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CANADA'S GREEN PLAN

ADVANCED HOUSES PROGRAM
PROGRAMME DE MAISONS PERFORMANTES

Design and Performance of the Waterloo Region Green Home

Prepared For:

CANMET Energy Technology Centre - Ottawa
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DISCLAIMER

NOTE

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EXECUTIVE SUMMARY

The Waterloo Region Green Home is one of ten houses built as part of the Advanced Houses Program of CANMET, Natural Resources Canada. The goal of the project was to demonstrate that houses can be built and operated in a manner that is environmentally responsible. The house contains the latest developments in energy efficiency, water conservation, waste management, CFC reduction and environmentally appropriate material use. Innovative features include precast basement walls, walls from engineered wood products, high-performance windows, reused and recycled materials, sealed-combustion gas stove, integrated heating ventilating appliance (IHVA), ground loop cooling, cistern, and energy-efficient appliances, lights and fans.

The house was built over the winter of 1992/93 and opened to the public in April 1993. For the first year, the house was open to the public. In May 1994, the house was sold and a family took occupancy. The performance of the house was monitored from July 1994 to June 1995.

Tests and monitoring show that the building envelope meets or exceeds design requirements. The airtightness was measured at 0.8 ACH at 50 Pa, almost half the design requirement of 1.5 ACH. The building space heating load met the design predictions. Formaldehyde, radon and VOC concentrations are significantly below the most stringent guidelines in the world.

Total energy use was 14,987 kWh or 65 kWh per square metre of floor area (natural gas use is converted to equivalent kWh). Although the energy use was 25% higher than predicted, it was within 8% of the Advanced Houses target and represents a 65% reduction over energy use in conventional new housing. The increased energy use is attributed to three main factors: lower than predicted IHVA efficiency, higher than predicted back-up water heating requirements and high plug loads. The IHVA had a seasonal efficiency of 65%, lower than the design value of 85%.

The total demand for city water was only 183 litres per day, 73% lower than conventional housing. The cistern provided half of the cold water used in the house. The five-person family consumed 108 litres per day of hot water, higher than the design value (based on a four-person family).

Furnace and HRV fan energy consumption was only 830 kWh per year, half the design value. The low use is attributed to the efficient ECM furnace fan motor and only operating the fans during the heating season. The electricity used for appliances, and lighting was close to design values. The plug loads and outdoor loads were higher than expected because of a transformer required to operate the European refrigerators and a sump pump which ran almost continuously during the spring.

The Green Home has demonstrated that houses can be built that have a much lower impact on the environment than conventional housing. Detailed monitoring and analysis has revealed the following reductions in environmental impact compared to conventional new housing:

- 65 % reduction in purchased energy,
- 33 % reduction in embodied energy (based on an analysis of the wall system),
- 73 % reduction in purchased water,
- 99 % reduction in use of ozone-depleting chemicals, and
- 98 % reduction in waste sent to landfill

RÉSUMÉ

La maison écologique de la région de Waterloo fait partie de dix maisons construites dans le cadre du Programme de la maison performante de CANMET, un élément de Ressources naturelles Canada. Le but du projet était de démontrer que des maisons peuvent être construites et utilisées d'une façon respectueuse de l'environnement. La maison est dotée des plus récents perfectionnements en matière de rendement énergétique, de conservation de l'eau, de gestion des déchets, de réduction des émissions de CFC et d'utilisation de matériaux sans danger pour l'environnement. Les éléments nouveaux comprennent, notamment, les murs préfabriqués du sous-sol, les murs fabriqués à partir de produits du bois, des fenêtres à haute performance, des matériaux réutilisés et recyclés, un poêle à gaz à chambre de combustion étanche, un appareil de chauffage-ventilation intégré, un système de climatisation à boucle souterraine, une citerne, et des appareils, des systèmes d'éclairage et des ventilateurs à haut rendement énergétique.

La maison a été construite au cours de l'hiver de 1992-1993 et elle a été ouverte au public en avril 1993. Pendant la première année, la maison était ouverte au public. En mai 1994, elle a été vendue et une famille s'y est installée. Le rendement de la maison a été étudié de juillet 1994 à juin 1995.

Les essais et la surveillance montrent que l'enveloppe de la maison satisfait aux exigences théoriques ou les dépasse. L'étanchéité à l'air a été mesurée à 0,8 renouvellement d'air par heure et à 50 Pa, soit presque la moitié de l'exigence théorique de 1,5 renouvellement d'air par heure. La charge de chauffage des locaux de la maison a été conforme aux prévisions théoriques. Les concentrations de formaldéhyde, de radon et de COV sont sensiblement inférieures aux normes les plus élevées au monde.

La consommation totale d'énergie s'est élevée à 14 987 kWh ou 65 kWh par mètre carré de surface de plancher (la consommation de gaz naturel est convertie en kWh équivalents). La consommation d'énergie a été de 25 % supérieure à la consommation prévue, mais elle n'a pas dépassé par plus de 8 % l'objectif fixé pour les Maisons performantes, et elle représente une baisse de 65 % par rapport à la consommation d'énergie dans les nouvelles maisons classiques. Cette consommation accrue d'énergie est attribuable à trois facteurs principaux : rendement de l'appareil de chauffage-ventilation intégré plus faible que prévu, besoins de chauffage d'eau d'appoint plus élevés que prévu et charges branchées aux prises de courant élevées. L'appareil de chauffage-ventilation intégré avait un rendement saisonnier de 65 %, ce qui est inférieur au rendement nominal de 85 %.

La demande totale d'eau municipale n'a été que de 183 litres par jour, soit 73 % de moins que dans les maisons classiques. La citerne a fourni la moitié de l'eau froide utilisée dans la maison. La famille de cinq personnes a consommé 108 litres d'eau chaude par jour, ce qui est plus élevé que la valeur théorique (basée sur une famille de quatre personnes).

La consommation d'énergie par la chaudière et le ventilateur-récupérateur de chaleur s'est élevée à seulement 830 kWh par année, soit la moitié de la valeur théorique. Cette faible consommation est attribuable à l'efficacité du moteur du ventilateur de la chaudière (moteur à commutation électrique) et au fait que les ventilateurs ont été utilisés seulement pendant la saison de chauffage. La consommation d'électricité par les appareils et par le système d'éclairage était voisine de la consommation théorique. Les charges branchées aux prises de courant et les charges extérieures ont été plus élevées que prévu parce qu'un transformateur a dû être utilisé pour faire fonctionner les réfrigérateurs européens et qu'il a fallu utiliser une pompe d'épuisement de façon quasi continue au printemps.

La projet de la maison écologique a permis de démontrer qu'il est possible de construire des maisons qui ont sur l'environnement des répercussions beaucoup plus faibles que les maisons classiques. La surveillance et l'analyse détaillées ont montré l'atténuation suivante des répercussions environnementales par comparaison aux nouvelles maisons classiques :

- réduction de 65 % de la quantité d'énergie achetée,
- réduction de 33 % de l'énergie intrinsèque (basée sur une analyse du système de murs),
- réduction de 73 % de la quantité d'eau achetée,
- réduction de 99 % de l'utilisation de substances chimiques appauvrissant la couche d'ozone, et
- réduction de 98 % de la quantité de déchets envoyés aux décharges.

1.0 INTRODUCTION

The Waterloo Region Green Home is one of ten houses built as part of the Advanced Houses Program of CANMET, Natural Resources Canada. The construction, promotion and monitoring of the house were a joint venture between Enermodal Engineering Limited and the Kitchener-Waterloo Home Builders' Association. The goal of the project was to demonstrate that houses can be built and operated in a manner that is environmentally responsible. The house contains the latest developments in energy efficiency, water conservation, waste management, CFC reduction and environmentally appropriate material use. The house was designed to consume less than 30% of the energy and water used in a conventional new home.

The house was built over the winter of 1992/93 and opened to the public in April 1993. For the first year the house was open to the public. In May 1994 the house was sold and a family took occupancy.

This report covers five aspects of the project:
- design features of the house,
- expected performance of the house,
- lessons learned during the construction and operation of the house,
- summary of communication activities, and
- energy and indoor air quality monitoring results.

2.0 HOUSE DESCRIPTION

2.1 Technical Requirements

The Advanced Houses Program of Natural Resources Canada set out technical requirements that each of the ten Advanced Houses were to meet [Dumont, 1992]. The purpose of the requirements was to demonstrate to the building community and the public that new homes can be built and operated in a manner that has significantly less impact on the environment than typical housing.

The primary requirement was that the total purchased energy of the house was to be less than 50% that required for an R2000 house. This corresponds to approximately a 70% reduction in energy use over conventional new housing. Individual energy targets were set for specific functions (e.g., space heating, appliances), although designers were free to trade energy demands between areas, provided the total met the target. For a 230 square metre house (including basement) in Waterloo, Ontario, the total energy target is 13,900 kWh or 60 kwh/m^2 (see Table 2.1).

Table 2.1 Advanced House Energy Target

Energy Use	Energy Target (kWh)	Energy Target (kWh/m^2)
Space Heating	5022	22
Space Cooling	420	2
Water Heating	4140	18
Fans and Appliances	3838	17
Indoor Lights	305	1
Outdoor Lights	183	1
Total	13909	60

The Advanced House Technical Requirements also included a number of prescriptive measures for performance of air handling systems, water conservation, recycling, waste management, use of CFCs, and indoor air quality. To supplement these requirements, the designers of the Green Home set performance requirements in these areas. The following design goals were set (all relative to conventional new housing):

- 70% reduction in energy use,
- 70% reduction in CO_2 emissions from energy use,
- 70% reduction in water use compared to conventional new housing,
- total avoidance of CFCs,
- indoor air quality should be better than the most stringent requirements in the world,
- construction materials that place the least strain on the environment (e.g., low embodied energy, low chemical content)
- no construction waste sent to the landfill site, and
- 50% of the house (by volume) constructed from recycled materials.

For some products these goals may be contradictory. For example, preserved-wood foundations may offer better insulating values and have lower embodied energy than concrete foundations, but toxic preservatives are an environmental hazard. In these cases, an assessment was made as to which considerations have highest priority in meeting the goals of the project.

Energy conservation and renewable energy sources were the fuel of choice. For energy demands not met by these, natural gas was given preference because of its low CO_2 and SO_2 emission rates. The burning of natural gas produces no sulphur dioxide and only 1/6th the carbon dioxide of a coal-fired power plant that produces electricity.

2.2 House Location and Form

The Green Home is a single-family detached house of 230 square metres total floor area (including finished basement) located on a corner lot in a new subdivision in Waterloo, Ontario. The house is a raised bungalow that is fairly conventional in exterior appearance. Nevertheless, several innovative concepts were incorporated into the house design to improve energy efficiency and reduce the amount of construction materials. The design philosophy was to have the minimum exposed surface area but with the maximum use of interior space.

Exposed surface area is kept to a minimum by using a fairly square house "footprint" and avoiding irregular facades. To prevent a "boxy" house form, a garage, front and back porches, and south-side overhang work were used. A south-side dormer allows natural light to penetrate to the north-side interior. The garage is oversized to permit storage of seasonal items, instead of using valuable heated indoor space for storage.

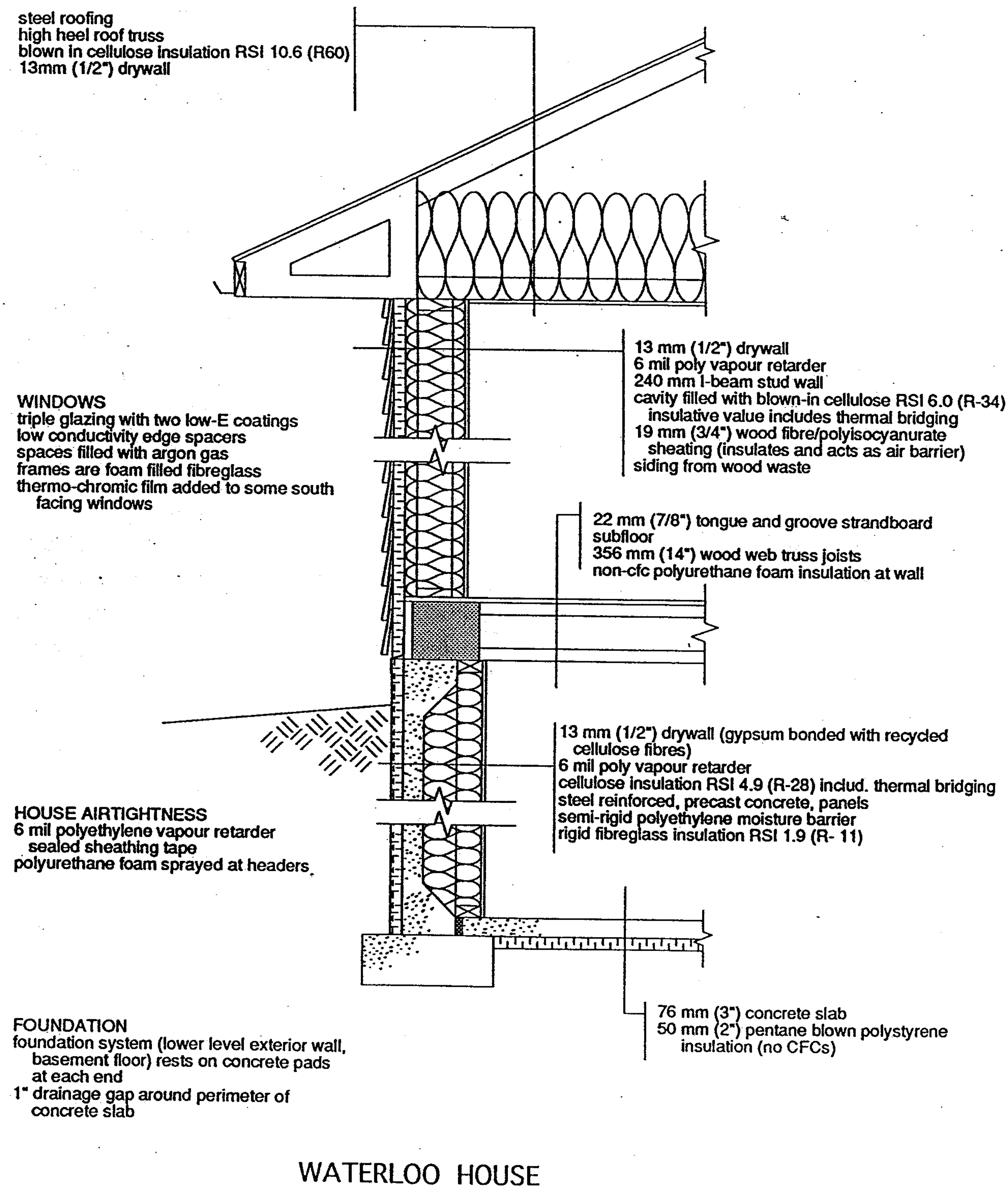
In most houses, basements are dark, susceptible to dampness, a potential source of radon and are generally used for storage and locating mechanical equipment. Given that a house without a basement would be difficult to sell, the Green Home design made maximum use of the basement. The house was raised so that the basement floor is only 1.2 metres below grade on the south-side instead of the more conventional 2.0 metres. The extra height above grade is used for additional windows to create a more desirable living space. With the extra storage space in the garage, most of the basement could be fully finished. The basement includes two bedrooms and a full bathroom so that it could be used as a separate apartment for grandparents, guests, or as extra space for a growing family. Basement bedrooms have several advantages: they increase the occupant density, thereby resulting in a more efficient use of available resources, and make use of the natural temperature stratification in houses (cool bedrooms are more comfortable for sleeping in both winter and summer).

In conventional homes, attics are also under-utilized space. In the Green Home, the living room and dining room have cathedral ceilings. Thus, some of the attic space is being used to create the feeling of larger rooms. The cathedral ceiling results in a moderately steep roof slope suitable for proper orientation for solar collectors (see plumbing section).

2.3 Building Shell

The building shell is well-insulated and airtight. The above- and below-grade wall section is shown in Figure 2.1. The basement wall is made up of 5 metre long precast panels with steel mesh reinforcing. The panels are flat on the outside and resemble a waffle on the inside. The panels are 200 mm thick at the edges but are only 50 mm thick in the middle. The result is a system that uses only half the concrete of a conventional poured wall with voids that can be easily insulated. The system does not require continuous footings, only pads at each end, which makes it easier to fully insulate under the floor slab. The floor slab is insulated with 50 mm of steam-blown polystyrene insulation. Including any thermal bridging effects, the below-grade wall and floor have U-values conductances of 0.18 and 0.6 W/m^{2}K respectively.

Figure 2.1: Above- and Below-Grade Wall Sections



WATERLOO HOUSE

The above-grade wall sections use a truss wall system made up of two load-bearing members connected by a thin web. The truss wall has many advantages over conventional stud walls, including lower material and labour requirements. Instead of using high grade lumber, the members are made of laminated strips from high-growth trees and the webs are made from recycled wood scraps. The truss can be made very wide to accommodate extra insulation and minimize the need for exterior insulated sheathing. For the Green Home, the wall cavity is filled with 235 mm of wet-blown cellulose insulation made from recycled newspapers to achieve a U-value of 0.14 W/m^2K. A combination strand board/steam-blown isocyanurate insulated sheathing is used on the exterior. The truss system is factory-built with the scraps re-used thereby eliminating any construction waste.

The wall truss system is also being used for the above-grade floor. It has the advantage of not using high-grade lumber and is stronger to permit 600 mm spacing of joists instead of the conventional 450 mm. A slightly thicker sub-floor is used to give a rigid floor, but the truss floor system, including the sub-floor, still uses 30% less wood than a conventional floor.

A six-mil polyethylene vapour retarder is used on the interior. All seams are sealed with non-drying two-sided tape. Drywall, containing a minimum of 25% recycled wastes and without paper covering, is used for all interior wall finishes. Siding made from wood wastes is used as the exterior wall covering. Exterior trim, soffits and flashing were made of steel instead of aluminum. The manufacture of aluminum requires larger amounts of energy and produces more pollution than the making of steel.

Roof trusses were factory-built to minimize waste and improve quality control. The trusses are constructed almost entirely of 2 X 4's (38 X 89 mm) instead of the commonly used 2X6s and 2X8s, so that smaller diameter trees can be used. Steel roofing is used instead of asphalt shingles. Steel roofing has a 25% recycled content, lasts the life of the building and can be recycled. Asphalt shingles last only 15 to 20 years and are a more toxic landfill product.

Windows and glass inserts for doors were selected to have high solar heat gain and low heat loss. The glazing units are triple-glazed with two low-emissivity coatings, insulated edge seal spacers and argon-gas fills. The window frames are foam-filled fibreglass. Windows are located to maximize winter gains and minimize summer gains and sized so as to avoid overheating. The exterior doors are constructed from polystyrene foam insulation covered with a durable fibreglass skin. The foam is blown with non-ozone depleting pentane. A wood storm door is attached to decrease door heat loss.

Table 2.2 compares the thermal performance of the Green Home building envelope to the requirements of the 1993 Ontario Building Code. The R-values of the Green Home assemblies are two to three times those of the current building code.

Table 2.2: Comparison of Insulation Levels in Conventional and Green Home

Component	Green Home	Conventional New Home
Above-Grade Wall	RSI 5.9	RSI 3.0
Below-Grade Wall	RSI 4.9	RSI 1.5
Floor Slab	RSI 1.4	0
Ceiling	RSI 10.6	RSI 5.6
Doors	RSI 1.1	RSI 0.5
Operable Windows[1]	ER +6	ER -15
Fixed Windows[1]	ER +12	ER -30

[1] Window values are given in terms of Energy Rating. The Energy Rating represents the average heat gain (or loss, if negative) of the window over the heating season in Watts/m^2

2.4 Finishes and Furnishings

The interior finishes and furnishings were carefully selected to address all environmental issues. In keeping with the reuse and recycle theme, all of the furniture on display during the demonstration period were antiques and yard sale design-finds. Resource depletion and disposal were addressed by re-using products wherever possible. The main floor hardwood flooring was recovered from a demolished building. A refurbished bathtub and sink are used in the lower floor washroom. Flooring tiles made from recycled glass, instead of petroleum-based vinyl, are used in the front entrance and bathrooms. Recycled materials were also used in the carpeting (manufactured from P.E.T. - plastic pop bottles) and the gypsum underlay for the tile floors contains used paper products.

Materials were chosen to reduce emissions of formaldehyde and volatile organic compounds (VOCs). Particle board furniture was avoided. Closet shelving is coated steel and the kitchen cabinets doors are solid pine. The cabinet interiors are made from particle board but sealed with acrylic latex to reduce off-gassing. Drapery fabric is a chemically untreated, down-proof cotton, with acrylic-based fabric paints used for colour. VOCs were avoided by using VOC-free latex paints and rubber-based adhesive tapes and silicone caulking.

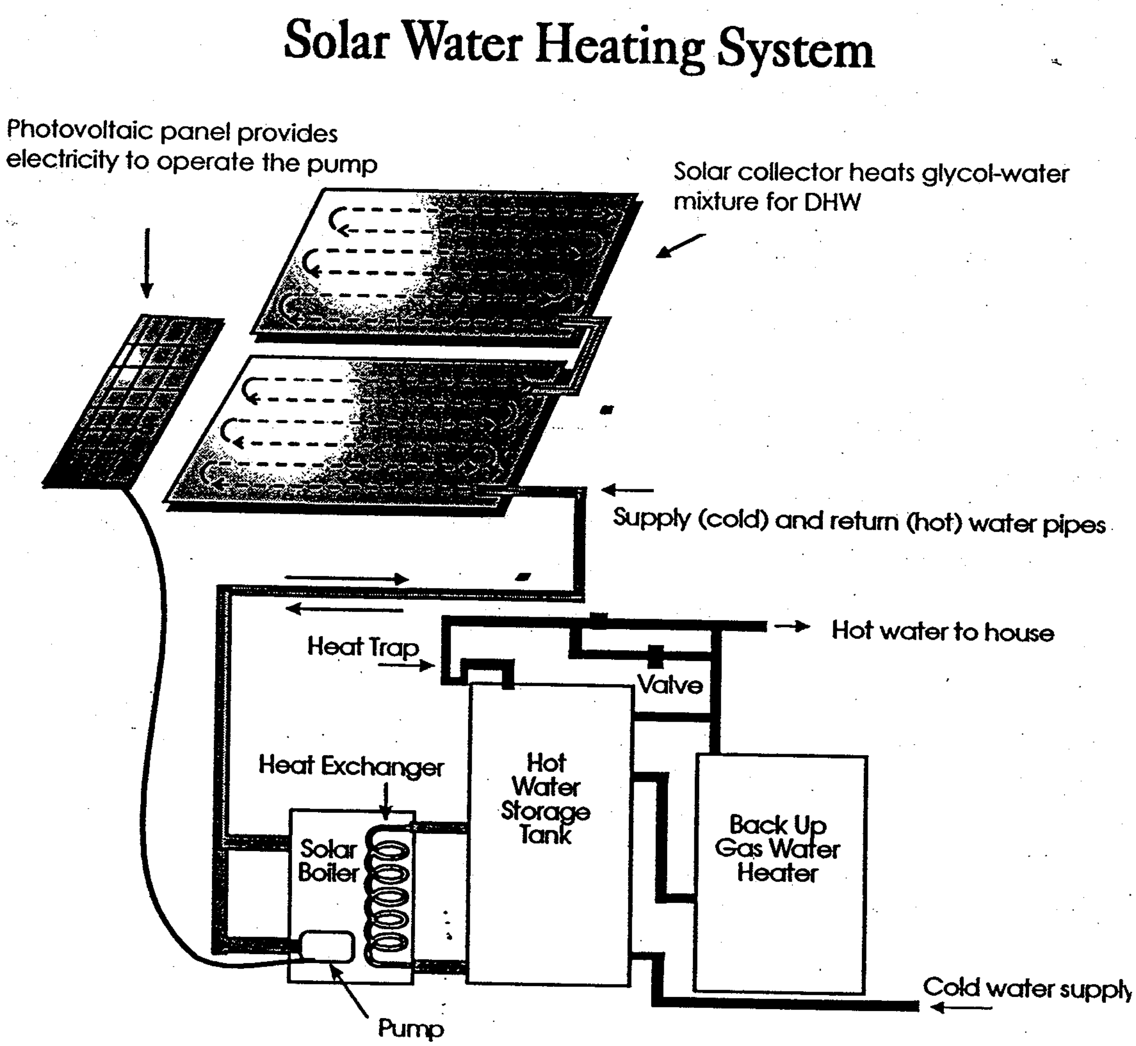
2.5 Plumbing Systems

The plumbing systems were designed to minimize both hot and cold water use and to make use of natural supplies of water. The toilets use only 3 l/flush instead if the standard 13 l/flush. The shower uses a low-flow showerhead and manual shut-off to conserve water when lathering. Aerators restrict bathroom faucets to a flow of 2 l/min and kitchen faucets to a flow of 6 l/min. The hard water found in Waterloo region requires water softening. The Green Home water softener is water conserving, regenerates only when necessary and softens only the hot water. The result is a two thirds reduction in softener water use. A cistern collects rainwater for watering the garden, flushing the toilets and washing clothes.

A solar domestic hot water system supplies the majority of the hot water needs (see Figure 2.2). A high-efficiency low-power pump is controlled and powered by photovoltaic cells. Driving the solar heat collection pump by PV power has the advantages of eliminating the need for a controller, simplifying the installation and providing better performance (since the pump flow rate varies with incident solar radiation). The system does not require any electricity to operate and uses thin flexible tubing to connect the collectors to the storage tank for easy installation.

During the months of low solar radiation, a high-efficiency, natural gas-fired boiler supplements the solar heat. This is a direct vent unit that mounts on the wall. The piping is set up so that the solar system and gas boiler use the same 454 litre storage tank. The solar system heats the bottom two-thirds of the tank and the gas boiler maintains the top one third at 50°C.

Figure 2.2: Solar Domestic Hot Water System Schematic



2.6 HVAC Systems

The space heating and ventilation are handled by a combined furnace/HRV (see Figure 2.3). This appliance, referred to as an integrated heating and ventilating appliance (IHVA), was developed by the Canadian Gas Research Institute. The system uses a conventional mid-efficiency furnace coupled to a small container of rocks with two compartments. Stale air from bathrooms and kitchen mixes with the furnace flue gases and passes through the first compartment of rocks. The large surface area of the rocks ensures that almost all of the heat in the exhaust air is given up to the rock. Outdoor air is heated up as it passes through the second compartment of rocks. Approximately every four minutes, a reversing valve switches the air streams to the two rock compartments, allowing the heated rocks to be cooled and cooled rocks to be heated. The outdoor air is distributed throughout the house via the furnace ductwork. Products of combustion are prevented from re-entering the house by pressurizing the outdoor air stream and shutting off the furnace just before every reversing valve operation.

This system has two main advantages over conventional furnaces and HRV's. First, it is energy efficient. The system recovers heat from exhaust air and furnace flue gases. The prototype unit was expected to have a combined furnace and HRV efficiency of 85% [Overall and Besik, 1989]. Second, this new system, when commercialized, is expected to be less expensive than a condensing gas furnace and HRV because it is integrated into one package and does not require a stainless steel heat exchanger.

The house and landscaping were designed, and appliances selected, to minimize the need for mechanical cooling. Nevertheless, a small cooling system was installed. To avoid the use of freon-based cooling systems, it was decided to make use of the cistern water and ground as the cooling source. When cooling is required, cistern water is circulated through plastic tubing buried below the basement floor slab and through a coil in the air-handling system (see Figure 2.4).

Figure 2.3: IHVA System Schematic

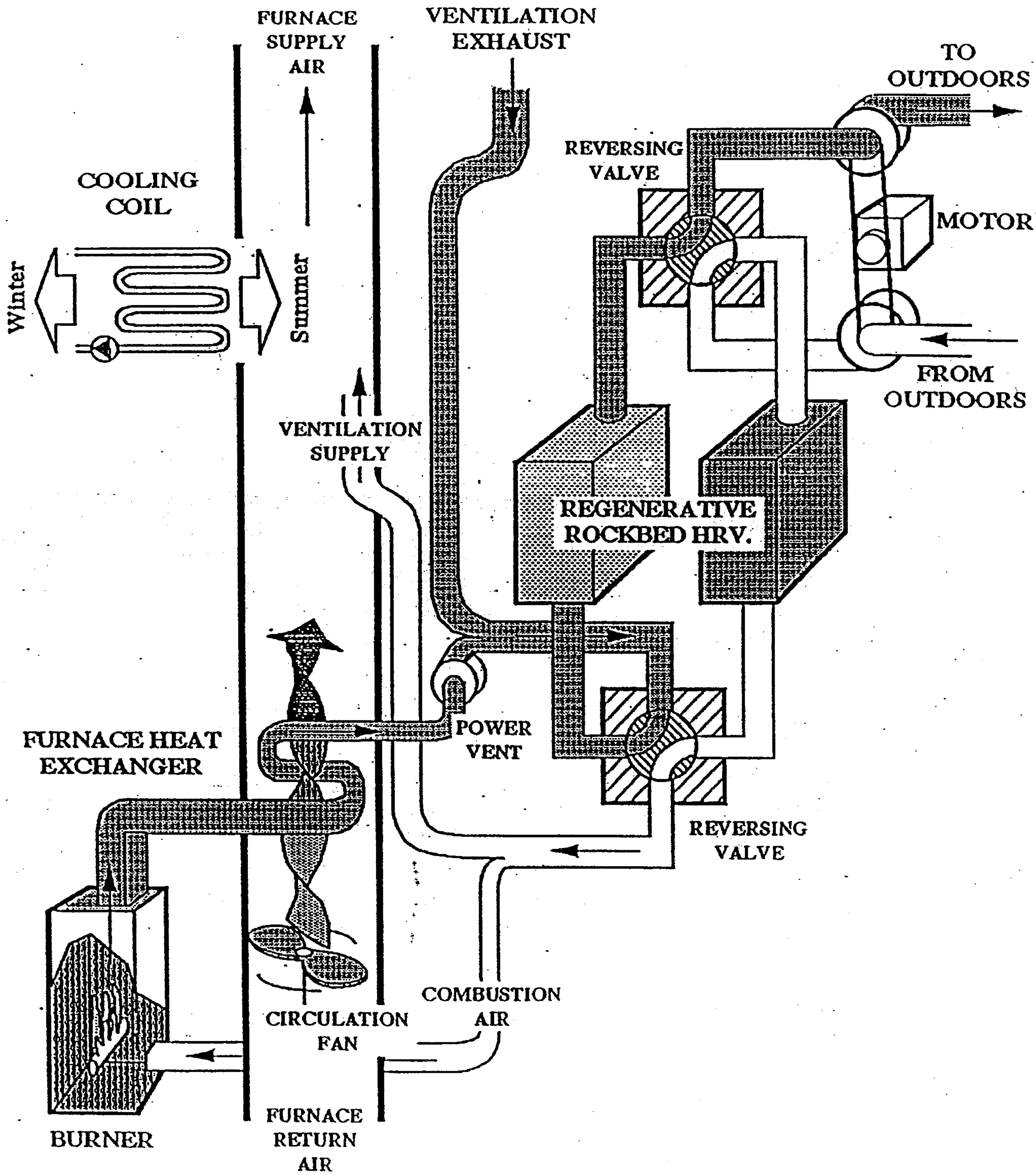
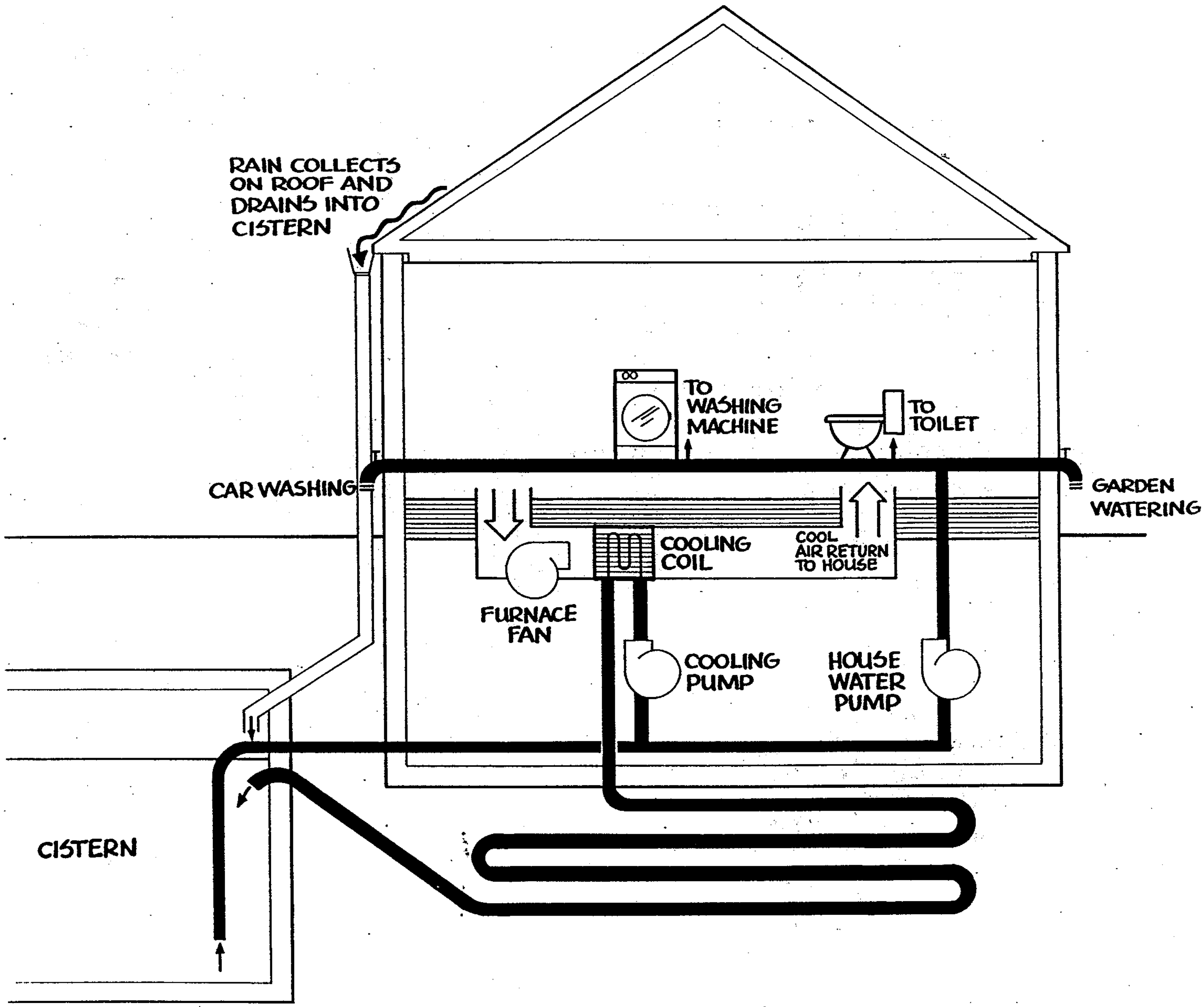


Figure 2.4: Cistern Cooling System Schematic



Circulating fans can be the largest consumer of electricity in a house. Several design features were added to decrease fan energy requirements. The HRV fan alone distributes ventilation air when the furnace is off. All ductwork is slightly oversized and fitted with turning vanes to reduce friction losses. Supply registers are located close to the distribution trunk (as opposed to under the windows). The cooling coil is on a sliding track so it can be easily removed in the winter to further reduce air friction. A DC electronically commutated motor was retrofitted to drive the furnace fan. A high-efficiency (50% ASHRAE dust spot efficiency) pleated air filter is used instead of an electricity-consuming electronic air cleaner.

In most houses with an HRV, the fresh air supply duct is connected to the furnace return. The HRV fan operates continuously to bring fresh air into the house and the furnace fan operates continuously to distribute the fresh air throughout the house. At the Green Home an innovative ducting system was installed to eliminate operating the furnace fan continuously. The HRV fresh air supply duct is connected directly to the furnace supply. A back-draft damper is located upstream of this connection to keep fresh air from flowing backwards through the furnace return ducting. The HRV fan alone is used to distribute fresh air when the furnace was off.

2.7 Appliances

Some of the most energy-efficient and water-conserving appliances are used in the house. As discussed in Section 2.1, after conservation, natural gas was the fuel of choice. Although not common in Ontario, both a natural gas clothes dryer and a stove were installed. Flexible stainless steel conduit was used to simplify the installation of gas lines to the appliances.

The gas stove is a prototype direct-vent natural gas stove incorporating a ceramic counter top for cooking. When it is turned on, a small fan brings in outdoor air for combustion. The air-gas mixture is burned and the products of combustion are vented to the outdoors.

A direct-vent natural gas fireplace is featured in the living room. The fireplace features spark ignition and fan-assisted heat delivery to ensure high efficiency. Outdoor air is used for fireplace combustion.

Electric appliances include a refrigerator, clothes washer and dishwasher. A Danish made refrigerator/freezer is used for food storage. This unit is one of the first CFC-free refrigerators commercially available. Two units were installed to meet the North American demands for storage volume: 200 litre freezer and 400 litre refrigerator. Energy-efficiency features include separate compressors and temperature controls for the refrigerator and freezer compartments, upgraded insulation and no interior light bulb.

The manufacturer's energy rating for the Green Home refrigerator is 27 kWh per month (54 kWh/month for two) according to the European DS/EN 153 standard. Ontario Hydro Research is developing a test procedure that is intended to accurately reflect in-field performance. One of the Green Home refrigerators was tested under this new procedure and achieved a rating of 35.5 kWh/month (71 kWh/month for two) [Howell, 1993]. The combined rating for the refrigerator and up-right freezer of equivalent volume with the lowest 1994 ENERGUIDE ratings is 81 kWh/month: 8 kWh/month higher than the Green Home units.

The German-made washing machine is front loading with a high-speed spin dry. This front-loading machine consumes 60% less water than top loaders. The spin dry part of the washer cycle operates at 1600 rpm instead of the more conventional 600 rpm, reducing the clothes water content from 100% to 50%. The lower moisture content cuts drying time and dryer energy consumption in half. The washer also features a high-efficiency DC motor for agitation. The dishwasher, from the same manufacturer, needs only 20 litres/wash, half the amount of conventional dishwashers.

Appliance plug loads were reduced by including a number of small single purpose appliances and hand appliances with the house. In general, it is more efficient to heat water in a small appliance than on a stove. Powered appliances (such as electric can opener and leaf blower) were avoided in favour of hand appliances (such as hand can opener and rake).

The expected energy use of the gas and electric appliances is given in Table 2.3. For comparison purposes, energy consumption values are listed for standard North American appliances.

Table 2.3: Appliance Annual Energy Consumption (in kWh)

Appliance	Green Home Appliances		Typical Appliances
	Elec. (kWh)	Gas (kWh)	Elec. (kWh)
Refrigerator/Freezer	840	-	1000
Stove	13	1040	780
Clothes Washer[1]	119	-	150
Clothes Dryer	30	546	1050
Dishwasher[1]	198	-	258
TV/small appliances	546	-	1086
Total	1,746	1,586	4,324
Total (all fuels)	3,332		4,324

[1]- values are for electrical use only, water heating requirements are excluded

2.8 Lighting and Electrical Systems

The most efficient lighting source is daylighting. Windows are carefully placed throughout the house to allow natural light into all rooms. An interior glass wall (made from recycled glass) admits natural light from the dormer windows into the north-side bathroom.

Most of the electric lighting systems are either full-spectrum T8 fluorescent tubes with electronic ballasts or compact fluorescent lamps. The lighting design emphasizes task lighting in which spot lights illuminate a specific area and not an entire room. In areas where lights are rarely used (e.g. closets), standard incandescent lights are controlled by timers to make sure the lights are not left on when not required. The installed lighting capacity was under 8 W/m^2.

Outdoor lighting demonstrates many ways costs can be reduced. The exterior house lighting features compact fluorescent lighting. The garden and yard lighting is solar powered: electricity generated during the day is stored for use at night.

2.9 Landscaping

Landscaping at the Green Home applies the underlying philosophy of environmental responsibility to the building lot. The landscaping creates an aesthetically pleasing setting for the homeowner while providing a positive effect on the local environment.

The landscape plan emphasizes the use of native plant species selected for hardiness, drought resistance and the provision of habitat for butterflies, birds and other wildlife. Trees and shrubs include white oak, downy serviceberry, red osier dogwood and bearberry. Deciduous trees are located so as to reduce house summer cooling loads and maximize winter solar gains. Woodland plants such as lady ferns and Solomon's seal and flowers such as lobelia and sedum are also used. Ground covers of perennial rye and fescue grasses and white dutch clover were selected because of their drought resistance and tolerance to foot traffic.

Aside from the low-water-demand plant material, several features are incorporated into the design to reduce water requirements. On-site water retention is maximized by terracing steep slopes and using hollow-core paving units in the driveway. Plantings are heavily mulched with shredded bark to reduce evaporative moisture loss, to lower soil temperatures and to allow rain water to soak into the ground.

The soil is supplemented with composted horse manure (mushroom farming by-product) to boost organic content, gypsum from waste drywall to improve drainage, and organic fertilizers to improve productivity.

The landscape plan also includes a vegetable garden and two composters: one for food waste and one for yard waste. On-site composting of yard and kitchen waste provides soil enrichment and eliminates organic matter from landfill garbage.

The manufactured materials used in the landscape include pre-cast concrete retaining walls rather than pressure treated lumber and recycled rubber walkway paving units.

3.0 EXPECTED PERFORMANCE

3.1 Energy Consumption

Detailed calculations and computer simulations of the expected energy use of the house were performed. To put these values in context, simulations were also performed assuming the house was built to conventional practice and just met the requirements of the Ontario Building Code (OBC). The OBC house was assumed to use a mid-efficiency gas furnace and standard gas water heater.

The space heating and cooling values were obtained using the ENERPASS computer program [Enermodal, 1992]. The Green Home water heating values are based on an water demand of 60 litres per day, a solar heating fraction of 65% and a gas heater efficiency of 80%. The conventional values are calculated using a hot water demand of 225 litres/day and a 50% seasonal water heater efficiency. The appliance energy use is taken from Section 2.3. The other electrical loads were as recommended in the Advanced House Technical Requirements [Dumont, 1992].

The annual energy usages are summarized in Table 3.1. Energy use is reduced by over 70% (note gas consumption is converted to an equivalent kWh) compared to a conventional new building. The predicted energy use is also 15% below the Advanced Houses technical requirement (see Table 2.1).

Based on local utility rate structures, the Green Home energy bill is only $642. (including gas fixed charge of $90 per year). This is approximately $1,000. a year lower than the energy bill for a conventional house.

Table 3.1 Predicted Annual Energy Use (in kWh)

Energy Use	Green Home		OBC House	
	Elec. (kWh)	Gas (kWh)	Elec. (kWh)	Gas (kWh)
Space Heating	-	5,282	-	18,554
Water Heating	-	977	-	12,422
Cooling	213	0	1,894	-
Gas Appliances	-	1,586	-	-
Electrical Appliances	1,200	-	3,238	-
Plug Loads	546	-	1,086	-
Indoor Lighting	479	-	1,760	
Outdoor Loads	20	-	75	-
Fans	1,632	-	2,037	-
Total	4090	7845	10,090	30,976
TOTAL	11,935		41,066	

3.2 Water Consumption

The art of predicting annual water use is not as well developed as energy use predictions. Most sources give average hot water use for families of four in the range of 200 to 250 litres per day. Hot water consumption is typically 1/3 of the total water use [Carpenter and Kokko, 1989]. Thus, a typical Canadian household consumes 683 litres per day of water. The Region of Waterloo has determined that the average water consumption is 209 litres/day per person [Walker, 1995]. This result is consistent with the 683 litres/day value assuming that a typical household is between 3 and 4 people. Table 2.3 compares the expected water use in the Green Home and a conventional home. The component breakdown is an average of several sources. The Green Home figures were derived based on the percentage reduction expected in each area. For example the green Home toilets are rated at 3 litres per flush as opposed to conventional toilets at 20 litres per flush or a 85 % reduction.

Purchased (i.e., city supply) water use is reduced by over 70 %, with the major reductions in lawn and toilet water consumption. Demand on the municipal sewer system is reduced by approximately two-thirds (sewer system must handle cistern water use). The annual savings in city water and sewer charges is $240.

Table 3.2 Daily Water Use (in litres/day)

Water Use	Green Home		OBC House
	city water	cistern water	city water
Lawn	-	20	96
Sinks	21	-	34
Toilet	-	39	260
Bathing	115	-	164
Appliances	21	21	96
Water Treatment	11	-	34
TOTAL	168	80	683

3.3 Use of Ozone-Depleting Chemicals

At the time of the Green Home design and construction, chloroflouro-carbons (CFCs) were commonly used in to operate refrigeration equipment and to produce many construction materials. Hydro-chloroflouro-carbons (HCFCs), which have 1/20th the ozone depletion potential of CFCs, were just beginning to be used as an alternative.

Ozone-depleting chemicals are often used in air conditioning equipment, refrigerators, and freezers. They are also used to produce insulated doors, carpet underpad, extruded polystyrene insulation, and polyurethane foam. The amount of halocarbons (i.e., CFCs and HCFCs) in a material depends on the type of foam. Flexible polyurethane, as used in furniture and underpading, contains 7% halocarbons by weight. Extruded polystyrene, as is often used for sheathing and underslab insulation, contains 10% halocarbons by weight. Finally, rigid polyurethane, as used for door slabs and sprayed-in-place foam insulation, is made up of 15 % halogens by weight [EPA, 1976].

Table 3.3 lists the amounts of ozone-depleting chemicals used in the Green Home and in a conventional house of similar size and insulation levels. These values were computed by multiplying the material quantities by the percentage halogen content. The Green Home has an ozone-depletion factor that is only 1 % that of a conventional house.

The regulations regarding the use of CFCs are changing and, with the exception of refrigerators, most residential materials are not allowed to use CFCs. Even under the current (1995) regulations, the Green Home uses only 15% of the ozone-depleting chemicals of a conventional home.

3.4 Embodied Energy

One of the design goals was to reduce the embodied energy of the house, that is, the amount of energy required to produce the materials used in the house. The embodied energy of a typical Canadian house has been calculated to be over 200,000 kWh, or the equivalent of almost 20 years operating energy for the Green Home [CMHC, 1991]. As houses become more efficient in the use of operating energy, embodied energy becomes a more important design consideration.

Values for the embodied energy of materials is somewhat incomplete and varies among researchers. Perhaps the most complete set of data is contained in the OPTIMIZE spreadsheet program [CMHC, 1991]. This data was used to perform the embodied energy analysis.

It was difficult to calculate the embodied energy for the entire Green Home because of the lack of data for some of the innovative and recycled materials and the complexity in determining the exact material quantities for every building material. Embodied energy calculations were carried out for the Green Home wall system because the material values were known and it represents a significant portion of the building envelope. Two other wall systems were calculated to allow for comparison. The wall system descriptions are as follows.

Conventional Wall Construction: The walls are framed with 2x6s (38 X 140 mm) on 400 mm centres and insulated with fibreglass to meet the requirements of the Ontario Building Code (RSI 3.2). The exterior is sheathed with 13 mm oriented strand board and aluminum siding. An air barrier house wrap, 6 mil polyethylene vapour barrier and standard drywall complete the building shell.

Upgraded Wall Construction: This wall system has upgraded insulation levels equal to that of the Green Home but constructed according to standard practice. A double stud wall system is used consisting of two 2x4s (38 x 89mm) walls separated 89 mm. The walls are insulated with 260 mm of fibreglass to achieve an RSI of 5.9. The rest of the materials are the same as the conventional wall.

Green Home Wall Construction: The walls are framed with engineered I-beams 600 mm on centre. 240 mm of cellulose is blown into the cavity. An air barrier and 19 mm sheathing (a combination of wood scraps and isocyanurate insulation) are on the outside of the framing. Hardboard siding finished with latex paint is the exterior of the wall. A 6 mil polyethylene vapour barrier and gypsum board made with recycled newsprint and half the amount of the water of conventional drywall are placed on the inside.

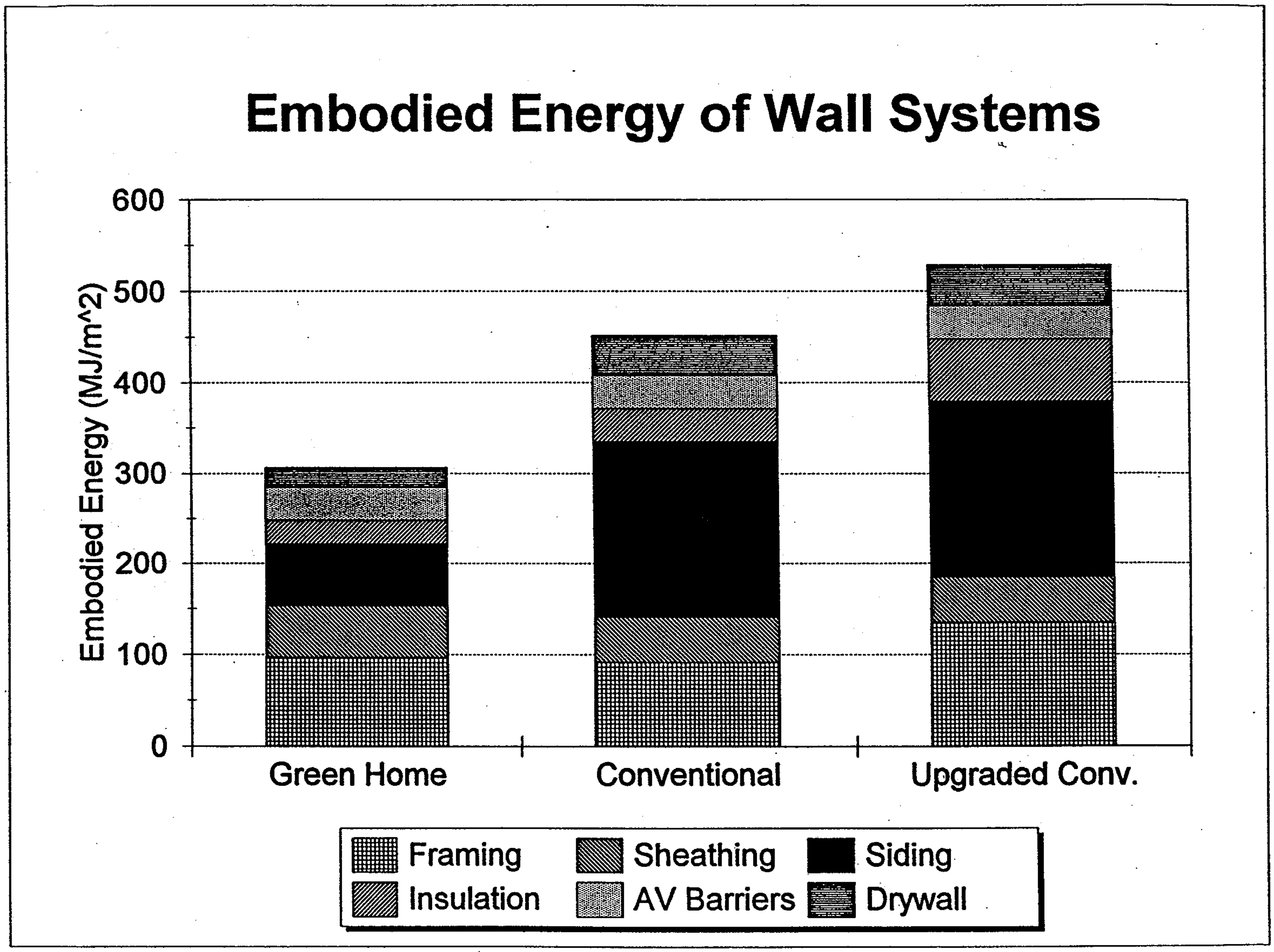
Figure 3.1 shows the embodied energy for the three wall systems. The calculations are contained in Appendix C. The embodied energy in the Green Home wall system is one third less than that of the conventional house even though it has almost twice the insulating value. The savings came from the wood siding in place of aluminum and the recycled gypsum board. When compared to the wall with an equivalent U-value, the embodied energy of the Green Home wall is 42 % lower. The additional savings came from lower embodied energy for the framing and insulation.

Although the embodied energy was not calculated for the other building components, similar savings are expected. The foundation system uses 50% less concrete, the drainage materials is made from recycled concrete and glass and many re-used and recycled materials were used for interior finishings (see Section 2.4).

Table 3.3 Use of Ozone-Depleting Chemicals (in kg of CFC equivalent)

Building Component	Quantity	Green Home		OBC House	
		CFC (kg)	HCFC (kg)	CFC (kg)	HCFC (kg)
Air Conditioner	One	-	-	-	2.5
Refrigerator/ Freezer Compressor	400/200 litres	-	-	0.9	-
Refrigerator/ Freezer Insulation	400/200 litres	-	0.2	0.2	-
Insulated Doors	Six	-	-	2.1	-
Carpet Underpad	110 m^2	-	-	6.9	-
Furniture Foam Padding	1.7 m^3	-	-	13.8	-
Insulated Sheathing	175 m^2 of 25 mm board	-	-	14.2	-
Under-Slab Insulation	120 m^2 of 50 mm board	-	-	19.7	-
Foaming of Ring Joist	15 m^2 150 mm thick	-	11.1	11.1	-
Total		0	11.3	68.9	2.5
TOTAL (CFC equivalent)		0.6		69.0	

Figure 3.1:


Embodied Energy of Wall Systems
Embodied Energy (MJ/m^2)
600
500
400
300
200
100
0
Green Home
Conventional
Upgraded Conv.
Framing
Sheathing
Siding
Insulation
AV Barriers
Drywall

4.0 HOUSE CONSTRUCTION

4.1 The Construction Process

House construction began in August 1992 and was completed in April 1993; the house was on display to the public for one year following construction. Because The Green Home was an innovative and "one of a kind" project, the construction process took more time than a conventional house project. In general, each construction phase was completed before the next one was started to ensure proper installation.

No specially trained work crews were used for the construction - in fact, technologies were chosen to match the installation skills of conventional tradesman. It was found, however, that considerable supervision was required to train tradesmen and to ensure that the goals of the project were meet (e.g., waste management). It was necessary to convince builders of the value of new methods of construction. Despite the education that was required, most of the workers were able to adapt easily to the new technologies.

After some initial reservations, house framers found the engineered wood wall and floor system easy to work with. Installation time was shortened because the floor joist and wall studs were extremely light and arrived at the site cut to the proper length. Electric wiring, flexible gas piping and water piping were easily routed through pre-drilled knock-outs in the I-beams. Members did not warp or twist and the floor is more rigid than conventional floors despite the wide spacing.

The precast basement walls were manufactured in lengths up to 5 metres (16 feet) and bolted together with a gasket between lengths. The system was factory built, so weather was not an impediment to construction, and once the pad footings were accurately positioned, the placement of the wall sections by crane was a simple matter.

Fibre-reinforced drywall, a mixture of old newspapers and gypsum, is 25 % heavier and up to three times stronger than conventional products of the same thickness. It provides additional thermal mass, sound dampening and damage resistance. On the negative side, the extra weight and strength made it harder to work with. Although the Green Home drywall costs about 10% more than conventional drywall, increased material costs are partially offset by labour savings because the butt joint seams do not have to be taped.

(No seams have cracked over the two years since construction.) An extra coat or thicker first coat of primer was needed to cover the grey tinge to the drywall.

The wood flooring is bird's eye maple salvaged from a demolished warehouse. The installation followed this sequence: removed old nails, discarded oil-soaked and severely damaged wood, cut damaged ends off worthwhile pieces, scraped dirt off the edges, nailed flooring to sub-floor, sanded with a belt sander and coated with a water-based urethane floor finish. Despite the extra work, the general response from the touring public was that the floor appeared far superior to new wood flooring.

The most troublesome construction items were the unique systems, specifically engineered for the Green Home project: the ground-loop cooling system and the cistern water system. When house cooling is required, cistern water is circulated through plastic tubing buried below and around the house foundation and through a coil in the air-handling system. Installation of the ground loop presented several problems. First, because contractors were not familiar with the system, constant supervision was required to ensure proper installation. Second, the piping was ruptured (and subsequently repaired) several times during construction. Third, when the system was commissioned, it was discovered that one of the three cooling loops was broken and had to be isolated.

A pump and expansion tank were required to deliver cistern water for domestic uses. The wall-mounted cistern pump was noisy and system could not maintain adequate water flow for an extended period of time. Several modifications had to made to get these systems to work.

4.2 Waste Management During Construction

The Green House construction process included a comprehensive waste management program that reduced the impact of house construction and operation on the environment. The program was based on reduce, reuse, and recycle - in that order.

The first of the three "Rs" requires a reduction in the amount of construction waste produced. The use of premanufactured components, such as ceiling, wall, and floor trusses, results in no cutting or waste generation at the construction site. At the factory, end cuts were reused for blocking. For site-built components, order quantities were close to exact requirements and excess material was returned to the supplier for re-use. Corrugated stainless steel conduit was used in the Green Home for natural gas piping, and because the piping was cut to exact lengths and connected with compression fittings, no waste was produced. Thin-wall "sausage pack" caulking tubes were an innovative alternative to conventional caulking tubes; the amount of packaging is extremely small and the reusable nozzle allows remaining caulking to be used when a new tube is installed in the gun.

The second "R" is reuse. Much of the wood waste was removed for use on other job sites. Wood pallets and tarpaulin-quality packaging were reused for storage of materials at other construction sites. Insulation scraps and other inert materials were placed in the attic for added insulation. Drywall scraps were inserted in interior walls for extra thermal storage. Leftover paint was either taken to another construction site or another coat was put on the walls.

Recycling was incorporated into construction practices. Concrete left over from pouring the floor slab was set in a field, crushed and used as aggregate on other construction sites. Recyclable materials such as cardboard and steel were taken to the Region of Waterloo Waste Management Facility for recycling. Materials thatwere not accepted at the local facility were taken to alternate recycling facilities.

Conventional construction practices result in 2.5 tonnes of waste being sent to the landfill site from every home construction site. In contrast, Green Home construction generated only a few green garbage bags of waste, an impressive 98 % reduction in waste.

4.3 Construction Costs

It is difficult to determine accurately the extra cost for the energy and environmental features of the Green Home for four reasons. First, several components (such as the direct-vent gas stove and IHVA) are prototype units and are not yet commercially available. Second, since the Green Home was a demonstration project, several possible solutions to design problems were presented, whereas the cost effective approach would be to select just one solution. Water heating, for example, was provided by a solar heating system *and* a high-efficiency natural gas water heater, although a typical home would have just one of these systems. Third, many products were donated and the true installed price is not known. Fourth, extra costs were incurred for purely decorative features (such as hardwood floors), for improved comfort or health (sealing kitchen cabinets to prevent release of formaldehyde), and to build a superior house (the steel roof will last the lifetime of the house). These features add extra cost to the home but should not be included in energy payback calculations.

While acknowledging the difficulties in costing the house, the incremental costs for the Green Home are estimated in Table 4.1. The construction cost for a house of similar size but built to conventional practice would be $110,000., excluding land and builder profit. With upgrade finishes (e.g., wood flooring), landscaping and appliances, the construction cost would rise to $125,000. The incremental construction cost for the Green Home is approximately $37,600. or 30% more than a conventional home of similar size. When the price of the land is included, the premium on the selling price would be 20%.

Table 4.1: Incremental Construction for the Green Home

Component	Estimated Incremental Cost ($)	Incremental Cost per Unit Floor Area ($/m^2)
Basement	1,900	8
Framing	2,300	10
Insulation/Air Sealing	2,400	10
Windows/Doors	5,000	22
Roof	5,000	22
Finishes	3,800	17
Plumbing Systems	8,700	38
HVAC Systems	1,000	4
Appliances	2,500	11
Lighting/Electrical	300	1
Landscaping	4,700	20
Total	$37,600	$163/m^2

Not all of the incremental costs were incurred for energy savings. Some of the costs are associated with water conservation, improved indoor air quality and other environmental benefits (e.g., recycled non-toxic materials). The cost breakdown for each of these benefits is as follows:

Energy Efficiency	$13,000.
Water Conservation	$8,100.
Indoor Air Quality	$2,500.
Other Environmental Impacts	$14,000.

The purpose of the Green Home project was to demonstrate the technical feasibility of environmentally-appropriate housing, without the constraint of current product cost. Nevertheless, each building component was carefully chosen, and is cost effective today, or will be when mass produced and familiar to the building community.

5.0 MONITORING RESULTS

5.1 Overview

The Green Home monitoring program consisted of three parts: long-term detailed monitoring, long-term cumulative monitoring and one-time performance tests. A PC-based data acquisition system (DAS) was installed at the Green Home to provide detailed monitoring results. Sixty-two channels were scanned every 60 seconds and performance data stored hourly. System installation and commissioning took place over much of the public demonstration period. The year from July, 1994 to June, 1995 provided the best data set for assessing the house.

In addition to the DAS, 12 kilowatt-hour meters, 2 gas meters and 6 water meters were read manually each month. They provide a permanent record of cumulative electricity, gas and water use. The results from the DAS were compared to the manual readings and the utility bills. There was good agreement between the three sources of data for the total gas, electricity and water consumption. There were a few cases where the energy consumption of individual appliances from the DAS deviated from the manual readings. In these cases, the manual readings were assumed correct and were used in assessment.

The final component of the monitoring program were one-time performance tests of indoor air quality, building airtightness and electro-magnetic radiation.

5.2 House and Equipment Operation

A five-person family (two adults, three young children) took possession of the house in June, 1994. All of the equipment and appliances described in Section 2 remained with the house. The only change in house contents was the replacement of display furnishings with the family's own furnishings.

The homeowners were instructed in the use of the equipment and were sympathetic to the goals of the project. The homeowners used the setback thermostat, with a daytime setting of 22 to 23 °C and a nighttime setting of about 16 °C. The homeowners did not operate the HRV over the summer, preferring instead to leave windows open to obtain outdoor air. The HRV was operated during the heating season, although the homeowners would shut the unit off if they were going out of the house for several hours.

The Green Home and its systems operated reliably over the monitoring period. Nevertheless, several pieces of equipment were changed during the monitoring period. The ceramic top on the gas stove cracked three times and was replaced each time. Monitoring results over the demonstration period indicated that the IHVA operating efficiency was below expectations. A second IHVA prototype was designed and installed in late November, 1994. A water leak occurred in the heat exchanger of the gas-fired water heater. The heater was replaced with a new model in early April, 1995.

The gas fireplace was ordered with electronic ignition; however, a unit with a standing pilot was delivered. Subsequent investigations revealed that although electronic ignition units were available in New York State, only pilot light units are available in Ontario. If the pilot light were lit, it alone would represent 20 % of the annual gas use in this energy-efficient house. Although a fireplace with an electronic ignition was finally delivered in December, 1994, the ignition failed shortly after the unit was installed. The fireplace was not used for the remainder of the monitoring period.

5.3 Weather Data over Monitoring Period

Figure 5.1 shows the monthly average ambient temperatures for the site and for the 30-year average (London, Ontario). In general, the temperatures sets are close. The Green Home site, is, however, slightly warmer in the summer (June and July) and early winter (December and January). On average the site is 1 Celsius degree warmer than the long-term average. This is consistent with Atmospheric Environment Service measurements of 8% fewer degree-days for the Waterloo Region over the same period.

Figure 5.2 shows the total (global) solar radiation incident on a horizontal surface at the building site and the typical meteorological year (TMY) for the Toronto airport. The two curves show the same trend, although the TMY data is higher in the summer months. The total solar radiation measured over the heating season is almost identical to the TMY data. Over the monitoring period the solar radiation at the site was 15% lower than the long-term average.

Figure 5.1

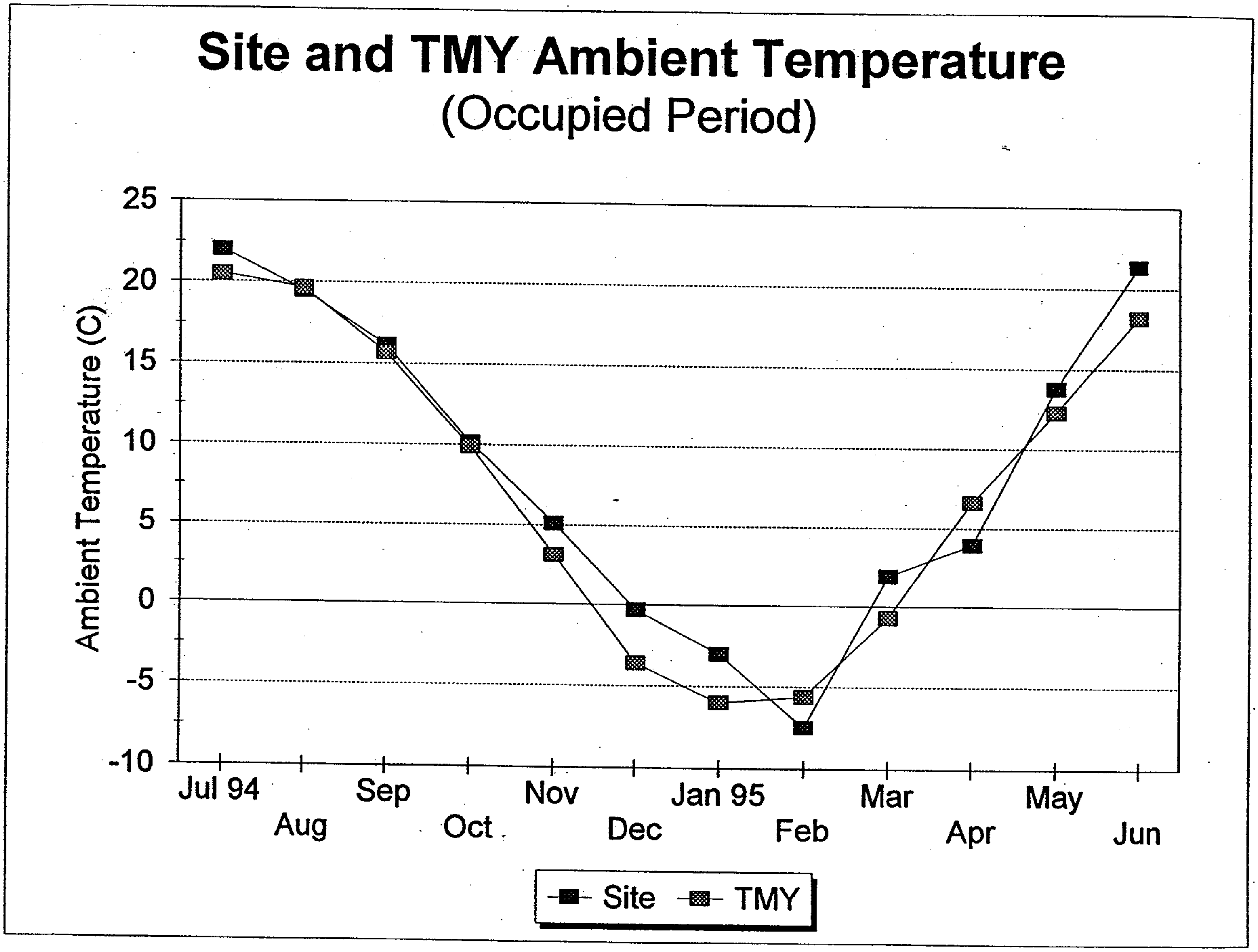
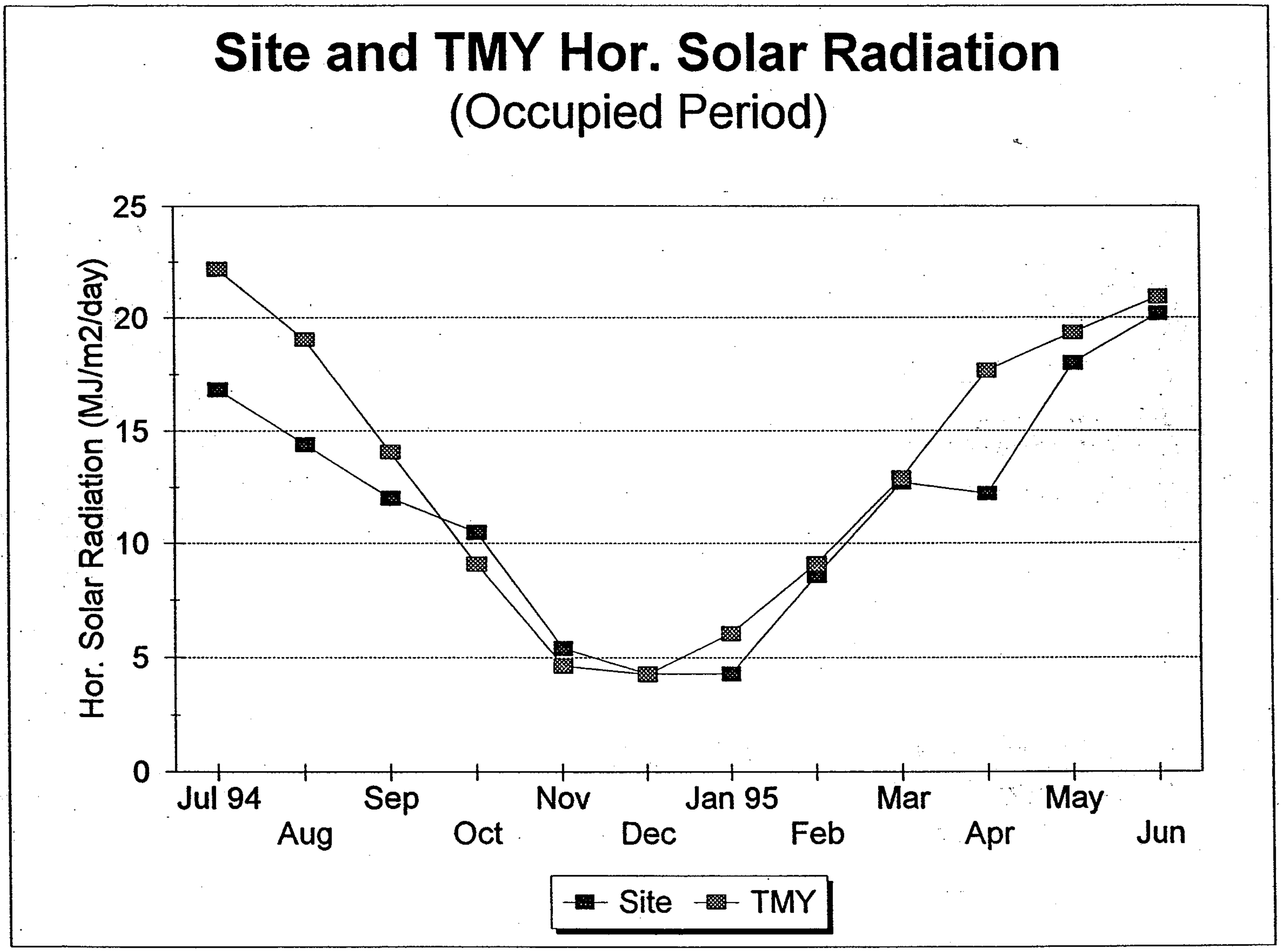

Site and TMY Ambient Temperature
(Occupied Period)
Ambient Temperature (C)
25
20
15
10
5
0
-5
-10
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun
Site
TMY

Figure 5.2


Site and TMY Hor. Solar Radiation
(Occupied Period)
Hor. Solar Radiation (MJ/m2/day)
25
20
15
10
5
0
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun
Site
TMY

5.4 Building Envelope

5.4.1 Building Airtightness and Ventilation

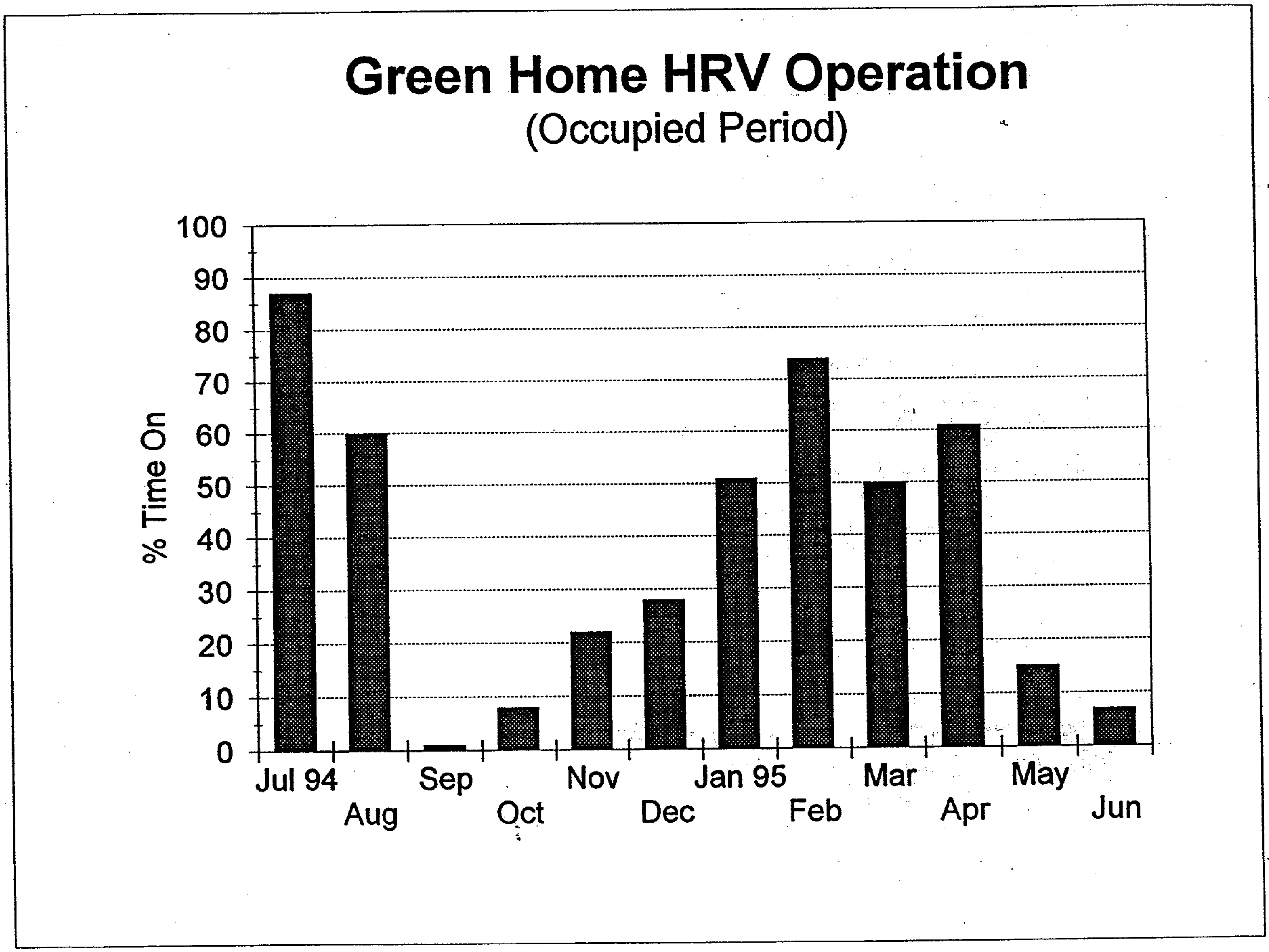
Building airtightness was measured twice during the monitoring period. The first test was performed just after construction completion. The airtightness measurement was 0.8 air changes per hour at 50 Pa, well below the Advanced Houses technical (and R2000) requirement of 1.5 ACH. The second blower door test was performed in March, 1995, almost two years later. The result of 0.94 ACH indicates a slight loosening of the envelope.

As discussed in Section 5.2, the HRV did not operated continuously. The percentage of time the HRV operated over the monitoring period is shown in Figure 5.3. During the first summer, the HRV and cooling system were operated. For the second summer, the HRV was shut-off and windows opened. During the winter, the homeowners turned off the HRV if they were going out for several hours.

The supply and exhaust airflow rates averaged 45 litres/sec during operation, slightly below the 50 litres/sec required by the CAN/CSA F326 standard. The measured flow corresponds to a forced ventilation rate of 0.25 ACH. The natural air change rate at typical pressures is approximately 15 times less than at 50 Pa or approximately 0.05 ACH. Thus, the total building ventilation rate is 0.3 ACH when the HRV is on.

The air change rate was also measured using a system of perfluorocarbon tracer (PFT) sources and passive samplers. The amount of tracer gas that ends up at the sampler is inversely proportional to the air-exchange rate. The first test gave an unusually low reading and contamination of the sampler was suspected. The second test, in August of 1994, gave a more realistic reading of 0.19 ACH. During the test, the HRV was on and windows closed.

Figure 5.3


Green Home HRV Operation
(Occupied Period)
100
90
80
70
60
50
40
30
20
10
0
% Time On
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun

One important concern with respects to the ventilation system was whether the HRV fan could provide sufficient air movement to distribute fresh air to all rooms in the house (without operation of the furnace fan). On February 15, 1995, the airflows at all registers were measured using a Wallec hot-wire anemometer. The total ventilation air flow was 60 litres/sec with the HRV set on high, and 40 litres/sec with the HRV set on low. Although the flows were below the lower threshold of the instruments accurate measuring capacity, each register had a flow of 3 to 9 litres/sec with the HRV on high speed and 2 to 6 litres/sec on low speed.

The test results show that fresh air can be adequately distributed throughout the house using only the HRV fan (assuming proper duct design and joint sealing). Distribution within each room was not measured. It is assumed, however, that distribution takes place through dispersion (as with low velocity displacement ventilation systems) rather than by velocity entrainment as with conventional air system design.

5.4.2 Indoor Air Quality

Formaldehyde, radon, VOCs and particulate concentrations were measured in November 1993, during the demonstration period. Formaldehyde levels were 0.03 ppm, well below the Canadian guideline of 0.1 ppm. The radon concentration was measured at 0.003 working level units (WLU), again well below the conservative U.S. guideline 0.02 WLU. The VOC concentration of 0.18 mg/m^3 is approximately half the European guideline of 0.3 units. These readings were among the lowest values in all Canadian Advanced Houses [Ortech, 1994].

The airborne particulate reading was 92 micro-grams/m^3, higher than some of the other Advanced Houses; it is attributed to the high outdoor particulate levels generated by nearby house construction.

The indoor air quality measurements were repeated in August 1994, after the homeowners had moved into the house. The formaldehyde reading tripled to 0.09 ppm, although still below the Canadian guideline. The higher reading is attributed to the replacement of display furnishings by the homeowners furnishings, some of which was manufactured from particleboard. Likewise, the VOC concentration was 45 % higher than the previous reading at 0.26 mg/m^3. The radon concentration was only slightly higher at 0.004 WLU.

The airborne particulate reading decreased by 75% to 22 micro-grams/m^3, presumably due to less nearby construction activity.

Carbon dioxide (CO_2) was measured continuously in the Green Home from mid-January 1995 to the end of August,1995. CO_2 is produced by people and can provide an indirect measure of ventilation effectiveness. The monthly average values ranged from a high of 685 ppm in January to a low of 218 ppm in July. The maximum daily average reading was 869 ppm. ASHRAE Standard 62 recommends a limit of 1,000 ppm to satisfy comfort criteria i.e., to limit odour build-up [ASHRAE, 1989], and thus the ventilation system as designed and operated in the Green Home provided adequate fresh air.

Detector tube tests were conducted to measure carbon monoxide (CO), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2). The tests were performed in January 1994. No detectable levels of any of these three gases were found at the supply registers while the furnace was operating.

The Advanced Houses technical requirements mandated a minimum indoor relative humidity of 30%. A humidifier was to be installed if required. In the Green Home the IHVA transfers moisture as well as heat from the outgoing stale air. Indoor humidity was measured continuously in the stale air stream of the HRV. The monthly average relative humidity was above 40% all winter. The minimum daily average humidity was 35%. Thus, the IHVA appears to be effective in maintaining adequate humidity levels in the house.

Electromagnetic radiation was measured at the Green Home in October 1993 using a Electric Field Measurement (brand) Gauss Meter. The recommended safe levels of electromagnetic radiation cover a wide range from 3 mGauss to 2,000 mGauss, depending on the authority cited. Average measurements in typical housing today is approximately 2 to 3 mGauss.

Throughout the Green Home the vast majority of measurements were well below 1 mGauss. The electronic ballasts used in the fluorescent fixtures and the low currents required for the energy-efficient appliances are two reasons for the low readings. There were a few locations where the readings were above 3 mGauss. Generally, these were not areas where people spent extended periods of time. Table 5.1 summarizes the electro-magnetic field readings.

Table 5.1: Electro-Magnetic Field Readings at the Green Home

Location	mGauss Reading Touching the Device	mGauss Reading 300 mm from the Device
Living Spaces	< 1	< 1
Microwave Oven	1,200	70
Compact Fluorescent	90	0.2
Electric Panel	76	3 to 10
Damper Motor[1]	30,000	10

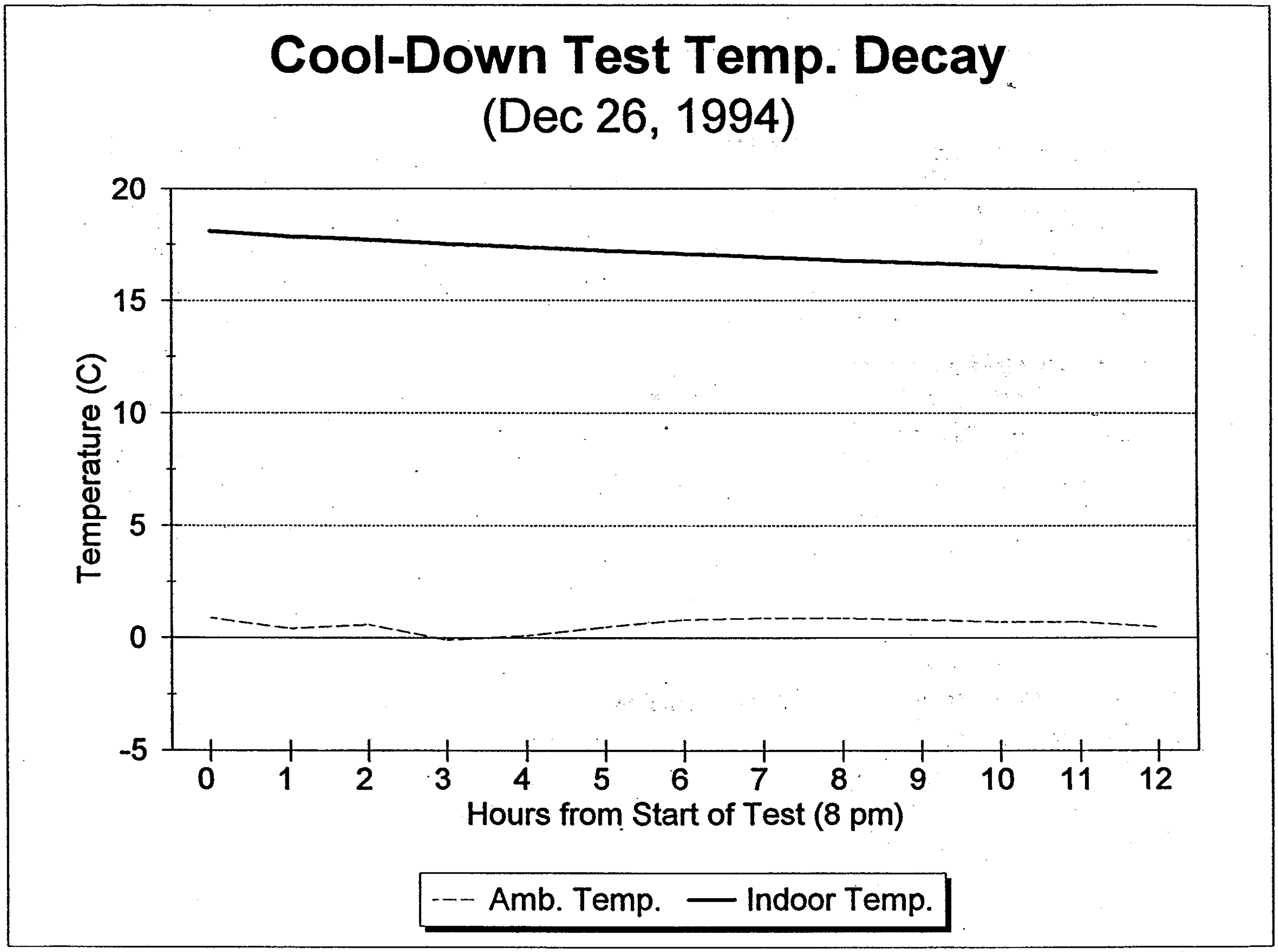
[1] - this damper has been since replaced by one that does not need a motor

5.4.3 Building Time Constant

The building time constant is a measure of how quickly the house air temperature falls in the absence of heat sources and is related to the ratio of the building heat loss coefficient to building thermal mass. Since the thermal mass of most wood frame housing is similar, it is also a good indicator of the energy efficiency of the building shell.

Figure 5.4 is a plot of actual indoor and outdoor temperatures over a 12-hour period from 8 p.m. December 26 to 8 am December 27, 1995. During this time the occupants were away, the IHVA was turned off and internal heat sources were only 410 Watts. The indoor air temperature fell less than 2 Celsius degrees over the twelve hours. A time constant (based on the slope of the indoor temperature line) of 80 hours was calculated for the house when internal heat sources were accounted for. This compares favourably with the time constant of 74 hours calculated using the ENERPASS simulation. Therefore, the building shell appears to performing as designed.

Figure 5.4


Cool-Down Test Temp. Decay
(Dec 26, 1994)
20
15
10
5
0
-5
Temperature (C)
0
1
2
3
4
5
6
7
8
9
10
11
12
Hours from Start of Test (8 pm)
Amb. Temp.
Indoor Temp.

5.5 Total Energy Use

Total house energy use is listed in Table 5.2 and illustrated in Figure 5.5 for the period July, 1994 to June 1995. Total energy consumption is 14,987 kWh or 65 kWh/m^2. Low cost natural gas accounts for over 70% of the total house energy use. Electricity use is only 11.9 kWh/day, significantly lower than the 24 to 30 kWh/day, typical of a conventional home. (Note: the monitoring system consumed 876 kWh of electricity but this has been excluded from the total.)

The total annual energy use is 25% higher than predicted, but only 7% higher than the Advanced Houses energy target. Nevertheless, this still represents 65% less energy use than a conventional new house. The difference between predicted and actual energy consumption is due to higher than expected use of natural gas for space and water heating. Possible reasons for this situation are discussed in Sections 5.6 and 5.7.

Although total electrical energy use is close to predicted values, there are significant variations within specific categories. The electricity use for outdoor loads and plug loads was higher than expected, while electricity use for fans was lower than predicted. The reasons for these discrepancies are discussed in Sections 5.8 to 5.10. Figure 5.6 shows the monthly breakdown of electricity use. Electricity use is fairly constant over the year. Electricity use does peak in the winter because of higher fan energy use for space heating. The peak electricity demand occurred on January 16, 1995 at 8:50 a.m. and was only 4.6 kW. This is less than the power draw of either an electric water heater or dryer and is half the peak demand of the Brampton Advanced House (Enermodal, 1992b).

Figure 5.5

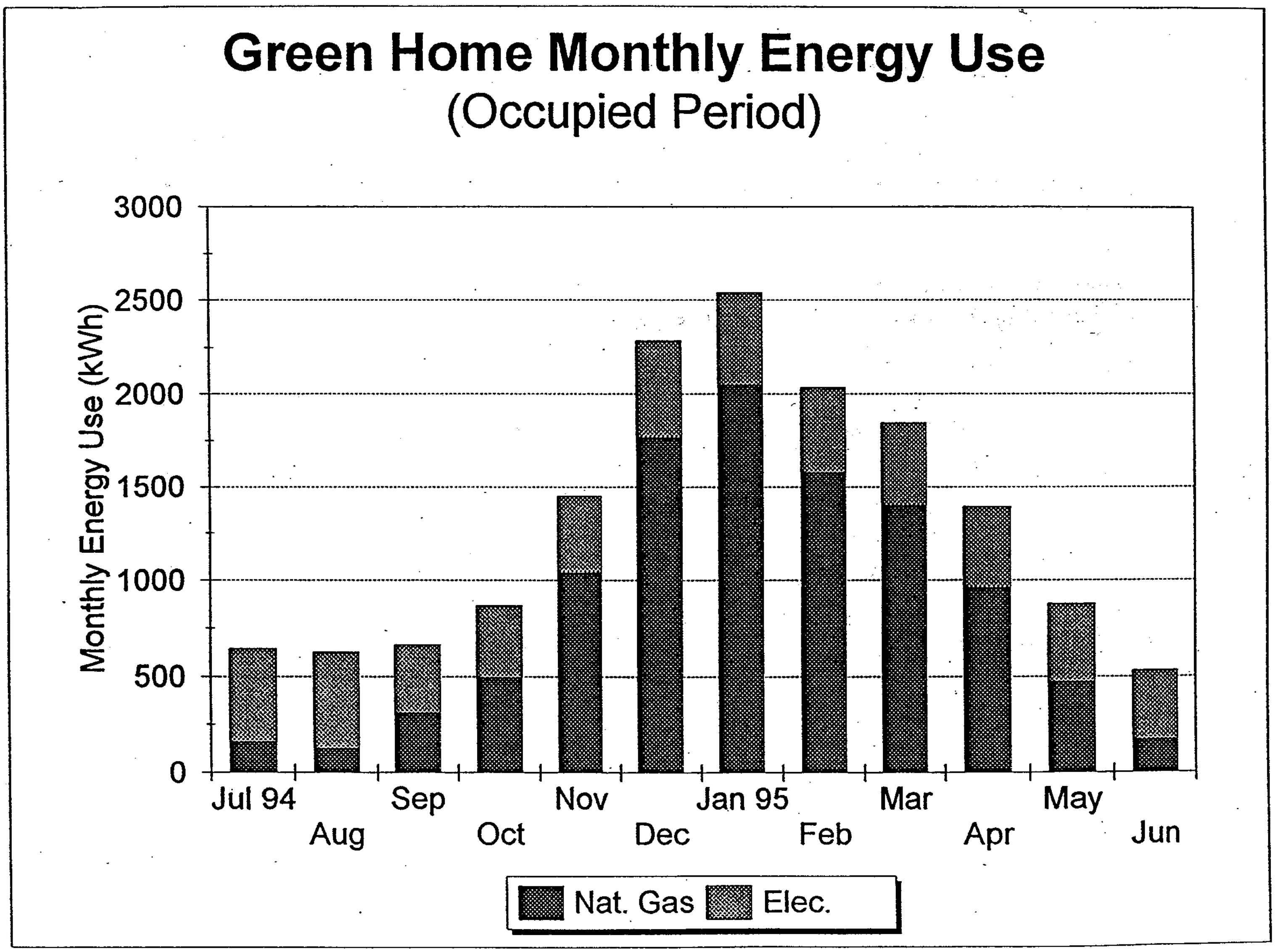

Green Home Monthly Energy Use
(Occupied Period)
Monthly Energy Use (kWh)
3000
2500
2000
1500
1000
500
0
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun
Nat. Gas
Elec.

Figure 5.6

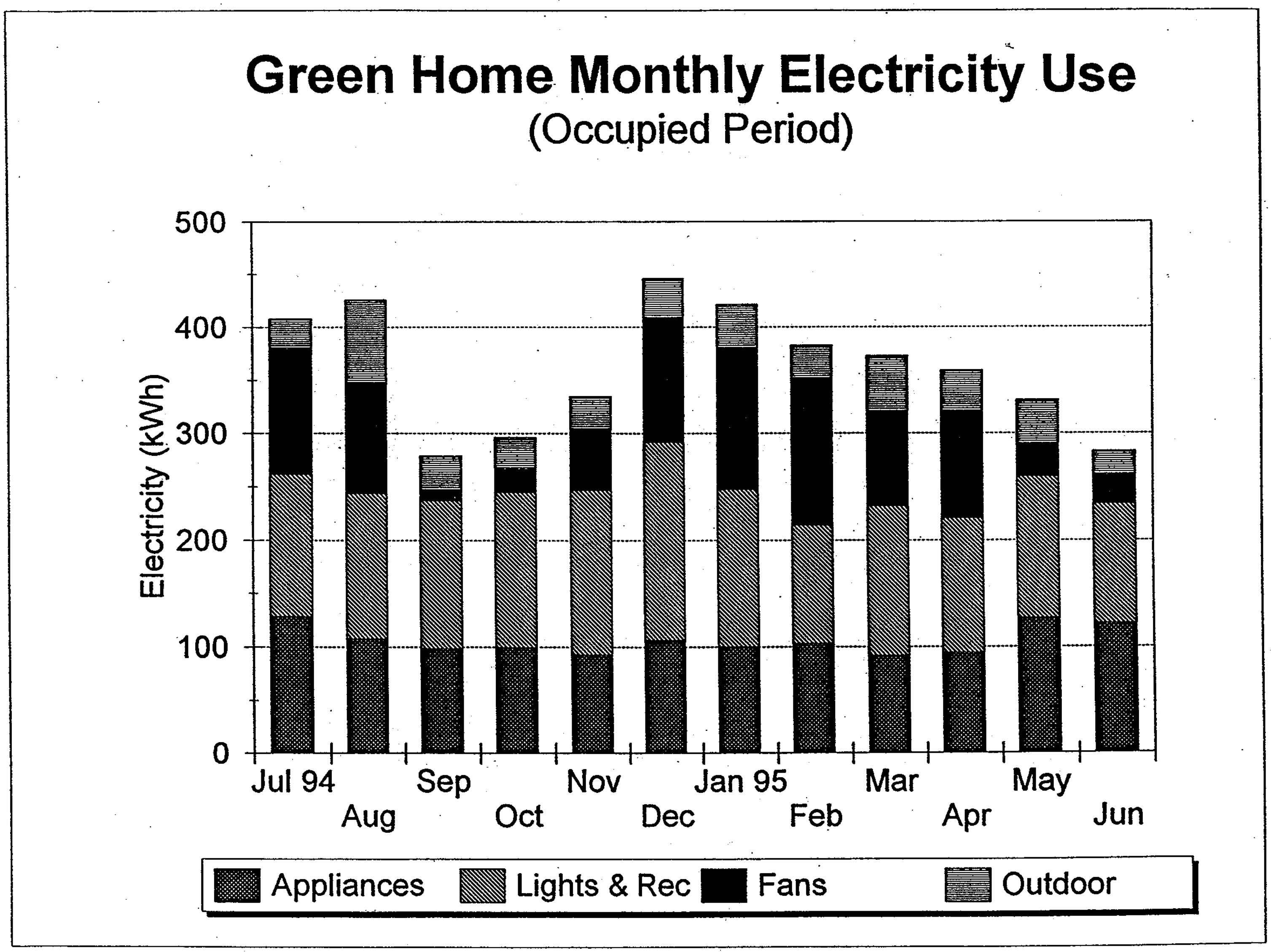

Green Home Monthly Electricity Use
(Occupied Period)
Electricity (kWh)
500
400
300
200
100
0
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun
Appliances
Lights & Rec
Fans
Outdoor

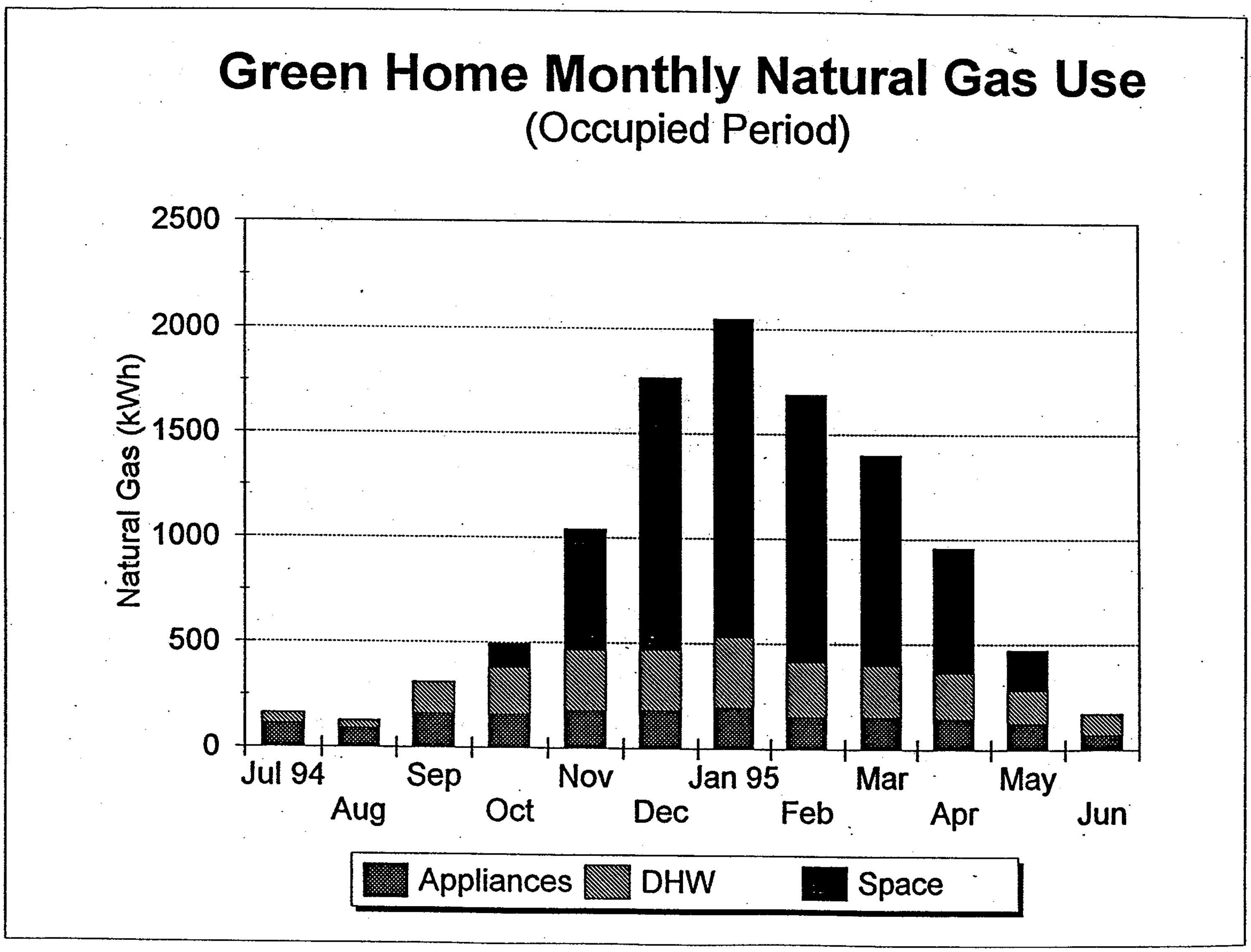
Table 5.2 Comparison of Predicted and Monitored Annual Energy Use

Energy Use	Predicted		Monitored	
	Elec. (kWh)	Gas (kWh)	Elec. (kWh)	Gas (kWh)
Space Heating	-	5,282	-	6,582
Water Heating	-	977	-	2,321
Gas Appliances	-	1,586	-	1,744
Electrical Appliances	1,200	-	1,384	-
Plug Loads	546	-	1,137	-
Indoor Lighting	479	-	540	-
Outdoor Loads	20	-	457	-
Pumps/Fans	1,845	-	822	-
Total	4,090	7,845	4,340	10,647
TOTAL	11,935		14,987	

5.6 Space Heating and Cooling

The total space-heating energy consumption over the monitoring period was 627 cubic metres of natural gas or the equivalent of 6,582 kWh. At current natural gas prices ($0.18/m^3), the annual cost for space heating is only $113 or less than $10 per month. The monthly distribution of natural gas use is shown in Figure 5.7. Space heating accounts for 62% of the natural gas use, most of which occurs from December through March.

Figure 5.7


Green Home Monthly Natural Gas Use
(Occupied Period)
Natural Gas (kWh)
2500
2000
1500
1000
500
0
Jul 94
Aug
Sep
Oct
Nov
Dec
Jan 95
Feb
Mar
Apr
May
Jun
Appliances
DHW
Space

Space heating energy use is 25% higher than expected. The primary reason appears to be the IHVA, which had lower than expected efficiency. The combined efficiency of this unit is defined as useful heat out divided by total energy available, or

$$\text{Efficiency} = \frac{\text{Heat transferred to building air and supply air}}{\text{Gas Use + Fan Energy + supply air flow*(inside temp-outside temp)}}$$

Using the above formula, a condensing gas furnace with a 350 to 600 Watt fan and a separate HRV (of 70% seasonal efficiency) would have a combined efficiency of between 75% and 80%. Based on testing of earlier prototypes by the Canadian Gas Research Institute (CGRI), a combined efficiency of 85% was predicted for the IHVA. The average monitored combined efficiency was only 65%. The 20 percentage-point difference in efficiency corresponds to a 30% increase in energy consumption.

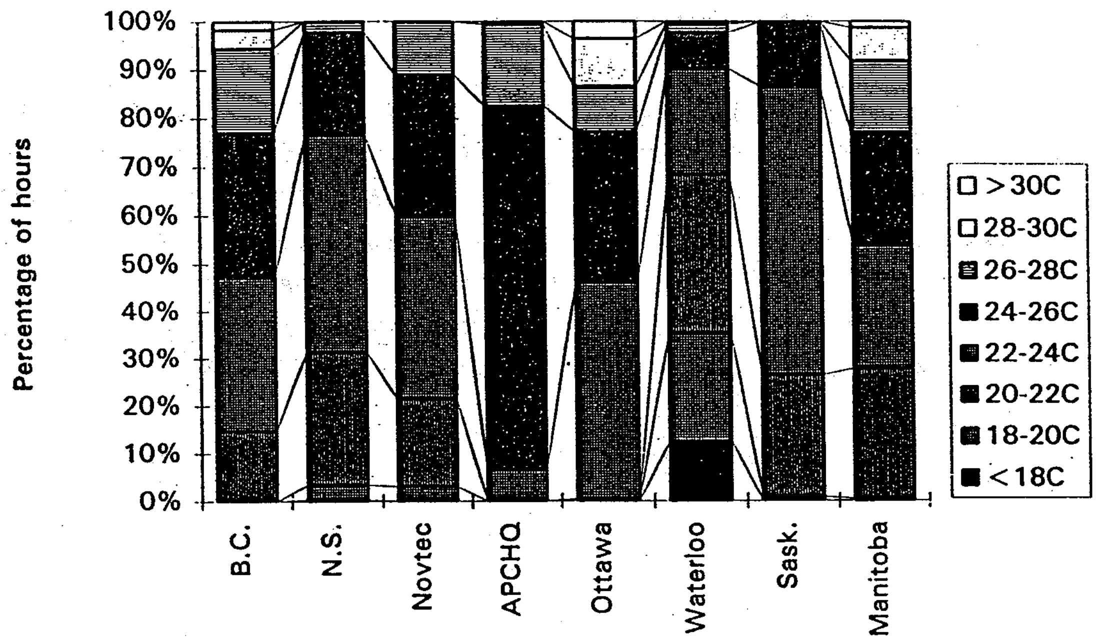
Given that the total increase in space heating energy can be attributed to the furnace/HRV efficiency, this implies that the building shell heat loss must be close to predictions.

The homeowners operated the cooling system for the month of June 1994, but found that it contributed little cooling to the house and required the continual operation of the furnace fan. According to monitored results, the cooling system delivered 1.2 kW of cooling to the space -- a 2.9 C° drop in air temperature across the cooling coil at a flow of 350 litres/s. The cooling system was shut-off for the remainder of the summer.

Despite the limited mechanical cooling, the Green Home seldom overheated during the summer. The average main-floor temperature for the period May to September 1994 was 20.8 °C, with a maximum temperature of 28.2 °C. Ninety-eight percent of the time the main floor temperature was below 26 °C. Although having the hottest summer, the Green Home stayed the coolest of all the Advanced Houses (see Figure 5.8). The passive cooling features (which included high insulation levels, high-performance windows, wide overhangs and clerestory windows for venting), were successful in reducing the need for mechanical cooling.

Figure 5.8: Main Floor (South) Temperature Frequency Distribution

(Source: Natural Resources Canada Advanced House Monitoring Comparative Result prepared by Ken Cooper, SAR Engineering, 1995.)



	B.C.	N.S.	Novtec	APCHQ	Ottawa	Waterloo	Sask.	Manitoba
Summer: May-Sep								
Avg. (C)	24.3	22.8	23.5	25.1	24.8	20.8	22.2	24.0
Min. (C)	20.2	15.4	18.1	22.4	21.7	11.9	18.9	16.8
Max. (C)	31.7	27.7	27.7	29.3	30.2	28.2	24.8	36.9
Percentage of hours								
<18C	0%	0%	0%	0%	0%	13%	0%	0%
18-20C	0%	3%	3%	0%	0%	23%	1%	0%
20-22C	15%	28%	18%	0%	1%	33%	26%	27%
22-24C	33%	45%	38%	6%	46%	22%	60%	26%
24-26C	29%	21%	29%	76%	31%	7%	13%	23%
26-28C	17%	2%	11%	17%	9%	2%	0%	15%
28-30C	4%	0%	0%	1%	10%	0%	0%	7%
>30C	2%	0%	0%	0%	4%	0%	0%	1%
%Complete	82%	89%	67%	64%	13%	99%	85%	54%

5.7 Water Loads

5.7.1 Water Consumption

Table 5.3 compares the predicted and monitored water use. The total annual water consumption was 292 litres per day, of which 93 litres was rainwater from the cistern. Thus, the purchased water supply was only 183 litres per day, a 73% reduction over conventional housing. The monitored values are slightly higher than the predicted values, in part because the predicted values were based on a four-person family and the monitored values are for a five-person family.

The 12,000 litre cistern supplied almost 40,000 litres of water to the house annually. Only once did the cistern require city water; in September 5,700 litres of city water was used. Thus, 34,000 litres of rainwater was supplied to the house for toilets, yard watering and clothes washing. Rainwater met 32% of the total water needs and 50% of the cold water use. Because of the cistern's capacity only about one quarter of the volume is used monthly. The additional capacity allows for storage during extended dry periods. During times of heavier rain, an overflow allows excess water to spill into the storm sewers.

Table 5.3 Predicted and Monitored Daily Water Use (in litres/day)

Water Use	Predicted	Monitored
Total	248	292
Cistern Supply	80	93
City Supply	168	183
Hot Water	75	108

5.7.2 Water Heating

The total hot water demand was 108 litres per day, a 55% reduction over a conventional house. The average hot water delivery temperature was 59 °C. The lower water use is particularly impressive when one considers that it is difficult to reduce hot water consumption for requirements such as bathing and hand washing. The monitored value is higher than the predicted value because of the family size (5 people instead of 4).

Total energy used for water heating was 3,114 kWh per year, of which tank losses account for an estimated 25%. The solar DHW system provided 1,318 kWh or 3.6 kWh/day of heat over the year, or 42% of the water heating load. This performance is similar to the results obtained from monitoring approximately 40 solar DHW systems [Enermodal, 1995]. These systems provide 3.8 kWh/day of heat for houses with similar water loads. The Green Home system was expected to provide a higher solar fraction because of its single large storage tank which allowed the solar system to meet some of the back-up tank losses.

A natural-gas fired boiler met the remainder of the water heating load. This unit mounts on a wall with ABS plastic pipes ducted outdoors for combustion air supply and flue gas exhaust. The unit had a seasonal combustion efficiency of 77% (this does not include any tank losses). The energy factor (which includes tank heat losses) was 72%, much higher than the 59% typical of conventional gas-fired water heaters. The water heater requires 155 Watts to power a circulating pump and exhaust fan when in heating mode.

5.8 Fan Energy

The IHVA consumed 822 kWh in electricity over the one-year monitoring period. Electricity is required in this unit for the furnace fan motor, the HRV fan motor and miscellaneous controls, shuttle valves and vent fan. The furnace fan is a standard, forward-curved, stamped-steel centrifugal fan. The furnace fan motor is an electronically-commutated direct current type. The HRV uses two centrifugal fans driven by a single standard P.S.C. motor. The vent fan uses a low-efficiency shaded pole motor.

During operation, the furnace fan delivers 320 litres/sec at a power consumption of only 134 Watts, one third the value of a conventional fan/motor combination. The furnace fan consumed only 150 kWh. over the year. The HRV fans, although moving 60 % less air, consumed 82 % more electricity when on high speed, or 244 Watts. Over the year the

HRV electricity consumption was 580 kWh, almost four times that of the furnace fan. Miscellaneous energy uses account for the remaining 122 kWh.

5.9 Appliances

Table 5.3 lists the predicted and monitored appliance energy consumption. In general, there is good agreement between the two sets of data.

The only significant discrepancy in electricity use is the gas stove. The gas stove was a prototype sealed-combustion unit. A conventional gas stove was modified to include a ceramic counter top and blower system to bring in outdoor air for combustion and exhaust combustion products to the outdoors. The stove gas consumption is close to initial predictions, but the stove's electricity consumption is surprisingly high, almost 0.4 kWh/day. This is because the igniter (450 Watts) runs continuously when the oven is on and the purge fan (50 Watts) runs for over ten minutes when the stove is shut off.

Table 5.3: Predicted and Monitored Appliance Annual Energy Consumption

Appliance	Predicted		Monitored	
	Elec. (kWh)	Gas (kWh)	Elec. (kWh)	Gas (kWh)
Refrigerator/Freezer	840	-	950	-
Stove	13	1040	125	1,258
Clothes Washer[1]	119	-	120	-
Clothes Dryer	30	546	32	486[2]
Dishwasher[1]	198	-	157	-
Total	1,200	1,586	1,384	1,744
Total (all fuels)	2,786		3,128	

[1]- values are for electrical use only, water heating requirements are excluded
[2]- estimated from electricity use

5.10 Lighting and Plug Loads

The monitored energy use for lighting and plug loads was 2,134 kWh, twice the amount that was predicted (see Table 5.4). Installed indoor lighting was close to the predicted value. (Plug-in lamps would show up as a plug load.) The total installed lighting load was 5 Watts/m^2 lower than the Advanced Houses target of 8 Watts/m^2.

The difference in predicted and actual plug loads is due to the transformer that converts the 120 Volt supply to 240 Volt for the European refrigerator (0.5 kWh/day) and an underestimation of miscellaneous energy use (value was taken from the Advanced House Guidelines). The high outdoor load is attributed to the sump pump that ran almost continuously in the spring.

Table 5.4 Predicted and Monitored Lighting and Plug Loads

Electricity Use	Predicted	Monitored
Plug Loads	546	1,137
Indoor Lighting	479	540
Outdoor Loads	20	457
Total	1045	2134

6.0 LESSONS LEARNED

Design, construction and monitoring of the Green Home was a three year process. Each of these phases provided an opportunity to assess the Green Home technologies. The Green Home was also a demonstration project and public response provided feedback on the consumer acceptance of these technologies. Public and homeowner reaction to the Green Home is summarized in Appendix A. The following describes the lessons learned from the Green Home project.

High-Insulation Levels Can Be Achieved with Fewer Structural Materials

Conventional wisdom states that to achieve a better insulated envelope, a thicker wall with more structural members (e.g., double-stud wall) is necessary. The Green Home wall system, composed of wooden I-beams, has twice the insulation level of conventional houses, but uses one third less wood. Likewise, the precast basement wall system used 50% less concrete than a typical basement wall. The waffle cavity was filled with insulation so that the overall thickness was similar to that of a conventional wall but, with three times the insulation level.

High-Performance Windows Offer More Than Just Energy Savings

The windows in the Green Home are triple-glazed with two low-e coatings, argon gas fill and silicone foam edge spacer mounted in an insulated pultruded fibreglass frame. Visitors were impressed with how warm they felt standing beside the windows, even on the coldest day of the year (-25°C). Throughout the one year of demonstration, the indoor relative humidity was above 30% and condensation was never observed on the windows. There were no cold drafts in the house even though no heating registers were placed under the windows. (In a typical home, registers are placed under windows to prevent drafts,)

High-Quality Recycled and Reused Materials Readily Available

There was a desire to incorporate recycled and reused materials in the Green Home as one approach to dealing with "waste" and to lower the embodied energy of the house. At the beginning of the project, there were concerns about the availability of products and their quality. With only modest effort, dozens of recycled and reused materials were located: insulation from newspapers, siding from wood wastes, tiles from crushed glass, carpet from PET bottles, salvaged hardwood floors and reglazed bathroom fixtures. Without exception the reused and recycled materials were found to be equal or superior in quality, durability and appearance to conventional construction materials.

IAQ Can Be Improved Through Careful Material Selection

Each material and product in the Green Home was carefully evaluated as to its potential for off-gassing. Indoor air quality measurement results show that Green Home pollutant concentrations were far below the most stringent regulations in the world. The formaldehyde concentration of the house tripled (although still below the guidelines) when the Green Home furnishings were replaced with the homeowners furniture.

Ground Loop Cooling Presents Difficulties

Mechanical cooling was provided by circulating cistern water through plastic tubing buried below and around the foundation and through a coil in the air-handling system. Installation of the ground loop presented several problems. First, because contractors were not familiar with the system, constant supervision was required to ensure proper installation. Second, the piping was ruptured (and subsequently repaired) several times during construction. When the system was commissioned, it was discovered that one of the three cooling loops was broken and had to be isolated. The monitoring showed that the cooling output was modest (2 kW), and did little to lower the house temperature. In conclusion, ground loop cooling is not recommended, however, passive cooling techniques appear to be effective.

Wide Range of High-Efficiency Gas Technologies Available

Natural gas fired equipment and appliances were favoured over electric devices because of the lower CO_2 emissions of natural gas (compared to coal-fired power plants). Natural gas devices are often viewed as a basic and static technology, yet six high-efficiency and innovative gas appliances were installed and monitored in the Green Home. Innovative technologies included an integrated heating ventilating appliance (IHVA), sealed combustion gas stove, and wall-mounted, direct-vent water heater.

Gas Appliances Can Have Hidden Energy Consumption

The total energy performance of two of the gas appliances warrant comment: gas stove and fireplace. The stove gas consumption was very close to initial predictions, but the stove's average electricity consumption was surprisingly high at 0.4 kWh/day. It was found that the igniter runs continuously when the oven is on and the purge fan runs for over ten minutes after the stove is shut off. There are no ENERGUIDE ratings for gas stoves presumably because it is thought that they use little electricity, an assumption that is not true in this case.

The gas fireplace was chosen as an efficient heating source. Although originally ordered with an electronic ignition, the fireplace was delivered with a standing pilot lighter -- standard practice in the Ontario market. If the pilot light were lit, it alone would represent 20% of the annual gas use in this energy-efficient house.

Major Reductions in Water Use Are Possible

Using building energy analysis programs, it is relatively easy to estimate reductions in building energy use from conservation measures. The effectiveness of water conservation measures is not as easily predicted. A somewhat arbitrary goal of a 70 % reduction was set. The monitoring showed that at least a 73% reduction was achieved compared to a typical 4-person family and 85% compared to the average five-person family.

Electronically Commutated Motor Provides Large Electrical Savings

It was expected that fans would be the largest consumer of electricity in the house. The monitored fan energy use was, however, only 50% of the predicted value. The electricity savings were due to two factors: operation of the fans only when necessary and the electronically commutated motor retrofit into the furnace fan. The furnace fan uses only 134 Watts at full speed -- one third that of fans with conventional motors.

Miscellaneous Loads Add Up To Major Electricity Use

Most experts consider miscellaneous electrical loads (i.e., minor appliances and lights) to be small. The Advanced House technical requirements suggested a value 546 kWh per year. The actual consumption was over twice this value. The energy requirements of the various electrical devices, even those that appear to be off (e.g., VCR digital displays, instant-on TV's) add up to a significant electrical load. The sump pump, which was installed as a rarely-to-be-used safety feature, consumed several hundred kilowatt-hours annually.

Significant Reductions in Environmental Impact Can Be Achieved

The largest unknown at the beginning of the project was whether a house could be built that had a much lower impact on the environment than a conventional house. Detailed monitoring and analysis have shown positive results with the following reductions in environmental impact compared to conventional new housing:

- 65 % reduction in purchased energy,
- 33 % reduction in embodied energy (based on the wall system),
- 73 % reduction in purchased water,
- 99 % reduction in use of ozone-depleting chemicals, and
- 98 % reduction in waste sent to landfill.

Public/Private Demonstration Programs Are Effective Technology Transfer Activities

The cooperation of the public and private sectors resulted in a successful and high-profile demonstration project. Already some of the benefits are being seen. The requirements of the R-2000 program have been upgraded to include some of the Advanced House requirements. Many leading-edge builders are incorporating Advanced House technologies into their housing. Engineered wood products are becoming the floor system of choice, fibreglass windows are seeing dramatic increases in market share, and the wall-mounted water heater is available for lease from natural gas utilities.

7.0 CONCLUSIONS

The Waterloo Region Green Home was designed to be energy efficient, environmentally responsible and meet the requirements of the Advanced Houses program. The house was expected to require only 30% of the energy and water of a conventional new house.

Tests and monitoring show that the building envelope meets or exceeds design requirements. The airtightness was measured at 0.8 ACH at 50 Pa, almost half the design requirement of 1.5 ACH. The building space heating load met the design predictions. Formaldehyde, radon and VOC concentrations are significantly below the most stringent guidelines in the world.

Total energy use was 14,987 kWh or 65 kWh per square metre of floor area (natural gas use is converted to equivalent kWh). Although the energy use was 25% higher than predicted, it was within 8% of the Advanced Houses target and represents a 65% reduction over energy use in conventional new housing. The increased energy use is attributed to three main factors: lower than predicted integrated heating ventilating appliance efficiency (IHVA), higher than predicted back-up water heating requirements and high plug loads. The IHVA had a seasonal efficiency of 65%, lower than the design value of 85%.

The total demand for city water was only 183 litres per day, 73% lower than conventional housing. The cistern provided half of the cold water used in the house. The five-person family consumed 108 litres per day of hot water, higher than the design value (based on a four-person family).

Furnace and HRV fan energy consumption was only 830 kWh per year, half the design value. The low use is attributed to the efficient ECM furnace fan motor and only operating the fans during the heating season. The electricity used for appliances, and lighting was close to design values. The plug loads and outdoor loads were higher than expected because of a transformer required to operate the European refrigerators and a sump pump which ran almost continuously during the spring.

The Green Home has demonstrated that houses can be built that have a much lower impact on the environment than conventional housing. Detailed monitoring and analysis has revealed the following reductions in environmental impact compared to conventional new housing:

- 65 % reduction in purchased energy,
- 33 % reduction in embodied energy (based on an analysis of the wall system),
- 73 % reduction in purchased water,
- 99 % reduction in use of ozone-depleting chemicals, and
- 98 % reduction in waste sent to landfill.

8.0 REFERENCES

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Appendix A: Waterloo Region Green Home Drawings

Figure A.1: Upper floor plan **Scale 1:100**

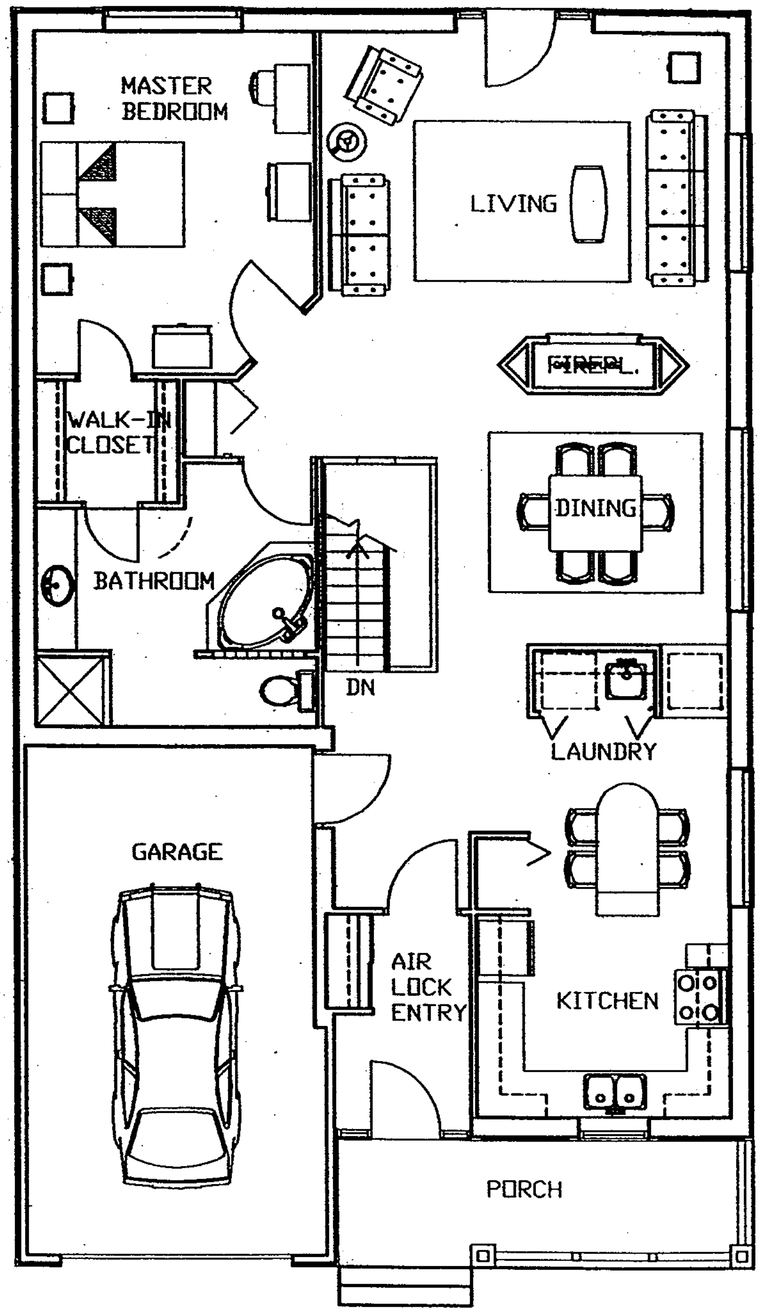


Figure A.2: Lower floor plan **Scale 1:100**

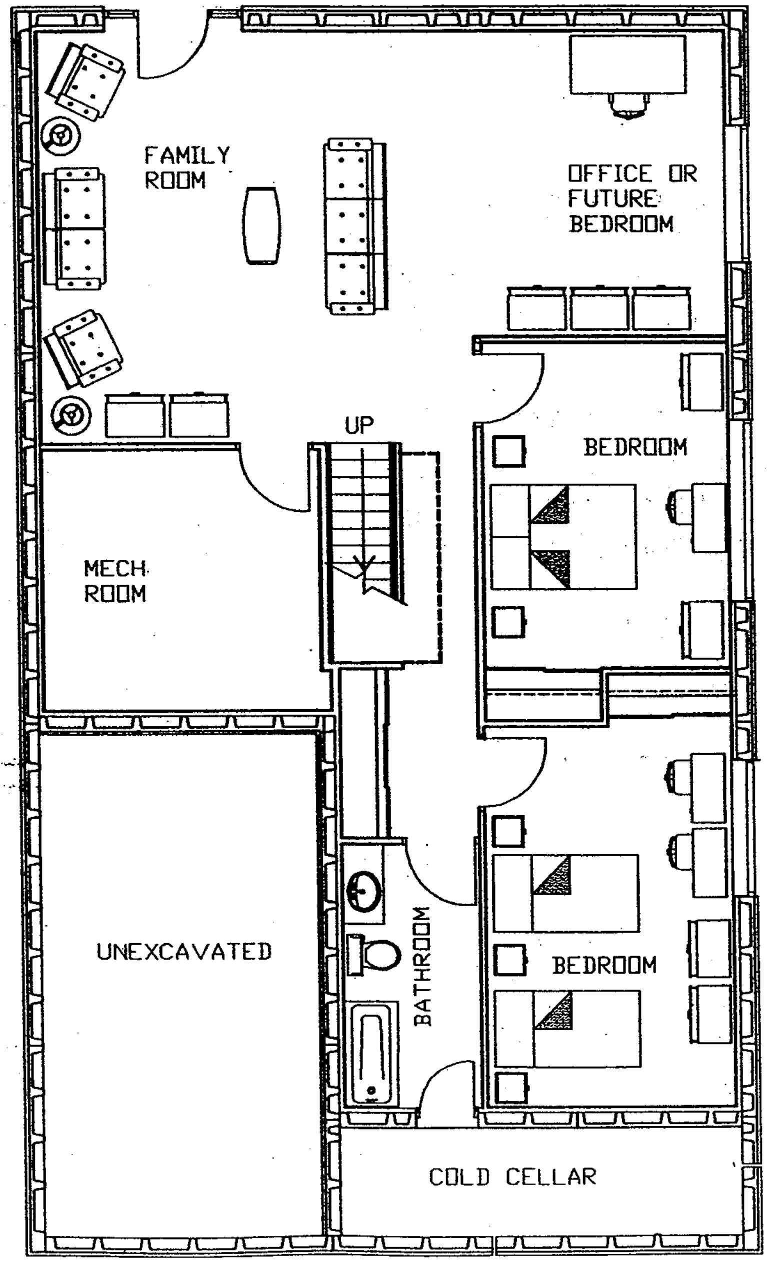
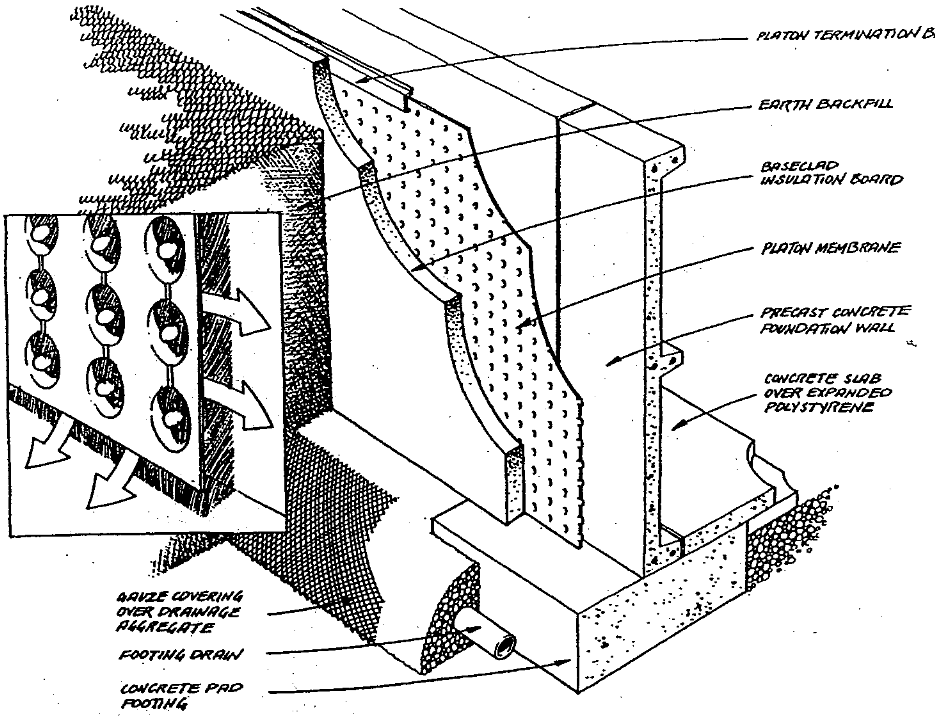
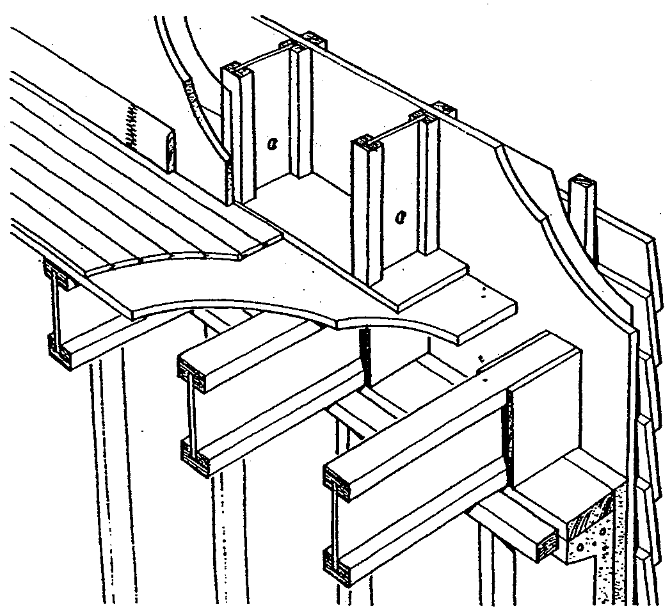


Figure A.3: Foundation Detail



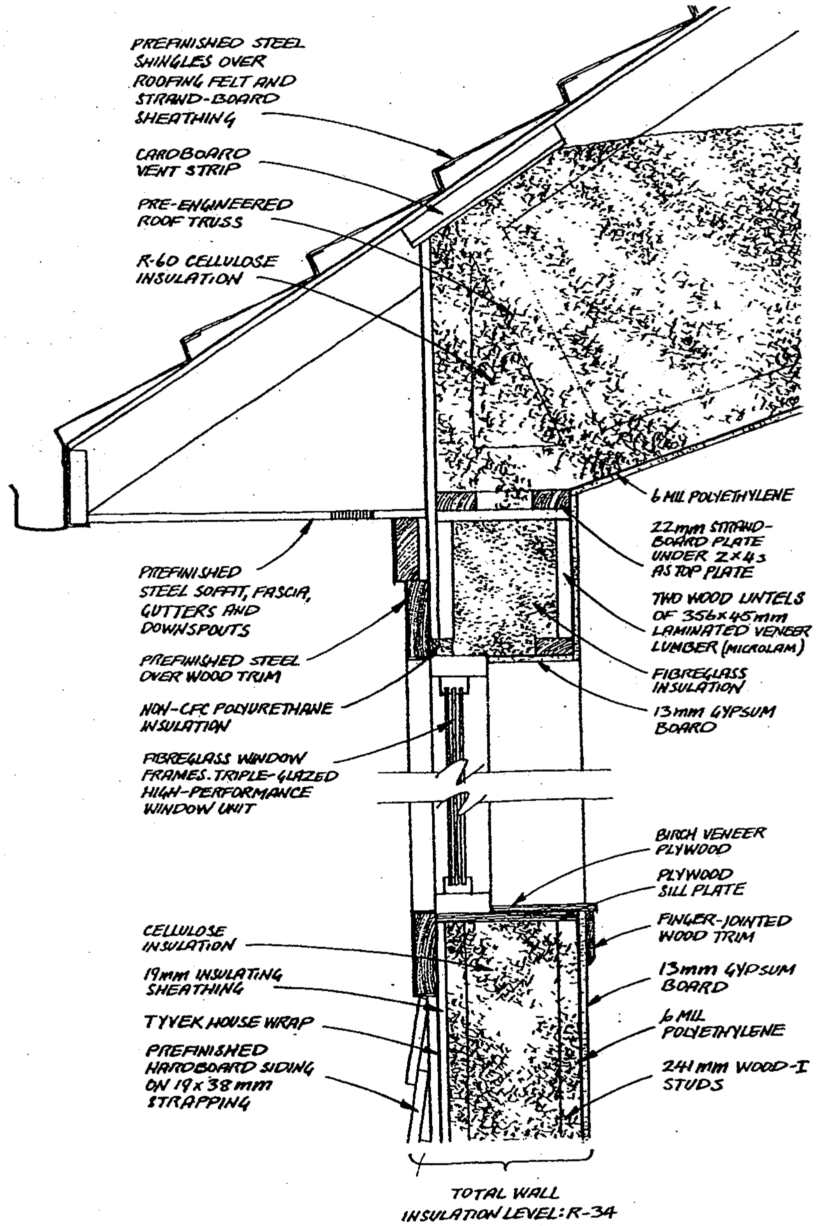
(Illustration courtesy of 'Green Home', by Wayne Grady, Camden House Publishing, 1993)

Figure A.4: Intermediate Floor/Wall Junction



(Illustration courtesy of 'Green Home', by Wayne Grady, Camden House Publishing, 1993)

Figure A.5: Window/Wall Junction



(Illustration courtesy of 'Green Home', by Wayne Grady, Camden House Publishing, 1993)

Appendix B: Communication Activities

B.1 PROMOTIONAL ACTIVITIES

Grand Opening

The Waterloo Region Green Home had its Grand Opening on April 25, 1993 from 12:30 - 5:00 p.m.. Local suppliers were on hand to provide product information and members of the Green Home design team conducted tours of the house throughout the afternoon. Union Gas supplied free hot dogs and drinks. Chevy and the Hubcaps performed 50's music and the Beirdo Brothers provided entertainment for the kids. By the end of opening day, a total of 1900 people had visited the Green Home.

Open House

The Green Home operated as an open house from April 25, 1993 to May 1, 1994. It was open to the public weekly. Hours of operation were as follows:

Monday	by appointment only
Tuesday	by appointment only
Wednesday	10:00 - 5:00
Thursday	10:00 - 8:00
Friday	10:00 - 5:00
Saturday	10:00 - 5:00
Sunday	10:00 - 5:00

The house was staffed by co-op students from the University of Waterloo, each for a four month period. The students were responsible for soliciting school, community and other groups, as well as co-ordinating and conducting tours. Tours were also conducted by members of the design team. Tours were given to many different groups: school classes (grades 1 to 13), environmental clubs, university and college groups, architects, home builders, interior designers, etc.

All project participants were invited to use the Green Home to hold meetings or special seminars.

Displays

In addition to tours by the staff, the Green Home was designed to enable visitors to take a self-guided tour. On the main floor, signs were located in the appropriate places to highlight and briefly explain the various energy-saving and environmentally responsible features. The lower living space was used as a demonstration area. A shelf along one wall contained samples of the various building materials used in the house construction and decoration. A set of 14 photographs, along with an explanation for each, was mounted to illustrate the construction process. Three charts posted on another wall showed comparisons between the Green Home and a conventional home of the same size. The charts outlined annual energy use, annual operating costs and daily water use. Graphs representing the same three items were also posted to further illustrate the differences between the two types of houses. House and landscape plans were displayed on a wall.

To demonstrate the construction and materials used for the building shell small sections of wallboard (drywall) were removed in various parts of the house to expose the inside of the wall. An opening in the master bedroom revealed a section of the wall construction. The foundation wall and the floor system were demonstrated by cutting a hole in the basement wall and one in the basement ceiling. A clearer demonstration of these building systems was set up in one of the two bedrooms on the lower level. Models of the floor, wall and foundation systems were built. For comparison the conventional equivalents of the these models were also included. While the wall cut-outs provided a working demonstration of the house construction, the separate models displayed in the downstairs bedroom proved to be much more useful as a visual aid for describing and illustrating the building shell construction.

The second bedroom was used as a "theatre" where the Green Home video, by Avard Productions, was shown to tour groups and other interested parties.

Lecture Series

The second Thursday of every month from 7:00-8:30 PM was booked for special seminars and presentations as part of the Green Home's "Lecture Series". Based on a variety of topics pertaining to energy efficient and environmentally friendly housing, the lectures were given by members of the design team and other project participants. The lectures were scheduled for June 1993 to April 1994 but were cancelled in January 1994 due to lack of attendance and the discontinuation of Lecture Series advertising.

Bill Inserts

Several bill inserts were produced and distributed during the demonstration phase of the Green Home project. All of the inserts provided a brief description of the house, directions to the site, the Green Home phone number and the open house hours. Inserts were produced and distributed by Union Gas, Kitchener Utilities and Ontario Hydro.

The Union Gas insert, which also had a brief description of the Hamilton NEAT Home, was included with the bills of its 600,000 customers in April 1993 when the Green Home first opened. Following this was the Kitchener Utility insert which was distributed to 100,000 customers in the June 1993. March 1994 was the final circulation of bill inserts for the Waterloo Green Home. These Ontario Hydro inserts were put out by Waterloo North Hydro and Guelph Hydro, each with 30,000 customers.

Newspaper Inserts

A larger version of the bill insert produced by Union Gas was used as a newspaper insert. It was distributed in the Waterloo Chronicle, the Kitchener-Waterloo Record, and the Elmira Independent. These newspaper companies distribute 25,000, 80,000, and 7,000 papers respectively.

Presentations

Various members of the design team made presentations and gave lectures to schools, service clubs, and many home-builder groups in Southwestern Ontario to increase awareness about the Green Home and invite groups to come to the Green home for a tour.

B.2 PROMOTIONAL MATERIALS

Booklet

A 22 page booklet was created to provide information about the main energy saving and environmental features of the house. Each page discussed a particular feature of the house and outlined the advantages of each (eg. appliances, lighting, landscaping, waste management, etc). The final few pages of the booklet listed each component of the house along with the address and phone number of its supplier. The back cover provided directions to the Green Home, hours of operation, the phone number, and an invitation to schools regarding the education kit and group tours. Publication of the booklet was made possible by support from Union Gas and Ontario Ministry of Environment and Energy. This booklet was available free of charge. 15,000 copies were printed and distributed.

Book

Wayne Grady, former editor of "Harrowsmith" magazine, is the author of the book "Green Home: Planning and Building the Environmentally Advanced House". The book is 208 pages in length and is an excellent documentation of the design and construction process of the Green Home. It covers all the various features of the house, from the crushed glass aggregate underneath the foundation to the recycled steel on the roof. It provides reasons behind many of the choices that were made and effectively outlines the technical details of the house in an easy-to-read fashion, making it accessible to a wide audience. The book was published by Camden House Publishing and was sold at the Green Home during the demonstration phase for $17.00. It is also available in book stores and libraries.

Poster

Along with a picture of the Green Home the poster provided general information about the house: the sponsors, the hours, directions to the house, and a catchy list of the 20 most interesting features about the house. The poster was available for general distribution and was included in the education package.

Video

A 20-minute video, produced by Avard Productions, was also developed. This video outlines many of the energy saving and environmental components of the house. It also features many of the people directly involved in the Green Home's design, construction, and interior finishings.

Education Kit

Developed by the Energy Educators of Ontario, the education kit was designed to be useful to most elementary and secondary grade levels (Grades 1 to 13). It was available to all school groups upon request at no charge. It has activities to complete before, during, and after visiting the Green Home. The various assignments and activities were compatible with environment and energy issues studied in the classroom. An answer code for teachers and an appendix of reading material for the various activities was also included.

Miscellaneous

Pencils and t-shirts were also available at the Green Home. The pencils were made of recycled paper and cardboard and were given out to groups and other visitors. The t-shirts had the Green Home logo on the front and were made from natural unbleached cotton. They were sold for $10.00 each.

B.3 MEDIA COVERAGE

Numerous articles about the Green Home were published in local and surrounding area newspapers. These articles began when the project was first proposed and continued through the demonstration phase. The majority of these articles outlined the initial program that led to the Green Home's construction and then outlined a number of its interesting energy saving and environmentally friendly features. The Green Home was also covered by magazines such as "Popular Science", "Your Home Magazine", "Alternatives", "Harrowsmith Magazine", etc. as well as in Union Gas' 1993 Annual Report.

B.4 VISITOR RESPONSE

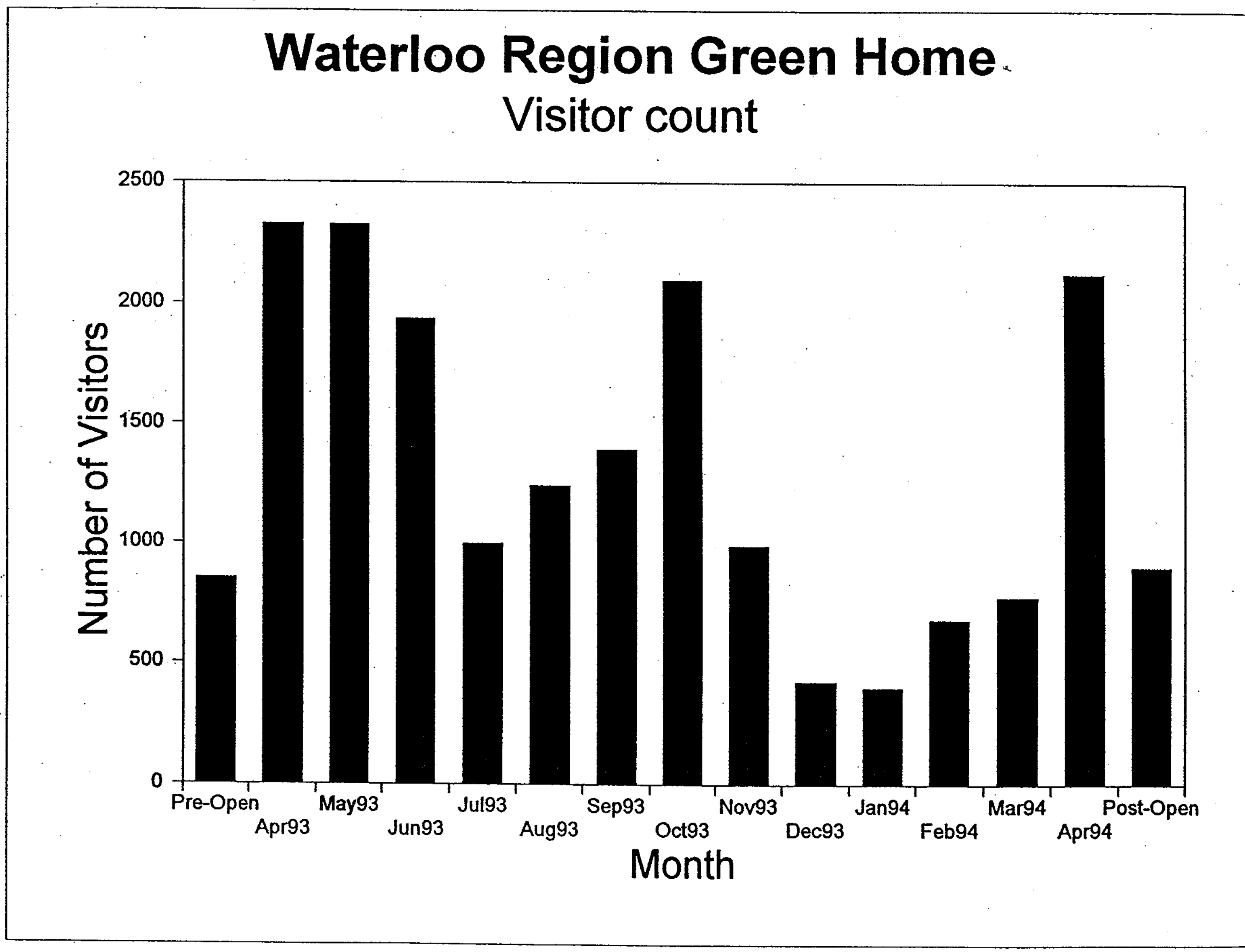
Approximately 20,000 people visited the Green Home. The monthly distribution in shown in Figure B.1. Groups that visited the home for prescheduled tours were primarily elementary and secondary school classes, interior designers, home builders etc. These groups usually came during the week from Wednesday to Friday. Visitors that came without booking a tour were primarily people looking into building their own home and those generally interested in energy efficiency and environmental responsibility in housing. Although some came during the week the majority of these visitors arrived on Saturday and Sunday.

Visitors to the Green Home were very impressed and excited with what they saw. Many people saw ideas in the Green Home as possibilities and opportunities for their own houses and for the building industry in general. Visitors were pleased to discover that the attractive design of a house doesn't need to be compromised in order to have a house that is energy efficient and environmentally friendly. Along with this general impression of the Green Home, there are also many specific features in the house that were very popular. The following chart lists these specific features and outlines the reasons for their popularity.

BUILDING SHELL

ITEM	POPULAR FEATURES
Wall Studs	- creates deeper wall to allow for more insulation - uses smaller dimensional lumber - reduces amount of wood used by 1/3
Insulation	- made from recycled newspapers
Basement Moisture Barrier	- more effective seal than tar
Foundation Walls	- use 50% less concrete than poured - can fill cavities with insulation

Figure B.1


Waterloo Region Green Home
Visitor count
Number of Visitors
0
500
1000
1500
2000
2500
Pre-Open
Apr93
May93
Jun93
Jul93
Aug93
Sep93
Oct93
Nov93
Dec93
Jan94
Feb94
Mar94
Apr94
Post-Open
Month

APPLIANCES

ITEM	POPULAR FEATURES
Refrigerator	- CFC-free - freezer on bottom, fridge on top, more efficient and convenient - uses less energy than conventional
Stove	- sealed ceramic top - natural gas without open flame - vents combustion products directly outside
Washing Machine	- uses 60% less water than top-loader - spin-dry cycle reduces water content in clothing therefore reducing dryer-time
Dryer	- uses natural gas - contains moisture sensor which ends drying cycle automatically

Interior Finishings and Furnishings

ITEM	POPULAR FEATURES
Carpeting	- made from recycled pop-bottles - naturally stain resistant
Underlay	- made from recycled rubber tires - provides both good cushioning and insulation from concrete floor slab
Hardwood Floor	- maple salvaged from warehouse and then refinished
Latex Paint	- can create attractive wall finishes without using wallpaper - free from VOC's and other chemicals found in wallpaper glues
Refurbished Sink and Bathtub	- makes use of existing fixtures - reduces use of chemicals and raw materials
Patio Lights	- use solar energy instead of electricity

Heating and Cooling

ITEM	POPULAR FEATURES
Cooling Loop	- use water from cistern through cooling loop below house
Water Heating	- heating done by solar energy - solar heating reduces costs
Heat Recovery Ventilator	- recycles heat from house air and flue gasses - provides controlled fresh air exchange

Windows

ITEM	POPULAR FEATURES
Windows	- no moisture build up - are well insulated therefore stay warm
Recycled Crushed Glass	- provides natural light to bathroom - attractive feature to bathroom and over staircase
Automatic Window Shading	- turns white automatically at 24°C - reflects sunlight away from house to reduce cooling load
Dormer Windows	- windows are operable to allow heat out in summertime to reduce cooling load

Waste Management

ITEM	POPULAR FEATURES
Drywall Scraps	- used to fill interior walls - provides added thermal mass and sound barrier - reduces waste sent to landfill
Recycling Centre	- convenient and tidy location for storing and sorting recyclable materials - containers for food scrap storage for outdoor composting

B.5 HOMEOWNER RESPONSE

The following is an article written by the Green Home owner and printed in a local Church newsletter.

LIVING IN THE GREEN HOME - by Rolf Theisen

Last May "94, we moved into the Waterloo Region Green Home. "What is the Green Home?" you may ask. It is the end result of a challenge put forth by CANMET (the research and technology development arm of Energy, Mines and Resources Canada) to the building industry, to design and build houses that promote energy efficiency and environmental responsibility. Ten such houses of varying design and technology were built across Canada.

So what makes this home "green"? Without undue explanation allow me to list some of the "green" features:

- *Construction materials are largely comprised of recycled materials. For example: the roof is constructed from auto bodies, the hardwood floors have been reclaimed from the Seagram's warehouses, the carpets are made from plastic pop bottles, the floor tiles from* *crushed glass, the insulation from newsprint, the drywall from newsprint and much of the lumber from wood chips,*

- *The windows provide high solar gain and low heat loss and face south to maximize the sun's energy.*
- *The plumbing is comprised of recycled copper, with low flow shower and faucet heads, and low flush toilets. A 14,000 litre underground cistern collects rain water to supply the toilets, washing machine and garden watering needs.*
- *The water heating is primarily supplied by solar panels.*
- *Home heating is supplied by a natural gas heat recovery/ventilator furnace.*
- *Appliances are the most efficient ones presently on the market.*
- *Indoor lighting consists of energy efficient fluorescent tubes or compact fluorescent lamps.*
- *The landscaping is terraced to stagger runoff and the plants are of the indigenous variety, thereby requiring minimal maintenance and watering.*
- *The insulation is comprised if recycled newsprint. Ceilings - R60 and walls - R34.*
- *Virtually no construction waste was contributed to a landfill site.*

The engineers claim that the Green Home will consume less than 30% of the energy and water of a typical home based on detailed calculations and computer simulations. The Thiessen family, having purchased the house, will have their energy and water consumption monitored throughout the first year of occupancy to see if indeed such savings can be realized.

What has it been like to live in the Green Home? Wonderful! The vaulted ceilings add an extra spaciousness to the house. The large, south facing windows make for a very bright interior. The layout and architectural lines are sensible and aesthetically pleasing. The combination furnace and heat recovery ventilator keep the air fresh and cosy warm.

I have usually viewed housing from a purely utilitarian perspective; a place where shelter and refuge could be found after a long day at work. The Green Home most certainly provides this and more. The Green Home has added a dimension of comfortable ambiance which previously had remained beyond my realm of appreciation. Not only is the house comfortable, it makes sense. The Green Home is to the home building industry what the Japanese car import is to the North American car industry. It brings innovation, efficiency, economy, practicality and packages it in an unpretentious, yet attractive dwelling.

Moreover, it feels good to have purchased a home that was environmentally friendly in its construction and use of resources. As a matter of fact, each and every construction material was assessed as to its environmental impact before being selected. Furthermore, it feels good to live *in a home that continues to operate in an environmentally friendly way regarding energy and water consumption, and it good knowing that the construction of this house contributed very little if anything to a landfill site.*

Having said all this, may I also say that my euphoria is tempered somewhat by precisely the unconventionality of this house. Naturally, I feel somewhat vulnerable concerning some of the prototype technologies and the additional fan motors and pumps used in the house. Will the energy savings provided by these features be wiped out by their maintenance and repair costs? Will all the promises of durability and longevity from the manufacturers of the various construction materials and appliances by accurate? I also am somewhat concerned about the resale value if ever we should decide to sell. I wonder how many other families are willing to pay extra for something "green"?

There are also some adjustments or compromises to be made in living in this unconventional home. For example, the laundry facilities are in the kitchen, the backyard is virtually nonexistent while the side yard is substantial, and there is no basement for storage or to hang laundry. None of these have proven to be major adjustments, but adjustments nonetheless.

Considering these questions and compromises, one can see that buying this house took considerable deliberation. So, what prompted us to buy such an unconventional house with built in compromises and questions?

This house had been open to the public as a demonstration model for 1 1/2 years. During this time had taken my geography students through the home at least 5 times. Although I was most impressed with the unique and innovative features of this house, I had not even remotely considered owning such a house. Basically, I was locked into the more conventional house dreams such as a double garage, palladium and bay windows, and a large treed lot. The Green Home offered none of these dreams. Furthermore, the reality of my meagre bank account effectively derailed any such grandiose aspirations. So, how did we end up in this house?

After much deliberation, the weighing of pros cons, many calculations and recalculations, numerous walk throughs, the seeking of advice and the eventual onset of decision making fatigue, it all boiled down to what felt right. What felt right was largely influenced by a deliberate decision to go "green". It fit our conceptions of stewardship theology, it made sense, the uniqueness and unconventionality become appealing to us. The more traditional house dreams faded. We feel privileged as residents of this house to participate and even contribute to the visions of the designers, architects, engineers and builders. All these things make the risk worth it for us. For *me, being able to purchase this house is like an unexpected gift. I am like a little boy who found something totally unexpected yet wonderful under the Christmas tree. I did not wish for such a house, I did not pray for such a house and initially I had no desire to even move. So, here we are feeling extremely fortunate, extremely blessed and extremely thankful.*

Appendix C: Embodied Energy Calculation

Item	Quantity Green Home	Quantity Conv. House	Quantity Upgrade Conv.	Bldr's Unit	Conv. to kg/ m^2	Energy Intensity (MJ/kg)	Embodied Energy (MJ/m^2) Green Home	Embodied Energy (MJ/m^2) Conv. House	Embodied Energy (MJ/m^2) Upgrade Conv.
FRAMING									
double stud of 2X4			72.00	Ft	0.15	7.38	0.00	0.00	80.97
double base of 2X4			12.00	Ft	0.15	7.38	0.00	0.00	13.49
double top of 2X4			24.00	Ft	0.15	7.38	0.00	0.00	26.97
2x6: studs		72.00		Ft	0.11	7.38	0.00	60.61	0.00
2x6: base		12.00		Ft	0.11	7.38	0.00	10.10	0.00
2x6: top		24.00		Ft	0.11	7.38	0.00	20.20	0.00
LVL beams, 2.5" x	6.30			Ft	0.82	11.86	61.60	0.00	0.00
5/8" OSB: web	0.90			Shts	1.82	8.96	14.78	0.00	0.00
5/8" OSB: base	0.42		0.42	Shts	1.82	8.96	6.79	0.00	6.87
5/8" OSB: top	0.83		0.42	Shts	1.82	8.96	13.59	0.00	6.87
							96.76	90.91	135.16
SHEATHING									
5/8" OSB: sheathin		3.00	3.00	Shts	1.82	8.96	0.00	49.04	49.04
5/8" Excel OSB	0.72			Shts	1.82	8.96	11.77	0.00	0.00
5/8" Excel-polyisocy	23.04			ft2	0.01	188.59	43.84	0.00	0.00
							55.61	49.04	49.04
SIDING									
Aluminum (painted)		96.00	96.00	Ft2	0.03	68.02	0.00	195.47	195.47
1/2" HD Fibreboard	3.00			Shts	1.46	9.82	42.93	0.00	0.00
Exterior paint	480.00			ft2	0.001	40.34	26.05	0.00	0.00
							68.98	195.47	195.47
INSULATION									
Fibreglass, 10.5"			96.00	Ft2	0.04	18.35	0.00	0.00	68.16
Fibreglass, 5.5"		96.00		Ft2	0.02	18.35	0.00	35.70	0.00
Cellulose, 9.5" spra	96.00			Ft2	0.06	4.36	26.16	0.00	0.00
							26.16	35.70	68.16
BARRIERS									
6 mil polyethylene	96.00	96.00	96.00	Ft2	0.001	188.59	26.39	26.39	26.39
Housewrap	96.00	96.00	96.00	Ft2	0.001	188.59	10.15	10.15	10.15
							36.53	36.53	36.53
GYPSUM BPOAR									
1/2" regular		96.00	96.00	Ft2	0.10	4.48	0.00	43.91	43.91
1/2" low-water recy	96.00			Ft2	0.10	2.24	21.96	0.00	0.00
							21.96	43.91	43.91
					Totals:		306.01	451.58	528.28

Notes: Quantities based on a 12 ft X 8 ft wall
Conventional House has a 2X6 wall (R18)
Ugraded House has a double stud wall (R34)