SOLAR TOWER BREATHES WITH THE WIND

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ABSTRACT

In downtown Winnipeg, this innovative office environment combines a parkade, a 3-story podium, containing offices, restaurants and retail, with two narrow 18-story office towers linked by winter gardens. Winnipeg with 6,032 heating degree-days, a winter design temperature of - 35°C and a summer design temperature of + 30°C presented the project team with unique climatic challenges. The building dynamically adapts to the continuously changing climatic conditions. Occupants can control their individual environment according to their own personal preference using operable windows, lighting and shading devices. Now under construction, this 65,000 m² building is predicted to consume 140 kWh/m²/year of primary energy for building operation, establishing it as the most energy efficient office tower in North America, 60% below a typical office tower. Beyond energy efficiency the Manitoba Hydro Corporate Head Office will provide a new level of thermal and visual comfort, with all workstations having access to the façade.

WINNIPEG CLIMATE CONDITIONS

Thorough investigation of the Winnipeg climate guided the development of a successful concept. The analysis is based on data from Canadian Weather for Energy Calculation (CWEC) files. Analysis revealed that the Winnipeg climate is characterized by extreme winter conditions with minimum temperatures of –35°C, an annual temperature swing of 70 Kelvin, relatively short but warm and humid summer, relatively high solar radiation all year, prevailing wind from south and relatively high average wind speed of about 5.3 m/s (at a height of 10m).

This gives primary importance to heating, and some importance to cooling and dehumidification. The large annual temperature swing suggests seasonal heat storage, and the generous amount of solar radiation is an opportunity for passive and active solar heating. The strength of the wind suggests the use of wind power, and its direction guides building orientation.

CLIMATE AND ENERGY CONCEPT DESIGN

Winter

Energy use is minimized during the cold season by carefully restricting heat losses, and collecting as much heat as possible from natural sources. Attention to radiant heat exchange further eliminates unnecessary energy use while providing superior thermal comfort.

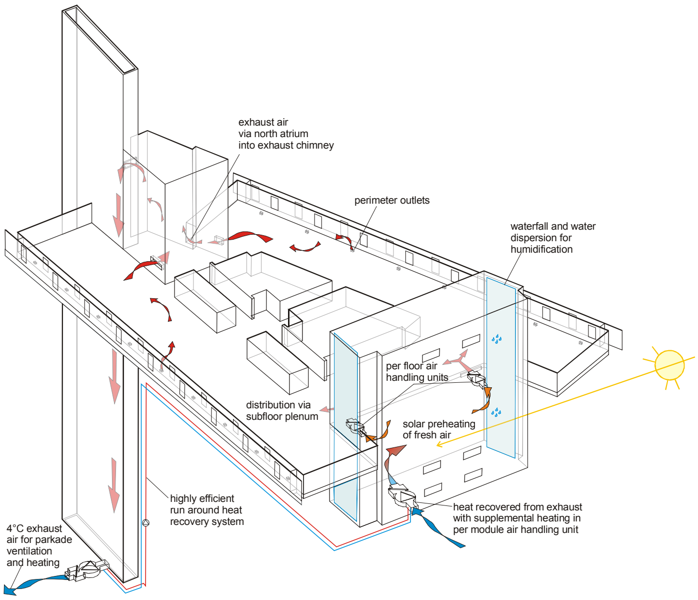

Figure 1 – Climate concept – Winter

Figures 1 shows the winter concept. The fresh air supply to each six-story module first exchanges heat with exhaust air via a run-around glycol loop in the per-module air handling unit. The air handling unit further heats it (when required) to 10°C, and blows it into the south atrium. The atrium is a buffer zone, mediating architecturally and energetically between indoors and out. It is a semi-heated, sunny space, less confining than an office interior yet protected from the elements. The minimum temperature of 10°C is not uncomfortable on sunny days. At the same time, the low temperature allows the atrium to efficiently heat incoming air. This is because the sun warmed surfaces transfer heat to the fresh air at a rate proportional to the difference of their temperatures. The atrium also features water walls that enrich the space while efficiently adjusting humidity. The water is heated for humidification in winter, chilled for dehumidification in summer, and achieves its efficiency by avoiding the use of fans. The intermediate temperature of the atrium also allows the interior glazing to act as part of the envelope. The building is effectively triple glazed on all surfaces, although in the north and south atrium and double facades, the envelope is delaminated into distinct single- and double-glazed walls, with a “buffer zone” between. By allowing the temperature between the two walls to fluctuate naturally for most of the winter, they maintain nearly the performance of a triple-glazed facade. While the buffer zones are configured in winter for thermal insulation and fresh air heating (in the case of the south atrium), their configuration changes with the seasons.

Per-floor air handling units further temper fresh air as necessary and blow it into a pressurized subfloor plenum on each level, from which it enters the office space at outlets located mostly along the perimeter.

Summer

The building stays cool by resisting heat gains and tapping natural sources for cooling and ventilation. Activation of the building mass provides comfortable radiant cooling and reduces the size of mechanical equipment.

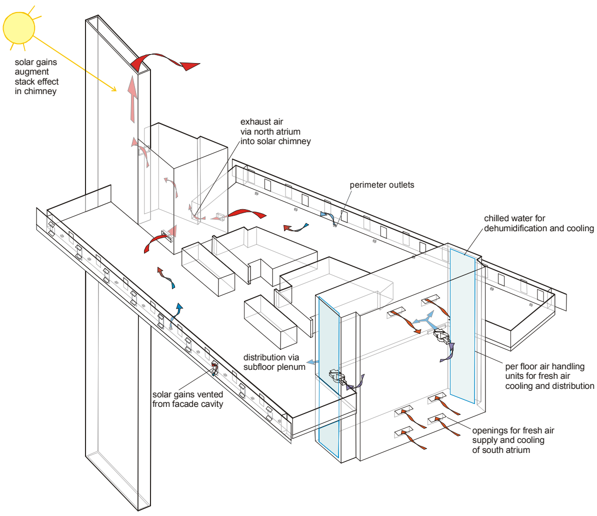

Figure 2 – Climate concept – Winter

Figures 2 shows the winter concept. Fresh air enters the module through the south atrium in summer as well, although in this case it flows freely, without the aid of the per module air handling unit, since heat recovery is no longer needed. An internal shade is drawn to block solar gains, and forms an exhaust plenum between itself and the facade. High and low openings feed the ventilation of the plenum. The water wall is activated, with chilled water to cool and dehumidify incoming air. Although it may seem strange, a water surface that is cooler than the dew point of the air will dehumidify it. The first mechanical air conditioning systems worked in a this way, by spraying droplets of cold water across a stream of air. The per floor fan coils further condition fresh air and blow it into the pressurized plenum, from which it continues through the displacement ventilation scheme. The double facade is reconfigured to reject solar heat and seal the interior to hot outdoor air. Whereas both facade walls were sealed in winter, in summer the line of enclosure retreats to the inner wall, behind the protection of the venetian blinds in the facade cavity. Solar heat absorbed by the blinds is purged through automatically opened flaps in the outer facade. The inner facade is kept closed to prevent the passage of hot air into the interior. As in winter, air exits to the chimney via the north atrium. However, rather than being blown down to the parkade, it rises naturally up the chimney. As it would in a fireplace chimney, the air rises because it is warmer, and therefore more buoyant, than the cooler air surrounding it, and because wind across the top of the chimney generates a draft. The long, west-facing side of the chimney collects solar heat in the afternoon, augmenting the buoyancy effect by warming the air within.

Intermediate Season

When outdoor conditions are pleasant, they are freely admitted to the building interior. While the direct use of natural sources maintains a comfortable environment, the air handling units and slab systems are deactivated. The conditions for this mode depend mostly on the temperatures of outdoor air and the facade cavity. At the current stage of design, the values are a minimum outdoor air temperature of 10°C, and a facade cavity temperature range of 15-25°C.

SIMULATION RESULTS

Detailed thermal simulations on TRNSYS evaluated the thermal conditions as well as building energy consumption. A comparison to a reference building – in accordance to Canada's Model National Energy Code for Buildings showed energy savings of 60 %.

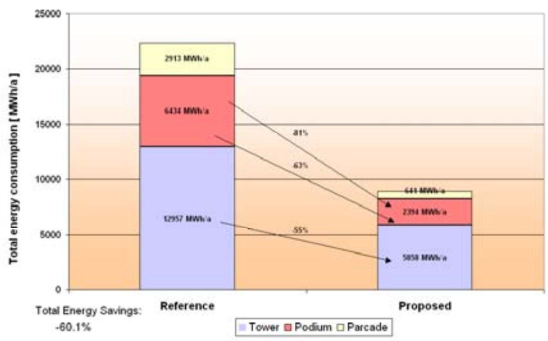

Figure 3 Simulation results on building energy performance

RADIANT SLABS

Each tower floor is 2,744 gross square meters, divided into two 828 gross square meters “loft” spaces, a 193 square meters central “bridge”, core area and two atria. The two lofts, and the central bridge, are the designated work space on each floor. Heating and cooling is achieved primarily via exposed radiant ceilings. The floors are constructed of 240 mm thick concrete, with 19 mm tubing, on 203 mm centers, embedded at a depth of 65 mm from the bottom of the slab. Each loft is divided into 9m x 12 m modules. Each floor has 12,192 linear m of embedded tubing, controlled from individual manifolds, in 120m sections. The slabs within the double wall cavities also have tubing, in a separate control zone from the interior space. In cooling mode, water between 18.3ºC and 20ºC is circulated through the tubing. Based on the modeled internal loads of 45 W/m^2 (average across the loft) this will maintain a ceiling surface temperature of between 20ºC and 22ºC. In heating mode, the slab tubing water temperature is adjusted to the range 23.9ºC and 29.4ºC, which maintains a ceiling surface temperature of between 22ºC and 25ºC. The slabs within the double wall façade are also maintained between 22ºC and 25ºC in heating mode. The above conditions result in operative space temperatures of 20ºC and 26ºC.

DISPLACEMENT VENTILATION

Ventilation is provided by an under floor, displacement system. As noted earlier, pre-conditioned 100% outside air is drawn in on each floor from the south floor atrium by four custom, under floor fan coil units, of 604 l/s each. Each unit consists of a centrifugal fan, heating coil and cooling coil. Humidification is maintained through surface evaporation, and condensation on a heated and cooled water feature in the Winter Garden. The fan coils do final tempering on the atrium air, discharging 18.3ºC air year round into the under floor plenum. The humidity of the discharged air is controlled between 15% (minimum winter) and 50% (maximum summer). The fan coils maintain a minimum plenum static pressure of 37.4 Pa. “In floor” displacement diffusers allow the air to pass into the occupied space at a maximum velocity of 0.2 m/s. A solar tower on the north end of the building draws stratified air from each floor, discharging at the top during the cooling months, or into the parkade during the heating months. During the cooling season, a black body absorber at the top of the solar tower is heated by solar radiation to enhance the natural draft of the stratified air from the floors. The parkade air handling units have heat recovery coils that extract excess energy from the solar tower air and return this energy as pre-heating to the under floor fan coil units.

GEOTHERMAL SYSTEM

All of the base building cooling season heat rejection is stored in a 280 borehole geo-exchange field beneath the building. Spaced at 4.5 m centers, each bore hole is 122 m deep, providing a total installed length of 68,320 linear meters. The average ground temperature at depth in downtown Winnipeg is approximately 11.1 ºC. The field rejects and absorbs heat to the ground at loop temperatures varying from -3.9ºC at peak extraction rate to 38.6ºC at peak charge rate. The energy stored and released is equivalent to 2,400 MWh/annum. Peak extraction rate is 1,406.8 kW and peak storage rate is 3,517 kW.

CHILLED WATER PLANT

Three 1,580 kW nominal screw chillers, using R-134a refrigerant, are used to charge and discharge the geothermal field. During winter (geothermal field discharge mode), the chillers operate at -3.9ºC/1.7ºC chilled water supply/return temperature and 32.2ºC/26.7ºC condenser water supply/return temperature. The condenser water is used to provide a low temperature (32.2ºC/26.7ºC supply/return) loop serving the main fan coil units in the tower. During summer (geothermal field charge mode), the chillers operate at 4.4ºC/11.1ºC chilled water supply/return temperature and 38.6ºC/32.7ºC condenser water supply/return temperature.

BOILER PLANT

To make up the total heating load, seven high efficiency, natural gas condensing boilers of 985 kW input capacity each are installed. These feed a high temperature (71ºC/50ºC supply/return) loop that serve pre-heat coils in the atria. The boilers have a nominal 90.4% efficiency (thermal) at peak operating conditions.The boilers provide 2,470 MWh/annum of the building heating load.

CONCLUSION

Manitoba Hydro set dauntingly high goals for their new downtown office building, in terms of workspace quality, signature architecture, positive urban impact, environmental performance, and competitive cost. Through a closely integrated design process, the design team, composed of client, architect, and consultants, industriously pursued these goals and produced a truly outstanding design. This building has the potential to set a new North American standard for the integration of workplace quality and energy efficiency with elegant, humane architecture. It may even become a leading global example for cold-climate integrated building design. Its value is not easily quantified. One can easily calculate direct costs, in terms of construction and operation; but how to calculate the benefits?