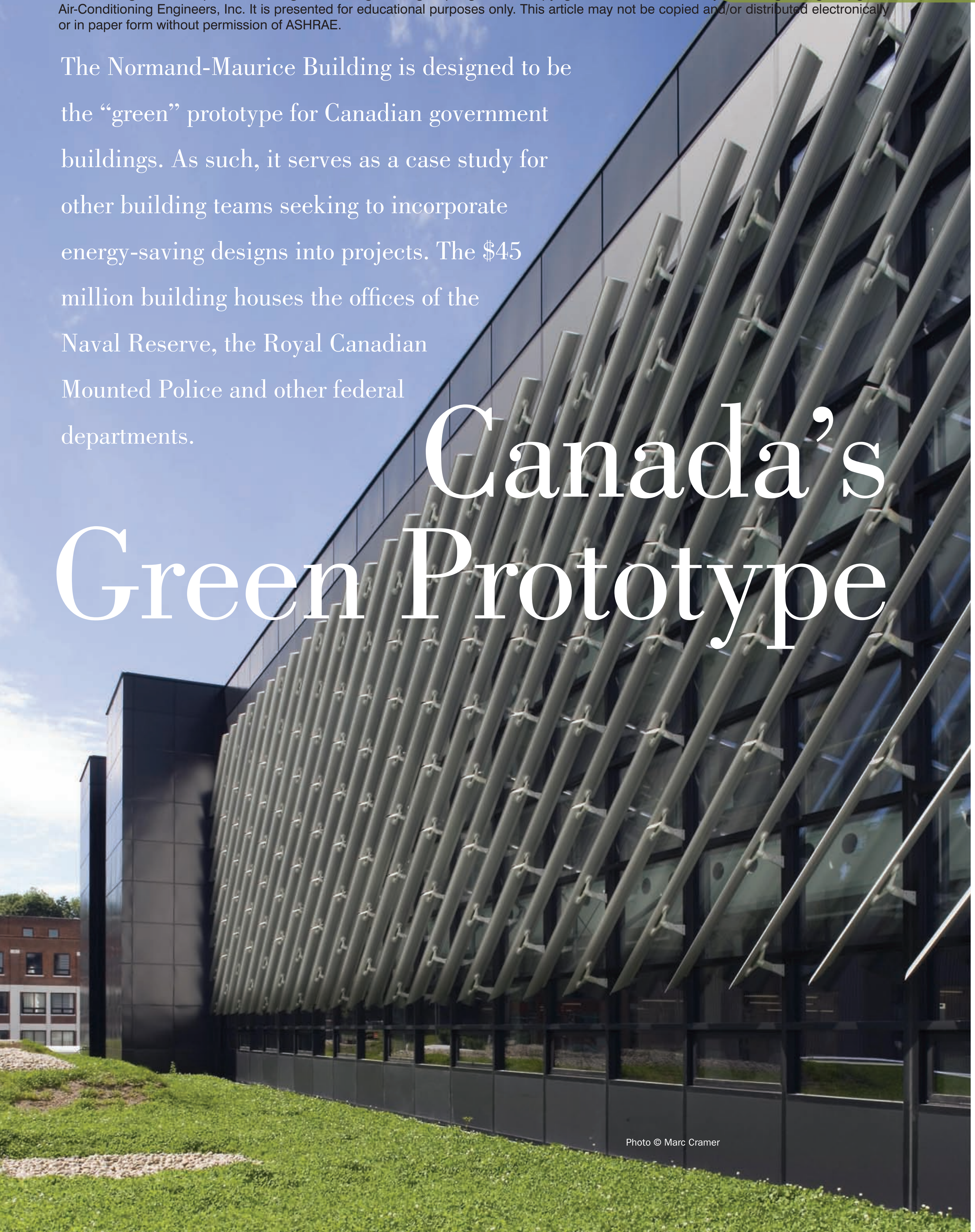


Photo © Marc Cramer

The Normand-Maurice Building is designed to be the "green" prototype for Canadian government buildings. As such, it serves as a case study for other building teams seeking to incorporate energy-saving designs into projects. The $45 million building houses the offices of the Naval Reserve, the Royal Canadian Mounted Police and other federal departments.

Canada's Green Prototype

BY ASHLY LYONS, MEMBER ASHRAE; FREDERIC GENEST, P.E., MEMBER ASHRAE; AND JACQUES DE GRACE, P.E., MEMBER ASHRAE

Design and Systems

Natural Ventilation

With the objectives of sustainable development and energy efficiency, natural ventilation was integrated for the Normand-Maurice Building early within the design. However, natural ventilation is restricted due to very cold peak winter conditions and the occasional very humid peak summer conditions. For this project, a hybrid ventilation system combined with dedicated heating and cooling systems was designed to separate the ventilation needs from the heating and cooling needs.

Natural ventilation or mechanical ventilation is used with complementary mechanical heating and cooling systems. When the outdoor conditions allow, the motorized windows located at the top of the multistory skylights, the gymnasium and the atrium open. The skylights are designed to allow daylight to penetrate all three levels of the building. The windows of the occupied spaces can be opened manually.

Mechanical Ventilation

Heating is mainly done with high efficiency energy recovery from the exhaust air (either enthalpy wheel or heat pipes). Adiabatic humidification is used in the main building HVAC system. Water is sprayed onto an evaporative media in the ventilation system instead of directly using vapor from a steam boiler. When the water evaporates, the air is cooled and, if required, later reheated by the low-temperature heating loop.

A dedicated outdoor air system supplies outside air to the other HVAC systems. It is equipped with an enthalpy wheel and provides suitably dehumidified air to prevent condensation on the cold radiant slabs. The outside airflow rates are modulated to compensate for required exhaust rate in sanitary spaces as well as to maintain acceptable CO_2 levels in the occupied spaces (using CO_2 sensors in the appropriate spaces).

Underfloor Air System

For offices and classrooms, an underfloor air-distribution system was selected. This technology pressurizes an underfloor plenum and uses floor diffusers to distribute air to the spaces. This method has several advantages, namely less horizontal ducts and less restriction to air movement, allowing a reduction of the fan power needed.

Low-velocity floor supply (i.e. displacement ventilation) prevents too much mixing in the space. While adequate indoor conditions are maintained in the occupied space, less adequate conditions can be maintained higher up. For instance, ASHRAE Standard 62.1-2007 suggests a ventilation efficiency of 120% with this approach, allowing a

BUILDING AT A GLANCE

Building Name Normand-Maurice Building

Location 740 Bel-Air Street, Montreal

Size 168,900 ft^2

Started 2002

Completed 2005

Building Use Offices, classrooms, meeting rooms, warehouses, gymnasium, firing range, cafeterias, workshops and 10 weather-protected truck docks

Cost $45 million CND

Distinctions International attention in Oslo at the annual Green Building Challenge in 2002, Excellence Award in 2005 from the Canadian Institute of Steel Construction, 2009 ASHRAE Technology Award

BUILDING TEAM

Owner Public Works Governmental Services Canada (PWGSC)

Contractor Décarel Inc.

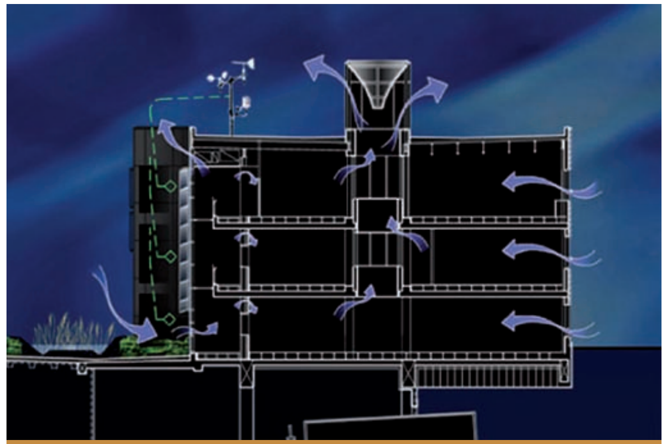
Architects ABCP, Beauchamp-Bourbeau and Busby Perkins+Will

Landscape Architects Rousseau Lefebvre

Sustainable Development Lyse M Tremblay architecte

Structural Engineers Saïa, Deslauriers, Kadanoff, Leconte, Brisebois, Blais

Mechanical/Electrical Engineers Pageau Morel



The natural ventilation system uses motorized inlets and outlets in the atrium (left). Multistory skylights (center) and operable windows in the office spaces (right) enhance ventilation and daylighting.

This interior view of the atrium shows the back of the blades shading the space. Windows separate the atrium from the office spaces to allow daylight.

Photo © Beauchamp-Bourbeau

reduction of 17% of the outside air requirements in the occupied space. Thermally, this translates with higher return air temperature, reducing cooling loads since more sensible and less latent cooling is required at the coil.

Many verifications of underfloor airtightness were made to ensure construction quality and limit leakage, ensuring adequate ventilation and air conditioning in all spaces. By opting for this type of air distribution, future repurposing of the spaces is simplified, and there is no duct to consider.

Heating/Cooling

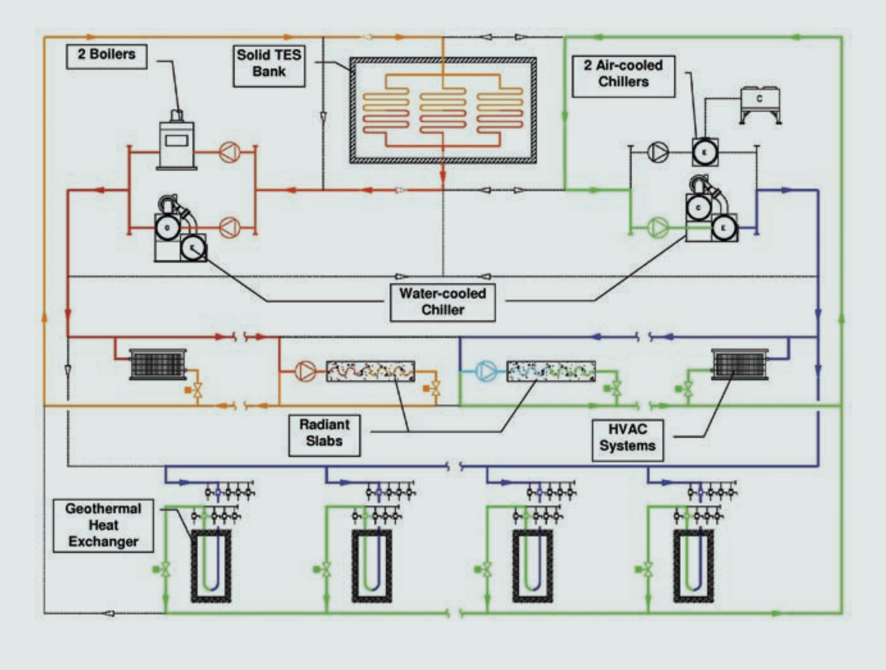
The heating and cooling of the spaces is mainly done with fluid-based radiant ceiling slabs. These systems have reduced power needs for the transportation of heat and cold compared to air-based systems. Additionally, all of the exposed areas of the slabs are radiant emitters that help maintain the fluid temperature required to heat and cool the space very close to the actual room temperature (more active surfaces, less temperature differential needed). This enables a low-temperature heating loop and helps prevent condensation when cooling.

The slab also acts as a thermal mass, storing energy and reducing the peak heating and cooling loads, delaying them until 12 hours later. Since the ventilation is an underfloor system and the indoor architectural design called for exposed ceilings, the piping was installed in the lower portion of the 12-in. slabs to better influence the lower surface, exposed to the level below.

To compensate for the high thermal inertia and to respond to the conditions of the different spaces, the slab is zoned and controlled in such a way to ensure a base cooling capacity (internal zones and summertime for perimeter zones), using the underfloor ventilation to supply additional cooling as required due to space usage and type. During wintertime, perimeter zones are heated high enough to maintain indoor conditions without heat gains, while the underfloor system recools as needed in response to the internal loads. The temperature of the perimeter zone slabs vary seasonally, while indoor zone slabs are maintained at constant temperature all year.

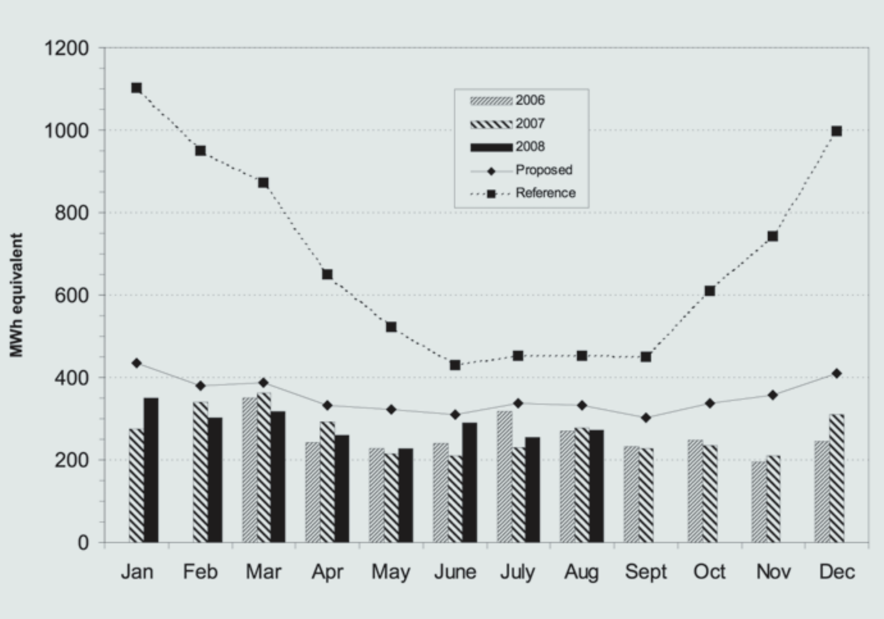
Special attention was needed for the use of a cold surface for cooling due to the risk of condensation. The success of such installations lies in the control of the humidity level in the spaces and a proper temperature of the cold surface with respect to the space due to the risks of condensation. To control the humidity level, the dedicated outdoor air system supplies the main HVAC system with dehumidified air.

CENTRAL THERMAL PLANT (DAYTIME WINTER MODE)



ENERGY PERFORMANCE

Monthly total energy consumption for the proposed, reference and actual buildings



Central Energy Plant

The central energy plant is made up of energy producers consisting of three HFC-based chillers (one water-cooled and two air-cooled) and two gas-fired hot water boilers, and energy consumers, such as the HVAC systems and the radiant slabs. Additionally, the plant is connected to a geothermal heat exchanger and a solid (sand-based) thermal energy storage system that act as either energy producers or consumers, depending on their use.

At all times, the water-cooled chiller produces chilled water and low-temperature heating water, acting as a heat pump. The internal zones need chilled water all year. During the heating season, the plant recovers the heat rejected by the water-cooled chiller to produce low-temperature heating water for the perimeter zones and to treat the

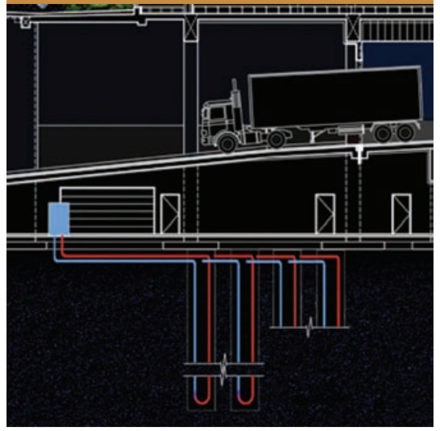
Photo © Pageau Morel

5x12 boreholes were drilled into the rock bed after excavation and before foundation work began. Each U-tube exiting the ground was located and protected by a pair of concrete blocks. The old foundry façade (right) was kept upright after the existing buildings were demolished.

Photo © Pageau Morel

The topmost layer of PEX piping, which makes up the solid thermal energy storage, is shown before the final backfill. The installation was done from "within" the building, before the slab on grade was poured.

The horizontal runs of the geothermal heat exchanger run below the underground parking slab. The horizontal runs were encased in concrete before final backfill and the pouring of the slab.



outside air. If there are not enough chilled water consumers, the geothermal exchanger acts as a virtual consumer. Supplied chilled water creates an additional load on the chiller to maximize the heat generated in heat pump operation. The boilers are used if needed. During the cooling season, the geothermal heat exchanger acts as a heat sink to reject the heat produced by the building, using the ground for seasonal energy storage.

During the winter, the solid thermal energy storage is used to preheat the returning heating water during the day, acting as an energy producer, whereas it is recharged at night with the water-cooled chiller (acting as a consumer).

The reverse happens during the summer. The charging and discharging of the thermal storage is controlled in order to prevent overloading the main chiller when charging and to avoid discharging it too quickly. This allows the system to benefit from the peak load shaving long enough to pass through the day. The main objective is to avoid starting a boiler or a backup air-cooled chiller.

Vertical Geothermal Exchanger

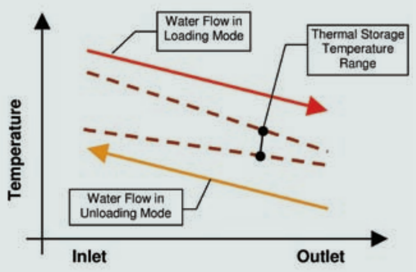
Originally, the heating and cooling energy of the building was to be mainly produced by a geothermal heat exchanger coupled with two 60-ton chillers intended to work as heat pumps. It called for a geothermal heat exchanger made of 100 450-foot boreholes. However, there was no open space left on the construction site to locate those boreholes. The only remaining available space was located under the building, but that space couldn't accommodate 100 boreholes while respecting recommended distances from the foundation elements and with the required spacing between boreholes.

Knowing that the peak loads on the geothermal exchanger are typically responsible for a sizeable portion of the total borehole length required, the building team sought to reduce peak loads, thereby reducing the size of the geothermal exchanger. However, the overall heat balance had to be maintained to obtain the desired building energy efficiency target. Thus, thermal energy storage needed to be used. It was designed to completely replace one of the original 60-ton chillers. The storage had to be capable of producing 60 tons during a period of at least eight hours after being charged. The peak loads perceived by the geothermal exchanger were reduced by half. With this new data, calculations determined that 60 boreholes were required, which could be drilled below the building.

Solid Thermal Energy Storage

This building benefited from a particular situation. A portion of land beneath one of the existing buildings was contaminated and needed to be excavated; however, it later had to be backfilled. It was decided that the backfilled space would be used as thermal energy storage. The perimeter of the excavated section was insulated with rigid insulation, and PEX piping was laid in multiple layers throughout the backfill. Sand was used to backfill the space to allow optimal contact with the piping and proper diffusion throughout the mass while protecting the pipes from damage.

THERMAL PROFILES IN THERMAL STORAGE



Literature on thermal storage almost exclusively covers tanks filled with liquid (using phase change or not); very little information exists on solid thermal storage. A simplified heat transfer model, based on finite-difference nodal networks, was used to establish the transitional behavior when charging and discharging the mass. This model allowed observation of the distribution throughout the mass and the conclusion that two important phenomas occur related to the rather slow thermal diffusion in the solid mass.

First, the heat is not evenly distributed along the pipes but follows the water temperature profile in the pipes during the charging. Consequently, for an optimal thermal exchange, the flows should be reversed in the two modes, creating the effect of a counter-flow exchanger.

Furthermore, penetration of heat for the anticipated operating condition was limited to a radius of 4 in. around the pipes. Therefore, a 2-D spacing of 9 in. between the pipes was chosen to limit the thermal interference between the charging and discharging cycles.

Control Systems

A fully centralized direct digital control system monitors all of the HVAC systems' performance to ensure proper operation with minimal

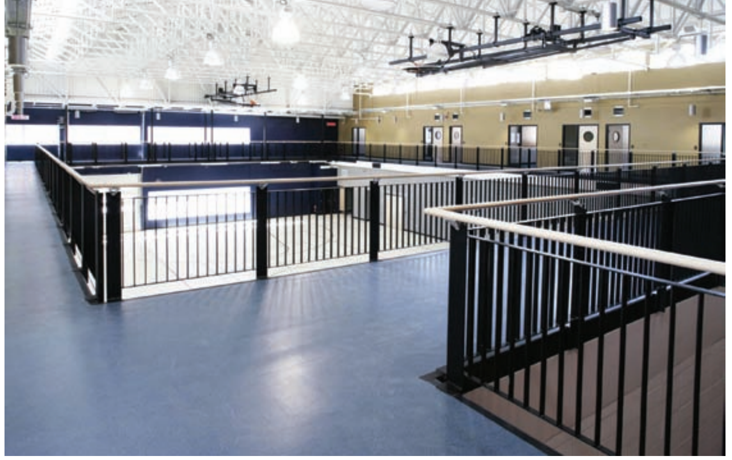


Photo © Pageau Morel

Photo © Marc Cramer

The interior design maximizes open and airy spaces. Top: A second-level balcony overlooks the gymnasium and provides access to other office spaces. Above: The smaller northern atrium serves as the main entrance to the building. The weight room/fitness center is completely open to the atrium. The top floor is a typical office space, before fitup.

Photo © Beauchamp-Bourbeau

The far wall of the atrium is composed of bricks recovered from the façades of the deconstructed buildings. The floors are active radiant slabs. Both the brick wall and the floors capture sunlight during the winter for passive solar heating.

human interaction. A modular control scheme was implemented using “independent modules” to control the various subsystems (each ventilation system, chillers, boilers, geothermal borefield, solid thermal energy storage and radiant slabs), simplifying system programming, integration and interaction.

Cost Effectiveness

Designers sought to reduce the energy used in the building by at least 50% compared to the requirements of the 1997 Model National Energy Code for Buildings (MNECB) of Canada. The overall cost for the building was approximately $45 million CND, which included roughly $1.5 million CND spent on sustainable development. Approximately $10 million CND was spent on the mechanical and electrical systems.

Using thermal energy storage reduced the size of the geothermal heat exchanger by 40% without sacrificing the overall energy efficiency. For the LEED Canada-NC certification, energy simulations were made using EE4-CBIP, a software program designed to demonstrate a building’s compliance to the requirements of Canada’s Commercial Building Incentive Program (CBIP), to establish the building’s energy performance.

It was estimated that the average annual coefficient of performance of the entire power plant (water-cooled chillers, air-cooled chillers and boilers) is 2.50 in heating and 4.35 in cooling. The total energy consumption for the MNECB-compliant reference building was estimated at 11.17 MBtu/ft^2, while the Normand-Maurice Building energy consumption was estimated at 6.34 MBtu/ft^2. This represents a 48.5% reduction in the energy consumption, corresponding to a reduction of 38.1% in energy costs (see *Table 1*).

For the period between April 2006 and March 2007, the actual energy consumption for the building was 9,327 MBtu of electricity and 1,509 MBtu of natural gas, for a total of 10,862 MBtu or 4.75 MBtu/ft^2. Compared to the reference building, this represents reductions of 61% in energy consumption and 55% in energy costs. The projected overall annual savings of $172,000 CND turned out to be $246,000 CND, totalling approximately $6 million CND over 25 years and corresponding to a simple payback of about six years (counting financial incentives).

Lastly, an overall annual reduction of 800 tons of CO_2 was achieved.

TABLE 1 SIMULATED BUILDING ENERGY PERFORMANCE

Regulated Energy Consumption	Proposed MWh eq	Reference* MWh eq	Difference % Energy
Lighting	654	1,116	–41%
Space Heating	752	3,470	–80%
Space Cooling	220	229	–4%
Heat Rejection	311	584	–47%
Pumps	89	78	+14%
Fans	513	1,052	–51%
Service Water Heating	197	198	±0%
Total	**2,525**	**6,726**	**-63%**
Total Energy Consumption**	**4,244**	**8,234**	**-48%**
Regulated Energy Cost	**$ CND**	**$ CND**	**Difference % Cost**
Electricity	133,423	202,034	–34%
Natural Gas	41,600	157,232	–74%
Total	**175,023**	**359,266**	**–51%**
Total Energy Cost**	**284,041**	**458,878**	**–38%**

*Based on a code-compliant building under Canada’s model energy code.
**Includes plug and process loads.

Photo © Marc Cramer

This northern view of the building shows the old foundry façade that serves as the main entrance of the building. Generally, the lower half of the building is used for storage and interior truck docks (identified by the brown brick façade), while the office spaces are located on the upper levels.

Sustainable Building Strategies

The building was erected on the site of an old foundry built in 1890. The original façade of the foundry was integrated to preserve the patrimonial heritage. One-hundred percent of the steel materials, 82% of the wood materials and 92% of the brick from the foundry was reclaimed and reused for the new building or otherwise recycled.

Three-quarters of the materials used in the old building were diverted from landfills. For the new building, more than 80% of the residual construction materials were recycled. For the new materials, when possible, those without volatile organic compounds or formaldehyde were used. Recycled materials also were used in many different components.

The new building was constructed of steel and concrete. Steel was used for most of the large spaces due to spans, rapid installation, lower cost and high recycled content. After being washed and painted, 64 35-ft beams from the old foundry were reused in the construction of the roof over the office area. Concrete, used elsewhere, contains 27% fly ash to replace cement.

Plumbing Systems

The plumbing system was designed to reduce the amount of potable water used. Rainwater and grey water from the sinks is treated on site and reused in the dual flush water closets and low-flush urinals. The green roof does not have an irrigation system since it is designed following xeriscaping principles. Overall, 30% less potable water is consumed, while 50% less potable water is used for sewer conveyance.

Building Envelope

The building envelope was designed with skylights that allow light to penetrate multiple building levels

The south atrium opens onto the green roof terrace, which is used for ceremonial purposes and some recreation. The inclination of the blades shading the atrium is designed to block the peak summer sun.

Photo © Marc Cramer

The shades' steep angle allows significant daylight and passive solar heating, while preventing snow accumulation.

Photo © Beauchamp-Bourbeau

and a south-facing atrium to provide daylighting. Moreover, the atrium is equipped with a shading device made of fixed blades strategically oriented.

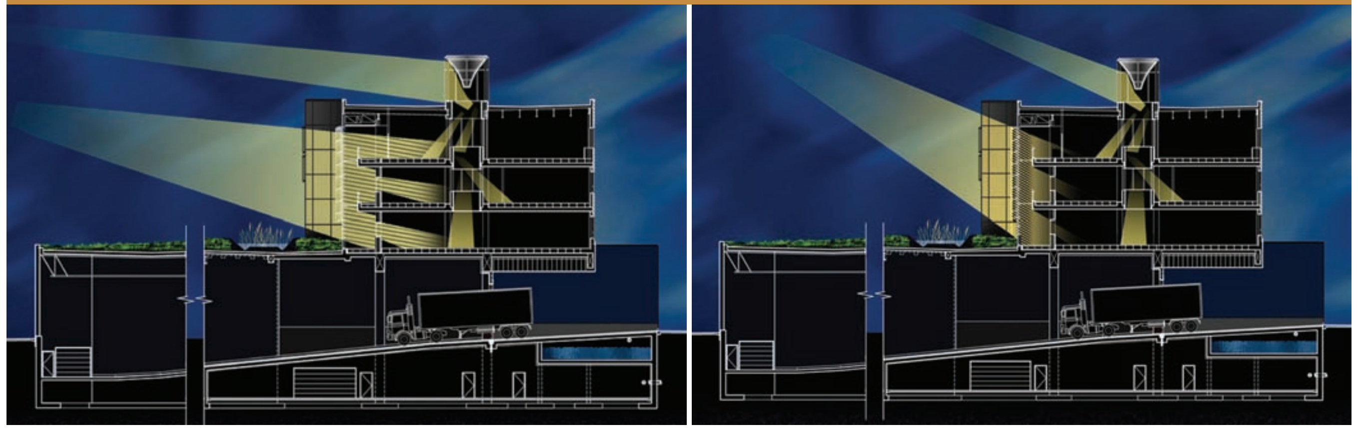
As shown in the pictures, the blades have a steep angle to prevent snow accumulation. Also, since the atrium is facing southeast, they are oriented westward to maximize natural daylight and passive solar heating during the winter while cutting out direct sunlight in the summer to prevent overheating the space. To maximize passive solar heating, the atrium has large areas of masonry walls and concrete floors serving as a solar collector. In case of overheating during the summer, natural ventilation in the atrium removes the heat. To complement the natural lighting, efficient direct/indirect lighting was used. The lighting is controlled based on sunlight and occupation of the space.

Finally, the building's green roof is accessible to the occupants. A separate area is dedicated to act as a bioswale to treat grey water recovered from the lavatories before storing it for later use as flushing water.

Conclusion

The Normand-Maurice Building, the first federal building in Quebec designed to meet the ecological goals of the Canadian government, has served as a case study for professionals and students seeking to incorporate sustainable features into other projects. Its significantly lower than average operating costs demonstrate that an energy-efficient building makes economic sense and can serve a variety of purposes. ●

The building was designed to maximize daylighting while controlling solar heat gains and glare. The winter sun penetrates deeply into the building, illuminating the office spaces through interior windows open to the atrium (left). External and internal shading blocks summer sunlight (right). Additionally, a system of skylights was designed to allow sunlight to penetrate the indoor spaces through the three office levels. A reflective cone at the top of the skylight helps daylight penetrate the building floors.



LESSONS LEARNED

- Extracting heat from the borefield during the winter requires below-freezing fluid temperature. Because the borefield was used both for heat rejection and extraction and was thus connected to both the hot water and chilled water loops, propylene glycol was used as antifreeze throughout the water loops (the alternative was separating the borefield loop with a heat exchanger, reducing the energy savings due to increased lift on the water-cooled chiller). This led to major difficulties in purging the air from the loops, pressurizing the system and fine-tuning its operation, as the glycol appears to hold more air than normally expected (unconfirmed, since the local chemical manufacturer representatives don't agree with our conclusions). It is felt that it is much better to limit the glycol to where it is needed and separate those loops from the others.
- A geothermal borefield underneath the building is feasible, workable and effective, though it must be designed and operated to prevent freezing of the underground soil (this is not a problem for the Normand-Maurice Building since it sits on bedrock). Careful management of the construction site is required, as is protection of the horizontal runs. (Here, they are encased in concrete.)
- Classical water-cooled chillers shouldn't be used as heat pumps during the heating season, especially with a geothermal borefield. They are designed to maintain the chilled water loop temperature, while the hot water loop temperature should be the active control parameter. Specialized systems or equipment would be much easier to commission and operate.
- Ceiling radiant slabs in cooling can be really effective. In this case, the underfloor air distribution system, which is partly variable air volume, maintained its boxes almost closed to prevent over-cooling the spaces (which lead to IAQ dissatisfactions). Current tube spacing in the slab is 12 in. and could possibly be increased to 18 in. without affecting performance.

ABOUT THE AUTHORS

Ashly Lyons, junior engineer at Pageau Morel, was the lead writer.

Frederic Genest, LEED AP, ASHRAE HBDP and associate at Pageau Morel, was project engineer and served as heating/cooling system designer.

Jacques de Grace, LEED AP, engineer, and principal associate at Pageau Morel, served as project manager and conceptual designer.