) agrees that the region around the Tiber River was probably perpetually deforested, but that most other parts of the Roman empire, except for Egypt, generally only suffered from temporary deforestation problems. Harris stresses that the issue for the Romans as well as for the Greeks was not necessarily complete deforestation, but an insignificant supply of specific types of trees, particularly those used for ship-building and construction. Malanima (2011, 7) suggests that southern Europe had been affected by deforestation, primarily due to agriculture, while Eastern Europe and Scandinavia still had plentiful dense forests in the fourth century AD. Thirgood 1981, 41; Meiggs 1998, 257.

The *Historiae Augustae* explains that Alexander Severus levied a special tax against lucrative professions, and that the money would go directly towards funding the operation of the public baths. The emperor also allotted particular forests for use by the baths for income:

> *bracariorum, linteonum, vitrariorum, pellionum, claustrariorum, argentariorum, aurificum et ceterarum atrium vectigal pulcherrimum instituit ex eoque iussit thermas et quas ipse fundaverat et 6 superiores populi usibus exhiberi; silvas etiam thermis publicis deputavit.*
>
> He imposed a very profitable tax on makers of trousers, weavers of linen, glass-workers, furriers, locksmiths, silversmiths, goldsmiths, and workers in other crafts, and gave orders that the proceeds should be devoted to the maintenance of the baths for the use of the populace, not only those that he had himself built, but also those that were previously in existence; he also assigned certain forests as a source of income for the public baths.[55]

The entry is unclear if the wood from the forests was meant to be sold elsewhere so that the bath could make a profit, or if the exclusive use of this forest for fuel would save the bath operators from having to purchase fuel. The description suggests that several baths would benefit from this edict, but it does not specify which ones. If all public baths, together, would benefit from the same forest is also open to speculation. The situation that can likely be deduced from this edict is that fuel was becoming more scarce and problematic for the supply of the public baths in the time of Alexander Severus (AD 222-235).[56]

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[55] The *Historiae Augustae* is a collection of biographies of emperors from Hadrian (AD 117-138) to Carinus (283-285). The biographies were written by several authors spanning the late third century to the early fourth century. *Hist. Aug. Sev.* 24.5-6, translated by David Magie, 1924.

[56] Meiggs 1982, 258.

Meiggs, in his discussion of deforestation, elaborates on the situation by describing that by the fourth century, the state of the fuel supply had only gotten worse. He mentions that in the same order sent by Valens and Valentinianus, those African ship operators who imported logs for the baths into Rome would continue to benefit from particular privileges they had been privy to.[57] Meiggs explains that Symmachus mentions that the salt merchants should be helped because of their involvement in fueling the baths. Meiggs also stresses that these documents illustrate that it was necessary by this date for emperors to intervene in the control of the supply of fuel for the public baths of Rome. Assuming that this meant that the forests of Italy were completely depleted by this period, however, should be avoided. Meiggs notes that the shortage involved firewood in particular, and was probably centered around Rome specifically. He mentions that, "in the early sixth century, Theodoric the Ostrogoth, ruling from Ravenna, was assured that Italy was supplying timber to the province, and he had no difficulty in finding sufficient cypress, pines, and fir to build a fleet of a thousand warships."[58]

III.c.3. Ancient Deforestation

Deforestation in some areas began very early on and had a significant impact on the environment, according to several scholars including J.V. Thirgood, David A. Perry, John Perlin, and Donald Hughes. Thirgood stresses, although his comment is somewhat vague, that it is thanks in part to this early deforestation that western culture was able to

[57] Meiggs 1982, 258-9.
[58] Meiggs 1982, 258-9.

develop.[59] Perlin recounts the story "The Forest Journey" in the *Epic of Gilgamesh*, which took place in Uruk. After Gilgamesh cut down all the trees, the people were plagued with ecological disasters.[60] Perry mentions that villages in Jordan had to be abandoned around 5000 BC because of soil deterioration caused by the cutting down of the oak forests and the over-grazing of goats.[61] Between 1200 and 900 BC, constantly growing settlements on the hills of Greece, Italy, and Israel again led to the cutting down of many trees. In fact, Theodore A. Wertime has estimated that each new household consumed one or two tons of firewood each year at that time.[62] Wood was constantly needed to supply the growing needs of the Roman empire, both for construction purposes and as fuel. As expressed by Paolo Malanima, wood served as the main source of fuel for the purpose of heating beginning sometime between 1,000,000 and 500,000 years ago, up until the Industrial Revolution.[63]

The Roman baths have sometimes been blamed for consuming large quantities of wood, leading to a tremendous impact on the forests of the empire. With increases in

[59] Radkau (2002, 134) mentions that deforestation in Greece began with the earliest farmers who were not equipped with enough experience to foresee the detrimental effects of their farming techniques. Thirgood 1981, 1-2; Hughes 1983; Perry 1994, 7; Perry, Oren, and Hart 2008, 5.
[60] For a further discussion on deforestation throughout history, see Perlin 1989. Perlin 1989, 35-8.
[61] Hughes (1976, 337, 338) mentions that the grazing of goat herds contributed significantly to deforestation. Moe, et al. (2007, 448) find that grazing contributed to damage of the treeline in the central Italian Alps between 3300 and 3200 before the present day. Grove and Rackham (2001, 70) mention that grazing does not always have a negative impact if the extent is properly monitored and controlled. In fact, goats prevent vegetation from accumulating too much and becoming potential fire hazards. Radkau (2002, 23-4, 28) discusses the historical aspects of the conflict between anti-goat lobbyists and groups like the "new cult of the goat". He mentions that even in the Middle Ages goats were prohibited from entering forest land, but that goats only eat young plants and not trees. Perry 1994, 7; Perry, Oren, and Hart 2008, 5.
[62] Malanima (2011, 4) mentions that in the second half of the nineteenth century, each person consumed an estimated 1.5 to 2 kilograms of firewood per day. In underdeveloped areas of the Mediterranean, where firewood is still heavily consumed, at least 1 to 1.5 kilograms are used each day. Wertime 1983, 446.
[63] Malanima (2011, 5) estimates that the average Roman consumed 625 kilograms of firewood in a year, including for industrial purposes (between twenty and thirty percent of the total). Rome, with estimations of populations surpassing a million inhabitants, would have needed fifty square kilometers of forest to supply such a demand. Harris 2011, 106; Malanima 2011, 5-6.

population, particularly in the city of Rome, more and more fuel was necessary both to heat dwellings in the winter months and to heat the baths year round, as Meiggs discusses.[64] Thirgood argues that ship building was the industry that consumed the most wood, however, and even that may not have led to deforestation.[65] According to archaeological evidence, the highest levels of deforestation in the Roman world occurred between the second century BC and the second half of the second century AD; plague greatly reduced the population numbers between AD 160 and 180.[66] Other scholars, including Fernand Braudel, Peregrine Horden, and Nicholas Purcell, posit that significant deforestation did not occur until the Middle Ages. Instead forests were still capable of regenerating themselves in ancient times.[67] In general, many scholars conclude that the most significant levels of deforestation occurred in the early modern period, rather than the Classical period in the Mediterranean area.[68]

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[64] Meiggs 1982, 237.

[65] Grove and Rackham (2001, 167-8) discuss wood use for the building of ships, and they mention that this industry was much less extensive in the ancient Mediterranean than it was in 18th century England, for example. Moreover, they (2001, 174) mention that the difficulties arising in fleet construction in the late Roman period were due to higher labor costs rather than a shortage of timber. Grove and Rackham (2001, 168) also minimize the claims that metallurgy led to significant deforestation in the ancient Mediterranean, suggesting that although many trees were consumed, they were also replaced. Thirgood 1981, 46; Thommen 2009, 39.

[66] According to Dallman (1998, 192), the Mediterranean Basin suffered from deforestation longer than any other area with a Mediterranean climate. Italy, Spain, and France are improving in the field of forest preservation today, increasing their wooded areas. Native trees are no longer desirable for construction purposes, thus reducing the demand. In addition, the populations of these countries have been increasing very slowly, resulting in less harvesting of timber and less need for clearing of land. Dallman 1998, 192; Harris 2011, 116; Malanima 2011, 5-6.

[67] Even Perry (1994, 7) mentions that although deforestation occurred in ancient times, it reached “new levels in the past one hundred and fifty years”. Horden and Purcell (2000, 184-5) state that certain areas of the ancient environments were deforested at particular times, but that this did not occur everywhere or at the same time.

[68] Perlin 1989, 15.

III.c.4. Deforestation and Climate Change

Deforestation has many detrimental effects on the environment, including erosion of soil and uncontrolled flooding.[69] Can climate also be altered by the elimination of forest land? As mentioned above, some ancient scholars blamed the removal of trees for increasing temperatures. For example, Theophrastus, a Greek philosopher who lived between 371 or 372 BC and 287 or 288 BC, blamed local temperature increases and the disappearance of local groundwater on the fact that all the trees had been cut down.[70]

Many scholars and climatologists have tried to model ancient climate patterns in order to answer questions related to temperature and weather patterns.[71] Some claim to have identified significant climatic variations during the Holocene period, and they seek reasons for the onset of these changes, particularly deforestation. In the study conducted by Oreste Reale, Paul Dirmeyer, and Jagadish Shukla a vegetation map of the Mediterranean region was created, and a general circulation model (CGM) experiment was run to test this theory. They concluded that although deforestation alone is not enough to alter climate patterns of a region, it was a substantial contributing factor.[72]

[69] Grove and Rackham (2001, 289-90) contend that proving that ancient deforestation led to erosion, or that evidence of erosion suggests previous deforestation, is much more complex than scholars usually recognize. Thommen 2009, 86.
[70] Theophrastus *Caus*. *Pl*. 5.14.5.
[71] For more information on these climate studies, see Jalut, et al. 2000, Reale and Dirmeyer 2000, Reale and Shukla 2000, Magny, et al. 2002, Anderson, et al. 2007, Neumann, et al. 2007, Sallares 2007, Chew 2008, and Veal 2012.
[72] Other factors contributing to climate change patterns, include severe storms, changes is soil chemistry, erosion, orbital variations, increases or decreases in ocean temperatures, and the ability of vegetation to respond positively to these alterations. Reale and Dirmeyer 2000, 163; Reale and Shukla 2000, 213.

IV. Conclusions

Many calculations were performed on the heated spaces of the Terme del Foro at Ostia in order to determine the variations incurred from heating the baths in different months of the year, heating the baths at different hours of the day, having different structural components, and using different types of fuel. These multiple results created a data set that accounted for many different possibilities. The likeliest choices made by the Romans were included in the base study, and values of fuel consumed were obtained for entire days, months, and years.

August was determined to be the month and midday was found to be the time of day with the least amount of necessary fuel consumption. Heat loss was most substantial in January, particularly from the hotter rooms of the facility, although at midday, this heat loss was dramatically reduced thanks to the rays of the sun. Furthermore, at night, when there was no benefit from solar radiation, heat loss was the highest than at any other time.

The computed values from this study were translated into volume of fuel, which was used to analyze how much heating the baths would have cost and how feasible it would have been to transport and store the wood. This study determined that storing the wood would not have been problematic in the Terme del Foro, but that transporting fuel to the site would have been more difficult. The number of trees needed to generate the required volume of fuel was also analyzed, and shown to not be tremendously substantial.

The Terme del Foro at Ostia did not contribute significantly to deforestation, according to the calculations made in this study and presented above. Indeed, even when assuming that the trees with the smaller diameter (0.45 meter) described above were used, fewer than one hundred and fifty ash trees had to be cut down to supply the Terme del Foro with enough fuel for the entire year (fig. 5-4). Precise calculations for other baths at Ostia would provide a more complete picture of deforestation related to bathing facilities within one city. Since the Terme del Foro was the largest bathing complex at Ostia, assuming the same quantities of fuel consumption for the other baths presents an extreme scenario. At least twenty baths have been identified at Ostia, both public and private. If a comparable value for fuel is assumed in the other two imperial facilities – the Terme di Nettuno and the Terme di Porta Marina – and half the amount of fuel is assumed for the other seventeen facilities, then 1,682 ash trees were needed to fuel all the baths of Ostia for one year.

Conclusions

Roman baths provide a great deal of information about ancient technology, social practices, and architecture. The Terme del Foro are an example of a large imperial bathing complex with unusual architectural features and well-preserved heating elements, making them an ideal case study. No test case is perfect, however, and although many of the walls of the structure are extant to a height of over six meters, the ceilings are completely missing and the walls and floors are not fully intact. Moreover, the baths were originally excavated in the late 1920s, when little attention was paid to stratigraphic evidence or small finds, and a great deal of reconstruction was undertaken to improve the overall appearance of the remains. The structure of the baths and the material remaining therein is still substantial and perfectly sufficient for a study of this nature. In fact, a structure that is perfectly intact does not allow for internal elements, such as wall *tubuli*, to be accessed and studied.

The exact height of the rooms of the Terme del Foro and the configuration of the ceilings is impossible to deduce with definitive accuracy. Distinguishing modern refurbishments from the many alterations that were made throughout the long life of the complex in antiquity also is problematic at times. Some reasonable assumptions had to be made based on the available evidence regarding the appearance of the building throughout its various phases. Since all the permutations tested as part of the heat study on the Terme del Foro were based on the same reconstruction, the comparative quality of the data is reliable. Additionally, using an interdisciplinary approach in all aspects of the project allowed for assumptions to be reduced to a minimum, since so many different factors are taken into account.

Benefits of Interdisciplinary Approach

Several assumptions regarding the operation of the ancient Roman baths had to be made due to an absence of ancient evidence pertaining to the temperatures of the heated rooms, the temperature of the outside environment, and the type of fuel utilized by each bathing complex. In order to make the most plausible selections for these values and fuel types, ancient literary sources, comparative facilities, and modern heat transfer studies were examined. Ancient sources do not provide any specific values for the temperatures inside or outside of the baths, but they do illustrate that there were differences between temperatures maintained in various baths and that not all patrons preferred the same conditions.

The modern Turkish *hamam* is an excellent source for indoor temperatures appropriate for the current study, since these facilities employ a very similar technology for heating as that used in the Roman baths, and both Yegül and Brödner's measurements taken there were utilized here.[1] Further temperature information was obtained from modern experimental heat transfer data, particularly the data recovered from the NOVA bath built near the site of Sardis, Turkey, where actual temperatures were recorded while

[1] Chapter 4, 224, 225; Brödner 1983, 109; Yegül 1992, 381.

the bath was operational.[2] Other useful studies, such as those by Basaran and Ilken, Rook, and Kretschmer, applied heat transfer principals to understand and model how heat moved in the ancient baths.[3]

Literary sources were also extremely beneficial for their discussions of trees and timber, since they expound on the benefits and the drawbacks of numerous species. Although ancient authors primarily focus on the value of particular types of wood for construction purposes, they also make some references to how well some types of trees burned. In addition, literary sources mention certain varieties of trees that grew in the region around Rome and Ostia.[4] These accounts have been supplemented for the purposes of the current study with archaeobotanical evidence collected near Ostia and at Pompeii, providing a more complete picture of the flora of each area.[5]

By incorporating various types of evidence in this study, a wide spectrum of data was compiled, reducing the number of assumptions necessary. The assumptions that are unavoidable are based on realistic conjectures from synthesizing multiple sources, such as ancient literary sources and modern comparative material. Therefore, the thorough nature of this research has resulted in a much more substantiated product than would have been possible from baseless suppositions and limited sources, as has too often been the case with past studies of Roman baths.

[2] The NOVA bath was built for a television show to illustrate how Roman baths were constructed in antiquity and how they operated. Experimental results were employed in the current study, and are discussed in Chapter 4, 228. Yegül and Couch 2003, 169.
[3] Kretzschmer 1958, 36; 1961, 12; Basaran and Ilken 1998, 4; Rook 2002b, 17.
[4] See Chapter 2, 88-9, for a discussion of these ancient sources on wood.
[5] On pollen studies and archaeobotanical investigations, see Chapter 4, 233-5.

Usefulness of Computational Method and Database Program

Archaeology is a field that has become not only increasingly interdisciplinary, as this study reflects, but also increasingly reliant on scientific methods and analyses.[6] A large quantity of data was collected and processed to obtain a result that is more reliable than any produced by a previous project, thanks to the computational method employed. Excel spreadsheets were used originally to store each of the measurements taken in each room of the Terme del Foro, and to insure that no essential values were missing from the data set. The numbers were transferred into a database program created in Access, and the properly adjusted heat transfer formulas were inserted to facilitate computations. Although a significant amount of time was needed to design the database and some calculations had to be performed by hand to test the accuracy of the results produced by the program, these operations only had to be conducted a single time. Otherwise, it would have been necessary to run the same formulas and procedures for every floor, wall, ceiling, window, opening, oculus, doorway, hour of the day, month of the year, and type of fuel. The automatic duplication of formulas and procedures for every room, as well as for every structural component of that room, was the major advantage of the database; and results were produced instantly.

The primary drawback of the database was that certain manipulations were too complex and time-consuming to design into the program, and adjustments had to be made by hand. For example, instead of being able to generate all of the permutation studies in one single file, an entirely new file had to be created to avoid altering the necessary base study conditions. In addition, some values, such as those related to the windows during

[6] Pollard 2012, 177.

night hours, were skewed by certain conditions not factored into the computations. The time and effort saved by employing the database still far outweighed any issues that arose in its use, but caution should always be exercised when relying on numerical results that are generated automatically by a computer program. With fewer time constraints and more extensive computational resources, it is hoped that the remaining adjustments will be performed in the database program for more convenient future applications.

Results of Heat Transfer Study

The results obtained from this research provide many possible scenarios of the way the ancient baths were constructed and operated. The extensive contribution of radiant heat from the hollow floors and walls was demonstrated to be indisputable. In addition, it was shown that a great deal of heat was lost through the ceilings, although an oculus opening may have been desirable for ventilation. The operation of the furnaces was determined to be more efficient if the baths were never allowed to go completely cold – this does not mean that the fires had to be burning all of the time, but that they had to be burning in the seasons and the hours of the day when sunlight was insufficient (or completely absent) to replace the heat lost from the openings and from the fabric of the baths.

Passageways, with and without wooden doors or other obstructions in them, were revealed only to affect the amount of heat lost from the system if they communicated with the outside or with a completely unheated space. Otherwise, the heat lost from one room increased the heat gain in another room without becoming a detriment to the overall system. Glazed windows were concluded to be preferable for the heated rooms of the baths, since glass did not drastically reduce the amount of solar radiation entering the space, and blocking the openings both prevented weather from coming in and limited the amount of heat that escaped. Being able to open or close glass windows would have been ideal, and double-panes of glass would have been desirable at times without sunlight. Testing the use of tarps and wooden shutters demonstrated that they would have reduced heat loss from open windows, but that too much energy would still have been lost. Closing wooden shutters over glazed windows would have been highly beneficial at night, both to reduce heat lost, and to protect the glass from wind damage or from vandals.

The heating capacity of various types of fuel was also examined to demonstrate the effectiveness of each. In general, most hardwoods have similar combustion properties, making it unnecessary for the people of Ostia to import wood from long distances. They had a reliable source of trees in the vicinity that burned efficiently, created little smoke, and was not needed significantly for other industries. Charcoal would have been very efficient for burning in the furnaces, but it would have required some initial treatment and processing, meaning that it may not have been as cost-effective to burn as wood. More research is needed on the properties and use of charcoal, which is currently being undertaken by Robyn Veal.[7]

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[7] Veal (2012) continues to collect charcoal samples from sites around Lazio, which will likely produce very important results. The work conducted as part of the early initial excavations of the Terme del Foro, eliminated any possible evidence of charcoal, soot, or ash, which could have been extremely useful for making more precise conclusions about fuel use in this facility.

Fuel Volumes and Operation of the Terme del Foro at Ostia

The purpose of this study was not only to determine how much fuel was needed to heat the Terme del Foro at Ostia, but also to understand how this quantity of wood was harvested, purchased, transported, and stored. The total number of ash trees needed to heat the Terme del Foro for a year (147 trees) is very low, suggesting that the impact on the surrounding environment was not extensive.[8] Although a significant number of trees would have had to be cut down to fuel all of the baths found in the city of Ostia, estimated to be less than 1700 trees, this quantity does not suggest that the baths caused dramatic levels of deforestation.[9]

Determining the cost of lumber needed to heat the Terme del Foro for a year was rather difficult and probably not that accurate, although the two methods employed produced similar results (5,191 or 5,645 *denarii*). The price of wood probably varied throughout the centuries, and perhaps, even from year to year, limiting the value obtained to a specific time period.[10] In addition, particular suppliers may have been especially expensive and the specific quality of the product may have had a significant effect on cost. Finally, relating the *denarius* to a modern currency value is not accurately feasible, although the buying power of this quantity of money can be gleaned.[11]

Transporting the fuel would have been rather labor intensive, since wood is heavy and bulky. The number of carts needed to convey the necessary wood to Ostia for use in the Terme del Foro was substantial (twenty-nine in autumn and spring months, forty-two

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[8] Chapter 5, 283.
[9] On deforestation and climate change with relation to ancient Roman practices, see Chapter 5, 293-4. On the total number of trees needed to operate all the baths at Ostia, see Chapter 5, 283.
[10] The estimations by DeLaine (1997) and Blyth (1999) for the prices of timber were both based on the *Price Edict*, a fourth century AD document put forth by Diocletian. See Chapter 5, 279-80.
[11] See Chapter 5, 280 n. 28, for more details on the *denarius* currency.

in winter months, and twenty in summer months) if deliveries were only made once a month. The need for many carts would have created an extensive caravan from the forests and to the city, therefore, it was considered more likely that carts of fuel were brought to the Terme del Foro once a week (eight in autumn and spring months, eleven in winter months, and five in summer months).[12] Fuel was probably brought to several baths at once within the city, but there is no way to be sure if every bath at Ostia patronized the same fuel supplier. Some fuel also may have been obtainable from within the city: from the pruning of gardens or from the leftovers generated by the building or ship construction industry, but these types of sources may not have been sufficiently reliable and no direct evidence is forthcoming.

Once arriving at the baths, the fuel had to be stored in a convenient place for eventual use. According to an ancient Roman inscription from Portugal, at least a month's supply had to be available by law, at least in that particular bath at Vipascum.[13] As was illustrated in Chapter 5, there was enough space in the Terme del Foro, both in Room a2 and in the substructures, to store a month's supply of wood without it becoming too cumbersome.[14] More substantial volumes of fuel could have also been kept out in the open in the *palestra* area during drier months of the year, or it could have been placed in the *palestra* under some sort of protective covering or designated enclosed space during times of greater precipitation.

The person in charge of running the baths, called the *balneator* or *conductor balinei* in ancient times, must have had some sense of how much fuel was needed in each

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[12] Chapter 5, 282.
[13] For inscription, see *CIL* II, 5181.
[14] Chapter 5, 281-2.

month to avoid acquiring fuel unnecessarily.[15] Too much wood may have become problematic to store, as well as expensive. That a bath operator would have learned through experience about how much fuel he needed to procure for a specific month, or at least seasonally, is not implausible. In fact, it is likely that most of the operation of the baths would have been conducted based on experience. For example, the correct amount of fuel and the proper time to insert it into each furnace would have been essential for maintaining the desired temperatures in the baths. Was there a specific person with the proper experience who monitored all of the slaves or workmen feeding wood into the fires? Were the slaves or workmen trained to know how to regulate fuel and temperatures themselves? Could they have acquired this knowledge over time by working in the baths?

According to ancient sources, being a bath worker would have been an extremely unpleasant occupation that was usually assigned to low status slaves and even criminals. Trajan wrote a letter to Pliny the Younger while Pliny was the governor of Bithynia, in Asia Minor, stating that older convicts and slaves were assigned to work in the baths as a type of forced labor. Trajan specifically indicates that they were forced to clean the baths, but he does not mention the furnaces.[16] Operating the *praefurnia* could not have been enjoyable work – the fires were hot, the spaces were tight and enclosed, and the quality of

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[15] Yegül (1992, 46) refers to the contract for the baths at Vispascum (*CIL* II, 5181), which has been previously discussed, when he explains that the *balneator* would have made a contract with either the owner of the baths or the individual leasing them. The bath operator would have been responsible for ensuring appropriate standards and service within the bathing facility. Yegül (1992, 47) also mentions that larger baths, like the Terme del Foro at Ostia, would have required an extensive staff to ensure that proper hygiene was maintained, metal implements were kept shiny and free of corrosion, and properly laundered linens were made available to the bath patrons. Moreover, employees or slaves were needed to provide additional services, such as give massages, perform depilations, and guard personal belongings. Bruun (1993, 223) implies that a *balneator* could also refer to a bath attendant. For more information on other duties performed in the baths, see Bruun 1993. Pasquinucci 1987b, 20-1.

[16] Other types of forced labor that these types of individuals performed included cleaning the sewers and making repairs to roadways. On the personnel of the baths, see Pasquinucci 1987b, 20-1. On Roman slavery, see Wiedemann 1987; Thompson 2003; George 2007. Plin. *Ep*. 10.32; Yegül 1992, 47.

the air could not have been ideal. Imagining individuals performing this type of labor as being skilled at maintaining proper temperatures or even as living for long periods of time seems somewhat unlikely. A more logical deduction may be that the *balneator*, or someone else assigned with this specific task, monitored the temperatures of the heated rooms and knew when to add fuel to the fires and when to let them rest. Perhaps having this type of assignment in a large and important complex like the Terme del Foro was only possible after many years of apprenticeship or employment in a smaller facility.[17]

Fueling the Baths of the Roman World

The Romans created lasting monuments that testify to their impressive engineering, artistic, and technological capabilities. Baths represent all aspects of these skills, incorporating grandiose architecture, elaborate decorative schemes, and complex heating systems. The heating systems of the baths are extant enough to provide evidence for understanding how these ingenious mechanisms worked and how much fuel was needed to operate them.

Previous studies related to the heating systems of Roman baths have usually been limited to only one aspect of evidence – in situ archaeological evidence, ancient literary sources, or modern experiments – and they have been restricted by the quantity and potential manipulation of data that they could perform. In this study, each of these forms of information were combined in an attempt to weave together a more complete picture of how the heating systems worked and of how significant their impact was on the

[17] On apprenticeship in the ancient Greek potter's and sculptor's workshops, see Hasaki 2012, 258, 267-8. On papyrological documentation of apprentices in the fabric industry of Greece and Rome, see Bergamasco 1995. On apprentices in the stone working industry, see Rockwell 1993, 250-1.

surrounding areas. Therefore, the results generated here are arguably much more reliable and significant than previous ones, and they were produced from both an archaeological and an engineering perspective. Many different possible scenarios related to the structure and operation of the baths were examined, demonstrating the most efficient choices that could have been made, while still allowing the reader to make his or her own conclusions based on the evidence provided.

Determining how much fuel was consumed in the Terme del Foro at Ostia was important, but taking the study further and illustrating all the practical aspects stemming from the magnitude of this quantity of fuel was useful and was unique to this project. Being able to visualize the kilograms of wood in terms of how much space was occupied when it was stacked up against the walls of the baths, how many carts it filled, how easy it would have been to move this fuel by hand through pedestrian sectors of the city, and how many trees needed to be cut down to produce this required amount, illustrates the complex nature of supplying an important facility with its necessary goods. Moreover, the impact of each aspect was elucidated both in terms of the Terme del Foro at Ostia, and in terms of Roman baths in general.

The interdisciplinary method employed in this study can easily be applied to other well-preserved bathing facilities anywhere in the Roman world, and it is hoped that other bath scholars will consider doing so. In this way, a much more complete picture of the impact of baths on the local and greater environment can be obtained in a scientific way. Two different, yet equally relevant, possibilities exist for pushing this research further. The first involves generating a thorough representation of the fuel use in the baths within the city of Ostia. By applying the same method and using the same assumptions, baths at

Ostia of all different dimensions and varying time periods can be examined, providing an interesting comparative study. Moreover, a reasonable estimation could be made for total fuel quantities needed in the city, generating a complete picture for fuel storage space, transportation of fuel to the city and through the city, and deforestation.

The second option for further study is to use the method established here to examine more closely bathing facilities with differing technological aspects and regional structural variations in order to understand how these factors affected fuel consumption. For example, the recently uncovered Hellenistic baths at Morgantina could be used as an example of an early bath that did not have wall heating or a fully developed hypocaust.[18] Testing the efficiency of these baths would show the benefits of having a more advanced heating technology.

Another interesting example could be one of the baths found in Sussex, England, such as the first century AD baths at Angmering, recently published by Lynne Lancaster.[19] As Lancaster describes, this bath had a heated ceiling vault formed of hollow voussoirs. Examining the impact of a heated ceiling vault on the use of fuel would be very informative. The climate of England is much colder than that of central and southern Italy and there is considerably less sunlight. These factors would have greatly affected the amount of heat lost through openings and windows, allowing potentially for very different results than those obtained at Ostia.

[18] See Chapter 2, 66-7 n. 46. Bell 1981; Lucore 2009.
[19] Lancaster 2012.

A third attractive case study would be the baths at Kourion in southern Cyprus (dated from the first century AD to the early second century AD).[20] The many archaeological treasures of Cyprus have not been studied or published sufficiently, depriving the field of Roman bath studies from having more information on these facilities that reflect both Roman and eastern Mediterranean technology and architecture. In addition, terracotta spacer pins were found at Kourion, providing the opportunity to test how these different wall heating implements would have affected the heat contribution of the walls.[21]

Roman baths continue to be a source of untapped possibility and further data that will continue to enhance our knowledge of the Roman world. By studying them in new ways and by using more advanced technological tools, even more can be understood about baths and about how ancient Roman people experienced them. Moreover, the ingenuity and efficiency of the heating systems of Roman baths may serve to improve how spaces are heated in the present, helping to reduce pollution in the environment and to conserve valuable resources for future generations.

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[20] Karageorghis 1987, 16, 39.
[21] See Chapter 2, 60-3, 65 on terracotta spacer pins. Kelly 2004-2005, 611.

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[1] All abbreviations for journal titles are based on the standards of the American Journal of Archaeology.

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Figures

Figure 0-1: Google Earth Image of Ostia (2007)

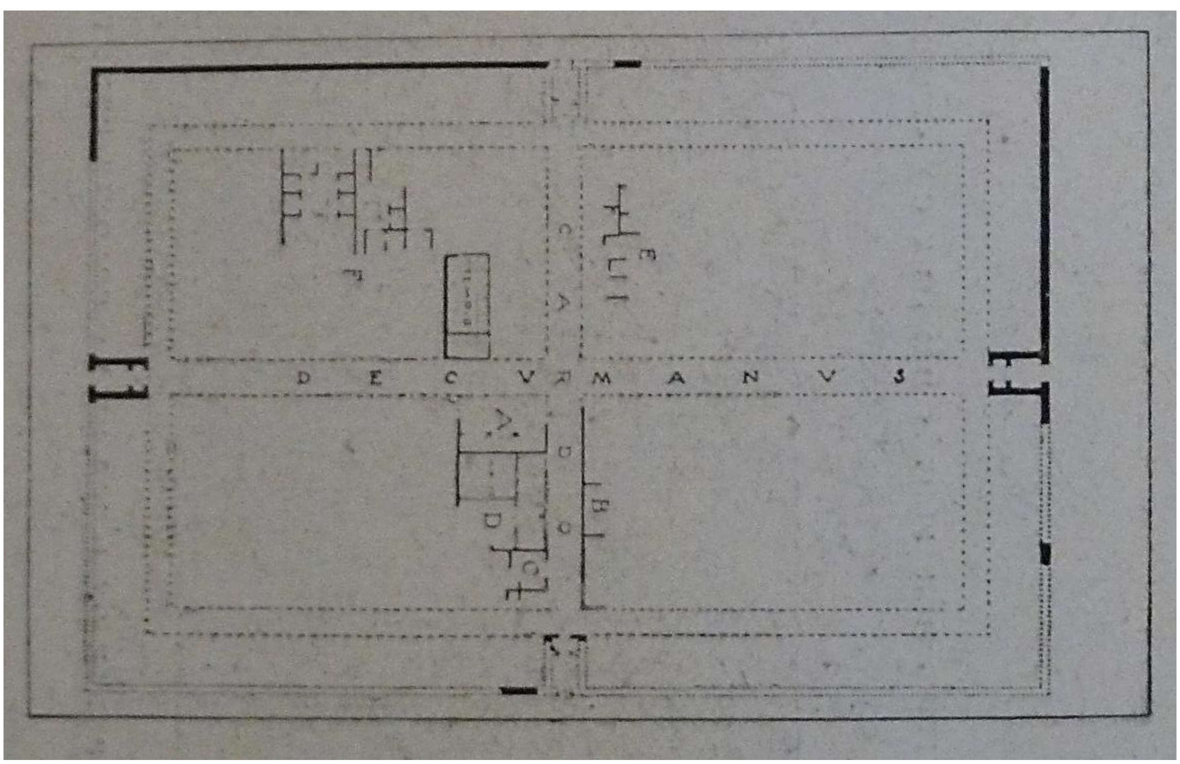

Figure 0-2: Plan of Ostia as a *Castrum* (Carcopino 1929, 61)

Figure 0-3: Plan of Ostia showing Bathing Facilities (Cicerchia and Marinucci 1992)

Figure 0-4: Terme di Porta Marina, Ostia

Figure 0-5: Terme di Nettuno, Ostia

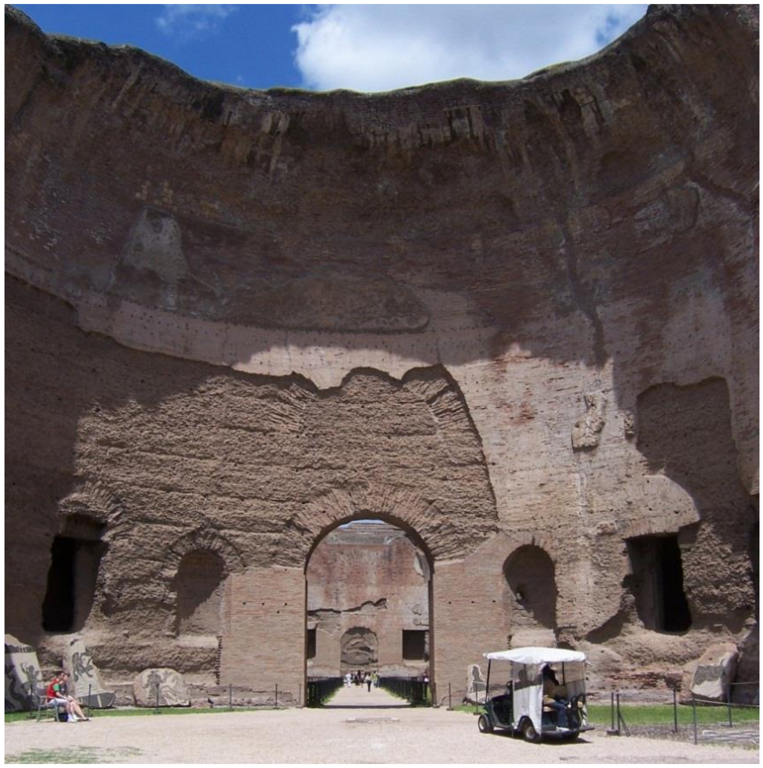

Figure 1-1: Baths of Caracalla, Rome

Figure 1-2: Farnese Hercules, Naples Archaeological Museum


Figure 1-3: Farnese Bull, Naples Archaeological Museum

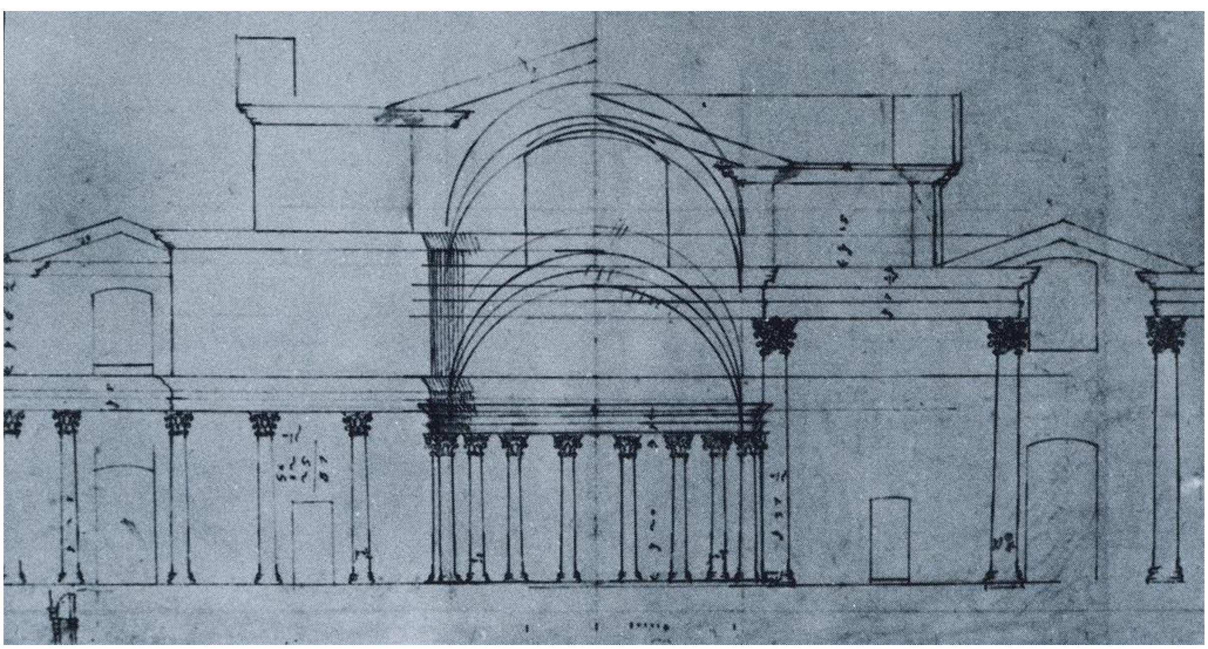
Figure 1-4: "Baths of Nero" by Andrea Palladio (Artstor 2013)

Figure 1-5: "Temple of Diana at Baiae" by Jan Brueghel the Elder (Artstor 2013)

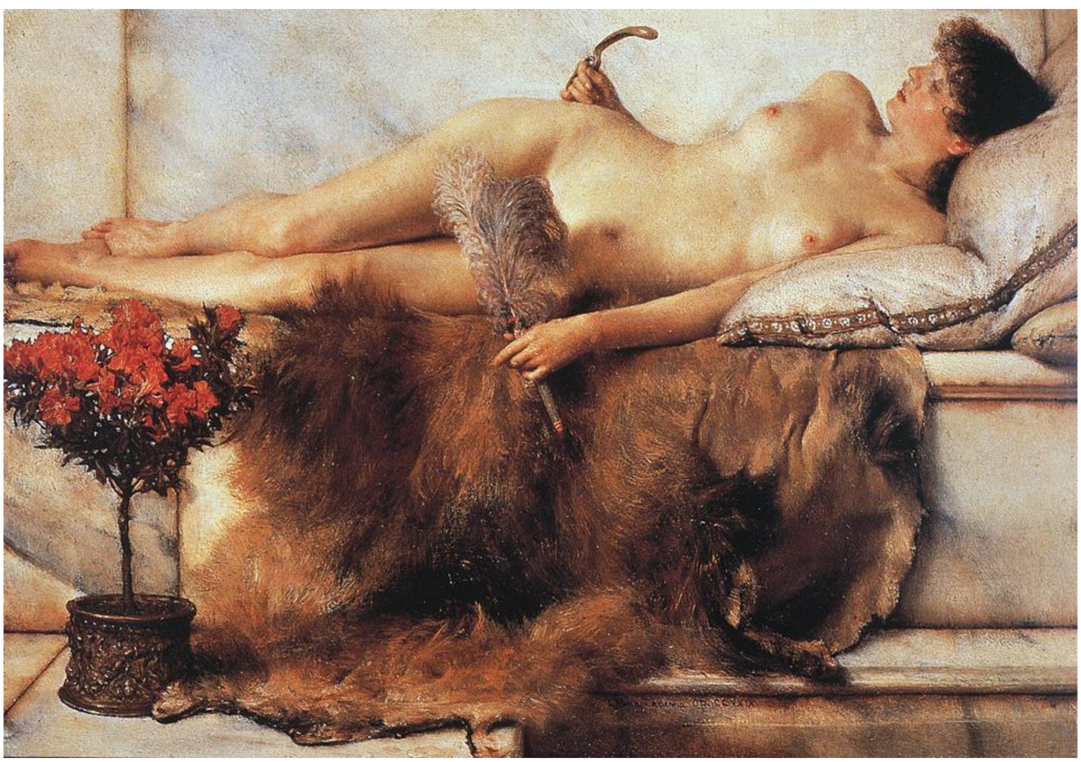

Figure 1-6: "In the *Tepidarium*" by Sir Lawerence Alma Tadema (Artstor 2013)

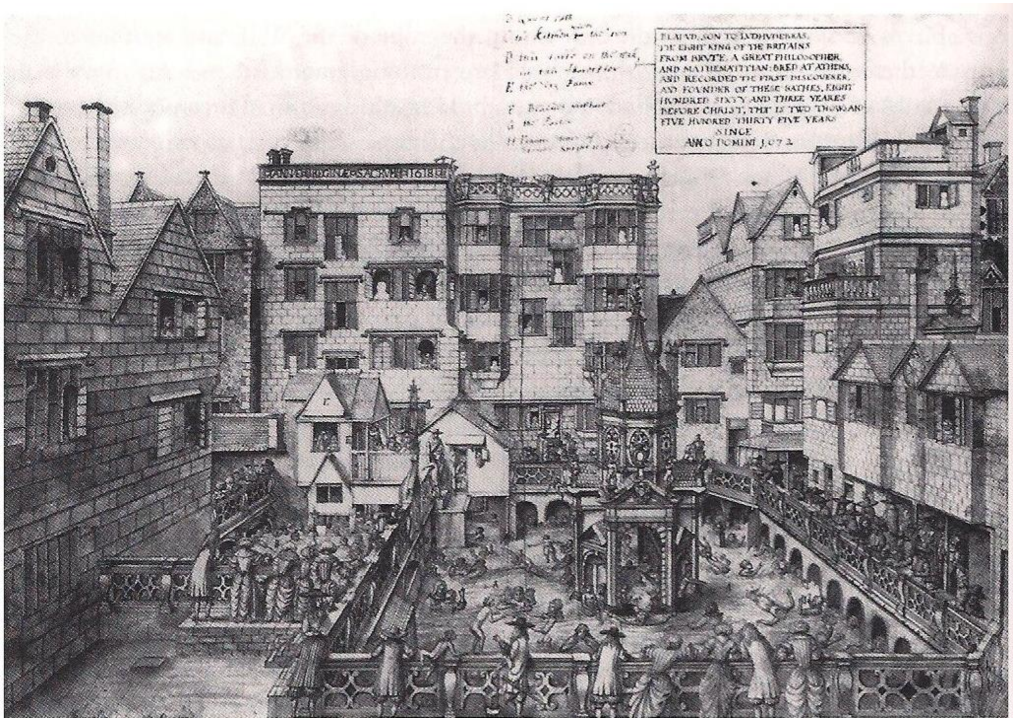

Fig. 1-7 King's and Queen's Bath at Bath, Looking West by Thomas Johnson (Cunliffe 2000, 20 fig.5)

Figure 1-8: Head of Sulis Minerva, Bath

Figure 1-9: “Temple” of Mercury, Baiae

Figure 1-10: Men’s *Caldarium* in Forum Baths, Pompeii

Figure 1-11: Women's *Caldarium* in Forum Baths, Herculaneum

Figure 1-12: Central Baths, Pompeii

Figure 1-13: Suburban Baths, Heculaneum

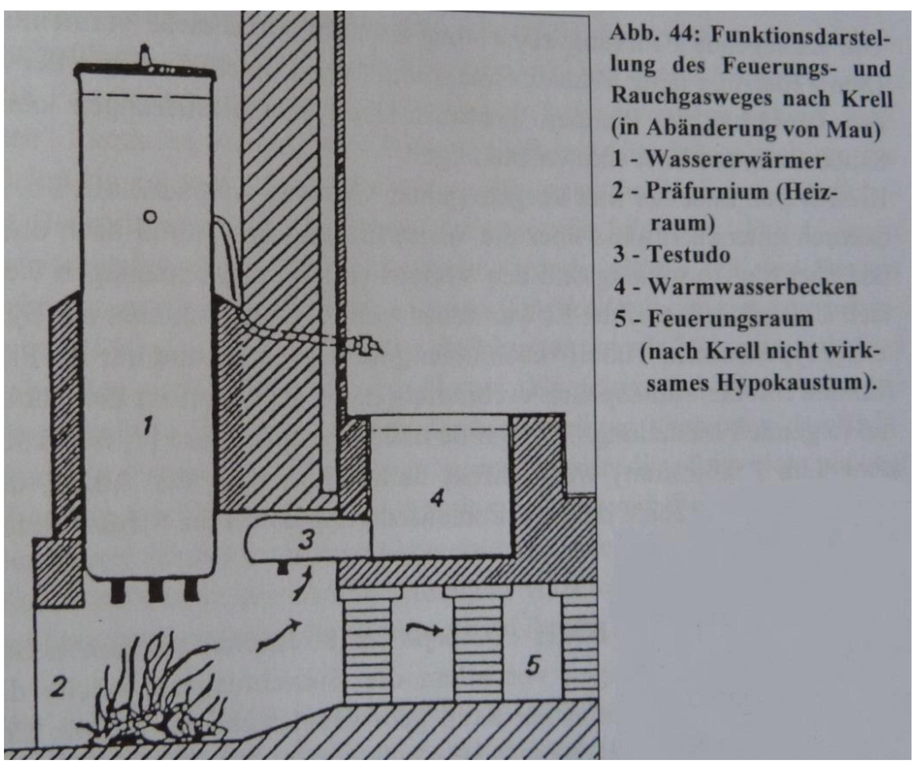

Figure 2-1: Drawing showing Furnace Heating Boiler, Water, and Hypocaust (Schiebold 2006, 69)

Figure 2-2: *Praefurnium* Opening of Room 18 facing Northeast

Figure 2-3: Spur Walls in *Praefurnium* of Room 19 facing North

Figure 2-4: Triangular "Chimney" Opening in the Grandi Terme at Hadrian's Villa, Tivoli

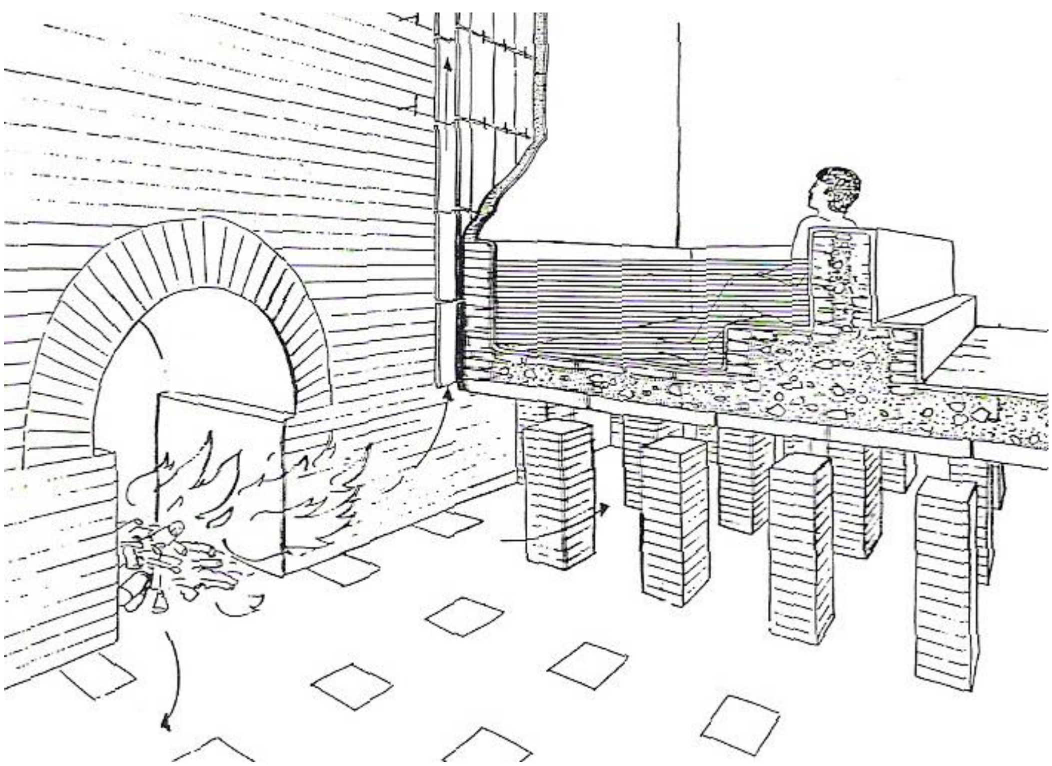

Figure 2-5: Drawing showing Heat Circulating in Hypocaust and through Walls (Shepard 1987)

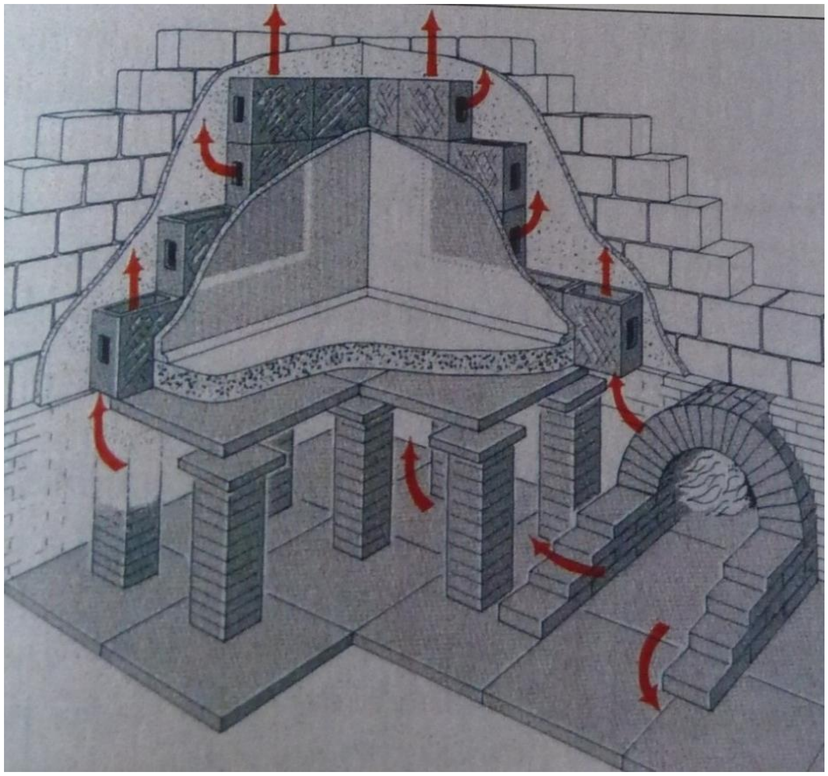

Figure 2-6: Drawing showing Heat Circulating through Hypocaust and Walls (Schiebold 2006, 25)

Figure 2-7: *Tegulae Mammatae* in the Stabian Baths, Pompeii

Figure 2-8: ***Tegulae Mammatae*** **attached to the Wall in the Stabian Baths, Pompeii**

Figure 2-9: Terracotta Spacer Tubes, Dion Archaeological Museum

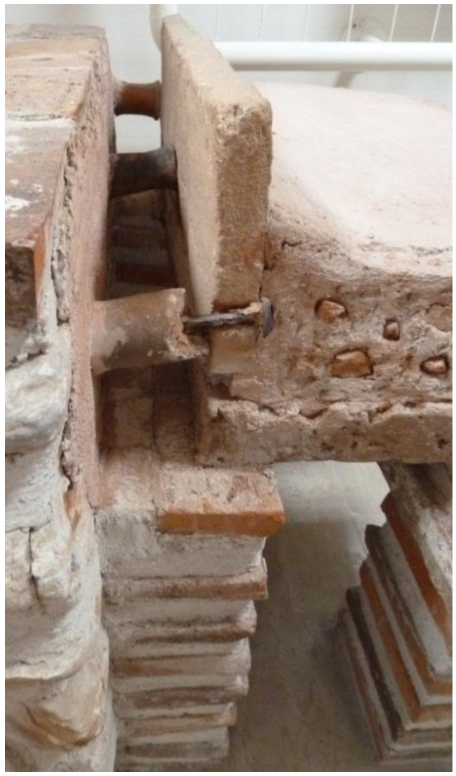

Figure 2-10: Model of Terracotta Spacer Tube System, Dion Archaeological Museum

Figure 2-11: *Tubuli* in Room 16 on Wall c in the Terme del Foro, Ostia

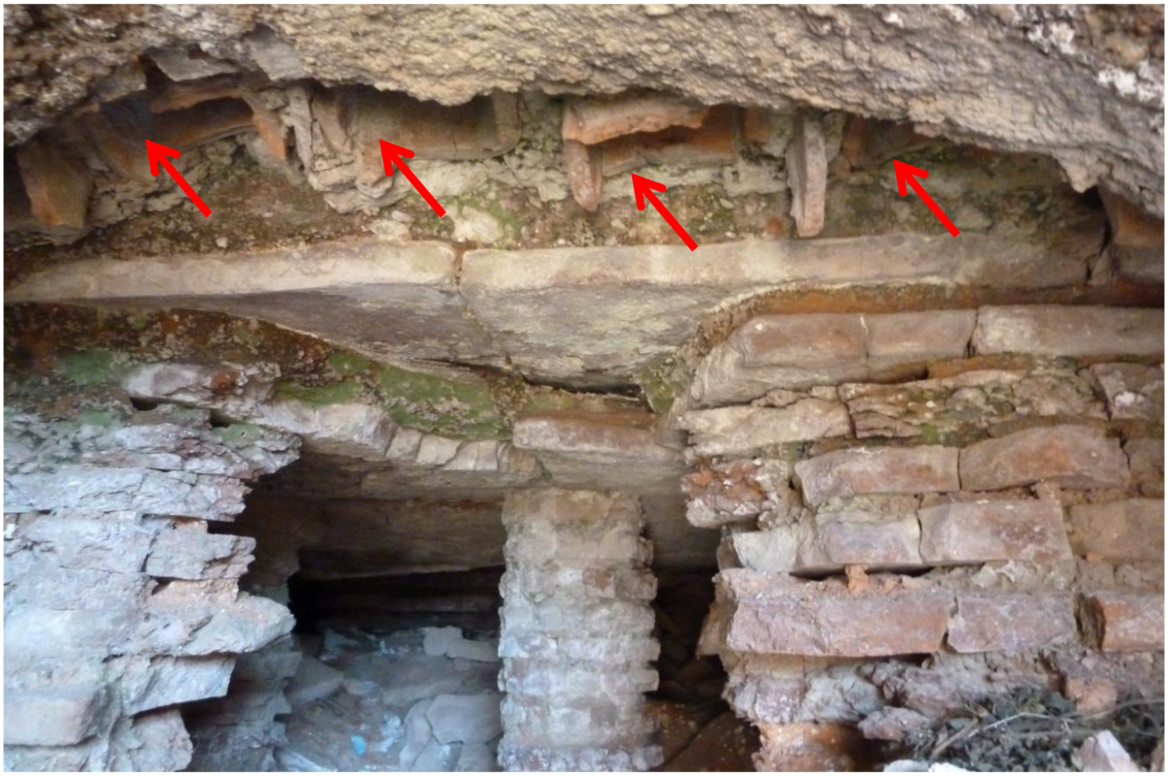

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Figure 2-16: Detail of Travertine Console showing Round Depression of Shutter Hinge

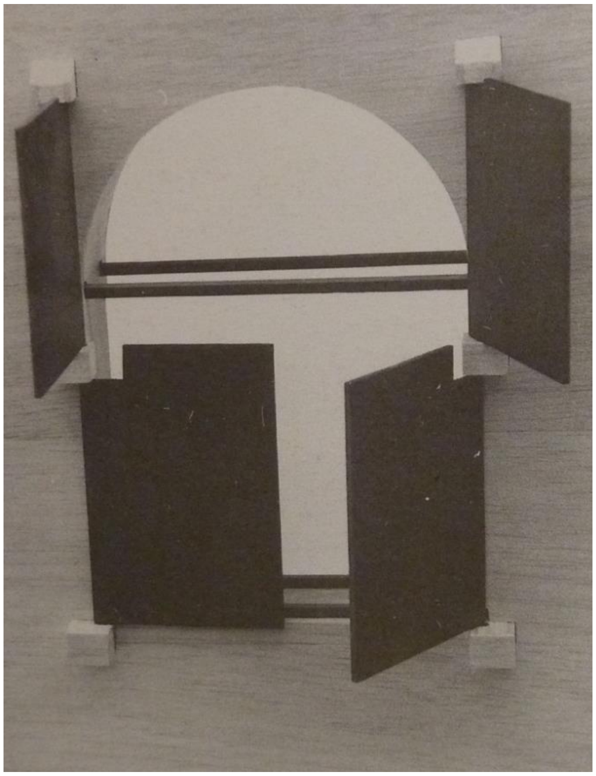

Figure 2-17: Reconstruction of Shutters Outside South Baths, Bosra (Broise 1991, 72 fig. 24)

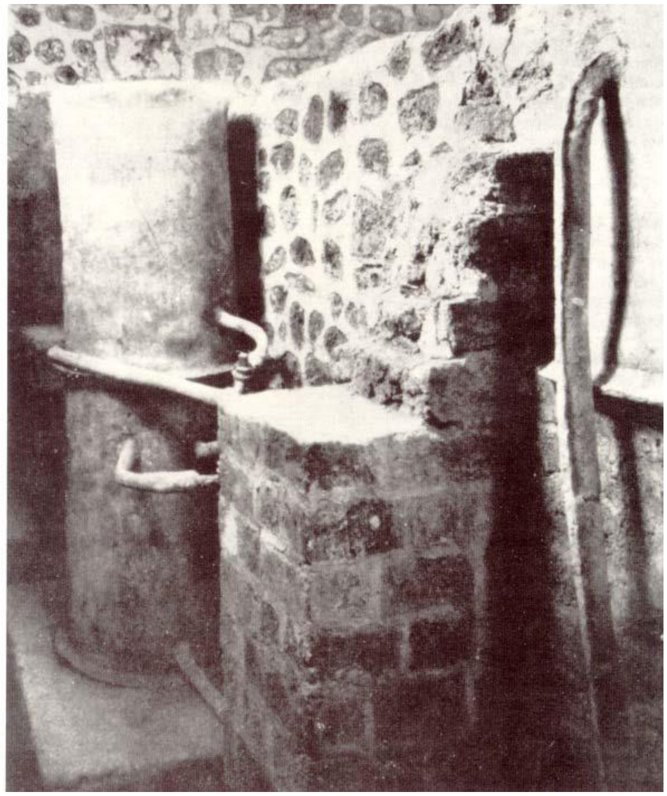

Figure 2-18: Boiler found In Situ at Boscoreale (Ragazzo 1999, 19)

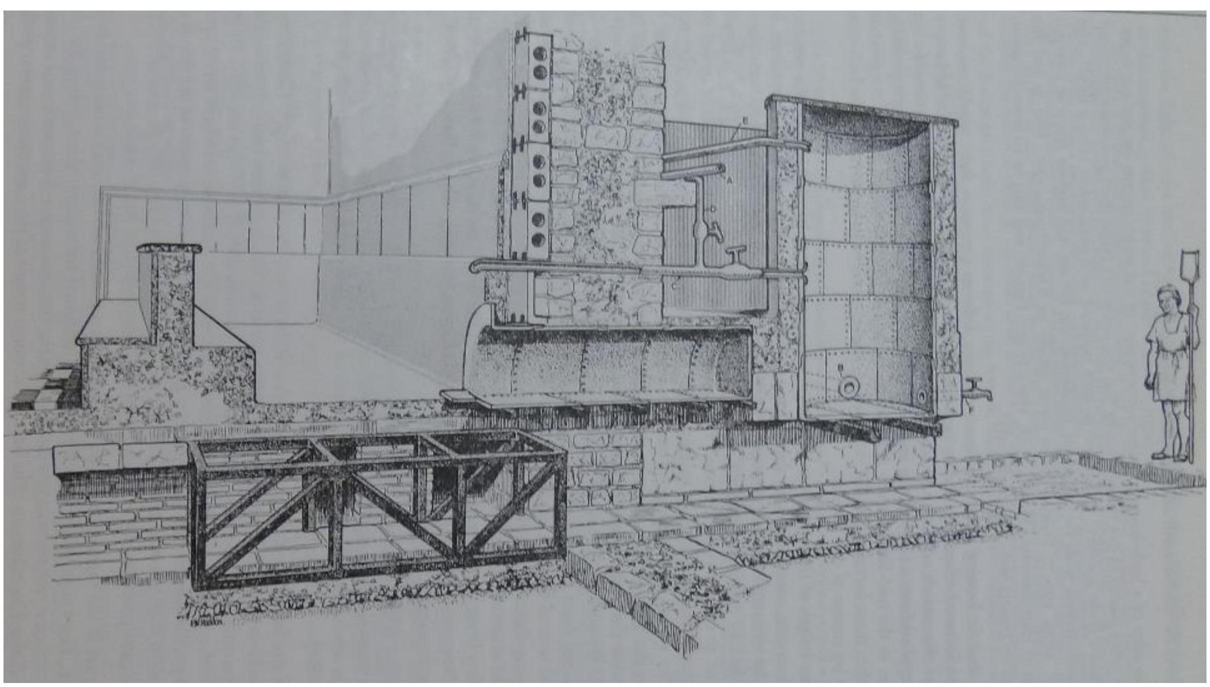

Figure 2-19: Drawing showing Southwest Caldarium Furnace House at Exeter (Bidwell 1979, fig. 8)

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Figure 2-25: Large *A Cappuccina* Drain in Pool δ in the Terme del Foro, Ostia

Figure 3-1: Plan of the Terme del Foro at Ostia showing Final Phase (Cicerchia and Marinucci 1992)

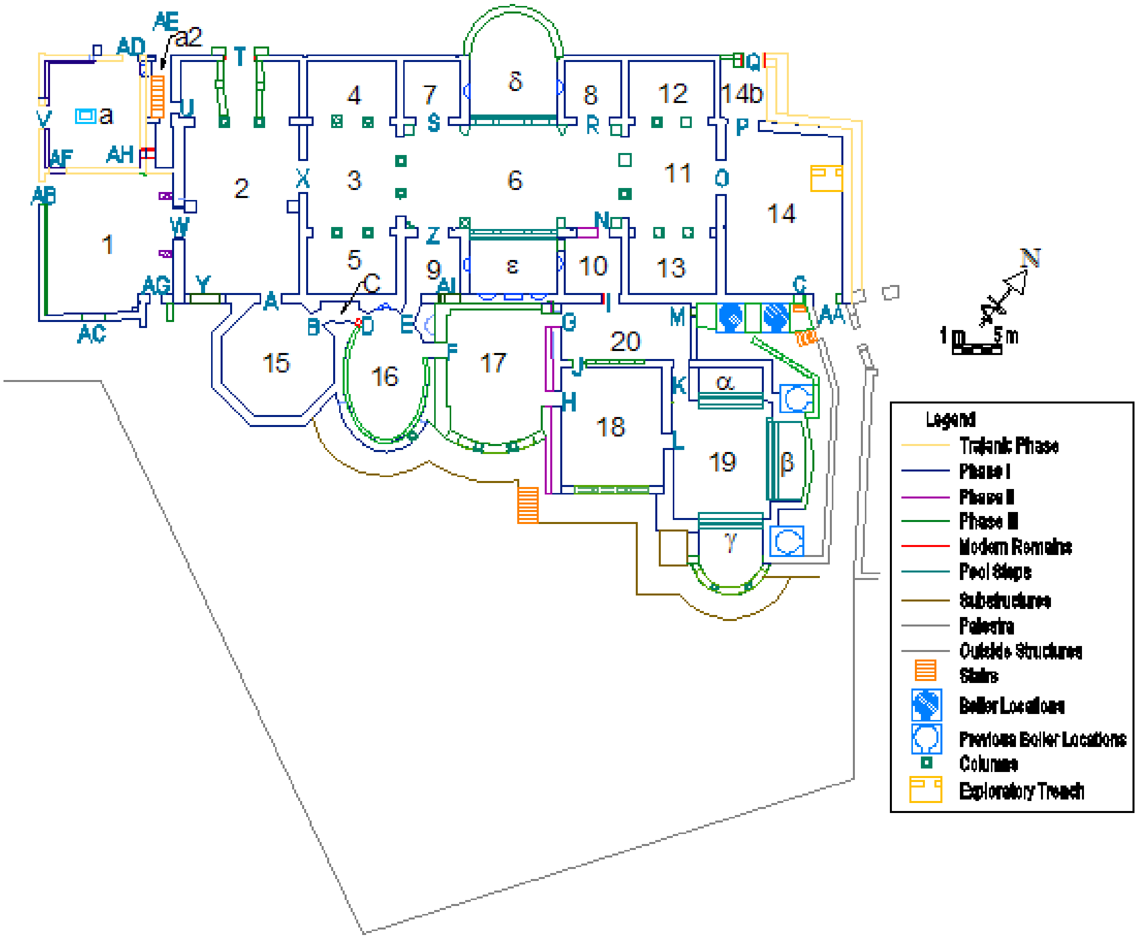

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Figure 3-3: Google Earth Image of the Terme del Foro, Ostia (2007)

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Figure 3-5: Excavation Photo showing South Rooms of Terme del Foro (Calza, *et al*. 1953, Tav. VI)

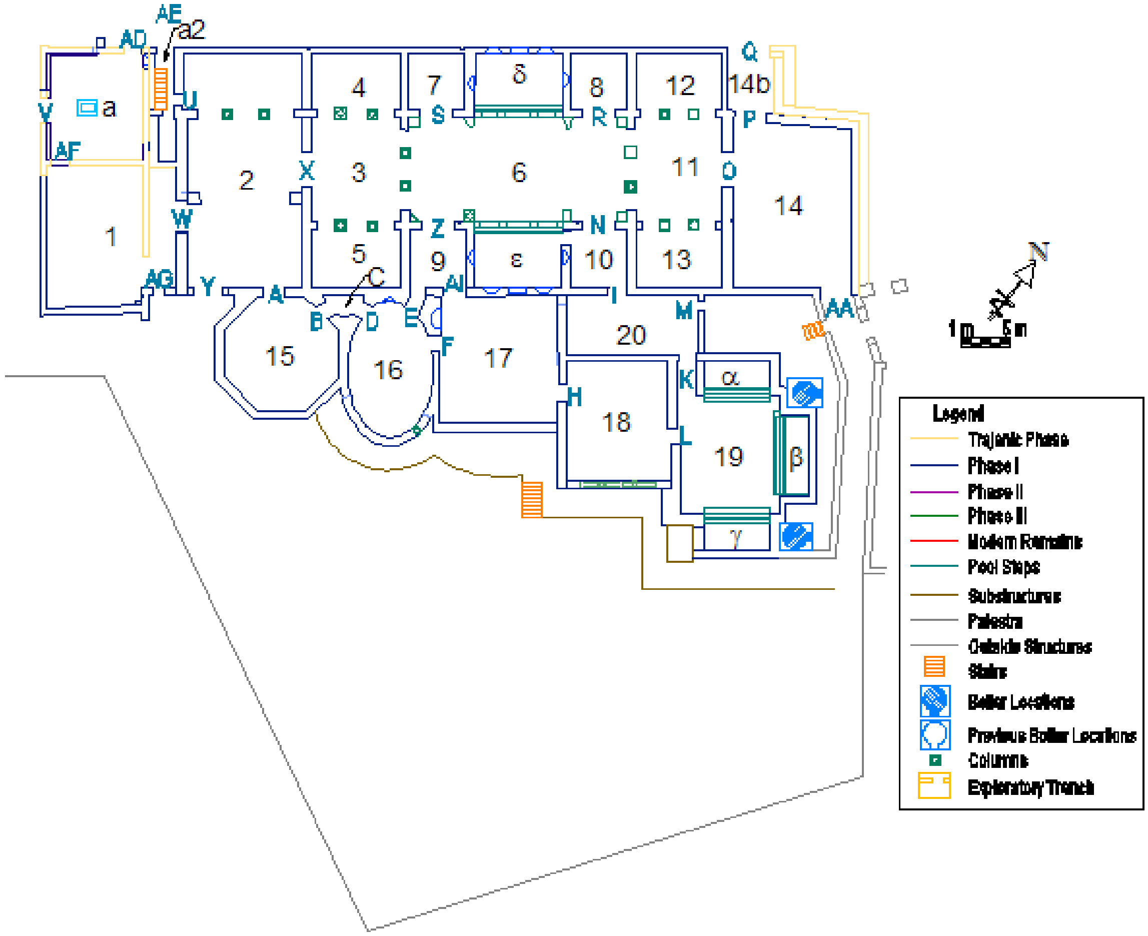

Figure 3-6: Plan showing Phase I of the Terme del Foro, Ostia

Figure 3-7: Inscription on Lead *Fistula* (Cicerchia and Marinucci 1992, fig. 151)

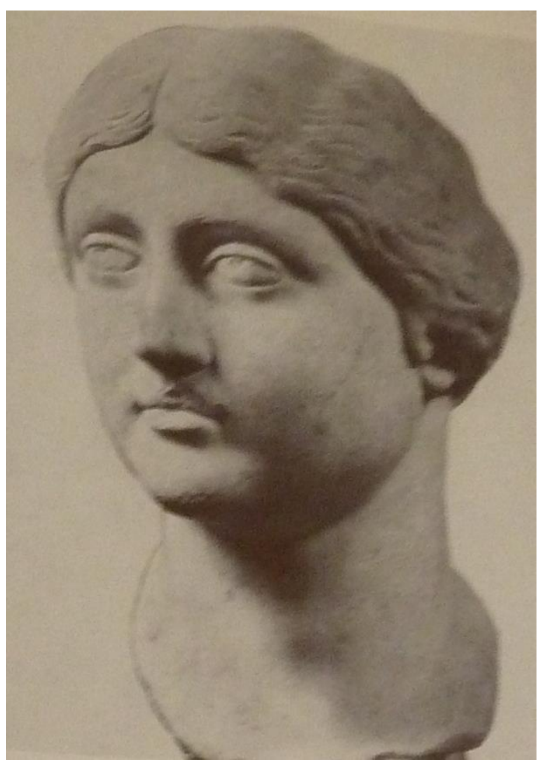

Figure 3-8: Statue of "Domitia Lucilla" (Calza 1977, Tav. IX)

Figure 3-9: Piazzale delle Corporazioni, Ostia

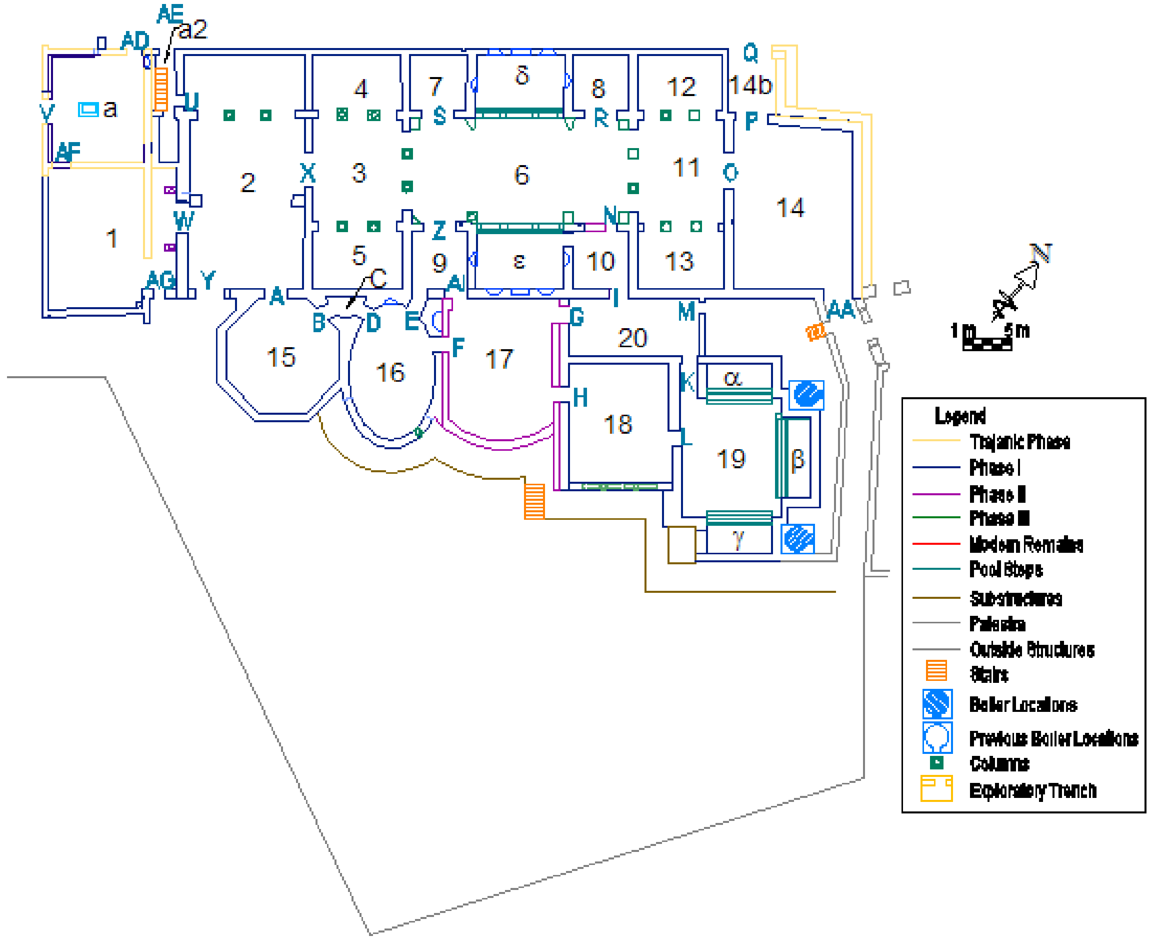

Figure 3-10: Plan showing Phase II of the Terme del Foro, Ostia

Figure 3-11: View Looking West in Room 17 showing Fortifying Pilaster and Door F

Figure 3-12: View Looking South in Room 17

Figure 3-13: View Looking East in Room 17

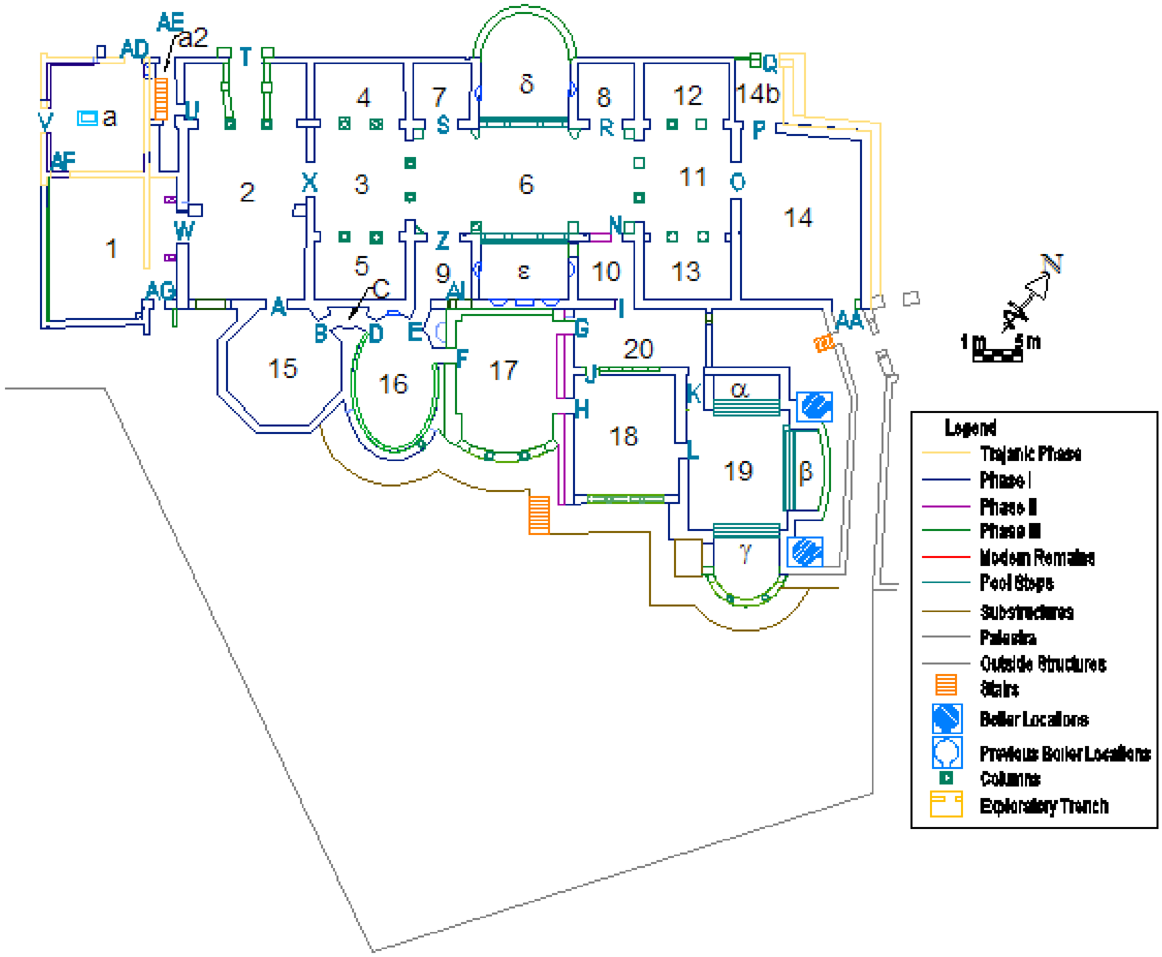

Figure 3-14: Plan showing Phase IIIa of the Terme del Foro, Ostia

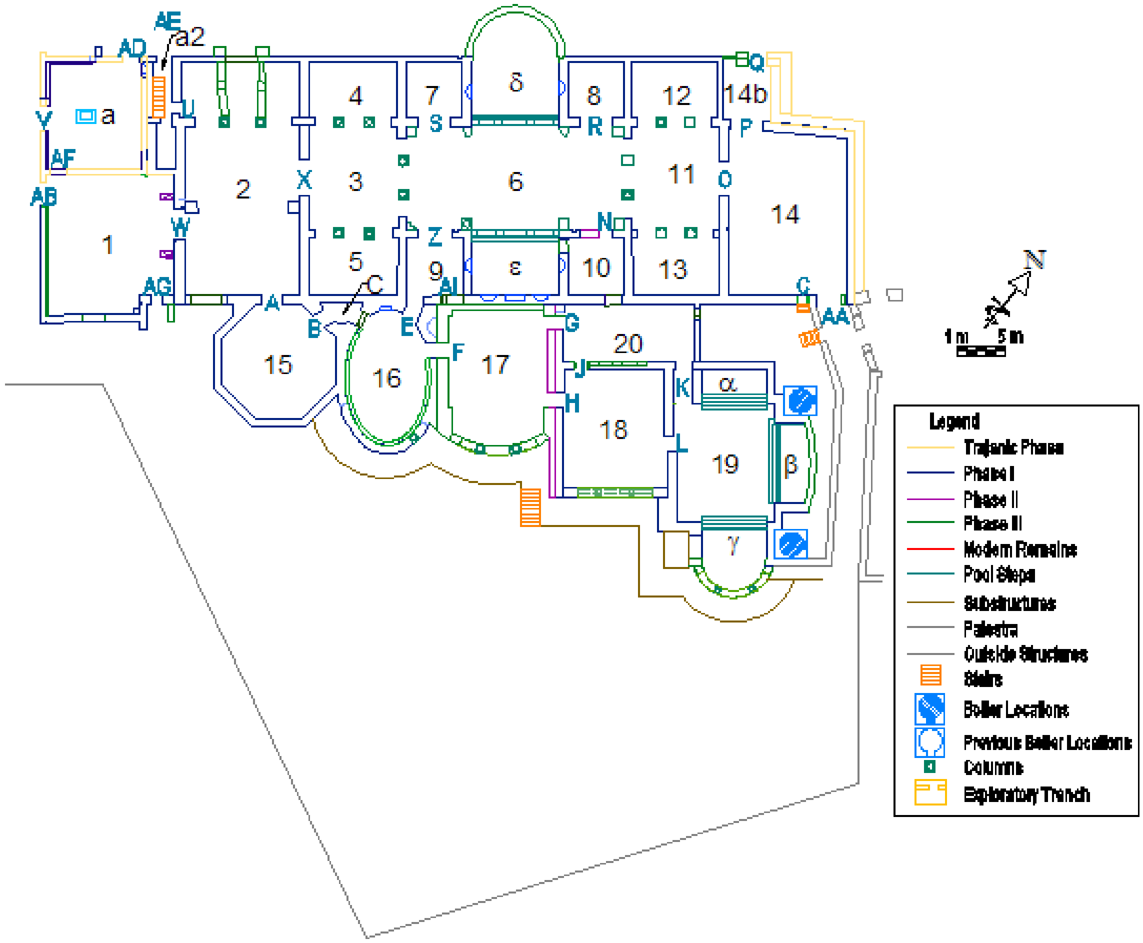

Figure 3-15: Plan showing Phase IIId of the Terme del Foro, Ostia

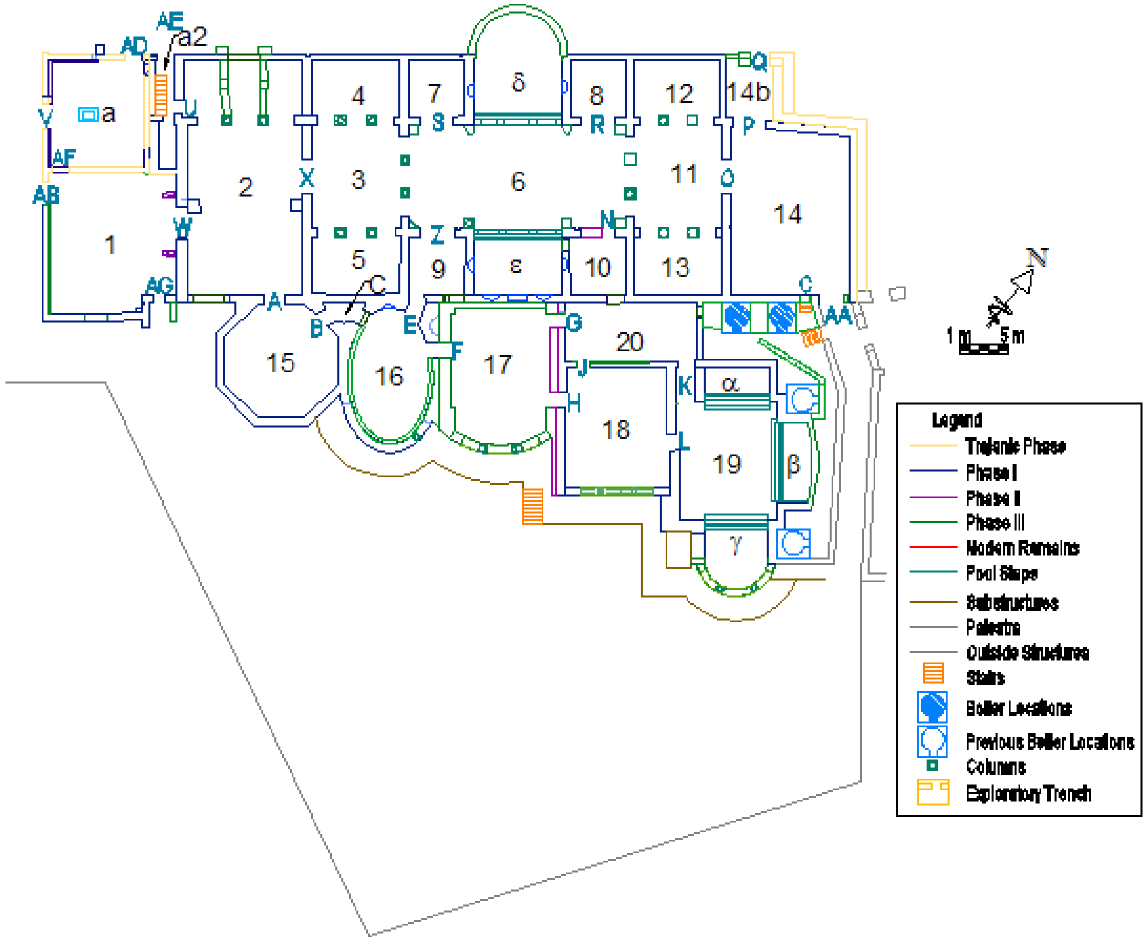

Figure 3-16: Plan showing Phase IIIe of the Terme del Foro, Ostia

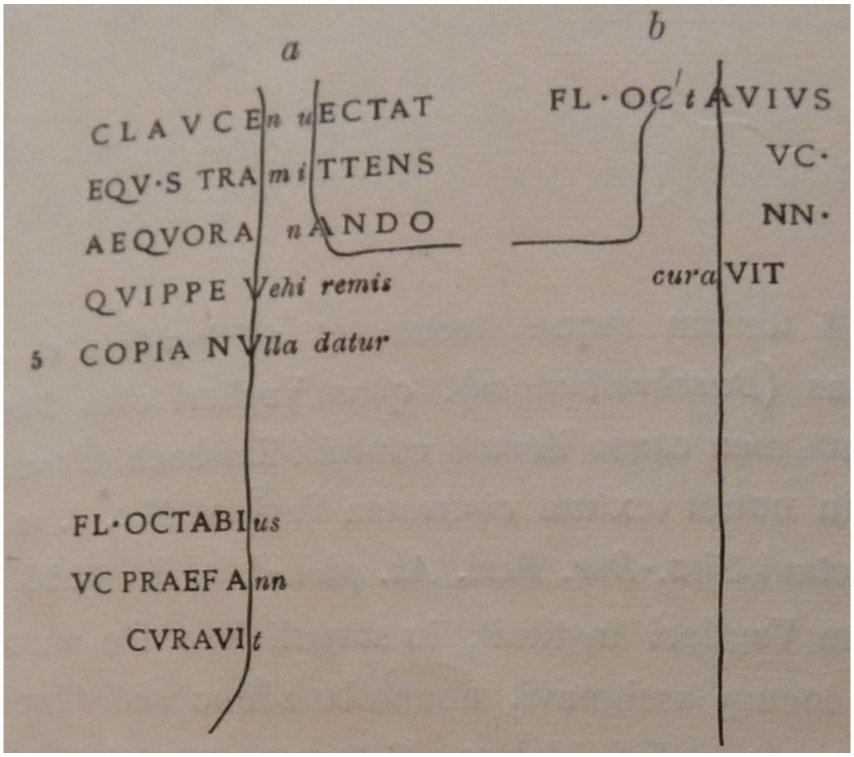

Figure 3-17: Inscription *CIL* VI 29769; XIV 4714

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Figure 3-21: Triangular Latrine on West Side of Terme del Foro, Ostia

Figure 3-22: Latrine on Via della Forica, Ostia

Figure 3-23: Pavement of Room 17 showing Reused Materials

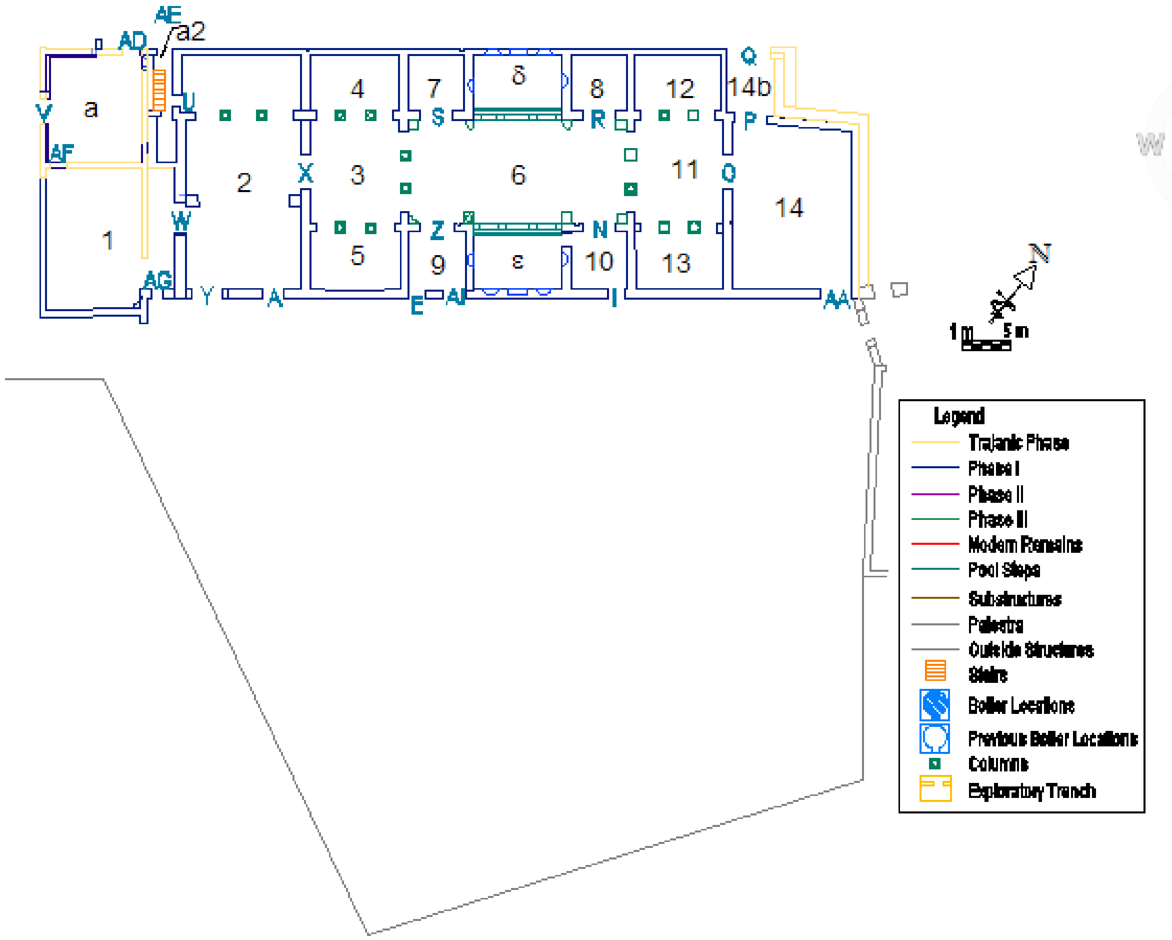

Figure 3-24: Plan showing Possible Phase Pre-Dating Antonine Phase of the Terme del Foro, Ostia

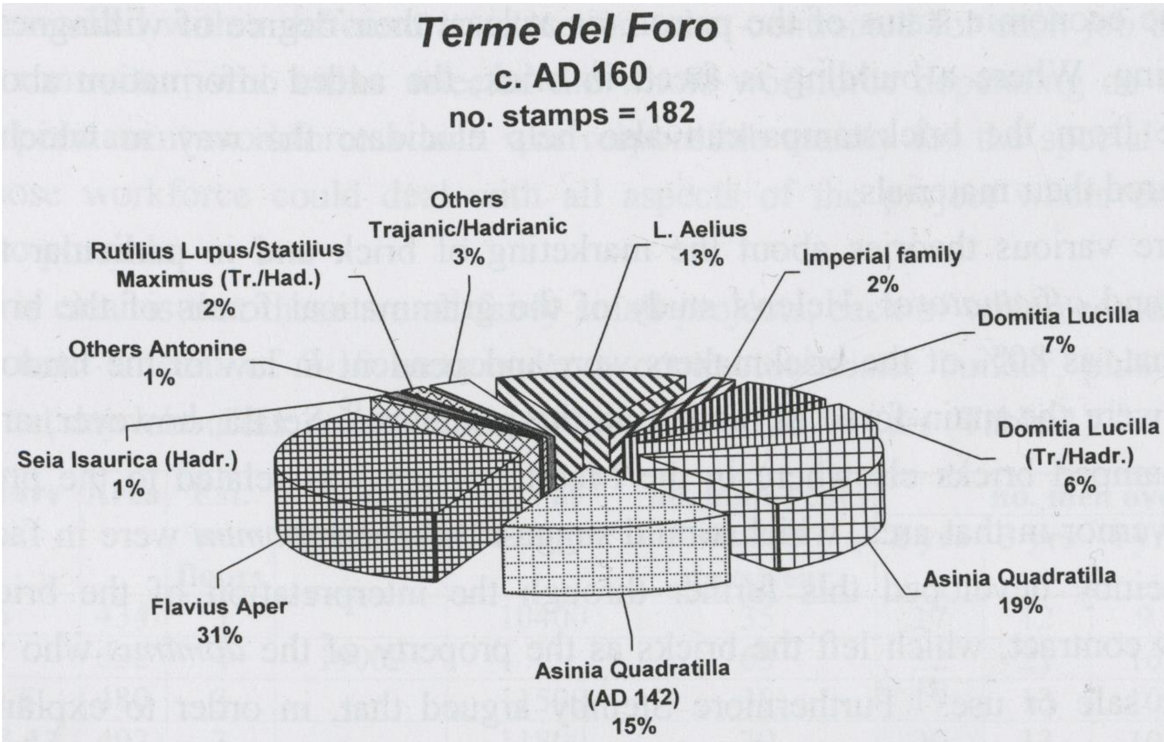

Figure 3-25: Brickstamps (DeLaine 2002, 50 fig. 5)

Figure 3-26:Walls Dividing Northern and Southern Sectors of the Terme del Foro, Ostia

Figure 3-27: Seam in Wall of Room 16 in Terme del Foro, Ostia

Figure 3-28: Door Q Leading into the Terme del Foro, Ostia

Figure 3-29: Door AA Leading into the Service Corridor of the Terme del Foro, Ostia

Figure 3-30: Early Entrance to the Terme del Foro from the Semita dei cippi

Figure 3-31: Staircase Leading to the Substructures below the Terme del Foro near Room 18

Figure 3-32: Staircase Leading to the Substructures below the Terme del Foro near Room 14

Figure 3-33: Oculus in Ceiling of the Substructures below the Terme del Foro

Figure 3-34: Covered Chamber near Room 19 in the Substructures of the Terme del Foro

Figure 3-35: Small Drainage Channel in the Substructures of the Terme del Foro

Figure 3-36: Mosaic Pavement over Vaulting of the Substructures of the Terme del Foro

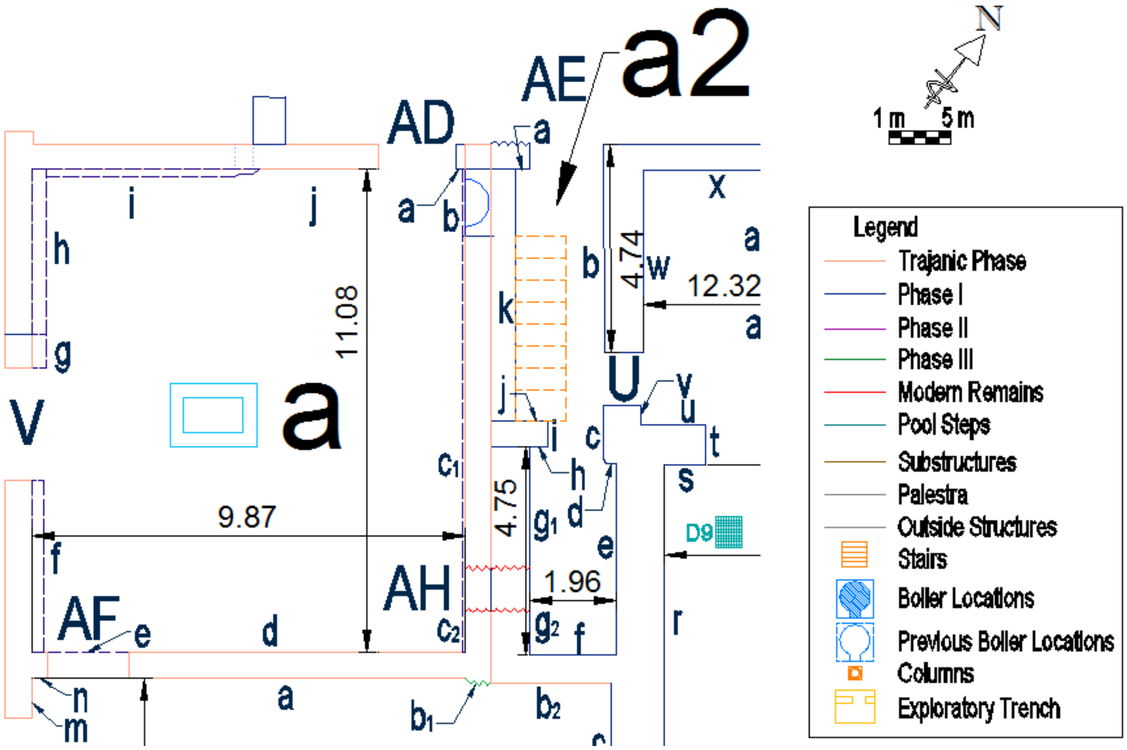

Figure 3-37: Plan of Room a

Figure 3-38: Brickstamp on the Floor of Room a

Figure 3-39: View Looking North in Room a

Figure 3-40: View Looking West in Room a

Figure 3-41: View Looking East in Room a

Figure 3-42: View Looking South in Room a

Figure 3-43: Staircase in Room a2 Possibly Leading to Upper Stories of Room a

Figure 3-44: Double Walls of Wall f in Room a

Figure 3-45:Small Pool or *Impluvium* in Room a

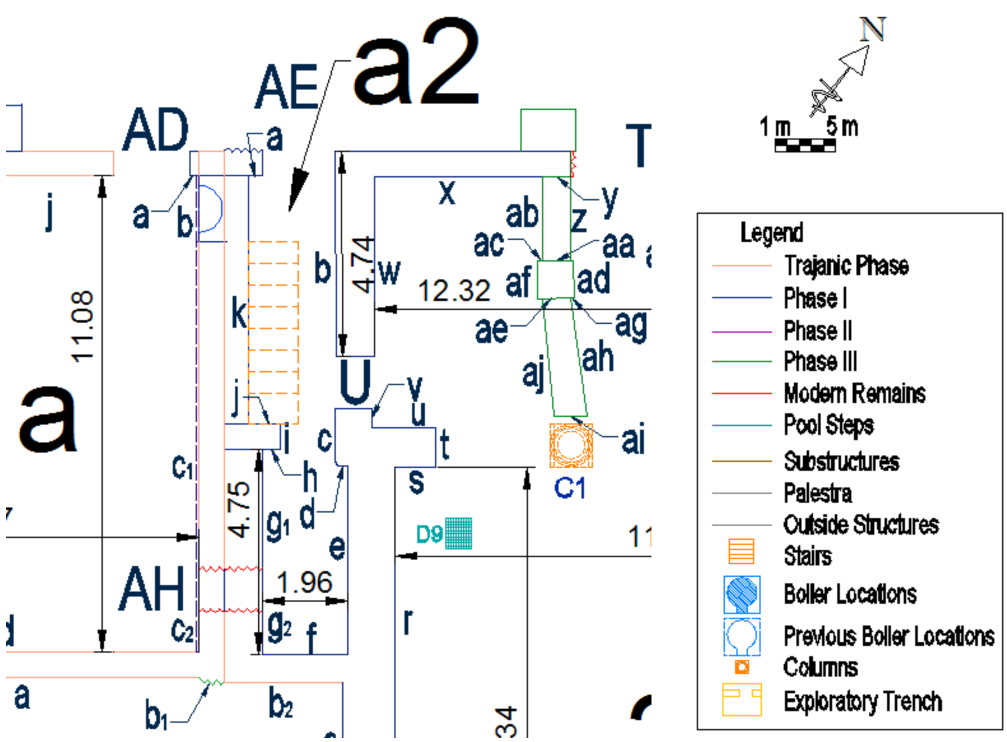

Figure 3-46: Plan of Room a2

Figure 3-47: View Looking North in Room a2

Figure 3-48: View Looking South in Room a2

Figure 3-49: Door AE with Access to Room a2

Figure 3-50: Door U with Access to Room 2

Figure 3-51: Possible Window in Eastern Wall of Room a2

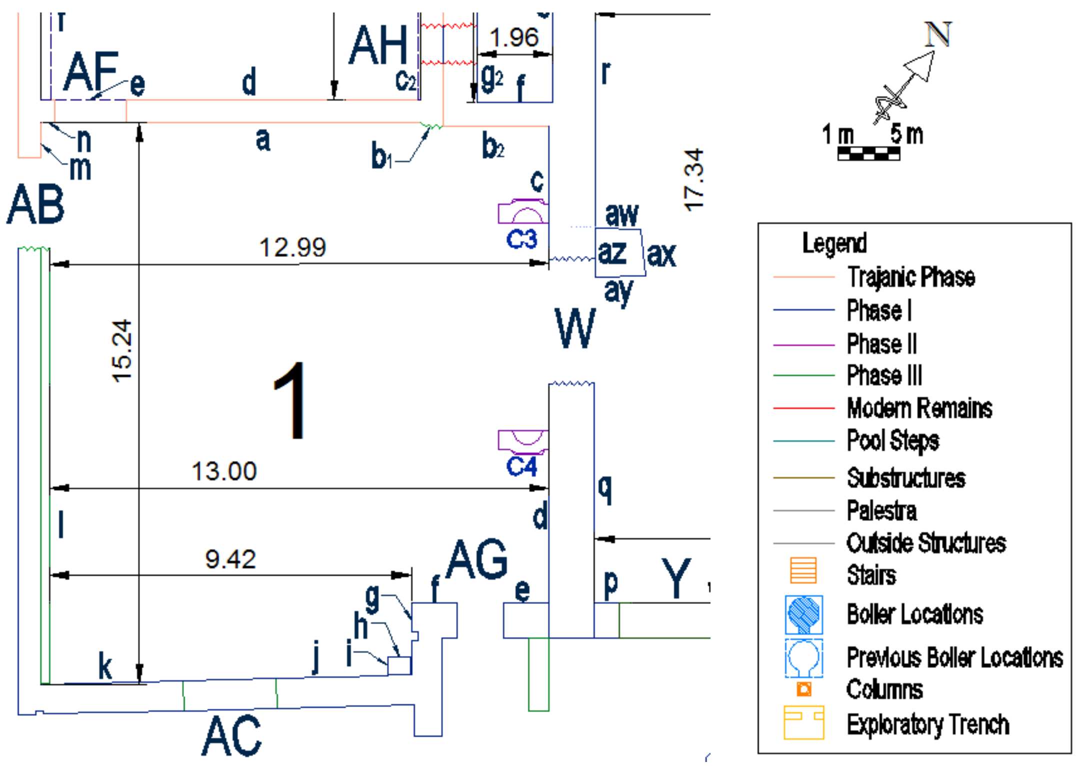

Figure 3-52: Plan of Room 1

Figure 3-53: View Looking West in Room 1

Figure 3-54: View Looking South in Room 1

Figure 3-55: View Looking East in Room 1 towards Room 2

Figure 3-56: Mosaic Pavement of Room 1

Figure 3-57: Mosaic Pavement of Room C

Figure 3-58: View Looking North in Room 1

Figure 3-59: Two Walls forming Wall l in Room 1

Figure 3-60: Outside of outer wall of Wall l showing Construction Seam

Figure 3-61: Feature C3 Located in Room 1 adjacent to Door W

Figure 3-62: Feature C4 Located in Room 1 adjacent to Door W and showing Door AG

Figure 3-63: Detail of Wall l showing Triangular Indentation

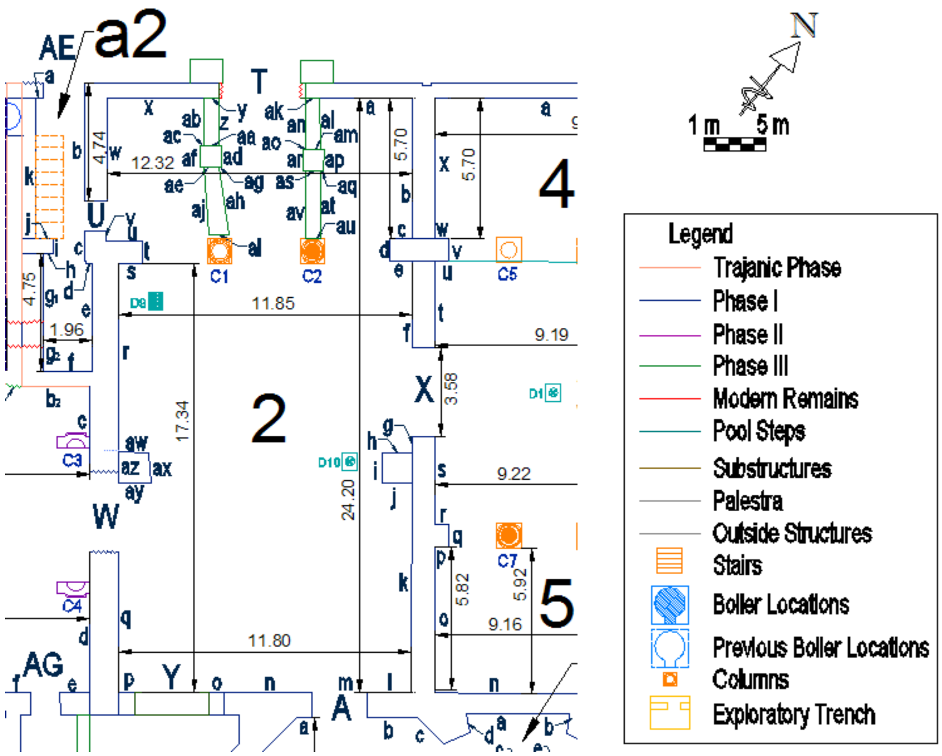

Figure 3-64: Plan of Room 2

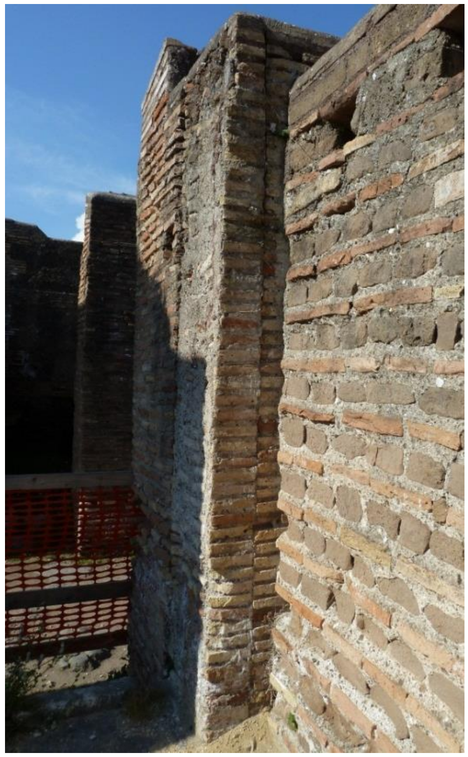

Figure 3-65: Additional Segment of Wall in Door T in Room 2

Figure 3-66: Walls z, ad, and ah in Room 2

Figure 3-67: Walls a, al, ap, as, at, and au and Column C2 in Room 2

Figure 3-68: View Looking North in Room 2

Figure 3-69: Large Drain D9 in Room 2 looking Northwest

Figure 3-70: View Looking West in Room 2

Figure 3-71: Drain D10 in Room 2

Figure 3-72: Drains D6 and D7 in Room 14

Figure 3-73: View Looking East in Room 2 into *Frigidarium*

Figure 3-74: *Fistulae* Slot in Wall k in Room 2

Figure 3-75: ***Fistulae*** **Slot in Wall l in Room 2**

Figure 3-76: View Looking South in Room 2

Figure 3-77: Walls n, o, p and q and Door Y in Room 2

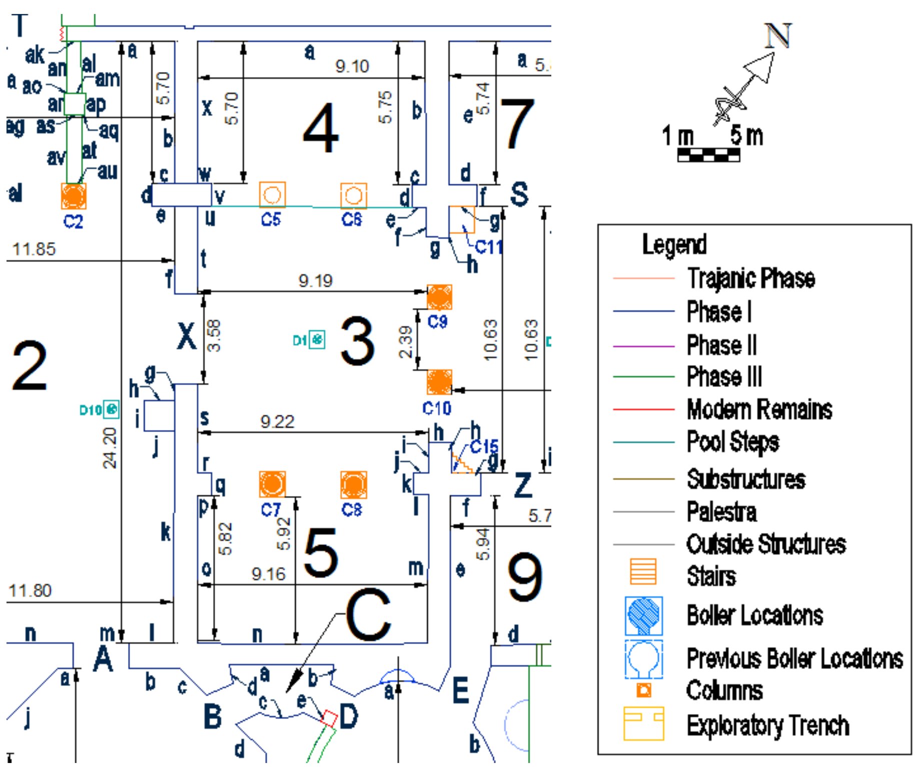

Figure 3-78: Plan of Rooms 3, 4, and 5


Figure 3-79: View Looking Northwest from above Room 9 into Room 3 and Room 4


Figure 3-80: View Looking South from Room 4 into Room 3 and Room 5

Figure 3-81: Drain D1 in Room 3

Figure 3-82: Series of Drains Passing Below *Frigidarium* looking East

Figure 3-83: Possible Window in Room 4

Figure 3-84: Pool δ in Room 6 looking Northwest

Figure 3-85: Pool ε in Room 6 looking South

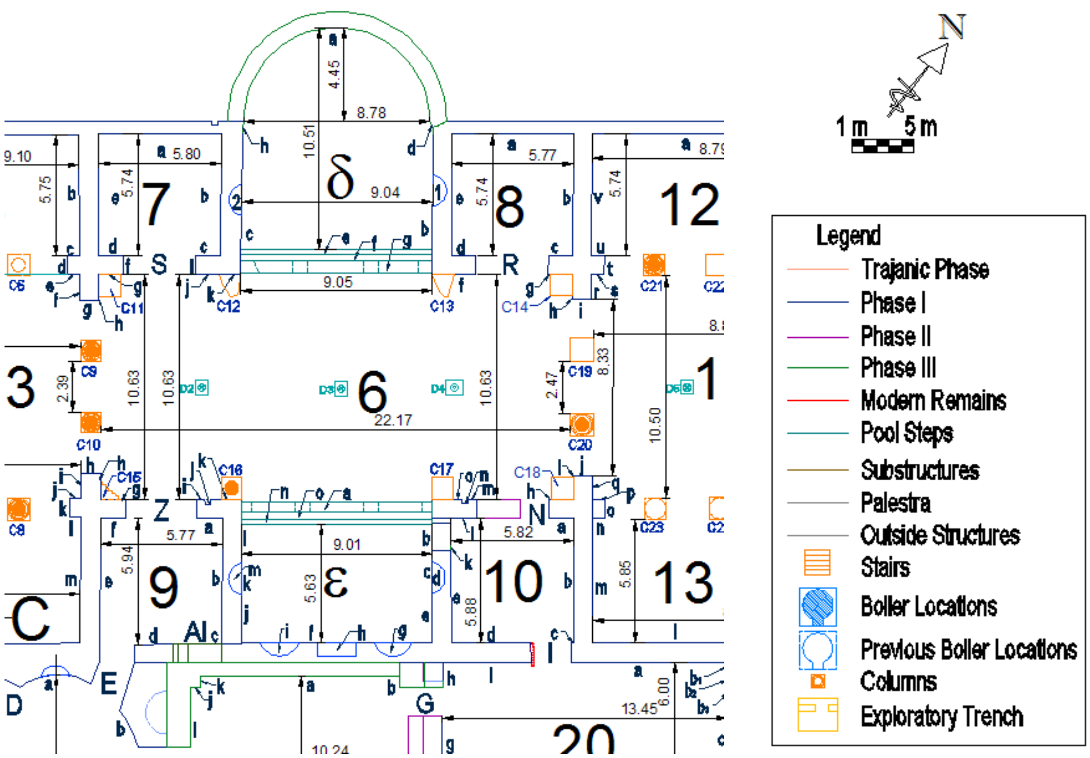

Figure 3-86: Plan of Rooms 6, 7, 8, 9, and 10

Figure 3-87: View Looking Northwest into Room 6

Figure 3-88: Steps of Pool δ in Room 6

Figure 3-89: Steps of Pool ε in Room 6

Figure 3-90: View Looking East in Pool ε in Room 6

Figure 3-91: View Looking West in Pool ε in Room 6

Figure 3-92: View Looking Southeast in Pool δ in Room 6

Figure 3-93: View Looking Southwest in Pool δ in Room 6

Figure 3-94: View Looking North into Room 7

Figure 3-95: View Looking North into Room 8

Figure 3-96: View Looking South into Room 9

Figure 3-97: View Looking South into Room 10

Figure 3-98: Blocked Door AI in Room 9

Figure 3-99: Door N Looking in Room 10 showing *Fistulae* Slots and Columns C17, C18, C20

Figure 3-100: *Tubuli* on Wall b and Opening in Wall a in Room 7

Figure 3-101: Opening in Wall b in Room 7

Figure 3-102: Channel between Room 9 and Rom 17

Figure 3-103: View Looking East in Room 9

Figure 3-104: View Looking West in Room 9

Figure 3-105: View Looking North in Room 10

Figure 3-106: *Fistulae* Slot Outside Room 9 and Column C16

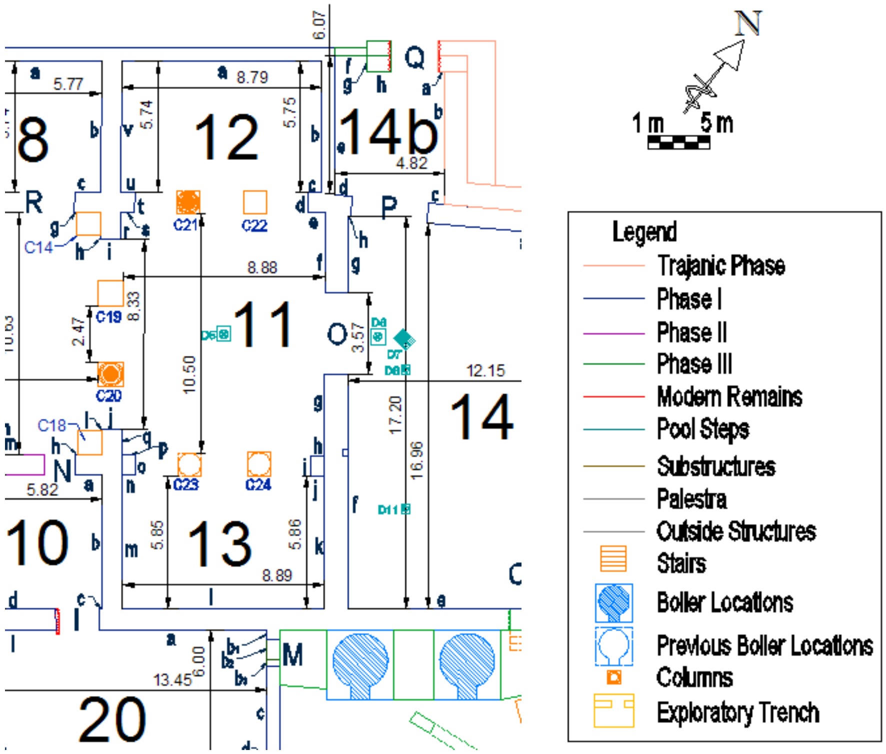

Figure 3-107: Plan of Rooms 11, 12, and 13

Figure 3-108: View Looking North into Room 12 from Room 11

Figure 3-109: View Looking South into Room 13 from Room 11

Figure 3-110: View Looking East into Room 12

Figure 3-111: View Looking East into Room 13

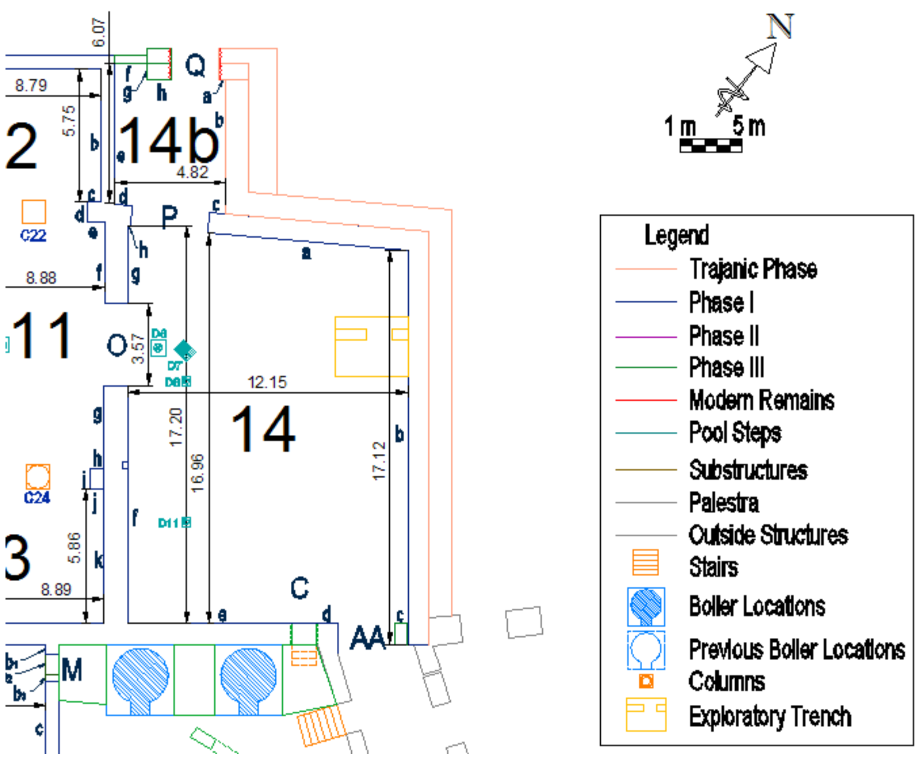

Figure 3-112: Plan of Room 14

Figure 3-113: View Looking South in Room 14 and showing Doors C and AA

Figure 3-114: View Looking North in Room 14 into Room 14b

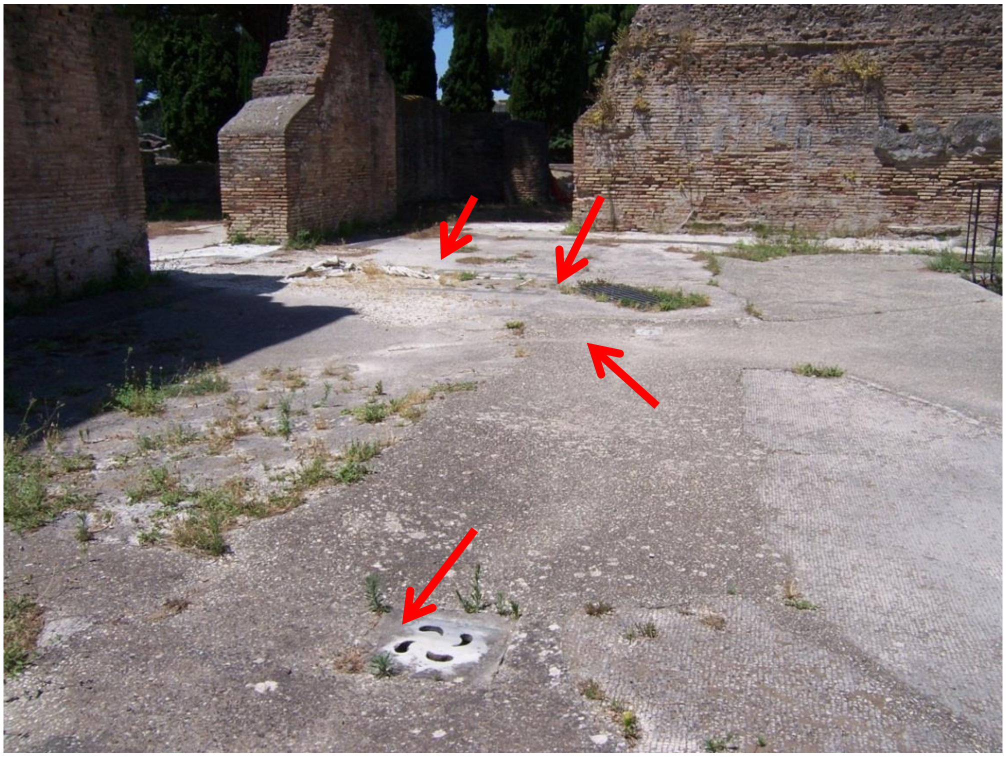
Figure 3-115: Drains D6, D7, D8, and D11 in Room 14 and Door O


Figure 3-116: View Looking East in Room 14 and Exploratory Trench

Figure 3-117: Inside Exploratory Trench Looking West

Figure 3-118: View Looking West in Room 14

Figure 3-119: *Fistulae* Slot in Wall f in Room 14

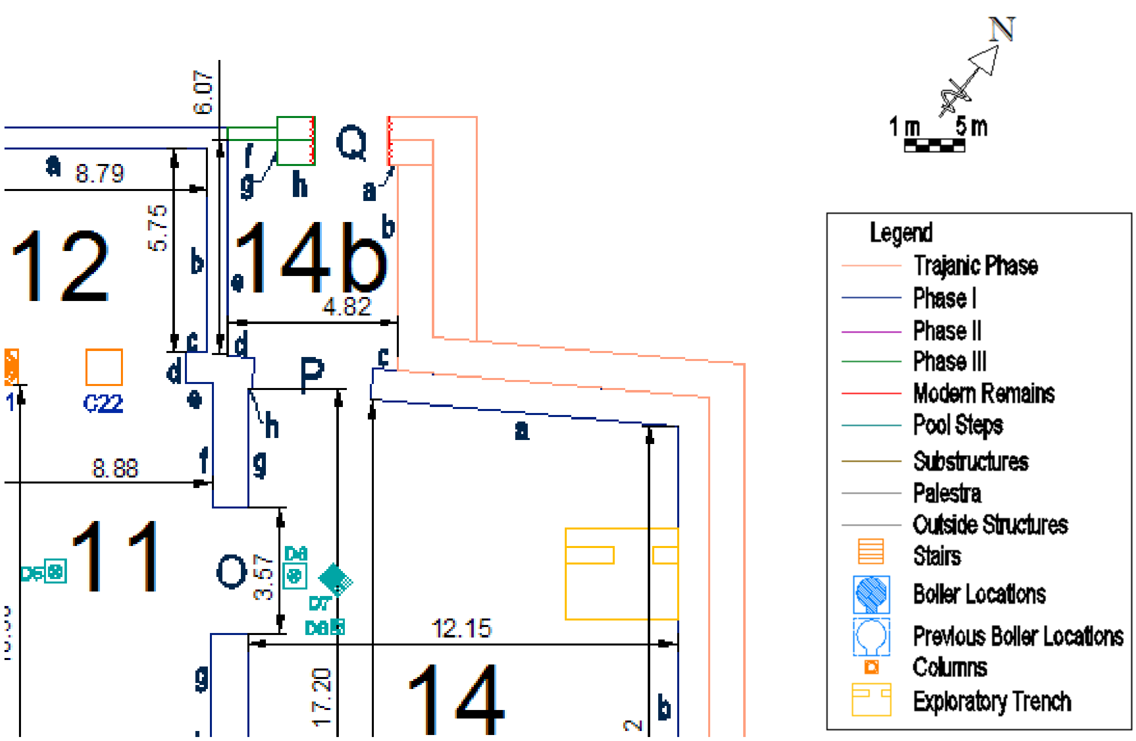

Figure 3-120: Plan of Room 14b

Figure 3-121: View Looking North into Room 14b from Room 14

Figure 3-122: View Looking East in Room 14b towards the Caseggiato della Cisterna

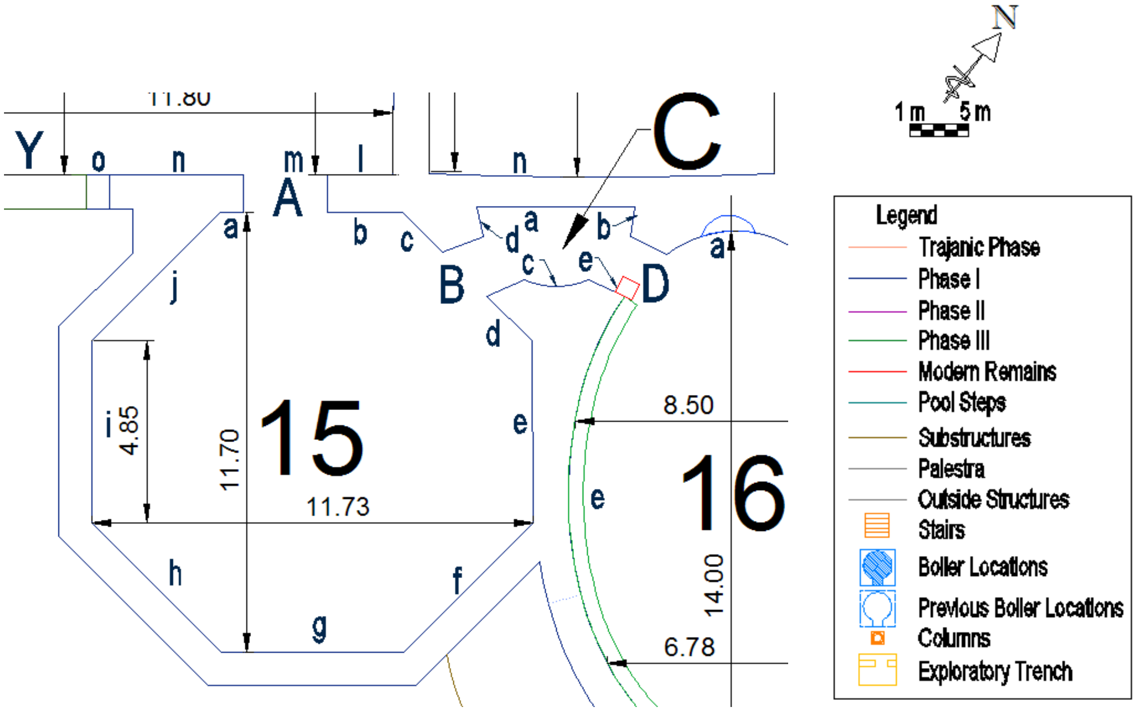

Figure 3-123: Plan of Room 15

Figure 3-124: View Looking Northwest into Room 15 showing Door A

Figure 3-125: View Looking Northeast in Room 15 showing Door B and Room C

Figure 3-126: Furnace Opening for Room 15 in Substructures

Figure 3-127: View Looking Southeast showing Window Evidence in Walls e and f in Room 15

Figure 3-128: View Looking Southwest showing Walls h, i, and j and Window Evidence in Room 15

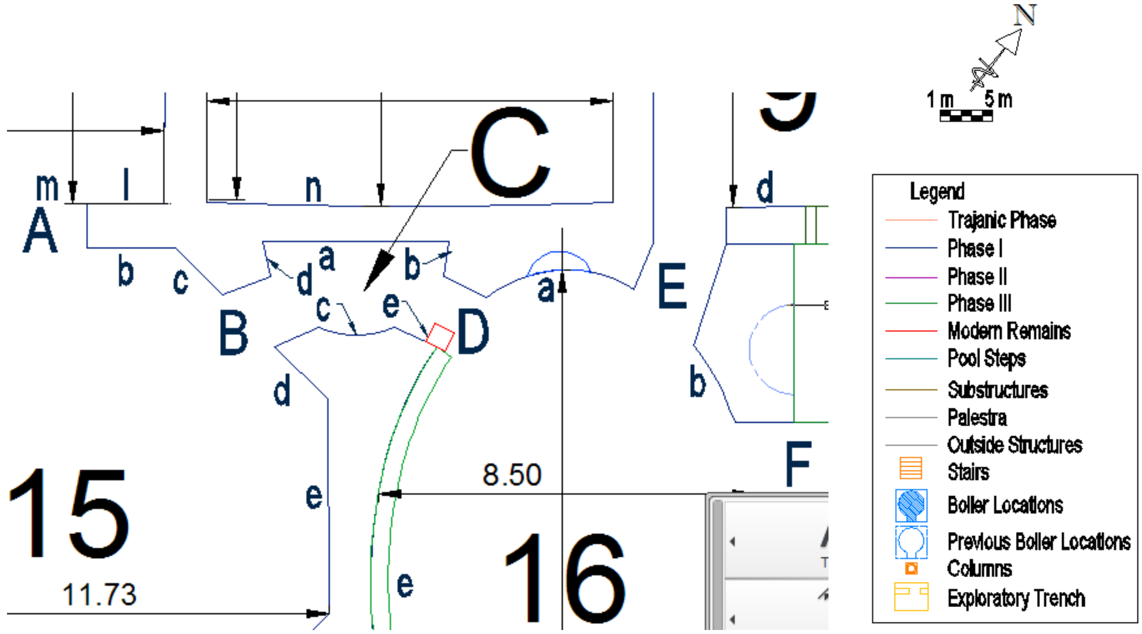

Figure 3-129: Plan of Room C

Figure 3-130: View Looking Northeast into Room C from Room 15

Figure 3-131: View Looking Southeast in Room C into Room 16

Figure 3-132: View Looking Southeast at Opening in Ceiling in Room C

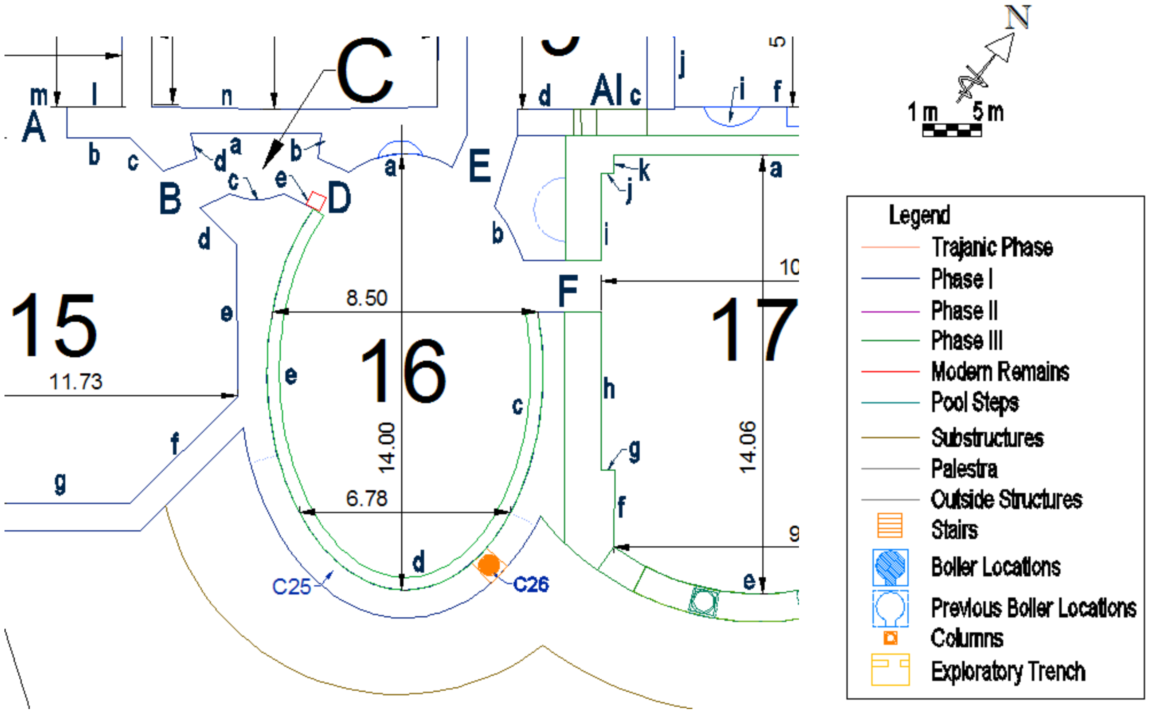

Figure 3-133: Plan of Room 16

Figure 3-134: View Looking Southwest into Room 16 showing Columns C25 and C26, and Bench

Figure 3-135: Furnace Opening with Visible Hypocaust Pillars for Room 16 in Substructures

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Figure 3-136: View Looking Northwest in Room 16 showing Niche and Doors C and E


Figure 3-137: View Looking West in Room 16 showing Mosaic Pavement and Bench


Figure 3-138: View Looking Southeast in Room 16 showing Bench and *Tubuli* and Door F

Figure 3-139: Excavation Photo showing Room 16 (Cicerchia and Marinucci 1992, fig. 41)

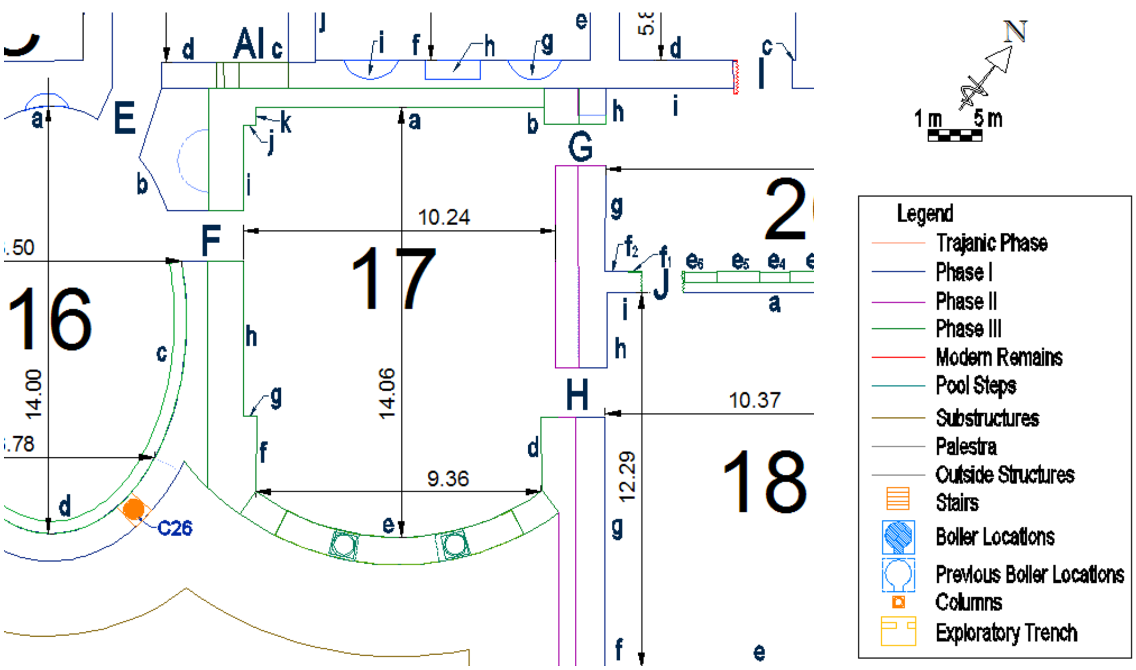

Figure 3-140: Plan of Room 17


Figure 3-141: View Looking North in Room 17 showing Wall a and Door G


Figure 3-142: View Looking South in Room 17 showing Columns C27 and C28, and Windows

Figure 3-143: Furnace Opening for Room 17 on Southwest Side in Substructures

Figure 3-144: Furnace Opening for Room 17 on South Side in Substructures

Figure 3-145: View Looking Northeast in Room 17 showing Double Walls and Door H

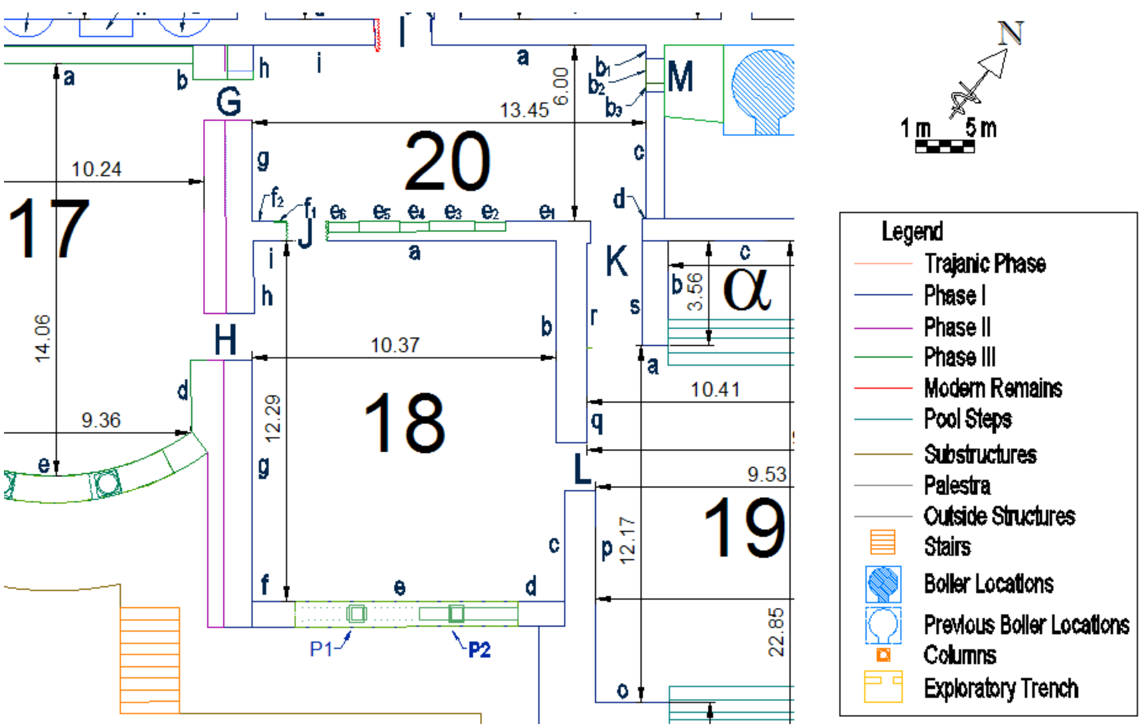

Figure 3-146: Plan of Room 18

Figure 3-147: View Looking North in Room 18 and showing Door J and Walls a and b

Figure 3-148: View Looking South in Room 20 and showing Door J and Walls e and f

Figure 3-149: Furnace Opening for Room 18 on West Side in Substructures

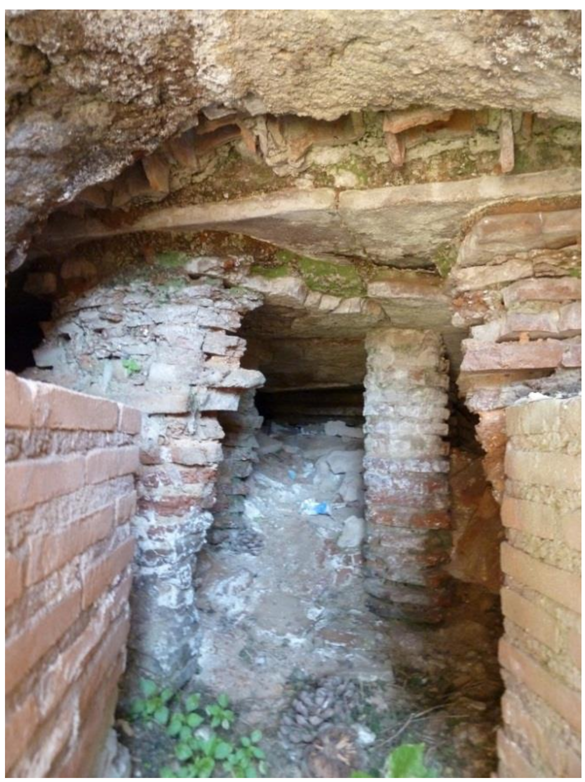

Figure 3-150: Furnace Opening showing Hypocaust for Room 18 on West Side in Substructures

Figure 3-151: Furnace Opening for Room 18 on Central Side in Substructures

Figure 3-152: Furnace Opening for Room 18 on Southwestern Side in Substructures

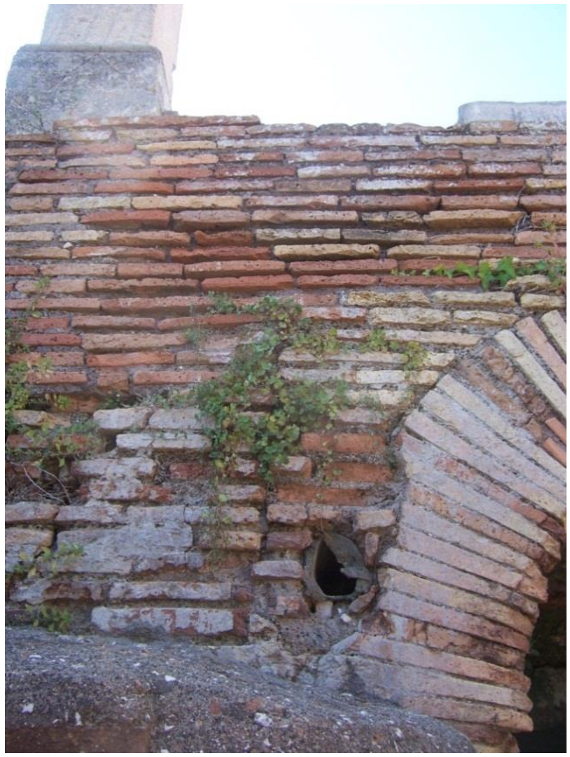

Figure 3-153: Outlet of North-South Running Lead Pipe below Center of Room 18

Figure 3-154: View Looking South in Room 18 showing Pillars P1 and P2 and Windows

Figure 3-155: View Looking East in Room 18

Figure 3-156: View Looking West in Room 18

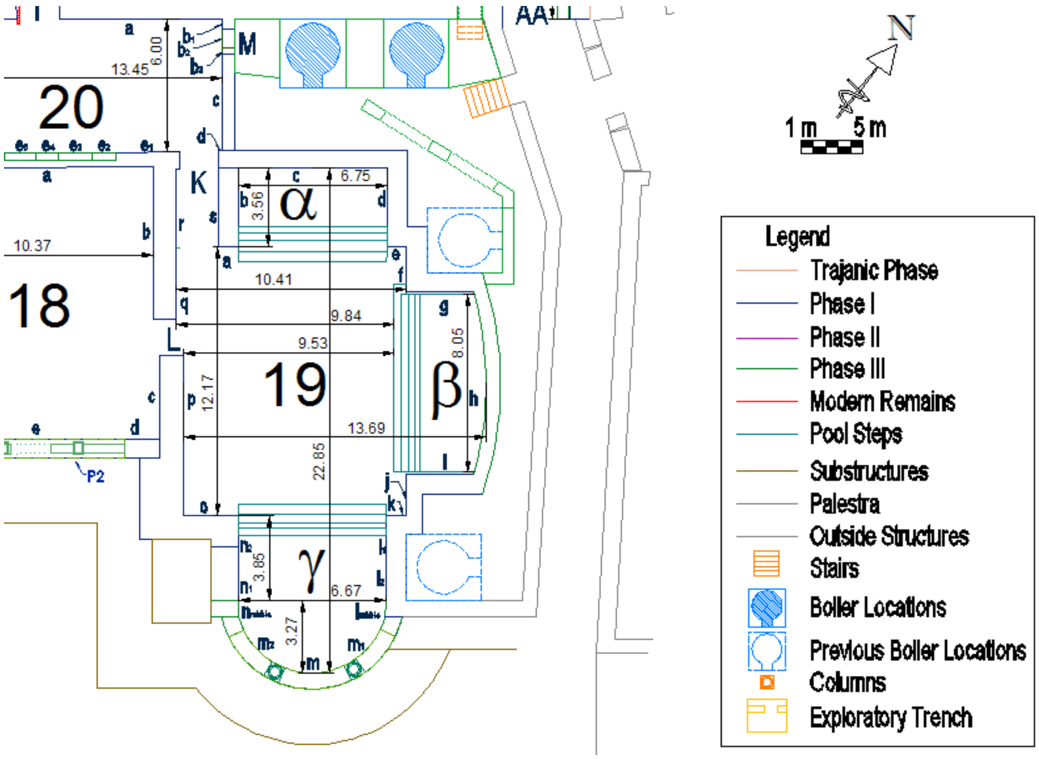

Figure 3-157: Plan of Room 19

Figure 3-158: View Looking North in Room 19 showing Pool α and Door K

Figure 3-159: View Looking East in Room 19 showing Pool β

Figure 3-160: View Looking South in Room 19 showing Pool γ and Columns C29 and C30

Figure 3-161: View Looking South in Pool γ in Room 19 showing *Tubuli* and Pavement

Figure 3-162: Pool γ in Room 19 showing Columns C29 and C30, and Opening to Furnace Below

Figure 3-163: Furnace Opening for Pool α in Room 19

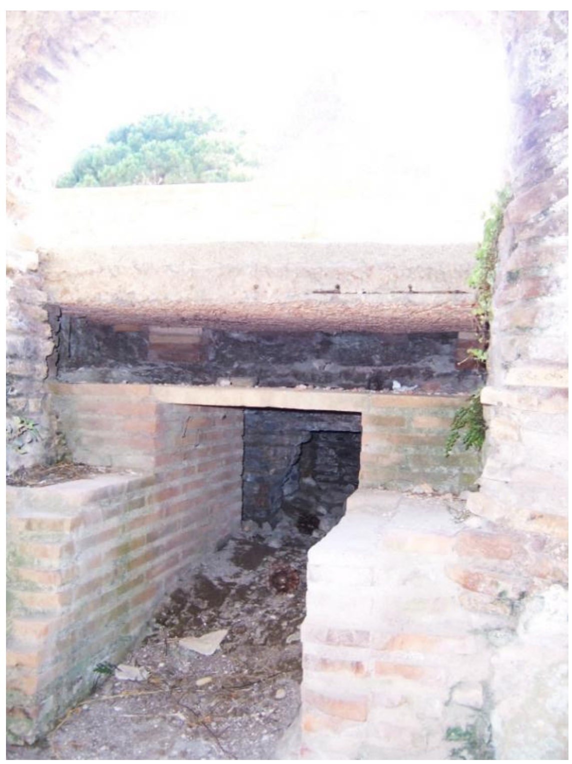

Figure 3-164: Furnace Opening for Pool β in Room 19 showing Damage to Floor and Walls

Figure 3-165: Furnace Opening for Room 19 in Southwestern Side in Substructures

Figure 3-166: Furnace Opening for Room 19 East of Pool γ in Substructures

Figure 3-167: Furnace Opening for Room 19 in Southeastern Side in Substructures

Figure 3-168: Furnace Opening for Room 19 by Pool β in Substructures

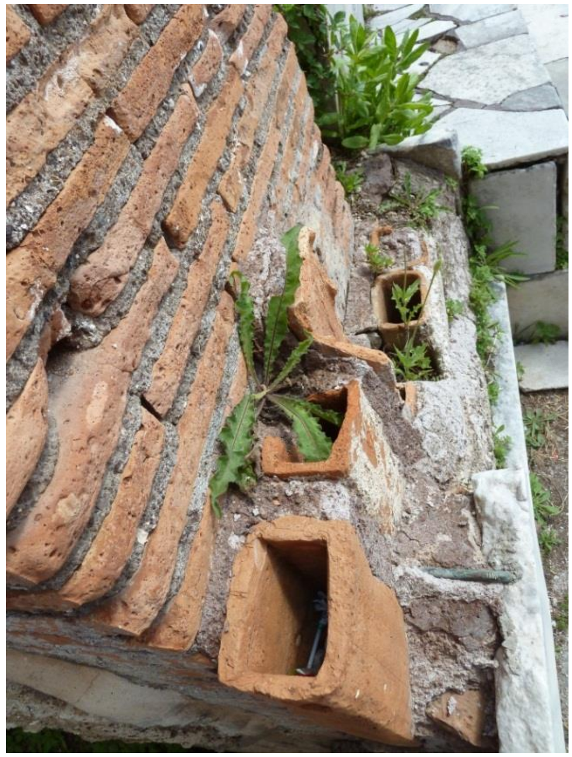

Figure 3-169: *Tubuli* with Dimensions 0.12 by 0.10 meters on Wall a in Room 19

Figure 3-170: *Tubuli* with Dimensions 0.13 by 0.10 meters on Wall d in Room 19

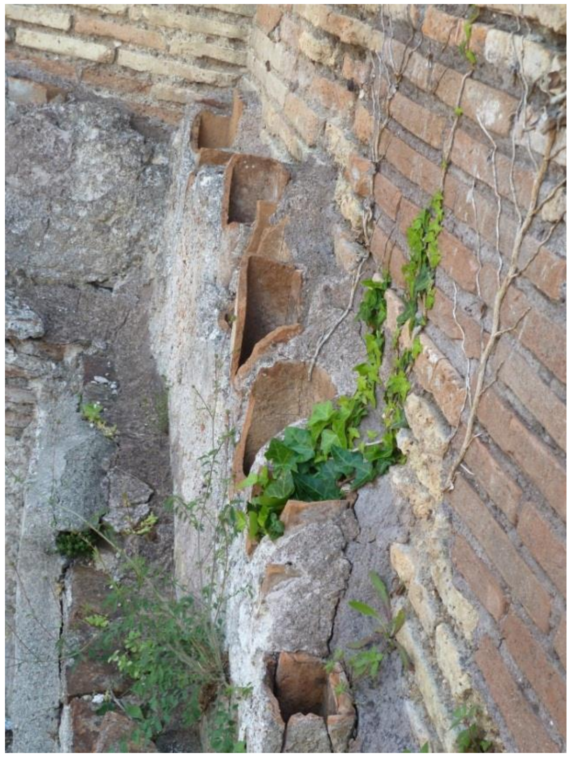

Figure 3-171: *Tubuli* with Dimensions 0.12 by 0.08 meters on Wall i in Room 19

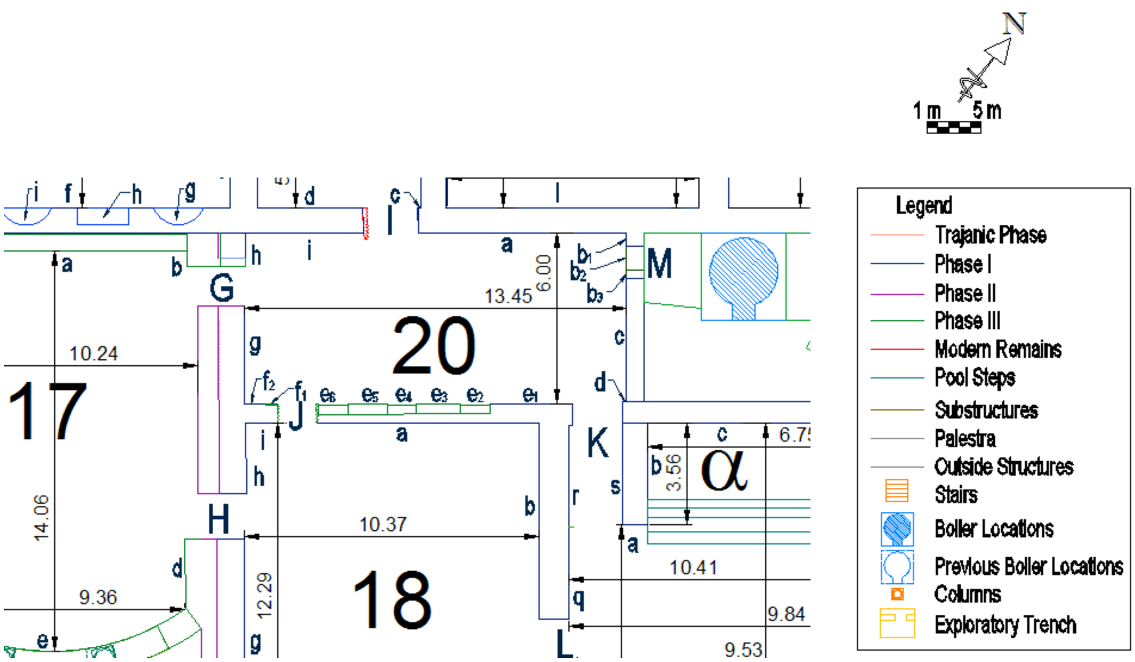

Figure 3-172: Plan of Room 20

Figure 3-173: View Looking Northeast in Room 20

Figure 3-174: View Looking East in Room 20

Figure 3-175: View Looking West in Room 20

Figure 3-176: *Tubuli* with Dimensions 0.14 by 0.08 meters on Wall a in Room 20

Figure 3-177: *Tubuli* with Dimensions 0.12 by 0.09 meters on Wall e in Room 20

Figure 3-178: *Tubuli* on Wall f in Room 20

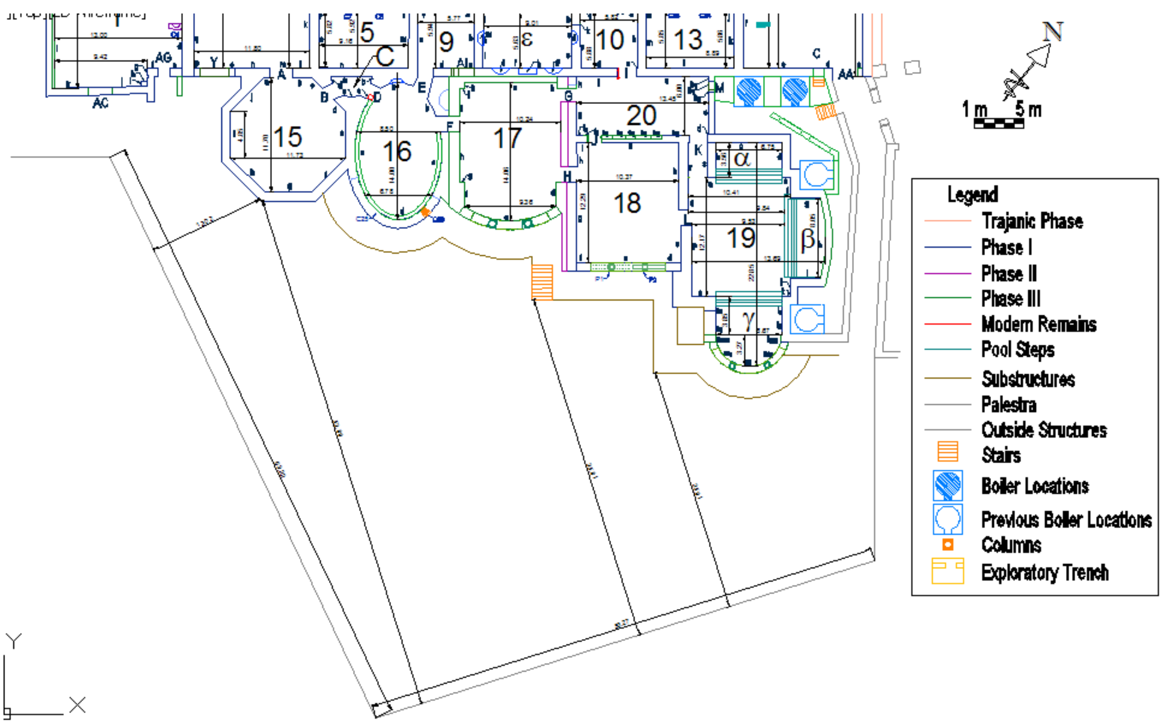

Figure 3-179: Plan of *Palestra*`

Figure 3-180: *Palestra* Looking Northwest

Figure 3-181: *Palestra* Looking West

Figure 3-182: View Looking South from *Palestra* into Headquarters of a Corporation

Figure 3-183: View Looking East into Headquarters of a Corporation showing Spiral Columns

Figure 3-184: Pillars P1 and P2 in Room 18 showing Possible Evidence for Window Frames

Figure 3-185: Excavation Photo showing only One Pillar in Room 18 (Johnson 1932, fig. 4)

Figure 3-186: Column C30 in Room 19 showing Traces of Mortar

Figure 4-1: Floor Makeup of Room 18

Figure 4-2: Marble Facing behind Bench in Room 16

Figure 4-3: Marble Facing on Surface of Bench in Room 16

Figure 4-4: View Looking North in Room 16 showing Niche, Wall a and Wall b

Figure 4-5: Inner Step of Pool α in Room 19

Figure 4-6: Inner Step of Pool β in Room 19

Figure 4-7: Inner Steop of Pool γ in Room 19

Figure 4-8: Wall Layers in Room 17

Figure 4-9: View Looking Southeast in Room 20 showing Intermittent Rows of *Tubuli*

Figure 4-10: Wall c showing Extra Layer of Brick Wall in Pool α in Room 19

Figure 4-11: Wall c and Niche n2 showing Extra Layer of Brick Wall in Pool δ in Room 6

Figure 4-12: Walls m2, nrubble, n1, and n2 in Pool γ in Room 19

Figure 4-13: Extra Brick Walls in Pool of the Terme di Nettuno, Ostia

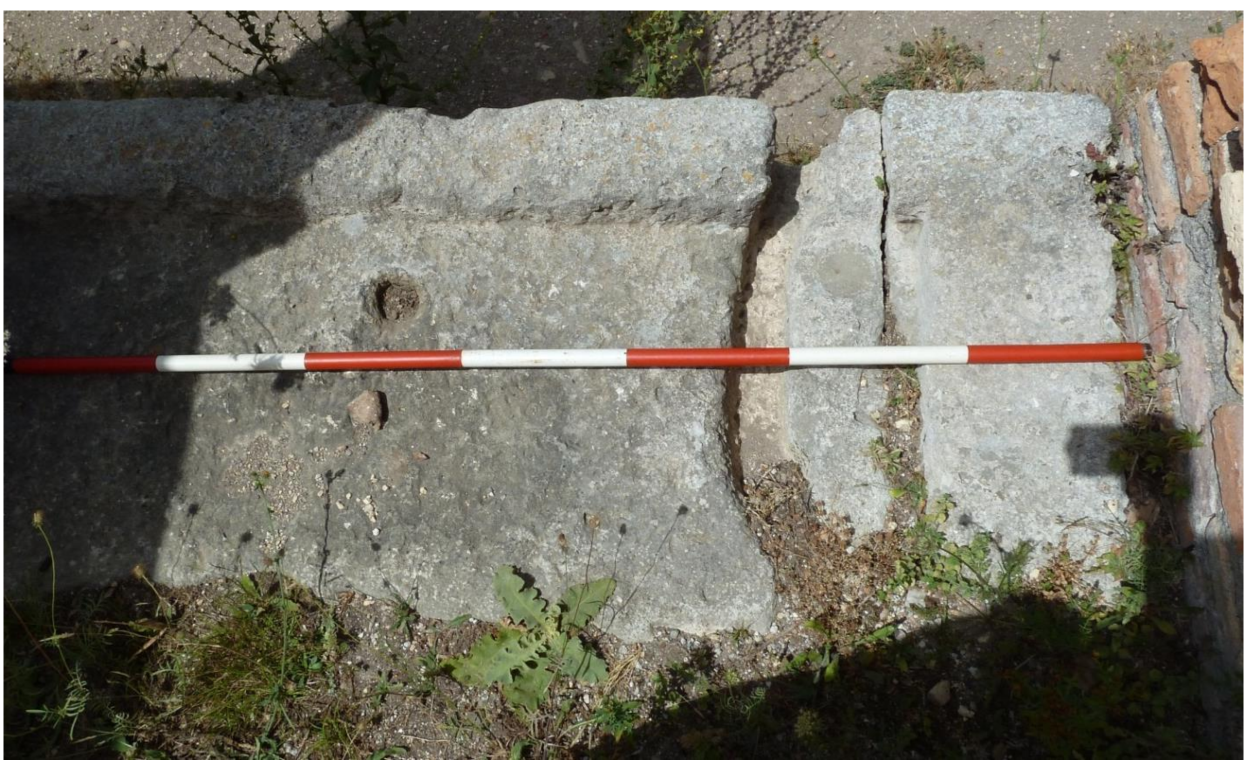

Figure 4-14: Threshold of Door AE showing Possible Evidence of Movable Door

Figure 4-15: Threshold of Door AC Looking South from Room 1 to Outside of Terme del Foro

Figure 4-16: Threshold of Door O showing Fragmentary/Dissimilar Pavement Composition

Figure 4-17: Door T Looking into Entranceway into Terme del Foro from the via della Forica

Figure 4-18: Door AC Looking South from Room 1 to Outside of the Terme del Foro

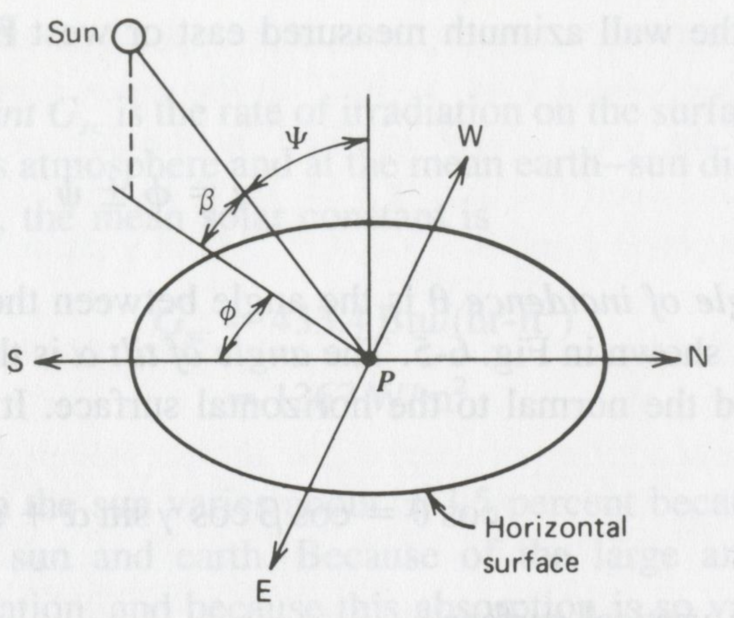

Figure 6-4 The solar altitude β, zenith angle Ψ, and azimuth angle ϕ.

Figure 4-19: Solar Altitude (McQuiston and Parker 1994, 193 fig. 6-4)

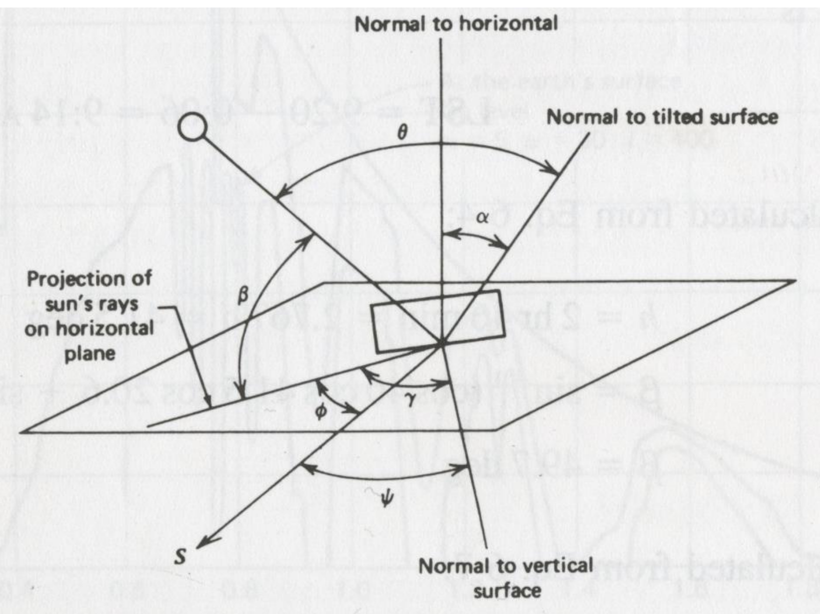

Figure 6-5 Wall solar azimuth γ, wall azimuth ψ, and angle of tilt α for an arbitrary tilted surface.

Figure 4-20: Solar Azimuth (McQuiston and Parker 1994, 193 fig 6-5)

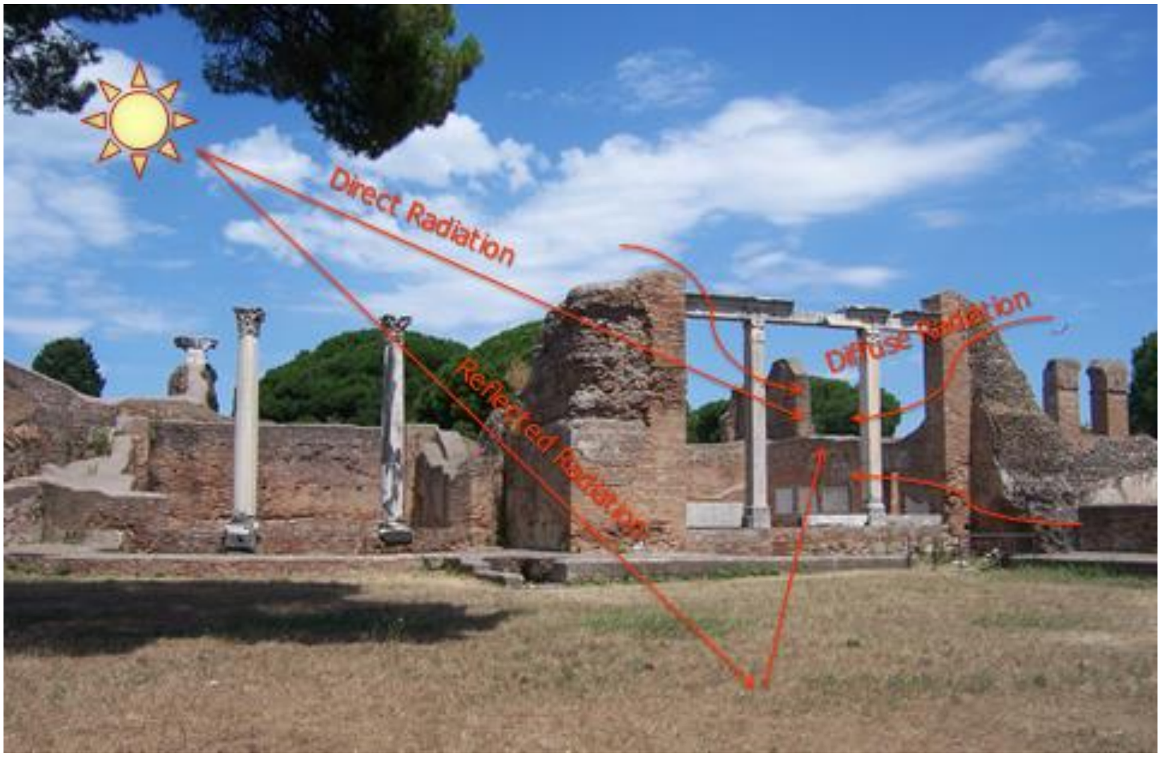

Figure 4-21: Diagram showing Rooms 17 and 18 with Direct, Diffuse, and Reflected Solar Radiation

Figure 4-22: Ceiling Fragment from the Terme dei Sette Sapienti, Ostia

Figure 4-23: Hypocaust in *Hamam* in Ioannina, Greece (Kanetaki 2004, 327 fig. 6.1.165)

Figure 4-24: NOVA Bath near Sardis (WGBH Educational Foundation 2000)

Figure 4-25: Decorated Wooden Sandals from Turkish *Hamam* (Kanetaki 2004, 77 fig. 3.47a)

Figure 4-26: “La Grande piscine à Brusa” by Gérôme (Artstor 2013)

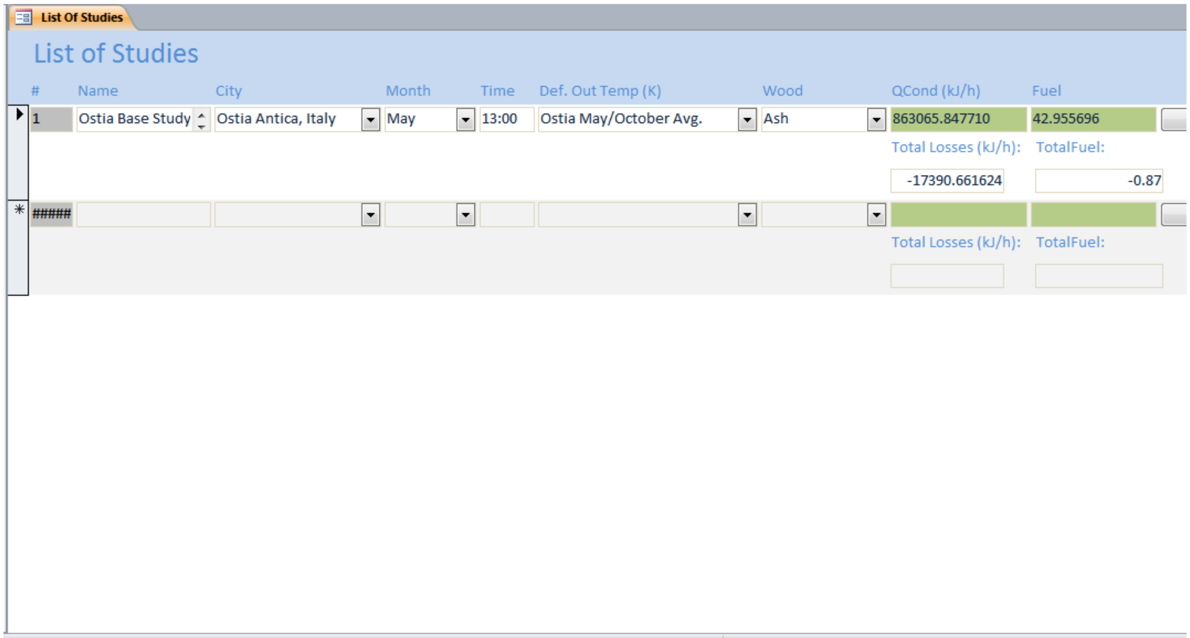

Figure 4-27: Opening Page of Database for Study 1

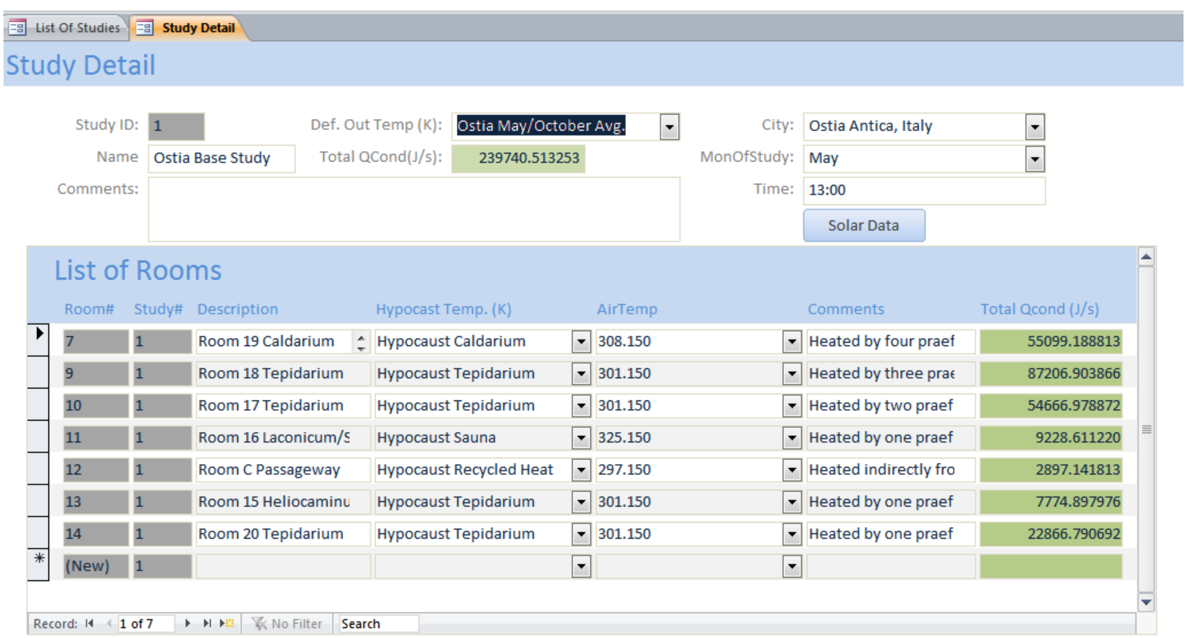

Figure 4-28: Study Detail Page for Study 1

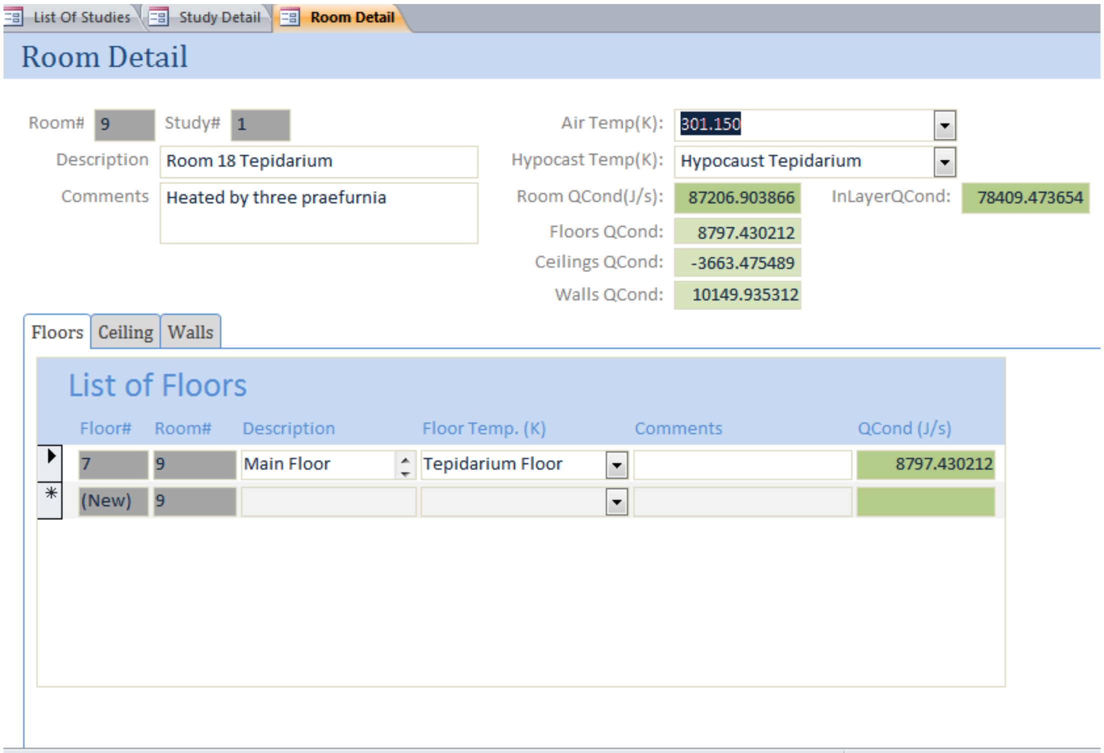

Figure 4-29: Room Detail Page for Room 18 of Study 1

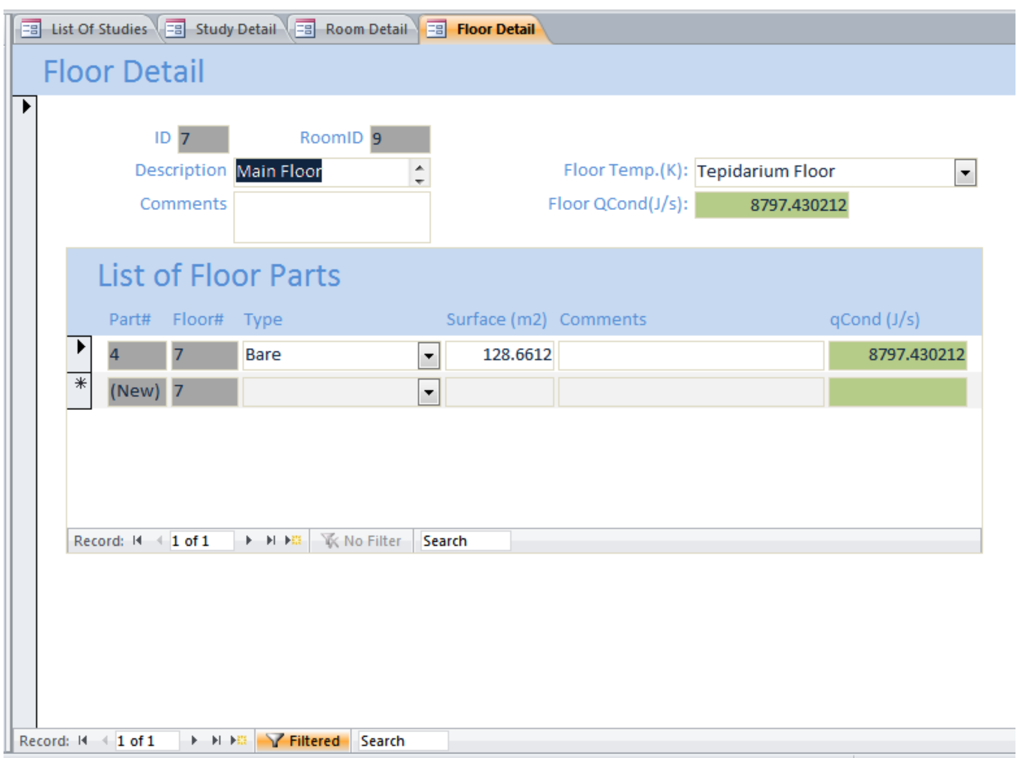

Figure 4-30: Floor Detail Page showing Floors for Room 18 of Study 1

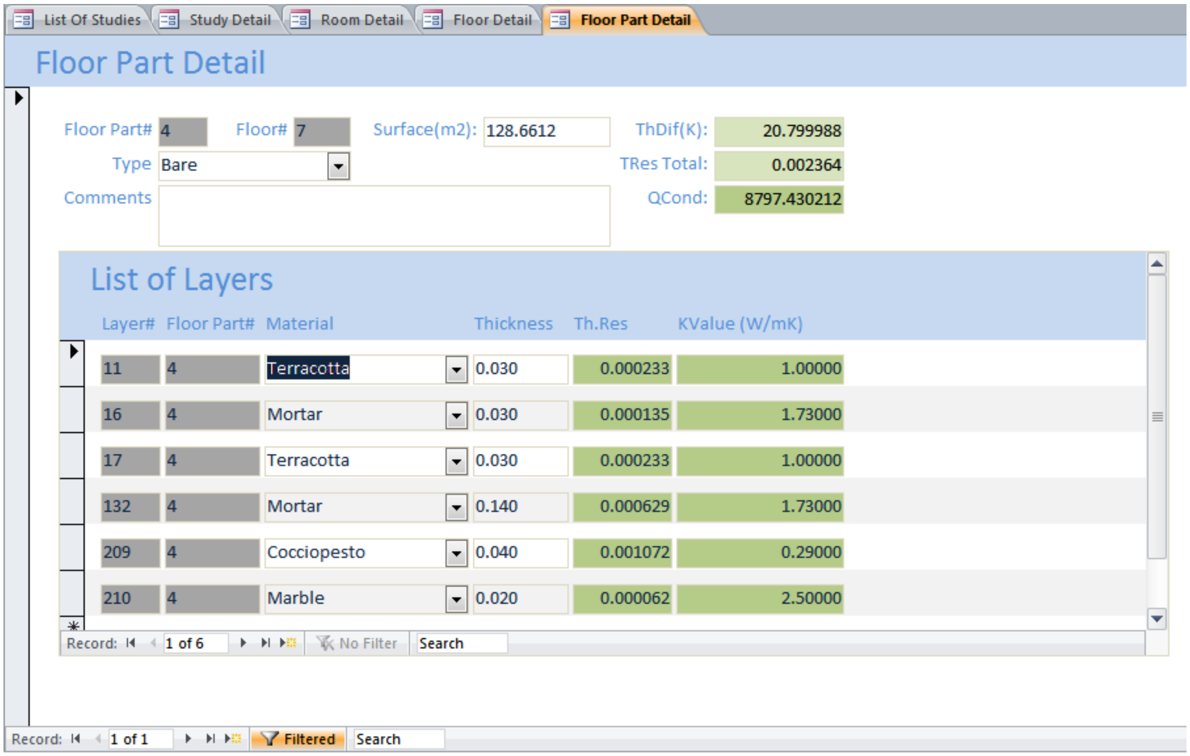

Figure 4-31: Floor Layer Detail Page showing Floor Parts for Room 18 of Study 1

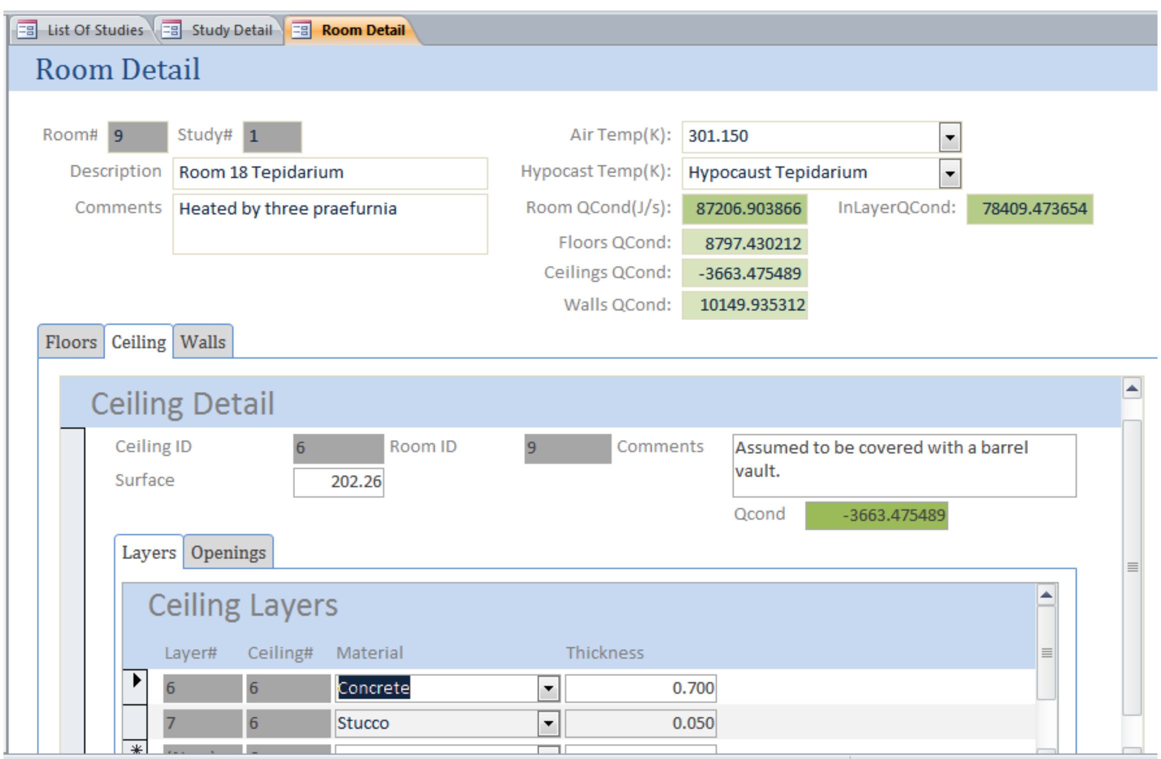

Figure 4-32: Ceiling Detail Page for Room 18 of Study 1

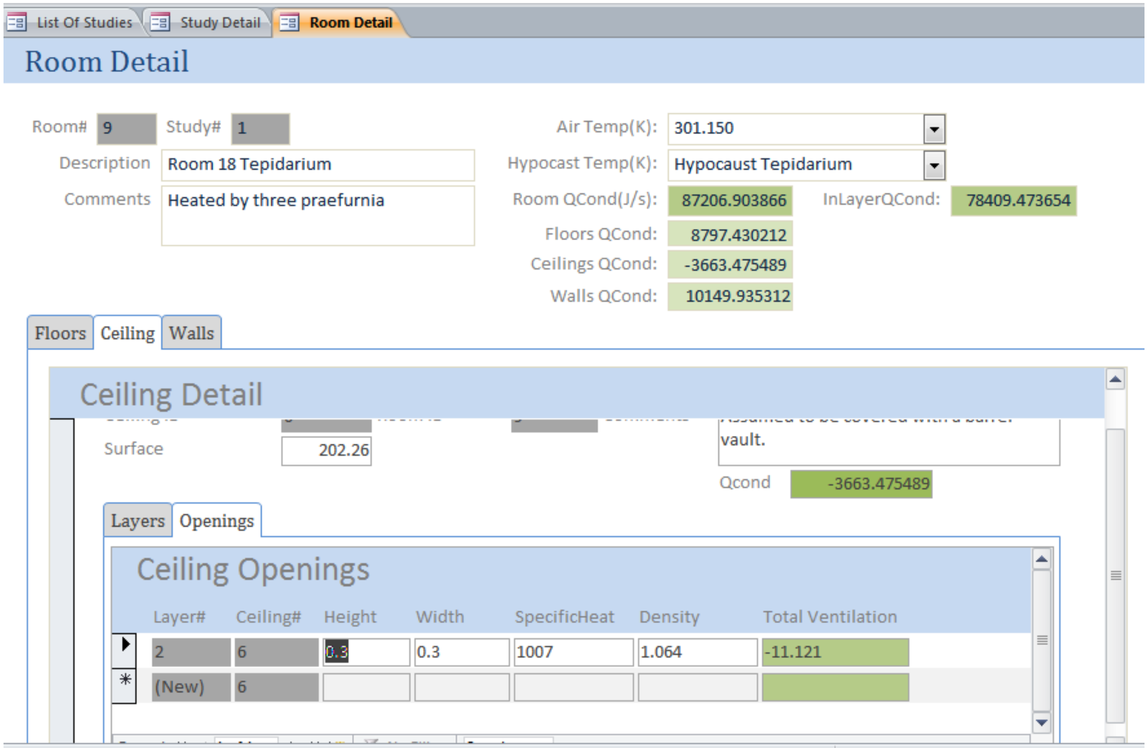

Figure 4-33: Ceiling Openings Detail Page for Room 18 of Study 1

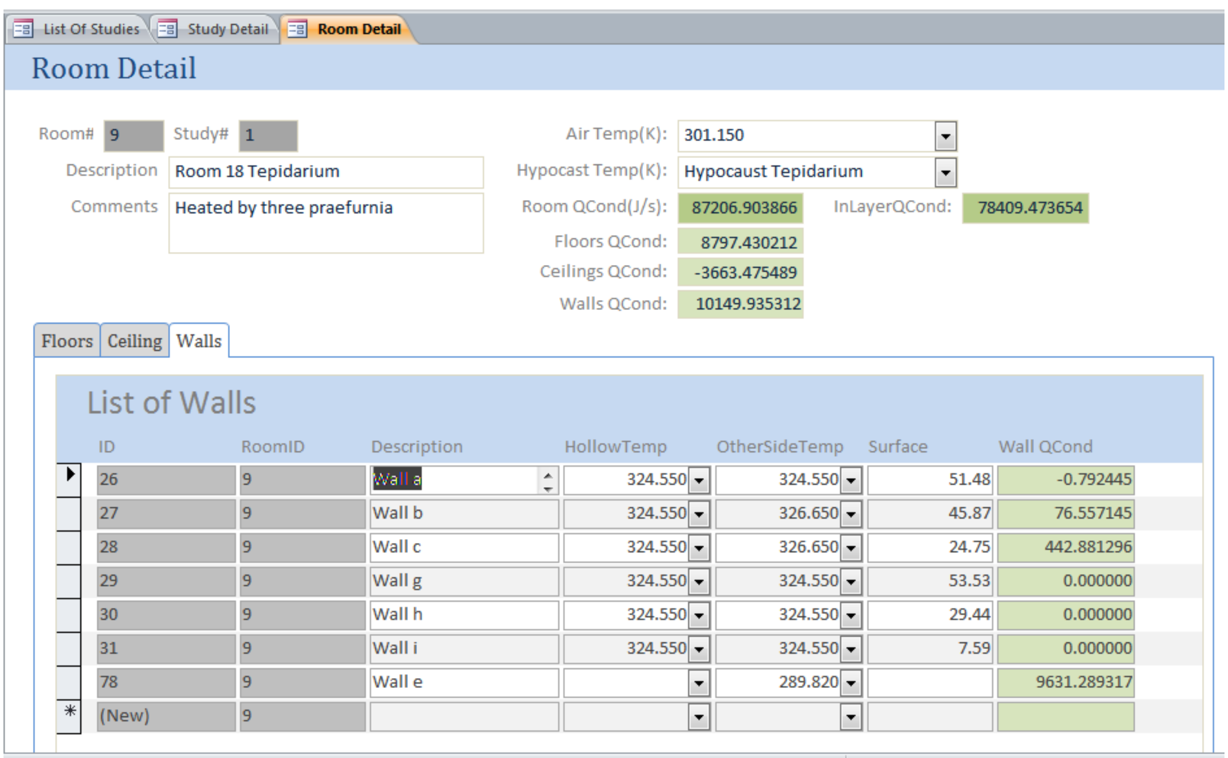

Figure 4-34: List of Walls Detail Page for Room 18 of Study 1

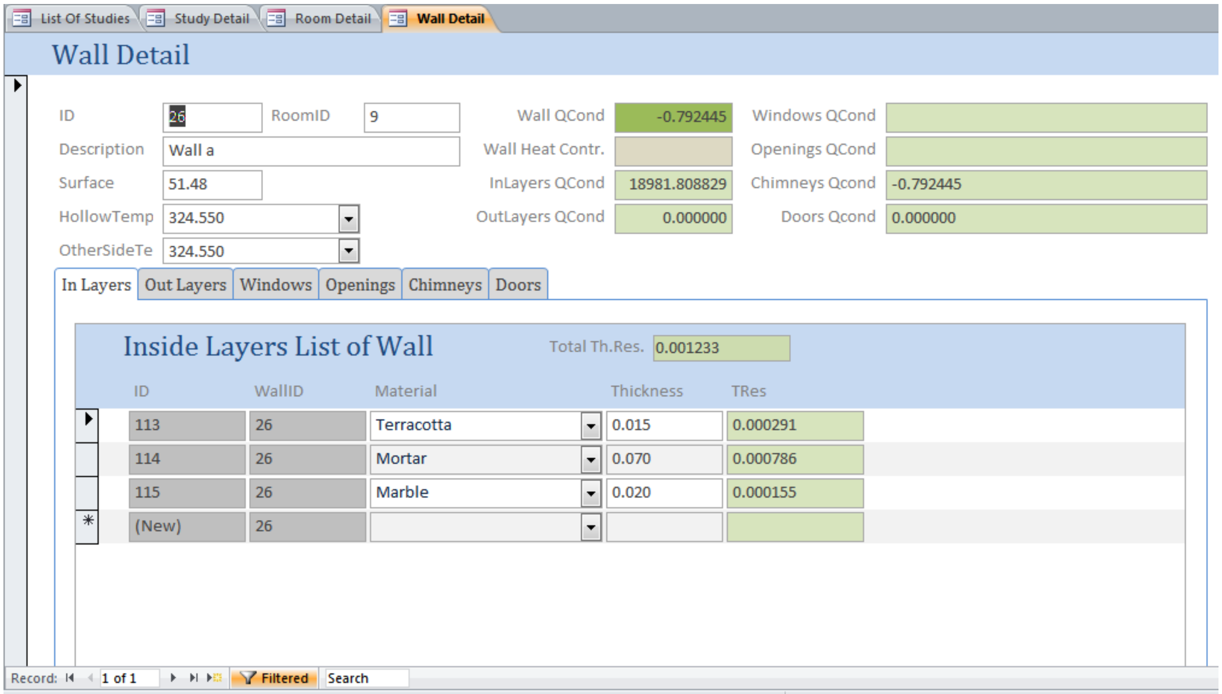

Figure 4-35: List of Inside Layers of Wall Detail Page for Wall a in Room 18 of Study 1

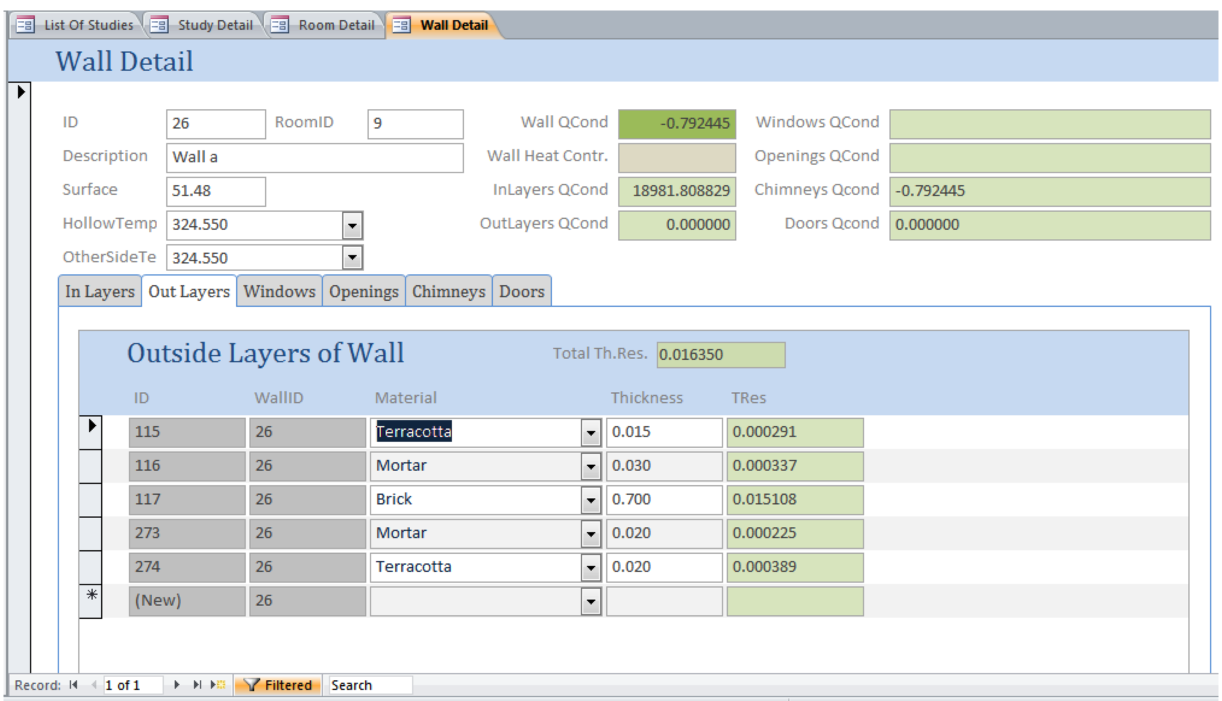

Figure 4-36: List of Outside Layers of Wall Detail Page for Wall a in Room 18 of Study 1

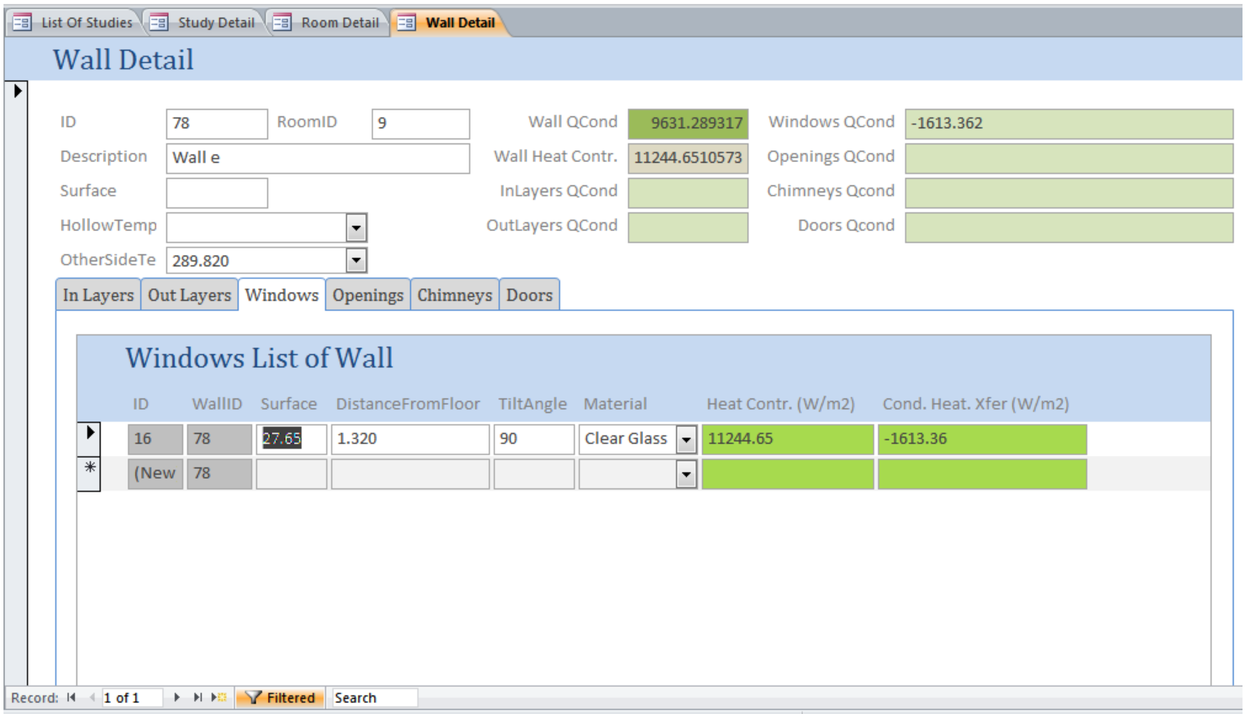

Figure 4-37: List of Windows of Wall Detail Page for Wall e in Room 18 of Study 1

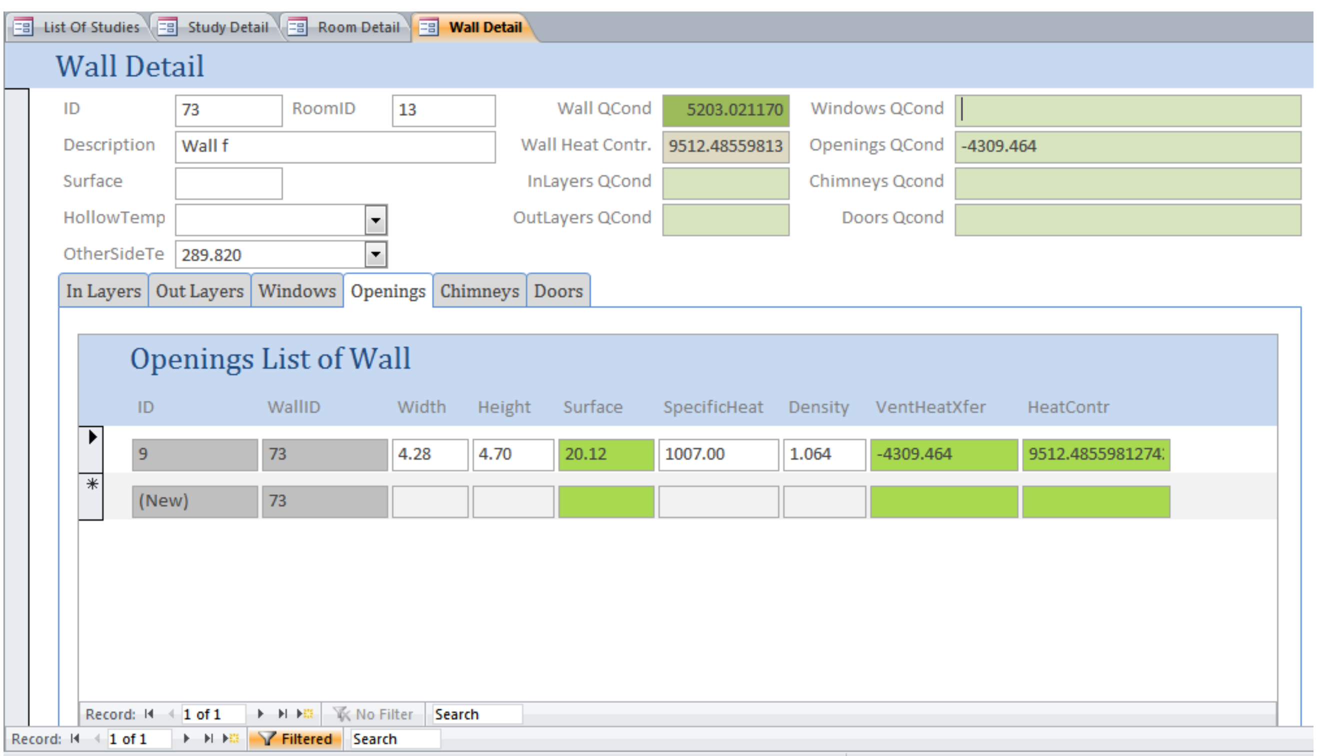

Figure 4-38: List of Openings of Wall Detail Page for Wall f in Room 15 of Study 1

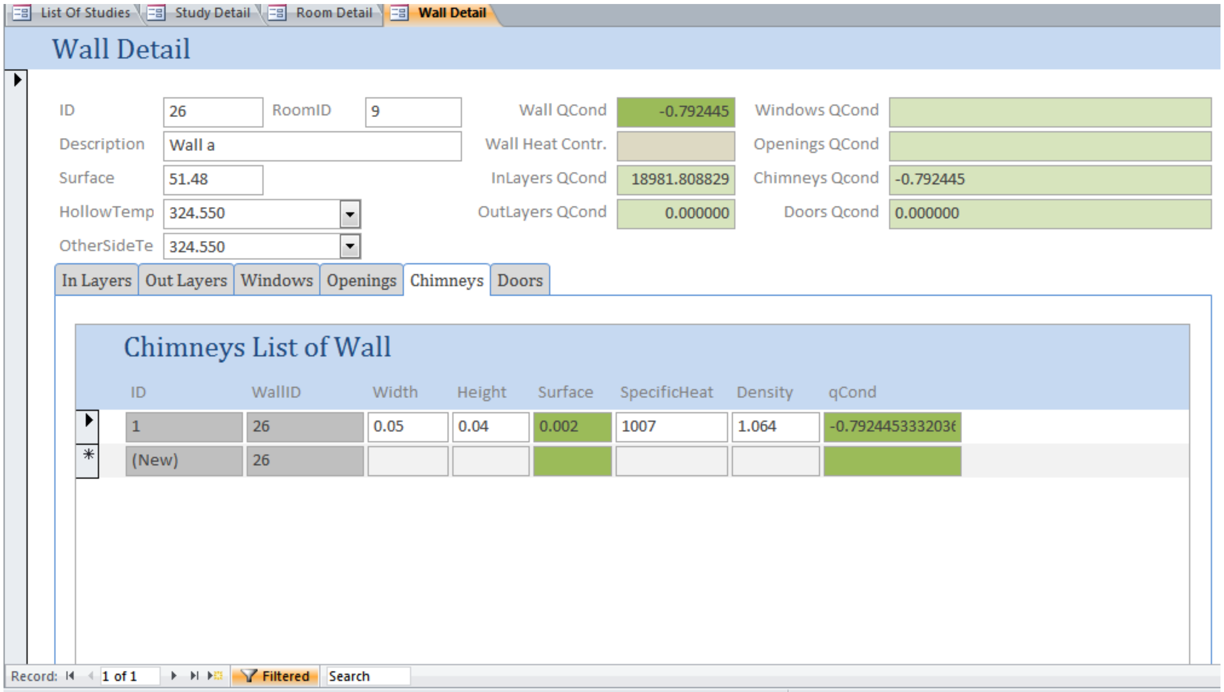

Figure 4-39: List of Chimneys for Wall a in Room 18 of Study 1

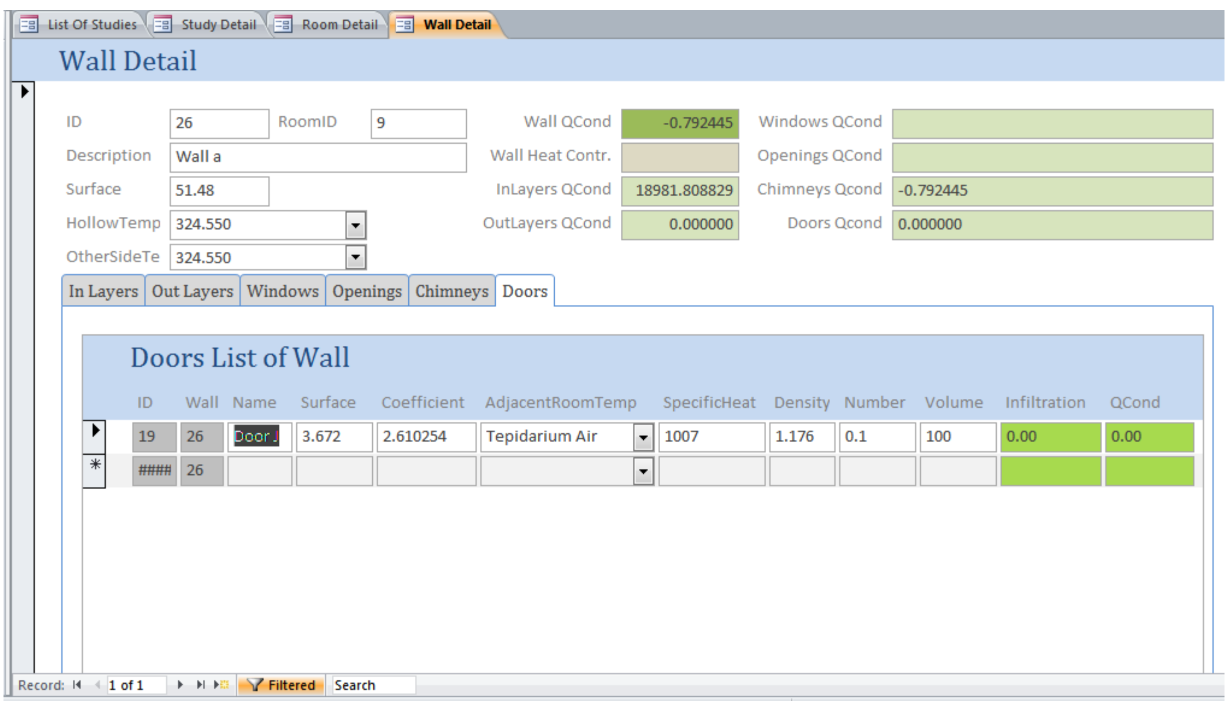

Figure 4-40: List of Doors of Wall Detail Page for Wall a in Room 18 of Study 1

Figure 5-1: Firewood Weighing 12.97 kilograms and with a Volume of 0.025 cubic meters

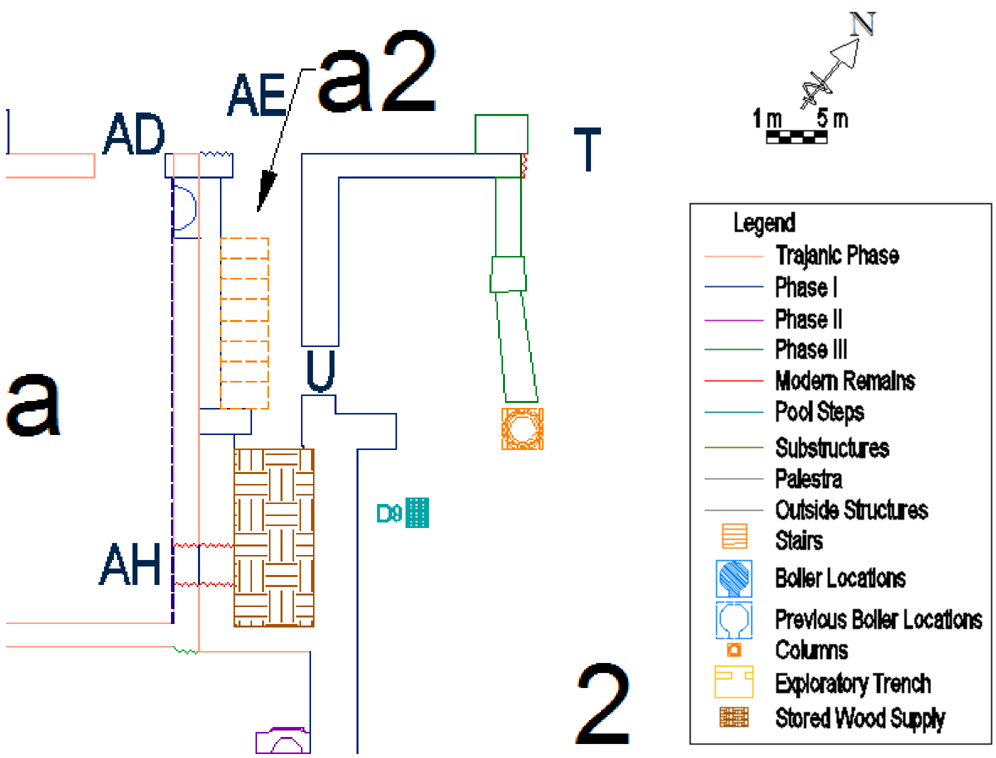

Figure 5-2: Possible Fuel Storage Space in Room a2

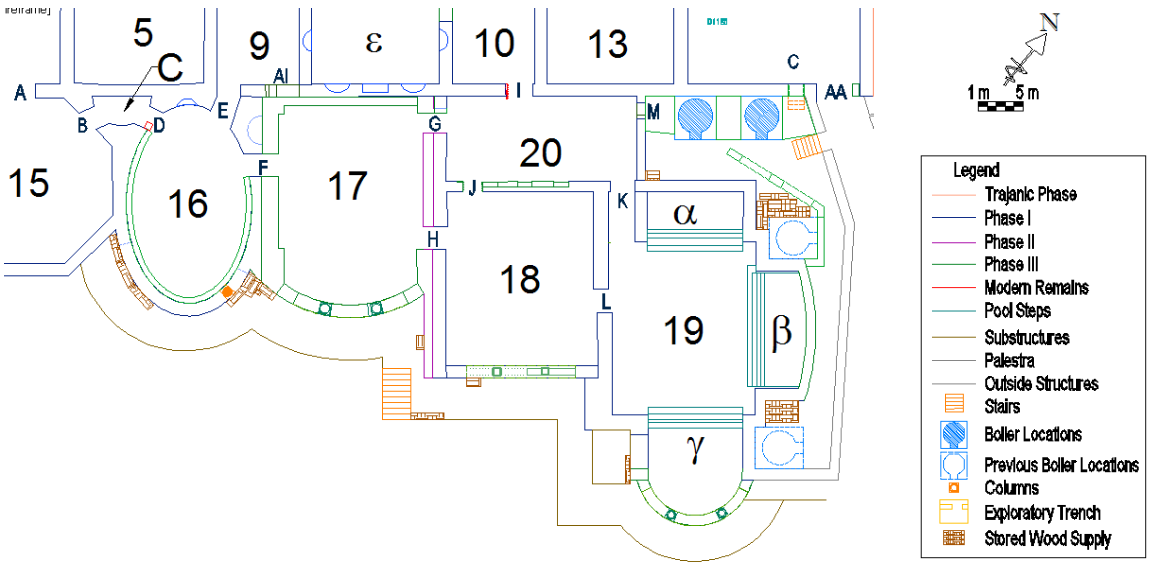

Figure 5-3: Possible Fuel Storage Spaces in Substructures for Month of January

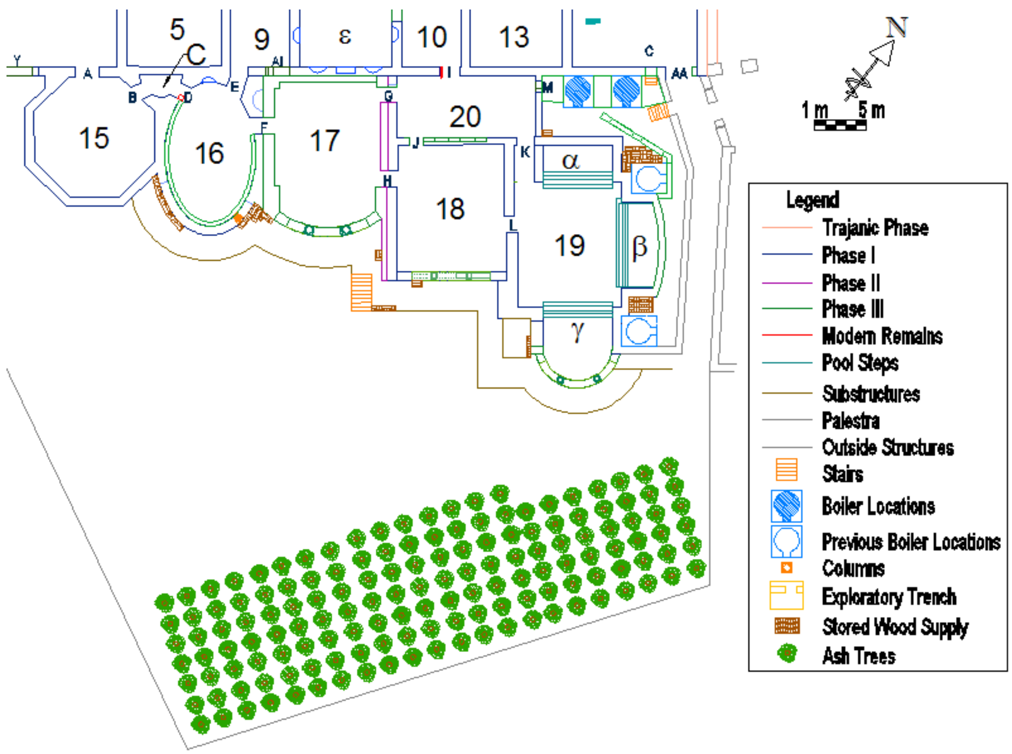

Figure 5-4: Annual Quantity of Trees (0.45 m diam.) Needed to Fuel Terme del Foro, Ostia

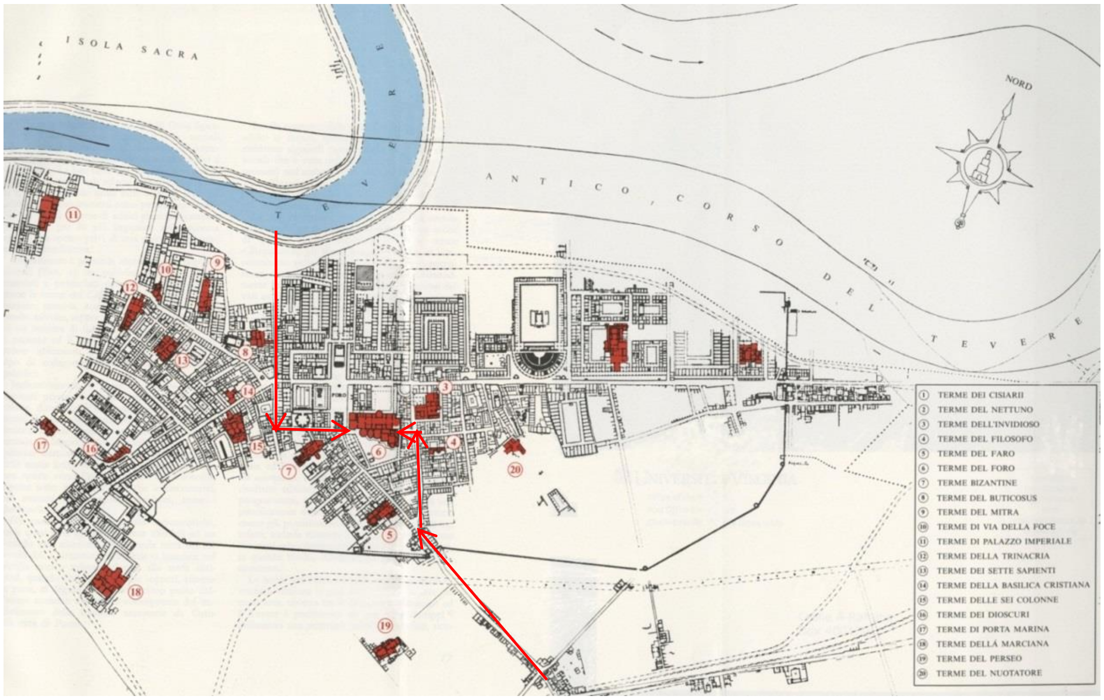

Figure 5-5: Fuel Paths to Terme del Foro (Modified from Cicerchia and Marinucci 1992)

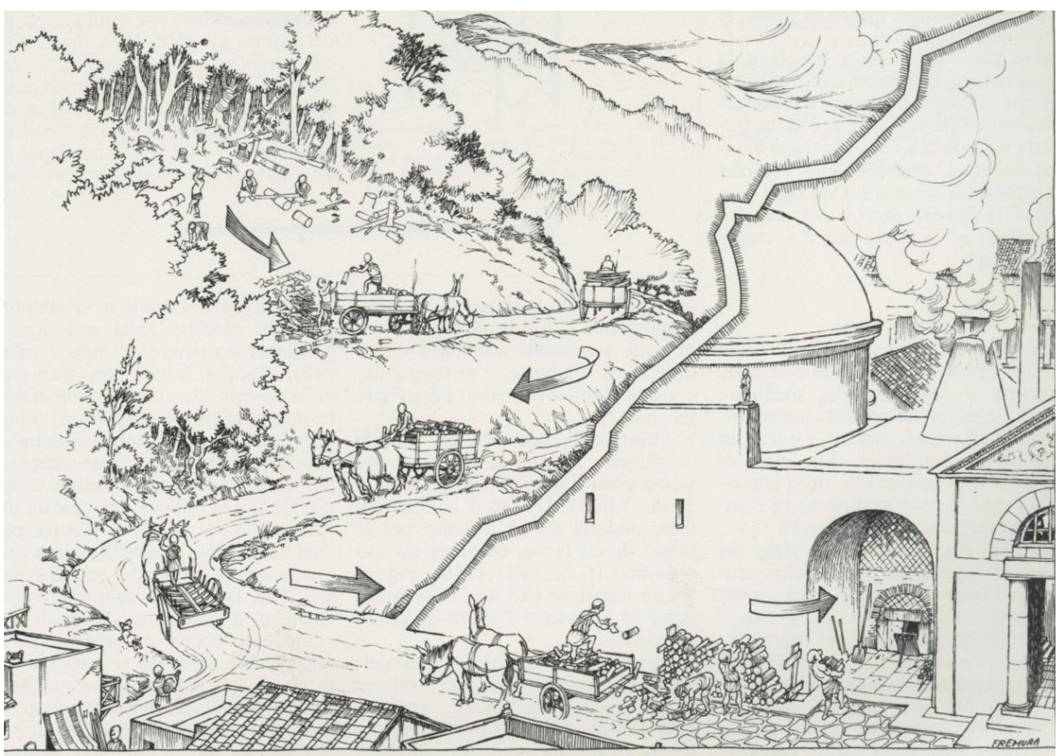

Figure 5-6: Drawing showing Harvesting and Transporting of Wood (Pasquinucci 1987c, 45 fig. 33)

Appendix 1: Constants and Solar Information

Table A1-1: Temperatures[1]

Location/Time of Year	Degrees (C)	Degrees (K)
Unheated Room Average	20.00	293.15
Recycled Heat Air	24.00	297.15
Recycled Heat Floor	30.00	303.15
Recycled Heat Hypocaust	51.00	324.15
Recycled Heat Hollow Wall	48.00	321.15
Tepidarium Air	28.00	301.15
Tepidarium Floor	34.20	307.35
Tepidarium Hypocaust	55.00	328.15
Tepidarium Hollow Wall	51.40	324.55
Caldarium Air	35.00	308.15
Caldarium Floor	45.00	318.15
Caldarium Hypocaust	65.00	338.15
Caldarium Hollow Wall	53.50	326.65
Sauna Air	52.00	325.15
Sauna Floor	64.00	337.15
Sauna Hypocaust	75.00	348.15
Sauna Hollow Wall	55.50	328.65
Ostia January Average	8.06	281.21
Ostia February Average	8.61	281.76
Ostia March Average	10.28	283.43
Ostia April Average	12.78	285.93
Ostia May Average	16.67	289.82
Ostia June Average	20.56	293.71
Ostia July Average	23.06	296.21
Ostia August Average	23.33	296.48
Ostia September Average	20.56	293.71
Ostia October Average	16.67	289.82
Ostia November Average	12.50	285.65
Ostia December Average	9.44	282.59
Ostia Annual Average	15.21	288.36
Ostia Autumn Average	16.57	289.72
Ostia Winter Average	8.70	281.85
Ostia Spring Average	13.24	286.39
Ostia Summer Average	22.31	295.46

[1] Monthly, seasonal, and annual temperature averages from WeatherChannel 3013.

Table A1-2: Solar Data[2]

Month	Average Temp C	Average Temp K	Equation of Time (min.)	Declination (degrees)	A (W/m^2)	B	C	U factor for glass	ρ Density kg/m^3
January	8.06	281.21	-11.2	-20.00	1202.529992	0.141	0.103	6.30	1.258
February	8.61	281.76	-13.9	-10.80	1187.387956	0.142	0.104	6.30	1.255
March	10.28	283.43	-7.5	0.00	1164.359444	0.149	0.109	5.15	1.248
April	12.78	285.93	1.1	11.60	1130.289864	0.164	0.120	5.15	1.237
May	16.67	289.82	3.3	20.00	1106.314974	0.177	0.130	5.15	1.220
June	20.56	293.71	-1.4	23.45	1092.434775	0.185	0.137	4.84	1.203
July	23.06	296.21	-6.2	20.60	1093.381152	0.186	0.138	4.84	1.193
August	23.33	296.48	-2.4	12.30	1107.261351	0.182	0.134	4.84	1.192
September	20.56	293.71	7.5	0.00	1136.283586	0.165	0.121	5.13	1.203
October	16.67	289.82	15.4	-10.50	1166.252198	0.152	0.111	5.12	1.220
November	12.50	285.65	13.8	-19.80	1190.227088	0.142	0.106	5.12	1.238
December	9.44	282.59	1.6	-23.45	1204.422746	0.141	0.103	6.30	1.251

Table A1-3: Ratio of Diffuse Sky Radiation Incident on Vertical Surface[3]

cos theta	GdV/GdH
-1.0	0.45
-0.9	0.45
-0.8	0.45
-0.7	0.45
-0.6	0.45
-0.5	0.45
-0.4	0.45
-0.3	0.45
-0.2	0.48
-0.1	0.50
0.0	0.54
0.1	0.60
0.2	0.65
0.3	0.70
0.4	0.76
0.5	0.84
0.6	0.90
0.7	1.00
0.8	1.10
0.9	1.23
1.0	1.29

[2] McQuiston and Parker 1994, 191 Tab. 6-1.
[3] McQuiston and Parker 1994, 200 fig. 6-9.

Table A1-4: Solar Transmission Factors[4]

Material	Thickness (m)	Transmission Factor
Clear Glass	0.0032	0.86
Clear Glass	0.0064	0.78
Clear Glass	0.0095	0.72
Clear Glass	0.0127	0.67
Tinted Glass	0.0048	0.74
Leather Tarp	0.0040	0.50
Woolen Tarp	0.0050	0.50
Double Pane 0.10 m Space	0.0032	0.71

Table A1-5: Thermal Conductivity Coefficients, *k*

Material	*k* (J/m·s·k)
Air	0.05
Basalt	3.5
Brick	0.9
Bronze	110
Concrete	1.4
Copper	401
Granite	2.2
Iron Cast	55
Lead	35
Limestone	1
Marble	2.5
Mortar	1.73
Sandstone	1.7
Stucco	0.97
Terracotta	1
Tuff	1.5
Water 313.15k	0.63
Wood Hardwood	0.16
Wood Softwood	0.12
Wool	0.07
Mosaic (Marble Tesserae)	2.5
Cocciopesto	0.29

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[4] McQuiston and Parker 1994, 207-9 Tab. 6-3, Tab. 6-4.

Table A1-6: Fuel Heating Values[5]

Fuel Type	Heat Energy Avg. (kJ/kg)
Alder (Black)	18284
Ash	20092
Beech	19610
Birch	20599
Black Locust	18840
Chestnut	18755
Charcoal	29600
Cypress	24769
Elm	19749
Fir	19417
Hornbeam	16987
Maple	18638
Oak (English)	18697
Peat	21143
Pine (Maritime)	22221
Poplar	19415
Spruce	19259
Willow	18279

[5] Approximations based on Tsoumis 1991, 200 Tab. 12-3.

Appendix 2: Raw Data from the Terme del Foro at Ostia
(Collected between 2009 and 2012)
(Notes should be referred to for highlighted cells)

Table A2-1: Room a: Shop

Length brick to brick (m)	9.87 a-i and 9.85 d-e										
Width brick to brick (m)	11.08 b-c2 and 11.07 f-h										
a/b to outer corner of e/f (m)	14.82										
c2/d to outer corner of h/I (m)	14.82										
Floor makeup	Terracotta bipedali with bollo stamps and grass where missing; impluvium in center of room 1.38 x 0.91 m inner pool										
Name of Wall	**a**	**b**	**c1**	**c2**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
Location in Room	**N**	**E**	**E**	**E**	**S**	**S**	**W**	**W**	**W**	**N**	**N**
Dimensions											
Length brick to brick (m)	0.220	1.520	7.680	0.960	7.660	0.370	3.930	0.760	3.760	4.630	3.280
Height of extant wall (m)	1.65	2.30	3.05	3.05	2.80	0.00	1.35	1.37	1.66	1.08	1.93
Height of reconstruction (m)	0.72	0.36	0.18	0.18	0.24	1.20	0.07	0.23	0.12	0.18	0.10
Height Total (m)	2.37	2.66	3.23	3.23	3.04	1.20	1.42	1.60	1.78	1.26	2.03
Abuts adjacent wall?	b	a, c1	b	d	c2	f	e	h on top	g on top	No	j
Joins adjacent wall?	No	c1	b, c2	c1	e	d	g, h, 1m	f, h	i	h, j	i
Doorway abutting?	AD	No	AH	AH	AF	AF	V	V	No	No	AD
Window?	No	Openings	Openings	Openings	Openings	No	Openings	No	Openings	No	No
Refurbished later?	1964	Is later	Opening	Opening	Opening	Opening	Yes and	Yes and	Yes and	Yes and	Yes and
		and 1964	and 1964	and 1964	and 1964	and 1964	1964	1964	1964	1964	1964
Wall Fabric											
Marble Type	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Marble width (m)	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Mortar width high (m)	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Total Width (m)	0.59	1.02	0.71	0.71	0.62	0.62	0.90	0.92	0.92	0.74	0.74
Outer Brick Wall Width (m)	-	-	0.65	0.65	-	-	0.60	0.59	0.59	0.58	0.58
Inner Brick Wall Width (m)	-	-	0.06	0.06	-	-	0.28	0.33	0.33	0.16	0.11
Inner Brick Wall Height (m)	-	-	0.52	0.52	-	-	0.93	0.94	0.94	0.73	0.73
Tubuli on other side of wall?	Outside	No	No	No	No	No	Outside	Outside	Outside	Outside	Outside

Notes:

Wall b	includes niche: steps up 0.06 m; niche 1.52 m wide, 1.905 m high, radius of 0.53 m, two openings on north side
Walls c1 and c2	total length 9.56; height is 2.90 m to threshold of Door AH; originally one wall broken through by opening Door AH; wall
	has width of 0.65 m on south part with short inner wall of 0.06 m, wall of a2 behind it is a separate wall 0.79 m thick;
	10 openings look like irregular scaffolding holes, 2.12 m up from new floor, approx. 0.13 m wide, 0.09 m high
Walls d	6 openings all in reconstructed area, 2.02 m from floor
Wall f	4 openings, 0.60 m high from floor, between 0.16 - 0.18 m wide, 0.145 m high
Walls f, g, and h	height to floor; walls originally one wall broken through by opening Door V, damage; Wall h joins Out b total length 4.79
Wall h	4 openings, 0.76 m high from floor, 0.11-0.14 m wide, 0.14 m high, see plan; large drain opening in bottom corner of
	h/i and of e/f, both on west wall, 0.54 m high, 0.36 m wide at widest, goes in diagonal, 0.28 m inner width
Wall j	height of walls to grass is an extra 0.22 m down; one wall with Wall i originally, but part of j abuts itself

Table A2-2: Room a2

Length brick to brick (m)	11.67		**b to f/g1 (m)**		11.74							
a/k to b/Door U (m)	4.56		**a/k perp. to j (m)**		5.72							
b to j/k (m)	6.66											
e/f to g2/h (m)	5.10											
g1/f to d/e (m)	4.71											
a/k to c/Door U (m)	5.66											
Floor Makeup	Unclear, space filled with broken stone blocks											
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g1**	**g2**	**h**	**i**	**j**	**k**
Location in Room	**N**	**E**	**E**	**NE**	**E**	**S**	**W**	**W**	**NW**	**W**	**SW**	**W**
Dimensions												
Length brick to brick (m)	0.300	4.740	1.320	0.170	4.370	1.960	1.000	2.750	0.410	0.590	0.730	5.720
Height of extant wall (m)	2.37	2.75	1.58	1.58	2.60	2.02	3.05	3.05	3.05	3.05	3.05	2.05
Height of reconstruction (m)	0.00	0.00	0.15	0.15	0.50	0.30	0.18	0.18	0.18	0.18	0.18	0.06
Height Total (m)	2.37	2.75	1.73	1.73	3.10	2.32	3.23	3.23	3.23	3.23	3.23	2.11
Abuts adjacent wall?	No	No	No	No	No	g	f	h	g2	No	k	j
Joins adjacent wall?	k	No	d	c, e	d, f	e	No	No	i, j	h, j	h, i	a
Doorway abutting?	AE	U, AE	U	No	No	No	AH	AH	No	No	No	No
Window?	No	No	No	No	Yes	No	Opening	Opening	No	No	No	No
Refurbished?	1964	1964	1964	1964	1964	1964	Opening	Opening	Later and	Later and	Later and	1964
							and 1964	and 1964	1964	1964	1964	
Wall Fabric												
Marble Type	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Marble width (m)	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Mortar width high (m)	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing	Missing
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.59	0.91	0.94	1.32	1.22	0.64	1.44	1.44	0.59	2.17	0.59	1.44
Tubuli on other side of wall?	Outside	No	No	No	No	No	No	No	No	No	No	No
Notes:												
Wall c	width is irregular since edge of adjoining door is irregular from damage											
Walls g1 and g2	formed one continuous wall but were perforated by later opening Door AH, g1+g2+Door AH=4.67; thickness is 0.65 in shop+0.79 in a2											

Table A2-3: Room 1

Length k/l to m/n (m)	15.24				**g/f to h/i (m)**			1.54
Width: c/w perp. to l (m)	13.02 (ends up at Door AB)				**h/i to j/Door AC (m)**			2.92
Length a/b1 to f/g (m)	12.33 (corners line up)				**k/Door AC to m/n (m)**			15.42
Length g/f perp. to l (m)	9.23				**d/Door W to e/Door AG (m)**			damaged
a/b1 to m/Door AB (m)	9.90				**d/Door W to f/g (m)**			blocked
a/b1 to c/Door W (m)	4.83							
Floor Makeup	mosaic with big irregular tesserae of reused marble: 0.04 x 0.03 or 0.05 m							
Name of Wall	**a**	**b1**	**b2**	**c**	**d**	**e**	**f**	**g**
Location in Room	**N**	**N**	**N**	**E**	**E**	**S**	**S**	**SE**
Dimensions								
Length brick to brick (m)	7.720	0.595	2.740	3.440	5.680	1.200	1.260	1.400
Height of extant wall (m)	1.53	2.02	2.02	1.16	2.00	1.15	0.10	1.20
Height of reconstruction (m)	0.71	0.30	0.30	0.75	0.52	0.00	0.00	0.00
Height Total (m)	2.24	2.32	2.32	1.91	2.52	1.15	0.10	1.20
Abuts adjacent wall?	b1	a, b2	b1	C3, 2az	e, C4	d	No	h
Joins adjacent wall?	n	No	c	b2?	No	No	g	f, j
Doorway abutting?	AF	No	No	W	W	AG	AG	No
Window?	Openings	No	No	No	No	No	No	No
Refurbished?	Broken	Rubble is	Rubble is	1964	Rubble is	Is a bit	No	No
	1924/1964	modern	modern		modern	later		
Wall Fabric								
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.58	0.64	0.64	1.22	1.18	0.90	3.48	2.15
Tubuli on other side of wall?	No	No	No	No	No	Outside	Outside	Outside

Name of Wall	**h**	**i**	**j**	**k**	**l**	**m**	**n**
Location in Room	**S**	**SE**	**S**	**S**	**W**	**W**	**N**
Dimensions							
Length brick to brick (m)	0.615	0.450	2.900	3.380	8.730	0.920	0.370
Height of extant wall (m)	1.20	1.20	1.29	1.23	5.05	0.36	0.36
Height of reconstruction (m)	0.00	0.00	0.05	1.80	0.00	0.00	0.00
Height Total (m)	1.20	1.20	1.34	3.03	5.05	0.36	0.36
Abuts adjacent wall?	g	j	i	No	No	n	m
Joins adjacent wall?	i	h	g	l	k, m	l, a w wall	a
Doorway abutting?	No	No	AC	AC	AB	AB	AF
Window?	No	No	No	No	Holes	No	No
Refurbished?	Is a bit	Is a bit	No	No	No	1924 and	1924 and
	later	later				1964	1964
Wall Fabric							
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No
Brick Wall Width (m)	0.45	0.62	0.78	0.75	0.82	0.58	0.58
Tubuli on other side of wall?	Outside	Outside	Outside	Outside	Outside	Outside	No

Notes:	
Walls a and n	originally one wall, opening Door AF added later; upper part of wall n all reconstruction
Wall b	thickness of wall b projects out further south than that of wall a
Walls c and d	wall d continues behind wall e 0.87 m, total length is 6.55
Wall g	fistulae slot begins 0.40 m from wall h, 0.23 m wide on outside, 0.12 m wide on inside,
	0.16 m deep, 0.75 m from wall f
Walls h and i	are separate block, 0.01 m space between wal i and wall j
Walls m and n	goes 0.36 m up from room floor, but down below floor 1.05 m and then another 0.37 m
	to the street outside with stairs
Wall l	5.05 m high to triangle, 5.85 m to top triangle, but this was probably to outside of roof;
	5 windows begin 2.70 m from ground, are 0.60 m high, various widths, now blocked
	with sculptural elements on the other side; brick 0.22 m thick on inside of wall, 0.60 m
	on outside, masonry looks different, inside goes behind last step, outside lines up with
	wall m

Table A2-4: Room 2

f/Door X perp. to r (m)	12.00	**j/k to m/l (m)**	8.68	**ah/ai to av/au (m)**	3.37
q/Door W perp. to k (m)	12.03	**q/Door W to p/Door Y (m)**	5.77	**a/b to ak/al (m)**	3.71
a/al to b/c (m)	6.83	**r/aw to s/t (m)**	7.67	**ai/aj to t/u (m)**	2.80
a/b to c/d (m)	5.83	**t/u to v/Door U (m)**	1.52	**ai/aj to w/x (m)**	6.88
a/b to al/inner ap (m)	4.24	**w/Door U to x/ab (m)**	5.70	**ad perp. to ar (m)**	3.43
a/b to at/C2 (m)	6.83	**w/x to ab/inner af (m)**	4.38	**ad/ag to aq/as (m)**	3.61
c/d to at/C2 (m)	2.90	**ae/af outer perp. to w (m)**	3.85	**aa/ac to an/ao (m)**	3.64
d/e to f/Door X (m)	3.65	**ai/aj perp. to v (m)**	4.25		
j/k to k/l (m)	8.46	**z/Door T to an/Door T (m)**	3.68		
au/av perp. to ai (m)	3.37	**as/at perp. to b (m)**	3.71		
Floor Makeup	Black and white mosaic, tight construction, relatively regular tesserae: 0.01 x 0.01 m, 0.21 m wide black band				

Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
Location in Room	**N**	**E**	**NE**	**E**	**SE**	**E**	**E**	**BL N**	**BL W**	**BL S**
Dimensions										
Length brick to brick (m)	4.335	5.730	0.890	0.900	0.890	3.550	0.650	1.220	1.215	1.205
Height of extant wall (m)	1.33	2.10	1.60	0.40	1.70	1.74	2.14	2.27	2.27	2.27
Height of reconstruction (m)	0.56	0.17	0.30	0.81	0.16	0.05	0.43	0.34	0.34	0.34
Height Total (m)	1.89	2.27	1.90	1.21	1.86	1.79	2.57	2.61	2.61	2.61
Abuts adjacent wall?	b, ak	a, c	b	No	f	e	h	g	No	k
Joins adjacent wall?	Door T-E	No	d, e, 3u-w	c, e, 3u-w	c, d, 3u-w	No	k	i, j	h, j	h, i
Doorway abutting?	T	No	Opening	Opening	Opening	X	X	No	No	No
Window?	Yes	No	No	No	No	No	No	Hole	No	Hole
Refurbished?	Yes and	1964	1964	1964	1964	Yes and	1964	Later and	Later and	Later and
	1964					1964		1964	1964	1964
Wall Fabric										
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	0.055	0.055	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.62	0.90	0.90	2.38	0.90	0.90	0.89	1.22	1.22	1.22
Tubuli on other side of wall?	Outside	No	No	No	No	No	No	No	No	No
Space (m)								0.02 to g		

Name of Wall	k	l	m =	n	o	p	q	r	s	t
Location in Room	**E**	**S**	**Door A**	**S**	**S**	**S**	**W**	**W**	**SW**	**W**
Dimensions										
Length brick to brick (m)	8.490	1.750	2.300	3.555	0.605	0.815	5.700	7.570	0.940	0.910
Height of extant wall (m)	2.83	2.08	1.94	1.94	1.86	1.71	2.52	2.60	1.26	1.26
Height of reconstruction (m)	0.05	0.19	0.11	0.11	0.18	0.00	0.13	0.50	0.55	0.11
Height Total (m)	2.88	2.27	2.04	2.04	2.04	1.71	2.65	3.10	1.81	1.36
Abuts adjacent wall?	j	No	-	o	n	q	p	s, az	r	No
Joins adjacent wall?	l	k	-	No	No	No	No	No	t, u	s, u
Doorway abutting?	No	A	Is A	A	Y	Y	W	W	Opening	Opening
Window?	No	No	No	No	No	No	No	Reconstr.	No	No
Refurbished?	Yes (slots)	1964	1964	Maybe and	1964	Later	Yes and	2 Blocks	1964	1964
	and 1964			1964		Abuts	1924/1964	and 1964		
Wall Fabric										
Marble Type	Pavonazzetto	Not visible	No	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	0.025	Not visible	No	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	0.07	Not visible	No	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.89	1.02	1.02	1.01	0.91	0.91	1.17	1.22	0.91	2.41
Tubuli on other side of wall?	No	No, heated	No, heated	No, heated	Outside	Outside	No	No	No	No
Space (m)					0.05 to n					
					same mas.					

Name of Wall	u	v	w	x	y	z	aa	ab	ac	ad
Location in Room	**NW**	**W**	**W**	**N**	**W BL N**	**W BL E**	**W BL S**	**W BL W**	**W BL N**	**W BL E**
Dimensions										
Length brick to brick (m)	1.465	0.445	4.140	3.890	0.630	1.940	0.630	1.890	0.880	0.850
Height of extant wall (m)	1.26	1.58	1.58	3.02	1.67	1.72	1.72	1.67	1.62	1.59
Height of reconstruction (m)	0.45	0.15	0.58	0.80	0.27	0.23	0.23	0.27	0.30	0.24
Height Total (m)	1.71	1.73	2.16	3.82	1.94	1.95	1.95	1.94	1.92	1.83
Abuts adjacent wall?	v	u	No	y	x	No	ac	No	aa	No
Joins adjacent wall?	s, t	No	x	w	z, aa, ab	y, aa, ab	y, z, ab	y, z, aa	ad, ae, af	ac, ae, af
Doorway abutting?	Opening	U	U	T	T	Opening	No	No	No	Opening
Window?	No	No	No	Yes	No	No	No	No	No	No
Refurbished?	1964	1964	1964	Yes and	Later and	Later and	Later and	Later and	Later and	Later and
				1964	1964?	1964?	1964?	1964?	1964?	1964?
Wall Fabric										
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.91	0.90	0.91	0.60	1.94	0.63	1.94	0.63	0.87	0.88
Tubuli on other side of wall?	No	No	No	Outside	No	No	No	No	No	No
Space (m)					0.025 to x					

Name of Wall	ae	af	ag	ah	ai	aj	ak	al	am	an
Location in Room	**W BL S**	**W BL W**	**W BL N**	**W BL E**	**W BL S**	**W BL W**	**EBL N**	**EBL E**	**EBL S**	**EBL W**
Dimensions										
Length brick to brick (m)	0.880	0.870	0.650	2.760	0.590	2.730	0.610	2.070	0.610	2.065
Height of extant wall (m)	1.62	1.62	1.64	1.64	1.64	1.40	2.36	2.36	2.36	2.27
Height of reconstruction (m)	0.30	0.30	0.14	0.14	0.14	0.14	0.12	0.12	0.12	0.18
Height Total (m)	1.92	1.92	1.78	1.78	1.78	1.54	2.48	2.48	2.48	2.45
Abuts adjacent wall?	ag	No	ae	No	C1	No	a	No	ao	No
Joins adjacent wall?	ac, ad, af	ac, ad, ae	ah, ai, aj	ag, ai, aj	ag, ah, aj	ag, ah, ai	al, am, an	ak, am, an	ak, al, an	ak, al, am
Doorway abutting?	No	No	No	Opening	Opening	Opening	No	No	No	T
Window?	No	No	No	No	No	No	No	No	No	No
Refurbished?	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and
	1964?	1964?	1964?	1964?	1964?	1964?	1964?	1964?	1964?	1964?
Wall Fabric										
Marble Type	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.87	0.88	2.76	0.65	2.76	0.65	2.07	0.61	2.07	0.61
Tubuli on other side of wall?	No	No	No	No	No	No	No	No	No	No
Space (m)							0.025 w			
							0.02 e to a			

Name of Wall	ao	ap	aq	ar	as	at	au	av	aw	ax
Location in Room	EBL N	EBL E	EBL S	EBL W	EBL N	EBL E	EBL S	EBL W	BL N	BL E
Dimensions										
Length brick to brick (m)	0.830	0.880	0.830	0.870	0.610	2.720	0.610	2.760	1.195	1.245
Height of extant wall (m)	1.66	1.66	1.66	1.69	1.66	1.66	0.39	1.69	1.48	1.33
Height of reconstruction (m)	0.08	0.08	0.08	0.07	0.08	0.08	0.00	0.09	0.10	0.17
Height Total (m)	1.74	1.74	1.74	1.76	1.74	1.74	0.39	1.78	1.58	1.50
Abuts adjacent wall?	am	No	as	No	aq	No	C2	No	r	No
Joins adjacent wall?	ap, aq, ar	ao, aq, ar	ao, ap, ar	ao, ap, aq	at, au, av	as, au, av	as, at, av	as, at, au	ax, ay, az	aw, ay, az
Doorway abutting?	No	No	No	No	No	No	Opening	Opening	Opening	No
Window?	No	No	No	No	No	No	No	No	No	No
Refurbished?	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and	Later and
	1964?	1964?	1964?	1964?	1964?	1964?	1964?	1964?	1964	1964
Wall Fabric										
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.88	0.83	0.88	0.83	2.76	0.610	2.76	0.610	1.25	1.33
Tubuli on other side of wall?	No	No	No	No	No	No	No	No	No	No
Space (m)										

Name of Wall	ay	az
Location in Room	BL S	BL W
Dimensions		
Length brick to brick (m)	1.325	1.260
Height of extant wall (m)	1.49	1.48
Height of reconstruction (m)	0.06	0.10
Height Total (m)	1.55	1.58
Abuts adjacent wall?	r	r
Joins adjacent wall?	aw, ax, az	aw, ax, ay
Doorway abutting?	Opening	Opening
Window?	No	No
Refurbished?	Later and	Later and
	1964	1964
Wall Fabric		
Marble Type	Not visible	Inside
Marble width (m)	Not visible	Inside
Mortar width (m)	Not visible	Inside
Evidence of Tubuli?	No	No
Brick Wall Width (m)	1.25	1.33
Tubuli on other side of wall?	No	No
Space (m)		

Notes:	
Wall a	length of segments: 3.685 m-wall, 0.61 m-behind ak, 0.04 m-edge, 0.18 m-new bit; ancient refurbishments: extra bit
	0.18 m added to north end near door and block Walls ak/al/am/an abutted later; Wall a(m): 0.89 high without window;
	windosill west end: 0.73+0.27 high, 0.44 wide; east end: 0.2+0.26 high, 0.3 wide; window: 2.96 m wide
Wall g	has a break in wall that is natural damage
Walls h, i, and j	separate block that was added later with rough masonry; hole begins 0.18 m+0.02 m of space from wall g; bottom
	1.10 m from floor; 0.12 m wide; 0.18 m high; 0.15 m high to broken brick on inside; hole mostly straight but turns a
	bit on j side, less regular; inside bulges in middle; outside of hole is 0.16 m wide on top and 0.11 m wide on bottom
Walls c, d, and e	are one continuous block with 4 u, v, and w
Wall f	there is a break in Wall f that begins 0.70 m from Wall e
Walls g and k	one continuous wall: 0.65 m-g + 1.215 m-i + 8.49 m-k = 10.355 m; Wall k has two fistulae slots marble revettment
	may be reconstruction work
Walls j and k fistulae slot	slot begins 1.22 from Wall j; 0.23 m deep, 0.23 m wide on wall face, 0.22 m wide inside slot; straight construction
	slot filled in in ancient time
Walls k and l fistulae slot	at the southern end of Wall k and eastern end of Wall l; cuts 1.02 m into the thickness of Wall l, la (inside of cut) is
	0.20 (at 0.17 m from back wall)-0.26 m wide (slot is semicircular), open face of slot is 0.23 m wide, lb (western wall
	of slot) is 0.15 m long; slot is 2.08 m high + 0.10 m modern; refurbished in 1964
Wall n	1.01 m thick at Door A, but gets thinner, 0.912 on the western side
Wall q and fistulae slot	continues past p for total length of 6.60: 5.11 m wall, 0.215 m-fistulae slot inside (qc), 0.05 m space within blockage
	of slot, 0.37 m corner p/q to fistulae slot, 0.91 m-width of p; slot blockage (qe) is 0.206 m wide and 1.85 + 0.29 m
	modern high; height (qa) is 1.86 + 0.32 m modern; slot goes in 0.21 m (qb/qd); slot blocked is ancient
Wall r	length: 7.57 m + 0.05 m small separate bit+1.26 m behind Wall az; thickness: 1.19 at az, 1.20 at 1b, 1.20 at a2f,
	1.22 at 2s; window is in reconstruction, no visible evidence to suggest window; starts 1.73 m from s, 2.20 m up from
	floor, 0.86 m wide, 0.32 m of reconstructed height above/next to window on the north side
Drain near walls r and s	see drawing; 0.71 m long N-S, 0.57 m wide E-W; 1.18 m from Wall r; 1.44 m south of Wall s, 0.25 m east of Wall s;
	at same level as surrounding mosaic; constructed down 0.73 m from floor/grating, then open; water level is close
Walls s, t, and u	walls form a separate block, but it is the same construction as the rest of the room; damage in Wall u is natural
Walls u and x floor area	area seems to have collapsed; all heights taken to original floor level
Wall x and window	length of segments: 3.88 m-wall, 0.63 m-behind Wall y, 0.075 m-edge; window starts 0.3 m from Wall w, 3.0 m wide,
	1.12 m to bit past y, 0.17 m-new bit; west pane:1.07 + 0.1 m high, east pane:1.19 + 0.8 m high; base 1.83 m to floor
Wall ac	comes out further than Wall aa 0.08 m on the east side and 0.11 m on the west side
Wall ae	comes out further than Wall ag 0.09 m on the east side and 0.12 m on the west side
Blocks y-aj and ak-av	higher height number used for inside walls such as Walls aa, ac, etc.
Blocks as-av	western end of base has an extra 0.06 m of width (not included) only at bottom; Wall au height is just south face
Block aw-az	brick width of Walls ax and az goes from 1.195 m on the north to 1.325 m on the south

Table A2-5: Rooms 3, 4, and 5

Length a to n (at v-q) (m)	24.08		**d/e perp. to a (m)**		6.64		**t/Door X to u/v (m)**		3.62		
Length a to n (at W C7) (m)	24.07		**d/e to k/l (m)**		11.51		**a/b to c/d (m)**		5.82		
Length a to n (at E C7) (m)	24.11		**a/b to w/x (m)**		10.87		**d/e to f/g (m)**		1.38		
Length a to n (at W C8) (m)	24.12		**a/b to s/Door X (m)**		16.59		**h/i to j/k (m)**		0.38		
Length a to n (at E C8) (m)	24.09		**a/b to t/Door X (m)**		13.75		**s/Door X to r/q (m)**		3.60		
Length a to n (d-k) (m)	24.08		**a/b to o/n (m)**		25.79		**n/o to p/q (m)**		5.92		
Width d/e to v/u (m)	8.05		**a/x to b/c (m)**		10.87		**m/n to k/l (m)**		5.96		
Width f/g perp. to t (m)	9.25		**a/x to f/g (m)**		12.05		**h/i to o/n (m)**		12.22		
Width i/h perp. to s (m)	9.23		**a/x to h/i (m)**		18.53		**m/n to o/n (m)**		9.21		
Width j/k to r/q (m)	8.07		**a/x to m/n (m)**		25.69		**m/n to s/Door X (m)**		13.81		
r/q to u/v (m)	10.50		**a/x to w/v (m)**		5.81		**m/n to o/p (m)**		10.91		
f/g to h/i (m)	8.31										
Floor Makeup	Room 3: reused polychrome marble; Rooms 4, 5: white mosaic, irregular tesserae 0.01-0.02 x 0.01-0.02 m; black										
	tesserae regular 0.0125 x 0.0125 m.; black band 0.13 m wide; Pavonazzetto band 0.87 m wide between v and d;										
	threshold between Rooms 2/3 is 0.895 m wide, between 3/6 is 1.10 m, between 3/4 is 0.87 m, between 3/5 is 0.90 m										
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**4 N**	**4 E**	**4 SE**	**4 E**	**3 N**	**3 E**	**3 OPEN**	**3 OPEN**	**3 E**	**3 S**	**5 E**
Dimensions											
Length brick to brick (m)	9.100	5.750	0.580	0.890	0.580	1.190	0.890	0.840	1.200	0.570	0.880
Height of extant wall (m)	2.30	2.55	1.90	1.90	1.90	1.70	0.23	1.70	1.65	1.78	1.79
Height of reconstruction (m)	0.00	0.00	0.26	0.26	0.26	0.26	1.05	0.23	0.23	0.35	0.35
Height Total (m)	2.30	2.55	2.16	2.16	2.16	1.96	1.28	1.93	1.88	2.13	2.14
Abuts adjacent wall?	No	No	No	No	No	No	No	No	No	No	No
Joins adjacent wall? Inside/Outside	b, x	a, c?	b?, d	c, e	c, f	e, g	f	i	h, j	i, k	j, l
Doorway abutting?	No	No	Opening	Opening	Opening	Opening	Opening	Opening	Opening	Opening	Opening
Window?	Yes	No	No	No	No	No	No	No	No	No	No
Refurbished?	Yes	Yes and	1964	1964	1964	1964	1964	Yes and	Yes and	Yes and	Yes and
		1924/1964						1924/1964	1924/1964	1924/1964	1924/1964
Wall Fabric											
Marble Type	Pavonazz.	Grigio	Grigio	Not visible	Cipollino?	Cipollino?	Pavonazz.	Pavonazz.	Not visible	Not visible	Not visible
Marble width (m)	0.0275	0.0200	0.0175	Not visible	0.0200	0.0200	Reused base		Not visible	Not visible	Not visible
Mortar width (m)	0.0250	0.0575	0.0575	Not visible	0.0500	0.0550	0.0400	0.0100	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.59	0.89	0.89	0.58	0.89	0.89	0.89	1.08	0.84	0.88	0.57
Tubuli on other side of wall?	Outside	Yes	Opening	No	No	Opening	Wall	Wall	Opening	No	No

Name of Wall	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**u**	**v**
Location in Room	**5 N**	**5 E**	**5 S**	**5 W**	**5 N**	**5 W**	**3 S**	**3 W**	**3 E**	**3 N**	**4 W**
Dimensions			not straight								
Length brick to brick (m)	0.570	5.920	9.160	5.880	0.590	0.900	0.590	3.550	3.520	0.590	0.890
Height of extant wall (m)	1.94	6.17	6.17	2.66	2.60	2.75	2.75	2.75	1.85	1.85	1.22
Height of reconstruction (m)	0.32	0.00	0.65	0.10	0.00	0.00	0.00	0.00	0.05	0.10	0.66
Height Total (m)	2.26	6.17	6.82	2.76	2.60	2.75	2.75	2.75	1.90	1.95	1.88
Abuts adjacent wall?	No	No	No	No	No	No	No	No	No	No	No
Joins adjacent wall? Inside/Outside	k, m	l, n	m, o	n, p	o, q	p, r	q, s	r	u	t, v	u, w
Doorway abutting?	Opening	Cut area	No	No	Opening	Opening	Opening	X	X	Opening	Opening
Window?	No	No	No	No	No	No	No	No	No	No	No
Refurbished?	1924 and	Yes and	1964	1964	1964	1964	1964	1964	Yes and	Yes and	Yes and
	1964	1964							Modern	1924/1964	1924/1964
Wall Fabric											
Marble Type	Grigio	Grigio	Grigio	Not Clear	Not visible	Not visible	Cipollino?	Cipollino?	Not visible	Cipollino?	Not visible
Marble width (m)	0.0120	0.0135	0.0150	0.0200	Not visible	Not visible	0.0210	0.0300	Not visible	0.0200	Not visible
Mortar width (m)	0.0570	0.0570	0.0550	0.0380	0.0500	Not visible	0.0500	0.0550	0.0300	0.0275	Not visible
Total width where missing (m)	-	-	-	-	-	0.110	-	-	-	-	0.700
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.88	0.89		0.90	0.90	0.59	0.90	0.89	0.87	0.89	0.59
Tubuli on other side of wall?	Opening	Yes	Yes	No	Opening	No	No	No	No	No	No

Name of Wall	w	x	y
Location in Room	4 S	4 W	3 E
Dimensions			
Length brick to brick (m)	0.590	5.700	0.210
Height of extant wall (m)	1.85	2.10	1.65
Height of reconstruction (m)	0.10	0.10	0.54
Height Total (m)	1.95	2.20	2.19
Abuts adjacent wall?	No	No	No
Joins adjacent wall? Inside/Outside	v, x	w, a	i
Doorway abutting?	Opening	No	Opening
Window?	No	No	No
Refurbished?	Yes and	Yes and	Yes and
	1924/1964	1924/1964	1924/1964
Wall Fabric			
Marble Type	Pavonazz.	Pavonazz.	Not visible
Marble width (m)	0.0200	0.0200	Not visible
Mortar width (m)	0.0600	0.0500	Not visible
Evidence of Tubuli?	No	No	No
Brick Wall Width (m)	0.89	0.87	0.84
Tubuli on other side of wall?	Opening	No	Opening

Notes:	
Wall a	windows partly refurbished; west starts 0.44 m from wall x, 2.07 m wide, another 0.44 m of frame; on east end is
	another reconstructed frame of 0.44 m against wall b; window opens directly in front of 4th cent AD latrine
Walls g and h	face of openings revetted with reused Pavon. block that probably served as column base before; marble is
	1.05 m at widest n both; 0.38 m high, 0.23 m thick on g; 0.36 m high, 0.26 m thick on h; C11 block would have been
	a column base of 1.05 m, perhaps this one
Wall m	break in wall m likely served as door; 2.00-2.265 m from l; 2.72-3.03 m to n; 0.59-1.15 m wide; 1.82-1.835 m high;
	north side 0.87 m from top, 1.39 m from top; width of marble goes from 0.012 to 0.015; used averages
Wall n	thickness of n varies because of Doorways B, C area, and D
Walls u, v, and w	are one continuous block with walls 2 c, d, and e
Wall y	is a fistulae slot
Thresholds	between Rooms 3/6 is 1.10 m, between Rooms 3/4 is 0.87 m, between Rooms 3/5 is 0.90 m

Table A2-6: Room 6

Length 7a mid to 9d mid (m)	24.12		C9 (south) to C10 (north) (m)	2.47
Length 8a mid to 10d mid (m)	24.06		C10 (south) to 5h/9h (m)	1.96
Pool d mid a to Pool e mid f (m)	29.02		8h/i to 10i/j (m)	8.23
Pool d a/h to Pool e i/j (m)	24.02		8h/i to C19 (m)	1.83
Length 7g/h to 9g/h (m)	10.56		C19 (south) to C20 (north) (m)	2.37
Length 7f/g perp. to 9g (m)	10.60		C20 (south) to 10i/j (m)	1.87
7i/j perp. to 9i (m)	10.65		Length Pool d: a/h to c/e (m)	6.65
7k/Pool d g perp. to 9k (m)	10.69		Length Pool d: a/d to b/e (m)	6.94
8f/Pool d g perp. to 10o (m)	10.63		Pool d: a mid perp. to e (m)	10.44
8f/Door R perp. to 10g (m)	10.64		Width Pool d: a/h to a/d (m)	8.81
8g/Door R to 10h/Door N (m)	10.68		Width Pool d: c/e to b/e (m)	8.35
8g/h to 10h/i (m)	10.70		Length Pool e: f/j to l/n (m)	6.80
4g/7h to 5h/9h (m)	8.25		Length Pool e: b/n to e/f (m)	5.31
4g/7h to C9 (north) (m)	0.90		Width Pool e: l/n to b/n (m)	9.08
5h/9h to 10i/j (m)	22.43		Width Pool e: f/j to e/f (m)	8.98
4g/7h to 8h/i (m)	22.48			

Name of Pool	Frigidarium Pool d				
Floor surface area (sq. m)	76.4917				
Floor Makeup	Paved with marble			rubble	curved
Name of Wall	a	b	c	d	h
Location in Room	N	E	W	E	E
Length of wall (m)	13.900	6.940	6.650	0.310	0.570
Height of extant wall (m)	1.58	1.41	2.25	1.50	1.33
Height of reconstruction (m)	0	0.54	0.32	0	1.35
Height Total (m)	1.58	1.95	2.57	1.50	2.68
Abuts adjacent wall?	d, h	d	h	a, b	a, c
Joins adjacent wall?	No	No	No	No	No
Doorway abutting?	No	No	No	No	No
Window?	Y, Opening	No	No	No	No
Refurbished?	Is Later	Yes and	Yes and	Later Fill	1988
	and 1988	1924/1964	1988		
Wall Fabric					
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Not visible	Not visible
Marble width (m)	0.02	0.02	0.02	Not visible	Not visible
Mortar width (m)	0.03	0.03	0.075	Not visible	Not visible
Cocciopesto width (m)	0.025	0.07	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No
Extra Brick Wall Width (m)	0.015	0.047	0.047	-	-
Extra Brick height from floor (m)	0.70	0.70	0.70	-	-
Brick Wall Width high (m)	0.78	0.83	1.00	0.83	0.83
Brick Wall Width low (m)	0.76	0.83	0.95	0.76	0.76
Tubuli on other side of wall?	Outside	Yes	Yes	Outside	Outside
Opening Name	1	2 in	2 out	3	
Location in Room	Step g in	Step e in	Step e out	wall a	
Distance from where?	wall b	wall b	wall b	seam in a	
Distance (m)	4.38	4.455	4.45	0.32	
Length (m)	0.24	0.115	0.26	0.30	
Width (m)	0.22	0.085	0.095	0.09	
Height from where?	Top of Step	Top of Step	Top of Step	Floor	
Height from location (m)	0.35	0.142	0.22	0.00	
Depth (m)	0.46	0.50	0.50	0.56	
Refurbished later?	No	Unclear	Unclear	Is Later fill	

Name of Niche	Niche 1	Niche 2	
Location in Room	E	W	
Distance from N or E end (m)	2.545	2.970	
Length of niche (m)	1.45	1.47	
Height from base to floor (m)	1.42	1.50	
Height from base to top (m)	Missing	Missing	
Height of reconstruction (m)	Missing	Missing	
Diameter niche surface (m)	0.64	0.61	
Marble Type on surface (m)	Not visible	Not visible	
Marble width (m)	Not visible	Not visible	
Mortar width (m)	Not visible	Not visible	
Refurbished later?	All new	Yes and	
		1924/64	
Steps of Pool Name	e	f	g
Steps of Pool Location	Step In	Step Top	Step Out
Length of step brick (m)	9.05	9.05	9.05
Refurbished later?	1988	1988	1988
Step face Inner			
Marble Type	Pavonazz.	Pavonazz.	-
Marble width (m)	0.02	0.025	-
Mortar width (m)	0.045	0.04	-
Cocciopesto width (m)	0.025	0.017	-
Brick width to next step (m)	0.23	0.30	-
Top surface of step			
Marble width (m)	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible
Height from pool floor (m)	0.42	0.86	0.10
Height of reconstruction (m)	0.00	0.00	0.23
Total height of step from floor (m)	0.42	0.86	0.33
Step face Outer			
Marble Type	-	-	Pavonazz.
Marble width (m)	-	-	Not visible
Mortar width high (m)	-	-	Not visible
Total width where missing (m)	-	-	0.08
Brick width to next step (m)	-	-	-

Name of Pool	Frigidarium Pool e							
Floor surface area (sq. m)	61.71							
Floor Makeup	Paved with marble							
Name of Wall	b	c	d	e	f	j	k	l
Location in Room	E	E	E	E	S	W	W	W
Length of wall (m)	1.270	1.690	1.490	2.350	9.010	2.275	1.500	3.025
Height of extant wall (m)	3.88	3.88	3.88	3.78	4.15	6.00	6.00	6.00
Height of reconstruction (m)	0	0.15	0.15	1.55	1.50	0	0	0
Height Total (m)	3.88	4.03	4.03	5.33	5.65	6.00	6.00	6.00
Abuts adjacent wall?	c	b	c, e	d	j?	f?, k	j, l	k
Joins adjacent wall?	c	b, e	No	c, f	e	k	j, l	k
Doorway abutting?	No	No	No	No	No	No	No	No
Window?	No	Niche	Niche	No	Niche	No	Niche	Opening
Refurbished?	Yes and	Is and	Is and	1924 and	Yes and	Yes and	Is and	Yes and
	1924/1964	1924/1964	1924/1964	1964	1954	Modern	Modern	Modern
Wall Fabric								
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Grn Brecia	Pavonazz.	Pavonazz.	Pavonazz.
Marble width (m)	0.02	0.02	0.02	0.017	0.02	0.02	0.013	0.02
Mortar width (m)	0.058	Unclear	0.035	Unclear	0.04	0.013	Unclear	Unclear
Cocciopesto width (m)	0.065	0.07	0.08	0.07	0.07	0.05	0.04	0.042
Evidence of Tubuli?	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.89	0.92	0.92	0.92	1.34	0.90	0.90	0.90
Tubuli on other side of wall?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Opening Name	1	2	3	4
Location in Room	wall l	wall k	niche m	step n
Distance from where?	s edge of l	s edge of k	s edge of l	wall l
Distance (m)	1.51	0.695	0.84	4.93
Length (m)	0.24	0.2025	0.15	0.24
Width (m)	0.375	0.28	0.15	0.15
Height from where?	Floor	Floor	Floor	Floor
Height from location (m)	1.74	1.26	2.47	0
Depth (m)	0.90	0.90	0.90	0.46
Refurbished later?	Blocked	Damaged	Is Later	No

Name of Niche	Niche d	Niche g	Niche h	Niche i	Niche m
Location in Room	E	S	S	S	W
Distance from N or E end (m)	1.690	0.960	3.600	6.300	3.025
Length of niche (m)	1.490	1.760	1.800	1.800	1.500
Height from base to floor (m)	1.54	1.50	1.50	1.50	1.59
Height from base to top (m)	2.74	3.02	3.02	3.02	2.43
Height of reconstruction (m)	0	0	1.5	0	0
Diameter of niche surface (m)	0.61	0.61	0.61	0.61	0.61
Marble Type on surface (m)	Pavonazz.	Pavonazz.	Not visible	Pavonazz.	Pavonazz.
Marble width (m)	0.025	0.025	Not visible	0.03	0.03
Mortar width (m)	0.015	0.02	Not visible	0.03	0.015
Brick cont into main wall m down		0.32	0.3	0.31	0.41
Refurbished later?	Is and	Yes and	Yes and	Yes and	Is and
	1924/1964	1954	1954	1954	Modern

Steps of Pool Name	a	n	o
Steps of Pool Location	Step Out	Step In	Step Top
Length of step brick to brick (m)	9.075	9.075	9.075
Refurbished later?			
Step face Inner			
Marble Type	-	Pavonazz.	Not visible
Marble width (m)	-	0.0125	Not visible
Mortar width high (m)	-	0.04	Not visible
Cocciopesto width (m)	-	0.06	Not visible
Brick width to next step (m)	-	0.22	-
Top surface of step			
Marble and Mortar	Not visible	Not visible	Not visible
Brick height from pool floor (m)	1.21	0.27	0.845
Height of reconstruction (m)	0.22	0.20	0.21
Total height of step from floor (m)	1.43	0.47	1.06
Step face Outer			
Marble Type	Pavonazz.	-	Not visible
Marble width (m)	0.0325	-	Not visible
Mortar width high (m)	0.075	-	Not visible
Total width where missing (m)	-	-	Not visible
Brick width to next step (m)	0.5	-	-

Notes:

Frigidarium Pool d	
Wall a	length follows curve; seam that follows windowsill starts 0.78 m from h; extra brick wall sticking
	out starts 0.7 m from ground; wall flush with Wall h fill; opening in area before seam, distance taken from
	bottom of opening, diagonal cut to outside, messy shape; windowsill is another 1.25 m higher
Walls b and c	were originally one wall, later work seems to separate them, 1.44 m up from pool floor
Wall c	brick wall comes out 0.05 m more on bottom, up until 0.69 m from the floor, makes wall even with Wall a
Wall d	length measurement follows diagonal wall curves on the bottom
Wall h	wall curves on bottom, measured above curve; sticks out 0.14 m from Wall c and 0.10 m from extra brick
	of Wall c, ends up flush with Wall a; all filled with mortar to compensate for the difference
Step g	outer face is mostly modern reconstruction; length given is total length
Opening 1	goes underground to a a capuccina drain
Opening 2	use is unclear; 0.095 m from floor of room 6
Frigidarium Pool e	
Step a	width varies: 0.49 m east, 0.51 m middle, 0.495 m west bit
Wall d	include as separate wall piece in addition to niche since there is extra piece; double marble extra 0.05 m
Wall j	6.00 m to spring of arch, another 1.50 m of arch, includes column capital and first piece on top
Wall k	separates at 1.35 m from pool floor
Niches	all seem to be added later, walls are otherwise all one piece, Niche D was originally an opening
Opening 2	width of opening ranges from 0.115 m to 0.28 m; hole starts 0.14 m down from brick of base of Niche m

Table A2-7: Room 7

Length d/f perp. to a (m)	5.81		**a/e to b/c (m)**		8.21		**f/g to 4g/h (m)**		1.78		
Length c/i perp. to a (m)	5.80		**a/b to d/e (m)**		8.22		**a/b to c/Door S**		5.91		
Width e/d to b/c (m)	5.86		**a/e to d/f (m)**		5.93						
d/f to c/i (m)	3.63										
Floor Surface Area (sq. m)	33.15		**Ceiling Surface Area (sq. m)**			50.32					
Floor Makeup	Marble Paving										
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**N**	**E**	**S**	**S**	**W**	**SW**	**NW**	**W**	**SE**	**NE**	**E**
Dimensions											
Length brick to brick (m)	5.800	5.730	1.180	1.160	5.735	0.890	1.160	1.240	0.890	1.150	0.970
Height of extant wall (m)	2.00	1.50	1.60	1.85	2.13	1.32	1.48	1.41	1.43	1.28	1.28
Height of reconstruction (m)	0.00	0.26	0.10	0.05	0.05	0.00	0.48	0.43	0.00	0.11	0.48
Height Total (m)	2.00	1.76	1.70	1.90	2.18	1.32	1.96	1.84	1.43	1.39	1.76
Abuts adjacent wall?	No	No	No	No	No	No	No	No	No	No	No
Joins adjacent wall?	b, e	a, c	b, i	e, f	a, d	d, g	f, h	g	j	i, k	j
Doorway abutting?	No	No	S	S	No	S	S	Opening	S	S	Opening
Window?	Opening	Opening	No	No	No	No	No	No	No	No	No
Refurbished?	Yes and	1964	Yes and	1964	Yes and	Yes and	1964	1964	Yes and	Yes and	1924 and
	1964		1964		1964	1964			1964	1964	1964
Wall Fabric											
Marble Type	Portasanta	Pavonazz.	Not visible	Not visible	Portasanta	Not visible	Column	Column	Not visible	Not visible	Column
Marble width (m)	0.02	0.03	Not visible	Not visible	0.03	Not visible	N/A	N/A	Not visible	Not visible	N/A
Mortar width (m)	0.05	0.04	Not visible	Not visible	0.025	Not visible	N/A	N/A	Not visible	Not visible	N/A
Cocciopesto width (m)	Not visible	0.03	Not visible	Not visible	0.045	Not visible	N/A	N/A	Not visible	Not visible	N/A
Evidence of Tubuli?	No	Yes	No	No	Yes	No	No	No	No	No	No
Mortar (m)	-	0.035-0.04	-	-	0.02	-	-	-	-	-	-
Total w where missing (m)	-	-	0.10	Not Visible	-	-	-	-	-	-	-
Brick Wall Width (m)	0.60	0.94	0.89	0.89	0.89	1.16	0.89	0.89	2.12	0.89	0.89
Tubuli on other side of wall?	Outside	No	Column	Column	No	Opening	Opening	No	Opening	Opening	Opening
Notes:											
Wall a	opening starts 0.79 m from Wall b, 0.175 m wide, 0.14 m deep, goes below floor; block of wall may not really belong										
Wall b	tubuli total width: 0.075-0.08 m, total length: 0.12 m, inner width: 0.055-0.06 m, inner length: 0.09 m; space between										
	tubuli: 0.03-0.04 m; opening in wall starts 0.24 m from Wall c, 0.69 m from floor, 0.43 m wide, 0.42 m high, 0.0155 m deep										

Table A2-8: Room 8

Length d/Door R perp. to a (m)	5.80		**a/e to d/Door R (m)**		7.42				
Length c/Door R perp. to a (m)	5.77		**a/b to c/Door R (m)**		7.42				
Width b/c to d/e (m)	5.74		**g/Door R to h/i (m)**		1.70				
c/Door R to d/Door R (m)	3.42		**a/e to b/c (m)**		8.18				
f/Door R to g/Door R (m)	3.41		**a/b to d/e (m)**		8.19				
Floor Surface Area (sq. m)	32.99		**Ceiling Surface Area (sq. m)**			49.80			
Floor Makeup	Unclear - grass								
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
Location in Room	**N**	**E**	**S**	**S**	**W**	**N**	**N**	**NE**	**N**
Dimensions									
Length brick to brick (m)	5.770	5.740	1.160	1.160	5.740	2.070	1.170	1.170	0.890
Height of extant wall (m)	0.50	1.07	1.20	0.83	0.17	1.02	1.45	1.45	1.91
Height of reconstruction (m)	0.32	0.81	0.05	0.17	0.46	0.05	0.05	0.05	0.28
Height Total (m)	0.82	1.88	1.25	1.00	0.63	1.07	1.50	1.50	2.19
Abuts adjacent wall? Inside/Outside	b?, e?	a?	No	No	a?	No	No	No	No
Joins adjacent wall? Inside/Outside	No	c	b, Door R	e?, Door R	d?	Door R	h, Door R	g, i	h
Doorway abutting?	No	No	R	R	No	R	R	Opening	Opening
Window?	Unclear	Unclear	No	No	Unclear	No	No	No	No
Refurbished?	1988	1964	Yes and	1988	1988	1988	Yes and	Yes and	Yes and
			1924/64/88				1924/64/88	1924/64/88	1924/64/88
Wall Fabric									
Marble Type	Not visible	Not visible	Portasanta?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	0.02	Not visible	Not visible	but column	but column	but column	Not visible
Mortar width (m)	Not visible	Not visible	0.45	Not visible	Not visible	was here	was here	was here	Not visible
Evidence of Tubuli?	No	Yes but	No	No	Not visible	No	No	No	No
		damaged							
Brick Wall Width (m)	0.575	0.89	0.89	0.89	0.85	0.89	0.89	0.89	Wall
Tubuli on other side of wall?	Outside	No	No	No	No	Yes	Yes	No	Wall
Notes:									
Wall b	tubulo is 0.04 m thick, mortar on wall is 0.015 m thick, nothing else remains								
Wall e	niche in this wall opens on other side but is 1.45 m wide and has a diameter of 0.64 m								
Wall i	earlier phase exists at a height of 0.29, which is included in the height of the next phase								
Windows	walls are too low to tell if there were windows								

Table A2-9: Room 9

Length f/Door Z perp. to d (m)	5.96		**e/f to b/c (m)**				8.27				
Length a/Door Z perp. to d (m)	5.95		**a/b to e/north threshold of Door E (m)**				8.28				
Width a/b to e/f (m)	5.77		**e/Door E to f/north thresh of Door Z (m)**				6.09				
a/Door Z to f/Door Z (m)	3.57		**b/c to a/Door Z (m)**				6.07				
g/Door Z to i/Door Z (m)	3.43		**g/Door Z to h/5 h (m)**				1.70				
Floor Surface Area (sq. m)	34.33		**Ceiling Surface Area (sq. m)**				51.28				
Floor Makeup	Unclear, grass										
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**N**	**E**	**S**	**S**	**E**	**N**	**SW**	**W**	**NE**	**NE**	**NE**
Dimensions											
Length brick to brick (m)	1.190	5.940	0.570	3.555	6.770	1.190	1.190	1.226	0.340	0.290	1.460
Height of extant wall (m)	6.05	6.05	6.05	2.40	6.05	1.92	1.92	1.92	1.17	1.39	1.41
Height of reconstruction (m)	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.15	4.88	4.66	4.64
Height Total (m)	6.05	6.05	6.05	2.40	6.05	2.12	2.12	2.07	6.05	6.05	6.05
Abuts adjacent wall?	No	c	b, d	c	No	No	No	No	No	No	No
Joins adjacent wall?	b, i	a, c	b, d	c, e	d, f	e, g	f, h	g	a, j	i, k	j
Doorway abutting?	Z	No	Blocked	E	E, break	Z	Z	Opening	Opening	Opening	Opening
Window?	No	No	No	No	Break	No	No	No	No	No	No
Refurbished?	Yes and	Yes and	Door blck	Yes	Opening	1994	Column	1994	1994	1994	1994
	Modern	1994	and 1994	and 1994	and 1994		and 1994				
Wall Fabric											
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Column	Basin	Basin	Basin
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Column	Area	Area	Area
Mortar width (m)	0.08	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Column	Pipes?	Pipes?	Pipes?
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.91	0.90	Varies	Block	0.89	0.91	0.91	0.90	0.91	0.67	Wall
Tubuli on other side of wall?	Opening	No-Pool	Yes	No	No	Opening	Opening	Opening	Opening	Opening	Opening
Notes:											
Walls a and b	height is 6.05 m to curve, 0.50 m of rubble on top (Room 6 is higher), 1.00 m more brick above rubble										
Walls c and d	blocked Door AI is 1.02 m long at floor level, extra chunk of Wall d in door is 0.505 m + 0.24 m + 1.79 m										
Wall e	length includes portion of Door E that is a continuation of the wall; for form of break in wall see drawing of Room 5,										
	sticking out brick begins at 2.11 m from Wall f, it is 1.18 m wide at that point and there is 3.48 m more wall to Door E										
Walls i, j, k	heights were taken to regular marble floor, not to lower basin (?) area; trapezoidal slot is 0.29 m wide on surface,										
	0.22 m in back of slot, 0.26 m diagonal, and 0.258 straight back										

Table A2-10: Room 10

Room 10: South-East Room										
Length f/Door N perp. to d (m)	5.94		l/k to b/c (m)		8.30		e/d to f/Door N (m)		6.80	
Length a/Door N perp. to d (m)	5.95		a/b to d/e (m)		8.30		d/Door I to e/k (m)		5.84	
Width e/d to b/c (m)	5.79		a/Door N to b/c (m)		6.05		e/k to l/f (m)		2.00	
Width k/l to a/b (m)	5.85		d/Door I to k/l (m)		7.04		e/k to f/Door N (m)		3.69	
h/Door N to i/j (m)	1.68									
Floor Surface Area (sq. m)	34.24		Ceiling Surface Area (sq. m)			51.49				
Floor Makeup	Unclear, concrete now									
Name of Wall	a	b	c	d	e	f	g	h	i	j
Location in Room	N	E	E	S	W	N	NW	NE	NE	NE
Dimensions										
Length brick to brick (m)	1.175	5.880	0.130	3.720	4.400	2.115	2.110	1.160	1.130	0.890
Height of extant wall (m)	3.26	3.38	2.64	1.50	3.21	1.45	1.45	3.76	3.26	3.26
Height of reconstruction (m)	0.00	0.60	0.00	0.25	0.50	0.00	0.10	0.00	0.00	1.59
Height Total (m)	3.26	3.98	2.64	1.75	3.71	1.45	1.55	3.76	3.26	4.85
Abuts adjacent wall?	No	Arch Door I	No	No	k	l	m	No	No	No
Joins adjacent wall? Inside/Outside	b	a, c	b	e	d	l	No	i	h, j	i
Doorway abutting?	N	No	I	I	No	N	N	N	Opening	Opening
Window?	No	No	No	No	No	No	Openings	No	No	No
Refurbished?	No	1964	Yes or	Yes and	Yes and	Maybe is	1924 and	No	No	No
			Modern	1924/1964	1924/1964	1924/1964	1964			
Wall Fabric										
Marble Type	Not visible	Pavonazzetto	Not visible	Not visible	Not visible	Not visible	Not visible	Column	Column	Not visible
Marble width (m)	Not visible	0.01	Not visible	Not visible	Not visible	Not visible	Not visible	was	was	Not visible
Mortar width (m)	Not visible	Unclear	Not visible	Not visible	Not visible	0.03	Not visible	here	here	Block 0.09
Cocciopesto width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	0.03	Not visible	-	-	-
Evidence of Tubuli?	No	No	No	No	Yes	No	No	No	No	No
Tubuli Total Width (m)	-	-	-	-	0.10	-	-	-	-	-
Tubuli Total Length (m)	-	-	-	-	0.08	-	-	-	-	-
Tubuli Inner Width (m)	-	-	-	-	0.06	-	-	-	-	-
Tubuli Inner Length (m)	-	-	-	-	0.08	-	-	-	-	-
Space between Tubuli (m)	-	-	-	-	0.035	-	-	-	-	-
Mortar (m)	-	-	-	-	0.03	-	-	-	-	-
Brick Wall Width (m)	0.89	0.89	0.89	0.89	0.89	0.90	0.90	0.89	0.89	Wall
Tubuli on other side of wall?	No	No	Yes	Yes	No	No	Yes	Yes	No	Wall

Name of Wall	k	l	m	n	o
Location in Room	W	NW	NW	NW	NW
Dimensions					
Length brick to brick (m)	1.510	1.190	0.335	0.280	1.430
Height of extant wall (m)	2.57	1.56	1.29	1.29	1.56
Height of reconstruction (m)	0.50	1.12	0.75	0.75	0.00
Height Total (m)	3.07	2.68	2.04	2.04	1.56
Abuts adjacent wall?	e	f	g	No	No
Joins adjacent wall? Inside/Outside	l	f, k	h	m, o	n
Doorway abutting?	No	No	Opening	Opening	Opening
Window?	No	No	No	No	No
Refurbished?	No	No	Maybe is	Maybe is	Maybe is
			1924/1964	1924/1964	1924/1964
Wall Fabric					
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	0.03	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	0.03	Not visible	Not visible	Not visible
Evidence of Tubuli?	Yes	No	No	No	No
Tubuli Total Width (m)	0.077	-	-	-	-
Tubuli Total Length (m)	0.115	-	-	-	-
Tubuli Inner Width (m)	0.05	-	-	-	-
Tubuli Inner Length (m)	0.092	-	-	-	-
Space between Tubuli (m)	0.035	-	-	-	-
Mortar (m)	0.03	-	-	-	-
Brick Wall Width (m)	0.89	0.90	0.90	0.69	0.90
Tubuli on other side of wall?	No	No	No	No	No

Notes:	
Walls b and c	thickness of Wall c makes it unlikely that there were tubuli on Wall b
Walls e, f, and l	walls join on bottom, seam between Walls f and l begins 0.45 m from floor, between Walls e and k begins
	0.22 m from floor; tubuli added after Wall k was built; structure (vasca?) 0.12 m from Wall e and 1.18 m from
	Wall d, 1.10 m long and 0.19 m wide at widest point
Wall n	slot 0.21 m deep, 0.28 m on inside; more gouged on bottom, goes straight back on top, more into wall on

Table A2-11: Rooms 11, 12, and 13

Length a (t-o) perp. to l (m)	24.02		**a/v to b/c (m)**		10.52		**d/e to f/Door O (m)**		3.62		
Length a (C23 W) perp. to l (m)	24.03		**a/b to u/v (m)**		10.62		**Door O/g to h (m)**		3.50		
Length a (C23 E) perp. to l (m)	24.02		**c/d to u/v (m)**		8.92		**e to h (m)**		10.57		
Length a (d-i) perp. to l (m)	24.04		**t to C21 W (m)**		1.85		**8i/r to s/t (m)**		1.40		
Width v/u to c/d (m)	8.82		**Edges C21/C22 (m)**		1.95		**d/e to f/Door O (m)**		3.66		
Width r/8i perp. to f (m)	9.47		**C22 W to d (m)**		1.85		**m/n to k/l (m)**		10.68		
Width q/10j perp. to g (m)	8.95		**s/t to d/e (m)**		7.645		**j/k to l/m (m)**		10.72		
Width m to k (m)	9.00		**s to q (m)**		8.24		**l/m to n/o (m)**		5.17		
o/p to s/t (m)	9.45		**a/v to t/u (m)**		5.84		**k/l to i/j (m)**		5.98		
h/i to d/e (m)	10.66		**a/b to c/d (m)**		5.84		**o/p to 10j/q (m)**		1.38		
Edges C23 /C24 (m)	2.03		**o/p to C23 W (m)**		1.85		**h/i to g/Door O (m)**		3.64		
C24 E to i (m)	1.85										
Floor Makeup	Room 11 is marble; 12 and 13 have mosaic floors, white and black tesserae: 0.015 x 0.015 or 0.0175										
	(13 w) m irregular, black band: 0.125 m wide, tesserae: 0.0125 x 0.013 m; tesserae are 0.025 m long and "modern"										
	hunk of mortar below is 0.045 m thick										
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**12 N**	**12 E**	**12 S**	**12 E**	**11 N**	**11 E**	**11 E**	**11 S**	**13 E**	**13 N**	**13 E**
Dimensions											
Length brick to brick (m)	8.790	5.750	0.740	0.890	0.740	3.520	3.540	0.600	0.890	0.600	5.870
Height of extant wall (m)	2.00	3.05	4.10	4.10	4.10	4.10	9.92	5.95	5.95	5.95	8.88
Height of reconstruction (m)	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Height Total (m)	2.00	3.15	4.10	4.10	4.10	4.10	9.92	5.95	5.95	5.95	8.88
Abuts adjacent wall?	No	c	b	No	No	No	h	g	No	k	j, l
Joins adjacent wall?	b, v	a	d	c, e	d, f	e	h	h, i	h, j	i	No
Doorway abutting?	No	No	Opening	Opening	Opening	O	O	Opening	Opening	Opening	No
Window?	No	Opening	No	No	No	No	No	No	No	No	No
Refurbished?	1988	Yes and	Yes and	Yes and	Yes and	Yes	Yes	Yes	Yes	Yes	No
		1988	1988	1988	1988	Modern	Modern	Modern	Modern	Modern	
Wall Fabric											
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Cipo/Pavona	Pavonazz.	Cipollino	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not clear	0.028	0.03	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not clear	0.044	0.03	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.60	0.60	0.89	0.90	0.89	1.03	1.03	0.88	0.60	0.88	1.03
Tubuli on other side of wall?	Vasca out	No	No	Wall	No	No	No	No	Wall	No	No

Name of Wall	l	m	n	o	p	q	r	s	t	u	v
Location in Room	**13 S**	**13 W**	**13 N**	**13 W**	**11 S**	**11 W**	**11 W**	**11 N**	**12 W**	**12 S**	**12 W**
Dimensions											
Length brick to brick (m)	8.890	5.860	0.585	0.890	0.590	1.120	1.180	0.600	0.900	0.595	5.740
Height of extant wall (m)	4.50	4.50	4.25	0.89	4.25	4.25	1.27	1.27	1.27	1.27	1.27
Height of reconstruction (m)	0.15	0.15	0.25	3.61	0.25	0.25	0.20	0.20	1.42	0.34	0.34
Height Total (m)	4.65	4.65	4.50	4.50	4.50	4.50	1.47	1.47	2.69	1.61	1.61
Abuts adjacent wall?	k, m	l, n	m	No	q	p	No	No	No	No	No
Joins adjacent wall?	No	No	o	n, p	o	No	s	r, t	s, u	t, v	a, u
Doorway abutting?	No	No	Opening	Opening	Opening	Opening	Opening	Opening	Opening	Opening	No
Window?	No	No	No	No	No	No	No	No	No	No	No
Refurbished?	1964	Yes and	Yes	Yes	No	No	1924 and	1924 and	1924 and	1924 and	1924 and
		1964	Modern	Modern			1964	1964	1964	1964	1964
Wall Fabric											
Marble Type	Not visible	Pavonazz.	Not visible	Not visible	Pavonazz.	Cipollino	Pavonazz.	Pavonazz.	Not visible	Pavonazz.	Not visible
Marble width (m)	Not visible	0.02	Not visible	Not visible	0.025	0.016	0.016	0.02	Not visible	0.016	Not visible
Mortar width (m)	0.025	0.06	0.06	Not visible	0.045	0.045	0.07	0.045	Not visible	0.05	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.87	0.89	0.89	0.59	0.89	0.88	0.90	0.90	0.60	0.90	0.90
Tubuli on other side of wall?	No	Yes	No	No	No	No	No	No	No	No	Yes

Notes:

Wall b	ovoid hole goes through to the other side, at floor level 0.93 m from Wall c, 0.45 m wide at base, 0.25 m at highest,
	inner hole has a diameter of 0.15 m
Walls g, h, i, j	height is 5.95 m to arch and 0.30 m of arch remain above that; g and h seem to abut on bottom and join on top (later)
Wall k	the springing of the vault begins at 5.92 m from the floor; the radius of the arch is 2.96 m.
Wall o	0.06 m of space where marble and mortar are missing

Table A2-12: Room 14

a/Door P perp. to e (m)	16.95		**g/h to d/Door AA (m)**	19.33				
h/Door P perp. to e (m)	17.17		**g/h to c/b (m)**	20.86				
g/Door O perp. to b (m)	12.00		**a/Door P to c/b (m)**	18.84				
f/Door O perp. to b (m)	12.00		**a/b to d/Door AA (m)**	16.48				
f/Door O to d/Door AA (m)	13.63		**a/b to e/f (m)**	20.25				
Floor Makeup	White mosaic with small irregular tesserae 0.012x0.012 m, with black band; large ditch							
	against wall b, 3.17 x 2.60 m, see plan							
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
Location in Room	**N**	**E**	**S**	**S**	**S**	**W**	**W**	**N**
Dimensions								
Length brick to brick (m)	8.500	17.120	0.570	0.900	7.100	10.330	3.360	0.130
Height of extant wall (m)	5.29	5.29	1.90	3.06	4.26	9.92	4.15	4.15
Height of reconstruction (m)	0.00	0.00	0.00	0.60	0.48	0.00	0.00	0.00
Height Total (m)	5.29	5.29	1.90	3.66	4.74	9.92	4.15	4.15
Abuts adjacent wall?	No	c	b	No	No	No	No	No
Joins adjacent wall?	b, 14b c	a	No	e	d, f	e	h	g, 14b d
Doorway abutting?	P	No	AA	C, AA	C	O	O	P
Window?	No	No	No	No	No	No	No	No
Refurbished?	1967	1967	Is later	Opening	1964	1964	No	No
				and 1964				
Wall Fabric								
Marble Type	Missing	Missing	Missing	Missing	Pavonazzetto	Missing	Missing	Missing
Marble width (m)	Missing	Missing	Missing	Missing	0.02	Missing	Missing	Missing
Mortar width (m)	0.05	0.04	Missing	Missing	0.07	0.07	Missing	Missing
Cocciopesto (outer) width (m)	0.03	Missing	Missing	Missing	0.02	0.02	Missing	Missing
Evidence of Tubuli?	No	No	No	No	No	No	No	No
Brick Wall Width (m)	0.90	Too high	0.89	Wall	0.90	1.04	1.02	0.86
Tubuli on other side of wall?	No	No	Service	Wall	Boilers	No	No	No

Notes:

All Walls	covered with holes for marble revettement
Walls a and b	width is only measured for inner walls, walls behind are older and part of another structure
Walls f	fistulae slot starts 3.33 m from Door O; starts 1.37 m from floor and goes all the way up; filled
	and bricks of Room 11 Wall g can be seen behind; 0.24 m wide, rectangular slot

Table A2-13: Room 14b

a/b perp. to e (m)	5.03		**a/b to d/e (m)**		7.53			
f/g to d/e (m)	6.30		**e/f to g/h (m)**		1.50			
e/f to b/c (m)	8.12							
Floor Makeup	Mosaic with small white irregular tesserae 0.012 x 0.012 m							
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
Location in Room	**N**	**E**	**S**	**S**	**W**	**N**	**NE**	**N**
Dimensions								
Length brick to brick (m)	0.350	5.950	0.730	0.750	6.130	1.400	0.560	0.960
Height of extant wall (m)	2.10	3.90	3.90	4.15	4.15	0.18	1.80	0.68
Height of reconstruction (m)	0.00	0.00	0.00	0.00	0.00	1.88	0.00	0.18
Height Total (m)	2.10	3.90	3.90	4.15	4.15	2.06	1.80	0.86
Abuts adjacent wall?	No	No	No	e	e, f	No	f	No
Joins adjacent wall?	b	a, c	b	No	No	e, g	h	g
Doorway abutting?	Q	No	P	P	No	No	No	Q
Window?	No	No	No	No	Opening	Opening	No	No
Refurbished?	Opening	No	No	Repair	1964	Yes and	1964	Opening
				Modern?		modern?		and 1964
Wall Fabric								
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick Wall Width (m)	1.35	Unclear	0.90	0.86	0.60	1.02	0.96	0.56
Tubuli on other side of wall?	Outside	No	No	Wall	No	Outside	Outside	Outside

Notes:

Wall a	length is only 0.10 m on the top part, damaged by opening Door Q; was originally same wall
	as Wall h; there was probably a fountain in front of this wall from extant basin
Wall e	semicircular opening is 1.13 m from Wall f, 0.30 m wide on bottom, 0.20 m high
Wall f	opening down through floor is 0.30 m from Wall e, 0.50 m wide, 0.12 m high, then below floor

Table A2-14: Room 15

Length a/Door perp. to g (m)	11.81		**d/Door B to e/f (m)**		6.20		**h/i to a/j (m)**			9.00
Width i/j perp. to e (m)	12.08		**e/f to g/h (m)**		8.95		**b/Door A to c/Door B (m)**			3.27
Floor Surface Area (sq. m)	113.7068		**Ceiling Surface Area (sq. m)**			229.22	**b/Door A to d/Door B (m)**			4.85
Floor Makeup	Unclear, grass						**g/h to i/j (m)**			9.05
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
Location in Room	**N**	**N**	**NE**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
Dimensions										
Length brick to brick (m)	0.600	2.000	1.510	1.660	4.850	4.850	4.850	4.880	4.880	4.850
Height of extant wall (m)	1.87	2.05	1.86	1.70	1.80	1.95	1.00	2.20	2.20	2.00
Height of reconstruction (m)	0.27	0.64	0.78	0.90	0.77	0.00	0.25	0.00	0.00	0.25
Height Total (m)	2.14	2.69	2.64	2.60	2.57	1.95	1.25	2.20	2.20	2.25
Abuts adjacent wall?	No	No	No	No	No	No	h in	g and i in	h in	No
Joins adjacent wall?	j	c	b	e	d, f	e, g	f, h out	g and i out	h out, j	a, i
Doorway abutting?	A	A	B	B	No	No	No	No	No	No
Window?	No	No	No	No	No	Yes	Unclear	Yes	Yes	No
Window starts (m from edge)	-	-	-	-	-	0.66	-	4.58	0.30	-
Window ends (m from edge)	-	-	-	-	-	Missing	-	Missing	4.58	-
Window length (m)	-	-	-	-	-	Missing	-	Missing	4.28	-
Window height extant (m)	-	-	-	-	-	0.59	-	0.72	0.69	-
Height from floor to window base (m)	-	-	-	-	-	1.37	-	1.48	1.51	-
Window pane width (m)	-	-	-	-	-	0.44	-	0.30	0.30	-
Refurbished?	Yes	Yes	Yes and	Yes	Yes	Yes	Yes and	Yes	Yes	Yes
	1964	1964	1964	1924/64	1924/64	1988	1988	1988	1964	1964
Wall Fabric										
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	No	No	No	No	No	No	No	No	No	No
Brick Wall Width (m)	1.00	1.00	1.15	1.15	0.90	0.85	0.88	0.88	0.88	0.88
Tubuli on other side of wall?	No	No	Yes	Yes	Yes	Substruc.	Outside	Outside	Outside	Outside

Notes:

Walls c and d	brick wall width varies per unusual shape of walls
Walls e and f	seem to join, unclear, outside corners abut with Room 16, but e/f clearly built with the corner of 16e
Wall f	window may actually be a seam and not a window at all, the seam meets the outer wall of Room 16
Walls h and i	the lower part of these walls is clearly joined, but there is a seam that begins on top, join on all of ouside

Table A2-15: Room C

Length brick to brick a-c center (m)	2.10				
Length brick to brick a-c end both (m)	1.94				
Length brick to brick a/b-e (m)	2.32				
Length brick to brick b/Door D-d (m)	3.90				
Length d/Door B to a/b (m)	4.12				
Length d/Door B to c/Door B (m)	1.60				
Length d/Door B to Door B/15d (m)	1.60				
Length d/Door B to c/e (m)	3.10				
Length b/Door D to c/e (m)	1.58				
c/Door B to d/Door B (m)	1.65				
c/Door B to a/d (m)	2.28				
c/Door D to a/b (m)	2.30				
c/Door D to 16a/Door D (m)	2.20				
Ceiling Surface Area (sq. m)	27.46				
Floor Surface Area (sq. m)	6.64				
Floor Makeup	Mosaic of reused marble, 0.04 x 0.05 m, 0.03 m thick				
Name of Wall	**a**	**b**	**c**	**d**	**e**
Location in Room	**N**	**NE**	**S**	**NW**	**SE (block)**
Dimensions					
Length brick to brick (m)	4.200	0.800	1.760	0.800	0.480
Height of existant wall (m)	6.50	6.50	6.50	2.68	0.75
Height of reconstruction (m)	0.00	0.00	0.00	0.00	0.00
Height Total (m)	6.50	6.50	6.50	2.68	0.75
Abuts adjacent wall?	No	No	No	No	D
Joins adjacent wall?	b, d	a	B, D	a	No
Doorway abutting?	No	D	B	B	D
Window?	No	No	No	No	No
Refurbished?	Unclear	Unclear	Unclear	Unclear	Later
Wall Fabric					
Marble Type	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	0.06	0.03	0.02	0.05	0.03
Cocciopesto width (m)	0.02	0.005	0.005	Not visible	0.005
Evidence of Tubuli?	Yes	No	No	No	No
Tubuli Total Width (m)	0.08	Not visible	Not visible	Not visible	Not visible
Tubuli Total Length (m)	0.12	Not visible	Not visible	Not visible	Not visible
Tubuli Inner Width (m)	0.05	Not visible	Not visible	Not visible	Not visible
Tubuli Inner Length (m)	0.09	Not visible	Not visible	Not visible	Not visible
Space between Tubuli (m)	0.01	Not visible	Not visible	Not visible	Not visible
Mortar width (m)	0.03	Not visible	Not visible	Not visible	Not visible
Brick Wall Width (m)	Unclear	1.07	Varies	1.15	0.47
Tubuli on other side of wall?	No	No	Wall	No	Yes
Notes:					
Wall c	straight length is 1.70 m				
Wall e	later block abutting Door D; 0.80 m from c/Door D				

Table A2-16: Room 16

Length mid a to mid d (m)	14.00				
Width brick to brick (m)	8.85				
Length b/Door F perp. to wall (m)	7.40				
Length c/Door F perp. to wall (m)	8.20				
Length seam to seam (m)	7.60				
Length from line of seam to e (m)	3.60				
b/Door E to b/Door F (m)	2.10				
c/Door F to seam (m)	7.82				
c/Door F to north corner of C26 (m)	8.01				
Edge C26 to e seam (m)	6.92				
e/Door D to e seam (m)	8.02				
a/Door D to c/Door F (m)	7.52				
e/Door D to c/Door F (m)	7.91				
a/Door D to e/Door D (m)	1.67				
Ceiling Surface Area (sq. m)	212.59				
Floor Surface Area (sq. m)	97.31	with bench, 87.36 withno bench, 9.95 bench			
Floor Makeup	Intermittent small white tesserae mosaic and modern floor				
	small are 0.01x0.01 m, large are 0.015x0.015 m				
Name of Wall	**a**	**b**	**c**	**d**	**e**
Location in Room	**N**	**NE**	**E**	**S**	**W**
Dimensions					
Length brick to brick on curve (m)	3.450	2.100	6.300	10.600	8.250
Length brick to brick straight line (m)	3.200	2.100	6.200	7.600	8.000
Height of extant wall (m)	3.90	1.32	2.13	2.08	3.35
Height of reconstruction (m)	6.00	1.32	0.00	0.00	10.00
Height Total (m)	9.90	2.64	2.13	2.08	13.35
Abuts adjacent wall?	No	No	d	c, e	d
Joins adjacent wall?	No	No	d	c, e	d
Doorway abutting?	D, E	E, F	F	No	D
Window?	No	No	No	No	No
Other?	Niche	No	No	Column, Arch	No
Refurbished?	1964	1964	1964	1964	1924/1964
Bench?	No	No	Yes	Mostly gone	Yes
Marble Type on facing of bench	-	-	Grigio	Grigio	Grigio
Marble width (m)	-	-	0.002	0.002	0.002
Mortar width (m)	-	-	0.03	0.03	0.03
Bench width of brick and mortar (m)	-	-	0.445	0.445	0.445
Bench width of brick (m)	-	-	0.40	-	-
Bench height of brick and mortar (m)	-	-	0.49	0.49	0.49
Bench height of brick (m)	-	-	0.44	-	0.44
Mortar on top surface of bench (m)	-	-	0.03	0.03	0.03
Marble type on top surface of bench	-	-	Not visible	Not visible	Not visible
Marble width on top of bench (m)			0.023	0.023	0.023

Wall Fabric					
Marble Type	Not visible	Not visible	Pavonazzetto	Giallo, Brecia	Giallo
Marble width (m)	0.01	Not visible	0.02	0.02	0.02
Mortar width (m)	0.095	Not visible	0.07	0.07	0.07
Evidence of Tubuli?	Up to niche	No	Yes	Yes	Yes
Tubuli Total Width (m)	0.09	-	0.08	0.08	0.08
Tubuli Total Length (m)	0.12	-	0.14	0.14	0.14
Tubuli Inner Width (m)	0.05	-	0.06	0.06	0.06
Tubuli Inner Length (m)	0.075	-	0.10	0.10	0.10
Space between Tubuli (m)	0.02	-	0.02	0.02	0.02
Mortar width high (m)	0.04	-	0.065	0.065	0.065
Mortar width low (m)	0.04	-	0.025	0.025	0.025
Brick Wall Width (m)	Unclear	2.20	2.47	0.99	2.20
Tubuli on other side of wall?	No	Wall	Yes	Outside	No/Outside
Niche					
Height of start of base from floor (m)	0.76				
Height from arch spring to floor (m)	2.83				
Height from spring to top of arch (m)	1.07				
Width brick to brick (m)	1.45				
Base Mortar thickness on face (m)	1.00				
Base Marble type	Bianco				
Base Marble thickness (m)	1.50				
Mortar thickness high (m)	0.08				
Mortar thickness low (m)	0.09				

Notes:

Wall a	wall is too high to measure exactly, but should be close
	to 10.00 m; brick wall width is 1.07 m at Door D, 1.10 m
	at Door E
Wall b and d	thickness of brick wall varies, but 2.20 m is thickest point,
	0.90 m on b
Wall c	bench begins at 0.75 m from north end; seam begins
	0.32 m from floor
Wall d	bench begins at 7.05 m from east seam on curve
Wall e	thickness is 0.90 m at corner with f and gets bigger;
	bench breaks at 5.70 m from west seam, resumes at
	6.80 m and then ends at 8.00 m
Walls c, d, and e	c/d join at the bottom, then abut, seem to match wall of
	Room 17; d/e are covered by bench but probably join on
	the bottom; seams clearly visible from outside
Bench	marble behind bench, did not remove when it was added,
	seems a bit piecemeal - Pavonazzetto and Breccia behind

Table A2-17: Room 17

Length mid e perp. to a (m)	14.29		**a/k to c/Door H (m)**		12.96		**a/b to f/e (m)**			15.70	
Width i/Door F perp. to c (m)	10.25		**a/k to d/Door H (m)**		13.80		**d/Door H to f/e (m)**			9.71	
Width e/f perp. to d (m)	9.37		**a/k to d/e (m)**		15.63		**g/f to d/e (m)**			9.65	
Width c/Door H perp. to h (m)	10.25		**a/b to i/Door F (m)**		10.41		**Outside bases C27 to C28 (m)**			4.34	
a/k to b/Door G (m)	9.45		**a/b to h/Door F (m)**		11.04		**a/k to c/Door G (m)**			10.02	
a/b to j/k (m)	9.44		**a/b to g/h (m)**		14.10		**a/b to g/f (m)**			13.80	
Floor Surface Area (sq. m)	134.74						**Ceiling Surface Area (sq. m)**			189.25	
Floor Makeup	Marble with modern sections										
Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**N**	**E**	**E**	**E**	**S**	**W**	**SW**	**W**	**W**	**NW**	**W**
Dimensions											
Length brick to brick (m)	9.420	0.530	6.600	2.420	10.170	2.480	0.440	5.080	2.800	0.430	0.580
Height of extant wall (m)	4.15	4.48	4.15	3.35	2.60	2.24	2.24	2.95	3.87	4.15	4.15
Height of reconstruction (m)	0.33	0.15	0.00	1.20	0.24	0.12	0.12	0.54	0.14	0.77	0.77
Height Total (m)	4.48	4.63	4.15	4.55	2.84	2.36	2.36	3.49	4.01	4.92	4.92
Abuts adjacent wall?	b, k	a	N/A	e	d, f	e	h	g	j	i	a
Joins adjacent wall?	No	No	N/A	No	No	g	f	No	No	k	j
Doorway abutting?	No	G	G, H	H	No	No	No	F	F	No	No
Window?	No	No	No	No	Yes	No	No	No	No	No	No
Refurbished?	Yes and	Yes and	Extra wall	Extra wall	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and
	1964	1964	and 1964	and 1964	1964	1964	1964	1964	1964	1964	1964
Wall Fabric											Pavonazz.
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Missing	Pavonazz.	Missing	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.
Marble width (m)	0.035	0.035	0.035	Missing	0.025	Missing	0.035	0.035	0.035	0.035	0.035
Mortar width high (m)	0.12	0.12	0.12	Missing	0.095	Missing	0.12	0.12	0.12	0.12	0.12
Mortar width low (m)	0.105	0.105	0.105	Missing	0.095	Missing	0.105	0.105	0.105	0.105	0.105
Empty space for missing (m)	-	-	-	0.07	-	0.07	-	-	-	-	-
Evidence of Tubuli?	Yes	Unclear	Yes	Yes	No	Missing	Missing	Yes	Yes	Unclear	Unclear
Tubuli Total Width (m)	0.11	-	0.11	0.11	-	-	-	0.11	0.11	-	-
Tubuli Total Length (m)	0.14	-	0.14	0.14	-	-	-	0.14	0.14	-	-
Tubuli Inner Width (m)	0.075	-	0.075	0.075	-	-	-	0.075	0.075	-	-
Tubuli Inner Length (m)	0.115	-	0.115	0.115	-	-	-	0.115	0.115	-	-
Space between Tubuli (m)	0.05	-	0.05	0.05	-	-	-	0.05	0.05	-	-
Mortar (m)	0.04	-	0.04	0.04	-	-	-	0.04	0.04	-	-
Brick Wall Width (m)	1.34	1.80	0.74 inner	1.15 inner	0.90	2.47	Wall	0.97	2.33	Wall	2.20
			0.94 outer	0.98 outer							
Tubuli on other side of wall?	Yes	Yes	Yes	Yes	Outside	Yes	Yes	Yes	Yes	Yes	Yes

Table A2-18: Room 18

Length i/Door J perp. to f (m)	12.48				
Length a/Door J perp. to e (m)	12.43				
Length a/b perp. to d (m) (not c/d)	12.33	(Wall c is set back further than wall b)			
Width h/Door H perp. to b (m)	10.44				
Width b/Door L perp. to g (m)	10.50				
Width c/Door L perp. to g (m)	10.62				
Width g/Door H perp. to b (m)	10.49				
a/Door J to b/Door L (m)	10.46				
c/Door L to f/g (m)	11.46				
g/Door H to c/d (m)	13.42				
i/Door J to h/Door H (m)	2.70				
h/i to f/g (m)	12.40				
Floor Surface Area (sq. m)	128.66		**Ceiling Surface Area (sq. m)**		**202.35**
Floor Makeup	Marble with modern sections				
Name of Wall	**a**	**b**	**c**	**d**	**e**
Location in Room	**N**	**E**	**E**	**S**	**S**
Dimensions					
Length brick to brick (m)	7.800	6.950	3.750	1.600	7.630
Height of extant wall (m)	4.72	4.26	5.04	6.58	1.14
Height of reconstruction (m)	1.21	0.00	0.00	0.00	0.00
Height Total (m)	5.93	4.26	5.04	6.58	1.14
Abuts adjacent wall? Inside/Outside	No	No	d	c	No
Joins adjacent wall? Inside/Outside	b	a	No	e	d, f
Doorway abutting?	J	L	L	No	No
Window?	No	No	No	No	Yes
Refurbished?	Broken and	Yes and	Wall added	Is and	Is and
	1988	1964	No Modern	No Modern	No Modern
Wall Fabric					
Marble Type	Pavonazzetto	Pavonazzetto	Pavonazzetto	Pavonazzetto	Pavonazzetto
Marble width (m) high	0.02	0.02	0.02	0.04	0.04
Marble width (m) low	-	-	-	0.03	0.03
Mortar width high (m)	0.07	0.07	0.07	0.08	0.08
Mortar width low (m)	0.03	0.03	0.03	0.07	0.07
Evidence of Tubuli?	Yes	Yes	Yes	No	No
Tubuli Total Width (m)	0.10	0.10	0.10	-	-
Tubuli Total Length (m)	0.14	0.14	0.14	-	-
Tubuli Inner Width (m)	0.07	0.07	0.07	-	-
Tubuli Inner Length (m)	0.10	0.10	0.10	-	-
Space between Tubuli (m)	0.02	0.02	0.035	-	-
Mortar (m)	0.03	0.03	0.03	-	-
Brick Wall Width (m)	0.70	1.06	1.09	0.87	0.87
	0.33 is orig.				
Tubuli on other side of wall?	Interspersed	Yes	Yes	Outside	Outside

Name of Wall	f	g	h	i
Location in Room	S	W	W	N
Dimensions				
Length brick to brick (m)	1.450	8.110	2.460	1.130
Height of extant wall (m)	6.58	5.81	3.80	2.65
Height of reconstruction (m)	0.00	0.00	0.00	1.31
Height Total (m)	6.58	5.81	3.80	3.96
Abuts adjacent wall? Inside/Outside	g	f	i, 20g	h, 20f1
Joins adjacent wall? Inside/Outside	e	No	No	20f2
Doorway abutting?	No	H	H	J
Window?	No	No	No	No
Refurbished?	Is and	Yes but does	Yes but	1924 and
	No Modern	not look mod	No Modern	1964 only
Wall Fabric				
Marble Type	Pavonazzetto	Pavonazzetto	Pavonazzetto	Pavonazzetto
Marble width (m) high	0.04	0.02	0.02	0.02
Marble width (m) low	0.03	-	-	-
Mortar width high (m)	0.08	0.07	0.07	0.07
Mortar width low (m)	0.07	0.03	0.03	0.03
Evidence of Tubuli?	No	Yes	Yes	Yes
Tubuli Total Width (m)	-	0.10	0.10	0.10
Tubuli Total Length (m)	-	0.14	0.14	0.14
Tubuli Inner Width (m)	-	0.07	0.07	0.07
Tubuli Inner Length (m)	-	0.10	0.10	0.10
Space between Tubuli (m)	-			
Mortar (m)	-	0.03	0.03	0.03
Brick Wall Width (m)	0.87	0.97 inner	0.91 inner	0.71
		1.04 outer	0.74 outer	
Tubuli on other side of wall?	Outside	Unclear	Yes	Interspersed

Notes:	
Wall a	total height is 4.72 m but only 1.41 m shows, then 1.21 incorrectly
	reconstructed, the rest is present as just slight ends of brick
Wall e	1.14 m high wall + 0.18 mass below pillars, 5.81 high with pillars
	and part above; pillars are 0.38 m wide (e-w) and 0.44 m long (n-s)
Wall g	0.03 m of space between two walls
Wall h	0.035 m of space between two walls

Table A2-19: Room 19

Length a/s perp. to o (m)	12.07		**i/j to g/h (m)**			8.82				
Length e/f perp. to k (m)	12.20		**i/j to k/l (m)**			2.02				
Width e/f perp. to q (m)	10.39		**p/Door L to o/n2 (m)**			7.61				
Width i/j perp. to p (m)	10.13		**m2/nrubble to m1/lrubble (m)**			6.85				
q/Door L perp. to instep b (m)	10.37		**o/n2 to l2/lrubble (m)**			7.78				
p/Door L perp. to instep b (m)	10.26		**k/l1 to n1/nrubble (m)**			7.77				
q/Door L perp. to f-j (m)	10.46		**m1 to C30 base cord (m)**			2.04				
p/Door L perp. to f-j (m)	10.35		**m1 to C30 base curve (m)**			2.10				
a/b to d/e (m)	6.79		**Base C30 inner width (m)**			0.66				
i/j to f/g (m)	8.25		**W base C30 to m2 curve (m)**			5.22				
k/l1 to o/n (m)	6.73		**W base C30 to m2 cord (m)**			4.77				
mid m perp. to inner step (m)	6.18		**m2 to C29 W base (out) (m)**			2.57				
a/b to c/d (m)	7.73		**Bases C29 to C30 out (m)**			3.33				
b/c to d/e (m)	7.60		**Base C30 outer width (m)**			0.60				
d/e to f/g (m)	2.26		**Base C29 outer width (m)**			0.60				
g/h to h/i straight (m)	8.25		**E base C30 to m1 (m)**			2.67				
f/g to h/i (m)	8.81		**g/h to h/i curved (m)**			8.40				
Floor Surface Area (sq. m)	226.17	Total	110.64	Just Floor	29.9183	Steps	77.6089	Pools	7.9949 just Door K	
Ceiling Surface Area (sq. m)	187.98 (bare floor) + 8.01 (Door K) + 36.26 (Pool a) + 36.07 (Pool b) + 71.15 (pool g) + 36.96 (pool g) = 376.43									
Floor Makeup	Marble; pool floors are on same level as floors									

Name of Wall	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**	**k**
Location in Room	**N**	**Pool a W**	**Pool a N**	**Pool a E**	**N**	**E**	**Pool b N**	**Pool b E**	**Pool b S**	**E**	**S**
Dimensions											
Length brick to brick (m)	0.900	3.560	6.750	3.560	0.900	2.065	3.010	8.400	3.060	1.850	0.900
Height of extant wall (m)	4.26	4.10	4.15	3.55	3.35	3.56	3.10	3.30	3.00	2.25	2.40
Height of reconstruction (m)	0.00	0.00	0.14	0.18	0.21	0.12	0.12	0.10	0.00	0.11	0.16
Height Total (m)	4.26	4.10	4.29	3.73	3.56	3.68	3.22	3.40	3.00	2.36	2.56
Abuts adjacent wall?	No	c	b	No	f	e	No	No	No	k	j
Joins adjacent wall?	b, s	a, s	d, 20d, K	c, e	d	g	f, h	g, i	h, j	i	l1
Doorway abutting?	K	No	No	No	No	No	No	No	No	No	No
Window?	No	No	No	No	No	No	No	No	No	No	No
Refurbished?	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes and	Yes
	1964	1964	1964	1964	1964	1964	1964	1964	1964	1924/1964	
Wall Fabric											
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Not visible	Not visible
Marble width (m)	0.02	0.03	0.04	0.03	0.03	0.03	0.02	0.02	0.02	Not visible	Not visible
Mortar width high (m)	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	Not visible
Mortar width low (m)	0.05	0.02	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	Not visible
Cocciopesto high (m)	0.02	0.03	0.03	0.03	Unclear	0.03	0.06	0.06	0.06	Not visible	0.04
Cocciopesto low (m)	0.02	0.02	0.02	0.02	Unclear	0.03	0.05	0.05	0.05	Not visible	0.04
Evidence of Tubuli?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tubuli Total Width (m)	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.10	0.10
Tubuli Total Length (m)	0.12	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Tubuli Inner Width (m)	0.05	0.075	0.075	0.075	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Tubuli Inner Length (m)	0.08	0.10	0.10	0.10	0.08	0.08	0.09	0.09	0.09	0.08	0.08
Space between Tubuli (m)	0.035	0.025	0.025	0.015	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mortar (m)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Brick Wall Width (m)	4.32	0.90	0.76	0.76	4.32	0.95	0.87	0.65	0.91	0.72	Unclear
Mortar tubuli to heat wall (m)	-	0.05	0.05	0.03	-	-	0.03	0.03	0.03	-	-
Heat Brick Wall Width (m)	-	0.14	0.14	0.14	-	-	0.20	0.20	0.15	-	-
Heat Brick Wall Height (m)	-	1.05	1.05	1.05	-	-	1.05	1.05	1.05	-	-
Tubuli on other side of wall?	Wall	No	Substrct	Substrct	Substrct	Substrct	Substrct	Substrct	Substrct	Wall	Wall

Name of Wall	l1	l2	l rubble	m1	m	m2	n1	n2	n rubble
Location in Room	Pool g E	Pool g E	Pool g E	Pool g S	Pool g S	Pool g S	Pool g W	Pool g W	Pool g W
Dimensions									
Length brick to brick (m)	0.880	2.950	0.830	0.610	7.960	0.630	2.450	1.400	0.750
Height of extant wall (m)	2.82	2.82	2.85	2.72	1.55	5.24	1.95	3.16	4.84
Height of reconstruction (m)	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Height Total (m)	2.87	2.87	2.85	2.72	1.55	5.24	1.95	3.16	4.84
Abuts adjacent wall?	l2	l1, lrubble	l1, m1	lrubble	No	nrubble	nrubble	No	m2, n1
Joins adjacent wall?	k	No	No	m	m1, m2	m	n2	n1, o	No
Doorway abutting?	No	No	No	No	No	No	No	No	No
Window?	No	No	No	Is window	Yes	Is window	Yes	No	No
Refurbished?	Yes	Yes	Is Later	Is Later	Is Later	Is Later	Yes and	Yes and	Is Later
				and 1966	and 1966	and 1966	1966	1966	
Wall Fabric									
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Not visible	Not visible	Not visible
Marble width (m)	0.03	0.03	0.03	0.02	0.02	0.02	Not visible	Not visible	Not visible
Mortar width high (m)	0.07	0.07	0.07	0.04	0.04	0.04	0.04	0.04	0.04
Mortar width low (m)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Cocciopesto high (m)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Cocciopesto low (m)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Evidence of Tubuli?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tubuli Total Width (m)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Tubuli Total Length (m)	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Tubuli Inner Width (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Tubuli Inner Length (m)	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Space between Tubuli (m)	0.04	0.04	0.04	0.01	0.01	0.01	0.01	0.01	0.01
Mortar (m)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Brick Wall Width (m)	Unclear	Unclear	0.74	0.74	0.70	0.74	1.26	1.26	Unclear
Mortar tubuli to heat wall (m)	-	-	-	-	-	-	-	-	-
Heat Brick Wall Width (m)	-	-	-	-	-	-	-	-	-
Heat Brick Wall Height (m)	-	-	-	-	-	-	-	-	-
Tubuli on other side of wall?	Substrct	Substrct	Substrct	Outside	Outside	Outside	Outside	Outside	Outside

Name of Wall	o	p	q	r	s	t
Location in Room	S	W	W	N	N	N
Dimensions						
Length brick to brick (m)	2.500	7.300	3.260	3.570	3.600	0.150
Height of extant wall (m)	3.10	5.04	4.26	2.95	2.95	2.95
Height of reconstruction (m)	0.00	0.00	0.00	0.00	0.00	0.00
Height Total (m)	3.10	5.04	4.26	2.95	2.95	2.95
Abuts adjacent wall?	p	o	No	t, Door K	Door K	r
Joins adjacent wall?	n2	No	r	q	a, b	K, 20e1
Doorway abutting?	No	L	K, L	Inside K	Inside K	Inside K
Window?	No	No	No	No	No	No
Refurbished?	1966	No	Yes and	Yes and	Yes and	Yes and
			1964	1964	1964	1964
Wall Fabric						
Marble Type	Not visible	Pavonazz.	Pavonazz.	Not visible	Not visible	Not visible
Marble width (m)	Not visible	0.03	0.06	Not visible	Not visible	Not visible
Mortar width high (m)	0.05	0.05	0.05	0.05	0.06	Not visible
Mortar width low (m)	0.03	0.04	0.04	0.04	0.06	Not visible
Cocciopesto high (m)	0.03	0.04	0.04	0.04	Not visible	Not visible
Cocciopesto low (m)	0.03	0.04	0.04	0.04	Not visible	Not visible
Evidence of Tubuli?	Yes	Yes	Yes	Yes	No	No
Tubuli Total Width (m)	0.10	0.10	0.10	0.10	Not visible	Not visible
Tubuli Total Length (m)	0.12	0.12	0.12	0.12	Not visible	Not visible
Tubuli Inner Width (m)	0.05	0.05	0.05	0.05	Not visible	Not visible
Tubuli Inner Length (m)	0.08	0.08	0.08	0.08	Not visible	Not visible
Space between Tubuli (m)	0.03	0.035	0.035	0.035	Not visible	Not visible
Mortar (m)	0.04	0.04	0.04	0.04	Not visible	Not visible
Brick Wall Width (m)	Unclear	1.04	1.06	1.05	0.90	0.74
Mortar tubuli to heat wall (m)	-	-	-	-	-	-
Heat Brick Wall Width (m)	-	-	-	-	-	-
Heat Brick Wall Height (m)	-	-	-	-	-	-
Tubuli on other side of wall?	Out/Wall	Yes/Out	Yes	Yes	Yes	Yes

Opening Name	1	2	3	4	5	6	7	8	9	10	11
Opening Location	c	c	c	d	e	f	g	h	h	h	h
Distance to opening (m)	1.57	2.50	5.15	1.48	0.42	0.165	0.95	1.9	4.00	3.2 outer	5.90
Height of start from floor?	1.1	Below floor	1.20	1.10	1.10	1.20	1.13	1.18	Below floor	5 to bottom	1.10
Width of opening (m)	0.24	1.05	1.10	0.265	0.15	0.15	0.23	0.25	0.26	0.128	0.24
Height of opening (m)	0.305	0.44	0.22	0.40	0.12	0.21	0.33	0.33	0.35	0.63	0.30
Thickness of opening (m)	0.72	0.75	0.31	0.72	1.00	0.92	0.90	0.58	0.55	0.60	0.59
Shape?	Rect	Furnace	Rect	Rect	Roundish	Rect	Rect	Rect	artly Blocke	Arch	y Blocked
Width of brick archway (m)	-	.25 inner	1.09	-	-	-	-		Rect	1.30	

Opening Name	12	13	14	15
Opening Location	j	m1	m	m2
Distance to opening (m)	0.90	4.60	7.89	4.59
Height of start from floor?	1.19	0.32	0.95	1.37
Width of opening (m)	0.19	0.23	1.32	0.13
Height of opening (m)	0.19	0.18	0.52	0.15
Thickness of opening (m)	0.87	0.72	0.50	0.72
Shape?	Irregular	Rect	Arch	Rect
Width of brick archway (m)			1.30	0.13

Notes:	
Wall a/b/vaulted arch of K	seems later than other walls
Wall c	pool floor is lower than regular floor; floor of c lower than floor of b
Wall e	thickness of opening number 5 is taken on a diagonal
Walls g, h, i	openings are relatively level with window of outer wall of corridor
Walls j and k	j abuts a chunk of new j and k, tubuli cover both but are different than other tubuli on j, tubuli on corner =
	0.11 x 0.13 m and 0.08 x 0.12 m
Wall l	tubuli and wall facing covers two different brick parts, rubble, and other walls are all together as one piece
Wall m	2.10 m to C30, 1.50 m high; 1.58 m to top of C30, 0.65 m long; 0.26 m of brick, 1.45 m high; 1.79 m wall, 1.23 m
	high; brick 0.48 m long, 1.55 m high; C29 0.58 m; 2.10 m wall, 1.33 m high; edge base of C29 to C30 is 2.54 m
Wall n1	window is 0.43 m long, 4.37 m high, starts at south edge
Walls q and r	marble cornice starts 0.465 m from floor, 0.07 m high, juts out 0.06 m; walls q and r are one wall 6.83 m total length
Walls r and s	both walls have extra sections that are door jambs (r) 0.74 m and (s) 0.77 m wide next to Room 20, not included
	in their lengths; r is original, s with vault over Door K is later
Walls b, d, g, l, l1, n2	tubuli and mortar fill space between wall and pool steps

Table A2-20: Room 19 – Pools

Name of Pool	Caldarium Pool a				Caldarium Pool b			
Location in Room	N				E			
Length of floor brick to brick (m)	6.7				7.57			
					North Width	Middle Width		South Width
Width of floor to brick step (m)	3.1				1.83	2.98		1.88
Floor	Pavonazzetto; slopes to northeast				Pavonazzetto			
Surface Area Pool floor (sq. m)	20.77				28.38			
Pipe Height from floor (m)	-				0.06			
Pipe Diameter (m)	-				0.15 Stopped up with concrete			
Refurbished?	Yes and 1964				Yes, and pools walls in 1964, steps in 1988			
Height of water assumed (m)	0.80				0.80			
Volume of water assumed (cu. m)	7.07				7.55			
Steps of Pools	Inner	Top	Outer by Pool	Outer	Inner	Top	Outer by Pool	Outer
Length of step brick to brick (m)	5.72	5.72	6.31	6.31	7.57	8.02	7.90	8.37
Step Surface Area (sq. m)	1.66	1.94	3.16	2.59	1.74	2.25	3.24	2.93
					Outer step comes out 0.38 m more on north side			
Horizontal surface of step					0.57 m step outside of Wall f, 0.54 m outside of Wall j			
Marble Type	Pavonazzetto	Not visible	Pavonazzetto	Pavonazzetto	Not visible	Not visible	Pavonazzetto	Pavonazzetto
Marble width (m)	Not visible	Not visible	0.02	0.02	Not visible	Not visible	0.02	0.03
Mortar width (m)	Not visible	Not visible	Not visible	0.14	Not visible	Not visible	0.02	0.03
Cocciopesto width (m)	Not visible	Not visible	Not visible	0.06	Not visible	Not visible	Not visible	0.02
Brick height from pool floor (m)	0.33	1.18	0.66	0.33	0.51	1.00	0.53	0.24
Water height on top of step (m)	0.47	0.00	0.00	0.00	0.29	0.00	0.00	0.00
Step face Inner								
Marble Type	Pavonazzetto	Pavonazzetto	-	-	Pavo/Pink/Port	Not visible	-	-
Marble width (m)	0.03	0.03	-	-	0.02	Not visible	-	-
Mortar width high (m)	0.07	0.04	-	-	0.07	Not visible	-	-
Cocciopesto width (m)	0.03	0.03	-	-	0.03	0.04	-	-
Brick width to next step (m)	0.29	-	-	-	0.23	-	-	-
Step face Outer								
Marble Type	-	Pavonazzetto	Pavonazzetto	Pavonazzetto	-	Not visible	Pavonazzetto	Pavonazzetto
Marble width (m)	-	0.03	Not visible	Not visible	-	Not visible	0.02	0.02
Mortar width high (m)	-	0.04	Not visible	Not visible	-	Not visible	0.03	0.03
Mortar width low (m)	-	0.04	Not visible	Not visible	-	Not visible	0.03	0.03
Cocciopesto width (m)	-	0.03	Not visible	Not visible	-	Not visible	0.03	0.03
Brick width to next step (m)	-	-	0.51	0.41	-	0.28	0.37	0.30
Total step width (m)		0.34	0.50	0.41	-	Not visible	0.41	0.35

Name of Pool	Caldarium Pool g			
Location in Room	S			
Length of floor brick to brick (m)				
Width of floor brick to brick step (m)				
Floor				
Surface Area Pool floor (sq. m)	37.72			
Pipe Height from floor (m)				
Pipe Diameter (m)				
Refurbished?	Is, and 1966, steps in 1988			
Height of water assumed (m)	0.90			
Volume of water assumed (cu. m)	34.24			
Steps of Pools	Inner	Inner Water	Top	Outer
Length of step brick to brick (m)	6.90	6.90	6.90	6.90
Step Surface Area (sq. m)	2.21	1.79	2.69	3.24
Horizontal surface of step				
Marble Type	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible
Mortar width high (m)	Not visible	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	0.05	Not visible	Not visible
Brick height from pool floor (m)	0.64	0.32	1.44	0.23
Water height on top of step (m)	0.26	0.58	0.00	0.00
Step face Inner				
Marble Type	Pavonazzetto	Pavonazzetto	Missing	-
Marble width (m)	0.03	0.03	Missing	-
Mortar width high (m)	0.05	0.05	Missing	-
Cocciopesto width (m)	Not visible	0.05	Missing	-
Brick width to next step (m)	0.35	0.28	Missing	-
Step face Outer	-	-	Missing	Missing
Marble Type	-	-	Missing	Missing
Marble width (m)	-	-	Missing	Missing
Mortar width high (m)	-	-	Missing	Missing
Mortar width low (m)	-	-	Missing	Missing
Cocciopesto width (m)	-	-	Missing	Missing
Brick width to next step (m)	-	-	0.39	0.47
Total step width (m)	0.32	0.26		

Table A2-21: Room 20

Length f1/Door J perp. to i (m)	6.02		**g/Door G to f1/Door J (m)**			3.66
Length e6/Door J perp. to i (m)	6.02		**g/Door G to e6/Door J (m)**			4.38
Length e1/Door K perp. to a (m)	5.96		**g/Door G to e1/Door K (m)**			12.07
Length a/Door I perp. to e (m)	6.02		**a/b1 to e6/Door J (m)**			12.49
Length j/Door I perp. to e (m)	6.02		**a/Door I to c/d (m)**			9.45
Length f2/g to h/i (m)	6.00		**a/Door I to b1/Door M (m)**			7.40
Width g/Door G perp. to c (m)	13.50		**a/Door I to c/b3(Door M) (m)**			7.55
Floor Surface Area (sq. m)	80.86		**Ceiling Surface Area (sq. m)**			127.66
Floor Makeup	Marble					
Name of Wall	**a**	**b1**	**b2**	**b3**	**c**	**d**
Location in Room	**N**	**E edge**	**E in M N**	**E in M S**	**E**	**East**
Dimensions						
Length brick to brick (m)	7.350	0.440	0.850	0.290	4.340	0.150
Height of extant wall (m)	4.72	4.72	1.10	1.10	4.72	2.95
Height of reconstruction (m)	0.05	0.05	0.00	0.00	0.17	0.05
Height Total (m)	4.77	4.77	1.10	1.10	4.89	3.00
Abuts adjacent wall? Inside/Outside	b1	a, b2	b1, b3	b2, c	b3, d	c, 19s
Joins adjacent wall? Inside/Outside	No	c	No	No	b1	K, 19c
Doorway abutting?	I	M	blocks M	blocks M	M	K
Window?	No	No	No	No	Yes	No
Refurbished?	1988	1988	Is Later	Is Later	1988	Yes?
Wall Fabric						
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.
Marble width (m)	0.04	0.04	0.04	0.04	0.04	0.04
Mortar width (m)	0.08	0.08	0.08	0.08	0.08	0.08
Cocciopesto width (m)	0.02	Missing	-	-	-	-
Evidence of Tubuli?	Yes	No	No	No	No	No
Tubuli Total Width (m)	0.08	-	-	-	-	-
Tubuli Total Length (m)	0.14	-	-	-	-	-
Tubuli Inner Width (m)	0.05	-	-	-	-	-
Tubuli Inner Length (m)	0.10	-	-	-	-	-
Space between Tubuli (m)	0.02	-	-	-	-	-
Mortar width (m)	0.03	-	-	-	-	-
Brick wall width (m)	0.87	0.60	0.29	0.60	0.60	5.37
Tubuli on other side of wall?	No	Substructure	Substructure	Substructure	Substructure	Hallway

Name of Wall	e					
Location in Room	South					
Length brick to brick (m)	9.050					
Doorway abutting?	K, J					
Window?	No					
Refurbished?	Yes/1988					
Tubuli Outer Width (m)	0.09					
Tubuli Outer Length (m)	0.12					
Tubuli Inner Width (m)	0.05					
Tubuli Inner Length (m)	0.09					
Space between Tubuli (m)	0.04					
Mortar width (m)	0.02					
Tubuli Vertical Length (m)	0.32					
Tubuli on other side of wall?	Yes					

Name of Wall	e1	e2	e3	e4	e5	e6
Location in Room	S	S	S	S	S	S
Abuts adjacent wall?	e2	e1, e3, 18a	e2, e4, 18a	e3, e5, 18a	e4, e6, 18a	e5,18a
Joins adjacent wall?	18a, 18b	No	No	No	No	No
Dimensions						
Length of segment (m)	2.900	1.070	1.550	1.010	1.390	1.130
Height of extant wall (m)	4.72	2.65	2.35	2.65	1.27	1.27
Height of reconstruction (m)	0.00	0.00	0.94	0.00	0.00	0.00
Height Total (m)	4.72	2.65	3.29	2.65	1.27	1.27
Wall Fabric						
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.
Marble width (m)	0.03	0.03	0.03	Missing	0.08	0.02
Mortar width (m)	0.08	0.10	0.10	0.05	0.10	0.12
Evidence of Tubuli?	No	Yes	No	Yes	No	Yes
Mortar Width	-	0.01	-	0.01	-	0.01
Tile Width	-	0.02	-	0.02	-	0.01
Mortar Width	-	0.03	-	0.03	-	0.01
Tubuli 1 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.05	-	0.02	-	0.02
Tile Width	-	-	-	0.02	-	0.02
Mortar Width	-	-	-	0.02	-	0.02
Tubuli 2 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.02	-	0.01	-	0.01
Tile Width	-	0.03	-	0.02	-	0.01
Mortar Width	-	0.03	-	0.03	-	0.01
Tubuli 3 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.04	-	0.05	-	0.03
Tubuli 4 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.02	-	0.05	-	0.03
Tubuli 5 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.05	-	0.05	-	0.02
Tile Width	-	-	-	-	-	0.02
Mortar Width	-	-	-	-	-	0.01
Tubuli 6 Width	-	0.12	-	0.12	-	0.12
Mortar Width	-	0.02	-	0.02	-	0.02
Tile or Brick Wall (e6) Width	-	0.02	-	0.03	-	0.07
Mortar Width	-	0.01	-	0.01	-	-
Brick wall width (m)	0.70	0.70	0.70	0.70	0.70	0.70

Name of Wall	f1	f2	g	h	i	j
Location in Room	S	S	W	W	N	N
Dimensions						
Length brick to brick (m)	0.420	0.781	3.130	1.170	4.180	0.150
Height of extant wall (m)	1.75	2.65	2.65	4.30	4.30	0.42
Height of reconstruction (m)	0.00	1.28	2.12	0.39	0.49	0.00
Height Total (m)	1.75	3.93	4.77	4.69	4.79	0.42
Floor Surface Area (sq. m)	80.66					
Abuts adjacent wall?	f2, 18i	f1, g	f2	No	j	i
Joins adjacent wall?	No	18i	18h	i	h	No
Doorway abutting?	J	No	G	G	I	I
Window?	No	No	No	No	No	No
Refurbished?	Yes	Yes	Yes and	Yes and	Yes and	Yes and
			1924/1964	1924/1964	1924/1964	1924/1964
Wall Fabric						
Marble Type	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Pavonazz.	Not visible
Marble width (m)	0.025	0.025	0.04	0.04	0.04	Not visible
Mortar width (m)	0.07	0.07	0.08	0.08	0.08	Not visible
Cocciopesto width (m)	-	-	0.03	0.03	0.03	Not visible
Evidence of Tubuli?	Yes	No	Yes	Yes	Yes	Not visible
Tubuli Total Width (m)	0.09	-	0.08	0.08	0.08	Not visible
Tubuli Total Length (m)	0.32	-	0.14	0.14	0.14	Not visible
Tubuli Inner Width (m)	0.05	-	0.05	0.05	0.05	Not visible
Tubuli Inner Length (m)	0.09	-	0.10	0.10	0.10	Not visible
Space between Tubuli (m)	0.02	-	0.015	0.015	0.015	Not visible
Mortar width (m)	0.02	-	0.03	0.03	0.03	Not visible
Tubuli 1 Width	0.12	-	-	-	-	-
Mortar Width	0.02	-	-	-	-	-
Tubuli 2 Width	0.12	-	-	-	-	-
Mortar Width	0.02	-	-	-	-	-
Tubuli 3 Width	0.12	-	-	-	-	-
Brick wall width (m)	0.71	0.71	1.68	1.8	0.84	1.07
Tubuli on other side of wall?	Yes	Yes	Yes	Yes room	Unclear	Unclear

Notes:

Wall c	window is 2.54 m from north and about 0.50 m wide; open at top so
	extant height of window is 0.47 m
Wall e	Brick wall width = 0.33 m on Room 18 side+0.37 m on Room 20 side;
	at 1.73 m from Door K height is 2.65 m; e6 has 0.025 m of mortar on
	its face + 0.09 m of greyer mortar; marble facing e5 is reused cornice
Walls e and f	e3 to f1 are all added later, maybe tubuli added later too; brick wall
	width of f1 includes 0.33 m of original wall and 0.38 m of later wall
Wall h	h1=0.30 m, h2=0.87
Wall j	extra blob of brick in Door I; 0.38 m from wall
Walls e and f	e3 to f1 are all added later, maybe tubuli added later too; brick wall
	width of f1 includes 0.33 m of original wall and 0.38 m of later wall
Wall h	h1=0.30 m, h2=0.87
Wall j	extra blob of brick in Door I; 0.38 m from wall

Table A2-22: Doorways

Name of Doorway	A	B	C	D	E	F	G	H
Between Room #	2	15	14	C	9	16	17	17
and Room #	15	C	Substructure	16	16	17	20	18
Width brick to brick (m)	2.24	1.60	1.09	1.61	1.64	1.63	1.38	1.61
Height to springing (m)	1.62	1.60	2.33	2.55	1.01	2.50	2.10	2.50
Height arch in center (m)	Broken	Broken	0.09	0.60	0.53	0.4	0.60	0.60
Height open door total (m)	Broken	Broken	2.32	2.77	2.73	2.55	2.30	2.75
Height wall abve door (m)	Broken	Broken	1.20	11.13	2.60	1.02	1.10	1.20
Floor Description	Marble	Under tiles	Under tiles	Marble	Modern	Modern	Modern	Marble
Threshold hole?	Broken	Broken	Elevated	Unclear	Modern	Modern	north,	No hole
Wall 1	E	NW	E	N	SW	NE	N	NE
Mortar width (m)	Not visible	Not visible	Not visible	0.02	Not visible	0.13	0.09	0.06
Cocciopesto width (m)	Not visible	Not visible	Not visible	0.005	Not visible	0.025	Not visible	0.06
Marble type	Not visible	Not visible	Not visible	Not visible	Not visible	Marble	Not visible	Marble
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	0.05	Not visible	0.04
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	1.00	1.15	0.90	1.07	1.10	1.13	2.05	0.95
Wall 2	W	SE	W	S	NE	SE	SE	SE
Mortar width (m)	Not visible	Not visible	Not visible	0.03	Not visible	0.04	0.09	0.06
Cocciopesto width (m)	Not visible	Not visible	Not visible	0.005	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Blockage	Not visible	Marble	Not visible	Marble
Marble width (m)	Not visible	Not visible	Not visible	Blockage	Not visible	0.05	Not visible	0.04
Evidence of Tubuli?	Not visible	Not visible	Not visible	Blockage	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	1.00	1.07	0.90	1.07	0.85	1.17	0.92	0.96
Wall 3					SE	NW	SW	NW
Mortar width (m)					Not visible	0.13	0.09	0.06
Cocciopesto width (m)					Not visible	0.025	Not visible	0.06
Marble type					Not visible	Marble	Not visible	Marble
Marble width (m)					Not visible	0.05	Not visible	0.04
Evidence of Tubuli?					Not visible	Not visible	Not visible	Not visible
Brick wall width (m)					2.36	1.30	0.72	0.75
Wall 4						SW		SW
Mortar width (m)						0.04		0.06
Cocciopesto width (m)						Not visible		Not visible
Marble type						Marble		Marble
Marble width (m)						0.05		0.04
Evidence of Tubuli?						Not visible		Not visible
Brick wall width (m)						0.75		1.14

Name of Doorway	I	J	K	L	M	N	O	P	Q	R
Between Room #	10	18	19	18	20	6	11	14	Entrance N	6
and Room #	20	20	20	19	Substructure	10	14	14b	Outside	8
Width brick to brick (m)	1.80	1.36	1.77	0.65	1.20	1.34	3.51	3.36	2.32	3.41
Height to springing (m)	2.70	1.63	2.95	2.85	1.97	Broken	Broken	Broken	Broken	Broken
Height arch in center (m)	0.60	Broken	0.16	0.56	0.60	Broken	Broken	Broken	Broken	Broken
Height open door total (m)	2.70	Broken	3.11	2.85	1.97	Broken	2.67	2.53	2.10	Broken
Height wall abve door (m)	0.75	Broken	0.60	0.36	2.14	Broken	Broken	Broken	Broken	Broken
Floor Description	Marble	Marble	Marble	Marble	Blocked	Missing	1.19 marble	Marble	2 Steps	Missing
Threshold hole?	west side	west side	Broken	north,	Covered	Modern	s, reuse?	w, small?	Missing	Broken
Wall 1	W	W	W-19r	N	N	E	N	E	Out E	E
Mortar width (m)	0.06	Not visible	0.01	0.06	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	Not visible	0.04	0.04	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Marble	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	0.07	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Yes	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.87	0.66	0.74	1.05	0.60	0.89	1.03	0.90	0.60	0.89
Wall 2	E	E	E-19s	S	S	W	S	W	Out W	W
Mortar width (m)	0.04	0.16	0.06	0.06	Not visible	Not visible	0.02	0.02	Not visible	Not visible
Cocciopesto width (m)				0.04	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Modern	Not visible		Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	0.07	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.87	0.66	0.77	1.05	0.60	0.89	1.03	0.90	0.65	0.89
Wall 3									E	
Mortar width (m)									Not visible	
Cocciopesto width (m)									Not visible	
Marble type									Not visible	
Marble width (m)									Not visible	
Evidence of Tubuli?									Not visible	
Brick wall width (m)									0.73	
Wall 4									W	
Mortar width (m)									Not visible	
Cocciopesto width (m)									Not visible	
Marble type									Not visible	
Marble width (m)									Not visible	
Evidence of Tubuli?									Not visible	
Brick wall width (m)									0.73	

Name of Doorway	S	T	U	V	W	X	Y	Z	AA	AB
Between Room #	6	2	a2	a	1	2	2	6	14	1
and Room #	7	Outside	2	Outside	2	3	Outside	9	Outside	Outside
Width brick to brick (m)	3.42	3.22	1.21	2.55	2.90	3.58	3.00	3.39	2.49	1.93
Height to springing (m)	Broken	3.82	2.06	Broken	Broken	Broken	Broken	Broken	No arch	Broken
Height arch in center (m)	Broken	Broken	0.19	Broken	Broken	Broken	Broken	Broken	Broken	Broken
Height open door total (m)	Broken	Broken	2.25	1.25	3.10	Broken	Broken	Broken	3.66	1.59
Height wall abve door (m)	Broken	Broken	0.83	Broken	Broken	Broken	Broken	Broken	Broken	Broken
Floor Description	Missing	Step	Unclear	Brick wall	Broken	0.895	Later wall	Marble	Marble	Staircase
Threshold hole?	Broken	east, center	Unclear	Unclear	Missing	Broken	Covered	west end	both ends	Broken
Wall 1	E	Out E	N	N	N	N	E	E	E	N
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.89	0.92	0.91	0.9	1.19	0.87	0.912	0.91	0.9	1.59
Wall 2	W	Out W	S	S	S	S	W	W	W	S
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	0.09	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.88	0.92	0.94	0.92	1.17	0.895	0.91	0.91	Wall	0.88
Wall 3		E								
Mortar width (m)		Not visible								
Cocciopesto width (m)		Not visible								
Marble type		Not visible								
Marble width (m)		Not visible								
Evidence of Tubuli?		Not visible								
Brick wall width (m)		0.62								
Wall 4		W								
Mortar width (m)		Not visible								
Cocciopesto width (m)		Not visible								
Marble type		Marble								
Marble width (m)		0.15								
Evidence of Tubuli?		Not visible								
Brick wall width (m)		0.595								

Name of Doorway	AC	AD	AE	AF	AG	AH
Between Room #	1	a	a2	a	1	a
and Room #	Outside	Outside	Outside	1	Outside	a2
Width brick to brick (m)	2.41	1.74	1.69	1.82	1.19	0.92
Height to springing (m)	Broken	Broken	2.22	Broken	Broken	Straight
Height arch in center (m)	Broken	Broken	Broken	Broken	Broken	Straight
Height open door total (m)	1.14	1.93	Broken	2.51	0.59	2.00
Height wall abve door (m)	Broken	Broken	Broken	Broken	Broken	1.23
Floor Description	0.83 marble	Marble	Marble	0.52 block	Marble	0.15 Wall
Threshold hole?	both ends	Modern	center	brick wall	Missing	Unclear
Wall 1	E	E	E	E	E	N Shop a
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.78	0.59	4.74	0.62	0.90	0.65
Wall 2	W	W	W	W	W	S Shop a
Mortar width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Cocciopesto width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble type	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Marble width (m)	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Evidence of Tubuli?	Not visible	Not visible	Not visible	Not visible	Not visible	Not visible
Brick wall width (m)	0.75	0.74	0.585	0.62	0.91	0.65
Wall 3						N a2
Mortar width (m)						Not visible
Cocciopesto width (m)						Not visible
Marble type						Not visible
Marble width (m)						Not visible
Evidence of Tubuli?						Not visible
Brick wall width (m)						0.79
Wall 4						S a2
Mortar width (m)						Not visible
Cocciopesto width (m)						Not visible
Marble type						Not visible
Marble width (m)						Not visible
Evidence of Tubuli?						Not visible
Brick wall width (m)						0.79

Notes:

Door A	marble is probably reused slabs 0.05 m thick
Door B	perpendicular width from east to west is 1.52 m
Door C	width is irregular since opening punctured through walls d and e; west wall goes 1.20 m
	further south; maybe elevated door hinge, but maybe modern addition
Door F	0.67 m on western; 0.88 m wall arch, then 0.14 m more above
Door G	northern wall is 1.66 m within doorway on the northeast, with 0.39 m of extra wall on west
Door H	steps down into Room 17 but 0.17 m; SW wall comes out 0.47 m further, which is included
	in measurement, eastern walls are flush
Door I	slightly blocked by 10c; arch is flatish and was probably added later
Door J	marble steps up 0.12 m; may be later break
Door K	Tubuli total width is 0.10 m, length is 0.12 m, inner width is 0.05 m, inner length is 0.08 m;
	space between tubuli is 0.035m; mortar width is 0.04m
Door M	blockage is 0.60 m wide and 1.92 m high; total open height is without blockage
Door Q	width is irregular since opening punctured through walls a and h; height Out E: 0.85 m to
	step, Out W: 0.98 m to step, E: 2.10 m to step, W: 1.02 m to step; outer step is 0.17 m
	above outside floor, next step up in doorway is 0.18 m higher of 0.04 m thick marble
Door T	width of step is 2.04 m, missing part is 1.32 m and 0.14 m is subtracted for walls that are
	jutting out; height east is 0.89 m, west is 3.02 m plus 0.80 m of modern; walls 3 and 4 were
	cut wall and rebuilt with later materials; square opening in wall 1; threshold hole in east end,
	small square hole in center; west end is broken
Door X	NW face is 0.65 high, SE face is 1.37 high
Door Y	NE face is 1.87 m high + refurbished 0.16 m, SW face is 1.71 m high; later wall refurbished
	in 1984; door jambs out of phase with other walls; blockage in two phases, east (2o) similar
	to 2n but abuts, west (2p) diffferent from other walls except for fistulae slot that is filled with
	similar brickwork; blockage on SW has no space or marble or mortar; blockage is 0.58 and
	0.79 m high; older part is 0.46 m high from floor and comes out 0.045 more on NE side,
	0.02 on S side
Door Z	band of extant marble in door is 0.91 m on SW and 0.96 on NE where there is a gap;
	0.10 m diameter round mark for door with center 0.35 m for S end of band; 0.40 space for
	missing wall elements on E wall and 0.34 on W wall
Door AA	was originally 3.06 m wide before the later addition of wall c; maybe just an opening
	originally or a separate structure; marble step is 0.23 m high; threshold made of different
	marble chunks, hole for door at each end, but do not really match up
Door AB	edge of wall 1m is smooth, but edge of wall 1l is irregular; 5 steps lead up
Door AE	east wall is formed by wall b

Table A2-23: Columns

Name of Column	Starts from?	Distance	Length Base (m)	Width Base (m)	Marble	Circ. (m)	Diameter (m)	Notes
C1	2x	7.20	0.99	0.99	Cipollino	Broken	Broken	
C2	2a	7.32	Reconstructed	Reconstructed	Missing	Missing	Missing	
C3	1b2	1.87	1.34	0.62	Brick/Marble	N/A	0.37 m diam.	Not column, semi-circ niche
C4	Door W	1.20	1.34	0.62	Brick/Marble	N/A	0.37 m diam.	Not column, semi-circ niche
C5	East of 4v	Missing	Missing	Missing	Missing	Missing	Missing	Space not exact
C6	West of 4d	Missing	Missing	Missing	Missing	Missing	Missing	Space not exact
C7	5q	1.89	1.03	1.03	Cipollino	Missing	Missing	
C8	5k	1.89	Reconstructed	Reconstructed	Cipollino	Missing	Missing	Reconstructed base
C9	3g	1.90	0.98	0.98	Cipollino	2.02	0.64	
C10	C9	2.47	0.98	0.98	Cipollino	2.10	0.67	
C11	7g/h	In corner	1.03	1.03	Missing	Missing	Missing	0.49 m high block
C12	7k/pool delta	At corner	Missing	Missing	Missing	Missing	Missing	Only blob remains
C13	8f/pool delta	At corner	Missing	Missing	Missing	Missing	Missing	Only blob remains
C14	8g/h	In corner	1.00	1.03	Missing	Missing	Missing	0.60 m high block
C15	9g/h	In corner	Missing	Missing	Missing	Missing	Missing	Only blob remains
C16	9k/pool epsilon	At corner	0.96	1.07	Cipollino	Missing	Missing	0.55 m high block
C17	10o/pool epsilon	At corner	Missing	Missing	Missing	Missing	Missing	Only blob remains
C18	10h/i	In corner	1.05	1.03	Missing	Missing	Missing	0.59 m high block
C19	8i	1.83	1.08	1.08	Missing	Missing	Missing	
C20	10j	1.87	1.08	1.08	Cipollino	2.05	0.65	
C21	C22	1.95	1.00	1.01	Cipollino	Missing	Missing	
C22	12d	1.85	Broken	0.99	Missing	Missing	Missing	
C23	C24	2.03	1.01	1.02	Missing	Missing	Missing	Broken bases
C24	13i	1.85	1.01	1.02	Missing	Missing	Missing	Broken bases
C25	16d	On bench	0.64	Broken	Missing	Missing	Missing	Original Location Unknown
C26	16c seam	2.08	0.64	0.63	Missing	Broken	Broken	Original Location Unknown
C27	17e/f	2.93	Broken	Broken	Cipollino	Missing	Missing	
C28	17d/e	2.90	0.75	0.76	Cipollino	Missing	Missing	
C29	19m2	2.57	0.64	0.60	Grigio	1.42	0.45	Base like others, rebult
C30	19m1	2.10	0.64	0.60	Grigio	Missing	Missing	Traces of marble on drum

Table A2-24: Hypocausts

Name of Hypocaust	F15a	F16a	F17a	F17b	F18a	F18b	F18c	F19a	F19b	F19c
Distance measured from ? (m)										
Distance measured (m)										
Dimensions										
Pilae height	-	0.71	0.74	0.75	0.70	-	-	-	-	-
Pilae width	-	0.21	0.24	0.22	0.20	-	-	-	-	-
Pilae length	-	0.21	Unclear	Unclear	0.20	-	-	-	-	-
Pilae space between low (m)	-	0.38	0.31	0.33	0.40	-	-	-	-	-
Pilae space between high (m)	-	0.38	0.41	0.33	0.40	-	-	-	-	-
How many bessalae on top?	-	2	1	2	2	-	-	-	-	-
Bessale on top thickness low (m)	-	0.04	0.03	0.03	0.03	-	-	-	-	-
Bessale on top thickness high (m)	-	0.05	0.04	0.03	0.03	-	-	-	-	-
Mortar thickness (m)	-	Unclear	Unclear	Unclear	0.03	-	-	-	-	-

Name of Hypocaust	F19d	F19e	F19area	F19f	F19g	F19h	F19i	F20a	F20b
Distance measured from ? (m)									
Distance measured (m)									
Dimensions									
Pilae height	Unclear	-	-	Unclear	0.57	0.60	-	Unclear	-
Pilae width	0.20	-	-	0.20	0.20	0.44	-	0.24	-
Pilae length	0.20	-	-	0.20	0.20	0.84	-	0.24	-
Pilae space between low (m)	0.30	-	-	-	0.30	-	-	-	-
Pilae space between high (m)	0.30	-	-	-	0.30	-	-	-	-
How many bessalae on top?	0	-	-	-	2	-	-	-	-
Bessale on top thickness low (m)	Missing	-	-	-	0.03	-	-	-	-
Bessale on top thickness high (m)	Missing	-	-	-	0.03	-	-	-	-
Mortar thickness (m)	Missing	-	-	-	0.04	-	-	-	-

General Location and Notes:

F15a	in corner by Room 16; opening about 0.55 m wide, section with holes added on bottom
F16a	in center of ellipse; archway below and further down; raised in some phase; 0.30 m opening led to it
F17a	in sw corner; poorly preserved; probably raised in some phase
F17b	in middle of room; pilae tiles are 0.03 m thick with 0.03 m of mortar in between; probably raised in some phase;
	poorly preserved with some burning
F18a	sw corner; can see straight up tubuli; degraded; burning on floor of praefurnium; 0.19 m space between bipedali
	and wall for tubuli
F18b	below P1; tunnel 0.60 m wide and 0.80 m high; can see far down channel, no pilae until very end over 5.00 m
	away; may communicate with F18c through a shaft
F18c	between P1 and P2; triangular channel 0.73 m base of outer, 0.70 m top slab, inner triangle inaccessible; may
	communicate with F18b through a shaft
F19a	w end of room; channel 0.60 m wide, 0.73 m high; mostly blocked up; tubuli visible on face; walls show
	evidence of burning
F19b	w of Pool g; pilae present but inaccessble; whole little room; looking e pilae visible; no signs of burning on inside
F19c	in Pool g; shaft 0.46 m wide, 0.60 m high; inaccessible; hole evident only by tubuli
F19d	in center of Pool g by pipe; where is water be drained to?; pilae look smaller but inaccessible
F19e	shaft 0.48 m wide, 0.60 m high; top covered by modern floor; difficult to see
F19area	maybe s of Pool b; heavily blocked up archway with high wall; visible tubuli from shaft to w, visible
	pilae of Pool g in shaft to n; 0.49 m wide, 0.60 m high
F19g	looking s into Pool g; tubuli visible going up and down to height of bessale
F19h	past Pool g; inaccessible; shaft with one visible pila; well preserved; cocciopesto on walls of room
F19i	middle of Pool g; no visible pilae; can only see modern structure; poorly peserved
F19j	pilae look bigger but not very clear
F19k	near Door M; shaft under archway 0.58 m wide, 0.67 m high; small archway