A Case Study of a Successful Innovative Multi-Unit Residential Building

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ABSTRACT

In 1995, a multi-unit residential building was constructed that embodied as many environmentally sound concepts and technologies as was possible within the confines of an extremely tight budget. The objective of the development team was to provide affordable housing with minimal environmental impact, enhanced durability and superior occupant health and comfort. After five full years of occupancy, Canada Mortgage and Housing Corporation initiated a review of the performance of the building, particularly with respect to energy and water consumption, indoor air quality and the operational experience with many of the "green" innovations included in the building. The review revealed that the enhanced insulation levels, high efficiency space and domestic hot water heating appliances, low E windows, heat recovery ventilation were economically sound choices. It also illustrated the costs associated with continuous ventilation strategies and the need for more efficient fan-motor set technologies and distribution systems. Many of the "green" features met, or exceeded expectations while others failed altogether. Overall, the building is a successful project as it managed to incorporate many environmentally sound design and construction practices and its experiences are readily available to others considering similar projects.

Introduction

The Conservation Co-op is a 4 storey, 9,070 m^2, 84 unit residential building located in Ottawa, Ontario, Canada. It is one of a growing number of multi-unit residential buildings in North America to incorporate a wide range of innovative design, construction and operational features. More importantly, this was accomplished within the context of an affordable housing project. Each step of the development process was governed by the Co-op's founding vision statement: *"To link everyday living with environmental protection through the conservation of energy, water and waste in the household and in the community"*. After 9 ½ months of construction, the Conservation Co-op was completed at a cost of $5,950,000. ($654CDN/m^2) which is similar to the construction costs of conventional buildings in the area. In the end, a building was successfully designed and constructed that reflected the environmental goals of the co-op.

General Description of the Project:

The Conservation Co-op was built in a well-established downtown neighborhood. The location is within walking distance of stores, parks, community centers, and educational facilities. The many large, mature, trees that were preserved during construction which provide shade and privacy for the building enhance the site. Additional indigenous trees, shrubs and ground cover surround the building and cover the site.

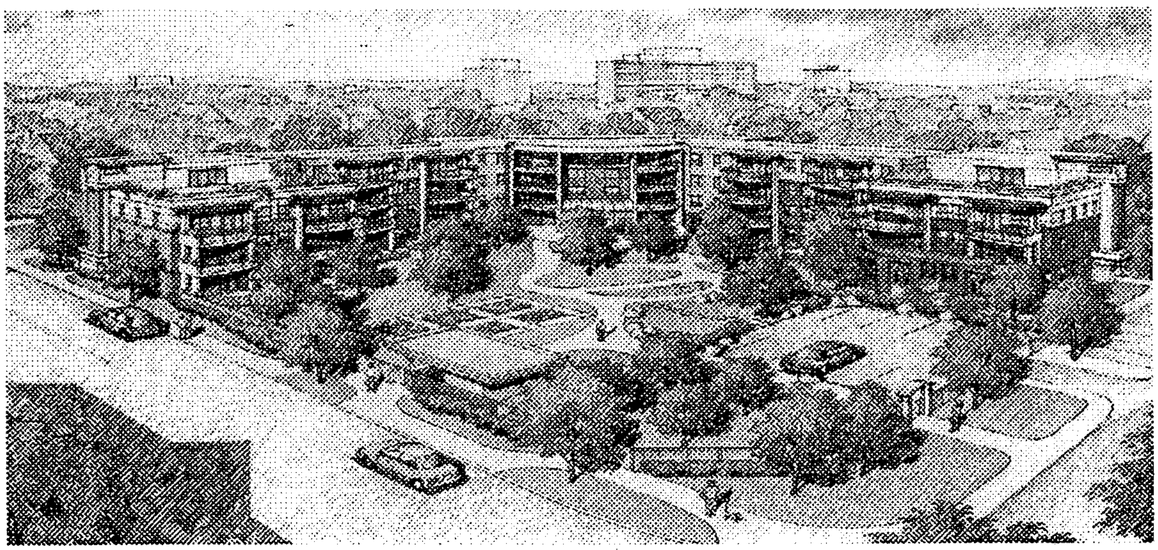


Figure 1: Conservation Co-op Building and Site

The building's "L" shape and orientation creates a wind-sheltered, sun filled, courtyard which provides a warm micro climate for site vegetation, playground and the extensive organic, vegetable and flower garden plots. Additional common area patios on the 4th floor are also available for gardens. Retention of storm water run-off is very important for the site as it is served by a combined storm and sewage sewer system. The limited amount of paved area, ample site vegetation, and the pervious nature of the remaining surfaces limits storm water run-off. An underground cistern and rain barrels retain rainwater collected from the roof for site irrigation. A large sub grade storm water infiltration-retention pond was provided to collect runoff, filter common surface pollutants and recharge ground water.

Construction Details:

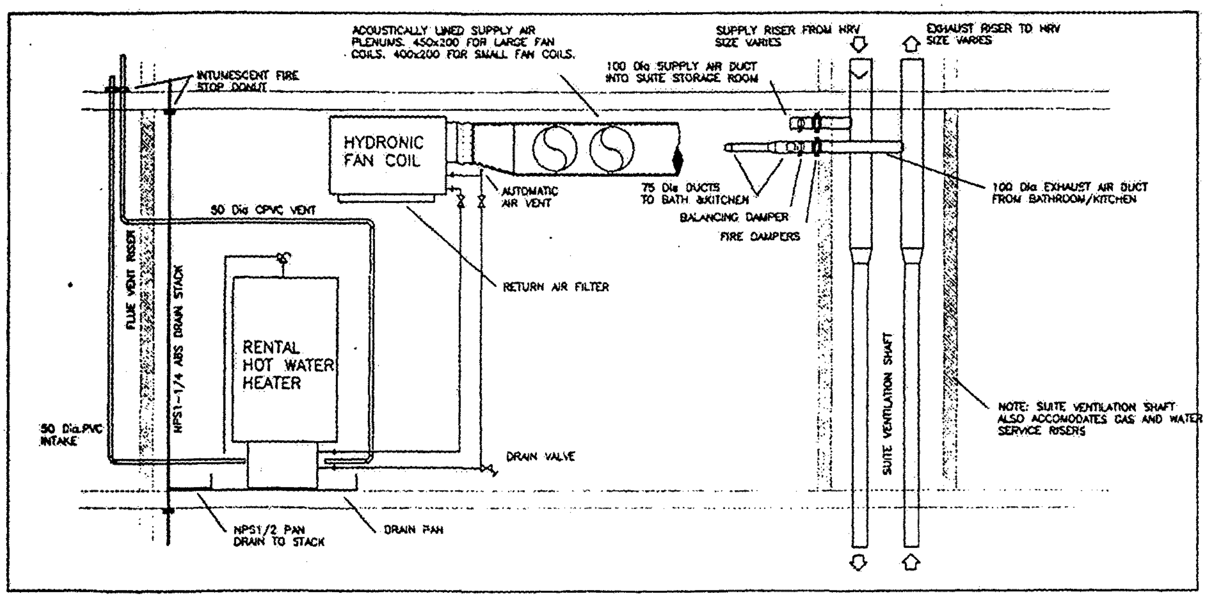
A steel reinforced, poured concrete, structure, supports the building. Freestanding columns support the balconies eliminating a major source of thermal bridging, heat loss, comfort problems and condensation-mould growth on adjacent floor and ceiling areas. Construction is also simplified as the building structure could be cast with conventional concrete while the balcony structures are cast separately with more durable air-entrained concrete. The roof is a flat concrete deck with an inverted membrane system (membrane is below the insulation) insulated to RSI 7.04 (RSI = Rvalue X 0.1761. The exterior walls are a combination of brick-veneer and stucco cladding systems insulated with 140 mm cellulose insulation and 38 mm of extruded polystyrene providing RSI 4.93. The below grade wall components are insulated using exterior grade, 50 mm, rigid insulation, RSI 1.76, to a depth of 610 mm below grade. Most of the windows in the building are double glazed, low-E, argon-filled, vinyl frame windows with insulated spacers. Well-developed air barrier details were integrated into the building envelope design and the air barrier system was well sealed. Solar gains are controlled by sunscreens incorporated into the balcony structures that provide shade in the summer but allow sunlight through during the winter (Figure 2).

Interior:

The Conservation Co-op offers four types of apartment layouts, some fully accessible for disabled persons, ranging in floor area from 48 m^2 to 107 m^2. Most apartments receive direct sunlight in their living areas. All apartments have balconies or patios that provide the residents with private outside spaces. A large, south-facing, common area solarium provides a sun-filled space for year-round planting. Sunlight from the solarium penetrates well into the common areas offsetting the need for artificial lighting. A thermostatically controlled fan in the solarium area transfers excess heat from the solarium to the bicycle storage room to offset space heating requirements. Large panels of glass in the stairwell towers provide natural lighting and a pleasant environment that encourages their use.

Space and Domestic Hot Water Heating Systems:

A central hydronic system consisting of a single, high efficiency, sealed combustion, condensing, natural gas hot water heats the common areas. The water heater is coupled to a distribution system of baseboard convectors and cabinet-type fan-coil units. The hot water heater also provides domestic hot water (DHW) for service sinks and the common laundry.



TYPICAL SUITE HEATING SYSTEM DETAIL

Figure 2: Schematic of Apartment Space and Domestic Hot Water Heating System

Each apartment contains a combination space and domestic hot water heating system (Figure 2). A high efficiency, condensing, natural gas domestic hot water heater provides hot water to a ducted fan-coil system for space heating. The heater also provides domestic hot water. Two 50 mm plastic pipes, side-wall vented or directed up through the roof, provide combustion air and vent the combustion products produced by the water heater. Within the apartments, each room receives warm air from the fan-coil through a short ductwork system. High wall, supply air grilles direct warm air into the rooms at ceiling level. Perimeter heating is not required due to the high thermal resistance of the walls and windows. Air is returned to the fan-coil via door undercuts and a central return air grille. Programmable thermostats control the space heating system in each apartment, giving the residents a high degree of control over indoor conditions and reducing fuel bills via the setback feature. Natural gas use is metered for each apartment to encourage accountability and responsible usage.

Heat Recovery Ventilation (HRV) Systems:

The Conservation Co-op is unique in that all rooms are directly, and continuously, ventilated with fresh outdoor air. Twenty-one rooftop HRV units supply fresh air to, and exhaust stale air from, the three or four apartments and the corridors below each unit. Outdoor air is drawn into the HRV units where sensible heat is recovered from the exhaust air stream. The tempered outdoor air is then ducted to the space heating fan-coil units in each apartment which distribute and circulate it throughout the apartments. Exhaust grilles in the bathrooms and kitchens, draw in stale air which is then ducted back to the rooftop HRVs. Exhaust air is also drawn from the common area recycling rooms located on each floor.

The high wall supply air diffusers of the apartment air distribution systems deliver the relatively cooler ventilation air at ceiling height where it mixes with warmer room air before falling into the occupied space. The continuous operation of the apartment fan-coil systems and rooftop HRVs provides a steady distribution and circulation of ventilation air throughout each apartment and all common areas. The system provides a building-wide air change rate of 0.32 ach. Each apartment receives 22.5 L/s to 30 L/s of outside air depending on size. Timer switches within each apartment are used to increase ventilation rates as need be.

A balanced supply-exhaust ventilation system strategy was chosen to ensure the quality of the indoor air, to prevent adverse building envelope pressure regimes, and to reduce draft-related occupant comfort problems. Window use is not required thereby enhancing occupant convenience, comfort and security. The quality of air in all areas of the building is quite good as complaints of odours, stale air, and humidity levels are rare. Measured carbon dioxide levels are below the American Society of Heating Refrigeration and Air-Conditioning Engineers Standard 62 recommended threshold of 1000 PPM indicating that the ventilation system works well (1). Indoor relative humidity levels were within Health Canada guidelines (29% RH average during January) and few condensation problems have been experienced.

Air Conditioning:

The construction budget was insufficient for the design and installation of an air-conditioning system. In any case, the Co-op's founding members were opposed to using capital funds for this purpose given the short cooling season in Ottawa. Comfortable conditions were to be achieved through the provision of sunscreens and fin walls on the balconies, continuous ventilation to prevent heat build-up, shading from the mature trees, low-E windows to minimize solar heat gains, and, high insulation levels in the walls and roof. This approach was not entirely successful as overheating during the summer has been experienced (see Lessons Learned section).

Domestic Water Systems:

Low-flow showerheads (max. 0.132 L/s), low-flow sink faucets (max. 0.119 L/s), self-closing faucets (for common area washrooms) and 13 liter per flush toilets were installed. Horizontal axis washing machines for the common area laundry room were not considered due to expense and availability. The water conservation strategies employed have been successful as Co-op consumes 11,900 m^3/yr of water at a cost $16,387/yr. Water use per apartment is 390 Liters/day which compares favorably with local averages of 530 Liters of water/day (1).

Grey Water Recovery System:

A pilot project grey water reclamation system was designed and installed in the building to evaluate their feasibility within multi-unit residential buildings (Figure 3). The bathtub drains from a vertical stack of 8 apartments (2 per floor) were connected to the grey-water reclamation. The system treats the bathtub water for reuse in the toilets of the 8 apartments. Regular connections to the municipal water and sewer system provide back-up water service as required. A building-wide reclamation system could not be justified due to uncertain costs, benefits and risks.

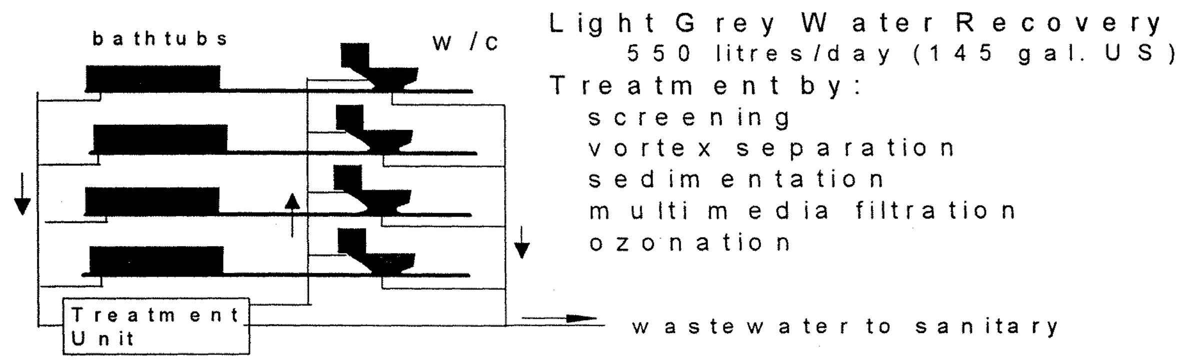


Figure 3: Schematic of the Grey Water Reclamation System

Early system monitoring revealed that the quality of the reclaimed water does not meet drinking water standards but was adequate for toilet use (2). It is estimated that 550 liters/day (145 US gallons/day) could be recovered by the system. While the water cost savings of the pilot system are not substantial ($331/year), the system demonstrates the possibilities for water savings and reducing sewage flows. If the system capacity was fully utilized, water could be recycled at a rate to 4,000 liters/day saving $2,400/year in water charges. The capital cost of the system was $11,300 CDN. Design and installation costs brought the total cost of the pilot project to $22,800 CDN. The annual cost of electricity to run the plant (pumps, controls) is estimated at $220 CDN. Since the early trial and monitoring stages, problems have been experienced with the operation and maintenance of the system that have resulted in the system being shut down. An investigation is planned to determine if the problems are inherent in the system itself or are related to operation and maintenance.

Site Irrigation Water Use:

No municipal water is used for site irrigation. The Conservation Co-op recovers rainwater for all landscaping and gardening water needs. Rain barrels collect water for use in the patio gardens on the 4th floor while water from roof drains is collected in an underground cistern. The water is pumped from the cistern with a hand pump for use in the courtyard gardens. Stored rainwater has been adequate for irrigation due to the indigenous, low water plants and grasses planted onsite.

Lighting, Appliances and other Equipment:

A combination of conventional incandescent, fluorescent and energy efficient compact fluorescent lamps are found in the apartments. There are approximately 208 F40T12 fluorescent lamps in the common areas with 152 lamps operating on a 24-hour basis. The lighting systems are activated with motion detectors in some low-traffic common areas. The building site is well lit by energy efficient lamps. A small solar powered photovoltaic system lights the communal garden shed. Refrigerators and stoves selected for the apartments are those found in the upper 25% of the Federal government's ENERGUIDE energy efficiency rating system. Electricity consumption is metered for each apartment in order to promote accountability and responsible energy use.

Other Environmental Aspects:

Construction Materials Resource Conservation: Recycled materials that were incorporated into the project include carpets made from recycled pop bottles, cellulose wall insulation, steel studs and gypsum board with recycled content and balcony planter boxes made from recycled plastics.

Durability: A concrete structure, brick exterior, rain screens, and solid concrete balconies were selected based on expectations of enhanced durability. Life cycle costing was performed prior to the finalization of the design to guide the project team on materials selection. Parquet flooring was chosen as it was determined to have the longest life-span with reasonable costs. Windows with long-life frames, glazing, and powder paint coating were also selected. Problems later experienced with some of these materials and systems (discussed in a subsequent section) demonstrate the limitations of lifecycle calculations - particularly with new materials and systems with limited service life experience.

Waste Reduction During Construction: A large-scale construction waste audit and reduction plan greatly reduced the wood, cardboard, gypsum board, and metal waste during construction. Four large bins were kept on-site for sorting and were used to take materials to recycling centers. The original waste volume target was 962 m^3 (1,260 cu. yards). The amount of waste actually generated was 642 m^3 (840 cu. yards) representing a 33 % reduction. In total, 31.5 tonnes of material were recycled.

Minimization of Automobile Usage: The founding Co-op members recognized that automobile use represents a large source of housing-related energy consumption and pollution emissions. Accordingly, the Co-op was located in the downtown core and only 8 spaces were provided for parking in consideration of the environmental goals of the Co-op. The limited parking discourages residents from automobile ownership and use. It also provides those who do not own cars with a housing option that does not require the expenditure of resources on the infrastructure and maintenance required for parking, access, security, etc. The absence of parking also opened up a significant area of land space for vegetation and gardening. The Co-op's decision alleviated the need to construct a parking facility allowing construction funds to be redirected to "green" features.

Provision of Bicycle Facilities: Bicycle ownership and use is encouraged through the provision of 200 indoor vertical-type bicycle racks. The racks are located in a well-lit room with a security card-activated door. The room is directly accessible from outside via a ramp and an automatic overhead door alleviating the need to carry bicycles through doors and up and down stairs.

Enhancing Indoor Air Quality: The quality of the indoor environment was a primary consideration in the design of the Co-op. The amount of pollutant emission off-gassing was reduced through the use of low emission, latex-based paint, and hardwood parquet floors (finished with a water-based sealer) in the apartments. Carpets are only used in the public corridors. Smoking is prohibited in all indoor common areas. Odour migration between apartments is prevented through the provision of balanced ventilation in all apartments, the steady supply of fresh air to the corridors and the venting of the recycling rooms. The corridor doors of each apartment are weather-stripped to prevent sound and odour transmission.

Waste Reduction and Recycling Program: No garbage chute was installed to reduce costs, to discourage unnecessary waste (residents must carry garbage to the basement garbage room themselves) and to encourage recycling. However, significant space was dedicated for recycling. Space was provided under the kitchen sinks in each apartment for recycling boxes and four recycling rooms per floor were provided for sorting glass, paper, metal and plastics. Recycled materials are removed from the recycling room by the maintenance staff. Organic waste is handled by the10 large composters and 2 tumbling composters which produce black earth for the rooftop planters and courtyard gardens. The Co-op also has reuse depots where residents exchange items such as clothing, furniture and appliances.

The Environment Code of Practice: All members must subscribe to an Environmental Code of Practice as a condition of occupancy. The Code requires occupants to be conscientious in their use of energy and water, to use environmentally friendly cleaning products, to accept the low-flow plumbing fixtures, to forego the use of window-type air conditioners, and to make use of the composting and recycling centers.

Energy Consumption:

The energy consumption of the Conservation Co-op has been defined in terms of the amount of energy embodied in the building, the energy consumed annually for operations and the total resultant life cycle energy consumption for the building. The information presented in the following sections is taken from two studies commissioned by Canada Mortgage and Housing Corporation to evaluate the embodied energy (3) and the operating energy characteristics of the building (1).

Embodied Energy: The initial energy embodied in the building for extracting or recycling raw materials, processing the materials into building products, transportation of the products to the site, and construction was calculated to be 47,800 GJ or 5.25 GJ/m^2 of floor area (3). The relative amounts of energy embodied in the different building materials used in the Co-op building are shown in Figure 4.

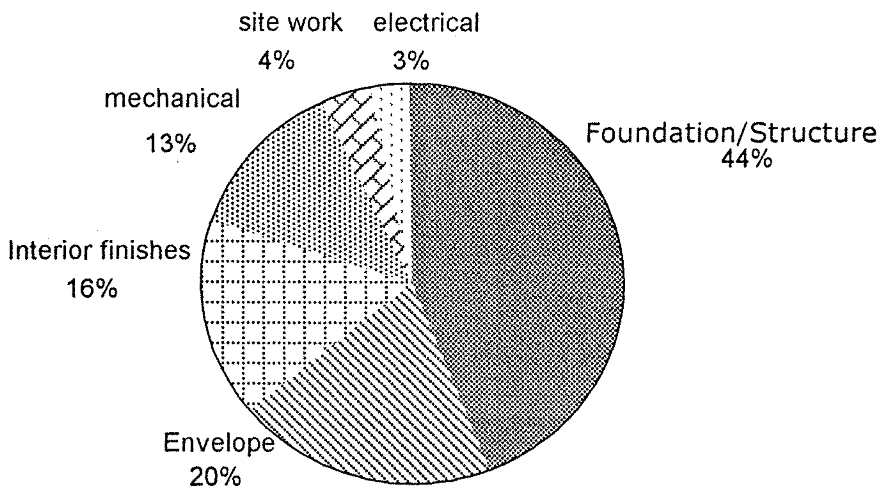


Figure 4: Embodied Energy Proportions by Building System

The development team had sought to limit embodied energy by selecting building materials having recycled content and by limiting the amount of materials consumed by the project. However, studies of the energy embodied in conventional buildings range from 4.7 GJ/m^2 to 5.6 GJ/m^2 indicating that the efforts to limit the energy embodied in the Conservation Co-op building were not entirely successful. Approximately 64 % of the initial embodied energy consumption is attributable to the building envelope and heavy structure of the building. Almost half (46 %) of the embodied energy of the foundation, structure and envelope can be attributed to structural steel (mainly rebar).

Life-Cycle Embodied Energy Consumption: Life-cycle embodied energy accounts for the initial energy embodied in the construction of the building and the energy embodied in the materials and activities required for the repair, maintenance and the eventual demolition and disposal of the building. An analysis of the lifecycle energy requirements estimated the 40 year lifecycle embodied energy of the building to be 79,000 GJ (3). Figure 5 shows a comparison of the initial embodied energy to the lifecycle embodied energy for the main building assemblies.

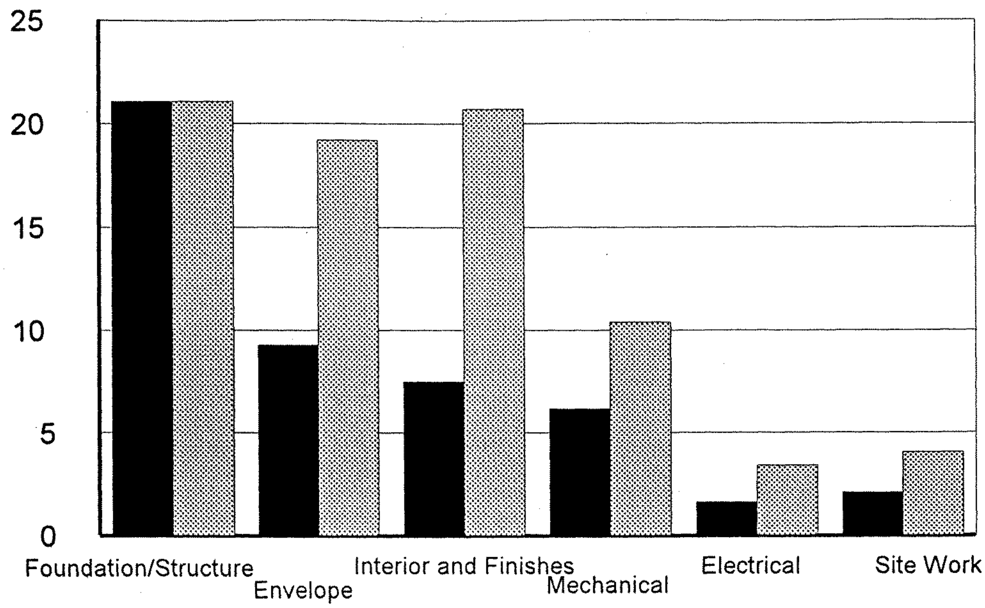


Figure 5: Initial Embodied Energy(■) and Lifecycle Embodied Energy(▒)

Concrete work remains the largest component of the life-cycle embodied energy. The results also show that the interior finishes (carpeting, paint, flooring, etc.) are a significant component of the life cycle embodied energy of the building.

Operating Energy Consumption: The DOE-2.1E building energy simulation computer program was used in conjunction with utility records to estimate the major energy end-use points in the building (1). Table 2 provides a summary of the total energy consumption and costs.

Table 2 Annual Energy Consumption and Costs

Description	Energy Consumption	Cost ($CDN)
Gas Equip. Rental	N/A	$20,109.60
Gas Use	103 636 m^3 (1,071,699 kWhe) (12,746 kWhe/suite or 117kWhe/m^2)	$20,663.89
Electricity Use	628,961 kWh (7,490 kWh/suite or 69.4 kWh/m^2)	$44,122.57
Taxes	-	$5,942.72
Total	**1,700,661 kWhe (186 kWhe/m2)**	**$107,225.92**

Compared to a reference case building built to 1993 Ontario Building Code (OBC) standards, the Co-op uses 51 % less natural gas, 28 % more electricity, and overall, consumes 22% less energy. The total energy use was 186 kWhe/m^2 per year (0.66 GJ/m^2/yr) or 0.036 kWh/degree-day/m^2 of floor area. In comparison, the average energy use index for similar buildings built in Ottawa during 1990-96 was 0.049 kWh/degree-day/m^2. The relatively low natural gas consumption was expected given the superior building envelope, high efficiency heating appliances, good use of solar gains and the responsible habits of the residents. However the high electricity consumption was somewhat unexpected and is likely due to the continuous operation of the ventilation system (42, ¾ - 1 hp, fan motor sets within the rooftop HRVs and 84, ½ to ¾ hp, fan motor sets in the apartment fan-coil units).

Life Cycle Energy: Life cycle energy is the sum of life cycle embodied energy and ongoing operating energy of the building. Based on the preceding analysis, the resultant life-cycle energy consumption total is 0.877 GJ/m^2/yr (3). Figure 6 shows the distribution of the energy components that make up the life-cycle energy consumption.

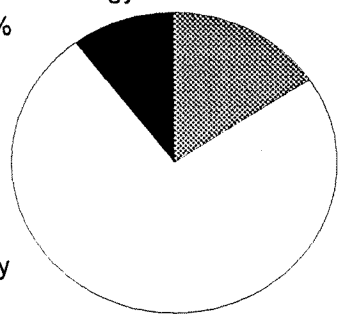


Figure 6: Distribution of Life-cycle Energy Consumption

The operating energy consumption represents almost ¾ of the total life cycle energy consumption of the building. This indicates that although the initial level of embodied energy of the Conservation Co-op is comparable to conventional buildings, the efforts to reduce operating energy were well placed given the significance of operating energy over the life of the building.

Table 3: Summary of the Cost-Benefit of the Energy Efficient Features (1)

Component	Annual Savings		Capital Cost	SimplePayback [Years]
	Energy [KWhe/yr]	$/yr		
Low E Windows	151,502	$4,531	$36,143	8.0
Air Leakage Control	41,081	$1,229	$5,880	4.8
Higher Insulation Levels	180,475	$5,398	$60,424	11.2
Heat Recovery ventilation	225,921*	$6,757	$88,200	13.1
high efficiency gas water heaters	242,931	$7,266	$54,600	7.5
Total of Components	**841,910**	**$25,180**	**$245,247**	**9.7**

*over base case with same ventilation rate w/o heat recovery

Table 3 summarizes the incremental costs of the energy efficient features of the Conservation Co-op and the associated savings. When the measures are bundled together, the overall payback period has an attractive time frame of 10 years.

Lesson Learned:

The Conservation Co-op is a very successful building project, however, there are several areas where the original intentions of the development team were not realized or where unforeseen problems later developed. Some of the more noteworthy "Lessons" follow.

Building Energy Use: Electricity use in the building is relatively high – likely due to the continuous operation of the fan-motor sets in the 42 HRVs and 84 fan-coils that make up the ventilation system. The energy performance of the building could have been improved had high efficiency motor fan sets been specified or had the system been configured to limit the number of fan-motor sets required for the distribution and circulation of ventilation air. Fan-motor energy consumption should be an important consideration whenever continuously operating ventilation systems are considered.

Indoor Comfort Conditions: Caution should be exercised when passive cooling strategies are considered for buildings located in hot, humid areas. Attempts to provide acceptable summer indoor air temperatures with the continuous operation of the HRV systems, shading devices, trees and a superior building envelope were not successful. The continuous ventilation of the building with hot and humid outdoor air and the location of the air intakes immediately above the hot roof deck no doubt contribute to the problem. Although there are sunscreens on the balconies to minimize solar gains, there are none on the other apartment windows. The courtyard's mature trees, although helpful, do not provide complete shading to all the building surfaces. The overheating problem has been sufficiently severe that the prohibition of air conditioners has been lifted for those residents with specific health concerns.

Grey Water Reclamation Project: The system has experienced problems due to its complexity and the ongoing need for inspection, monitoring and service. It has been found that the superintendent's ability to deal with the system is understandably limited. The operation and maintenance requirements of any unfamiliar or technically complex system must be taken into account when being considered for building projects. This is particularly true for residential projects that do not have onsite building operators.

Apartment Space and Domestic Hot Water Heating Systems: The use of rental hot water heating equipment allowed the reallocation of the construction budget to other "green" building features. It also placed water heater maintenance and replacement responsibilities with the local gas utility. However, the residents must pay rental fees that, in some cases, are more than the costs of the natural gas consumed each month. The relatively high rental charges ($30CDN /month) has been an ongoing irritant to the building's residents. The presence of the individual gas meters also incurs a monthly service charge for each apartment and limits the opportunity to capitalize on commercial gas rates and bulk gas purchases. The use of individual natural gas appliances within each apartment also limits the future fuel flexibility of the building. Conversion to alternative energy sources would be more easily accommodated at some point in the future had a central boiler been installed

"Green" Products: The untried nature of certain green products or their unfamiliarity with the contractors, led to problems. The low VOC parquet floor adhesive failed to keep the parquet fixed to the floor. The recycled plastic planter boxes on balconies have been damaged as they tend to expand and contract against their fixed mountings with temperature changes. The low emission latex paint that was used in stairwells and corridors has been unable to hold up to the traffic in these areas. Credit must be given to the development team for using such products. Hopefully others will benefit from their unfortunate experience.

Apartment Lighting: Compact fluorescent lights were originally installed within the apartments but residents have found that replacement costs are prohibitive thus conventional incandescent lighting ends up being used instead (except in the kitchen, bathroom and storage rooms where fluorescent tube-type fixtures were installed). Consequently building electricity use is higher and the additional internal gains contribute to summer overheating problems.

Conclusions:

To a large extent, the Conservation Co-op building achieved its goals of conserving energy, water, reducing waste while promoting healthy, affordable community living. Most importantly, these goals were met while keeping the project budget within the limits set out by the Ontario Ministry of Housing. The end result was a relatively conventional structure that incorporates intelligent energy-efficient, water conserving, and healthy environment design features.

Acknowledgements

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REFERENCES

Scanada Consultants Limited, "Energy Efficiency Audit of the Conservation Co-operative Housing", a draft final report prepared for Canada Mortgage and Housing Corporation, September, 1999.

Totten, Sims Hubicki Associates, "Conservation Co-op Residential Water Reclamation Case Study", Prepared for Canada Mortgage and Housing Corporation, July, 1999.

Sheltair Scientific Ltd, "Analysis of the Embodied Energy of the Conservation Co-op", an internal report prepared for Canada Mortgage and Housing Corporation, June 1998.