Pacific Northwest
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PNNL-33405

Using Open Data to Characterize Building Stock Trends for Energy and Equity Evaluation

September 2022

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Abstract

This project provides a methodology for retrieving data from both existing public data and municipal open data sets to characterize changes in the building stock, socioeconomic, demographic, and climate indicators at a neighborhood scale. This methodology forms the basis for a geospatial dashboard to analyze and share the data. The developed methodology may be used to collect data for further energy equity analyses. Additional data sets, such as from other municipalities, may be incorporated in the future to expand the extents of the possible analysis.

Acknowledgments

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The authors would like to thank David Anderson, James McNeill, Michael Tillou, and James Witherington for their contributions to this project.

Acronyms and Abbreviations

ACS	American Community Survey
CDC	Centers for Disease Control
CEQ	Council on Environmental Quality
DOE	Department of Energy
GIS	Geographic information systems
HSPF	Heating Seasonal Performance Factor
HVAC	Heating, ventilation, and air conditioning
PNNL	Pacific Northwest National Laboratory
SCL	Seattle City Light
SEER	Seasonal Energy Efficiency Rating

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Introduction

The Biden Administration's Justice40 Initiative outlined in Executive Order 14008[1] sets a goal that 40 percent of the overall benefits of federal investments within covered programs (e.g., energy efficiency) should accrue to disadvantaged communities. To evaluate progress toward this goal, additional data is needed for determining the level of benefit that communities and socioeconomic groups gain from federal investments in building sector energy efficiency. Using publicly available data, improvements related to energy efficiency investment can be characterized over time, allowing the resolution of both temporal and spatial trends.

Multiple existing tools that characterize vulnerability and seek to identify underserved or overburdened communities include housing and energy indicators at the census tract level. A sample of tools and indicators is listed in Table 1.

Table 1. Sample of Existing Geospatial Tool Housing and Energy Indicators

Source	Housing Indicators	Energy Indicators
Centers for Disease Control and Prevention (CDC) Social Vulnerability Index (CDC 2021)	• Multi-unit structures • Mobile homes • Crowding • Group quarters	-
Council on Environmental Quality (CEQ) Climate and Economic Justice Screening Tool (CEQ 2022)	• Housing cost burden • Lead paint	• Energy burden
Department of Energy (DOE) Justice40 Disadvantaged Communities (OIED 2022)	• Renters • Incomplete plumbing • Homes built before 1960 (lead paint indicator) • Housing costs • Mobile home • Homelessness	• Outage events • Outage duration • Energy burden • Non-grid-connected heating fuel

With these existing tools there is a gap in data availability at a block level or individual building level and a need for information about building energy efficiency and interventions presented with an equity lens. To bridge the gap between building characteristics and underserved community indicators, this work evaluates open building permit data available from a pilot municipality and other geospatial data sets for the purpose of generating building stock characterizations, determining energy impacts, and assessing equity metrics (i.e., energy burden, property value, and displacement indicators such as gentrification) with a high degree of granularity.

A generalized methodology for data retrieval, transformation, and analysis is developed that can be expanded to additional municipalities in the future. This work includes the creation of a geospatial dashboard for displaying the final transformed data. In addition to the methodology and tools, this project develops new and novel geospatial data sets for broad use in the emerging analytics space of equity and environmental justice.

[1] https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad

Dashboard Concept

Geospatial tools are useful to present a large amount of data in a manner that is valuable for technical audiences and accessible to non-technical audiences. Layering information can also reveal correlations between disparate data sets. The intended audience for the dashboard and data are city employees, planners, and analysts, policy makers, and utilities. Contractors, installers, manufacturers, and non-profits and community groups focusing on efficient energy use also may find the information useful. While not intended as the main audience, we felt it was important to ensure the dashboard is accessible to the public, owners, and building occupants, as affected parties and decision makers in technology selection.

Multiple platforms were assessed for displaying geospatial data. The prototype dashboard utilizes Power BI[2] for its ease of development and use; interactive features, such as filters and time animation; and because there is no additional license needed (it is included as part of Microsoft 365 subscription and shareable within Pacific Northwest National Laboratory [PNNL]). The current report is accessible to team members in a Power BI workspace and may be hosted here for free as long as PNNL maintains the Microsoft Office 365 Enterprise license. A Power BI report may be embedded into a public website and accessed by people without a Power BI license. Currently no website is set up to host the dashboard publicly, so only users with PNNL login credentials have access. If the report is embedded in a website in the future, the cleaned permit data may be made available for download.

Reference layers available publicly will likely not be made available for separate download; however, we plan to make any custom geospatial reference layers publicly available. ArcGIS for Power BI's publicly available American Community Survey (ACS) reference layers automatically update with the latest ACS release, making ongoing data management for these layers possible without manual updates. Permit data would need to be manually updated as additional areas and municipalities are added and as additional years of data become available.

One constraint with the Power BI platform requiring further investigation is the ability to add multiple reference layers to a single map. The dashboard currently displays demographic, socioeconomic, and environmental reference layers on separate tabs rather than selectable from a single tab. This is something that could be possible to overcome with additional programming.

Tableau[3] was considered as an alternative platform which could be utilized in place of Power BI. However, Tableau requires the purchase of a license that may need to be maintained annually. There is an option to explore using the free public platform for long-term maintenance and sharing. Tableau public also offers an embedded data download directly from the dashboard.

[2] https://powerbi.microsoft.com
[3] https://www.tableau.com

Analytical Approach

Identifying Open Data

Municipal Data

The permit data used in this analysis was gathered from the Seattle Open Data Portal,[4] a platform for data generated by the City of Seattle on topics such as city businesses, finances, permits, transportation, and more. For this study, we utilized permit data sets. Each of these data sets contain permit-level data for each permit type issued or in progress in Seattle.

We began by exploring building, electric, land use, and trade permit data sets for all data available through April 12, 2022 (when data was accessed). Each category does not necessarily have the same start date available as the others (building permit data goes back to 1986, electric and trade to 2002, and land use to 2005). We limited the permits to those for multifamily or single-family/duplex properties. Each record can have parameters such as permit type, description, issue date, estimated cost, and completion date. Table 2 lists the number of variables, date range, number of included permits, and average percent of completed fields.

Table 2. Permit Data Sets

Permit Data Set	Number of Variables	Number of Permits Included	Average Percent of Completed Fields	Issued Date Range
Building[1]	26	105,759	79%	Jul. 1986–Apr. 2022
Electric[2]	21	225,806	93%	Jul. 2002–Apr 2022
Land Use[3]	27	14,620	75%	Dec. 2005–Apr. 2022
Trade[4]	22	186,558	94%	Jul. 2002–Apr. 2022

[1] https://data.seattle.gov/Permitting/Building-Permits/76t5-zqzr
[2] https://data.seattle.gov/Permitting/Electrical-Permits/c4tj-daue
[3] https://data.seattle.gov/Permitting/Land-Use-Permits/ht3q-kdvx
[4] https://data.seattle.gov/Permitting/Trade-Permits/c87v-5hwh

Other cities around the United States have similar data portals, including Portland, Minneapolis, Chicago, New York, and San Francisco. The online portals could be mined in future studies for similar permit data to study how the same model could be applied to other cities.

Socioeconomic and Demographic Data

Census blocks are the smallest geographic area for which the census tabulates data collected. The boundaries are formed by streets, water bodies, and other physical features and legal boundaries. These polygons are updated every 10 years with each decennial census. We used the census block groups with the ACS data—an ongoing survey that provides updated, community information on a yearly basis. These data are summarized at the census block group level and provide important insight to the spatial variation of community attributes such as occupations, educational attainment, and home ownership.

[4] https://data.seattle.gov

Using geographic information systems (GIS) software, we joined the 2016–2020 five-year estimates from the ACS to the 2020 census block group polygons. This provided a spatial basis for us to join the permit data by latitude and longitude location, associating the permit data to a specific census block within which it falls.

The following variables were selected illustrating demographic and socioeconomic groups:

- Race
- Education
- Age
- Income.

Environmental Data

In addition to demographic measures, we were also interested in the spatial relationship between new home energy appliance installations and Seattle's physical environment. We drew on data from King County's Urban Heat Watch program[5], which measured the temperature and humidity across the Seattle area in the summer of 2020. Using sensors mounted on cars and bikes, volunteers from the program took over 100,000 heat and humidity samples, which, interpolated over the entirety of Seattle, provided a digitized temperature profile (rasters) of the entire city (CAPA Strategies 2020). We used QGIS software[6] to compute the mean temperature in every census block group (zonal statistics) and saved the values to a table. We then joined results to the associated permits.

Policy and Incentives

In an effort to see if there is a correlation between local energy efficiency incentives and the electrification[7] (and hence on the decarbonization) of the municipal building stock considered in this study, current and past incentive programs offered by Seattle City Light (SCL) through the studied period were researched. Except for current incentive programs that can be accessed through SCL's website, data on this particular topic were not directly available. Web archive searches were performed for every year where data were available[8] to retrieve the information from previous versions of SCL's and the City of Seattle's website. This effort was focused on heat pump (HP) incentives since this mature technology is by far the most common energy efficiency retrofit in the Pacific Northwest conducive to building stock electrification.

Based on the team's research, a single-family residential heat pump pilot downstream incentive program was first initiated in 2010. In 2011, the rebate program became a fixture and evolved through the subsequent years: the rebate amount fluctuated between $1,500 and $300 per installation. In 2018, the structure of the program changed to be based on unit size and efficiency, probably to encourage retrofitting existing heat pumps. That structure currently is still used. Table 3 provides a list of all iterations of the program through the years, along with the maximum rebate amount offered to SCL customers.

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[5] https://www.arcgis.com/home/item.html?id=bf022429473343bdae548c7d5b1c9a0e
[6] https://qgis.org
[7] In the context of this report electrification refers to the process of replacing technologies operating on fossil fuel with technologies that operate on electricity.
[8] Starting in 2008.

Table 3. SCL Single-Family Residential Heat Pump Incentive Programs from 2010 to 2022

Year	Name of the Program	Maximum Rebate	Notes
2010	Ductless Heat Pump – Pilot Program	$ 1,200.00	-
2011	Ductless Heat Pump Program	$ 1,200.00	-
2013	Ductless Heat Pump Program	$ 1,500.00	-
2014	Ductless Heat Pump Program	$ 1,200.00	-
2017	Ductless Heat Pump Program	$ 800.00	-
2018	Energy Efficient Heating and Cooling	$ 1,200.00	Rebates depend on configuration of old/new system: • ductless HP to a unit with Heating Seasonal Performance Factor (HSPF) of 11.0: $100 • zonal electric or forced air heat to single mini split with HSPF of 9.0: $800 • zonal heat to multizone mini split with HSPF of 8.2: $1,000 • electric forced air to multizone mini split with HSPF of 8.2: $1,200
2020	Energy Efficient Heating and Cooling	$ 600.00	Based on efficiency: • ductless with HSPF 9.5–10.9: $400 • ductless with HSPF of 11+: $600 • air-source HP with HSPF 9.0–9.9: $300 • air-source HP with HSPF 10+: $500
2021	Heating and Cooling Solutions, Discounts, and Rebates	$ 600.00	Based on efficiency: • ductless with HSPF 9.5+: $600 • air-source HP with HSPF 9.0+: $300
2022	Heating and Cooling Solutions, Discounts, and Rebates	$ 600.00	Based on efficiency (and < 5.4 tons) • ductless with HSPF 9.5–10.9 and Seasonal Energy Efficiency Rating (SEER) 16+: $400 • ductless with HSPF of 11+ and SEER 16+: $600 • air-source HP with HSPF 9.0–9.9 and SEER 15+: $300 • air-source HP with HSPF 10+ and SEER 15+: $500

Calculated Metrics

Cost Burden

Costs related to procuring and using energy constitute a significant dimension of inequity and injustice in society (Simshauser and Downer 2016). Broadly, when the net benefit of using energy is low or negative, it creates financial and social burdens on the well-being of households (Biswas et al. 2022). The energy bill cost burden is most used to quantify burdens of energy. Calculated as the fraction of total household income, it is usually agreed that a regular energy bill over 6 percent to 10 percent of the total income represents a high to severe financial strain (Drehobl et al. 2020). However, it is acknowledged to be limited in capturing several other ways in which energy systems create burdens for households (Sareen et al., 2020). For instance, the cost of owning and replacing energy appliances, backup power supply, and recurring costs of repairs or upgrades due to quality of appliances and workmanship are some key types of financial burdens that are independent of the energy bill. Therefore, cost burdens associated with energy must include forms of burdens created by the broader energy system and not simply the supply cost of energy. This need for wider scoping of cost burdens on the household becomes even more relevant when historically marginalized or currently underserved populations and geographies are concerned. This is due to the fact that, although energy supply rates may be uniform for all, discrimination is more likely in other non-supply related aspects of the energy system (Wang et al. 2021).

The geospatial dashboard captures one such cost associated with installing air conditioners, heat pumps, and gas furnaces in Seattle. Permits for each type of installation record the estimated total cost of materials, equipment, and labor.[9] Plotting the permit cost value on the city map illustrates a pattern of spending on a particular type of installation project. This information can be inferred in the following ways:

1. Project cost distribution: a relative project cost visualization across the city, with patterns for each block group or census tract.
2. Project cost in relation to building age: a representation of the quantum of expense for buildings with different ages.[10]

Project costs are displayed in the geospatial dashboard in five groupings by natural breaks in the data. Each data point is displayed and sized by its group. Smaller project costs are represented by smaller points, while larger costs are represented by larger points (see Figure 9 example). The estimated project cost is not adjusted for inflation, so comparison should not be made across years, only within years.

It must be noted that the information visualized in this dashboard is not necessarily an energy burden. It may indicate a potential energy burden and should be determined by using this information in conjunction with additional data points. We propose future investigation into using the square-foot area of the building as the additional data point to determine if a particular project cost contributes toward energy burden. Since the project cost extracted from permits varies with the size and scope of the projects, a common denominator is required to make the costs comparable. Using the square footage of the building where the project is executed as the common denominator can result in calculating the following relative cost burden metric:

$$\%\,Relative\ cost\ burden\ = \frac{\frac{Actual\ cost\ of\ project}{sq.foot\ area} - \frac{Average\ cost\ of\ project}{sq.foot\ area}}{\frac{Average\ cost\ of\ project}{sq.foot\ area}} * 100\%$$

[9] Many permit records are missing data in the estimated project cost field. Of 22,463 total records, 7,701 have estimated project cost data. Multifamily project costs were excluded since the projects tend to be significantly larger and higher cost than single-family and duplex projects, leaving 5,275 single-family permits with estimated project costs, or 23 percent of all records.

[10] Data on building age is joined with permit data but is not yet added to the geospatial dashboard. This may be added as a data layer in the geospatial dashboard in the future.

Municipal Data Cleaning and Analysis

The municipal permit data used in this study contains a lot of information, some of which was provided through a standardized input format (e.g., permit issue date, address) and some provided though a “free-form” input format. Data provided through a free-form input format is much harder to parse and analyze as it can contain unnecessary characters, typos, abbreviations, etc. As such, before attempting to analyze the data were cleaned and standardized.

Data Cleaning

Basic data cleaning steps were applied to all fields of interest for every record in the permit data. All numerical values, duplicate and English stop words, and punctuation characters were removed. All words were also converted to lower case.

Data Analysis

The goal of the analysis was to identify a set of queries that could be used to select a subset of permits that would allow us to answer specific research questions. To achieve this target, we performed a keyword analysis on the permit data description (a free-form field). We calculated the number of occurrences of each unique keyword identified in the description field for multiple permit sets (building, electrical, land use, and trade permit). In most cases, we observed that two types of keywords were among the most frequently used: actions (e.g., install, replace, repair, etc.) and subjects (e.g., furnace, heat pump); see Figure 1 for an example.

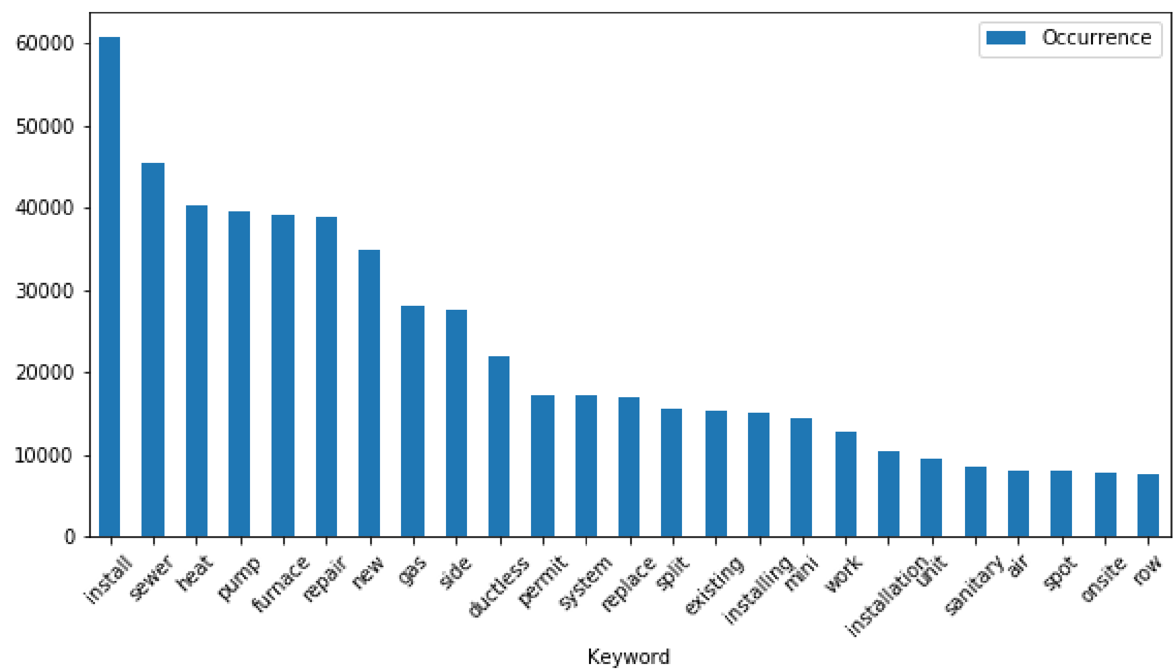


Figure 1. 25 Most Used Keywords in the Trade Permit Data

Based on this finding, queries could be created using most frequently used actions and subjects. The following actions were selected to build queries: replace, install, and repair. The following subjects were selected to build queries: air conditioner, gas furnace, heat pump, heat pump water heater, and tankless water heater. At this point, additional cleaning was necessary before running any query to address similarities, typos, and compound words in keywords. For example, the following keywords are all related to ductless mini split heat pumps but are effectively different from each other: “ducless,” “ductless,” “dudctless,” “dutless,” “mini,” “minisplit,” “minisplits,” “spit,” “split,” and “splits.” The analysis showed that only the trade permit data would be relevant to our research questions, so all other permit data were excluded from the study.

After running a few queries, we observed that, while this approach worked well for installations, it did not always work well for replacements (one subject being replaced by another one), for instance, an oil furnace being replaced by a gas furnace. These instances are very sensitive to the context of the description field and using some arbitrary order to identify the subjects does not always work well, as we have seen in practice. To correctly handle replacements, natural language processing methods would be necessary; due to time and budget constraints, we did not include replacements as part of this analysis and focused on installations. The number of permits for heat pump water heater or tankless water heater installation were significantly smaller than the ones for air conditioner, heat pump, and gas furnace, so they were also excluded from the analysis.

Geospatial Dashboard Results

Navigation and User Guide

The dashboard is designed to be interactive, allowing the user to make selections across three dimensions: equipment type, permit class, and time. The overall dashboard view is shown in Figure 2.

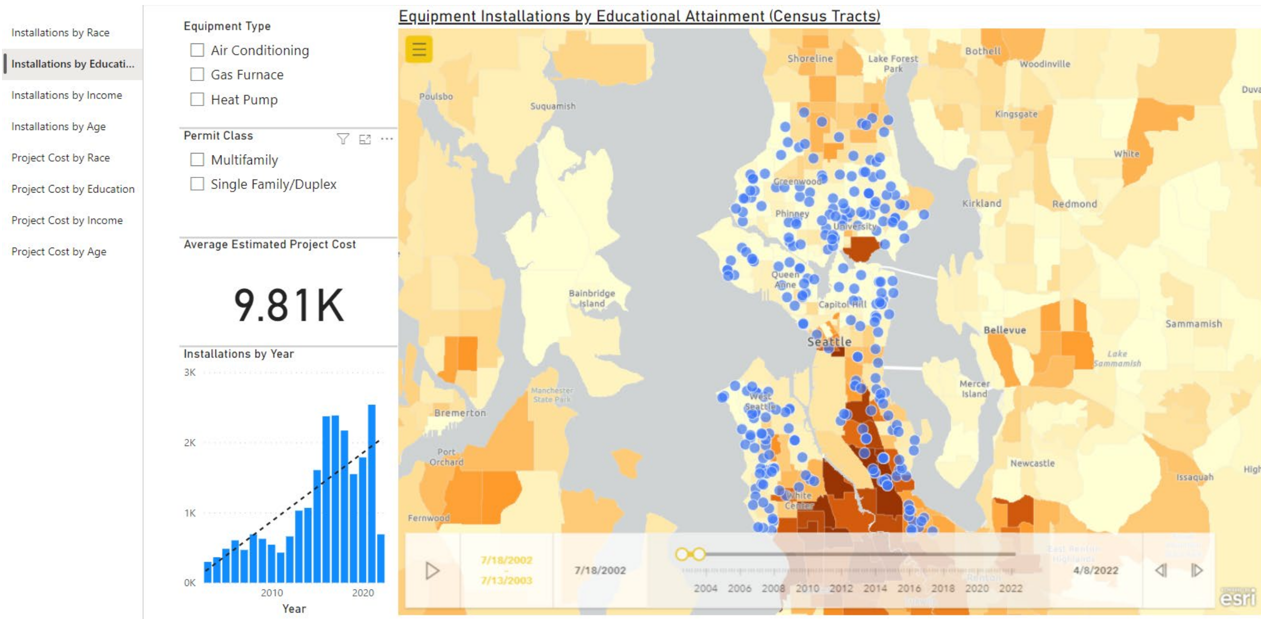


Figure 2. Overall Dashboard View

The equipment type selection is a single selection for air conditioning, gas furnace, or heat pump, while the permit class selection allows multifamily or single-family/duplex filtering (see Figure 3). The filters may be cleared by clicking on the checkbox selection again. A multi-select option is available when CTRL or Command + click is used. These selections filter the “Average Estimated Project Cost” card, the “Installations by Year” bar chart, and the map.

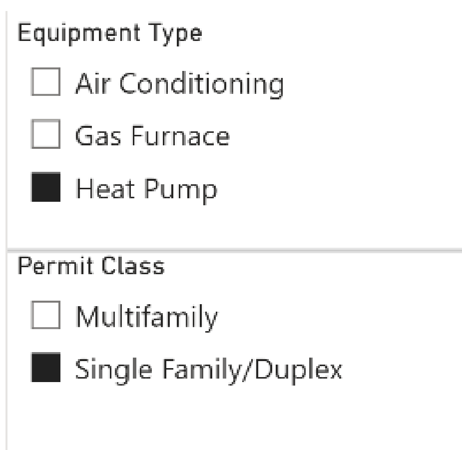


Figure 3. Screenshot of Equipment Type and Permit Class

The time filter may be applied in two ways. The “Installations by Year” chart filters both the map and the “Installations by Year” bar chart (see Figure 4). A year is selected, and the filter applied when the user clicks on a bar. Multiple years may be selected when CTRL + click is used. The filter may be cleared by clicking on the selection again.

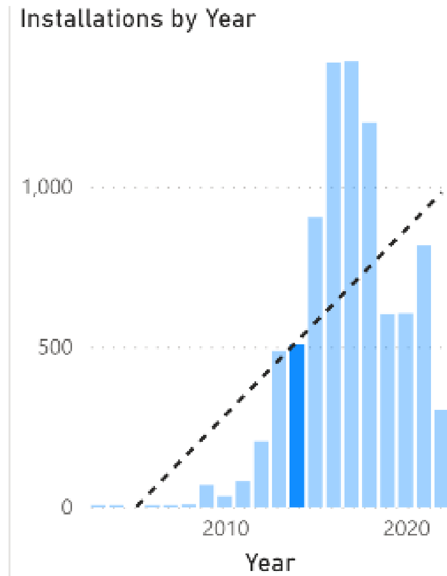
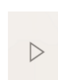
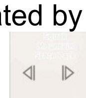


Figure 4. Screenshot of Installations by Year

The second way to filter dates is with the date slider located at the bottom of the map (see Figure 5). Either end of the slider may be clicked and dragged to select the desired time period.

Figure 5. Screenshot of Date Slider

This selection may be animated by clicking Play , or stepped forward or backward by clicking the Next or Previous  buttons.

Demographic and socioeconomic reference layers may be selected by clicking on the pages on the left of the dashboard (see Figure 6).

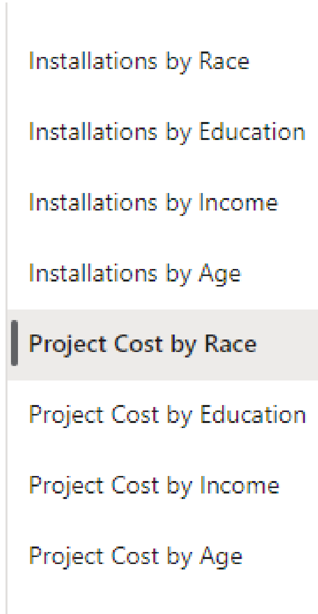


Figure 6. Screenshot of Reference Layers on the Dashboard

Results

The equipment type installations by year reveal that installations of heat pumps and air conditioners are increasing, while gas furnace installations are decreasing, as shown in Figure 7.

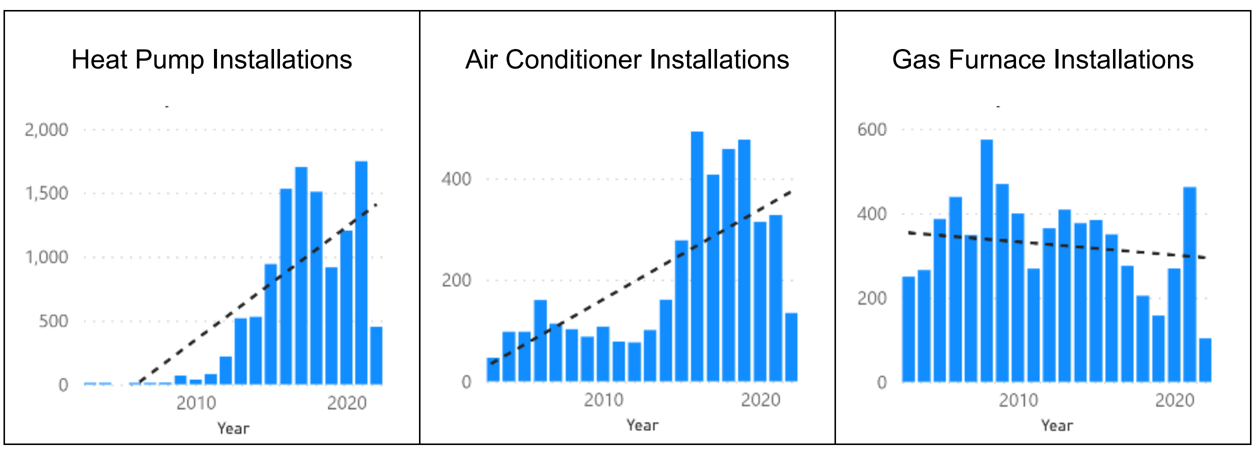


Figure 7. Equipment Installations by Year

The earliest available online permit data for heat pump installations in Seattle (2003 to late 2009) in single-family homes and duplexes show that installations are exclusively in predominantly Non-Hispanic White census tracts (Figure 8). Although residential heat pump technology has been available for decades, this finding could indicate that non-Hispanic White populations tend to be early majority adopters, while neighborhoods with Asian, Black or African American, or Hispanic or Latino predominance tend to lag.

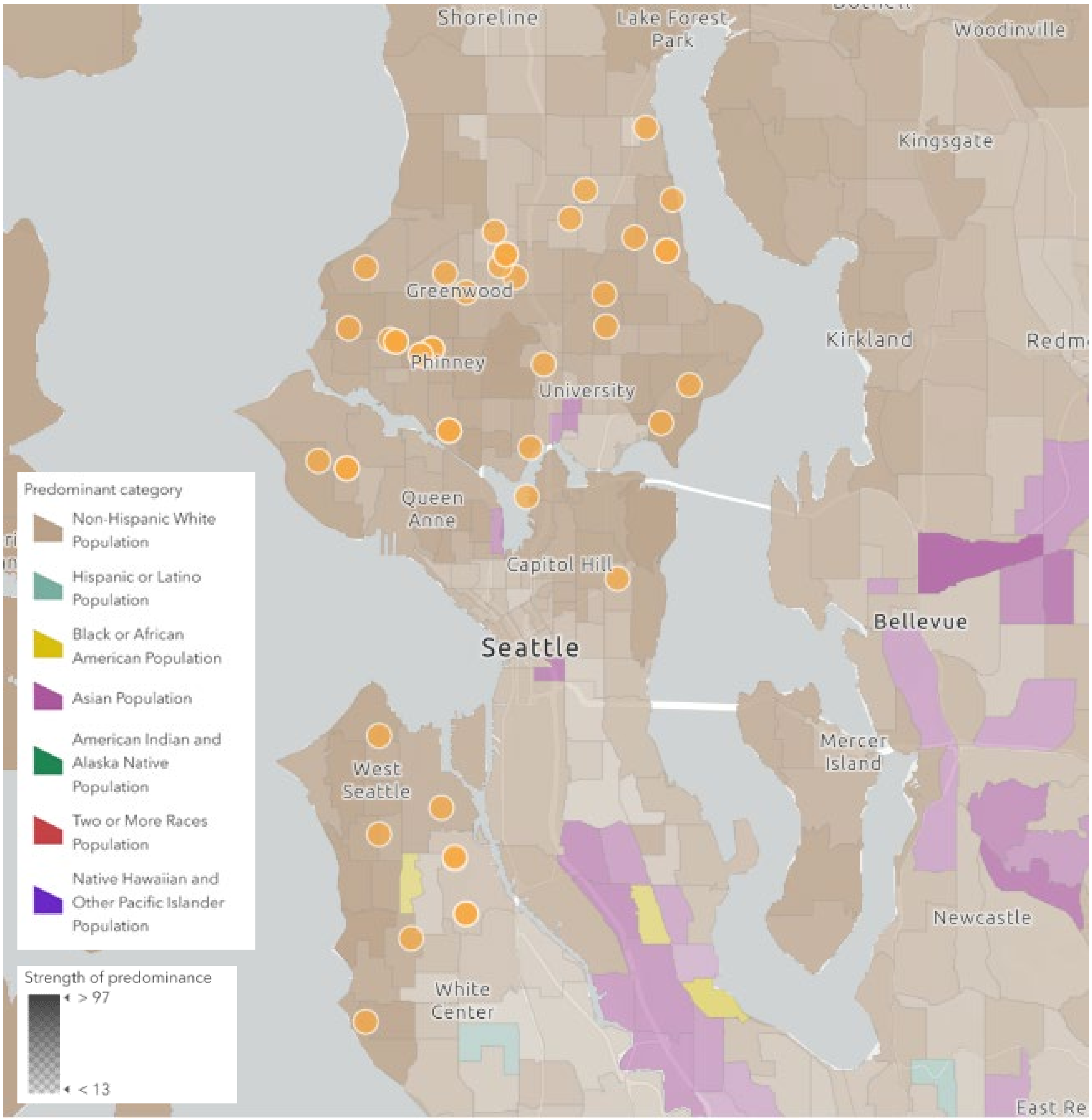


Figure 8. Single-Family and Duplex Heat Pump Installations by Race (09/2003–09/2009)

From 2003 through early 2011, only two heat pumps were installed in census tracts that are not predominantly Non-Hispanic White. One was installed in a tract that is predominantly Asian and another in a tract that is predominantly Black or African American. As heat pumps have become more widespread, more installations have occurred in Asian and Black or African American tracts, but the density of installations remains higher in predominantly White neighborhoods.

Although air conditioning installations are more evenly distributed across race than heat pumps, air conditioning installations tend to be clustered in neighborhoods that have a high predominance of Non-Hispanic White populations.

These trends in heat pump and air conditioning installations may indicate that residents in census tracts that are primarily Non-Hispanic White are better positioned to withstand dangerous heat waves (in that they have access to cooling in their homes and are therefore less susceptible to heat-related illness and death), and a vulnerability may exist in those census tracts that are predominantly Asian, Black, or African American. Additionally, delayed adoption of energy-efficient technologies in neighborhoods other than those that are Non-Hispanic White could indicate a higher energy burden and a need for targeted programs and policies to ensure equitable access to technologies.

Estimated project costs are clustered in five natural groupings. The groupings for the single-family/duplex permit class for heat pump installations are shown in Table 4.

Table 4. Estimated Project Cost Groupings for Single-Family/Duplex Heat Pump Installation Permits

Estimated Project Cost Range
$96,500–1,300,000
$37,765–96,500
$17,500–37,765
$7,600–17,500
$0–7,600

Across all years, installations in the two highest-cost groupings fall in census tracts that are above the national median household income. These project costs are higher than the majority of estimated project costs. Three installations in the mid-range grouping fall within census tracts below the national median household income. Census tracts below the national median household income are better represented in the bulk of the data, or the three groupings from $0 to $37,765. Filtering for the most recent year for which we have complete data (2021), some households in lower-income tracts appear to have invested in higher-cost projects (Figures 9 and 10).

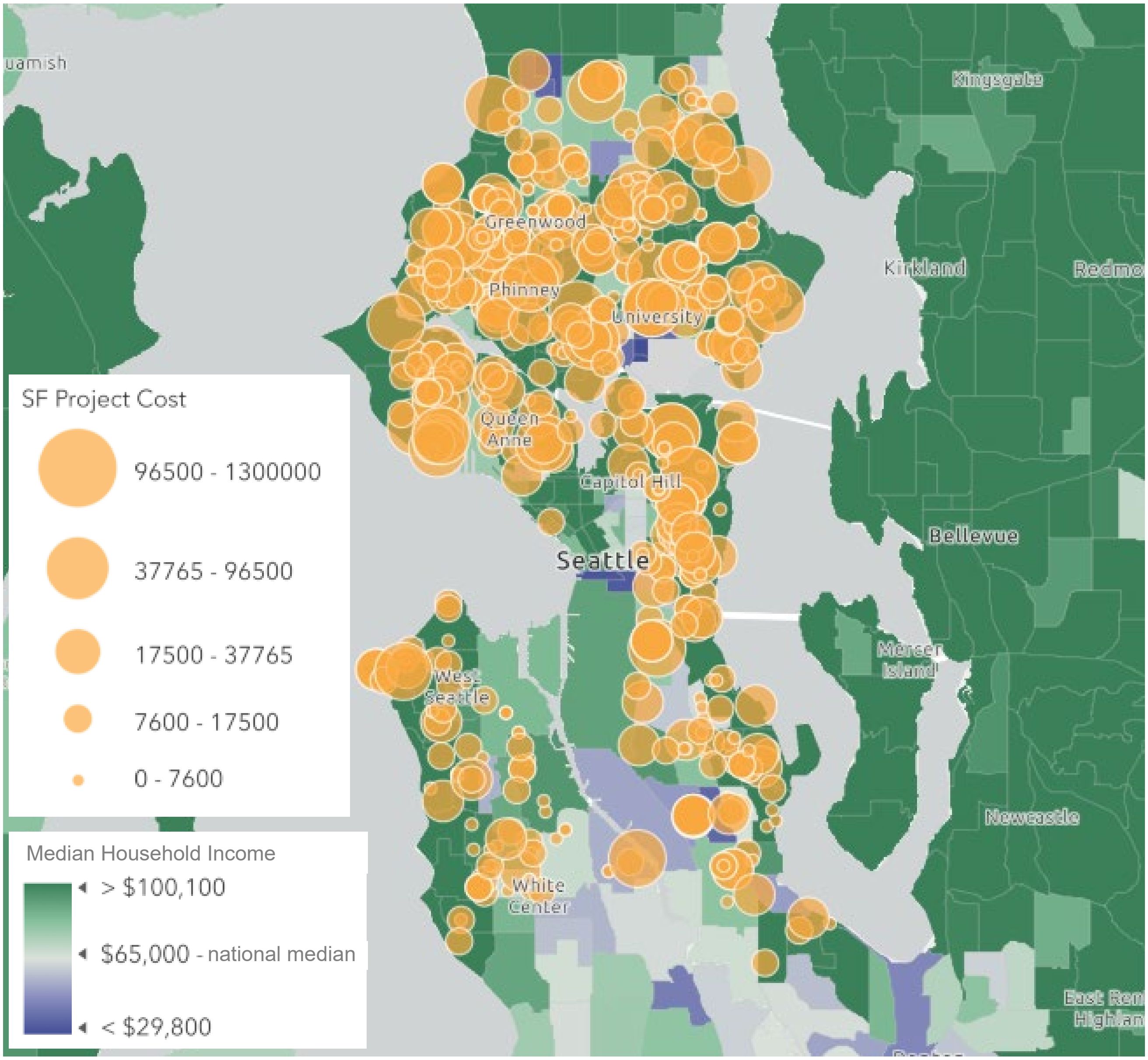


Figure 9. Single-Family and Duplex Heat Pump Installations by Estimated Project Cost (2021)

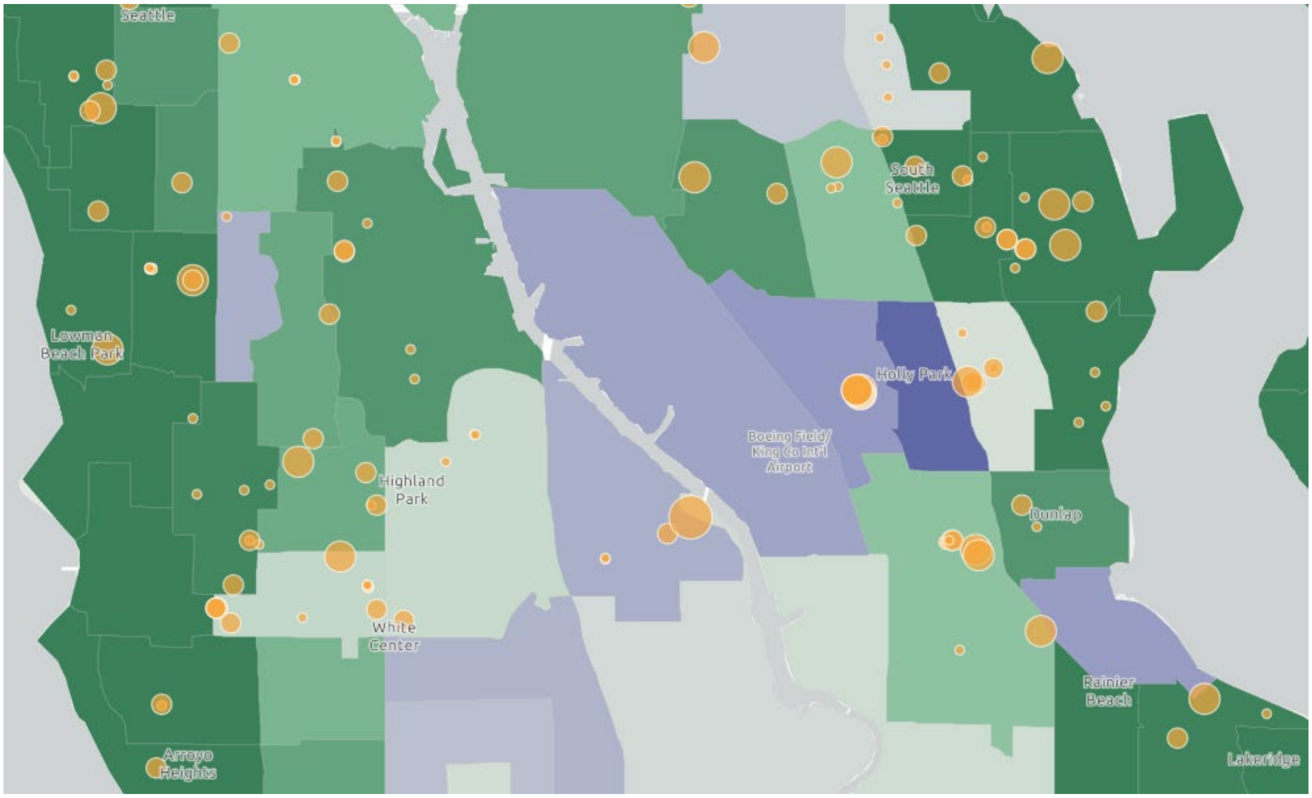


Figure 10. Single-Family and Duplex Heat Pump Installations by Estimated Project Cost (South Seattle Detail, 2021)

While the number of heat pump installations are lower in below-median income tracts, the finding that project costs are not necessarily limited to the lowest cost grouping could yield some insights into household decision-making, priorities, and neighborhood changes such as gentrification. For example, a low-income household may decide to invest in energy-efficient equipment to save on monthly energy bills.

These findings are meant to illustrate some ways the dashboard may be used to review building energy efficiency and equipment installations with an equity lens. They are not a complete assessment of the data compiled for Seattle. As the dashboard exists currently, there are nearly a thousand different views of socioeconomic and demographic data overlaid with permit data, presented in a user-friendly format. Additional layers may be added, and specific analysis conducted to explore different research questions.

Data Limitations

A single property may have multiple permits. These were not reviewed for duplicative work, as clarifying the reason behind multiple permits could necessitate engaging the permit office and is not realistic for a large dataset.

A single permit may also include multiple installations. This is more common at multifamily properties but may also occur within the single-family and duplex permit class. This research does not quantify the number of pieces of equipment installed per permit, so the estimated number of equipment installations may be understated. Additionally, the estimated project cost does not control for the number and size of equipment installed per permit.

Estimated project costs are not adjusted for inflation. As a result, the estimated project costs are comparable within years but not over a period of many years. This could be addressed in future versions, to make costs comparable across years.

Due to time and funding limitations the custom geospatial layers created for demographic and socioeconomic data and environmental data were not added to the geospatial dashboard. If a website is developed at some point, these may be made available for download or added to the geospatial dashboard. In place of these layers the dashboard uses publicly available ACS reference layers at the census tract level, which is a more summarized level of the block group data. Another consideration is ease of ongoing maintenance. The block group data that was joined with permit data would have to be manually updated with each new data release (annually), while the publicly available reference layers automatically update with the latest ACS data release.

Relevance of Project for Sponsors

Outside of aggregated sales or billing data, there is little granularity in our understanding about how energy-efficient technologies are adopted at a neighborhood scale and how technologies diffuse by sociodemographic status. Building stakeholders at all levels—federal, state, municipal, and city—need of better tools to understand the opportunities and barriers for energy efficiency investments and ways to determine how those investments can be focused to increase energy justice in communities often left by the wayside. This investigation leveraged publicly available data, specifically focused on heating, ventilation, and air conditioning (HVAC), to note the spatial distribution of furnaces, air conditioners, and heat pumps and tie the technology distribution to sociodemographics. DOE has done similar assessments using Home Energy Score data (Antonopoulos et al., 2020), but unlike permit data, the Home Energy Score data set is not as widely available or accessible.

The methods and outcomes explored here provide a basis for stakeholders to develop policy and programs targeted toward energy-efficient technology diffusion using readily accessible permit data. The methods laid out are designed to be easily replicated by jurisdictions throughout the country, and the geospatial dashboard provides a platform for similar assessments across the United States. These analyses can support policy and program development, inform incentive initiatives, and quantify and qualify program outcomes. These methods can be combined with other metrics, such as heat and social vulnerability indices to identify areas that are in most need of technology diffusion.

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