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Electrification of Commercial and Residential Buildings

An evaluation of the system options, economics, and strategies to achieve electrification of buildings

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EXECUTIVE SUMMARY

Over the past five years, at a cost of $50 billion, almost 200,000 new residential dwellings have been built in Colorado, and over $30 billion has been placed into new commercial space[1]. In 2019 alone, $16.3 billion was invested into new residential and commercial buildings[2]. The overwhelming majority of this new construction, both residential and commercial, relies on natural gas for space and water heating.

Based on the State of Colorado 2015 Greenhouse Gas Inventory, residential and commercial building onsite fossil fuel combustion, primarily natural gas, is responsible for around 13% of the state's total greenhouse gas emissions[3]. According to the Energy Information Administration (EIA), natural gas is the primary heating source for 70% of homes in Colorado[4] along with most of our businesses. Based on the EIA energy end-use consumption data, space and water heating account for approximately 78% of natural gas use in commercial buildings and 95% of natural gas use in residential buildings[5].

↓ 90% by 2050

To achieve Colorado's greenhouse gas reduction goal of 90% fewer emissions by 2050[6], onsite natural gas emissions in buildings must be materially reduced. Electrifying space heating and water heating enables renewable energy to take the place of natural gas, greatly reducing carbon emissions. Replacing natural gas space heating and water heating in every residential and commercial building in Colorado with electric equipment powered by renewable energy sources would reduce statewide emissions by 11%.

This study, commissioned by Community Energy[7], finds that the upfront costs in new residential and commercial buildings of all-electric heating and cooling are lower than similar systems powered by natural gas. Additionally, electric systems provide a comparable level of comfort and accelerate achievement of the state's carbon reduction goals. However, this shift to all-electric construction has not yet occurred in significant part due to higher operating costs.

This report also concludes that once a new building is constructed, the economics of retrofitting from natural gas to all-electric are borderline cost prohibitive in terms of both the upfront capital cost and ongoing operating expenses. As a result, Colorado is currently building tens of thousands of new residential and commercial buildings every year that both cost more upfront and lock-in higher CO_2 emissions for the majority of the +50-year building life.

Through a detailed case study of single-family home and office building economics, our analysis concludes that energy rate structures and rebates should be quickly modified to lower the costs of all-electric buildings as compared to natural gas buildings. This will help drive an aggressive transition toward all-electric buildings starting with new construction which provides first cost savings. While further work is needed to incent the retrofit market, simple changes today can make a large difference in the low-hanging fruit of new construction.

[1] U.S. Census Bureau and the Colorado Business Economic Outlook Committee; https://www.colorado.edu/business/sites/default/files/attached-files/2020_colo_business_econ_outlook.pdf
[2] McGraw-Hill Construction Research and Analytics and the Colorado Business Economic Outlook Committee; https://www.colorado.edu/business/sites/default/files/attached-files/2020_colo_business_econ_outlook.pdf
[3] https://www.colorado.gov/pacific/cdphe/colorado-greenhouse-gas-reports
[4] https://www.eia.gov/state/analysis.php?sid=CO
[5] https://www.eia.gov/consumption/residential/, https://www.eia.gov/consumption/commercial/
[6] https://leg.colorado.gov/bills/hb19-1261
[7] www.communityenergyinc.com

Study Summary and Findings

This study evaluates system options, economics, and strategies to achieve electrification of commercial and residential buildings. The economic analysis uses historical utility data from two existing buildings in Colorado:

- 3,000 sq.ft. single family home with a natural gas/DX furnace and a tank natural gas water heater
- 28,000 sq.ft commercial office building with 9 packaged gas fired/ DX cooling Roof Top Units (RTUs) and a tank natural gas water heater

We developed a calculator to analyze different scenarios for first costs, rebate levels, and utility rates. All scenarios evaluate the use of air-source heat pump technology to replace standard natural gas equipment. Xcel Energy utility rates are utilized along with typical costs provided by local contractors. Operating costs are all based on the existing building utility data. Actual operating costs will vary for new construction buildings and existing buildings with different loads or operating characteristics.

The results show that installing air-source heat pumps for space and water heating at the time of new construction can provide first cost savings. However, replacing natural gas equipment with air-source heat pumps has a higher cost than like-for-like equipment. All scenarios have a higher operating cost for standard Xcel Energy rates as summarized in the tables below.

Table 1: Comparison of First Costs

Type	First Cost for Electric Equipment	First Cost for Natural Gas Equipment	Current HP Rebate	First Cost Delta w/ Rebate	% Delta in First Cost w/ Rebate
Single Family Home					
Single Family Home New Construction	$ 16,600	$ 21,900	$ 700	$ (6,000)	**-27%**
Single Family Home Retrofit[1]	$ 20,400	$ 0	$ 700	$ 19,700	**N/A**
Single Family Home End-of-Life	$ 20,400	$ 17,600	$ 700	$ 2,100	**12%**
Office Building					
Office Building New Construction	$ 221,300	$ 239,400	$ 0	$ (18,100)	**-8%**
Office Retrofit[1]	$ 241,200	$ 0	$ 0	$ 241,200	**N/A**
Office Building End-of-life	$ 241,200	$ 236,600	$ 0	$ 4,600	**2%**

Table 2: Comparison of Operating Costs with Standard Xcel Energy Rates

Type	Utility Cost Natural Gas Equipment ($/Yr)	Utility Cost All Electric Equipment ($/Yr)	Increase in Total Utility Cost ($/Yr)	% Delta in Utility Cost
Single Family Home	$ 1,043	$ 1,396	$ 353	**34%**
Office Building	$ 55,031	$ 60,246	$ 5,215	**9%**

[1]The retrofit option presented above assumes that natural gas heating equipment is not at the end of useful life and would therefore have no replacement first cost. With a high retrofit cost for heat pumps and an increase in utility costs, retrofitting equipment before the end of useful life is not cost effective. This study therefore assumes that all existing building scenarios include replacement at the end of equipment life when both the cooling and heating equipment need to be replaced.

Net Present Cost Analysis

By applying time-of-use rates to the spreadsheet model for the all-electric cases, more favorable economics are realized than the standard rates since more heating occurs at off-peak times during the winter. The spreadsheet model was used to test reduced time-of-use rates along with higher rebates to determine the levels needed to achieve 15-year Net Present Costs equivalent to the baseline gas heating scenario. The following provides example rebates and rate reductions that produce an equivalent 15-year Net Present Cost:

Table 3: Example Rebates and Time-of-use Rate Reductions to Achieve Equivalent 15-Year Net Present Costs

Type	Rebate for Space Heating/Cooling HP	Rebate for HP Water Heater	Time of Use Rate Reduction
Single Family Home New Construction	$ 300/ central HP	$ 400	Winter 20% Off Peak Use Reduction
Single Family Home End-of-Life	$ 3,400/ central HP	$ 1,200	Winter 20% Off Peak Use Reduction
Office Building New Construction	$ 300/ RTU	$ 400	Winter 5% Peak Demand and 5% Off Peak Use Reduction
Office Building End-of-life	$ 1,200/ RTU	$ 800	Winter 5% Peak Demand and 5% Off Peak Use Reduction

Driving Adoption

Generating widespread adoption of building electrification will require a significant effort with a wide range of strategies. Starting with a focus on new construction will provide first cost savings and increase familiarity with the technology for both the installers and customers. As costs for all electric equipment lower with economies of scale, it will become more feasible to transform the retrofit market. In addition to lower first costs, driving adoption in the retrofit market will require higher incentives and an emphasis on the co-benefits that come with all electric buildings.

The following summarizes key strategies that can help drive adoption:

Create New Rates and Increase Rebates

- Provide higher rebates that allow fuel switching
- Pilot reduced electric time-of-use utility rates
- Create and promote financing mechanisms

Target Timing of Implementation

- Focus on new construction first
- Provide marketing/education on heat pumps
- Lower first cost with economies of scale
- Move toward end-of-life replacements

Implement Policies

- Require all-electric new buildings
- Implement Net Zero Energy building codes
- Expand policies to include major renovation for commercial buildings

Emphasize the Co-Benefits & Health

- Emphasize the co-benefits of all electric buildings including comfort, health, and safety
- Use education and marketing to convey available technologies and benefits

Consider Equity

When developing programs or policies around building electrification, it is important to consider equity and the impacts on low-income customers. Low-income customers have a higher energy burden and will be more impacted by higher heating costs. Additionally, as customers leave the natural gas system, costs will increase for those that do not have the means to leave the system. Equity should be a focus of electrification efforts including an evaluation of first cost impacts, targeted incentives to low-income residents and non-profit businesses, additional program support to address barriers, and policies that have considerations for these groups.

BUILDING TYPES AND SYSTEMS EVALUATED

Group14 utilized building data from two existing buildings in the Denver metro area including historical utility data and existing equipment information. All proposed systems utilize air-source heat pump equipment that is currently available on the market. While traditional electric heating technologies such as electric baseboards, furnaces and space heaters are known for their inefficient electric resistance heating elements, heat-pumps provide higher efficiency by transferring heat between the space and ambient environment. The heat pumps evaluated in this study have efficiencies ranging from 210-430% with varying ambient conditions.

Markets in the U.S. are expanding with the development of low-ambient air-source heat-pump technologies for harsher U.S. climates. Other types of high efficiency heat pumps are available, such as water-source heat pumps which use the ground or a water source to exchange heat. However, these other heat pump types have a higher first cost and are not feasible in all applications. This study therefore focuses only on air-source heat pumps with low ambient technology that can be widely deployed in the Colorado climate.

Residential

Air-source heat pumps can be widely deployed for Colorado homes by replacing the natural gas central furnace with a ducted heat pump air handler and the exterior condensing unit with an outdoor, single-zone, low-ambient heat pump heating and cooling unit. Natural gas tank-type water heaters can be replaced with heat pump tank water heaters which require an additional electrical connection.

In existing homes, components and ductwork can be reused to distribute the warm or cool air throughout the home. Modern heat pump systems also have the option to incorporate multiple zones with additional indoor units and refrigerant lines connected to a single outdoor unit. Having multiple zones can greatly improve the comfort in a home that has varying exposures and multiple levels.

New construction has the same system options available with greater ease of installation since refrigerant lines and additional zone devices can be installed prior to finishing interior surfaces. Refrigerant lines are typically smaller than 2” and can be distributed easily through stud cavities. This can eliminate the need for large ductwork soffits and chases which are expensive and reduce valuable interior square footage. All-electric new homes can also eliminate the natural gas connection and piping which reduces first costs.

Single-Family Home Description

The following summarizes the details of the single-family home used in this analysis:

Table 4: Single Family Home Information

Building Information	
Location	Arvada, CO
Building Area	3,077 SF
Building Type	2-Story home
Existing Heating and Cooling System	Gas furnace with DX cooling; 80% efficient furnace
Replacement Heating System	Residential low ambient heat pump - Mitsubishi M-Series ducted air handler with single zone cooling and heating outdoor unit

Building Information	
Replacement Water Heater	Residential heat pump water heater – Rheem ProTerra 50 gallon hybrid high efficiency smart tank electric water heater

Commercial

Commercial buildings have a wider array of typical heating systems. The following summarizes examples of natural gas heating equipment in commercial buildings:

- Single zone packaged Roof Top Units (RTUs)
- Single zone split systems with gas furnaces and outdoor condensing units
- Central air handlers serving zone devices with hot water or electric reheat
- Central boiler systems serving baseboard or zone air side devices such as terminal boxes or fan coil units

Small-to-Medium Commercial Buildings

Single-zone rooftop units (RTU) are typically used in small-to-medium commercial buildings such as office buildings, strip malls, food service buildings, etc. Converting single-zone RTUs to heat pumps is a more straightforward retrofit than other more complex natural gas heating systems. The retrofit requires replacement of the packaged gas fired/DX RTU with a packaged heat pump RTU.

For new construction, the same type of single-zone, heat pump RTU can be used. Similar to residential, implementing heat pumps at the time of new construction offers cost savings by eliminating the natural gas hookup and piping. The focus of this study is single-zone systems; however, new construction offers more opportunity to incorporate a mix of single-zone and multi-zone heat pump systems cost effectively which can improve the comfort in buildings with varying zone loads.

Larger Commercial Buildings

In Denver, buildings larger than 25,000 square feet make-up less than 20% of the buildings by quantity but consume more than 57% of the total commercial energy use in the city[8]. To meet aggressive climate goals, heating systems more complex than single-zone rooftop units will also need to be addressed.

To replace existing central boiler heating scenarios, an air-to-water or water-to-water heat pump can be used. This can be a complicated retrofit. For example, the central heating water heat pump may need to be in a different location than the existing boiler and the hot water zone devices may require higher temperature water than the heat pump can provide.

Variable Refrigerant Flow (VRF) systems are also viable solutions for electric heating and cooling in commercial buildings. VRF systems are widespread in other countries and are expected to become more popular in the U.S. as electric buildings become more prevalent. Ground-source heat-pumps are another efficient electric alternative for new construction projects but have higher installation costs than air-source equipment.

[8] https://crej.com/news/denvers-interactive-map-shows-energy-usage/

Office Building Description

The following summarizes the details of the commercial office building used in this analysis:

Table 5: Office Building Information

Building Information	
Location	Lakewood, CO
Building Area	28,000 SF
Building Type	Office
Existing Heating System	(9) 10-ton packaged Rooftop Units, 80% efficient heating
Replacement Heating System	Packaged heat pump RTU – Trane Precedent 10-ton high efficiency heat pump
Replacement Water Heater	Heat pump water heater – Rheem ProTerra 50 gallon hybrid high efficiency smart tank electric water heater

ECONOMIC RESULTS OF ELECTRIFICATION

To evaluate the economics of utilizing electric heat pumps for heating in place of natural gas equipment, a spreadsheet electrification calculator tool was developed. This tool includes detailed operating cost calculations with peak energy use, off peak energy use, and peak demand. Detailed first cost inputs and net present cost (NPC) calculations are also included. Group14 ran multiple scenarios under current and adjusted electric rate structures to assess the impact on annual operating costs and overall economic feasibility for the residential and commercial example buildings.

The following summarizes assumptions used and analyses notes for both the residential and commercial scenarios:

- Cooling savings are not considered in the example scenarios due to the following:
  - The equipment is assumed to be installed at the time of new construction or end-of-life. In these cases, a new heat pump is being compared with new high efficiency air conditioning equipment.
  - The delta between standard cooling equipment efficiencies and heat pump cooling efficiencies for new equipment can vary with some heat pumps being more efficient and some less. While cooling savings are not included in the scenarios presented, the calculator tool can be utilized to run options with cooling savings or penalties considered.
- Net present cost (NPC) calculations assume a 15-year timeline to represent the average life of heat pump equipment according to ASHRAE[9].
- Baseline heating systems are assumed to be 80% efficient. For retrofits, older equipment may have lower efficiencies which would produce additional operating cost savings when compared to the new heat pump retrofit.

[9] http://weblegacy.ashrae.org/publicdatabase/system_service_life.asp?selected_system_type=1

- Energy use and operating costs are all based on the existing building utility data for the (2) buildings evaluated. Actual results will vary for new construction buildings and existing buildings with different loads or operating characteristics. New construction buildings may have lower natural gas consumption depending on the current code requirements, envelope design, and equipment efficiencies. A lower natural gas baseline will reduce the cost penalty of converting to all electric.

The following describes the modification considerations for both residential and commercial:

- Time-of-use rates were used to test rate reductions. Greater reductions were applied to off-peak rates in the winter which aligns with the highest heating times. This also has a lower impact on the overall utility peak demand. However, the grid utility peak demand could change as large numbers of buildings electrify.
- Higher rebate levels were tested in conjunction with the rate reductions to achieve a Net Present Cost similar to the natural gas option.

Additional scenarios applying different rate structures, differing summer/winter rates, or inclusion of cooling savings can be run in the tool.

Operating Cost Summary

Single Family Home

The following describes the rates used in the analysis:

- The standard rate used is Xcel Energy's General Residential which does not have time of use or peak demand charges.
- The time of use rate used is Xcel Energy's Time of Use Pricing Residential rate.
- Peak-demand pricing structures were not assessed for the residential scenarios due to the limited number of households that use this rate.

The following figure shows the annual operating costs for the existing single family home evaluated and the electrified scenarios:

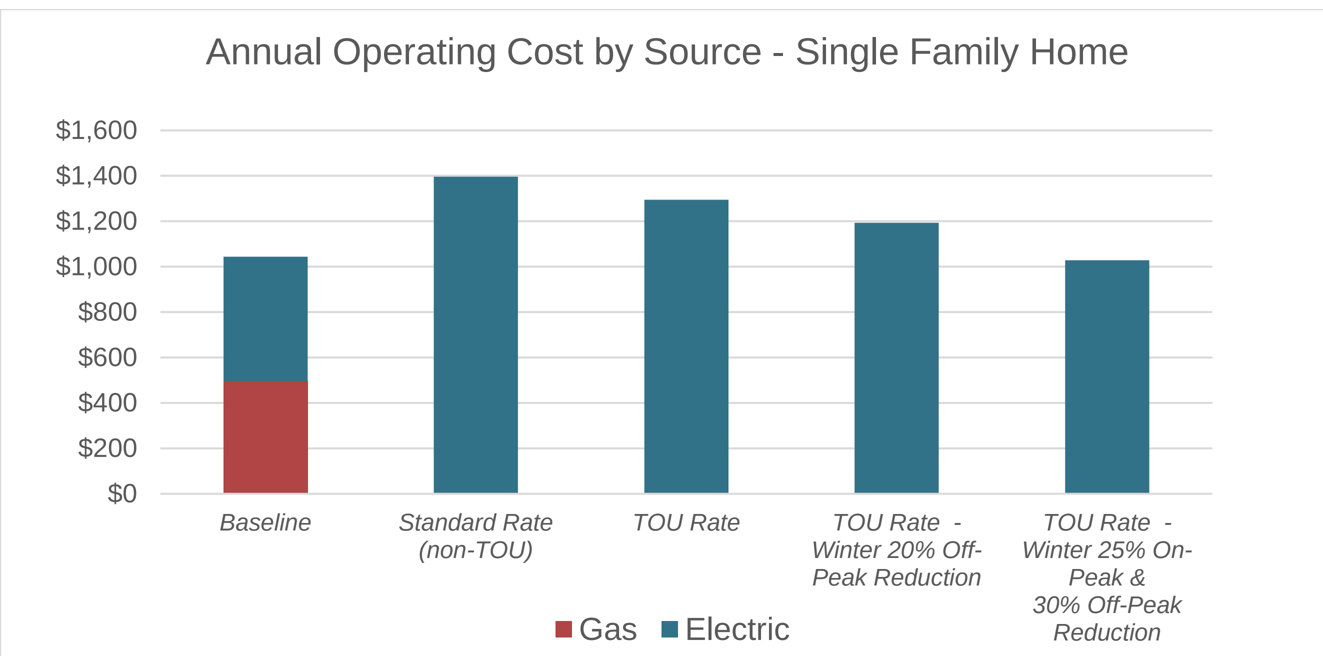

Figure 1: Annual Operating Cost by Source - Residential

The following summarizes findings:

- Compared to the baseline, both the standard and TOU rates increase the operating heating costs for the electrified building by $250-350/yr or **24% - 34%** of total utility costs.
- To achieve equivalent operating costs, the TOU rate would need to be **reduced around 25% On-Peak and 30% Off-Peak**.
- To achieve equivalent Net Present Costs, a rate **reduction of 20% Off-Peak** was applied in conjunction with higher rebates.
- Including the impact on cooling energy for a retrofit provides an additional savings of $24/yr for the reduced rate case due to an increased seasonal energy efficiency ratio (SEER) from 10 to 12.

While the calculator is configured to test electric rate reductions, savings would also be achieved for the standard rate scenario if the cost of the heating fuel is above $1.70/therm. This is a 171% increase compared to the average annual natural gas rate of $0.82/therm from the utility data. Natural gas prices have been flat for many years so this level of increase is not expected. However, this energy cost can be realistic for other fuel sources such as propane.

Office Building

The following describes the rates used in the analysis:

- The standard rate used is Xcel Energy's Secondary General (commercial) rate. This rate includes different summer and winter peak demand costs. It does not have time of use energy charges.
- The time of use rate is Xcel Energy's Primary General (commercial) rate.

The following figure displays the annual operating costs for the existing commercial building evaluated and the electrified scenarios:

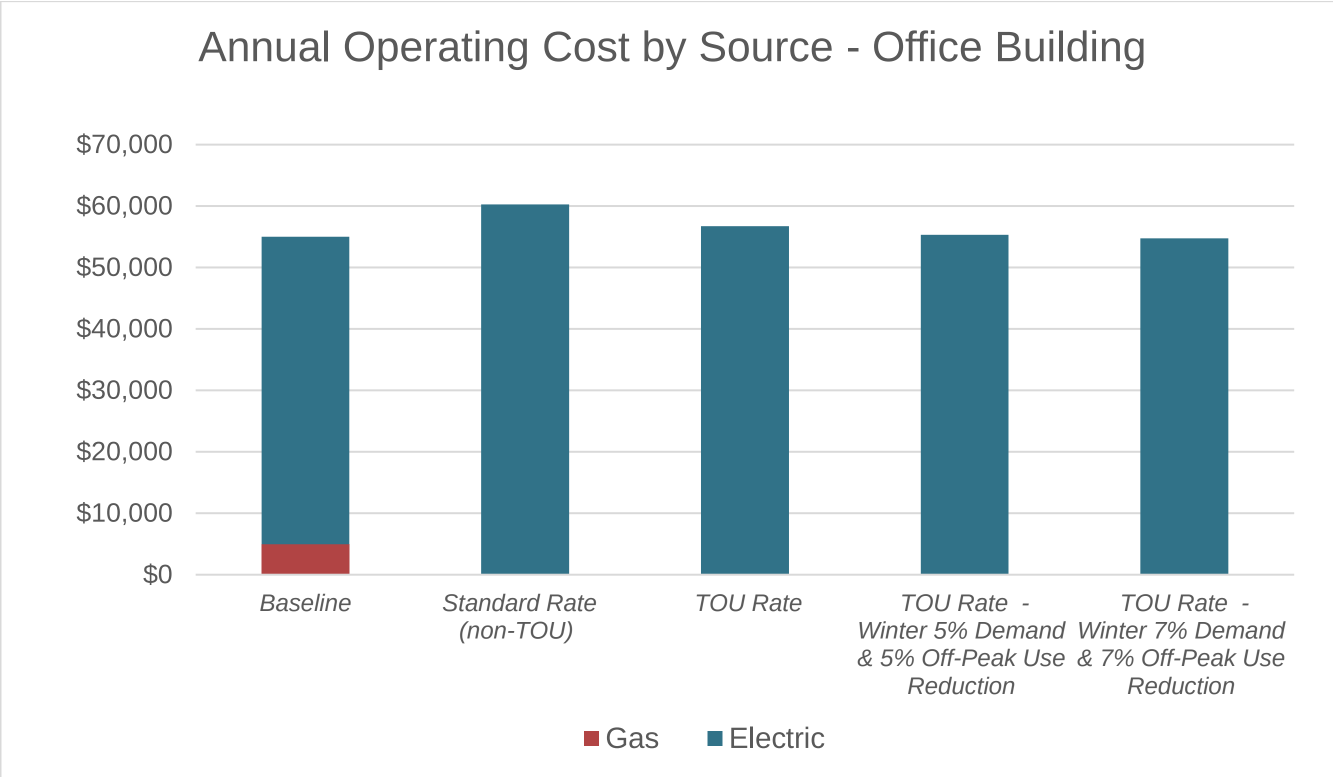

Figure 2: Annual Operating Cost by Source - Commercial

The following summarizes findings:

- Similar to the residential scenario, the unmodified standard rate and TOU rates do not provide annual heating savings for the example commercial building. Electrification under these existing rates increases annual heating costs by $1,700 - $5,215/yr or **3 - 9%** of total utility costs.
- To achieve equivalent operating costs, the TOU rate would need to be **reduced around 5% for Winter Peak Demand and 5% for Winter Off-Peak Use**
- To achieve equivalent Net Present Costs, a rate **reduction of 5% Winter Peak Demand and 5% Winter Off-Peak Use** was applied in conjunction with higher rebates.
- Including the impact on cooling energy for a retrofit provides an additional savings of $1,141/yr for the reduced rate case due to an increased seasonal energy efficiency ratio (SEER) from 10 to 12.

Despite representing 34% of the commercial building's energy consumption, natural gas accounts for only 9% of the baseline utility costs. Increasing natural gas costs is an additional path to achieve cost savings from electrification. Using the standard rate case, a natural gas rate above $1.37/therm would produce savings which is a 205% increase from the current natural gas annual average rate of $0.67/therm.

First Cost Summary

The installation costs were evaluated for the various scenarios to compare the cost of heat pump equipment with standard natural gas equipment. The delta in cost between these options is used to evaluate the overall economics of the conversion. For retrofit scenarios, it is assumed that the conversion to heat pumps would only occur at the end-of-life replacement. Local contractors in the Denver area were consulted to determine the costs of installing heat pump equipment and natural gas equipment. The following summarizes additional considerations:

- For the retrofit scenarios, additional electrical costs are included to make the modifications needed to accommodate the central electric heat pump and heat pump water heater.

- For the new construction scenario, the cost savings of eliminating the natural gas hookup and piping are considered.

- The operating cost calculations assume that all natural gas equipment is removed from the building. This provides first cost savings for new construction and eliminates the natural gas monthly service fee. Costs for a heat pump domestic water heater are included in addition to the central heating and cooling heat pump system. However, costs for other appliance replacements were not included such as gas ranges, fireplaces, or outdoor grilles. There would be additional costs to address these items in the retrofit scenario.

- For both the heat pump and natural gas options, high efficiency equipment is assumed.

The following sections summarize the costs that are used in the analysis:

Single Family Home

Pricing was gathered from GB3 Energy Smart Homes, a residential contractor specializing in high efficiency equipment. New construction cost ranges were also provided by HM Capital, a real estate development firm. The following summarizes the information provided and assumptions used in the analysis:

<u>Retrofit</u>

- Typical installed cost for a single-zone, large (48kbtu) high efficiency, cold-climate air-source heat pump is around $14,000 - $16,000.

- Typical installed costs for multi-stage, variable-speed, high efficiency gas furnaces are around $6,500 - $7,500. For multi-stage 18+ SEER AC units, typical costs are around $7,500 - $8,500. The total cost for a high efficiency furnace and AC is $14,000 - $16,000.

- Typical heat pump water heater installed costs are between $3,800 and $4,500 depending on whether a new electrical circuit is needed, how far electrical needs to be run, and whether the new heat pump is connecting to intake and/or exhaust ducts.

- For a retrofit, a new electrical circuit for the central heat pump is typically around $1,200. For some existing homes with AC units, you can re-use the existing circuit for the new central heat pump so a new circuit is not needed. For other homes, a new circuit is needed because the existing circuit is not big enough, AC was not in place previously, the existing circuit doesn't meet code, or the heat pump requires an additional circuit for backup heat. There will also be an electrical cost to add a circuit for the heat pump water heater if it is replacing a natural gas water heater.

<u>New Construction</u>

- For new construction, the cost of a central heat pump system is similar to a high efficiency furnace with AC. Installed system costs range from $12,000 - $15,000.

- New construction is expected to have a smaller electrical add, primarily for the heat pump water heater connection. The electrical cost for a new central heat pump should be similar to a new standard AC system.

- Natural gas piping and connection for new construction typically costs $5,000 - $8,000. This includes the Xcel Energy natural gas connection fee.

- System costs are typically lower for new construction developers with larger economies of scale.

The following table summarizes the costs used in the residential analysis:

Table 6: Single Family Home First Costs

	End-of-Life Replacement		New Construction[1]	
Description	**Heat Pump**	**Natural Gas**	**Heat Pump**	**Natural Gas**
Central heating/cooling system (including install)	$15,000	$15,000	$13,000	$13,000
Tank type domestic hot water heater	$3,300	$2,600	$3,100	$2,400
Electrical modification	$2,100	----	$500	----
Natural gas connection and piping (new construction only)	----	----	----	$6,500
Total Cost	**$20,400**	**$17,600**	**$16,600**	**$ 21,900**
Delta in Cost for Heat Pump		***$2,800***		***$ (5,300)***

[1]The costs shown in the table are estimated for custom installations at a single-family home. Larger projects by developers are expected to have lower first costs. Developer first costs are estimated to be around $12,250 total for the heat pump option compared to $18,200 total for the natural gas option, including the electrical and natural gas connections, which is a cost savings of **$5,950** or **33%**.

Office Building

Commercial system pricing was gathered from three contractors: Haynes, Murphy, and Tryg Group. The following summarizes the information provided and assumptions used in the analysis:

- Packaged heat pumps and gas fired/DX roof top units typically range from $2,400 - $2,600/ ton installed.
- Some pricing indicated that heat pumps are slightly higher cost, and some indicated that gas/DX RTUs are slightly higher cost. The cost delta varied for different equipment manufacturers, equipment models, and installing contractors. We assumed that the first cost is the same for both equipment types, not including electrical changes or gas connections.
- Heat pump water heater costs are assumed to be slightly higher than the residential scenario.
- It is assumed that the electrical connection costs are similar for heat pumps and DX RTUs. Therefore, no electrical costs are assumed for the heat pump RTUs in either the retrofit or new construction scenario. Electrical modification costs for the heat pump water heater are assumed to be slightly higher than the residential scenario. It should be noted that the electrical modification costs could be much higher if the heat pump water heater requires a long electrical run or there are other issues with aging electrical infrastructure at the RTUs.
- For the new construction scenario, the natural gas connection to the gas fired RTUs is assumed to cost $2,000/ unit plus $3,000 for the main connection.

The following table summarizes the costs used in the commercial analysis:

Table 7: Office Building First Costs

	End-of-Life Replacement		New Construction	
Description	**Heat Pump**	**Natural Gas**	**Heat Pump**	**Natural Gas**
Central heating/cooling system (including install)	$234,000	$234,000	$216,000	$216,000
Tank type domestic hot water heater	$4,200	$2,600	$3,800	$2,400
Electrical modification	$3,000	----	$1,500	----
Natural gas connection and piping (new construction only)	----	----	----	$21,000
Total Cost	**$ 241,200**	**$ 236,600**	**$ 221,300**	**$ 239,400**
Delta in Cost for Heat Pump		***$ 4,600***		***$ (18,100)***

Economic Analysis

Combining the first cost considerations and operating cost impacts outlined in the previous sections, a 15-year economic analysis was completed for each building type and rate structure. Both end-of-life replacement and new construction scenarios were assessed. For both residential and commercial buildings, it was found that adjustments to the rate structures and rebates are necessary to achieve an equivalent 15-year Net Present Cost. Furthermore, new construction installations have more favorable economics compared to end-of-life replacements due to first cost savings from avoided natural gas infrastructure. Tabular data for the figures provided is included in the Appendix.

Single Family Home

The figures below display the Net Present Costs for electrification of the example residential building. For the reduced rate scenario, a 20% reduction was applied to the Winter Off-Peak portion of the Time of Use rate.

For new construction, the heat pump scenarios have a lower Net Present Cost for all rates tested. This is due to the substantial savings from the elimination of the natural has hookup and piping. Although Net Present Costs are lower, additional incentives will help encourage adoption and lower costs across the market. The current heat pump rebate of $400 for the HP water heater and $300 for the central heat pump ($700 total) produces a 14% savings in Net Present Costs.

For end-of-life replacements, the heat pump scenarios have a higher Net Present Cost with the current utility rates. With a rate reduction of 20% applied to the Winter Off-Peak potion of the TOU rate, a rebate of $1,200 for the HP water heater and $3,400 for the central heat pump ($4,600 total) is needed to produce a Net Present Cost equivalent to the natural gas replacement option.

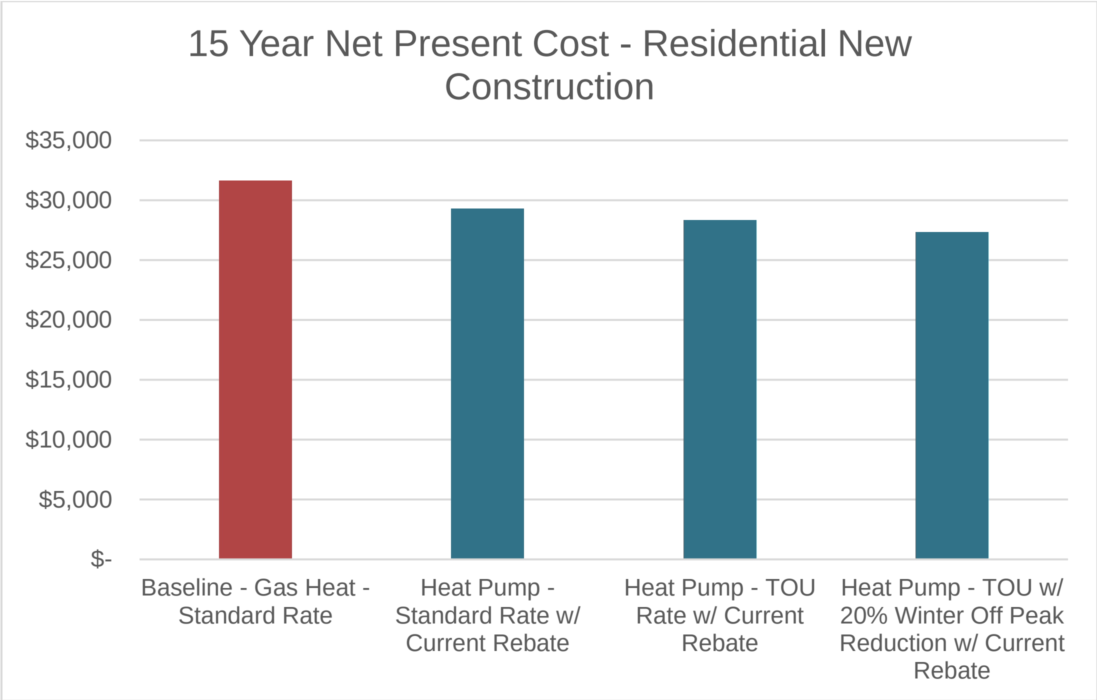

Figure 3: 15-Year Net Present Cost – Residential New Construction

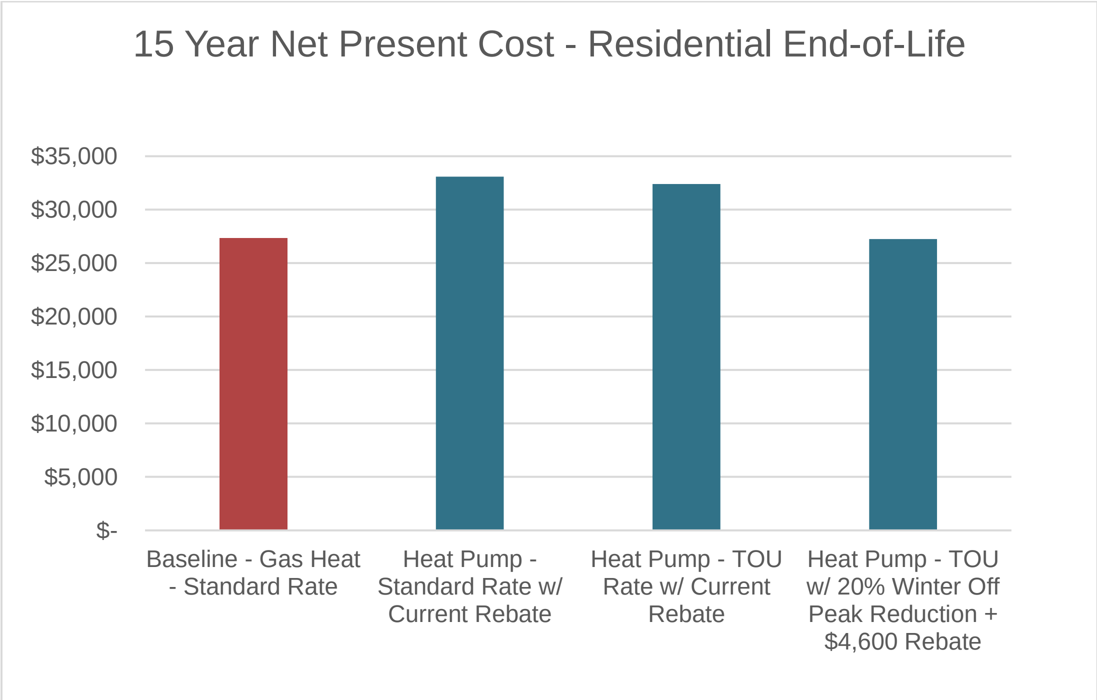

Figure 4: 15-Year Net Present Cost – Residential End-of-Life

Office Building

The following figures display the net present costs for electrification of the example commercial office building. For the reduced rate scenario, a 5% reduction is applied to both the Winter Peak Demand and the Winter Off-Peak Use portions of the Time of Use rate.

For new construction, the heat pump scenarios have a higher Net Present Cost for all rates tested. While the first costs are around 9% lower, the higher operating costs result in higher Net Present costs over the lifetime of the equipment. With the utility rate reduction applied, rebates of $400 for the HP water heater and $300 per RTU ($3,100 total) are needed to have an equivalent 15-year Net Present Cost.

For end-of-life replacements, the heat pump scenarios have a higher Net Present Cost for all rates tested. There is not savings from the natural gas supply in this scenario making the Net Present Costs higher than the new construction scenario. With the utility rate reduction applied, rebates of $800 for the HP water heater and $1,200 per RTU ($11,600 total) are needed to have an equivalent 15-year Net Present Cost.

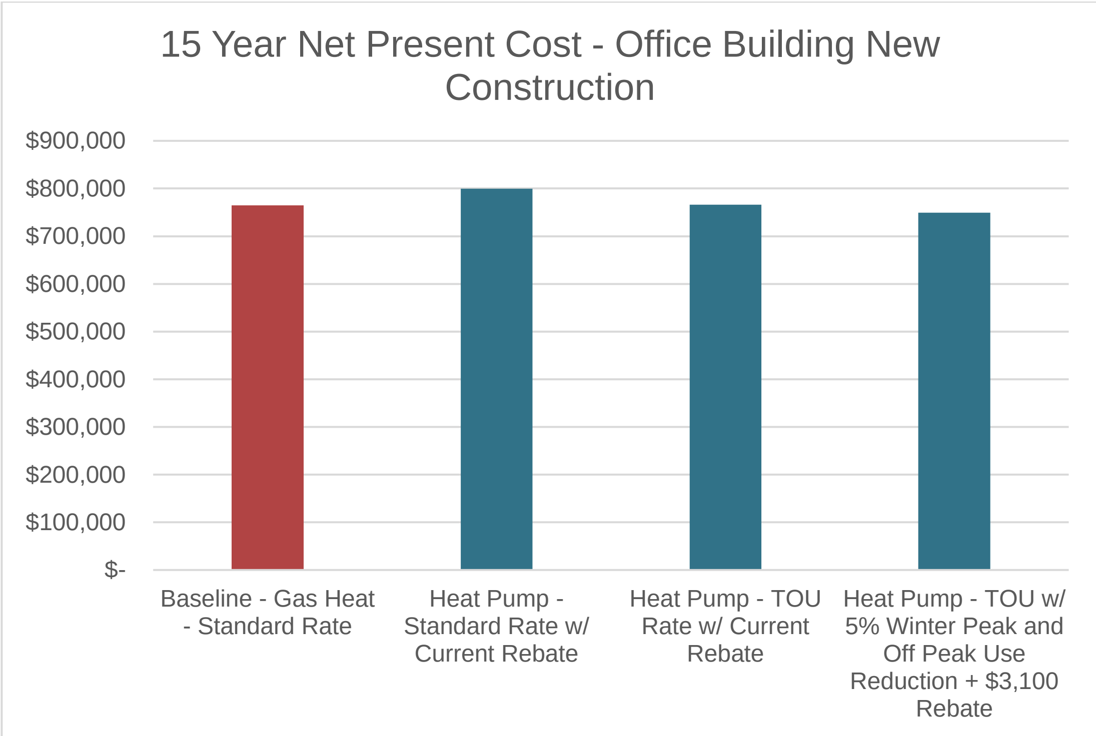

Figure 5: 15-Year Net Present Cost – Commercial New Construction

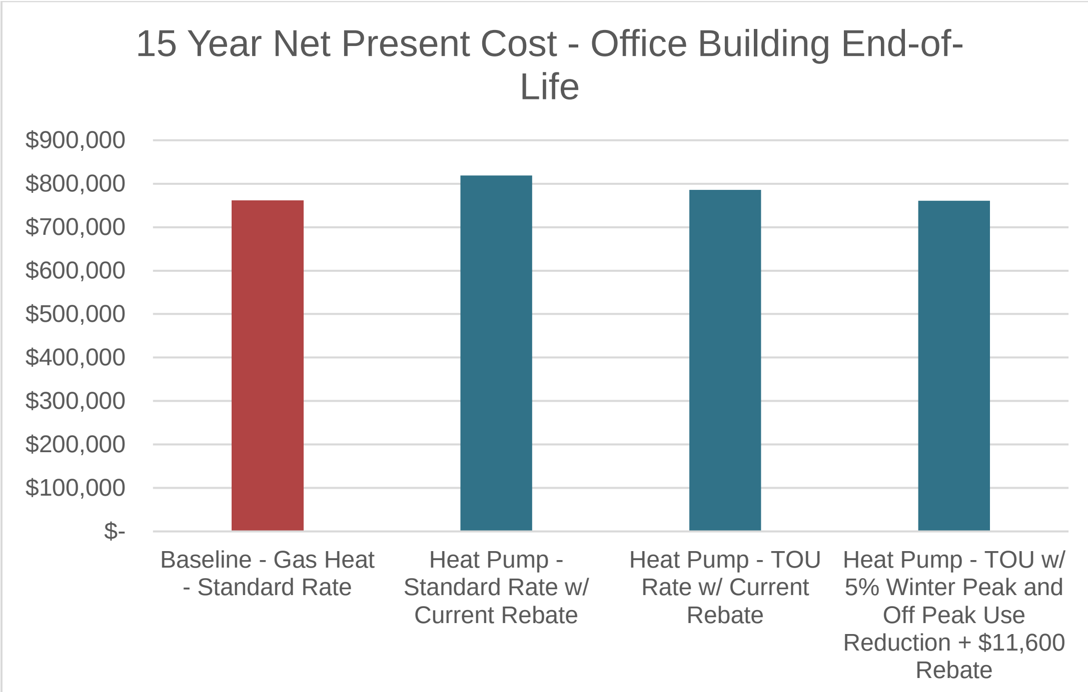

Figure 6: 15-Year Net Present Cost – Commercial End-of-Life

DRIVING ADOPTION OF ELECTRIFICATION

With the low cost of natural gas and the widespread use of natural gas equipment for space and water heating, electrification of buildings will require a significant effort with a wide range of strategies. Possible strategies include new utility rates, rebates/incentives, policies, and significant marketing and education to shift the market. While the economics of utilizing electricity for heating are challenging, there are many benefits beyond decarbonization. Educating building owners and occupants on those benefits will further increase demand.

The following sections summarize the various strategies that can help increase adoption.

Create New Rates and Rebates

New Time of Use Electric Rates

As described in the economic results section, electric utility rate reductions were tested in conjunction with higher rebates to achieve an equivalent Net Present Cost. Pilot electric rates could be explored with Xcel Energy to incentivize this switch. Pilot rates should consider time of use with lower costs during high heating times such as winter mornings.

Natural gas rates could also be increased with gas taxes or carbon taxes. However, there are challenges to implementing fuel taxes with equity concerns and opposition from utility companies.

Higher Rebates

To make the economics of heat pumps more favorable, the first cost could be lowered by offering rebates and incentives. The tables below summarize existing heat pump rebates offered by Xcel Energy in Colorado and the proposed rebates presented in this study. There are currently only heat pump rebates available for residential customers. Xcel Energy has general efficiency rebates available for commercial customers but not rebates specifically focused on heat pumps.

Table 8: Current Heat Pump Rebates

Current Heat Pump Rebates (Residential Only)	
Heat-Pump Water Heater (50gal)	$400
High Efficiency Heat Pump (>15 SEER or 12.5 EER)	$500
Std. Efficiency Heat Pump (<15 SEER or 12.5 EER)	$300

The current rebate levels are small compared to the cost increase for retrofitting to heat pumps over standard natural gas equipment in residential buildings. While commercial heat pump systems are more favorable for new construction, additional up-front rebates will help incentivize building owners to shift to this equipment type. Rebate rules will also need to be addressed to allow incentives for fuel switching from natural gas to electricity. The following summarizes proposed rebate levels evaluated in the study:

Table 9: Proposed Example Rebates

Type	Proposed Rebate for Space Heating/Cooling HP	Proposed Rebate for HP Water Heater
Residential New Construction	$ 300/ central HP	$ 400
Residential End-of-Life	$ 3,400/ central HP	$ 1,200
Commercial New Construction	$300/ RTU	$ 400
Commercial End-of-life	$ 1,200/ RTU	$ 800

Other Financing Mechanisms

In addition to rebates, financing and loan programs could be utilized to implement retrofit projects. The Colorado C-PACE program has been revised to allow electrification as a measure even though it does not reduce operating costs. This allows the retrofit to be financed through the C-PACE program and re-paid through property taxes. Other loan programs could be developed by the state or municipalities to help fund retrofits.

Target Timing of Implementation

Start with New Construction

New construction has the most favorable economics due to the reduced cost of natural gas hookups and piping. It is also less costly to incorporate an electric system starting from design than it is to retrofit an existing system. Although new construction represents a smaller quantity of buildings when compared to existing buildings, electrification in new construction provides the best opportunity for early market adoption.

To drive adoption in new construction, there will need to be marketing and education to increase designer familiarity and contractor know-how of heat pump systems. Equipment manufacturers will also need to increase product availability to cover a wider array of sizes and temperature needs. There are initiatives among organizations such as ASHRAE to promote a wider array of heat pump equipment to meet varying building needs. Marketing the lower first cost will also help the adoption among developers which will further spread the technology.

Follow with End-of-life Replacement

With widespread adoption of heat pump technology in new construction, it is expected that costs will decrease and building owners and operators will become more comfortable with heat pump systems. This will help make retrofit options for existing buildings become more attractive. For retrofits, electrification is best implemented when existing equipment has reached the end of its useful life. With an end-of-life scenario, the cost delta between the two systems can be considered in lieu of the full retrofit cost and the building owner will be more prepared for the capital project.

Develop and Adopt New Technologies

While single zone packaged heat pump equipment was evaluated in this study since it offers the most straightforward retrofit, there are other technologies that offer greater efficiency. This includes VRF (Variable Refrigerant Flow) systems with variable speed compressors that can perform much more efficiently at part load and reduce demand costs. VRF systems include multiple interior evaporator coils to provide individual temperature control in various comfort zones. Energy modeling performed by Group14 for other projects shows that VRF systems with a Dedicated Outside Air System (DOAS) and energy recovery have lower operating costs than standard natural gas Variable Air Volume (VAV) systems.

Additional technologies and equipment types will need to be brought to market to implement widespread adoption of all electric buildings. This includes larger roof top units and large air-to-water equipment to replace central boilers. It will be important to provide research funding and marketing to increase technology options, improve equipment efficiencies, and lower costs.

Emphasize the Co-Benefits and Building Health

All electric buildings have many benefits over buildings with natural gas equipment. As more buildings make the shift to eliminating natural gas, it is expected that consumer familiarity with heat pumps will increase along with a greater appreciation for the other benefits.

- **Create Healthier buildings** – Studies have indicated that natural gas heating and cooking can have negative impacts on human health. According to a Rocky Mountain Institute report, children in a home with a gas stove have a 24 - 42% increased risk of having asthma[10]. There has been an increasing focus on healthy buildings throughout the building industry which helps to make this a strong driver.

- **Increase Safety** – Removing natural gas from buildings reduces safety risks associated with carbon monoxide poisoning and gas leaks. These are especially important in the home where incidents can happen while people are sleeping. While major explosions are rare, removing natural gas eliminates these risks.

- **Utilize Simpler Systems** – During installation, the construction of all electric buildings is simpler with no natural gas piping and less complex system types. The building operation can also be simpler with a combined heating and cooling system and limited large central equipment.

- **Improve Comfort with Zoning** – Heat pump systems offer more flexibility than standard single zone systems since small refrigerant lines are used between zone devices in lieu of large air ducts. This makes it feasible to retrofit buildings with more zones and improve comfort conditions.

Provide Marketing and Education

Driving change will require a significant marketing and education effort. Key focus areas include:

[10] https://rmi.org/indoor-air-pollution-the-link-between-climate-and-health/

- **Equipment Available for Cold Climates** – Many people have the perception that heat pumps do not work well in cold climates. While low ambient heat pumps have been available for many years, education is still needed on the availability and quality of this technology.

- **Quality of Induction Cooking** – A barrier to residential electrification is the perception that a gas range is needed for high quality cooking. This often stems from familiarity with older electric element technology. Modern induction equipment can allow for high quality cooking while being safe and easy to control.

- **Overall Electrification Benefits** – Broad messaging can be used to emphasize the co-benefits outlined above in addition to the environmental benefits of utilizing renewable electric energy for all building needs.

Implement Policies

A key strategy to drive implementation of building electrification is through policies and building codes. To date, thirty California municipalities have started initiatives encouraging or mandating building electrification. Abroad, countries such as Norway, Germany and the Netherlands have already enacted bans on fossil-fuel based heating[11]. The City and County of Denver's recent Climate Taskforce has recommended a Net Zero Energy all electric building code for new construction by 2030 which will increase the prevalence of electric heating equipment.

Building electrification policies are most applicable to new construction buildings. This can be implemented for both residential and commercial buildings. Electrification policies and codes can be expanded to major renovation applications but will likely require exceptions when converting to electric equipment is not feasible. Renovation requirements are most likely applicable only to commercial buildings since homeowners may not be able to afford the higher first cost or operating costs of heat pump equipment.

Requiring electric equipment through policies and codes will help to further the awareness and acceptance of these equipment types. As costs come down through economies of scale and industry professionals become more familiar with this equipment, more retrofits to electric heat pumps will likely be performed even when not required.

Consider Equity

When developing programs or policies around building electrification, it is important to consider equity and the impacts on low-income communities. According to the Greenlining Electrification report, the majority of low-income communities are renters and may not have the opportunity to make the conversion to electric space and water heating equipment. As customers leave the natural gas system, the result will be higher costs spread across fewer remaining customers. Higher gas bills will drive customers with means to leave the system due to financial, health and environmental reasons causing increasing costs for those that remain[12].

The following example strategies can be used to address equity concerns:

- The impact of higher electric equipment operating costs should be carefully evaluated to ensure that all people can afford to heat their homes and water.
- Incentives and programs should be targeted first to low income residents and non-profit businesses.
- Additional program support can be offered to evaluate barriers and assist low-income communities with electrification.
- Policies and rates should include provisions to address low-income communities.

[11] https://www.greentechmedia.com/articles/read/electrifying-space-heating-will-require-a-herculean-effort
[12] https://greenlining.org/publications/reports/2019/equitable-building-electrification-a-framework-for-powering-resilient-communities/

APPENDIX - ECONOMIC RESULTS TABLES

Operating Cost Analysis

Single Family Home

Cost Category	Gas Equipment	Electric Equipment			
	Baseline	Standard Rate (non-TOU)	TOU Rate	TOU Rate - Winter 20% Off-Peak Reduction	TOU Rate - Winter 25% On-Peak & 30% Off-Peak Reduction
Annual Gas Costs	$ 496	$ -	$ -	$ -	$ -
Annual Electric Costs	$ 547	$ 1,396	$ 1,295	$ 1,193	$ 1,028
Total Annual Costs	$ 1,043	$ 1,396	$ 1,295	$ 1,193	$ 1,028
Change from Baseline		$ 353	$ 252	$ 150	$ (15)
Change from baseline:		34%	24%	14%	-1%

Office Building

Cost Category	Gas Equipment	Electric Equipment			
	Baseline	Standard Rate (non-TOU)	TOU Rate	TOU Rate - Winter 5% Demand & 5% Off-Peak Use Reduction	TOU Rate - Winter 7% Demand & 7% Off-Peak Use Reduction
Annual Gas Costs	$ 4,983	$ -	$ -	$ -	
Annual Electric Costs	$ 50,048	$ 60,246	$ 56,752	$ 55,329	$ 54,760
Total Annual Costs	$ 55,031	$ 60,246	$ 56,752	$ 55,329	$ 54,760
Change from Baseline		$ 5,215	$ 1,721	$ 298	$ (271)
Change from baseline:		9%	3%	1%	0%

Economic Analysis

Residential - New Construction	Rebate Level	First Cost W/ Rebate	First Cost Delta ($)	First Cost Delta %	Operating Cost ($/yr)	Operating Cost Delta ($/yr)	Operating Cost Delta %	15 Year Net Present Cost	Net Present Cost Delta ($)	Net Present Cost Delta %
Baseline - Gas Heat - Standard Rate	--	$ 21,900	--	0%	$ 1,043	--	--	$ 31,640	--	--
Heat Pump - Standard Rate w/ Current Rebate	$ 700	$ 15,900	$ (6,000)	-27%	$ 1,396	$ 353	34%	$ 29,292	$ (2,348)	-7%
Heat Pump - TOU Rate w/ Current Rebate	$ 700	$ 15,900	$ (6,000)	-27%	$ 1,295	$ 252	18%	$ 28,331	$ (3,309)	-10%
Heat Pump - TOU w/ 20% Winter Off Peak Reduction w/ Current Rebate	$ 700	$ 15,900	$ (6,000)	-27%	$ 1,193	$ 150	12%	$ 27,349	$ (4,291)	-14%
Current Rebate is $400 for HPWH and $300 for heat pump										
No change to rebate proposed										

Residential - End-of-Life	Rebate Level	First Cost W/ Rebate	First Cost Delta ($)	First Cost Delta %	Operating Cost ($/yr)	Operating Cost Delta ($/yr)	Operating Cost Delta %	15 Year Net Present Cost	Net Present Cost Delta	Net Present Cost Delta %
Baseline - Gas Heat - Standard Rate	--	$ 17,600	--	0%	$ 1,043	--	--	$ 27,340	--	--
Heat Pump - Standard Rate w/ Current Rebate	$ 700	$ 19,700	$ 2,100	12%	$ 1,396	$ 353	34%	$ 33,092	$ 5,752	21%
Heat Pump - TOU Rate w/ Current Rebate	$ 700	$ 19,700	$ 2,100	12%	$ 1,295	$ 252	18%	$ 32,405	$ 5,065	19%
Heat Pump - TOU w/ 20% Winter Off Peak Reduction + $4,600 Rebate	$ 4,600	$ 15,800	$ (1,800)	-10%	$ 1,193	$ 150	12%	$ 27,249	$ (91)	0%
Current Rebate is $400 for HPWH and $300 for central heat pump										
Proposed Rebate is $1,200 for HPWH and $3,400 for central heat pump										

Commercial - New Construction	Rebate Level	First Cost W/ Rebate	First Cost Delta ($)	First Cost Delta %	Operating Cost ($/yr)	Operating Cost Delta ($/yr)	Operating Cost Delta %	15 Year Net Present Cost	Net Present Cost Delta	Net Present Cost Delta %
Baseline - Gas Heat - Standard Rate	--	$ 239,400	--	0%	$ 55,031	--	--	$ 764,765	--	--
Heat Pump - Standard Rate w/ Current Rebate	$ -	$ 221,300	$ (18,100)	-8%	$ 60,246	$ 5,215	9%	$ 799,383	$ 34,618	5%
Heat Pump - TOU Rate w/ Current Rebate	$ -	$ 221,300	$ (18,100)	-8%	$ 56,752	$ 1,721	3%	$ 765,860	$ 1,095	0%
Heat Pump - TOU w/ 5% Winter Peak and Off Peak Use Reduction + $3,100 Rebate	$ 3,100	$ 218,200	$ (21,200)	-9%	$ 55,329	$ 298	1%	$ 749,109	$ (15,656)	-2%
Current Rebate is $0 for commercial										
Proposed Rebate is $400 rebate for water heater and $300 per RTU										

Commercial - End-of-Life	Rebate Level	First Cost W/ Rebate	First Cost Delta ($)	First Cost Delta %	Operating Cost ($/yr)	Operating Cost Delta ($/yr)	Operating Cost Delta %	15 Year Net Present Cost	Net Present Cost Delta	Net Present Cost Delta %
Baseline - Gas Heat - Standard Rate	--	$ 236,600	--	0%	$ 55,031	--	--	$ 761,965	--	--
Heat Pump - Standard Rate w/ Current Rebate	$ -	$ 241,200	$ 4,600	2%	$ 60,246	$ 5,215	9%	$ 819,283	$ 57,318	8%
Heat Pump - TOU Rate w/ Current Rebate	$ -	$ 241,200	$ 4,600	2%	$ 56,752	$ 1,721	3%	$ 785,760	$ 23,795	3%
Heat Pump - TOU w/ 5% Winter Peak and Off Peak Use Reduction + $11,600 Rebate	$ 11,600	$ 229,600	$ (7,000)	-3%	$ 55,329	$ 298	1%	$ 760,509	$ (1,456)	0%
Current Rebate is $0 for commercial										
Higher Rebate is $800 rebate for water heater and $1,200 per RTU										