SUMMER 2020

# Building Performance Journal

# HVAC

## Quality Installation

**ALTERNATIVE PATHS to Net-Zero Energy**

**GAS AND OIL Furnace Input**

**COLD-CLIMATE Heat Pump Mistakes**

**ALSO INSIDE:**
BPA virtual conference roundup, notes from the field, COVID-19's impact, policy update, and more.

# COLD-CLIMATE HEAT PUMP DOS & DON'TS

by Jon Harrod

Inverter-driven air source heat pumps are becoming increasingly popular in colder climates. They can be used in a variety of applications, from single-room comfort improvements to ducted, whole-house solutions. Their efficiency and relatively simple installation make them a cost-effective alternative to propane, fuel oil, and electric resistance. By reducing or eliminating fossil fuel use, they offer a truly scalable path to decarbonizing our building stock.

The market for cold-climate heat pumps has exploded in areas where heat pumps and central air conditioning were previously rare. Traditional "furnace and boiler" contractors are now adding heat pumps to their offerings, as are other trades such as electricians, solar installers, and home performance contractors.

But the boom in cold-climate heat pump installations has not been without problems. Although simple to install and quite flexible in their application, these systems are unforgiving when it comes to poor design and workmanship. Done right, cold-climate heat pumps can offer a high level of comfort, a decent life span, and excellent efficiency. But done wrong, they can generate all kinds of expensive callbacks for excessive noise, poor temperature control, high energy costs, and early failure.

The recommendations below—dos and don'ts—are based on manufacturer's instructions and trainings, guidelines developed by the Northeast Energy Efficiency Partnership (NEEP), discussions with other installers, and my own (sometimes painful) experience. My hope is that, by following best practices and avoiding common mistakes, we can make good on the promise of cold-climate heat pumps: satisfied customers, energy savings, and a cleaner environment.

DO SIZE EQUIPMENT THOUGHTFULLY. Because cold-climate heat pumps, especially single-zone systems, can modulate across a wide range of heating and cooling outputs, it's easy to become casual about sizing and to either apply rules of thumb or adopt a "one size fits all" approach. But proper sizing is essential to getting a good result in any HVAC application, and cold-climate heat pumps are no exception. A system that is oversized will cycle frequently, leading to temperature swings, noise, and excessive energy use. In cooling mode, it won't run long enough to provide adequate dehumidification. An undersized system, on the other hand, won't be able to maintain temperature under extreme conditions. Take the time to do accurate heat loss and heat gain calculations in accordance with ACCA Manual J; if possible, use blower door numbers instead of qualitative airtightness ratings. When selecting equipment, look not just at "nameplate" capacity but at extended tables showing performance at local design conditions. Pay attention to minimum as well as maximum capacity; equipment with lower modulation limits will perform better under mild conditions. NEEP provides an excellent eight-page guide with more tips on properly sizing and selecting equipment for both whole-house and partial-displacement applications. (See "learn more".)

DON'T PUT DUCTLESS HEADS IN SMALL ROOMS. Many a glossy manufacturer's brochure touts multi-zone systems with ductless heads in almost every room. But this approach can cause problems, especially in smaller rooms. It may be hard to find a location where air isn't blowing directly on a bed, desk, or sitting area. And even the smallest ductless heads (6,000-7,000 Btu/h maximum output) are badly oversized for bedrooms and home offices with design loads of 2,500 Btu/h or less. Problems are even worse if small-room heads are connected to multi-zone outdoor units; in such cases, the maximum capacity of the indoor head may be less than the minimum capacity of the outdoor unit. If only the small room is calling for heating or cooling, the outdoor unit will cycle excessively. It may also bleed refrigerant through other heads, leading to comfort and noise complaints. A compact-ducted air handler is usually a better solution, since its output can be divided between multiple rooms. Rooms like bathrooms with very small heating loads and negligible cooling loads may also be served by electric resistance heaters.

DO ELEVATE THE OUTDOOR UNIT. Cold-climate heat pumps need to be elevated above the average maximum snow depth to ensure proper air flow. Just as importantly, elevating the outdoor unit allows water that drips off the coils during the defrost cycle to drain away. Ice buildup can block airflow through the coils, reducing heating capacity; in extreme cases ice can rupture the coils. Mount the outdoor unit on a stand or wall bracket with good drainage below. Ice problems can be further mitigated by placing outdoor units away from roof drip lines. In very snowy climates, awnings may help reduce snow and moisture loads.

DON'T MOUNT OUTDOOR UNITS ON WOOD-FRAME WALLS. L-shaped wall brackets offer a convenient way to elevate outdoor units. However, mounting outdoor units on wood-frame walls can lead to unacceptable noise and vibration in the living space. Use wall brackets only on masonry walls. If direct attachment to masonry is not an option, set the outdoor unit on a ground-mounted stand.

DON'T MOUNT INDOOR UNITS TOO CLOSE TO THE CEILING. Most "high-wall" ductless heads draw in room air through the top and blow it out through the bottom front. To ensure good airflow, and to avoid drawing in only the warmest


Cold-climate heat pumps must be elevated above the average maximum snow depth. Be sure to allow for free drainage below the unit.

For optimum performance, high-wall units should be mounted at least 6 inches below the ceiling.

air closest to the ceiling, it's important to allow at least 6 inches of clearance when possible.

DO SEAL WALL PENETRATIONS. If holes for refrigerant lines and wires are not properly sealed, insects and outdoor air can enter the living space. In summer, hot, humid air coming into contact with cooler surfaces in the indoor head and adjoining wall assemblies can lead to condensation problems. Because most ductless heads monitor room temperature with a thermistor mounted in the head itself, outdoor air leaking into the head through an improperly sealed wall penetration can also wreak havoc on temperature control. These problems can be avoided by thoroughly sealing wall penetrations with expanding foam. In wall cavities with batt or blown-in insulation (or no insulation!), a wall sleeve is required to contain the expanding foam and achieve a good seal. This can be 3-inch PVC cut to length; DiversiTech and RectorSeal also sell products purpose-made for this application. NEEP also recommends rodent-proofing wall penetrations with copper wool or other suitable material.

DO DRAIN CONDENSATE RIGHT. Wall-mounted ductless heads are designed to collect the condensate that forms in cooling mode in a drain pan, then drain it away by gravity, usually to a tube that runs down the exterior wall. To function properly, the indoor head must be mounted level. The drain tube must pitch downward continuously with a minimum drop of ¼ inch per foot of horizontal run. Securing the condensate drain with zip ties or straps helps ensure that it remains in the correct position and free of kinks during and after installation. Terminating the drain a few inches off the ground reduces chances of clogging with soil and yard debris. When a properly-pitched gravity drain is not possible, you can install an aftermarket condensate pump, sometimes within the ductless head itself. Condensate pumps designed for ductless heads include a safety switch that stops system operation if the pump fails. Aftermarket drain pan switches (such as the RectorSeal Safe-T-Switch) can also be offered as an add-on for gravity-drained systems.

DO USE TORQUE WRENCHES. Refrigerant tubing in cold-climate heat pumps is connected largely with flares. If made properly, flares can provide durable, leak-free joints. Good flaring technique requires cleanly cutting and deburring the copper tubing and forging each flare to the correct dimensions. Then, the flare nut, which presses the flared tubing onto the brass cone, must be tightened to the correct torque. Too little torque and the metal surfaces don't form a tight seal; too much and the copper flare can be crushed, causing a catastrophic leak. Torque specs vary with diameter, from 10–19 ft-lb for ¼ inch tubing to 45–59 ft-lb for ⅝ inch tubing. Without torque wrenches, there will be a tendency to over-torque and crush smaller tubing and to under-torque larger tubing. (Side note: flares that are tested and found to leak must always be cut out and the tubing re-flared; applying additional torque to a defective flare will not fix the leak and may make it worse.)

DON'T SKIMP ON LEAK TESTING. Even a tiny refrigerant leak will eventually compromise a heat pump's performance. It's critical to thoroughly test all site-made refrigerant connections to ensure that they are leak free. A comprehensive leak check involves:

1. A STANDING PRESSURE TEST. Pressurize the line sets with nitrogen as recommended by the manufacturer, typically to around 500 psi. Once the system has reached equilibrium, there should be no detectable change in pressure readings, as long as outdoor temperatures remain constant.
2. BUBBLE TEST. The standing pressure test can be confounded by changing outdoor temperatures. The resolution of pressure gauges (even digital gauges accurate to within 0.1 psi) is insufficient to detect small leaks within the 1–24 hour period typically allotted for the test. For both these reasons, it's critical to check every connection with a leak detection solution. With the line sets pressurized, apply solution to each flare. Wait 5–30 minutes, then check for the formation of bubbles or foam. Use an inspection mirror to check flares from all angles.
3. VACUUM DECAY TEST. The primary purpose of the evacuation process is to remove air and moisture from the lines prior to charging them with refrigerant. Evacuation also provides an additional opportunity to check for leaks. Pump the system down to its target vacuum level (typically 250 microns or below). Isolate the system and shut off the vacuum pump. All systems will show a small rise in micron level when isolated, but a tight, dry system will remain below the decay target (I use 500 microns) for the specified test period (I use 10 minutes). Bluetooth-enabled micron gauges like the BlueVac Pro, paired with mobile apps, can extrapolate the rate of vacuum decay, in many cases giving a "pass" or "fail" result in a minute or less.
4. FINAL CHECK WITH ELECTRONIC LEAK DETECTOR. Once the line sets have been filled with refrigerant and the system is running, perform a quick final check with an electronic leak detector. Check all site-made

While the line sets are filled with high-pressure nitrogen, apply a leak-testing solution to all flares.

connections, along with service valves and charging ports, which are not tested during the standing pressure or vacuum decay tests.

**DON'T BRAZE WITHOUT NITROGEN.** Joining refrigerant tubing by brazing is common throughout the ACHR industry but less common in cold-climate heat pump installations. Brazing provides a highly durable, leak-free joint; replacing flares with brazed connections is a great choice, especially when the location will be difficult to access in the future. But brazing must be done properly to avoid damage to the system. In the presence of atmospheric oxygen, the heat of brazing causes oxides to form inside the tubing. Later, the oxide particles break loose and circulate, clogging screens and fouling critical components like electronic expansion valves. For this reason, it's absolutely essential to flow low-pressure nitrogen through the tubing while brazing.

**DO PAY ATTENTION TO LINE SET INSULATION.** All refrigerant lines need to be carefully insulated to avoid unwanted heat losses and gains and to prevent condensation, both at the indoor head and in walls and other building assemblies. Unlike conventional air conditioners, which require insulation only on the cold suction line, heat pumps require insulation on both refrigerant lines to prevent summer condensation. This is because their metering devices (electronic expansion valves) are in the outdoor units; in cooling mode, both lines are on the low-temperature, low-pressure side of the system.

**DO GET THE TRIM CHARGE CORRECT.** Ductless systems are shipped pre-charged with refrigerant in the outdoor unit. The factory charge covers installations with line sets up to a specified length. If the line sets exceed this length, the installer must calculate and weigh in additional refrigerant (the "trim charge") according to a formula that takes into account the length and diameter of the line sets, and in some cases, the capacity of the indoor heads. Failure to add the correct trim charge, which can result from measurement or calculation errors, can lead to poor system performance. Line set lengths and trim charge calculations should be recorded in the job file for future reference. I also like to write this data in permanent marker on the outdoor unit access panel.

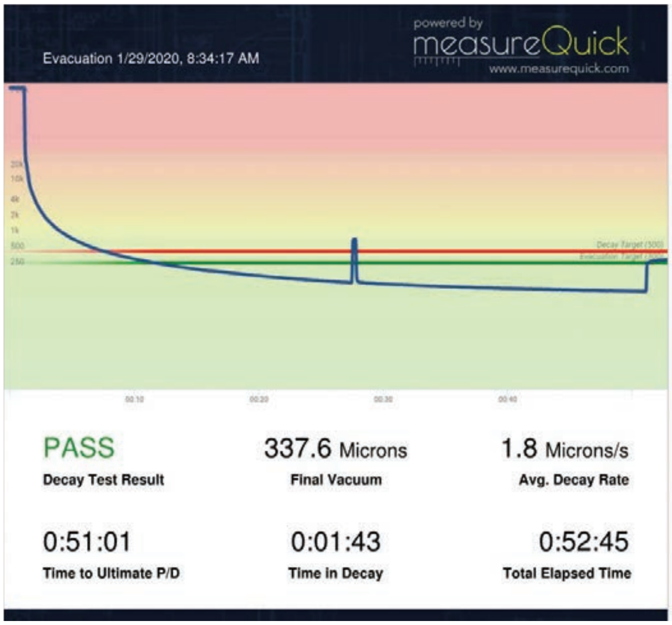
**DON'T GET YOUR WIRES CROSSED.** In a typical inverter-driven heat-pump system, the communication wires supply line-voltage AC power from the outdoor to the indoor unit. They also transmit information back and forth using a variable low-voltage DC signal. For the system to work correctly, it's critical to use the wire sizes specified by the manufacturer. In typical household or HVAC wiring, there's no negative consequence (other than cost) for using a thicker wire. But if you're wiring an inverter-driven heat pump, and the manual says 16-gauge wire, use 16 gauge; anything else is asking for a callback.

Splices and junctions may also interfere with communication, so it's best to use unbroken wire between the indoor and outdoor unit. And, of course, make sure that the screws holding the wires to the terminal blocks are firmly tightened down.

In systems with multiple indoor heads connected to a single branch box or outdoor unit, double check that communication wires are connected to the correct terminal blocks. As obvious as it sounds, an error due to crossed wires can easily be missed at startup, especially if the test procedure involves running all heads simultaneously. Only weeks or months later will the contractor get the call that one head isn't cooling, and another is a block of ice. The best way to avoid this issue is to carefully bundle and label communication wires with the corresponding line sets.

**DON'T CONNECT GAUGES.** The refrigerant manifold gauge, with its hoses, is an indispensable tool for diagnosing and servicing conventional air conditioners and heat pumps with fixed speed compressors. In these systems, the relationship between air temperatures and refrigerant pressures is well defined and allows charge to be adjusted based on gauge and thermometer readings. In cold-climate heat pumps with variable speed compressors, these methods cannot be used. These systems can't be "topped off"; the only way to ensure proper charge during servicing is to recover and weigh the refrigerant and compare it to the nameplate factory charge (plus any trim charge required).

Hooking up gauges provides little or no useful information. Worse, each time gauges are connected, a small amount




The BluVac micron gauge, used with the measureQuick app, can speed up the vacuum decay test and provide a time-stamped digital record.

of refrigerant is lost to the atmosphere or stranded in the hoses. In inverter-driven systems, many of which have total refrigerant charges of less than 4 pounds, cumulative losses from connecting gauges can add up to affect operation. It's best to check performance using non-invasive methods (for example, measuring temperature split across the indoor unit and comparing it to the manufacturer's recommended range). Don't touch the refrigerant circuit unless these non-invasive diagnostics point to a problem with charge; if they do, be prepared to recover and weigh all the refrigerant in the system.

DO EDUCATE CUSTOMERS. You can prevent many callbacks and complaints with good customer education. This begins during the sales and design process with realistic projections of how cold-climate heat pumps will impact energy costs (usually for the better, but subject to local pricing) and frank discussions about whether a particular design will meet the customer's comfort needs. It's also important to let customers know that, while these systems can be very quiet, they're not silent; minor noise from refrigerant and the expansion of plastic parts during heating are a normal part of operation.

It's important to prepare customers for the fact that heat from ductless or ducted heat pumps will feel different than heat from a fossil-fuel based forced air or hydronic system. The temperature of the supply air coming out of the registers may be cooler than they are used to. I always let customers know that most ductless heat pumps sense air temperature at the head itself, rather than at the remote control; the temperature at the head (typically 6 or so inches below the ceiling) will not be the same as the temperature at occupant level.

Customers also need instruction in the efficient operation of their system. While thermostat setbacks may have made sense with their old fossil-fuel equipment and single-stage A/C, cold-climate heat pumps perform best when indoor temperature settings are left more or less constant. This allows the system to spend more of its time in the middle of its modulation range, where efficiency is maximized, rather than ramping up to maximum output. A correctly-sized heat pump will also be quite slow to recover from a deep setback, especially in extreme conditions. For both these reasons, I recommend a "set it and forget it" thermostat strategy.

Customers should be given a hands-on demonstration of basic maintenance, especially checking and cleaning filters and changing batteries on remote controllers. I like to show customers how to power down and restart their equipment, either at the electrical panel or the outdoor disconnect; a significant fraction of no heat/no cooling calls are due to transient errors caused by power interruptions or software glitches rather than actual problems with the equipment. These can often be cleared by asking the customer to power cycle their equipment. If the problem reoccurs, a technician can make a visit to diagnose and repair.

Unfortunately, customer education is usually an afterthought, done in a rush at the end of a long day, if done at all. And manufacturers' user manuals are often poorly written and confusing. I like to leave customers with a concise, one-page "cheat sheet" that guides them through basic operation and maintenance and answers frequently asked questions.

If you install cold-climate heat pumps, you'll no doubt make mistakes, some of which will be expensive to correct. My hope is that, by following the do's-and-don'ts I've described above, you'll benefit from lessons some of us have already learned the hard way. With good design and attention to the fine points of installation, these systems can perform very well. It's up to us, the contractors, to make sure that cold-climate heat pumps reach their potential to reduce emissions, save money, and deliver a high level of comfort.

**JON HARROD** *is president of Snug Planet, a building performance and HVAC company based in Ithaca, New York.*

*This article was supported with funding from DOE's Weatherization Assistance Program.*

**>> learn more**

NEEP provides excellent guides with more tips for properly sizing, selecting, and installing cold-climate heat pumps. Go to www.neep.org.

For the 8-page guide mentioned above on properly sizing and selecting heat pump equipment for both whole-house and partial-displacement applications go to https://neep.org/guide-sizing-selecting-ashps-cold-climates.

# CONTRIBUTORS

## Karin Haerter

"Notes from the Field: On-the-Fly Changes (aka As Built)" pg. 30

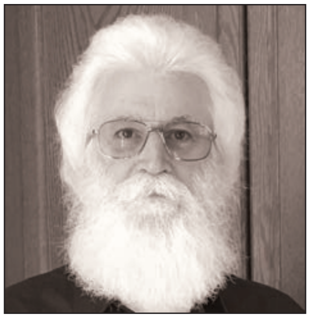
Karin says she hopes readers will be inspired to share their own tales of things that go wrong and how to fix them, especially in urban multi-family high-rises, which are Karin's focus. "My impetus to write was to share my unique experiences—and hope others will share—because I would like hear what people are seeing on their jobs in the field."

Karin was interested in energy efficiency very early, doing her own research into renewables. "One thing that definitely made a difference in my life, was that when I was a kid, my dad added a wing to our house. I watched him build single-handed. Almost no power tools. My dad convinced me that I could do anything that I wanted. So, I did."

**Journal readers may not know that** Karin is active in cat rescue. "When I bought my house, it came with feral cats. So, I got certified to do TNR (trap, neuter, return). As a sideline, I build shelters and feeding stations for the animals."

## Bruce Davis

"Alternative Paths to Net-Zero Energy Homes" pg. 22



Bruce would like readers to realize that they have options to impact climate change. "Then I hope that a stream of readers would take steps toward the goal."

Bruce's career path went from farm, to farmette, to Sociology Graduate School. It pivoted when "I was hungry and worked as a carpenter for a community action agency providing weatherization services for low-income elderly. Over the decades I have earned my living in the field of applied building science."

**Readers may not know that** Bruce and Kathryn, his wife, inherited half the Arkansas family farm where he was born. The land had been abandoned for years so they made improvements and a local farmer now produces rice.

## Jon Harrod

"Cold-Climate Heat Pump Dos and Don'ts" pg. 16

With his article, Jon wanted to "share some of my learning around heat pumps with the hope that I would help others avoid some of the mistakes I've made and some of the ones I've read about. Really at the end of the day, I just want energy efficiency to go well."

Jon's direction in school as a Forest Ecologist changed course when he was listening to a "very well-respected professor in my field on NPR and the interviewer asked him what the things an average person could do to help the planet. This prominent ecologist was kind of stumped and then kind of gave a lame answer about recycling. And I thought, 'no we really need to do better than that. We've got the get some practical answers.' And that was the moment I decided to leave academic research and go into home performance."

**Readers may not know that** Jon enjoys bicycling, cross-fit, and reading science fiction. He's currently reading Ray Bradbury's *The Martian Chronicles*.

## Tom WIlson

"Using Surface Temperatures to Calculate Effective Insulation Levels" pg. 38

One of Tom's favorite quotes is from George Box: "All models are wrong but some are useful" U x A x ΔT is the most basic element of the heat transfer models that drive almost all our present day building science computer algorithms. Tom actually has little faith that any of these programs can accurately predict the performance of any particular home, but nonetheless he finds it useful to explore the underlying principles on which these models are built, resulting sometimes in surprising results.

Tom's career took a turn when "in 1975 or so, I was working as a crew chief for a New Jersey winterization program (weatherization was not a term yet) when we had the idea to put on a series of community solar workshops. This inspired me to construct the first two residential Trombe wall retrofits in the country and join the Board of Directors of the Mid-Atlantic Solar Energy Association."

**Readers may not know that** on April 18, 1977 Tom testified before the Federal Energy Administration in New York City calling for increased funding and expanded measures for the first draft of 10 CHR Part 440 Weatherization Assistance for Low-income Persons. That same evening President Jimmy Carter made his famous "Moral Equivalent of War" Speech.