Cost Optimal Decarbonization: A Regional Analysis of Electric versus Gas Supplemental Heating for Heat Pumps

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ABSTRACT

As the built environment undergoes decarbonization, air source heat pumps (ASHPs) have emerged as a viable alternative to traditional gas heating. However, ASHP efficiency declines in colder climates, necessitating supplemental heating. While previous research has analyzed the greenhouse gas emissions impact of electric versus gas supplemental heating for ASHPs, operational cost considerations remain a critical factor in determining optimal heating strategies. This study expands on our prior emissions focused publication by evaluating the financial feasibility of electric versus gas supplemental heating throughout the U.S. To quantify cost differences, this study employs detailed hourly energy modeling using the Department of Energy's EnergyPlus simulation engine with models aligned with ASHRAE Standard 90.1 (Appendix G) and common commercial building types across U.S. climate zones. Utility rates for electricity and natural gas were sourced from the U.S. Energy Information Administration, ensuring an accurate representation of current energy pricing. Results show that electrifying supplemental heat raises operating costs nationwide, though the magnitude of impact varies significantly by region and building type. Ventilation-dominated buildings such as schools and hospitals in colder climates experience the steepest cost increases, while envelope-driven buildings show marginal cumulative cost increases over the next 15-years compared to dual-fuel systems, apart from the upper Midwest and Northeast. The small efficiency gain from resistance heating is insufficient to offset higher electricity prices compared to gas, particularly in colder climates and high-cost electricity regions. These findings highlight the importance of regionally nuanced, building-specific strategies to ensure that electrification pathways align with both environmental and economic objectives.

INTRODUCTION

In the United States, buildings account for roughly 70% of electricity use and about 30% of operational greenhouse gas (GHG) emissions, approximately two-thirds of which are attributed to electricity consumption and one-third to direct on-site fuel combustion, primarily natural gas (EIA 2022; EPA 2023). Decarbonizing this sector is therefore critical to achieving climate targets, with building heating representing a key lever for reducing emissions. Among available technologies, air source heat pumps (ASHPs)—particularly air-to-air systems—have emerged as the dominant solution in North America (DOE 2024; DOE 2023).

A persistent challenge, however, lies in the reduced efficiency of ASHPs during extreme cold weather. To maintain comfort under these conditions, supplemental heating is typically required. While motives vary, electric resistance heating is

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often selected based on its perceived sustainability advantage over gas supplemental heating. Yet, in our prior analysis presented at the 2025 ASHRAE Annual Conference, we demonstrated that electrifying supplemental heating frequently delivers little to no emissions benefit relative to gas supplemental heating (Houssainy et al. 2025). More specifically, electrifying supplemental heating increases emissions in 15 of the 18 U.S. electric grid regions when evaluated using 2022 renewable energy shares. Furthermore, a cumulative 15-year emissions assessment (2025–2040) that incorporates projected grid evolution showed that all-electric systems continue to produce higher emissions than dual-fuel alternatives in two regions—underscoring the need for region-specific strategies that challenge mainstream design assumptions favoring universal electrification (Houssainy et al. 2025).

Over the past decade, a growing body of work has assessed the impacts of fully electrifying space heating through ASHP with electric resistance supplemental heat (Wilson et al. 2024; Pistochini et al. 2022; Bayer 2024; Flores et al. 2024; RMI 2023; Deetjen 2021; CaraDonna 2023). While these studies consistently highlight the potential of full electrification, most overlook dual-fuel configurations that integrate gas supplemental heating with ASHP's. Recent research has begun to explore dual-fuel implications (Shekhadar et al. 2024; Landman et al. 2024; Nienhuis et al. 2017; Dichter et al. 2020), but these existing studies are geographically constrained, focused on residential applications, or lack a comprehensive forward-looking framework for U.S. commercial buildings. Our previous work began addressing this gap through a nationwide GHG emissions assessment of gas versus electric supplemental heating for ASHP's in the commercial sector, with an assessment extrapolating through 2050 (Houssainy et al. 2025).

Still, emissions represent only one dimension of the decision-making process. For building owners, operational cost—and its impact on lifecycle costs and total cost of ownership—remains a critical factor. Several recent studies examine the economics of fully electrifying space heating through heat pumps (Wilson et al. 2024; Rosenow et al. 2025, Jan et al. 2025), but they neglect to isolate the trade-offs of supplemental heating options or consider dual-fuel systems.

This study builds directly on our prior emissions-focused analysis and addresses the existing gap in the literature by providing a nationwide cost assessment of electric versus gas supplemental heating for ASHPs across diverse commercial building types and electric grid regions in the U.S. Specifically, we: 1) Isolate the operational cost implications of supplemental heating strategies, 2) Evaluate outcomes across commercial building types that span U.S. electric grid regions and climate zones, 3) Incorporate region-specific utility pricing from the U.S. EIA, and 4) Link cost outcomes to our previously established emissions findings to provide a more holistic framework for cost-optimal decarbonization strategies.

By uniting emissions and cost perspectives, this study offers new insights into the trade-offs of supplemental heating strategies. The results highlight the importance of regionally nuanced approaches to building decarbonization design and policy, ensuring that both environmental and economic priorities are considered in the transition toward sustainable building systems.

METHODOLOGY

This section details the methodology used for modeling the energy consumption and operational costs of ASHP supplemental heating scenarios across various building types and U.S. electric grid regions using physics-based energy simulations. First, we describe the electricity and gas prices used in the analysis, followed by the building energy models and modeled scenarios. We also explain how the cost analysis approach is consistent with our previously published emissions focused assessment to provide a comprehensive evaluation of supplemental heating options.

Electricity and Gas Prices

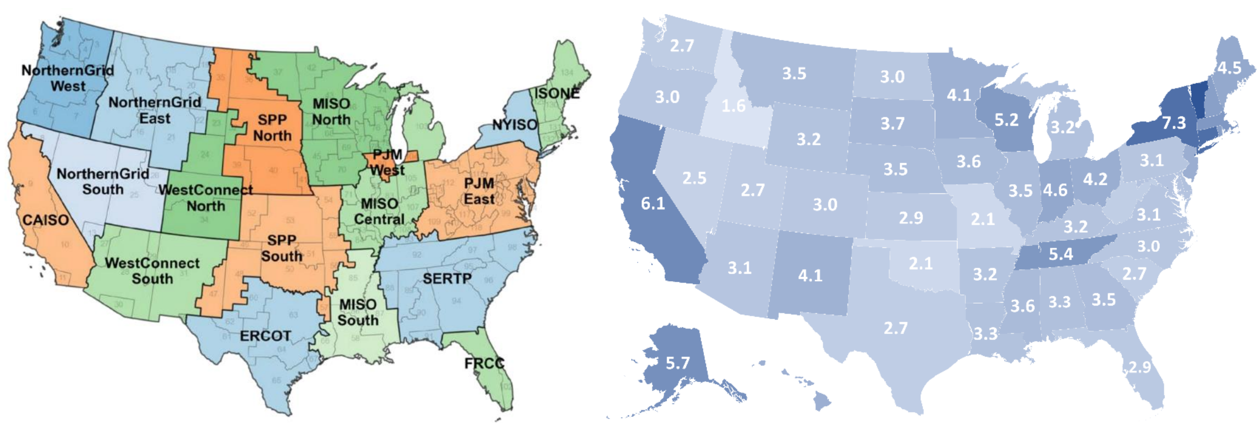
The U.S. Energy Information Administration (EIA) average electricity and gas prices were leveraged for the analysis. EIA calculates average electricity and natural gas prices by state using utility-reported data on total revenues and sales volumes. Electricity prices are derived by dividing total revenue by total kilowatt-hours sold, yielding a weighted average that reflects consumption across residential, commercial, and industrial sectors. Similarly, natural gas prices are calculated by dividing total revenue by total volume sold, with sector-specific breakdowns. These averages provide a consistent, high-level view of energy costs across regions and are published annually to support policy analysis and market comparisons.

To maintain consistency with our previously published paper on emissions impacts of supplemental heat options, we selected the same representative cities to model the 18 electric grid regions across the U.S. Table 1 summarizes the 18 electric grid regions, the associated representative cities modeled in this analysis, along with their corresponding commercial electricity and gas prices based on EIA's reported dataset as of February 2025.

Table 1. Modeled Representative Cities, Electricity Prices, and Gas Prices for Each Electric Grid Region Across the U.S.

Electric Grid Region	Modeled State, City	Electricity Price $/kWh (*$/MMBtu*)	Gas Price $/MMBtu (*$/kWh*)
NorthernGrid West	Washington, Seattle	0.1138 (*33.33*)	12.30 (*0.0420*)
CAISO	California, Los Angeles	0.2406 (*70.51*)	11.64 (*0.0397*)
NorthernGrid East	Montana, Helena	0.1085 (*31.80*)	9.092 (*0.0310*)
NorthernGrid South	Nevada, Las Vegas	0.0951 (*27.89*)	11.24 (*0.0384*)
SPP North	South Dekota, Pierre	0.1011 (*29.63*)	8.043 (*0.0275*)
WestConnect North	Colorado, Denver	0.1139 (*33.36*)	11.20 (*0.0382*)
WestConnect South	New Mexico, Santa Fe	0.1050 (*30.77*)	7.584 (*0.0259*)
MISO North	Minnesota, International Falls	0.1172 (*34.34*)	8.399 (*0.0286*)
SERTP	North Carolina, Raleigh	0.1057 (*30.97*)	10.22 (*0.0349*)
SPP South	Kansas, Kansas City	0.0940 (*27.56*)	12.92 (*0.0441*)
ERCOT	Texas, Temple	0.0864 (*25.30*)	9.411 (*0.0321*)
PJM West	Illinois, Chicago	0.1282 (*37.58*)	10.60 (*0.0362*)
MISO Central	Indiana, Indianapolis	0.1342 (*39.33*)	8.640 (*0.0295*)
MISO South	Mississippi, Jackson	0.1262 (*36.98*)	10.27 (*0.0351*)
ISONE	Maine, Augusta	0.2018 (*59.15*)	13.14 (*0.0449*)
NYISO	New York. Queens	0.2067 (*60.58*)	8.249 (*0.0281*)
PJM East	Pennsylvania, Philadelphia	0.1215 (*35.61*)	11.49 (*0.0393*)
FRCC	Florida, Tampa	0.1161 (*34.05*)	11.74 (*0.0401*)

Figure 1 presents a map of the 18 electric grid regions modeled in this analysis and illustrates the electricity-to-gas price ratio by state based on EIA data. As shown, electricity is generally more expensive than gas on a per-unit energy basis across the U.S., with the lowest ratio observed in Idaho (1.59) and the highest in Vermont (8.7), Connecticut (7.4), New York (7.3) and California (6.1). The national average ratio is 3.82.



a) b)

Figure 1 a) Modeled U.S. electric grid regions, aligned with emission factor datasets used in our previously published emissions focused study of supplemental heat options (Houssainy et al. 2025; NREL 2023). (b) State-level commercial electricity-to-gas price ratios (unitless), based on EIA's average reported prices as of February 2025, illustrating the relative regional variations in prices nationwide.

Building Energy Models

Hourly whole-building energy models were developed using the U.S. Department of Energy's (DOE) EnergyPlus simulation engine, version 23.1 (DOE 2025). This study focuses on the same four common commercial building types analyzed in our previously published emissions focused assessment: Office (125k-ft^2/11.6k-m^2, 4 stories), Multifamily (35k-

ft^2/3.3k-m^2, 5 stories), Hospital (240k-ft^2/22.2k-m^2, 5 stories) and School (210k-ft^2/19.5k-m^2), 3 stories). The building models were fully articulated based on ASHRAE Standard 90.1 2004, reflecting existing buildings likely due for an HVAC replacement (ASHRAE 2004). ASHRAE Standard 90.1 2004 assumptions were used to inform model inputs such as internal load definitions, equipment power densities, lighting power densities, and envelope insulation. The DOE commercial building prototype models were used to inform space type definition and allocations (DOE 2025b). Square geometry footprints were modeled for all building types, and typical meteorological year (TMY3) hourly weather files for the representative cities shown in Table 1 were used in the simulation to reflect each of the 18 electric grid regions spanning the U.S.

Modeled Scenarios

The following three space heating system type scenarios were modeled across all 4 building types and all 18 electric grid regions throughout the U.S:

1. **Gas-Fueled Heating Baseline:** Packaged single-zone rooftop air conditioner (PSZ-AC) with direct expansion (DX) cooling and gas combustion space heating. This scenario serves as the baseline throughout the results and reflects system type 3 in Appendix G of ASHRAE Standard 90.1 2022 (ASHRAE 2022). The whole-building energy cost savings for scenario 2 and scenario 3 below are compared to this baseline scenario.
2. **Dual Fuel:** Packaged single-zone rooftop, air-to-air heat pumps (PSZ-HP) with DX cooling, electric heat pump heating, and gas supplemental heating. This scenario reflects system type 4 in Appendix G of ASHRAE Standard 90.1 2022 (ASHRAE 2022) with gas supplemental heating.
3. **All Electric:** Packaged single-zone rooftop, air-to-air heat pumps (PSZ-HP) with DX cooling, electric heat pump heating, and electric resistance supplemental heating. This scenario reflects system type 4 in Appendix G of ASHRAE Standard 90.1 2022 (ASHRAE 2022) with electric supplemental heating.

To enable consistent comparison across building types, all scenarios were modeled with packaged single zone rooftop systems. While representative of typical rooftop units in schools and small offices, this choice simplifies HVAC configurations in hospitals and multifamily buildings, which often use more complex systems. This approach isolates the impact of supplemental heating strategies across climates and building types. The gas coil in scenario 1 is sized for the design heat load, the heat pumps in scenarios 2 and 3 are sized for the design cooling load, and the DX cooling performance is identical in all three scenarios. Variable speed supply fans and compressors were modeled for all scenarios. The following system level specifications were detailed in the model for each system type based on commercially available product specifications: Heat pump COP of 3.5 at 47F (8.33C), and COP of 2.335 at 17F (-8.33C), gas combustion coil efficiency of 80%, electric supplemental heat efficiency of 100%, and heat pump compressor shutoff temperature of -10F (-23.33C). Heat pump efficiency assumptions are aligned with ASHRAE 90.1 2022 requirements reflecting system replacement scenarios. Defrost cycles were not considered in this analysis. A total of 216 simulations were produced for this study (18 regions x 4 building types x 3 scenarios = 216 whole-building energy simulations on an hourly timestep and over an annual period).

Operational Cost Savings Calculation:

The primary results of interest in this study include the whole-building operational energy cost savings of ASHP's with gas supplemental heat (dual fuel) compared to all-gas space heating solutions, and the added whole-building operational energy cost savings associated with electrifying the supplemental heat. The results are presented in two cost savings calculations outlined in Equation 1 and Equation 2, as shown below. The annual cost variables in Equations 1 and 2 are calculated by summing the hourly gas and electricity costs over an annual period. The hourly electricity costs are derived by multiplying EIA's regional electricity prices by the modeled annual whole-building electricity usage. Hourly gas costs are determined by multiplying EIA's regional gas prices by the modeled annual whole-building gas consumption.

$$\%\,Cost\ Savings_{DualFuel} = \frac{Annual\ Cost_{All\ Gas} - Annual\ Cost_{DualFuel}}{Annual\ Cost_{All\ Gas}} \times 100 \quad (1)$$

$$\%\,Incremental\ Cost\ Savings_{All\ Electric} = \frac{Annual\ Cost_{DualFuel} - Annual\ Cost_{All\ Electric}}{Annual\ Cost_{All\ Gas}} \times 100 \quad (2)$$

RESULTS

Figure 2 shows the annual operational energy cost savings for each building type when comparing all-gas systems to dual-fuel heat pumps with gas supplemental heat, followed by the added cost savings from electrifying supplemental heat, based on Equations (1) and (2) respectively. The results show a clear and consistent outcome: electrifying supplemental heat never yields positive operational cost savings. Across all modeled building types and U.S. regions, replacing gas (80% efficient) with electric resistance supplemental heat (100% efficient) results in higher operating energy costs, though the percentage increase is marginal in most regions with the exception of MISO North, SPP North, and ISONE grid regions. The small efficiency gain from resistance heating is insufficient to outweigh the higher unit price of electricity relative to gas, and the penalty becomes especially pronounced in colder climates with greater supplemental heat run hours and in regions where electricity prices are significantly higher than gas prices.

The operational cost savings results from all gas to a dual fuel heat pump is more nuanced. When comparing operational costs between gas-fired rooftop systems and dual fuel heat pumps in Figure 2, one of the most important drivers of performance is the relative contribution of building ventilation loads versus envelope loads. The distinction between these two sources of heating demand is central to understanding why dual fuel heat pumps show relatively stronger economic advantages in certain building types (such as schools and hospitals) while appearing less favorable in others (such as multifamily buildings or offices) compared to all gas heating.

Envelope-driven heating loads occur primarily through conduction and infiltration across walls, roofs, windows, and other building surfaces. These losses are most severe during periods of very low outdoor air temperature, when the temperature difference between indoors and outdoors is greatest. Under these cold conditions, heat pump efficiency—measured by the coefficient of performance (COP) declines significantly. A heat pump that may deliver a COP of 3.5 at 47°F ambient could see its COP fall below 2.0, or in some cases near 1.0 at much colder conditions in systems not designed for cold-climate operation. Gas heating equipment, on the other hand, maintains relatively flat and predictable efficiency in the 80% range regardless of outdoor temperature. As a result, in envelope-dominated buildings with relatively lower ventilation requirements, such as offices or multifamily housing, the high price of electricity combined with reduced heat pump efficiency at cold temperatures often leads to higher operating cost differences for dual fuel heat pumps compared to all gas systems.

Ventilation-driven heating loads behave differently. These loads are determined by the requirement to condition outdoor air brought into the building for indoor air quality. Unlike envelope losses, which are greatest in the coldest weather, ventilation loads occur consistently whenever outdoor air is required and are far more present during milder winter conditions as compared with envelope driven heating loads. When outdoor air is 35–50°F, a heat pump may still be operating at a COP of 3–3.5. In this range, the heat pump's efficiency advantage compared to a gas coil's ~80% efficiency becomes substantial. Buildings such as schools and hospitals, which require high rates of outdoor air ventilation, therefore experience disproportionately greater benefit from dual fuel heat pumps. The higher the ventilation fraction of the heating load, the more leverage the heat pump's superior COP has in offsetting the higher unit cost of electricity. This study did not consider dedicated outdoor air systems (DOAS) or the potential for energy recovery within DOAS configurations, which could improve performance outcomes—particularly in ventilation-dominated buildings.

The result is a divergence by building type: in low-ventilation buildings, heating costs are driven largely by envelope losses under the coldest conditions, where gas maintains an advantage. In high-ventilated buildings, heating costs are dominated by the conditioning of outdoor air, including ambient air under milder conditions, where heat pumps operate most efficiently. This dynamic explains why the results in Figure 2 consistently shows that dual fuel heat pumps reduce operational costs in schools and other ventilation-heavy facilities across most U.S. climates, while showing less favorable economics in some regions for office or multifamily buildings. It is important to note that for all building types, dual fuel heat pumps demonstrated higher operational costs compared to all gas heating in California and New York, due to their currently high electricity to gas price ratios.

Assessing these technologies and supplemental heat options over the lifespan of typical HVAC equipment presents a more pragmatic design scenario and offers an alternative perspective on their operational cost impacts. Figure 3 shows the cumulative operational cost savings over a 15-year period, for all modeled buildings, in dollars rather than percentages relative to all gas heating baseline. Figure 3 shows the cost savings of dual fuel ASHP's with gas supplemental heating, along with the added savings from electrifying the supplemental heat

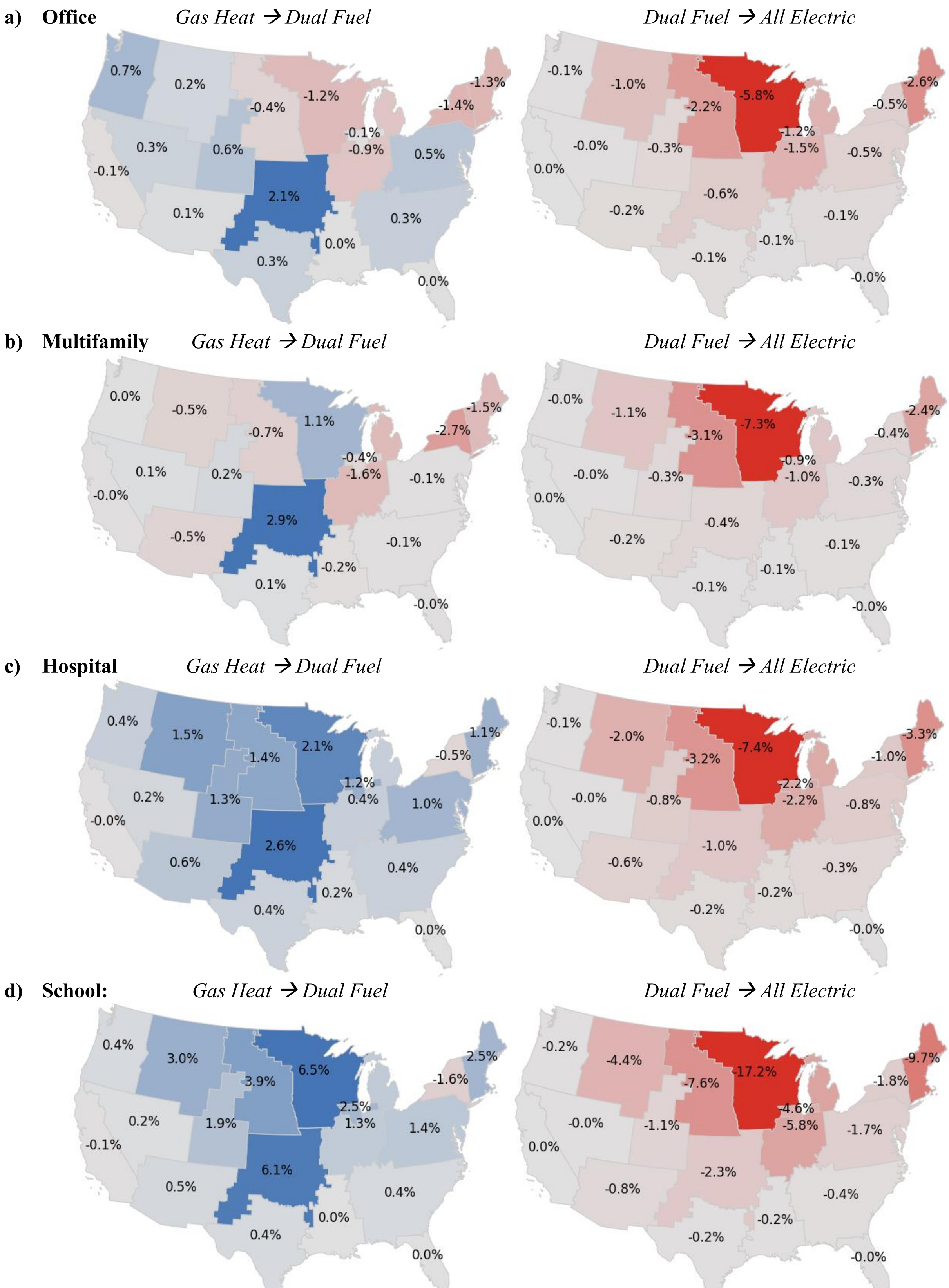


Figure 2 Modeled operational cost savings for the (a) office, (b) multifamily, (c) hospital, and (d) school buildings..

These results highlight the nuanced performance of heat pumps across different electric grid regions and utility price structures, with schools and hospitals consistently realizing greater cost benefits compared to offices and multifamily buildings. In contrast, electrifying supplemental heat often leads to consistently higher operating costs, though the magnitude is marginal in many regions with the exception of the upper Midwest and Northeast. This finding is particularly important when viewed alongside the relatively modest marginal emissions savings from electrifying supplemental heat, as illustrated in Figure 4.

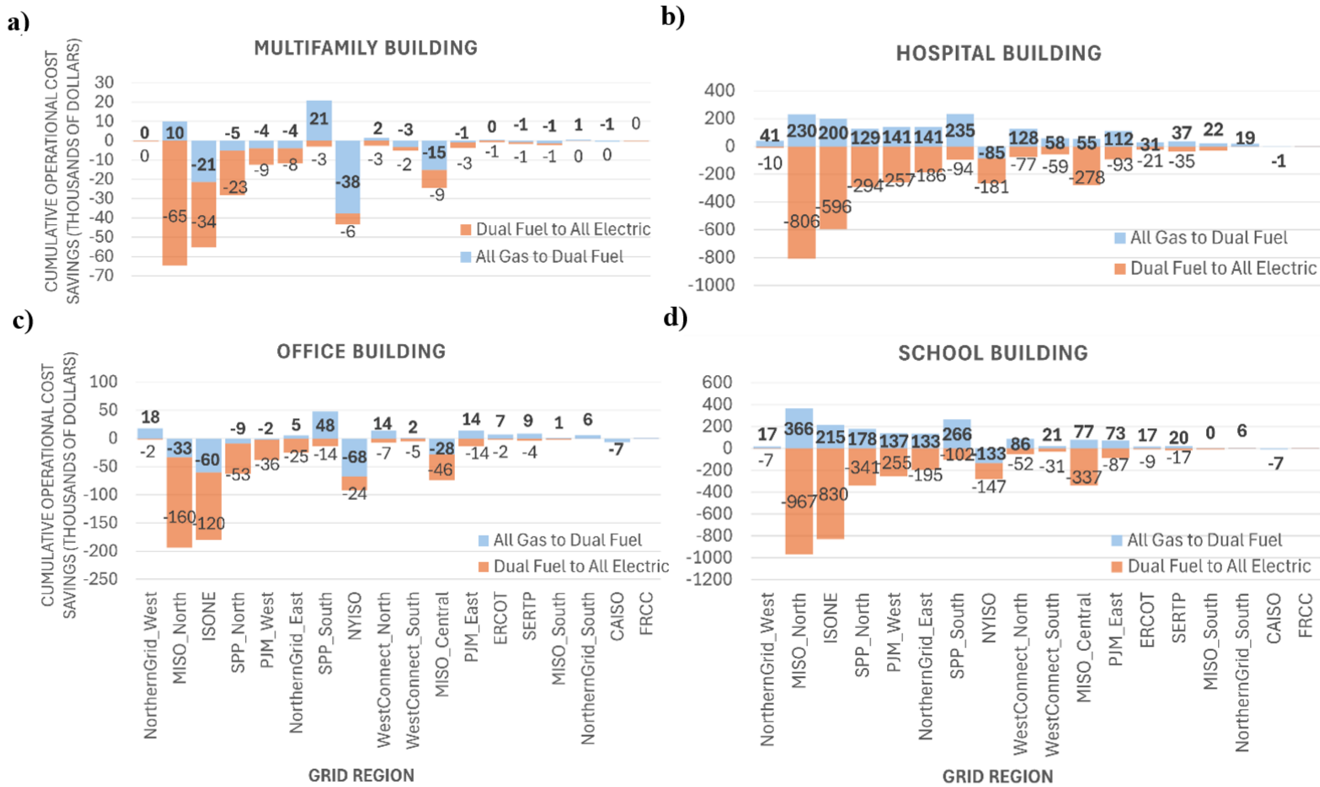


Figure 3 Modeled whole-building operational cost savings over a 15-year period from ASHPs with gas supplemental heating compared to gas-fueled heating, and the incremental savings from electrifying the supplemental heat for the (a) multifamily (b) hospital (c) office and (d) school building types.

Figure 4 was reproduced from our previous publication (Houssainy et al. 2025), where we analyzed the emissions savings of gas versus electric supplemental heat options for ASHPs, through similar building energy models and over the same electric grid regions across the United States. Taken jointly, Figures 3 and Figure 4 demonstrate that for the modeled Office and Multifamily building types, the small incremental emissions savings from electrifying supplemental heat in most of the U.S results in increased operational costs nationwide, with dual fuel heat pump emissions offering varying emissions and cost savings performance. Dual fuel ASHPs in the modeled hospital and school building demonstrate relatively consistent cost savings throughout the U.S. in addition to substantial emissions savings. However electrifying supplemental heat comes at an expensive trade off. Most regions result in minimal, or negative, emissions savings with relatively high opreational costs over a 15-year period, with MISO North, ISONE, SPP North, PJM West, and Northern Grid East exhibiting highest increases in operational costs from full electrification compared to dual fuel systems.

It is important to note that the electricity rates reported by the U.S. Energy Information Administration (EIA) represent an average blended rate—calculated by dividing total electricity revenue by the total energy delivered within each state. While this approach implicitly incorporates time-of-use (TOU) and demand charges, these components are effectively "rolled up" into a single average electricity price. As a result, relying solely on EIA's blended rates may lead to an underestimation of actual electricity costs in site-specific scenarios, particularly where TOU pricing and peak demand charges play a significant role.

To maintain consistency and broad applicability, we've deliberately chosen to use the blended rate approach rather than incorporating detailed TOU and demand-based tariffs. Although a more granular structure could improve accuracy for site specific assessments, such tariffs vary significantly by utility and region and would compromise the general scope of our analysis. This tradeoff is important to acknowledge when interpreting the cost results in Figure 2 and Figure 3.

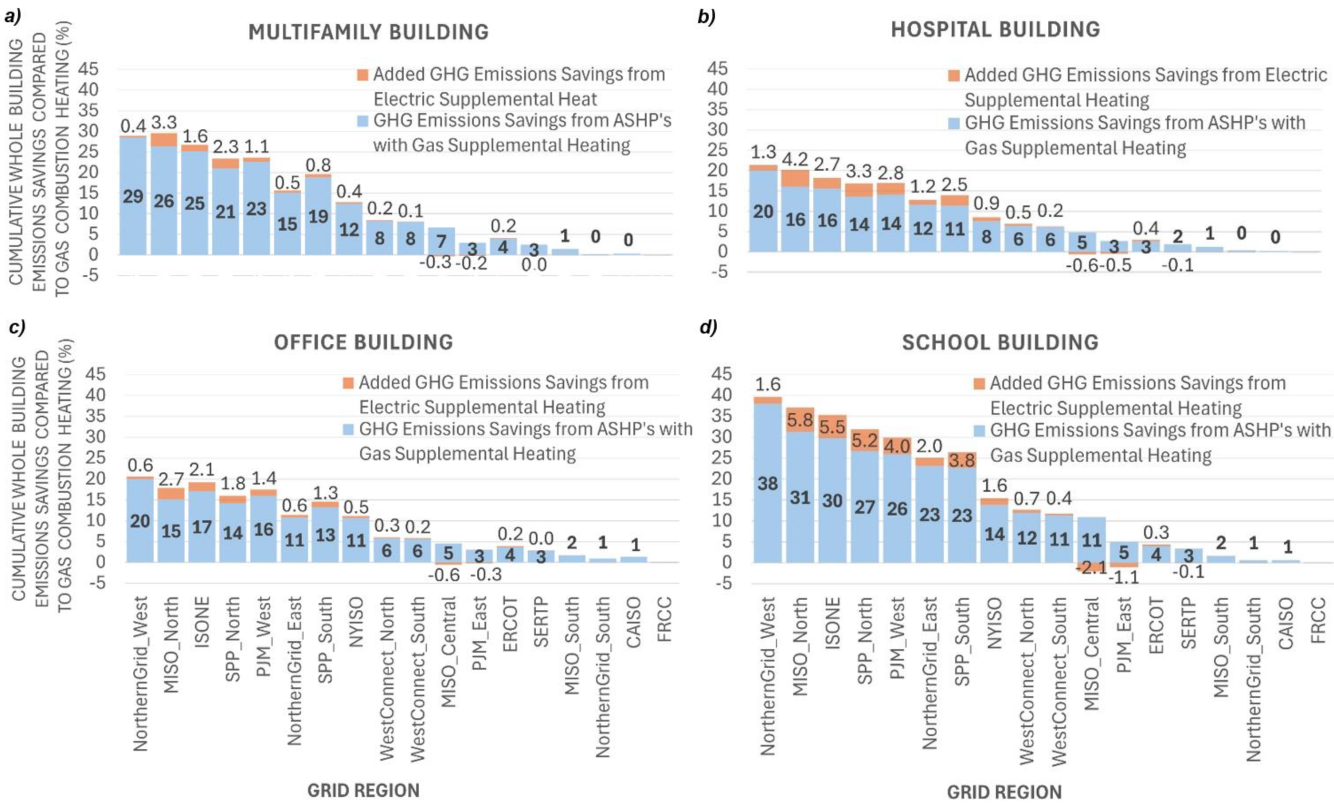


Figure 4 Prior published results of the modeled whole-building emissions savings over a 15-year period (2025-2040) from ASHPs with gas supplemental heating compared to gas-fueled heating, and the incremental increase in savings from electrifying the supplemental heat for the (a) multifamily (b) hospital (c) office and (d) school building types. (Houssainy et al. 2025)

CONCLUSION

This study provides a cost assessment of supplemental heating strategies for air source heat pumps in U.S. commercial buildings, linking operational costs with our previously published emissions outcomes to create a more holistic framework for evaluating decarbonization strategies. The results demonstrate that while dual-fuel ASHPs with gas supplemental heat can reduce operating costs relative to all-gas systems, the economics vary significantly by building type and regional utility price structures. Ventilation-driven buildings such as schools and hospitals consistently benefit the most, achieving both cost and emissions savings across most climates, while envelope-dominated buildings like offices and multifamily housing show more limited or even negative cost savings potential in certain regions.

A critical and consistent finding is that electrifying supplemental heat always produces higher operational costs compared with gas supplemental heat nationwide, though the magnitude is marginal in most regions with the exception of the upper Midwest and Northeast. The marginal efficiency gain of electric resistance compared with gas heating is insufficient to offset the higher electricity prices throughout the U.S. When paired with the limited incremental emissions reductions observed in our previous analysis, this outcome underscores the need for greater precision in supplemental heat electrification strategies.

Together, these findings challenge the prevailing assumption that electrifying supplemental heating is always the more sustainable or cost-effective choice. Instead, they highlight the importance of tailoring decarbonization strategies to local grid conditions, utility prices, building type, and load characteristics. Policymakers, designers, and building owners must carefully weigh both emissions and cost outcomes when considering electrification pathways.

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