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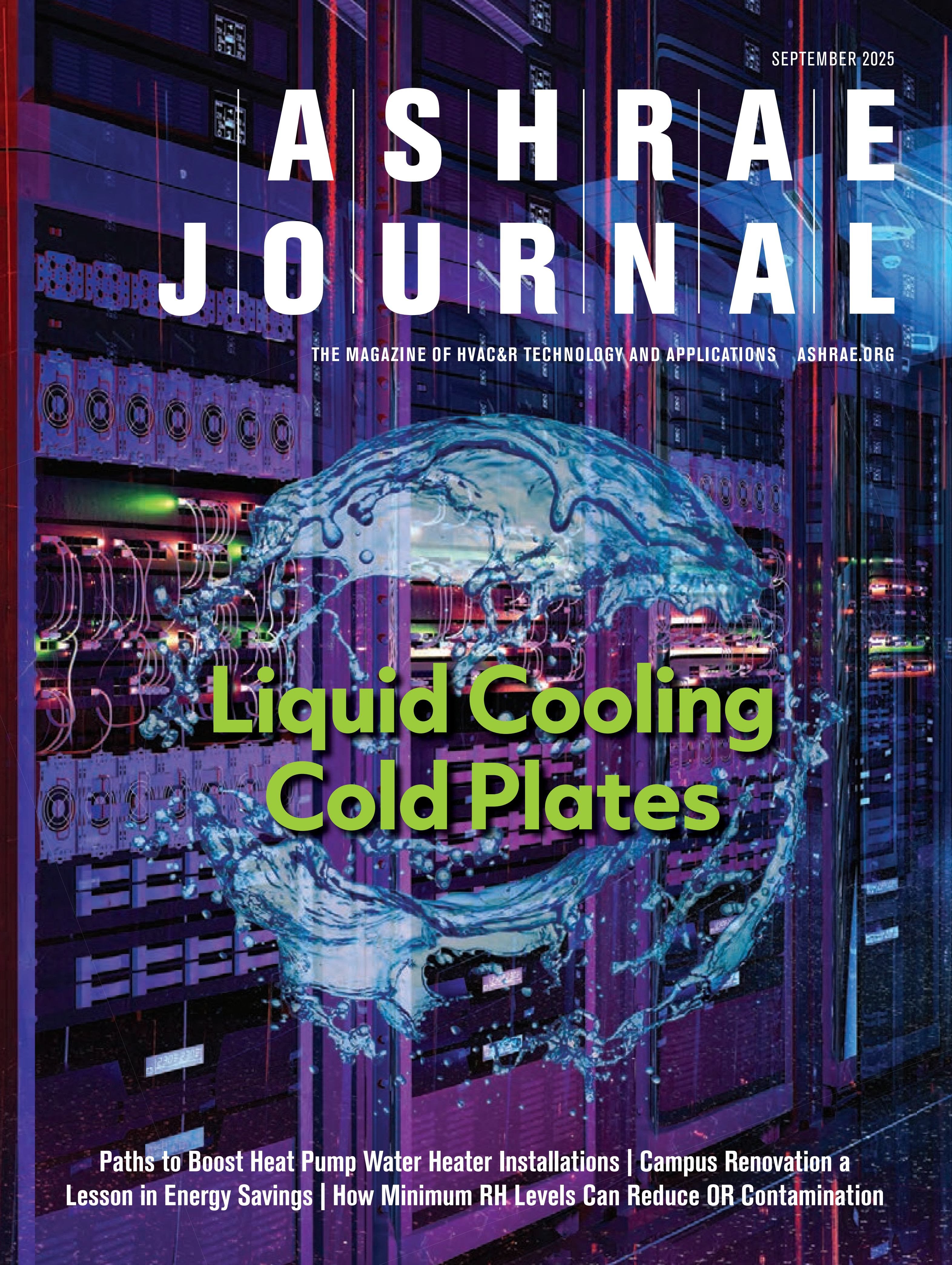

Liquid Cooling Cold Plates

Paths to Boost Heat Pump Water Heater Installations | Campus Renovation a Lesson in Energy Savings | How Minimum RH Levels Can Reduce OR Contamination

Alexander S. Butkus

Low-Hanging Fruit

Why You Should Install a Heat Pump When Replacing Your Residential AC

BY ALEXANDER S. BUTKUS, P.E., FELLOW/LIFE MEMBER ASHRAE

In northern climates, many residential HVAC systems consist of a natural-gas–fired furnace and an electric-driven central air conditioner. The author recently replaced a 20-year-old central air conditioner and natural-gas–fired furnace (due to excessive age) with an electric-driven heat pump (compliant with requirements of the local utility rebate and U.S. 2023 Federal Residential Energy Credits, Part II, Section B) and a natural-gas–fired furnace. This type of system is referred to as a hybrid heat system or dual-fuel heat pump system.

Project benefits included:

- The utility rebate and energy tax credit exceed the heat pump cost premium by more than $2,000, making the heat pump cheaper than a cooling-only air conditioner.
- The ability to choose an energy source for heating based on natural gas and electric utility costs.
- The potential reduction of site energy emissions by more than 50% if electricity is chosen as the primary heating energy.

Background

The residential HVAC system was replaced in September 2023. The new system included the following:

- Two-stage variable speed natural-gas furnace with an annual fuel utilization efficiency (AFUE) of 96%, 84,000 Btu/h (24.6 kW) output;
- Inverter-driven split system heat pump, refrigerant R-410A, AHRI 210/240-2023 performance ratings:
  - SEER2: 18 (SCOP2C: 5.28);
  - EER2 (A Full): 10.5 (COP2C: 3.08);
  - HSPF2 (Region IV): 8.5 (SCOP2H: 2.49);
  - Heating capacity (H1 Full)-High Stage (47°F

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[8.3°C]): 33,000 Btu/h (9.7 kW); and

- Cooling capacity (A Full)-High Stage (95°F [35°C]): 34,400 Btu/h (10.1 kW)

- MERV 13 filter, 4 in. (102 mm) pleated; and
- Third-generation smart thermostat.

The heat loss for the residence has been estimated using a linear regression of actual natural gas use as metered by the utility and heating degree days from the nearby Aurora (IL) Municipal Airport (*Figure 1*).

2020/2021 data were used for the analysis because these data had the highest correlation compared with more recent years. (These data reflect nearly 100% daily occupancy of the residence due to COVID, which eliminated thermostat setbacks due to travel. This scenario should provide a better estimate of the actual heat loss.) The regression provided an estimated peak hourly heat loss for the residence at –10°F (–23.3°C) outdoors and 70°F (21.1°C) indoors of 34,500 Btu/h (10.1 kW).

FIGURE 1 Regression of monthly heating degree days (HDD) and natural gas use, 2020/21 heating season.

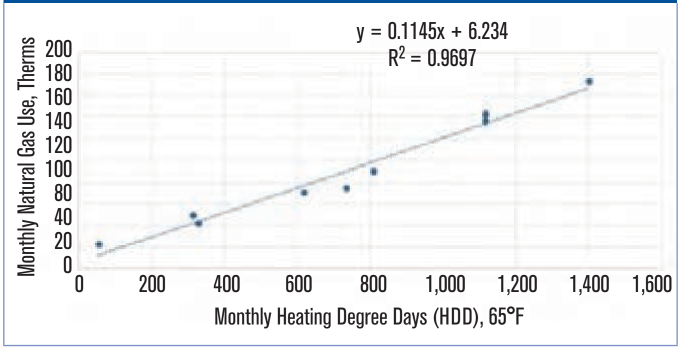
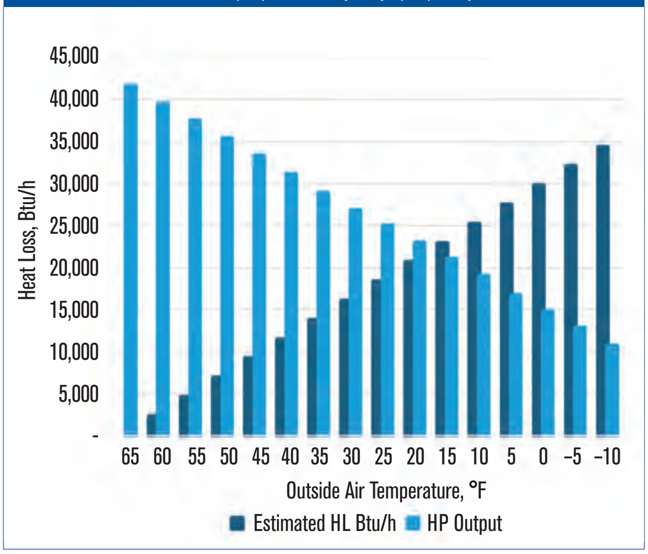


FIGURE 2 Home heat loss (HL) vs. heat pump (HP) output.



Heat Pump Operation Decisions

Operating the heat pump requires two primary decisions. First, at what ambient condition should the system switch between natural gas and heat pump? Second, how does a homeowner determine when it makes economic sense to use the heat pump rather than natural gas, or vice versa?

The first question is relatively straightforward. One can compare the residence's heat loss to the output capacity of the heat pump at various outdoor temperatures. Since the building's heat loss increases as the temperature drops, and the heat pump capacity does the inverse (output capacity decreases as the outdoor temperature drops), the two will likely be equal at some point (*Figure 2*).

At slightly less than 20°F (–6.7°C) outdoors, the rated output of the heat pump and the residence's heat loss are equal. Based on these data, 25°F (–3.9°C) was chosen as a changeover between natural gas and electricity as the heating fuel, based on system capacity alone. One could choose a higher switchover temperature if the relative economics of natural gas and electric-driven heating so dictated.

The second question—when is it economically favorable to operate the heat pump over natural gas, and vice versa—is more complicated. Here are many factors that must be considered in this analysis:

- The natural gas marginal cost may be changing monthly.
- The electricity marginal cost may be changing monthly (or hourly, in some situations).
- The price change dates for both fuels may not coincide.
- The heat pump heating efficiency changes as the outdoor temperature changes.
- The net efficiency of the natural-gas–fired furnace changes as the temperature changes, but not as dramatically as the net efficiency of the heat pump.
- The above issues may cause the fuel switchover temperature to change due to a change in the economics of each fuel.
- One often does not know the utility costs until the billing period is over.

Table 1 shows the hourly operating costs of natural gas (NG) and heat pump operation at various utility costs and based on heat pump ratings at various outdoor

TABLE 1 Hourly operating cost of system.

OAT, °F	COST TO OPERATE PER HOUR NATURAL GAS (NG) AND HEAT PUMP (TO PRODUCE HP OUTPUT)							
	NG (2023/2024) $0.60/THERM	NG $0.80/THERM	NG $1.00/THERM	NG (2022/2023) $1.15/THERM	HP $0.10/kWh	HP (2022/2023) $0.125/kWh	HP (2023/2024) $0.146/kWh	HP $0.16/kWh
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
65	$0.26	$0.35	$ 0.43	$0.50	$0.31	$0.39	$0.45	$0.50
60	$0.25	$0.33	$ 0.41	$0.47	$0.30	$0.38	$0.44	$0.48
55	$0.23	$0.31	$ 0.39	$0.45	$0.30	$0.37	$0.43	$0.47
50	$0.22	$0.30	$ 0.37	$0.42	$0.29	$0.36	$0.42	$0.46
45	$0.21	$0.28	$ 0.35	$0.40	$0.28	$0.34	$0.40	$0.44
40	$0.19	$0.26	$ 0.32	$0.37	$0.26	$0.32	$0.37	$0.41
35	$0.18	$0.24	$ 0.30	$0.35	$0.24	$0.30	$0.34	$0.38
30	$0.17	$0.22	$ 0.28	$0.32	$0.24	$0.30	$0.34	$0.38
25	$0.16	$0.21	$ 0.26	$0.30	$0.24	$0.30	$0.35	$0.38
20	$0.14	$0.19	$ 0.24	$0.28	$0.24	$0.30	$0.35	$0.38
15	$0.13	$0.18	$ 0.22	$0.25	$0.24	$0.29	$0.34	$0.38
10	$0.12	$0.16	$ 0.20	$0.23	$0.23	$0.28	$0.33	$0.36
5	$0.10	$0.14	$ 0.17	$0.20	$0.22	$0.27	$0.31	$0.34
0	$0.09	$0.12	$ 0.15	$0.18	$0.20	$0.25	$0.30	$0.32
-5	$0.08	$0.11	$ 0.13	$0.15	$0.19	$0.24	$0.28	$0.31
−10	$0.07	$0.09	$ 0.11	$0.13	$0.18	$0.22	$0.26	$0.29

conditions. The author chose to operate the system in the heat pump mode for the 2023/2024 heating season for data-gathering purposes. Columns 2 and 8 (yellow) are based on the mean marginal utility costs for the billing months of October through March 2023/2024.

Observations include:

- Natural gas would have been the fuel of choice in the 2023/2024 heating season.
- The natural gas advantage ranges from 42% at 65°F (18.3°C)—$0.26 per hour vs. $0.45 per hour—to 54% at 25°F (-3.9°C)—$0.16 per hour vs. $0.35 per hour.

On the other hand, the 2022/2023 heating season would have favored the heat pump. See columns 5 and 7 (orange), which are based on the mean marginal utility costs for the billing months of October through March 2022/2023. (The heat pump is apparently less costly to operate per hour as the outside air temperature drops because the heat pump output is dropping as colder conditions prevail. The costs in the table are based on total heat pump output at each outside air temperature.)

Observations of the 2022/2023 data include:

- The heat pump showed a 22% reduction ($0.50 per hour vs. $0.39 per hour) at 65°F (18.3°C).
- However, due to the heat pump's loss of efficiency at lower outdoor temperatures, the advantage disappears at 25°F (–3.9°C), with both systems costing $0.30 per hour to operate.
- The heat pump would have been the choice to operate in 2022/2023 until the temperature had fallen to 25°F (–3.9°C), at which point heat pump and natural gas operating costs were equal.

The homeowner does not typically have the luxury of a professional engineer to analyze the data for making the fuel source decision. However, smart thermostat manufacturers have most, if not all, the data to assist in this decision. They know the system type in the home, the zip code (hence the local utility), and the switchover temperature set on the thermostat. Algorithms in some smart thermostats are already involved in decisions such as demand control, limiting equipment operation in peak demand periods in some locations.

Site Emissions Reduction

The system has been operating in the heat pump mode since September 2023. *Figure 3* shows linear and nonlinear regression equations for natural gas use and heating degree days (same airport as previously referenced) for the 2023/2024 heating season. The nonlinear regression resulted in a higher correlation (R^2) compared with the linear equation (0.9876 vs. 0.8535).

In *Table 2* hybrid heating and natural-gas–fired furnace heating natural gas use are projected based on regression models for each system type and typical heating degree days. As previously noted, the nonlinear equation appears to be a better model for projecting the hybrid heating system's annual natural gas use.

For the natural-gas–fired furnace projected use, the author chose data from the 2020/2021 heating season that is consistent with the heat loss data previously presented. The regression used is:

Natural gas use, therms = 0.1145 × heating degree days + 6.234; correlation = 0.9697.

The hybrid heating system is projected to use 226.9 therms (6,650 kWh) per year (plus attendant increase in heat pump electric use, not shown), and the natural-gas–fired furnace heating system is projected to use 743.9 therms (21,802 kWh) per year.

The analysis projects a 69% reduction in natural gas use, and, hence, site emissions. Source emissions may also be analyzed (for a macro view of total emissions), considering the local utility's power generation profile (i.e., a utility using primarily fossil fuels for power generation vs. a utility largely driven by non-fossil fuels such as nuclear, hydro, wind and solar).

The analysis did not directly account for two factors that would change the natural gas reduction estimate. First, the original furnace (in use during the 2020/2021 heating season) and replacement furnace are unlikely to be equal efficiencies, although they are both condensing furnaces. Second, homeowner activities that affect heating energy consumption have not been adjusted for.

FIGURE 3 Regressions for heat pump (HP) operation—monthly natural gas use vs. HDD after HP install.

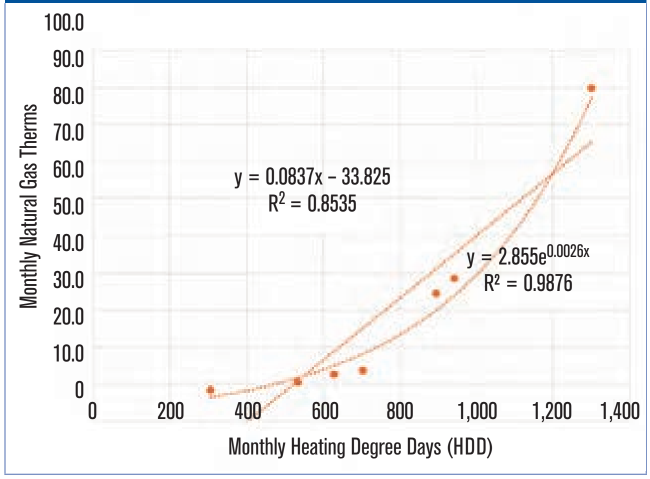


TABLE 2 Projected natural gas use hybrid system vs. natural gas furnace.

PROJECTED GAS USE BY SYSTEM TYPE–TYPICAL YEAR			
MONTH	AVERAGE HEATING DEGREE DAYS	HYBRID HEATING PROJECTED GAS USE	GAS-FIRED FURNACE PROJECTED GAS USE
January	1,233	70.5 therms	147.4 therms
February	1,047	43.4 therms	126.1 therms
March	808	23.3 therms	98.8 therms
April	468	9.6 therms	59.8 therms
May	198	4.8 therms	28.9 therms
September	116	3.9 therms	19.5 therms
October	355	7.2 therms	46.9 therms
November	713	18.2 therms	87.9 therms
December	1,069	46.0 therms	128.6 therms
TOTALS	**6,007**	**226.9 therms**	**743.9 therms**
REDUCTION IN GAS USE		**69%**	

Conclusions

The author's contractor estimated a $500 to $1,000 incremental cost to install the heat pump system. This was more than offset by more than $3,000 in tax credit and utility rebate funds. With the cost offset, everyone with natural-gas–fired furnaces should strongly consider installing a hybrid heat system when replacing their equipment. Even if the cost offsets did not occur, one should consider buying a heat pump given the uncertainty of utility costs over the life of the system. As the two recent years in the Chicago area showed, one year favored heat pump operation and another favored natural gas use.

Decision-making tools should be developed to simplify operating decisions for contractors and homeowners. Heat pump manufacturers, utilities and smart thermostat manufacturers should collaborate in this regard, helping homeowners determine the proper switchover temperature and make intelligent fuel choice decisions.

Acknowledgments

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