HVAC Best Practices in Arctic Climates

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Abstract. Arctic climates provide unique challenges for designers of HVAC, plumbing, and thermal energy systems. The importance of considering the operation outside air temperatures, system reliability, and building resiliency cannot be understated. The paper describes best practice examples of robust and reliable systems with the emphasis on their redundancy, durability, and functionality. The paper also discusses the most common heating and ventilation system approaches used in arctic climate with the emphasis on the importance of a maintenance program that allows building operators to successfully troubleshoot and maintain buildings in the arctic. More detailed discussion of concepts presented in this paper can be found in the Guide [1] where these concepts are illustrated by best practice examples from U.S. military bases in Alaska and Søndre Strømfjord, the international airport of Greenland that previously was used as a U.S. military base. The paper results from experts' discussions during the Consultation Forum "Thermal Energy Systems Resilience in Cold/Arctic Climates" [2] and research conducted under the IEA EBC Annex 73, the Environmental Security Technology Certification Program (ESTCP) Project "Technologies Integration to Achieve Resilient, Low-Energy Military Installations" and U.S. Army Program project 633734T1500 under Military Engineering Technology Demonstration. The paper is complementary to the ASHRAE Cold Climate Design Guide [3] with a focus on resilience of thermal energy systems.

1 Introduction

Arctic climates can experience extremes with high summer temperature spikes to extensive periods of cold temperatures and darkness during the winter. Building owners have typically been willing to increase first cost investment on both reasonable energy reduction measures and reasonable comfort measures. In cold climates, the indoor environment can be a welcome relief for occupants and for many, there are more hours spent indoors than outdoors during the winter months. Creating a good indoor environment with comfortable, reliable, and sustainable spaces is a high priority and design decisions should consider the life cycle cost effectiveness of building and energy systems holistically, including current and future anticipated functions.

To provide a design that is robust, adaptable, and affordable, it is important to understand the aspects of the geographic location that will impact equipment selections, operating hours, and maintenance needs. Another consideration is the ability of a building to withstand an outage in the heating plant, either locally or from a centralized source.

In extreme cold climates, a drop in indoor temperature can pose a risk of freezing plumbing and wet sprinkler piping. Freezing pipes can lead to pipe burst and flooding of the interior. Pipe breaks due to freeze conditions are common in Alaska in both commercial and residential contexts. Flooding in commercial buildings can cause enormous damage and cost thousands of dollars to repair in addition to the impact of the loss of workspace in an office building.

Therefore, it is necessary not only to look at the building HVAC installations, but at the building envelope and the whole energy infrastructure. The large thermal capacity of concrete and brick walls, internal water pipes, critical system redundancy, and a reasonable layer of outside insulation without weak point can all offer protection from unpredicted outages.

2 Heating Systems in Artic Climates

Unlike in comparatively warmer climates, heating with air is not typical in construction in cold climates. This is due to high heating loads endemic to cold climates. Heating with air in a commercial application should be used with caution. Air heat from above is not effective unless it reaches the floor, and it cannot reach the floor from above without significant velocity. Since warm air is less dense than that of cold air, chances are that, unless it is propelled with sufficient velocity, warm

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air will remain at ceiling level, outside of the working area of the occupants of the space.

As noted, heating systems in arctic climates are considered critical infrastructure. It may take days or even weeks to get a failed heating system component fixed and operational. Increased reliability in mechanical system design is first achieved through system redundancy. Examples of this include:

- Two or more boilers sized to be able to keep the facility above freezing under reduced operational conditions when one unit is down for maintenance. Reduced operation may include temporarily turning off the ventilation system. This has traditionally been achieved by using two boilers sized at 66% of peak heating load or three boilers sized at 50% peak load.
- For critical pumps, such as main circulating pumps, two pumps are provided in a primary/backup configuration with independent starters/variable frequency drives and power circuits.
- The use of multiple heat sources. This may be adding gas-fired roof top units to a hydronic system, having fuel-fired space heaters, or having a solid fuel backup heat source.
- Multi-fan arrays where ventilation is a mission-critical part of the facility.

In critical infrastructure, this may mean the use of N+1 levels of redundancy at all levels of the building systems including power generation and controls.

Working fluid. Hydronic heating is the preferred method [4] and typically uses a glycol/water solution as the heating system fluid. Some examples of hydronic systems used in Alaska are shown in Figure 1. This provides freeze protection and allows the heating system fluid to be used in air handling unit heating coils that heat incoming air that could be as low as -60 °F (-51 °C). Glycol to water percentages are selected based on a conservative winter design temperature and either the glycol's associated freeze or burst protection volume percentage. Typical glycol mixture percentage in extreme temperature zones is 50%; some building owners opt for up to 60% glycol heating system fluid. There is a thermal performance derate and significant viscosity increase when using glycol over water which needs to be considered when designing hydronic systems. Ethylene glycol and propylene glycol are the most typical heating system mediums. Ethylene glycol performs better from a derate and pressure drop perspective as compared to propylene glycol. However, in some cases, it may be preferred to use propylene glycol as it is not toxic to humans.

Chiller systems that are expected to be filled and/or operated year-round also use glycol. The preferred fluid for these systems is ethylene glycol due to the better viscosity performance at lower temperatures.

In addition to a performance derate, the wetted surfaces of equipment must be compatible with glycol to prevent premature failure of components. The most common issue relates to pump seals and gaskets. Pump seals and system gaskets compatible with the glycol mixture concentration should be selected. Glycol is also susceptible to degradation under high temperatures, which can form acid molecules. It performs well in cast iron sectional boilers but can degrade in water tube boilers.

Glycol must have regular maintenance to ensure a proper pH balance and the presence of corrosion inhibitors. Annual testing of the pH and glycol freeze protection is recommended. Fluid should be tested, and treatments added as needed. Improperly maintained glycol can become acidic and corrode pipes and gaskets and seize control valves.

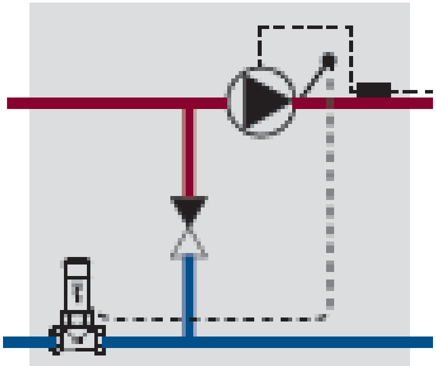
When using glycol as a heating or cooling medium, it is recommended that the system not be connected to the domestic water system for make-up as is traditionally done with water-based systems. A stand-alone, automatic feed glycol make-up tank is recommended. History has shown that water make-up systems will slowly dilute the glycol over time, either through unseen system leaks or maintenance drain-down operations. This lower glycol percentage results in freezing and bursting of coils.

Perimeter Heat Using Finned Tube Radiators. The high thermal flux across the building envelope is best addressed at the bottom of the envelope with either finned tube radiation (FTR) cabinets or radiant panel heating. In areas of significant glass such as architecturally appealing entry lobbies this is typically handled with FTR cabinets. Heating with FTR cabinets is most economical when using high fluid temperatures of about 180 °F (82 °C) compared to floor radiant heating systems that typically should have a maximum fluid temperature of 120 °F (49 °C). This makes combining the two systems using a single distribution system difficult and expensive as it requires separate piping systems or a control valve and pump at each radiant manifold. When using cast iron sectional boilers, the return water temperature should be considered during design. A temperature differential too high can result in cracked sections rendering the boiler inoperable.

A benefit of using finned tube and radiant panel radiators is the ease of renovation. In applications where renovations are expected at relative frequency, it is recommended to use these approaches. Heating zones are easily modified, and piping is accessible in the ceiling space or in the floor below.

Compared to radiant slab heating systems, which will be discussed in the following section, perimeter radiant heat using finned tube or radiant panels radiators will result in faster temperature degradation if there is an outage or equipment failure than a radiant slab heating system due to the high thermal mass of the heated slab.

a



b

c

d

Figure 1. Hydronic Heating System: (a) system interface with district steam system (designed by Design Alaska); (b) mixing shunt; (c) Finned Tube Radiator at a Perimeter Wall; (d) Radiant Tubing Manifold During Construction

A benefit of using finned tube radiators is the ease of renovation. In applications where renovations are expected at relative frequency, it is recommended to use this approach. Heating zones are easily modified, and piping is accessible in the ceiling space or in the floor below.

3 Radiant Slab Heating

In-floor radiant heating, also known as radiant slabs, can be used successfully to address building heating load, but the output is limited by the allowable surface temperature before it exceeds the rated temperature of the flooring assembly or acceptable floor temperature for given building function. For example, in areas where sedentary work is performed, such as many office spaces, floor surface temperature based on comfort and safety when wearing normal footwear is limited to 84oF (29oC) that results in the flux capacity for floor based radiant heating system limited to 31 Btu/hr ft^2 (99 W/m^2) [5, 6].

A driver for many building owners opting for radiant heating systems is the quality of heat it provides. Radiant heating provides a fairly uniform heat which is welcome during cold periods in arctic climates. Since the heating is within the floor assembly, the furniture layout is not driven by the location of heating terminal units as is sometimes the case with FTR cabinets.

Building owners and system designers should consider the ability to renovate spaces when selecting radiant slab heat. When tubing is located within the slab, relocating interior walls can require careful coordination to avoid puncturing a tube when anchoring new walls into the slab. In some cases, tubing is located in a sand bed below the slab to allow for anchorage into the slab during initial construction and in the future with limited risk of damage to the radiant tubing. Locating the tubing in a topping slab would also be a consideration. In this case the tubing would be re-poured in a remodel. All radiant floor systems should use insulation under the slab (or under floorboards in staple-up applications) to direct the heat upwards towards the occupant and improve heating efficiency. In garages and hangars, it is recommended to install a hydrocarbon resistant liner above the insulation to ensure that fuel and oil leaks do not erode rigid insulation.

Another complication of radiant heating is zoning. While heating zones can be customized to the current programming during building design, this can change dramatically over time. Additional zones results in additional cost for construction; therefore, spaces with similar loads are often zoned together with the controlling temperature sensor located in the highest priority space, a manager's office in an office space for example. A downfall to fewer and larger zones is that it is less adaptable to floor plan changes. A remedy to this challenge is to have many smaller zones in a grid pattern provided the project budget can sustain the added cost. Types of spaces that are typically renovated often, such as hospital patient treatment areas, should be considered with care. Significant cost may be added to all future renovations to accommodate the needs of programming changes.

Manifolds should be located at permanent features such as bearing walls or columns as these will be consistent in future renovations. Manifolds can also be located in interior walls near fairly permanent spaces such as mechanical rooms or bathroom groups as these walls are typically more consistent during the life of a building compared to typical space divider walls. With larger diameter tubing, the manifold itself can be abandoned for smaller rooms. The radiant tubing can be run up to the ceiling space to avoid a wall accessible connection.

In the same way that temperature loss is slowed with the use of radiant slabs, the ability for a space to maintain setpoint temperature is also reduced. Radiant slabs are slow reacting, both to heat up and to cool down, therefore design consideration should be given in areas that may experience rapid temperature loss such as garages and loading docks. In these areas, it is typical to provide a supplementary hydronic unit heater that can pick up temperature quickly before there is a risk of freezing plumbing piping. Care must also be taken when locating plumbing within areas with garage doors or other large openings. For more information about radiant systems see [6, 7].

4 Centralized and Decentralized Heat Supply Systems

Historically, in the Fairbanks area in Alaska, the majority of commercial building owners who are not connected to district steam or heating water use redundant boilers. Until recently, these were almost exclusively fuel-oil fired, cast-iron sectional boilers. Owners of large facilities stock spare parts for these boilers to reduce downtime; this approach has worked well to prevent freeze-up conditions due to equipment failure.

With the introduction of natural gas, this has remained virtually the same except that natural gas boilers rely on the natural gas distribution system. In Fairbanks, natural gas arrives as liquid natural gas (LNG), and is vaporized and distributed through underground piping. To date, these systems have been comparable in reliability to oil-fired equipment except that the variety of gas-fired boilers is much greater.

Local schools and the hospital operate dual-fuel boilers that switch between oil and gas depending on the cost and availability of gas. When the distribution system is heavily loaded, there is an arrangement with the utility whereby these users switch back to oil.

The two military bases near Fairbanks, Alaska, Fort Wainwright and Eielson Airforce Base, rely on district steam generated by coal-fired cogeneration power plants. These plants distribute steam through below ground utilidors at medium pressure between 65 and 85 psi. Once inside the building, the pressure is reduced to 15 psi low pressure steam where it is typically used in a shell-and-tube heat exchanger to produce high temperature glycol for distribution throughout the building to heating terminal units. The utilidors are also used to distribute domestic water and sometimes sanitary sewer.

Scandinavian experience with heat supply systems in cold climate [8] shows that there are many advantages to using hot water district heating compared to steam systems, in particular low temperature system with a maximum supply temperature of 212 °F (100 °C). For example, the system:

- is simple, which makes it easy to operate and maintain in remote areas.
- is low risk and more resilient in case of breakdown.
- has access to many efficient low carbon heat sources, as well as free heat from local diesel generators.
- has the ability to store energy at low cost in thermal storage tanks.
- is characterized by having lower heat losses.
- is characterized by lower total costs.

To improve their resilience, distribution networks for building heating serving mission critical facilities can include redundant branches configured as loops (Figure 2) sectioned by stop valves that ensure heating energy backup [8]. In some small communities in Greenland with micro grids, a significant part of the heat demand is produced by excess heat from diesel generators.

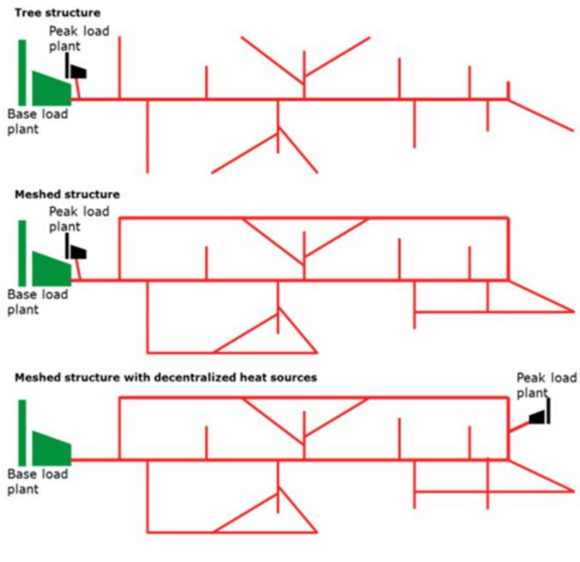


Figure 2. Heat supply strategies using local backup or a meshed network structure.

5 Cooling

Although Interior Alaska has high record temperatures exceeding 90 °F (32 °C), the number of annual hours when mechanical cooling is required is low (about 70 days with outside air temperature above a 65 °F (18 °C) base annually) [4]. Therefore, the least expensive form of mechanical cooling, direct expansion refrigeration (DX), is typically most appropriate.

DX systems function through the refrigerant vapor expansion and compression cycle. Refrigerant in the evaporator coil, often located within an air handling unit, cools air passing across the coil by absorbing heat from the airstream. Refrigerant is returned to the condenser to reject the absorbed heat to the ambient. Typically, a condenser is located on a pad outside where it can reject heat to the ambient environment; however, this can pose some challenges.

Due to the low angle of the sun during the winter and shoulder seasons as well as the amount of time on the horizon, many buildings will require cooling even when the outside air temperature is below the occupied space temperature. The preferred method of cooling during these conditions is by using an economizer function that increases the percentage of outside air in central ventilation systems. Other systems that require cooling year-round, such as data centers, may not be conducive to either the low-humidity air from a central ventilation system or the limited occupancy schedule and mechanical cooling system is preferred. Depending on the operating temperature range of the outdoor condenser, it may not be recommended to run the condenser and these outside air temperatures. This can be mitigated, to some extent, by selecting condensers that have low ambient options, extending the operating range.

DX systems benefit from a relatively low installation cost while providing high performance. In addition, compared to chillers, they have a low noise level.

For larger, year-round cooling loads, a closed loop, chilled glycol system may be desired. The preferred exterior heat rejector is a multi-fan, dry cooler rather than the use of cooling towers due to the potential for freezing. Piping can be done to bypass the chiller during the winter months and use "free-cooling" through the dry coolers to reject the heat.

Mini split systems, sometimes referred to as ductless or split A/C units, have been used successfully particularly in renovation projects where retrofitting a cooling coil into an air handling unit or ductwork is not feasible. In this application, small wall- or pad-mounted condensers are located outside or in a mechanical space. Evaporators are located in occupied spaces and can be integrated into the ceiling grid or mounted on the wall. Routing condensate to a mop sink, floor drain can be a challenge depending on the location of the evaporator therefore selecting a unit with a small condensate receiver and pump provides more flexibility in pipe routing for condensate disposal.

While technology such as chilled beams might save energy, their economic payback is very low. These and similar systems have not been adopted due to increased maintenance and high first cost. Well water cooling systems have been successful, particularly in applications where the rejected water can be discharged to the storm drainage system. Reinjection has been successful as well but is coming under greater and greater regulatory scrutiny due to concerns that groundwater pollution sources might be moved or influenced by the system. All designs that intend to use well or domestic water for cooling should be first vetted by the local utility as well as local environmental permitting agency.

6 Ventilation Systems

Due to low outside air temperatures, the heating load from heating outside air to distribution temperature is high. This load can be offset by recovering the heat in the exhaust air stream. Heat Recovery Ventilators (HRVs) can be used to reduce the size of coils and the load on the heating plant by extracting heat from the exhaust air stream that would otherwise be discharged to the outside (Figure 3).

Figure 3. Small Light Commercial HRV.

Several different types of air-to-air heat recovery cores and systems are available; all have their use, and depending on the application, one technology may be more appropriate than others. The most common technology that is used in cold climates is the plate style, heat recovery core [4].

Certain considerations must be made when using HRVs. Due to low outside air temperatures, the exhaust air stream through the heat recovery core can frost to the point that air is restricted or completely blocked. A common packaged controls method of defrosting the heat exchanger in commercial equipment is to turn off the outside air and allow warm exhaust air to defrost the exhaust air stream. In a commercial building where ventilation is required by code, it is typically not acceptable to have no outside air ventilation during occupied periods. ASHRAE 62.1 [9] does permit an exception that allows temporary loss of outside air ventilation; however, the conditions are limited and often cannot be met in an office space. In smaller residential type units, the defrost function is done by recirculating the exhaust back into the supply air system. Since the exhaust side of a HRV is typically taken from restrooms, this is functionality is not code compliant in commercial and multi-family type applications.

To prevent frosting of the heat recovery core, hydronic preheat coils can be installed in the outside air duct prior to the HRV heat exchanger. These coils must have glycol. The use of preheat coils in a ventilation system is a common in cold-climate mechanical system design for energy efficiency and controllability of adding heat to an air stream. With preheat coils, two filter banks are provided. One filter is placed upstream of the coil, referred to as the “summer filter” that protects the coil from dirt during the summer, and a filter bank is placed after the preheat coil, referred to the “winter filter.” The reason for the winter filter is that during the winter, extreme cold temperatures can frost and plug filters installed upstream of the preheat coil. The winter filter is typically located where the air stream temperature is above freezing. A filter is only located in one of these locations and is switched seasonally.

For HRV defrost control, preheat coils should be sized to heat incoming air to keep the exhaust air stream just above freezing. The higher the temperature delta across the core, the more efficient heat transfer will be; therefore, incoming outside air should be heated only as much as needed to prevent frosting. A heating coil will be needed after the core to bring the final delivery temperature to an appropriate range for occupied spaces.

Due to the exceptionally dry air in cold-climate buildings, some control strategies have extended the frost control strategy to using dew point of the exhaust stream as the control setpoint. This allows the exhaust air to be below the dry bulb freezing temperature without frosting (because it is above dew point), increasing the temperature differential and thereby increasing the heat exchange efficiency. This can also result in very low supply air temperatures downstream of the heat exchanger so this needs to be considered in sizing of the main heating coil; alternatively, a secondary stage of preheat coil control is added that maintains a set inlet air temperature on the main heating coil or discharge air temperature setpoint.

Note that the outside air stream may be below freezing after the preheat coil and in some extreme locations, even after the heat exchanger. Therefore, the “winter filter” may need to be located after the heat exchanger to remain frost-free. The operating conditions should be carefully modeled by the designer and equipment manufacturer to ensure that the heating coil is adequately sized to bring the air up to discharge temperature setpoint.

While HRVs do not eliminate the need for heating coils, they can offset the load which saves energy and operating cost for the facility. It is not uncommon in extreme cold environments for the ventilation system to be the highest heating load in the building, even more than the heating load across the building envelope.

Heat recovery systems should be designed with the capability to bypass or turn off the heat exchange function when the outside air temperature is above the supply temperature setpoint.

Ventilation systems air intakes require careful consideration due to frost buildup, snow, and wind. For more information on air intake designs specific to cold regions see the ASHRAE *Cold Climate Buildings Design Guide* [3].

7 Humidification System Design

Historically, humidification of commercial buildings in Alaska is uncommon with the exception of hospitals and process sensitive spaces requiring humidity to be controlled within certain limits. During the winter months, the relative humidity of outside air is almost zero, meaning that a significant amount of moisture must be added to increase to a given setpoint. In recent years humidification has been considered more broadly.

In the absence of specific humidification requirements, typical spaces that are humidified include data centers, server rooms, fitness centers, and hospitals.

It is generally accepted that the recommended minimum relative humidity level for human health is 30%. When humidifying to this level, there are important factors that must be considered to ensure that it is done correctly, and to limit the risk of harm to the occupants as well as to the building structure.

In many cases, the moisture that must be added to the air to meet a setpoint of 30% relative humidity is significant. It is best practice to limit the relative humidity of the supply air in the ductwork to 80% to limit the risk of condensing on the inside of the duct surface. Condensing within the ductwork can lead to mold growth, which is detrimental to human health. Control strategies should be in place to limit discharge air relative humidity.

Electrode canister type humidifiers are comprised of a small reservoir, on board control module, and electrodes extending into the reservoir. The steam outlet piping is connected to a humidification grid or can be discharged to the space depending on the application. This option is somewhat maintenance intensive as the reservoirs develops scale from mineral deposits as water is converted to steam and must be cleaned or entirely replaced on a regular basis.

Figure 4. Electrode Humidifier [10]

It is not recommended to use steam directly from a district steam source or steam boiler due to the contaminants and treatments added. An alternative is to use a steam-to-steam humidifier that takes source steam and uses it to generate clean steam, which is then used as the humidification medium.

Figure 5. Steam-to-steam humidifier [11]

Outbreaks of Legionnaires disease, a form of pneumonia that can be lethal, have been linked to humidification equipment in commercial buildings. Legionella is particularly susceptible to proliferation in stagnant water. Designers should evaluate the potential for stagnant want within the humification equipment and any associated tank or canister. This should be considered during the operating condition as well as non-operating condition as well as length of time in each. Some canister type humidification systems are equipped with an automatic purge function on startup that flushes the contents of the reservoir.

While the issue of humifying buildings has a number of considerations related to the HVAC systems and equipment, it is paramount that the impact on the building envelope be analyzed.

8 Plumbing System Design

Due to low ambient temperatures, it is considered a freeze-up risk to locate plumbing piping in exterior walls. Typically, significant design effort is spent locating fixtures such that plumbing piping is located in interior walls or within chases. Even piping located within a chase on an exterior wall may be vulnerable to freezing if enough temperature degradation occurs before restoration of the heating system. It is not uncommon for plumbing chases on the exterior of the building to have a heat source with a local thermostat.

Construction of the building envelope can significantly affect plumbing walls. For instance, plumbing wet walls that are built perpendicular to an exterior wall without a continuous vapor barrier between the wall and the exterior wall will allow cold air to enter the wall and freeze water piping. The same is true for interior plumbing walls where the roof vapor barrier has been compromised.

Mechanical rooms pose a freeze potential for water piping as this is typically the location of the water entry and water heater. Mechanical rooms with fuel fired equipment require combustion air, which is typically brought into the space through a passive opening. If not handled adequately, the cold air can sink to the floor and form pockets of low temperature that is missed by the room temperature sensor. A method to reduce this risk is to provide a unit heater, typically hydronic, oriented such that the discharge faces the combustion air opening. In this case, air is heated as it comes into the space reducing the potential for pockets cold enough to freeze piping to develop.

The International Plumbing Code (IPC) and the Uniform Plumbing Code (UPC) indicate minimum vent through roof (VTR) sizes according to connected drainage fixture units and piping length. In the arctic climate, the saturated vapor discharged through a VTR quickly freezes and generates frost on the outlet pipe. A frosted over vent can disrupt system drainage resulting in dry fixture traps and result in sewage odors entering the building. Some local code authorities in Alaska have instituted an amendment for the VTR to be increased by two pipe sizes prior to leaving the building to reduce the likelihood of frost closing the outlet. For commercial buildings it is recommended to use a 4 in. (10-cm) VTR if possible, as even 3-in. (7.6-cm) outlets have been observed to have frosting issues at prolonged cold temperatures. It is recommended that the vent lines be insulated a minimum of 3 ft (0.9 m) from the roof penetration and continuously through unheated spaces like attics. In extreme cold locations, the pipe above the roof can be insulated and even electrically heat traced to ensure the vent remains open.

Roof drains are also prone to freezing in extreme climates, resulting in water buildup and potential structural failure. It is recommended that roof drains, and their associated overflow drains if applicable, be located above the heated portion of the building. If the space below the drain is unheated, such as in building canopies or cold roofs, then the designer should consider adding electric heat trace. Overflow drains or roof scuppers within 2 in. (5 cm) of the normal roof drain are recommended. It is possible that a stormwater system can freeze underground outside of the building. Overflow spouts on the main storm water line at the building exit point can help protect against such a freeze plugging the line and creating an overload condition on the roof.

The critical nature of domestic hot water depends on the type of facility. Office buildings may be fine without hot water, but hotels and commercial kitchens cannot function without it. Where redundancy is needed in domestic hot water, the use of multiple water heaters is desired. Where natural gas is available, gas fired water heaters are preferred. Where buildings are heated with fuel oil fired boilers or a district heating system, the preferred system is the use of indirect-fired water heaters. This reduces the number of fuel-fired appliances, which has traditionally meant less maintenance. With indirect-fired water heaters, the hydronic supply temperature must be hot enough to provide the desired hot water temperature. Redundancy is needed in all components of indirect system including multiple boilers and individual pumps for each water heater.

9 Operation and Maintenance

By planning a comprehensive operation and maintenance (O&M) program, the risk of unexpected system failure that will lead to the need for emergency measures can be reduced. The term "Operation and Maintenance" covers many facets of facility management. A common definition is the administration of programs that complete preventative maintenance and reactive repair of systems. But it also includes the lobbying of proper funding budgets both in annual funding to complete regularly scheduled maintenance as well as long-term capital improvement project planning that allows for predictive replacement of equipment and systems before they fail. It includes the development of written standards and active involvement in the design of projects to ensure that systems are constructed with maintenance in mind and to minimize long-term operational costs. It includes the ongoing training of both facility maintenance staff and user groups to ensure that systems operate efficiently and effectively.

Resiliency, like redundancy, relies on backup equipment such as generators and secondary sources of heat, and on the ability to quickly get systems back online. O&M is critical in ensuring that these secondary systems will operate when needed. This includes regular testing of equipment such as standby generators, as well completing scheduled maintenance and overhauls of that equipment and its supporting systems. Standby generators need to have adequate amounts of clean fuel available. For fuel-oil-based systems, this would include regular inspection and testing of the stored fuel to remove water and ultimately replace old fuel with new fuel.

Training, a vital part of O&M, is needed so that operators know how to implement resiliency plans. There needs to be clearly written checklists, and potentially photos and/or diagrams, available to onsite personnel to assist them in implementing the various plans that should be in place to address multiple threats. The operators need to have familiarity for where key components are located within the facility such as diverting valves or exterior portable generator connections as well as how to manipulate those components to implement a resiliency plan.

If there is a failure and a resiliency plan need to be initiated, the ability to quickly get the original/primary systems operational is a combination of both training and having the appropriate tools and spare parts available. Aside from static measures, most resiliency plans are based on activities that are intended to be temporary. The backup solutions are also typically sized to only maintain minimum critical infrastructure such as maintaining a building temperature just above freezing temperature. The resiliency solution will likely not be sized to provide full indoor air quality or environmental control, leaving occupants with a less than ideal working and living condition. Most secondary systems, such as electric heat, can be very expensive to operate; therefore, the need to get the original systems fixed and back to normal operation is highly important.

Proper operation and maintenance is important for all facilities. However, it is especially important in cold climates because buildings temperatures can quickly drop to critically low values in sub-zero temperatures. When a heating system goes cold, it is a race against time. Freezing of water pipes or wet sprinkler systems is inevitable without action, resulting in significant property damage and loss of mission readiness.

Transportation access to sites can be very challenging. It is not uncommon in Alaska and other arctic regions for sites to be off the road system and only accessible by air or snowmobile during the winter. These means of access can be made unavailable for several days due to winter storms. In these locations, having replacement parts onsite, or even complete assemblies such as pumps, can provide corrective fixes regardless of weather conditions.

Power outages can be caused by multiple reasons in cold climates. Snow and ice, as well as high velocity windstorms, can cause trees to fall on power lines. Alaska has seen avalanches destroy high voltage power distribution systems. And there is the occasional wildlife mishap that can result in power loss. A standby generator, or the ability to plug in a portable standby generator, is common for most facilities. As noted above, performing regular maintenance on these standby generators will ensure they will operate when needed.

There are several steps to being prepared for urgent maintenance events:

1. Identify what can fail. That is pretty much everything, but there are more traditional items that a facility team addresses as well as system critical components will require immediate action.
2. Have an accurate set of Record Drawings of the facility systems design available both in paper and electronically. This will help locate important features such as isolation valves or system diagrams to better evaluate system functionality. Having an electronic copy available will benefit remote technicians in the help of troubleshooting issues.
3. Have maintenance documentation available onsite for at-risk systems and materials. This is traditionally the Operation and Maintenance Manual. This includes information about the product, exploded view of parts with part numbers, troubleshooting guide, warranty information, and preferably contact information for the local supplier of parts and maintenance technicians (if applicable). This is also beneficial to have electronically and in hard copy.
4. Identify and have on-hand spare parts and tools that will be needed for critical system repair.
5. Have an organized spare part location so that parts and tools can be readily found. Complete regularly scheduled inventory of tools and parts to ensure they are available when needed.
   a. Keep track electronically of what spare parts are available and when they are used on a project to ensure that replacement materials are ordered so that they are ready for the next incident.
6. Provide training and/or have training videos available onsite that can show how to perform needed maintenance/repair to the system.

10 Conclusions

The cold temperatures experienced for sustained periods of time in arctic climates make it imperative to design, construct, and maintain resilient, robust, and maintainable HVAC systems. The design process must identify points of failure and implement features that limit system downtime and reduce impact on the facility's ability to maintain temperature during planned or unplanned outages.

Redundancy provides a high degree of reliability. Heating system components such as hydronic circulation pumps and boilers should be design with redundancy such that a failure does not result full system failure. This provides building owners with a method of maintaining the building heating system by taking some equipment offline without impacting building functions.

Where practical, emergency measures such as connections for remote boilers may be necessary to ensure functionality of the facility or campus in the case of an equipment or infrastructure failure in the district heating system.

In remote locations where availability maintenance personnel are limited, and where spare parts may need to be delivered by air, the building systems should be designed to be as simple as possible, and a supply of spare parts should be stored on site.

Glycol should be used as the heating system fluid in hydronic systems to prevent freezing, and the derate in performance should be accounted for when sizing terminal units.

Best practices for plumbing piping freeze protection should be implemented, such as locating piping in interior walls or plumbing chases. Location of pipes in exterior walls should be avoided.

The strategies outlined in this article will improve energy systems resilience, which in turn will provide protection to facilities' infrastructure and contents. Frozen pipes and damage to contents can be extremely costly, and in some cases can cause irreparable damage to the programming activities housed in the building. It is the responsibility of the designer, in partnership with the owner, to identify the sensitivity of the facility and to build in resiliency features appropriate to the acceptable level of risk while still managing project costs. This may result in shifting priorities from other features to cover resiliency measures if the level of risk tolerance for the owner is low. For more information about energy systems resilience, see [12].

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