An Analysis on Common HVAC Systems and How They Can Spread Harmful Dust Particles

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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

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Introduction

HVAC systems have become a common luxury, especially in the U.S. where approximately 90% of residential buildings are equipped with at least one unit (Graham, 2023). These systems are very useful for regions that experience hotter temperatures as they can make the summers more bearable by utilizing cooling technology. They've only gained extensive use in countries that are both wealthy and hot. However, with rising temperatures and the growing market, it will become more prevalent globally. Recently in 2022, the United Kingdom, a relatively cold climate country, experienced five heatwaves that led to the death of 2,985 (UK Health Security Agency, 2022). This was the highest death toll due to increased weather seen in the country's recorded history and has caused alarm in their standard infrastructure. Since these devastating events, the UK has seen increasing installations of HVAC units in homes to combat the threat of high indoor temperatures through consumer demand.

There is an expected increase in the HVAC industry across the globe for the same reasons that are apparent in the UK. This technology is one that is lifesaving now more than ever, however, these systems see frequent problems arise. It would be foolish to gain more problems from a solution, one coming from the issue of spreading dust. The inside of a house or building is a closed environment that creates dust particles from many sources such as dead skin cells, cloth fibers, outdoor airborne particles tracked in, etc (Taylor, 2024). These dust particles get trapped inside and become part of the circulation of air from HVAC units. Over a short period of time, as little as a month, it is recommended by experts that air filters must be replaced due to dust accumulation (Baugh, n.d.). From prolonged exposure to dust particles, the respiratory system can become agitated leading to health problems which are heightened for those with pre-existing respiratory conditions (HealthyWA, 2022).

With this increase in demand for HVAC systems, the shortcomings that come along with it must be evaluated and improved upon for the future. Apart from health concerns, the accumulation of dust on air filters greatly decreases the efficiency of operation for HVAC systems (Rae, 2024). This comes from the fact that dust restricts airflow which requires more time and energy for the system to cool or heat the environment to the same effect. This paper will delve into the history of HVAC systems and analyze the infrastructure of the technology through a social lens as well as technical. While providing a useful function for citizens to feel more comfortable at home, this thesis will investigate how HVAC systems can cause harm by spreading dust if not maintained properly, leading to respiratory issues and sickness.

Case Context

The first HVAC system was invented over a century ago by Willis Carrier that enabled the manipulation of temperature and humidity in a closed environment. Many improvements were made to the technology since then that have taken a lot of time and resources to update across the world. In the early applications, they required the use of a low cost, high durability, high heat resistance material to act as an insulator in the ducts. This led to the use of asbestos, which at the time was not seen to have negative impacts. However, by the late 1970's research was conducted that showed the effect on respiratory health from asbestos particles entering the air circulation. Since then it has left the standard practice and is still being removed from buildings that have not yet noticed the dormant danger (Stone, 2024). Buildings built in the 20th century have a high chance of having asbestos, which is still a major issue in the air quality of around 20% of buildings.

HVAC systems became integrated with infrastructures once they became standardized in new building construction. The ducts were built into walls and ceilings, giving them permanent residency in the majority of homes built since the latter half of the 20th century (U.S. Department of Energy, 2015). This entanglement of HVAC with all the other technologies and infrastructures in buildings led to great difficulty in making drastic changes in the design. This can be seen with the asbestos example, where the common insulation convention needed an immediate change. However, with many of the components in the walls and not easily accessible, not every unit could be checked and updated. This has led to stagnation in the innovation of the system in application. The research area of interest, dust mitigation, has thus seen limited growth being contained to a simple filtration plate with tiny gaps that only air can pass through.

The air filtration systems have seen variations in design, beginning with metallic mesh filters (Magninat, 2024). These designs were successful in stopping larger particles like hair, but limited in its effectiveness against smaller allergen dust particles. The next evolution was fiberglass filters, which were slightly better in trapping smaller dust particles but still far from adequate. The current design used is called the MERV (minimum efficiency rating value) filter which, when new and clean, traps around 70% of particles larger than .3 microns. Physical mesh filters have been made to capture more dust than the MERV filters, one such being the HEPA (high efficiency particulate air) filter. This is used in some circumstances where it is even more important that a room be kept sterile like in hospitals. The most effective method for filtering out harmful pollutants from the air is through ESP, electrostatic precipitation, 99.9% effective for .1 micron and larger particles (Naqvi, 2022). This is a technology that takes in air, charging the particles within negatively, which then attracts them to positively charged plates as seen in Fig. 1. There is then a mechanism that cleans the plates and disposes the particles back into the outside environment. Cooking is a common practice in homes and is a major cause of fine smoke particle generation which EPs can help reduce whereas standard filters will not. However, it is a much more complicated process making it hard to change installation practices. This research will evaluate if current dust mitigation through HEPA filters is a sufficient standard in keeping air clean.

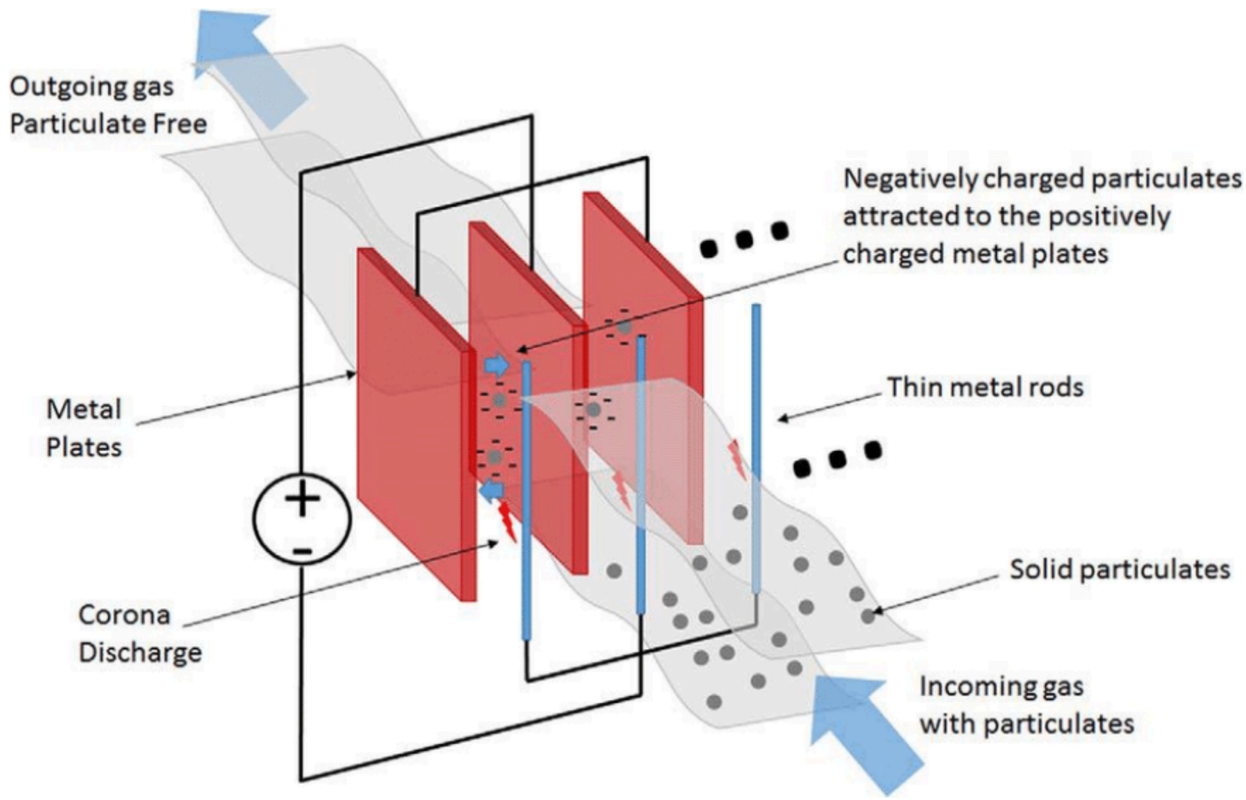

Figure 1: Diagram of Electrostatic Precipitation Technique

STS Topic

In order to further understand the reasons for why it may be a huge strain to change the technology used in residential buildings, the ethnography of infrastructure framework by Susan Leigh Star will be used to evaluate HVAC technology (Star, 1999). She views technology as intertwined with human organizations, leading to the definition of infrastructures having the properties of embeddedness, reach and scope, embodiment of standards, visible upon breaking, and fixed in modular increments. Embeddedness is when the infrastructure is sunk into other structures. This paper focuses mainly on residential home HVAC use, however, these systems have been incorporated into almost all buildings and transportation vehicles. Businesses, such as grocery stores, include HVAC systems in order for customers and employees to feel comfortable and be more inclined to return. Vehicles include this technology to cool the heat created from the engine or heat up the system from cold weather (Sheldon, 2022). These two examples are very different situations, with vehicles having less physical space for changes in air filtration technology.

The reach and scope of a technology is when it has progressed further than a singular instance of application. This technology has grown to an immense extent in many countries with the US, Japan, South Korea, Saudi Arabia, and China all having a majority of homes built with HVAC systems. The market for installations in homes is projected to grow all across the globe, becoming less of a luxury and more of a necessity, leading to an increase in demand for technician labor (Batongbakal, 2024). These technicians are stretched thin from having to install new systems and going back to fix old damaged ones. With the increase in demand, it will become harder the longer change in design is prolonged. Even more units will be installed out of date and needing an update in the future should a change in practice be recommended.

The property of embodiment of standards is when a system gets incorporated into an infrastructure in a way that becomes standardized. With HVAC technology being common for the past century, every newly constructed building has been designed in tandem with the infrastructure of HVAC systems. Space in the walls, ceilings, and utility rooms have been reserved for standardized ducts that spread the cooled/heated air to different rooms (U.S. Department of Energy, 2024). The controls for different electronic components have been standardized to connect to a control panel that is used by technicians to troubleshoot areas of failure in design. If the technologies change, like an ESP, the electric technicians will have to learn a whole new concept and system connected to the controls of HVAC. This would put a financial and educational burden on hundreds of thousands of workers and institutions.

A more tangible property of infrastructures is when it is visibly broken. There are many invisible avenues for HVAC dust filtration systems to be diagnosed as broken that signify how the current method of filtration needs to be innovated to account for this problem. The discussed issues that come with this industry is the spreading of harmful dusts, which are oftentimes not visible to the naked eye. These issues can be observed through their symptoms: coughing, sneezing, breathing issues, etc. Once this is observed, the problem can be attributed to a fault in the air filtration system. When dust builds up in the air it becomes apparent when light is shined on it in the day and an increased amount of dust can be found on appliances. There would also be visible signs of the air filter being coated in dark grey dust particles. If the building that these issues occur in are old, the ducts may need to be inspected for asbestos. This contaminant is not easily identifiable through looks and must be tested in a lab (Whitmer, 2024).

The final property that is being investigated is how the infrastructure is fixed in modular increments. This is when changes must be made bit by bit, by different organizations and over some time. The scope of this technology only keeps growing while there is a finite amount of workers and a multitude of leading companies. Although at the moment there is a general standardization of practices, different companies may use different materials or have different wiring schematics (Dhumne, 2023). This goes to show that changes made are not done as a whole, and should a change be made in the air filtration system it would be done unilaterally. Therefore, a convincing difference between HEPA filters and ESPs in mitigating harmful dust particles must be observed. With all these obstacles involved in such a big technology, we must ask; is the current infrastructure for HVAC systems inadequate in filtering dust?

Methods

The effectiveness of dust filtration in residential HVAC units is both a technical dilemma as well as a social concern. The advantage of EPs in collecting dust particles is known through experimental data, however, it is a much more complicated mechanism than a mesh air filter. Another filtration technology is the HEPA filter which is already used sometimes in households and yields better results than MERV filters. If the effectiveness of the newer technology has a significant impact on the mitigation of harmful dust particles, then there is an argument for its implementation regardless of the resources required for the change. One of the main reasons the MERV filter spreads dust is due to the negligence of the homeowner either forgetting or never knowing the frequency it should be checked. It is also imperative to gather the extent of damage that can be caused to humans from household dust particles, such as a numeric death toll.

In order to ascertain the differences in MERV, HEPA and EP filtration, research papers will be a primary source of gathering information. Data on each filtration system will be collected to get a more accurate representation of the dust mitigation of both technologies from cross-referencing multiple research studies (Mizuno, 2002). Prior literature will be scoured to gain an extensive list of all the different types of contaminants that can build up and spread in HVAC systems as well as their harmful effects (Christian, 2021). From researching the effects of dust particulates, a preventative solution such as HEPA or EP filtration can be recommended or a responsive solution such as adding dust sensors (Ahn et al, 2020). The properties of technology laid out by Star will also need to be evaluated for each solution to check if it solves the inherent problems.

Results

The outcome of the research conducted on the current infrastructure of HVAC and its many components resulted in some very surprising results. The significance of the problem at hand is staggering. The World Health Organization (WHO) estimates an annual death toll of 3.8 million to indoor air pollution (Tran, 2020). The most common air filter in houses, MERV, only has an effectiveness of 70% for particles between 3 and 10 microns wide. With many pollutants even being below this range, it can be seen how there is a significant death toll. HEPA filters are very good at collecting particles .01 microns and larger, which is small enough to collect most gases. EPs can collect particles below .1 micron with a 95% effectiveness rate. The analysis on the effectiveness of MERV filters has yielded the answer that current HVAC infrastructure is not adequate in mitigating household deaths, and better solutions should be implemented. Through Star's framework, it is hard to see that the current system is visible when broken and therefore should be fixed in modular increments especially as its reach and scope along with its standard practices are expanding.

There are health risks to the respiratory system that come from toxic tiny particles in the air. These are more than just the large visible dust particles commonly categorized as allergens, Table 1. Smaller particulate matter found in gases come in sizes 1 micron diameter across or smaller which MERV filters are less effective at reducing (IQAir, 2018). All of these pollutants combined have led to a yearly death rate of 3.8 million, which highlights the problem and why it should be addressed. Most of the larger particles get caught by all filtration systems, however 90% of indoor air particles are under 1 micron wide (California Air Resources Board, 2025). Most filters cannot mitigate pollutants of this size, which is why there are already smoke/carbon monoxide detectors in houses. The property of visible when broken is the most important drive of this research and when these particles making it through the filters are on the scale of microns, it is apparent that the infrastructure is not ideal. Dust sensors are not commonly used in houses, however alongside smoke detectors it can help detect larger particulate matters to successfully recognize unhealthy air.

Table 1. Information of indoor pollutants with their causes and effects

Pollutants	Causes	Effects
Particulate Matter (PM)	Outside air, cooking, combustion, cleaning	Premature deaths for those with existing heart/lung diseases, increased respiratory systems
Volatile Organic Compounds (VOCs)	Paints, pesticides, woods, waxes, lubricants, dyes, fuels, plastics, tobacco, perfumes	Eye/nose/throat irritation, headache, nausea, liver/kidney/central nervous system damage, cancer
Nitrogen Dioxide (NO_2)	Gas-fueled cooking and heating	Asthma attacks, respiratory damage
Ozone (O_3)	Outdoor air, air purifying, disinfectants	DNA/lung damage, asthma attacks, decreased respiratory functions
Sulfur Dioxide (SO_2)	Cooking, fireplaces, outdoor air	Decreased respiratory functions, asthma attacks
Carbon Oxides (CO_x)	Cooking, tobacco, fireplaces, gas powered equipment, outdoor air	Fatigue, chest pain, impaired vision, reduced brain function
Heavy Metals	Outdoor air, fueled products, incense, smoking	Cancer, brain damage, respiratory illnesses
Aerosols	Tobacco, building materials, consumer products, incense, cleaning, cooking	Cardiovascular/respiratory diseases, allergies, lung cancer, irritation
Radon	Soil gas, building materials, tap water, outdoor air	Lung cancer
Pesticides	Insecticides, disinfectants,	Eye/nose/throat irritation,

	building materials, outdoor air	kidney/central nervous system damage, cancer
Allergens	House dust, pets, mold, pollens, insects, plants	Asthma/allergy attacks, respiratory infections
Microorganism	Bacteria, viruses, fungi	Fever, digestive problems, infections

MERV filters are the most common filtration system used in household HVAC systems. They are designed to balance dust mitigation and high airflow to reduce issues arising in low circulation of air. The median effectiveness of a MERV filter in mitigating particles from 1-3 micron is 72% (Jones et al, 2021). MERV filters have ratings, where the higher the number the more effective it is at reducing dust. For example, a MERV 13 filter can prevent 85% of dust particles in this range. The standard healthy amount of dust in the air is suggested to be 9 $\mu g/m^3$. The statistics for these filters are clearly not ideal, however due to the reach and scope as well as existing standards practiced by technicians, this technology has remained the standard regardless of its inefficiencies. A solution to this dust problem can then be to keep using these filters and pair it with a dust sensor to detect when the filter is no longer mitigating the dust to this standard level. This would be the most promising method to have a visible cue that there is a problem as dust sensors would start an audible alert showing that dust levels in the house are too high.

Upon reviewing research on the technology of HEPA filtration, it is apparent that they are extremely effective at filtering dust particles of a wide range. Many manufacturers advertise a 99.97% effectiveness for particles with .3 micron diameters, see Fig. 2 for experimentally determined data supporting this statistic (Bahnfleth, 1999). This is not the minimum size for effectiveness but rather the minimum effectiveness for particles .01 microns and above (Donaldson, 2014). Therefore this would be an effective filter in reducing many gaseous pollutant particles. An upside to these filters is that they are commonly found in the same dimensions as the MERV filters, making them easily replaceable in current HVAC infrastructure. A downside to this technology is that it is more restrictive on airflow which can lead to more maintenance and potential failures. The reduced airflow will cause the HVAC system to work less efficiently, taking longer to circulate air and more money and energy to achieve the same climate control as MERV filters. This issue could hinder the infrastructure's ability to comply with certain standards and thus is possibly not the best solution.

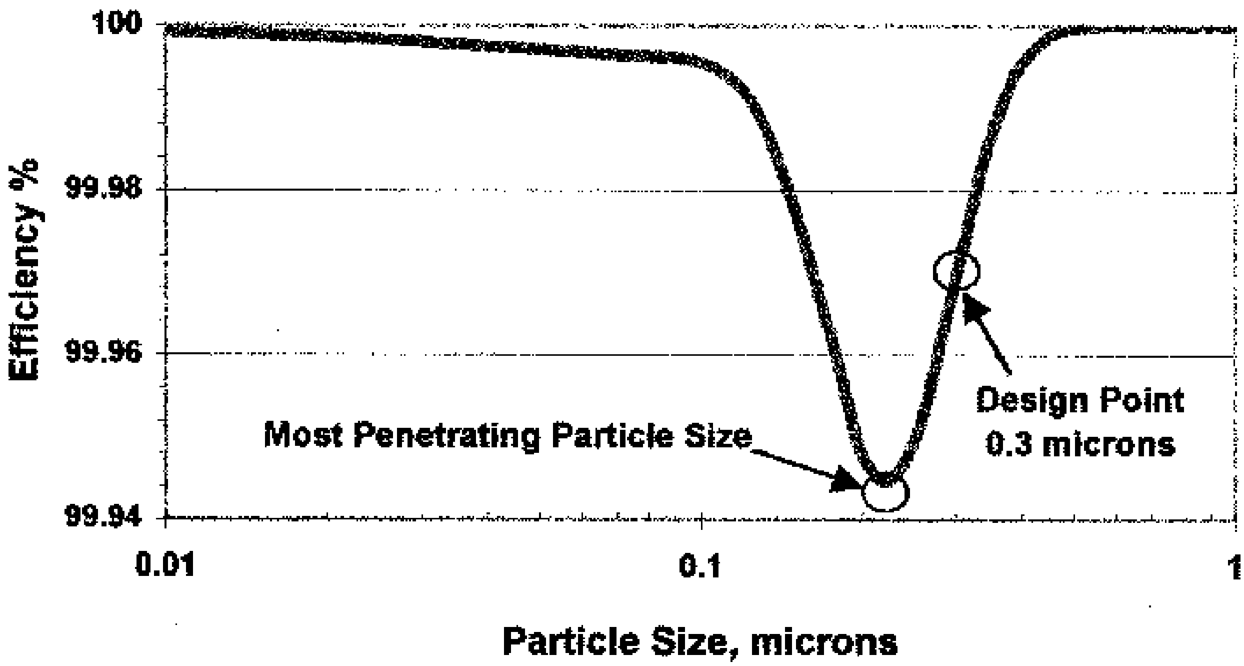

Figure 2: HEPA filtration efficiency for different particle sizes

EPs are an advanced form of dust mitigation commonly used in coal mines to clean up the air of ultrafine particles, .1 micron or less (Afshari, 2020). They are 95% effective with collecting particles in this range and 99-100% effective with larger particles. When directly compared with HEPA filters, this rate is actually worse at collecting ultrafine particles. This technology requires the use of high voltage power which is more dangerous and harder to maintain than mesh filters. On top of this, they produce and emit ozone gases which add on to pollutants in the air. This technology does not improve upon the current infrastructure mainly as it would decrease the reach and scope of HVAC due to its complexity and high cost. It would also not be a solution that resolves the issue of visibility when broken, in fact worsening it as the dust collection plates would be hidden unless manually accessed. This would also be hard on technicians to learn the safety and installation processes of it, largely changing the standards of the industry. It would also not be a modular process for change and would require a very large change in design and practice. So overall this technology is rightfully not being used in residential buildings as it shows no social or technical benefits.

Discussion

This research dives into the functionality of three existing dust mitigation technologies as well as an observation of unaddressed issues with household HVAC systems. When looking at the problem and solutions through Star's framework, the responsive solution of adding dust sensors seems to be the best approach to improve social concerns with the technology. The motivation behind this research was that people often do not change out their dust filters, and this stems from the fact that there are no clear visible cues that would remind them to. The preventative solutions offered no benefit in this regard, as well as adding some negative social issues. The HEPA filters would contradict with the embodiment of standards as it would indirectly cause problems with airflow in HVAC systems. EPs failed to improve any of the social concerns as well as being less effective in reducing household dust compared to HEPA filters regardless. Through the research and analysis with the aid of Star, it can be seen why the industry has stuck with MERV filters as opposed to these other options.

A significant limitation in this research is data on the average frequency that household HVAC systems' filters are replaced. There has been no study conducted that polled a sample size, however, this paper is assuming that many households do not change their filters within 3 months. An experiment would also need to be conducted to measure the effectiveness drop of an air filter that has become dirty. It is a known fact that the airflow becomes restricted and filtration becomes less reliable, however there is no quantitative data that shows a trend of time to filter effectiveness. This paper also did not extensively research the cost for consumers to switch their HVAC systems, like adding an EP to the house. Dust sensors and HEPA filters would however be relatively inexpensive with dust sensors costing under \$10-\$50 and HEPA filters costing slightly more but requiring less frequent replacement.

Following up on the limitations outlined, a poll would be very beneficial to understand the extent of the issue. It would be imperative to poll UVA faculty as they would be more likely to take care of household chores and be more representative of average homeowners. Ideally having experimental data on the effectiveness of used air filters would be beneficial in understanding the decrease in performance over time. It would help justify the need to be more cautious with the MERV filtration system that does not have safety guards for improper maintenance. An analysis on the financial costs of each three systems in a household would have been a good way to objectively compare each method. Restrictive airflow from HEPA filters would indirectly increase the energy used by the HVAC system and add an additional financial burden, however it's unknown if that effect would be significant.

This research on HVAC systems has helped me advance my skills at conducting literature reviews. The subject matter of research is also relevant to the work I could do in the future in the field of HVAC. In my previous internship, I learned a lot about how HVAC systems work in regard to temperature control and airflow, therefore this additional knowledge on the differing dust mitigation systems is beneficial information. Conducting research like this has helped me further my ability to extensively learn about issues related to engineering fields and how to list pros and cons of different solutions to a problem. Especially with the results of this research yielding two good solutions, it shows that when tackling a problem in engineering there is not always one objectively correct avenue, and multiple methods will yield large benefits and some consequences.

Conclusion

The results of this research are relevant to the general realm of engineering solutions where there is no one ultimate solution to a problem. When looking from a technical lens, all of the filtration systems have their benefits, however when adding in a social analysis the differences become more apparent. I believe the next steps for HVAC in households would be the widespread recommendation and application of dust sensors as they are simplistic, cheap, and would alert many people of immediate faults in their systems. This would require minimal altering to HVAC infrastructure as it is a commercial product that does not need to be adapted to buildings and can be installed in any part of the house one is most concerned with having dust. From there, HEPA technology should then be advanced to allow more airflow without reducing efficiency greatly and potentially adapted to HVAC infrastructure. These findings highlight the fact that the current implementation of dust filtration systems has some room for improvement. A broader variety of solutions working in tandem can decrease the negative health consequences of the current design which relies on the responsibility of the user for satisfactory results.

References

Afshari, A., Ekberg, L., Forejt, L., Mo, J., Rahimi, S., Siegel, J., Chen, W., Wargocki, P., Zurami, S., & Zhang, J. (2020, October 22). *Electrostatic precipitators as an indoor air cleaner-A literature review*. MDPI. https://www.mdpi.com/2071-1050/12/21/8774

Ahn, K. H., Lee, H., Lee, H. D., & Kim, S. C. (2020, January). Extensive evaluation and classification of low-cost dust sensors in laboratory using a newly developed test method. Indoor Air, 30(1), 137-146. doi: 10.1111/ina.12615.

Bahnfleth, W. P., Kowalski W. J., & Whittam T. S. (1999, January). Filtration of Airborne Microorganisms:Modeling and Prediction. https://www.researchgate.net/publication/242434719_Filtration_of_airborne_microorganisms_Modeling_and_prediction

Batongbakal, L. (2024, November 16). *HVAC industry trends and outlook for 2025*. Workyard. https://www.workyard.com/construction-management/hvac-industry-trends

Baugh, T. (n.d.). *How Often to Change Air Filters in Your Home.* Carrier. https://www.carrier.com/residential/en/us/products/air-conditioners/air-conditioner-maintenance/how-often-to-change-air-filter/

Christian, T. A. (2021, July 8). *What exactly can an air purifier catch?*. Consumer Reports. https://www.consumerreports.org/air-purifiers/what-can-an-air-purifier-catch/

Dhumne, M. (2023, January 16). *Should you use the same company for your HVAC* *maintenance and Furnace Maintenance?*. Comfort Systems. https://comfortsystems.net/should-you-use-the-same-company-for-your-hvac-maintenance-and-furnace-maintenance/

Graham, Adam. (2023, July 4). *The Use of AC Across the World: Putting America's Obsession Into Perspective*. FIXR. https://www.fixr.com/articles/the-use-of-ac-across-the-world

HealthyWA. (2022, February 11). *Health effects of dust*. https://www.healthywa.wa.gov.au/articles/F_I/Health-effects-of-dust

HEPA Filtration Facts. Donaldson Filtration Solutions. (2014). https://donaldsonaerospace-defense.com/library/files/documents/pdfs/042665

Indoor air pollutants: What's in the air we breathe? IQAir. (2018, October 26). https://www.iqair.com/us/newsroom/indoor-air-pollutants-dangers?srsltid=AfmBOoo5nvBchtDZFIgDJw-Kml_q6yfrRWIXJXjPiGE0gpbvAVg2kWHh

Inhalable Particulate Matter and Health (PM2.5 and PM10). California Air Resources Board. (2025). https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health#:~:text=Particles%20are%20defined%20by%20their,5).

Jones, E. R., Laurent, J. G. C., Young, A. S., MacNaughton, P., Coull, B. A., Spengler, J. D., &

Allen, J. G. (2021, August). The effects of ventilation and filtration on indoor PM2.5 in office buildings in four countries. Building and Environment, 200(1). https://doi.org/10.1016/j.buildenv.2021.107975

Magninat, J. (2024, September 12). *Air filtration systems: How air conditioners have evolved*. Classic Air Conditioning & Heating. https://classicairconditioningandheating.com/evolution-in-airconditioner-air-filtration-systems/

Mizuno, A. (2002, August 6). Electrostatic Precipitation. IEEE, 7(5), 615-624. doi: 10.1109/94.879357

NASA. (2023, March 17). *How dust affects the world's health*. https://earthobservatory.nasa.gov/images/151100/how-dust-affects-the-worlds-health#:~:text=The%20airborne%20particles%E2%80%94thirty%20times,disease%2C%20and%20lower%20respiratory%20infections.

Naqvi, S. Z., Ramkumar, J., and Kar, K. K. (2022). Handbook of Fly Ash. Butterworth-Heinemann, 3-33. https://doi.org/10.1016/B978-0-12-817686-3.00006-2

Rae, D. (2024, April 23). *Dust impact on AC Efficiency: Collin County, TX*. Airmax Air Conditioning & Heating - Collin County, TX. https://www.airmaxntx.com/impact-dust-ac-efficiency-collin-county

Sheldon, A. (2022, June 2). *The history of air conditioning in Cars*. Your AAA Network.

https://magazine.northeast.aaa.com/daily/life/cars-trucks/auto-history/the-history-of-air-conditioning-in-cars/

Star, S. L. (1999). The ethnography of infrastructure. American Behavioral Scientist, 43(3), 377-39.

Stone, N. (2024, September 3). *Asbestos and your HVAC system: Everything you need to know*. Fitch Services. https://fitchservices.com/asbestos-in-your-hvac-system/

Taylor, M. P, Barlow, C. F., Fry, K., and Gillings, M. M. (2024, November 21). *What is dust? and where does it all come from?*. The Conversation. https://theconversation.com/what-is-dust-and-where-does-it-all-come-from-168265

Tran, V. V., Park, D., & Lee, Y.-C. (2020, April 23). *Indoor air pollution, related human diseases, and recent trends in the control and improvement of Indoor Air Quality*. International journal of environmental research and public health, 17(8), 2927. https://doi.org/10.3390/ijerph17082927

UK Health Security Agency. (2022). *Heat mortality monitoring report: 2022*. GOV.UK. https://www.gov.uk/government/publications/heat-mortality-monitoring-reports/heat-mortality-monitoring-report-2022

U.S. Department of Energy. (2015, July 20). *History of air conditioning*. Energy.gov. https://www.energy.gov/articles/history-air-conditioning#:~:text=By%20the%20late%201960s%2C%20most,states%20like%20Arizona%20and%20Florida

U.S. Department of Energy. (2024, December 30). *Central Air Conditioning*. Energy.gov. https://www.energy.gov/energysaver/central-air-conditioning

Whitmer, M. (2024, November 21). *Guide to asbestos in the home: What does asbestos look like?*. Mesothelioma Center - Vital Services for Cancer Patients & Families. https://www.asbestos.com/exposure/home/