AGA
American Gas Association

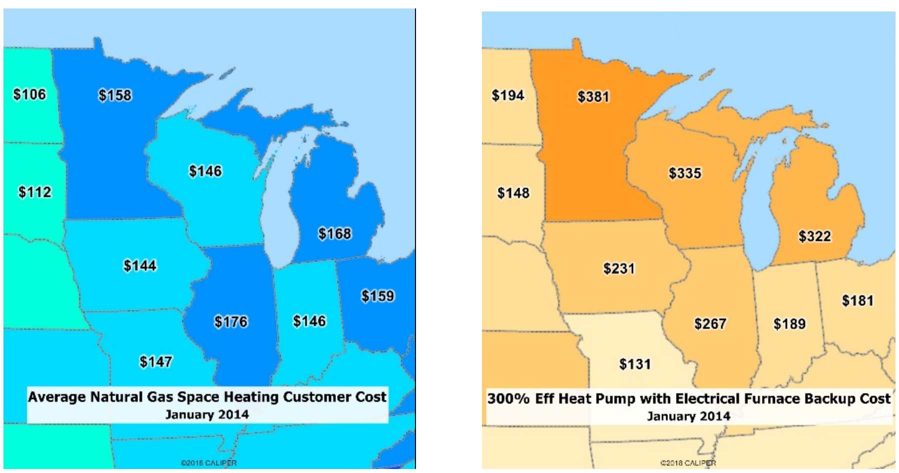
Energy Analysis

ENERGY ANALYSIS GROUP
400 N. Capitol St., NW
Washington, DC 20001
www.aga.org

EA 2019-01 February 19, 2019

A COMPARISON OF SPACE HEATING APPLIANCE COSTS DURING EXTREME COLD WEATHER EVENTS

Figure 1: Regional Comparison of Average Natural Gas and Electric Operating Costs for Space Heating



Extreme cold weather events can have significant effects on costs associated with space heating requirements. These costs are shaped by the amount of energy consumed, which is dependent on the heating load requirements, consumer behavior, the type of energy used, and the performance of the space heating appliance. In addition to home heating fuels such as natural gas, during winter periods, cold temperatures may significantly increase electricity demand also.

The events of January 2019 share many similarities to what took place a few years earlier in January 2014, when most of the Midwest was subjected to arctic temperatures for a prolonged period. This analysis examines the average consumption and space heating costs associated with natural gas and electricity use during an extreme cold weather event. Using weather and energy consumption data collected from the 2014 polar vortex, this paper compares the cost of natural gas and electric space heating scenarios. Noting the same time of year and a comparable array of temperatures, households may see similar costs in January of 2019 that were present in January of 2014.

The study concludes that conventional natural gas furnaces on average have an operational cost advantage over other heating sources, including advanced heat pumps, particularly on the coldest days

Copyright © 2019 American Gas Association. All Rights Reserved.
See Final Page for Notices and Copyright

when space heating requirements are the highest and electric heat pump efficiency and heating capacity is the lowest.

These findings are particularly relevant to ongoing state and federal policy discussions about *residential electrification*. Policies designed to incentivize the electrification of space heating could lead to additional upfront and operational costs to consumers.

<u>Background</u>

Natural gas, electricity, propane, and fuel oil provide nearly all energy for space heating in the United States, which accounts for 43 percent of all energy consumed in a typical home. Space heating requirements, which are concentrated during the coldest winter months, account for the single-largest cost for energy in a typical residential household, nationally.

Based on the most recent EIA Residential Energy Consumption Survey[1], the average midwestern household with an electrical furnace and specified electricity as only fuel in the home spends $911 a year on space heating in general. For households with a heat pump as a primary source of heat the average total heating electric heating bill was $783, for households using propane the average bill was $937, and for households with natural gas as the primary heat source the average total heating bill was $595 per year.

The *polar vortex* of 2014 provides a real-world scenario in which we can examine energy requirements during a significant cold weather event. The polar vortex was a cold wave that descended across North America, bringing unusually cold temperatures to Canada, as well as the north-central and eastern United States during the winter of 2013-2014. More than 100 million people were affected. Ten US states encountered extreme low temperatures for nearly a week, with temperatures dropping below -20 degrees Fahrenheit in some locations. The event was similar to the recent cold wave during January of 2019 but persisted longer.

During January 2014, US homes and businesses saw a significant increase in space heating requirements. On January 1, 2018, the US set a record at the time for natural gas demand in the residential and commercial sector at 79 billion cubic feet.[2] This volume of natural gas contains the equivalent amount of energy that nearly 1,000 gigawatts of electric capacity could generate during 24 hours.

This analysis examines the cost of space heating met by natural gas in the US Midwest during January 2014 and then estimates those same costs if the same heating requirements were met by all-electric heating.

Electric furnaces utilize resistive heat during the coldest periods. While rated at nearly 100% "efficient," on a full-fuel-cycle basis resistive heat is quite inefficient. By contrast, electric heat pumps, which move heat rather than combusting fuel or using resistive elements, operate at efficiencies often ranging

[1] Energy Information Administration - Residential Energy Consumption Survey 2015 https://www.eia.gov/consumption/residential/index.php
[2] S&P Global Platts

between 250-400%. However, heat pump performance degrades as temperatures decline and heat pumps become less efficient, provide less heat output, and the discharge air temperature gets lower.[3]

Analysis

This study first evaluates the heating energy requirements met by natural gas during the polar vortex in January 2014. Then a range of counterfactual scenarios is constructed to assess the potential heating costs of other fuels to meet equivalent energy demand.

The range of costs of the average usage per natural gas customer over all types of residential construction for the month of January 2014 is first determined. These average costs reflect space heating and other end uses such as water heating and cooking. To separate the space heating component, we need to subtract the non-heating "baseload" from the total amount of gas consumed.

Typically, natural gas use in July and August has a zero or near-zero space heating component. Therefore, we assume that natural gas demand during July and August is representative of all non-heating loads. This approach slightly overestimates gas usage for space heating since a water heater's supply water temperature is colder than in summer months. Using monthly EIA natural gas consumption data, average customer usage for the months of July and August (2013 and 2014) subtracted from the total natural gas demand in January 2014. Serves as a surrogate to eliminate the non-heating baseload from the total average usage. Energy costs were derived by multiplying the appropriate EIA residential price by state for the same month of January.

Next, estimates of heat pump performance at various temperature levels were developed. Based on the 2018 AGA study on the *Implications of Policy-Driven Residential Electrification*[4], the typical heat pump efficiency is best when the outdoor source air is above 35-45 degrees Fahrenheit. It is at these temperatures that the heat pump can achieve a 300% or better efficiency. However, as temperatures begin to drop below 35 degrees, this advantage begins to erode and is unlikely to work well below 0-5 degrees.[5] This study applies a conservative estimate that 300% efficiency is achievable at a lower 25-degree outdoor air temperature. The performance of the heat pump also does not take into account a defrost cycle or the age of the unit, both of which may reduce the over efficiency of the unit.

Consequently, customers must rely on other forms of space heat such as electrical resistance or natural gas furnaces to supply auxiliary or back-up heat. As the temperature outside drops, the thermostat is programmed to begin to supplement heating load from the auxiliary source up until the point where the outdoor source air drops low enough to require the entire heating load to come from the secondary provider.

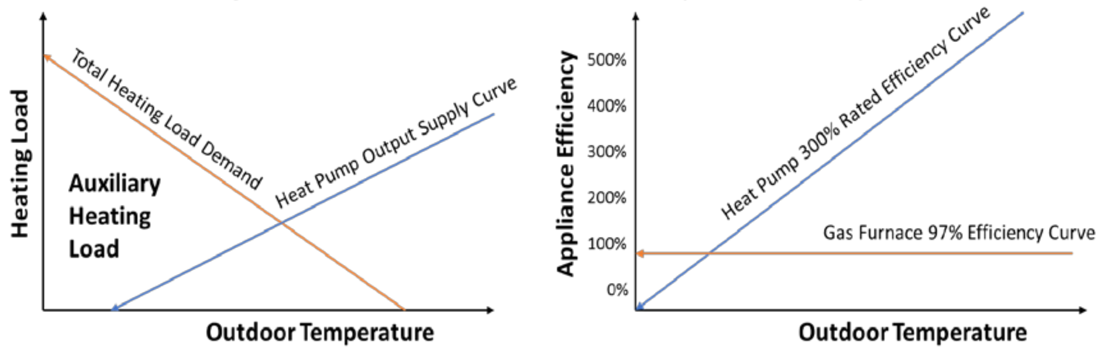
---

[3] Implications of Policy-Driven Residential Electrification. AGA study prepared by ICF. July 2018. https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification/

[4] Implications of Policy-Driven Residential Electrification. AGA study prepared by ICF. July 2018. https://www.aga.org/research/reports/implications-of-policy-driven-residential-electrification/

[5] Note, the analysis presented here is sensitive to these heat pump performance assumptions. If heat pumps perform better or worse than the scenario presented here, whether due to changes in technological capability or calibration by an HVAC installer, the costs can similarly vary higher or lower.

Figure 2: Theoretical End Use Efficiency of Heat Pump



*For source review 2016 ASHRAE Handbook, HVAC Systems and Equipment: Chapter 49 Page 10 Fig. 13 "Operating Characteristics of Single-Stage Unmodulated Heat Pump"

To bracket the range of potential electric costs, we assume electric heating performance between 99% (heating met with the resistive element) and 300% (heating met by a heat pump).

Based on the estimated heat load from natural gas homes during January 2014, an equivalent home with equal heating loads operating an electrical resistance furnace would have incurred a heating bill of between $268 and $652 for the month of January 2014. A heat pump without any backup heat with a similar heating load averaged across a month would have cost between $115 and $315. However this does not include any issues with extreme temperatures beyond the operating range of the appliance and unlikely to provide adequate comfort over all of January 2014.

In order to estimate actual average electric heating performance, this study used NOAA heating degree data to estimate the number of days during January 2014 that homes in a given state would have experienced temperatures below 25 degrees (again, this is the threshold at which we assume heat pump performance begins to degrade).

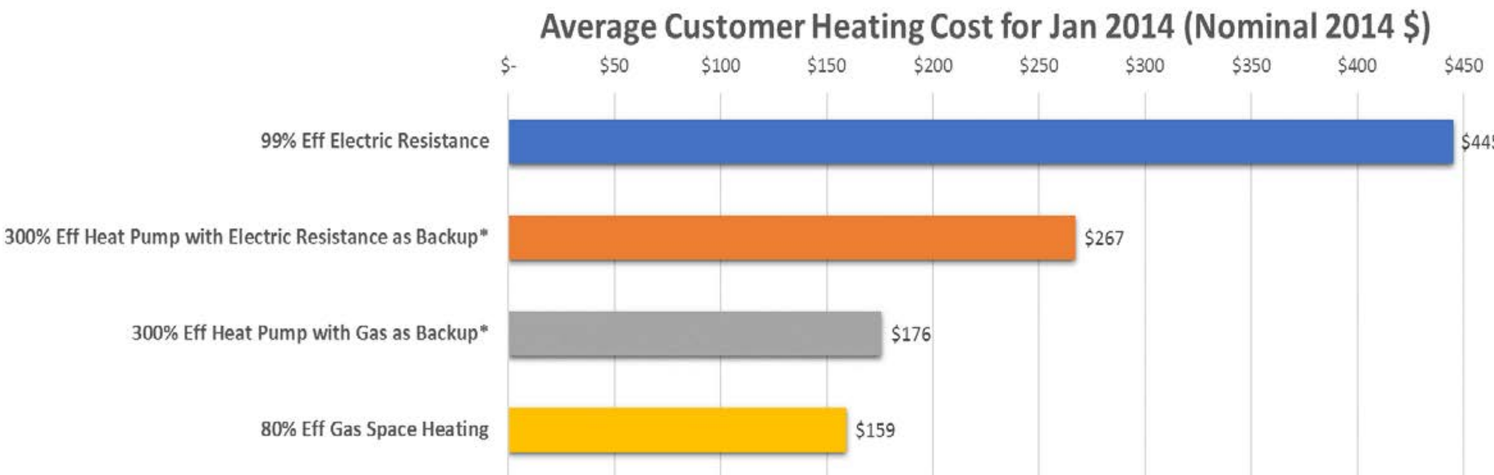
For each of the ten states evaluated, every week where the average temperature was below 25 degrees some or all the space heating demand came from an auxiliary source[6]. Most weeks in January 2014 had average temperatures well below 25 degrees Fahrenheit, suggesting that many households with heat pumps would likely have had to use at least some or only backup heat. For example, in Minnesota, it is estimated that a heat pump rated at 300% efficiency would have operated at an average actual efficiency of 152% over the entire month due to the extreme cold temperatures. This analysis does not address whether the electric system scenarios provide a a comfortable level of heat; the anlaysis replied upon week-long average temperature data and not hourly data, which would be required to make that kind of determination.

For households with back up heat, this represents a potential for the auxiliary furnace to be operating between 5% and 72% of the time or on average 34% of the time across the region. The typical household using electrical resistance heat for backup had heating bills between $131 and $381 in the month of January. The typical customers using an 80%+ efficiency natural gas furnace to supplement a heat pump in the same regions had heating bills between $99 and $203. For customers using either

[6]2016 ASHRAE Handbook, HVAC Systems and Equipment: Chapter 49 Page 10 Fig. 13 "Operating Characteristics of Single-Stage Unmodulated Heat Pump"

natural gas as a primary source of heat or for auxiliary heat; their monthly heating bills were subjected to much less uncertainty since gas-fired appliance efficiency and capacity are not significantly impacted at cold temperature.

Figure 3: Appliance Operating Cost Comparison for Polar Vortex Affected States



*80% efficiency gas and 99% efficiency electrical resistance furnaces operated as auxiliary heat for an estimated 34% of the Jan '14 heating load

Ultimately, consumers cannot make timely changes to the energy source used for space heating. When faced with long term uncertainty over the course of years, customers need to look for both efficiencies and cost to ensure a well-heated home. For customers living in cold climates, the direct use of natural gas for space heating or as auxiliary heat can provide them with less of a shock than those with all-electric heating.

<u>Methodology</u>

The average cost and use per customer were calculated using data provided by EIA for the month of January 2014. By dividing the total residential consumption for that month by the customer count for 2014, an average consumption for each state was calculated. To determine space heating only, an average baseload value was generated by taking the average consumption during July and August of 2013 and 2014 and dividing it by the average annual customer count. The typical household consumption was then estimated by subtracting the average baseload consumption from the overall consumption for January 2014. Cost per customer was determined by applying EIA's price for natural gas for the month of January 2014.

Electrical comparisons are based on the average consumption of natural gas and the regional efficiency of natural gas space heating appliances estimated to be 80% based on EIA projections for the average gas furnace efficiency. By multiplying the final consumption average by the overall gas efficiency, a typical customer heating load for the month was estimated. Applying the heating load to the theoretical efficiency of both a 99% efficient electrical resistance furnace and a 300% equivalent heat pump, we estimated energy consumption for each appliance. Electricity costs per customer were determined by applying EIA's price per state for each fuel for the month of January 2014.

Table 1: Weekly Average Temperature Based on NOAA Heating Degree Day Data

						Estimated Impact from Weather on Heat Pump Efficiency	
	28-Dec	4-Jan	11-Jan	18-Jan	25-Jan	% Heat Pump Eff w/o Aux Heat	% Heating Load w/ Aux Heat
Illinois	24 F	15 F	12 F	26 F	15 F	248%	27%
Indiana	29 F	22 F	18 F	29 F	16 F	282%	15%
Iowa	17 F	8 F	8 F	24 F	15 F	215%	42%
Michigan	25 F	16 F	15 F	28 F	12 F	253%	26%
Minnesota	11 F	-2 F	0 F	18 F	6 F	152%	72%
Missouri	27 F	22 F	20 F	34 F	25 F	306%	6%
North Dakota	11 F	-1 F	2 F	21 F	13 F	174%	62%
Ohio	34 F	24 F	23 F	31 F	16 F	304%	5%
South Dakota	19 F	12 F	13 F	29 F	24 F	255%	26%
Wisconsin	17 F	6 F	4 F	22 F	9 F	191%	54%
Regional Average Impact on Efficiency						**238%**	**34%**

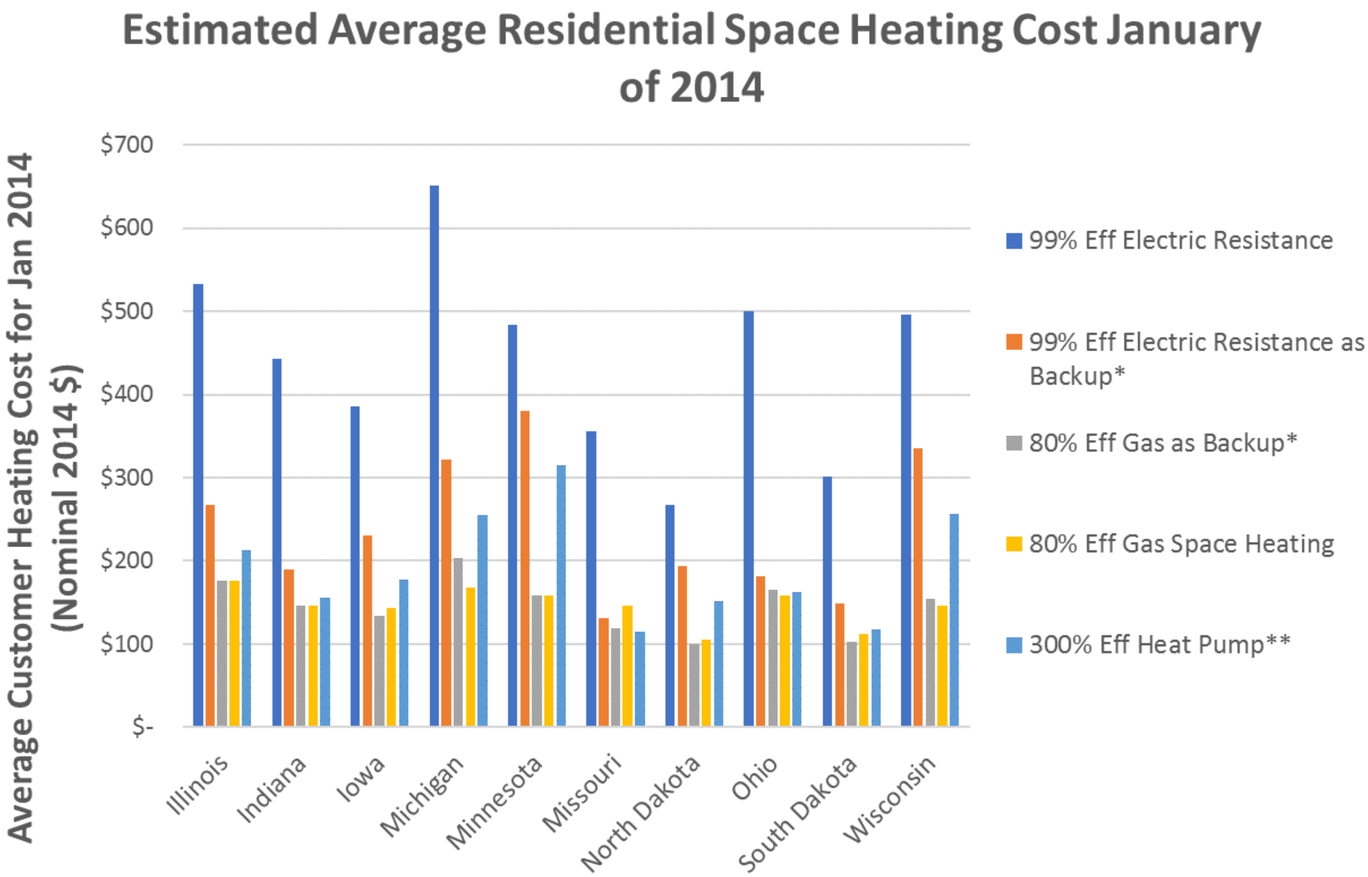
*Weekly average temperatures marked in blue were below the 25-degree threshold and signified a need for auxiliary heat

Due to the below average temperatures in the region, heat pumps are unlikely to be operating 100% of the time. We converted NOAA heating degree day to an average weekly temperature for each state. Every week the temperature dropped below 25 degrees, the average temperature above 0 degrees was divided by 25 to reflect the share of the heating load provided by the heat pump. The use of 25 degrees marks the last point that the heat pump will operate without the need for back-up heat to meet the building's heat loss and 0 degrees marks the moment that all the heat will be provided by the backup appliance. The average of five weeks was multiplied by the optimized operational efficiency of 300% for a heat pump that can remain at peak efficiency despite lower temperatures because of a backup heat source. The remaining percent of the heating load was multiplied by the equivalent cost to operate an auxiliary unit for the same monthly load. This method allows for maximum efficiency for the entire system regardless of outdoor air temperature.[7]

For households using only a heat pump, the same methodology for determining the ratio of degrees above and below 25 degrees was applied to the ideal efficiency of 300% at 25 degrees. For weeks with an above 25-degree average, the efficiency would be above 300%; for weeks below 25 degrees, the average efficiency would decrease based on the same ratio. Compared to the backup heating scenario, when temperatures drop below 0 degrees, rather than use only back up heat the heat pump would continue to operate independently but would result in a less than 100% efficiency due to the required heating load far exceeding the estimated parameters of the appliance. As a result, in some states, the cost to operate a heat pump exceeded the cost to operate an electrical resistance furnace because the average efficiency was below that of a conventional electric furnace.

[7] This method ignores the energy associated with heat pump defrost cycles which increase as the temperature drops. The method also ignores heat pump systems that cannot operate below 25 degrees and would require 100% backup heat to meet the building heat loss.

Figure 4: Appliance Cost Comparison for Polar Vortex Affected States



*80% efficiency gas and 99% efficiency electrical resistance furnaces operated as auxiliary heat for an estimated 34% of the Jan '14 heating load

**The 300%-efficient heat pump is the design efficiency and as a standalone unit was estimated to operate regionally around 238% because of lower outdoor air temperatures

Table 2: Estimated Average Appliance On-Site Energy Consumption for January 2014 (MMBtu)

	99% Efficiency Electric Resistance	99% Eff Electric Resistance as Backup*	80% Efficiency Gas as Backup*	80% Efficiency Gas Space Heating	300% Efficiency Heat Pump Only
Illinois	19	10	11	24	8
Indiana	15	7	7	19	5
Iowa	14	8	10	17	6
Michigan	17	8	9	21	7
Minnesota	15	12	15	19	10
Missouri	14	5	5	18	5
North Dakota	12	9	11	15	7
Ohio	16	6	6	20	5
South Dakota	11	6	6	14	4
Wisconsin	13	9	11	17	7
Regional Average	**16 MMBtu**	**9 MMBtu**	**10 MMBtu**	**20 MMBtu**	**7 MMBtu**

Copyright © 2019 American Gas Association. All Rights Reserved.

In issuing and making this publication available, AGA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is AGA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. The statements in this publication are for general information and represent an unaudited compilation of statistical information that could contain coding or processing errors. AGA makes no warranties, express or implied, nor representations about the accuracy of the information in the publication or its appropriateness for any given purpose or situation.

This publication shall not be construed as including, advice, guidance, or recommendations to take, or not to take, any actions or decisions in relation to any matter, including without limitation, relating to investments or the purchase or sale of any securities, shares or other assets of any kinds. Should you take any such action or decision, you do so at your own risk. Information on the topics covered by this publication may be available from other sources, which the user may wish to consult for additional views or information not covered by this publication.