What it Takes to Decarbonize All Homes in a Cold Climate City

Katie Jones, Josh Quinnell, Arbor Otalora-Fadner, and Rebecca Olson, Center for Energy and Environment

ABSTRACT

As the coldest major city in the U.S., Minneapolis has high energy needs. Like many communities, the City of Minneapolis has aggressive climate and equity goals, with an end target of carbon neutrality by 2050. Meeting this requires addressing the energy use of residential buildings. In collaboration with diverse City and community stakeholders, the project team facilitated a process to explore the challenge.

Residential decarbonization technologies are already available and hinge on weatherization and electrification. Using these technologies and data from the City assessor, national energy surveys, home inspections, and local energy audits, energy models were created for 1,000 homes. The models were applied across the full building set to determine the home energy retrofit pace needed to meet climate goals. Following input gathered from stakeholders, the models were updated to account for upfront costs, operational costs, geography, and other factors. This additional modeling work produced estimates for the total cost to retrofit homes and the necessary workforce capacity. Finally, land use and regulatory recommendations were developed for the City to reduce barriers to decarbonization projects. The result is a roadmap to decarbonize the city's 88,000 homes.

By translating retrofit project metrics from tons of carbon to building counts, project costs, and workers needed, the roadmap puts climate planning into language that City decision makers understand. Following this process, the City is standing up a new climate fund to support the necessary building retrofit initiatives to place the City on a path to achieve its climate goals.

Introduction

Over 70% of the greenhouse gas emissions (GHGs) in Minneapolis are from energy used in buildings (City of Minneapolis 2023). Reducing and decarbonizing the energy used in residential buildings is therefore key to any viable climate action plan.

The two main energy sources in Minneapolis buildings are electricity and fossil gas[1]. In Minneapolis' cold climate, most of buildings' annual energy use is for heating. About 90% of Minneapolis homes use fossil gas for space heating. This trend can be attributed to the historically favorable economics of fossil gas for heating compared to electricity. Electricity, however, has a greater potential to become cleaner over time. The electric grid is already decarbonizing. This process is on an accelerated pace in Minnesota due to state law requiring 100% carbon-free electricity generation by 2040 (State of Minnesota 2023). Leveraging the progressively cleaner grid by transitioning energy uses to electricity from fossil gas is called electrification. Developments in renewable fossil gas are not expected to achieve economically viable results, and technical constraints limit the use of alternative gases like hydrogen (Sara, Esposito and Tallackson 2022) (Energy Transitions Commission 2018). For these reasons, the

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[1] The City of Minneapolis refers to natural gas as fossil gas, and accordingly, the term fossil gas was used throughout the project.

City sought to study electrification as a primary opportunity to maximize the potential for long-term decarbonization (CEE 2023).

An important step was to identify a suitable electric heating technology that can economically meet the decarbonization goals. Air source heat pumps (ASHPs) were identified as the most promising technology to quickly scale heating electrification in one-to-four-unit residential buildings. ASHPs are effectively air conditioners that can run in both directions to either heat or cool a building. Due to recent technological advancements, ASHPs can now provide heat to a home even when outdoor temperatures are well below freezing. Those units that can provide heat at a coefficient of performance (COP) of >1.75 at 5°F are labeled "cold climate" air source heat pumps (ccASHPs) (Northeast Energy Efficiency Partnerships 2023), and are an established, commercially available technology for one-to-four-unit residential buildings.

Beyond decarbonization, there are additional advantages of focusing on one-to-four-unit residential buildings. Weatherization measures (insulation and air sealing) for such buildings are widely available and deliver reliable energy savings. Other building functions that commonly use fossil gas, such as water heating, clothes drying, and cooking, can be transitioned to feasible electric options to save costs and promote health and safety. Finally, ASHPs also provide efficient cooling, which can help residents better endure increasingly severe and long heat events. For these reasons, this analysis focuses on how to electrify one-to-four-unit residential buildings with strategies using ccASHP heating technology and weatherization measures.

Methodology

Overview

This project sought to identify a feasible pathway to electrify the city's one-to-four-unit homes. Through the analysis, a set of building retrofit measures were identified that could be completed using the following criteria: achieve the City's climate target and timeline in a way that advances equity, uses existing technology, can be deployed in today's regulatory environment, and is scalable in the most cost-effective way possible for both upfront and utility bill costs. The approach involved multiple modeling scenarios that were iterated via feedback provided through a stakeholder process from September through December 2022.

Stakeholder Process

City staff and a community stakeholder group were engaged to develop the feasibility pathway. The representatives of the City staff group comprised about a dozen members working in energy, sustainability, city planning, or residential buildings. The community stakeholder group consisted of about 15 members representing a diversity of interests, geographic areas, and lived experiences that would be relevant for any future electrification plan. These members, including utility representatives, members of relevant City committees, energy experts, and community advocates, were eligible for $50 compensation gift cards per workshop.

Three, two-hour workshops were convened with each respective group for a total of six workshops. During each workshop, models were presented, and discussions were facilitated. The groups' questions and interests expanded and refined the modeling for each successive workshop.

Modeling Analysis

The primary objective for modeling was to create a baseline dataset representing the current state of all one-to-four-unit residential properties in Minneapolis. This was done using data from home energy audits, assessor data, rental data, Census data, the Energy Information Administration's Residential Energy Consumption Survey, and home sale inspection data. Establishing this baseline dataset allowed us to run a variety of scenarios to determine upfront cost, utility bill cost, decarbonization impact, and workforce needs for various electrification measures.

Scenario models focused on the impacts of weatherization and electrification measures. Weatherization measures were selected based on local weatherization and utility programs and their likelihood for savings. The weatherization measures included wall insulation, attic insulation, air sealing, rim joist insulation, and ventilation. Electrification measures were selected by how widely they could be implemented in Minneapolis homes and the potential impact of those measures to save greenhouse gas emissions. The selected electrification measures reflect a holistic view of electrification and included an electric service upgrade, furnace replacement with ducted ccASHP, boiler replacement with multi-split ccASHP, domestic hot water replacement with heat pump water heater, clothes dryer replacement with heat pump clothes dryer, and cooking equipment replacement with induction range and electric oven. New scenarios were modeled following each workshop's discussion and feedback. The scenarios discussed and iterated included upfront and bill costs, impact of utility rates, grid impacts, impacts of full electrification and dual fuel approaches, labor requirements, market efficiencies, and the pace of retrofits needed to achieve goals.

Baseline Model

A process following that of a previous research project (Quinnell and Genty, 2022) was used to create a baseline building stock model estimating heating loads in Minnesota single-family buildings. The methodology duplicates one developed to analyze the technical and economic potential of energy efficiency upgrades in the national building stock (Wilson et al. 2017). Residential building data were pulled from over 2,000 records of Minneapolis home energy audits as well as prior research project results (Edwards et al. 2013). The correlations between building characteristics in these audit data were used to produce a representative building sample of one-to-four unit buildings. This sampled modeled data was merged with City assessor data based on correlated characteristics to estimate the property characteristics of all Minneapolis one-to-four-unit buildings.

Heating and cooling loads were determined following ASHRAE residential heat balance method (ASHRAE 2021) using modeled home characteristics in the dataset. Annual loads are estimated as the sum of these load calculations for each hour below the balance point temperature of 65 °F for Minneapolis TMY3-2020 weather data (Sengupta et al. 2018). Annual loads are normalized to 8,000 heating degree days (HDD) based on an assessment of typical meteorological year (TMY3) data and NOAA hourly weather data for Minneapolis/St. Paul. Appliance energy loads were estimated from regional residential consumption survey data (DOE 2017).

To examine weatherization impacts, the model weatherizes existing building stock according to the criteria listed in Table 1. Weatherization measures include attic insulation, wall insulation, rim joist insulation, general air sealing efforts, and continuous exhaust ventilation. The results of applying these measures are consistent with those observed in local weatherization programs; insulation provides resistance to conduction and modestly lowers infiltration through building assemblies (International Energy Conservation 2015).

Table 1. Weatherization measures, housing unit qualification criteria, and post-retrofit performance.

Measure	Qualifying Criteria	Outcome
Air sealing	> 1.08 CFM_{50}/ft^2	0.85 CFM_{50}/ft^2
Wall insulation	< R-8	R-11 and 0.9 CFM_{50}/ft^2
Attic insulation	< R-21 overall value including bridging, knee walls, slants, peak, and open floor areas for 1.5 and 1.75 story homes / R-50 for open attic floors	R-21 / R-50 and 0.9 CFM_{50}/ft^2
Rim joist insulation	R < 4	R-10 and 0.95 CFM_{50}/ft^2
Continuous exhaust ventilation	< 50% IECC 2012 ventilation requirements served by infiltration	N/A

The baseline model was then modified to assess energy and cost impacts of the selected electrification measures. The measures were established in conjunction with the City based on market readiness, relative complexity, upfront cost, bill costs, and greenhouse gas emissions impact. While not all electrification measures were considered, those here are estimated to account for over 95% of fossil gas use in the city’s building stock. Actual installation cost data from bids and contractor price lists used in utility and lending programs and 2022 retail data were used to estimate upfront costs for electrification measures on this building stock.

Building Characteristics

There are 88,441 one-to-four-unit buildings with a combined 102,788 individual units in Minneapolis (City of Minneapolis 2022). The building stock is old, with the average age being over 90 years old. In terms of size, the buildings average around 2,400 ft^2. Minneapolis homes depend heavily on fossil gas. About 90% use gas for space heating, and 80% use gas for water heating. Most space heating, around 85%, is delivered by furnaces, while the remainder use boilers. There is comparatively less use of fossil gas for clothes drying and cooking. This may reflect the smaller operational cost difference for these energy uses between fossil gas and electricity compared to that for space and water heating. Roughly 45% and 25% use gas for clothes drying and cooking, respectively. Lastly, less than 20% of these buildings have electric service of 150 Amps or greater. Powering heating, appliances, and other loads in a Minneapolis home requires significant electric load and therefore will likely require at least 150 Amps of service.

Insulation represents a major opportunity for saving energy in one-to-four unit residential homes. 46% of the buildings have inadequate wall insulation, as defined by having insulation values less than R-8. Further, 56% of homes have inadequate attic insulation. Roof and attic geometry greatly impact the insulation potential. The value of adequate insulation for unfinished attics was defined as R-50 minimum and for finished attics with slanted ceilings as R-21 minimum.

Results and Discussion

Stakeholder Feedback

Modeling results were presented to the workshop stakeholders and their feedback was collected. Workshop 1 focused on understanding foundational values and areas of concern to guide the process. After viewing an initial round of scenarios, participants were asked for their reactions to the modeling analysis and results. A major benefit that nearly all participants noted was a positive impact of weatherization on bill costs and energy load, which subsequently reduced electrification upfront costs. Others also expressed surprise that total electrification of home energy was even technologically possible. Among concerns, upfront costs and bill costs garnered the strongest reaction. This foundational feedback guided subsequent models to focus on maximizing climate mitigation on the timeline needed to meet the City's goals, controlling costs especially for disadvantaged areas of the city, and fine-tuning assumptions.

Upfront Costs

Over the approximately 20-year timeline in which decarbonization is needed to meet the City's climate goals, nearly all currently installed heating equipment and appliances will reach their end of life and require replacement. As such, two electrification scenarios were modeled against a Baseline, which assumes like-for-like replacement of equipment (primarily gas equipment replaced with gas equipment) at the end of the equipment's life (Figure 1).

The High Estimate scenario assumes no market efficiencies due to scaling, while the Low Estimate scenario assumes incremental equipment and soft cost improvements over time, similar to solar technology trends. No workforce efficiencies were included based on stakeholder feedback. Stakeholders reasoned that current workforce insufficiency along with unfavorable workforce demographic trends counteract any typical labor efficiencies from market maturation.

The total upfront cost to weatherize and electrify the 88,441 buildings was estimated to range between $2.12 and $2.73 billion. This topline cost captures equipment and labor but does not include estimates for program administration. This compares to the approximate $1.06 billion upfront cost that will be needed to replace existing equipment at end of life with similar technology. As a result, the incremental upfront cost of weatherization and electrification is estimated to be between $1.06 billion and $1.67 billion.

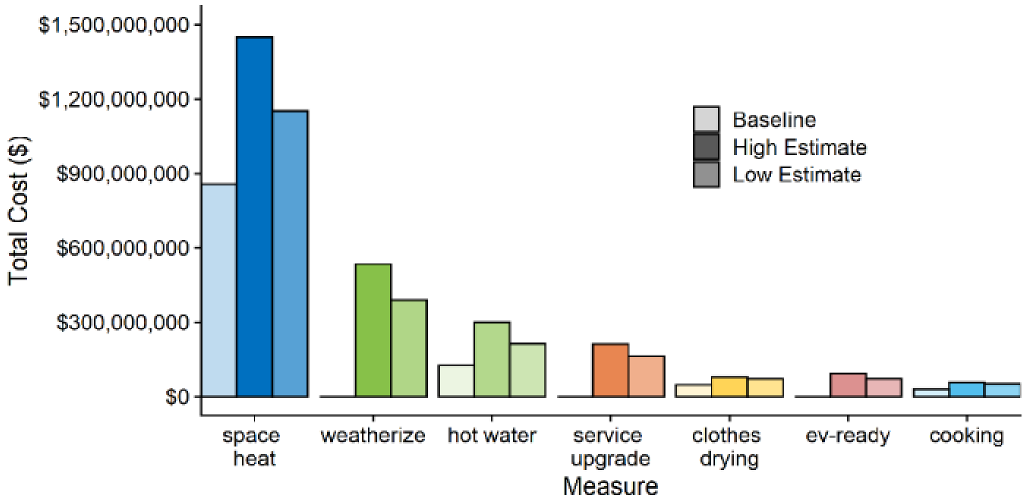

Figure 1. Low and high estimates of costs of weatherizing and electrifying compared to Baseline

Error! Reference source not found.1 shows the breakdown of measure costs for all buildings. ccASHP retrofits ("space heat") command more than half the total cost. Weatherizing the building stock has the second highest total cost. For context, the total upfront cost for the High scenario is equal to about 8% of the assessed value of the building stock. Divided across all buildings, the total upfront cost for the High scenario comes to an average of $30,900 per building and an average incremental upfront cost of $18,900 per building. Virtually all buildings need ccASHPs and HPWHs and most buildings need at least one weatherization measure; however, other measures are needed in lower quantities, such as electric ranges and clothes dryers, due the higher incidence of existing electric units.

Home weatherization and electrification retrofit projects will need to be completed at a pace shown in Figure 2 to meet the City's decreasing S-curve climate targets (City of Minneapolis 2021). This is described further in **Error! Reference source not found.**. The annual incremental upfront costs needed to complete retrofit projects per year is estimated to be $77 million in 2024 and ramp up to over $200 million in 2029.

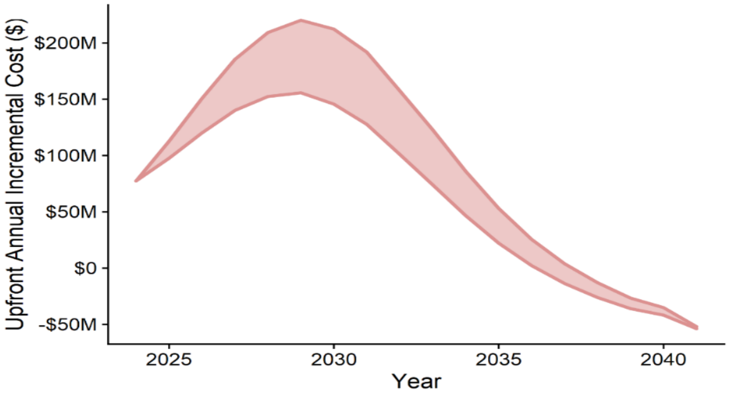

Figure 2. Estimated annual incremental upfront costs of weatherization and electrification projects needed to meet the City of Minneapolis' science-based climate emissions targets. The upper and lower bounds of the band represent the High and Low upfront cost scenarios in **Error! Reference source not found.**.

Utility Bill Costs

Throughout the stakeholder process, utility bill impacts were a major subject of discussion and concern. For this reason, we analyzed several potential utility bill impact scenarios.

Weatherization impact

The models show that most buildings achieve energy and utility cost savings from weatherization, although the impact varies. Scenarios were analyzed with constant utility rates at the October 2022 fully loaded volumetric rates[2], with gas at $1.05/therm and electricity at $0.155/kWh. The full electrification with weatherization analysis shows that median energy bills would only increase on average by 4% (or $120 per year). However, outcomes vary greatly across the building stock; 25% of customers will see more than $880/year in savings, 25% of customers will see increases of $580/year or more, and the remaining 50% of customers lie in between. Under 10% of customers would see little bill change.

On the other hand, excluding weatherization from the full-electrification program, as shown in Figure 3, yields substantial bill increases for nearly all customers. Without weatherization, the average annual bill increase is $980 (34% above current), 75% of households would see annual costs increase by more than $600 (14% above current), and 25% of households would see bills increase by more than $1,310 (46% above current). The disparity in outcomes is due to the very large energy savings offered by weatherization. In other words, the higher energy costs of electrification are mostly balanced by energy savings from weatherization

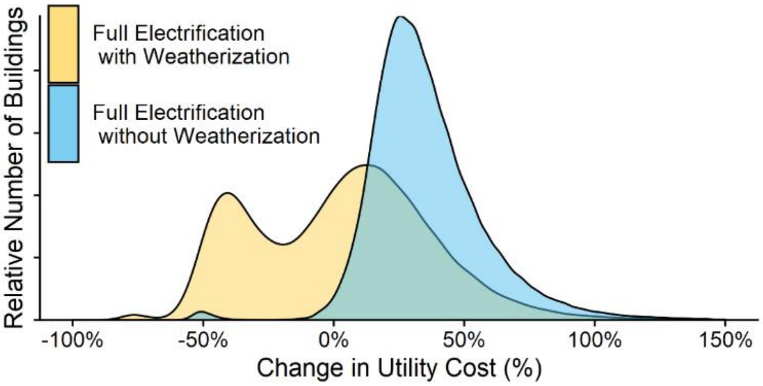

Figure 3. Distribution of buildings by the % change of utility costs in electrification scenarios with and without weatherization measures

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[2] The fully loaded volumetric rates are comprised of gas bill totals, including all riders, taxes, and fees, divided by the energy consumed. The price of fossil gas is passed directly through to customer bills and is driven by market forces. The volatility of this price made determining an appropriate "current" rate for analysis challenging. A 12-month average of $0.88/therm was used at the start of the process in September 2022. The price of gas increased through the workshop process such that the fully loaded volumetric rates surpassed $1.20/therm in January 2023. Given that the 12-month average of $0.88 did not fully reflect the global reality of gas supply due to forces such as the war in Ukraine, we reasoned that taking a rate of $1.05, which was the fully loaded volumetric rate in October 2022 at the time of the first workshop was reasonable and even conservative to use as the "current" rate for analysis. Rates were held constant over 20 year period for simplicity and because any escalator used would have been the same across all compared rates.

Weatherization is the critical path, providing large, cost-effective emissions savings regardless of heating equipment present. Approximately 75% of potential decarbonization savings come from weatherization and space heating electrification measures. Switching from gas to clean-energy-powered electric heat pumps cuts emissions drastically, and weatherization is vital to ensuring the switch is cost-effective.

Building age impact

Low performing buildings have high energy loads and often no or low amounts of wall and attic insulation. Among the dataset, building age was the best predictor of low performing buildings; the older the building, the less likely the building has any or sufficient insulation. Analysis of electrification and weatherization of the building set found that the bill costs for older buildings were less likely to increase than that for newer buildings (Figure 4). 60% of all buildings are older than 1930 and are more likely to benefit from weatherization and electrification. As building age data is much more readily available than information on insulation and air tightness, using building age as a proxy for savings potential could be a useful outreach strategy.

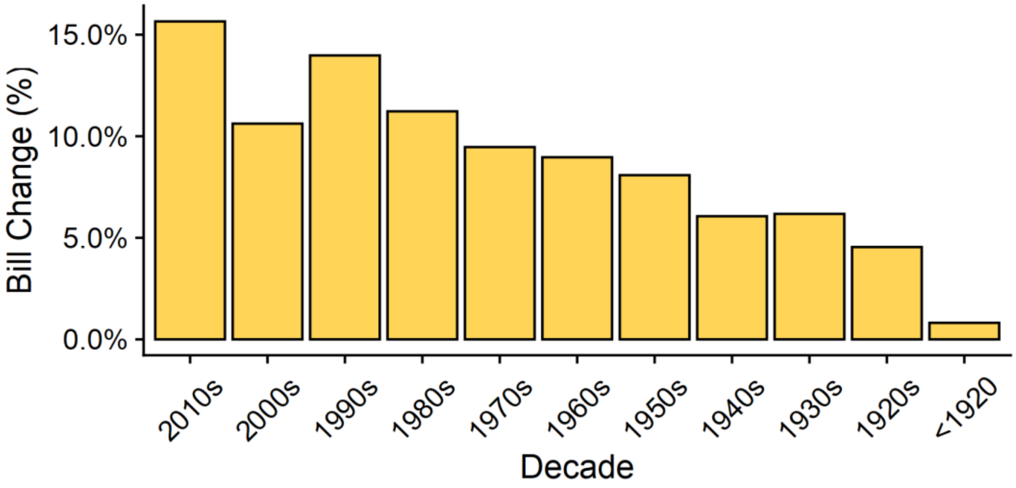

Figure 4. Utility bill cost impacts of full electrification and weatherization of buildings based on decade built using current standard electric and gas rates.

Geographic and equity impact

Historical development patterns have resulted in building differences across the city. Analysis of electrification and weatherization of the building set found trends in bill decreases or increases based on ZIP Code (Figure 5). Buildings in wealthier ZIP Codes, even when comparing to similarly aged buildings in less-wealthy ZIP Codes, are more likely to have been weatherized previously. In Minneapolis, Green Zones are the designated environmental justice zones. Analysis of the Green Zone ZIP Codes found an overlap of greater potential bill savings in the Southside Green Zone (55404) and a slight bill increase in the Northside Green Zone ZIP Codes (55411, 55412). The reason for this is unknown and should be explored.

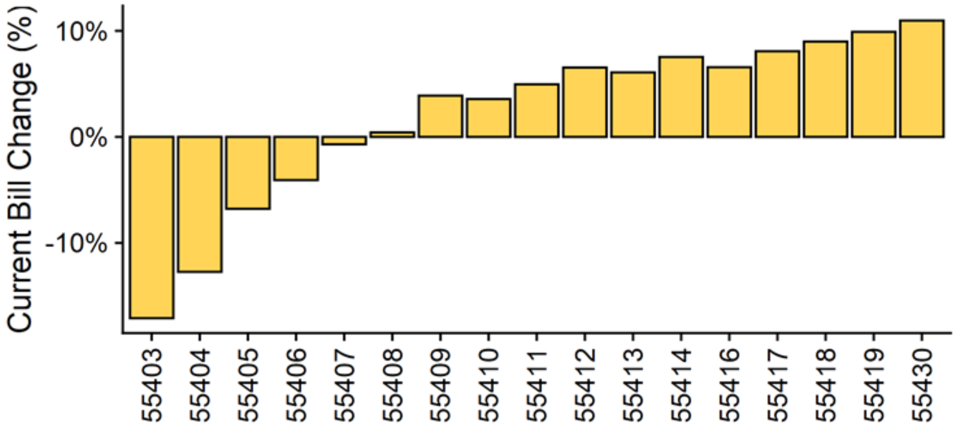

Figure 5. Utility bill cost impact of electrification and weatherization compared to current bills by ZIP Code.

Rates used for analysis

Numerous scenarios were analyzed using eight fully loaded volumetric rates, which are the bill totals, including all riders, taxes, and fees, divided by the energy consumed (Table 2, Table 3. Fully loaded electric rates analyzed. 3). Given historical trends, gas rates are unlikely to be at the level of the Low rate in the future and are anticipated to increase, although the exact rate of increase is unknown. Future electric rates are based on the E21 Study, in which a broad group of stakeholders were convened to explore and develop recommendations around decarbonizing Minnesota fossil gas end uses. In the E21 Study, future rates were assumed to be designed to avoid super high electric demand and the related need for significant infrastructure investments by relying on existing gas infrastructure for winter peak energy demand periods. This approach would support fossil gas back-up for dual fuel systems (CEE and GPI 2021).

Table 2. Fully loaded gas rates analyzed.

Gas Rate Category	Cost/gas unit ($/therm)	Description
Current	$1.05	Gas rates as of October 2022
Future Low	$1.30	Reasonable future escalation given historical trends and volatility
Future High	$1.50	Reasonable future second escalation given historical trends and volatility

Table 3. Fully loaded electric rates analyzed.

Electric Rate Category	Cost/electric unit ($/kWh)	Description
Current All-Electric	$0.11	Current Xcel Energy all-electric heat rate
Current Dual Fuel	$0.10	Current electric rate when using dual fuel
Current Standard	$0.15	Current standard electric rate with no discount for electric heat

Future Standard	$0.22	Future standard electric rates, assuming gas winter peak from the E21 Study (CEE and GPI 2021)
Future All-Electric	$0.275	Future all-electric rate (CEE and GPI 2021)

Current Rates

Analysis shows that weatherizing and electrifying today could be cost-effective from a utility bill perspective, although results vary significantly (Figure 6). The median home that is weatherized, electrified, and utilizes the existing utility all-electric heating rate could see annual bill savings of 24%. Buildings on the all-electric heat rate benefit from the rate in the winter months but are on the standard rate for the rest of the year. For the median home, which is weatherized, has appliances converted to run on electricity, and space heating is converted to a dual fuel heat pump (at 80% electric utilization) using the dual fuel heating rate, annual utility savings are 4%.

It is important to recognize that outcomes remain highly variable even with special rates. All-electric rates bring savings to 84% of households, but 16% of households will still see net bill increases. Dual fuel rates bring savings to 59% of households, while 41% of customers will see net bill increases. **Error! Reference source not found.**6 shows the wide distribution of p ossible outcomes.

At current costs, both dual fuel and all-electric pathways offer the majority of one-to-four-unit buildings in Minneapolis net savings on utility bills. Typically, dual fuel applications offer more savings than all-electric applications; however, due to recently high gas prices and additional savings when applying the electric heat rate to the existing electric load in the winter, all-electric systems currently offer the best opportunity. It's important to note that the current favorable all-electric and dual-fuel rates are not guaranteed in the future and will likely change.

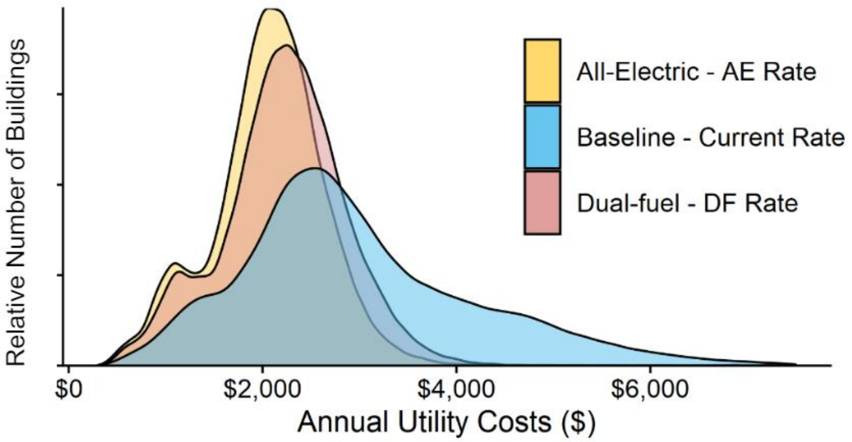

Figure 6. Annual utility bill costs at All-Electric, Baseline, and Dual-fuel rates.

Future Rates

Analysis of future rates similarly indicates potential benefits of weatherization and electrification retrofits. A baseline analysis examining an average home with gas equipment to a future scenario in which there is no weatherization or change to mechanical equipment shows median annual utility bill cost increases of 30% to 55%. Given no changes to the building stock, annual utility bills would be expected to rise.

In the case of decarbonization via electrification retrofits without weatherization, analysis shows an increase of 43% to 79% in median annual utility bill costs in the all-electric case compared to the baseline and a nearly neutral impact in the dual fuel case (at 80% electric utilization) with annual median bill changes ranging from 26% to 57% (Figure 7). The distributions show that outcomes vary by building. Dual fuel systems still offer more flexibility to achieve savings under different rate combinations. For example, dual fuel systems could be set up with a utilization rate that is economically optimal to give customers flexibility as rates change.

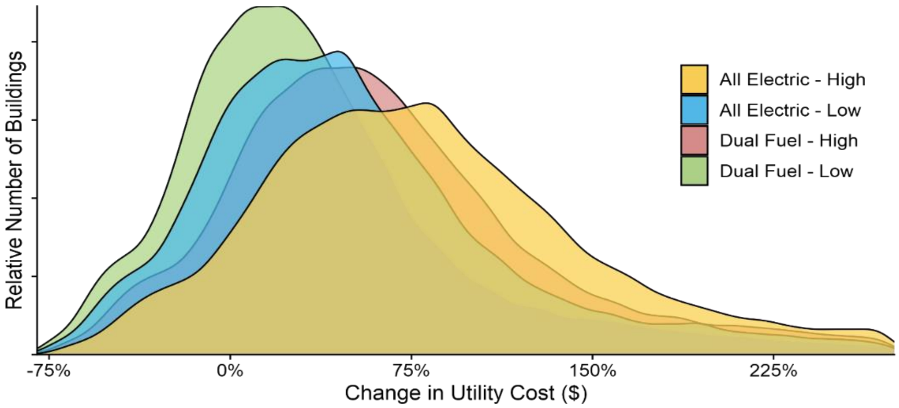

Figure 7. Distributions of expected future annual utility bills by scenario and rates.

In summary, utility bill costs are expected to rise if buildings are neither weatherized nor electrified. All electric and dual fuel utility rate scenarios present opportunity for savings, although the distributions are very wide. The operating costs of the all-electric case are 13%–24% beyond anticipated increases in baseline bill costs, whereas the operating costs of the dual-fuel case is -4% to + 2% compared to the anticipated increases in baseline bill costs.

Grid Impact

A fully electrified scenario with weatherization would result in an estimated four times increase in electricity load compared to today's peak load (shown as "Electrified" in Figure 8). This scenario assumes electric resistance back-up heat, which has been demonstrated in Minneapolis as necessary for most homes to meet the winter design temperature. As a result, summer peak is expected to stay roughly the same but will be a third or less of the future winter peak. Today's grid, which is designed for summer peaking and a high availability of fossil gas, will likely struggle to accommodate the doubling to tripling or more of volumetric electricity sales per customer as well as the tripling or more the potential peak load that is shifted from summer to winter.

There are a few ways to mitigate the future increase in winter peak and total annual electricity demand. Critically, the highest load condition occurs on a very cold winter morning when ccASHP equipment can provide the least heat to the building. The resulting draw on the back-up heating source, electric resistance, is high not only due to the high heating need but also because the efficiency of electric resistance heating of near 100% is low compared to ccASHPs, which can be as high as 400%. A practical strategy to mitigate this issue is to use dual fuel systems for homes where ccASHPs cannot meet full heating loads. Additionally, employing load control strategies for EVs, hot water, and other appliances, allows customers to shift energy usage to non-peak times. Further advancements in ccASHP technologies to continue to operate at even lower temperatures may also help reduce peak load.

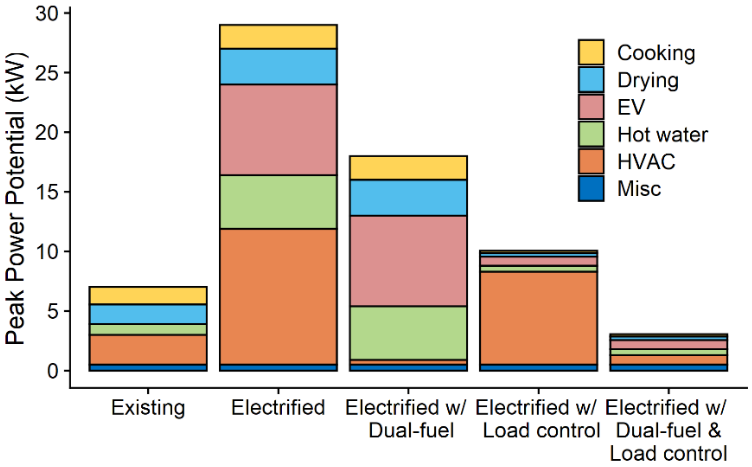

Figure 8. Total estimated peak power load under various electrification scenarios

Labor Requirements

Electrification and weatherization projects require a diverse workforce of weatherization technicians, electricians, plumbers, mechanical installers, and other general labor. The workforce required to do this would need to match the pace of retrofits to meet the City's climate targets. Thus, the workers needed would change over time, peaking in 2029 at nearly 1000 people. The greatest worker requirement would be for weatherization, which peaks at over 300 workers, while the need for mechanical technicians, electricians, and general labor support peaks around 200 each. The job area requiring the fewest workers, 50, would be in plumbing, which is only needed for heat pump water heaters.

Electrification Emission Reduction by Measure

Due to Minneapolis' cold winters and resulting high heating load, weatherization and decarbonizing space heating generally represents 75% of the decarbonization opportunity in Minneapolis homes. Looking more closely, the relative impact of actual whole home decarbonization opportunities differ slightly between an all-electric retrofit scenario and a dual fuel scenario, which show a 95% and 85% decarbonization potential respectively (Figure 9). The all-electric scenario replaces existing space heating equipment with ccASHPs with an electric resistance back-up heat source. The dual fuel scenario involves an ASHP retrofit that utilizes electricity 80% of the time and gas as a back-up system. The remaining greenhouse gas emissions are assumed to stem from assorted garage, lawn, and other equipment as well as gas fireplaces and other fossil fuel burning devices.

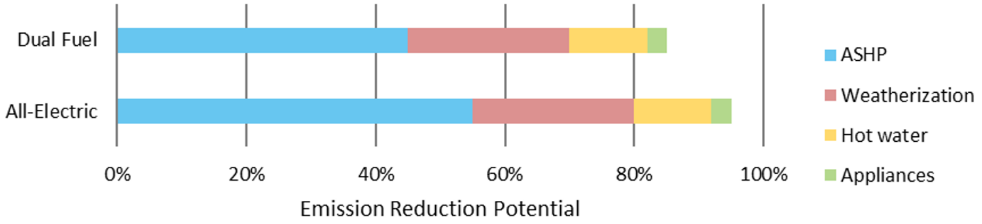

Figure 9. Breakdown of climate emissions reduction potential from all-electric and dual fuel retrofits

Conclusions

Modeling estimates that it will cost $2.12 billion to $2.73 billion to fully weatherize and electrify one-to-four-unit residential buildings in Minneapolis (CEE 2023). This is incrementally $1.06 billion to $1.24 billion more than what will already be spent on routine end-of-life equipment replacements. These topline costs capture equipment and labor but no program implementation cost estimates.

With such a high cost to fully weatherize and electrify one-to-four-unit residential buildings, stakeholder discussions focused on identifying the most valuable strategies, measures, and applications to prioritize. The clearest point of agreement among the stakeholder groups was that two measures would make the greatest difference in advancing the City's climate goal: addressing unmet weatherization needs and partially or fully electrifying space heating.

This project's success was identifying the metrics that city officials needed to understand the problem and ways to operationalize solutions. By focusing on building counts and costs to reach climate goals, the results of this work were used in City work plan and budget discussions for 2024. Those have led to further engagement in utility rate and utility program design. These conversations also led to over $10 million in new sustainability funding primarily targeted for weatherization, with low-income households being eligible for more funding per project. Although this falls short of the $77 million modeled need in 2024, the City has said that complexities in hiring and launching new programs is driving the pace of the work and anticipates scaling investment in the future.

Replication in Other Jurisdictions

Driving climate action can be challenging even in seemingly favorable environments simply due to communication. This project provides a positive case study for translating carbon and energy metrics to the count and cost metrics more readily understood by decision makers. Jurisdictions can use this approach with the recommended steps below to study what is needed to build decision maker and community support for decarbonizing small residential buildings.

1. Establish goals and criteria for the analysis. Because decarbonization strategies vary widely in terms of complexity, cost, and effectiveness, it is valuable to set clear objectives and boundaries. Doing so makes it easier to communicate with stakeholders and to ensure the project is focused enough to result in a useful outcome.
2. Identify the study area. Consider the ease of identification of the area (e.g., ZIP Code, city, county, set of census tracts defining a neighborhood). Consider the target

audience—government, utility, general public, or other entity—for the results of the analysis.

3. Identify the available building data and energy data from the area along with the savings impact of decarbonization measures. Sourcing local building energy audit data is ideal for the most accurate location-specific analysis. Secondary options are to source local building records from local property assessors along with the national Residential Energy Consumption Survey (DOE 2017). Decarbonization measure impacts may be available from utility program technical resource manuals.
4. Identify stakeholders. Those who make decisions around sustainability, energy, or housing budgets or programs, energy efficiency and electrification implementers, and community members who represent diverse perspectives should be considered.
5. Identify the stakeholder engagement process. Consider the project objective, how large the stakeholder group is, and what group arrangements may elicit the most constructive feedback. Consider the length of time needed educate stakeholders to the point at which they all have a working knowledge of the topic and feel confident contributing feedback. During this analysis, three two-hour workshops were found to be a decent fit for stakeholders' availability and capacity and allowed for sufficient discussion. However, other groups may want and need more or less engagement.
6. Develop an initial model. Use the methodology outlined in the Baseline Model section to provide stakeholders something against which to react.
7. Establish the "why" as the first stakeholder activity. In our case study project, stakeholders became more bought into a process when they got to fully partake in defining their purpose for participation. Collect stakeholders' stated values and reasons to influence later discussion questions about the Baseline model.
8. Present Baseline model to stakeholders and collect feedback through facilitated discussion. Gather comments and summarize additional scenarios to model.
9. Iterate the model based on stakeholder input, present the new scenarios, receive new stakeholder feedback, and repeat as many times as defined in the stakeholder process or until there are scenarios that achieve the originally stated goals.
10. Summarize the work and report out in stakeholders and the target audience. Consider the audience when selecting the scale of home retrofit cost and other metrics to communicate. For example, city decision makers build budgets at the scale of tens of millions of dollars, while the general public may better understand a loan for the cost of retrofit investment relative to a monthly mortgage payment.

Defining what it takes to decarbonize homes in a set area is possible with available data. Developing that while engaging stakeholders and using the language and metrics of a defined target audience can help drive action.

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