

HVAC



Heat Pumps in the Age of Electrification

To be successful, we need to better understand heat pumps

BY STEVE EASLEY

Concerns over climate change have sparked a movement toward electrification—the process of switching from fossil fuels for space heating, water heating, cooking, and transportation. Washington recently became the first state to mandate electrification by banning gas for new multifamily and commercial buildings, while legislatures in at least four states—Rhode Island, Massachusetts, New York, and Maryland—are vying for their state to be the next to impose similar bans that may include single-family homes. The move away from gas began at the city level, with Berkeley, Seattle, and New York City being the first to ban gas use for all new buildings. Some 60 cities in over 20 states have laws that ban gas, propane, and heating oil in new buildings.

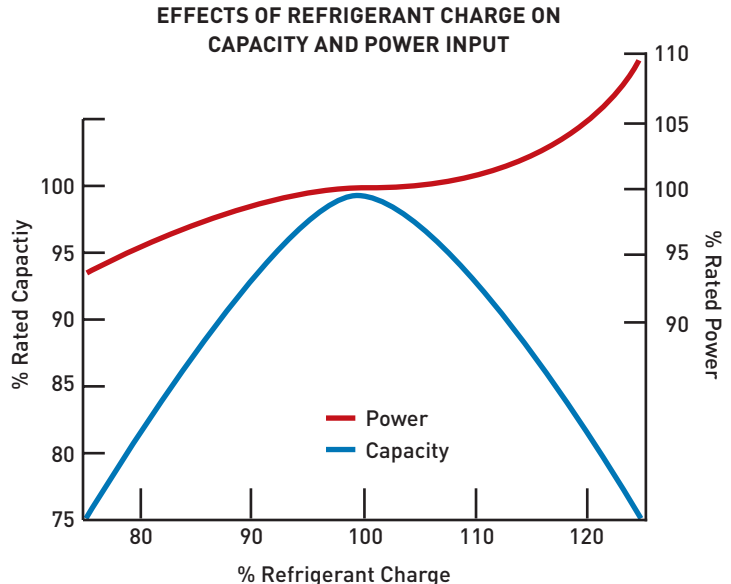
But the issue has become intensely political, and there are also now more than 20 states with counter laws that prevent cities from banning gas use in buildings, and 10 other states that prohibit electric utilities from encouraging customers to switch away from gas.

Regardless of how the politics play out, electrification is coming. In many U.S. cities, natural gas used in buildings is the second-largest source of emissions behind vehicles. About 20% of greenhouse-gas emissions across the U.S. comes from residential energy use. That doesn't include the leaks from gas lines. A study published in *Science* found there were enough natural gas (90% of which is methane, a potent ozone-depleting gas) leaks from U.S. oil and gas operations to fuel 10 million homes each year. In order to

Photos by Steve Easley, except (1) by Ted Cushman



Failure to charge an air-source heat pump to 100% has a severe impact on not only the unit's rated capacity but also on power draw, as shown in the graph at right. Pressure testing (1) ensures a leak-free refrigerant line.



move the needle on greenhouse-gas emissions, we will increasingly need to reduce fossil-fuel consumption at every level. It's happening with cars and trucks—the biggest source of fossil-fuel consumption—and it will happen with buildings, including homes.

We're on that path already: According to the Energy Information Administration (EIA), natural gas and electricity are the two biggest sources of energy used in U.S. homes. Figures from the EIA's Residential Energy Consumption Survey show that natural gas was used in 58% of homes in 2015 but that usage fell to 42% in 2020 and is now running almost neck and neck with the consumption of electricity, which has taken over as the biggest source of residential energy use, at 43%. Space heating accounts for about 43% of a home's energy use and water heating adds an additional 19%. Heat pumps offer a real solution—possibly the only technology solution we currently have—to providing the space and water heating portion because they make such efficient use of electrical energy.

GETTING IT RIGHT

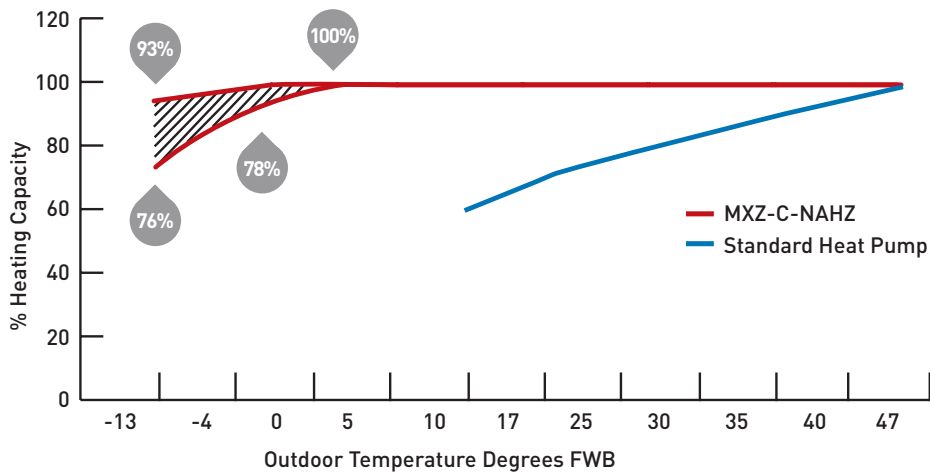
While the shift toward electricity is happening, not all of that electricity used to heat homes is helping the climate. Electric furnaces and strip-resistance heaters are sometimes called “efficient” (100% of the electrical energy coming into the heater is converted to heat), but it's only 100% efficient inside the building. The generation of that electricity at a power plant was probably 30% to 40% efficient after taking into account power grid and transmission losses, so the net efficiency is poor. The bottom line is it's easier clean up the emissions from a few power plants than from millions of furnaces and water heaters in buildings and homes. Fortunately, utilities are moving toward renewable energy sources for electricity generation in place of fossil fuels.

An air-source heat pump (ASHP) is essentially an air conditioner that runs in reverse, making it an ideal appliance for homes because the same piece of equipment can be used for both heating and cooling. In heating mode, an ASHP uses the refrigeration cycle to move heat from the outdoors to an enclosed space, gradually warming the indoor air. A kilowatt hour of energy consumed as electricity can pull the equivalent of 3 kilowatt hours of energy from outdoor air. That 1 kilowatt hour of energy the heat pump consumes is used to run a fan, compressor, and blower to run a refrigeration cycle; the heat itself is transferred from a refrigerant that releases energy that it absorbed from the outdoor air.

The compressor uses electrical energy to change the pressure and the temperature of a refrigerant. When the refrigerant changes state from a liquid to a gas, heat is absorbed. By exploiting the energy release from this phase change, ASHPs used for space heating can reach efficiencies of 200% to 400%. And if we use hydro-, solar-, or wind-generated electricity instead of climate-damaging, fossil-fuel-generated electricity, the net efficiency becomes even greater. That's what excites everyone about electrification, and why space heating and water heating is shifting over to heat pumps.

But for this to succeed, building professionals at all levels need to know how to design, install, operate, and maintain heat pumps. Otherwise, while trying to make a difference on the environment, we may just end up making homeowners more uncomfortable, with higher energy bills, and fail to save energy. If heat pumps don't perform as well as the old dinosaur burners they are replacing, the technology will lose favor with consumers, and the reduced emission goals won't be achieved. Certainly, there are other huge infrastructure challenges to making electrification work. In this article, I am going to focus only on what building professionals need to get right in homes, with the expectation that larger

H2I MXZ HEATING CAPACITY AT LOW TEMPERATURES



An inverter-type heat pump can maintain 100% heating capacity down to 5°F and produce heat down to -13°F. The graph at left from Mitsubishi compares different models in its H2i series with a fixed-output heat pump that starts losing capacity below 47°F.

issues relating to the U.S. electric grid, and scaling non-fossil-fuel electrical production, can be solved.

MEASURING HEAT PUMP EFFICIENCY

ASHP efficiency is measured a few different ways:

Heating efficiency of a specific heat-pump unit (not the efficiency with which a space is heated) is defined as the quantity of heating or cooling delivered by the heat-pump unit per the amount of energy required to run the unit. We measure that as a heating season performance factor (HSPF), which is equal to the total space heating (in Btu) provided by the ASHP over the heating season divided by the total electrical energy (in watt hours) consumed by the ASHP over that same heating season.

COP, the coefficient of performance, is another way heat pump efficiency is measured. A COP of 1 means that 1 kilowatt of energy consumed by the ASHP delivers 1 kilowatt of heat output—an efficiency of 100%. A COP of 3 means I get 3 kilowatts of heat output for every 1 kilowatt of input—an efficiency of 300%, and so on. These high efficiencies are possible because we are extracting that heat from the outdoor air. Even in winter, air at zero degrees still has quite a bit of heat in it. (Air has some heat all the way down to absolute zero—459 degrees below zero!)

Cooling efficiency is similar, except we are now looking at how much heat is removed. We measure this as an energy efficiency ratio (EER), which is equal to the heat removed in Btu/hour divided by the electricity used in watts. If an air conditioner puts out 48,000 Btu per hour and consumes 4,000 watts, then the EER would be 12. And the SEER, or Seasonal Energy Efficiency Ratio, is the energy efficiency ratio calculated over the entire cooling season, at an average temperature of about 83°F.

Efficiency vs. capacity. Conventional ASHP efficiency is related to outdoor air temperature. The colder the air, the lower the efficiency.

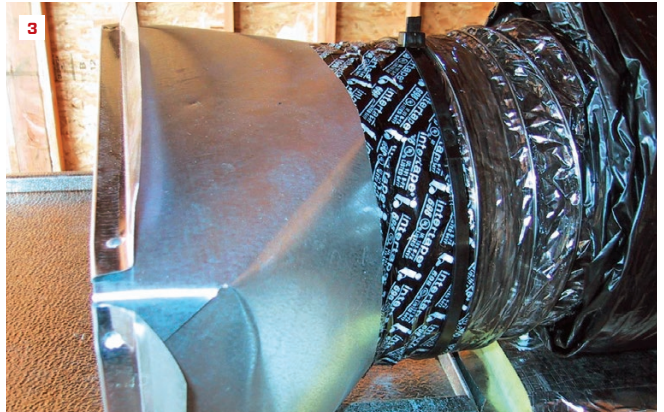
Heating capacity is the output number of Btu. The heating ca-

capacity of a conventional ASHP starts to diminish when the outdoor temperature drops below about 50°F. Both the output capacity and the speed at which a conventional ASHP can heat a home or recover the heat lost from a home is also a function of the outdoor temperature: Colder outdoor air means diminished performance.

This becomes very clear to a homeowner when we switch out the heating appliance from a fossil-fuel furnace to a standard ASHP. Gas furnaces discharge air through the supply plenum at around 110°F to 140°F, regardless of the outdoor temperature. Homeowners are used to feeling this hot air. Particularly in a drafty house or one that's not well insulated, they look to this blast of sensibly warm air to feel comfortable. Typically, a conventional heat pump can provide air to the room at 15 to 25 degrees warmer than the room air temperature. But if the discharge temperature drops below the temperature of the body's skin, around 92°F, the air coming out of the unit doesn't feel warm at all, even though that air can raise the indoor air temperature. For this reason, in colder climates, conventional heat pumps have traditionally had to rely on resistance back-up strips, which are expensive to operate, to provide enough heat to maintain comfort.

COLD CLIMATE HEAT PUMPS TO THE RESCUE

It is a myth that heat pumps can't work in subfreezing temperatures. Cold-climate heat pumps can maintain 100% heating capacity down to 5°F, and they can operate at lower capacity but still put out sufficient heat to warm the indoors at outdoor temperatures as low as -13°F to -15°F (see chart above for an example). These "inverter type" heat pumps have the ability to recover waste heat from the compressor to maintain output and recovery without depending on resistance back-up strips. They also monitor the set-point temperature and outdoor temperature and use an inverter-driven compressor that varies the compressor speed to match the exact load indoors, keeping the indoor air at an even



This sort of connection (2) is all too common with flex duct. The inner liner and the outer jacket must be taped separately and the connection mechanically reinforced (3). Keep ducts as straight as possible. A 90-degree turn is the smallest any bend should be; bends should not look like this (4). This metal duct has some, but not all, seams sealed, and it is not insulated (5)—conditions that will significantly lower the discharge temperature at the supply register.

temperature. This eliminates the huge temperature swings that occur when a conventional unit switches on when the indoor air falls below set point and switches off when it goes above that temperature. The compressor also operates at a much lower wattage draw because it isn't continually ramping up from a dead stop.

This technology has come a long way in the last 10 years, but misinformation persists in the marketplace. Bad experiences with conventional, or “fixed output,” ASHPs continue to be discussed, and the internet is full of blogs by HVAC contractors who might be pushing mini-splits for summertime air conditioning but downplaying them as a viable heating option in colder climates. In part this happens because the experience with a heat pump at low outdoor temperatures is not going to give you that satisfying blast of warm air, and contractors are shy about customer complaints. And because recovery times are slower, any ASHP is going to be much more sensitive to both building performance and system performance than fossil-fuel systems.

ENSURING SYSTEM PERFORMANCE

If we expect to deliver the comfort and energy savings that customers expect, builders need to oversee heat-pump installations to ensure we get these details right:

Enclosure. First, be sure to pay close attention to the building enclosure and be diligent to air-seal and test for airtightness, as well as properly insulate the shell. This will make it easier for an ASHP to meet and maintain thermostat set points.

Equipment sizing. Correct unit sizing using ACCA Manual J, current version, is important for a fixed-output heat pump to match the actual loads. Generally, the unit should be sized no more than 10% greater than the Manual J load calculation, based on an ASHRAE-recommended design temperature. But one advantage of an inverter-type heat pump is that it operates at a speed to match actual loads. Oversizing these units does not create the typical penalties we see with single-speed equipment. They are more efficient when running at the lower end of their capacity



Smooth-wall ducts and all connections sealed with mastic will ensure efficient delivery of supply air (6). And after sealing, every duct installation should be tested for total duct leakage or duct leakage to the outside (7).

range. Larger equipment gets more expensive, though, so you still want to do a Manual J calculation to make an informed decision and to be sure you aren't undersizing the unit.

Refrigerant charge. Failure to charge an ASHP to 100% has a severe impact on not only the unit's rated capacity but also on power draw. As you can see in the chart on page 44, overcharging and undercharging can create a big drop-off in capacity and a surge in power consumption once you move off a 100% charge.

Coil performance. Keeping evaporator coils clean and unblocked helps maintain capacity. Be sure the filters are easily accessible to homeowners, and make sure homeowners understand their importance and timely replacement. Similarly, outdoor coils must be placed where they have plenty of room to move air efficiently and where they are not blocked by greenery or anything that is going to restrict air circulation. Also, keep outdoor units out of roof drip lines where they can ice over in winter. Refrigerant line sets must not be longer than the manufacturer's recommendations and must be fully insulated and be as straight as possible.

Distribution. Ductless mini-splits largely avoid problems with ducts. But some people don't like the indoor wall units. With the improvements in the technology of inverter-type outdoor units has come a lot of innovation with indoor distribution as well. In the house I am building now, I am using ceiling cassettes like the one being installed on the cover of this magazine. Four-way ceiling distribution modules are also available. Both types provide good circulation and are amazingly quiet. Inverter-driven units can also function with conventional ductwork to move air where it's needed and to match the comfort requirements that customers expect.

Ducts should be sized per Manual D calculations. All bedrooms need return air ducts, or jump ducts, and grilles designed to Manual D specifications. (Don't rely on undercutting doors. If you need 200 cfm of return air to a room, you would have to undercut the typical 30-inch-wide door 3.2 inches!) Be sure to seal ducts using mastic or an appropriate tape, and test to keep the total leakage below 5 cfm per 100 square feet of conditioned floor area or the amount of duct leakage to the outside under 4 cfm (these are minimums for tested leakage per the building code). You can do a lot better than this.

Ductwork outside conditioned space should always be insulated to at least R-8. This is even more important for heat pumps since they can have lower register discharge temperatures; poorly insulated ducts will drive winter discharge temperatures even lower.

How ducts are run through homes has an impact on both airflow and leakage. Keep runs straight with no kinks or crushed areas.

For heat pumps, it's even more critical to understand that duct leakage is not simply about losing conditioned air along the way and not delivering it to rooms. Duct leakage also creates pressure imbalances within the home. Supply-side leaks in an attic, basement, or crawlspace will create negative air pressures in the living space, which can pull outdoor air into the space and increase the loads and lengthen the amount of time the unit takes to reach the thermostat set point. Leaks on the return side will create positive pressures in the living space that will force conditioned air out of the building. This is no different than a forced-air system that burns fossil fuels, but again, because the recovery time is so much slower with an ASHP, the impact will be more noticeable.

Duct leakage, of course, becomes a much smaller problem when the ducts are brought inside the living space. Too often, they are running through an attic or crawlspace that is effectively at the outdoor air temperature in winter, and, in attics, significantly hotter than outdoor temperatures in summer.

Maintaining good airflow through the ducts is also essential. It's important that installers measure the airflow at supply registers to confirm the design airflow. Flex duct creates enormous air friction, which combines with tight bends and restrictions to drop airflow well below the desired flow rate. You might have the best unit in the world, but it's useless if you can't deliver conditioned air to rooms. When using flex duct, attach boots and couplers to framing members so you can stretch the duct to reduce friction loss. Make sure ducts are straight runs and have wide, smooth bends that keep static pressures low.

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