The Energy Performance of the NOVTEC Advanced House

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A Thesis

in

The Department

of

Building, Civil, and Environmental Engineering

Presented in Partial Fulfilment of the Requirements
for the Degree of Master of Applied Science (Building Engineering) at
Concordia University
Montreal, Quebec, Canada

December 2000

0-612-59296-0

ABSTRACT

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In keeping with its vision to develop sustainable, energy efficient housing, in 1992, Canada launched the Advanced Houses Program, a program to showcase Canadian Innovation and affirm our commitment to fostering a greener environment. Presented herein is an analysis of the energy performance of one of the ten houses built as part of this federal initiative, the NOVTEC Advanced House. Through the use of a house-as-a-system design philosophy and innovations such as an EIFS (exterior insulation and finish system) wall assembly, and an integrated home comfort system consisting of two ground source heat pumps, the NOVTEC Advanced House is one of the world's top energy performers. The implementation of a comprehensive monitoring plan which included the installation of over 100 sensors and an automated data acquisition system, allowed the authour to collect more than 21 months of data. This data showed that the house consumed 42% less energy than a typical R-2000 house (60 kWh/m²/yr vs. 104 kWh/m²/yr), and 72% less energy than a typical house built in the late 1970s. A detailed end-use energy analysis as well as an analysis of the seasonal efficiencies of the ground source heat pumps (GSHP) is presented herein. GSHPs can play an important role in improving the energy performance of our residential building stock and in helping Canada reduce its green gas emissions. However, in order for GSHPs to gain

widespread acceptance, further R&D efforts are required to optimise their life cycle costs , namely the costs required to install, maintain, repair, and retrofit/replace them.

ACKNOWLEDGEMENTS

In attaining this important milestone in my career, I have much to be thankful for. First, I would like to thank Concordia University for providing an education in building engineering which has allowed me to develop the skills to design software and provide services which improve the performance of buildings and the quality of life of its occupants. To my mentor, Dr. Fazio, thank you for your continuous support, for sharing your vision and wisdom, and for being a great role model in both my professional and personal life. I hope I can one day do the same for a young engineer with lots of ideas but little confidence. To Dr. Zmeureanu, thank you for your patience, guidance, and expertise, and for making learning enjoyable and enlightening. To Sebastiano, thank you for your insight, your encouragement, and for being a true friend and teammate. I would like to thank Linda Farinaccio for her vitality and for assisting me in the collection, compilation, and analysis of data.

To my wife Marisa, thank you for your support, your love, and for being a continuous source of inspiration. Finally, I would like to thank my children Julia, Isabella, and Dante, and my Mom and Dad, Adriana and Renzo, for their support and their love.

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1.0 INTRODUCTION

1.1 Background

In keeping with its vision to develop sustainable, energy efficient housing, in 1992, Canada launched the Advanced Houses Program, a program to showcase Canadian Innovation and affirm our commitment to fostering a greener environment. As part of the nation's Green Plan, this program pushed the boundaries of building technology to maintain Canada's reputation as the world leader in energy-efficient, environmentally responsible housing[1].

The primary objective of the Advanced Houses Program was to field test innovative energy efficient and environmentally friendly technologies, and to assess their suitability for adoption by the Canadian home building industry[2]. In addition to environmental performance targets (water usage, recycling, etc.) stipulated by the program, the most difficult challenge was to demonstrate that we can build advanced houses which consume only 50% of the energy consumption of an equivalent R-2000 house (already considered as the worldwide standard of excellence in energy-efficient construction), and only 25% of the energy consumption of a conventional house[3]. The key to attaining this ambitious energy performance target was to adopt a house-as-a-system approach. Contrary to traditional practice whereby a house is designed and built as a collection of independent systems, the house-as-a-system approach forces designers to rethink how one system in a house interacts with other systems or components, and to explore integrated solutions which optimise the overall performance of the house.

The subject of the thesis presented herein is an analysis of the energy performance of one of the ten houses[4] built as part of this federal initiative, the NOVTEC Advanced House. Through the use of innovations such as an EIFS (exterior insulation and finish system) wall assembly, and an integrated home comfort system consisting of two ground source heat pumps, the NOVTEC Advanced House is one of the world's top energy performers.

To ensure the successful market integration of innovative Canadian technologies such as those showcased in the NOVTEC Advanced House and other advanced houses, NRCan has formed an industry consortium project called AIMS[5] whose primary objective is to develop, validate and bring to market Advanced Integrated Mechanical Systems (AIMS). An AIMS product is defined as an integrated system which provides space heating, domestic hot water heating, and mechanical ventilation to achieve a high level of energy efficiency and performance. The energy performance results of the NOVTEC house's Integrated Home Comfort System which are presented herein will serve as a good benchmark for the performance of AIMS products.

The advancement of integrated mechanical systems plays a key role in building a greener environment and their adoption by industry is one of the ways Canada intends to establish itself as a leader among the nations committed to meeting the objectives of the Kyoto protocol[6], a global treaty signed by 160 nations in 1997 to limit the production of greenhouse gases.

1.2 Authour's Contribution

The authour was part of the NOVTEC design team and was primarily responsible for compliance verification to the Advanced Houses Program's technical requirements. The contributions of the authour which are presented in this thesis are:

- The design and implementation of the monitoring plan which allowed the authour to evaluate the overall energy performance of the house and its different sub-systems on an hourly basis;
- A detailed analysis of the energy performance of the Integrated Home Comfort System (IHCS) in comparison to its design objectives and recommendations to improve the performance of similar integrated mechanical systems;
- A comparison of the actual energy performance of the house to its expected performance based on energy simulations performed at the design stage;
- An analysis of the impact of parasitic loads such as pumps and fans

on overall efficiency; and

- The design and evaluation of control strategies to optimise energy performance and improve occupant comfort.

Section 2.0 provides a description of the house and of the ten innovations showcased in it. Section 3 discusses the Advanced Houses Program's technical requirements and the NOVTEC House's expected energy performance prior to monitoring (through energy simulations). Section 4.0 describes the monitoring plan, the instrumentation, and the software used to monitor, collect and process the data. Lastly, Section 5.0 summarises the energy performance results for the 21-month period from November 1993 to September 1995 and Section 6 draws conclusions and makes recommendations to further enhance the house's performance and to contribute to the advancement of integrated residential mechanical systems.

2.0 HOUSE DESCRIPTION

2.1 DESIGN PHILOSOPHY

The main challenge for the NOVTEC design was to demonstrate that the stringent energy, indoor air quality, and environmental requirements of the Advanced Houses Program could be achieved through the use of readily available building materials and equipment, so long as a house-as-a-system approach was used. This approach led to the award-winning design in 1992 and to the construction, monitoring, and technology transfer activities of the project from 1993 to 1995.

The performance-based technical requirements of the Advanced Houses Program were developed so as to encourage the use of innovative technologies. The requirements cover three main areas:

i. purchased energy consumption;
ii. indoor comfort and health (indoor air quality, ventilation, and occupant comfort);
iii. water conservation and eco-management (water use, waste management, and environmental protection).

Energy targets are specified for each end-use; space heating, space cooling, domestic hot water heating, lights and appliances, and outdoor electric energy consumption. The total purchased energy target was to be less than 50% of that of an equivalent size R-2000 house. This target also corresponds to approximately 25% of the total energy use of a conventional house built according to the 1975 NBCC. End-use energy targets could have been exceeded so long as the total energy target was respected. Also, because the requirements applied to purchased energy, there was no restriction on the use of "free" energy, i.e. solar energy, renewable energy or heat recovery. In addition to these requirements, all houses had to comply with local and provincial codes and standards or to the 1990 edition of the National Building Code of Canada[7].

2.2 GENERAL CHARACTERISTICS

The NOVTEC Advanced House is a single family detached, 2½ storey, 3 bedroom home and is located in Laval, Quebec, approximately 35 minutes from downtown Montreal. . The house has 222 m^2 (2390 ft^2) of heated floor area and a volume of 602 m^3 (21,263 ft^3), excluding the garage. The front facade shown in Photograph 2.2.1(a) faces North and the back facade includes a large south-facing atrium window (Photograph 2.2.1(b)). The south-facing glazing area to wall ratio is 50%, approximately 3 times that of a conventional house. This large glazing area combined with the interior open-plan design (shown in Figure 2.2.1) allows natural light and passive solar energy to enter at all levels of the house.

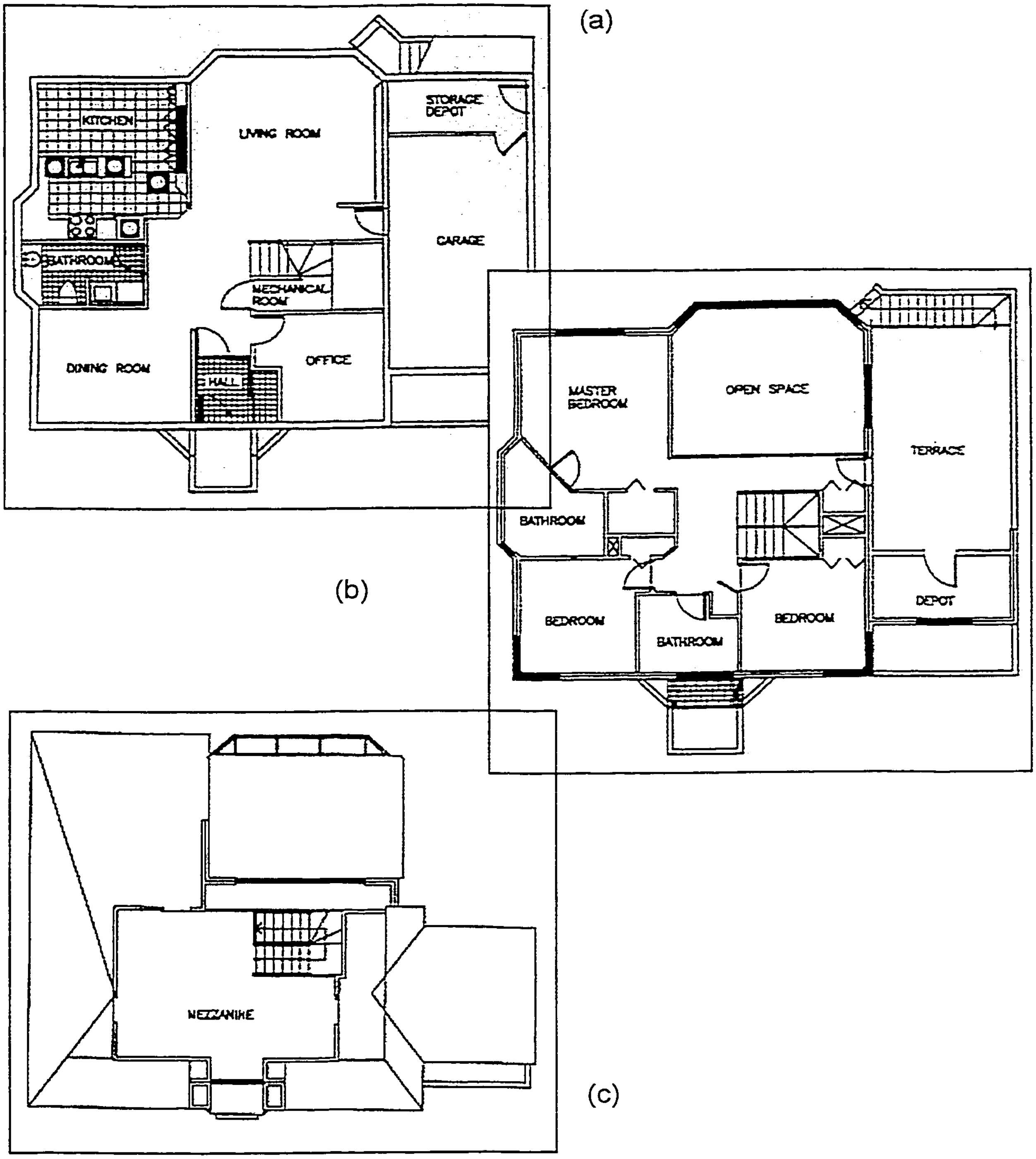
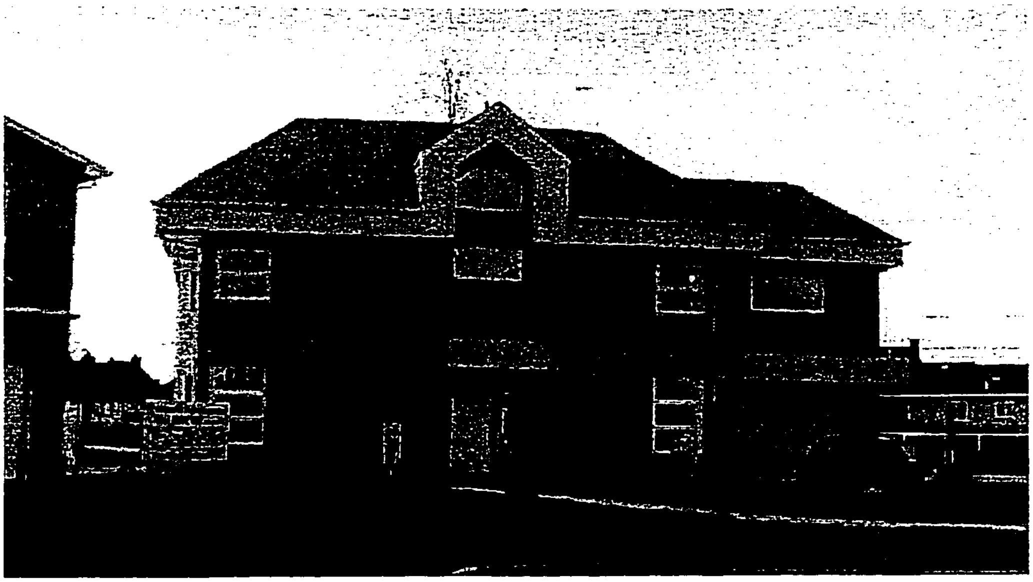
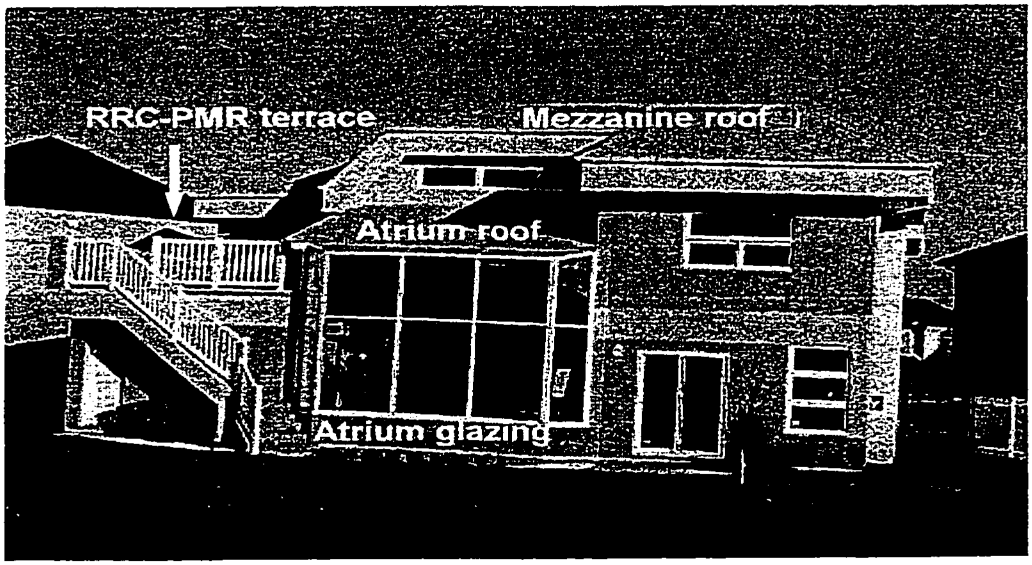


Figure 2.2.1: Plans of the (a) ground floor, (b) first floor and (c) mezzanine floor of the NOVTEC Advanced House



(a)



(b)

Photograph 2.2.1: (a) North and (b) South facade of the NOVTEC Advanced House

2.3 INNOVATIONS

This section provides a description of the ten innovations developed in the NOVTEC Advanced House:

1. Exterior insulation and finish system,
2. Integrated home comfort system: dual ground source heat pumps,
3. Radiant slab-on-grade heating,
4. Home automation and energy management system,
5. Recycled rubber crumb - protected membrane roof system,
6. Pollutant metabolizing plants,
7. Reverse osmosis and water filtration system,
8. Natural lighting and high performance windows,
9. Environmentally friendly construction and landscaping, and
10. Energy efficient lighting and appliances.

2.3.1 Exterior Insulation and Finish System

Design and Objectives

The exterior insulation and finish system (EIFS) of the NOVTEC Advanced House consists of a sheet of exterior-grade plywood sandwiched between two layers of non-CFC extruded polystyrene exterior insulation and covered with a brick/stucco finish, as illustrated in Figure 2.3.1.1. The EIFS is attached to a 38 x89 mm (2" x 4") wood frame with an interior gypsum board finish. The interior finish is coated with one layer of latex emulsion primer and a second layer of alkyd pearl enamel paint, which results in a type II vapour barrier protection. The wall's stud cavities are filled with R14 glass fibre batts. The design team wanted to demonstrate that through the use of an airtight EIFS wall assembly, moisture migration is minimised, and hence there is no need for the traditional air cavity behind the brick, nor the need for building paper or a polyethylene vapour retarder.

The shiplapped exterior rigid insulation, combined with a modified Airtight-Drywall Approach, presents an innovative air barrier system capable of complying to the stringent airtightness requirements (1.5 ACH@50Pa) of the Advanced Houses Program. In addition to proving compliance to the Program's technical requirements, the objectives of the EIFS were to demonstrate the following advantages over conventional 38 x 152 mm (2" x 6") wall assemblies:

- Increased thermal performance and reduced wall thickness,
- Increased air barrier performance,
- Reduced risk of moisture damage, and
- Improved cost-to-benefit ratio.

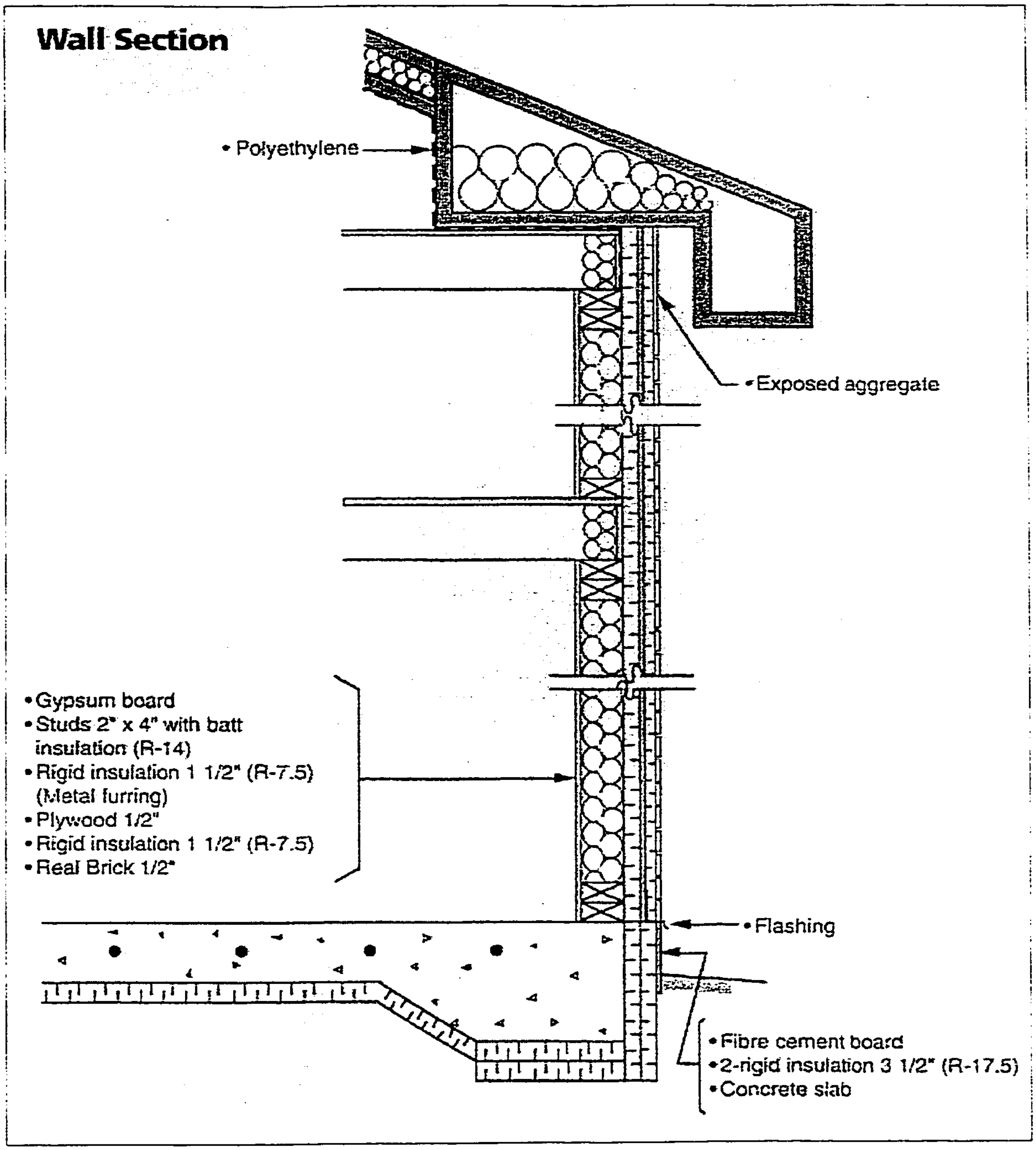


Figure 2.3.1.1: Cross-section of the Exterior Insulation and Finish System

Construction

The EIFS wall assembly was constructed in two phases. Phase 1 involved the erection of the 38 x 89 mm (2 "x 4") stud framework with 38 mm (1½") of shiplapped extruded polystyrene and 13 mm (½") plywood fastened to it. The extruded polystyrene panels are specially grooved to secure the metal furring which is used to fasten the plywood to the frame. This first layer of insulation was sealed to the bottom plate, which was anchored to the concrete floor slab, and to the top plate at the roof level. In the mezzanine, a polyethylene air/vapour barrier was clamped to the rigid insulation and sealed along the entire length of the top plate in order to ensure that the air barrier was continuous in the roof space (see Figure 2.3.1.1).

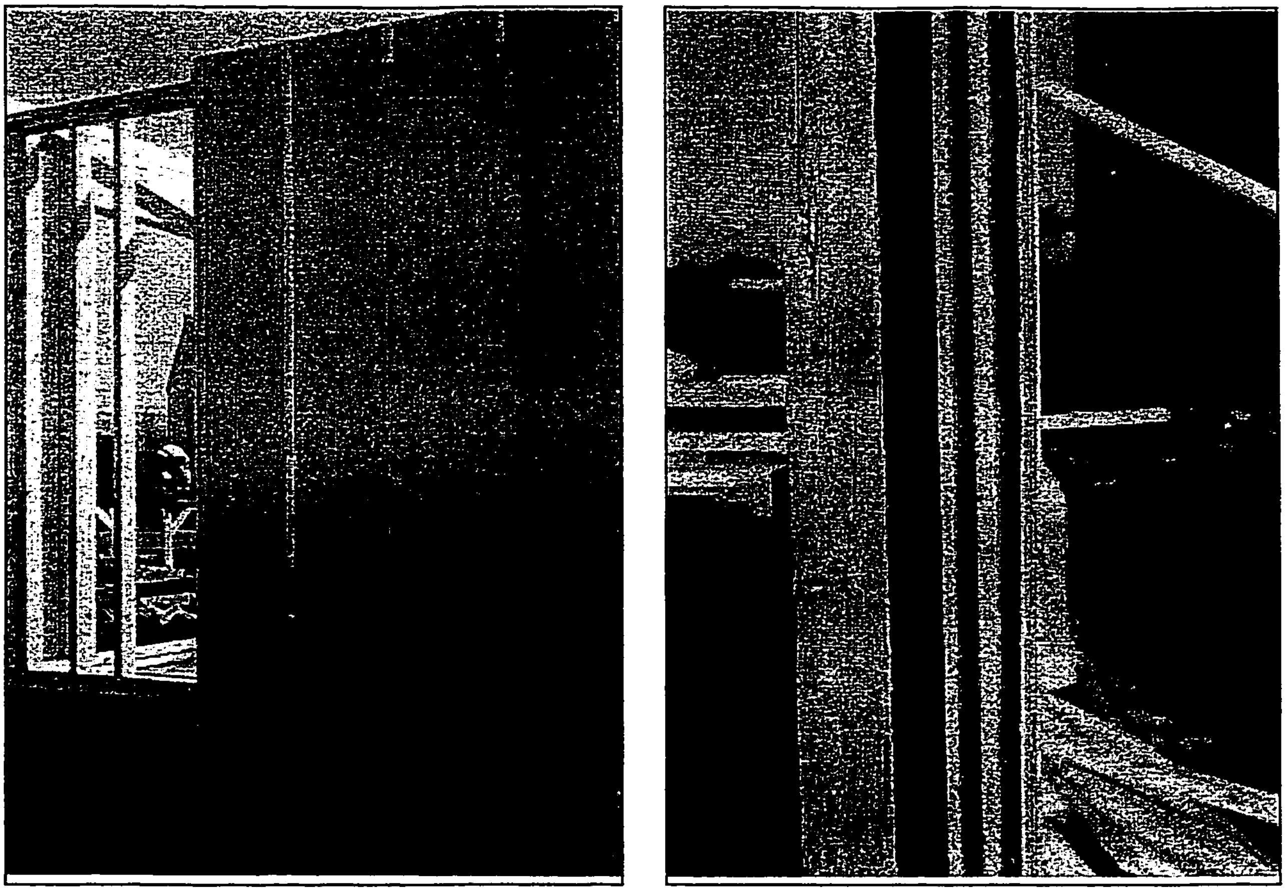
Phase 2 consisted of attaching a second layer of polystyrene to the plywood with metal screws and plastic discs. To this outer layer of insulation, one of three exterior finishes, namely

- **U.S. Brick System** (also known as Real brick), 13 mm thick clay brick affixed to a vacuum-formed polymer facing, that is factory laminated to the outer face of the rigid insulation. On site, the courses of thin bricks were glued within the retainer slots in the panels and the joints were pointed with mortar to give the appearance of a traditional brick finish. Foam rods and silicone sealant were then used to provide expansion joints for the wall.

- **Supraboard**, a fibre cement board was placed over the rigid insulation along the slab-on-grade and fastened to the metal furring (see Figure 2.3.1.1).

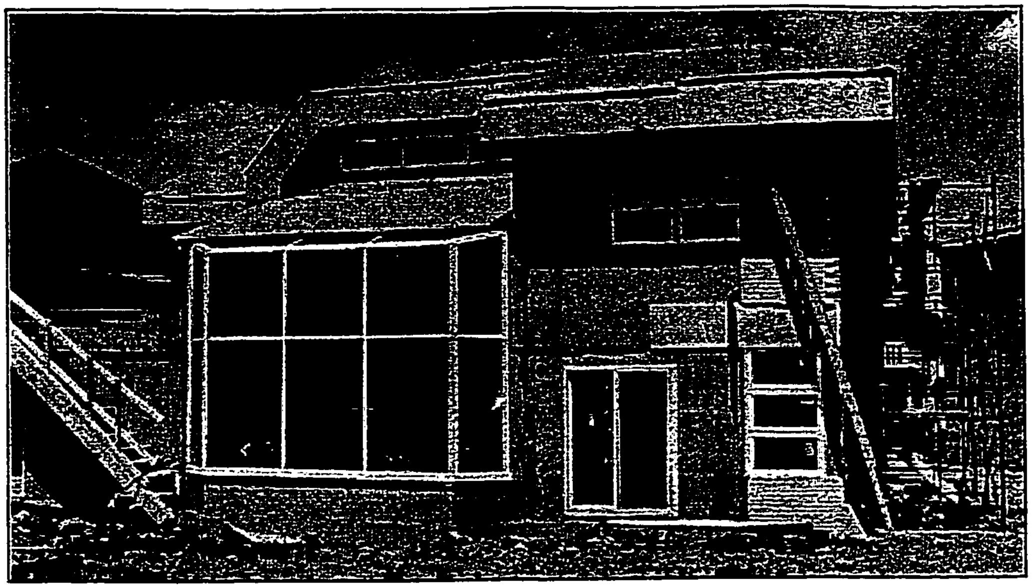
- **Gemite stucco**, a natural aggregate finish was applied to the Supraboard at the exterior wall-to-floor and wall-to-roof junctions and the west side terrace wall. Joints between boards were filled with cement mortar.

was applied. Photographs 2.3.1.2 through 2.3.1.4 illustrate the EIFS wall assembly during its construction.

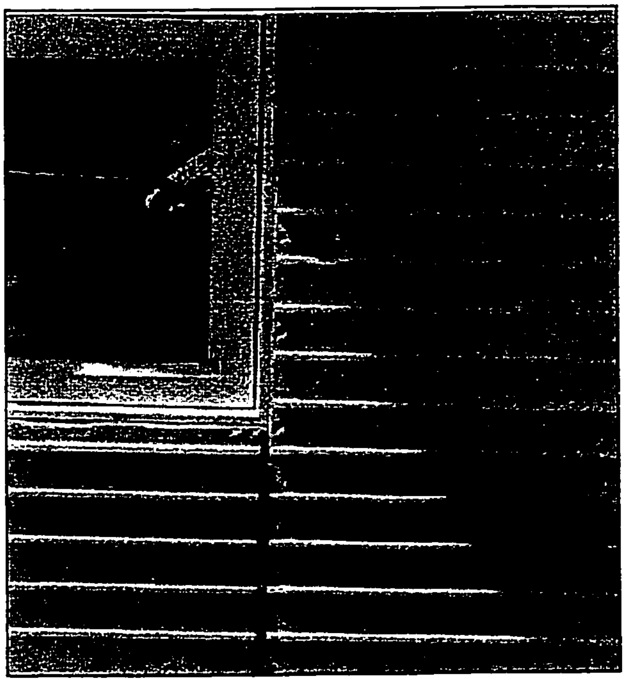


(a) (b)

Photograph 2.3.1.2: (a) Metal furring channel used to attach polystyrene to framework and fasten plywood to polystyrene, and (b) cross-sectional view of stud, first layer of insulation, and plywood

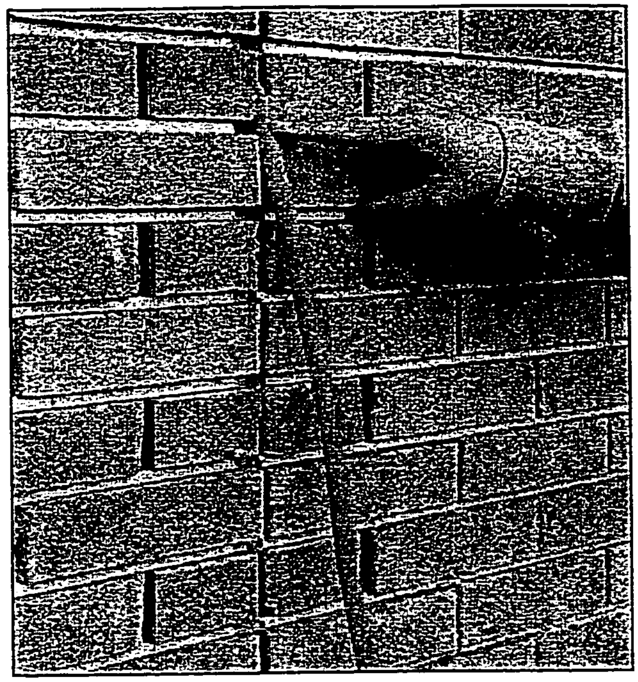


(a)



(b)

Photograph 2.3.1.3: Second layer of insulation attached to (a) plywood with (b) metal screws and plastic discs



Photograph 2.3.1.4: Foam rods used for expansion joints

2.3.2 Integrated Home Comfort System: Dual ground source heat pumps

Design and Objectives

The integrated home comfort system (IHCS) was designed to ensure high levels of thermal comfort, while minimizing energy consumption. The IHCS provides heating, cooling, ventilation, and domestic hot water heating with two ground source heat pumps (GSHP). The dual ground source heat pumps use a non-CFC refrigerant and share a common horizontal ground loop with an exhaust air heat recovery unit as illustrated in the figure below.

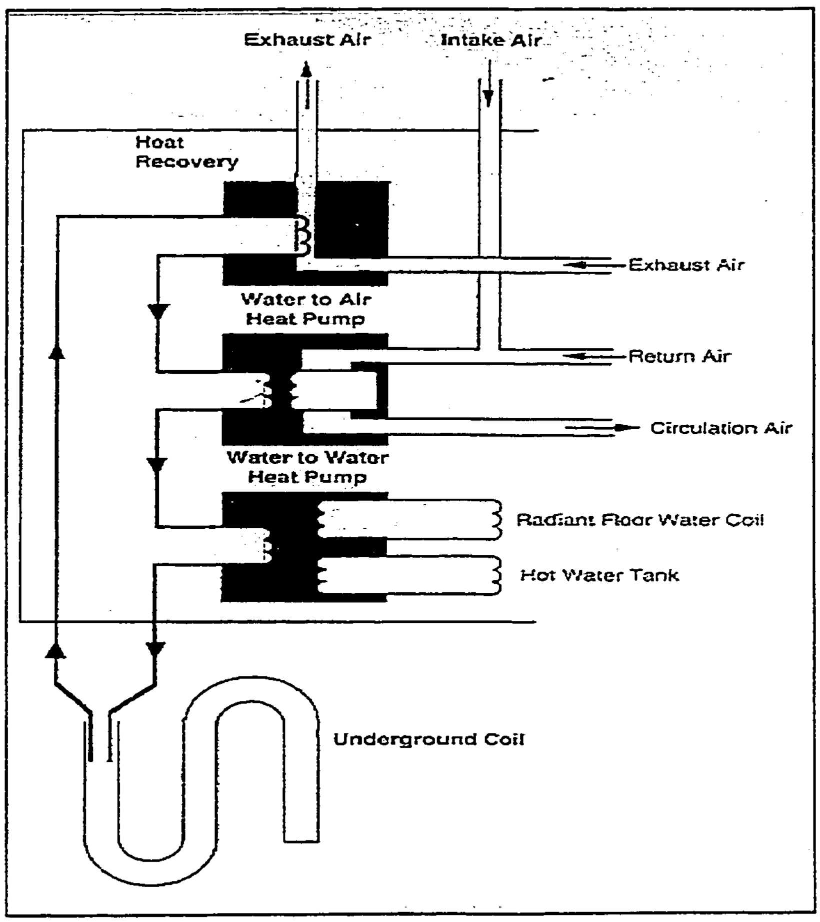


Figure 2.3.2.1: Schematic of the Integrated Home Comfort System

Ground source heat pumps achieve higher efficiency ratings when compared to conventional heating systems because they utilize the refrigeration cycle for both heating and cooling. They provide the same amount of heat as an electric furnace at approximately one third of the operating cost. Unlike air source heat pumps, GSHPs operate year-round due to the fact that ground temperatures are higher than outdoor air temperatures during winter.

The ground source heat pumps installed in the NOVTEC Advanced House operate to extract heat from the ground in winter for space heating, and reject heat to the ground in summer for cooling. They work simultaneously but have different functions. The water-to-air heat pump (WAHP) provides both space heating and cooling, and the water-to-water heat pump (WWHP) operates in heating mode only. In winter, the WAHP distributes warm air to each room through ducts, while the WWHP provides hot water to both the domestic hot water tank and the radiant floor heating system. When cooling is required, the cycle of the WAHP is reversed and heat removed from the house is either used by the WWHP for domestic hot water heating or is transferred to the ground via the ground loop. The general characteristics of the IHCS are presented in table 2.3.2.1.

Table 2.3.2.1: General Characteristics of the IHCS[8]

Component	Characteristics	Value
Heat recovery ventilator	Power input Air flow - high Air flow - low	278 W 60 l/s 30 l/s
Water to air heat pump	Heating/Cooling Capacity Air flow - heating Air flow - cooling Air flow - high speed	7 kW 470 l/s 500 l/s 660 l/s
Water to water heat pump	Heating/Cooling Capacity Pumps - radiant heating Pump - domestic hot water	7 kW 178 W, 0.3 l/s 75 W, 0.2 l/s
Ground loop pumps	Ground loop pumps	250 W, 1.2 l/s

The forced air system uses a three-speed electronic commutated motor (ECM) which has a 78% efficiency, over twice that of a regular motor. In contrast to conventional fan motors which yield a poor efficiency at part load, the efficiency of ECM motors remain relatively constant over their entire operating range[9].

The house is also equipped with a demand controlled ventilation system which ensures a minimum supply of fresh air of 30 l/sec and activates the heat recovery ventilator to high speed (60 l/sec) when the carbon dioxide or relative humidity levels exceed their respective setpoints. The carbon dioxide sensor is located in the master bedroom and the relative humidity sensor is located in the exhaust duct. The ventilation system was designed according to the "Residential Mechanical Ventilation Systems" Standard CAN/CSA-F326-M91[10]. The standard recommends a continuous ventilation rate of 55 l/s based on the type and quantity of rooms in the house, but allows for the use of a lower ventilation rate if a demand controlled ventilation system is installed. The minimum rate of 30l/s was established arbitrarily, and was to be modified based on occupant feedback.

The two-speed heat recovery ventilator draws exhaust air from the dryer, kitchen, and bathrooms and transfers the recovered heat to the water-ethanol loop before it enters the heat pumps. The heat recovered from the house exhaust raises the heat pumps' inlet temperature and, as a result, increases the efficiency of the heat pumps in heating mode.

The WAHP is an XHE-2 Earth Energy Liquid to Air prototype with a rated Coefficient of Performance (COP) of 3.5 under CSA-C446[11] standard conditions of 0°C water inlet temperature for closed loop units. The WWHP is an ETL HotSpring-2 Liquid to Water/DHW prototype and had not been rated for a COP. The ground loop pumps have a rated output of 1/6 horsepowers.

Construction

The IHCS was designed and installed by Richard Kerr of Sunworks. The transfer of heat between the two heat pumps and the ground is accomplished by 550 metres (1800') of PVC piping known as the "ZVEC" spiral coil. The coils were buried in three 25 metre (80') long trenches with the top of the coil placed below the frost line at a depth of 1.2 metres (4') below grade. Constructed of highly resistant plastic and protected from damage by a layer of sand, the 30 mm (1 3/16") tubing contains a water-ethanol mixture. Use of the spiral coil permits a large amount of piping to be installed in the relatively small confines of the backyard. Photographs 2.3.2.2 through 2.3.2.4 illustrate the sequence of installation of the ground coil.

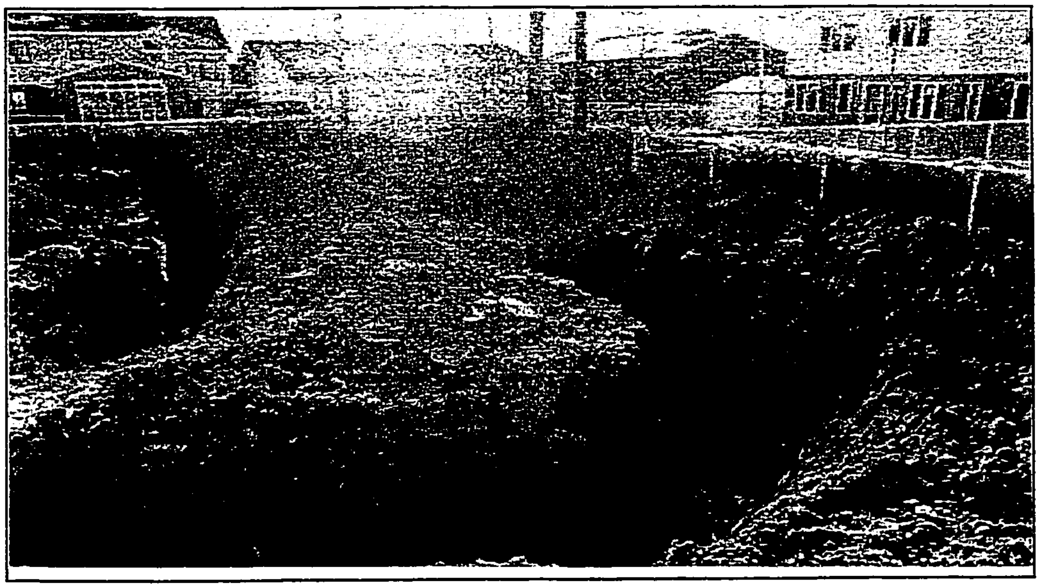


Figure 2.3.2.2: Trenches excavated in the backyard to lay the spiral coil

Figure 2.3.2.3: Installation of horizontal spiral coil

Figure 2.3.2.4: Spiral coil covered with a layer of sand

2.3.3 Radiant Slab-On-Grade Heating

Design and Objectives

The NOVTEC design called for a slab-on-grade foundation, illustrated in Figure 2.3.3.1, instead of a conventional basement wall foundation to demonstrate the superior thermal comfort offered by a concrete radiant floor heating system and to eliminate any potential problems associated with basements such as little natural lighting, poor air circulation, high humidity, and soil gas infiltration.

Radiant floor heating offers a high level of thermal comfort and contributes to a healthy indoor environment because heat is radiated to the occupants and the room's surfaces via the floor rather than only through convection. This phenomenon leads to less air movement, a higher mean radiant temperature of the space, and a lower ambient room temperature, resulting in energy savings. Since it is integrated into the building envelope, it also saves living and working space.

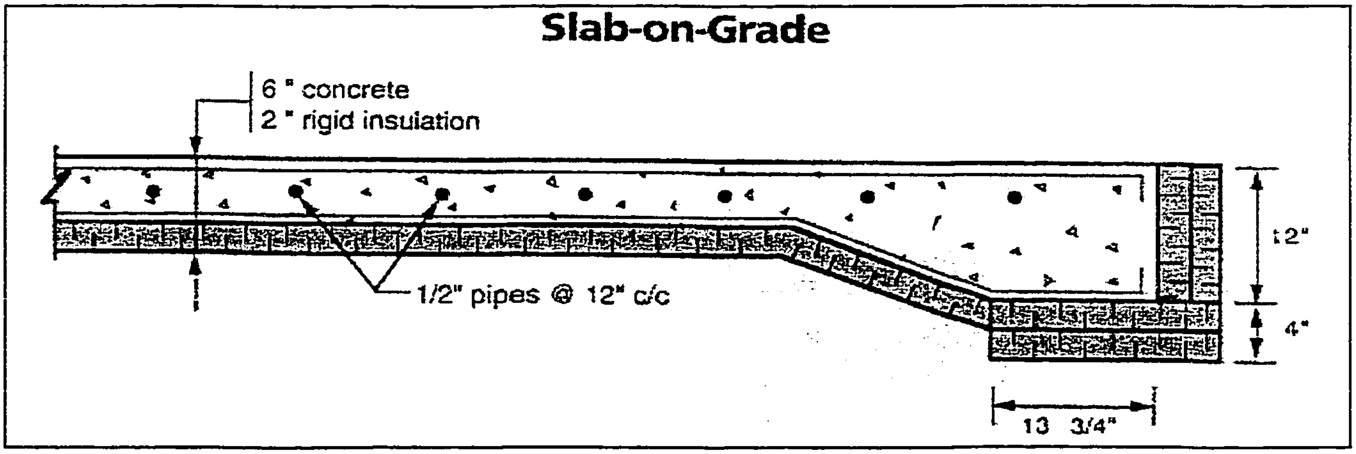


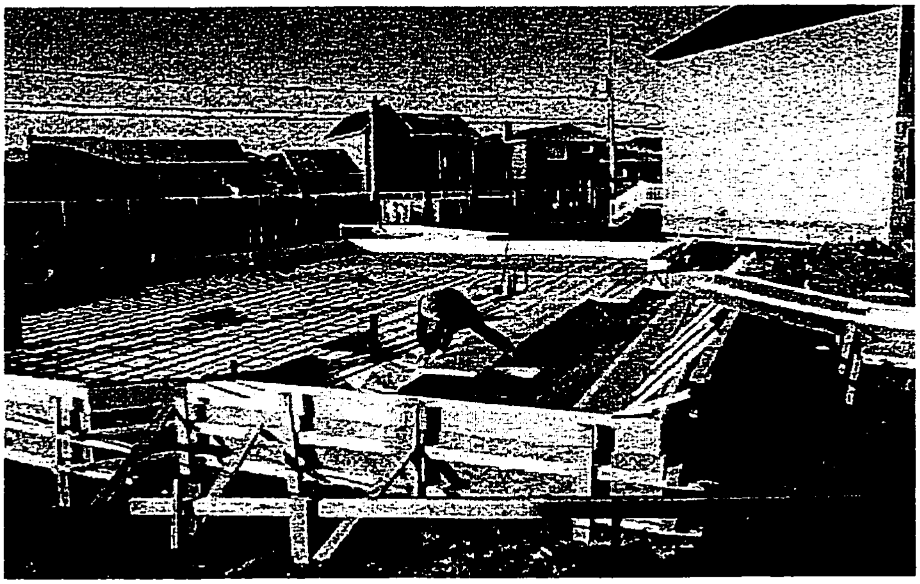
Figure 2.3.3.1: Radiant slab-on-grade foundation

One of the design objectives was to maintain the radiant floor surface temperature to within 5°C of the ambient air temperature but not above 29°C. The upper limit of 29°C is based on current standards[12] and is to avoid discomforting cramps in the occupants' lower legs. To satisfy these conditions, the radiant heating system was designed to ensure uniform slab surface temperatures between 22°C and 25°C, while the indoor air temperature was selected to be 20°C.

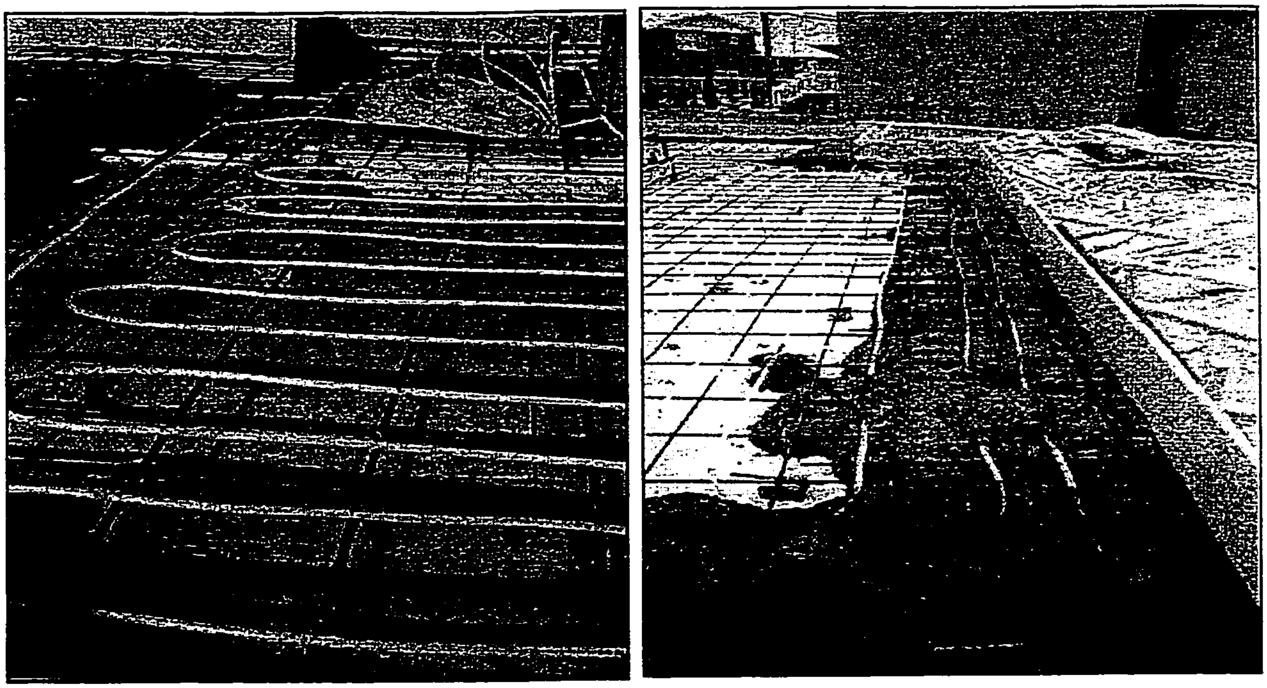
Construction

Embedded in the concrete slab-on-grade is a closed circuit of 13 mm (½") diameter polyethylene piping which circulates hot water from the WWHP. The water pipes, spaced at 30 cm center-to-center and measuring a total length of 275 m, were attached to the slab reinforcement with metal ties. The grid of water pipes consisting of four parallel circuits was installed in five hours by a 2-man crew with relative ease. This installation included the piping connections for the four water circuits to a central manifold.

The concrete slab-on-grade is 152 mm (6") thick at the center of the slab and 304 mm (12") along the perimeter. It is insulated from the ground using one layer (50 mm or 2") of rigid insulation underneath the center of the slab, and two layers (100 mm or 4") underneath the perimeter of the slab and wrapped around its edges, so as to reduce lateral heat conduction. The alternative of placing two layers of rigid insulation throughout the entire slab was considered but the risk of freezing the ground below the center of the slab excluded this option. The rigid insulation used was a CFC-free extruded polystyrene insulation in 50 mm (2") thick panels with a nominal thermal resistance of Rsi-1.76 (R10). Photographs 2.3.3.2 through 2.3.3.4 illustrate the radiant slab-on-grade during its construction.

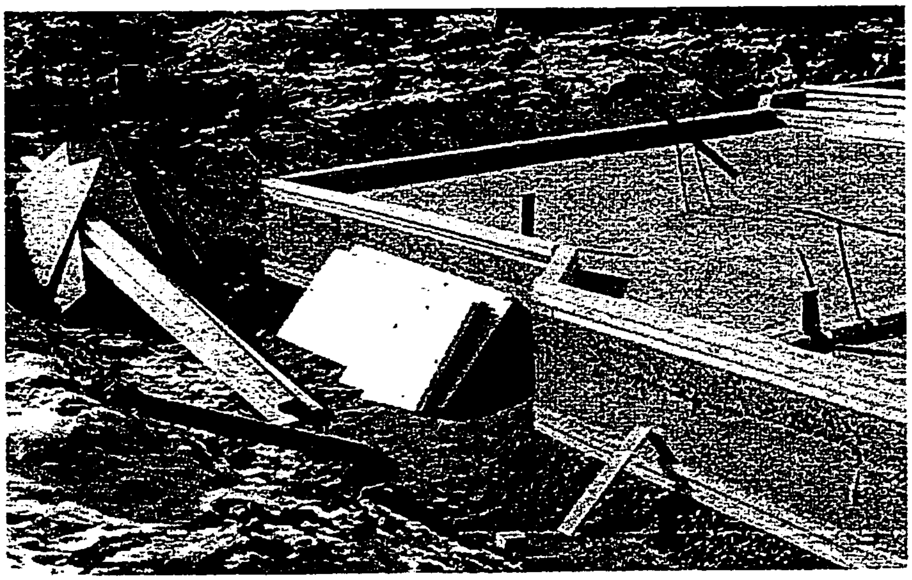


Photograph 2.3.3.2: Placement of insulation underneath center and along perimeter of slab



(a) (b)

Photograph 2.3.3.3: Grid of pipes attached to (a) slab reinforcement with metal ties and (b) embedded in the concrete slab-on-grade



Photograph 2.3.3.4: View of radiant slab after concrete pouring

2.3.4 Home Automation and Energy Management System

Design and Objectives

To maximize energy efficiency, the NOVTEC Advanced House is equipped with a home automation system which integrates household security, lights, appliances, energy management, and telecommunications. The system also incorporates algorithms to optimize the operation of the Integrated Home Comfort System (IHCS).

The IHCS is controlled by two thermostats (one on each floor) using a set of programmed algorithms which were developed and tested by the authour and Richard Kerr of Sunworks. These algorithms are presented in Figure 2.3.4.1. The ground floor thermostat (#2) controls the WAHP (forced air heating and cooling) and the WWHP (radiant heating). The radiant heating system is activated first when the ambient air temperature falls below one differential of the setpoint temperature (T3). If radiant heating is not sufficient to maintain the indoor air temperature within two differentials of the setpoint temperature (T4), the home automation system activates the WAHP (represented by the term "Chauffage"). If the indoor air temperature falls below three differentials of the setpoint temperature (T5), the backup electric heating element is activated. When the ambient air temperature exceeds the thermal comfort level by one differential (T1), the home automation system will activate the WAHP blower (represented by the term "Ventilateur") to operate at high speed until the indoor air temperature is brought back down to within one differential of the setpoint temperature. The cooling system is activated (at T2) when the room temperature exceeds the setpoint temperature by two differentials. Regardless of the radiant heating demand, the WWHP gives priority to the DHW heating demand.

The thermostat on the first floor (#1) controls the WAHP only and operates on the same principles as the thermostat on the ground floor. The authour was concerned of the potential conflict which may arise from the fact that the single zone WAHP was controlled by two thermostats. The energy consumption of the heatpumps in heating mode would provide a good indication of the frequency of occurrence of the conflict whereby the WAHP would be activated by the second floor thermostat while the first floor thermostat would be calling for radiant heating.

Other energy saving features of the home automation system include: 1) an "energy watchdog function" which prompts the occupants if they want to shut down the operation of mechanical systems when doors or windows have been open for more than 10 minutes, 2) an "automatic temperature setback function" which is activated by telephone or when occupants leave the home, and 3) an "action-reaction function" where motion sensors control the lights in the house.

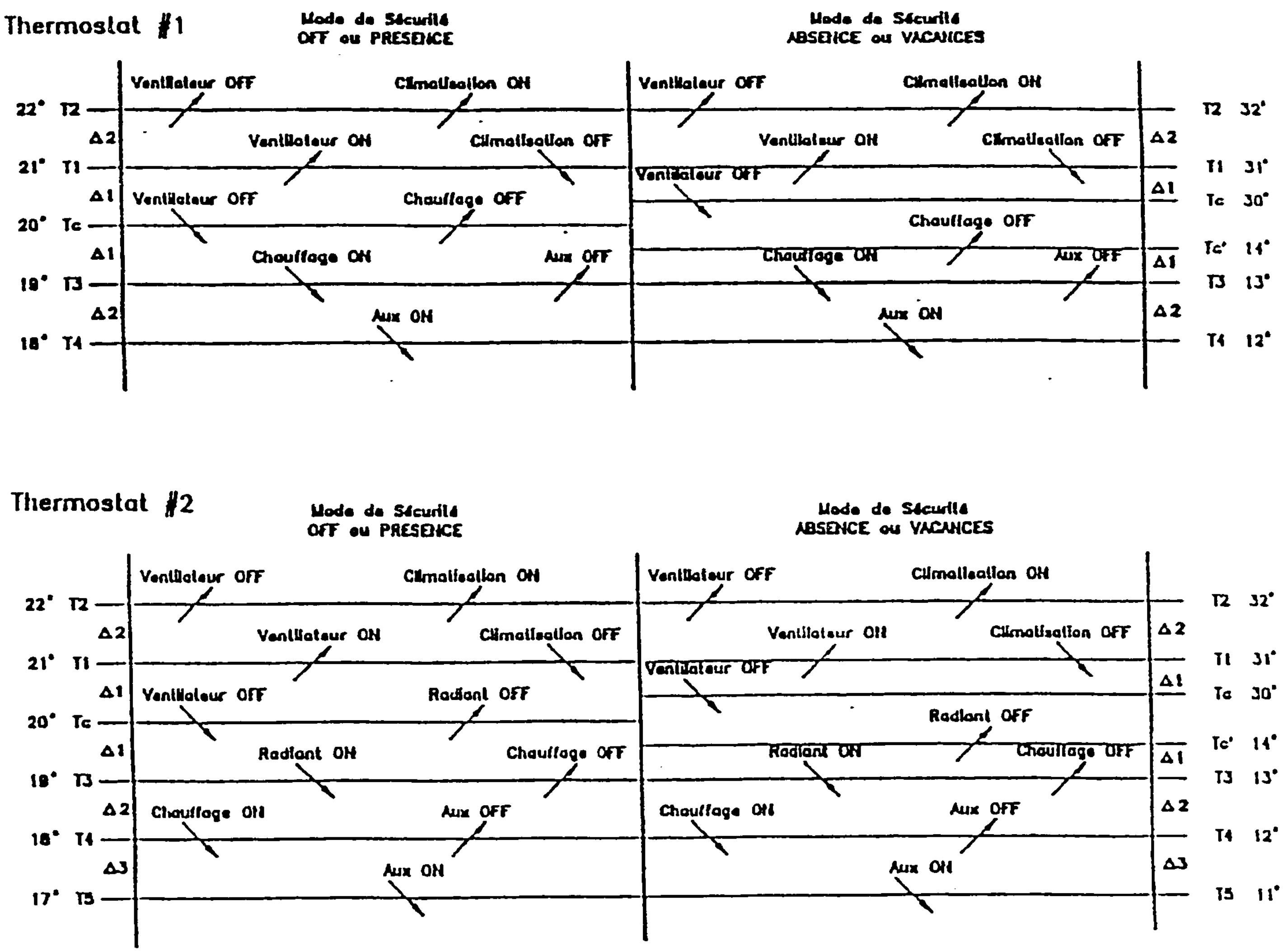
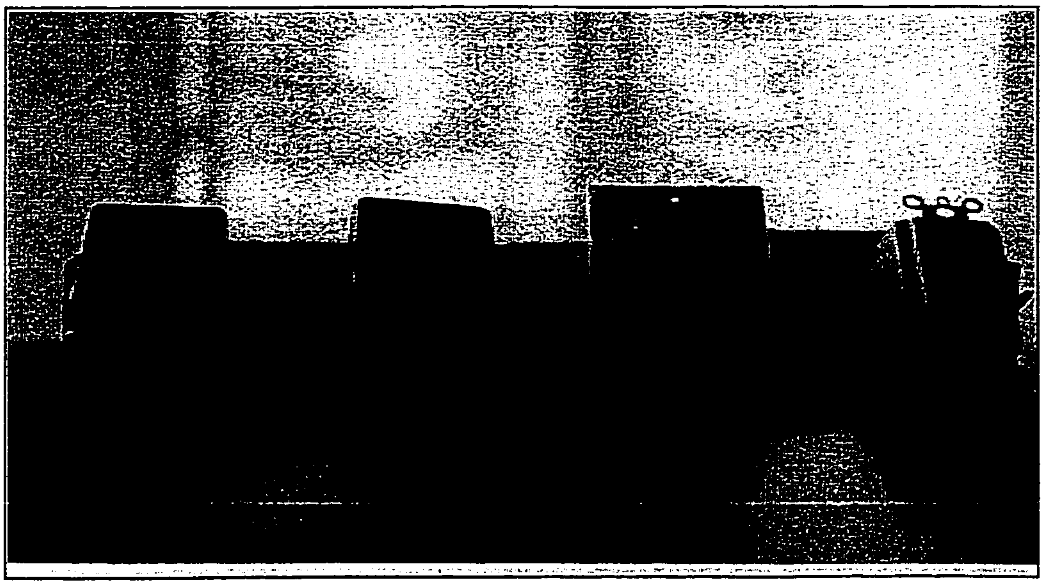


Figure 2.3.4.1: Thermostat algorithms for the heat pumps

Construction

The home automation system was designed and installed by SECANT. The switches and outlets manufactured by Leviton use the X-10 communications protocol. No special wiring is required to install the system controls because all signals are transmitted through the standard 120-volt AC power line. The system includes a central control module, a programmable keypad, security sensors, motion and smoke detectors, thermostats, humidistats, and communication switches which are all linked by a house BUS. The homeowner has access to four keypads and can access the system remotely through the use of a touch-tone telephone. Furthermore, the system can communicate with a remote station to alert people in the case of an emergency by automatically dialing a pre-programmed telephone number. Photographs 2.3.4.2 (a) and (b) illustrate the components of the Secant home automation and energy management system.



Photograph 2.3.4.2: (a) X-10 switches and outlets

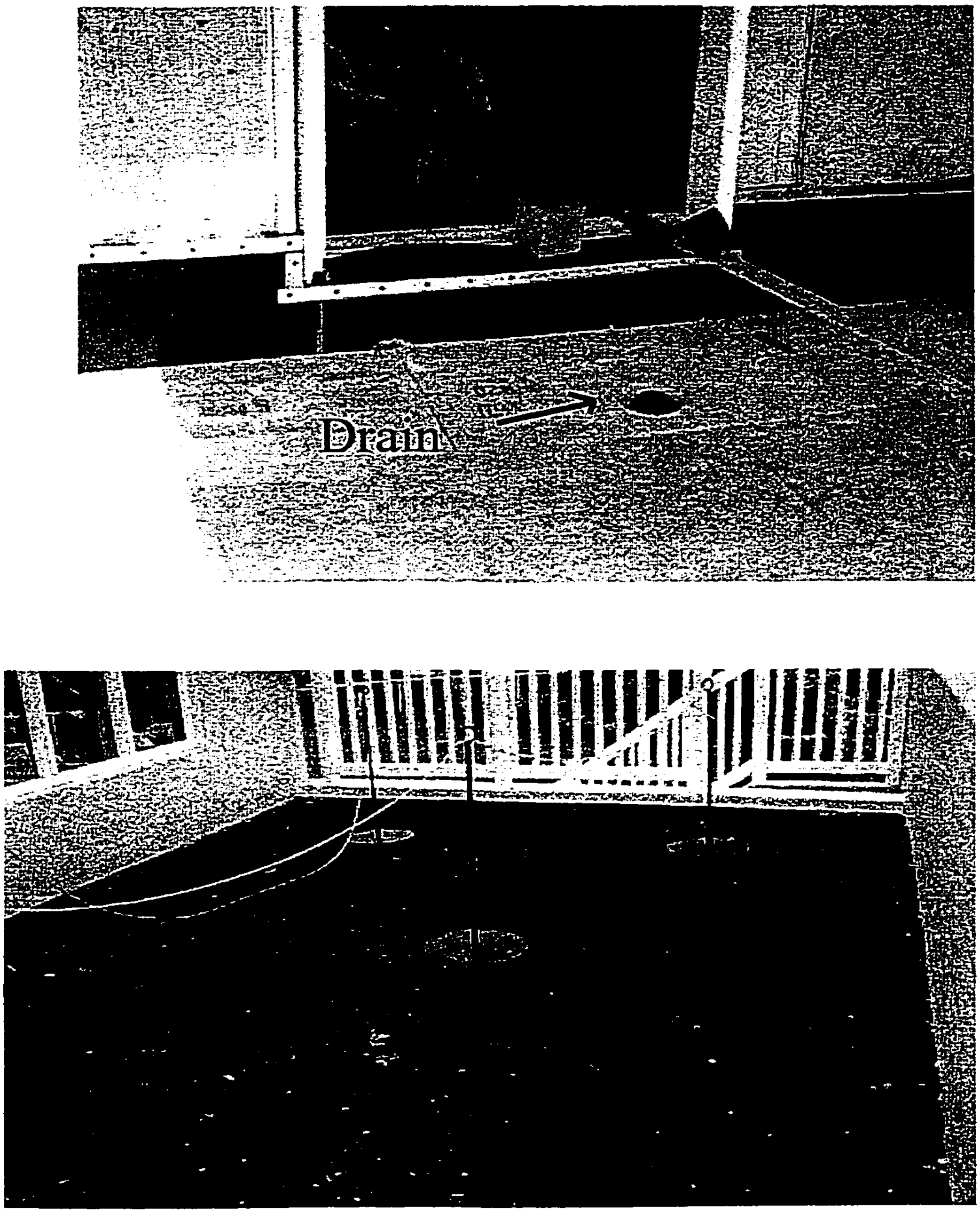
2.3.5 Recycled Rubber Crumb Protected Membrane Roof System

Design and Objectives

Over the garage, a roof terrace was constructed instead of a traditional inclined roof in order to provide additional outdoor recreational space. A protected membrane roofing (PMR), used mainly in commercial applications, was selected based on its functionality, durability, impermeability, and energy efficiency characteristics. Stemming from the NOVTEC design philosophy of using cost-competitive building materials, the PMR system was built using common and recycled building materials. In order to protect the roofing system from ultraviolet radiation and wind uplift, a permeable recycled rubber crumb covering (RRC) was chosen for its environmental advantages, light weight, and easy installation. RRC coverings had been successfully used in the United Kingdom for years. Its application in the NOVTEC Advanced House marked a first in Canada.

Construction

The roof is supported with wood trusses and was waterproofed by means of a single-ply membrane. A geotextile covering separates the membrane from the exterior plywood decking in order to prevent premature wear. To ensure watertightness, the membrane was extended up the face of adjacent walls and sealed along its perimeter. The membrane was then covered with 100 mm (4") of extruded polystyrene rigid insulation (Foamular 300), a high density product capable of withstanding compressive pressures of up to 240 kPa. The exterior placement of the insulation reduces the temperature fluctuations on the waterproofing membrane and provides a nominal thermal resistance of Rsi-3.5 (R20). Channels cut on the underside of the insulation facilitate drainage. The RRC cover was glued to the surface of the insulation. The combined thermal resistance of the RRC-PMR system is Rsi-4.44 (R25). Photographs 2.3.5.1 (a) and (b) illustrate the PMR system during construction.



(a)

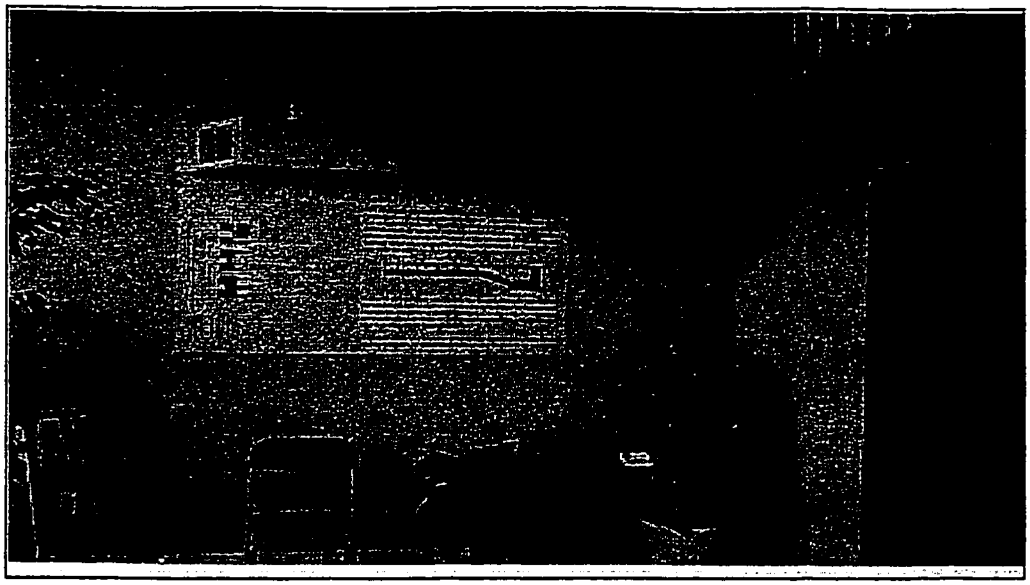
(b)

Photograph 2.3.5.1: Waterproofing membrane (a) extended up against adjacent walls and sealed along its perimeter, covered with rigid insulation, and (b) RRC covering placed over insulation

2.3.6 Pollutant Metabolizing Plants

Plants which revitalize the air by extracting and metabolizing pollutants were placed in the house. The house plants were selected on the basis of results from a study conducted by NASA which demonstrated that plants can be used for indoor air purification and waste water treatment[13]. In all, 13 different species of plants were selected for the NOVTEC Advanced House to help reduce levels of toxic gases such as formaldehyde, benzene, toluene, and carbon monoxide, released by building materials, interior finishes, furniture, and from smoking. Photograph 2.3.6.1 illustrates the numerous plants placed in the atrium family room. The plant species included:

- Aloe vera,
- Chinese evergreen,
- English ivy,
- Ficus,
- Golden pothos,
- Marginata,
- Mass cane,
- Mini-schefflera,
- Mother-in-law's tongue,
- Peace lily,
- Spider plant,
- Arrowhead plant, and
- Warneckei.



Photograph 2.3.6.1: Pollutant metabolizing plants placed in the atrium family room

2.3.7 Reverse Osmosis and Water Filtration System

A reverse osmosis and carbon filter water treatment system was installed in the kitchen to purify the potable water and provide high quality drinking water. A separate tap at the kitchen sink provides the purified water. A small reservoir, placed beneath the sink, holds a maximum of 10 litres of purified water. The system is unique in its use of a natural based product of citrus extracts to control any biological pollutants present in the water reservoir tank. The concentration levels (in PPM) of natural extract is controlled by a volumetric pump. The reverse osmosis and carbon filter water treatment system was not chemically tested by the authour.

In addition, to help the occupants reduce the demand for fresh water, low-flow plumbing fixtures and water saving toilets which use only 6 litres/flush were installed in the bathrooms, a savings of up to 80% from conventional toilets. In addition, a composting toilet was installed on the second floor for the one year open house period to demonstrate its potential use in remote housing with no drainage facilities.

2.3.8 Natural Lighting and High Performance Windows

The strategically located windows of the NOVTEC Advanced House provide optimum natural lighting. The ceiling-high corner windows are positioned so as to admit as much sunlight as possible into the living space. The large south-facing atrium, shown in Photograph 2.2.1(b), combined with the interior open-plan design allows natural light to enter at all levels of the house and consequently reduces the heating energy demand. Over 9 feet high, the atrium consists of triple-glazing, low-E coated windows with heat mirrors 66 (vertical panes) and 88 (sloped panes). Thermally broken aluminium frames were used with steel spacers. The atrium has an energy rating[14] of -8, an overall U-value of 2.05 W/(m²°C), and a solar heat gain coefficient of 0.52.

The PVC-framed windows used in the rest of the house, are double-glazed, low-E coated and argon-filled with a thermal resistance of Rsi-0.6 (R3). Thermal insulating spacers are used to enhance the energy performance of the windows. The windows have an energy rating of -13, an overall window U-value of 2.15 W/(m²°C), and a solar heat gain coefficient of 0.48.

2.3.9 Environmentally Friendly Construction and Landscaping

The NOVTEC team sought design solutions that were both energy efficient and environmentally sound. This was clearly demonstrated throughout the interior and exterior of the house. Special emphasis was placed on conserving wood by using only 38 x 89 mm (2" x 4") lumber, premanufactured glue laminated beams, and open-web floor joists.

The landscaping around the NOVTEC Advanced House was designed to create a microclimate that promotes energy efficiency. Trees reduce local exterior pollutants, provide soil stabilization, reduce CO_2 levels and release oxygen, filter airborne dust particles and rainborne pollutants from the air, and help filter ground water.

The broad-leaved trees placed around the house were chosen on the basis of two criteria. The first selection criteria was the size of the crown, which determines the amount of shade the tree will provide in summer and the density of the branches which affects the amount of solar radiation the home will be exposed to in winter. The second criteria was the rate of growth of the trees and the capacity to eliminate air-polluting gases like carbon dioxide. Three specific kinds of trees were planted on the southeast and southwest areas of the backyard in order to provide ample shade for the home during the summer months; these include the American linden tree (Tilia americana), the mountain sorb or service tree (Sorbus acuparia var, fastigiata), and the Norwegian maple (Acer platanoïdes).

2.3.10 Energy Efficient Lighting and Appliances

Major household appliances and lighting fixtures were selected on the basis of their energy efficiency. The criteria for the major appliances was their Energuide ratings (ratings shown in technical compliance checklist). Low voltage halogen and compact fluorescent lights were used for most indoor lighting tasks.

3.0 EXPECTED PERFORMANCE BASED ON COMPUTER SIMULATIONS

3.1 EXPECTED ENERGY PERFORMANCE

The expected whole-house annual energy consumption for the NOVTEC Advanced House under occupied conditions was 11,860 kWh or 53 kWh/m², approximately 50% of the annual energy consumption of a typical R-2000 house[15] (built in 1985 or earlier) which is 104 kWh/m². Heating and cooling was expected to account for 50% of the whole-house energy consumption, and DHW heating for just under 9%. These estimates were obtained through energy simulations performed by the authour using HOT-2000, version 6.02.

HOT-2000, developed by Natural Resources Canada, is an energy simulation program which combines monthly energy balance calculations and bin hour heat-loss calculation methods to predict the annual end-use energy consumption for space heating, cooling, ventilation, domestic hot water heating, and lighting and appliances. It uses the AIM-2 model (Alberta Infiltration Model) for simulating the heating demand due to infiltration based on temperature and pressure differences, chimneys, house height, and wind exposure factors. Designed mainly for simulating houses, Hot-2000 is the industry recognized energy simulation tool, and it has been validated with other established energy simulation programs such as BLAST and DOE-2[16].

The software provides a user-friendly interface to input information required for a detailed energy analysis. The NOVTEC House's energy characteristics were entered under the following categories:

- Building Envelope Components - thermal resistance, airtightness, dimensions, and characteristics of walls, roofs, slab-on-grade, etc.;

- Windows - dimensions, orientations, and type of frames, spacers, glazings, low-e films, heat mirrors, etc. of windows and skylights;

- Mechanical Systems - Type, capacity, efficiency, fuel source, and other performance data related to heating, cooling, ventilation, and domestic hot water heating systems;

- Indoor Environment - Number of occupants and the expected daily hot water, lighting, and appliances energy consumption based on ENERGUIDE ratings.

- Weather data - City, latitude and longitude, and shielding factor for estimating infiltration due to wind.

Figure 3.1.1 illustrates the Advanced Houses Program's (ADVP) energy targets versus the NOVTEC Advanced House's expected energy performance. Although the expected annual energy consumption was 2% greater than the target, the design was accepted by NRCan because it was within 5% of the target. The main discrepancy between end-use energy consumption values were those for DHW heating. The low energy consumption expected for DHW heating was mainly attributed to its use of the "free" heat rejected by the cooling system and the high efficiency of the water-to-water heat pump.

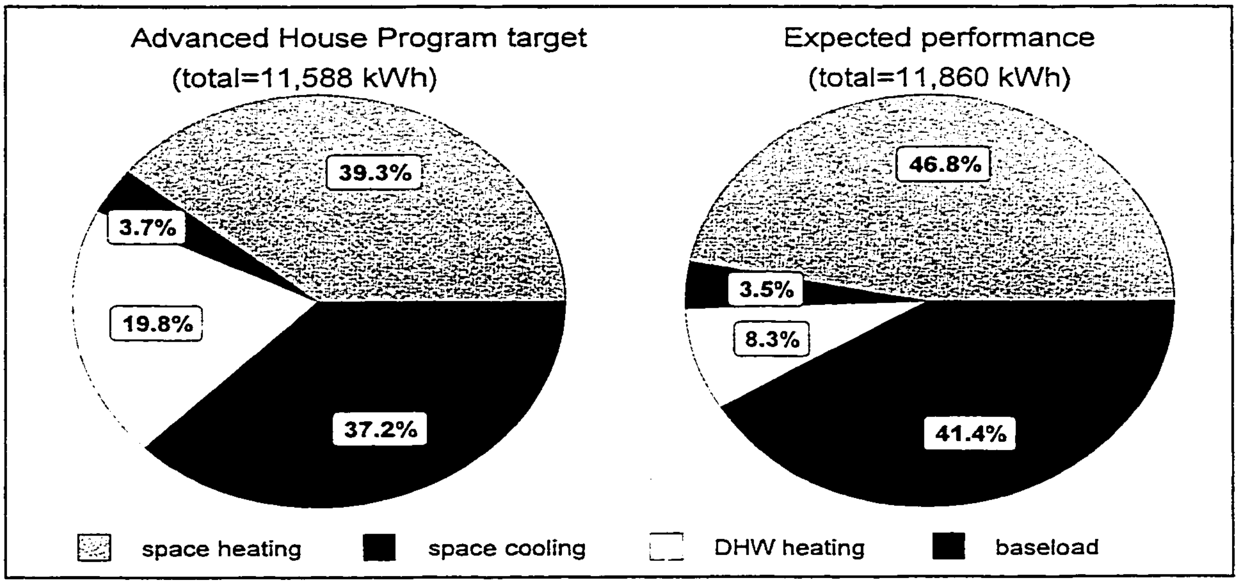


Figure 3.1.1: ADVP targets versus expected energy use for the NOVTEC Advanced House

Figure 3.1.2 compares the heat loss density of the NOVTEC Advanced House to that of different age groups of Quebec housing stock. The NOVTEC Advanced House has a design heat loss density (W/m^2) of 49% of that of a Quebec house built within 1981-90 and 42% of that of a Quebec house built within 1971-80[17].

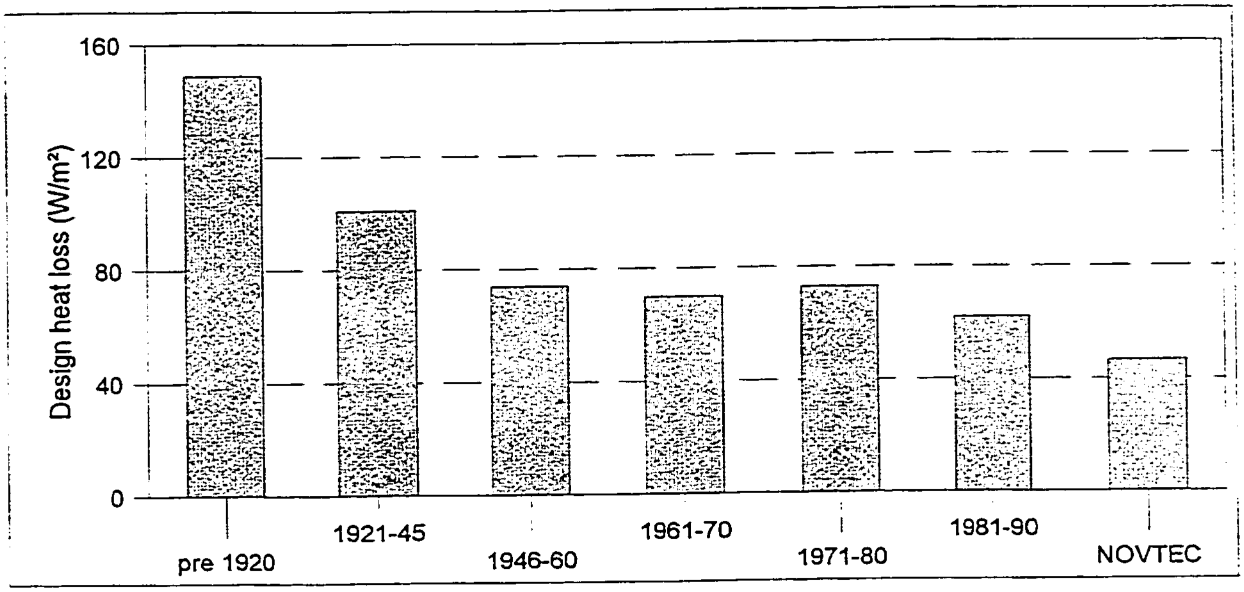


Figure 3.1.2: Comparison of the heat loss density of the NOVTEC Advanced House to various Quebec housing stock

3.2 ADVP TECHNICAL COMPLIANCE CHECKLIST

The Advanced Houses Program technical compliance checklist of the NOVTEC Advanced House is summarized in Table 3.2.1.

Table 3.2.1: Advanced House Program technical compliance of the NOVTEC Advanced House

category	expected performance	ADVP target	compliance
Building Envelope			
Airtightness @ 50 Pascals	< 1.5 ACH@50Pa	1.5 ACH@50Pa	✓ 1.32 ACH@50Pa
Appliances			
Refrigerator	660 kWh/yr	240 kWh/yr	✗
Stove	768 kWh/yr	780 kWh/yr	✓
Clothes washer (excl. hot water)	100 kWh/yr	144 kWh/yr	✓
Clothes dryer	828 kWh/yr	1140 kWh/yr	✓
Dishwasher	210 kWh/yr	252 kWh/yr	✓
Lighting			
Lighting density	8.6 W/m²	8.0 W/m²	✗
Average fixture output	not available	40 lumens/watt	n/a
Fan energy (with forced air heating)			
Consumption rate	0.6 W/L/s	0.75 W/L/s	✓
Water Use			
Urinal	3 to 6 L/flush	n/a	n/a

Water Use			
Faucets	4 @ 8.3 L/min. & aerators	5.6 L/min. & aerators	✘ (accepted)
Toilets	1 @ 6 L/flush, 2 @ 13.25 L/flush	7 L/flush	✓
Shower heads	1 @ 9.4 L/min., 1 @ 20 L/min.	10 L/min.	✓
Washing machine	158 L/cycle	n/a	n/a
Dishwasher	40 L/cycle	n/a	n/a
Annual energy use			
Space heating	5552 kWh	4550 kWh	✕
Space cooling	419 kWh	423 kWh	✓
DHW heating	981 kWh	2300 kWh	✓
Baseload	4908 kWh	4315 kWh	✕
TOTAL	11,860 kWh	11,588 kWh	2.3% more (accepted)

Legend:
- ✔ compliant
- ✘ non-compliant
- n/a not applicable

3.3 Limitations of the Research

Presented below are the principal limitations of the research which should be considered in future research projects which deal with the in-situ performance of residential mechanical systems:

i. ***The absence of occupants*** did not permit the authour to monitor and thoroughly evaluate the domestic hot water heating system, the impact of increased air change due to the opening and closing of doors and windows, and the impact of the occupants' interaction with the integrated home comfort system and the home automation system;

ii. ***The absence of shading devices*** permitted more passive solar gains to enter the home, thus causing an unrealistic demand on the cooling system and a reduction on the heating demand;

iii. ***The use of carpet on the ground floor*** reduced the heating output of the radiant heating system to the space and also prevented the concrete slab from attaining its heat storage capacity, thus not presenting a true portrait of the system's potential.

4.0 MONITORING PLAN

The monitoring plan was designed to verify compliance to the Advanced Houses Program technical requirements[18] and to evaluate the performance of individual systems.

Two critical performance criteria which had been used to predict the annual energy consumption and which needed to be confirmed through testing and monitoring were the:

Airtightness of the house : measured by performing a blower door test according to the Canadian CGSB Standard 149.10-M86[19]. The airtightness of a house or building is measured in ACH50 which represents the number of volumetric air changes which occur when the building envelope is subjected to a depressurization of 50 Pa. Compliance to the building envelope airtightness target represented the first critical technical milestone of the project. A blower door test[20] performed in May 1993 revealed an airtightness level of 1.32 ACH@50Pa, thus attaining compliance to the ADVP target of 1.5 ACH@50Pa.

Seasonal Efficiency of the IHCS. This value, also known as the «Coefficient of Performance - COP» is the ratio of the output energy of the IHCS (space heating, space cooling, domestic hot water heating) to the purchased electrical energy used by the IHCS (two ground source heatpumps, circulating pumps, blower, controls, etc.). A seasonal COP between 2.5 and 3.5 would bring the house's total purchased energy consumption within reach of the Advanced Houses Program's target.

This section presents the monitoring plan which was implemented to monitor the energy performance of the house and to monitor the COPs of the IHCS and of the individual ground source heat pumps.

The NOVTEC Advanced House energy performance monitoring plan is based on the Level B monitoring guidelines[21] developed by CANMET (Canada Centre for Mineral and Energy Technology). A combination of continuous, short-term, one-time and manual measurements were obtained to assess the following parameters:

- Whole House Energy Consumption,
- Integrated Home Comfort System Efficiency (heating, cooling, and DHW),
- End-Use Energy Consumptions, and
- DHW Usage.

The monitoring system consisted of two computers (IBM 286ATs), four Data Acquisition Systems[22], and over 100 sensors (pressure transducers, thermocouples, flow meters, energy meters, etc.). The monitoring plan consists of the following methods of data collection:

- Continuous measurements at intervals of one minute, integrated and stored into hourly and daily averages or sums using a software called Copilot[23];
- Collection and storing of continuous data for short selected periods using standalone monitoring equipment;
- Bi-weekly short term measurements collected using thermocouples and moisture pins;
- One-time measurements using handheld equipment;
- Local weather data monitored at Dorval and obtained from Environment Services Canada;
- Visual inspections of the building systems; and
- Manual meter readings of the main house meter and automatic electronic meter readings of individual appliances and sub-systems.

Quality assurance of the data collection process was achieved by periodically (two to three times a week) analysing real time data via a remote computer and a modem which were located in the authour's office. Validity checks were also performed automatically through the data collection software.

Once the raw data was collected, a spreadsheet-based processing software, which was customized for each of the ten Advanced Houses, was used to produce daily and monthly summaries. The analysis software was developed by Ken Cooper of SAR Engineering of Burnaby, B.C. using Microsoft Excel spreadsheets and sub-programs. The software allows the user to import monthly batches of ASCII data, from the Copilot data acquisition software, into a database template. The processing software then extracts one day of hourly raw data at a time, performs numerous calculations, and then places the results into a standard report format. Presented below is a summary of the monitored parameters and sensors used. The complete monitoring plan is presented in Appendix A and a typical monthly monitoring report is included in Appendix B.

Monitoring Parameter	# of Locations	Sensor Type
1. Air Temperature	16	Thermistors& Thermocouples
2. Ground Temperatures	17	Thermocouples
3. Relative Humidity	2	RH Sensors
4. Solar Radiation	2	Pyranometers
5. Electric Energy	15	kWh meters with pulse output
6. Water temperature	10	Thermistor Probes with Pete Plugs
7. Equipment Status (On/Off)	3	Voltage Status Sensors
8. Water flow	4	Flow meters with pulse output\
9. Air Flow	3	Hot Wire Anemometer, Pitot Arrays & Pressure Transducers

5.0 ENERGY PERFORMANCE RESULTS

The energy performance results are based on monitored data collected over a 21-month period from November 1993 to July 1995. The results are presented in the following sections:

- 5.1 Summary of climatological data during the monitoring period,
- 5.2 Whole house energy performance,
- 5.3 Whole house energy balance,
- 5.4 Integrated home comfort system performance,
    - 5.4.1 overall system performance
    - 5.4.2 water-to-air ground source heat pump
    - 5.4.3 water-to-water ground source heat pump
    - 5.4.4 ground loop pumps
    - 5.4.5 space heating
    - 5.4.6 space cooling
    - 5.4.7 domestic hot water heating
    - 5.4.8 heat recovery ventilation
- 5.5 Lights and appliances

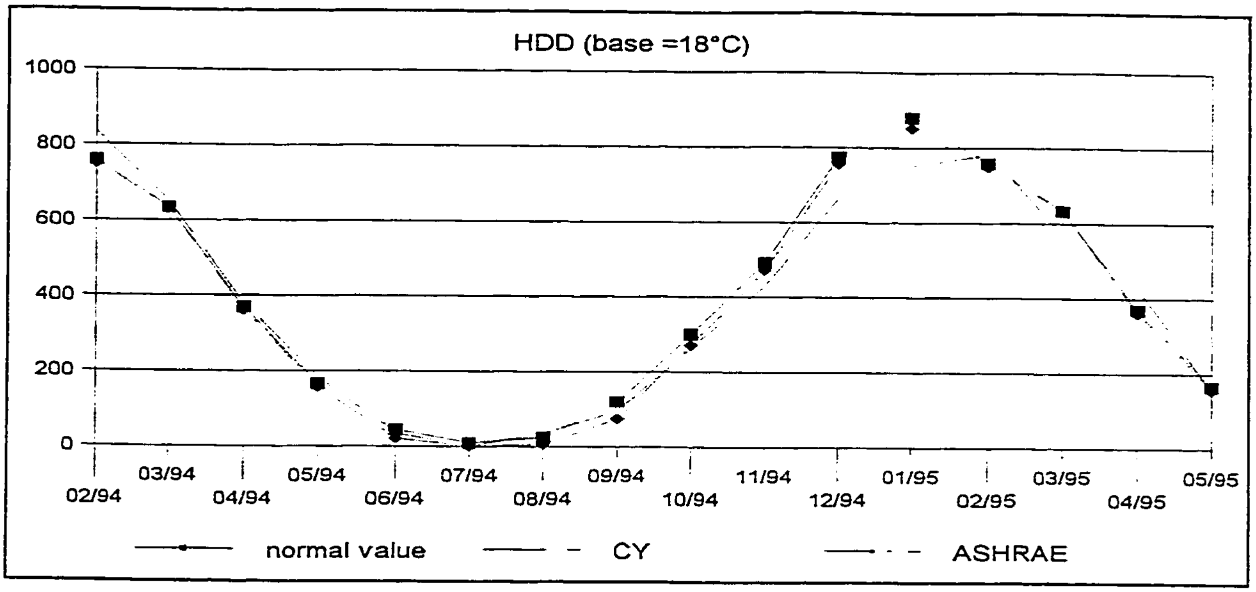
Although the house was unoccupied during the monitoring period, the **occupied** ADVP targets were used to evaluate the energy performance of the house because:

- The home was heated and cooled so as to maintain occupied thermal comfort conditions.
- Annual energy consumption for lights and appliances during the public open house period (including monitoring equipment and plug loads) averaged 15 kWh/day, 27% more than the Program's target for lighting and appliances. This base load energy consumption corresponds to that of a typical family.
- The continuous operation of the ground loop pumps accounted for 50% of the DHW heating system's standby losses. If the operation of the ground loop pumps was based on hot water demand, it is estimated that the added DHW heating energy consumption during the occupied period (assuming 186 litres/day and COP = 3.3) would result in an increase of only 1 to 2% in the house's total energy consumption.

5.1 SUMMARY OF CLIMATOLOGICAL DATA

Monthly current year (CY), normal values, and ASHRAE design climatological data for the region of Montreal[24] for the monitoring period from February 1994 to May 1995 are shown in Figure 5.1.1. The normal values represent the 30-year average from 1961 to 1990.

Slightly warmer temperatures during the winter months of December 1994 and January 1995 accounted for a 12% decrease in the CY heating degree days (HDD) for those two months and an overall 4% decrease in the HDD for the monitoring period as compared to the normal values. The average monthly standard deviation of heating degree-days (HDD) for the three sources listed was 31 degree days with a maximum of 76 degree days. The average monthly standard deviation of cooling degree-days (CDD) for the two sources shown was 17 degree days with a maximum of 29 degree days.



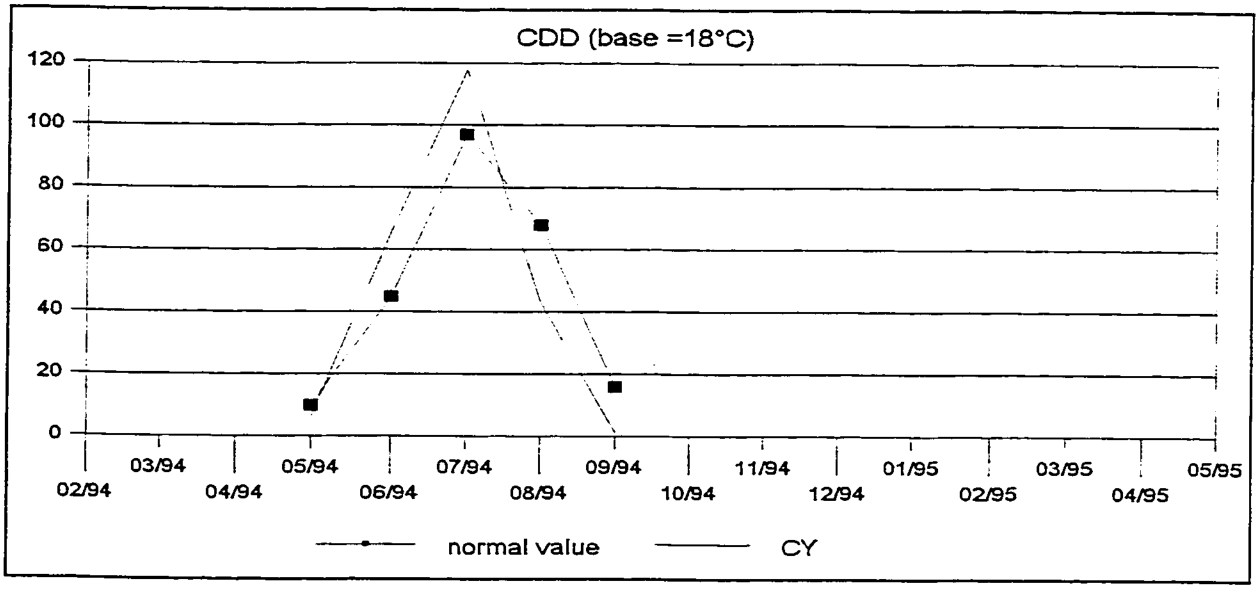


Figure 5.1.1: Comparison of (a) heating degree-days and (b) cooling degree-days for Montreal

5.2 WHOLE HOUSE ENERGY PERFORMANCE

Figure 5.2.1 compares the ADVP annual energy consumption target to the expected energy performance and the actual energy consumption for the NOVTEC Advanced House. The actual energy consumption (13,227 kWh) was 11% more than the expected performance (design stage simulations) and 14% more than the ADVP target.

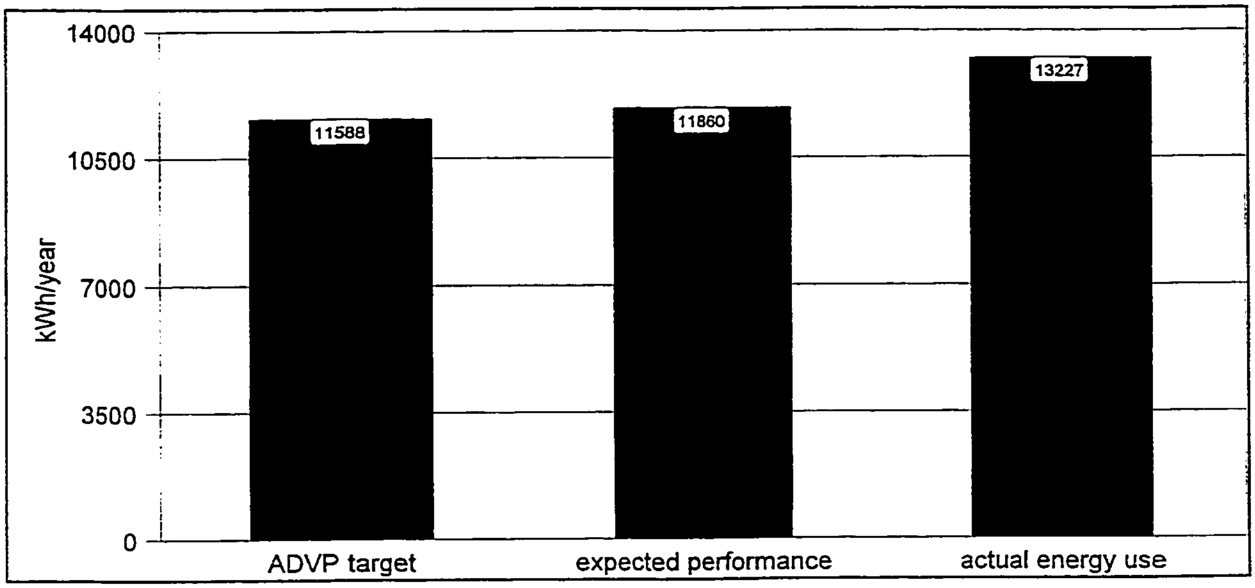


Figure 5.2.1: Comparison of annual energy consumption

Figure 5.2.2 presents the monthly actual and expected energy consumption for the 1½ year monitoring period. During this period, the total energy consumption was 9% more than expected. During the heating season months of October to March, the monthly difference between the actual and the expected energy consumption varied from -6% (March 1994 & 1995) to +2% (February 1995) with an average of -3% for the winter of 1994, almost 0% for the winter of 1994/95, and an overall winter average of -2%. From April to September, the difference between the actual and the expected energy consumption varied from +4% (May 1995) to +69% (August 1994) with an average of +34% for the summer of 1994, +22% for the summer of 1995, and an overall summer average of +29%. The large discrepancy during the summer months was due to the influx of solar energy through the south-facing atrium. The use of shading devices during the occupied period is expected to reduce the cooling energy consumption and bring the total energy consumption during the summer months to within expected levels. An analysis of the space cooling performance is presented in section 5.4.6.

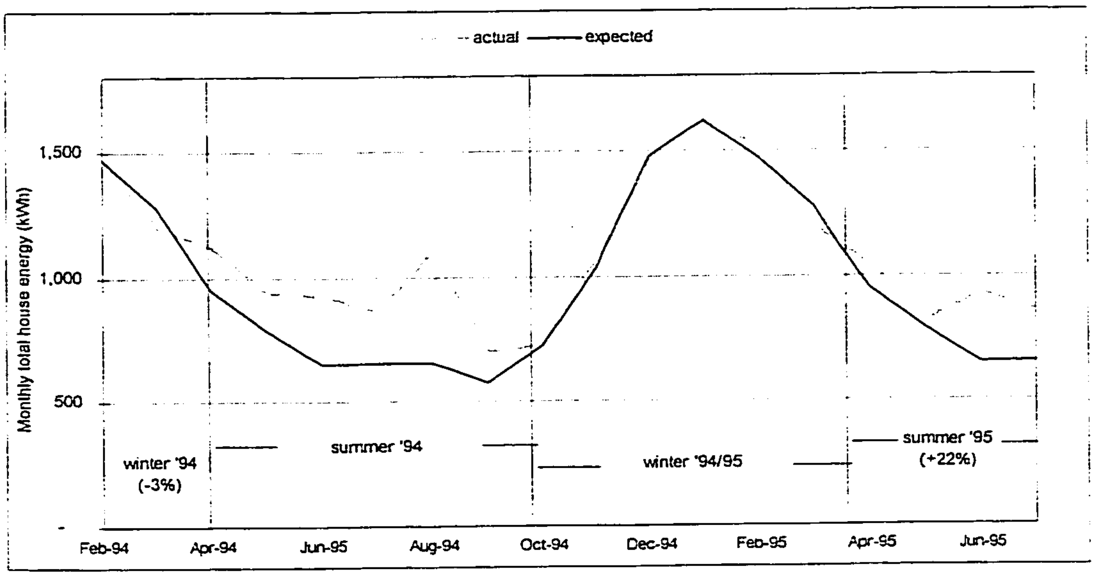


Figure 5.2.2: Comparison of monthly energy use (expected and actual)

Figure 5.2.3 compares the annual energy consumption of the NOVTEC Advanced House, to that of an R-2000 House built before 1986, a 1983 Measures House (A house built according to the 1983 Federal Energy Efficiency Measures Standard), and a typical 1975 NBCC House[25]. The NOVTEC Advanced House consumed 60 kWh/m² which corresponds to 42% less energy per heated floor area (kWh/m²) than an R-2000 House, 64% less than a 1983 Measures House, and 72% less than a typical 1975 NBCC House.

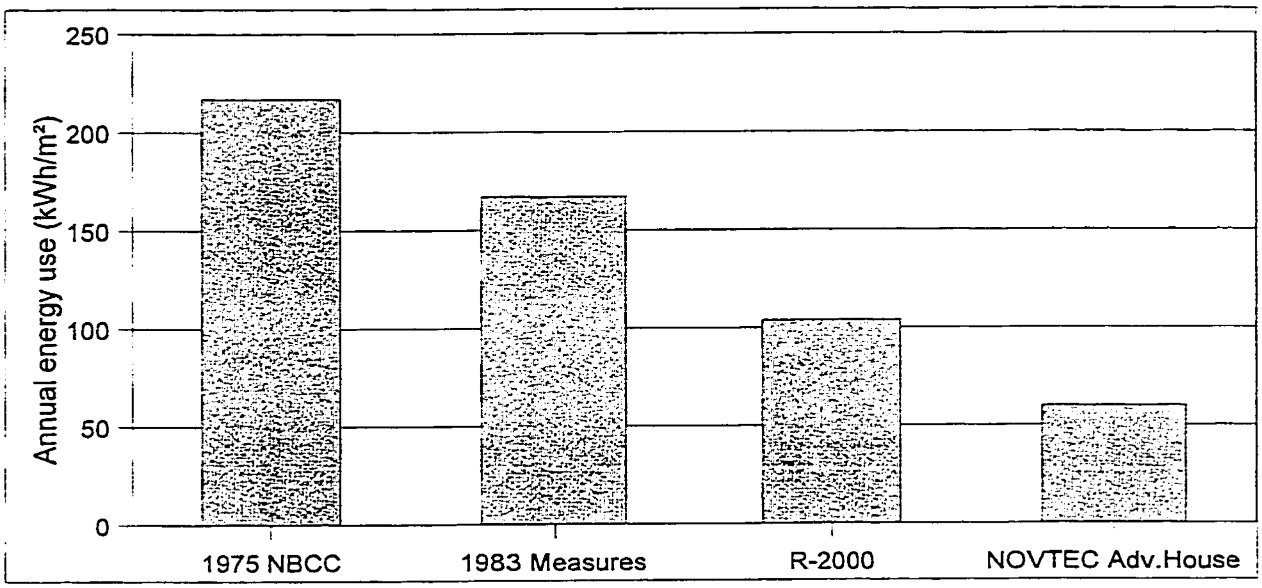


Figure 5.2.3: Comparison of annual energy use of the NOVTEC Advanced House to various housing stock

Figure 5.2.4 presents the breakdown of annual energy consumption by end-use for the NOVTEC Advanced House. Lights and appliances accounted for the largest portion (42% or 5481 kWh) of the total energy consumption. This category includes all monitoring equipment, ventilation supply and exhaust fans, and outdoor and indoor lights and plug loads. Space heating, which includes both forced air and radiant heating systems, accounted for 37% of the total energy consumption. The cooling system, which was used for more than 190 days throughout the year, accounted for only 8% of the total energy consumption. The energy consumed by the blower in recirculation mode (WAHP was not heating or cooling), accounted for the same percentage as the energy consumed by the cooling system (8%). DHW demand during the unoccupied period was sporadic and , hence, DHW energy consumption was mostly attributed to standby losses.

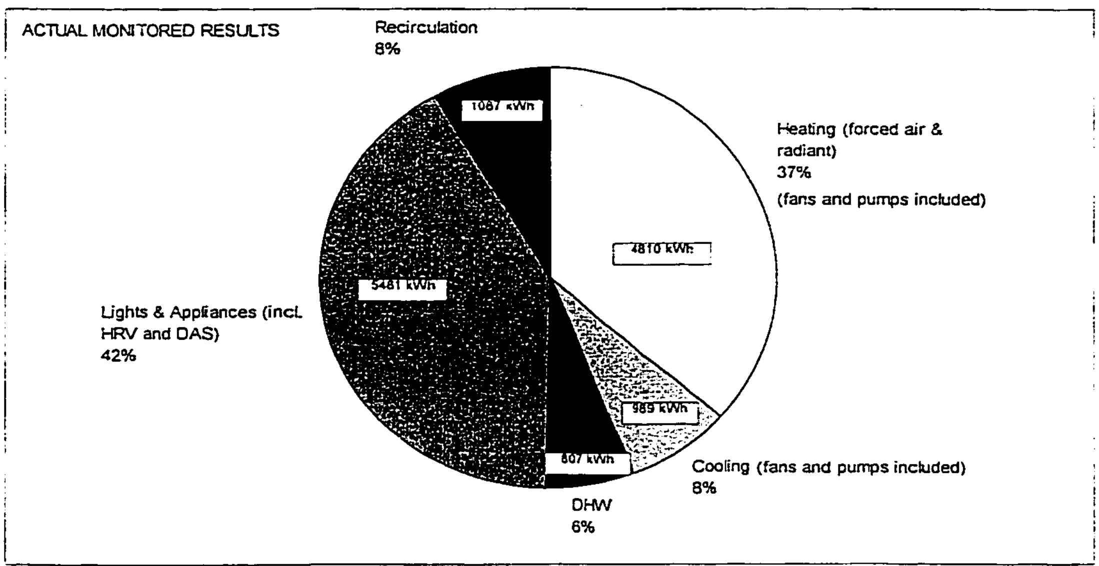


Figure 5.2.4: Breakdown of annual actual energy consumption by end-use

The annual actual energy consumption for space heating, cooling, DHW heating, and lighting and appliances are compared to the ADVP targets and the expected performance in Figure 5.2.5. Energy consumption for space heating was 6% more than the ADVP target consumption but was 13% less than the expected energy consumption. The lights and appliances energy consumption was more than both the ADVP target consumption (27%) and the expected consumption (12%). This was due to mostly to the continuous operation of the monitoring equipment. The discrepancy is higher when compared to the ADVP target because the target does not include HR fan energy. Both the ADVP target, as well as, the expected performance for space cooling energy consumption were surpassed by over 100%. The discrepancies between the actual and the target values for space heating, space cooling, and DHW heating are further discussed in section 5.4.

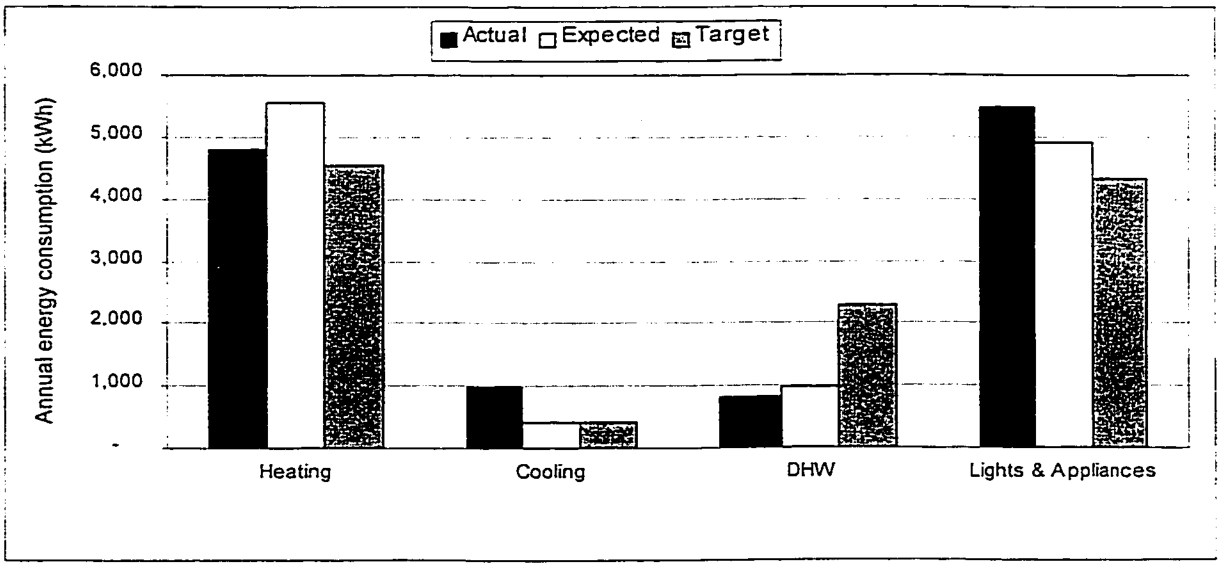


Figure 5.2.5: Comparison of energy consumption by end-use

Figure 5.2.6 presents the breakdown of monthly energy consumption by end-use for the 1½ year monitoring period. The maximum monthly space heating percentage (forced air and radiant systems) was 70% (January 1995) and the maximum space cooling percentage was 27% (August 1994). The energy consumption of the fan during recirculation mode varied from almost 0% (February 1995) to 23% (July 1995) of the total month energy use.

The average baseload energy consumption of the house (including indoor and outdoor plug loads and lighting, ventilation supply and exhaust fans, home automation system, and monitoring equipment) was 460 kWh per month, or 15.0 kWh per day. This average was 27% more than the ADVP baseload target of11.8 kWh per day.

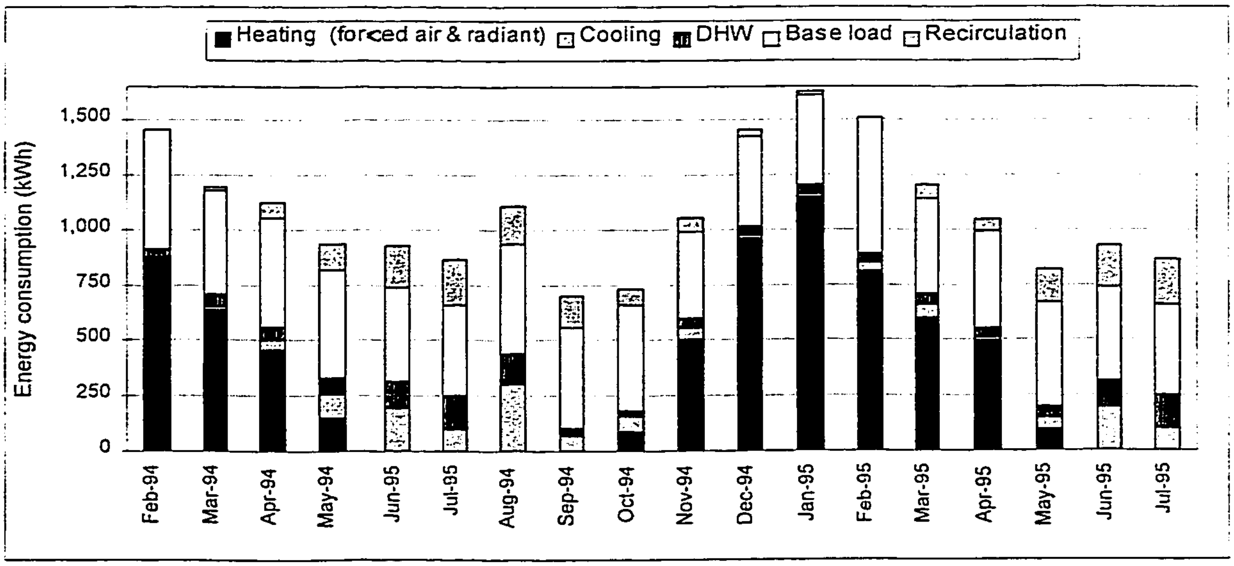
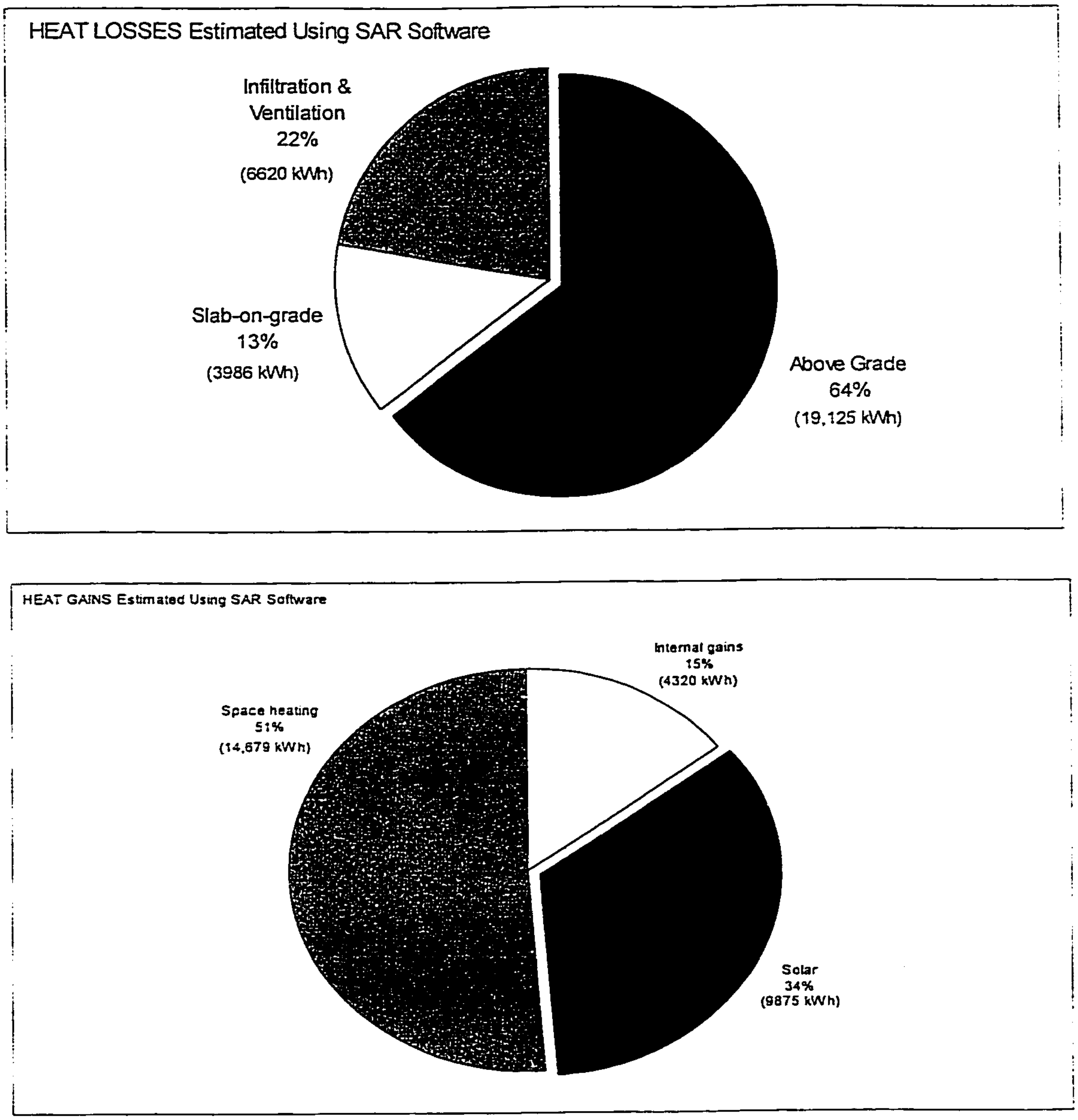


Figure 5.2.6: Breakdown of monthly actual energy consumption by end-use

5.3 WHOLE HOUSE ENERGY BALANCE

A whole house energy balance for the NOVTEC Advanced House was performed by using monitored temperature differences, actual thermal resistance values of the building envelope components, and monitored insolation levels recorded at the house.

Figure 5.3.1 shows the largest estimated heat loss is due to above-grade envelope components (64%) and that space heating covered 51% of the total heating demand. The total annual losses (29,731 kWh), normalized for heated floor area, was 134 kWh/m^2 or, normalized for CY HDD (4330), was 6.9 kWh/HDD. The annual space heating output (14,679 kWh) was 66 kWh/m^2 or 3.4 kWh/HDD.



(a)

(b)

Figure 5.3.1: Calculated annual heat (a) losses and (b) gains of the NOVTEC Advanced House

Figure 5.3.2 presents the monthly site-monitored solar gains, the SAR[26] estimated solar gains, the actual usable solar gains, and the HOT-2000 design usable solar gains profile across the atrium glazing for the 1994-95 heating season. The SAR estimated solar gains profile is based on monitored exterior horizontal plane solar radiation and the window's orientation and characteristics.

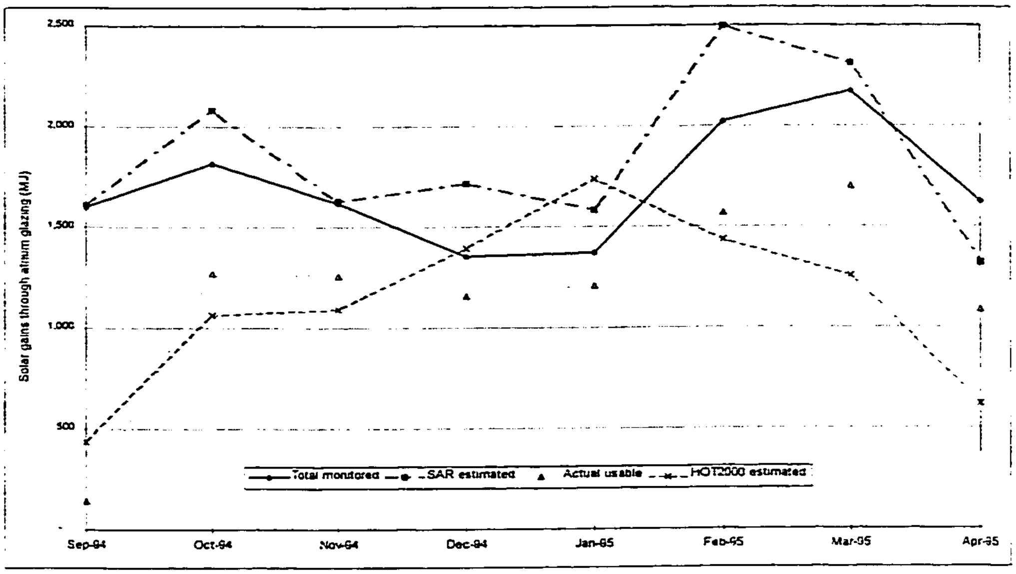


Figure 5.3.2: Monthly solar gains across the atrium glazing

Hot-2000 calculates the daily solar heat gains[27] from windows based on:

i Direct and diffuse vertical solar radiation from global radiation on a horizontal surface;

ii The effect of shading from overhangs

iii Passive solar heat gains for each orientation due to incident radiation, solar transmission coefficients, shading attenuation factors, solar gain off-angle incident factors, and window area; and a iv Usable passive solar heat gains fraction based on heating loads, building mass, and house temperature characteristics.

The actual usable solar gains profile was determined by multiplying the monitored solar gains across the atrium by the fraction of hours during each month in which the ambient temperature in the atrium was below 22°C. Multiplication by this fraction takes into account the non-usable contribution of solar gains during periods of overheating (> 22°C) in the atrium.

The profiles illustrate that the non-usable solar gains (difference between total and usable profiles) increases during the shoulder months and thus increases the cooling load of the house. The results also indicate that the profiles of monitored and SAR estimated solar gains closely correspond. The impact of the non-usable solar gains on the cooling system is quantified in section 5.4.6.

5.4 INTEGRATED HOME COMFORT SYSTEM PERFORMANCE

5.4.1 Overall System Performance

The IHCS accounted for 59% of the total annual energy consumption, from which, 34% was consumed by parasitic loads such as pumps and fans. The overall IHCS Coefficient of Performance (COP) was 2.6. The monthly COP varied from 2.0 (May

1994) to 3.4 (November 1994) with a seasonal COP of 2.7 during the fall and winter months and 2.5 during the spring and summer months. The seasonal COP for DHW heating was not calculated due to the minimal demand during the unoccupied monitoring period.

Figure 5.4.1 shows the breakdown of the IHCS energy use by end-use and their corresponding COP. Space heating, which includes forced air and radiant heating systems, accounted for the largest portion of energy consumed (62%) by the IHCS. Between heating and cooling modes, there is a 3°C intermediate mode of high velocity (660 L/s) air recirculation only. The IHCS energy consumption in recirculation mode (14%) was similar to its energy consumption in cooling mode (13%).

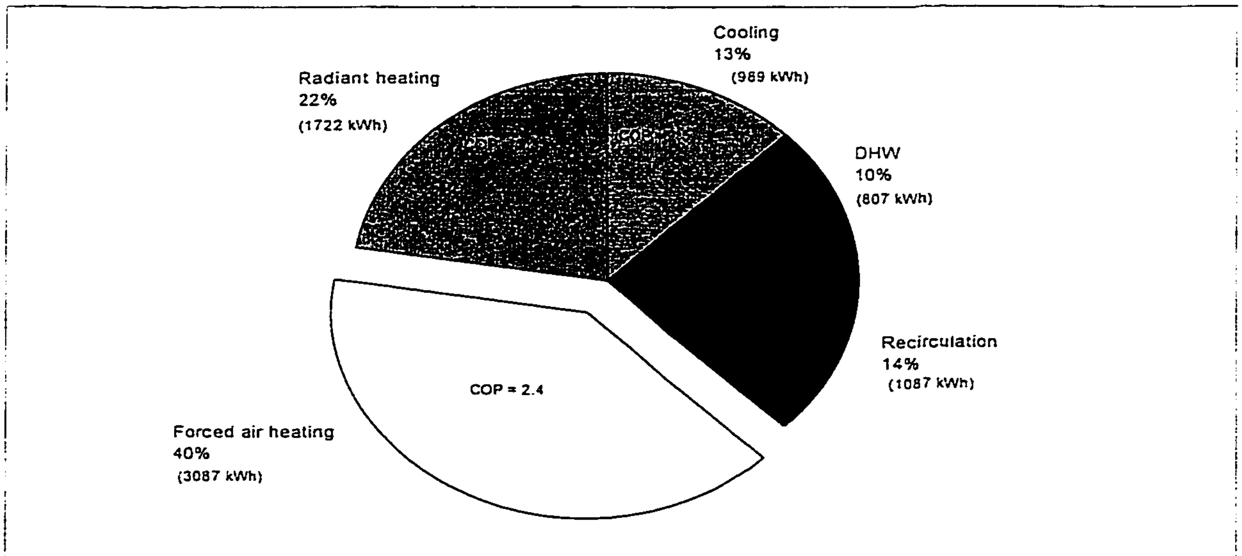


Figure 5.4.1: Breakdown of annual IHCS energy consumption by end-use

The equations used to calculate the COP are shown below:

$COP_{forced\ air\ heating} = Q_{out}/E = m*C_p*\sum(\blacktriangle T*t)\ /\ E,$

where

$m =$ 470 l/s * 1.2 kg/1000l = 0.56 kg/s

$C_p =$ Specific Heat of Air = 1.02 kJ/kg°C (at 25°C)

$\blacktriangle T =$ temperature difference between supply air and return air, °C

$t =$ hours in operation, hr

$E =$ WAHP electric input energy, kWh

$COP_{cooling} = Q_{out}/E = m*C_p*\sum(\blacktriangle T*t)\ /\ E,$

where

$m =$ 500 l/s * 1.2 kg/1000l = 0.60 kg/s

$C_p =$ Specific Heat of Air = 1.02 kJ/kg°C (at 25°C)

$\blacktriangle T =$ temperature difference between return air and supply air, °C

$t =$ hours in operation, hr

$E =$ WAHP electric input energy , kWh

$COP_{radiant\ heating} = Q_{out}/E = m*C_p*\sum(\blacktriangle T*t)\ /\ E,$

where

$m =$ 0.3 l/s * 1.0 kg/l = 0.3 kg/s

$C_p =$ Specific Heat of Water = 4.19 kJ/kg°C

ΔT = temperature difference between supply and return water temperatures, °C

t = hours in operation, hr

E = WWHP electric input energy, kWh

Figure 5.4.2 presents the energy breakdown of the IHCS energy use by heat pump and their corresponding seasonal COP. The WAHP produced a seasonal COP of 2.5 and accounted for 67% (5164 kWh) of the total energy consumed by the IHCS, twice that of the WWHP (2578 kWh) which produced a seasonal COP of 3.3. The lower WWHP energy consumption is due to the minimal and sporadic demand of DHW heating during the unoccupied period. Whereas, the WAHP operated year round either in cooling, heating, or recirculation mode.

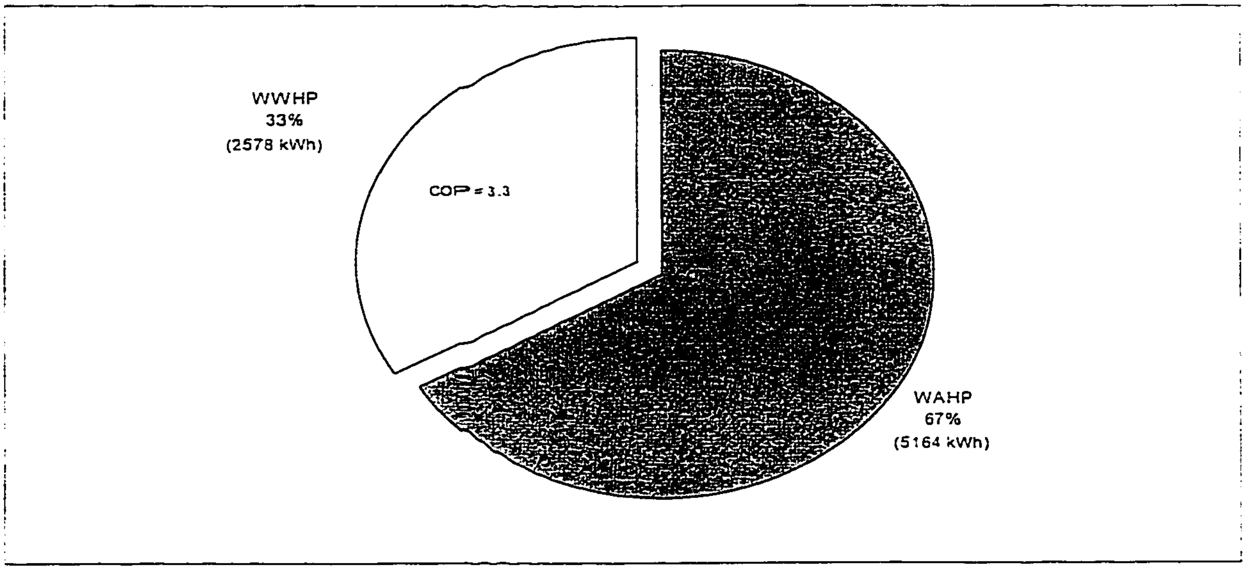


Figure 5.4.2: Breakdown of annual IHCS energy consumption by heat pump

5.4.2 Water-to-Air Heat Pump

Contrary to air-source heat pumps, ground-source heat pumps operate continuously in winter because ground temperatures remain above the freezing point of the ground coil's heat exchange fluid[28]. Figure 5.4.3 plots the daily average outdoor air temperatures and the WAHP inlet ground loop temperatures for the period of February 1994 to February 1995.

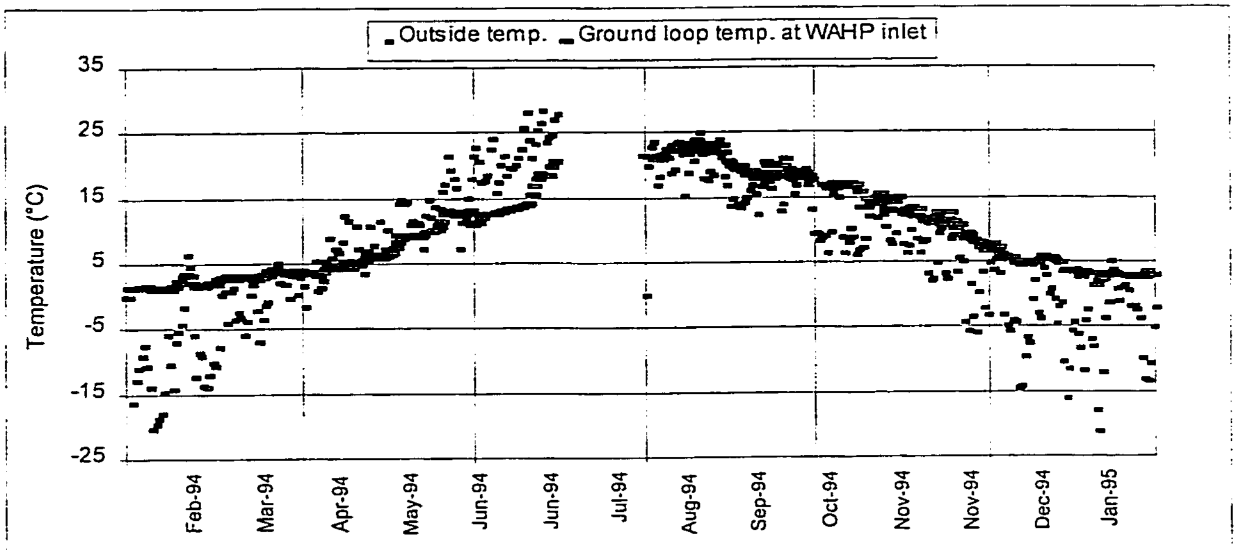


Figure 5.4.3: Outdoor air temperatures and ground loop temperatures

Table 5.4.1 summarizes the seasonal average outdoor air temperature, the WAHP inlet ground loop temperature, and the WAHP COP.

Table 5.4.1: Comparison of outdoor air and ground loop temperatures (°C)

	1994 heating season February to March		**1994 cooling season April to September**		**1995 heating season October to March** [a]	
	average	range	average	range	average	range
outdoor air	-5.5	6.3 to -20.5	15.5	28.3 to -1.7	-0.2 (-3.6)	16.2 to -22.7 (7.4 to -22.7)
ground loop (at WAHP inlet)	2.4	4.2 to 0.9	13.9	23.7 to 3.1	6.6 (3.0)	17.2 to 0.7 (4.7 to 0.7)
WAHP COP	2.2	2.1 to 2.3	2.4	2.0 to 2.8	2.7	2.6 to 2.9

(a) values in brackets represent the period from February to March 1995 in order to compare with the 1994 heating season data.

The seasonal COP of the WAHP was 2.4 for the 1994 cooling season, 2.6 for both heating seasons, with an overall COP of 2.5. Figure 5.4.4 plots the daily COPs of the WAHP in its forced air heating (referred to as "forced air" in the figure) and cooling modes for (a) the 1994/95 heating season (October through March) and (b) the 1994 cooling season (April through September).

The WAHP COP is a time-weighted average of the COP during forced air heating and cooling modes only (excluding recirculation). Therefore, the energy consumed by the blower when the WAHP was in recirculation mode, is not included in the COP calculations. WAHP COP values are reported for days in which the heat pump operated in either heating or cooling modes for a minimum daily accumulated time of 2.5 hours, in order to correct for the DAS's inaccuracy in monitoring temperature and energy data during periods of frequent heat pump cycling.

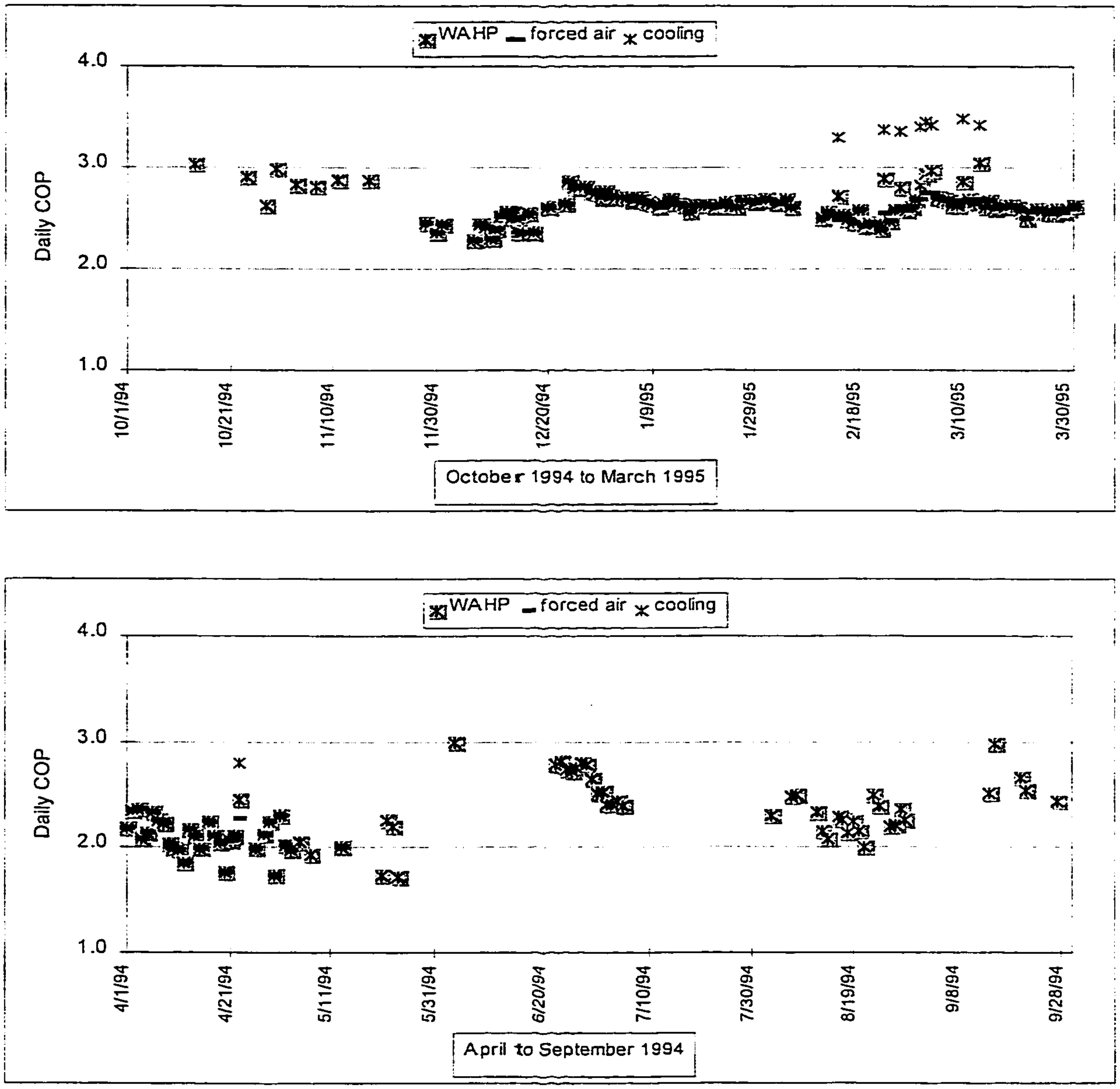


Figure 5.4.4: Daily WAHP COP in forced air heating and cooling modes for the (a) 1994/95 heating and (b) 1994 cooling seasons

The WAHP energy consumption breakdown by end-use is shown in Figure 5.4.5. The blower energy consumed during the recirculation mode is the difference between the sum of the space heating and cooling consumptions and the total WAHP consumption, which was approximately 21% (1087 kWh) of the WAHP's annual energy use.

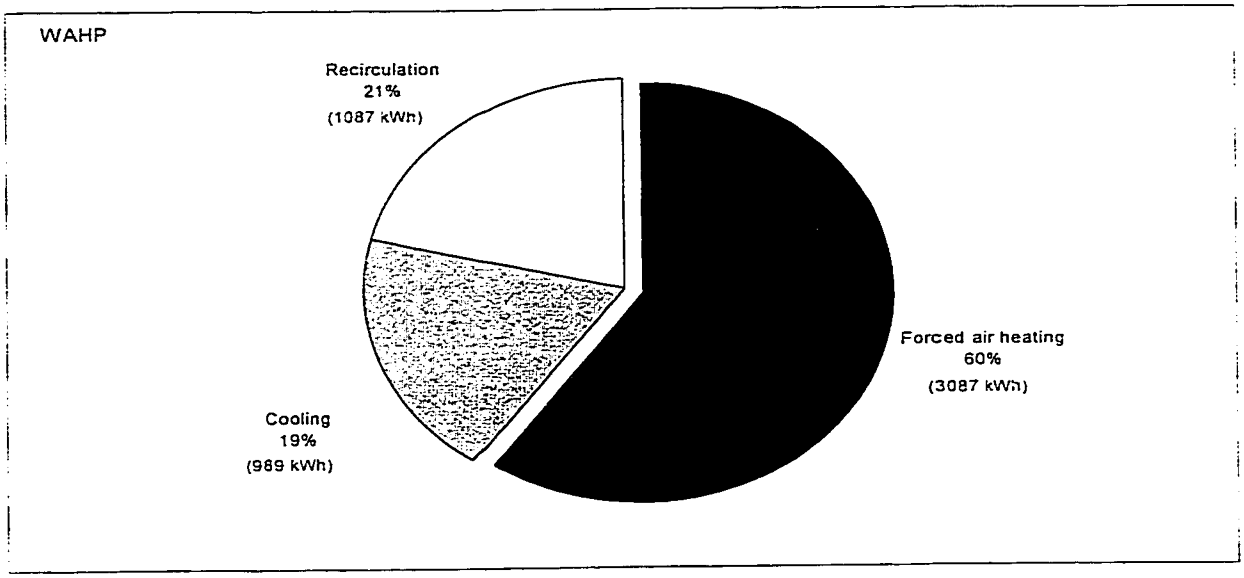
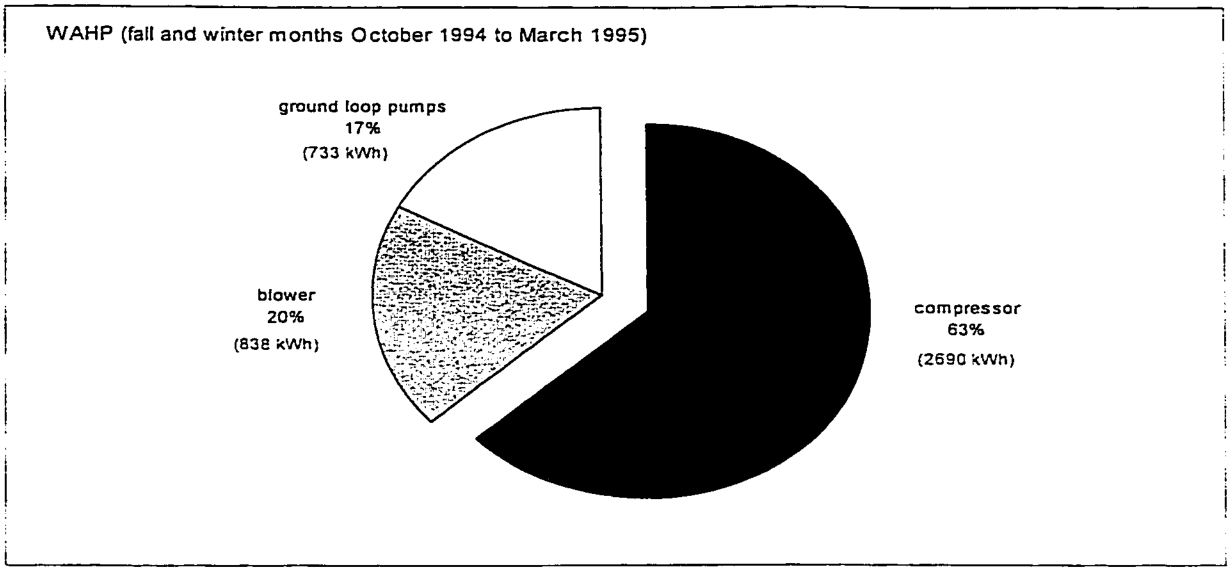


Figure 5.4.5: Breakdown of WAHP energy consumption by end-use

Figure 5.4.6 presents the energy use for the WAHP compressor, blower, and ground loop pumps for the (a) 1994/95 heating and (b) 1994 cooling seasons. It can be observed that the percentage of the blower's energy use during the cooling season is almost twice of that during the heating season due to the increased air recirculation which occurred in summer. The results also show that the ratio of energy used by the ground loop pumps to the compressor remained constant for both the heating (27%) and cooling (30%) seasons. This indicates that the operation of the ground loop pumps is proportional to the WAHP demand.



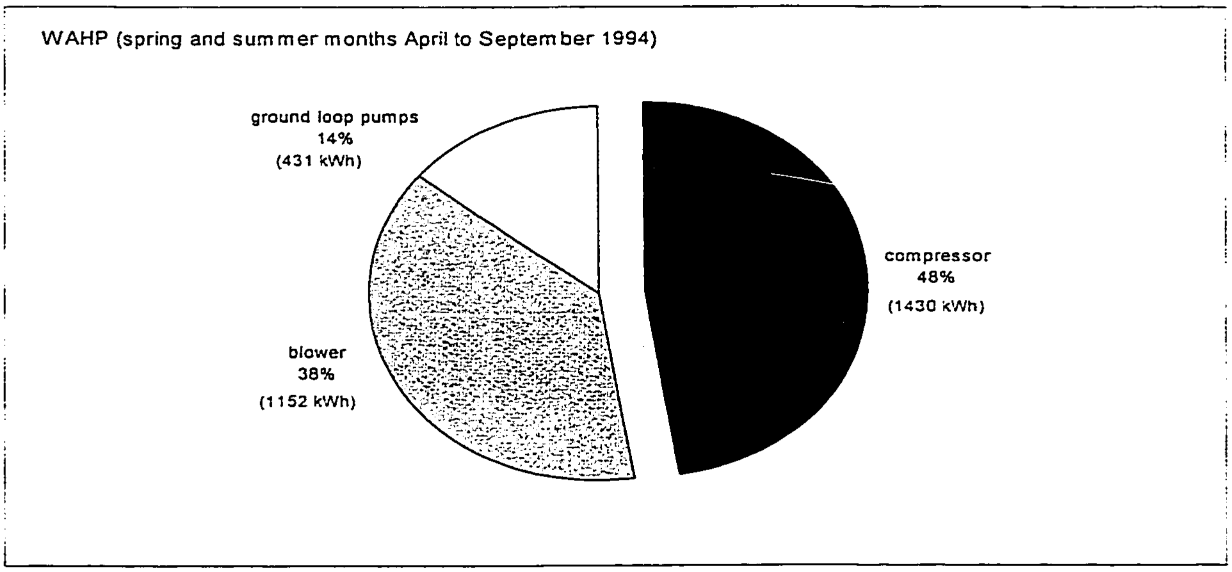


Figure 5.4.6: Breakdown of WAHP energy use by component for the (a) 1994/95 heating and (b) 1994 cooling seasons

5.4.3 Water-to-Water Heat Pump

The WWHP is located downstream of the WAHP for DHW heating purposes, allowing it to benefit from the heat rejected by the cooling system during summer.

The seasonal COP of the WWHP, in radiant heating mode, varied from 2.7 (March 1994) to 3.5 (November 1994) with an overall average COP of 3.3. Due to the minimal and sporadic use of DHW during the monitoring period and the resulting frequent cycling of the heat pump, the seasonal COP of the WWHP in DHW mode was not calculated. However, the results of a one-time test are presented in section 5.4.7. The WWHP COP in DHW mode is expected to be slightly higher than that of the radiant heating mode (COP=3.3) because it uses only one pump. Figure 5.4.7 plots the daily WWHP COP in radiant heating mode for the fall and winter months of 1994/95 (October through February).

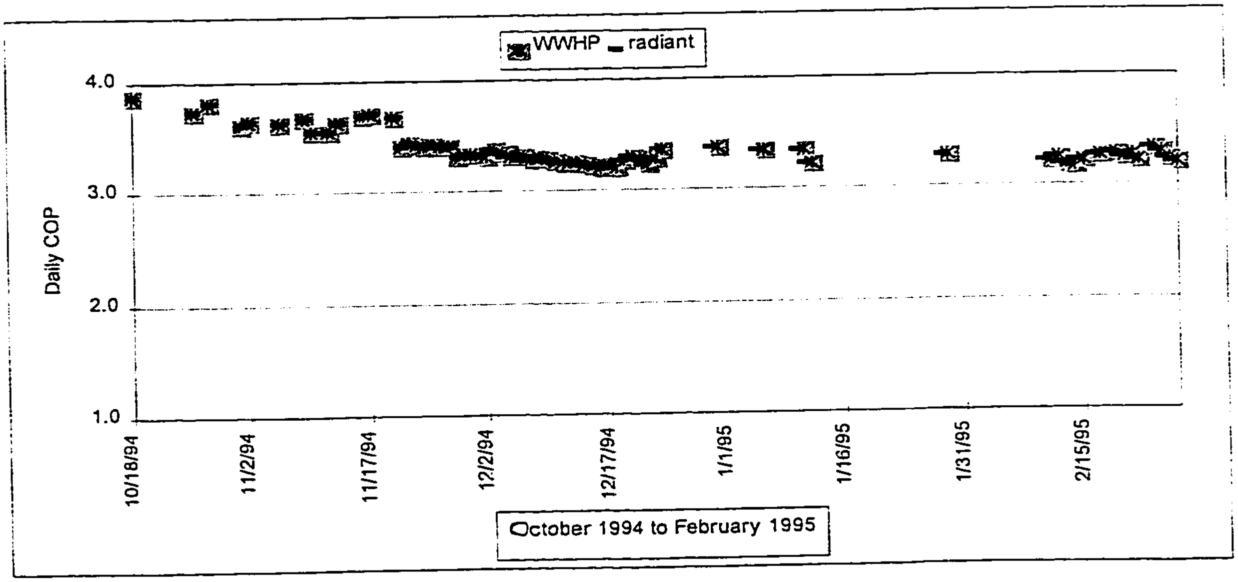


Figure 5.4.7: Daily WWHP COP in radiant heating mode

The energy consumption breakdown of the WWHP by end-use, shown in Figure 5.4.8 shows that radiant heating accounted for 68% (1722 kWh), and DHW heating energy consumption accounted for 32% (807 kWh) of the total WWHP energy consumption. Standby losses accounted for most of the DHW energy use. The IHCS was designed so that the heat rejected by the cooling system would be transferred to the WWHP to heat the DHW. To assess the effectiveness of this design, further monitoring during occupied conditions is required.

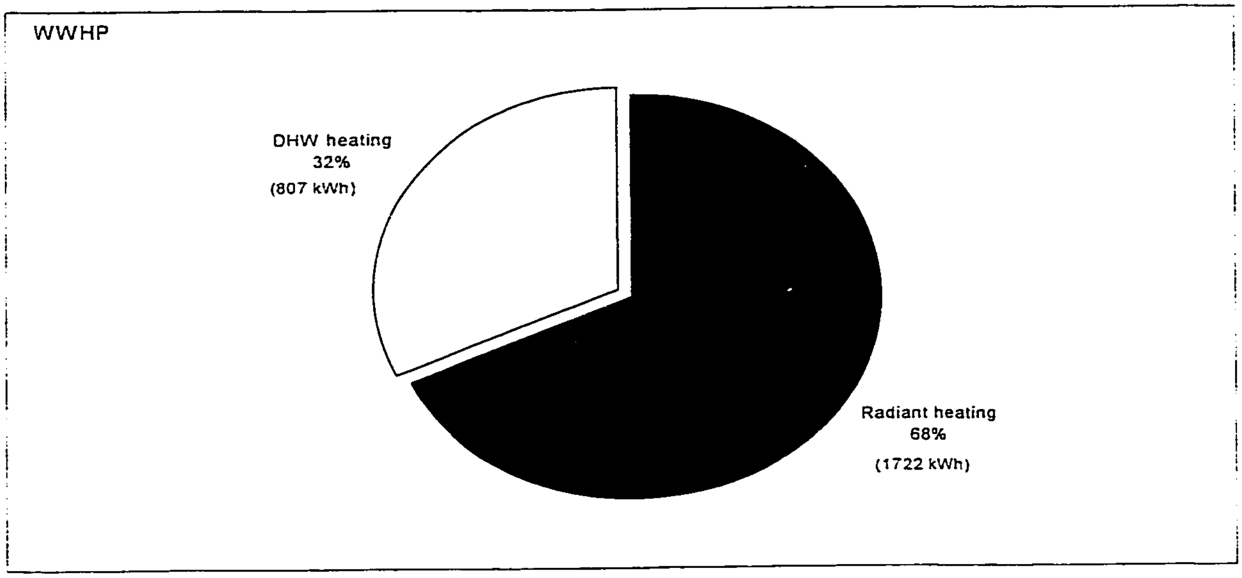
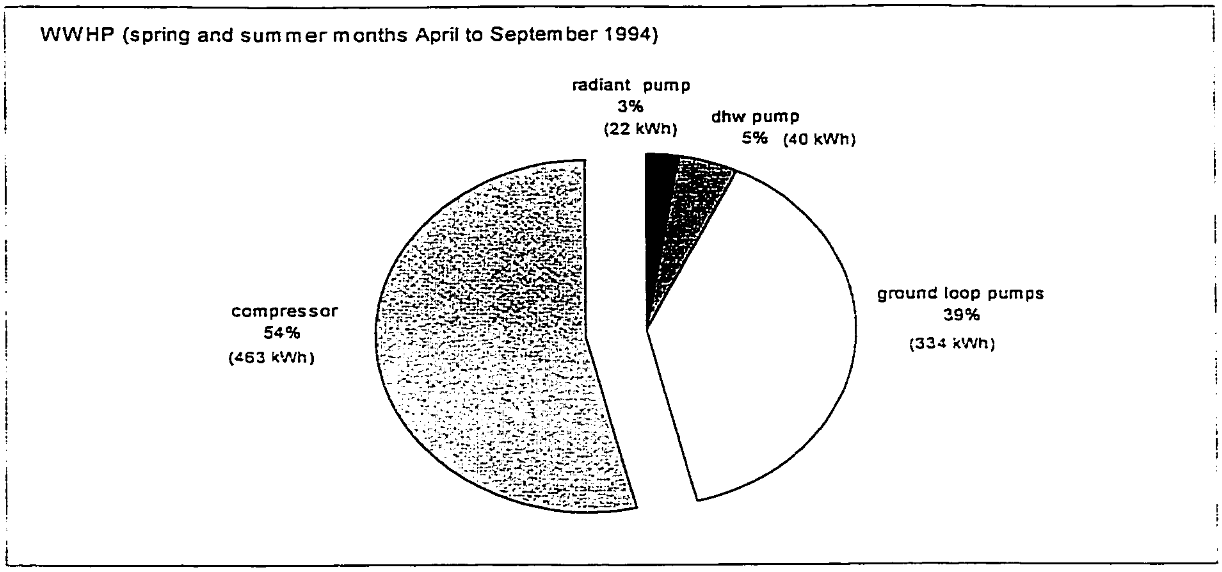


Figure 5.4.8: Breakdown of WWHP energy consumption by end-use

Figure 5.4.9 presents the WWHP's energy use for the DHW pump, radiant pump, ground loop pumps, and the compressor for the (a) 1994/95 heating and (b) 1994 cooling seasons. The energy consumed by the compressor during the spring and summer months (463 kWh) was 24% less than the energy it consumed during the fall and winter months (1961 kWh). This difference is due to the minimal DHW heating demand during the spring and summer months.

The ratio of the energy used by the ground loop pumps to energy used by the compressor was eight times more during the spring and summer months (0.72) than during the heating season (0.09). This large discrepancy indicates that the controls for the ground loop pumps are not adequate for the current DHW demand. In comparison, the same ratio for the WAHP remained constant throughout the year at approximately 30%.



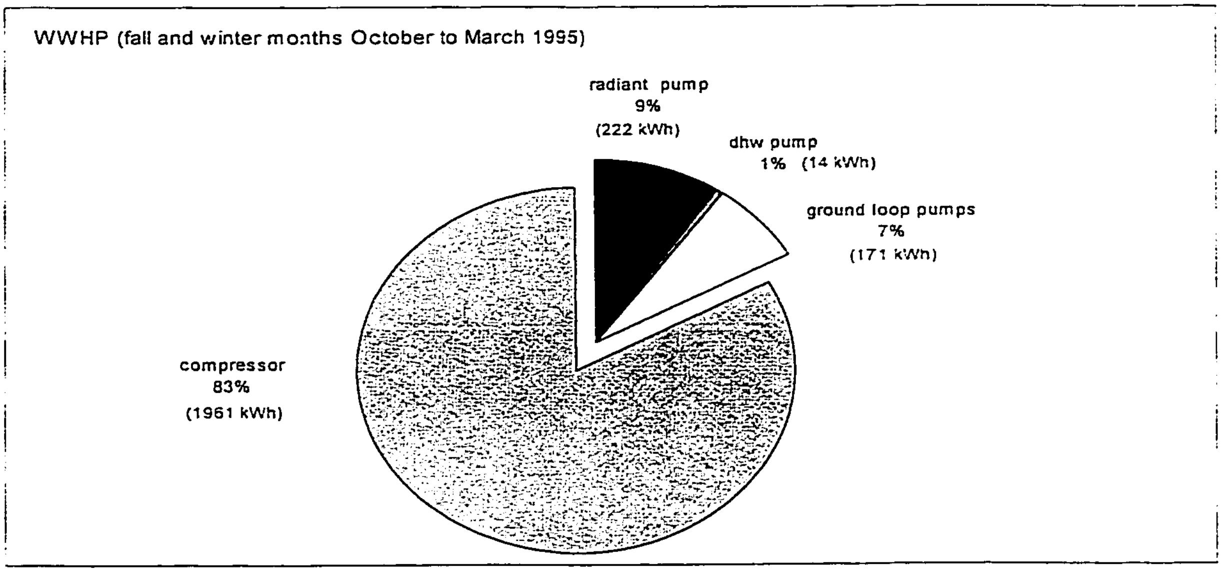


Figure 5.4.9: Breakdown of WWHP energy use by component for the (a) 1994/95 heating and (b) 1994 cooling seasons

5.4.4 Ground Loop Pumps

The energy used by the ground loop pumps was distributed among the four heat pump operating modes (forced air heating, cooling, radiant heating, and DHW heating) based on the ratio of operation time of each mode to the total accumulated IHCS operation time.

Both pumps were controlled so as to operate only when there was a demand from either heat pump. However, there were two periods in which the ground loop pumps operated continuously:

i. February to June 1994 - the controls had not yet been installed;

ii. June to August 1995 - a power surge erases the controls' programs.

These periods of continuous operation were especially evident during the cooling season when the WAHP was in recirculation mode and there was only a minimal and sporadic DHW demand. This occurrence is reflected by the ratio discussed in the previous section for the WWHP. Optimized controls should have the ground loop pumps operate on demand, and ensure that there is no risk of freezing the water-ethanol solution in the ground loop during winter (through the use of a temperature sensor). This added control feature would result in an energy savings of approximately 400 to 500 kWh per year.

5.4.5 Space Heating

The space heating demands of the house are met by two means; (1) a forced air heating system, and (2) a radiant floor heating system. Although the garage was heated by an electric baseboard heater, its energy consumption was not considered in the house's total energy consumption because garages were not considered as heated spaces in the Program targets.

The total heating energy consumption (4810 kWh), normalized for heated floor area was 21.7 kWh/m², or normalized for CY HDD (4330) was 1.1 kWh/HDD.

The IHCS controls were designed to use the radiant heating mode as the primary space heating source. However, according the actual monitored energy consumption (Figure 5.4.10), the forced air heating system accounted for 64% (3087 kWh) of the annual energy use for space heating (4810 kWh), as compared to 36% (1722 kWh) for the radiant heating mode. It was also observed that the WWHP experienced less cycling than the WAHP in space heating mode. This was due to the simultaneous operation of both heating systems which occurred when the second floor thermostat (which only controls the forced air heating system) would trigger the operation of the WAHP while the WWHP was in operation. The activation of the forced air heating system by the second floor thermostat reduces the operating time of the radiant heating system because the forced air heating system serves both floors. Therefore, in order to increase the operation of the radiant heating system, the authour suggests that the forced air heating system be re-zoned so as to serve the second floor only.

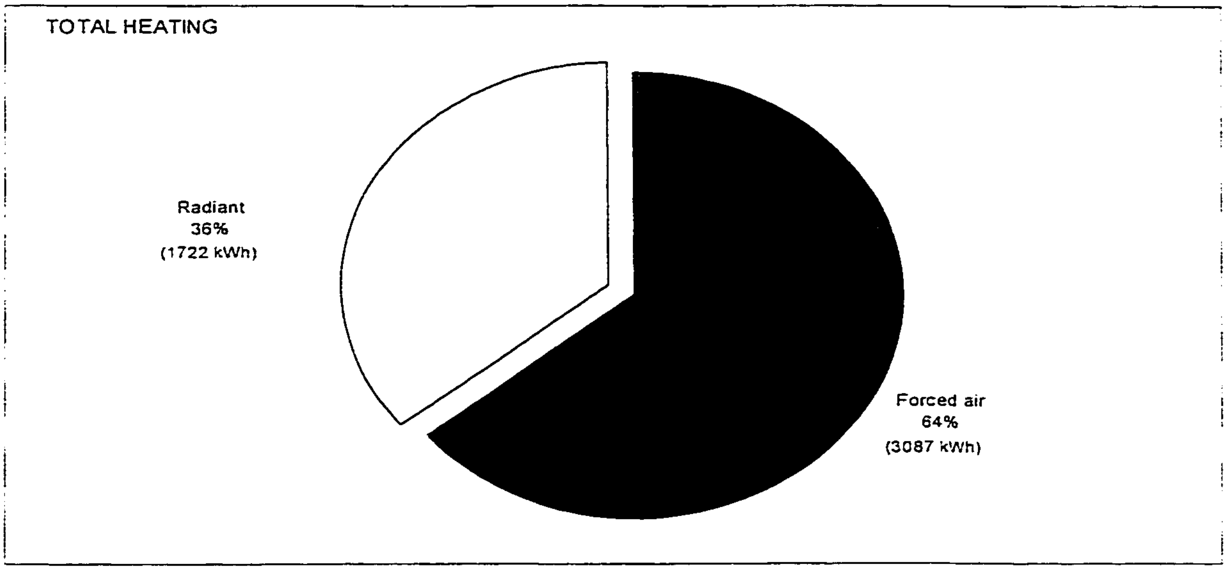


Figure 5.4.10: Distribution of annual space heating energy

The monthly average COP of the radiant heating system varied from 3.1 (February and March 1994) to 3.5 (November 1994) with a seasonal COP of 3.3. In comparison, the monthly average COP of the forced air heating system varied from 2.1 (March, April, and May 1994) to 2.7 (January 1995) with a seasonal COP of 2.4.

5.4.6 Space Cooling

The annual space cooling energy consumption was 989 kWh, or 4.2 kWh/CDD. The seasonal COP of the cooling system was 2.5 during the 1994 cooling season (April through September) and increased to 3.1 during the 1994/95 heating season (October through March), with an overall COP of 2.5.

Figure 5.4.12 presents the monitored space cooling energy consumption, total monitored solar gains and the actual usable solar gains profiles (see definition in section 3.5) for the south-facing atrium for the months of February 1994 to April 1995. The absence of shading devices resulted in overheating during summer and also triggered a demand for cooling during 78 afternoons of the 1994/95 heating season. Under these conditions, the cooling system is undersized and requires an additional 3.5 kW (1 ton) of cooling capacity. Shading devices will reduce the amount of incoming solar energy and hence reduce the cooling energy required to keep the house within comfort levels. Also, the use of a floor finish with a lower thermal resistance than the existing carpet would greatly increase the heat storage capacity of the radiant floor and maximise the heating output of the radiant floor system[29]. Once stored, this energy would be released to the space over a longer period of time thus reducing overheating and consequently reducing energy consumption and optimising thermal comfort. The use of the carpet has the combined negative effects of acting as an insulator to the radiant heating system and a barrier to the storage of passive solar gains in the concrete floor.

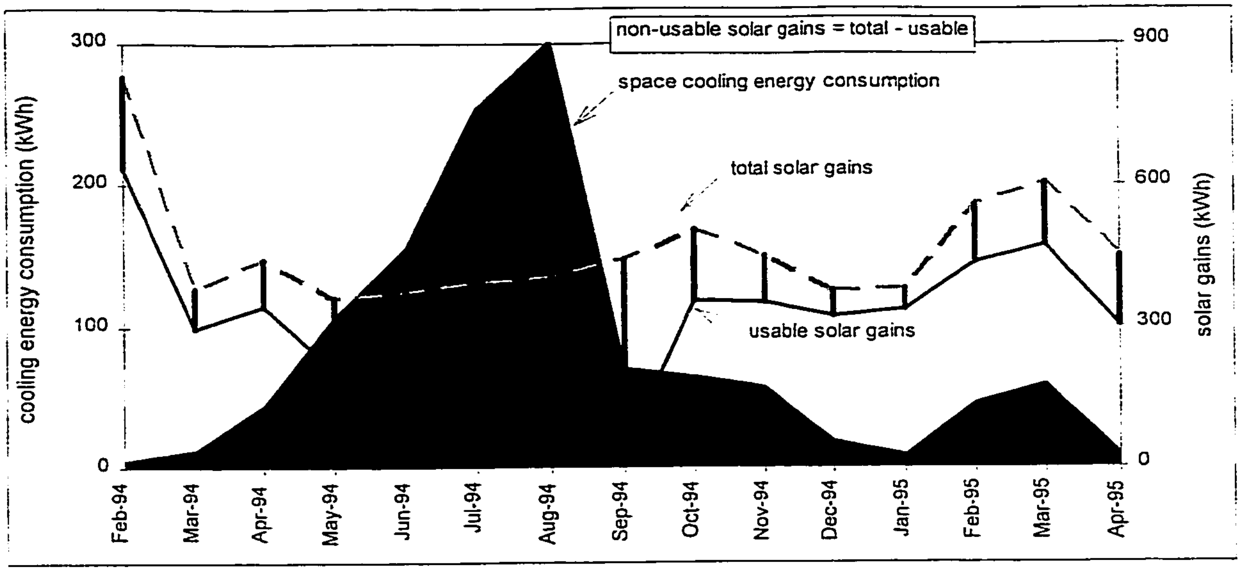


Figure 5.4.12: Monthly space cooling energy use versus atrium solar gains

It is estimated (through Hot-2000 simulations) that an interior shading device (horizontal or vertical blind) with an effective reflectance of 0.50[30] reduces the peak cooling load (T_{out} = 30°C), by 16.5% (1562 Watts) if installed on the vertical atrium glazing alone, or 30% (2884 Watts) if installed on all (vertical and ceiling) south-facing glazing. Under these conditions, a 30% reduction in the cooling load would indicate that the cooling system is no longer undersized. The dollar savings gained by installing shading devices is approximately $50.

5.4.7 Domestic Hot Water Heating

Although the house was unoccupied during the monitoring period, the minimal DHW demand resulted in an annual energy use of 82% of the expected energy consumption. The energy use of the IHCS in DHW heating mode was attributed mostly to the operation of the ground loop pumps.

When the WAHP was in recirculation mode, the total pump energy was allocated to DHW heating, even though the system usually operated for only a few minutes per day. During the spring and summer months, 39% of the total WWHP energy use was due to ground loop pumps. Therefore, optimizing the ground loop pumps' controls will have the largest impact on DHW heating energy use. To assess the seasonal performance of the system further monitoring during occupied conditions is required.

The average monitored hot water supply temperature (at the storage tank outlet) was 44°C for the period of February 1994 to May 1995. This average falls 10% below the DHW tank set point (49°C or 120°F). This difference in temperatures is due mostly to siphoning losses from the tank and the fact that the temperature sensor was located on the hot water supply pipe, directly above the tank where it is exposed to the ambient air temperature. Field inspection of the storage tank revealed that siphoning effects occur up to 1.5 feet away from the center of the tank. In order to minimize these losses it is recommended that the hot water pipes be insulated up to 2 feet away from the center of the tank. Figure 5.4.13 plots the daily hot water supply temperatures for the period of February 1994 to May 1995.

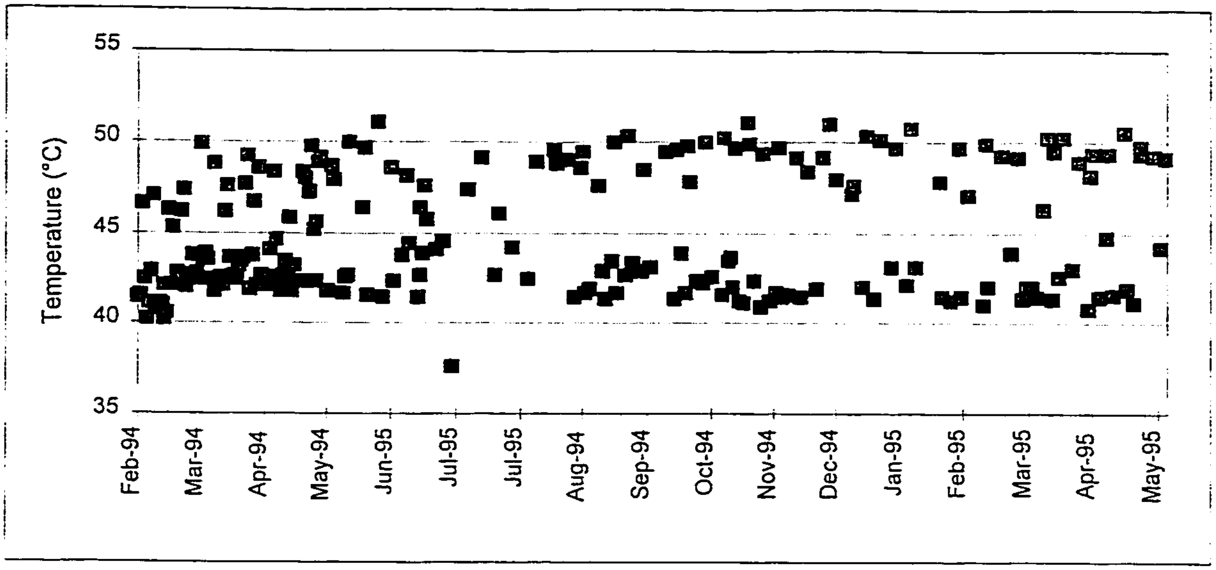


Figure 5.4.13: Daily DHW supply temperatures

A one-time test, performed on August 25th 1995, revealed that under continuous maximum hot water demand, the storage tank (capacity of 273 litres) supplied temperatures of approximately 50°C for 25 minutes (flow rate=9 .1 l/s) before the water at the faucet dropped to 27.1°C. The WWHP then raised the storage tank temperature at a rate of almost 0.4°C/minute, without use of the backup electric element. This indicates that the mixing of the water in the storage tank is adequate. The WWHP coupled with the electric backup element, raised the storage tank temperature at a rate of 0.6°C/minute, an increase of 55%. The energy that the electric backup element consumed during this heating cycle was 287 kJ/°C. The WWHP consumed 187 kJ/°C, almost 35% less energy per degree Celsius. It was also observed that the WWHP was triggered when the storage tank temperature dropped to 46.3°C. Whether the backup electric element will be required to the meet the DHW demands during occupied conditions will depend on the number of occupants and their activities.

5.4.8 Heat Recovery Ventilator

The annual heat recovery exhaust fan energy consumption was 601 kWh or 4.5% of the total annual consumption of the house. A maximum of 619 watt·hours per day was recovered by the system, with an average of 215 watt·hours per day. This yields approximately 26 kWh over 4 months during the heating season. The IHCS was designed such that the heat recovered by the system is transferred to the water-ethanol fluid before it enters the first of the two heat pumps, thus resulting in a higher system efficiency. Figure 5.4.14 plots the energy recovered by the heat recovery system (kWh/day), the temperature of the ground loop fluid in the field and at the WAHP inlet for the 1994/95 heating season. The figure shows that the increase in WAHP inlet temperature (▲T) is proportional to the energy recovered.

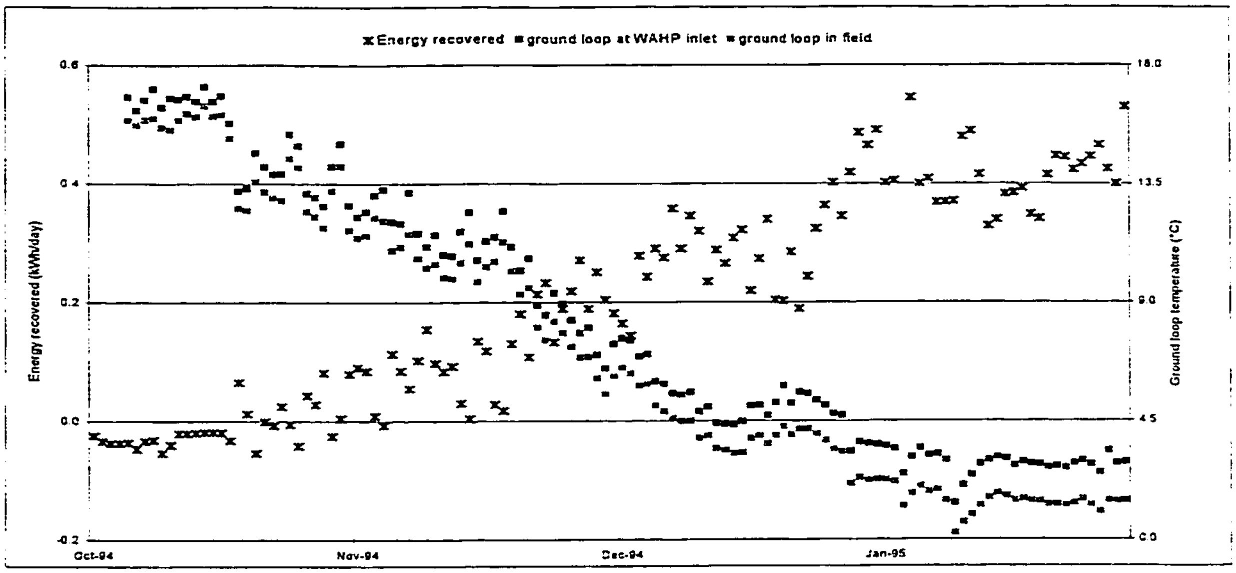


Figure 5.4.14: Heat recovery energy versus ground loop temperature

5.5 LIGHTS AND APPLIANCES PERFORMANCE

Figure 5.5.1 presents the breakdown of energy consumption for the lights and appliances. An annual total of 5481 kWh was consumed by interior lights and plugs, DAS monitoring equipment, exterior lights and plugs, and the heat recovery fan. The refrigerator was the only "white good" appliance which consumed energy during the monitoring period. The total annual energy use was 27% more than the ADVP target (4315 kWh) and 12% more than the expected performance (4908 kWh). The 12% difference is attributed mostly to the unexpectedly high energy consumption of the monitoring equipment. The energy consumption of the heat recovery fan was factored into the expected performance value (through energy simulations) but not in the ADVP target. The outdoor lights and plugs energy use was 175 kWh, 4% below the ADVP target. This end-use estimate is based on installed wattage and estimated times of usage.

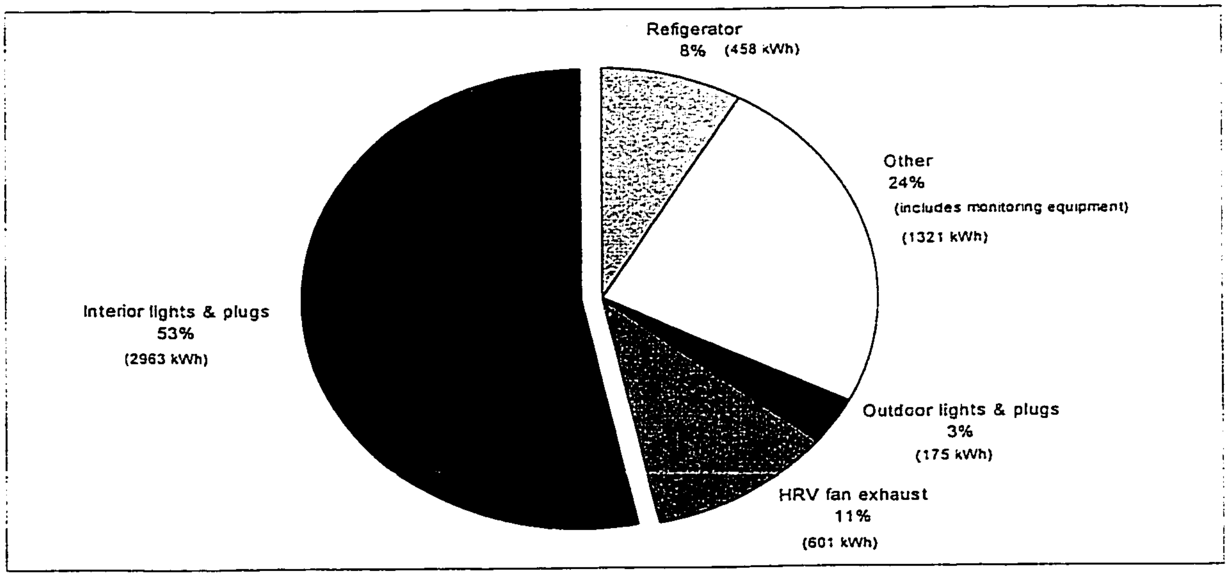


Figure 5.5.1: Breakdown lights and appliances energy use by component

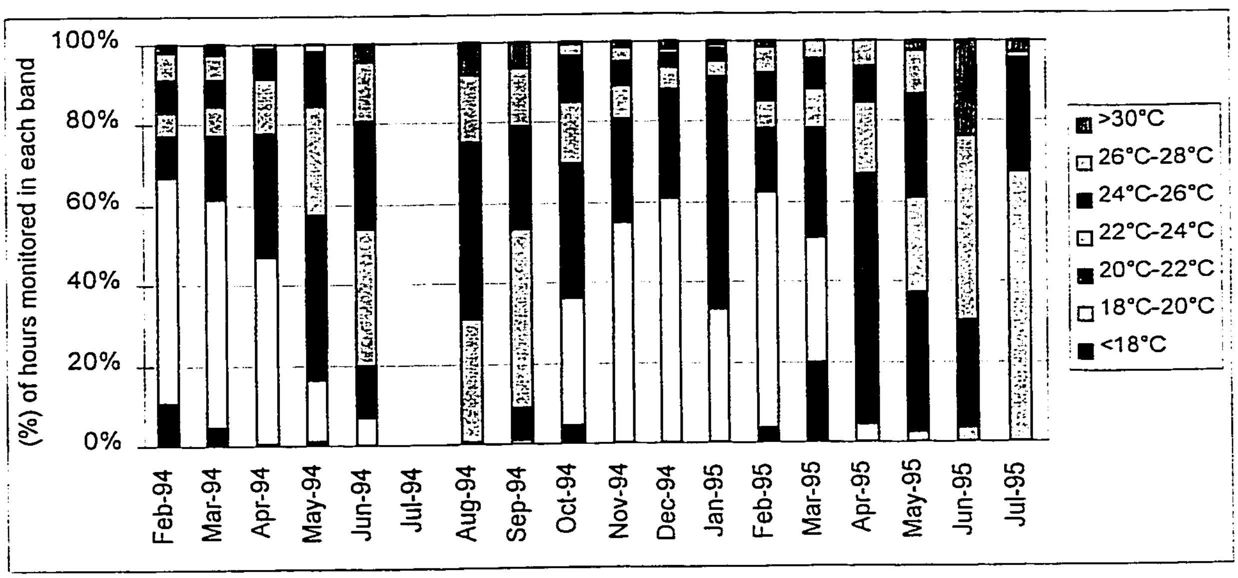
5.6 THERMAL COMFORT

During the monitoring period, indoor air temperature and relative humidity measurements were recorded in several rooms of the house in order to evaluate thermal comfort.

5.6.1 Indoor Air Temperature Profiles

Frequency histograms showing the percent frequency of hours within 2°C temperature bands are presented in Figure 5.6.1.1 for the atrium, kitchen, and dining room which are located on the first floor. Figure 5.6.1.2 shows the frequency histograms for the master bedroom and NW bedroom which are located on the second floor.

(a)



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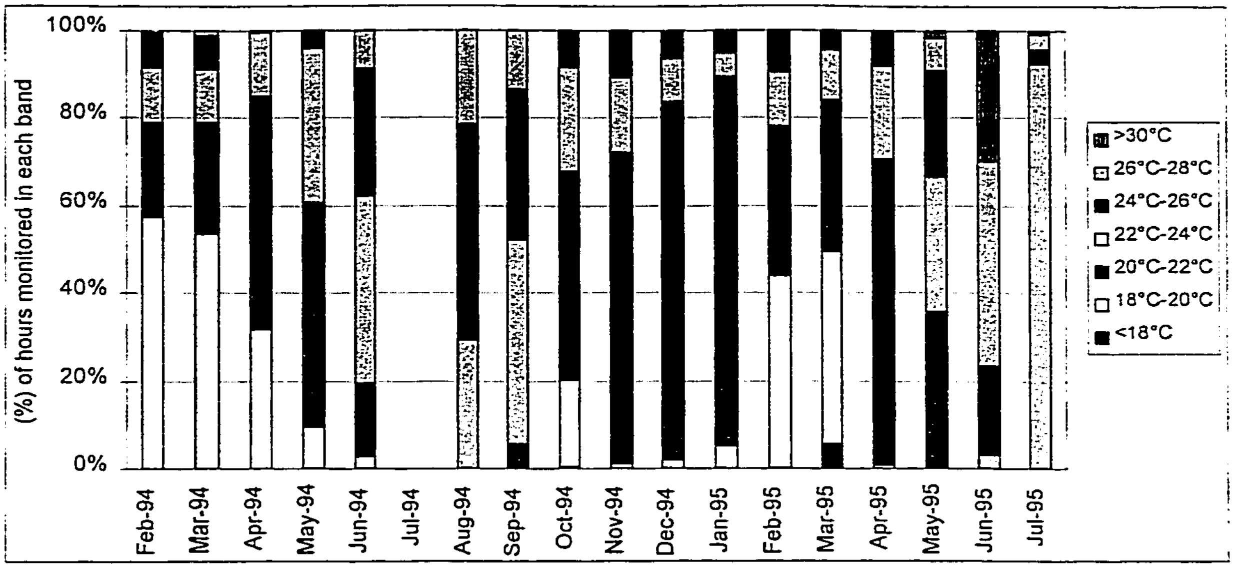

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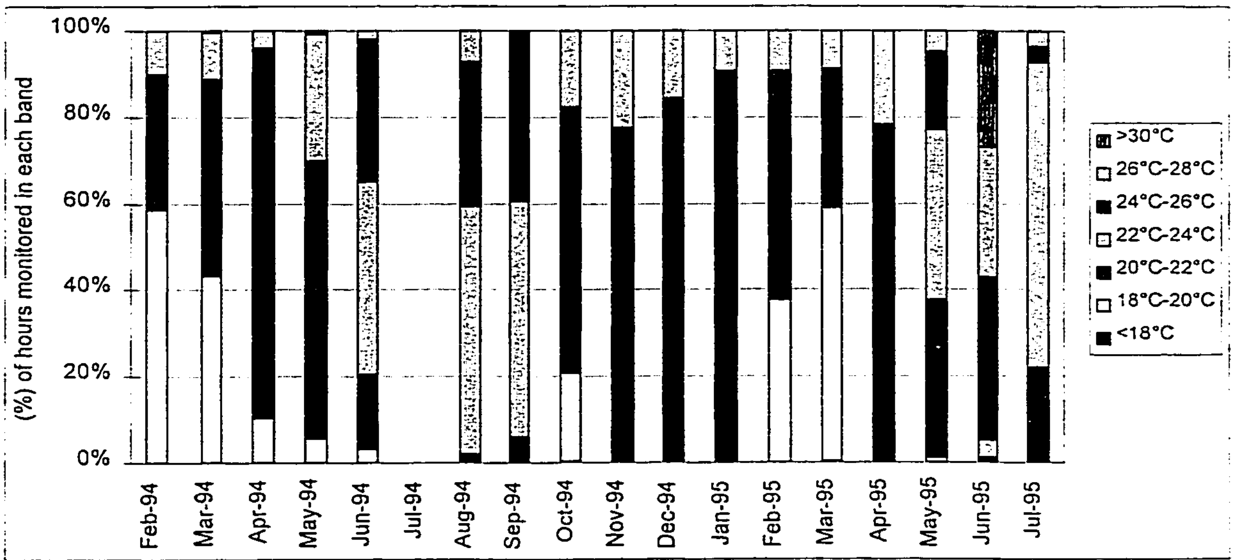
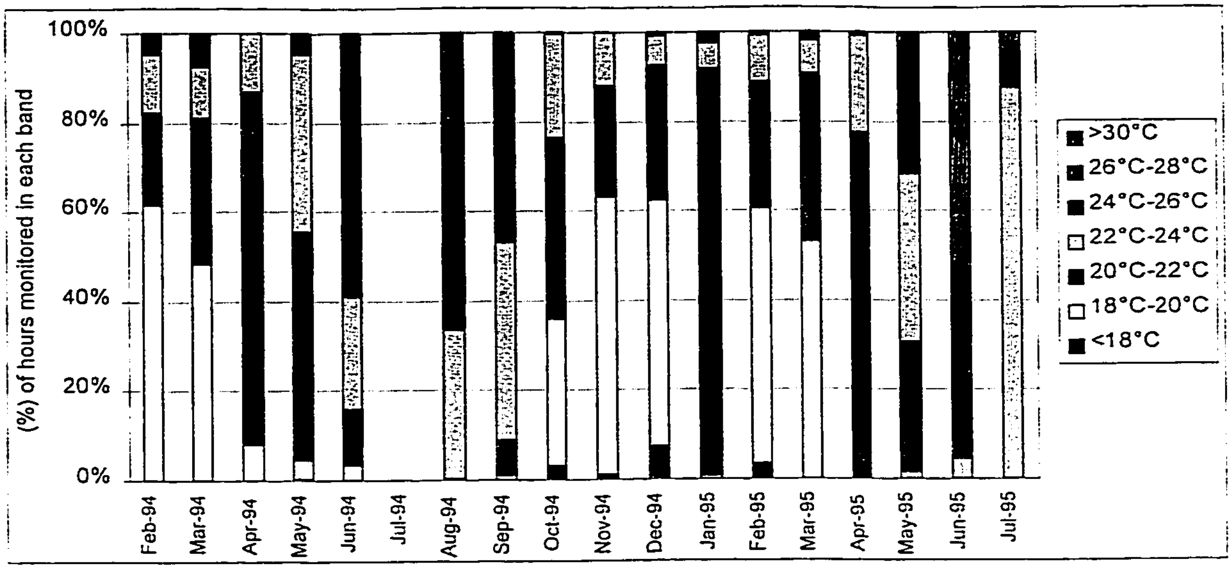


Figure 5.6.1.1: Temperature distribution profiles for the (a) atrium, (b) kitchen, and (c) dining room

(a)



(b)

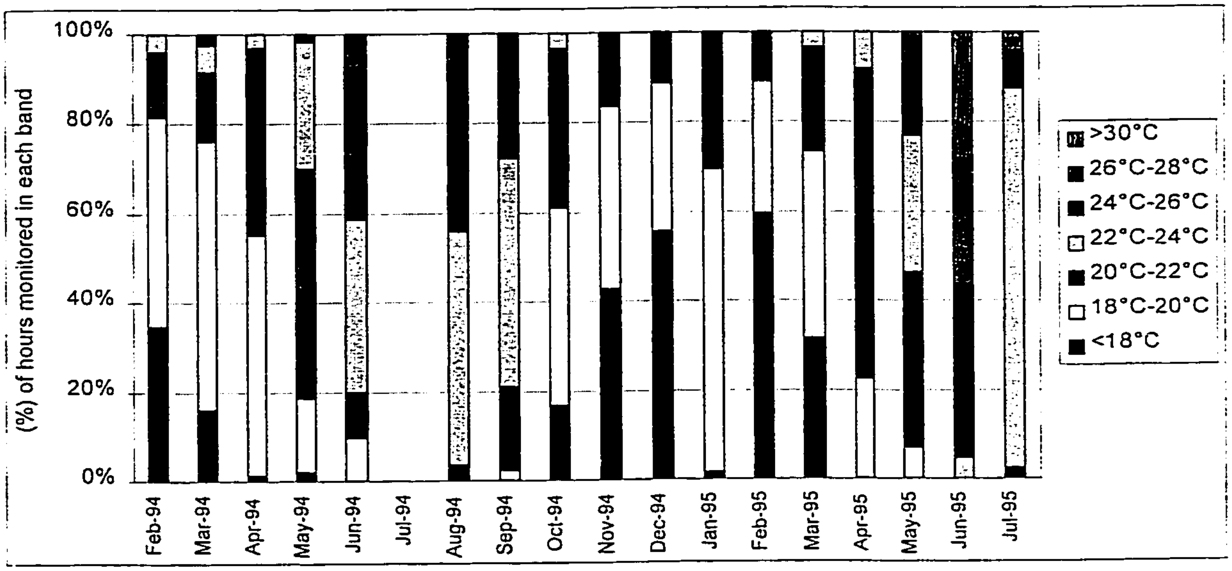


Figure 5.6.1.2: Temperature distribution profiles for the (a) master and (b) NW bedrooms

The results show that during the winter months, temperatures in the atrium typically ranged from 18 to 28°C, with the largest portion of time (47%) occurring in the 18 to 20°C range. During the summer months, temperatures in the atrium typically ranged from 20 to 30°C, with the largest portion of time (39%) occurring between the 22 to 24°C range. For the rest of the house, temperatures typically ranged from 19°C to 24°C during the winter months and 20°C to 26°C during the summer months.

The atrium and the kitchen experienced significant variations in temperature distribution throughout the year and had higher ambient temperatures than the rest of the house. Both these spaces are exposed to large areas of south-facing glazing which have no shading devices. As a result, they act as heat sources during sunlight hours and heat sinks during nocturnal hours. In comparison, the temperature distribution observed in the dining room is relatively constant, whereby, the dining room faces north and is not exposed to a large glazing area. Higher temperatures were also monitored in the master bedroom (which faces SE), than in the NW bedroom.

The results reflect the overheating which occurred in the house throughout the year and which was quantified in earlier sections. The use of shading devices with automatic controls based on solar gains influx and the use of floor finishes with a lower thermal resistance than the existing carpet (such as ceramic tiles) would greatly reduce the number of hours of overheating, reduce energy consumption, and optimise thermal comfort.

5.6.2 Relative Humidity Profiles

During the winter and spring months the relative humidity was between 20 and 30% for 31% of the time, and between 30 and 40% for also 31% of the time. These monitored levels fall within the ASHRAE comfort zone[31] of 20 to 60% but did not always satisfy the minimum relative humidity of 30% stipulated by the Advanced Houses Program technical requirements. Moisture generation resulting from occupant-related activities is expected to increase the number of hours in which the relative humidity level is above 30% during the winter. During the summer and fall months, the relative humidity ranged from 40 to 60%. The percentage of hours monitored in the relative humidity bands of intervals of 10% are shown in Figure 5.6.2.1 for the entire 1½ year monitored period. The RH sensor was located in the heat recovery exhaust (to core).

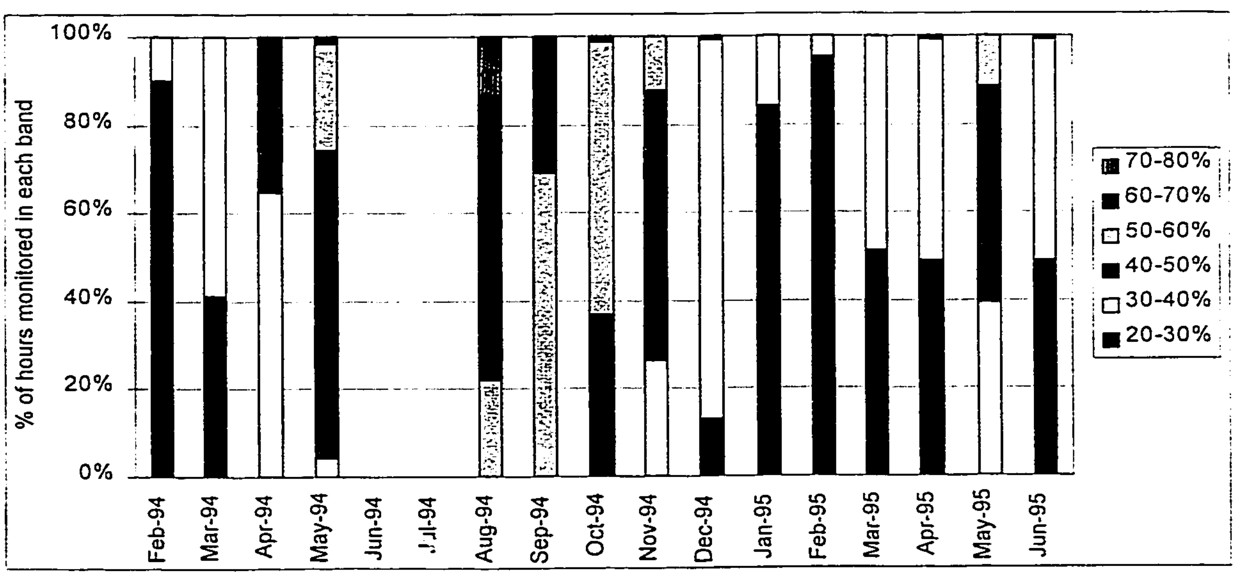


Figure 5.6.2.1: Relative humidity distribution profile

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

- The annual energy consumption of the NOVTEC Advanced House was 60 kWh/m². This corresponds to 42% less energy than a typical R-2000 House (104 kWh/m²), 64% less energy than a house built according to the 1983 Federal Energy Efficiency Measures, and 72% less energy than a typical house built in the late 1970s. During the 1½ year monitoring period, the energy consumption of the NOVTEC Advanced House was 9% more than had been expected at the outset based on energy simulations performed with Hot-2000.

- The overall Coefficient of Performance (COP = Output Energy / Input Energy) of the Integrated Home Comfort System (IHCS) was 2.6 and accounted for 59% of the total annual energy use. The overall Water-to-air Heat Pump (WAHP) COP was 2.5 and the overall Water-to-water HeatPump (WWHP) COP was 3.3. The WAHP accounted for twice the energy consumption of the WWHP. The WAHP operated year round in either cooling, heating or recirculation mode, and the domestic hot water (DHW) demand was minimal and sporadic during the unoccupied period.

- The energy performance of the IHCS can be further optimised (~10%) by modifying the controls such that the ground loop pumps operate on heating or cooling demand only, provided there is no risk of freezing the water-ethanol solution in the ground loop.

- The energy performance of the house and the thermal comfort of its occupants can be improved through the installation of shading devices with automatic controls based on solar gains influx and the use of a floor finish which has a lower thermal resistance than the existing carpet such as ceramic tiles. This would maximise the heating output of the radiant floor system and take advantage of the heat storage capacity of the concrete slab, thus reducing energy consumption, reducing overheating, and optimising thermal comfort.

- The lights and appliances energy consumption accounted for the largest portion (42%) of the total energy use, from which 24% was consumed by the monitoring system alone.

6.2 RECOMMENDATIONS

- Ground source heat pumps (GSHP) can play a vital role in improving the energy performance of our residential building stock and in helping Canada to reduce its greenhouse gas emissions as set out in the Kyoto Protocol. GSHPs are up to 5 times more energy efficient than traditional heating systems because they use the refrigeration cycle for heating and they use the ground as a heat source/sink. The energy performance results of the IHCS will serve as a good benchmark for the evaluation of integrated mechanical systems through the AIMS program.

- The main obstacle preventing the widespread acceptance of GSHPs is their cost. Since the main objective of the IHCS design was to demonstrate Canadian know-how and to push the boundaries of energy efficiency, its payback period (~ 15 years) was not the principle performance criteria. In order for GSHPs to gain widespread acceptance, they must either demonstrate a reasonable payback period (~ 5 years) or be part of a government subsidised program. Therefore, further research should be focussed on optimising production, installation, and maintenance costs, and demonstrating the benefits of GSHPs from both an economic and environmentally-friendly perspective.

- The horizontal "Zvec" coils which were used as the heat exchange medium between the ground and the water-ethanol mixture are well suited to suburban areas and district heating systems. Further research should be performed to evaluate the economic viability and performance of a shared ground loop which would serve a group of houses.

- Evaluating the viability of innovative mechanical systems involves the evaluation of their life cycle costs, namely their life span and the costs[32] to operate, maintain, repair, and replace them. Integrating components such as pumps, fans, controls, compressors, and heat exchangers, requires the implementation of a preventive maintenance plan which will optimise the durability and performance of the system. A major obstacle towards gaining market acceptance of integrated mechanical systems are their maintenance requirements. Unlike its counterpart in commercial buildings applications, residential mechanical systems are seldom maintained adequately. Hence, systems which require the least amount of maintenance are generally more readily accepted. Researchers must incorporate maintenance requirements and consumer attitudes towards maintenance when designing integrated systems.

- We often use *purchased energy consumption* as a criteria for evaluating the performance of a house and in assessing our contribution to the environment. However, in order to assess the direct impact of energy conservation measures on the environment, it is important to consider how the purchased energy is produced. For example, if the primary objective is to reduce CO_2 emissions, a house equipped with a condensing gas boiler may outperform a house equipped with a GSHP which uses electricity that is generated from a fossil fuel plant, regardless of their purchased energy consumptions.

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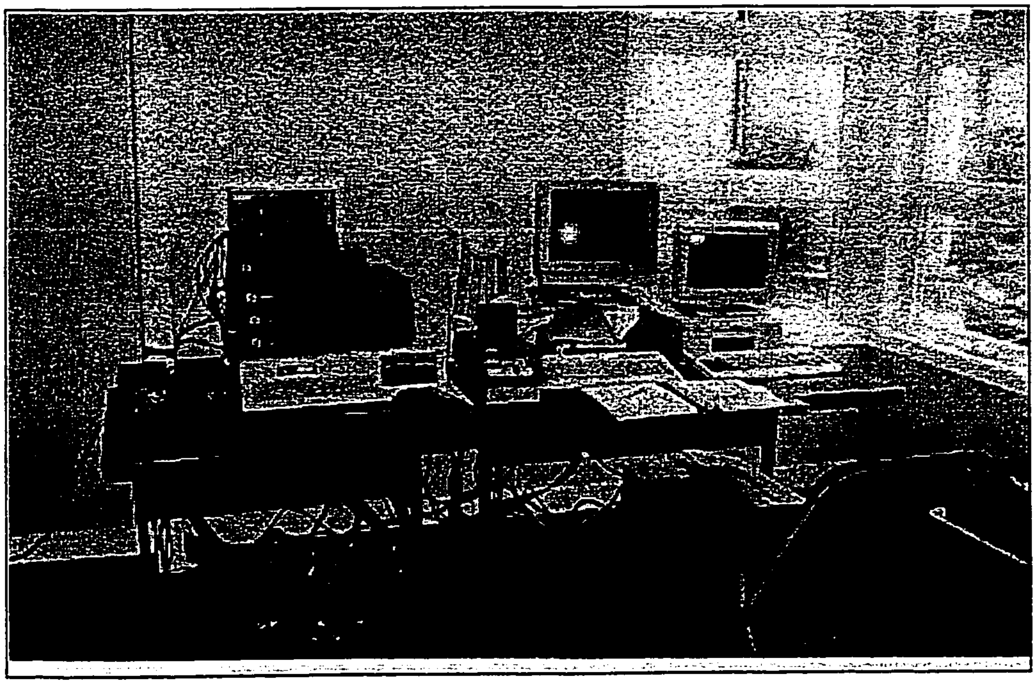
APPENDIX A: NOVTEC Advanced House Monitoring Plan

The NOVTEC Advanced House Monitoring Equipment

The long term data was collected by a Sciemetrics computer controlled DAS setup in the house, shown in Photograph A.1. A software called Copilot was used to manage the raw data, provide error checks, and produce preliminary on-line results. Data scanned at intervals ranging from 5 to 60 seconds was accumulated into hourly averages or sums. Copilot is an integrated data acquisition, management and analysis software package produced by Howell-Mayhew Engineering of Edmonton, Alberta. The package was initially developed for research level monitoring of all R-2000 houses, and was well suited to the long term monitoring objectives of the NOVTEC Project.



Photograph A.1: DAS setup in the NOVTEC Advanced House

Table A.1 summarizes the monitoring plan of the NOVTEC Advanced House and Table A.2 lists the sensors installed in the house. Further information regarding connection diagrams, calibration, and other manufacturer's information for specific sensors installed can be found in the Monitoring Equipment Installation Document prepared by Howell-Mayhew Engineering.

Table A.1: Summary of Monitoring Plan

NOVTEC ADVANCED HOUSE - MONITORED PARAMETERS							
category	**component**	**monitored parameter**	**monitoring objective**	**type of analysis**	**monitoring protocol**	**save rate**	**type of sensor**
BUILDING ENVELOPE							
Outside Conditions	Envelope	Horizontal radiation	Determine heat loss coefficient Compare with long term trends	Effect of solar gains on balance point	Locate sensor at roof peak in unobstructed area	Hourly	Pyranometer
		Outside temperature	Determine envelope heat loss	Wall, window, door and ventilation heat loss	Locate sensor in shaded area on north side of house	Hourly	Shielded thermistor
		Outside RH and temperature	Determine moisture added to inside Determine additional load on heating	Heat recovery efficiency Energy balance	Locate RH sensor in supply air duct, close to outside wall	Hourly	RH sensor
					Locate temperature sensor next to RH sensor	Hourly	Thermistor
Inside Conditions	Third floor	Temperature	Determine envelope heat loss	Wall, window, door and ventilation heat loss using weighted values based on heat loss associated with each temperature zone Bin and graph all temperatures for comparison with other Advanced Houses	Locate sensor mid-height on wall adjoining west storage area	Hourly	Shielded thermistor
	Second floor	Temperature - S, master bedroom			Locate sensor mid-height on wall adjoining bathroom	Hourly	Shielded thermistor
		Temperature - N, bedroom			Locate sensor mid-height on North exterior wall	Hourly	Shielded thermistor
		Temperature - S, hallway			Locate sensor mid-height on wall opposite stairs	Hourly	Shielded thermistor
	First floor	Temperature - S, kitchen			Locate sensor mid-height on wall adjoining family room	Hourly	Shielded thermistor
		Temperature - N, dining room			Locate sensor mid-height on wall adjoining bathroom	Hourly	Shielded thermistor
	Atrium	Temperature - S, atrium			Locate sensor mid-height on wall adjoining hallway	Hourly	Shielded thermistor
		Vertical radiation in atrium	Determine radiation into atrium	Correlate solar gains with atrium temperature	Locate sensor inside the atrium to measure vertical radiation	Hourly	Pyranometer
Adjoining Spaces	Attic - north/east and west	Temperature	Determine envelope heat loss	Ceiling heat loss HOT2000 attic model	Locate sensor mid-height in center of vented roof truss space	Hourly	Thermocouple
					Locate sensor mid-height in center of west attic	Hourly	Thermocouple
	Garage			Adjoining wall heat loss	Locate sensor mid-height on wall adjoining storage depot	Hourly	Shielded thermistor
Additional Monitoring	Roof air/vapour barrier using rigid insulation	Plywood and joist moisture content and temperatures	Determine moisture levels	Document results	Weekly measurements	Daily/Weekly	Thermocouples, Duff moisture pins
	Terrace recycled membrane	Plywood and joist moisture content and temperatures	Determine moisture levels	Document results	Weekly measurements	Daily/Weekly	Thermocouples, Duff moisture pins
	US Brick exterior wall cladding system	Plywood and joist moisture content wall temperatures and pressure	Determine moisture levels	Document results	Weekly measurements	Daily/Weekly	Thermocouples, Duff moisture pins, transducer
	Radiant heating in slab on grade	Temperature - slab surface	Evaluate comfort levels	Document results	Locate sensors on slab-on-grade	Daily/Weekly	Thermocouple*
		Temperature - under slab	Evaluate temperature gradient		Locate sensors at gravel/insulation interface	Daily/Weekly	Thermocouple*
		Temperature - under slab			Locate sensor at insulation/slab interface		Thermocouple*
MECHANICAL SYSTEMS							

NOVTEC ADVANCED HOUSE - MONITORED PARAMETERS

category	component	monitored parameter	monitoring objective	type of analysis	monitoring protocol	save rate	type of sensor
Energy Supply to Space Heating and DHW Systems	WAHP	Total electric consumption	Determine input energy	Calculate integrated system COP Calculate heat pump COP Calculate DHW system COP Energy balance HOT2000 fan input Verify technical requirement	Locate sensor in line dedicated to compressor and fan	Hourly	kWh meter with pulse output
		Fan electric consumption			Obtain from controller terminal board	Hourly	Voltage status sensor
		Electric backup status/power draw			Locate sensor in line dedicated to electric backup	Hourly	kWh meter with pulse output
		Ground loop circulating pumps			Locate sensor in line dedicated to pumps	Hourly	kWh meter with pulse output
	WWHP	Total electric consumption	Determine input energy		Locate sensor in line dedicated to heat pump	Hourly	kWh meter with pulse output
	Heat pump ground loop	Loop temperature after exhaust air coil	Determine temperature in strategic points in loop	Document results	Locate sensor in heat pump loop after exhaust air fan coil	Hourly	Thermistor probe
		Loop temp. after water/air heat pump			Locate sensor in heat pump loop after water/air heat pump	Hourly	Thermistor probe
		Fluid flow in loop			Locate sensor in heat pump loop	Monthly	Flow meter
		Fluid supply temperature to field	Determine temperature of methanol/ water flow medium	NRC to evaluate flow medium characteristics	Locate sensor at point where fluid exits house	Hourly	Thermistor probe
		Fluid return temperature from field			Locate sensor at point where fluid enters house	Hourly	Thermistor probe
		Ground temperatures	Evaluate effect of spiral coil on ground temperatures	Document results	Locate sensors in soil at various intervals along spiral coil	Daily	Thermocouples (17)
	Radiant slab pump	Electric consumption	Determine input energy	Calculate heat pump and DHW system COP Energy balance Verify technical requirement	Connect sensor to detect on/off voltage signal from pump control Measure power draw using a Wattmeter	Hourly	Voltage status sensor
	DHW tank	DHW tank /heat pump fluid flow			Locate sensor in supply line to, or return line from, DHW tank	Hourly	Flow meter with pulse output
		Supply temperature to DHW tank			Locate sensor at DHW tank	Hourly	Thermistor probe
		Return temperature from DHW tank			Locate sensor at DHW tank	Hourly	Thermistor probe
	DHW circulation pump	Electric consumption			Connect sensor to detect on/off voltage signal from pump control Measure power draw using a Wattmeter	Hourly	Voltage status sensor
	Electric DHW tank				Locate sensor in line dedicated to DHW tank	Hourly	kWh meter with pulse output
	Garage electric baseboard			Energy balance	Connect sensor to detect on/off voltage signal from baseboard control. Measure power using a Wattmeter.	Hourly	kWh meter with pulse output
Energy Demand from Space Heating and DHW Systems	Fan coil unit	Air flows - programmed speeds	Determine output energy	Energy balance Integrated system efficiency	Manufacturer's performance constants to be verified on site	Monthly	Hot wire anemometer
		Supply temp. from space heating coil			Locate sensor in return air duct after fresh air inlet	Hourly	Thermocouple grid
		Return temp. to space heating coil			Locate sensor in warm air supply from fan coil	Hourly	Thermocouple grid
	Radiant slab heating	Fluid flow from heat pump to slab			Locate sensor in return line from radiant slab	Hourly	Flow meter with pulse output
		Supply temperature to radiant floor			Locate sensor close to heat pump	Hourly	Thermistor probe

NOVTEC ADVANCED HOUSE - MONITORED PARAMETERS							
category	component	monitored parameter	monitoring objective	type of analysis	monitoring protocol	save rate	type of sensor
		Return temperature from radiant floor				Hourly	Thermistor probe
	Domestic hot water	Hot water consumption		Calculate DHW system COP Energy balance and DHW demand HOT2000 DHW model	Locate sensor in cold water line to DHW tank	Hourly	Flow meter with pulse output
		Temperature of cold service water			Locate sensor close to DHW tank	Hourly	Thermistor probe
		Temperature of hot water to house			Locate sensor at outlet from instantaneous heater to house	Hourly	Thermistor probe
Ventilation System	Heat recovery ventilation system	Fan electric consumption	Determine heat recovered from exhaust air by ground loop	Energy balance Heat recovery efficiency	Locate sensor in line supply and exhaust fans	Hourly	kWh meter with pulse output
		Supply air flow to house			Locate sensor in warm side supply duct	Hourly	Pitot array and transducer
		Exhaust air flow from house	Determine house RH		Locate sensor in warm side exhaust duct	Hourly	Pitot array and transducer
		Exhaust air temperature to coil	Evaluate ventilation system		Locate sensor at exhaust air intake to HRV	Hourly	Thermocouple grid
		Exhaust air temperature at hood			Locate sensor as close to outside wall as possible	Hourly	Thermocouple grid
		Exhaust air RH			Locate sensor in warm side exhaust duct	Hourly	RH sensor
		321 Thermocouple junction temperature	Determine thermocouple temperatures	None required	Locate sensor inside DAS near thermocouple channels	Not required	Thermistor
		161 Thermocouple junction temperature				Not required	Thermistor
INSIDE ENVIRONMENT							
Air Quality and Comfort	Ventilation system and source control measures	Carbon dioxide	Verify acceptable exposure levels Determine system effectiveness Determine source strengths	Correlate with ventilation rates Document results	Locate sensors in master bedroom	Hourly	CO2 sensor
		Other parameters as specified in the Advanced Houses Indoor Environment Monitoring Requirements			As specified in the Advanced Houses Indoor Environment Monitoring Requirements	Short-term	As specified in Indoor Environment Monitoring Requirements
UTILITIES							
Electrical Service	Total house	Electric consumption	Determine input energy	Energy balance Verify technical requirements Validate HOT2000 defaults	Locate sensor in electrical service line to panel	Hourly	kWh meter with pulse output
	Stove				Locate sensor in line dedicated to stove	Hourly	kWh meter with pulse output
	Refrigerator				Locate sensor in line dedicated to refrigerator	Hourly	kWh meter with pulse output
	Microwave				Locate sensor in line dedicated to microwave	Hourly	kWh meter with pulse output
	Dishwasher				Locate sensor in line dedicated to dishwasher	Hourly	kWh meter with pulse output
	Clothes washer				Locate sensor in line dedicated to clothes washer	Hourly	kWh meter with pulse output
	Clothes dryer		Determine input energy		Locate sensor in line dedicated to dryer	Hourly	kWh meter with pulse output
		Temperature - exhaust air	Determine utilizability factor	Energy balance	Locate sensor in exhaust line from dryer	Hourly	Thermistor
	Inside lights & outlets	Electric consumption	Determine input energy	Verify technical requirement	Locate sensor in line dedicated to lighting and outlets	Hourly	kWh meter with pulse output
	Monitoring system		Determine contribution to space gains	Energy balance	Measure power draw using Wattmeter	One-time	Wattmeter
Water Service	Total house	Water consumption	Determine total water consumption	Verify technical requirement	house meter installed by local utility	Monthly	Utility water meter
	Outside water		Determine outside water consumption		Locate submeter to measure total outside consumption	Monthly	Water meter
MONITORING SYSTEM							

NOVTEC ADVANCED HOUSE - MONITORED PARAMETERS

category	component	monitored parameter	monitoring objective	type of analysis	monitoring protocol	save rate	type of sensor
Monitoring Hardware	Data acquisition unit	Voltage constant for 321	Verify operation of DAU	None required	Install according to senor connection diagram in senor documentation manual	Hourly	Resistor
		Resistance constant for 321 + WDT				Hourly	Resistor
		Voltage constant for 161				Hourly	Resistor
		Resistance constant for 161				Hourly	Resistor
		Voltage constant for Labmate				Hourly	Resistor
		Resistance constant for Labmate				Hourly	Resistor

Table A.2: List of sensors installed in the NOVTEC Advanced House

Sensor type	Monitored parameter	Quantity
fluid meter	DHW tank/heat pump fluid	1
	fluid from heat pump to radiant slab	1
	domestic hot water	1
kWh meter - pulsed	subsystem energy consumption	5 x 3 = 15
pilot array	HRV air flow pressures	2
pressure transducer	HRV air flow pressures	2
pressure transducer	pressure measurements across the south wall	1
pyranometer	horizontal solar radiation	1
	atrium solar radiation	1
relative humidity	outside relative humidity	1
	HRV exhaust air to coil	1
3K thermistor	outside air temperature	1
10K thermistor	inside temperature	8
30K thermistor	fluid temperature	10
	clothes dryer exhaust temperature	1
thermocouple grid	supply air temperature to house	1
	return air temperature to house	1
	exhaust air temperature to coil	1
	exhaust air temperature at hood	1
voltage status relays	detects on-off mode of heat pumps and ground loop pump	3
water meter	outside water use	1
CO2 detector	northwest bedroom CO2 levels	1
Moisture Pins	wood moisture content, various locations in the envelope	20
thermocouples	building envelope temperature gradients	20
thermocouples	ground temperatures	10

APPENDIX B: Typical Monthly Monitoring Report

Dino Gerbasi

Novtec Advanced House Monitoring Report

JANUARY, 1995

The NOVTEC Advanced House was monitored for 21 months (November 1993 through July 1995). The first 3 months' data was used to calibrate the DAS system and fine-tune the operation of various equipment within the home.

A total of 2 months' data was not recorded during the monitored period because of DAS failures due to power surges and hardware malfunctions.

Version 2.82

Novtec Advanced House — JANUARY, 1995 — Month: 22

OPERATING CONDITIONS:

	Horizontal Insolation (MJ/m2)	Degree Days Heating base<18C)	Degree Days Cooling base>18C)	Outside Temp. (C)	Outside RH (%)	Inside Temp.# (C)	Inside RH (%)	Bedroom CO2 (ppm)
AVERAGE	4.1	23	0	-5.5	96%	20.9	26%	478
Daily Min.	0.4	13	0	-21.4	84%	19.8	21%	463
Daily Max.	11.9	39	0	5.0	100%	21.8	31%	500
Hourly Min.				-24.7		17.4	20%	452
Hourly Max.	1.9			9.1		#REF!	34%	538
Sum		728	0					
Long Term	17.2	25	68	19.4	72% <<compare with boxed values above			

SUPPLIES:

	Electrical (kWh) Total (using submeters)	Space + DHW	Utilities	Garage heating	Outside (Garage + est. lights)	Water (L) Municipal Total	Hot	Outside
peak hourly	6.19			2.01			62.0	
per month	1,944	1,410	129	309	324		142	
per day (DAS)*	62.7	45.5	4.2	10.0	10.4		4.6	
per day (Meter)	26.5			0.0		0.0	0	0.0
DAS/.Meter	236.7%							

SPACE HEATING ENERGY BALANCE:

	SUPPLIES: Appl. (kWh)	Space (kWh)	Solar*** (kWh)	LOSSES: Foundation (kWh)	Abv. Fdtn. (kWh)	Infiltration + Ventilation (kWh)	Humidification (kWh)	Total (kWh)	Buffering (kWh)
AVERAGE	11	108	25	11	95	40	0	147	5
Daily Min.	7	75	0	11	57	23	0	91	2
Daily Max.	14	205	78	11	146	59	0	215	11
SUM*	329	3,354	775	356	2,946	1,240	0	4,542	140

Solar SUM calculated from Insolation: 0 kWh (does not include effect of overhangs or utilization of solar energy)

MECHANICAL - Heating systems: Cooling system: Ventilation Air:

	Space heat Output (kWh)	Space heat Input (kWh)	Cooling Output (kWh)	Cooling Input (kWh)	COP	HRV fan Energy (kWh)	Balanced Exhaust Ventilation (L/s)	Balanced Exhaust Ventilation (ach)	Natural Infiltration (ach)	Total Ventilation (ach)
AVERAGE	103.0	37.1	1.1	0.3	2.8	1.7	31	0.051	0.079	0.323
Daily Min.	71.1	26.3	0.0	0.0		1.6	19	0.031	0.047	0.289
Daily Max.	193.9	68.8	8.1	2.1		1.8	38	0.063	0.134	0.369
SUM	3,193	1,151	35	9		53				

DHW System: / Parasitic Consumption:

	Hot Water Demand (L)	Temperatures: Cold inlet (C)	Hot output (C)	DHW Energy Output (kWh)	DHW Energy Input (kWh)	COP	Circulation fan Energy (kWh)	Pump Energy (kWh)	Total Parasitic (kWh)
AVERAGE	4.6	11.0	49.1	2.8	1.4	2.0	4.0	5.3	9.3
Daily Min.	0.0	8.7	41.3	2.1	1.0		2.9	3.5	
Daily Max.	65.0	25.1	50.4	5.5	2.3		5.3	10.7	
SUM	142			88	43		124	163	287

NOTES:
* Supplies/day for DAS (Data aquisition System) & Meters may be for slightly different time periods (depending on date & time of meter reading)
** SUMS in the energy balance are the number of days in the month multiplied by the daily average (therefore, the sum of the components may not exactly equal the total shown for months with incomplete records).
***Calculated from difference of Total losses and Sum of known supplies (compare SUM with Solar SUM from insolation).
Based on space-weighted averages (except for hourly minimum and hourly maximum, which are extremes for the space)

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Detailed Inside Conditions

Inside Temp. (%of hours monitored in each band)	MbdrmS	BdrmN	DiningN	KitchenS	Atrium	Inside RH	RHexh	Inside CO2	M.Bdrm
<18C	0.0%	1.5%	0.0%	0.0%	0.0%	<20%	0.0%	<350	0.0%
18C - 20C	0.8%	68.0%	0.0%	5.1%	31.9%	20% - 30%	84.1%	350 - 450	0.0%
20C - 22C	91.0%	30.5%	90.9%	84.1%	55.9%	30% - 40%	15.9%	450 - 550	100.0%
22C - 24C	5.9%	0.0%	9.1%	5.8%	3.5%	40% - 50%	0.0%	550 - 650	0.0%
24C - 26C	2.3%	0.0%	0.0%	4.7%	2.8%	50% - 60%	0.0%	650 - 750	0.0%
26C - 28C	0.0%	0.0%	0.0%	0.3%	1.2%	60% - 70%	0.0%	750 - 850	0.0%
28C - 30C	0.0%	0.0%	0.0%	0.0%	0.8%	70% - 80%	0.0%	850 - 950	0.0%
>30C	0.0%	0.0%	0.0%	0.0%	3.9%	>80%	0.0%	>950	0.0%
Hrs. monitored	744	744	744	744	744		744		744
Completeness	100%	100%	100%	100%	100%		100%		100%

Average Power Profiles:

Electrical:

Hour	HVAC + DHW (kW)	Outside Average (kW)	Total Electrical Average (kW)	Std. Dev. (kW)
1	2.29		2.93	0.73
2	2.18		2.85	0.86
3	2.32		2.95	0.77
4	2.29		2.99	0.80
5	2.33		2.98	0.88
6	2.28		2.96	0.84
7	2.42		3.09	1.05
8	2.54		3.20	0.99
9	2.38		3.09	1.12
10	1.92		2.59	0.91
11	1.05		1.80	0.88
12	1.16		1.85	0.91
13	1.31		1.91	0.85
14	1.28		1.82	0.88
15	1.44		2.01	0.72
16	1.45		2.01	0.74
17	1.77		2.29	0.74
18	1.57		2.21	0.91
19	2.18		2.80	0.74
20	2.34		2.95	0.71
21	2.18		2.83	0.82
22	2.25		2.87	0.80
23	2.27		2.89	0.87
24	2.26		2.88	0.81
Sum	47.46		62.72	
Max. hourly	4.07		6.19	using submeters
Time of max.			hr. to 900	

Data completeness:

Hours monitored	Temperatures	IAQ (RH, CO2)	Energy Supplies
100%	100%	75%	90%

Novtec Advanced House JANUARY, 1995 Month: 22

Electrical Appliance Energy Supplies

	Refrigerator (kWh)	Stove (kWh)	Microwave (kWh)	ishwasher (kWh)	Washer (kWh)	Dryer (kWh)	Lights & plugs (kWh)	Outside* (kWh)	Garage (kWh)
AVERAGE	1.05	0.00	0.00	0.00	0.00	0.00	7.13	10.44	9.96
Daily Min.	0.93	0.00	0.00	0.00	0.00	0.00	6.13	0.48	0.00
Daily Max.	1.18	0.15	0.00	0.00	0.00	0.00	9.20	38.85	38.37
peak hourly	0.129	0.150	0.000	0.000	0.000	0.000	0.718		2.012
Monthly SUM	32.7	0.2	0.0	0.0	0.0	0.0	221.1	323.6	308.8

Notes: *Outside energy use is sum of estimated light use plus garage heating

Monthly End-Use Summary:

End-Use			Electric Energy Consumption (kWh)	% of Total		Remarks
House Total			1,944	100.0%		using submeters
Integrated Home Comfort System			1,230	63.2%		
	Water-to-Air Heat Pump		982	50.5%		
		Space Heating	955	49.1%		
		Space Cooling	9	0.5%		
	Water-to-Water Heat Pump		247	12.7%		
		Radiant Heating	196	10.1%		
		DHW Heating	43	2.2%		
	Parasitic Loads		279	14.3%		
		DHW pump	2	0.1%		included in WWHP
		Radiant Heating pump	23	1.2%		included in WWHP
		Ground Loop pumps	130	6.7%		divided between WAHP & WWHP
		Circulation fan	124	6.4%		included in WAHP
Ventilation	HRV fans		53	2.7%		
Lighting and Appliances			254	13.1%		not including HRV
	Stove		0	0.0%		
	Refrigerator		33	1.7%		
	Microwave		0	0.0%		
	Dishwasher		0	0.0%		
	Clothers Washer		0	0.0%		
	Clothes Dryer		0	0.0%		
	Lights & plugs		221	11.4%		incl. ext. plugs
Outdoors:			324	16.6%		incl. default outdoor lights
	Garage		309	15.9%		
Other:	meters, home automation, etc.		84	4.3%		

Notes:

DAILY SUMMARY

Operating Conditions

Novtec Advanced House

JANUARY, 1995

Day	Mo.	Yr.	Wind (AES) (m/s)	Insolation (MJ/m2)	(hr)	Outside Temp. (C)	(hr)	Heating Degree Days (DD<18C)	Cooling Degree Days (DD>18C)	Outside RH (%)	(hr)	Attic Temp. (C)	(hr)	Garage Temp. (C)	(hr)	Inside Temp. (C)	(hr)	Inside RH (%)	(hr)	Day of Week
1	jan	95	2.4	0.9	24	-5.7	24	23.7	0.0	100%	24	-3.3	24	9.1	24	20.5	24	25%	24	Sun
2	jan	95	3.6	0.4	24	-4.3	24	22.3	0.0	99%	24	-3.0	24	8.6	24	20.6	24	26%	24	Mon
3	jan	95	5.0	1.5	24	-6.2	24	24.2	0.0	96%	24	-5.3	24	8.5	24	21.0	24	26%	24	Tues
4	jan	95	5.8	5.0	24	-8.4	24	26.4	0.0	95%	24	-7.8	24	8.5	24	21.0	24	26%	24	Wed
5	jan	95	8.0	5.4	24	-12.0	24	30.0	0.0	95%	24	-11.3	24	7.4	24	20.7	24	24%	24	Thur
6	jan	95	6.4	3.4	24	-4.2	24	22.2	0.0	86%	24	-3.6	24	7.7	24	20.7	24	25%	24	Fri
7	jan	95	1.8	0.6	24	-2.5	24	20.5	0.0	100%	24	0.3	24	9.0	24	20.8	24	26%	24	Sat
8	jan	95	3.3	1.3	24	-7.2	24	25.2	0.0	95%	24	-3.6	24	8.9	24	21.2	24	26%	24	Sun
9	jan	95	4.9	6.5	24	-8.2	24	26.2	0.0	84%	24	-6.4	24	10.2	24	21.4	24	25%	24	Mon
10	jan	95	2.7	8.9	24	-18.1	24	36.1	0.0	100%	24	-11.6	24	11.8	24	21.3	24	24%	24	Tues
11	jan	95	5.3	3.0	24	-21.4	24	39.4	0.0	100%	24	-17.8	24	11.6	24	19.8	24	21%	24	Wed
12	jan	95	6.4	0.9	24	-12.2	24	30.2	0.0	100%	24	-10.8	24	12.0	24	20.3	24	21%	24	Thur
13	jan	95	3.5	1.4	24	-3.8	24	21.8	0.0	100%	24	-1.9	24	12.2	24	20.6	24	23%	24	Fri
14	jan	95	3.8	2.7	24	-1.3	24	19.3	0.0	100%	24	0.2	24	12.3	24	20.6	24	25%	24	Sat
15	jan	95	4.0	2.0	24	5.0	24	13.0	0.0	100%	24	5.8	24	12.0	24	20.7	24	28%	24	Sun
16	jan	95	5.3	1.3	24	3.7	24	14.3	0.0	100%	24	4.6	24	12.3	24	20.7	24	31%	24	Mon
17	jan	95	2.4	2.2	24	0.6	24	17.4	0.0	100%	24	2.1	24	11.8	24	20.7	24	30%	24	Tues
18	jan	95	4.5	3.2	24	-1.0	24	19.0	0.0	100%	24	0.0	24	8.9	24	20.7	24	29%	24	Wed
19	jan	95	2.8	1.6	24	1.0	24	17.0	0.0	100%	24	2.3	24	8.1	24	20.7	24	29%	24	Thur
20	jan	95	7.0	1.7	24	1.3	24	16.7	0.0	100%	24	1.9	24	7.5	24	20.6	24	29%	24	Fri
21	jan	95	7.9	2.5	24	0.5	24	17.5	0.0	100%	24	1.0	24	6.9	24	20.6	24	29%	24	Sat
22	jan	95	6.0	2.8	24	-1.9	24	19.9	0.0	100%	24	-1.1	24	7.3	24	20.6	24	29%	24	Sun
23	jan	95	1.8	2.0	24	-2.1	24	20.1	0.0	100%	24	-0.3	24	6.9	24	20.7	24	28%	24	Mon
24	jan	95	2.4	2.2	24	-2.5	24	20.5	0.0	100%	24	-0.7	24	7.2	24	20.6	24	28%	24	Tues
25	jan	95	4.1	5.9	24	-3.8	24	21.8	0.0	92%	24	-3.0	24	7.2	24	21.4	24	29%	24	Wed
26	jan	95	5.0	11.0	24	-10.1	24	28.1	0.0	99%	24	-9.3	24	7.1	24	21.7	24	29%	24	Thur
27	jan	95	5.6	10.8	24	-13.3	24	31.3	0.0	92%	24	-12.3	24	7.1	24	21.5	24	27%	24	Fri
28	jan	95	4.6	11.0	24	-13.4	24	31.4	0.0	91%	24	-12.6	24	6.8	24	21.5	24	26%	24	Sat
29	jan	95	1.5	11.9	24	-10.8	24	28.8	0.0	91%	24	-9.3	24	6.9	24	21.7	24	25%	24	Sun
30	jan	95	5.1	10.1	24	-5.2	24	23.2	0.0	84%	24	-4.8	24	6.5	24	21.8	24	26%	24	Mon
31	jan	95	5.1	3.2	24	-2.1	24	20.1	0.0	92%	24	-1.5	24	6.6	24	20.7	24	25%	24	Tues
Average:			4.5	4.1	24	-5.5	24	23.5	0.0	96%	24	-4.0	24	8.9	24	20.9	24	26%	24	
Std.Dev.			1.8	3.6		6.2		6.2	0.0	5%		5.7		2.1		0.5		3%		
Minimum:			1.5	0.4	24	-21.4	24	13.0	0.0	84%	24	-17.8	24	6.5	24	19.8	24	21%		
Maximum:			8.0	11.9	24	5.0	24	39.4	0.0	100%	24	5.8	24	12.3	24	21.8	24	31%		
SUM:								728	0.0											

DAILY SUMMARY Operating Conditions			Novtec Advanced House																		JANUARY, 1995				
Date			2nd floor:		NW bedroom		Master bdrm		S. side	1st floor:		Dining room		Kitchen		S. side	Atrium		M. Bedroom		Family Room		Day of
Day	Mo.	Yr.	Temp.		N. side temp.		S. side temp.		Temp. swing	Temp.		N. side temp.		S. side temp.		Temp. swing	S. side temp.		CO2		CO2		Week
			(C)	*(hr)*	(C)	*(hr)*	(C)	*(hr)*	(C)	(C)	*(hr)*	(C)	*(hr)*	(C)	*(hr)*	(C)	(C)	*(hr)*	(ppm)	*(hr)*	(ppm)	*(hr)*	
1	jan	95	20.5	24	19.5	24	20.8	24	0.4	20.6	24	21.3	24	20.3	24	0.4	20.0	24	472	24		0	Sun
2	jan	95	20.7	24	20.0	24	20.9	24	0.5	20.6	24	21.4	24	20.4	24	0.5	20.1	24	468	24		0	Mon
3	jan	95	20.9	24	19.8	24	21.2	24	1.9	21.2	24	21.5	24	20.9	24	2.8	21.4	24	463	24		0	Tues
4	jan	95	20.9	24	19.7	24	21.2	24	1.6	21.3	24	21.4	24	21.0	24	3.3	21.4	24	467	24		0	Wed
5	jan	95	20.5	24	19.3	24	20.9	24	1.3	21.0	24	21.5	24	20.8	24	3.1	20.8	24	470	24		0	Thur
6	jan	95	20.7	24	19.8	24	20.8	24	0.5	20.8	24	21.6	24	20.6	24	0.7	20.3	24	465	24		0	Fri
7	jan	95	20.7	24	19.8	24	20.9	24	0.5	20.9	24	21.5	24	20.6	24	1.3	20.5	24	470	24		0	Sat
8	jan	95	21.0	24	19.8	24	21.5	24	3.4	21.5	24	21.4	24	21.1	24	4.5	21.9	24	477	24		0	Sun
9	jan	95	21.2	24	19.9	24	21.7	24	3.9	21.6	24	21.5	24	21.3	24	5.0	22.2	24	483	24		0	Mon
10	jan	95	20.9	24	19.2	24	21.6	24	3.7	21.6	24	21.2	24	21.2	24	5.2	22.2	24	500	24		0	Tues
11	jan	95	19.6	24	17.9	24	20.2	24	0.8	20.0	24	20.7	24	20.0	24	1.2	19.4	24	496	24		0	Wed
12	jan	95	20.1	24	18.6	24	20.6	24	0.8	20.4	24	21.2	24	20.2	24	0.4	19.8	24	478	24		0	Thur
13	jan	95	20.6	24	19.6	24	20.9	24	0.7	20.7	24	21.4	24	20.4	24	0.5	20.1	24	485	24		0	Fri
14	jan	95	20.6	24	19.7	24	20.9	24	0.5	20.7	24	21.4	24	20.4	24	0.5	20.3	24	493	24		0	Sat
15	jan	95	20.9	24	20.2	24	21.1	24	0.6	20.8	24	21.5	24	20.5	24	0.5	20.4	24	488	24		0	Sun
16	jan	95	20.9	24	20.2	24	21.2	24	0.3	20.6	24	21.3	24	20.4	24	0.2	20.2	24	477	24		0	Mon
17	jan	95	20.8	24	20.1	24	21.1	24	0.4	20.7	24	21.4	24	20.5	24	0.4	20.3	24	489	24		0	Tues
18	jan	95	20.8	24	19.9	24	21.0	24	0.6	20.7	24	21.3	24	20.5	24	0.5	20.3	24	489	24		0	Wed
19	jan	95	20.8	24	20.0	24	21.0	24	0.4	20.7	24	21.4	24	20.5	24	0.3	20.2	24	483	24		0	Thur
20	jan	95	20.7	24	19.8	24	21.1	24	0.5	20.6	24	21.3	24	20.4	24	0.3	20.1	24	475	24		0	Fri
21	jan	95	20.7	24	19.6	24	21.1	24	0.6	20.7	24	21.3	24	20.5	24	0.8	20.3	24	468	24		0	Sat
22	jan	95	20.7	24	19.7	24	21.0	24	0.5	20.6	24	21.3	24	20.4	24	0.5	20.1	24	470	24		0	Sun
23	jan	95	20.8	24	20.0	24	21.0	24	0.5	20.7	24	21.4	24	20.5	24	0.6	20.3	24	471	24		0	Mon
24	jan	95	20.7	24	19.8	24	20.9	24	0.5	20.7	24	21.4	24	20.5	24	0.8	20.3	24	474	24		0	Tues
25	jan	95	21.2	24	20.0	24	21.6	24	3.6	21.7	24	21.6	24	21.5	24	4.6	22.0	24	478	24		0	Wed
26	jan	95	21.2	24	19.6	24	21.8	24	4.0	22.1	24	21.6	24	21.8	24	5.7	22.9	24	472	24		0	Thur
27	jan	95	21.0	24	19.3	24	21.6	24	4.2	22.0	24	21.5	24	21.7	24	5.8	22.7	24	473	24		0	Fri
28	jan	95	20.8	24	19.1	24	21.4	24	4.6	22.0	24	21.5	24	21.8	24	6.4	22.7	24	476	24		0	Sat
29	jan	95	21.1	24	19.5	24	21.6	24	4.6	22.1	24	21.6	24	21.9	24	6.2	22.9	24	489	24		0	Sun
30	jan	95	21.3	24	19.9	24	21.7	24	4.1	22.2	24	21.9	24	22.0	24	5.1	22.8	24	479	24		0	Mon
31	jan	95	20.6	24	19.8	24	20.9	24	0.8	20.9	24	21.6	24	20.8	24	0.6	20.4	24	481	24		0	Tues
Average:			20.8	24	19.6	24	21.1	24	1.7	21.1	24	21.4	24	20.8	24	2.2	20.9	24	478	24		0	
Std.Dev.			*0.3*		*0.5*		*0.4*		*1.6*	*0.6*		*0.2*		*0.6*		*2.2*	*1.1*		*9*				
Minimum:			19.6	24	17.9		20.2	24	0.3	20.0	24	20.7	24	20.0	24	0.2	19.4	24	463	24		0	
Maximum:			21.3	24	20.2		21.8	24	4.6	22.2	24	21.9	24	22.0	24	6.4	22.9	24	500	24		0	
SUM:																							

DAILY SUMMARY — Novtec Advanced House — JANUARY, 1995

Energy Supplies

Date Day	Mo.	Yr.	ELECTRIC: Refrigerator (kWh)	(hr)	Clothes washer + Dryer (kWh)	(hr)	Lights+Plugs (kWh)	(hr)	Total Utilities (kWh) (hr)	HVAC+DHW (kWh) (hr)	Outside (incl. garage) (kWh)	(hr)	TOTAL (using submeters) (kWh)	(hr)	Energy Use Breakdown: Stove (kWh)	(hr)	DHW (kWh) (hr)	HVAC (kWh) (hr)	Pumps & Fans (kWh) (hr)	Monitoring + Controls (kWh)
1	jan	95	1.07	24	0.00	24	8.86	24	6.22	49.50	12.29	12	70.65	24	0.00	24	2.65	49.44	11.33	2.9
2	jan	95	1.06	24	0.00	24	8.64	24	6.25	46.02	8.70	12	63.62	24	0.00	24	2.78	45.96	10.51	2.9
3	jan	95	0.99	24	0.00	24	8.61	24	6.38	39.52	9.43	12	57.98	24	0.00	24	2.16	39.48	9.47	2.9
4	jan	95	1.09	24	0.00	24	9.20	24	6.65	41.19	9.94	12	60.42	24	0.00	24	2.99	41.13	9.92	2.9
5	jan	95	1.09	24	0.00	24	9.04	24	5.44	59.65	12.25	12	79.99	24	0.00	24	3.24	59.58	13.41	2.9
6	jan	95	0.99	24	0.00	24	8.72	24	6.28	45.96	10.71	12	65.58	24	0.00	24	2.75	45.90	10.53	2.9
7	jan	95	1.06	24	0.00	24	8.78	24	6.80	40.29	9.54	12	59.27	24	0.00	24	2.59	40.23	9.54	2.9
8	jan	95	1.13	24	0.00	24	8.96	24	5.68	43.73	10.95	12	63.01	24	0.00	24	2.97	43.67	11.00	2.9
9	jan	95	0.96	24	0.00	24	8.58	24	4.87	42.64	11.43	12	61.59	24	0.00	24	2.67	42.58	11.01	2.9
10	jan	95	1.09	24	0.00	24	6.99	24	2.42	54.59	26.98	12	86.63	24	0.15	24	2.65	54.53	13.62	2.9
11	jan	95	1.02	24	0.00	24	6.84	24	1.64	77.67	38.85	12	120.80	24	0.00	24	3.64	77.59	17.18	2.9
12	jan	95	0.93	24	0.00	24	6.35	24	3.23	55.67	30.04	12	91.59	24	0.00	24	2.68	55.60	12.15	2.9
13	jan	95	1.07	24	0.00	24	6.39	24	3.90	47.50	17.49	12	71.53	24	0.00	24	2.88	47.44	10.89	2.9
14	jan	95	1.04	24	0.00	24	6.31	24	4.37	39.85	14.14	12	61.00	24	0.00	24	2.83	39.79	9.45	2.9
15	jan	95	0.96	24	0.00	24	6.34	24	4.74	32.49	9.14	12	49.01	24	0.00	24	2.54	32.43	8.10	2.9
16	jan	95	1.08	24	0.00	24	6.35	24	4.44	37.47	9.78	12	54.33	24	0.00	24	2.69	37.41	9.20	2.9
17	jan	95	1.03	24	0.00	24	6.16	24	4.21	37.99	6.15	12	50.99	24	0.00	24	2.74	37.92	9.15	2.9
18	jan	95	0.97	24	0.00	24	6.88	24	4.48	43.70	0.49	12	51.32	24	0.00	24	5.56	43.59	10.20	2.9
19	jan	95	1.08	24	0.00	24	6.33	24	4.00	40.95	0.48	12	48.07	24	0.00	24	3.34	40.67	9.76	2.9
20	jan	95	1.07	24	0.00	24	6.36	24	4.08	42.72	0.48	12	49.93	24	0.00	24	2.65	42.66	10.18	2.9
21	jan	95	0.93	24	0.00	24	6.13	24	3.61	41.10	0.48	12	47.83	24	0.00	24	2.38	40.84	9.82	2.9
22	jan	95	1.09	24	0.00	24	6.48	24	4.01	45.58	4.78	12	57.01	24	0.00	24	2.78	45.52	10.74	2.9
23	jan	95	1.10	24	0.00	24	6.36	24	3.75	43.11	2.16	12	51.67	24	0.00	24	3.21	42.62	10.09	2.9
24	jan	95	0.95	24	0.00	24	6.40	24	3.93	44.11	4.32	12	55.00	24	0.00	24	2.66	44.05	10.45	2.9
25	jan	95	1.13	24	0.00	24	6.67	24	1.23	44.66	4.46	12	53.00	24	0.00	24	5.59	42.40	10.97	2.9
26	jan	95	1.17	24	0.00	24	6.39	24	2.77	43.01	8.31	12	56.73	24	0.00	24	2.62	42.95	11.22	2.9
27	jan	95	1.13	24	0.00	24	6.44	24	2.48	47.50	11.61	12	64.23	24	0.00	24	2.70	47.43	12.12	2.9
28	jan	95	1.03	24	0.00	24	6.43	24	1.74	52.58	12.37	12	69.34	24	0.00	24	2.80	52.52	13.45	2.9
29	jan	95	1.16	24	0.00	24	6.37	24	2.39	46.70	12.52	12	64.25	24	0.00	24	2.72	46.64	12.10	2.9
30	jan	95	1.18	24	0.00	24	6.36	24	2.88	39.44	8.04	12	53.00	24	0.00	24	2.73	39.38	10.65	2.9
31	jan	95	1.03	24	0.00	24	6.37	24	4.16	42.75	5.33	12	54.89	24	0.00	24	2.62	42.69	9.98	2.9
Average:			1.05	24	0.00	24	7.13	24	4.16	45.47	10.44	12	62.72	24	0.00	24	2.96	45.31	10.91	2.9
Std.Dev.			*0.07*	*0*	*0.00*	*0*	*1.12*	*0*	*1.54*	*8.21*	*8.52*	*0*	*15.22*	*0*	*0.03*	*0*	*0.75*	*8.24*	*1.74*	*0.0*
Minimum:			0.93	24	0.00	24	6.13	24	1.23	32.49	0.48	12	47.83	24	0.00	24	2.16	32.43	8.10	2.9
Maximum:			1.18	24	0.00	24	9.20	24	6.80	77.67	38.85	12	120.80	24	0.15	24	5.59	77.59	17.18	2.9
SUM:			33		0		221		129	1,410	324		1,944		0		92	1,405	338	91

DAILY SUMMARY

Space heat balance

Novtec Advanced House

JANUARY, 1995

Date			Space heat Energy Gains (supplies x utilizability):				Solar =	Space heat Energy Losses (calulated):					Buffer	Infiltration (AIM2):	
Day	Mo.	Yr.	Occ. (kWh)	Appl. (kWh) *(hr)*	Ventil. (kWh) *(hr)*	Space (kWh) *(hr)*	Loss - Gain (kWh)	Foundation (kWh)	Abv. Fdtn. (kWh)	Infil.+Ventil. (kWh)	Humidificatio (kWh)	Total (kWh)	effect (kWh)	stack:wind (ach)	Total (ach)
1	jan	95	3.2	13.0		123.8	4.4	11.5	94.3	38.7	0.0	144.4	5.1	0.06	0.32
2	jan	95	3.2	13.0		113.5	7.3	11.5	89.9	35.6	0.0	137.0	4.0	0.07	0.30
3	jan	95	3.2	13.1		96.6	37.2	11.5	98.4	40.2	0.0	150.1	4.3	0.08	0.31
4	jan	95	3.2	12.4		97.8	49.8	11.5	106.5	45.2	0.0	163.2	4.7	0.10	0.33
5	jan	95	3.2	11.4		155.0	16.7	11.5	118.0	56.8	0.0	186.3	5.7	0.13	0.37
6	jan	95	3.2	13.0		112.2	14.0	11.5	90.1	40.8	0.0	142.4	3.5	0.10	0.35
7	jan	95	3.2	13.6		96.7	14.5	11.5	83.5	33.0	0.0	127.9	4.4	0.05	0.31
8	jan	95	3.2	12.4		100.5	39.2	11.5	101.8	42.1	0.0	155.3	6.1	0.07	0.32
9	jan	95	3.2	10.0		98.7	50.2	11.5	106.3	44.3	0.0	162.1	5.7	0.09	0.32
10	jan	95	3.2	9.1		131.7	62.2	11.5	139.1	55.6	0.0	206.2	11.2	0.07	0.31
11	jan	95	3.2	8.1		204.5	0.0	11.5	146.4	57.6	0.0	215.4	10.3	0.10	0.30
12	jan	95	3.2	10.0		134.4	30.5	11.5	116.1	50.5	0.0	178.1	7.1	0.11	0.33
13	jan	95	3.2	10.7		113.9	6.8	11.5	87.3	35.7	0.0	134.5	5.1	0.06	0.32
14	jan	95	3.2	9.5		92.8	17.4	11.5	78.7	32.6	0.0	122.8	4.3	0.06	0.32
15	jan	95	3.2	11.5		74.6	1.9	11.5	57.1	22.6	0.0	91.2	2.2	0.06	0.30
16	jan	95	3.2	11.2		90.1	0.0	11.5	61.3	24.9	0.0	97.7	2.7	0.08	0.31
17	jan	95	3.2	11.0		91.2	5.7	11.5	72.3	27.3	0.0	111.0	3.6	0.05	0.29
18	jan	95	3.2	11.1		104.1	2.3	11.5	78.7	30.5	0.0	120.6	3.1	0.07	0.30
19	jan	95	3.2	10.8		98.4	0.0	11.5	71.5	26.9	0.0	109.8	2.4	0.05	0.29
20	jan	95	3.2	10.9		104.3	0.0	11.5	70.6	31.3	0.0	113.3	2.0	0.10	0.34
21	jan	95	3.2	10.4		100.9	5.0	11.5	73.5	34.5	0.0	119.5	2.0	0.12	0.36
22	jan	95	3.2	10.8		112.2	3.0	11.5	81.8	35.9	0.0	129.2	2.9	0.09	0.34
23	jan	95	3.2	9.1		102.4	11.3	11.5	82.6	31.9	0.0	126.0	3.2	0.05	0.30
24	jan	95	3.2	10.7		107.1	7.8	11.5	83.8	33.6	0.0	128.9	3.5	0.05	0.31
25	jan	95	3.2	7.4		90.8	39.8	11.5	91.5	38.3	0.0	141.2	3.2	0.07	0.32
26	jan	95	3.2	9.4		91.7	72.8	11.5	114.9	50.6	0.0	177.0	4.9	0.09	0.34
27	jan	95	3.2	9.1		105.5	78.1	11.5	125.7	58.7	0.0	195.9	6.1	0.10	0.36
28	jan	95	3.2	8.4		120.2	62.6	11.5	125.8	57.1	0.0	194.4	5.8	0.09	0.35
29	jan	95	3.2	9.0		102.3	62.0	11.5	117.3	47.7	0.0	176.5	5.3	0.06	0.31
30	jan	95	3.2	8.0		83.4	57.9	11.5	98.2	42.8	0.0	152.4	3.3	0.08	0.34
31	jan	95	3.2	10.9		102.9	14.3	11.5	83.1	36.6	0.0	131.2	2.6	0.08	0.34
Average:			3.2	10.6		108.2	25.0	11.5	95.0	40.0	0.0	146.5	4.5	0.08	0.32
Std.Dev.			*0.0*	*1.7*		*23.9*	*25.2*	*0.0*	*22.2*	*10.3*	*0.0*	*32.2*	*2.1*	*0.02*	*0.02*
Minimum:			3.2	7.4		74.6	0.0	11.5	57.1	22.6	0.0	91.2	2.0	0.05	0.29
Maximum:			3.2	13.6		204.5	78.1	11.5	146.4	58.7	0.0	215.4	11.2	0.13	0.37
SUM:			99	329		3,354	775	356	2,946	1,240	0	4,542	140		

DAILY SUMMARY
Heat Recovery Ventilator

Novtec Advanced House

JANUARY, 1995

Date Day	Mo.	Yr.	Supply out flow (L/s)	(hr)	Exhaust in flow (L/s)	(hr)	Flow Imbalance (L/s)	Flow Imbalance (%)	Exh. RH to core (%)	Exh. Temp. to core (C)	Exhaust core dT (C)	HRV Fan Energy (kWh)	(hr)	DHW Demand: Water (L)	(hr)	Cold supply (C)	(hr)	Hot out (C)	(hr)	Energy (kWh)
1	jan	95	30.7	24	47.4	24	-16.7	-54.4%	25%	21.9	12.8	1.8	24	0.0	24		0		0	0.0
2	jan	95	33.1	24	42.8	24	-9.7	-29.2%	26%	22.0	12.5	1.7	24	0.0	24		0		0	0.0
3	jan	95	32.6	24	41.3	24	-8.6	-26.4%	26%	21.8	10.4	1.7	24	0.0	24		0		0	0.0
4	jan	95	33.7	24	41.0	24	-7.3	-21.5%	26%	21.7	10.1	1.7	24	4.0	24	17.1	1	47.1	1	0.1
5	jan	95	37.9	24	40.5	24	-2.6	-6.9%	24%	21.9	13.8	1.7	24	15.0	24	13.3	2	47.6	2	0.6
6	jan	95	36.1	24	44.0	24	-7.8	-21.7%	25%	22.1	12.7	1.7	24	0.0	24		0		0	0.0
7	jan	95	30.8	24	46.3	24	-15.5	-50.4%	26%	21.9	11.0	1.7	24	0.0	24		0		0	0.0
8	jan	95	32.7	24	46.1	24	-13.4	-41.1%	26%	21.8	10.6	1.8	24	0.0	24		0		0	0.0
9	jan	95	31.8	24	43.1	24	-11.3	-35.6%	25%	21.8	9.8	1.7	24	3.0	24	24.8	1	42.0	1	0.1
10	jan	95	28.7	24	43.9	24	-15.2	-53.1%	24%	21.5	10.9	1.7	24	0.0	24		0		0	0.0
11	jan	95	18.8	24	39.0	24	-20.2	-107.3%	21%	21.5	16.6	1.7	24	24.0	24	9.1	2	50.4	2	1.2
12	jan	95	25.2	24	42.9	24	-17.7	-70.2%	21%	21.9	16.0	1.7	24	0.0	24		0		0	0.0
13	jan	95	30.2	24	45.9	24	-15.8	-52.2%	23%	21.9	13.7	1.7	24	0.0	24		0		0	0.0
14	jan	95	30.3	24	46.6	24	-16.3	-53.6%	25%	21.8	11.6	1.7	24	3.0	24	24.4	1	41.3	1	0.1
15	jan	95	31.0	24	44.3	24	-13.3	-43.0%	28%	21.8	8.9	1.7	24	0.0	24		0		0	0.0
16	jan	95	28.6	24	43.3	24	-14.8	-51.6%	31%	21.7	10.0	1.7	24	0.0	24		0		0	0.0
17	jan	95	29.4	24	44.0	24	-14.6	-49.6%	30%	21.8	11.0	1.6	24	0.0	24		0		0	0.0
18	jan	95	27.2	24	41.7	24	-14.5	-53.5%	29%	21.9	12.0	1.7	24	65.0	24	8.7	2	50.1	2	3.1
19	jan	95	29.2	24	43.5	24	-14.3	-48.9%	29%	21.8	11.3	1.7	24	0.0	24		0		0	0.0
20	jan	95	25.0	24	44.8	24	-19.8	-79.2%	29%	21.7	11.7	1.7	24	0.0	24		0		0	0.0
21	jan	95	25.5	24	45.8	24	-20.3	-79.9%	29%	21.7	11.3	1.7	24	0.0	24		0		0	0.0
22	jan	95	28.0	24	45.7	24	-17.7	-63.0%	29%	21.7	12.5	1.7	24	0.0	24		0		0	0.0
23	jan	95	31.4	24	44.8	24	-13.4	-42.8%	28%	21.8	12.0	1.7	24	3.0	24	24.8	1	43.1	1	0.1
24	jan	95	31.6	24	46.5	24	-14.9	-47.1%	28%	21.7	11.9	1.7	24	0.0	24		0		0	0.0
25	jan	95	32.8	24	45.5	24	-12.7	-38.6%	29%	21.7	10.9	1.7	24	22.0	24	10.0	2	49.7	2	1.0
26	jan	95	34.3	24	45.3	24	-11.0	-32.2%	29%	21.6	10.7	1.7	24	0.0	24		0		0	0.0
27	jan	95	34.6	24	47.4	24	-12.8	-36.9%	27%	21.6	10.9	1.8	24	0.0	24		0		0	0.0
28	jan	95	35.4	24	47.5	24	-12.0	-34.0%	26%	21.5	11.1	1.8	24	0.0	24		0		0	0.0
29	jan	95	32.7	24	45.4	24	-12.7	-38.7%	25%	21.6	11.0	1.7	24	0.0	24		0		0	0.0
30	jan	95	35.0	24	45.0	24	-10.0	-28.5%	26%	21.9	9.6	1.7	24	3.0	24	25.1	1	42.1	1	0.1
31	jan	95	36.7	24	46.0	24	-9.3	-25.3%	25%	21.8	12.2	1.7	24	0.0	24		0		0	0.0
Average:			31.0	24	44.4	24	-13.4	-45.7%	26%	21.8	11.7	1.7	24	4.6	24	11.0	0	49.1	0	0.2
Std.Dev.			4.0		2.1		4.0	20.0%	3%	0.1	1.7	0.0		12.8		7.4		3.8		0.6
Minimum:			18.8	24	39.0	24	-20.3	-107.3%	21%	21.5	8.9	1.6	24	0.0	24	8.7	0	41.3	0	0.0
Maximum:			37.9	24	47.5	24	-2.6	-6.9%	31%	22.1	16.6	1.8	24	65.0	24	25.1	2	50.4	2	3.1
SUM:												53		142						6

DAILY SUMMARY
Water-Air Heat Pump

Novtec Advanced House

JANUARY, 1995

Date Day Mo.	Yr.	Ground Loop Temperatures: from field (C)	(hr)	WAHP inlet (C)	(hr)	WAHP outlet (C)	(hr)	Air Temperatures: Supply (C)	(hr)	Return (C)	(hr)	Space Heating: Output (kWh)	(hr)	Input (kWh)	COP	Space Cooling: Output (kWh)	(hr)	Input (kWh)	COP
1 jan	95	2.2	24	3.6	24	0.6	24	29.4	24	21.7	24	98.5	24	36.3	2.7	0.0	24	0.0	
2 jan	95	2.3	24	3.6	24	0.6	24	29.0	24	21.7	24	93.3	24	34.5	2.7	0.0	24	0.0	
3 jan	95	2.3	21	3.5	21	0.7	21	27.7	24	21.6	24	77.7	24	28.7	2.7	0.0	24	0.0	
4 jan	95	2.2	19	3.4	19	0.5	19	27.7	24	21.6	24	78.4	24	29.0	2.7	0.0	24	0.0	
5 jan	95	1.3	23	2.5	23	-0.5	23	29.8	24	21.5	24	105.7	24	39.5	2.7	0.0	24	0.0	
6 jan	95	1.7	24	3.1	24	0.1	24	29.1	24	21.6	24	94.2	24	34.9	2.7	0.0	24	0.0	
7 jan	95	2.0	24	3.5	24	0.6	24	28.1	24	21.6	24	81.3	24	30.4	2.7	0.0	24	0.0	
8 jan	95	1.8	20	3.2	20	0.4	20	27.8	24	21.8	24	76.1	24	28.6	2.7	0.0	24	0.0	
9 jan	95	1.9	19	3.2	19	0.8	19	28.1	19	21.8	19	66.7	24	25.2	2.6	0.0	24	0.0	
10 jan	95	1.5	20	3.0	20	0.5	20	28.0	24	21.7	24	81.4	24	31.1	2.6	0.0	24	0.0	
11 jan	95	0.2	24	1.4	24	-1.5	24	30.8	24	21.2	24	126.6	24	47.9	2.6	0.0	24	0.0	
12 jan	95	0.7	24	2.1	24	-1.2	24	30.8	24	21.6	24	120.9	24	45.1	2.7	0.0	24	0.0	
13 jan	95	1.0	24	2.4	24	-0.6	24	29.2	24	21.7	24	95.9	24	36.2	2.6	0.0	24	0.0	
14 jan	95	1.3	24	2.9	24	0.1	24	28.2	24	21.6	24	81.4	24	30.8	2.6	0.0	24	0.0	
15 jan	95	1.6	23	3.0	23	0.3	23	26.6	24	21.6	24	62.3	24	23.7	2.6	0.0	24	0.0	
16 jan	95	1.7	24	3.1	24	0.6	24	26.7	24	21.5	24	63.6	24	24.9	2.6	0.0	24	0.0	
17 jan	95	1.6	24	3.1	24	0.5	24	27.5	24	21.6	24	69.8	24	26.5	2.6	0.0	24	0.0	
18 jan	95	1.5	24	2.8	24	0.1	24	27.9	24	21.6	24	79.1	24	30.1	2.6	0.0	24	0.0	
19 jan	95	1.5	24	2.9	24	0.4	24	27.5	24	21.5	24	74.0	24	28.2	2.6	0.0	24	0.0	
20 jan	95	1.5	24	2.9	24	0.2	24	27.7	24	21.5	24	76.6	24	29.2	2.6	0.0	24	0.0	
21 jan	95	1.4	23	2.8	23	0.4	23	27.5	22	21.5	22	72.5	24	27.7	2.6	0.0	24	0.0	
22 jan	95	1.3	24	2.7	24	0.1	24	28.1	24	21.5	24	83.0	24	31.5	2.6	0.0	24	0.0	
23 jan	95	1.3	24	2.8	24	-0.1	24	28.2	24	21.6	24	83.4	24	31.5	2.7	0.0	24	0.0	
24 jan	95	1.3	24	2.7	24	0.0	24	27.9	24	21.5	24	80.9	24	30.9	2.6	0.0	24	0.0	
25 jan	95	1.4	22	2.9	22	1.2	22	26.2	24	21.7	24	64.0	24	24.5	2.6	7.2	24	2.0	3.6
26 jan	95	1.5	22	3.0	22	1.6	22	26.8	24	21.7	24	70.1	24	26.3	2.7	5.7	24	1.5	3.8
27 jan	95	1.3	21	2.8	21	0.9	21	27.6	24	21.7	24	80.0	24	30.0	2.7	3.9	24	1.1	3.6
28 jan	95	1.1	21	2.5	21	1.0	21	27.1	24	21.5	24	78.4	24	29.4	2.7	6.4	24	1.7	3.7
29 jan	95	1.5	21	3.4	21	2.1	21	26.6	24	21.7	24	70.9	24	26.7	2.7	8.1	24	2.1	3.8
30 jan	95	1.5	20	2.9	20	1.5	20	26.5	24	21.8	24	62.0	24	23.2	2.7	3.8	24	1.0	3.9
31 jan	95	1.5	24	2.9	24	0.1	24	28.3	24	21.5	24	86.1	24	32.1	2.7	0.0	24	0.0	
Average:		1.5	23	2.9	23	0.4	23	28.0	24	21.6	24	81.8	24	30.8	2.7	1.1	24	0.3	3.7
Std.Dev.		0.4		0.5		0.7		1.1		0.1		15.5		5.7	0.0	2.5		0.7	0.1
Minimum:		0.2	19	1.4	19	-1.5	19	26.2	19	21.2	19	62.0	24	23.2	2.6	0.0	24	0.0	3.6
Maximum:		2.3	24	3.6	24	2.1	24	30.8	24	21.8	24	126.6	24	47.9	2.7	8.1	24	2.1	3.9
SUM:												2,535		955		35		9	

DAILY SUMMARY

Water-Water Heat Pump

Novtec Advanced House

JANUARY, 1995

Date Day	Mo.	Yr.	Ground Loop Temperatures: WWHP inlet (C)	(hr)	WWHP outlet (C)	(hr)	Radiant Heating: Slab supply (C)	(hr)	Slab return (C)	(hr)	Output (kWh)	(hr)	Input (kWh)	COP	DHW Heating: DHW supply (C)	(hr)	DHW return (C)	(hr)	Output (kWh)	(hr)	Input (kWh)	COP
1	jan	95	0,6	24	-0,2	24	28,4	16	21,4	16	19,7	24	5,8	3,4	52,3	5	49,1	5	2,6	24	1,3	2,0
2	jan	95	0,6	24	-0,1	24	27,9	14	21,1	14	15,2	24	4,5	3,4	52,9	4	49,6	4	2,7	24	1,3	2,1
3	jan	95	0,7	21	0,0	21	28,3	10	21,4	10	14,6	24	4,2	3,5	53,3	3	49,7	3	2,1	24	1,0	2,1
4	jan	95	0,5	19	-0,3	19	28,4	11	21,4	11	15,0	24	4,4	3,4	53,7	4	50,0	4	2,9	24	1,3	2,2
5	jan	95	-0,5	23	-1,5	23	30,5	11	23,7	11	41,7	24	12,5	3,3	52,8	5	49,3	5	3,2	24	1,5	2,1
6	jan	95	0,1	24	-0,5	24	28,4	9	21,7	9	13,0	24	3,9	3,4	52,7	4	49,4	4	2,7	24	1,4	2,0
7	jan	95	0,6	24	0,1	24	27,9	10	21,0	10	11,0	24	3,2	3,4	53,1	4	49,8	4	2,6	24	1,3	1,9
8	jan	95	0,4	20	-0,5	20	28,9	11	22,0	11	19,7	24	5,7	3,4	52,1	4	48,6	4	2,9	24	1,4	2,1
9	jan	95	0,8	19	-0,4	19	29,9	14	22,9	14	27,1	24	8,0	3,4	53,1	4	49,8	4	2,7	24	1,3	2,0
10	jan	95	0,5	20	-0,7	20	30,6	13	23,7	13	43,5	24	13,0	3,3	52,7	5	49,5	5	2,6	24	1,3	2,0
11	jan	95	-1,5	24	-2,9	24	31,8	17	25,2	17	67,4	24	20,9	3,2	52,6	7	49,4	7	3,6	24	1,8	2,0
12	jan	95	-1,2	24	-1,6	24	28,7	8	22,2	8	7,8	24	2,4	3,2	52,3	4	49,3	4	2,7	24	1,4	1,8
13	jan	95	-0,6	24	-1,2	24	28,1	9	21,3	9	12,8	24	3,8	3,4	53,2	6	49,9	6	2,9	24	1,3	2,1
14	jan	95	0,1	24	-0,4	24	27,3	9	20,6	9	7,2	24	2,1	3,3	53,1	4	49,8	4	2,8	24	1,4	2,0
15	jan	95	0,3	23	-0,3	23	27,5	9	20,7	9	8,8	24	2,6	3,4	53,2	5	50,0	5	2,5	24	1,3	2,0
16	jan	95	0,6	24	-0,4	24	28,1	16	21,1	16	21,9	24	6,4	3,4	53,1	5	49,8	5	2,7	24	1,4	2,0
17	jan	95	0,5	24	-0,4	24	28,0	14	21,1	14	16,9	24	5,0	3,4	52,9	4	49,7	4	2,7	24	1,4	1,9
18	jan	95	0,1	24	-0,8	24	28,5	14	21,5	14	19,9	24	5,8	3,4	51,3	4	47,4	4	5,5	24	2,3	2,4
19	jan	95	0,4	24	-0,6	24	28,1	15	21,3	15	19,6	24	5,7	3,4	53,6	5	50,1	5	3,1	24	1,5	2,1
20	jan	95	0,2	24	-0,8	24	28,5	15	21,6	15	22,6	24	6,7	3,4	52,9	4	49,8	4	2,7	24	1,4	1,9
21	jan	95	0,4	23	-0,7	23	28,6	15	21,8	15	23,4	24	7,0	3,4	52,8	4	49,4	4	2,2	24	1,0	2,1
22	jan	95	0,1	24	-0,9	24	28,5	16	21,6	16	23,8	24	7,0	3,4	52,6	5	49,4	5	2,8	24	1,4	2,0
23	jan	95	-0,1	24	-0,8	24	27,7	12	21,0	12	14,2	24	4,2	3,3	53,3	4	50,0	4	2,7	24	1,4	2,0
24	jan	95	0,0	24	-0,9	24	28,1	14	21,3	14	21,0	24	6,2	3,4	53,0	4	49,8	4	2,7	24	1,4	2,0
25	jan	95	1,2	22	0,2	22	29,0	11	22,1	11	22,0	24	6,5	3,4	53,1	4	49,6	4	3,5	24	1,8	2,0
26	jan	95	1,6	22	0,8	22	29,7	8	22,8	8	17,1	24	5,0	3,4	52,9	4	49,7	4	2,6	24	1,3	2,0
27	jan	95	0,9	21	0,1	21	29,6	7	22,9	7	20,3	24	6,0	3,4	52,5	5	49,3	5	2,7	24	1,4	1,9
28	jan	95	1,0	21	-0,1	21	30,1	12	23,5	12	35,4	24	10,8	3,3	53,2	4	49,8	4	2,8	24	1,3	2,1
29	jan	95	2,1	21	1,1	21	30,2	8	23,4	8	26,0	24	7,8	3,4	53,0	4	49,6	4	2,7	24	1,3	2,1
30	jan	95	1,5	20	0,7	20	29,9	10	23,0	10	17,3	24	5,1	3,4	52,5	4	49,1	4	2,7	24	1,3	2,2
31	jan	95	0,1	24	-0,6	24	28,5	11	21,9	11	12,1	24	3,6	3,4	52,2	4	49,0	4	2,6	24	1,3	1,9
Average:			0,4	23	0	23	29,3	12	22,5	12	21,2	24	6,3	3,4	52,8	4	49,5	4	2,8	24	1,4	2,0
Std.Dev.			0,7		1		1		1,1		12,1		3,7	0,1	0,5		0,5		0,6		0,2	0,1
Minimum:			-1,5	19	-3	19	27	7	20,6	7	7,2	24	2,1	3,2	51,3	3	47,4	3	2,1	24	1,0	1,8
Maximum:			2,1	24	1	24	32	17	25,2	17	67,4	24	20,9	3,5	53,7	7	50,1	7	5,5	24	2,3	2,4
SUM:											658		196						88		43	

DAILY SUMMARY
System Summary

Novtec Advanced House

JANUARY, 1995

Date Day	Mo.	Yr.	Total Energy Consumption (kWh)	(hr)	Intetrated Home Comfort System Energy (kWh)	% of total (%)	COP	Water-to-Air Heat Pump Energy (kWh)	% of total (%)	COP	Water-to-Water Heat Pump Energy (kWh)	% of total (%)	COP	Lights & Appl. (incl. HRV) Energy (kWh)	% of total (%)	Other (kWh)
1	jan	95	70.6	24	43.8	62%	2.8	36.4	52%	2.7	7.3	10%	3.0	11.7	17%	Sun
2	jan	95	63.6	24	40.6	64%	2.7	34.5	54%	2.7	6.0	9%	3.0	11.4	18%	Mon
3	jan	95	58.0	24	34.3	59%	2.8	29.0	50%	2.7	5.4	9%	3.1	11.3	19%	Tues
4	jan	95	60.4	24	35.6	59%	2.7	29.7	49%	2.6	5.9	10%	3.0	11.9	20%	Wed
5	jan	95	80.0	24	53.8	67%	2.8	39.4	49%	2.7	14.4	18%	3.1	11.8	15%	Thur
6	jan	95	65.6	24	40.4	62%	2.7	35.0	53%	2.7	5.4	8%	2.9	11.4	17%	Fri
7	jan	95	59.3	24	35.1	59%	2.7	30.4	51%	2.7	4.7	8%	2.9	11.6	20%	Sat
8	jan	95	63.0	24	37.5	59%	2.6	30.1	48%	2.5	7.3	12%	3.1	11.8	19%	Sun
9	jan	95	61.6	24	36.5	59%	2.6	26.9	44%	2.5	9.6	16%	3.1	11.2	18%	Mon
10	jan	95	86.6	24	47.7	55%	2.7	33.0	38%	2.5	14.7	17%	3.1	10.0	12%	Tues
11	jan	95	120.8	24	71.1	59%	2.8	47.9	40%	2.6	23.2	19%	3.1	9.6	8%	Wed
12	jan	95	91.6	24	49.2	54%	2.7	45.2	49%	2.7	4.0	4%	2.6	9.0	10%	Thur
13	jan	95	71.5	24	41.8	58%	2.7	36.3	51%	2.6	5.4	8%	2.9	9.2	13%	Fri
14	jan	95	61.0	24	34.6	57%	2.6	30.9	51%	2.6	3.7	6%	2.7	9.1	15%	Sat
15	jan	95	49.0	24	27.9	57%	2.6	23.8	49%	2.6	4.1	8%	2.8	9.0	18%	Sun
16	jan	95	54.3	24	32.8	60%	2.7	24.9	46%	2.6	8.0	15%	3.1	9.1	17%	Mon
17	jan	95	51.0	24	33.2	65%	2.7	26.7	52%	2.6	6.6	13%	3.0	8.8	17%	Tues
18	jan	95	51.3	24	38.6	75%	2.7	30.1	59%	2.6	8.4	16%	3.0	9.5	19%	Wed
19	jan	95	48.1	24	35.8	74%	2.7	28.2	59%	2.6	7.5	16%	3.0	9.1	19%	Thur
20	jan	95	49.9	24	37.7	75%	2.7	29.3	59%	2.6	8.3	17%	3.0	9.1	18%	Fri
21	jan	95	47.8	24	36.0	75%	2.7	27.8	58%	2.6	8.3	17%	3.1	8.7	18%	Sat
22	jan	95	57.0	24	40.3	71%	2.7	31.6	55%	2.6	8.7	15%	3.0	9.3	16%	Sun
23	jan	95	51.7	24	37.4	72%	2.7	31.5	61%	2.6	5.8	11%	2.9	9.2	18%	Mon
24	jan	95	55.0	24	38.9	71%	2.7	31.0	56%	2.6	7.9	14%	3.0	9.1	17%	Tues
25	jan	95	53.0	24	36.4	69%	2.7	27.9	53%	2.6	8.5	16%	3.0	9.5	18%	Wed
26	jan	95	56.7	24	36.3	64%	2.6	29.7	52%	2.5	6.6	12%	3.0	9.3	16%	Thur
27	jan	95	64.2	24	40.5	63%	2.6	32.9	51%	2.5	7.6	12%	3.0	9.3	15%	Fri
28	jan	95	69.3	24	45.5	66%	2.7	33.1	48%	2.6	12.4	18%	3.1	9.2	13%	Sat
29	jan	95	64.2	24	39.9	62%	2.7	30.6	48%	2.6	9.3	15%	3.1	9.3	14%	Sun
30	jan	95	53.0	24	33.0	62%	2.6	26.3	50%	2.5	6.6	12%	3.0	9.2	17%	Mon
31	jan	95	54.9	24	37.4	68%	2.7	32.2	59%	2.7	5.2	9%	2.8	9.1	17%	Tues
Average:			62.7	24	39.7	64%	2.7	31.7	51%	2.6	8.0	13%	3	9.9	16%	
Std.Dev.			*15.2*		*7.8*	6%	*0.0*	*5.3*	5%	*0.1*	*3.9*	4%	*0.1*	*1.1*		
Minimum:			47.8	24	27.9	54%	2.6	23.8	38%	2.5	3.7	4%	2.6	8.7	8%	
Maximum:			120.8	24	71.1	75%	2.8	47.9	61%	2.7	23.2	19%	3.1	11.9	20%	
SUM:			1,944		1,230			982			247			307		