Portative Pipe Organ

The Legal Fight for HVAC Sustainability

A Thesis Prospectus
In STS 4500
Presented to
The Faculty of the
School of Engineering and Applied Science
University of Virginia
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science in Mechanical Engineering

By
Matt Hutchison

October 27, 2022

Technical Team Members:

Jacobo Pastor Trujillo

Braden Seale

David Hatter

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISORS

Dr. MC Forelle, Department of Engineering and Society

Dr. Gavin Garner, Department of Mechanical and Aerospace Engineering

Introduction:

The movement of air is an indispensable aspect of proper building design. In the interstitial spaces in buildings, a vast network of mechanisms prime the grungy outdoor air for indoor circulation. This network is a building's heating, ventilation, and air conditioning system, or HVAC, as it is colloquially known. In 1902, Willis Carrier invented the concept of HVAC, and his eponymous company, Carrier Global Corporation, is one of the premier manufacturers of HVAC equipment still today.

Estimations suggest that HVAC systems, on average, account for roughly 35% of a building's energy consumption—a preponderance of its total energy use (Bonacorda, 2017). With HVAC systems using so much energy, it is incumbent on mechanical engineers to inquire further into the nature of HVAC energy consumption. Namely, mechanical engineers must continuously find ways to reduce aggregate HVAC energy expenditure and offer new, cleaner mechanisms to the federal government for legislative assent.

HVAC's antiquated energy-sourcing technology and guidelines pervade the MEP (Mechanical, Electrical, and Plumbing) landscape. Many HVAC systems are vestiges of a more environmentally ignorant past. Accordingly, mechanical engineers have developed several environmentally friendly retrofits and improvements to existing HVAC designs. The hard work of mechanical engineers over the last few years has laid the blueprint for a sustainable energy transition in the MEP sector (Luther, M. B., 2022). Still, the associated politics have not been in lockstep. As new, promising technologies present themselves, bureaucratic morasses impede their implementation. Authoritative bodies such as The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the Consortium for Energy

Efficiency (CEE) do not have plenary, unilateral power and cannot make changes overnight. It is not unusual for HVAC technology to take years before it comes to fruition.

This stagnancy is too familiar in the HVAC industry, imperiling engineering design. As new ASHRAE handbooks are released, and cutting-edge research is unveiled, many mechanical engineers wonder if these technologies will fall by the wayside because of tepid government policy or poor executive structure. Government and powerful interests have spurned climate policy efforts in the U.S., leading to decades of federal government inaction and heightened attention at the state level, where there has been comparative progress (Rura, 2022). In California, for instance, state law mandates that newly designed buildings carry LEED (Leadership in Energy and Environmental Design) certification, which reflects the state's firm commitment to environmental sustainability. In most cases, however, this devolution of environmental policy to the states will result in dereliction as seen time and time again.

Government and private interest juggernauts have treated sustainable design as an afterthought at best, not an inevitable, necessary means to thwart climate change and promote public health. While good-faith initiatives like LEED and WELL incentivize sustainable building practices and spearhead the sustainability movement, their programs alone cannot engender environmental conscientiousness at a critical mass. While proactive, these programs need more statutory backing (Glasgow, 2021). While great strides have been made in sustainable HVAC design, the current legal movement to enact these environmental safeguards has not been as impressive. As the threat of climate change marches on, many legislators have skirted or outright impugned the issue of climate change. In many ways, the government has put the kibosh on the sustainability progress of the HVAC industry.

My technical project aims to research one of the foremost innovations in sustainable HVAC design: dynamic setpoints. Mechatronic systems, a portmanteau of mechanical and electronics, form the crux of dynamic setpoints. A thorough understanding of mechatronics systems and their instrumental role will illuminate the pathway to sustainability. Furthermore, my research will address why there has not been a commensurate legal movement for sustainability despite notable strides in mechanical engineering innovation.

Technical Topic:

Mechatronics is a burgeoning subdiscipline within mechanical engineering. While strictly mechanical systems still exist, the synergy of mechanical engineering and electrical engineering seems to be on a steady course. Mechanical designs incorporating transistors, solenoids, and other electronics prove to be more precise and less prone to failure, besting their storied, cumbersome predecessors. In light of electronics' demonstrable utility in mechanical engineering applications, most machinery nowadays has some electrical component, which has ushered in a new epoch of mechanical engineering design: mechatronics.

Mechatronics touches every corner of mechanical engineering design. Every day, captivating, game-changing mechatronic innovations improve the engineering world, whether it be refining a manufacturing technique, presenting a novel function, or just giving more vitality to an atrophied system. Mechatronics seeks to transform an old, obsolete machine into a thing of the 21st century—having the same functionality but with an assurance of longevity and precision. With many HVAC systems being so old, mechatronics retrofitting will become especially important on the road to sustainability.

While broaching ideas for our capstone, one of my teammates, Jacobo Trujillo Pastor, mentioned Drexel University's ExCite Center, a department that uses interdisciplinary research and discovery to connect technology and communities (ExCITe Center, 2012). We discussed mechatronic valves for modulating airflow as a possible capstone idea, which reminded him of a project he did in high school. Our team wanted to dovetail mechatronics and air movement; this led us to choose a portative pipe organ as our capstone project. In understanding how to meld mechatronic systems with air transport systems, we can create newer airflow designs to be more efficient and energy-saving.

The pipe organ is a combination of a piano and a flute. The keyboard keys activate valves that allow air to escape from the wind box; resonance ensues, and a euphonic pitch sounds off. Although one of the most complex musical instruments, "the organ has the longest and most involved history and the largest oldest extant repertoire of any instrument in Western music" (Britannica, 2020).

A mechatronic self-played organ is a novel project which presents a true engineering challenge. At the outset, the team established attainable, timely goals so that we could deliver a working, economical project at the end of 6 weeks. Some of these requirements were the size factor, the materials needed, the production method for each part, the microcontroller, the air system, and the overall looks and dimensions. The size factor was the most glaring bottleneck, so we all agreed to keep the cross-sectional area of the opening below four square inches. We decided that the most complex parts—the 24 flues—would be made out of ABS plastic and manufactured using a 3D printer.

At the beginning of the prototyping process, acrylic as the material for the pipes struck a happy medium between affordability and durability. While most of the design only needed to be utilitarian, the pipes would be prominently displayed and required more of an aesthetic touch. For the machine's brain, the microcontroller, the group dithered between P2 and an Arduino Uno.

While the Arduino Uno provided a more familiar interface, with a bevy of open-source code and compatibility with other market products, such as the Leap Motion Sensor, the lack of input and output pins (16 vs. 64) led us to choose the P2 microcontroller. Finally, the air system and the overall dimensions were two related constraints. In keeping with the spirit of an organ, we landed on an automatic bellow system that builds up pressure in the wind box to channel the air to the pipes.

STS Topic:

Climate change remains one of our time's most challenging, intractable problems. Progress is like pulling teeth with many competing interests and a tempestuous dialogue. As scientific evidence accumulates and the reality of climate change becomes more incontrovertible, the political class remains obdurate. Many politicians do not believe climate change is a big deal, or so they publicly say. Behind the blithe attitude of many politicians and, by extension, the drought of supportive sustainability legislation lies a complex sociotechnical explanation (Kamarck, 2022).

Insufficient jurisdiction has been one of the biggest issues in tackling climate change; no one knows how much everyone else is culpable for the ongoing mess. When we establish jurisdiction, we can set rules, laws, and accountability for adherence to the law–the three mainstays of democratic governance. "In the absence of jurisdiction, everyone is accountable, and therefore no one is accountable," Bonacorda (2017) puts it. We can write laws to empower the HVAC artifact and give it safeguards against its use in environmental impropriety. In this way, we can forge a new social construction of the HVAC artifact as not just a system that keeps air comfortable but as a critical legal tool in our repertoire of climate change efforts.

The fight against global warming will entail a collective effort, but many wonder why they should make personal sacrifices if there are no consequences for the freeloaders. "It is the lack of trust in government that may be one of the foundational barriers to effective environmental action" Kamarck (2022) says. Individual responsibility within a milieu that does not enforce it can pose a grave challenge. Many people shirk individual responsibility because they know others will not hold themselves to the same standard. Many manufacturers, designers, and even the end user do not see the reason to change their environmentally deleterious habits, creating a vicious cycle in which no one feels obligated to do the right thing.

A further look into this lack of jurisdiction evinces a legal but arguably objectionable tactic: lobbying. Non-renewable energy leviathans like ExxonMobil and Chevron bankroll endless lobbying ventures so that non-renewable energy friendly laws continue to exist. Not just this, but these oil and gas companies take it a step further and try to instill their message in the public perception. "In many cases, oil and gas companies try to change public perception using the same messages with which they lobby politicians. This includes portraying themselves to the public as part of a solution to climate change, rather than a cause, and highlighting their investments in clean energy while funneling far more money into dirtier fuels," says Faye Holder, a climate expert at the UK think tank Influence Map (Glasgow, 2021). Clearly, the energy sector has its own politics that embody a specific form of power and authority (Woolgar, 1991).

Institutions only have power insofar as the people give it up. While climate change tends to be considered a contentious issue, a recent survey reveals that roughly 78% of Americans support federal government requirements to reduce carbon emissions from power plants and utilities (Harvard University, 2017). It is time for the people to redefine the politics of HVAC and demand policymakers hew closely to the will of the people.

Research Question and Methods:

It is evident that the social and engineering urgency for climate change is there, yet the implementation of these ideas has not quite caught up. Legal backing is the only missing piece to environmental prosperity. In my research, I will find the answer to the following question: how do social attitudes and behaviors toward climate change, even in the wake of tremendous sustainable engineering feats, impact sustainable energy policy?

Throughout my summer internship, I was tasked with looking into how my MEP firm could better pursue sustainability in HVAC design. I conducted extensive research on industry conventions and the logistics of implementation. I spoke with experts in the field who shared my concerns and knew more could be done. This experience was my motivation to explore this topic.

Understanding the legacy of non-renewable energy will entail an ethnographic study. One may speculate that the American economy is so charry of a non-renewable energy departure because non-renewable energy has been an American staple since America's founding. This method is apt to relate discourse to practice and the promises of sociotechnical imaginaries to the history of state-sponsored technoscientific projects. An ethnography of non-renewable energy will shed light on the jarring dissonance between optimistic sustainability conversations and the dire engineering squelch at the hands of existing laws.

U.S. federalism allows comparisons between states and how ideas are reified in law. Each state in the U.S. is vastly different in its culture, allowing us to examine the cultural differences brought to bear for the writing of sustainability policy. One state's view and consequent policy on climate change may differ from those of another. I want to attend to these cultures of meanings and identities to see what it means in the context of broader national sustainability policy for HVAC applications.

Conclusion:

One of the most pressing issues of our time is the perennial threat of climate change. In just a few short years, if engineers do not exercise their due diligence, carbon emissions will warm the Earth to an unprecedented degree, crippling the world as we know it. The good news is that engineers can forestall this.

A key point in addressing climate change is knowing its contributors, one of which, historically, has been HVAC. Fortunately, robust HVAC systems now exist that do not rely on natural gas and operate off of fully clean energy. Even so, contemporary, real-time engineering and many firms' systems do not reflect this. The engineering will is there, but not the legal. The lack of implementation of these better, cleaner systems is not an engineering failure but rather a legal one.

Mechatronic systems optimize airflow systems by using as little energy as possible. Understanding the social dimensions of climate change activism alongside more sophisticated mechatronic airflow systems will lay the groundwork for a sustainable future. The engineering acumen is already there, meaning whittling away at the social and legal barriers to effective climate change policy will foster an unparalleled American infrastructure.

Bibliography:

1. Bonacorda, P. (2017, October 26). *HVAC efficiency: What it is, why it matters and how to get started*. Alliance to Save Energy. Retrieved October 27, 2022, from https://www.ase.org/blog/hvac-efficiency-what-it-why-it-matters-and-how-get-started

2. Virta, M. (2021). HVAC Commissioning Guidebook (1st ed.). CRC Press. https://doi-org.proxy01.its.virginia.edu/10.1201/9781003173014

3. Woolgar S (1991) Configuring the user: the case of usability trials. The Sociological Review 38(s1): 58–99. https://www.cl.cam.ac.uk/teaching/1314/R215/Woolgar-ConfiguringTheUser.pdf

4. Idahosa, L. O., & Akotey, J. O. (2021, July 1). A social constructionist approach to managing HVAC energy consumption using social norms – A randomized field

experiment. Energy Policy, 154.
https://www.sciencedirect.com/science/article/abs/pii/S0301421521001622

5. Luther, M. B., Martek, I., Amirkhani, M., & Zucker, G. (2022, August 15). Special Issue "Environmental Technology Applications in the Retrofitting of Residential Buildings". Energies (19961073), 15(16), 5956 - 5959. https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S0301421521001622?via%3Dihub

6. Siddique, Md. N. I., Hasan, S. M. M., Kabir, Md. A., Prottasha, F. Z., Samin, A. M., Soumik, S. S., & Trianni, A. (2022, October 1). Energy management practices, barriers, and drivers in Bangladesh: An exploratory insight from pulp and paper industry. Energy for Sustainable Development, 70, 115 - 132.

7. Nilofar Asim, Marzieh Badiei, Masita Mohammad, Halim Razali, Armin Rajabi, Lim Chin Haw, & Mariyam Jameelah Ghazali (2022, January 1). Sustainability of Heating, Ventilation and Air-Conditioning (HVAC) Systems in Buildings—An Overview. International Journal of Environmental Research and Public Health, 19(1016), 1016.

8. Franco, A.; Bartoli, C.; Conti, P.; Miserocchi, L.; Testi, D. Multi-Objective Optimization of HVAC Operation for Balancing Energy Use and Occupant Comfort in Educational Buildings. Energies 2021, 14, 2847. https://doi.org/10.3390/en14102847

9. JACHMAN, M. (2022, September 12). HVAC Firms Focus on Sustainability. *Air Conditioning, Heating & Refrigeration News*, 277(1), 8 - 9.

10. RAJECKI, R. (2017, December 25). Providing an Assist to Assisted Living: HVAC contractors can help senior living communities meet their comfort and sustainability goals. *Air Conditioning, Heating & Refrigeration News*, 262(17), 1 - 4.

11. Sanzana, M. R., Maul, T., Wong, J. Y., Abdulrazic, M. O. M., & Yip, C. (2022, September 1). Application of deep learning in facility management and maintenance for

heating, ventilation, and air conditioning. *Automation In Construction*, 141. https://www-sciencedirect-com.proxy01.its.virginia.edu/science/article/pii/S0926580522003181?via%3Dihub

12. Harvard University. (2017, October 26). *HVAC efficiency: What it is, why it matters and how to get started*. Alliance to Save Energy. Retrieved October 27, 2022, from https://www.ase.org/blog/hvac-efficiency-what-it-why-it-matters-and-how-get-started

13. Rura, N. (2022, June 24). *Poll: Facing extreme weather is changing Americans' views about need for climate change action*. News. Retrieved October 27, 2022, from https://www.hsph.harvard.edu/news/press-releases/poll-facing-extreme-weather-is-changing-americans-views-about-need-for-climate-change-action/

14. Glasgow, A. N. (2021, November 5). *Lobbying threat to global climate action – DW – 11/05/2021*. dw.com. Retrieved October 27, 2022, from https://www.dw.com/en/lobbying-threat-to-global-climate-action/a-59726541

15. Golden, R., & Bottorff, C. (2020, April 23). *New analysis: Heat pumps slow climate change in every corner of the country*. Sierra Club. Retrieved October 27, 2022, from https://www.sierraclub.org/articles/2020/04/new-analysis-heat-pumps-slow-climate-change-every-corner-country

16. Kamarck, E. (2022, March 9). *The challenging politics of climate change*. Brookings. Retrieved October 27, 2022, from https://www.brookings.edu/research/the-challenging-politics-of-climate-change/

17. Williamson, C. (2014, January 9). *HVAC systems common target of sustainability projects*. Facilitiesnet. Retrieved October 27, 2022, from https://www.facilitiesnet.com/green/article/HVAC-Systems-Common-Target-of-Sustainability-Projects--14686
18. Ma Z., Ren H., Lin W. A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar

Decathlon houses. *J. Clean. Prod.* 2019;**240**:118158. doi: 10.1016/j.jclepro.2019.118158.

19. Jung W., Jazizadeh F. Human-in-the-loop HVAC operations: A quantitative review on occupancy, comfort, and energy-efficiency dimensions. *Appl. Energy.* 2019;**239**:1471–1508. doi: 10.1016/j.apenergy.2019.01.070.

20. Rafique M.M., Rehman S. *Sustainable Air Conditioning Systems.* Books on Demand; Norderstedt, Germany: 2018. Renewable and Sustainable Air Conditioning.

21. *Expressive & Creative Interaction Technologies Center*. ExCITe Center. (n.d.). Retrieved October 27, 2022, from https://drexel.edu/excite/

22. Encyclopædia Britannica, inc. (n.d.). *Organ*. Encyclopædia Britannica. Retrieved October 27, 2022, from https://www.britannica.com/art/organ-musical-instrument