CASE STUDY OF SUSTAINABLE DESIGN

By Richard M. Lay, P.Eng.

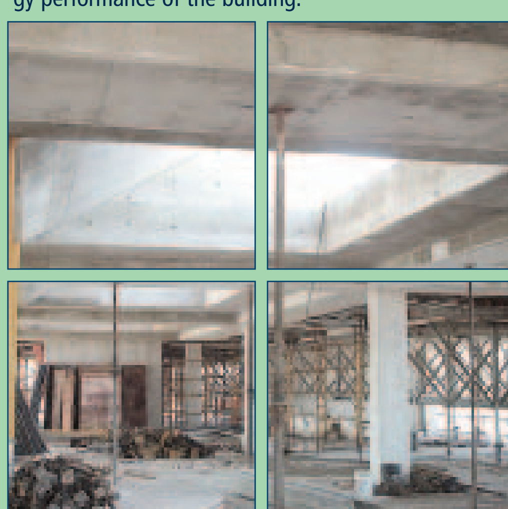
Designing and building a green/sustainable building presents special challenges to engineers and other design professions. The Earth Rangers Wildlife Centre north of Toronto incorporates many features that could become the norm in the quest for sustainable design.

The Earth Rangers Wildlife Centre is a 5800 m^2 facility at the Kortright Centre for Conservation north of Toronto for wildlife rescue, rehabilitation, oil spill response, education and research. Its design is an example of the many green/sustainable buildings being undertaken by Canadian engineers.

These can be ambitious and challenging projects for the designers. They require a high degree of cooperation among the various design professionals to integrate the design of the envelope with the site and building systems. In addition to having to meet the owner's normal requirements for function and cost, they have additional criteria of low energy use, water conservation and re-use, enhanced indoor environmental conditions, materials with high recycled content and low embodied energy, and minimal environmental impact on the site. This obviously requires more design time, effort and cost than conventional design and construction.

Green buildings in Canada usually qualify for funding under the Commercial Building Incentive Program (CBIP) offered by Natural Resources Canada (NRCan). Designers are required to model the building with NRCan's EE4 software and demonstrate that it will use at least 25 per cent less energy than a reference building that just meets the *Model National Energy Code of Canada for Buildings* (MNECB). Applications undergo detailed, third-party scrutiny, which not only enforces compliance with the energy code but also with embedded design codes like ASHRAE 62–*Ventilation for Acceptable Indoor Air Quality*. Unlike the normal application for a building permit, it is not sufficient for an engineer to merely sign a certificate stating compliance with these codes.

Earth Rangers Wildlife Centre features large masses of concrete and masonry to take advantage of thermal storage qualities and to improve the comfort and energy performance of the building.



The common approach to reducing energy use is first to optimize the envelope to minimize heating and cooling (HVAC) loads, through increased insulation, air tightness and quality of windows. Since conditioning ventilation air is a major energy cost, most green buildings use some form of ventilation heat recovery. Designers then look for natural systems to minimize HVAC loads, for example, daylighting, natural ventilation, evaporative cooling and thermal storage. Energy-efficient mechanical systems, e.g. high efficiency boilers, chillers and air handlers, are then specified to meet the remaining loads.

The Earth Rangers project had particularly challenging design requirements by nature of the occupants–beavers, deer, raptors, songbirds and other wildlife. The rehabilitation rooms and treatment areas had to be durable, water-resistant, offer no escape or hiding places, and provide a healthy, low-stress environment. Ventilation had to be 100 per cent outside air with no recirculation. The design had to demonstrate innovative technologies and be guided by the Leadership in Energy and Environmental Design (LEED) standard of the Canadian Green Building Council. The energy target was to exceed the MNECB by 50 per cent.

Construction

The building structure is reinforced concrete, with load-bearing masonry walls in the animal areas. All insulation is on the the exterior, so that approximately 4000 m^3 of concrete is on the interior, conditioned side of the insulation. This enables the large mass of the concrete and masonry to act as thermal storage and improve the comfort and energy performance of the building. Insulation values shown in the table are the "effective" R-values calculated by the EE4 program and account for parallel heat flow through composite assemblies, e.g. steel stud walls. Exterior insulation was detailed per the requirements of the MNECB to minimize thermal bridging.

North-facing clerestory skylights cast into the roof slab of the 2nd floor offices provide diffuse daylighting without glare and offer a south-facing surface for mounting 16 solar collectors for heating domestic hot water and future photovoltaic modules for generating electricity.

Radiant concrete slabs

All space heating and cooling is provided by the 3400 m^2 of exposed concrete slabs with embedded polyethylene tubing that carries chilled or heated water. Even the cast-in-place cathedral ceilings in the animal rooms and the skylights have embedded tubing. This concept of "structural slab radiant cooling" or "thermally activated radiant slabs" uses the slabs both for space conditioning and for thermal storage, and is gaining increased acceptance by Canadian engineers.

Radiant slab design is constrained by cooling conditions, even though annual cooling energy use is much less than heating energy. Typically, for Canadian low-energy buildings, if the slab has adequate capacity for cooling, it will have more than enough capacity for heating. Overhead heating with low-temperature heated slabs or panels does not produce radiant asymmetry ("hot head syndrome") and is comfortable when combined with a tight, well-insulated building envelope with high-performance windows.

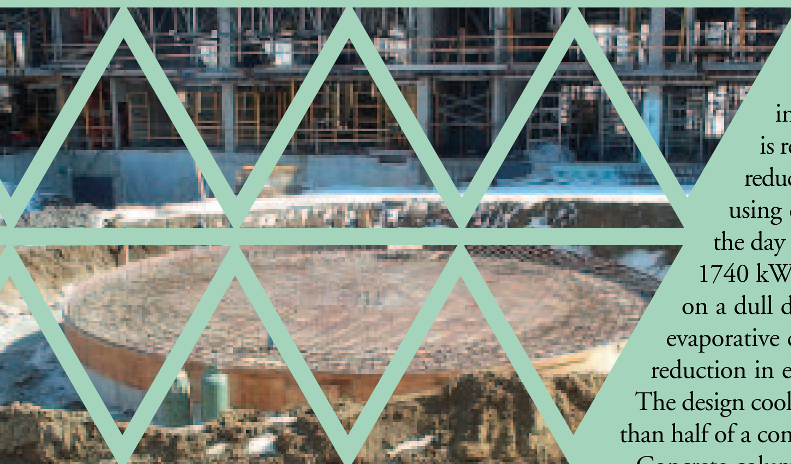
Cooling capacity depends on the temperatures of both the cooled ceiling and the uncooled surfaces in the space. Cooled slabs have a low specific cooling capacity but compensate by their large area. The wildlife centre is designed with slab temperatures of about 20°C and capacity of 35 W/m^2. Analysis during preliminary design concluded that a cooled slab system could both meet the cooling load and cost less than a comparable design with chilled metal panels.

Cross-linked polyethylene (PEX) tubing is installed midway in the 200- to 300-mm thick suspended slabs, suspended on chairs and 150 x 150-mm wire mesh between the two layers of reinforcing steel. This provides about 75 mm of clearance from future fasteners drilled in below for pipe and duct hangers, etc. Some threaded inserts were also set into the bottom form for mechanical anchors. Coordination was required with the installation of electrical conduit and mechanical slab penetrations–the radiant slabs cannot be core-drilled after they are poured. A total of 21 km of tubing was installed, spaced 150 to 300 mm on centre and distributed by about 20 manifolds. Although most of the concrete was placed during -10 to -25°C weather in the winter of 2003, concrete surface quality after form-stripping was excellent and suitable, with painting as the finished architectural surface. After all the construction traffic on the tubing, there were no leaks.

Cooled slabs benefit from the large mass of concrete that is actively cooled by the circulating water. The cooled slabs have a mass of about 1570 t and a heat-storage capacity of 1570 MJ per degree of temperature change. Thermal cool storage allows a build-

Top left: One of the centre's vent tunnels under construction.
Top right: Solar collectors for heating domestic hot water.
Bottom: Two views of the polyethylene tubing embedded in exposed concrete slabs at the centre. A total of 21 km of tubing carries chilled or heated water throughout the complex.

COMPONENT	CONSTRUCTION	
Walls	Masonry or steel stud with rigid EPS exterior insulation, finished with stone masonry or EIFS stucco.	R30 (RSI 5.3)
Roof	200- to 300-mm reinforced concrete slab with 200-mm polyisocyanurate insulation. Flat roofs have white TPO membrane or vegetated "green roof." Sloped roofs are recycled rubber/plastic shingles.	R40 (RSI 7.0)
Slab-on-grade	200-mm reinforced slab on 50-mm EPS insulation.	R9 (RSI 1.6)
Glazing, skylights & curtainwall	Double glazed, low-e, argon, insulating edge spacer, aluminum frame with thermal break.	USI 2.13 SHGC 0.32 VT 0.57



Construction of the centre's concrete underground cistern, used to collect rainwater from the roof and treated sanitary effluent from a high-performance membrane system.

ing to offset the time when a cooling load is experienced and when it is rejected from the building. The required peak cooling capacity is also reduced. The design intent here is to cool the slabs to about 18°C overnight using cooling tower water, then allow them to warm up to 22°C during the day as they absorb heat from the space. This represents a heat storage of 1740 kWh (500 Ton-hours), enough to provide much of the cooling energy on a dull day. Since this energy can be provided by a low-energy-consuming evaporative cooling tower rather than the electric chiller, there is a substantial reduction in electricity use, as well as a reduction in the size of the chiller plant. The design cooling load for ventilation and space conditioning is only 64 Tons–less than half of a conventional building.

Concrete columns and masonry walls are also left exposed as much as possible to give additional thermal mass and stabilize indoor temperatures. However, in cooling season, temperatures will be allowed to drift over the course of the day to minimize load on the heating/cooling plant and to allow heat transfer between the space and the structure. This is different from the regular North American practice of trying to maintain constant (and low) space temperatures at all times. Space conditions will still stay within the comfort range defined by ASHRAE 55 and ISO EN 7730.

Ventilation tunnels and double foundation

As a health care facility, the wildlife centre has a high ventilation rate of over 9400 L/s, averaging 2.5 air changes per hour (ACH) of outdoor air and as high as 6 ACH in hospital surgery and lab areas. Air supplied to spaces is 100 per cent outside air; there is no recirculation. Supplementing the heat-recovery ventilation system in the air-handling units is an underground air inlet structure of pre-cast concrete pipes and a double foundation wall plenum, designed for ground-to-air heat exchange.

Outdoor air is drawn through a louver and dust filters into a cast concrete inlet structure, tunnel and header structure, which feeds a grid of nine, 900-mm-diameter, 20-m-long, pre-cast concrete pipes buried 1.5 m below grade. The pipes open into a plenum space inside the concrete foundation wall created by a second wall of insulated masonry block. The tunnels and double foundation wall provide a total of 1500 m^2 of thermally conductive surface between the ventilation air and the ground. Since the soil temperature varies seasonally between only 4 and 17°C at that depth, while the air varies from -30 to 35°C, there is considerable potential for beneficial heat transfer. The system will temper outside air by an average of 3°C in winter and summer. This represents a 30-kW reduction in heating and cooling load, a 12 per cent increase in ventilation heat-recovery effectiveness, and an estimated $7,000/year operating cost reduction.

A heat-transfer analysis was conducted using FRAME software to calculate tunnel wall surface temperature, based on the thermal resistance of the soil in the region of the pipe wall. Further analysis is required to determine long-term effects on soil temperature in the vicinity of the pipe wall and the foundations. Transsolar Energietechnik of Germany calculated the overall thermal performance of the system.

This is believed to be the largest ground-heat exchange system of its type in a North American building. Despite reported problems in the past with excessive moisture, incompatible materials and excessive pressure drop, considerable experience with ground ducts in Europe suggests that they can be designed successfully and that airborne pathogens, e.g. molds and spores, can be effectively controlled.

The design features of the system at the Earth Rangers Wildlife Centre include:

- all-concrete construction, felt to be more tolerant than steel or plastic of condensing conditions, and less likely to collect standing water from condensate;
- filtered inlet louver;
- all surfaces sloped for drainability;
- pipe tunnels straight and large enough for inspection and maintenance;
- double foundation plenums that are accessible to walk through;
- ultraviolet light irradiation at the end of the plenums to inactivate mold spores and bacteria; and
- liquid desiccant dehumidifiers that remove airborne contaminants.

Rainwater/wastewater cisterns

A 310,000-litre, cast-in-place, concrete underground cistern collects rainwater from the roof and treated sanitary effluent from the high-performance membrane treatment system. Already required for on-site fire protection water supply, the cistern was enlarged by 25,000 litres to provide a reserve of non-potable water for toilet flushing, cage cleaning and filling animal ponds, and is expected to reduce well water consumption by 60 per cent. No special liner or surface coating was needed–silica fume was used as densifier in lieu of waterproofing. The concrete mix was the same as for the suspended slabs–32 MPa C2 concrete, 0.45 water/concrete ratio, 6 to 8 per cent air entrainment, super-plasticizer and 20 to 25 per cent slag–plus silica fume.

Flat portions of the roof are a vegetated "green roof" for storm water improvement and landscaping. The concrete roof did not require any additional reinforcement to support the 150 kg/m^2 (30 psf) design load of the soil and vegetation.

Energy and environmental performance

As modeled with NRCan's EE4 software for energy simulation, the Earth Rangers Wildlife Centre will use 65 per cent less energy than a reference building just meeting the MNECB energy code.

High-mass concrete buildings have been criticized for having a high embodied energy. Assuming one-half of the 4000 m^3 of concrete in this building is in a standard foundation and one-half in the special features (cistern and above-grade structure), the embodied energy of the "special features" half is approximately 15,000 GJ. Since the estimated annual energy saving of the building is 8260 MJ/year, this embodied energy is recovered in only two years of energy savings. The embodied energy content is therefore not significant compared to the energy savings, especially over the life cycle of the building.

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Residential units catch up in sustainability

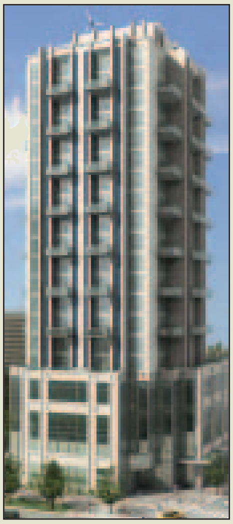
Sustainable building design elements aren't limited to structures so closely identified with nature, wildlife and conservation.

In north Toronto, construction has begun on the One Avondale complex, a 22-storey business/luxury condominium building that will incorporate a number of sustainable elements that its builder believes will lead to cost savings in the future.

One Avondale is being built by the Shane Baghai Group of Companies.

Vlad Knop, P.Eng., an engineer working with the Shane Baghai group on the One Avondale project, predicts that many of the sustainable design features to be incorporated in the building will become commonplace in high-rise residential buildings within the next 10 years.

One of the most unique sustainable design features, Knop says, is a small wind turbine that will sit atop the building to augment generation of electrical power. While the turbine is expected to generate only 900 to 1500 watts of electricity, its very presence in the project is something of a breakthrough in the residential/condominium market.



"Its actual output is negligible, but I think it indicates the positive direction we are going in terms of designing more energy-efficient buildings," Knop says.

Andrew Bigauskas, lead architect of One Avondale, agrees the building is something of a breakthrough in efficient building design.

"Our whole approach has been to start engaging all of these technologies that are available to us, so that is the first step," Bigauskas told *Engineering Dimensions*. "It's not a zero-use energy building by any stretch of the imagination, but we've got to start engaging this whole process of incorporating these sustainable technologies into the buildings we build every day."

In addition to the wind generator, the One Avondale building will feature solar panels to reduce the building's heating costs, especially in terms of hot water "pre-heating." As well, the building will feature what Bigauskas calls "duel fuel" power generation: "This is a matter of using diesel generation to meet the requirements of the building code in terms of emergency power but, in addition to that, generation can run on natural gas."

The duel fuel aspect brings additional benefits. As well as supplying immediate power in the case of an outage, the system allows the possibility of self-generation during periods of peak energy demand. It's anticipated that with the advent of smart metering, building owners can save on energy costs by reducing demand–or by permitting self-generation during high-demand, high-priced periods.

The interior of the building will also feature a number of sustainable, cost-saving elements, ranging from the use of super-efficient appliances to the types of lighting used throughout. Even the building's underground parking garage is expected to demonstrate sustainable thinking. Instead of having the carbon monoxide (CO) exhaust fans blowing day and night, the building will feature a detection system that will trigger the exhaust fans only as the concentration of CO rises.

Bigauskas says the commitment to more sustainable buildings has been evident since the 1970s, but only recently has it reached the condominium/apartment environment. With sustainability being the watchword in the building industry, it's anticipated the One Avondale experience could set a trend for residential/multi-unit buildings for the next decade and beyond.

Construction of the One Avondale building is scheduled to begin in mid-October, with an anticipated completion in 18 months.

Michael Mastromatteo