ELECTRIC POWER RESEARCH INSTITUTE

Quick Insights

Extreme Cold Weather and Heat Pumps

RESEARCH QUESTION

What impacts do extreme cold weather events such as the January United States "polar vortex," which brought sustained sub-zero temperatures to much of the upper Midwest, have on residential heating systems, and can heat pumps "rise to the occasion?"

KEY TAKEAWAY

Effective operation of gas and electric heating systems, and the systems that supply energy to them, may be challenged during extreme cold. During periods of high demand associated with extreme cold weather, an advanced residential heating system combining a high-efficiency heat pump with a gas furnace allows for flexibility in heating fuel (electricity and/or natural gas) to mitigate spikes in heating bills and for increased customer resilience.

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KEY POINTS

- The sustained operation of resistance backup heat during sub-zero (0°F) temperatures—standard heat pumps are often designed to switch to backup heat below about 30°F—instead of the heat pump may lead to disproportionate increases in customer heating bills and extended electric system peak periods.
- In colder U.S. climates, fossil-fueled heating may represent 75% of operating heating equipment during extreme cold, straining fuel supply in systems that rely heavily on natural gas for electricity generation.[1,2]
- EPRI is helping vendors develop an advanced residential heating system, a highly-efficient, tandem of a next-generation heat pump and gas furnace with the ability to provide higher-efficiency heat from the heat pump at cold temperatures (down to or below 5°F), and capable of flexible operation (gas heat with no grid power) during times of uncertainty in fuel price/supply.

1 Ducharme, Jamie. "Michigan Residents Told to Turn Down Thermostats After Fire at Gas Plant." Time. January 31, 2019. Accessed February 05, 2019. http://time.com/5517441/michigan-utility-companies-cold-snap/.

2 Hughlett, Mike. "Xcel Exploring How to Fix Issues that Caused Outages During Polar Vortex." AP NEWS. March 1, 2019. Accessed March 12, 2019. https://www.apnews.com/23bd0eb233d040b484a573730fb384cc.

SPACE HEATING IN THE UNITED STATES

Access to energy resources and relative economics drive heating system adoption. In the United States, fossil-fueled heating currently has 80% saturation in colder climates, compared to less than 50% in milder winter climates (see Figure 1). Electric heat pumps account for only 10% of primary heating equipment in colder climates, compared to about 25% in warmer climates.

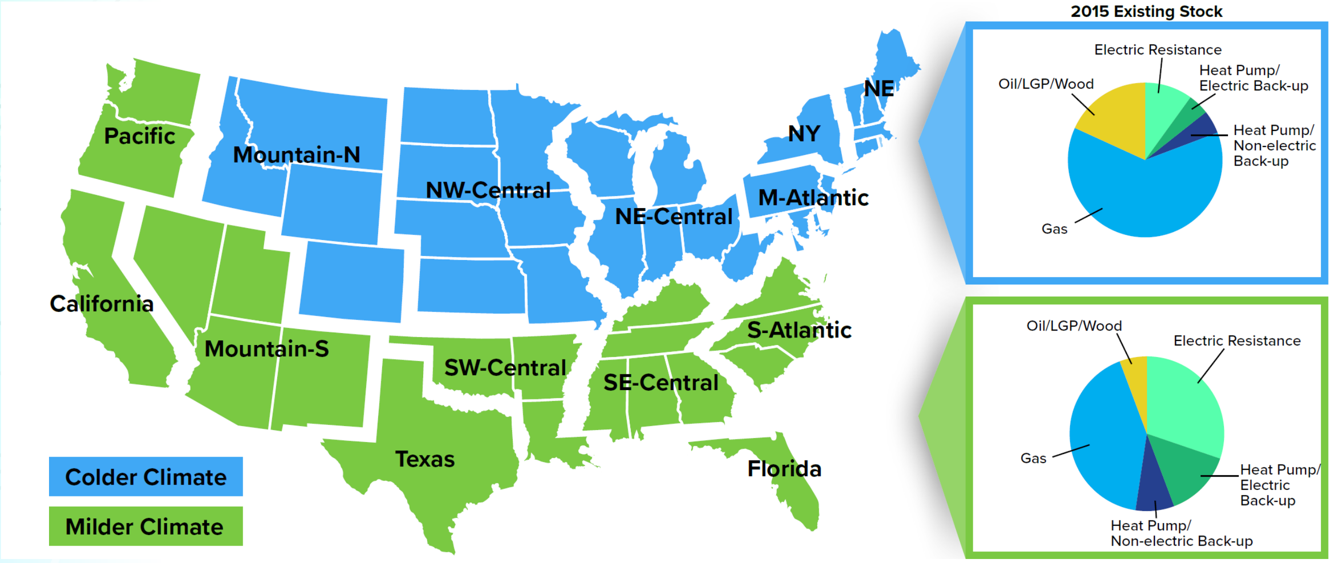

Figure 1. 2015 U.S. primary heating equipment saturation

While today's single-speed heat pumps with fossil-fueled or resistance backup have a small penetration in U.S. markets, technologies such as the next-generation heat pump or the advanced residential heating system (electric and gas) could disrupt the building space conditioning market in these regions. EPRI projects the market share of heat pumps could increase significantly by 2030 in both colder climates and milder climates, particularly in new construction, enabled by these technology advances (Figure 2).[3]

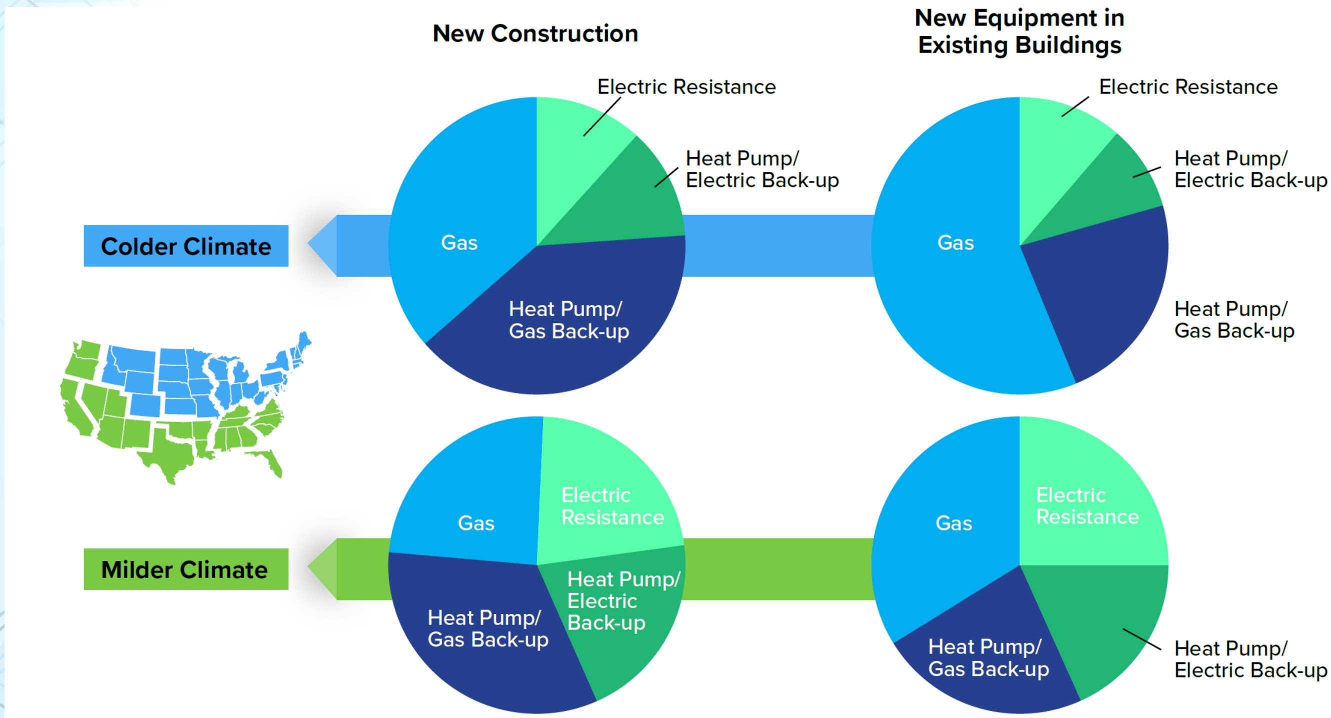

Figure 2. EPRI-estimated 2030 primary heating equipment saturation

3 Market data and figures derived from EPRI's U.S. Regional Economy, Greenhouse Gas, and Energy (US-REGEN) model, https://eea.epri.com/models.html.

SPACE HEATING DURING THE EXTREME COLD

During the "polar vortex" event in the last week of January 2019, temperatures across the northern U.S. dropped to sub-zero (0°F) levels for several days, below standard design conditions for most heating systems in this region. At these extreme conditions that are outside of typical design standards, heating systems struggle to meet maintain comfortable conditions indoors.

Heating systems are sized to provide comfortable indoor conditions at a typical low temperature for the area. In many cases a 99% design condition is used for sizing, to maintain comfortable conditions 99% of the hours in a typical year. Critical applications—for instance, hospitals—are designed for 99.6% design conditions, leading to a larger system with higher heat output. Regardless of fuel type, a heating system cannot provide more thermal energy than it is was sized to provide.

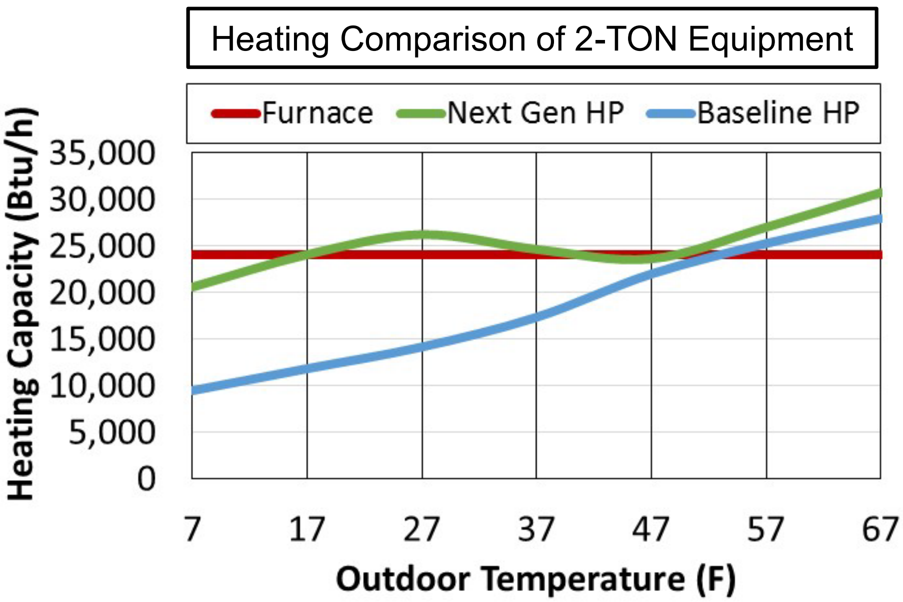

Figure 3. Heating capacity of 2-ton heating systems as a function of outdoor temperature

Consider an example heating system designed to provide 24,000 Btu/h of heating output ("2 tons") to maintain set point temperature 99% of the year (Figure 3). Heating capacity for a 2-ton electric heat pump varies with outdoor temperature. While fossil-fueled heating output is essentially independent of outdoor temperature, all systems will struggle to maintain desired indoor temperatures when the heating load of the building exceeds the 2-ton design output at low temperatures.

AIR-SOURCE HEAT PUMPS AND GAS FURNACES IN COLD CLIMATES

At the outdoor temperature at which the heat pump can no longer meet the heating load efficiently—called the *balance point*—the system will engage a backup heating source (typically electric resistance or a fossil-fueled furnace) to provide additional heat. Balance points for air-source heat pumps are typically around 30°F.

When backup electric heat is used, the customer's electricity consumption for heating may increase by a factor of 5—from about 3 kW for the heat pump to 20 kW for resistance backup—resulting in disproportionate bill and energy demand increases.

Lowering indoor temperature set points effectively decreases the heating needs of the building, and the coldest hours during a year typically occur overnight during setback periods. In prolonged cold spells, a building may remain below the thermostat set point for tens of hours or even multiple days, leading to both customer impacts (decreased comfort) and energy system impacts (extended winter system peak periods).

Electric resistance backup heating *is sized to operate in tandem with the heat pump, with the heating output being additive. For typical residential applications, electric resistance backup is sized between 5 and 20 kW. Oversizing electric backup heating systems is relatively inexpensive and can serve as a safety factor during extreme cold.*

With ***gas-fired backup heating*** *(commonly termed "dual-fuel") the gas furnace—which may use natural gas, propane, or fuel oil—is coupled to the electric heat pump, which operates in an either/or arrangement in which the heat pump covers the entire load down to its balance point; below the balance point, the furnace takes over.*

From a utility perspective:

- *In colder climates, fossil-fueled heating may represent 75% of operating heating equipment. Systems relying heavily on natural gas for electricity generation, or concurrent faults in the gas system may lead to fuel supply limitations that impact customers, in some cases resulting in interruptions to gas heat.* [1,2]
- *In milder climates, in which heat pumps are more prevalent, electric resistance constituting 45% of operating heating equipment. The higher-demand operation of backup resistance heat and the impacts on system load are expected for a few hours on cold winter mornings, however conditions described here would extend that contribution to system winter peak.*

EMERGING COLD-CLIMATE HEATING TECHNOLOGIES

Next-Generation, Variable-Capacity Heat Pumps

Current EPRI Work
Demonstration of next-generation heat pumps—smart, variable-speed systems with fossil-fueled backup—as a high-efficiency customer option with enhanced demand response capabilities.

Variable-capacity heat pumps (VCHP)[4] are the key building block of the next-generation heat pump. Compared to a standard-efficiency, single-speed heat pump, VCHPs can modulate their output to satisfy part-load conditions at a higher efficiency. Some VCHPs are designed to meet all of the heating load using the heat pump only at low temperatures.

Depending on how the system is sized, a variable-capacity heat pump that meets a cold-climate specification could mitigate the need for backup heat altogether, reducing higher bills associated with electric backup, and shifting backup gas heating back to the efficient heat pump. Several manufacturers now offer variable-capacity heat pumps capable of sustained and productive operation well below 5°F. By integrating off-the-shelf or near-term technology, a next-generation heat pump can improve overall space conditioning efficiency—both heating and cooling—by more than 50%, compared to incumbent systems.

Furthermore, next-generation heat pumps will be connected devices, enabling additional customer and utility value through enhanced monitoring and controls for continuous commissioning, predictive maintenance, and enhanced demand response.

Advanced Residential Heating Systems

Current EPRI Work
Collaborating on development of advanced residential heating system specification with goal to work with an HVAC manufacturer in development of a prototype.

Today, the heat pump with natural gas backup (commonly known as a dual-fuel or hybrid heat pump) is a mature technology. This system is a simple combination of an electric heat pump and gas furnace, combined physically but operated independently. The system design and supply constraints encountered during the recent extreme-cold event points to a need for an advanced hybrid heating system that extends the concepts of dual-fuel and next-generation, variable-capacity heat pumps in the following way:

- Simultaneous operation of the next-generation heat pump and backup source: Today's heat pump controllers do not allow simultaneous operation of the heat pump and backup sources. The cross-over temperature is defined in design and installation to turn off one unit and turn on the other. This precludes the heat pump from providing a portion of the energy at lower temperatures, when it cannot provide the full heating needed. Simultaneous operation removes this constraint, enabling more flexible operation of the heat pump/backup system—in an either/or manner or in an additive manner.

4 Residential Variable-Capacity Heat Pumps. EPRI, Palo Alto, CA: 2015. 3002008505. https://www.epri.com/#/pages/product/3002008505/

- **Efficient electric components with backup power**: Incorporating more efficient electrical components, and backing up these components with a battery system or on-site generation in the event of a power outage, provides a more resilient space conditioning solution. In particular, the system will have the capability to heat the home using the natural gas furnace, running the blower fan in the absence of grid power.

Building on the high-efficiency next-generation heat pump, EPRI aims to maximize the efficiency, resiliency, and flexibility of dual-fueled residential heating systems through complete system and digital connection.

NEXT STEPS/ONGOING EPRI WORK

The capability to use either a high-efficiency electric heat pump or a gas furnace, or some combination, can give customers options to maintain comfort levels and mitigate bill increases in extreme weather conditions or extended power system outages. Through its Technology Innovation (TI) program in 2019, EPRI is working to help develop the advanced residential heating system.

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