PERFORMANCE OF THE BRAMPTON ADVANCED HOUSE

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1.0 INTRODUCTION

In 1989 the "Advanced House" was constructed in Brampton, Ontario as an example of leading-edge energy-efficient and environmentally responsible housing. It is part of Canada's contribution to the International Energy Agency Task XIII Advanced Solar/Low Energy Residential Buildings, which examines innovative methods of reducing residential energy consumption.

The energy performance of the house was predicted using the detailed computer simulation program, ENERPASS. A monitoring system was installed to assess the actual energy performance of the house and its innovative energy-conserving technologies. This paper compares the predicted and monitored performance results of the Advanced House from June 1990 to October 1992. Energy usage figures are quoted only for the period when the house was occupied (July 1991 to October 1993). Readers are referred to the full report or previously published papers for a more complete description of the house, monitoring system and the results [Enermodal, 1992; White and Carpenter, 1990; Carpenter, Kokko and White, 1991].

2.0 GENERAL HOUSE DESCRIPTION

Designed to fit into an upscale suburban subdivision, the Advanced House has a total 408 square metres floor area (including the basement, but not the two-storey south-facing sunspace). The floor plans are shown in Figure 1. Although the house appearance is conventional, the house contains many novel energy-efficient features.

The building shell is well insulated and airtight. The above-grade walls are insulated with 240 mm of wet-blown cellulose and 25 mm of rigid fibreglass. Basement walls are insulated over the full height with 175 mm of cellulose. A cross-section of the walls is shown in Figure 2. The basement floor slab is insulated with 50 mm of extruded polystyrene. The house includes one of the first demonstrations of high-performance windows (triple-glazed with two low-e coatings, argon gas fills and an insulating edge spacer, total U-value = 1.1 W/m^2*C).

This house uses energy-efficient appliances and lighting systems. The refrigerator is the most energy-efficient unit available at 20 kWh/month. The washer and dryer are front loading European models. No incandescent lighting is used in the house. Most fixtures are fluorescent, with a few halogen bulbs in the kitchen. Energy-efficient fans are used to exhaust stale air and circulate furnace air. Water demand is reduced by installing low-water-use appliances and water fixtures.

The most innovative aspect of the house is the prototype integrated mechanical system (IMS). This system recovers waste heat from exhaust air, grey water and building overheating and stores it by melting an ice slurry. A heat pump transfers the heat from the ice storage tank

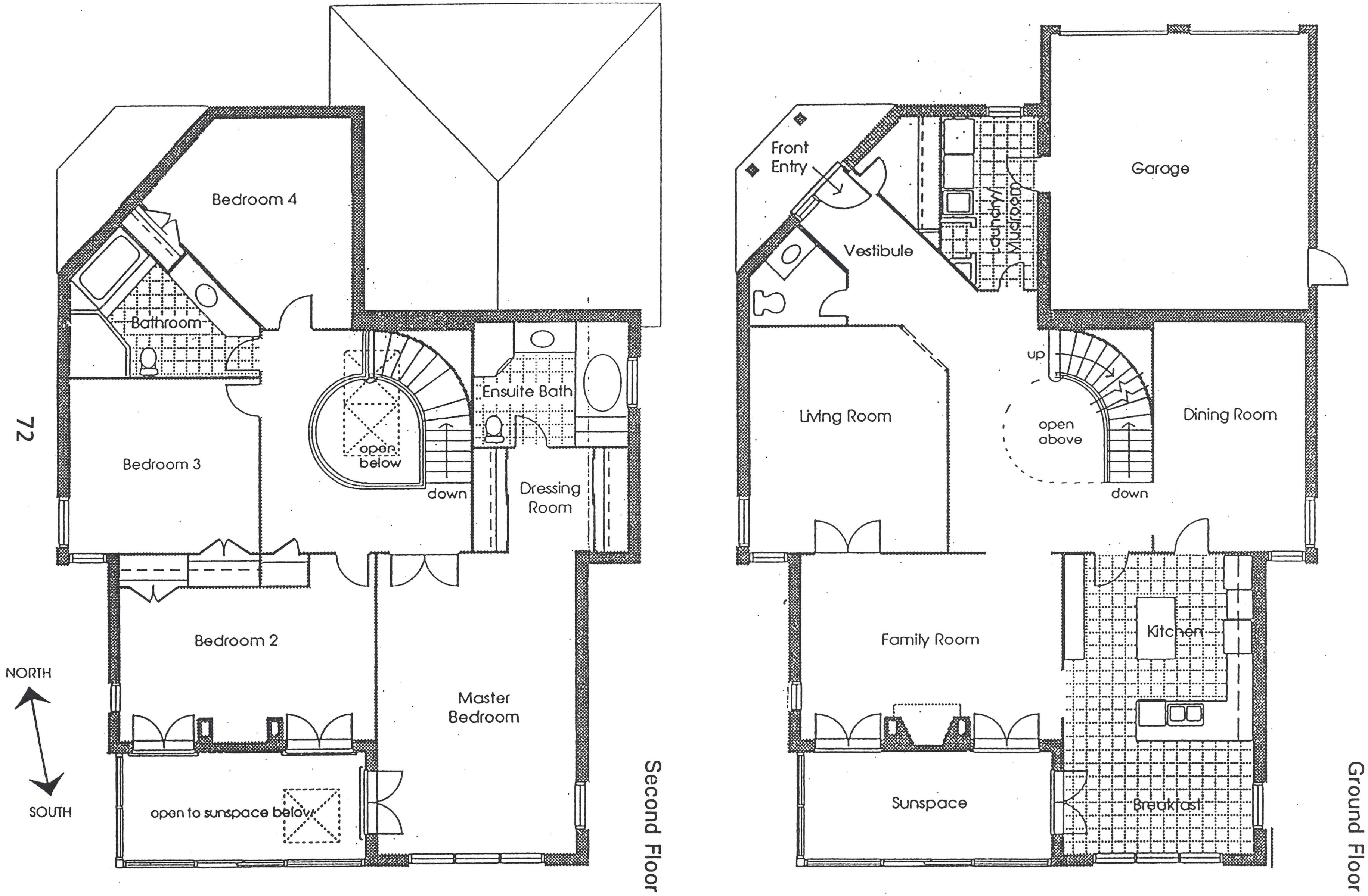
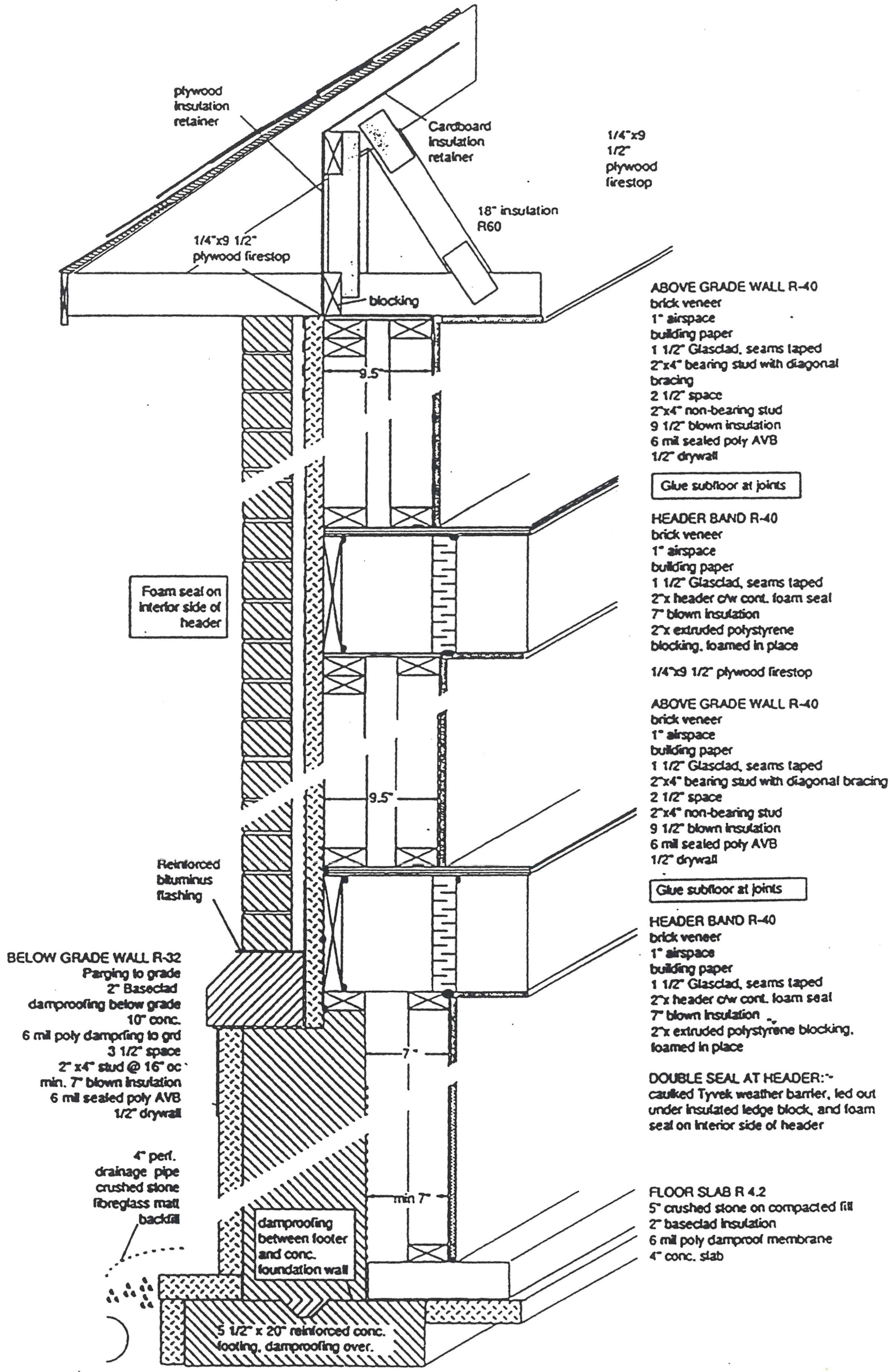


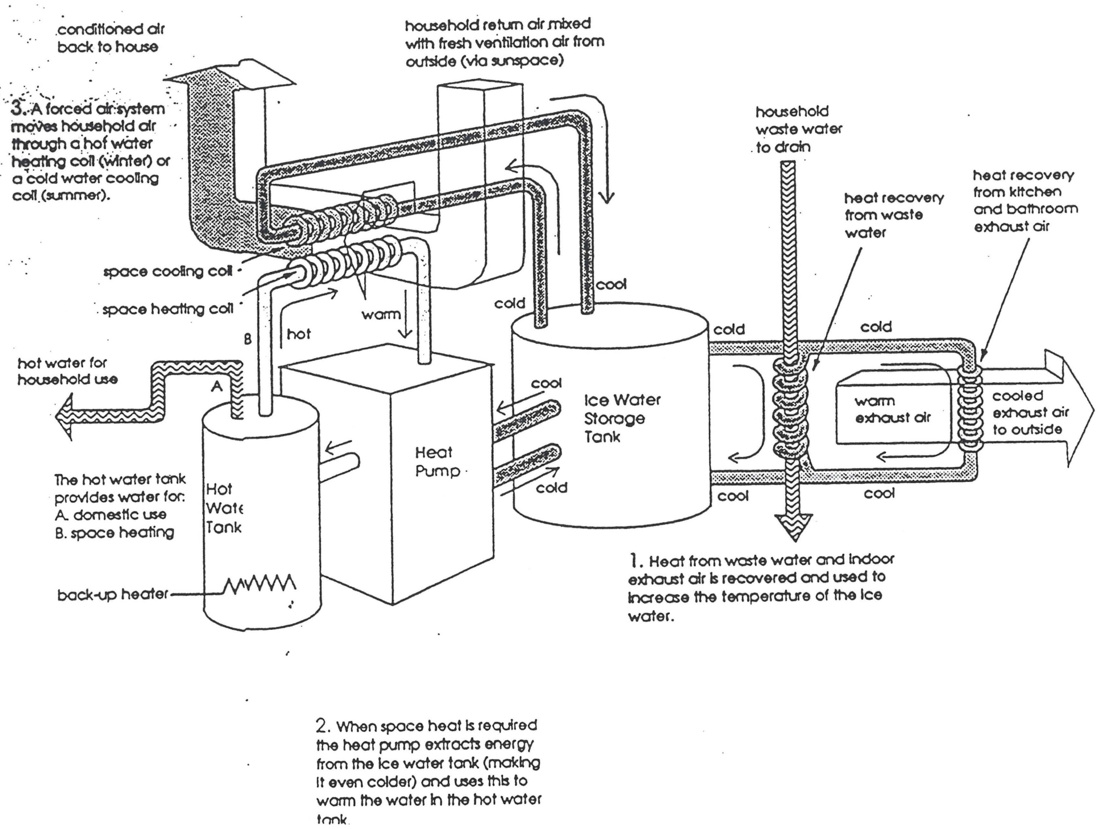
Figure 1 Floor Plans

Figure 2 Wall Construction



to a hot water tank to provide space heating and water heating (see Figure 3.). When the DHW tank becomes cool, the compressor shuts off and the back-up element comes on. When the ice tank becomes too hot, hot water is dumped to drain, causing the compressor to turn on and cool the ice tank. The system was expected to reduce space and water heating costs by 50%. A two-storey sunspace on the south side is used to temper building ventilation air. Air is pulled from the outdoors, into the sunspace, then out through pipes in the floor slab and into the return duct of the IMS.

Figure 3 Integrated Mechanical System Schematic



The house was expected to consume 30.7 kWh/m^2 of conditioned floor area or a total of 12,507 kWh annually, of which 11.8 kWh/m^2 was for space heating. According to the simulations, the IMS was expected to have a Seasonal Performance Factor (SPF, i.e., the ratio of useful energy delivered divided by all energy input), of 2.0 over the heating season.

The Advanced House was designed to significantly reduce energy consumption in all areas. Column 2 of Table 1 shows the predicted energy use in the Advanced House components as predicted by ENERPASS over a typical year with the house located in Toronto (4,257 Celcius degree-days).

2.1 Comparison to Conventional House Designs

To put the energy consumption in perspective comparisons were made as if the same house design were built to the 1985 Ontario Building Code (OBC) and R2000 standards. The differences between these methods of construction are summarized in Table 1. For the OBC and R2000 houses it was assumed that the sunspace did not preheat ventilation air.

Table 1 Comparison of House Designs

	Advanced House	R2000 House	1985 OBC House
Insulation (RSI, in m^2-°C/W)			
Basement Above-Grade Walls	6.55	3.52	1.4
Remaining Above-Grade Walls	6.89	3.52	2.1
Basement Below Grade Walls	6.55	3.52	1.4*
Ceiling	10.57	7.0	5.5
Basement Floor	1.6	0.2	0.2
Windows (U-Value)	1.2	2.0	2.85
Air Exchange			
- mechanical (l/s)	66	66	0
- natural	15	15	97
Heat Recovery Effectiveness	0.75	0.7	0.0

* to 0.6m of depth, RSI 0.2 for remaining depth (uninsulated)

Computer simulations of the two conventional designs were run using ENERPASS. Adjustments were made to the heating system capacity and furnace fan size to maintain the temperature distribution through the house and reflect the energy consumption of conventional equipment. The energy consumption of the three houses is shown in Table 2.

Table 2 Comparison of Energy Predictions (kWh)

Load	Advanced House	R2000 House	1985 OBC House
Space Heating	4822	8826	23438
Domestic Hot Water	2016	5261	5277
Lights / Appliances	4042	8085	8085
Air Conditioning	225	1828	1568
Fans	1402	4292	1402
TOTAL	12507	28292	39769
Increase over Ad. House		15785	27262

[redacted] [redacted]

The Advanced House was expected to save two-thirds of energy used in the same house built to the OBC standards. At 1991 electricity rates (6.66 cents/kWh) this represents an annual savings of over $1,800. The space heating energy consumption should be only 21% that of a house built to the 1985 Building Code.

3.0 MONITORED RESULTS

3.1 House Operation

Construction of the Advanced House was completed in February, 1990. The house was open for public viewing from March 1990 to March, 1991. The house was subsequently sold and the homeowners took possession in June 1991. The new homeowners, a three-person family, moved in June 1991. In periods of cold weather, they used the fireplace instead of the electric resistance back-up to maintain the house temperature. The exhaust air flow rate was originally set to 68 L/s, the homeowners increased the ventilation rate to 87 L/s in July 1991.

3.2 Building Heat Loss Characteristics

A co-heating test was conducted to determine an "as-built" building heat-loss coefficient (UA-value). The co-heating test results show that the house shell is performing very close to predictions. The monitored results are 5% below the ENERPASS predictions. The design heating load of 8.0 kW at an outdoor temperature of -19°C obtained using ENERPASS (sunspace doors to the house closed) appears to be a reasonable estimate of actual house performance.

The airtightness of the house (including sunspace was first measured in early 1990 at 0.9 ACH @ 50 Pa or 0.60 cm^2/m^2 normalized leakage area @ 10 Pa. The test was repeated eighteen months later in September 1991. The measured airtightness was 1.34 ACH @ 50 PA or 0.77 cm^2/m^2 normalized leakage area @ 10 Pa. No obvious reasons for the increased leakage were identified. Nevertheless, both tests are below the R2000 building airtightness requirement of 1.5 ACH @ 50 Pa.

Blower door testing also showed that there was a constricted vent opening between the outdoors and the sunspace and high air leakage between the house and the sunspace. These two factors combine to limit ventilation air being drawn in and pre-heated by the sunspace. It is estimated that only 25% of the building ventilation is being preheated in the sunspace with the remaining air infiltrating through the building shell.

Radon and formaldehyde levels were measured and found to be well within accepted guidelines.

3.3 Water Usage

The average hot water demand was 164 litres per day at an average delivery temperature of 45°C during the occupied period. The hot water heating demand at the Advanced House is only 60% that of a typical family when compared to the average family use of 236 litres/day of hot water at 55°C [Perlman and Mills, 1985]. The low hot water demand at the Advanced House indicates the impact of the water conserving appliances in the house.

Daily cold water use, for the months when no water was dumped to maintain IMS cooling capacity, was 264 litres per day. Ignoring dumped water, the total daily water use was 428 litres per day, of which 38% was for hot water. A typical Canadian house uses 683 l/day of water [Carpenter and Kokko, 1993]. In the summer, however, cold water use (including dumped water for cooling) was typically 1500 litres per day.

3.4 IMS Performance

On an annual basis, the IMS consumed 13,287 kWh during the period when the house was occupied. The compressor is the largest energy user, representing 65% of IMS energy use. The back-up element energy use was only 7% due in large part to use of the wood fireplace. The fireplace provided an estimated 1,700 kWh of space heating. Perhaps somewhat surprising is the high parasitic energy use (the remaining 28%). The supply and exhaust fans operate continuously at a combined power draw of between 180 and 200 Watts. The two circulating pumps and controls consume a total of between 230 and 310 Watts depending on the temperature of the glycol. The parasitic energy accounts for 3,750 kWh of electricity use per year. Although parasitic energy use represents a significant proportion of total house energy use, it is only slightly higher than that for a conventional house.

The performance of the heat pump appears to be slightly below design expectations. The condenser output ranged from 4 to 5.5 kW at COP values of between 1.7 to 2.1. (Design values were 6 kW at a COP of 2.5 to 3.0.). The capacity of the heating coil is between 4.4 and 5.5 kW at a coil inlet temperature of 55°C. This capacity is slightly lower than the design value of 6 kW. The low heating-coil capacity was traced in part to low house circulation airflow. The low COP values are due to lower than expected heat output and higher than expected pump power. The hourly IMS heating output varied from a high of 4.4 kW to a low of 3.0 kW with an average of 3.7 kW. A variation in heating output was caused by changes in the heating coil inlet water temperature.

The exhaust-air heat-recovery coil appears to be working well. At an air flow of 75 L/s, the system had a monthly average heat recovery of 1.7 kW. The coil sensible heat effectiveness was 0.74 over this time period. The grey-water heat exchanger also appears to be working well. Over the 1991/92 heating season, the heat exchanger recovered heat equivalent to 63% of the water heating load.

During the cooling season, the IMS had a cooling COP of 1.7 and an average heat removal rate of 1.9 kW. Cooling COP is defined as heat removed by the evaporator divided by electrical energy required to operate the compressor, pumps and controls.

The Seasonal Performance Factor (SPF) averaged 1.54 over the heating season and 0.85 over the cooling season for the period when the house was occupied. The reader is cautioned not to compare the SPF values over the cooling season to a conventional air-conditioning system. The values quoted in this report include the energy required to supply hot water and circulate and exhaust air; these energy quantities that are not normally included in air-conditioning COP's.

3.5 Appliances

The energy consumption of four appliances were monitored independently: refrigerator, washer/dryer, dishwasher and stove. The energy consumption of the microwave oven and small appliances was included in the general electricity use of the house. In general, there is reasonable agreement between the appliance energy ratings of 1608 kWh (adjusted to exclude water heating) and monitored energy use of 1502 kWh (see Table 3). High consumption for the refrigerator is partly due to mechanical problems and setting adjustments. Low washer/dryer consumption is due to non-use of the dryer because clothes were often hung to dry.

Excluding the monitoring system energy consumption, lighting and receptacle energy use was 3340 kWh annually (or 278 kWh/month) 37% above the annual design value of 2434 kWh. Receptacle loads used more than twice the electricity of the major appliances in the house. The design target for the combined appliance and receptacle energy use was 4042 kWh per year or half that of a typical house. The monitored annual energy use was 4842 kWh; 20% above the target.

Table 3 Appliance Energy Use

Appliance	Annual Energy Rating Including Hot Water (kWh)	Adjusted Annual Energy Rating[1] (kWh)	Monitored Energy Use[1] (kWh)
Refrigerator	240	240	385
Washer/Dryer	1320	762	512
Dishwasher	672	258	217
Stove	348	348	388
Total	2580	1608	1502

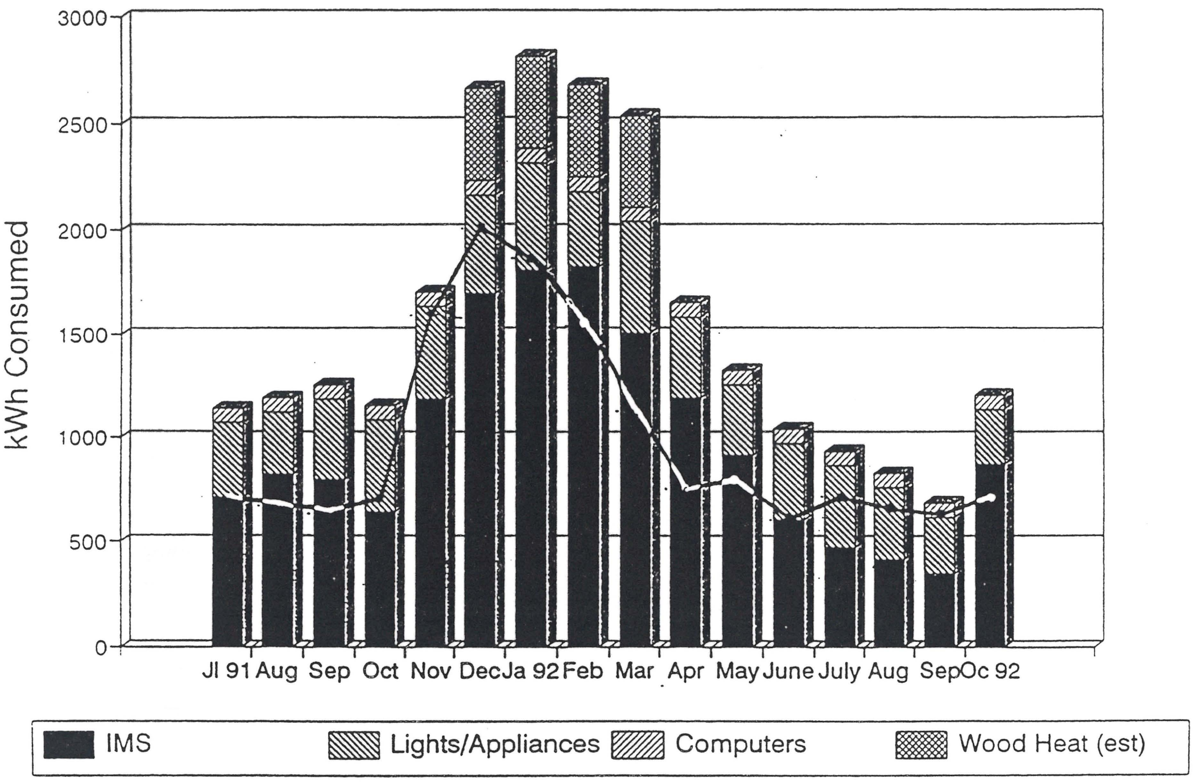
1 excluding energy required to heat water

3.6 Whole House Analysis

Whole house energy consumption for the period when the house was occupied is shown in Figure 4. The line in Figure 2 shows the predicted performance for similar weather conditions. The monitored energy use has the same trend as the predicted energy use, but is almost 60% higher than the predicted. Including the contribution from wood heat, total annual energy use is 19,834 kWh or 49 kWh/m^2. Nevertheless, even this higher than expected energy use is only half the value of the average R2000 home [Martin, 1989].

The major discrepancy is with the compressor and pump energy; the monitored value for this component is more than twice the predicted value. Energy required for back-up heating (including wood), fans and combined receptacle/appliance loads are reasonably close to predictions.

Figure 4 Comparison of Predicted and Monitored Energy Use



There appear to be five factors that contribute to the discrepancy between predicted and monitored energy use. First, high exhaust air flow rates and higher-than-expected air leakage from the house to the sunspace (thereby reducing the effectiveness of the sunspace preheating) result in high ventilation air heating load. Second, the average indoor air temperature over the heating season was 23°C, above the 21°C setting assumed at the design phase. Third, the IMS Seasonal Performance Factor (SPF) over the heating season averaged 1.54, lower than the predicted value of 2.0. Fourth, a lower than expected heat output meant that the heating system had to use more back-up energy than predicted. Finally, the pumps, fans and controls consumed 400 to 500 Watts continuously. Over the year, this represents an energy use of 3750 kWh or 30% of the predicted house energy consumption.

4.0 CONCLUSIONS

The Advanced House was designed to use 12,500 kWh per year, approximately 30% the total energy consumption of a similar house built to the 1985 Ontario Building Code and using conventional electric mechanical systems.

Monitored energy consumption was 60% higher than predicted when the house was occupied, although the house still consumes less than half the energy of a typical R2000 house. The annual energy use during the occupied period was 19,834 kWh or 49 kWh per square metre of heated floor area.

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In summary, monitoring of the Advanced House has shown that extremely energy-efficient buildings are achievable. A wide range of commercially available energy-saving products were successfully used to reduce energy consumption in all systems in the house. Although there were a few minor problems with the prototype Integrated Mechanical System, this technology has the potential to offer large energy savings.

5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES

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