Designing HVAC For Cold Climates

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Working in each climate zone presents its own challenges. In the June Engineer's Notebook column Eric DeSplinter and Jeff explored differences when designing in humid vs. arid climates. This month's column focuses on what you must consider when designing HVAC systems in cold climates.

Jeff started his career in the upper Midwest in Illinois, Iowa, and Wisconsin, ASHRAE climate zone (CZ) 5A and 6A (cold winters and humid summers), and never left. Wil started his career just a few years ago in the Minneapolis market (CZ 6A) and has primarily worked on projects in the upper Midwest.

Don't Freeze Coils

One of the main concerns in cold-climate HVAC design is the interface between water and cold air. Proper freeze protection of the heating and cooling coils is essential. Without this, coils can burst, sending water running down the building and causing shutdowns and costly repairs. Both can be expensive and result in legal action by the owner. However, many ways exist to avoid this. Freezing and bursting are different. Freezing means that liquid stops moving. Bursting means you have a mess to clean up and a coil to patch or replace.

The safest method to prevent coils from freezing is to use vertical integral face and bypass (VIFB) steam coils. Horizontal (IFB) coils are nearly as freeze resistant. We often use VIFB coils in hospitals that have existing steam boilers or in universities with central campus steam. If piped correctly (follow manufacturers' recommendations), they are virtually impossible to freeze. Piping the steam condensate properly requires significant height below the coil outlets and large steam traps.

The disadvantage of VIFB and IFB coils is they can use significantly more energy. This is partially because steam production is normally not as efficient as heating water production; it's also because minimum heat production is high due to conduction heat transfer and incomplete closing and heat transfer from closed clamshell dampers, which can cause economizers to open in very cold temperatures. This is because the steam valve is fully open at low temperatures and clamshell dampers modulate the heat but can't modulate to low percentages of maximum capacity. Some manufacturers permit modulation of the steam valves, which we prefer from an energy standpoint. Using multiple coils can minimize, but not eliminate, this energy waste. We have seen up to 15°F (8°C) of unwanted heat gain at face and bypass dampers.

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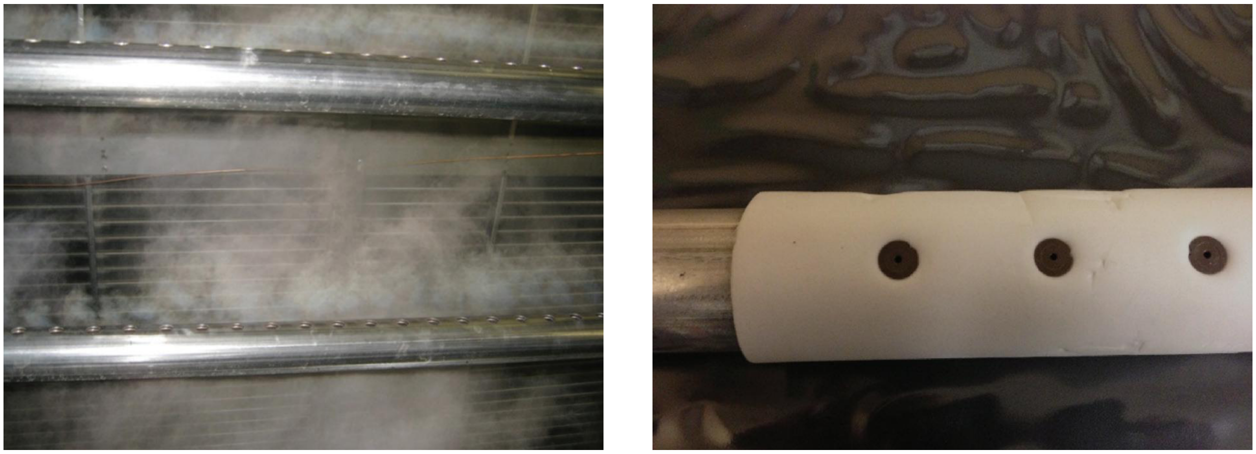
FIGURE 1 Uninsulated steam bayonet (left) and insulated bayonet (right).



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For steam coils some controversy exists about where to locate vacuum breakers to allow condensate to drain. We believe they belong on the inlet of IFB (horizontal) and VIFB (vertical) coils and on the outlet of distributing coils.

Tied for second hardest to freeze are opposite-ended steam distributing coils with top inlet and bottom outlet, although some of our staff has had trouble with control of distributing coils.

Also tied for second are glycol coils which, depending on the concentration of glycol used, are tough to freeze or burst. In all cases pumping power and heat transfer efficiency will be worse than for water. Properties of glycol solutions will be discussed in a future column.

Hot water coils with circulating pumps are effective against stratification freezes, which in our experience are 90% of coil freezes. The circulating flow brings water that was in a section of the coil that is in contact with subfreezing air back into areas that are in contact with warm (return) air. This also helps make the air temperatures reaching downstream coils more uniform. But recirculation will not protect a coil if the heating control valve does not open or if the main heating system pump quits when the entering air temperature is more than a few degrees below freezing.

The only source of heat is the pump energy and a little heat transfer from pipes outside of the AHU, while the full heat transfer of outdoor air is cooling the coil fluid. Some engineers believe that recirculation will protect coils in this situation, but flowing water can freeze.

Another option is to add air blenders in addition to or instead of recirculating coils. This works if the blender you choose blends well and if you pick a good geometry. When using multiple blenders, they should be placed perpendicular to the outdoor air/return air (OA/RA) orientation. If the OA comes in on the left and the RA on the right and you have two side-by-side blenders, the result is well-blended freezing air and well-blended warm air crossing the downstream coil. Orient the blenders so the OA and RA are blended. Mixing OA and RA far upstream of the AHU is usually effective. AHU mixing box dampers are usually not very effective.[1]

Energy recovery units also offer protection to coils in addition to saving energy and reducing CO_2 emissions.

If chilled water does not run year-round, an energy recovery chiller can be an excellent solution for small loads in cold weather. In one example, we used this technology to heat a football practice field while providing chilled water to campus chilled water mains to serve winter cooling loads.

Another source of unwanted heat that can cause economizer dampers to open is heat from humidifier tubes, where the issue is not the heat of the steam, which moves nearly vertically on a psychrometric chart (a hair to the right), but the sensible heat transfer of the tubes (*Figure 1*). ASHRAE Standard 90.1 now requires insulation of humidifier bayonets.

Piping Freeze Concerns

It is common to freeze pipes in boiler rooms with large boilers that pull combustion air through a large combustion air louver and then the boiler room. To address this, we usually use a vertical unit heater near the combustion air louver and set the fan to stay on whenever the outdoor air is below 35°F (2°C) to mix air near the louver and avoid pooling of cold air along the floor. Sealed combustion boilers (e.g., with direct piped combustion air and venting) do not use combustion air louvers.

Frozen condensate drains in winter are an issue. It is common to install a P-trap outside rooftop units (RTUs) and route the drain to the roof. The problem is water in the P-trap freezes in winter and bursts the trap. If the trap freezes and breaks, the coil drain will overflow when the coil begins dehumidifying and is likely to drain accumulated water into the building. This also applies to humidifier drains for rooftop equipment. The only solutions we have used are insulating, heat tracing or keeping the trap in a warm location. We've heard of people disconnecting the trap in winter, but if it isn't reconnected in spring, condensate will overflow.

Bury depth of pipes is very different in cold climates than warm climates. We know of chilled water pipes that froze when buried 9 ft (2.8 m) deep under a street in Superior, Wis. Frost penetration is deeper in plowed areas. However, burying pipes very deep in warm climates is a waste of money, and as a coworker from Phoenix pointed out, "If we bury sanitary pipes 6 ft (1.8 m) deep, we will need lift stations at the property line." Frost depth maps are available from several sources including the National Oceanic and Atmospheric Administration (NOAA) and the National Fire Protection Association (NFPA).

Pipes in exterior walls should have the insulation on their outdoor side. This is mainly an issue in stud walls, and we recommend that contractors install fibrous insulation to go behind the pipes, not around them. It gives up a tiny amount of R-value, but frozen pipes are a larger issue.

Don't Forget the Chiller

In the Midwest, it is common to experience weather where chillers are needed, even with economizers, followed only a few hours later by extreme cold. Those accustomed to designing in hot climates will know that a chiller (air-cooled or water-cooled) provides an effective means of handling cooling loads. However, what may be less intuitive is the necessity of freeze protection for this equipment.

In the case of air-cooled chillers there are four freeze-protection methods that can be pursued. The first is using glycol. If the chiller will not be operated in freezing weather, the glycol percentage can be reduced to the burst temperature instead of the freeze temperature, so the fluid in the loop turns to slush, but no risk of bursting is present. The second is to split the system into outdoor and indoor loops with a plate and frame heat exchanger. We often see this used when an owner prefers not to have glycol in their whole building and to maximize heat transfer at the coils.

The third method is designing isolation and drain down for the system, usually just the outdoor portion of the loop. After draining, this typically requires blowing out with compressed air. The fourth is to use an indoor evaporator and outdoor condenser. The downside is the extra refrigerant piping between them and a slight degradation of chiller efficiency.

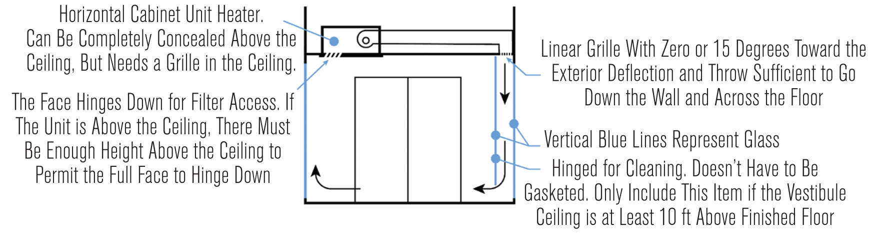
For water-cooled chillers, our main concern is the cooling tower. Some facilities, especially in the healthcare and industrial sectors, may require cooling year-round. Evaporative cooling equipment requires some form of freeze protection if it must operate in subfreezing conditions. The safest method is to use an indoor sump, so water alternates between full-flow over the cooling tower and full-flow to the sump based on water temperature. Another approach is basin heaters, which use energy but are less expensive and don't require an indoor sump. They should be controlled to turn off whenever water is flowing or when the basin is above 35°F (2°C).

In either case all piping must drain to a warm location and pipes that will stay filled must be heat traced. We prefer to automatically drain to a warm location. Even if the system does not require subfreezing operation, proper drain down provisions should be included.

For the chiller and its associated condenser water loop to be used during subfreezing conditions, the winter cooling load should be large enough that the inclusion of freeze protection makes economic sense. If not, smaller split systems or other means of cooling should be used. In this case, if direct-expansion (DX) cooling is used, special consideration should be given to the use of outdoor condensing units that can either operate in very low ambient conditions, or to units that can be installed in an interior space that is semi- or fully conditioned.

Outdoor air-cooled systems that have defrost cycles, e.g., variable refrigerant flow (VRF), can create small skating rinks.

FIGURE 2 All-glass vestibule.



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Keep People Comfortable

Meet the heating load in extreme weather. Some safety factor is needed. You probably don't need to maintain 72°F (22°C) when it's below design conditions outside, but it should be livable and first cost vs. a few hours outside of design conditions should be discussed with the owner. The actual design condition will depend on your client's needs. The 99.6% design condition in Madison, Wis., is –6.8°F (–22°C), but two winters ago the city recorded –26°F (–32°C), which resulted in HVAC and sprinkler freezes and shutdown of many air-cooled heat pump and VRF systems.

Keep your entrance staff happy. If 14,000 cfm (6607 L/s) of –10°F (–23°C) air comes through your vestibule into your elevators and up to the penthouse due to negative pressure, the people entering the building will be happy in their winter clothing, but the greeting staff in street clothes will not be happy at all. We had this situation on a project that had 12 elevator doors creating stack effect from the lobby.

The solution was to add a tempered glass wall on the mezzanine level, so we had only six elevators connected to the lobby; add a third set of doors at the elevator lobby to increase the odds that all three sets are not open simultaneously; and add infrared heat on a dial controller to heat the backs and shoulders of the entrance staff. A revolving door would also have solved the problem, but that was not acceptable to the client, who was very happy with our solution.

Getting heat to the floor to minimize tracking of snow indoors is important. Ceiling-mounted cabinet heaters with no supply ducts do not work adequately due to stratification. Inverted hydronic cabinet heaters that discharge hot air to the floor work well. If something more architecturally pleasing is desired, refer to *Figure 2*.

Human thermal comfort is best predicted by operative temperature (T_o), which is described in ANSI/ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy,* Appendix A, and can be approximated as (dry bulb temperature + mean radiant temperature)/2 in still air (<40 fpm [0.2 m/s]). Mean radiant temperature is effectively the average of the surface temperatures in a space. This means that in cold weather, in rooms with perimeter windows people will feel the radiant effect (chill) of the window even if the thermostat is satisfied. People will increase the thermostat setpoint to offset the effect of the cold window, which is the opposite of what to do for energy conservation.

The best solution is to improve the window U-value to increase the indoor surface temperature and thus the tendency to raise the thermostat. This also saves energy. If you must use overhead air for heating in spaces with large amounts of glass, a good solution is linear diffusers located about 8 ft (2.4 m) from the glass with two slots pointed toward the glass (for winter comfort) and one toward the interior (for summer comfort). Fin tube or radiant panel heat always works but is often precluded by cost or aesthetic considerations. ASHRAE RP-426[2] has an excellent explanation of what will and will not provide adequate comfort. Fan-powered VAV boxes can also increase warm air throw down exterior windows.

Mounting thermostats on exterior walls is discouraged, even with thermal bases because they are likely to sense temperatures lower than the room temperature in cold weather.

Issues with Snow

Rooftop air intakes should be above the snowline. *Figure 3* shows an exhaust hood (you can tell because it melted the snow near it) that probably should have been on a taller curb. If it had been an intake hood, it would have been buried in snow and/or would have sucked in snow. Intakes near a vertical wall can be especially challenging due to snow drifts.

Louvers and even hoods such as in *Figure 3* cannot stop all snow penetration. Especially in very cold weather, snow tends to be very low density and can easily move upward in light wind currents. This is probably why no industry rating exists for louver or hood snow penetration—nothing would pass. Louvers are best located away from the prevailing winter wind and with their bottoms well above the roof line and away from corners to avoid

FIGURE 3 Rooftop hood in snow.

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FIGURE 4 Snow on prefilters.

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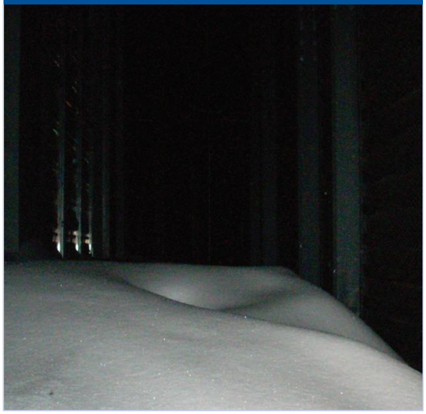
FIGURE 5 Snow in AHU.



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swirling air. Intake penthouses, as in *Figure 3,* do better in windy situations than louvered penthouses where wind can blow through the penthouse and deposit snow halfway through.

Louvers are subject to swirling winds also when wind blows over a rooftop penthouse and forms a vortex that deposits snow past the louver with upward motion. Louvers with vertical blades *might* be more effective in preventing snow penetration, but we have not found test data justifying this. After snow penetrates an intake, it can plug prefilters (*Figure 4*). Normally the solution is to remove the preheat filters and rely on downstream higher-efficiency filters, since dust loading is typically low in winter. Jeff has seen snow go through OA intake ducts, including an elbow, and deposit inside an AHU (*Figure 5*). Eventually this snow melts.

One solution is a short wind barrier in front of the intake louver. Electric screen heaters behind louvers are an option also, but they require a lot of electric power.

Since we can't completely keep snow out of AHUs, the areas where it could accumulate should be watertight and have drains that won't freeze. Sometimes this requires a little self-regulating heat tape.

Summary

Successful cold-climate design depends on having the experience to know what items might cause problems or failures. We presented those we believe are most common. Another good resource as you design in cold climates is ASHRAE's *Cold-Climate Buildings Design Guide*.

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