EARTH RANGERS WILDLIFE CENTRE – CASE STUDY OF CONCRETE USE FOR ENERGY EFFICIENCY

R. M. Lay, M.A.Sc.,P.Eng.
Enermodal Engineering Ltd., Kitchener, Canada

ABSTRACT: The Earth Rangers Wildlife Centre is a 5800 m^2 structural concrete building under construction at the Kortright Centre for Conservation north of Toronto and scheduled to open late 2003. It will be the most energy efficient education and health care facility in Canada, and the use of concrete makes a significant contribution. Exposed structural concrete slabs with embedded polyethylene tubing provide 100% of the space cooling and heating and act as thermal storage during the cooling season. Concrete underground ventilation tunnels and a double foundation wall temper all outside air for ventilating the building. A 310,000 litre cast-in-place reservoir collects rainwater and treated sanitary wastewater for re-use in the building. Annual energy use is calculated to be 65% less than required by the Canadian energy code. The Wildlife Center is expected to earn a LEED Silver rating for sustainable design.

1. INTRODUCTION

The Earth Rangers Wildlife Centre is designed to be the world's most advanced wildlife centre. Able to treat up to 5000 animals per year, the 5800 m^2 facility will conduct wildlife rescue, rehabilitation and release, oil spill response, public and professional education, and research. It is presently under construction at the Kortright Centre for Conservation north of Toronto, Canada, and scheduled to open late 2003.

The project has a number of challenging design requirements. The rehabilitation rooms and treatment areas must be durable enough to accommodate the tough patients—deer, large predators, racoons, etc., offer no escape or hiding places for the small or flying patients—songbirds, raptors, small predators, etc., withstand the humid or wet environment of the waterfowl and beavers, and provide a healthy environment conducive to the speedy recovery of all. Ventilation rates are high, which is typical of human health care facilities, yet energy use must be as low as best available technology allows—the target was a 50% energy reduction compared to Code. This despite the fact that this heating and cooling of large amounts of ventilation air is the major energy load in human hospitals. Another Wildlife Centre mandate is to demonstrate innovative technologies to achieve these objectives and to qualify for certification under the Leadership in Energy and Environmental Design (LEED) standard of the US Green Building Council.

2. CONSTRUCTION

The building structure is reinforced concrete throughout, with load bearing masonry walls in the animal areas to provide a durable, moisture resistant interior surface. All insulation is on the building 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. Table 1 below shows the component R-values, all of which exceed the requirements of the Canadian Model National Energy Code for Buildings (MNECB).

Table 1. Building envelope thermal specifications

Component	**Construction**	
Walls	masonry or steel stud w/ rigid EPS exterior insulation, finished with stone masonry or EIFS stucco	R30 (RSI 5.3)
Roof	200-300 mm reinf conc slab w/ 200 mm polyiso insulation. Flat roofs have white TPO membrane or vegetated “green roof”. Slope roofs are recycled rubber/plastic Enviroshakes	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	U_{SI} 2.13 SHGC 0.32 VT 0.57

Insulation values are the “effective” R-values as calculated by the EE4 software from Natural Resources Canada to account for parallel heat flow through composite assemblies, eg. steel stud walls. Exterior insulation was detailed per the requirements of the MNECB to minimize thermal bridging.

North-facing clerestory skylights were cast into the roof slab of the Second Floor offices to provide diffuse, glare-free daylighting and a 30 degree south-facing mounting surface for solar collectors for heating domestic hot water and generating electricity.

Figure 1. Skylights for daylighting and solar collector mounting. Exposed concrete structure.

3. RADIANT CONCRETE SLABS

All space heating and cooling is provided by the 3400 m^2 of exposed concrete slabs with embedded polyethylene tubing carrying chilled or heated water. This concept of "structural slab radiant cooling" or "thermally activated radiant slabs" uses the slabs both for space conditioning and for thermal storage. The theory of radiant heat transfer for buildings is well documented (ASHRAE, 1999; Mumma, 2000, 2001), as are guidelines for human thermal comfort in buildings (ASHRAE Std 55, ISO EN7730, Oleson 2000). The surface temperature of a person's surroundings affects comfort just as air temperature, humidity and air movement do. For example, warm air temperatures can be comfortable in summer if the surrounding surfaces are cool.

Although the application in heated slabs is widespread, the use of radiant cooled slabs requires more design effort and is new to North America. One manufacturing plant near Parry Sound has a massive 2000 m^2, 1300 t structural slab floor cooled only with cooling tower water and delivering 35 kW (10 t) of cooling to the production area. Cooled ceiling slabs provide base load cooling in the 16,000 m^2 ICT facility at the University of Calgary. Sawers (2001), Mumma (2000), and McDonell (2003) describe design and installation details and discuss controlling slab surface temperature and humidity in the space to avoid condensation on the cooled surfaces.

Cooling capacity depends on the temperatures of both the cooled ceiling and the uncooled surfaces in the space. The Green on the Grand C2000 Office Building in Kitchener receives 100% of its space sensible cooling from metal radiant ceiling panels operating at about 17 °C and delivering a total of 80 W/ m^2 from radiation and convection (CANMET 1996). Cooled slabs have a lower specific cooling capacity, but compensate by their greater area. At the high end of slab cooling output, an 18 °C slab ceiling in a 26 °C space has a cooling capacity of 66 W/ m^2. The Wildlife Centre is designed with more moderate slab temperatures of 20 – 22 °C and more a more conservative design capacity of 35 W/ m^2. A performance and cost analysis during preliminary design concluded that despite the higher specific cooling capacity of chilled metal panels such as in the Green on the Grand system, a cooled slab system could both meet the cooling load and cost less.

Dehumidification

Since the slab surface must be maintained slightly warmer than the room air dewpoint to avoid condensation, a warmer design surface temperature reduces but does not eliminate the need for dehumidification in urban southern Ontario. Toronto frequently has hot humid summer weather with dewpoint temperature above 20 °C about 200 hours a year. Dehumidification at this building is provided by liquid desiccant, chilled water coil and enthalpy heat-and-moisture recovery wheel. The Wildlife Centre is probably the largest application in a warm humid environment in North America where the slab provides 100% of the space sensible cooling, and is the first known installation in sloped cathedral roof slabs.

Polyethylene 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 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, but the designers still wanted to permit future drilling into the slab without risk of puncturing the tubing. Coordination was also 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. Most of the concrete was placed during -10 to -25 °C weather in Jan-Mar 2003. Concrete surface quality after form-stripping was excellent and suitable, with painting, as the finished architectural surface.

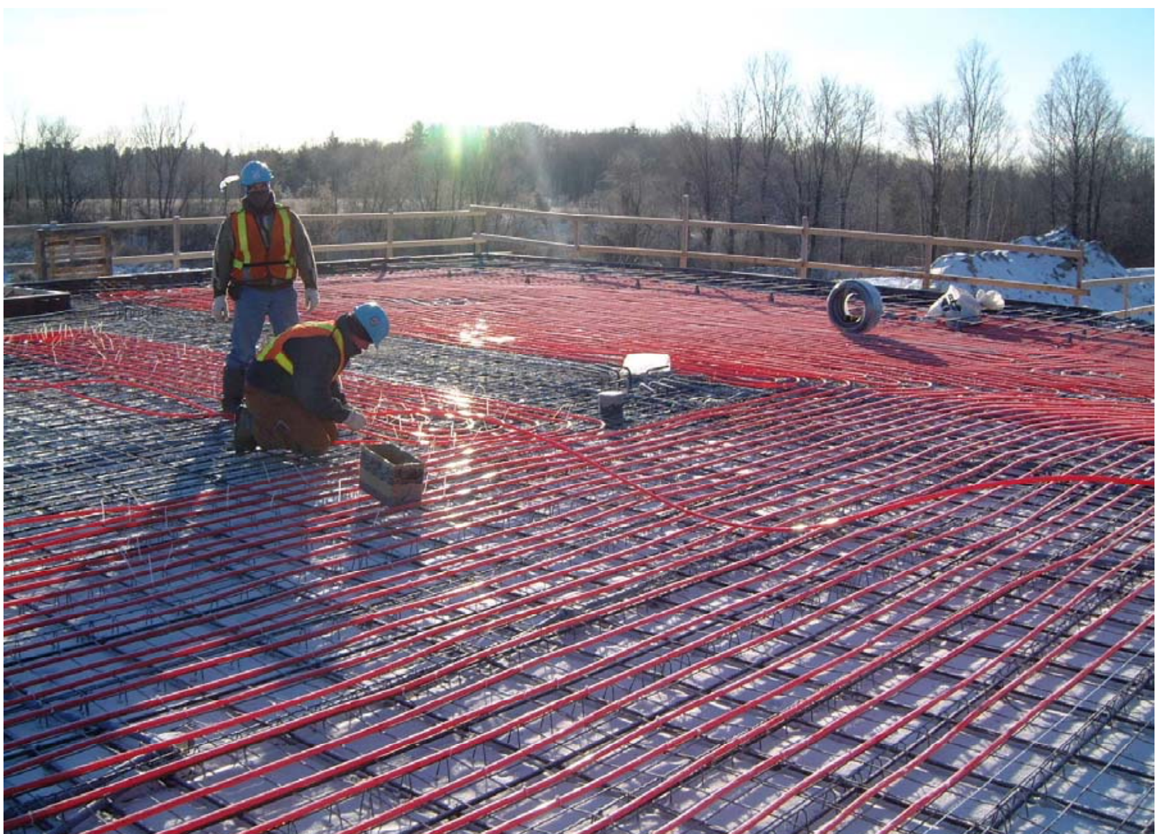

Figure 2. Installation of slab tubing on a dedicated layer of support mesh, prior to placing top layer of steel. This is the roof slab of the Ground Floor and will provide heating and cooling from the ceiling.

Radiant slab design is constrained by cooling conditions, even though annual cooling energy is only 6% of heating energy, typical of many low energy buildings in Canada. 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 very comfortable when combined with a tight, well-insulated building envelope with high performance windows.

Unlike overhead metal panel systems, cooled slabs benefit from the large mass of concrete which is actively cooled by the circulating water. The 3400 m^2 of 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 building 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 design day. Since this energy can be provided by a low-energy consuming 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—about one half of a conventional building.

Concrete columns and masonry walls are also left exposed as much as possible to give additional thermal mass. The result will be an indoor environment with very stable 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 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.

4. 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 of outdoor air and as high as 6 ACH in hospital surgery and lab areas. Air supplied to spaces is 100% outside air; there is no recirculation. Supplementing the heat recovery ventilation system in the air handling units is an underground air inlet structure of precast concrete pipes and a double foundation wall plenum, designed for ground-to-air heat exchange.

Outdoor air is drawn in 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 precast 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 °C 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 degrees in winter and summer. This represents a 30 kW reduction in heating and cooling load, a 12% increase in ventilation heat recovery effectiveness, and an estimated $7000/y operating cost reduction.

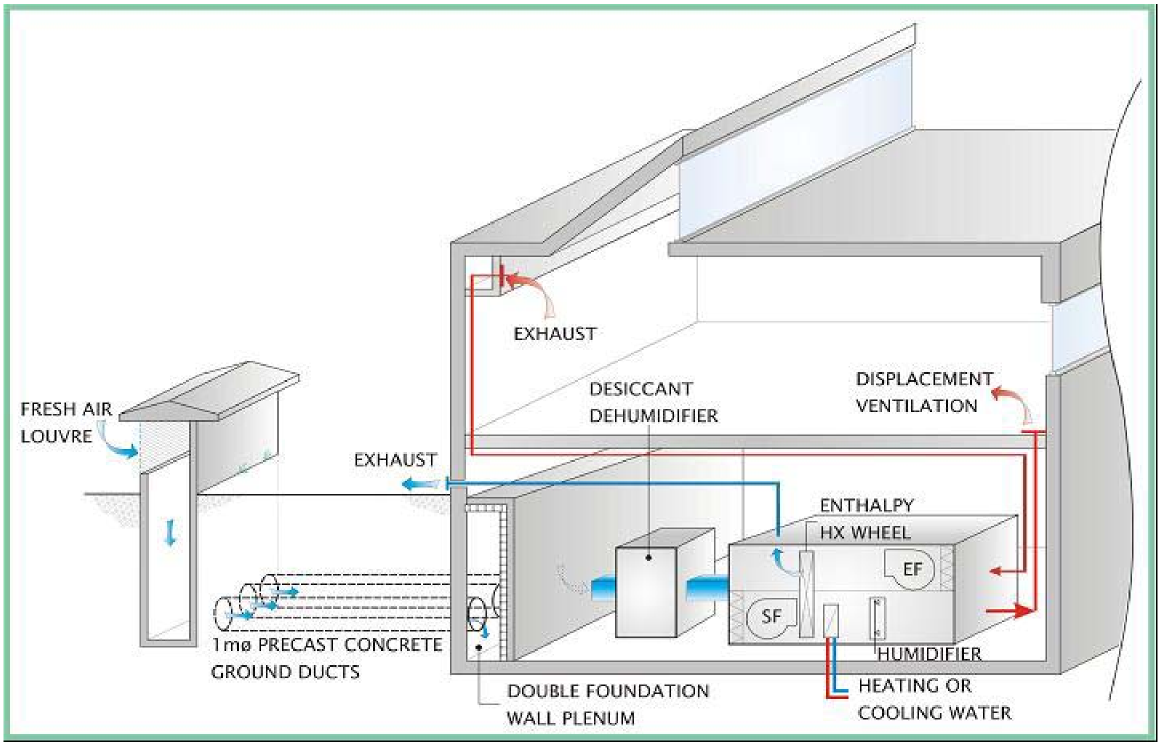

Figure 3. Ventilation concept using precast concrete pipes and masonry double foundation wall for tempering outside.

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 will be the largest ground heat exchange system of its type in a North American building. Previous attempts here at using the tempering effect of deep soil temperature on ventilation air have encountered difficulties with excessive moisture, incompatible materials, and excessive pressure drop. However, there is considerable built experience with ground ducts in Europe, particularly Germany, Italy and Switzerland, which suggests that they can be designed successfully and that airborne pathogens, eg. molds and spores, can be effectively controlled.

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

- all concrete construction, felt to be more tolerant than steel or plastic of condensing conditions and less likely to collect standing water from condensate
- storm-proof louver to prevent entry of rain and snow
- low-pressure loss inlet filters to keep dust out of tunnels
- all surfaces sloped for drainability
- pipe joints sealed against radon soil gas entry
- low air velocity and smooth inside surfaces for low air pressure drop
- pipe tunnels are straight and large enough for inspection and maintenance
- all double foundation plenums are accessible to walk through
- ultraviolet light irradiation at the end of the plenums to inactivate mold spores and bacteria
- liquid desiccant dehumidifiers for removal of airborne contaminants
- mid-efficiency filters on inlets to air handling units

Air temperature and humidity sensors in the tunnel will allow the building automation system to monitor the performance.

5. RAINWATER/ WASTEWATER CISTERNS

A 310,000 litre cast-in-place concrete underground cistern will collect 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. The concrete tank did not require any special liner or surface coating for these applications, and helps reduce well water consumption by 60%. The concrete mix was the same as for the suspended slabs – 32 MPa C2, 0.45 water/concrete ratio, 6-8% air entrainment, super-plasticizer and 20-25% slag - plus silica fume as densifier in lieu of waterproofing.

Flat portions of the roof are finished with 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.

The Earth Rangers Wildlife Centre will house Canada’s largest facility to treat waterfowl contaminated by oil and other liquid wastes. Birds in Canada are suffering one major oil-spill a week and most of them die from either ingesting the oil, from skin contact with the oil or from losing feather waterproofing. Oil-contaminated birds must be washed quickly and with large amounts of water. This generates a correspondingly large and sudden volume of oily wastewater which is not suitable to discharge to the on-site treatment plant. Oily wastewater will therefore be collected in a buried 50,000 litre precast concrete tank—the largest available—for treatment off site.

6. ENERGY AND ENVIRONMENTAL PERFORMANCE

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

As a percentage of the reference building, energy consumption by end use is:

- space heating 27%
- space cooling 42%
- lighting 50%
- cooling tower and pumps 28%
- heating and chilled water pumps 96%
- fans 59%
- domestic hot water 50%

As a percentage of total building use, space heat, fans and lights use the most energy, shown in Figure 4.

The building is expected to earn 34 of a possible 69 points under the Leadership in Energy and Environmental Design (LEED) standard of the US Green Building Council and qualify for a Silver award. The use of concrete in the features described above contributes to 1 point for stormwater management, 5 points for water efficiency, 10 points for energy performance, 2 points for local/regional materials, 1 point for thermal comfort, and 3 points for innovation.

High mass concrete buildings have been criticized for having a high embodied energy. Assuming one half of the 4000 cu m 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 [Mackley]. Since the estimated annual energy saving of the building is 8,260 MJ/y, this embodied energy represents only 15,000/(20 x 8,260) = 10% of the 20 year energy savings.

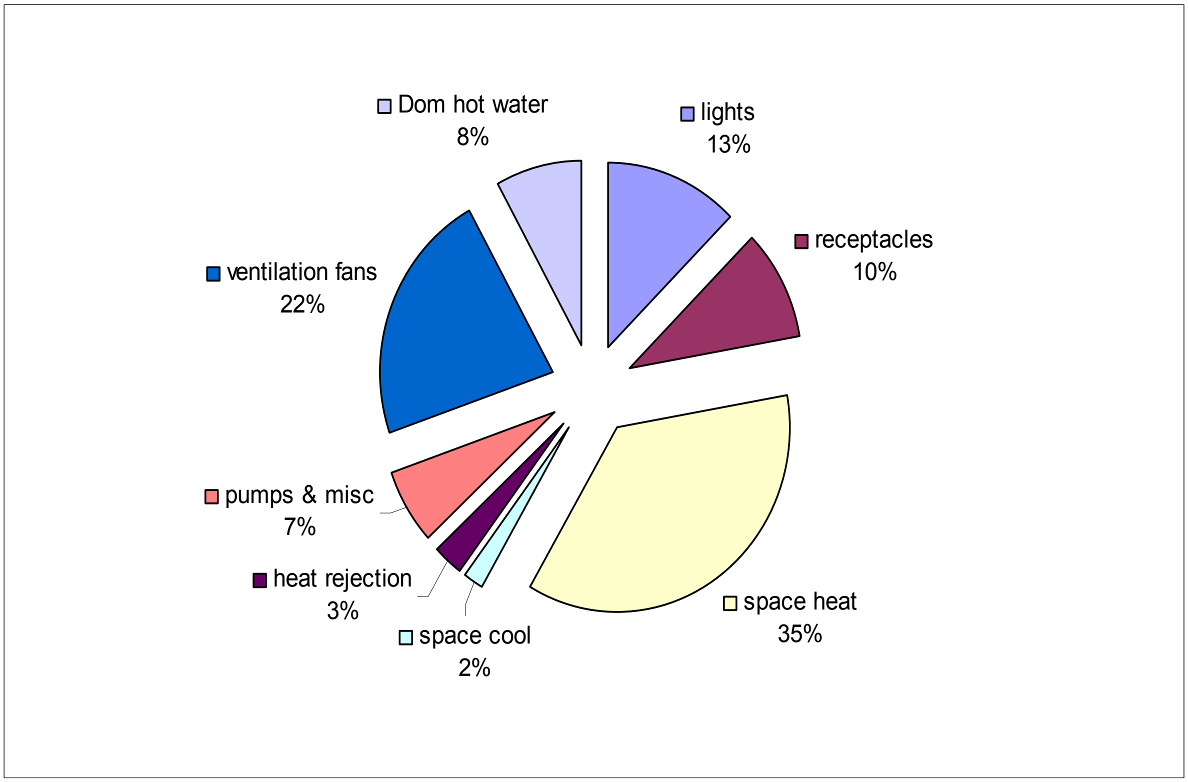

Figure 4. Proportional energy consumption by end use

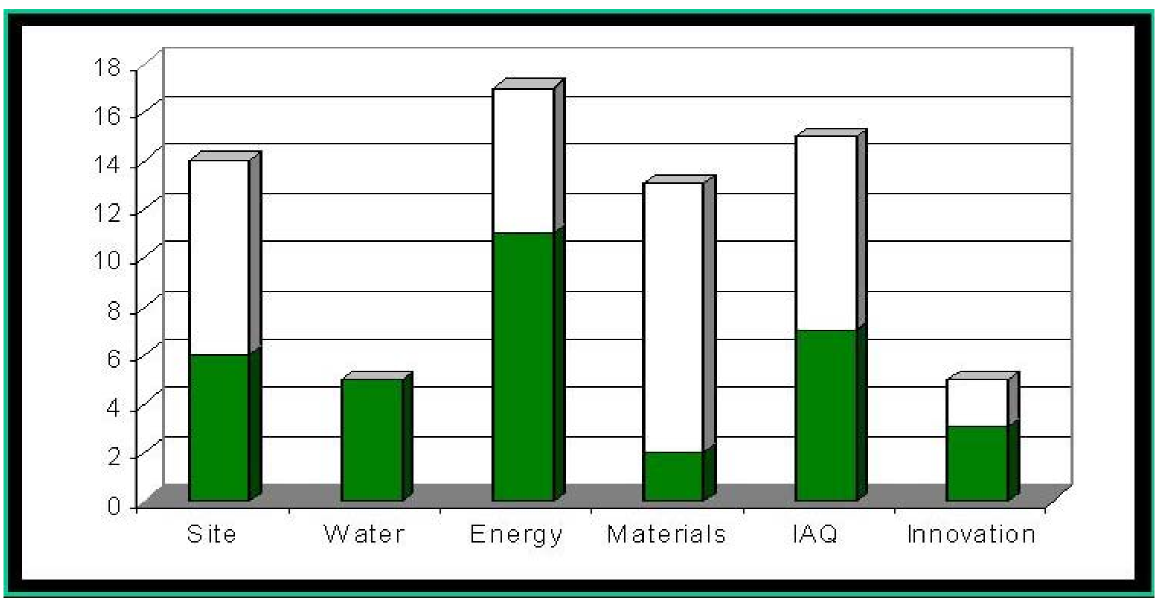

Figure 5. LEED Assessment scoring

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8. Acknowledgements

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Client: Earth Rangers Foundation

Project manager: Husky Injection Molding Systems Ltd.

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Mechanical contractor: State Group