Analyzing Heating System Electrification in New Construction

An Interactive Qualifying Project Report submitted to the faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science.

By:
Aiden Higuera, Carlos Medina, Warwick Barker, Yitao Hong

Advisors:
Professor Adrienne Hall-Phillips
Professor Lauren Mathews

Sponsor:
Atlas Public Policy

December 8th, 2023

Abstract

The residential heating sector creates ever-increasing quantities of greenhouse gases as new homes are built. Electric heat pumps, an alternative heating system, can reduce residential heating emissions. However, policymakers lack a system to collect and analyze data about where they are being installed. This project, sponsored by Atlas Public Policy, resulted in the creation of an automatic data collection and visualization tool that streamlines identification of correlations between heat pump adopters in different areas. This tool assists policymakers in understanding how to focus new legislation to increase the adoption of heat pumps in newly developed homes, thereby decreasing the residential heating sector's toll on the environment—even as more homes are built.

Acknowledgements

We would like to acknowledge the following individuals for assisting us in the completion of this project:

Our advisors Dr. Hall-Phillips and Dr. Mathews, for their guidance and support during the project process. Dr. Stimmel for preparing us for our work on this project. The Washington, DC project center director, Dean Rissmiller, for securing Atlas Public Policy as our sponsor and overseeing the work at our project center.

The Atlas Public Policy personnel, especially our primary contacts Zachary Strauss and Hannah Beilinson, for their time and expertise. We would also like to thank the founder of Atlas Public Policy, Nick Nigro, for giving us the opportunity to work on this project.

Authorship Notes

When writing and editing this paper, our process was very collaborative. Each section was claimed by one person and written to a good degree. Then, others joined in to help flesh out the section and update it as new info came in. Finally, there was an overall editing process that was done by all members to help create the final blend of styles as seen here.

Executive Summary

Climate change is one of the world's most pressing issues. Concerned citizens and government agencies are seeking ways to mitigate further environmental degradation. The residential heating sector creates 13% of the nation's greenhouse gas[1] due to the abundance of fossil fuel-burning systems. Constant new home construction means home heating's negative environmental impact will only worsen unless changes are made. Electric heat pumps minimize the greenhouse gas emissions associated with residential heating because of their increased efficiency and because they can be powered without burning fossil fuels. Current United States incentive programs promote the adoption of heat pumps when replacing old heating systems, but policymakers lack ways to track changes in heat pump adoption over time. This project aimed to create a proof-of-concept tool for Atlas Public Policy analysts to quickly develop reports on heat pump adoption in any U.S. metropolitan statistical area (MSA) so that they can advise policymakers on how best to allocate resources to limit the environmental impact of the residential heating sector.

To start, we conducted additional literature research and interviewed realtors to understand what factors impact heat pump adoption. We used this information to ensure our tool collected the most crucial data and we can reinforce the correlations in our sample analyses through other research and market experts.

We collected data by using various application programming interfaces (APIs[2]). We used Redfin as our housing data source as their data was monetarily free to access. Since Atlas is a company that would like to sell its analyses, options for licensing a data source that would permit this were discussed and can be viewed in Appendix I. Additionally, we used the U.S. Census Bureau's five-year American Community Survey data and the U.S. Energy Information Administration's (EIA) fuel type price data. The collected census data relates to income, race, and educational attainment at a ZIP code level. The EIA's data gives fuel prices for heating oil, natural gas, electricity, and propane broken down by state. These two sources provide

---

[1] Frank, J., Brown, T., Ha, H., Slade, D., Haverly, M., & Malmsheimer, R. (2023). A comparative analysis of the cumulative greenhouse gas emissions and financial viability of residential heating systems located in New York state. *Biofuels, Bioproducts and Biorefining*, *17*(1), 18–28. https://doi.org/10.1002/bbb.2442

[2] API – A way for pieces of software to communicate with each other either through the internet or local programs running on the same computer

augmenting data to help create a better picture of correlations between different heat pump adoption trends.

To make the tool usable for analysts, we created a graphical user interface (GUI). The GUI has a search bar for analysts to enter the desired MSA name, along with any filters for the housing data, such as the minimum and maximum year built. The GUI also allows the user to view a graph of the energy price and census data by clicking a link to an external website.

To display the housing and census data, we used QGIS, a geospatial mapping and analysis program. We used its Python library to create a script that transforms houses into geographic points based on their latitude and longitude and transformed census data into ZIP code-based layers with color ramp styling (the bigger the number, the darker the shade). The combination of layers allows an analyst to find an area of interest and quickly go through the census and housing data, noting any patterns in the heating type of the area's houses.

Although the tool can be used on any MSA, we only created a sample analysis for three due to time restrictions. We selected the Washington, DC; Phoenix, AZ; and Denver, CO MSAs. Each area has a population between three million and seven million (Census Reporter, 2023), with at least two thousand new single-family homes each year (Chamber of Commerce, 2023), which means there are enough houses for our sample analyses later in the project. We differentiated each area by climate zone and the source of their electricity. Our three MSAs represent hot, intermediate, and cold climate zones (International Code Council, 2021) with differing distributions of renewable systems, natural gas, and coal as electricity sources (U.S. Energy Information Administration, 2022b, 2023d, 2023e). We desired differing characteristics to gain a greater perspective on heat pump usage in different settings, which should be shown through varying correlations in the data.

To demonstrate the possible impact of this data, we created reports on each of our three selected metropolitan areas with an analysis of the greatest and least heat pump-adopting areas. We found that colder climates may avoid heat pumps due to efficiency reduction and that developer communities are the best place to focus on increasing heat pump usage in warmer climates.

In all, our work on this project resulted in a two-part workflow. First, raw housing, census, and energy data are collected. Second, the data is transformed into spatial layers and points for further processing by Atlas Public Policy analysts, enabling them to determine correlations between heat pump adoption and other factors in different regions. As a result, Atlas Public Policy can better advise policymakers on how their legislation has impacted constituents to improve future work and reduce the environmental toll from the residential heating sector.

Table of Contents

1.0 | Introduction

Home heating in the United States has long been dominated by fossil fuels, which emit greenhouse gases that lead to increased levels of pollution. Conventional heating systems, such as natural gas furnaces and fuel oil, rely on non-renewable resources, contributing to about 7% of the U.S.' total greenhouse gas emissions (U.S. Energy Information Administration, 2023a; International Energy Agency, 2023). These systems are longstanding and resilient, but their use takes a heavy toll on the environment. Still, their reliability and popularity make them the common choice in new home developments.

As metropolitan populations grow and more houses are built, continued installation of conventional heating systems will exacerbate the greenhouse gases that homes collectively produce, increasing this sector's carbon footprint. One option to combat greenhouse gas emissions in the residential heating sector is to reduce the installation of fossil fuel-burning appliances. Specifically, this means adopting alternative heating systems. Governmental incentives can help make electric heat pumps the ideal heating system choice for new homes by making them more affordable, thereby increasing adoption rates (Shen et al., 2022).

Heat pumps use electricity to exchange thermal energy with an external medium, such as air or water, to heat or cool the inside of a house. Heat pumps reduce greenhouse gas emissions by operating on electricity, which means they can be close to zero emissions when powered by renewable energy (Addo-Binney et al., 2022). Crucially, if a heat pump is supplied with electricity from a coal-fired power plant, it may have little to no positive impact relative to conventional, non-electric systems (Udovichenko & Zhong, 2019). Still, heat pumps can reduce local emissions as they are much more energy efficient than conventional systems, which means less of the energy they consume is wasted in uncontrolled ways. Heat pumps are closed systems, meaning they recycle refrigerant for continued use and do not produce byproducts from combustion. Additionally, due to how they work, only a set amount of refrigerant can escape from a heat pump before it stops working. Even if the refrigerant escapes, for an average house built in 2018, the global warming potential equivalent in CO_2 over twenty years of a refrigerant leak is about 28% as much as that of a behind-the-meter natural gas leak (Pistochini et al., 2022).

Policymakers have noticed that these incentives work and have passed legislation, such as certain provisions in the Inflation Reduction Act of 2022, to enact widespread changes toward more efficient heating systems. However, granular historical measures of the country's heating stock are lacking. Currently, a source or tool that creates timely reports on these issues does not exist. However, the federal government releases non-regional data, published annually at most. While these are informative, they do not give information below the state/region level and thus are ineffective for state or local governments (U.S. Energy Information Administration, 2023a; U.S. Census Bureau, 2022). These policymakers are looking for up-to-date data that enables them to understand how new policies affect heat pump adoption to determine and reevaluate their methods for increasing heat pump adoption.

Our goal was to deliver an automated data collection tool and a data display tool that will assist Atlas Public Policy (henceforth referred to as Atlas) in advising policymakers on heating system electrification trends that will help reduce the carbon footprint of new home construction.

2.0 | Background

In this chapter, we begin by detailing how residential buildings with inefficient and polluting heating systems contribute to the increasingly dire consequences of climate change. Second, we explain how electric heat pumps can significantly reduce greenhouse gas emissions from the residential sector. Finally, we describe current heat pump usage trends and examine some underlying causes for those trends.

2.1 | Effects of Current Heating Methods

A shift toward high-efficiency electrification of residential heating systems will decrease the United States' carbon footprint. The U.S. commercial and residential heating sector currently creates 13% of the nation's greenhouse gas (GHG) emissions (Frank et al., 2023). The residential sector consumes 21% of U.S. domestic energy (Frank et al., 2023). Without intervention, the residential sector will continue expanding to consume more energy and emit more greenhouse gases. High-efficiency electric heating methods can reduce GHG emissions significantly.

2.1.1 | Current Heating Systems

Currently, about 60% of U.S. heating systems are furnace-fired (U.S. Energy Information Administration, 2023b). These rely on burning natural gas (NG) or propane to produce warm air that gets blown into a building. The installation of electric heat pumps can lead to a reduction in the GHG production of fossil fuel combustion. Depending on the season, heat pumps can operate in heating and cooling modes. Electric air conditioners and heat pumps have similar environmental impacts during cooling seasons. However, as an alternative to conventional heating systems, many of which rely on burning fossil fuels, heat pumps can significantly reduce the aggregate environmental impact of residential heating.

The current adoption of heat pump systems is not widespread in the U.S. but rather hyper-regional (see section 2.4) and represents a small portion of all U.S. heating systems. Only 13% of U.S. houses utilize heat pumps as their central heating system (U.S. Energy Information Administration, 2023b). Carthan (2023) reveals that some potential factors behind the low usage rate are prohibitive upfront costs, utility costs, and harsh winters that hinder heat pump performance. The main detractor is financial cost, as heat pump systems are typically more expensive to install than conventional systems, and electricity costs are substantially more expensive than NG (Carthan, 2023). However, contrary to common conception, the utility costs for operating each system are similar because less electrical energy is needed than energy from NG to heat the same space.

2.1.2 | Emissions Reduction Potential

Retrofitting and original installation of heat pumps constrain the continued environmental impact of residential construction. Heat pumps significantly reduce GHG emissions compared to standard, fossil fuel-based methods: depending on the electric grid, “with the highest heat pump implementation shares (100% for new buildings and 50% in retrofits buildings [*sic*]), CO2 [equivalent] emissions dropped by 46%” (Carvalho et al., 2015, p. 757). By increasing the installation of heat pumps in new construction, the increasing GHG emissions from the residential sector will diminish towards a constant amount, assuming clean energy sources are prevalent (Pistochini et al., 2022). Residential areas powered by cleaner energy sources, such as nuclear or renewable energy, create less emissions than areas powered by more heavily polluting methods (e.g. coal). In an analysis of select Canadian cities, researchers Udovichenko and Zhong (2019) found that heat pumps are not beneficial in Edmonton because of the abundance of coal-fired power plants. Compared with conventional natural gas furnaces, the reduction in GHG emissions is minor. Conversely, buildings powered solely by renewable energy sources can reduce emissions per kWh by as much as 99% (Addo-Binney et al., 2022). However, the most common heat pump systems work poorly in cold climates. For Edmonton and other parts of Canada, harsh winter temperatures create a need for backup heating systems for use when heat pumps struggle to operate.

Extra expenses to install backup systems may deter many potential heat pump adopters, which can make heat pump installation prohibitive in many colder regions. The typical backup heating system is resistive heating strips that still use electricity but are much less efficient than heat pumps (Addo-Binney et al., 2022; Udovichenko & Zhong, 2019). Low-efficiency electric systems require more energy to heat the same space, so utility costs significantly increase when buildings use the backup system. To combat the low functionality issue, engineers developed other types of heat pumps to operate in harsher temperatures. However, these systems are significantly more expensive to install or are less commercially available.

2.2 | Heat Pump Attributes

In this section, we explore the differences between various electric heat pumps and conventional heating systems by examining the price difference and the impact of heat pumps on the grid.

2.2.1 | Types of Heat Pumps

Electric heat pumps come in various types that operate in different ways, but all types are used for both heating and cooling buildings by transferring air between hot and cold environments. Whether heat pumps cool or heat the air varies depending on the season (Addo-Binney et al., 2022). In warm months, heat pumps will pull hot air out, cool it down, and return it to the house. In colder months, heat pumps pull cool air out and return warm air. There are two primary types of heat pumps, air source heat pumps (ASHP) and geothermal heat pumps (GTHP), each with distinct configurations. ASHPs are installed above ground and serve as a convenient replacement for traditional HVAC systems. However, ASHPs have limitations. Their heating efficiency diminishes as the outdoor air temperature drops, making them less effective in cold climates (Udovichenko & Zhong, 2019). On the other hand, geothermal heat pumps (GTHPs) harness thermal energy from the ground to moderate indoor air temperatures (Carvalho et al., 2015). This method provides a more stable heat source, making GTHPs suitable for regions with harsh winters.

Heat pump efficiency is commonly evaluated using the Heating Seasonal Performance Ratio (HSPF), where units typically score from 8.2 to 13 (Carthan, 2023). A higher HSPF value indicates better performance and energy efficiency, making it an essential metric for homeowners considering heat pump installations.

2.2.2 | Heat Pump Properties

The cost difference for installing the two main types of HPs in new construction can be large (Carthan, 2023). Air source heat pumps (ASHPs), known for their simple installation, come with a relatively moderate price for the complete system, ranging from approximately $4,500 to $8,000 (Carthan, 2023). In contrast, geothermal heat pump (GTHP) units often carry a similar initial price range to ASHPs, but their installation can substantially elevate the overall cost. This significant cost difference comes from the necessity of hiring specialized crews to excavate and prepare the land where the GTHP system will be installed. For these reasons, GTHP units typically fall within the price range of $6,000 to $20,000 (Carthan, 2023). Table 1 shows estimated installation costs for ASHPs by their size. Note that installation costs do not consider the extra markup that home developers will add to the home's price when selling, so heat pump systems will cost even more for the final owners.

Table 1
Estimated Installation Cost of Air Source Heat Pumps by Tonnage

Home Size (Square Footage)	Heat Pump Size (Capacity in Tons)	BTUs Needed	Average Cost (Installed)
900 – 1,500 sq. ft.	2 Tons	24,000	$3,200 – $5,500
1,200 – 1,600 sq. ft.	2.5 Tons	30,000	$3,500 – $6,000
1,600 – 2,000 sq. ft.	3 Tons	36,000	$3,700 – $6,300
1,800 – 2,300 sq. ft.	3.5 Tons	42,000	$3,800 – $6,500
2,000 – 2,400	4 Tons	48,000	$4,000 – $7,500
2,400 – 3,300	5 Tons	60,000	$4,500 – $9,000

Note: From Toma, 2023

2.2.3 | Electrical Grid Impacts

With an increase in the adoption of heat pumps, the demand on the electric grid will increase. This increased load (from greater electricity demand) will require an increase to the grid's capacity of up to 70% and may increase electricity prices (Waite & Modi, 2020). Many grids still rely on "dirty" electricity generation methods, such as coal, for their base load, with natural gas as a supplement for days when the coal plant's generation capacity is too low to meet higher demand. In such cases, the grid's carbon footprint may offset the environmental benefits of transitioning to electric heat pumps (Udovichenko & Zhong, 2019). If a house's electricity is from a clean energy grid, converting from a fossil fuel-based system to electric heat pumps is more beneficial. Aneli et al. (2023) notes that installing solar panels alongside heat pumps may help, as this would reduce the load from heat pumps on the grid. This strategy would cause the load on the grid to peak only during the winter months when less sunlight is present (Aneli et al., 2023). Balancing environmental concerns, energy efficiency, and cost-effectiveness is essential in making informed choices about the adoption of heat pump technology in the context of the broader energy landscape.

2.3 | Home Heating Trends in Selected Regions

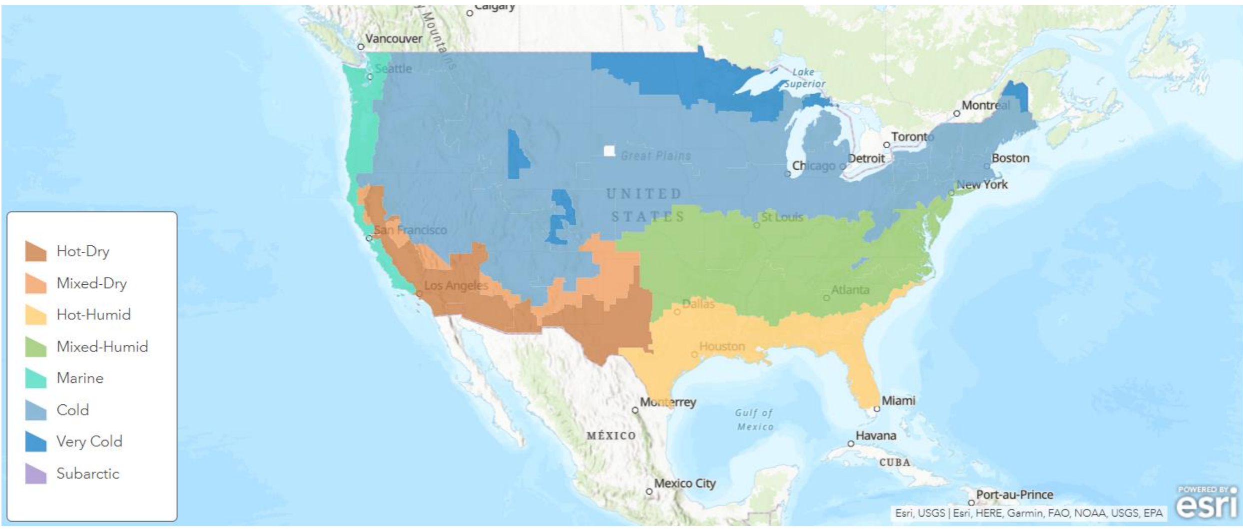
In this section, we outline factors affecting heat pump adoption. These factors are then discussed individually to explain how they might affect the heat pump adoption rate. Characteristics that can influence adoption include consumer mindset, climate zone, utility prices, and being in an urban area (Poblete-Cazenave & Rao, 2023; Shen et al., 2022). Since strictly urban areas can include a high density of people, which may affect the types of housing, thereby affecting certain building characteristics, this project will focus on both urban and suburban areas.

2.3.1 | The Climate Factor

Climate zone is the most significant overall driver of heat pump adoption. Climate zones are broken into geographic regions (as shown in Figure 1) based on similarities in heat and moisture. Poblete-Cazenave & Rao (2023) found that the mixed humid zone 4a has the highest probability of a randomly surveyed, homeowning adult expressing a willingness to adopt heat pumps (respondents may not have installed a heat pump). This result is due to its mild winters, which lengthen the lifespan of many types of heat pumps because they operate more efficiently than in more extreme climate zones (Poblete-Cazenave & Rao, 2023). Extreme temperatures lead to inefficiencies in heat pumps, increasing the mechanical strain on the system, decreasing the unit's lifespan, and limiting its useful days, which may drive down willingness to adopt. For heating to be supplied in these conditions, the heat pump would have to be a more expensive cold-climate heat pump (McCabe, 2023), or home heating would fall back on expensive and inefficient resistive heaters or other backup systems to ensure the house is livable (Poblete-Cazenave, 2023).

Figure 1

Map Showing the Different Climate Zones.



Note: Zone 4a, the current largest zone of heat pump adoption, is the mixed-humid region (from U.S. Energy Information Administration, 2023f).

2.3.2 | The Utilities Factor

Another important factor in regional differences is utility costs. While most of the interior of the U.S. has electricity prices around $26.38 per million BTU (nine cents per kilowatt hour), California, the New England states, Hawai‘i, and Alaska have significantly higher prices (U.S. Energy Information Administration, 2023c). Natural gas has relatively stable pricing at around $14.24 per million BTU across the continental United States, with only Hawai‘i being an outlier, having four times the national average at around $54.96 per million BTU due to its physical separation from mainland infrastructure (U.S. Energy Information Administration, 2023g).

2.3.3 | The Urban Factor

Urbanization leads to differences in electricity prices and may be a reason to adopt or avoid heat pumps. Urban residents typically have lower electric bills even though electricity usage rates for urban and rural areas are roughly the same (Kujala, 2016). Delivering electricity to rural areas wastes more electricity during transmission, so rural residents pay more for distribution, and rural homes tend to be less energy efficient, so they require more energy to make up for additional losses (Levy, 2018). Also, urban areas have a higher population density, which can further decrease distribution costs. The higher electricity costs in rural areas mean residents may prefer fossil fuel-based methods to heat their homes—if price were the sole factor. However, low population density and the costs of running natural gas infrastructure across large distances may prevent the distribution of an alternative to electric heating, and rural homeowners might be stuck with electricity.

2.3.4 | Incentives

Incentive programs are an excellent method to increase heat pump adoption rates. However, they may not be as effective as they seem, mainly because these types of programs usually only attract those who would have converted without an incentive (Alberini et al., 2016). In a survey of homeowners conducted by Alberini et al. (2016), respondents who installed incentivized heat pumps indicated that they would likely have installed a heat pump without any incentives. Detailed and frequent analysis of heat pump adoption following incentives taking effect will help determine what incentives are the most effective and where additional incentive funds can be directed to increase heat pump use most effectively.

The Inflation Reduction Act of 2022 is one example of an incentive package intended to increase heat pump adoption, the first and only applicable federal incentive program. It contains two provisions that enable homeowners to get a tax credit equal to 30% of improvement expenses up to $2,000 (Internal Revenue Service, 2023a) and a tax credit of 30% of clean energy system improvement costs, which includes GTHPs but not ASHPs, with no limit (Internal Revenue Service, 2023b). Residents in every state can apply for these incentives, but there is some variance between states on additional incentives. State and local governments have also enacted similar, but often smaller, incentives. Utility companies even sponsor some minor incentives for their customers. For example, Tampa Electric, servicing Tampa, FL, offers a $135 rebate to homeowners using heating systems with high seasonal energy efficiency ratings (SEER) for their heating and cooling needs (Tampa Electric Cooperative, n.d.), but this rebate does not differentiate between fuel types. More environmentally friendly programs provide rebates to customers who install heat pump systems with high SEER, such as Mohave Electric Cooperative's (servicing rural parts of Arizona) rebate program that returns $200-$2,000 depending on the heat pump's SEER (Mohave Electric Cooperative, Inc., 2020). This means homeowners are only incentivized to install heat pumps rather than high-efficiency NG furnaces. The competing incentives create a need for further analysis.

2.3.5 | The Consumer Psychology Factor

The opinions of consumers on any product can lead to success or failure. While generally less emphasized than other home preferences, consumers have personal opinions on heating system options. Incentives described in the previous section help reduce the cost factor discussed in Section 2.2.2, but maintenance and installation disruptions, system familiarity, and environmental awareness also affect heat pump adoption. Maintenance and installation will disrupt the comfort of homes, which detracts many potential adopters (Karytsas & Theodoropoulou, 2014). This reduces the rate of retrofits, but not new installations, as any system will need regular maintenance throughout its lifespan. Another critical factor is familiarity with other systems. Younger homeowners are more willing to adopt heat pumps, suggesting that older people prefer a conventional system (Corbett et al., 2023). However, exceedingly environmentally aware people do not consider many other factors when looking to switch to environmentally friendly heating systems (Neves & Oliveira, 2021).

To alleviate misgivings, researchers have recommended minimizing financial barriers, clear efficiency labeling, and addressing effectiveness concerns (Corbett et al., 2023; Neves & Oliveira, 2021). Corbett et al. (2023) also suggested connecting people who installed heat pumps with others because they found that knowing someone with a heat pump increased the likelihood of adoption.

2.4 | Hyper-Regionalization of Heat Pumps

In the United States, regional differences cause a vast difference in residential heat pump adoption. In South Carolina, heat pumps used for primary heating systems are installed in 41%

of homes, while Illinois and Massachusetts are tied for the lowest rate at 2% of homes. Only nine states have at least 25% of homes with heat pumps as their primary heating system (U.S. Energy Information Administration, 2023b. This section examines the two most significant, high-level differences between these metropolitan areas.

2.4.1 | Climate Differences

As was previously discussed, colder temperatures reduce the efficiency of heat pumps. In colder climates, heat pumps may require backup systems at further expense, which could discourage the adoption of heat pumps. While weather-tolerant heat pumps exist, these are typically more expensive. South Carolina has a predominantly warm climate, so heat pumps operate at a typical heat pump efficiency for most of the year. States with low adoption rates, such as Illinois and Massachusetts, tend to be in the colder northern climate zones (International Code Council, 2021). Additionally, states in the coldest regions of the U.S., such as Alaska and the upper Midwest, do not have federally reported data for heat pump usage due to large error margins or tiny sample sizes (U.S. Energy Information Administration, 2023b). The lack of federal data in these regions with a common climate suggests that homeowners in these states have reservations about relying on these systems during winters, thereby decreasing adoption and limiting data collection.

2.4.2 | Incentive Differences

Differences in the reduction of heat pump costs through incentives may also contribute to the hyper-regionalization of heat pumps. Notably, most incentives only apply to retrofits rather than new construction. In South Carolina, the state government instituted a tax credit for 25% of GTHP retrofit costs up to $3,500 (South Carolina Department of Revenue, 2022). In the future, the South Carolina government plans to offer two rebates of up to $14,000 and $8,000 for installing high-efficiency electric appliances, including heat pumps, and for saving energy through various retrofits, respectively (South Carolina Department of Energy, 2023). There are also rebates for ASHPs from two major South Carolina utility providers, Dominion Energy and Duke Energy, at $500 and $550, respectively (Dominion Energy, 2023; Duke Energy, n.d.). However, a natural gas supplier in South Carolina also offers a rebate on natural gas-fueled equipment (Piedmont Natural Gas, n.d.), so there is some rebate competition. Illinois has a rebate from an additional utility provider, ComEd, at $1,400 to $2,000 for ASHPs (Munch's Supply, n.d.). MidAmerican Energy also provides up to $600 for heat pump systems and up to $213 for natural gas furnaces (Midamerican Energy Company, 2023). These rebates only apply to retrofit systems with high seasonal energy efficiency ratings, whether a heat pump or NG furnace. Even though South Carolina plans to institute a massive rebate program that could catapult heat pump retrofits, there is little to no difference in South Carolina and Illinois incentives for originally installing heat pumps because of a lack of incentives for new construction. So, the hyper-regionalization of heat pumps, as influenced by incentives, can mainly be attributed to retrofits rather than new construction.

3.0 | Methodology

The goal of this project was to deliver a data collection and data display tool that will assist Atlas Public Policy in advising policymakers on heating system electrification trends, which will help reduce the carbon footprint of new home construction.

To achieve this goal, four objectives were created:

1. Develop a data collection and storage process that captures a house's heating fuel and appliance type, as well as collecting socio-economic and demographic data.
2. Create a display tool that incorporates the heating data with the socio-economic and demographic data.
3. Identify metropolitan areas that will be the focus of our final analysis.
4. Write a report on residents' heating system choices by analyzing results from the data display tool for each chosen metropolitan area.

3.1 | Objective One: Develop Data Collection Tool

The purpose of this objective was to select a source of data and develop a data retrieval method (database, API, or web scraping[3]) for the data collection portion of the final tool. We researched possible sources of data collection and evaluated small sample data sets to evaluate each method. Downloading and processing are done automatically after a desired search location is given by the user of the program.

[3] Web scraping – Extracting data from a webpage through computer programming

3.1.1 | Source Evaluation

As part of our data collection strategy, we focused on APIs for realty websites, such as Redfin and Zillow, and noted the Terms and Conditions for their allowed uses. Before permanently settling on a source, we ensured that the data collection speed was reasonable and that the frequency at which we could collect data worked for development. Please see Appendix C for in-depth reasoning behind our evaluation criteria. We selected Redfin as our housing data source after all sources were evaluated.

3.1.2 | Redfin Data Collection

The collection of Redfin data was achieved by using their Stingray API, allowing us to download a Redfin listing in textual form. Once this document was downloaded, the tool scanned the text document for certain sequences of letters corresponding to the different heating fuel and appliance types we wanted to collect. This data was saved to a comma-separated value (CSV) file.

3.1.2 | Interface Development

We created a graphical user interface (GUI) that exposes the tool's functionality in an easy-to-use way. GUI creation was an iterative process, and we first mocked up the design and had it evaluated by Atlas. The tool provides search and result filtering capabilities and the ability to generate relevant U.S. Census tables and view utilities prices by state.

3.1.3 | Socio-Economic and Demographic Data Collection

We decided to collect data on race, income (including area median income), age, education level, and utility prices. We determined these would be the most important factors during our analysis, particularly education level, as it may correlate with awareness of the benefits of heat pumps and increased adoption. We used the U.S. Census Bureau’s API to collect data from the American Community Survey 5-year (ACS5) DP05[3], ACS5 S1501[4], and ACS5 S1901[5] tables. Utilities price data was collected from the U.S. Energy Information Administration’s (EIA) Open Data API[6].

3.2 | Objective Two: Develop a Display Tool

We initially looked at ArcGIS to display any possible geographic information system (GIS) maps we would produce. However, after talking with Atlas, they said that they do not have a license to this program. To ensure that our project would continue to be useable, we used a free alternative called QGIS. A native Python approach was not pursued due to time restrictions and lack of GIS domain specific knowledge.

QGIS has Python bindings[4] for interacting with their suite of internal tools. We used these to transform our housing data into points based on their latitude and longitude, and the U.S. Census data into layers with a color ramp to show number ranges. Because we used an off-the-shelf and actively supported piece of software, many powerful tools are available to do further analysis.

3.3 | Objective Three: Identify Three Metropolitan Areas

This objective aimed to identify a set of United States metropolitan areas from which we could collect heating data before interviewing housing experts to understand their perspectives on client perceptions of heating systems. For the scope of this project, we limited the number of metropolitan areas to three.

3.3.1 | Select Metropolitan Areas

First, we pared down the U.S. Census' list of MSAs to twenty by only considering areas with a population between three million and fifteen million. We only considered more populated areas to analyze data for socio-economic and demographic factors originating from larger sample sizes. Second, we removed the four metropolitan areas with the lowest number of new homes constructed in previous years to maximize the data points collected in later objectives. Before continuing, we selected Washington, DC as a baseline area to compare the climate and electrical grid in other regions. We selected D.C. as it is the location of our project center and has an intermediate climate (the median temperature zone in the U.S.), so D.C. is a good datum for comparison.

Next, we used climate and electrical grid as differentiators. We used the Department of Energy's map of climate zones from 2021 to group cities by climate zone. We selected areas with different climates to understand how a region's climate influences heat pump adoption. We

---

[4] Binding (programming) – A wrapper program that bridges two programming libraries so that a library for one programming language can be used in another programming language

then found the electrical grid source (renewable, N.G., nuclear, and coal) information for each area so that we could select areas with differing makeups to allow us to draw conclusions about potential correlations between the source electricity and heat pump usage.

Initially, we selected the Minneapolis, MN, metropolitan area as one focus point because of its cold climate and different electrical grid makeup from D.C. However, as we progressed to data collection, we were unable to collect most of the housing data for the area. We were only able to collect fifty-two houses, whereas other areas had upwards of 3,000, likely due to complications in our collection method (see section 5.4). So, we verified that most of the new homes in an area are collected when the tool is run.

Due to the seven-week timeline's time restrictions, we selected three metropolitan areas: Denver, CO; Washington, DC; and Phoenix, AZ. We expected the differences in climate to affect heat pump adoption trends, so larger differences in climate were preferable to make any differences in heat pump usage more noticeable. These areas also had a wide variance in electrical grid source makeup, which we desired so that we could get an idea of the potential correlations between grid source and heat pump adoption.

3.3.2 | Determine Critical Socio-economic and Demographic Factors

We conducted additional literature research in online databases to determine some of the most critical, data-driven factors impacting heat pump adoption. We also conducted semi-structured interviews with three realtors in the Washington, DC, area (please see Table 2 and our consent script in Appendix A). In these formal interviews, we asked various questions intended to help us determine what factors most significantly impact heat pump adoption (please see our interview guide in Appendix B). We analyzed the interviews to determine what socio-economic and demographic data points should correlate most to heat pump adoption rates for different groups of people. These interviews also served to draw conclusions about where allocated funding could be best utilized to increase heat pump adoption.

Table 2
Interview Details

Name	Title	Interview Date
Anthony Graham	Keller Williams Capital Properties Real Estate Agent	11/29/2023
Anonymous	Real Estate Agent	11/29/2023
James Kim	McEnearney Associates Real Estate Agent, REALE Forms Committee Board Liaison	11/29/2023

3.4 | Objective Four: Write Reports

The purpose of this objective was to create a report on each metropolitan area that displays the data and suggests potential reasons behind different groups' heating system choices. We intended for these reports to be used in drawing conclusions for this project and to summarize the results of our socio-economic and demographic research as a sample of how the tool can be useful for Atlas analysts. For the reports, we used our display tool to locate areas of high heat pump usage, low heat pump usage, and high natural gas usage before creating charts to determine if there were any correlations between the socio-economic and demographic factors and heating system choice. The charts were created by manually extracting the desired data from QGIS for each selected ZIP code and then copying this data into an Excel spreadsheet for conversion into charts. This process allowed for a stronger conclusion about where policymakers could focus efforts to increase heat pump adoption as it detailed the reasons behind low adoption rates that differ from areas with high adoption rates.

Since QGIS is a powerful geospatial analysis tool, we wanted to showcase its usages beyond creating layers and points. To do this, we created a second report for the Washington, DC, metropolitan area to display how QGIS' installed tools can aid the analysis of a large amount of data to gain insight into possible factors behind apparent trends.

4.0 | Results and Analysis

This section describes the results of each of our four objectives. Further analysis is described in the next chapter for any applicable topics.

4.1 | Objective One: Develop Heating Data Collection Tool

We created a tool that collects residential heating system data for new construction, along with socio-economic and demographic data when a user searches for any MSA. Although we focused our analysis on only three MSAs, this tool can collect data for any U.S. MSA, provided that the data exists.

We selected Redfin as our source of housing data since it was the only source with a free and public API for retrieving home data. See section 5.0 for more details on using Redfin in the future. During development, we worked with an Atlas analyst to ensure that we collected housing data that would suit their needs. We determined these needs to be the heating fuel and appliance types. When initially collecting data, we noticed that some houses only had one or the other, but we determined that this was acceptable for the purposes of the tool. The format of the full data captured is given in Appendix D.

4.1.1 | Housing Data Collection Tool Development

The collection tool interacts with the Redfin Stingray API, which is an unofficial API that Redfin uses to populate the listing facts and other data for homes on their main website. By utilizing a third-party library named redfin[5] and analyzing the Stingray API calls made by the Redfin website when performing the actions that we wanted to emulate, we could generate our queries to the Stingray API to get the data we wanted. To avoid overloading the Redfin servers, we implemented rate limiting, a delay of about 1.5 seconds per API request. While the tool was retrieving home data, it stored the data in an in-memory data frame provided by the Polars[6] library. The results were filtered to extract relevant data using regular expression to extract specific parts of text from the Stingray API response. These parts were found by correlating what was in the response to what was displayed on the website. The tool performed additional basic statistics, such as summing up the count of the categories of each fuel and appliance type, while it was in this form. After analyzing all entries for a particular ZIP code, the tool exported the data frame to a CSV file. Since this is a simple text file, this storage method allows Atlas to easily use the data from our collection tool with other analysis programs if they choose to do so.

Census and energy data can also be collected while the tool is running. This was done by using their respective APIs, described in section 3.1.3, and filtering the data to focus on income, race, and educational attainment.

---

[5] https://github.com/reteps/redfin
[6] https://doi.org/10.5281/zenodo.7697217

4.1.2 | Interface Development

First, we created a mockup of an interface design using Figma, an online collaborative design tool. We then worked with Atlas employees who will be using the tool to evaluate the usability of the graphical user interface (GUI) design. During the project, the design changed due to feedback and reevaluation of what should be displayed. Once we reached a version that Atlas was satisfied with, we developed the GUI using CustomTkinter[7], a Python library that facilitates GUI creation. After finishing the first version of the operational GUI, we went through iterative design loops to ensure that we addressed Atlas' user feedback, program issues, and functionality. Finally, we landed on a three-page design consisting of a filter page, a search page, and a waiting page. The filters page resembles Redfin's search filters, and the waiting page displays a chart with the price per effective thousand BTUs by selected utility types available in the search area. The search page has an entry field to search for an MSA; this feature has an autocomplete drop-down box. The efficiency data used in utility prices and effective BTU calculation was taken from Efficiency Maine (2023), which Atlas recommended as a trusted source. The tool provides additional census information through links to Census Reporter (Census Reporter, 2023). We used this website as it displays the same census tables that we are using in the next objective while providing a cleaner interface.

---

[7] https://github.com/TomSchimansky/CustomTkinter

Figure 3

Screenshot of Collection Tool Filters Page

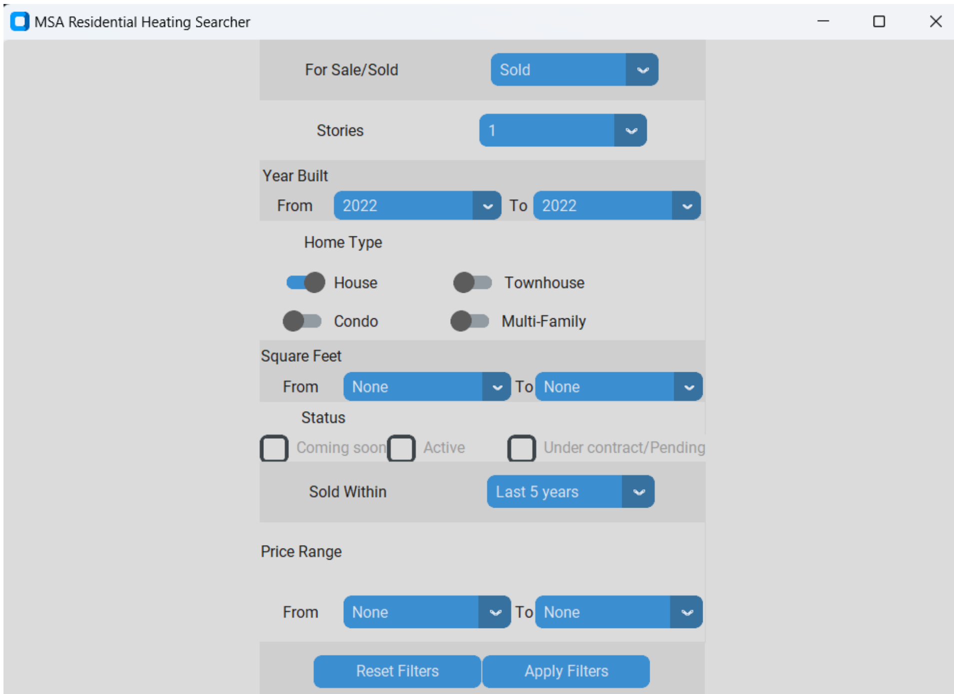
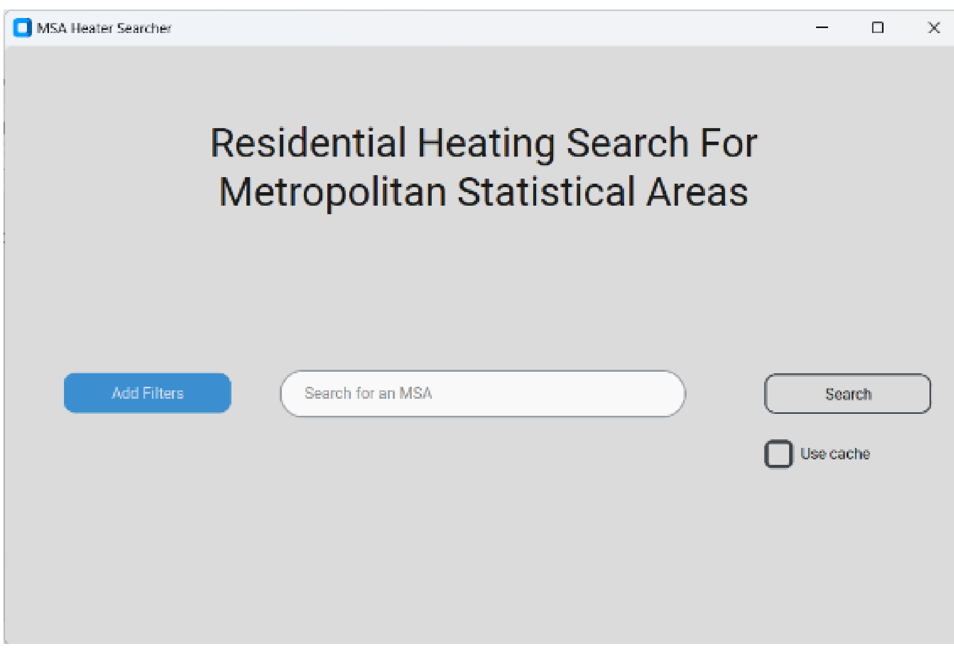


Figure 4

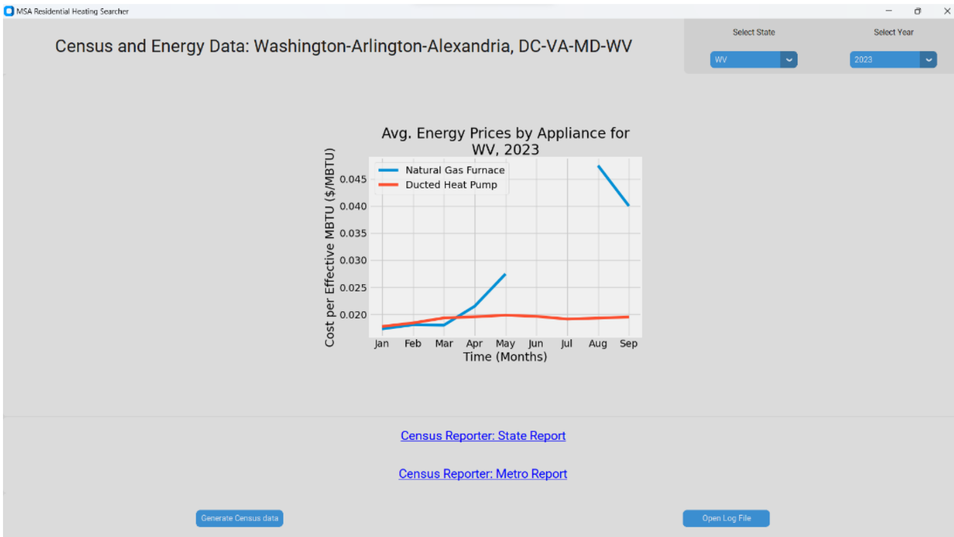
Screenshot of Collection Tool Search Page



Note: The "Use cache" checkbox uses a previously generated ZIP code index. This allows the user to go straight to generating housing information.

Figure 5

Screenshot of Collection Tool Waiting Page



Note: The price per thousand BTU is based on available data, and may not be current, or may have time gaps. Since a metropolitan area may span different states, a dynamic drop-down is available to choose which state to generate a graph for. The last five years are also available as a drop-down. The two buttons on the bottom generate census data and open the log file, respectively.

Figure 6

Screenshot of Collection Tool Logging Output

```
2023-11-22 15:14:10 - INFO: ================================
2023-11-22 15:14:10 - INFO: Starting logger.
2023-11-22 15:14:10 - INFO: ================================
2023-11-22 15:14:19 - INFO: Searching Washington-Arlington-Alexandria, DC-VA-MD-WV with
2023-11-22 15:14:19 - INFO: Estimated search time: 2327.0
2023-11-22 15:14:22 - INFO: Did not find any houses in 22663.
2023-11-22 15:14:25 - INFO: Did not find any houses in 20001.
2023-11-22 15:14:29 - INFO: Did not find any houses in 20003.
2023-11-22 15:14:32 - INFO: Found data for 32 houses in 20058.
```

Note: The log file is a basic text file and can be opened by anyone.

4.2 | Objective Two: Develop a Display Tool

For this objective, we made a Geographic Information Systems (GIS) map using QGIS and wrote Python code that automatically imports the data collected by the data collection tool (Objective One) into several layers.

We created a few base layers that remain the same for any selected area. The base map for these layers contains city names and infrastructure, such as any named roads, designated parks, and silhouettes of many buildings in metropolitan areas (provided to QGIS by OpenStreetMap). On top of the base map, we added layers for all state borders, census-defined metropolitan areas, and census-defined ZIP code tabulation areas (ZCTAs). To create these layers, we used professionally curated layer features from ArcGIS resources (ESRI, 2023a, 2023b, 2023c). The styling for these layers makes it clear where the borders are while still facilitating understanding of the important data included in additional layers through opacity and style adjustments (see Figure 7).

The accompanying Python script creates a new series of layers containing the data collected in Objective One. The script completes this process in three parts: plotting individual housing units on one layer, creating heatmap layers based on heating type spatial density, and creating socio-economic and demographic factor visualization layers for select categories. The first part of this process, plotting individual housing information on a layer, pulls the data from the housing data CSV generated in Objective One and creates each house as a feature, which is displayed on top of the project's base layers (see Figure 8).

The second part of this process generates separate heatmap layers for each home heating type using the heating type data from the housing data CSV (see Figure 9). The heatmaps are generated based on the proximity of a house with a certain heating type to other houses with the same type. This visualization is useful in showing the large concentrations of a specific heating type and where they are sparser. Darker portions of the heatmap indicate a greater concentration of a heating type. Since the program generates many heatmaps upon launch, they are grouped and automatically turned off for ease of use, where the user can then enable visibility on each layer as desired.

Finally, the third part generates layers for specific socio-economic and demographic data. These layers are cloned from the ZIP code tabulation area (ZCTA) base layer, where the remaining data generated from Objective One (data collected from the U.S. Census Bureau) is sorted and stored in each ZCTA feature (see Figure 10). From there, each ZCTA is colored based on the stored data, where darker shades represent larger values and lighter shades represent smaller values. Since the program generates many layers on launch, all social layers are grouped together by census table and automatically turned off for ease of use, where the user can then enable visibility of each layer as desired.

Figure 7

Screenshot of QGIS Base Layers Around Washington, DC, with Annotations

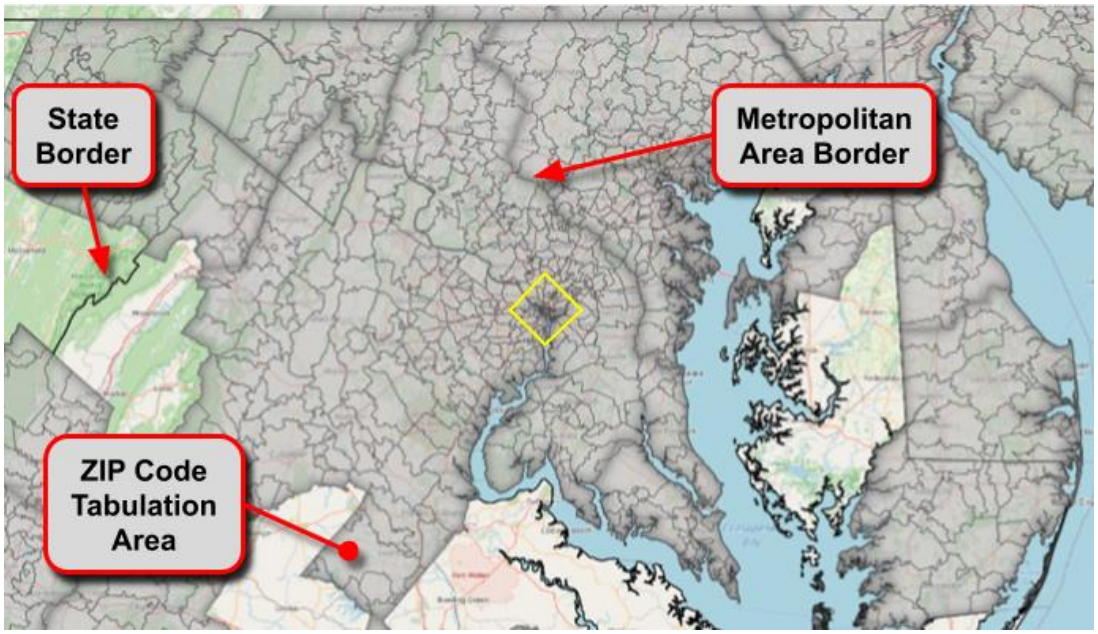
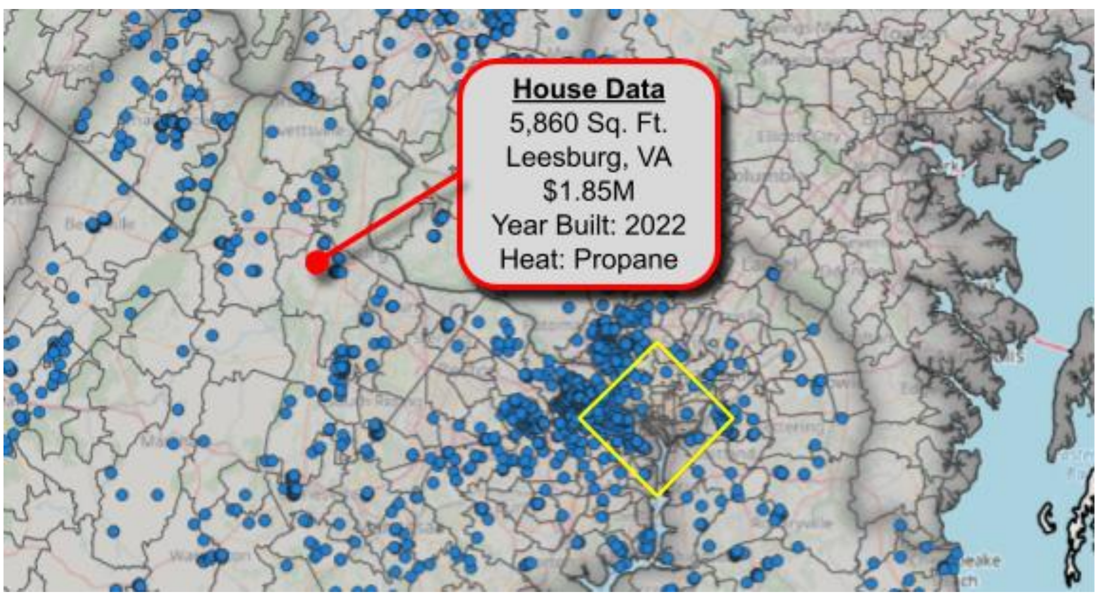


Figure 8

Screenshot of QGIS Housing Points Layer Around Washington, DC, with Annotation



Note: Callout displays some of the available information that would be displayed when this house is inspected in QGIS

Figure 9

Screenshot of Heatmap Layer Around Washington, DC, with Annotations

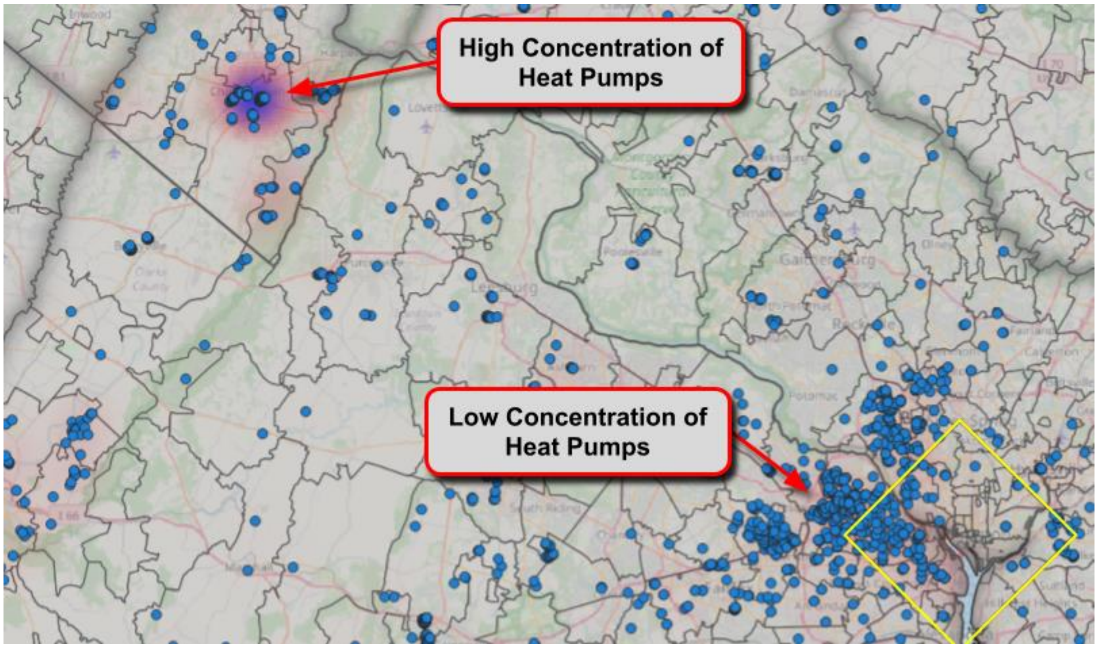
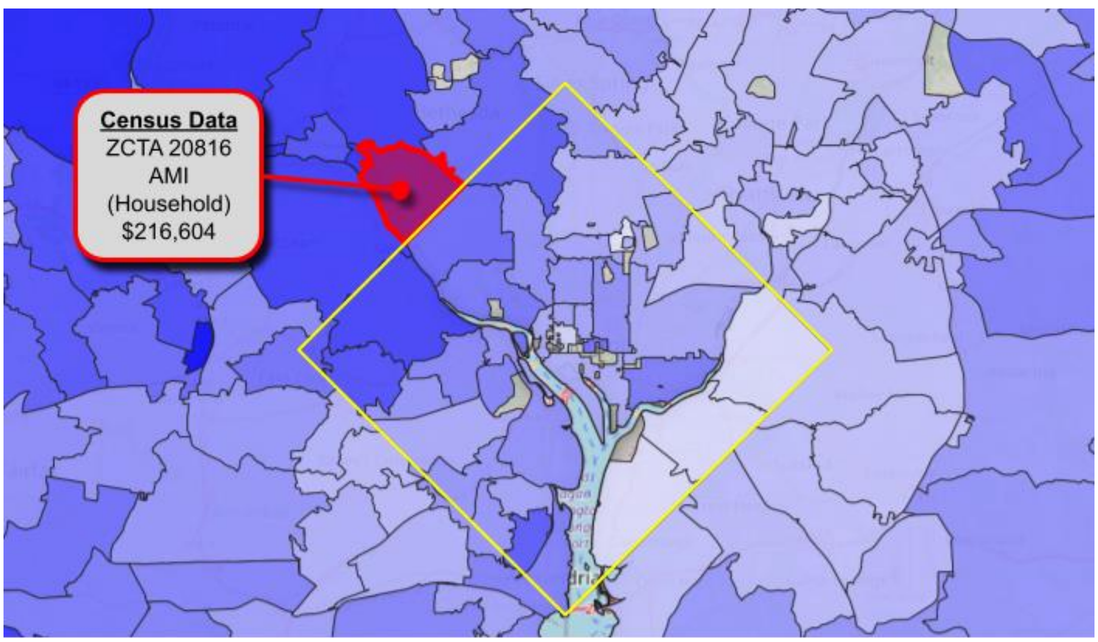


Figure 10

Screenshot of Census Data Layer Around Washington, DC, with Annotation



Note: AMI stands for area median income.

4.2.1 | QGIS Analysis Tools

QGIS comes with many tools to process geospatial data. We used three of these tools to create our sample reports, as mentioned in section 4.4. These three were “Extract Location,” “Reproject Layer”—a coordinate reference system (CRS) reprojection, and the “DBSCAN” clustering algorithm. “Extract Location” was used to keep houses within the Washington D.C. MSA. We used the intersect option, as this kept points that were physically inside of the MSA’s polygon. The effect of this can be seen in Figures 11 and 12. Next, since the “DBSCAN” algorithm needs accurate distances between points to work, we needed to use a CRS that preserves distances between these points. We used the CRS “ESRI:103375” since this provides an accurate distance for the Maryland area—the Washington, DC, MSA was the only area we ran the DBSCAN algorithm on due to time constraints. Finally, we ran the “DCSCAN” algorithm. We used the results as a proxy for developer communities. The parameters for this algorithm were to keep any cluster with more than five houses where each house is less than or equal to 110 meters (about 360 ft) from each other. We took the results of this algorithm as a proxy for communities created by developer companies since it might be fruitful to see what commercial builders are installing as their heating system. The results of this algorithm can be seen in Appendix G.

Figure 11

Screenshot Showing All Housing Points from the Data Collection Program

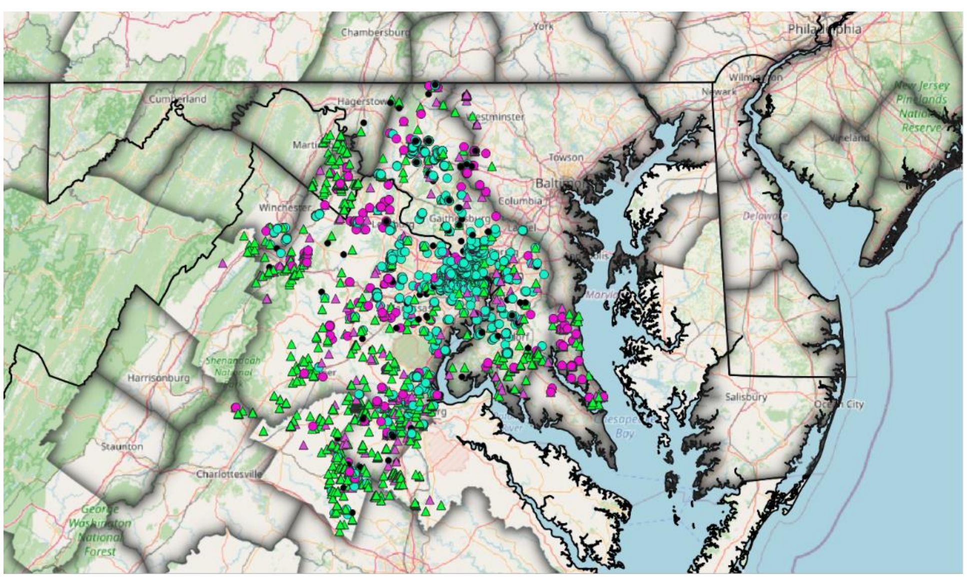
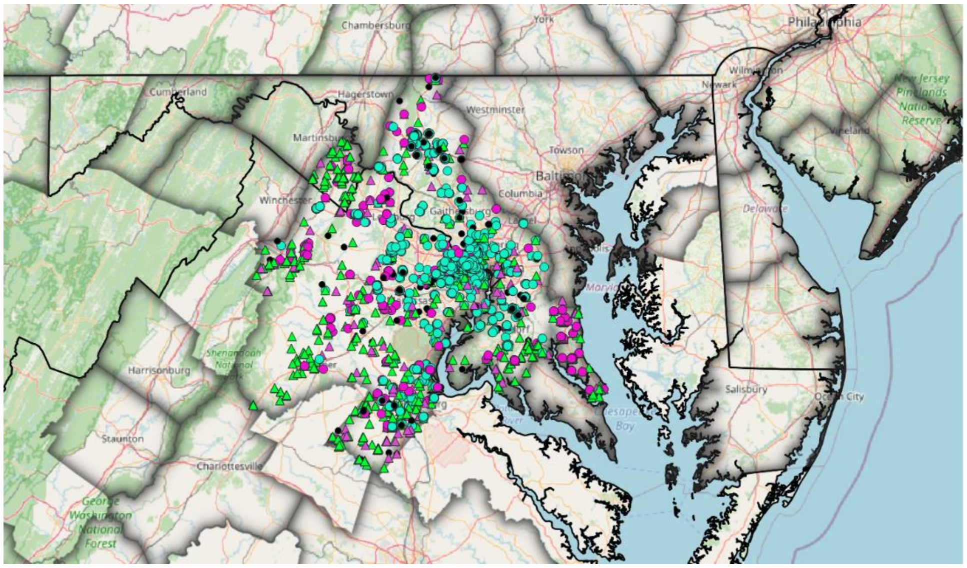


Figure 12

Screenshot Showing the Housing Locations that Fall Inside of the Washington, D.C., MSA



4.3 | Objective Three: Identify Three Metropolitan Areas

In this objective, we selected three metropolitan areas on which to focus our research. The Washington, DC; Denver, CO; and Phoenix, AZ metropolitan areas have highly dissimilar climate zones and some variance in electricity supply sources (see Table 3). Each area's climate differs by about two temperature zones from each other, so there is one hot zone, one cold zone, and one intermediate zone. Denver has a large amount of coal usage, almost 50% in previous years, so we expect, in addition to its cold climate, the factors that encourage heat pump adoption result in comparatively small decreases in carbon emissions. Phoenix uses a mix of large natural gas and nuclear power to supply its electrical needs. In a climate sense, the use of natural gas results in lower emissions than coal since it produces about half of the CO2 per million BTUs (U.S. Energy Information Administration, 2022a). Washington, DC has the cleanest grid out of our selected metropolitans, as 63% of its supply is from renewables.

Table 3
Properties of the Three Selected Metropolitan Areas

Core City	Metropolitan Population	New Single-Family Homes	Metropolitan Climate Zone	State Electrical Grid Source Makeup (Renewable, Natural Gas, Nuclear, Coal)
Denver	2,985,871	2,540	5B/7	37% R, 26% NG, 0% N, 36% C
Phoenix	5,015,678	6,597	2B	18% R, 45% NG, 29% N, 8% C
Washington, DC	6,373,756	3,591	4A	63% R, 32% NG, 0% N, 0% C

Note: Population numbers are from Census Reporter (2023). Single family home numbers are from Chamber of Commerce (2023). Climate Zone information is taken from the International Code Council map (2021). State electrical grid make up is from the U.S. Energy Information Administration (2022b, 2023d, 2023e).

4.3.1 | Factors Contributing to Heat Pump Adoption

From three interviews with realtors from the Washington, DC area and three articles from Hafner et al. (2019), Hove (2023), and Peran & Phillips (2023), we found that the most prominent factor impeding heat pump adoption is consumer awareness. All interviews and several articles indicated that consumers are often unaware of all their options or how to use different systems. Interviewees also indicated that, over time, decreasing numbers of clients care about what heating system is in their home; however, realtor James Kim stated that homeowners have started to care about the safety of gas stoves (preferring electric or induction stoves) and he expects to see more clients avoiding gas furnaces in the future for similar reasons. Realtor Anthony Graham stated that the predominant reason clients with a large enough budget would buy homes with electric heating systems (the common choice for system replacements) is mostly because they were newer and provided greater peace of mind.

4.4 | Objective Four: Write Reports

From our four reports (see Appendix E-H for the report documents), we found different correlations in each area. In Washington, DC, and Phoenix, AZ, we determined that the best place to allocate funding is towards making it easier and cheaper for new home developers to install heat pumps (Appendix F and G). There were no new developer communities (indicated by properties within 110 meters of one another, which we presumed to be communities built by a single developer) in Denver, CO and few heat pumps overall. We determined that for this area to see greater heat pump adoption, efforts are best spent improving heat pumps to work better as this is the coldest climate region of our selected metropolitan areas with little difference in the socio-economic and demographic factors compared with the other metropolitan areas (Appendix E). Our second report for the Washington, DC, area showcases the analysis tools embedded in QGIS that can be used manually to track the overall statistics of an area (Appendix H).

4.5 | Delivery

We delivered four items to Atlas: the data collection tool, the QGIS script, a QGIS project, and ten tutorial videos. To ease the installation and set-up of the collection tool, we created two scripts for Atlas analysts to run. The first script creates a Python virtual environment and installs the necessary third-party libraries. The second script automatically runs the data collection tool. The QGIS runs completely inside of QGIS, so analysts do not need to run anything external. The QGIS project includes three base layers: a ZIP code layer, an MSA layer, and a state border layer. We also provided them with 33 census table layers. The ten tutorial videos cover Python installation, data collection tool usage, QGIS installation, QGIS project creation, QGIS script usage, and possible QGIS analysis.

5.0 | Discussion

In this section, we discuss how the work in this project impacts the housing decarbonization effort as well as the impacts on other research areas related to our work. We also discuss the ethics and legal implications of our data collection method before acknowledging the limitations of our work and proposing improvements for alleviating the limitations we encountered.

5.1 | Focused Implications

Our tool helps climate-conscious policymakers track the effectiveness of different incentives aimed at increasing heat pump adoption. Our tool can collect nationwide data in a format conducive to creating understandable visualizations in QGIS. The insights provided by our tool can help policymakers rework old programs or devise new incentives to increase adoption and lower the environmental impact of the U.S. residential heating sector. Over time, visible increases in our tool capturing more heat pump systems in new houses adoption may indicate that incentives are working and could also represent a reduction in the gases negatively impacting climate change, depending on the electrical grid's energy source.

Our interviews and sample analyses indicate that, currently, incentive funds intended to increase heat pump adoption are best allocated into two areas: towards the education of home buyers on the existence and benefits of heat pumps and towards increasing heat pump adoption by large community developers. The realtors we interviewed stated that their clients often had no heating system preference and that other factors outweighed the consideration of the installed heating appliance type. Increasing awareness of heat pumps, including their emissions reduction and potential cost savings, could be one of the best ways to increase adoption among these potential home buyers, as this may convince these home buyers to spend more for the environmental benefits. Additionally, we found that most developer communities had natural gas systems installed—especially those in the Washington, DC, MSA. Thus, increasing incentives for developers to install heat pumps during new residential construction could be one of the best ways to increase installations. Notably, despite having similar socio-economic and demographic statistics compared with Washington, DC, and Phoenix, AZ, Denver had fewer heat pumps. Since Denver has a distinctly colder climate than the other areas, targeted incentives that can cover the extra cost of specialized cold-climate heat pumps could increase adoption. However, since the coldest temperatures in Denver may still fall below the ratings of most cold-climate heat pumps, technology may need to improve for home buyers to feel comfortable using these systems independently. Altogether, we believe these methods are the best way to decrease the environmental impact of the residential heating sector.

5.2 | Broader Implications

Beyond the decarbonization of the residential sector, our tool can be adapted, or combined with other, similar tools, to analyze data on numerous social issues in the United States where data on individual homes is crucial. The large amount of collectable housing data means software engineers can modify the tool to collect a different set of primary data (the heating system data, in our case), shifting the focus of the tool to other societal facets where understanding an area's housing stock could be an important part of understanding the issue. One example is food deserts. Our work may be adapted to collect data on a wider breadth of homes to gain a better perspective on the issue. By adding onto our tool to collect data on grocery stores and their offerings, transportation availability, and cost of goods in different areas, analysts could look for correlations between factors around food deserts or identify food deserts that would benefit from legislative action.

5.3 | Restrictions on Data Use

After examining the Terms and Conditions and testing data retrieval from various websites, we determined Redfin was the only viable option for our project. This is because they do not currently block access to their Stingray API. However, the MLS data that this API provides is copyrighted and cannot be used for commercial purposes. While we are comfortable using this data for our investigative purposes of analyzing heating appliance types and fuel types for our undergraduate project, commercialization of this tool would likely infringe on the copyright of Redfin and their MLS partners. We emphasized this point with Atlas, and they have agreed not to use Redfin as their data retrieval source. As an alternative, we have presented multiple paid API options with a commercial use license, and Atlas has agreed to transition our data collection method into one of these options.

5.4 | Research Limitations

During our work, we encountered a few issues that limited the data we could collect. These issues can be resolved with more robust and expensive solutions incorporated during further tool development. One area for improvement in our assessment of critical factors to heat pump adoption stems from limited interviews. Our pool of Washington, DC, area realtors might not adequately represent diverse client populations or regional climate impacts that realtors in other areas would represent. Future research may work to find more realtors and other residential real estate experts to interview in different regions. Additionally, we could not find any new home developers willing to be interviewed, so there is a gap in our understanding of how decisions are made when installing a heating system in new home construction.

The most significant limitation we encountered was a lack of data access in certain areas. Lack of data collected through our program does not imply that the data does not exist, but simply that we were unable to access such data. One of our original metropolitan area choices, Minneapolis, had to be revised because we were unable to collect data on a majority of the new properties that should be in the area. For this area, it was most likely due to local MLS rules. In other areas, this could be due to a limitation in Redfin's API system, or it may stem from a different source entirely. This issue can be alleviated using a different data collection method or API, particularly a paid, licensed option. Similarly, during interviews, we learned that discrepancies between listings on one site may be due to a real estate agent error when inputting a new home into the MLS database, which is a source of error that will likely be impossible to eliminate.

Additional data quality issues were present. On multiple occasions (roughly 1 per 100 houses in our ~6,600-house data set), properties were duplicated in our response data. Typically, this was due to the land being listed for sale, someone buying the plot, building a house, and then relisting it. Redfin advertises filtering data by its "home type," such as by single-family residence, land plot, condominium, etc., but this filtering did not seem to work as expected in these cases. We had to contend with these issues by manually filtering out the faulty data for our reports. Similarly, Redfin's "year built" filter did not work in some instances. This was discovered after we ran the collection tool, when reviewing the data, so these houses had to be manually filtered out. We believe we have fixed both issues in the latest software version, and we describe their fixes in Appendix D.

To best alleviate these issues, we recommend switching to a paid API service for retrieving property data to enable complete data collection in more areas and prevent legal issues from commercializing copyrighted data (this process is described in Appendix I).

5.5 | Improvement Recommendations

We recommend updating the ACS5 data used in the tool to reflect the most recent publications as they are released to the U.S. Census Bureau API. Update the year by finding the API call and changing the "2019" in the link to the most recent available year. However, it is essential to note that the U.S. Census Bureau API may not be updated with the most recently released data, as was the case for 2020 and 2021 data during our development.

We recommend switching from QGIS to ArcGIS for improved analysis tools and functionality. While QGIS is free and open source, it lacks the performance and stability of ArcGIS. During our work, we experienced unexpected crashes using QGIS, sometimes without error reports, and lengthy loading times when opening new windows. ArcGIS would improve user experience but requires a paid license to use. If the analysis portion of the tool is used often enough, switching to ArcGIS would prove valuable to analysts' workflows. However, it would require reworking the automatic layer formatting in our script as it is QGIS-specific. Alternatively, we recommend investing in QGIS software development to improve performance, which would address some of the usability issues we experienced during development. If a native Python experience is desired, we recommend looking into Plotly, GeoPandas/GeoPolars, Shapely, PySal, or Fiona. Other spatial analytical software options are GDAL and Kepler.gl.

We recommend adding layers to the GIS map, especially some containing more demographic and regional data. For example, some layers that could be added are average monthly temperature per metropolitan area, average heating days per ZIP code, and average energy prices per state. These additional layers would allow for further analysis of heat pump adoption trends. Further, we recommend investing time in learning geospatial analysis. When displaying points and layers, analysis is much easier when the user learns some simple core concepts. Concepts such as spatial projection types, storage types, and types of spatial joins can help create a better narrative with the collected data.

6.0 | Conclusion

We have developed and delivered a data collection, storage, and visualization tool that Atlas Public Policy can use to collect and analyze data on U.S. residential electric heating trends in new construction. Atlas can use the tool to analyze the trends, make the data available to the public, and help advise businesses, legislators, and policymakers on housing electrification. Atlas may additionally use this data to advise said groups on environmental policies.

We hope this tool can reduce the environmental impact of residential heating systems by informing policymakers about the usage of climate-saving heat pumps and how much they minimize pollution depending on spatial variables. Policymakers can then work to enact legislation that increases heat pump usage and converts operational electricity supply to greener sources.

7.0 | References

Addo-Binney, B., Agelin-Chaab, M., Bamfo, E., & Koohi-Fayegh, S. (2022). A comparative life cycle assessment of a cascade heat pump and a natural gas furnace for residential heating purposes. *Integrated Environmental Assessment and Management*, *18*(2), 572–580. https://doi.org/10.1002/ieam.4494

Alberini, A., Gans, W., & Towe, C. (2016). Free riding, upsizing, and energy efficiency incentives in Maryland homes. *The Energy Journal*, *37*(1), 259–290.

Aneli, S., Arena, R., Marco Tina, G., & Gagliano, A. (2023). Improvement of energy self-sufficiency in residential buildings by using solar-assisted heat pumps and thermal and electrical storage. *Sustainable Energy Technologies and Assessments*, *60*, 103446. https://doi.org/10.1016/j.seta.2023.103446

Carthan, A. (2023, March 24). *How much does a heat pump cost?* This Old House. https://www.thisoldhouse.com/heating-cooling/reviews/heat-pump-cost

Carvalho, A. D., Mendrinos, D., & De Almeida, A. T. (2015). Ground source heat pump carbon emissions and primary energy reduction potential for heating in buildings in Europe—Results of a case study in Portugal. *Renewable and Sustainable Energy Reviews*, *45*, 755–768. https://doi.org/10.1016/j.rser.2015.02.034

Census Reporter. (2023). *Census reporter: Making census data easy to use*. https://censusreporter.org/

Chamber of Commerce. (2023, June 6). *Cities with the most new homes (2023)*. https://www.chamberofcommerce.org/new-home-construction

Corbett, M., Rhodes, E., Pardy, A., & Long, Z. (2023). Pumping up adoption: The role of policy awareness in explaining willingness to adopt heat pumps in Canada. *Energy Research & Social Science*, *96*, 102926. https://doi.org/10.1016/j.erss.2022.102926

Dominion Energy. (2023, May 24). *Replacing new equipment | South Carolina*. https://www.dominionenergy.com/south-carolina/save-energy/heating-and-cooling-rebates/replacing-new-equipment

Duke Energy. (n.d.). *Smart $aver—HVAC install*. Retrieved November 6, 2023, from https://www.duke-energy.com/home/products/smart-saver/hvac-install

Efficiency Maine. (2023, October 17). *Residential heating system cost calculator*. https://www.efficiencymaine.com/at-home/heating-cost-comparison/

ESRI. (2023a, February 6). *USA core based statistical area GIS layer*. ArcGIS Online. https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/usa_cbsa/FeatureServer

ESRI. (2023b, February 8). *USA states generalized boundaries GIS layer*. ArcGIS Online. https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/USA_States_Generalized_Boundaries/FeatureServer

ESRI. (2023c, June 20). *Census zip code tabulation areas gis layer*. ArcGIS Online. https://services2.arcgis.com/FiaPA4ga0iQKduv3/arcgis/rest/services/Census_ZIP_Code_Tabulation_Areas_2010_v1/FeatureServer

Frank, J., Brown, T., Ha, H., Slade, D., Haverly, M., & Malmsheimer, R. (2023). A comparative analysis of the cumulative greenhouse gas emissions and financial viability of residential heating systems located in New York state. *Biofuels, Bioproducts and Biorefining*, *17*(1), 18–28. https://doi.org/10.1002/bbb.2442

Hafner, R., Elmes, D., & Read, D. (2019). Exploring the role of messenger effects and feedback frames in promoting uptake of energy-efficient technologies. *Current Psychology*, *38*(6), 1601–1612. https://doi.org/10.1007/s12144-017-9717-2

Hove, A. (2023). *Analysis: Policy barriers to heat pump adoption need further attention* (Synergies between China’s Whole County PV Program and Rural Heating Electrification, pp. 17–19). Oxford Institute for Energy Studies. https://www.jstor.org/stable/resrep49251.11

Internal Revenue Service. (2023a, August 24). *Energy efficient home improvement credit*. https://www.irs.gov/credits-deductions/energy-efficient-home-improvement-credit

Internal Revenue Service. (2023b, August 28). *Residential clean energy credit*. https://www.irs.gov/credits-deductions/residential-clean-energy-credit

International Code Council. (2021). *Climate zone map from IECC 2021*. Building America Solution Center. https://basc.pnnl.gov/images/climate-zone-map-iecc-2021

International Energy Agency. (2023, March). *CO2 emissions in 2022 – Analysis*. https://www.iea.org/reports/co2-emissions-in-2022

Karytsas, S., & Theodoropoulou, H. (2014). Public awareness and willingness to adopt ground source heat pumps for domestic heating and cooling. *Renewable and Sustainable Energy Reviews*, *34*, 49–57. https://doi.org/10.1016/j.rser.2014.02.008

Kujala, B. (2016, August 31). *Do customers of rural utilities have higher electricity bills?* Northwest Power and Conservation Council. https://www.nwcouncil.org/news/2016/08/31/do-customers-rural-utilities-have-higher-electricity-bills/

Levy, G. (2018, July 20). *Report: Energy costs are a higher burden on the rural poor*. U.S. News & World Report. https://www.usnews.com/news/national-news/articles/2018-07-20/report-energy-costs-are-a-higher-burden-on-the-rural-poor

McCabe, L. (2023, May 10). *How much does a heat pump cost in 2023?* EnergySage. https://www.energysage.com/heat-pumps/costs-and-benefits-air-source-heat-pumps/

Midamerican Energy Company. (2023, March 24). *Illinois residential instant discounts and rebates*. https://www.midamericanenergy.com/il-residential-rebates

Mohave Electric Cooperative, Inc. (2020, July 25). *Heat pump rebate*. https://www.mohaveelectric.com/energy-solutions/rebates/heat-pump-rebate/

Munch's Supply. (n.d.). *ComEd residential rebate form*. Retrieved November 6, 2023, from https://www.munchsupply.com/comed_residential_rebate_form

Neves, J., & Oliveira, T. (2021). Understanding energy-efficient heating appliance behavior change: The moderating impact of the green self-identity. *Energy*, *225*, 120169. https://doi.org/10.1016/j.energy.2021.120169

Peran, A., & Phillips, J. (2023). *Navigating obstacles to clean heat deployment* (Supporting Warmer Homes For Rural Communities, pp. 21–27). E3G. https://www.jstor.org/stable/resrep52718.9

Piedmont Natural Gas. (n.d.). *Rebate terms & conditions for South Carolina*. Retrieved November 7, 2023, from https://gasadvantage.piedmontng.com/EnergyEfficiency/SCRebateTerms/

Pistochini, T., Dichter, M., Chakraborty, S., Dichter, N., & Aboud, A. (2022). Greenhouse gas emission forecasts for electrification of space heating in residential homes in the US. *Energy Policy*, *163*, 112813. https://doi.org/10.1016/j.enpol.2022.112813

Poblete-Cazenave, M., & Rao, N. D. (2023). Social and contextual determinants of heat pump adoption in the US: Implications for subsidy policy design. *Energy Research & Social Science*, *104*, 103255. https://doi.org/10.1016/j.erss.2023.103255

Shen, X., Qiu, Y. L., Liu, P., & Patwardhan, A. (2022). The effect of rebate and loan incentives on residential heat pump adoption: Evidence from North Carolina. *Environmental and Resource Economics*, *82*(3), 741–789. https://doi.org/10.1007/s10640-022-00691-0

South Carolina Department of Energy. (2023, September 26). *Home energy rebate programs*. Energy.SC.Gov. https://energy-stage.sc.gov/programs/funding/home-energy-rebate-programs

South Carolina Department of Revenue. (2022, February 23). *Tax credits for SC homeowners – Check to see if you qualify*. https://dor.sc.gov:443/resources-site/media-site/communications/tax-credits-for-sc-homeowners-%E2%80%93-check-to-see-if-you-qualify

Tampa Electric Cooperative. (n.d.). *Heating & cooling program*. Retrieved November 6, 2023, from https://www.tampaelectric.com/residential/saveenergy/heatingcooling/

This Old House Reviews Team. (2023, February 3). *Heat pump vs. air conditioner (2023 guide)*. This Old House. https://www.thisoldhouse.com/heating-cooling/reviews/heat-pump-vs-ac

Toma, L. (2023, October 1). How much does a heat pump cost in 2023? *HVAC Gnome*. https://hvacgnome.com/blog/cost/heat-pump-price/

Udovichenko, A., & Zhong, L. (2019). Application of air-source heat pump (ashp) technology for residential buildings in Canada. *IOP Conference Series: Materials Science and Engineering*, *609*(5). https://doi.org/10.1088/1757-899X/609/5/052006

U.S. Census Bureau. (n.d.). *CHARS - Current data*. Retrieved December 5, 2023, from https://www.census.gov/construction/chars/current.html

U.S. Energy Information Administration. (2023a). *Monthly energy review*. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

U.S. Energy Information Administration. (2022a, November 7). *Natural gas and the environment*. https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php

U.S. Energy Information Administration. (2022b, December 15). *District of Columbia profile and energy estimates*. https://www.eia.gov/state/analysis.php?sid=DC

U.S. Energy Information Administration. (2023b, March). *Highlights for space heating in U.S. homes by state, 2020*. https://www.eia.gov/consumption/residential/data/2020/state/pdf/State%20Space%20Heating.pdf

U.S. Energy Information Administration. (2023c, May). *Electricity data browser—Average retail price of electricity*. https://www.eia.gov/electricity/data/browser/#/topic/7?agg=0,1&geo=g&endsec=o&linechart=~ELEC.PRICE.US-RES.M&columnchart=ELEC.PRICE.US-ALL.M&map=ELEC.PRICE.US-ALL.M&freq=M&start=200101&end=202309&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0

U.S. Energy Information Administration. (2023d, May 18). *Colorado profile and energy estimates*. https://www.eia.gov/state/analysis.php?sid=CO

U.S. Energy Information Administration. (2023e, June). *Arizona profile and energy estimates*. https://www.eia.gov/state/?sid=AZ#tabs-4

U.S. Energy Information Administration. (2023f, June 16). *Climate zones—DOE building America program*. US Energy Atlas. https://atlas.eia.gov/datasets/eia::climate-zones-doe-building-america-program/about

U.S. Energy Information Administration. (2023g, October 31). *Natural gas data browser—Average residential price*. https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_DMcf_m.htm

Waite, M., & Modi, V. (2020). Electricity load implications of space heating decarbonization pathways. *Joule*, *4*(2), 376–394. https://doi.org/10.1016/j.joule.2019.11.011

8.0 | Appendices

Appendix A: Informed Consent Agreement for Participation in a Research Study

Investigator: Adrienne Hall-Phillips, PhD
Contact Information: ahphillips@wpi.edu (preferred); (508) 831-4934
Title of Research Study: Analyzing Heating System Electrification in New Construction
Sponsor: Atlas Public Policy

Introduction

You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: To develop a data collection and visualization tool to inform policymakers and the general public of electric heat pump trends and the factors behind these trends within the U.S.

Procedures to be followed: You will answer questions applicable to your knowledge of heating systems, preferences in heating, concerns about electric heat pumps, and incentives that might influence the installation of electric heat pumps.

Risks of studying participants: There are no anticipated risks.
Benefits to research participants and others: There are no direct benefits to you for participating in this research study.

Record keeping and confidentiality:

Only the research team will have access to your records. All data will be kept in a secure file that only the research team can access. All data reported in a research poster and manuscript will be aggregated. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or its designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identifies you by name. Any publication or presentation of the data will not identify you. The information that you give will be kept anonymous.

Compensation or treatment in the event of injury: This research involves minimal risk of injury or harm. You do not give up any of your legal rights by signing this statement.
Cost/Payment: There is no financial compensation for participating in this study.

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: The investigator (Dr. Adrienne Hall-Phillips, WPI School of Business, Tel. 508-831-4934, Email: ahphillips@wpi.edu), or the IRB Manager (Ruth McKeogh, Tel. 508 831- 6699, Email: irb@wpi.edu) and the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: ___________________

Study Participant Signature

____

Study Participant Name (Please print)

____ Date: ___________________

Signature of Person who explained this study

Appendix B: Script for interviews with realtors

We are a team of students from Worcester Polytechnic Institute in Massachusetts, U.S. We are working on developing a data collection and analysis method to understand current heat pump adoption rates and factors affecting adoption. Our goal is to learn more on the topic of the expressed desires and focus of clients regarding heating systems.

Your knowledge on the topic would be very beneficial to understanding the factors impacting heat pump adoption and with your consent will be used in our publicly available report. If you would like to be credited, should your comments be directly cited or paraphrased in our report, we will collect your name and you will not remain anonymous on any citations. However, if you would like to remain anonymous, we will not collect your name.

Your participation is greatly appreciated and completely voluntary. You may opt-out at any time or refuse to answer any question. For accurate representation, we also would like to take notes and record this discussion. Are you okay with this?

Question 1:
How long have you been involved in real estate? What are your specialties or focus?

Question 2:
How often do clients express interest in purchasing homes with specific heating systems?

Question 3:
What percent of buyers specifically seek housing with electric heat pumps?

Follow-up if they don't mention clients' awareness of heat pumps – Of those who are not seeking heat pumps, do most prefer another option or have no preference?

Question 4:
What are the differences between buyers who are looking for a heat pump system vs those looking for a conventional heating system?

Question 5:
What are other factors you as a realtor, or your clients, consider when looking at the heating systems of houses to purchase?

Appendix C: In-Depth Source Evaluation Criteria

Any viable data source must have allowed us to collect the data at a reasonable rate so that we could collect complete sets of useful data to rapidly fix bugs in the code or resolve larger issues with data collection. However, Atlas intends to run the tool occasionally to collect data over the next several years as they aggregate the data into a long-term analysis, so frequency is less important outside of tool development. Some listings were not consistent with others, whether that was due to privacy laws or missing MLS database user input. This forced us to create strong validation in our business logic to handle such cases and prevent a software crash or misinterpretation of the data. To ensure the tool suits Atlas' purposes and collects their desired data points (see Appendix D), we incorporated their feedback into the development process.

Appendix D: Collector Related Information and Resources

Since our project created a software tool, we have decided to host its code on a public repository on GitHub, available at: https://github.com/Atlas-B2023/ResidentialElectrificationTracker.

Many third-party libraries were used and can be found at: https://github.com/Atlas-B2023/ResidentialElectrificationTracker/blob/main/requirements.txt.

Documentation for the data collection tool is available at: https://atlas-b2023.github.io/ResidentialElectrificationTracker/.

Attributes copied from the Stingray API response are:

Address, City, State or province, ZIP or postal code, Price, Square feet, Year built, Latitude, Longitude

Heating related attributes that we derived based on data within a house's listing are:

Electricity, Natural Gas, Propane, Diesel/Heating Oil, Wood/Pellet, Solar Heating, Heat Pump, Baseboard, Furnace, Boiler, Radiator, Radiant Floor

These attributes are Boolean values; "True" or "False." We utilized specific regexes, which are sequences of characters that form a search pattern, and simple business logic to extract the fuel and appliance types for each house. However, due to the nonstandard nature of an MLS data entry, we had to fall back to only capturing the appliance type for some houses. Additionally, some houses list no information on their heating systems and thus contain "False" for all possible heating-derived attributes.

Data duplication has been fixed by performing group by and aggregation operations on the latitude and longitude columns of our housing data and performing a Boolean and value "max" operation for all fields in the aggregation. This trickles down all True values and keeps all string values the same since they are identical across the same longitude and latitude pair aggregations. The same longitude and latitude pair is used as a proxy for the same house entity.

Additional year filtering was performed by discarding entries with a year-built entry less than the minimum allowed year or greater than the maximum allowed year.

About 53% of houses returned from the Stingray API had usable heating information. These numbers are given in Table 5.

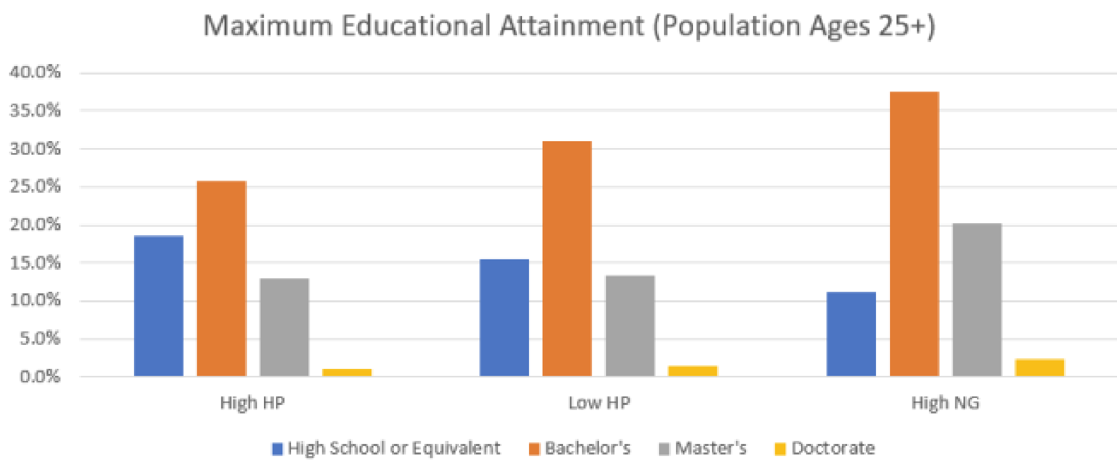
Table 4

Collection Numbers for Selected Metropolitans

Denver	Phoenix	Washington, DC
406	7,582	4,462

Note: Numbers are for homes that are single family houses, that have at least one story, and were built in the year 2022. Data collection numbers are houses that have been returned directly from the Redfin API, with minimal processing to remove duplicates, using an older version of the software.

Appendix E: Sample Report of Denver, CO Created Using Our GIS Tool.



Analysis

There are no developer communities installing one type of heating. Most data points for heating were few and far between, so these areas have fewer installations than in other reports. The high propane and natural gas areas may be individual builders working on homes in one area but not a large development. The low heat pump area is more likely to be the work of isolated builders due to the lack of new homes in that area.

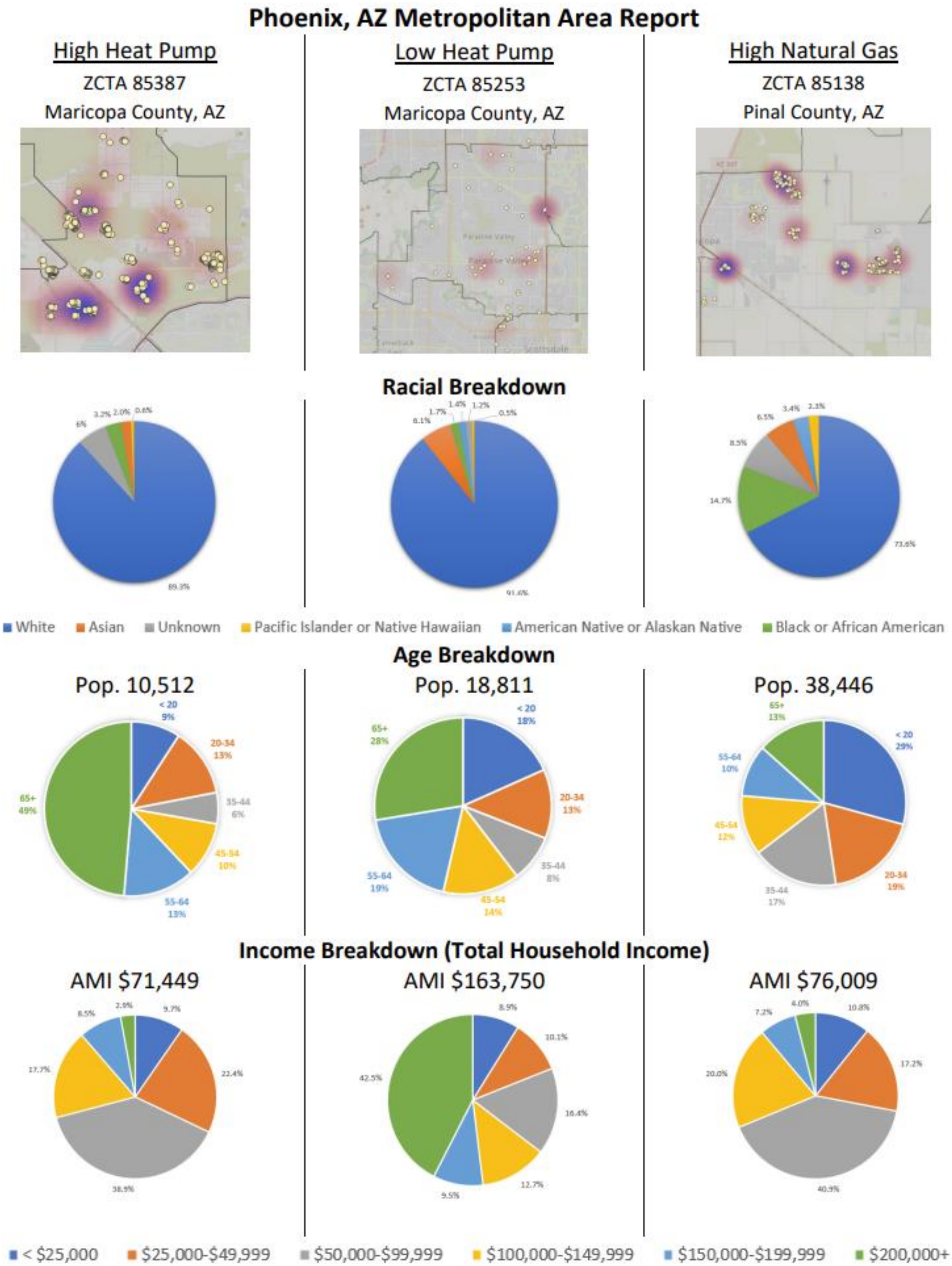
The racial makeup in each area is predominantly white (around 90%), with Asian and Black or African American as the next largest groups. There are few Pacific Islanders or Native Hawaiians in the three areas.

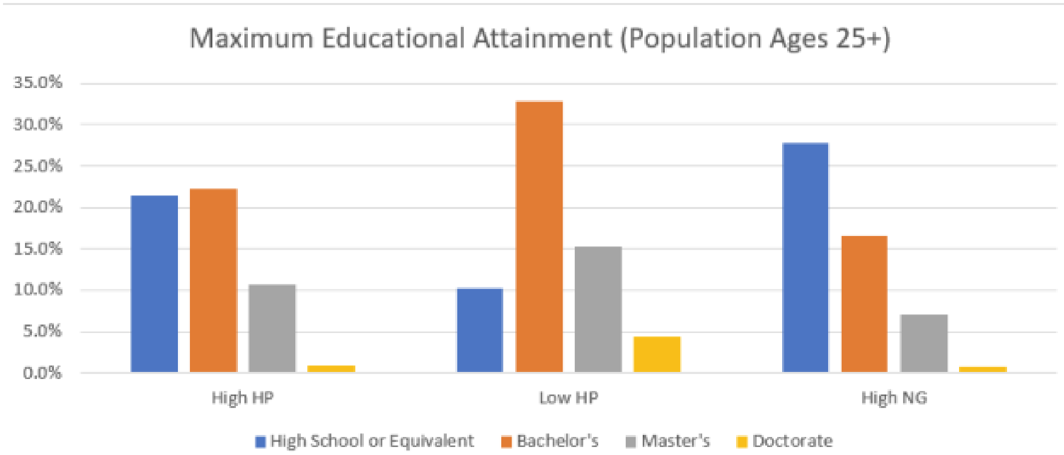
The age makeup of each area is relatively constant, with the total population reflecting similar consistency.

The education levels are rather similar between the three areas. Variances in the portions of the population earning $200k per year reflect the differences in the number of Bachelor's and Master's educational attainments. The AMI of the high propane area is about $20k below that of the other areas at $97,925. The slightly greater numbers of people aged 20-34 combined with lower education compared with the high natural gas area indicates that these areas are seeing younger people who have not yet invested in education beyond a bachelor's as much as the high natural gas area.

One significant insight from this comparison is the overall lack of heat pumps. We could not analyze an area with high heat pump usage as there was none. We suspect this is due to the reliability of heat pumps in the cold Denver climate. The lack of purchases may stem from being forced to invest in backups as well, although most of the cost should not be the most prominent issue for most of the population. As such, the best ways to increase heat pump usage in Denver, and colder climates in general, are to improve heat pump operation in cold temperatures and help offset the costs of backup systems through financial incentives.

Appendix F: Sample Report for Phoenix, AZ Created Using Our GIS Tool





Analysis

The high heat pump and natural gas areas are a series of several new developments whose builder chose to install one system in all their properties. The low heat pump is a more populated area changing from a suburban to an urban environment where a single developer may not have built all the homes.

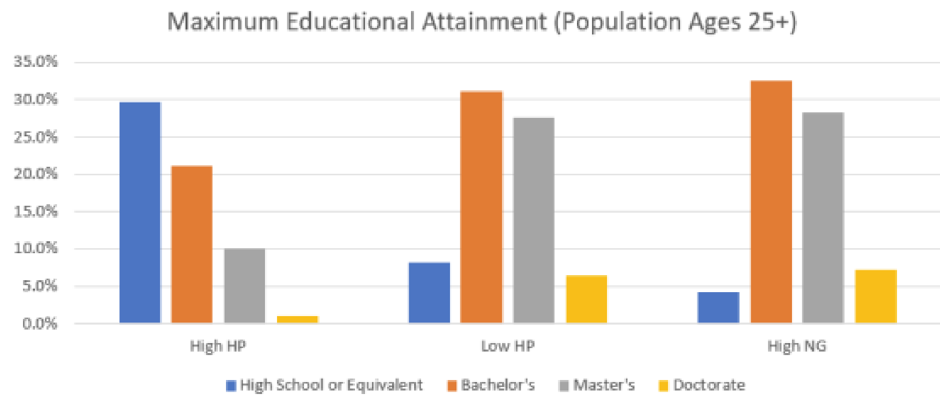
The racial makeup in each area is predominantly white; however, the high natural gas area has a significantly lower percentage of white residents (73.6%) compared with the other areas (~90%).

The age makeup of each area differs consistently between each area, and the high natural gas area has at least double the total population of the other areas. The age breakdowns indicate that the areas have a majority of people in different stages of their life. The high heat pump area has mostly retirees whose children have grown up and moved out. The low heat pump area has more people starting to retire and younger people getting ready to move away. The high natural gas area has a much greater number of families whose children have not yet graduated high school.

The education levels vary significantly between each area. The low heat pump area has the highest number of college graduates at every level and, relatedly, the highest AMI. The AMI of the low heat pump area is about $90k above the other areas at $163,750. A potential explanation for the lower number of college graduates in the high natural gas area is a higher number of people with less education who work in various jobs helping the larger retiree populations in other communities.

There are many instances of tightly packed developments with heat pumps as their primary heating method. Other developments prefer natural gas. The high heat pump area could also be considered a high natural gas area, depending on the subdivision of interest. One Phoenix-area developer likely prefers heat pumps, while the other prefers natural gas heating systems. The complete usage of one heating system in each developer community suggests that increasing incentives for developers to install heat pumps may currently be the best way to increase heat pump adoption as the Phoenix, AZ, metropolitan area expands.

Appendix G: Sample Report for Washington, DC Created Using Our GIS Tool



Analysis

The high heat pump area is a new development in a growing suburban area of Jefferson County, WV, whose developer chose to install heat pumps in all their properties. The low heat pump and high natural gas areas are more populated areas, changing from a suburban to an urban environment where a single developer may not have built all the homes.

The racial makeup in each area is predominantly white (around 80%), with Asians as the second largest group. There is little to no Black or African American and American Native or Alaskan Native in the three areas.

The age makeup of each area is relatively constant, with almost half the population between twenty-one and sixty-two. However, the high heat pump area has a little over half the total population of the other areas. The lower population combined with the development style indicates the high heat pump area may see large population growth in the coming years.

The education levels vary significantly between the high heat pump area and the other areas. Near-inverted high school and Master's educational attainments indicate a potentially lower AMI due to less earning potential. The AMI of the high heat pump area is about $100k below that of the other areas at $82,103. Because the high heat pump area is a new development, it likely attracts a greater diversity of ages, educations, and, therefore, incomes, which is apparent in the income breakdown chart.

One significant insight from this comparison is the correlation between higher AMI areas choosing systems besides heat pumps. This likely is not an issue of increased costs compared to more common systems because these areas have nearly 50% of the population making $200k a year, indicating cost may not be the most important factor to mitigate in this area. It is more likely that the selected system is based on personal preference and familiarity with other systems in these areas.

The complete usage of heat pumps in the developer community suggests that increasing incentives for developers to install heat pumps may currently be the best way to increase heat pump adoption as the Washington, DC, metropolitan area expands.

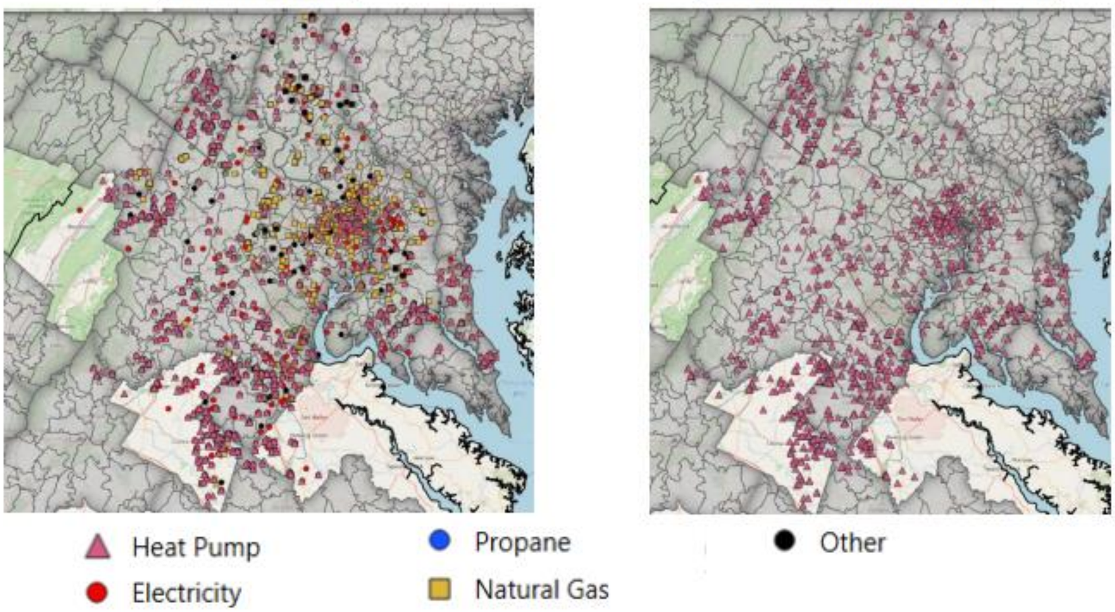
Appendix H: Sample Report #2 for Washington, DC Using QGIS Analysis Tools

Washington, DC Metropolitan Area Report #2

Raw Data Counts:

Electricity: 1225, **Natural gas:** 1786, **Oil Fed:** 0, **Propane:** 264, **Wood Fed:** 2, **Solar:** 0, **Heat Pump:** 1055, **Baseboard:** 4, **Furnace:** 0, **Boiler:** 0, **Radiator:** 2, **Radiant Floor:** 5, **Electricity OR Heat Pump:** 1426

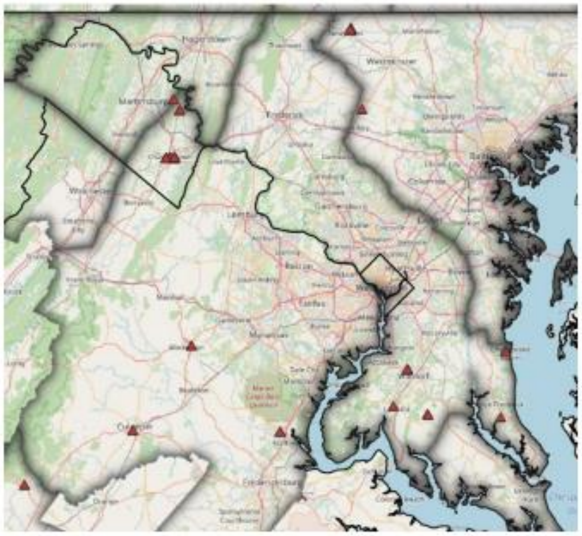
All Heating Types | Heat Pump and Electricity Only

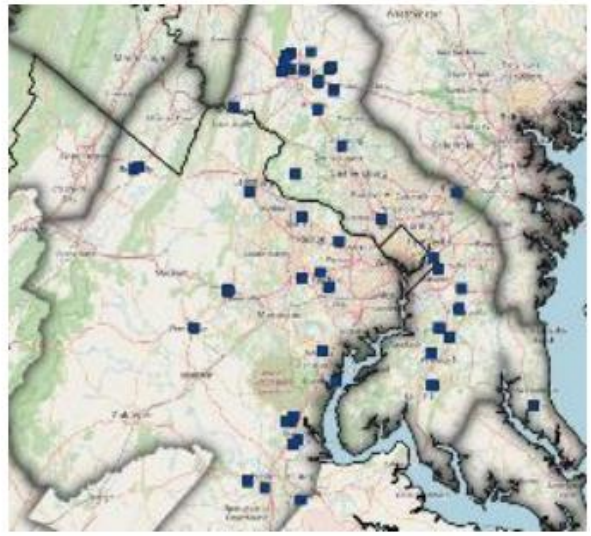


To compare metropolitan areas and try to gain insight into why one area may have more electrified heating system installations than another, we used the DBSCAN algorithm in QGIS to cluster houses together that were within 110 meters (361 ft) of each other and were in groups of at least 5 houses. We also filtered out locations that were outside of the Washington, DC MSA region. These points are in the dataset due to ZIP code boundaries not following metropolitan boundaries or from other data quality issues. Clustering simulates a developer project and shaves down the data we must analyze. The results for the Washington, DC metropolitan area are below:

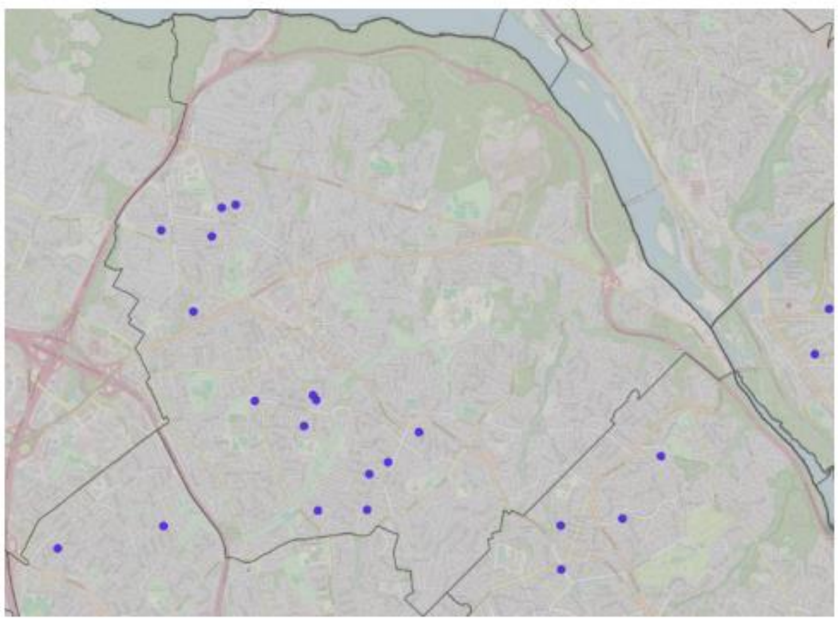
In total, there were 13 developments that utilized electricity or heat pumps in the metropolitan area (left), specifically in Maryland, West Virginia, and Virginia. The zip codes were 22701, 20187, 22554, 20603, 20646, 20617, 25414, 25443, 20678, 20732, 20637. The biggest development was in Charlestown, WV with 64 new homes in a single project.

There were 54 developments that utilized natural gas (right). The biggest development included 67 homes.





Most of the metropolitan area's development happened within already established communities. A typical ZIP code has construction dispersion similar to the figure below (ZCTA 22101: Fairfax County, VA).



We noticed a significant concentration of natural gas-heated homes closer to the center of the metropolitan area hub, while electricity-powered homes were more dispersed. As a note, electricity is just fuel. Appliances that can use electricity are furnaces, resistive heaters, and heat pumps.

Using the DESIRE (https://programs.dsireusa.org/system/program) incentives database, we noted number of available incentives in the three constituent states and the District of Columbia:

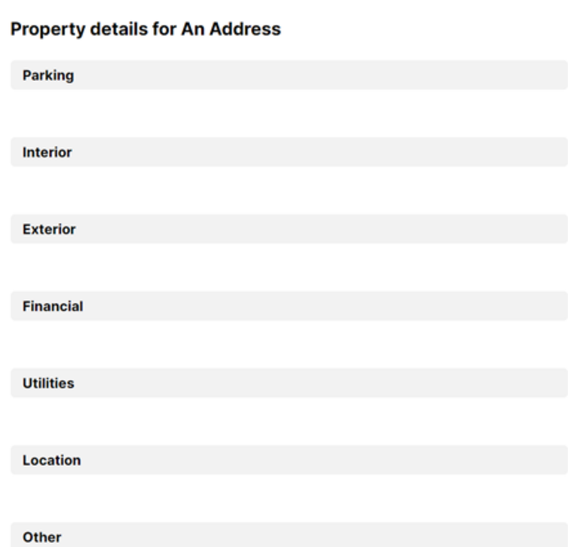
Maryland: 58, **Virginia:** 30, **West Virginia:** 3, **D.C.:** 6, **U.S. (federal incentives):** 5

Appendix I: Process to Switch Data Collection API

Once an API license and key are acquired, the program's data source can be easily changed. One class is doing all the API request calls and response analysis. This class is called "RedfinApi," and is inside the file "redfinscraper.py." To change the API used to collect housing data in place of the Stingray API, you must understand how the Stingray API and the chosen paid API work. For the Stingray API, the program first creates an index of houses for a single ZIP code. This includes house data and a link to the listing page. Since a paid API likely lists all information belonging to a house when searching for a ZIP code, this index part might not happen. The code must be changed to parse housing information directly from the first paid API response since heating information will likely be in this first response when searching by a ZIP code. Parsing the heating information for a house happens in three methods under the "RedfinAPI" class: "get_heating_terms_dict_from_listing," "get_super_groups_from_url," and "get_heating_info_from_super_group." "get_heating_terms_dict_from_listing" calls "get_super_groups_from_url" to get a list of "super groups" from a Redfin listing URL. For each super group that "get_super_groups_from_url" returns, "get_heating_info_from_super_group" is called to extract the heating information contained, if there is any. Figures 11, 12, and 13 show how these three methods combine to break down property details into usable heating-related data.

Figure 11

The Titles of Super Groups for a Redfin.com Listing



Note: Contents have been removed from each super group for the sake of clarity (see Figure 12 for usual content)

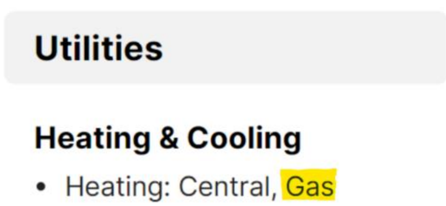
Figure 12

Contents of a Typical Super Group That Contains Heating Information

Note: Only certain super groups are examined. These are ones that have contain “utilit,” “heat,” “property,” or “interior” in their name. Additionally, subgroups (“Utility Information” and “Heating & Cooling” in this example) are filtered to only be processed if their name contains “heat,” “utilit,” or “interior”. This is done to ease data collection, as we can make certain assumptions about the contents of subgroups with these names.

Figure 13

Visual Display of Matched Heating Related Subgroup Item



Note: The only part that gets saved from this super group is the word “Gas.” This figure simply shows how that word is extracted.