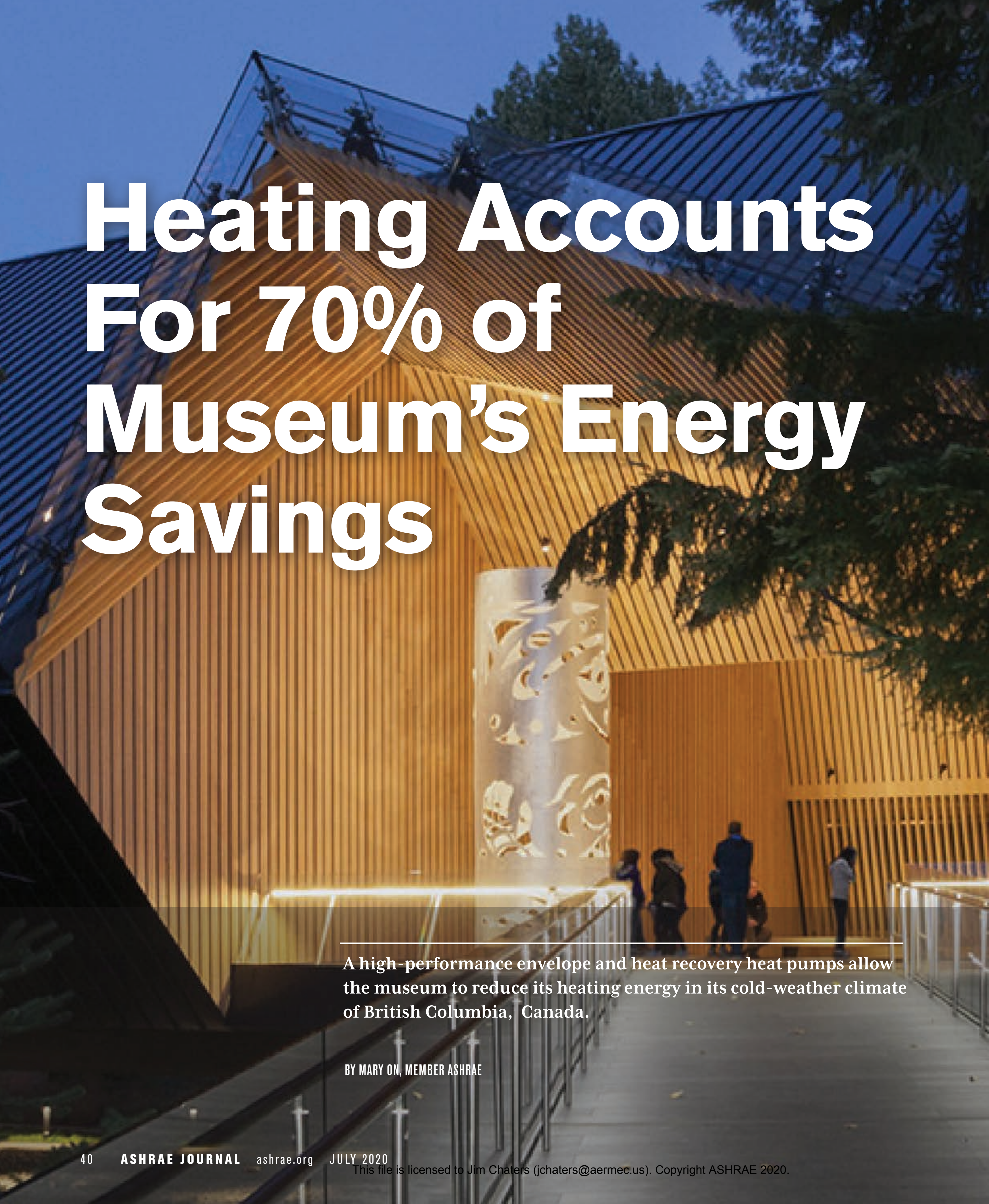
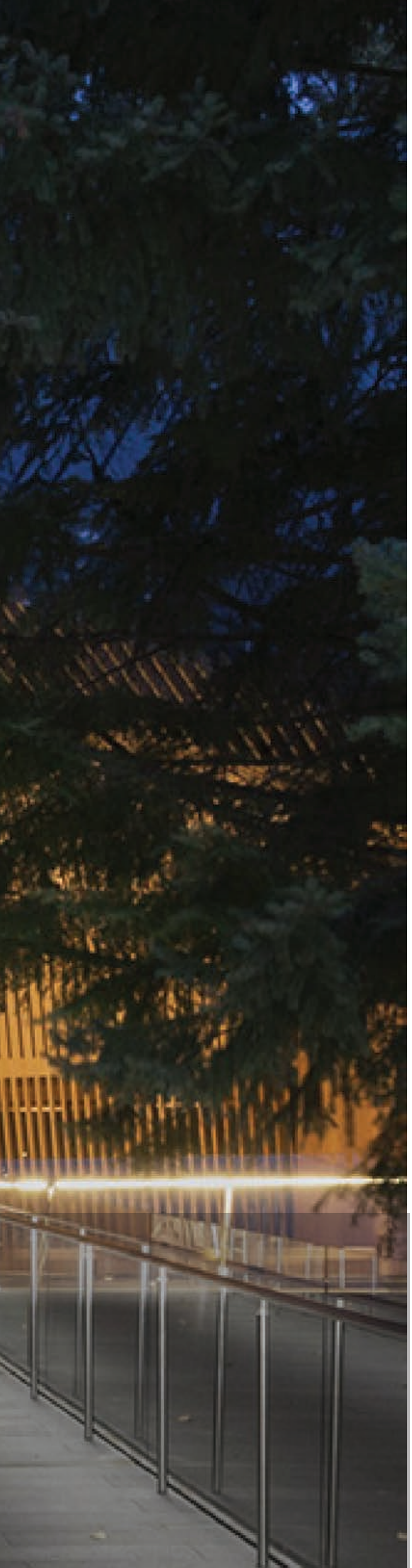


Heating Accounts For 70% of Museum's Energy Savings

A high-performance envelope and heat recovery heat pumps allow the museum to reduce its heating energy in its cold-weather climate of British Columbia, Canada.

BY MARY ON, MEMBER ASHRAE



The Audain Art Museum is located on Blackcomb Way, in the resort municipality of Whistler, British Columbia, Canada. The new, two-story, Class AA museum, with a total gross area of approximately 4750 m^2 (51,130 ft^2), contains permanent and temporary exhibit galleries, workshops, a public lobby, a gift shop, education space, offices and a suite for a live-in building manager.

The project followed an integrated design process, with a strong focus on sustainability and the environment. As part of the project's commitment to energy and the environment, the building was designed to target a gold rating under LEED® Canada for New Construction and Major Renovations 2009. The main objective of this project is to house, display, and preserve the museum art collection within a secure, sustainable, energy-efficient building. The heating, cooling, ventilation, and plumbing systems must meet the following design and performance criteria:

- A stable and consistent temperature and humidity must be maintained in the space, and airborne pollutants must be filtered out, for the preservation of artwork.
- The systems must be robust and reliable with redundancy, so that continuous, 24-hour/day, 7-days/week operation is maintained.
- They must have an optimal equipment life cycle and ease of operation and maintenance, as well as life-cycle replacement.

System flexibility with independent control is needed in the temporary exhibit gallery to meet the environment requirements of traveling exhibits.

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Energy Efficiency

As the building was designed to target the LEED Canada NC 2009 Gold rating, an energy model was created using eQuest 3.64 to compare the energy performance of the proposed design against an ANSI/ASHRAE/IESNA Standard 90.1-2007 baseline building. The model predicted that the proposed building's annual energy consumption would be 1,730,575 kWh (5,900,000 kBtu), 40% less than the baseline building.

The majority of the energy savings comes from space-heating energy reduction. The proposed building is simulated to use 368,833 kWh (1,258,500 kBtu) of space heating energy, 31% of the proposed building. Taking humidification heating energy into account, the overall heating energy saving accounts for 70% of the total energy savings. The heating energy reduction is primarily a result of a high-performance

Building at a Glance

Audain Art Museum

Location: Whistler, BC, Canada

Owner: Audain Art Museum Foundation

Principal Use: Museum

Gross Square Feet: 51,130

Conditioned Square Feet: 51,130

Substantial Completion/Occupancy: June 2016

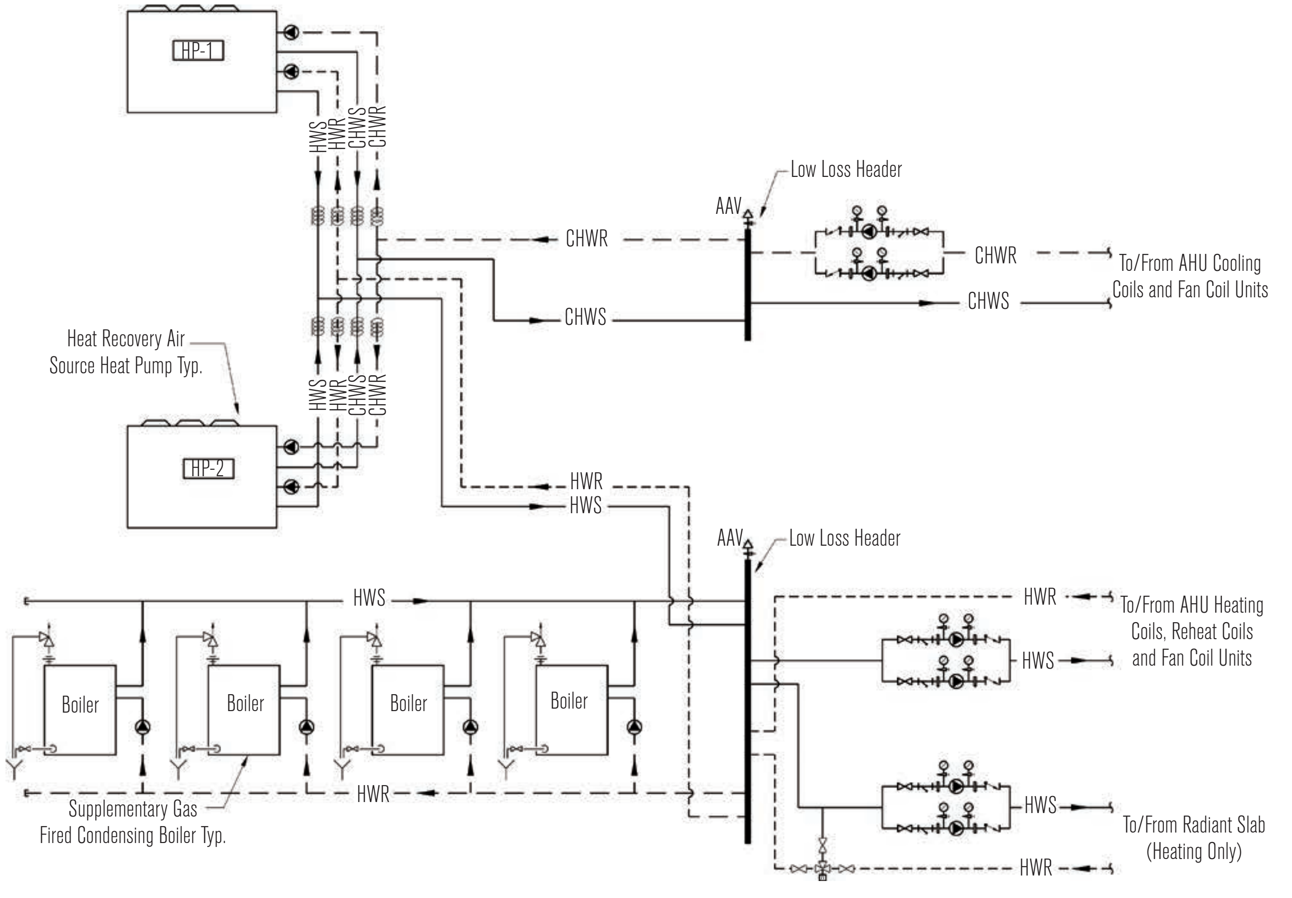

FIGURE 1 Hot water and chilled water central plant schematic.

building envelope and the use of air-source heat pumps with heat recovery to generate the building's heating water needs, as well as air-to-air heat recovery wheels in air-handling units (AHUs) to recover waste heat and moisture from the exhaust air.

Building Envelope

Located in a cold-weather climate, with 4,180 heating degree-days below 18°C (64°F) (BC Building Code 2012), the building utilizes a high-performance building envelope to reduce envelope heat loss, thus reducing the heating energy consumption and helping to maintain a stable indoor temperature for the exhibit. The building's envelope includes an R-55 (RSI-9.7) roof, an R-23.3 (RSI-4.1) wall, and triple-glazed windows, compared to the baseline model with an R-20 (RSI-3.5) roof, an R-15.6 (RSI-2.7) wall, and double-glazed windows.

Hydronic Systems

Heating and cooling in the building are provided by hot water and chilled water, generated by two 175 kW (50 ton) air-source heat recovery heat pumps, and four (three duty/one standby) 145 kW (495 MBH) supplemental gas-fired condensing boilers. Hot water and chilled water from the heat pumps are connected to separate hot-water and chilled-water low-loss headers. Boilers are also connected to the hot-water low-loss header. Refer to *Figure 1* for the hot-water and chilled-water plant schematic.

The air-source heat recovery heat pumps generate hot water and chilled water simultaneously, and internally recover the heat of compression from the compressors to increase the heating COP. When more heating is required than can be recovered, the heat pumps use the ambient air as a heat source to increase the heating output. As the heating demand increases in the winter season and the heat pumps cannot keep up with the building heating demand, the supplemental boilers stage on to inject hot water into the heating loop. The energy model predicted that the heat pumps could satisfy 76% of the annual heating demand of the building.

Ventilation Systems

The building contains spaces with different indoor environmental conditions: exhibit galleries that require tight temperature and humidity control to meet the Class AA museum standard, and general, non-gallery spaces, such as a public lobby, a gift shop, offices, and a living quarter that do not require Class AA museum grade environment. Two ventilation systems—one for the gallery and one for the non-gallery spaces—provide separate zone control in order to reduce the heating, cooling, humidification, and dehumidification energy of non-gallery spaces than if one system was to be provided for both spaces.

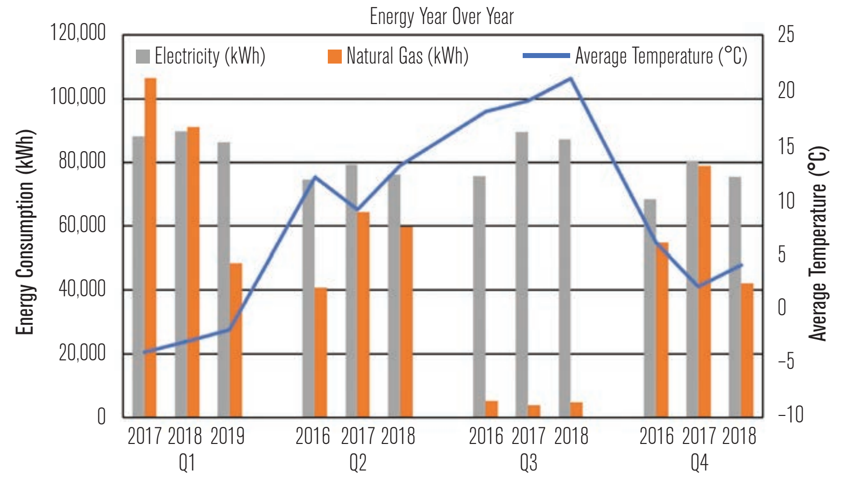

FIGURE 2 Total metered energy consumption and average outdoor air temperature.

The gallery ventilation system consists of an energy recovery ventilator, two AHUs with an energy recovery ventilator, a heating coil, cooling coils, a humidifier, and supply and exhaust fans. The energy recovery ventilator supplies ventilation air to the gallery AHUs, which, in turn, provide ventilation, heating, and cooling to the gallery. Ventilation air is returned from the storage rooms back to the energy recovery ventilation (ERV) system and exhausted. The energy recovery wheel recovers sensible and latent energy to reduce heating, cooling, humidification, and dehumidification load.

The non-gallery ventilation system consists of an energy recovery ventilator with energy recovery wheel, heating coil, cooling coil, humidifier, supply and exhaust fans, plus four-pipe fan-coil units. The energy recovery ventilator supplies ventilation air to the fan-coils and exhausts air from the washrooms, catering warming kitchen, janitor's room, and the first-aid room. Space heating and cooling is provided by the four-pipe fan-coil units. The non-gallery spaces act as a thermal buffer zone between the outdoor and the gallery spaces, so humidification is provided in the heat recovery AHU to humidify the dry, incoming outdoor air in the winter to maintain the minimum space humidity level. The cooling coils in the AHU and fan-coil units will dehumidify moist air to prevent excessive humidity level in the space during the summer months.

The total building energy consumption for the first and second year of operation based on the electricity and gas utility bills was 1,502,384 kWh (5,126,300 kBtu) and 1,735,811 kWh (5,922,800 kBtu), respectively, 13% lower and on par with the energy model. In March 2018, the third year of operation, it was discovered that the supplementary boilers were operating when the building heating demand was within the heat pumps' heating capacity, and the boilers' supply water temperature was also higher than design. This was rectified, and the building energy consumption dropped to 1,387,886 kWh (4,735,600 kBtu), 20% less than the modeled building energy consumption. Refer to *Figure 2* for the building's metered electricity, gas, and total energy consumption for the first three years of operation.

Indoor Air Quality (IAQ) and Thermal Comfort

IAQ

The gallery's air system has filtration that meets the Canadian Conservation Institute's Class A HVAC filter system for advanced degree of preservation. The energy recovery ventilator contains a MERV 8 pre-filter and carbon filter to deal with forest fire season, and the AHUs contain a MERV pre-filter and an electronically enhanced filter. The electronically enhanced filter contains three sections. The first section emits equal amounts of positive and negative charges, and particles in the air become polarized. The second section is an electrically charged field, and the polarized particles are captured in this section. The final section uses a pulsed, high-voltage electrodynamic field to force any particles that escaped the second section to have an inelastic

Photo 1 Entrance lobby with triple-glazed window and radiant floor heating.

collision. The inelastic collisions create larger particles that have a neutral charge and are then captured. The electronically enhanced filter is equivalent to a MERV 15 filter. A spare filter rack is also provided in the AHUs in case a carbon or chemical adsorption filter is required in the future. Furthermore, the building is maintained at a positive pressure relative to the outdoors to minimize infiltration of contaminants and odor from the outside. The non-gallery ERV system contains a MERV 8 filter, and the fan-coils contain MERV 13 filters.

Thermal Comfort

Gallery Space. The objective of the design is to maintain space temperature and humidity in the exhibit area to the Class AA museum space condition requirement, which is 21°C, ±1°C (70°F, ±2°F) and 50%±5% RH all year round. This condition also satisfies occupant thermal comfort based on an average metabolic rate of 1.4 and a clothing insulation value of 1.0, per ANSI/ASHRAE Standard 55-2004. The museum has floor-to-ceiling glazing in the main lobby and the corridor, leading from the lobby to the exhibit areas. Triple-glazed window and radiant floor heating are provided in the lobby and corridor to minimize the cold radiant window effect to maintain comfort and also reduce the amount of air that would have been required if heating was to be provided only by air to minimize potential drafts. Supply air within the exhibit space is supplied at the ceiling level with ceiling return air, with an air-distribution effectiveness of 1.0. The terminal air velocity from the supply air grilles is designed at 0.1 m/s (20 fpm) to minimize draft at the occupied level, both for human comfort and art preservation. Temperature, humidity, and CO_2 sensors are provided in each exhibit space.

Non-Gallery Space. As noted previously, the non-gallery spaces act as a thermal buffer zone between the outdoor and the gallery spaces. The non-gallery space condition is controlled to 21°C, ±1°C (70°F±2°F), 40%, ±10% RH in the winter and 23°C, ±1°C (73°F, ±2°F), <60% RH in the summer. This condition satisfies occupant thermal comfort based on an average metabolic rate of 1.4 and a clothing insulation value of 1.0 per ANSI/ASHRAE Standard 55-2004. Supply air within the exhibit space is supplied at the ceiling level with ceiling return air, with an air-distribution effectiveness of 1.0. The maximum terminal air velocity from the supply air grilles is designed at 0.8 m/s (160 fpm). Temperature, humidity, and CO_2 sensors are provided for each fan-coil zone in the non-gallery area.

Innovation

The museum is located in a heating-dominant location, with a 1% heating design outdoor air temperature of –20°C (–4°F) (BC Building Code 2012). The building is able to reduce its heating energy in this climate due to a high-performance envelope and heat recovery heat pumps. Highlights of the envelope and mechanical system's energy-saving features are as follows:

- Overall exterior roof conduction 62% lower than the baseline case.
- Overall exterior wall conduction 32% lower than the baseline case.

- Overall window conduction 53% lower than the baseline case.
- Air-to-air heat recovery system to recover waste heat from the exhaust air to reduce the energy required to condition the outdoor air.
- Demand-controlled ventilation prevents overventilating unoccupied or lightly occupied spaces and reduces the energy required to condition the outdoor air.
- Air-side economizer to utilize the outdoor air to provide free cooling in the building when the outdoor air condition is favorable.
- Building is heated by heating water generated by a central heating plant consisting of high-efficiency air-source heat recovery heat pump at 2.5 COP seasonal efficiency and backup high-efficiency gas-fired condensing boilers with 94% efficiency.
- Building is cooled by chilled water generated by high-efficiency air-source heat recovery heat pump at 4 COP seasonal efficiency.
- Domestic hot water is generated by electric hot-water tanks to avoid any thermal losses for this low-demand building.
- Occupancy sensors in offices, meeting room, and workshops to turn off lights and reduce supply air volume when the space is unoccupied.

Operation and Maintenance

Mechanical systems typically have a life expectancy of 30 to 40 years, if well maintained. As the building will have a life of 50 to 100 years, this means that the systems will fail at some point during the life of the building. It is therefore critical that the failure does not result in damage to the art collection. The damage could come from leaking pipes, a faulty humidifier, or accidental damage to a sprinkler head. While some pipe joining methods are stronger and more reliable than others, it is necessary to ensure that water services are located away from the gallery so that if leakage does occur, water does not drip or migrate to the gallery or other spaces containing the art collection. All mechanical rooms and equipment that require access, such as air valves and fan-coil units, are located away from the exhibit space for ease of access and maintenance. Leak detectors are also placed in the washrooms and under sinks for early leak detection, even if the fixtures are not located directly above the exhibit space.

Commissioning of the gallery mechanical system began long before the arrival of artwork to ensure the system is capable of maintaining a stable temperature and humidity set point. Once the gallery mechanical system was tested and commissioned, the temperature and humidity readings in the gallery were logged on the DDC for 14 days prior to setting up the exhibits.

Cost-Effectiveness

Cost of electricity is slightly lower than the cost of natural gas in Whistler. The marginal electricity rate is $0.0462/kWh, and the gas rate is $15.629/GJ ($0.056/kWh). The cost difference is not large, so the annual energy savings of using a combination of heat pumps and supplemental boilers compared to boilers only is estimated at $2,837. The cost of the heat pumps is approximately $155,000 more than a boiler-only system. The payback period is longer than the equipment's life expectancy; however, the project is strongly committed to sustainability, and the carbon emission reduction is a higher priority than economic payback.

Environmental Impact

Based on the energy model, the building uses 1,730,575 kWh (5,904,900 kBtu), or 40% less energy, than the baseline building. British Columbia has hydroelectric power generation, with carbon emissions almost ten times lower than natural gas (0.09 kg CO_2e/kWh vs. 0.185 kg CO_2e /kWh). Of the 368,833 kWh (1,258,500 kBtu) of modeled heating energy consumption, 281,450 kWh (960,000 kBtu) is consumed by electrically driven heat pumps, and the rest is consumed by the supplemental gas-fired boilers. The modeled proposed building saves 216 529 kg (476,364 lb) CO_2e compared to the baseline building with only gas-fired boilers, which is equivalent to the average annual emission of 47 passenger vehicles. The actual emission is less, given the actual measured energy consumption is less than the modeled result.

The museum site is located next to a forest and near Fitzsimmons Creek. The site utilizes natural surroundings and has dedicated open space for the life of the building, as well as encouraging planting of native species. The construction of the building was careful not to disturb and pollute the natural environment. Seventy-five percent of the total weight of construction waste generated onsite was recycled and diverted from the landfill. ■

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