Electrification of American HVAC Infrastructure: The Way Forward

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Aidan Jacobs

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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

Advisor

Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Introduction

It is a universal truth that humans need energy to live more comfortable lives; however, the primary method the population uses to accesses energy is not sustainable. The threat of climate change caused by human action will cause an inconceivable amount of damage if serious steps are not taken to mitigate the issue. Coastal areas will be flooded as sea levels rise displacing millions of people and major storms will intensify and become more frequent (Forster, May 4 2020 p. 1). Specifically, the most important action for humans to take is to reduce emissions of carbon dioxide and other greenhouse gasses that are contributing to the warming of the planet.

Low emissions electric technology has already been developed that could help achieve this goal, but it can only do that if it is actually adopted by the public. Despite the fact that new more efficient technology is available, the majority of homes and rental properties are still using their own older systems, continuing to burn oil, coal, and natural gas. This is a particular problem in lower income communities where the cost barrier to upgrade can actually dissuade individuals from buying new appliances. The research shows that taking steps to make your home or building more sustainable, such as adding solar panels or replacing a gas burning furnace with an electric heat pump actually pays for itself fairly quickly (less than 10 years) (Deters, Feb 16 2021 p. 1) through long term monthly savings on electricity and heating bills that continue after the appliance has 'broken even' so to speak. This of course begs the question, "If these projects save money in the long term, why has the public been hesitant to adopt these new technologies on a large scale?"

It is possible these non-adapters are simply not aware of the global implications of only a few degrees of warming. Climate change is a growing problem that experts predict is only going

to accelerate if human actions do not change dramatically (Loarie 2009 p. 2). The human race is emitting far too much carbon dioxide (as well as other gasses like methane) into the atmosphere with no particularly strong plan on how to re-collect it and this has had a number of unintended consequences. The most significant of those consequences, as it essentially causes the rest of the consequences, is the warming of the planet that has been occurring over the past century or so. A warmer planet means more intense storms, and, less frozen ice in the arctic coupled with the ocean's thermal expansion causes a rise in sea levels that will flood millions of people out of their homes and cause what could be the greatest global crisis of misplaced people the world has ever seen.

This research paper will be focused on analyzing the relationship between newer greener technologies and the public. There have certainly been serious environmental efforts made by some parties that have made a difference, but this is not a problem that is solvable if only *some parties* are working towards a solution. This is a global problem that requires a global solution. Newer technologies are available that would help reduce emissions (and electric bills) everywhere, but the public is not as eager to upgrade as the situation suggests they should be.

Part I: Converting HVAC Systems Is a Feasible Way to Slash Emissions

Just as the auto industry has begun branching out into fully electric vehicles, the HVAC landscape must start converting to fully electric heat pumps. It will not be a quick transition nor an easy one to convert millions of buildings, however it is a necessary step to reach net zero emissions because even if the grid is powered without the help of coal, oil, or natural gas, buildings all across America and the rest of the world are not equipped to heat themselves with just electricity. The United States doing its part will not solve the problem either, to reach a sustainable level of emissions, there will have to be serious reductions in emissions globally.

Given the fact that carbon dioxide and other greenhouse gasses being emitted are causing the large majority of climate change problems, the simple solution is to greatly reduce the quantity of these gasses being emitted. The easiest way to do that is to eliminate fossil fuels in the everyday supply of power to heat and cool homes.

As it stands, not including the embodied emissions involved in construction, figure 1 (*Why the Building Sector*? 2018) shows that building operation accounts for over a quarter of all global emissions. It may seem surprising that building operation is such a large share; however, it can be explained by the fact that most buildings have air conditioning or at the very least some form of heating. Controlling the temperature of an area when the surrounding area is vastly different is a very energy intensive process. In commercial buildings, HVAC appliances account for 40% of all power usage (Bonacorda Nov 2015 p. 1) and in residential homes there is more variability, but the estimates say about half of all power usage which is the most of any single appliance in both cases. This is simply a tradeoff people have decided to make time and time again: consume more energy and improve quality of life.

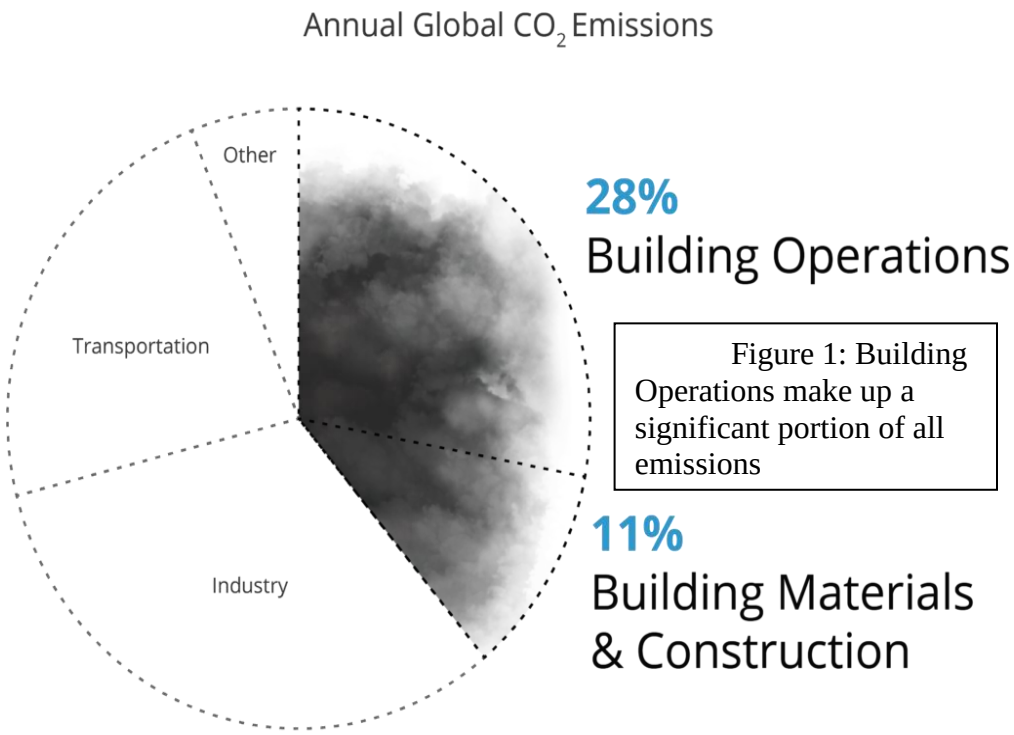

Figure 1: Building Operations make up a significant portion of all emissions

The problem with that unfortunate truth is the number of homes and other buildings in America that still rely on fossil fuels as their main or only source of heat. Approximately half of homes are heated with natural gas only about one percent of homes actually have a modern electric heat pump (Roberts 2018, p. 1). About a third of homes do use electric heat in the form of inefficient baseboard heating; however, this is primarily in the south where heating demands are significantly less and a top-of-the-line heat pump would realistically be overkill. The areas that really need heat rely heavily on emissions heavy fuel sources like natural gas and oil and need to start electrifying. It wouldn't even necessarily have to be an environmentally minded decision for homeowners as a heat pump would actually reduce costs and end up paying for itself in the long run. As figure 2 (Rosenow June 2019) shows, the overall electrical demand of the building will increase, but the demand for gas energy is eliminated altogether. Electric heaters are actually more efficient than boilers and furnaces as they are capable of harnessing and recycling the energy from ambient heat and therefore capable of producing three units of heat per unit of energy inputted compared to a gas boiler that outputs 0.9 units of heat per energy unit of gas (Rosenow June 2019 p. 1). The overall effect of the change is a sizeable drop in total energy consumed, a drop in the heating bill, and a reasonable drop in carbon dioxide emissions. Even in new development, of all houses built in 2019, only 43 percent had electric heating (Sichelman Feb 2021 p. 1). It is certainly a better proportion than the one percent of all

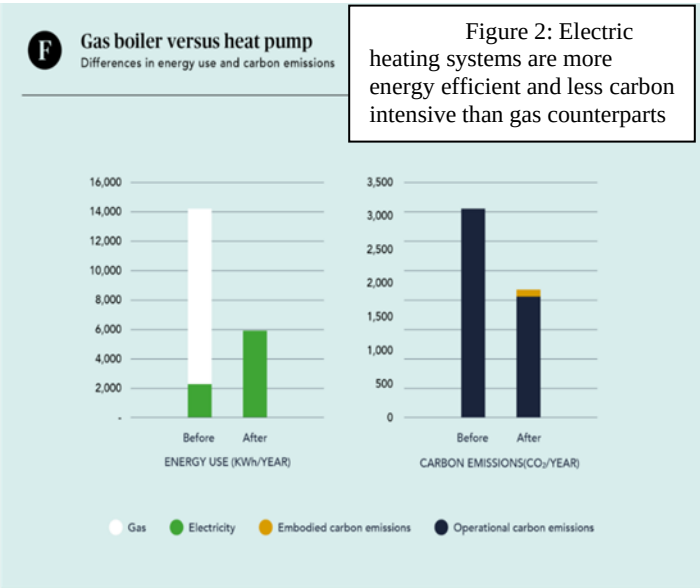

Figure 2: Electric heating systems are more energy efficient and less carbon intensive than gas counterparts

houses that have highly efficient pumps already, but it seems quite shortsighted to be outfitting more than half of all new homes to run on fuel that is on the decline.

What is arguably the most valuable part of this theoretical conversion is the fact that it sets the user up for a fully sustainable future. As of now, sourcing electricity from the grid does still cause carbon emissions as America's grid is still powered by a number of different sources including fossil fuel power plants. However, as time advances, the proportion of the electrical grid supplied by renewable and low emission sources is growing, especially on specific regional grids (Mallapragada 2020 p. 11). The problem with solar has always been that if the sun is obscured, power production is hindered and in the past the numbers of batteries needed for the system to function primarily on solar would've been prohibitively expensive, but as battery technology has advanced, it has become possible to store the energy captured from the sun and save it to be transmitted as the public needs it. In fact, the technology has increased far enough that solar farms are capable of selling power at rates lower than fossil fuel power has ever been sold for (Service 2019, p. 1). If this is any indicator of how the energy markets will advance in future years, it looks like solar will certainly be on the rise along with other renewable energy strategies that have long been limited by battery technology such as wind and hydroelectric power. One step still remains, even if the United States strengthens its renewable energy production to the point of meeting all demand for energy, boilers and furnaces are incapable of converting electricity into heat. The switch to electric heating is a fundamental step on the road to net zero emissions (the amount of CO_2 emitted is less than or equal to what is absorbed by plants and captured) and the earlier any nation commits to the switch, the sooner it can begin to reap the benefits. As of now, properties all across the country have yet to make the change and this research paper is concerned with determining the reasoning for why they have not.

Part II: Understanding the Public's Lack of Adoption of Green Technologies Through Geels' Multi-Level Perspective on Sustainability Transitions

In order to properly understand what was causing the public's reluctance in upgrading to newer, greener, and more efficient models, a framework for my research had to be determined. The framework that would best encompass all the possible factors playing into the property owners' decision not to upgrade would be the one detailed in Geels' "Multi-level Perspective on Sustainability Transitions" (2011). Geels explains how multiple levels must be recognized and analyzed within the system: niches, regimes and landscapes. The question this research is seeking to answer pertains to the actions of individual homes and buildings so it makes sense to use a bottom-up approach to STS instead of the more common top-down approaches.

Niche: New Technology Development

Geels explains how the niche level of the system is made up of a small group of users who have special demands in order to push the bounds of innovation. This is the level at which change begins and the technology or practices that are capable of altering the world are developed.The users are attempting to revolutionize their fields, but not everything they do is adopted at a large scale for any number of reasons usually having to do with the regime in place.

The niche level is considered a "safe space" as it is in the public's best interest that the users within this level be allowed to develop freely and without hinderances from outside forces. In regard to this research specifically, the niche is the developers of greener alternative technologies, specifically electric heat pumps. They have essentially been allowed to develop to technology necessary for a sustainable future, but it has yet to engulf the larger landscape.

Regime: The Beneficiaries of Current Technology

The next level of the system to analyze is the regime in place. As figure 3 (Geels 2011) shows, the regime is made up of a large number of different factors that can all influence what new technology is adopted at a large scale. Even when one technology seems better than another by all the seemingly most important metrics, the inferior can possibly prevail if an unforeseen factor, such as the fact that it would put a large industry in jeopardy, plays a big role in the active regime's process. Breaking it down, a sociotechnical regime is made up of several smaller, more focused regimes including the dominant forces in the market, the sociotechnical and cultual beliefs held, the policymakers in power as well as those who determine what scientific research and technological development are worth funding. Often, parts of regimes in place now will work against the adoption of niche development (as it could potentially lead to a change in regime structure) and use what are called 'lock-in mechanisms' to do so. Lock-in mechanisms are tools or practices used to ensure one technolgy remains the standard for years even if something superior comes along shortly after. Over the past several decades, the American sociotechnical system could be defined by how much influence the fossil fuel industry wields as it can be seen in policymakers' decisionmaking and even in what scientific fields of research are allocated funding. Elected officials who received significant

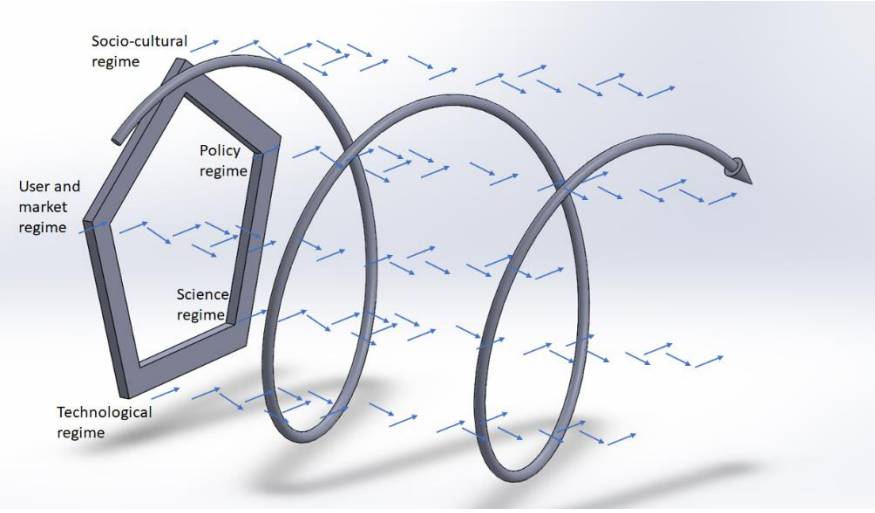

Figure 3: Diagram visualizing how different factors of the regime influence technological development

campaign contributions from lobbyist groups are less likely to support renewable energy initiatives and more likely to approve other lock-in mechanisms.

Landscape: How Outside Trends and Changes Affect Regimes

The final and broadest look at the sociotechnical system that Geels entails is analysis at the landscape level. The landscape level is similar to the regime level in that is a broad overview of the system at large and tends to change at a slower pace than smaller more specific levels, but it differs in the fact that it also includes the large scale events of movements which no individual actors within the regime are capable of affecting or stopping. These events however, can affect the actors within a regime significantly; in fact, events at the landscape level are often what finnally brings change to regimes that have remained beyond their usefulness through lock-in mechanisms. Landscape events come in many forms such as changes in societal opinion, changes in demographic (due to immigration or otherwise), rises in political idealologies, macroeconomic trends, and more. It is also often difficult to recognize a landscape change while it is ocurring and only become particularly clear after the fact.

Part III: The Reasoning for Widespread American Hesitation

The final step of the process is identifying why there has not already been widespread adoption of this superior technology. It is a widely accepted reality that the fossil fuel industry has a number of lock in mechanisms including multi-year contracts to supply fuel, as well as intense spending on infrastructure like oil rigs and pipelines that would become useless if we were to abadon fossil fuels quickly. It has been a strategic move to develop in a way that the inevitable transition will be more difficult and therefore gets put off for a longer time giving the

current regime more time in power, and thus demonstrates the unfortunate brilliance of lock-in mechanisms.

Applying Geels' framework to the delay in HVAC upgrades that has been observed allows for easier identification of the root of the problem which lies, in this case, at the regime level. A combination of the influence held by the fossil fuel industry as well as the lack of permanent affordable housing, which has increased the number of people who have to rent the home or apartment they live in as opposed to purchasing, has created a 'perfect storm' of sorts to delay the electrification of HVAC systems.

Some Americans Face Financial Barriers

Upon researching to find if there are any particular patterns in regard to income levels and heating type there were not particularly strong trends in unit type, but a pattern did lie in unit age. Unsurprisingly, lower income communities tend to have older less efficient appliances (Cluett Mar 2016 p.1), and, as a result, a larger proportion of their total income goes toward paying the utility bill. As of now, it appears that there is a trend ocurring within the current landscape that is working against niche adoption. In order for this new technology to become mainstream, at least one other movement within the landscape must begin. The currently active trend I refer to is the widening of the wealth inequality in America (Keister 2000 p. 1) leaving the lower (and even some middle) class families financially incapable of upgrading their systems to greener alternatives. Despite the fact that a heat pump is an investment likely to pay for itself and more, not everyone has the funds on hand to shell out thousands for an unexpected upgrade (home level pumps seem to run from $2000-$5000). The fact that in the long run the upgrade will pay for itself is irrelevant when a significant portion of the population is financially incapable of actually investing in such an upgrade.

The necessary landscape movement to counteract the affects of the widening wealth gap will be one of political awakening. For this fossil fuel dependent regime to be replaced with one with a plan for a sustainable future, public perception must shift. Government programs to financially assisst the poor so upgrades could be made should be viewed as government investments in the environment as those not directly receiving assistance are less likely to object. Society has to view the environment as the fragile resource it is and recognize that anything done to preserve it is mututally beneficial to everyone living on this planet.

The fossil fuel regime has had control over how society accesses energy and normalized a practice that is pushing everyone towards disaster. This new technology seems to be a crucial step on the road to a net zero emissions; however, it has yet to be implemented on a large scale. The lack of public adoption of this green technology could be due to a number of reasons. The sociotechnical landscape of America is defined in part by income as some users are able to wield more or less influence and control industry standards.

There is also a considerable population in this country renting the residence they live in and unless the landlords will increase rent, potentially driving away tenants, they are not particularly incentivized to install costly upgrades that lower tenant's utility costs. The rental scenario is tricky because, between the two parties (landlord and tenant), it seems that if one were to invest in a heat pump, the other would be the one realizing most of the benefits. Ultimately, the inability of a large number of homes and buildings to make the smartest upgrades for the future now is a result of wealth inequality in America. Low-income individuals and communities are both less likely to upgrade given the financial barrier and more likely to be renting property instead of owning it and thus fall into the difficult situation with their landlords.

It is of the utmost importance that as we move forward with sustainability that the benefits be allowed to reach all communities.

The problem facing renters as well as the cost barrier preventing lower income communities from upgrading could possibly both be solved by government intervention. Recent commitments made for the Paris Climate Agreement by the American government indicate it is very willing to spend, committing to spend over 36 billion (Newburger, May 2021, p. 1) towards battling climate change. However, none of the 36 billion is allocated towards replacing individual fossil fuel units with electric alternatives. A government program in which loans are awarded for the purpose of upgrading and could be paid off with future savings is the solution that many Americans who've been rendered unable to upgrade are looking for. Currently, the funding is dedicated towards climate research and subsidies for green industries like renewable energy, but to get through a crucial step of the decarbonizing process, the government has to assist private citizens as well as green minded businesses.

Some Americans Hold Misconceptions Regarding Electric Heat

There is, however, another group that has yet to upgrade and does not have as direct of a reasoning for doing so. There are plenty of Americans with boilers or furnaces who are more than capable of affording the electric alternative, but they have not yet decided to make a change. The explanation as to why they haven't decided to upgrade is complicated and multifaceted. Some of them are simply unaware the option exists and are too busy with their everyday lives to look into ways to make their homes more efficient. Others may have an image of electric heating of the past, which at a reasonable power consumption level was not capable of producing heat at the level of traditional fuels and was typically only used in warmer areas where heating was not a major concern. These individuals have a notion in their head that the greener system is less

capable of producing adequate heat and as a result are not looking into switching their homes to it. Technology has advanced quietly rendering this notion incorrect without alerting those who hold this notion to its inaccuracy. Nowadays electric heat pumps can heat a building just as well as a traditional furnace and they can do it at a reduced cost. Even if the benefits do outweigh the costs a couple of years out not everyone will be willing to go through the trouble of switching their HVAC unit as it certainly would be a major home decision. They know their old unit works and have no particularly strong reason to trust this new technology unless they have studied the topic thoroughly. HVAC companies should be putting more effort into advertising the new electric models because the inevitable switch to electric, whenever it does occur, will be a significant source of new customers for any HVAC company. To bridge the gap (Craig, Feb 2022, p. 1) to these new customers now, HVAC advertising has to get consumers to trust that electric heating has improved past the quality of oil and gas systems.

Conclusion

In summary, the greatest threat facing all of humanity today is the possibility of the worst-case scenario climate change predictions. In order to prevent the worst-case scenario from occurring there has to be a significant drop in the amount of greenhouse gas emissions from all sources. One fairly significant source of emissions is building operation and specifically the heating and cooling. As the grid becomes more powered by low emissions sources, electrifying the heating and cooling of buildings is an easy way to continually reduce both the emissions and energy cost of any building.

The useful questions this paper analyzes are “Why has the public not already adopted this new technology?” as well as “What must be done in order for this technology to become the standard?”. Both questions have many answers as different portions of the population have

different holdups. Lack of adoption appears to be a result of financial barriers in some cases, and in others ignorance: either to the technologies existence or to its superiority.

The best way to solve these problems is to attack them at their respective sources. If this technology is to be adopted by the general public, their issues must be addressed. Government programs could assist and incentivize lower income homeowners and landlords of lower income housing to upgrade their properties. Those people whose problem lies in ignorance simply need to be educated. If the HVAC industry put their advertising effort into informing the public the number of ways electric heat pumps are superior to traditional fossil fuel heating, it's likely that many of those who can afford to upgrade now will. Electrifying the heating of homes and buildings is a necessary step towards a net zero future and the sooner the switch is made the sooner everyone can begin reaping the benefits: both environmental and financial.

References

Bonacorda, P. (2015, November 24). *HVAC Efficiency: What It Is, Why It Matters and How to Get Started*. Alliance to Save Energy. https://www.ase.org/blog/hvac-efficiency-what-it-why-it-matters-and-how-get-started

Cluett, R. (2016, March). *Building Better Energy Efficiency Programs for Low-Income Households*. 46.

Craig, T. (2022, February 14). *Heat Pump Awareness Grows from Residential, Commercial Customers*. Retrieved April 22, 2022, from https://www.achrnews.com/articles/146156-heat-pump-awareness-grows-from-residential-commercial-customers

Deters, T. (2021, February 16). How Long Does It Take Solar Panels to Pay For Themselves? *Green Ridge Solar*. https://greenridgesolar.com/2021/02/solar-panels-payback/

Forster, P., & Le Quere, C. (2020, May 4). Climate change is getting worse but it is no worse than we predicted. *Climate Change Committee*. https://www.theccc.org.uk/2020/05/04/climate-change-is-getting-worse-but-it-is-no-worse-than-we-predicted/

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Keister, L. A. (2000). *Wealth in America: Trends in Wealth Inequality*. Cambridge University Press.

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B., & Ackerly, D. D. (2009). The velocity of climate change. *Nature*, *462*(7276), 1052–1055. https://doi.org/10.1038/nature08649

Mallapragada, D. S., Sepulveda, N. A., & Jenkins, J. D. (2020). Long-run system value of battery energy storage in future grids with increasing wind and solar generation. *Applied Energy*, *275*, 115390. https://doi.org/10.1016/j.apenergy.2020.115390

Newburger, E. (2021, May 28). *Biden's budget proposal calls for more than $36 billion to fight climate change*. CNBC. https://www.cnbc.com/2021/05/28/bidens-budget-proposal-calls-for-36-billion-to-fight-climate-change.html

Roberts, D. (2018, June 20). *Most American homes are still heated with fossil fuels. It's time to electrify*. Vox. https://www.vox.com/energy-and-environment/2018/6/20/17474124/electrification-natural-gas-furnace-heat-pump

Rosenow, J. (2019, June 26). Foresight | Why I replaced my new gas boiler with a heat pump. *Foresight*. https://foresightdk.com/why-i-replaced-my-new-gas-boiler-with-a-heat-pump/

Service, R. F. (2019). Solar plus batteries is now cheaper than fossil power. *Science*, *365*(6449), 108–108. https://doi.org/10.1126/science.365.6449.108

Sichelman, L. (2021, February 7). The All-Electric House Makes a Comeback. *Banker & Tradesman*. https://www.bankerandtradesman.com/the-all-electric-house-makes-a-comeback/

Why The Building Sector? – Architecture 2030. (2018). Retrieved February 28, 2022, from https://architecture2030.org/why-the-building-sector/