UNIVERSITY OF MANITOBA

AN EVALUATION OF THE AMBIENTE HOUSING SYSTEM FOR USE IN THE NORTHERN CANADIAN CLIMATE

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BY

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

Of

MASTER OF SCIENCE

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LIST OF SYMBOLS

a	Thermal diffusivity (mm^2/s)
A	Area (m^2)
$\dot{A}$	Rate of air flow (L/s)
c_o	Specific Heat Capacity – measure of the amount of heat that a unit mass of dry material can store ($J/kg \cdot K$)
$\frac{dq}{d\theta}$ or $\dot{Q}$	heat flow rate – the time rate at which heat energy moves (W)
DD	Degree-days (dimensionless)
E	Energy – capacity to do work (J)
ER	Energy rating for windows (dimensionless)
F	Solar heating coefficient for windows (dimesionless)
h_c	Convective heat transfer coefficient or film coefficient ($W/m^2 \cdot K$)
l	Length of flow path or thickness of material (m)
m	Mass (g or kg as indicated)
P	Pressure (Pa)
$\dot{q}$	Heat flux – the heat flow per unit area (W/m^2)
Q	Quantity of heat (J)
R_g	Gas constant (R_{wv}=461.5 $J/kg \cdot K$)
R_v	Vapour resistance ($s \cdot m^2 \cdot Pa/ng$)
RSI	Thermal resistance (SI units) – is the reciprocal of conductance ($m^2 \cdot K/W$)
S	Space heating coefficient for the R-2000 program (MJ or kW·h as indicated)
t	Temperature (K or °C as specified)
U	Inverse of RSI ($W/m^2 \cdot K$)
v	Volume (m^3)
V	Vapour transmittance ($ng/s \cdot m^2 \cdot Pa$)
α	Absorptance of a given surface (dimensionless)
ε	Emittance of a given surface (dimensionless)
ϑ	Relative humidity (dimensionless)
λ	Coefficient of thermal conductivity – a material property which indicates the quantity of heat flow across a unit area, through a unit thickness under a unit temperature potential ($W/m \cdot K$)
ρ	Density of the material (kg/m^3)
σ	Boltzmann constant (5.673×10^{-8} $W/m^2 \cdot K^4$)

DEFINITIONS

Temperature Index – The temperature index is the percentage of thermal resistance to the point that the sensor is placed within the wall from the interior.

$$T_i = {RSI_{\text{int}}}/{RSI_{Total}}$$

Window Ratings as defined in CSA A440

A – Air Tightness – The average volume of air that passes through a closed window from both the exterior to the interior or the interior to the exterior at a given fixed wind pressure defines the window air tightness. In this case, the volume of air passing through a window is measured under ambient temperature conditions (20°C) at an induced pressure differential of 75 Pa, which represents a wind speed of 40 km/h.

B – Water Tightness – The water tightness test requirement and test method require that there be no water leakage when tested at a test pressure of 300 Pa (Window Rating B3). For the water tightness test, the sample is mounted in a chamber and an even film of water at a specified rate is sprayed onto the outside surface while the window is subjected to the pressure differential. During the test, the pressure is cycled four times, each cycle consisting of 5 minutes of pressure applied and one minute with no pressure.

ER – Energy Rating – There are several determinants for energy efficient window design: solar heat gains, heat loss transmission, and heat loss by air leakage. Due to this complicated interaction, CSA put together an indicator, Energy Rating (ER) that incorporates all of these aspects for a heated home.

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ABSTRACT

It is well known that adequate and comfortable housing is a requirement for a healthy society. In many northern Canadian communities this basic need is not being met. Homes are overcrowded, poorly constructed and poorly maintained. As a result, the occupants are living with poor indoor air quality and therefore a lower quality of life.

Many projects have been undertaken to solve this problem. Several homes have been constructed in northern communities using innovative approaches to design and construction. Canadian Mortgage and Housing Corporation (CMHC) has been a leader in innovation by sponsoring several Healthy Homes™ throughout northern Canada. Another area of development for northern homes has been in panellized housing systems.

Ambersham Technologies has invented a housing system that purports to combine some of the best of both of these approaches. The Ambiente housing system is a panellized house made entirely of composite materials. The house is constructed on site in a short time and post-tensioned to the foundation. The company is selling the product as simple to construct, energy efficient and environmentally friendly.

The objective of this project is to evaluate the Ambiente housing system for use in the northern Canadian climate. As well, the project is designed to provide standardization for the composite housing industry. There are two components of this project, the first to test the structural strength and stability of the materials and the second to determine the durability and energy efficiency of the system. This thesis focuses on the second component of the project.

Testing included thermal considerations, windows, water vapour transport, durability and indoor air quality. The objective is to compare the performance of the Ambiente housing system to standards as well as Canada's R-2000 requirements.

The results from the testing performed on the Ambiente housing system, within the scope of this thesis, indicate that the system satisfies current standards.

A small test house, called the Experimental House, was constructed to determine the system's characteristics in terms of energy consumption and durability. The Experimental House performed very well under air leakage examination. The post-tensioned design takes some reliance off the joints providing a tight, durable system. The window design for the Experimental House met the prescriptive requirements of Canadian code, however condensation was noted during testing. Water vapour transport through the Experimental House was monitored and some weakness was found in the roof joint.

Based on the results of testing performed as a part of this project and results reported by Ambiente, a HOT2000 energy prediction was completed to determine compliance with the R-2000 requirements. Based on the parameters entered into the computer program, a house of similar construction to the Experimental House will meet or exceed R-2000 requirements.

Component testing was also performed to determine the durability of the panels including freeze-thaw and UV testing.

While a substantial amount of work was conducted under the scope of this thesis, additional testing is required in the following areas: thermal conductivity, bulk water transport, thermal expansion and contraction and sustainability of mould growth on the materials.

These areas will be addressed in a separate study at the University of Manitoba through the construction of a full-scale demonstration house.

1 INTRODUCTION

Good quality housing is the desire of all peoples and the peoples of Northern Canada are no exception. Hancock goes so far as to point out that poor housing quality has a direct effect on the health of the inhabitants (Hancock 1996). The severe climate of the north provides some additional challenges not faced in climates that are more temperate. Further, housing is not a luxury in the far north; it is essential to survive the extreme climate. There are four main challenges facing northern Canadian communities.

1) There is no way to survive in the cold outdoors all winter. The community must therefore house all its inhabitants. To prevent overcrowding there must be provision for enough houses for all peoples within the community.

2) These units must be built to withstand the extreme climate of the north as well as the unique needs of the aboriginal people.

3) The construction of durable homes with little need for maintenance is an issue in more remote communities, where there is limited access to trades people and equipment. Materials required for construction may not be available until winter roads are cleared or they have to be flown in at great expense.

4) Indoor air quality must be addressed to ensure the health of the occupants. This is particularly important in a tightly built home that will be closed all winter to reduce heating costs. Low air exchange rates require that volatile organic compounds, moulds, and other contaminants must be kept at low levels.

Provision of adequate shelter for all must be high priority if we are to create healthy human settlements (Hancock 1996). The problems associated with overcrowding, poor construction, poor maintenance, and deterioration of the indoor air quality of houses is discussed in the next section.

1.1 OVERCROWDING

Overcrowding is a real issue in northern communities. "Up north, homeless people can't live on the streets, as they can in the south," says Amy White, policy analyst with the Nunavut Housing Corporation. "It is too cold. Everyone has to be inside all the time. That's why we call them the hidden homeless—you can't see them" (National Housing Research Committee 2002).

On average, 36 percent of on-reserve homes are not within the National Occupancy Standards (NOS) as compared to 2.3 percent in Canada as a whole (CMHC 1987). The NOS are used to determine what size of dwelling is suitable for a household by taking into account the gender and age of the household members. The criteria for overcrowding according to the National Occupancy Standards are:

1) A maximum of two and a minimum of one person are allowed per bedroom;

2) parents are eligible for a bedroom separate from the children;

3) household members aged 18 or more are eligible for a separate bedroom unless married or cohabiting as spouses; and,

4) dependants aged 5 years or more of opposite gender do not share a bedroom.

Thirty-six percent of northern Canadian homes fail to meet this standard. Many of these communities are also in poverty situations and have inadequate facilities. The World Health Organization (WHO) has recognised this combination of unhealthy circumstances as increasing the transmission rates of such communicable diseases as tuberculosis, pneumonia, bronchitis, and gastrointestinal infections (WHO 1989).

1.2 POOR CONSTRUCTION

Much of the existing housing needs in the north are being fulfilled with prefabricated trailers designed for southern Canadian climates. While these units are economical to build and ship, they have typically had problems providing adequate heating. They are also not designed for the stress inherent with overcrowding. Humans naturally make a humid environment through breathing, cooking and cleaning. The combination of high humidity and cold walls results in frost build-up on walls and windows. This in turn results in extensive mould growth in these locations (Manitoba Northern Affairs 1999).

1.3 MAINTENANCE

On average, 43 percent of northern housing units are in need of major repair as opposed to 13 percent throughout Canada (CMHC 1987). There are three main causes for this level of need for maintenance. First, most of the homes built in northern communities are typically built with low quality materials to keep initial construction costs low (Manitoba Northern Affairs 1999). Second, the homes are not purposely built for the people using them and the climate they are expected to weather. For example, frost heaving is a main cause of window breakage in northern communities. A rigid structure or high quality foundations would help to solve this problem. Finally, maintenance in remote communities often takes a long period, as repairs must wait for trades people, or materials to arrive via winter roads or plane.

1.4 INDOOR AIR QUALITY

Poor quality northern housing construction typically provides for a high level of air leakage throughout the home. While this tends to cause other problems in the home, the result is generally low levels of indoor air pollutants. Some examples of common indoor air pollutants include polluted outdoor air, volatile organic compound emissions from construction and furnishings, and mould. Mould growth occurs in locations of high moisture within the home and does not appear to be reduced by well-designed ventilation (Morrison Hershfield 1995).

1.4.1 Mould

Mould is everywhere and therefore cannot ever be entirely abated. That said, high levels of certain types of mould will decrease the indoor air quality and can cause health-related problems, particularly if exposure is for a longer period, such as in a child's bedroom (Manitoba Department of Labour 2000).

The four main components necessary for mould growth are a suitable surface to grow on, suitable temperatures, nourishment, and a relatively constant source of water (Morrison Hershfield 1995). In northern homes, problems with mould are concentrated on and in the walls. Here, the cellulose in the wall assembly serves as an excellent food source for the mould. In addition, the temperatures within a home are generally suitable for mould growth. The only variable in which the occupant has any control is a constant source of moisture. As discussed earlier in this paper, construction of northern houses has typically been such that constant frost build-up is common on interior walls. Frost melt provides a constant water source to support mould growth. This high level of mould infestation increases the risk of the occupants contracting illnesses ranging from rhinitis to invasive diseases (Federal-Provincial Committee on Environmental and Occupational Health 1995).

1.4.2 Chemical Pollutants

In addition to mould, chemical pollutants can decrease the air quality within a home. These pollutants can be divided into two groups: the inorganic gaseous pollutants, and the volatile organic compounds.

Inorganic gaseous pollutants such as carbon monoxide, chlorine, and ammonia can enter the home air through improper exhaust of combustion gases, and cleaning. If proper ventilation is not installed in a home, these pollutants will affect human health. The severity of the effect varies from immediate health hazards, to intoxicants, to respiratory irritants (CMHC 1990).

The volatile organic compounds comprise a wide range of chemical compounds that vary from simple to complex, and contain carbon and hydrogen in their molecular structures. Hydrocarbons, aldehydes, alcohols, phenols, and ketones are examples of classes of organic compounds. The sources are many and include building materials, furniture, carpets, and synthetic floor coverings, wallpapers, plastics, household products, bedding, toiletries, etc. The toxicity of these volatile organic compounds varies and in some cases is unknown. In some cases they are recognised carcinogens, or may affect the central nervous system, and many are mild intoxicants that affect everyone even at low levels (CMHC 1990).

1.4.3 Particulates

Another common indoor air quality issue is particulates. These are generally the smaller house dust particles that remain airborne and can easily enter the lungs. These particles come in two categories, biological and non-biological.

Biological particulates include dust mites, mould spores, pollens, animal dander, bacteria, and viruses. Some of these particles trigger an immune response in people who are sensitive to that agent. Others are pathogenic and cause disease directly

(CMHC 1990).

Non-biological particulates include asbestos, glass fibre, lead, natural and synthetic fibres, dust from soils, combustion particles from automobiles, smokers, industry, furnaces, stoves and fireplaces and other dusts such as plaster from construction, etc. These particulates generally act as an irritant (CMHC 1990).

1.4.4 Radon

Soil radiation from natural sources enters homes in some affected regions and increases lung cancer risk. Radon gas from the natural breakdown of radium in soil, rock, and groundwater decays indoors into products called radon progeny. The radon progeny then easily attaches itself to dust particles that are then inhaled by humans. In the lungs, the radon progeny emit hazardous alpha radiation that can cause lung cancer (CMHC 1990).

In order to provide adequate housing for northern Canadian communities, all the issues mentioned above need to be considered in the design of the home. It is important that enough well constructed homes with a healthy living environment are provided. Building design, materials, and construction techniques should produce durable structures that provide a safe, dry, comfortable abode that shelters residents against vermin, extremes of temperature and recurring hazards of nature (World Health Organization 1989). Deficiencies in housing have serious implications for physical health, stress on individuals and relationships, educational performance, and even the probability of securing and maintaining employment (Manitoba Family Services and Housing 2001).

1.5 NEW TECHNOLOGY IN HOUSING CONSTRUCTION

Many approaches have been taken to solving housing problems in Canada. This section outlines two such approaches and provides details of the Ambiente housing system.

1.5.1 First Nations Housing

Climactic factors, poor construction, and overcrowding usually limit the life expectancy of houses in the north to only five or six years (Williamson 1996). Consequently, many northern Canadian residents are living in either dilapidated or over-crowded houses. Housing conditions in the north have reached crisis proportions (Green 2001).

CMHC in recent years has initiated, and to some degree sponsored, four First Nation Healthy House™ projects in an attempt to address this crisis: Eagle Lake, Tyendinaga, Kahnawake and Roseau River. Each of these projects differs slightly in their approach and Table 1.1 shows some of the innovative approaches taken. These projects required the designer to incorporate occupant health, environmental responsibility, energy efficiency, natural resource efficiency, and affordability. For the purposes of this thesis, discussion will be limited to the first four points.

Table 1.1: CHMC Healthy House Approach (Green 2001)

Issue		Eagle Lake	Roseau River	Tyendinaga	Kahnawake
Occupant Health	Heat Recovery Ventilation Unit	✓	✓	✓	✓
	In-floor radiant heating	✓	✓	✓	✓
	Concrete slab on grade	✓	✓	✓	✓
	Limit use of VOC emitting materials and toxic resins	✓	✓	✓	✓
	Kitchen and bathroom exhaust		✓	✓	
	Fire-proof exterior	✓	✓		
	Built-in vacuum with discharge to the exterior				✓
	No closet doors to increase air circulation	✓			
Environmental Responsibility	Use of alternative energy production techniques	✓			✓
	Innovative sewage treatment	✓		✓	✓
	Low flow faucets and toilets		✓	✓	✓
	Efficient landscaping techniques				✓
	Renewable construction				✓
	Use of recycled materials in construction				✓
	Use of windows to create natural day-lighting				✓
	Sharing of wells for drinking water				✓
Energy Efficiency	High insulation values	✓	✓	✓	✓
	High quality glazing	✓	✓	✓	✓
	High efficiency appliances	✓	✓	✓	✓
	High efficiency light fixtures	✓			✓
	High efficiency heating system	✓	✓		✓
	Low flow faucets and toilets				✓
	Use of alternative energy production techniques	✓			✓
	Landscaping to take advantage of natural windbreaks and shading and passive solar gain	✓	✓		✓
Natural Resource Efficiency	Use of water usage and/or treatment reduction techniques	✓	✓	✓	✓
	Use of passive design to reduce heating loads	✓	✓		✓
	Low volume fixtures and toilets	✓		✓	✓
	Construction materials from low energy sources	✓			✓
	Straw-board cupboards	✓			
	Low maintenance materials		✓		
	Use of recycled materials in construction			✓	✓

As can be seen in Table 1.1, the designers of these homes have taken innovative steps in overall housing design. Long-term results on the performance of these homes are not yet available.

1.5.2 Panellized Construction

The most common panellized system is known as Structural Insulated Panels (SIP). A structure built with SIP looks the same from the outside as traditional timber frame construction. It is inherently different, however, in its construction and assembly.

Most structural insulated panels (SIP) are load-bearing laminates of foam and wood sheathing materials. They are used for the exterior walls, roof, and floor. Manufactured in factories, the panels are shipped to a building site and assembled by framing crews. When properly assembled, the resulting home or commercial building provides an extremely strong, well-insulated, and comfortable building shell (Build Central Inc. 2003).

Structural insulated panels have many advantages as well as disadvantages over traditional homes. They have proven to be very strong, up to forty percent more energy efficient, air tight, and less damaging to the environment in terms of overall resource consumption. However, SIP have also been plagued with problems. One recent example of such problems occurred in Juneau, Alaska. In Juneau, homes that were built between 1994 and 1996 have major roof problems. The roof panels were not properly installed allowing water into the roof joints (Andrews 2004). The result was the growth of mushrooms from the joints.

As with all construction, SIP must be properly installed to perform well. With this type of construction, the joints are a critical part of the system and must be sealed in order for the home to be lasting and durable.

1.5.3 Ambiente's Proposed Solution

The Ambiente system is a new composite panellized system that does not employ wood or steel in its construction. According to the inventors of this system, this innovative approach increases occupant health, environmental responsibility, and energy efficiency.

This housing system is comprised of panels, fitted between pultruded structural columns and beams, and interconnected with a net of composite cables anchored to the foundation. All components are made of composite materials.

1.6 OBJECTIVES

The objectives of the research and development program at the University of Manitoba are to evaluate the Ambiente housing system and to make recommendations for adaptation to the harsh northern Canadian climate. This program was carried out in two phases, conducted in parallel, each being complementary to the other. The first phase involved the structural performance of the Ambiente housing system while the second phase focused on the building envelope. This thesis focuses on the second phase. The objectives of this phase of the project are to:

1. Test the Ambiente housing system and its components to meet northern Canadian housing needs in terms of energy efficiency, condensation control, freeze-thaw durability, UV stability and indoor air quality; and,

2. Develop standards for energy efficiency in composite panellized housing, consistent with R-2000 requirements.

This section outlines the test methods used in this project, covering the theoretical background and the objectives of each test.

2 PHYSICAL CHARACTERISTICS OF THE AMBIENTE HOUSING SYSTEM

2.1 CONSTRUCTION PROCESS

The perimeter foundation of the Ambiente housing system is comprised of a concrete line footing supporting a composite pony wall. The centre beam is supported on individual spread footings with adjustable posts. The entire home is secured to the foundation with post-tensioned composite cables. Appendix A shows details of the construction procedure of the test house, as well as structural details of a demonstration house.

Electrical conduit and outlet boxes are built in the panels making on-site installation of pre-assembled wiring kits and fixture packages quick and easy. Bath and kitchen packages with plumbing chases, vent stacks, and fixture connections are also designed for quick and efficient installation.

After the foundation is completed, the first step is to secure the floor track for the perimeter and the centre walls. The track is placed on a bed of mastic sealant for waterproofing and attached to the foundation with connection bolts.

Assembly is started at the intersection of the rear and centre walls to form a "T" for temporary support. The first wall panels are set in place and the vertical box beam is attached at this junction. Then the cables are passed through the panels. As each panel is put in place vertical cables are connected at the floor and anchored to the foundation through a 2"x2" alignment tube which is pushed into a vertical groove in the edge of the panel. Then the cables are tensioned and locked holding each panel precisely in place. This procedure is continued until all the wall panels, including doorframes, are in place and tensioned. The vertical and horizontal cables are interconnected but independent of each other. This creates a redundancy within the system, but it provides the flexibility for future expansion without compromising the structural integrity of the rest of the system.

After the walls are erected, a composite track is put on the top of the walls and the ridge beam is put in place on the centre wall. The cables are then tensioned and locked. At this point, the walls are structurally sound and ready to receive the roof panels. The first roof panel is set on the wall and ridge beam at one end of the house and locked in place. Then a joint/spacer sealant tube is placed into the grooved edge of the panel, the next roof panel is slid into place, and the cables are tensioned and locked. The roof structure is now structurally sound and anchored to the foundation.

The rest of the procedure is detailing. After all panels are in place, the doors and window cartridges are snapped into place and secured. All joints are sealed by means of a gasketing system that is placed in the joints between the panels when the spacer tube is installed. Once the cables are tensioned, a watertight seal is formed. Any excess sealant is squeezed out and removed. The sealant is the same colour as the panel and the joints virtually disappear. Once the house structure is complete, the exterior trim pieces are installed.

2.2 MATERIALS

The Ambiente housing system is a panellized modular building system that combines high technology materials with advanced engineering. The following outlines the materials and manufacturing processes used to make the building components.

2.2.1 Cappings, Wall and Roof Panels

The walls and roof consist of four-foot wide modular panels. The height of which is variable and location specific. The panels are six inches thick, consisting of a sandwich design with skins of composite material on each surface and a structural core of Ambi-Core. Cappings typically consist of the skin material alone.

The core material consists of closed cell spherical beads, "Ambi-Cells", of specified size and wall thickness cast in a filled resin system. The Ambi-Cells are created from waste glass using a proprietary process of crushing, chemical reaction, extrusion, and heat resulting in the finished glass bead product. This process has the capability to produce glass beads from 1/64 inch to ½ inches in diameter. Ambi-Cells are technically called cenospheres which means that they are perfectly spherical on the exterior, but the interior is made up of several cells full of encapsulated air. The Ambi-Cells are then coated in resin and pressed into blocks. Pictures of the core material were taken with a microscope and are included in Appendix B.

The skin or surface material is produced in a closed mould process by injecting a mixture of polyester resin and aluminium trihydrate filler around a continuous glass filament matrix. This material, which is used on all interior and exterior surfaces, provides the weathering surface and protects the core material of the panel. The surface finish can be customized, as required, and may be made to resemble a variety of traditional finishes. It can also be coated with a bonding coat for enhanced adhesion of standard paints.

2.2.2 Cables

The housing panels are reinforced by an interconnected network of composite cables running through each wall and roof panel, in effect forming a net within the entire structure. This interconnected net of cables ties the structure together as a single unit. This system was originally designed to provide hurricane resistant homes for southern climates.

2.2.3 Components

Components are the angles, tracks, and beams that are used for structural connections within the panel system. These sections are pultruded, a manufacturing process described below.

The glass, glass rovings, or woven fabrics, dependent on the structural element being manufactured, are strung and secured to a pulling mechanism. The fibres are then completely saturated with a thermo set resin that includes the polyester fillers, catalyst, and pigments. Sections are designed with a 75% glass fibre 35% resin mixture. The saturated fibres are pulled through a controlled heated die, passing through various stages of heat. This initiates several catalyst systems to react within the laminate allowing the layers of reinforcements to be mechanically fixed to each other resulting in the solidified product exiting the die.

Upon exit of the die, the profile continues its journey towards the puller. The puller is typically made in a caterpillar design that sandwiches the profile between a series of pads that are connected to a drive mechanism, keeping the laminate moving. Upon exiting the puller, the laminate passes to the final stage where a saw cuts it to length (Bedford Reinforced Plastics, Inc. 2004).

This combination of innovative construction and materials is a unique solution for northern Canadian communities. The subsequent chapter deals with the evaluation of this system in terms of its ability to meet some of the demands of these communities.

3 BACKGROUND

The building envelope is that portion of any building that separates the interior environment from the exterior environment. As such, it fulfils four important functions; control, support, distribute, and finish.

The control function of the building envelope controls water flow, in vapour and liquid form, and heat flow such that the interior environment is affected little by the exterior environment. The building envelope also supports wind and snow loadings, generally transferring these loads to stronger, supporting members. The building envelope must also distribute services such as plumbing and electrical within the building. Finally, the building envelope serves as the finish for the building. Each of these functions is equally important in having a good building envelope, and therefore a good building design.

3.1 ENERGY EFFICIENCY

Energy efficiency in a residential house is obtained through the control of air and heat flow through the building envelope. This project seeks to confirm compliance with the Manitoba Building Code and Canada's R-2000 Program in terms of energy efficiency. The Manitoba Building Code is a standard that governs the construction of most buildings within the province. This standard is compulsory and broad based. This phase of the project concentrates on those components of the standard that relate to energy efficiency in residential construction. The technical requirements of the R-2000 Standard include measures for the efficient use of energy, improved indoor air quality and better environmental responsibility in construction and operation of a house. The R-2000 Standard is a voluntary national standard.

3.1.1 Thermal Resistance

Understanding the heat transfer and temperature distribution through building materials and assemblies is important for assessing energy use, thermal movements, durability and the potential for moisture problems.

Heat transfer occurs by three modes, acting alone or in some combination. These three modes are:

1. Conduction: flow of heat through a material by direct molecular contact. This contact occurs within a material or by two materials in contact.

2. Convection: the transfer of heat by the movement or flow of molecules with a change in their heat content.

3. Radiation: the transfer of heat by electromagnetic waves through a gas or vacuum. Heat transfer by this mode requires a line of sight connection between the surfaces involved.

The transfer of heat through the building envelope is complicated due to the many factors that influence the flow of heat and the complicated nature of the interaction of the three modes of heat transfer. It is therefore difficult to make precise calculations. However, experience has given us much experimental data on which to base reliable estimates.

3.1.1.1 Fundamentals of Heat Transfer

In the usual situation all three modes of heat transfer occur simultaneously, however they will be considered separately in this section for clarity.

3.1.1.1.1 Conduction

Thermal conduction is the mechanism of heat transfer between parts of a continuum because of the transfer of energy between particles or groups of particles at the atomic level (McQuiston and Parker 1994). The Fourier equation expresses steady-state conduction in one dimension (Equation 1).

$$\frac{dq}{d\theta} = -\lambda \cdot A \cdot \frac{dt}{dx} \tag{1}$$

The rate of heat flow is $dq/d\theta$ (W), A is the area transverse to the flow, dt/dx is the temperature gradient, and λ is the coefficient of thermal conductivity (W/m·K). The negative sign in Equation 1 is a consequence of the fact that heat flows from high temperatures to low temperatures.

In many practical building science situations, Equation 1 can be written as

$$\dot{q} = \frac{l}{RSI} \cdot (t_1 - t_2) \tag{2}$$

Where, $\dot{q}$ is the heat flux per unit area; l is the length of the flow path; RSI is the thermal resistance of the material; and, t_1 and t_2 are the temperatures on either side of the material of interest.

Thermal resistance is analogous to electrical resistance, and $\dot{q}$ and $(t_1 - t_2)$ are analogous to current and potential difference in Ohm's law. This analogy provides a very convenient method of analysing a wall made up of two or more layers of dissimilar material. The equation that describes this process is Equation 3.

$$RSI = RSI_1 + RSI_2 + RSI_3 + \ldots + RSI_n \tag{3}$$

Some typical thermal conductances are listed in Table 3.1, below.

Table 3.1: Typical Thermal Conductances (Hutcheon and Handegord 1995)

Description	Density ρ (kg/m^3)	Thermal Conductivity λ (W/(m·K))	Unit Conductance C (W/(m^2·K)
12.5mm Gypsum	800	--	12.5
Wood	510	0.12	--
89-162mm Glass Batt Insulation	5-32	--	0.30
Concrete	1600	0.52	--

3.1.1.1.2 Convection

Thermal Convection is the transport of energy by mixing, in addition to conduction (McQuiston and Parker 1994). Convection occurs, in most practical situations, between a moving fluid and a solid surface when the two are at different temperatures. The usual simplified approach in convection is to express the heat transfer rate as:

$$\dot{Q} = h_C \cdot A \cdot (t_S - t_\infty) \quad [4]$$

where, $\dot{Q}$ is the heat flow (W); A is the surface area (m^2); t_s is the surface temperature; and, t_∞ is the fluid temperature at a distance far enough from the surface not to be affected by its temperature. The proportionality constant h_c is called the convective heat transfer coefficient, or film coefficient, with units W/m^2·K. For building science purposes, the value of h_c does not vary with the magnitude of the temperature difference. For special situations, and especially during evaporation and condensation, h_c is a variable (Straube 1997).

The term h_c depends on the type fluid, the fluid velocity, the flow channel, and the degree of development of the flow field. Many correlations exist for predicting the film coefficient under various conditions.

3.1.1.1.3 Radiation

The transport of heat by electromagnetic waves does not require the presence of a material, as does conduction or convection. In fact, radiation occurs most efficiently through a vacuum (Straube 1997).

Since all materials, even cold ones, radiate, the net radiation exchange defines the heat transfer. This phenomenon is too complicated to calculate in a general way, as each surface is a factor. However, for the special and useful case of a relatively small surface exchanging radiation with a large area (e.g., between a wall and the outdoors, or a roof and the sky) the heat flux is:

$$\frac{\dot{q}}{A} = \varepsilon \cdot \sigma \cdot \left(t_s^{\ 4} - t_a^{\ 4}\right) \qquad [5]$$

where, t_s is the surface temperature (K); t_a is the ambient or outdoor surface temperature (K); ε is the emittance of the surface (a dimensionless material characteristic available in reference materials); σ is the Boltzmann constant (5.673 X 10^{-8} $W/m^2 \cdot K^4$); and, A is the envelope surface area (m^2).

The thermal resistance for radiation cannot be easily computed, however, because of the fourth power temperature relationship of Equation 5. For this reason and because of the inherent uncertainty in describing the physical situation, theory and experiment have combined to develop combined or effective unit thermal resistances and effective unit thermal conductances for many typical surfaces and air spaces in limited temperature ranges.

3.1.1.1.4 Heat Storage

All materials above absolute zero contain some heat energy. The amount of this energy is given in the form

$$E = c_o \cdot m \cdot t \qquad [6]$$

Where, E is the amount of energy (J); c_o is the specific heat capacity (J/kg·K or J/g·K); m is the mass (g or kg); and, t is the absolute temperature (K).

The amount of heat energy required to change a material from one temperature to another can be described by:

$$Q = c_o \cdot m \cdot \Delta t \qquad [7]$$

Heat capacity values for common materials are listed in Table 3.2.

Table 3.2: Specific Heat Capacity of Some Common Materials (Straube 1997)

Material	Heat Capacity (J/g·K)
Air at 20 °C	1.0
Concrete, brick, rock, minerals	0.9
Wood, wood products	1.9 – 2.4
Water	4.2
Ice at 0°C	2.1
Foam Plastics, plastics	1.5
Steels, metals	0.4
Aluminium	0.8

3.1.1.2 Calculating Steady State One-Dimensional Heat Flow

In most building science applications, radiation and convection are simplified based on the climate and materials in play. Conduction is also simplified to a steady state one-dimensional flow. These assumptions create small errors, but allow simple interpretation of results and accurate comparison of energy consumption. These simplifications are discussed in the following sections. Latent heat will not be discussed, as its affect on energy consumption is minimal.

Based on the fundamental equations 1 and 2, defined earlier one can consider the heat flow through multiple layers or composite constructions. Two facts are important to note:

1) The heat flux across the entire assembly must pass through each layer (Conservation of Energy), and

2) The sum of the *resistances* of each layer gives the total resistance; one *cannot* sum the conductances.

Thus for an assembly of n layers:

$$\dot{q} = \frac{\dot{Q}}{A} = \frac{t_{\text{int}} - t_{ext}}{\sum_{i=0}^{n} RSI_i} \qquad [8]$$

where, t_{int} is the interior temperature; t_{ext} is the exterior temperature; and, RSI is the thermal resistance of the composite section. Equation 8 is used to determine the composite thermal resistance of various components of the system (Straube 1997).

To account for radiative and convective heat transfer modes at the exterior and interior surfaces of building components, the radiative and convective heat transfer coefficients are used in the form of an equivalent conductance. These factors also take into consideration the ability of the materials to store heat energy. Tables 3.3 through 3.5 list some useful equivalent conductances and surface temperatures that account for these effects. Two values of surface emittance are given to show the dependency of the equivalent conductances on both direction of airflow and radiative effects.

Table 3.3: Equivalent Conductances for Exterior & Interior Surfaces for two Values of Emittance (W/m^{2}·K) (Straube 1997)

Surface Position	Flow Direction	Equivalent Conductance	
Still Air (indoors)		ε = 0.90	ε = 0.05
Horizontal (ceilings and floors)	Upward	9.3	4.3
	Downward	6.1	1.3
Vertical (walls)	Horizontal	8.3	3.4
Moving Air (outdoors)			
6.7 m/s (winter)	Any	34	34
3.4 m/s (summer)	Any	23	23

Table 3.4: Equivalent Conductances for Plane Airspaces (W/m^{2}·K) (Straube 1997)

Position of Surface	Direction of Flow	Plane Airspace Thickness (mm)/ Surface Emittance							
		13		20		40		90	
		0.05	0.90	0.05	0.90	0.05	0.90	0.05	0.90
Mean Temperature 32°C									
Horizontal	Up	2.78	7.69	2.56	7.69	2.38	5.26	2.13	7.14
	Down	2.44	7.14	1.72	6.67	1.06	5.88	1.45	5.56
Vertical	Horizontal	2.44	7.14	1.75	6.67	1.56	6.67	1.67	6.67
Mean Temperature -18°C									
Horizontal	Up	2.78	4.55	2.63	5.56	2.44	5.26	2.17	5.00
	Down	2.00	5.00	1.41	4.35	1.18	3.70	1.82	3.45
Vertical	Horizontal	2.00	5.00	1.59	4.55	1.69	4.55	1.69	4.55

Table 3.5: Radiation Induced Surface Temperatures (Sol-Air*) (°C) (Straube 1997)

Situation	Thermally Massive	Thermally Lightweight
Roofs: direct sun	$t_a + 42\alpha$	$t_a + 55\alpha$
Roofs: sun plus reflected/re-emitted radiation	$t_a + 55\alpha$	$t_a + 72\alpha$
Roof Exposed to night sky	$t_a - 5\varepsilon$	$t_a - 10\varepsilon$
Walls: winter sun	$t_a + 35\alpha$	$t_a + 48\alpha$
Walls: summer sun	$t_a + 28\alpha$	$t_a + 40\alpha$
Walls exposed to night sky	$t_a - 2\varepsilon$	$t_a - 4\varepsilon$

*Sol-Air is a term used to describe radiation induced Surface Temperatures
α = Absorptance of the surface (dimensionless)
ε = Emittance of the surface (dimensionless)

3.1.2 Air Leakage

Air leakage, though often overlooked, is of considerable importance to the energy efficiency of a home. Leakage occurs through pores in materials, cracks, holes or other openings. The driving force behind the airflow is the air-pressure difference from interior to exterior. Exfiltration is airflow from the interior to the exterior, and the inverse is infiltration. Ventilation is the intentional supply or removal of air.

There is a substantial energy cost associated with infiltration and ventilation. The sensible heat required to bring outdoor winter air to room temperature is

$$Q = 1.21\dot{A}\left(t_{\text{int}} - t_{ext}\right) \qquad [9]$$

where, Q is the heat required (W); $\dot{A}$ is the rate of airflow (L/s); and, t_{ext} and t_{int} are the outdoor and indoor air temperatures (°C). Various estimates have shown the infiltration heat losses to be from 30% to 40% of total heating requirements for insulated houses of good construction (Hutcheon and Handegord 1995).

Depending on natural air infiltration to meet the fresh air requirements of a household is unreliable. A home with too much air infiltration will feel draughty in the winter, whereas a tight home will be stuffy. The answer therefore lies in providing an airtight home with adequate ventilation to meet occupant needs.

3.1.3 Windows

Windows are another portion of the building that requires special consideration in building design and testing. They are, however, one of the most complex. This is because the effect of solar radiation on buildings is complex. Windows transmit their energy through a combination of solar radiation, conduction, and convection. Conduction and convection in windows is relatively straightforward. The rate at which solar radiation energy is delivered, however, is highly variable with latitude, time of year, time of day, weather, surroundings, orientation of receiving surfaces and transmitting areas and absorptance and emittance of receiving surfaces. The resulting transient and cyclical heat flows are not easy to deal with.

In addition, windows are expected to provide daylighting and ventilation. In a conventional suburb, a house will face the street – regardless of which way the street runs. In rural areas, houses most often face the best view – regardless of which direction the view lies. Both practices severely constrain the opportunity to use the sun for passive solar heating or daylighting.

Making the best use of the sun's heat and light is a central principle in green design. Day-lit buildings use substantially less energy while providing a welcome connection to the outdoors. Natural daylighting contributes to reduced energy consumption, and the health and well being of occupants. It also provides a superior quality of light (Barnett and Browning 1999).

3.1.4 Thermal Mass

As discussed in Section 3.1.1.1.4, different materials have different abilities to store heat energy. The term thermal mass is commonly used to mean the ability of materials to store significant amounts of thermal energy and delay heat transfer through a building component. This delay has three important results:

1. The slower response time tends to moderate indoor temperature fluctuations during outdoor temperature swings;

2. In cold climates, energy consumption is less than that for similar low-mass buildings; and

3. Building energy demand can be moved to off-peak periods because energy storage is controlled through correct sizing of the mass and interaction with the Heating Ventilating Air Conditioning (HVAC) system.

The ability of a material to store heat energy is its heat capacity, which is defined as the amount of heat necessary to raise the temperature of a given mass by one degree Kelvin (Equation 7). Thermal mass is not easily quantifiable due to its dependence on the material as well as its location both within the structure and in relation to the external environment. It is therefore useful to be able to characterize thermal mass by the thermal diffusivity of the building material, i.e.

$$a = \frac{\lambda}{\rho c_o} \qquad [10]$$

Where, λ is the thermal conductivity; ρ is the density; and c_o is the specific heat of the material. The lower the value of a, the higher the thermal mass.

Heat transfer through a material with high thermal diffusivity is fast, the amount of heat stored in it is relatively small, and the material responds quickly to changes in temperature. The effect of thermal mass on building behaviour varies primarily with the climate at the building site, and the position of the wall insulation relative to the building mass (ASHRAE 1999).

Calibrated hotbox tests have shown that in walls with identical heat capacities, those with higher RSI (thermal resistance) values cause larger reductions in temperature swings (Van Geem 1986). In order to simulate the complex interactions of all envelope components, computer simulations are necessary.

3.2 CONDENSATION CONTROL

Moisture in its various forms is the largest single cause of premature building envelope deterioration, damage, and performance problems. Liquid water, from precipitation and building uses, or from the soil is a major source of moisture in buildings. This section considers the moisture in the air since the ability of air to transport moisture makes it especially important.

When moisture is in its gaseous state, it is variously called water vapour, humidity, or steam. Water vapour behaves as an ideal gas and acts as part of a mixture of gases that comprise air.

The terms absolute humidity, humidity ratio, relative humidity and vapour pressure all reflect the same fact: air contains varying amounts of moisture in vapour form.

The absolute humidity is merely another name for humidity ratio. The humidity ratio is a fundamental measure defined as the ratio of the mass of water vapour to the mass of (dry) air.

Dalton's Law states that the total pressure of a mixture of gases is the sum of the partial pressure of each of the gases. The partial pressure exerted by water vapour pressure is termed the vapour pressure or water vapour pressure.

At any given temperature, there is a maximum amount of vapour that air can hold. No more vapour can be added to air by evaporation or sublimation. The warmer the air, the more water vapour that can be held. When air contains the maximum amount of water vapour for its temperature condition, it is saturated. The ratio of the actual amount of water vapour to the maximum possible amount of water vapour at that temperature is called the relative humidity.

Calculating vapour flows follows the same general principles as the calculation of heat flow. However, the results of the calculations tend to be much less accurate for several reasons:

1. The values for vapour permeability are difficult to ascertain accurately and vary widely with moisture content and temperature. Variations of an order of magnitude are common for some materials. Extrapolating from tests on samples of different thickness further reduces accuracy.

2. The moisture storage capacity of most building materials is so large that steady state conditions almost never occur in practice. The process of evaporation and desorption act as moisture sources and sinks within the envelope.

Vapour diffusion is also often a relatively small contributor to vapour transport: the bulk movement of air may transport up to one hundred times as much water vapour than diffusion.

Despite the inaccuracies and limitations of steady state diffusive vapour flow calculations, such calculations are still useful in that they provide a relative measure of vapour movement that, if carefully and thoughtfully applied, may be correct within an order of magnitude.

Just as for heat flow through multiple layers or composite constructions, there are two important facts to remember:

1) The vapour flux across the entire assembly must also pass through each layer, and

2) The sum of the resistances of each layer gives the total resistance; one cannot sum the permeances.

One normally calculates V from Equation 11 to access the assembly's ability to control diffusive vapour flow. Then it is a simple matter to calculate the vapour pressure across every layer using Equation 12.

$$V = \frac{1}{\sum_{j=0}^{n} R_{v_j}} \qquad [11]$$

$$\Delta P_j = V \cdot (P_{\text{int}} - P_{ext}) \cdot R_{v_j} \qquad [12]$$

Where, V is the vapour transmittance of the system; P_{int} is the interior pressure; P_{ext} is the exterior pressure; and, R_{v_j} is the vapour resistance of each layer, j.

The dewpoint temperature (t_d) [Equation 13] is that temperature at which condensation will occur for a specific absolute humidity (P_w)[Equation 14]. Equation 13 is empirical and may be used in most building science applications. Equation 14 is based on the fundamental gas law.

$$t_d = \frac{4030.183}{18.6686 - \ln\left(\frac{P_w}{133}\right)} - 235 \qquad [13]$$

$$P_w = \frac{m_w \cdot R_g \cdot t}{v} \qquad [14]$$

Where m_w is the mass of water vapour in the air, R_g is a constant, different for specific gases (R_{wv}=461.5 J/kg·K for water vapour), t is the temperature of the air and v is the volume of air.

Relative humidity [Equation 15] is the mass of water vapour over the mass of water vapour if the air were saturated, or the Vapour Pressure [Equation 14] over the Saturation Vapour Pressure [Equation 16]. Equation 16 is an empirical equation that can be used in most building science applications.

$$\vartheta = \frac{m_w}{m_{ws}} = \frac{P_w}{P_{ws}} \qquad [15]$$

$$P_{ws} = 1000 \cdot e^{\left(52.58 - \frac{6790.5}{t} - 5.028 \ln t\right)} \qquad [16]$$

3.3 DURABILITY

The durability and rate of deterioration of building products are all significantly influenced by both the material composition, as well as the climactic conditions to which they are exposed (Jones 2002). Damage may occur due to various forces including temperature, water, freezing or exposure to ultraviolet light. In this project, the durability of the Ambiente products in freeze-thaw cycling and in exposure to ultraviolet sunlight was also investigated.

3.3.1 Freeze-Thaw Durability

Damage to porous building materials can occur if they are exposed to freezing temperatures when wet (Hutcheon and Handegord 1995). In fact, the freezing of water in porous materials is perhaps the most important cause of weathering of materials in Canada (Sereda 1969). In order for damage to occur to a material due to freeze-thaw cycling, it must have exposure to many freeze-thaw cycles, be exposed to water and have a porous structure. The Ambiente houses to be built in Canada will be exposed to a climate in which freeze-thaw cycles are prevalent. The panels must therefore be tested to evaluate their durability performance.

3.3.2 Ultraviolet Stability

The degradation of organic building materials attributable to ultraviolet can take two paths. With some, the energy starts a process the reverse of the polymerization reaction that produced the large molecules (Ashton 1969). This process essentially "unzips" the plastic causing large-scale failure of the material. This process is stopped through the inclusion of pigments that reflect the ultraviolet or absorb it preferentially to the polymer (Ashton 1969). Alternatively, the ultraviolet light may trigger more cross-linking than was originally present. This results in a material that becomes harder and more brittle. Even in organic materials that are stable in ultraviolet light, discolouration of the polymer surface affecting the aesthetic appeal of the material may occur (Jones 2002). Substantial body of research exists in this area and technologies have been developed to protect the composite material from any structural deterioration that may result from UV exposure. These technologies have already been incorporated in the Ambiente products.

4 TESTING PROGRAM

A testing program was designed to determine the energy efficiency and durability of the Ambiente product in Canadian conditions.

4.1 ENERGY EFFICIENCY

4.1.1 Thermal Resistance

The minimum performance requirements for the experimental program in this study are based on Canada's R-2000 requirements that thermal insulation levels must meet or exceed provincial requirements. These requirements are outlined in Section 9.25.2 of the Manitoba Building Code (MBC). Note that trade-offs are permitted in the thermal resistance values specified by the National Building Code (NBC) and shown in Table 4.1 if it is demonstrated, using good engineering practice, that the building will not use more energy than it would if it complied with Table 4.1. In addition, nominal thermal resistance values can be used when determining compliance with Table 4.1 and the effects of sheathing, finishing materials, air films and thermal bridging of framing members disregarded.

While values in Table 4.1 are nominal values, calculations show that these closely reflect reality in wood construction (Appendix C). This is because the negative effect of thermal bridging is greatly offset by the additive effect of air films and sheathing materials. For the purpose of analysing the Ambiente system, however, a different approach will have to be taken. In this system, there is virtually no thermal bridging and therefore the calculations will be done taking into account sheathing, air films caused by convection, and finishing.

Table 4.1: Minimum Thermal Resistance for the Building Envelope (Manitoba Building Code (MBC) Table 9.25.5.2)

Building Assembly	Southern Manitoba[1]	Northern Manitoba[2]
Foundation Walls[3],[4] -Interior -Exterior	 RSI-2.1[5] RSI-3.5[6] RSI-2.1	 RSI-4.2 RSI-3.0
Floors on Ground -Heated -Unheated (less than 0.6 m below grade) -Unheated (0.6m or more below grade)	 RSI-0.88 (Full Area) RSI-0.88 (1m Perimeter) no requirement	 RSI-0.88 (Full Area) RSI-0.88 (1m Perimeter) no requirement
Floors Above Unheated Spaces	RSI-5.6	RSI-5.6
Walls Above Grade	RSI-3.5	RSI-4.6
Roofs -Attics -Sloped Ceilings	 RSI-7.0 RSI-7.0 (Trusses/I-Joists) RSI-4.9 (Solid Lumber)	 RSI-8.8 RSI-7.0 (Trusses/I-Joists) RSI-4.9 (Solid Lumber)

Notes to Table 9.25.5.2:

(1) South of the 53rd Parallel
(2) At or north of the 53rd Parallel
(3) See Sentence 9.25.5.3.(1) MBC for minimum depth of insulation below grade
(4) See Sentence 9.25.5.4.(1) MBC for foundation walls that extend more than 1.2 m above ground level
(5) For dwellings using natural gas as the heating source
(6) For dwellings using other than natural gas (e.g. electricity, oil, propane, wood) as the principal heating source.

Testing to determine the thermal resistance of the Ambiente building materials will be completed by a third party in accordance with ASTM C1393-97 "Standard Test Method for Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus". This test method is designed to measure the heat transfer through a specimen in steady state controlled conditions of: air temperature, air velocity, and thermal radiation. At the time of the writing of this paper this testing was underway at the National Research Council of Canada under the direction of Ambiente Canada.

4.1.2 Air Leakage

The basis of the air leakage target for the experimental program is Canada's R-2000 requirement, listed below.

> The building envelope shall be constructed sufficiently airtight such that either the air change rate at 50 Pascals is no greater than 1.5 air changes per hour, or the Normalized Leakage Area at 10 Pascals does not exceed 0.7 cm^2/m^2, when measured in accordance with CAN/CGSB-149.10-M86 (*Determination of the Airtightness of Building Envelopes by the Fan Depressurisation Method*).

In order to determine the air leakage of the assembly, an Experimental House was constructed. The Experimental House was constructed in the fall of 2002, and consisted of an 8 square metre building. The construction drawings for this building are shown in Appendix A.

There are several ways of determining the qualitative and quantitative air leakage in a building. This project employs three methods.

4.1.2.1 Blower Door Test

As described in the R-2000 standard, testing in accordance with CAN/CGSB-149.10-M86 (*Determination of the Airtightness of Building Envelopes by the Fan Depressurisation Method*) is required to determine the airtightness of a building. In this test, a fan is used to exhaust air from the building at a rate required to maintain 50 Pa air pressure difference across the building envelope. The airflow and the pressure difference are measured. The intention is to subject the complete envelope to a simultaneous and similarly directed air pressure. The flow is corrected to reference temperature and reference pressure. The relationship between flow and pressure difference is used to calculate the equivalent leakage area of the building envelope.

4.1.2.2 Monitoring Program

The detection of air leakage in an exterior wall may also be determined through monitoring sensors. Sensors, detecting the interior and exterior temperatures and pressure difference across the cavity, were placed in several locations along the building envelope and measurements were taken during winter conditions. To detect air leakage, the theoretical temperature profile is compared to the sensor data. If the recorded core temperature is lower than that obtained through theory, this is indicative of air leakage through the envelope. The sensor data is evaluated by calculating the temperature index, this should correspond to the theoretical percentage of thermal resistance to any specific point in the wall. This parameter is detailed in Equation 17. A detailed description of the testing methodology is provided in Appendix D (Quirouette 1999).

$$t_{index} = \frac{t_{ext} - t_{\text{int}}}{t_{ext} - t_{core}} \qquad [17]$$

4.1.2.3 Infrared Photography

Thermography is the use of an infrared imaging and measurement camera to see and measure thermal energy emitted from an object.

Thermal, or infrared energy is light that is not visible because its wavelength is too long to be detected by the human eye. This is the portion of the electromagnetic spectrum perceived as heat. The higher the object's temperature, the greater the infrared radiation emitted.

Infrared pictures were taken of the Experimental House during a cold night to see where the higher and lower heat emitting portions of the building are located. The darker the object in the photo, the colder it is. While this does not provide a quantitative measure of air tightness, if there are bright spots at or near joints, this is indicative of air leakage.

4.1.2.4 Visual Observation

In addition to the testing outlined in the previous sections, a visual review of the Experimental House after one year of weathering in a typical Winnipeg winter was performed. Special attention was paid to the joints and the sealant to determine the long-term durability of the joints and therefore potential for air leakage over time.

4.1.3 Windows

The orientation of each house and placement of windows is pre-determined by the architect. The focus of this paper is the design and testing of the individual units and their effect on the energy efficiency of the building. The windows are designed to meet the combined requirements of CSA A440 in terms of energy efficiency and water tightness and Canada's R-2000 Program. Windows are classified using the following prescriptive elements: Airtightness (A1, A2, A3 or Fixed), Water Tightness (B1, B2 or B3), Condensation Resistance, and Energy Rating (ER)

Each element is based on the occupant usage, specific orientation of the window, and location of the building.

4.1.3.1 Air Tightness

The average volume of air that passes through a closed window from both the exterior to the interior or the interior to the exterior at a given fixed wind pressure defines the window air tightness. In this case, the volume of air passing through a window is measured under ambient temperature conditions (20°C) at an induced pressure differential of 75 Pa, which represents a wind speed of 40 km/h.

The windows in the current project are designed to meet the maximum air leakage rates:

1) 0.25 $(m^3/h)/m$ for a fixed window, and

2) 0.55 $(m^3/h)/m$ for an operating window or fixed window with a sash (A3).

4.1.3.2 Water Tightness

The water tightness test requirement and test method require that there be no water leakage when tested at a test pressure of 300 Pa (Window Rating B3). For the water tightness test, the sample is mounted in a chamber and an even film of water at a specified rate is sprayed onto the outside surface while the window is subjected to the pressure differential. During the test, the pressure is cycled four times, each cycle consisting of 5 minutes of pressure applied and one minute with no pressure.

4.1.3.3 Condensation Resistance

Because of Canada's cold climate, condensation resistance is an important window selection criterion. In addition to the aesthetic issue of reduced visibility or window view, condensation runoff can cause damage to curtains, carpets, and wall finishes, cause mould and wood rot, lift paint and plaster and eventually result in significant damage to building materials. Furthermore, the penetration of condensation runoff into the glazing cavity may result in premature failure of insulating glass unit edge seals.

The formation of condensation on window surfaces is dependent on a number of factors, including the outdoor temperature and the relative humidity and temperature inside the building. As the outside temperature falls, the indoor window surface temperature also falls. Condensation will occur when the indoor surface temperature falls below the dewpoint temperature. The dew point temperature is a function of the relative humidity and temperature of the air. The higher the relative humidity and temperature are, the higher the resulting dew point temperature is. This means that with the same window surface conditions, condensation will occur sooner in a room with a higher indoor relative humidity and temperature. The recommended interior relative humidity, in accordance with the recommendations in CSA A440, is not over 15% (CSA A440.1—2000).

It is important to note however, that although this relative humidity is most suitable for the windows, it is not within the researched comfort zone for humans. It is anticipated that occupants will want to keep relative humidity levels closer to 25-30% relative humidity for health and comfort (Watson and Labs 1983). Some condensation is therefore expected when exterior temperatures drop below -18°C (CSA A440—2000).

4.1.3.4 Energy Rating

There are several determinants for energy efficient window design: solar heat gains, heat loss transmission, and heat loss by air leakage. Due to this complicated interaction, CSA put together an indicator, Energy Rating (ER) that incorporates all of these aspects for a heated home.

The target window performance for the experimental program is based on Canada's R-2000 requirements. Therefore, the minimum energy rating required for an operable window is –13 and for a fixed window is –3. These dimensionless parameters incorporate all aspects of energy efficient window design.

The window manufacturer provides performance results regarding compliance with the above requirements. Conformance was evaluated through the review of the test results.

In addition, regular visual observation of the performance of the window joint was performed for the Experimental House. Attention was paid to the formation of mould, and the condition of the interior and exterior-caulking joints.

4.1.3.5 U-Value

A fifth parameter often used to measure the performance of a window is its U-Value, or thermal transmittance. This is a measure of the amount of energy that is passed through the glass and frame through conduction and is mathematically the inverse of thermal resistance. There is no code requirement for the U-Value of the window.

4.1.4 Thermal Mass

To view the effect of the thermal mass of the material, analysis of the sensor data was performed to see the actual response time of the building material under normal Winnipeg winter conditions.

4.1.5 Computer Modelling

HOT2000 is a computer-modelling program that was developed by the Buildings Group of Natural Resources Canada (NRCan). This program was designed to model and compare small residential buildings in terms of their energy performance on a monthly or annual basis. This program was used to estimate the energy consumption of a full sized house based on the results of the testing in this project and claims of the Ambiente Canada.

4.1.6 Overall Energy Efficiency

In order to determine the overall energy efficiency of the Experimental House an electric heating system was installed to monitor the energy used to maintain the interior temperature.

The R-2000 standard recommends the use of HOT2000 computer modelling program in order to determine compliance with the standard requirements. In addition, there is a space heating energy target outlined in the standard based on the degree-day model. The R-2000 space-heating requirement is outlined in Equation 18.

$$Q_s = S * \left(\frac{49 * DD}{6000} \right) * \left(40 + \frac{v}{2.5} \right) \qquad [18]$$

Where

S = 4.5 megajoules (MJ) for fuel-fired space heating systems, or

S = 1.0 kilowatt hours (kW·h) for electric space heating systems.

DD = Celsius heating degree-days for the locality (5900 for the City of Winnipeg).

v = Interior heated volume, including basement (m^3).

The degree-day procedure was common before wide use computer simulations became the norm. McQuiston and Parker recommend more sophisticated methods of energy estimation be considered even for residential construction, as this equation is not highly accurate, especially under unique conditions (McQuiston and Parker 1994). The accuracy of this equation was tested in this study by comparing the results from Equation 18 to published results shown in Figure 4.1.

The straight-line data marked Winnipeg, St. John's and St. John were the calculated theoretical energy consumption of R-2000 homes within this region using Equation 18. Data was then taken from Manitoba Hydro (Manitoba Hydro 2004), Newfoundland Power (Newfoundland Power 2003), and New Brunswick Power (Énergie NB Power 2004) and correlated onto Figure 4.1.

As shown in Figure 4.1, Equation 18 is only representative of some cases, but is not flexible enough to be applied to every case. Thus, Equation 18 will not be relied upon

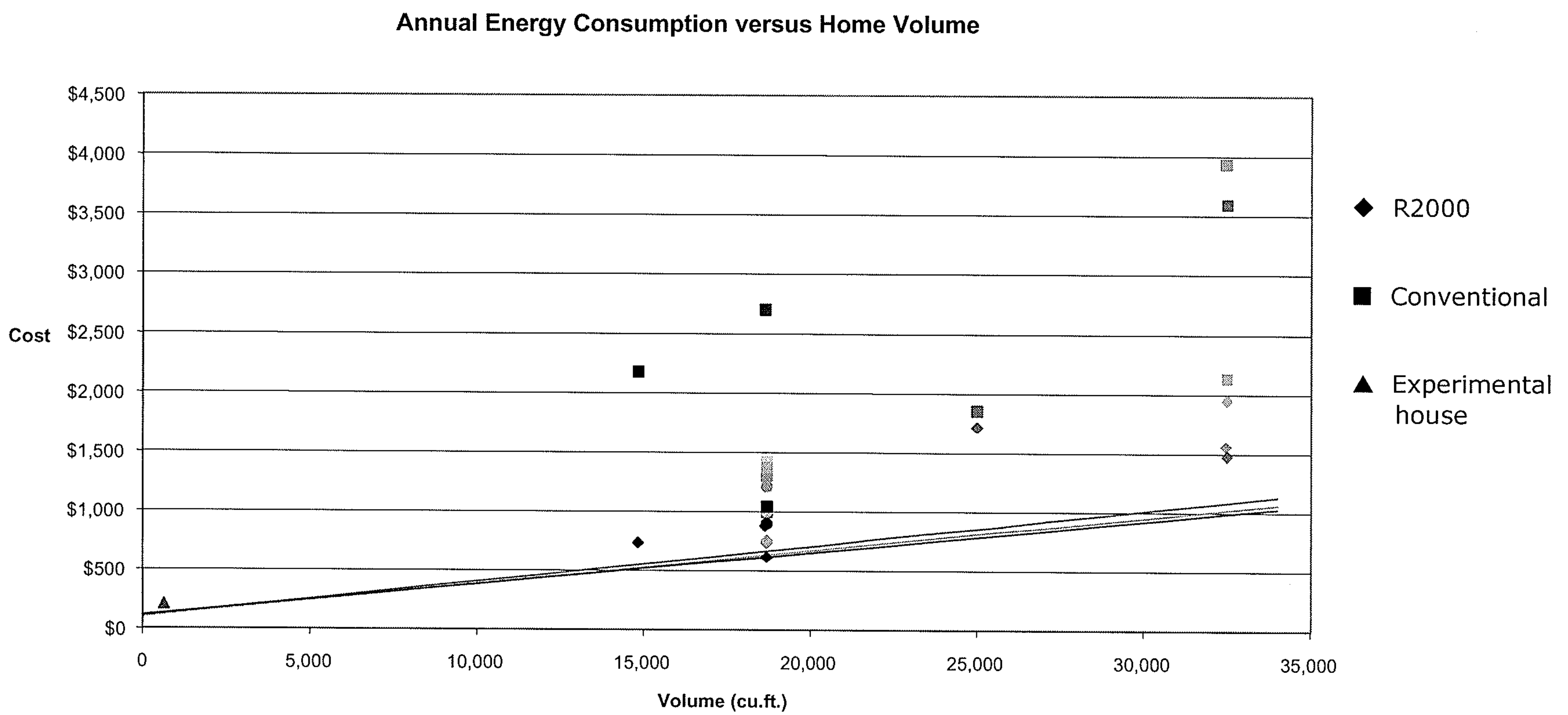


Figure 4.1: R-2000 Target Equation

in the final analysis of the test data, but will be included in the discussion for comparison purposes only.

4.2 CONDENSATION RESISTANCE

The National Building Code of Canada requires that a vapour barrier be installed in all residential homes to provide a barrier to diffusion of water vapour from the interior into wall spaces, floor spaces, roof spaces, or attics. The vapour barrier is required to have an initial permeance not greater than 45 $ng/(Pa \cdot s \cdot m^2)$. In addition, in an attempt to reduce the possibility of condensation within wall cavities, the code requires that the vapour barrier be installed close to the warm side of the insulation.

Tests were performed to determine the vapour permeance of the material as well as monitoring over a three-week period to determine the presence, if any, of moisture within the walls.

4.2.1 Vapour Permeance Test

Vapour permeance tests were conducted at the Human Ecology Department at the University of Manitoba, by bonding specimens on top of circular containers containing distilled water and measuring the time it will take the water to evaporate through the specimen. During the tests, specimens were rotated at a constant speed, in order to ensure constant airflow on top of the specimens. Air temperature and relative humidity were constant (CAN/CGSB-4.2 no.49, m77).

4.2.2 Monitoring Program

In addition to the temperature sensors placed throughout the interior, exterior and within the walls of the Experimental House, relative humidity sensors were also installed in these locations. The temperature and humidity within the Experimental House were kept at levels comparable to living conditions in the North. It was assumed that if relative humidities within the wall cavity were at or near 100%, condensation had occurred. Complete test procedures are given in Appendix E.

4.3 DURABILITY

4.3.1 Freeze-Thaw Durability

To determine the freeze-thaw durability of the material, samples were cut and placed in an environmental chamber where temperature was cycled over a period. The samples were then compared in strength and mass to before the cyclical testing. This is a qualitative test only since no standard procedure exists. The test procedure was based on ASTM C1262-98 "Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units". More information is provided in Appendix F. This test was designed to determine a trend in deterioration, but not to determine a quantitative measure of deterioration with time.

4.3.2 Ultra Violet Stability

To determine the ultraviolet stability of the material nine samples were prepared and tested in accordance with ASTM D4587-91 "Standard Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light and Water Exposure Apparatus" and ASTM G53-91 "Standard Practice for Operating Light and Water Exposure Apparatus for Exposure of Non-metallic Materials".

4.4 INDOOR AIR QUALITY & CONTROL OF MOULD GROWTH

As discussed earlier, indoor air quality, particularly the control of mould growth is very important to maintaining occupant health. One of the goals of this project was to examine whether composite materials support the growth of mould.

5 DISCUSSION OF COMPONENT TEST RESULTS

5.1 VAPOUR PERMEANCE

Testing of five samples was completed in accordance with CAN/CGSB-4.2 no.49, m77. This test included the placement of test samples over a container of water and measurement of the amount of water lost over a specific period of time. The following graphs outline the results of each of the test samples. To determine the vapour permeance, we take the final straight-line portion of the graph and average the results. The test results are shown in Figures 5.1 through 5.5, below. The test results are summarized in tabular format in Table 5.1, and the full test report is included in Appendix G.

For the skin material, the measurements stabilized at 0.033 ng/Pa·m^2·s. This is considerably lower than the target value of 45 ng/Pa·m^2·s as outlined in the National Building Code.

For the core material the measurements stabilized at 2.822 ng/Pa·m^2·s. While this result is higher than the skin, it is still considerably lower than the target value of 45 ng/Pa·m^2·s as outlined in the National Building Code.

To determine how the materials work together as a system, a sample was cut 29-mm thick with the skin material attached. This composite sample still performed well, and as expected was between the values for the skin and the core alone. This is due to the fact that some of the water vapour will have escaped through the sides/core of the sample as well as through the top. This composite test stabilized at 0.193 ng/Pa·m^2·s. Again, the measurement is considerably lower than the target value of 45 ng/Pa·m^2·s as outlined in the National Building Code.

A second test with a thinner sample was tested to determine how the materials work together as a system. In this case, the sample was cut 15-mm thick with the skin material attached. This composite test stabilized at 0.241 ng/Pa·m²·s. Again, the measurement is considerably lower than the target value of 45 ng/Pa·m²·s as outlined in the National Building Code.

A final test was performed on the pultruded material to determine its vapour permeance level. The pultruded section also performed well, stabilizing at 0.056 ng/Pa·m²·s. Again, the measurement is considerably lower than the target value of 45 ng/Pa·m²·s as outlined in the National Building Code.

Table 5.1: Vapour Permeances in Typical Units

Measure	Skin (ng/Pa·m²·s)	Core (ng/Pa·m²·s)	Composite 28-mm (ng/Pa·m²·s)	Composite 15-mm (ng/Pa·m²·s)	Pultruded Section (ng/Pa·m²·s)
1	0.654	16.281	2.868	3.100	1.455
2	0.138	3.687	1.901	1.696	0.500
3	0.036	2.998	1.449	0.990	0.297
4	0.032	2.869	1.001	0.632	0.167
5	0.030	2.883	0.284	0.296	0.070
6	0.042	2.901	0.180	0.251	0.065
7	0.028	2.689	0.156	0.213	0.044
8	0.025	2.801	0.153	0.206	0.045
Vapour Permeance					
	0.033	**2.822**	**0.193**	**0.241**	**0.056**

The vapour permeance for each test is determined after the samples reached steady state. Here, the samples reached steady state after four measures. The average of the last four measures was calculated and is tabulated in Table 5.1. These values are much lower than the target value of 45 ng/Pa·m²·s as outlined in the National Building Code. The results indicate that all the construction materials used in this house are very vapour resistant.

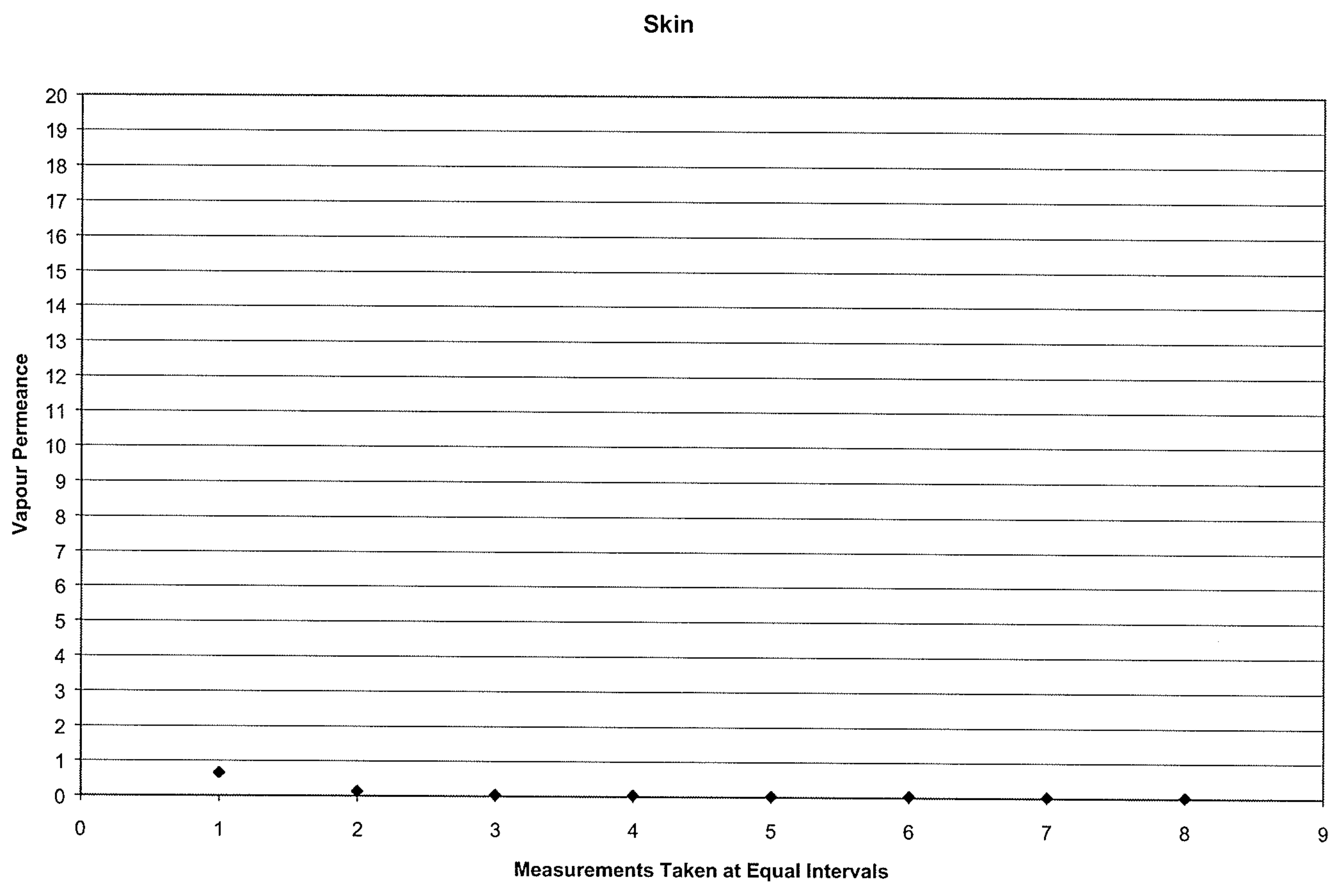


Figure 5.1: Vapour Permeance Measurements of Skin Material

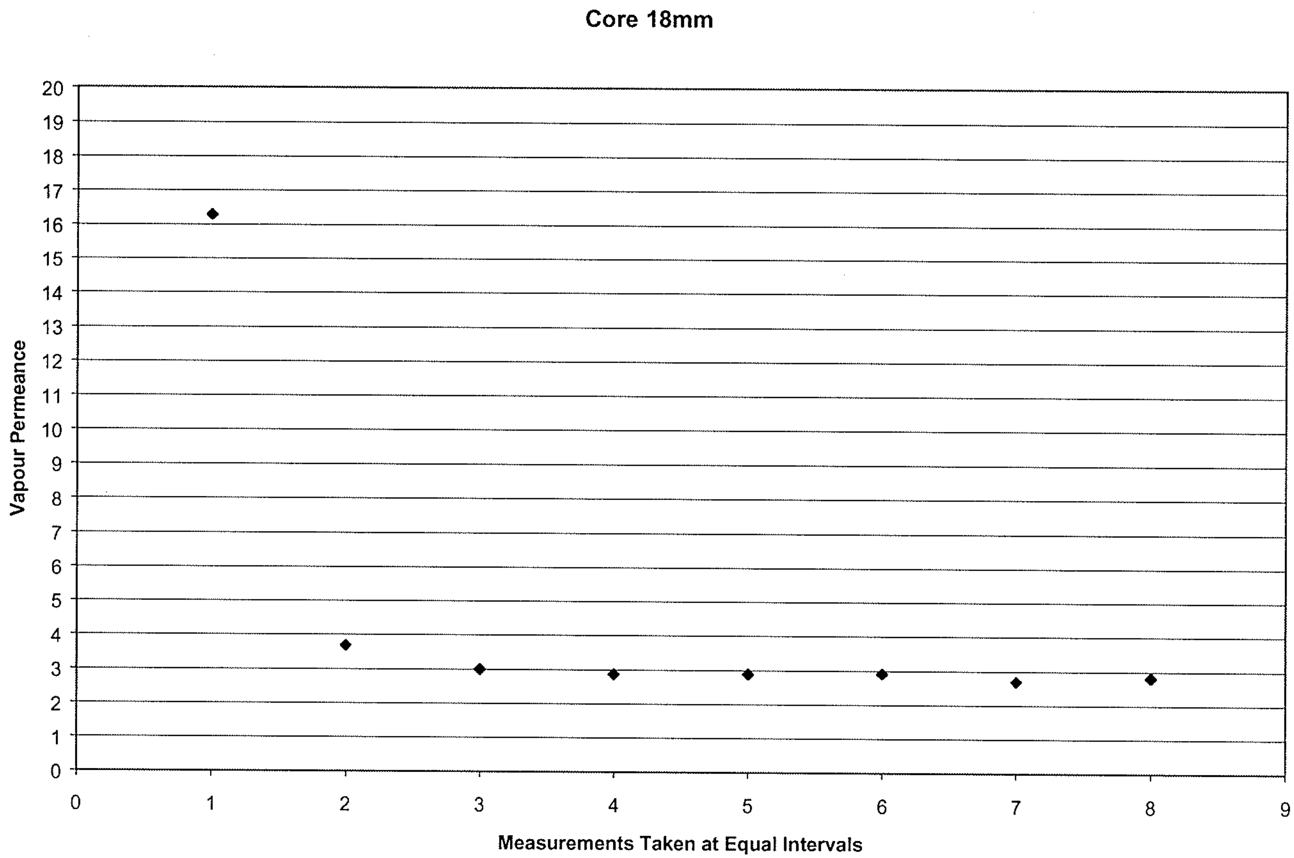


Figure 5.2: Vapour Permeance Measurements of Core Material

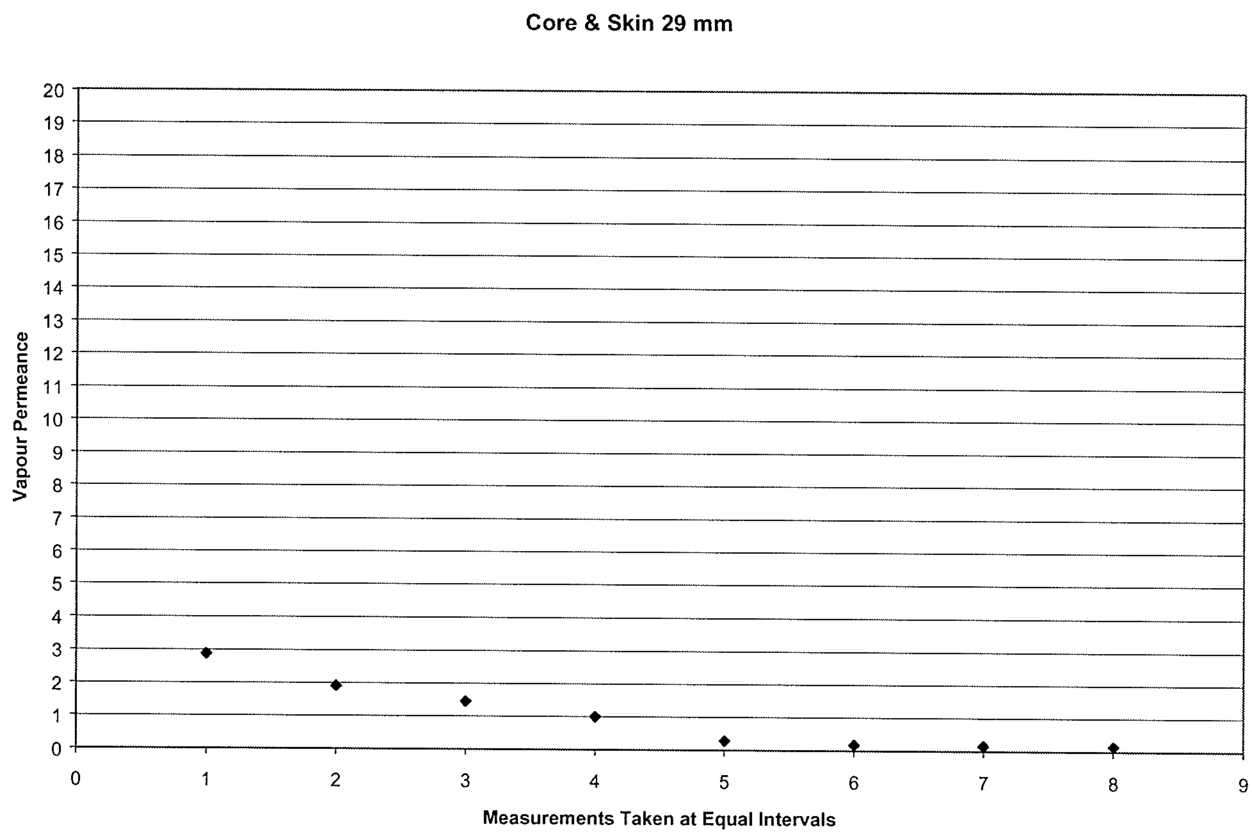


Figure 5.3: Vapour Permeance Measurements of Skin & Core Materials (29 mm thick)

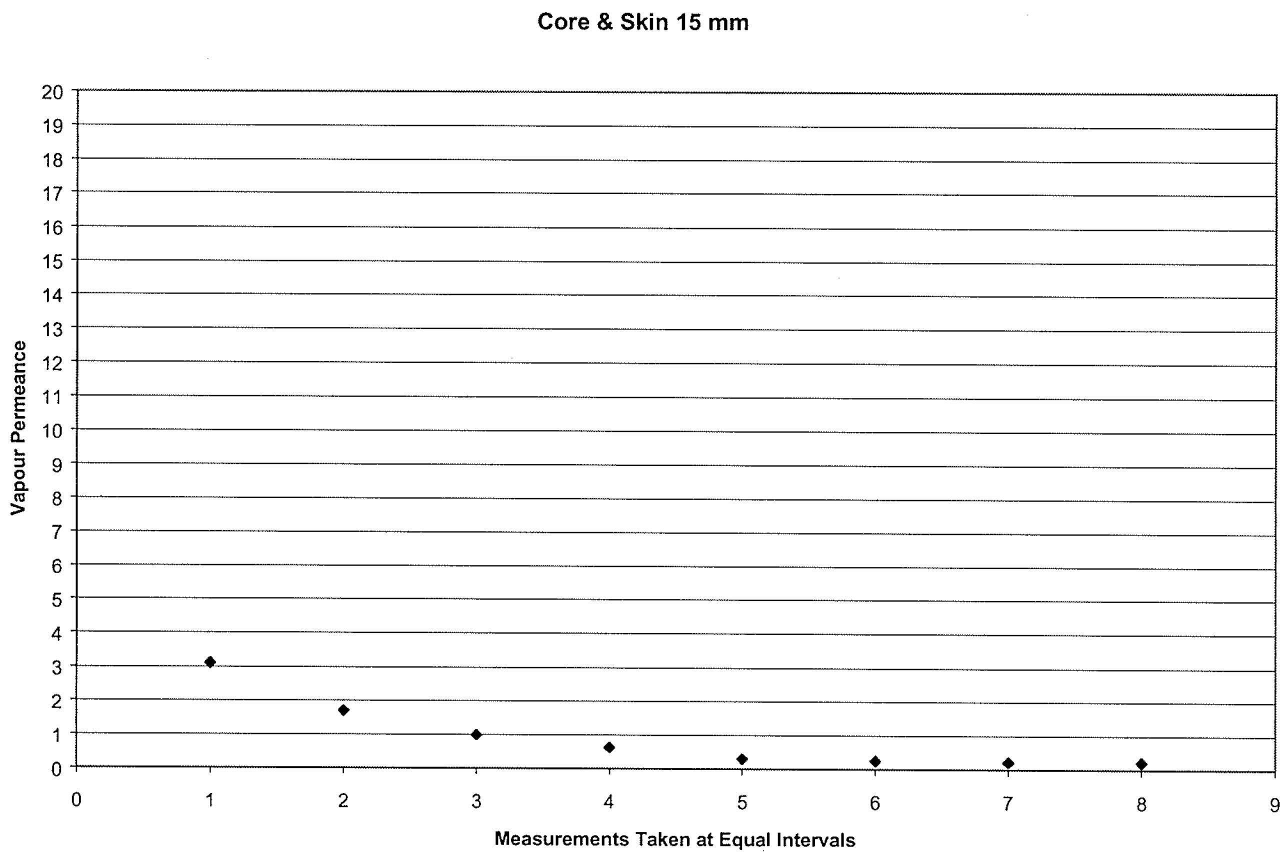


Figure 5.4: Vapour Permeance Measurements of Skin & Core Materials (15 mm thick)

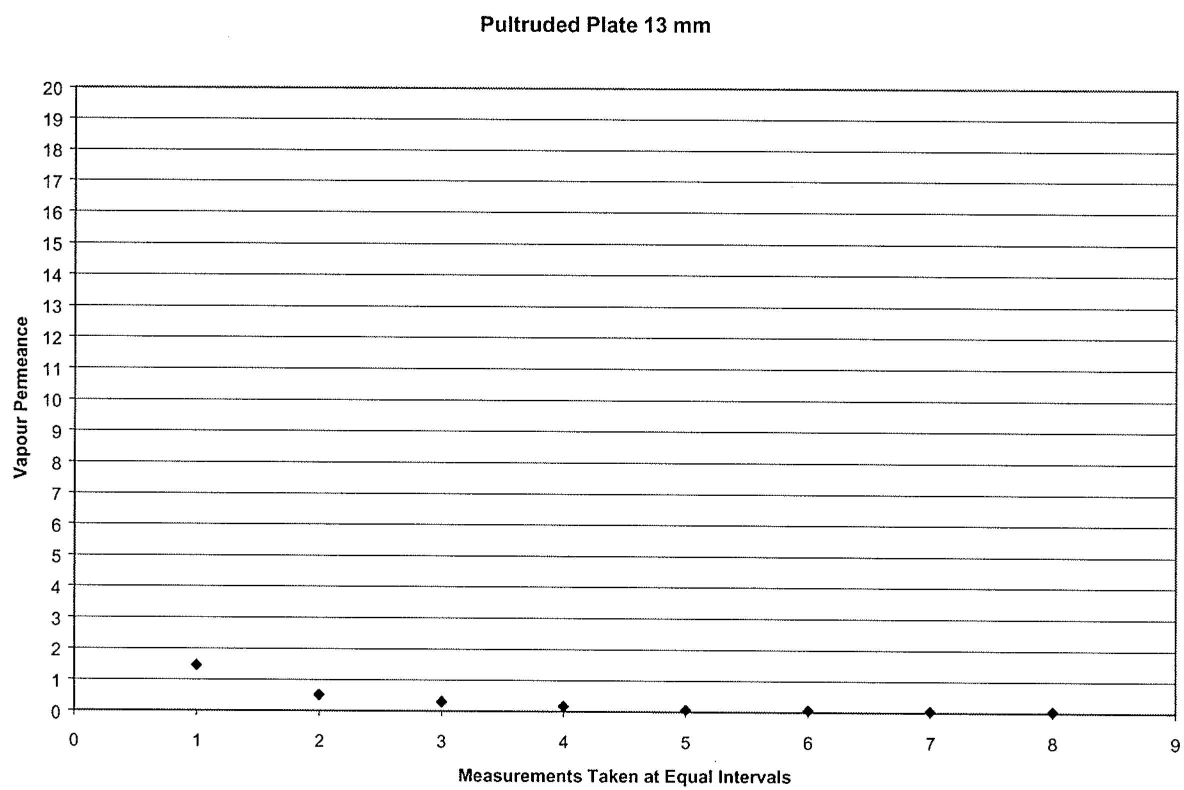


Figure 5.5: Vapour Permeance Measurements of Pultruded Material

5.2 DURABILITY

5.2.1 Freeze-Thaw Durability

Freeze-thaw testing was completed in order to determine the relative ability of the material to withstand freeze-thaw action over time. Half the samples were coated with West System Epoxy and the other half uncoated to see the effect of this on the durability of the material. Table 5.2 shows the results of this test.

Table 5.2: Average Freeze-Thaw Test Results

Sample	Volume (V_p) (cm^2)	Weight of Sample ($W_{initial}$) (g)	Weight of Sample (W_p)	Weight of Filter Paper (W_f)	Weight of Residue & Filter Paper (W_{f+r})	Weight of Specimen (W_{final})	Compressive Strength (MPa)
1	332.48	--	--	--	--	--	2.01
2	335.54	195.00	235.71	1.74	2.26	194.48	2.14
3	334.74	189.55	240.22	1.72	2.30	188.97	1.59
4	332.68	191.19	249.73	1.76	2.36	190.59	1.50
5	333.15	--	--	--	--	--	1.81
6	332.16	231.84	246.25	1.75	1.77	231.81	1.30
7	332.78	231.35	237.61	1.73	1.77	231.31	1.39
8	333.34	236.94	251.56	1.73	1.78	236.90	1.49

1 – 0 cycles
2 – 20 cycles
3 – 25 cycles
4 – 30 cycles
5 – 0 cycles (coating)
6 – 20 cycles (coating)
7 – 25 cycles (coating)
8 – 30 cycles (coating)

Compressive strength results are for comparative purposes only, and do not represent the actual strength of the material. Full test results are in Appendix H.

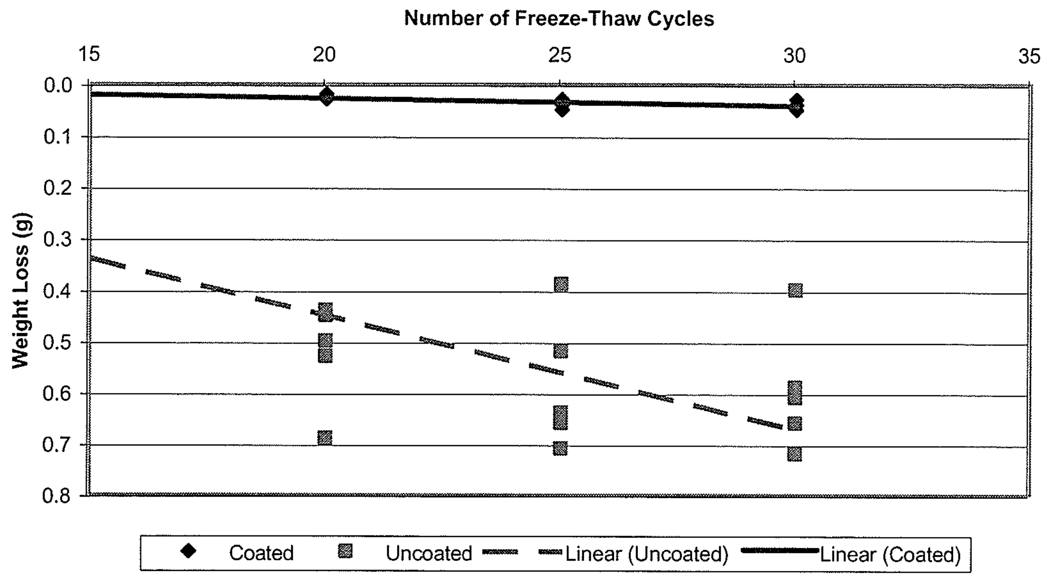


Figure 5.6: Weight Loss After Freeze-Thaw Cycling

Measurements indicate that durability of the core structure is protected by application of a coating to the exterior of the samples. While Figure 5.6 seems to show a great advantage to adding a coating, there is only a 0.3% average weight loss, compared with 0.02% in the coated samples. The integrity of the samples remained good after 30 cycles.

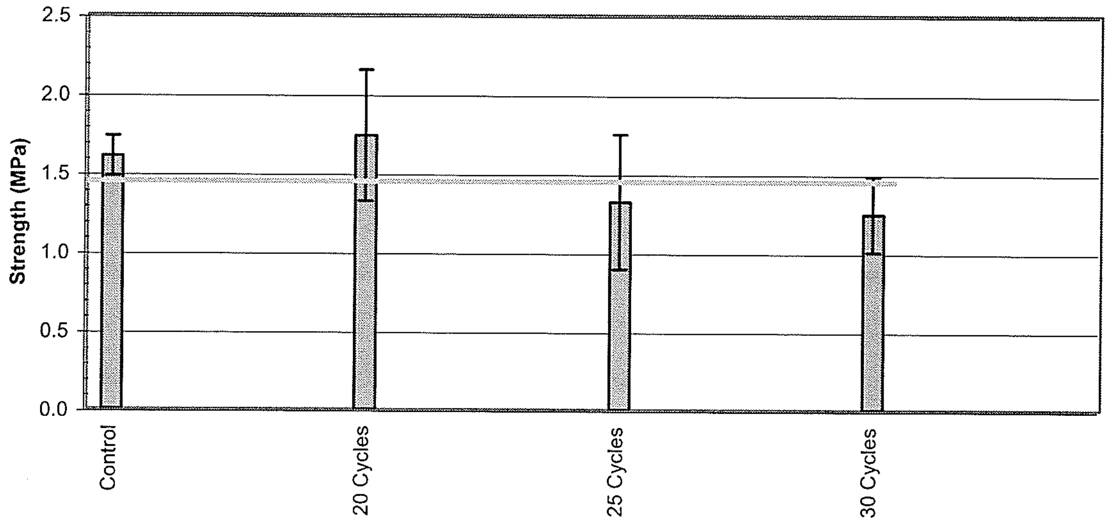


Figure 5.7: Group Comparison with 5% Standard Deviation for Each Group – Uncoated Samples

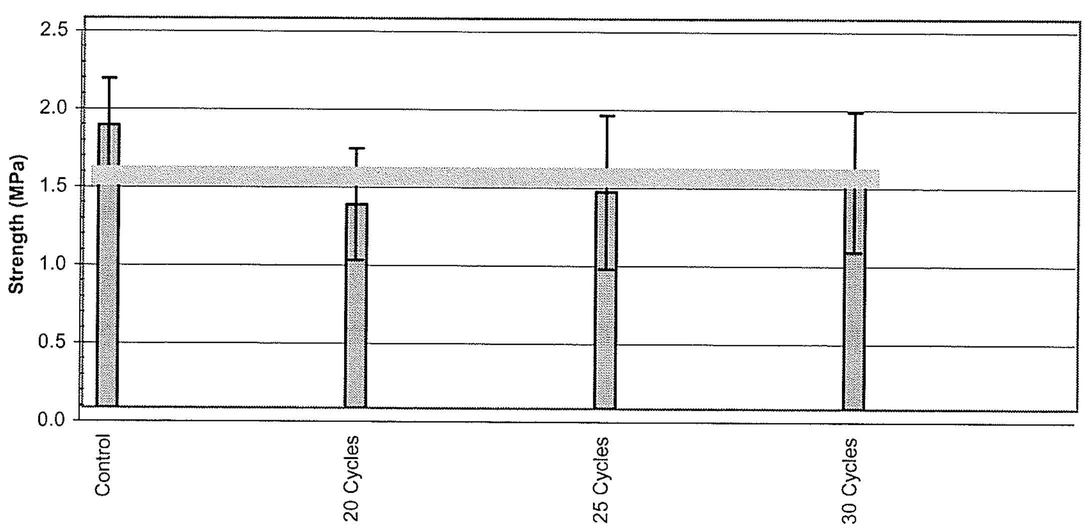


Figure 5.8: Group Comparison with 5% Standard Deviation for Each Group – Coated Samples

Figure 5.7and Figure 5.8 show the comparison of compressive strengths as tested in the laboratory. The strengths obtained are quite scattered due to the natural variability of the material tested. Analysis shows that there is a general trend of decrease in strength after freeze-thaw cycling. The decrease represents an average 20% reduction in strength. However, the test results are within the 5% standard deviation of each sample. The striped bar across the graphs shows the area of overlap between each of the sample sets. As this result could be significant in the long-term performance of the core material; it is recommended that further testing be performed to determine if this trend in decreasing strength has any significant effect on the structural performance of the panels. It is also important to note that the coating did have any effect on the freeze-thaw behaviour of the samples.

5.2.2 Ultraviolet Stability

5.2.2.1 Strength Testing

Testing of the skin material was completed to determine the effect of ultraviolet light on the composite materials. Two performance indicators were checked: the colour stability of the skin and the tensile strength of the same. The tensile test results are summarized in Table 5.3. The samples marked U1 through U9 were not exposed to the ultraviolet test, and E1 through E9 were. Testing was completed for an equivalent 288-hour period. This testing period does not correspond to actual hours of field exposure.

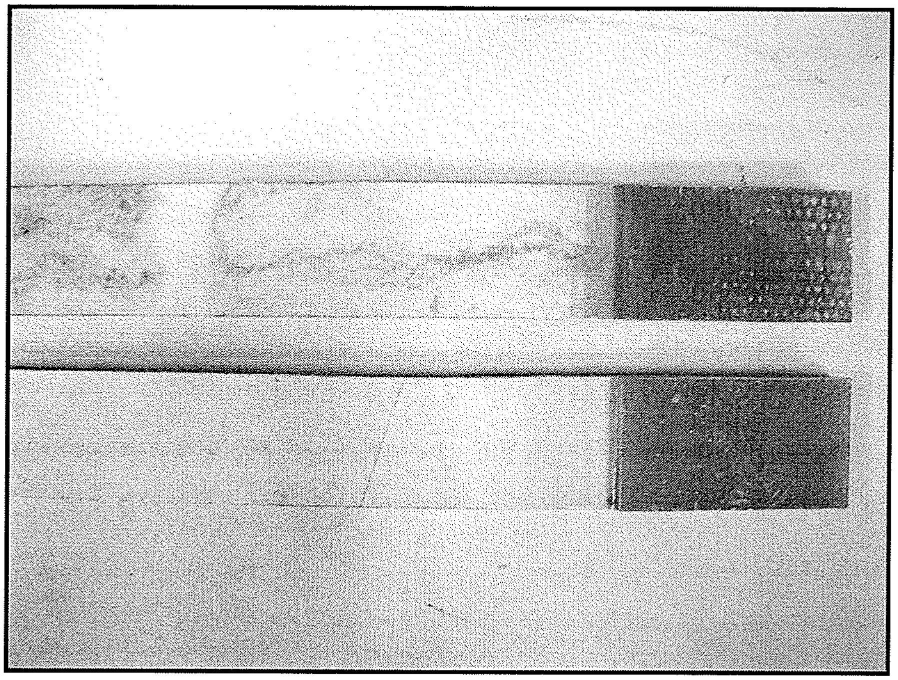
Table 5.3: Summary of Ultraviolet Test Results

Specimen	Ultimate Stress (MPa)	Specimen	Ultimate Stress (MPa)
U1	51.4	E1	50.4
U2	58.0	E2	54.5
U3	53.7	E3	51.7
U4	64.9	E4	64.4
U5	58.8	E5	56.9
U6	53.9	E6	55.4
U7	62.9	E7	49.5
U8	52.2	E8	55.2
U9	59.4	E9	66.3
Mean	57.2	Mean	56.0
Standard Deviation	4.77	Standard Deviation	5.84

Testing shows that the skin material is stable in terms of strength after a long period of exposure to ultraviolet rays.

5.2.2.2 Colour Stability

Visual observation of the samples after exposure to ultraviolet light shows a change in colour or yellowing of the material as shown in Figure 5.9. While this will not affect the performance of the material, it will affect the long-term aesthetics of the home unless the material is protected against ultraviolet light. It should be noted that the specimens tested were purposely left unprotected as part of the experimental program. Ultraviolet inhibitors are widely used in the composite industry.



Exposed Sample

Unexposed Sample

Figure 5.9: Colour Stability after Exposure to Ultraviolet Light

6 DISCUSSION OF EXPERIMENTAL HOUSE TEST RESULTS

6.1 BLOWER DOOR

Testing in accordance with CAN/CSGB-149.10 *Determination of the Airtightness of Building Envelopes by the Fan Depressurisation Method* was performed at the Experimental House on April 14, 2003 by Gary Proskiw of Proskiw Engineering. The results are outlined below, and a complete report is included in Appendix I.

Table 6.1: Blower Door Test Results

	Normalized Leakage Area at 10 Pa (NLA_{10})	Normalized Leakage Rate at 75 Pa (NLR_{75})
Experimental House	0.65 cm^2/m^2	0.61 $l/s{\cdot}m^2$
Maximum air leakage rate permitted by the Manitoba Building Code for new houses	2.0 cm^2/m^2	
Maximum air leakage rate permitted for R-2000 houses	0.70 cm^2/m^2	
Maximum air leakage rate in 1995 National Building Code for Part 5 buildings (not mandatory)		0.10 $l/s{\cdot}m^2$ (for relative humidities of 27% to 55%)
Typical air leakage rates for larger (Part 5), existing multi-unit residential buildings (Canada)		1.18 to 6.37 $l/s{\cdot}m^2$
Typical air leakage rates for larger (Part 5), existing office buildings (Canada)		1.44 to 4.01 $l/s{\cdot}m^2$

The term Normalized Leakage Area (NLA) or Normalized Leakage Rate (NLR) are used in both residential and larger buildings to express the quantity of air infiltration or exfiltration in a building. NLA_{10} expresses the equivalent leakage area if there were one hole in a one square metre area through which all the air was escaping at a pressure difference across the envelope of 10 Pa. This value is typically used for residential construction. NLR_{75} is the amount of air that escapes the building envelope over a second and over a one square metre area of wall, while the pressure difference across the envelope is maintained at 75 Pa. This value is usually used in larger buildings.

The results show a general compliance with the R-2000 target of 0.70 cm^2/m^2. It is important to also note that due to the small size of the Experimental House, small errors are amplified. For example, a preliminary test was completed with two small holes in the envelope and the results of this test were 36% higher than those reported here. It is expected therefore that a larger home will perform even better than the results reported in this project.

6.2 DETECTION OF AIR LEAKAGE THROUGH SENSORS

As discussed in Section 4.1.2.2, a qualitative analysis of the assembly air leakage may be accomplished through the correct placement and monitoring of sensor data. In this project, sensors were placed in the north, southeast and west walls and the roof. The location of the sensors and specifications are shown in Appendix J. Data was collected over a three-week period from February 24 to March 18, 2003.

6.2.1 North Wall Monitoring

Along the north wall, temperature and relative humidity sensors were placed at the centre joint near the window. A pressure tap was also placed on this wall 114 mm east of the other sensors. This placement was chosen to determine the probability of air leakage at the joint, which according to research is a likely place for air leakage and, therefore, long-term condensation problems. Figure 6.1 (see Appendix K for select data) shows the temperature profile over the monitoring period. The exterior skin temperature swings from 18°C during the peak of the sunlight hours and down to -30°C at night. Interior temperatures were controlled to between 10°C and 30°C over the monitoring period.

To determine the potential for air leakage at this point, the temperature index must be analysed. (Temperature index is defined in the Definitions page at the beginning of this thesis and in Appendix E.) The nominal temperature index at this location is 0.47 (the sensor was placed very close to the centre of the wall). Figure 6.2 shows a variation in measured temperature index from 0.40 to 0.52 resulting in a standard deviation of 2%. The pressure difference across the envelope varied from −135 Pa to over 300 Pa. As the temperature of the cavity is only very slightly affected by changes in the pressure difference, very little air leakage is occurring at this location.

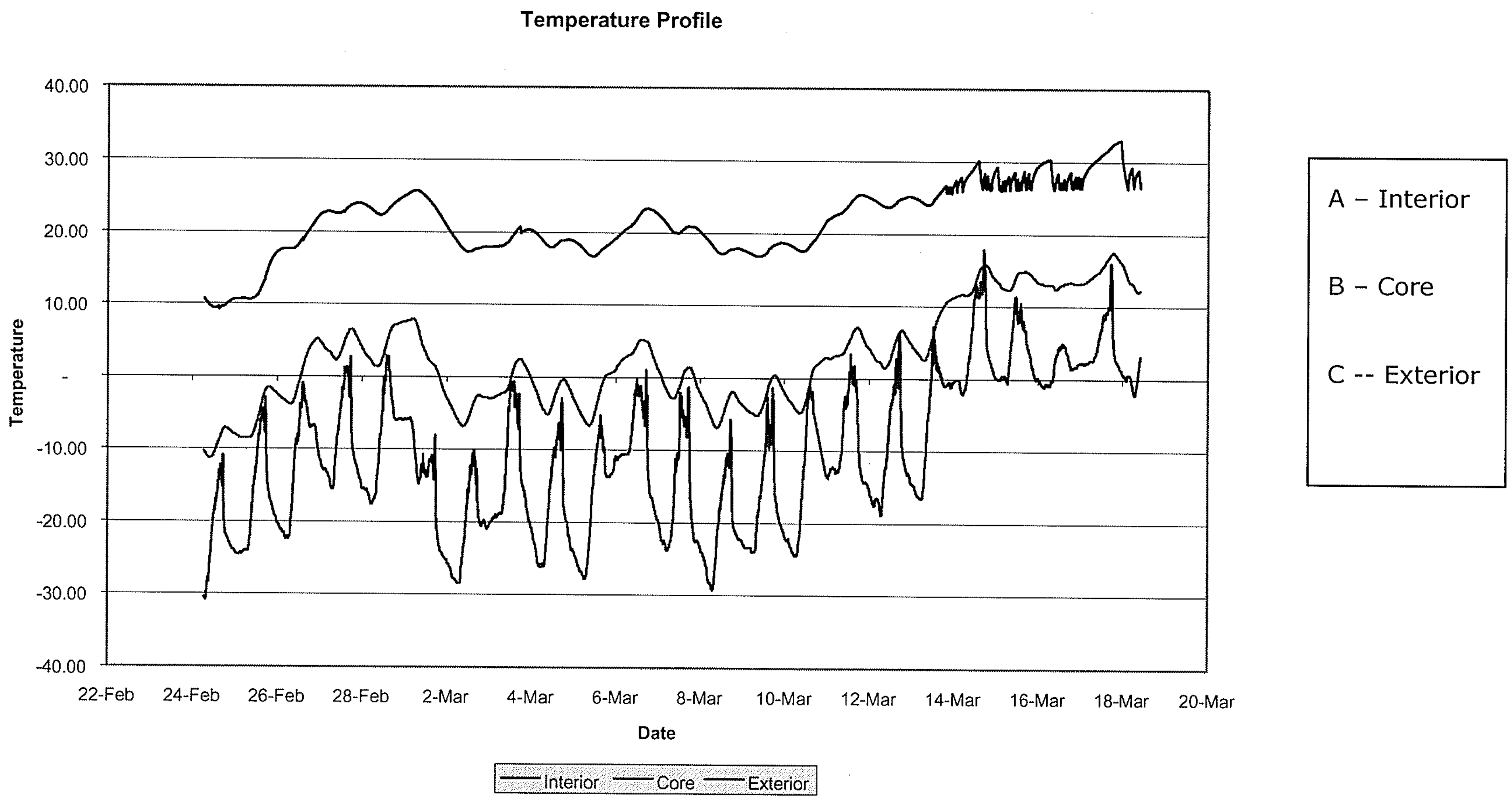


Figure 6.1: North Wall Temperature Profile

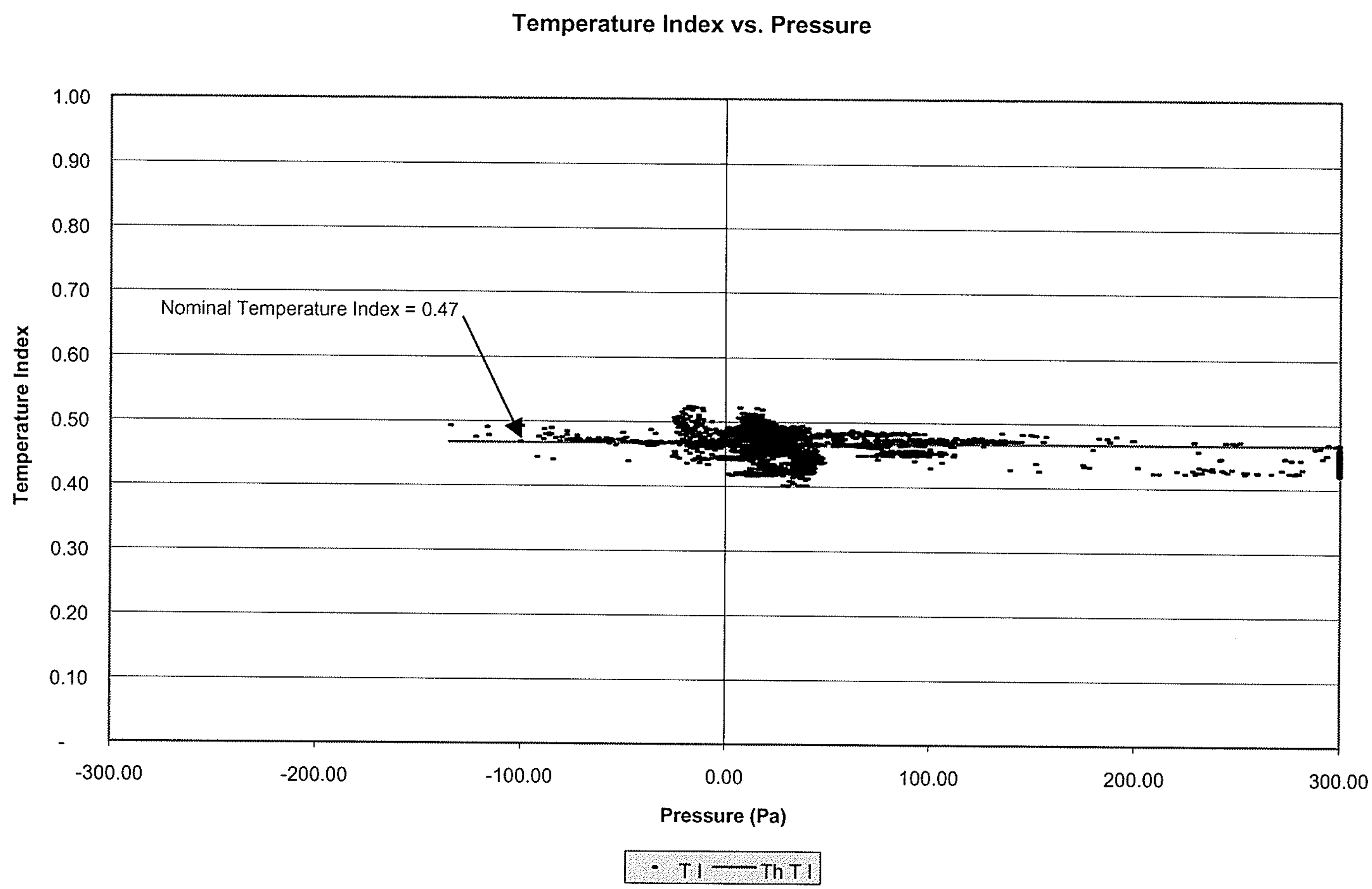


Figure 6.2: North Wall Temperature Index

6.2.2 Southeast Wall Monitoring

At the Southeast corner, monitoring was performed at a corner joint to determine the likelihood of air leakage at this location. Temperature sensors were placed on the exterior and interior surfaces. In the joint, a temperature and relative humidity sensor was installed close to the exterior surface. The placement of this sensor is due to the construction of the joint. A pressure tap was installed and pressure differences at this corner monitored as well. Figure 6.3 (see Appendix K for select data) shows the temperature profile at this location. The exterior wall temperature varied from 12°C during the day to -25°C at night. Interior temperatures were maintained between 10°C and 30°C.

In order to determine the potential for air leakage, an analysis of the temperature, shown in Figure 6.4, was performed. At this location the nominal temperature index is 0.24 (as the sensor is relatively close to the exterior wall). In this location the measured temperature index varies from 0.20 to 0.28 with a standard deviation of 5%. In this case, the pressure difference across the envelope varies from zero Pa to over 300 Pa with very little change in the measured temperature index. The numbers at this location are slightly higher than measured in the north wall, however are still small in comparison to the large pressure difference across the envelope. This is indicative of very little air leakage at this location.

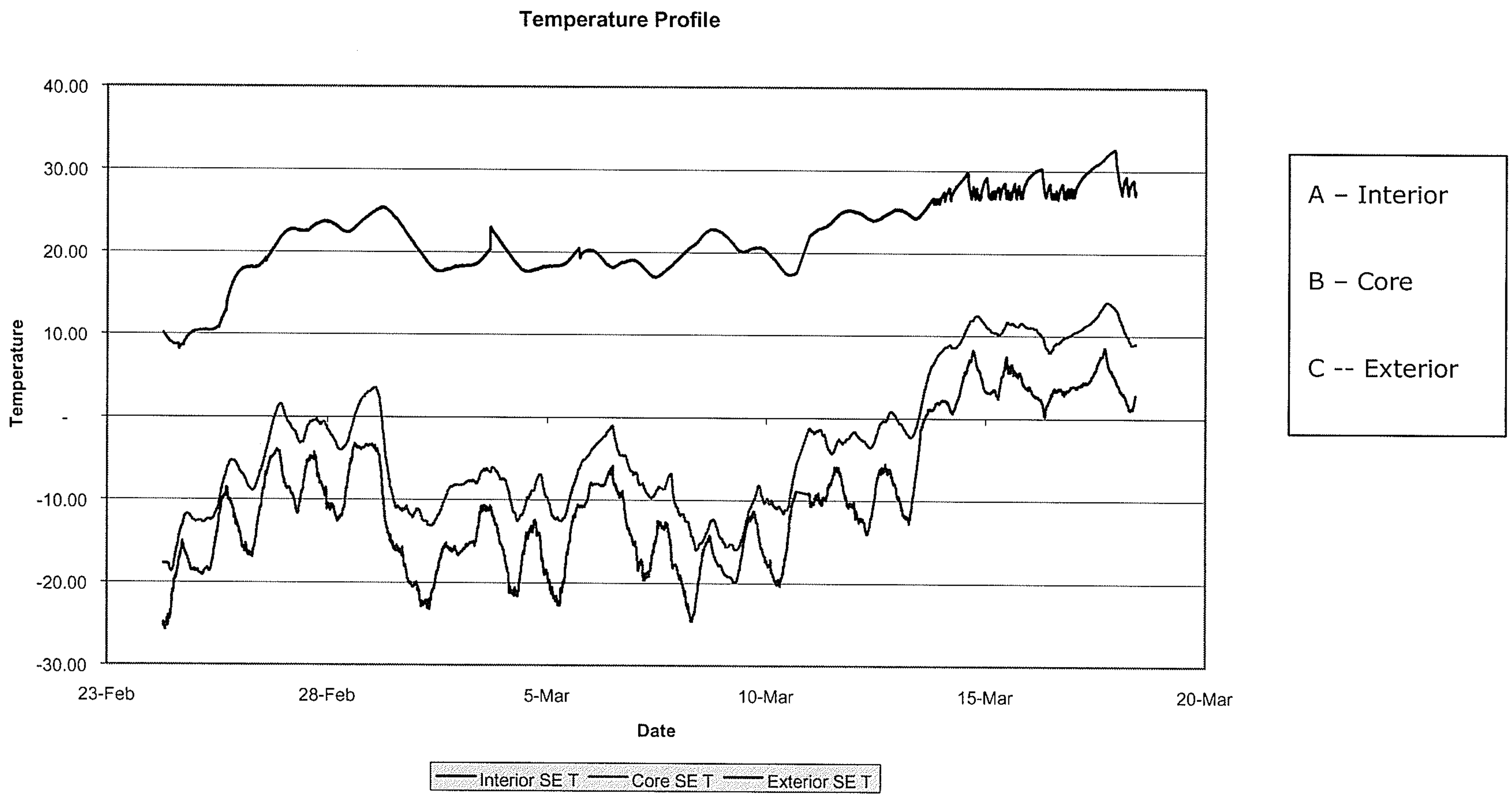


Figure 6.3: Southeast Temperature Profile

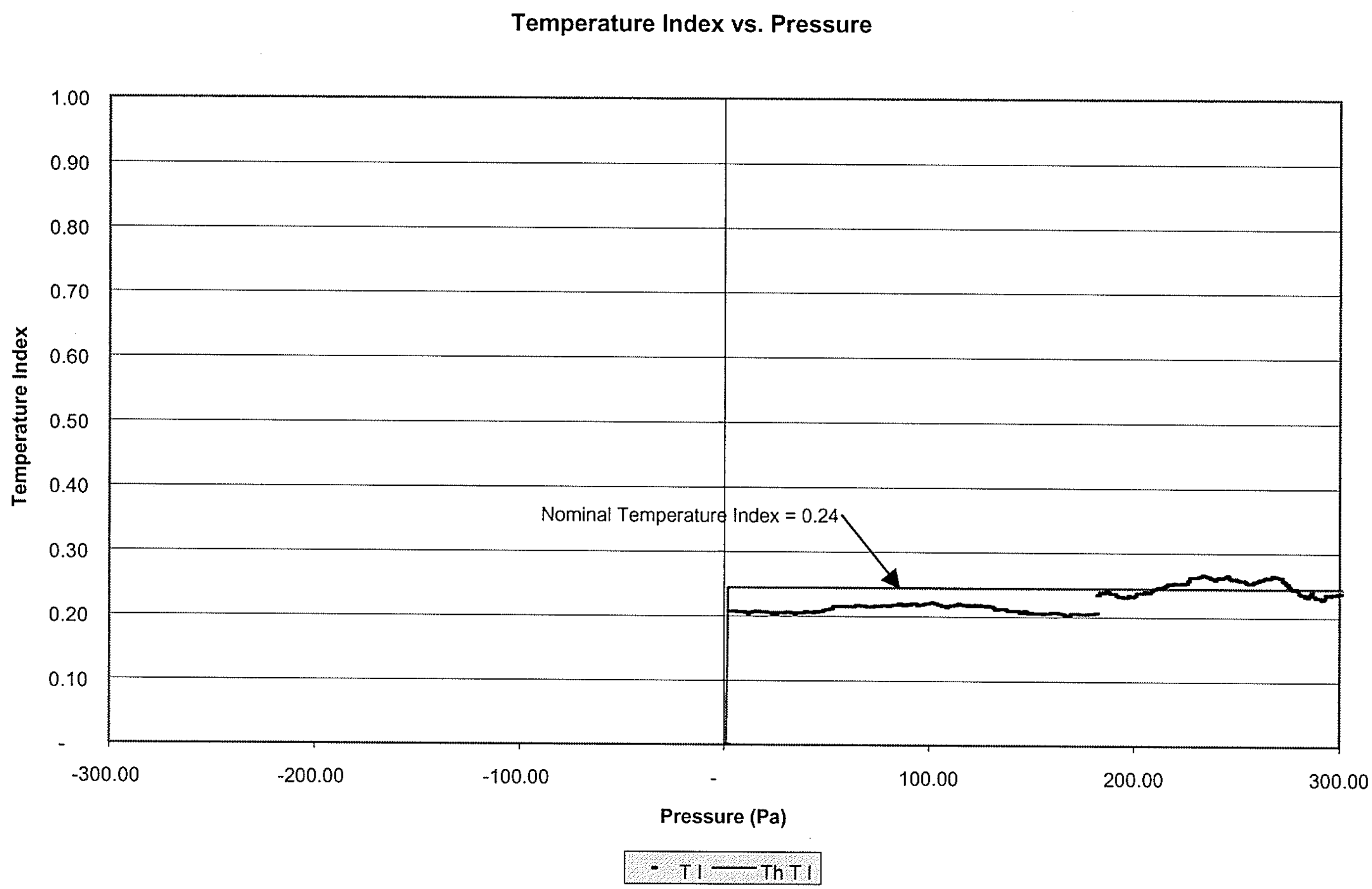


Figure 6.4: Southeast Wall Temperature Index

6.2.3 West Wall Monitoring

The west wall monitoring was performed through the centre of an otherwise uninterrupted wall section. A small section of the wall was removed and temperature and relative humidity sensors were placed within the core. This section was then replaced in the hole and sealed with caulking. While it is understood that this method of testing disturbed the homogeneous nature of the product, it was useful to determine the air permeance of the construction materials themselves. In addition to the core sensors, temperature sensors were placed on the exterior and interior surfaces. The pressure tap was placed at the joint, about 600mm south of the temperature sensors. Figure 6.5 (see Appendix K for select data) shows the temperature profile on this wall. Exterior wall temperatures varied from 12°C during the day to -30°C at night. Interior temperatures were maintained between 10°C and 30°C.

Pressure differences on the west wall were significantly smaller than the other two walls, with variations from –7 Pa to 18 Pa. The nominal temperature index at this location is 0.23, and the measured index varies from 0.18 to 0.31. The standard deviation of the measured index is 3%. Here the variation is slightly higher than that observed in the other two locations. It is believed that this is because of the changes made in the construction in order to accomplish monitoring. The results are still positive, however, as the deviation with pressure is low. These results are shown in Figure 6.6.

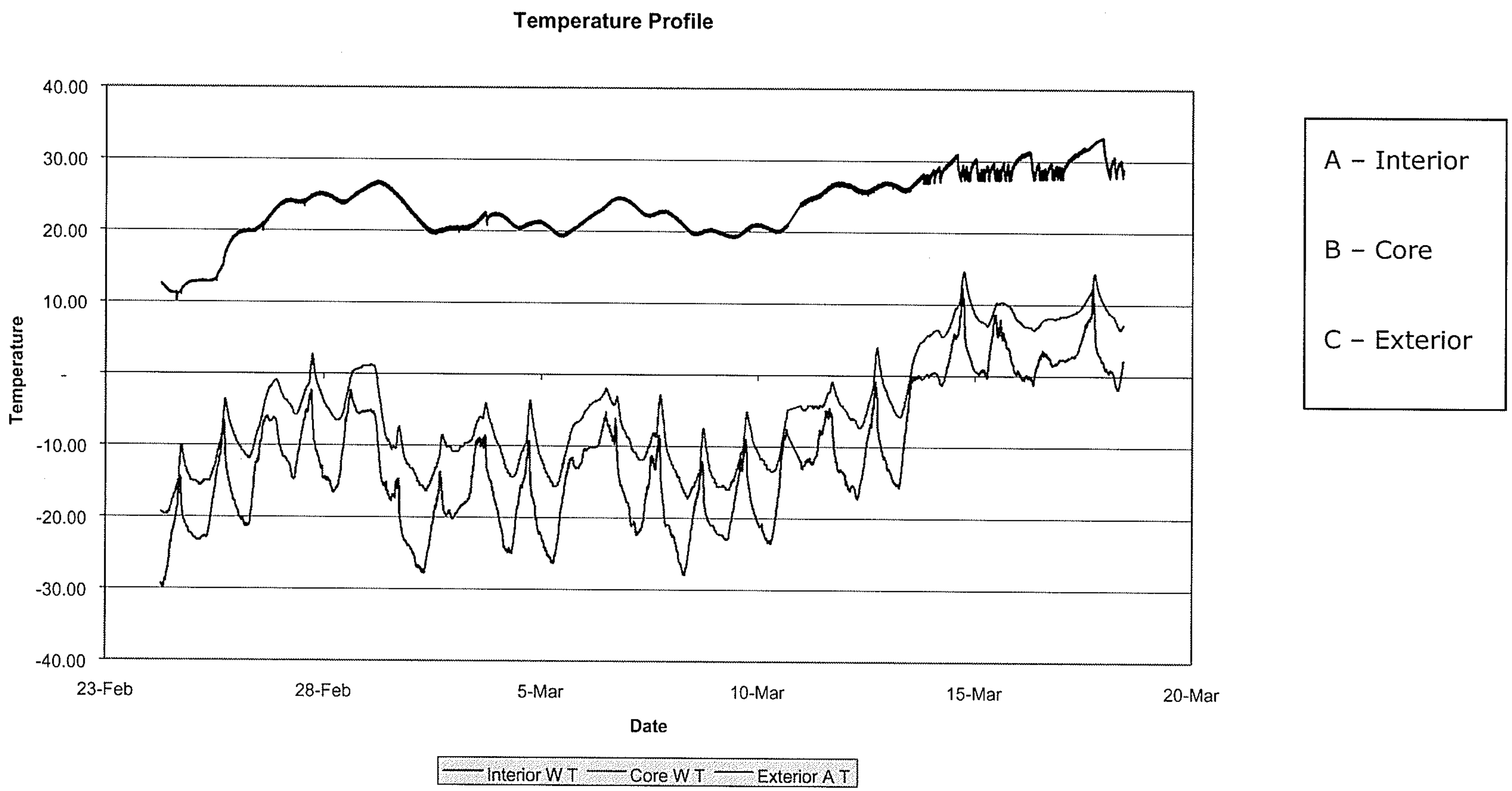


Figure 6.5: West Wall Temperature Profile

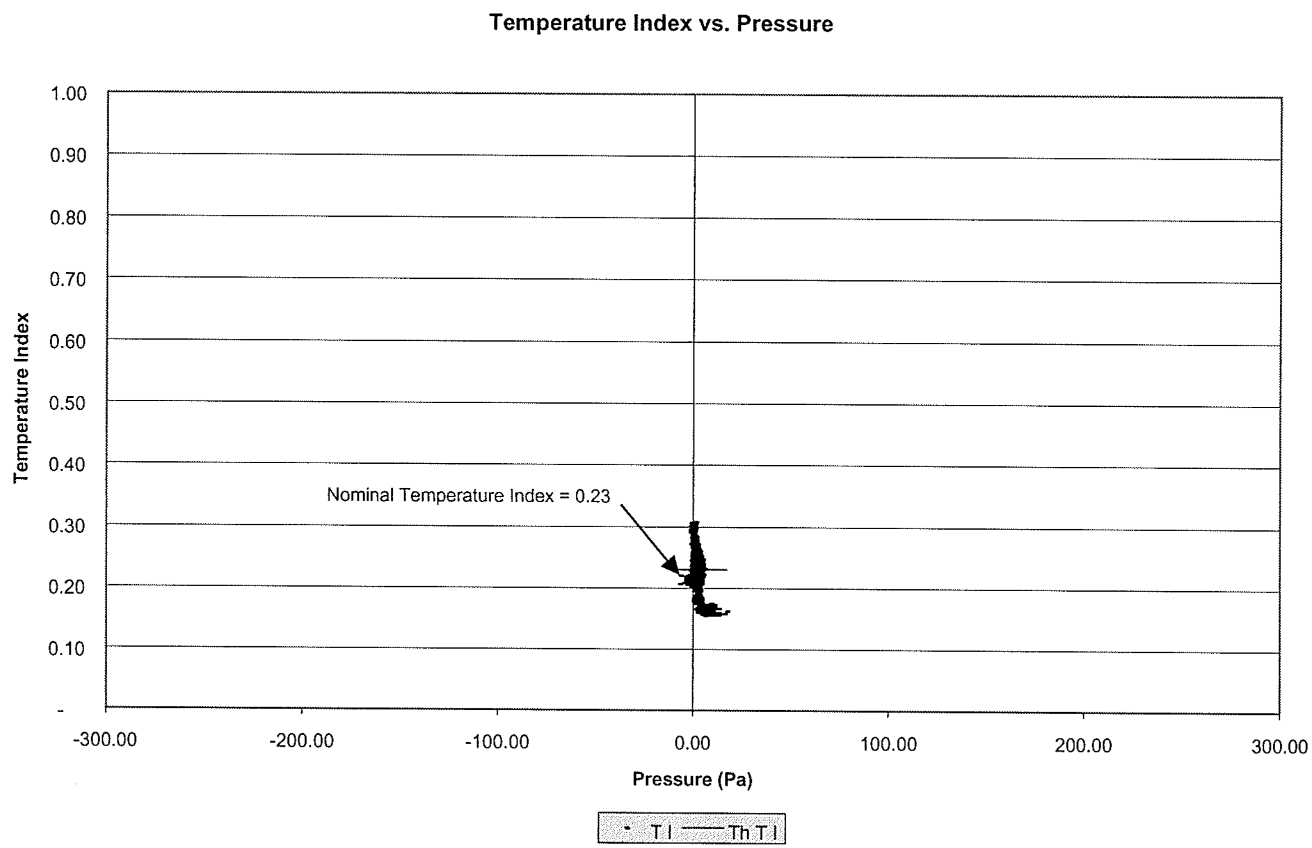


Figure 6.6: West Wall Temperature Index

6.2.4 Roof Monitoring

Monitoring at the roof level is the most important of the locations studied thus far. As noted in the Juneau, Alaska study (Build Central Inc. 2003), the roof joint is the most common point of failure for panellized systems. In this location, temperature and relative humidity sensors were placed both within the roof joint and on either side of the interior surface (either side of the partition wall). The sensors within the joint were placed close to the exterior surface due to the complicated nature of the joint. An exterior temperature sensor was also installed at the roof peak as well as a pressure tap located 150mm south of the roof joint. Figure 6.7 (see Appendix K for select data) shows the temperature profile at this location. As the temperature was not significantly different on either side of the partition wall, the north temperatures are used for analysis. As in the other two locations, exterior temperatures ranged from -30°C to 12°C, and interior temperatures from 10°C to 30°C.

The nominal temperature index in the roof is 0.04 due to its close proximity to the exterior, as shown in Figure 6.8. The measured temperature index varies from 0 to 0.08 with a standard deviation of 1%. In this case, the pressures vary from zero to over 300 Pa with the smallest deviation in the measured temperature index. This indicates a very tightly sealed roof joint.

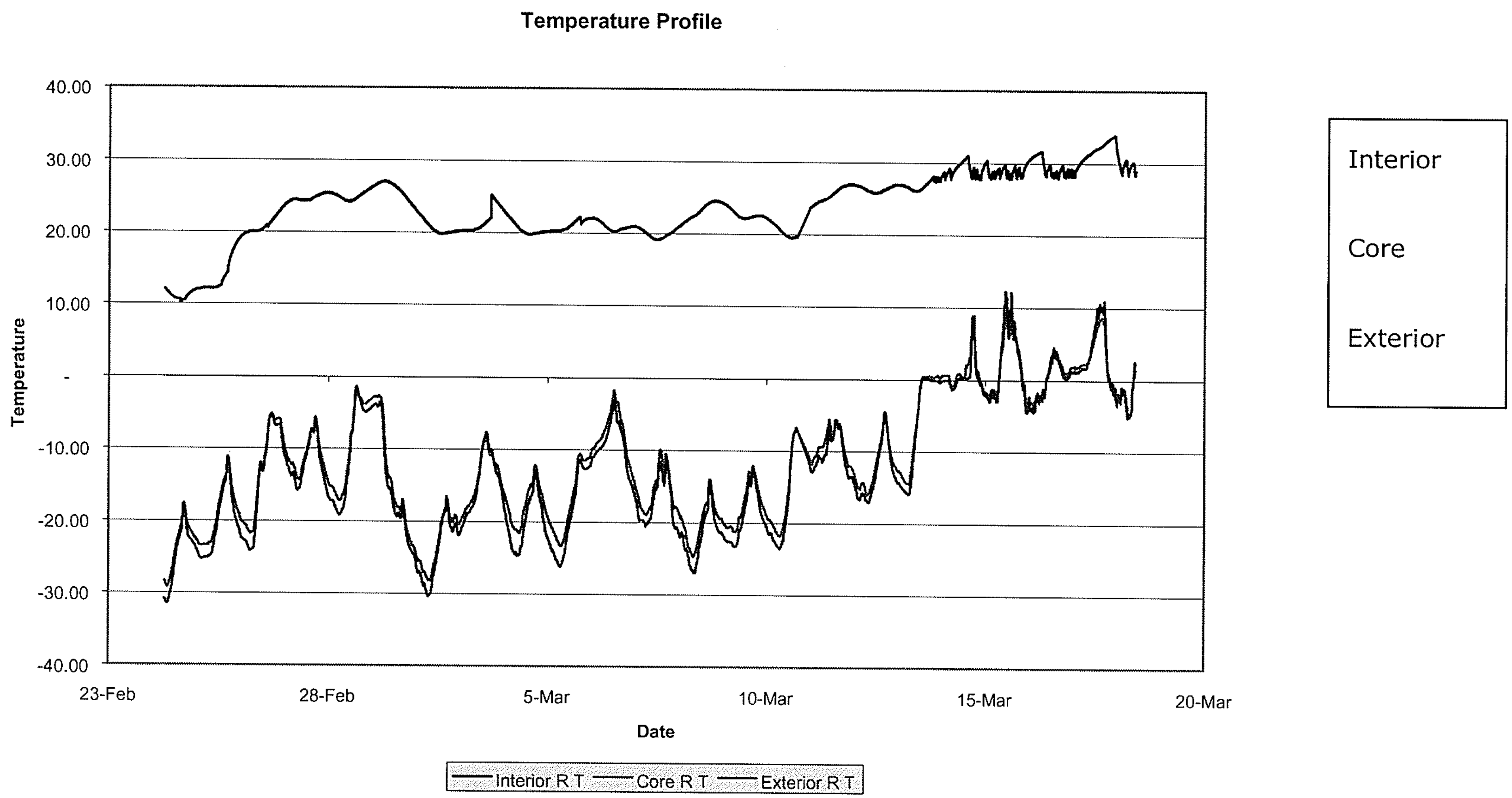


Figure 6.7: Roof Temperature Profile

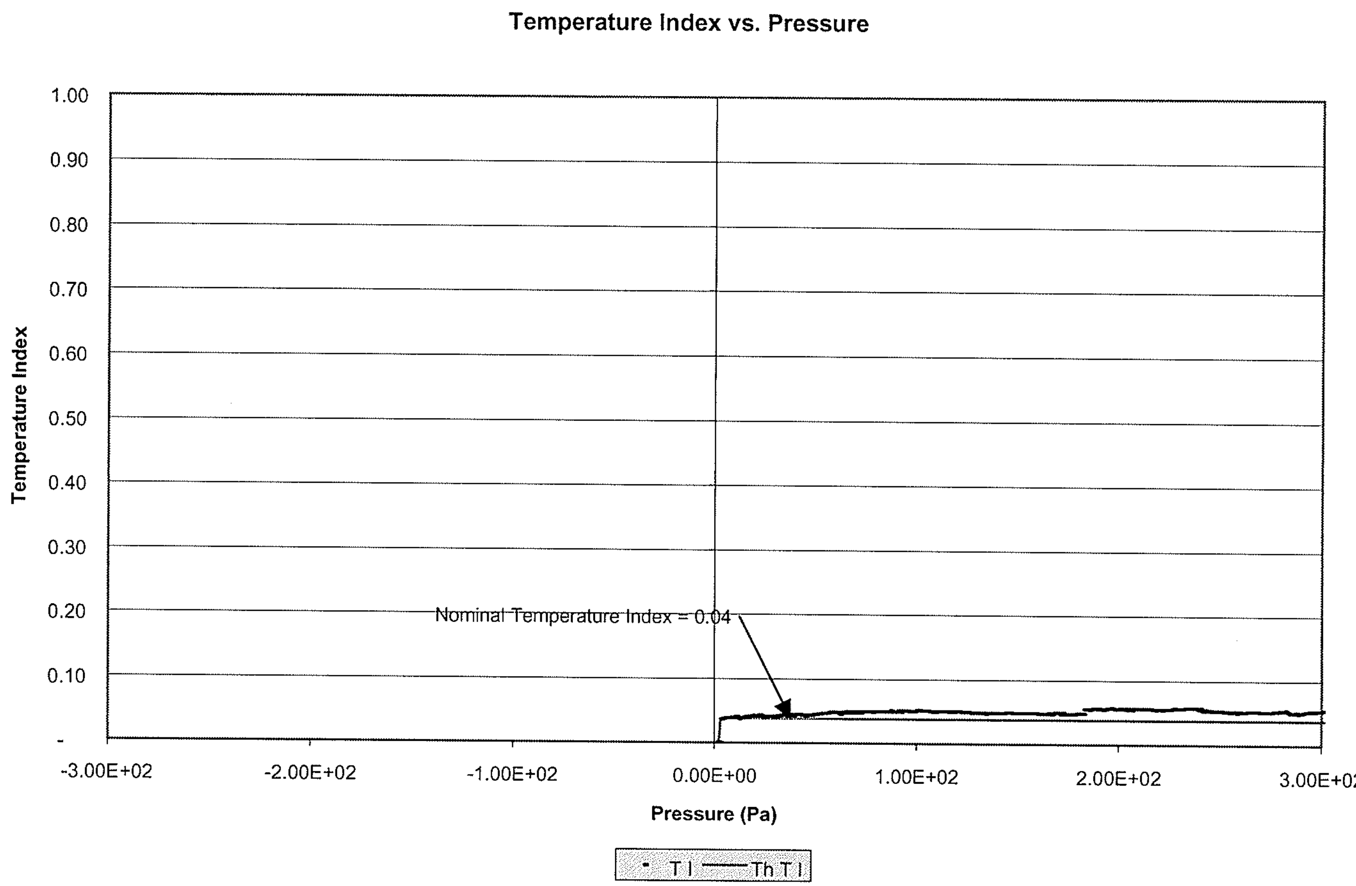


Figure 6.8: Roof Temperature Index

6.3 INFRARED PHOTOGRAPHS

Mark Taylor of Insight Infrared took infrared photographs on March 10, 2003. A report is included in Appendix L. The exterior temperature, at the time of testing, was -20°C. The interior temperature was 20°C. The general condition of the building was excellent with no appreciable heat loss. The only problem noted during the inspection was heat loss at the window and door joints. This was considered minor in nature and normal. The door was subsequently replaced with one having a higher insulating value and better weather seal.

6.4 VISUAL OBSERVATIONS

A thorough review of the exterior and interior joints was completed in the Experimental House after one year of weathering in a typical Winnipeg year. In general the condition of the house was good after this time. No damage to the panelling was visible. Several locations of sealant failure were noted. Figure 6.9 shows one example of such a failure. This is of importance as the joints are a critical air leakage point in the building. Testing has shown however, that the post-tensioned nature of this construction type, takes reliance off the integrity of the joints.

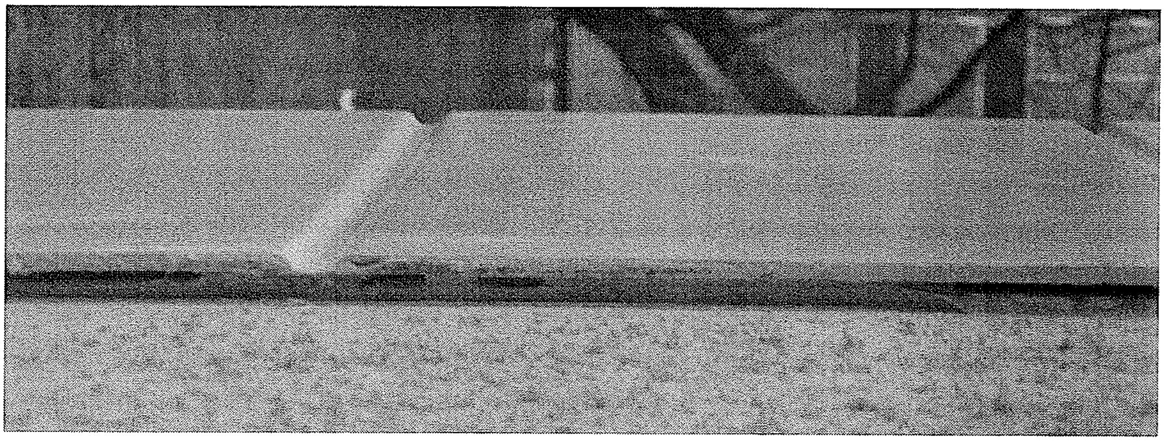


Figure 6.9: Caulking Failure at Corner Joint

6.5 WINDOWS

The one window installed in the Experimental House has the following ratings:

- The window is fixed and passes the FIXED Rating for CSA A440.
- The water tightness rating is B7, better than the B3 rating required by CSA A440.
- The ER, Energy Rating as defined in Section 3.1.3, for the window is 5.07, better than the required rating of -3. Equation 19 shows the calculation of the ER rating, Appendix M shows the manufacturer reported results.

$$ER = 72.20F_w - 21.90U_w - 0.54\left(\dot{A}_{75}/A_w\right) \qquad [19]$$

Therefore the ER is equal to:

$$ER = 72.20 \cdot 0.63 - 21.90 \cdot 1.84 - 0.54\left(0.02/0.09\right) = 5.07$$

One year after the construction of the Experimental House, visual observations of the window joint was completed. The sealant performed well over this time and no failures were noted. On the windowsill however, extensive mould growth was noted.

This is due to extensive window condensation during the three-week test period the previous winter. Mould growth was noted only on the wood trim piece and no mould was found on the composite panelling. Figure 6.10 shows the extent of mould growth after three weeks of extreme humidification.

Figure 6.10: Mould on Window Sill

The U-Value of the frame is 1.64 W/m^2K and of the glazing is 1.84 W/m^2K.

6.6 R-2000 ENERGY TARGET

The energy target for the Experimental House constructed on campus in the fall of 2002 is to be in accordance with the R-2000 requirement. That is, the annual space heating energy consumption shall be no more than the result of Equation 16.

For the Experimental House, the space-heating unit was an electric heater and the volume of the space in cubic meters is 22.9. Therefore the energy target for this home is:

$$Q_S = 1.0 * \left(\frac{49 * 5900}{6000} \right) * \left(40 + \frac{22.9}{2.5} \right) = 2,368.7 kWh / year$$

The amount of energy used to maintain interior heated space of the Experimental House was recorded from February 24, 2003 at 6:29 until March 18 at 9:57. The total energy consumed was 445.0 kWh. A more detailed account of energy consumption is recorded in Appendix K. Over that period, the outdoor temperature was also recorded. We can therefore predict the annual energy consumption by proportioning the average degree-days for Winnipeg over the degree-days during the recorded dates. The mean exterior temperature from 18°C over the recorded time of 22.2 days is 29.6°C. Therefore, the degree-days tested were 22.2*29.6 = 656.1 degree-days. Therefore the projected energy consumption of the Experimental House is

$$Q_S = 445.0 * \frac{5900}{656.1} = 4,001.7 kWh / year .$$

This result is 69% higher than the target energy consumption. We must note the following errors inherent in this prediction:

1. The target equation is based on average yearly weather data calibrated for a full size home with average window and door areas.

2. As the windows and doors take a disproportionate surface area and the walls are better insulators, this will affect the energy consumption.

3. The test area is small compared to the R-2000 standard home. This means that error in measurement and calculation will have a great effect on the results.

6.7 MEASUREMENT OF CONDENSATION POTENTIAL THROUGH MONITORING

Sensors were placed in the north wall joint, southeast corner joint, within the west wall, in the roof joint and in the northwest corner joint. These sensors measured both the cavity temperature and relative humidity versus time. From these data, the cavity dew point is calculated and presented in graphical format to easily determine the potential for condensation within the cavity.

Determination of the likelihood of mould growth is also studied through the use of these results. It is known that the optimum conditions for mould and mildew development exist when temperature is above 21°C and relative humidity is above 70% (Biotech Environmental Limited). It is also known that a food source is required for the growth to be sustainable. While testing of the panel material is not part of the scope of this project, the chemical composition does not contain the typical mould food source in houses, cellulose. It is useful however to study the potential for mould growth as the interior walls may be painted by the occupant, a food source for mould, and contaminants such as dirt will collect over time.

The potential for condensation is also studied. Once the dew point temperature is calculated, using the relative humidity and temperature at the monitoring location, this is compared to the core temperature. If at any time the core temperature is lower than the dew point temperature, condensation will occur.

6.7.1 North Wall

The north wall sensors were placed within the centre wall joint; see Appendix J for the exact location. Figure 6.11 shows the temperature and relative humidity profile within the joint. Temperatures within the cavity ranged from -10°C to 15°C and relative humidities from 25% to 55%. Therefore in these conditions it is unlikely that mould formation would occur within the joint.

Figure 6.12 shows the potential for condensation within the joint cavity. Condensation is likely if the cavity temperature at any time goes below the dew point temperature. In this case the spread between the temperatures is maintained at about 10°C indicating no chance of condensation during the test period.

6.7.2 Southeast Wall

The southeast wall sensors were placed within the corner wall joint; see Appendix J for the exact location. Figure 6.13 shows the temperature and relative humidity profile within the joint. Temperatures within the cavity ranged from –15°C to 15°C and relative humidities from 20% to 50%. Note that this is a good indication that mould growth within the joint will not occur in these conditions as growth can only occur if relative humidities exceed approximately 70%.

Figure 6.14 shows the condensation potential within the southeast corner joint. As can be seen in the figure, the cavity temperature is typically 10°C above the dew point temperature. Under these conditions we therefore do not expect to see condensation in the corner joint.

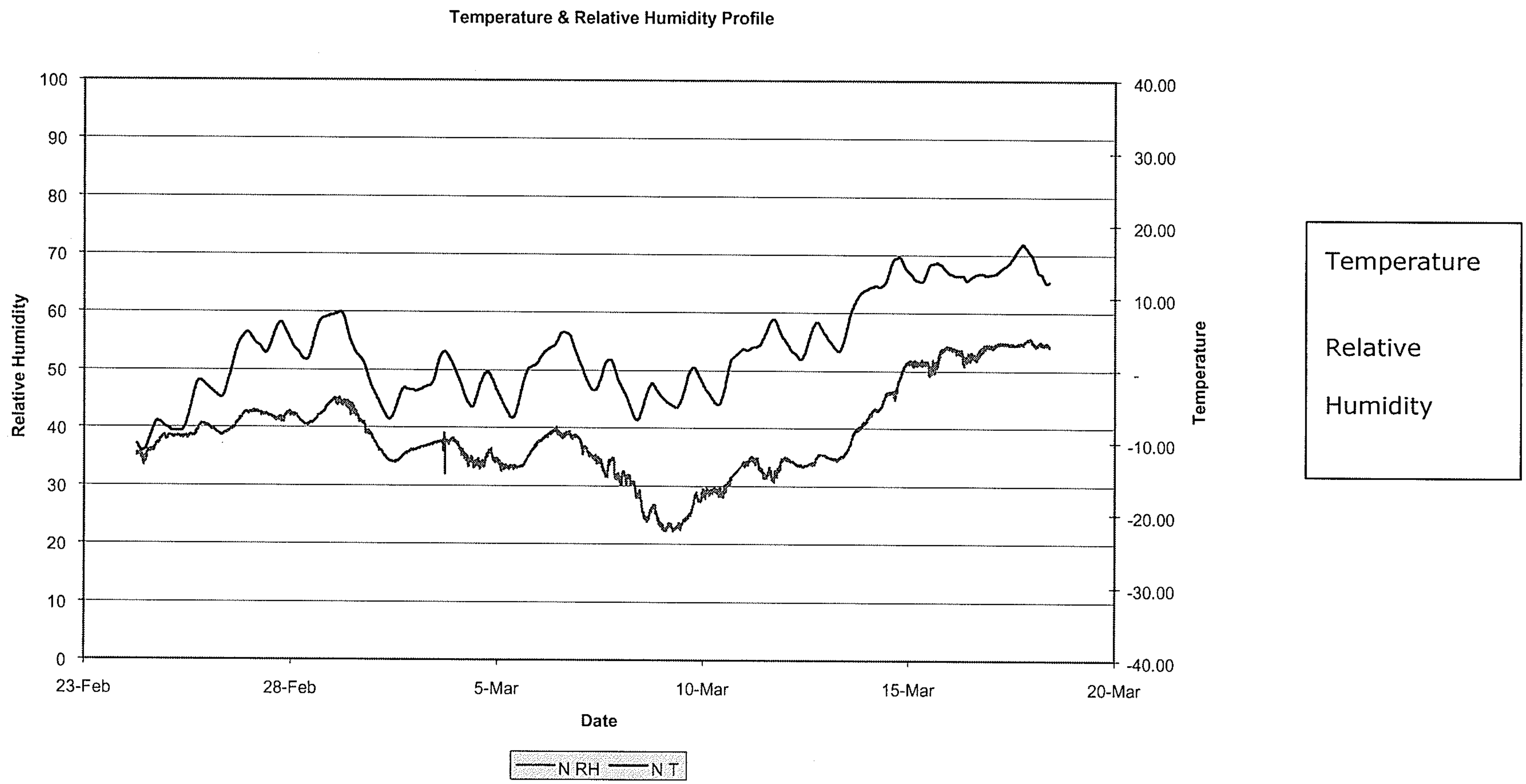


Figure 6.11: North Joint Core Temperature & Relative Humidity Profile

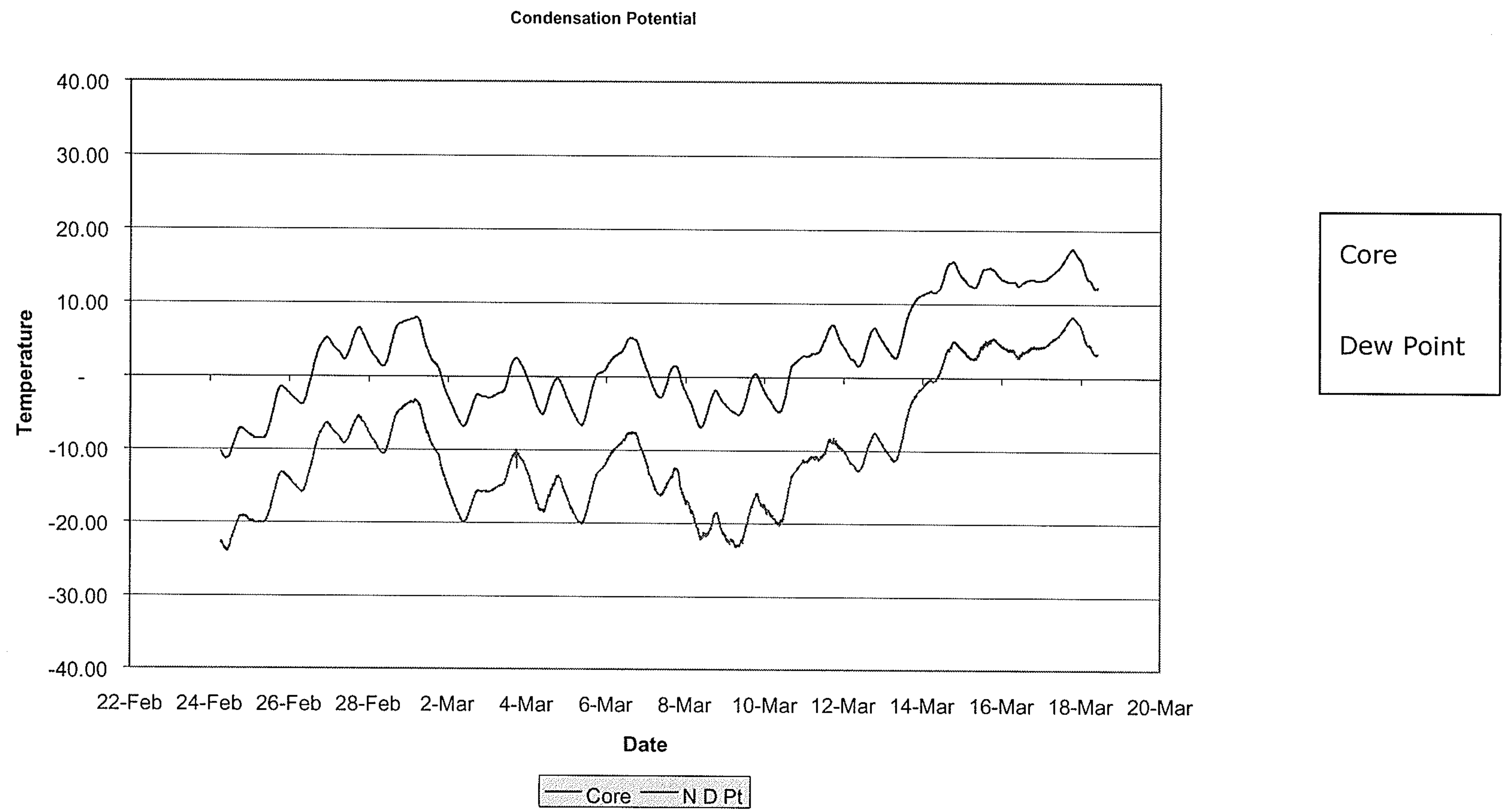


Figure 6.12: North Joint Condensation Potential

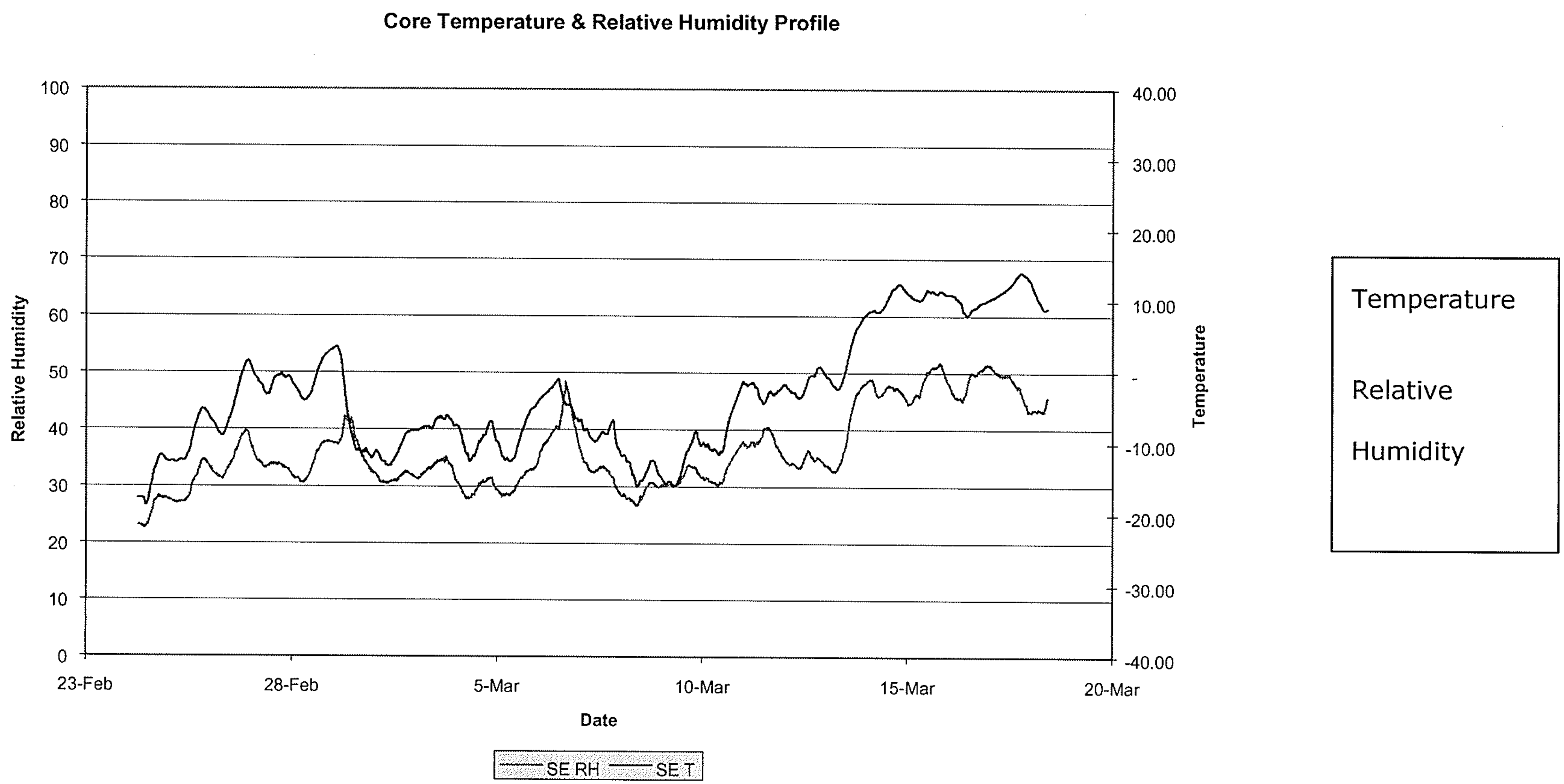


Figure 6.13: Southeast Corner Joint Core Temperature & Relative Humidity Profile

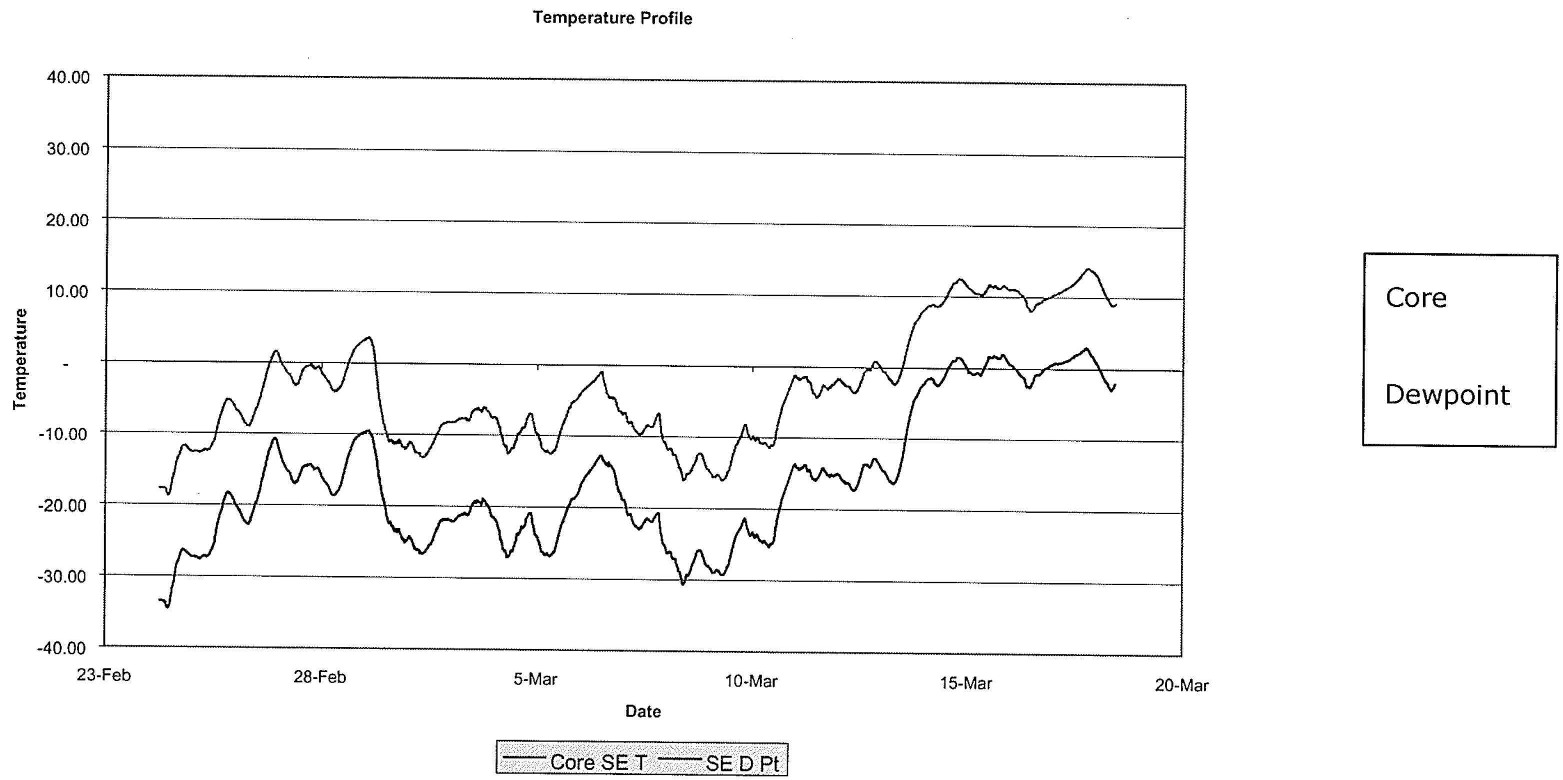


Figure 6.14: Southeast Joint Condensation Potential

6.7.3 West Wall

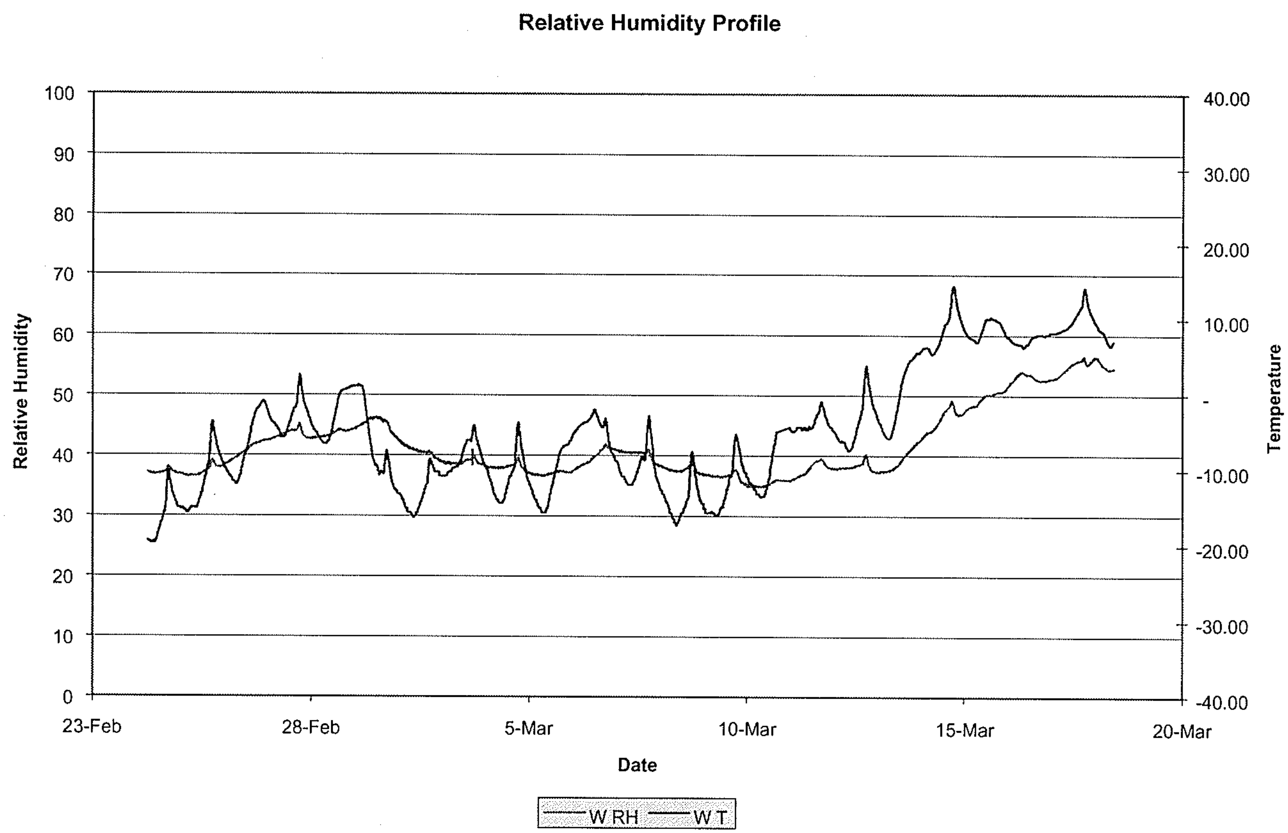
Sensors were installed in the west wall such that a representative through wall section could be obtained. The relative humidity in this location measured between 35% and 55% during the test period, as shown in Figure 6.15. Temperatures ranged from -20°C to 15°C over the test period. These results are again indicative of an environment that is not conducive to mould growth.

Figure 6.16 shows the comparison between the measured temperature and the calculated dew point temperature in the cavity. The cavity temperature is consistently higher than the dew point temperature by about 10°C indicating that condensation did not occur over the test period.

6.7.4 Roof

Measured relative humidity within the roof joint is significantly higher than the walls. Values range from 40% to 95% over the test period. Values this high are indicative of the convective currents within the Experimental House. In short, warm air rises and with it comes moisture. Temperatures vary from -25°C to 10°C (Figure 6.17). This is not unexpected due to the close location of the sensor to the exterior side of the joint. Conditions within this joint are such that mould growth could be sustained with an adequate food source.

The roof joint also shows the most susceptibility to condensation. The calculated dew point temperature stays mostly below the cavity temperatures (Figure 6.18). When temperatures start dipping over the late evening, the temperatures almost overlap. There is potential for condensation at this location.



Temperature

Relative

Humidity

Figure 6.15: West Wall Core Temperature & Relative Humidity Profile

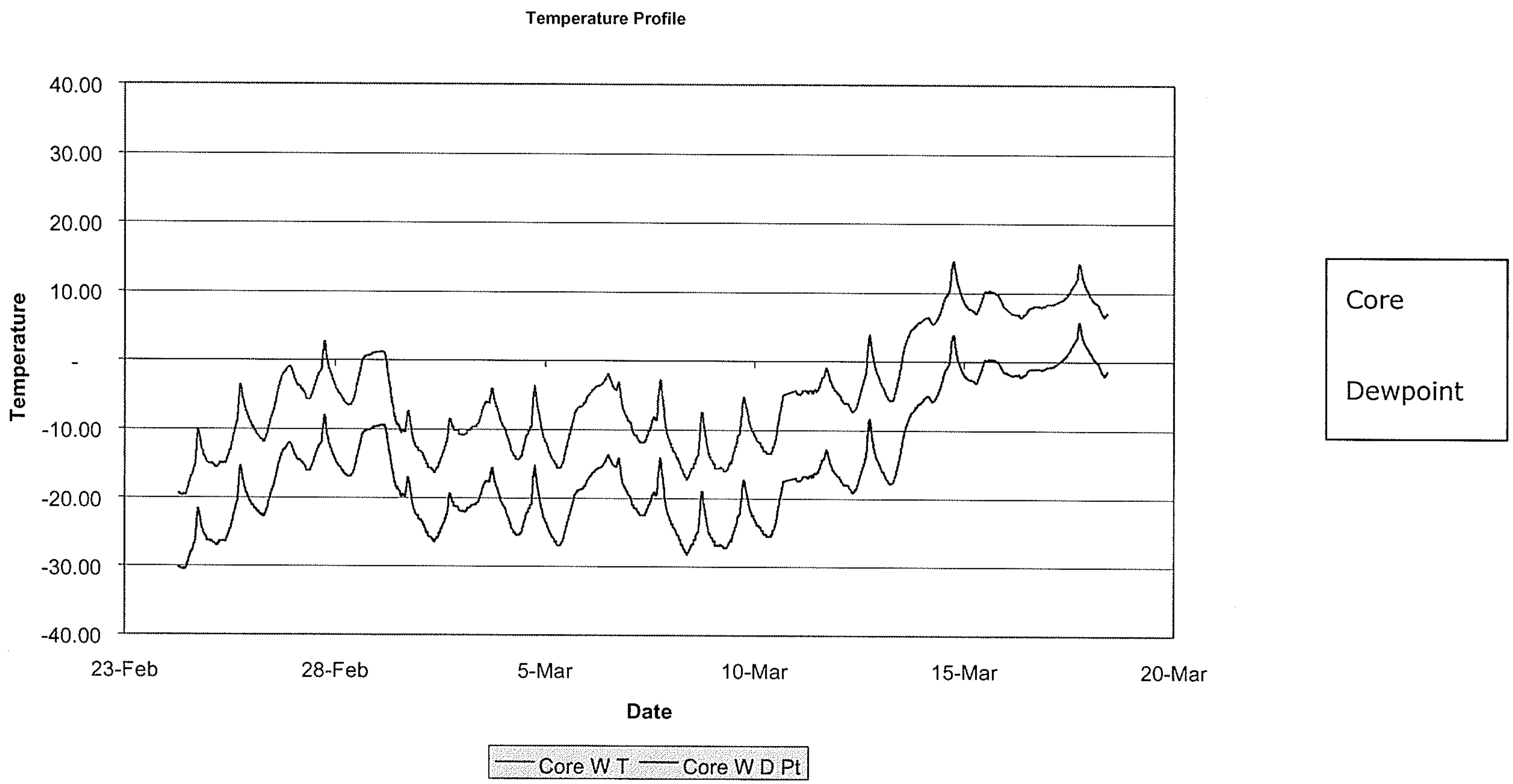


Figure 6.16: West Wall Condensation Potential

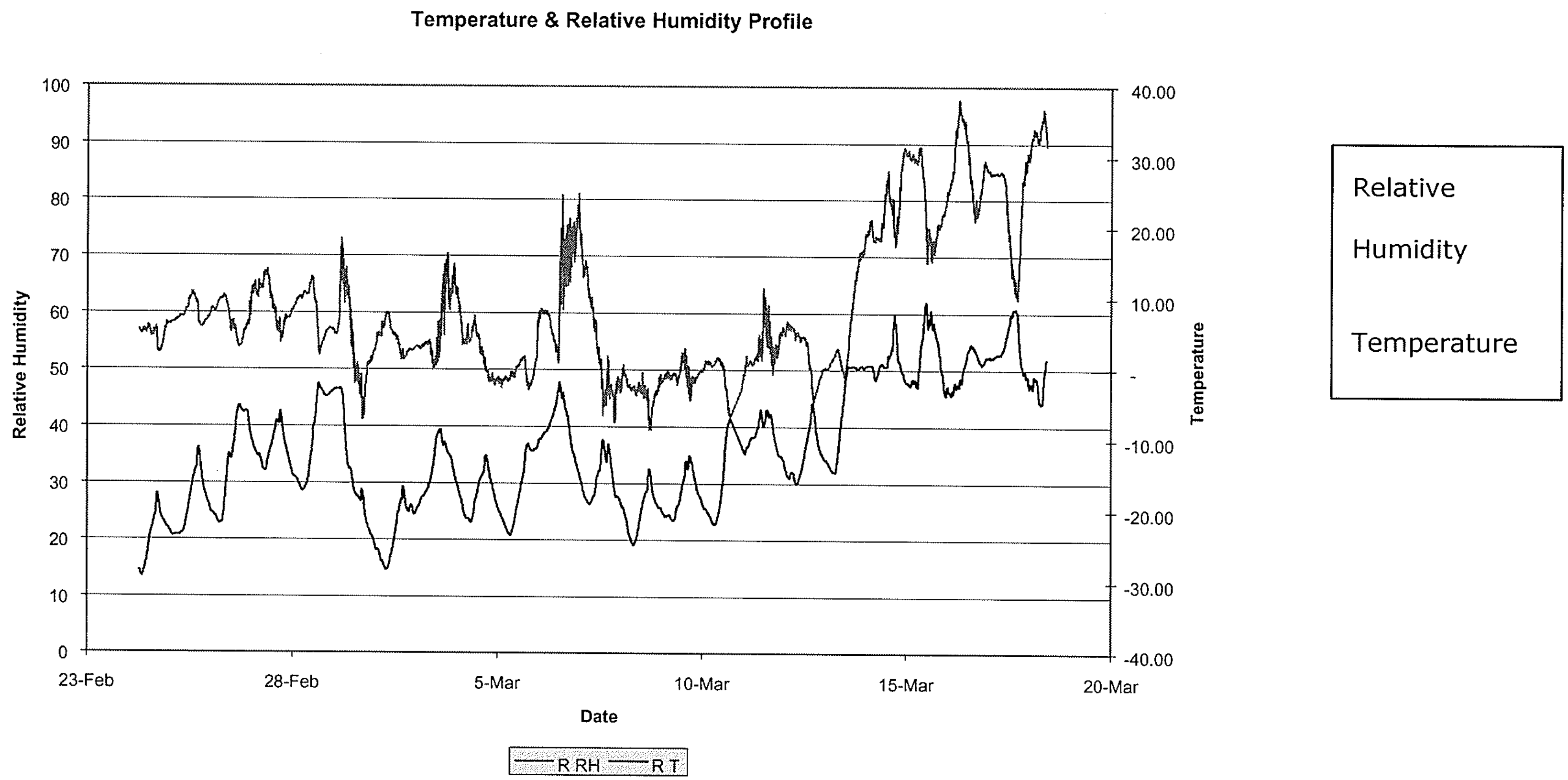


Figure 6.17: Roof Joint Core Temperature & Relative Humidity Profile

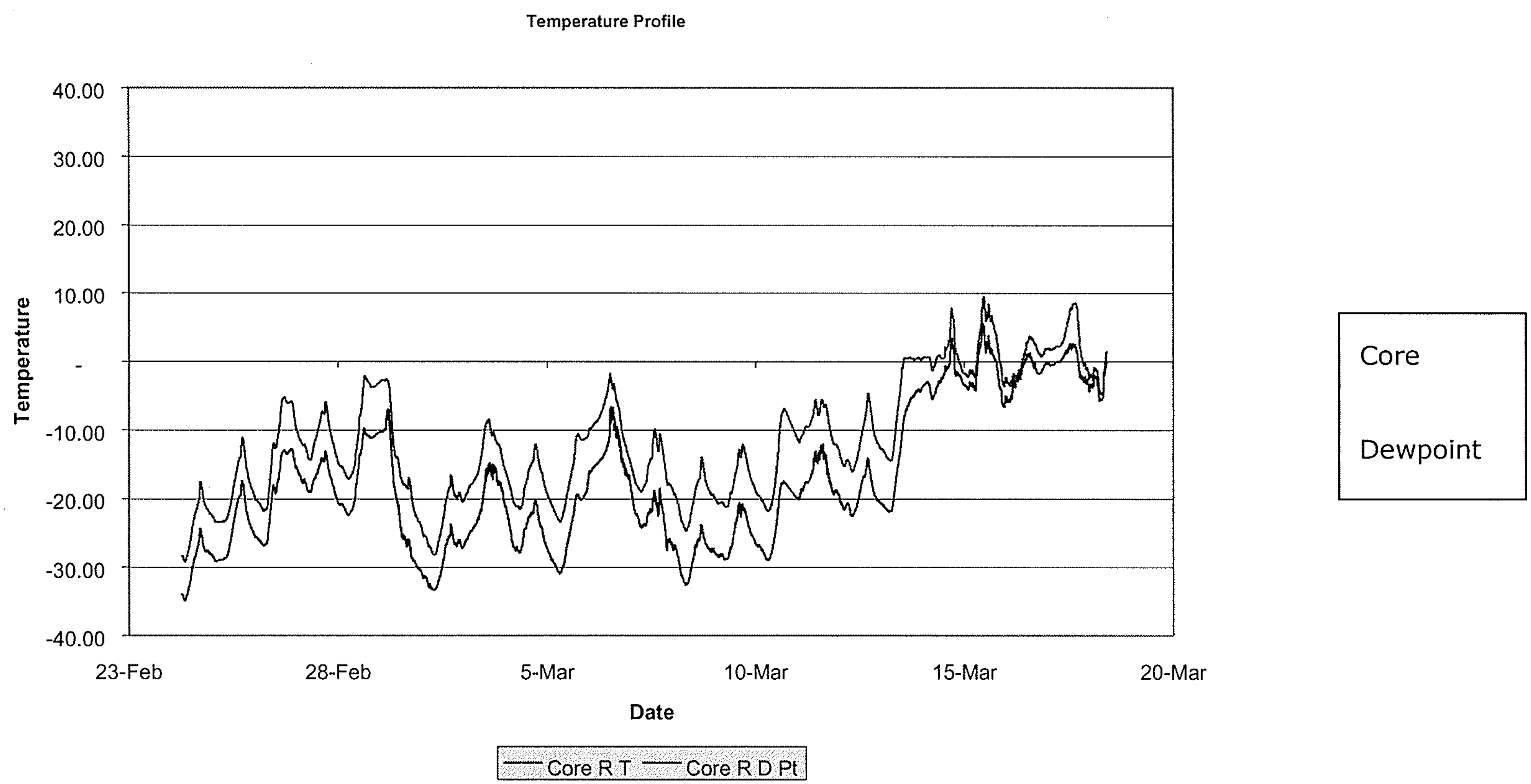


Figure 6.18: Roof Joint Condensation Potential

6.7.5 Northwest Wall

The relative humidity profile shows little variation from 40% to 50%, whereas the temperature swings from -5°C to 25°C (Figure 6.19). These conditions are not conducive to mould growth.

The calculated dew point temperature in this location also indicates no potential for condensation in these conditions, as the cavity temperature is consistently 15°C higher than the dew point (Figure 6.20).

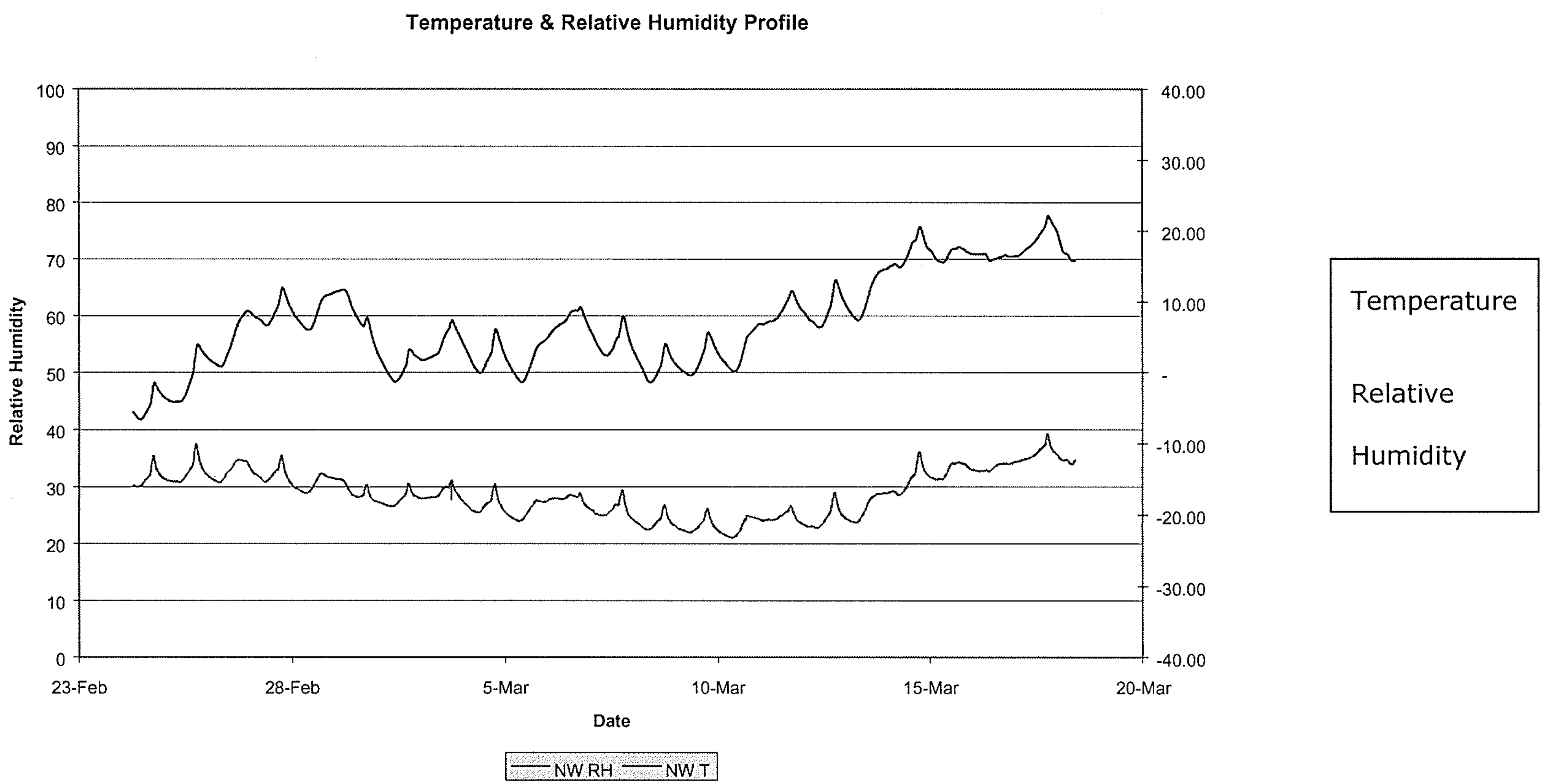


Figure 6.19: Northwest Joint Core Temperature & Relative Humidity Profile

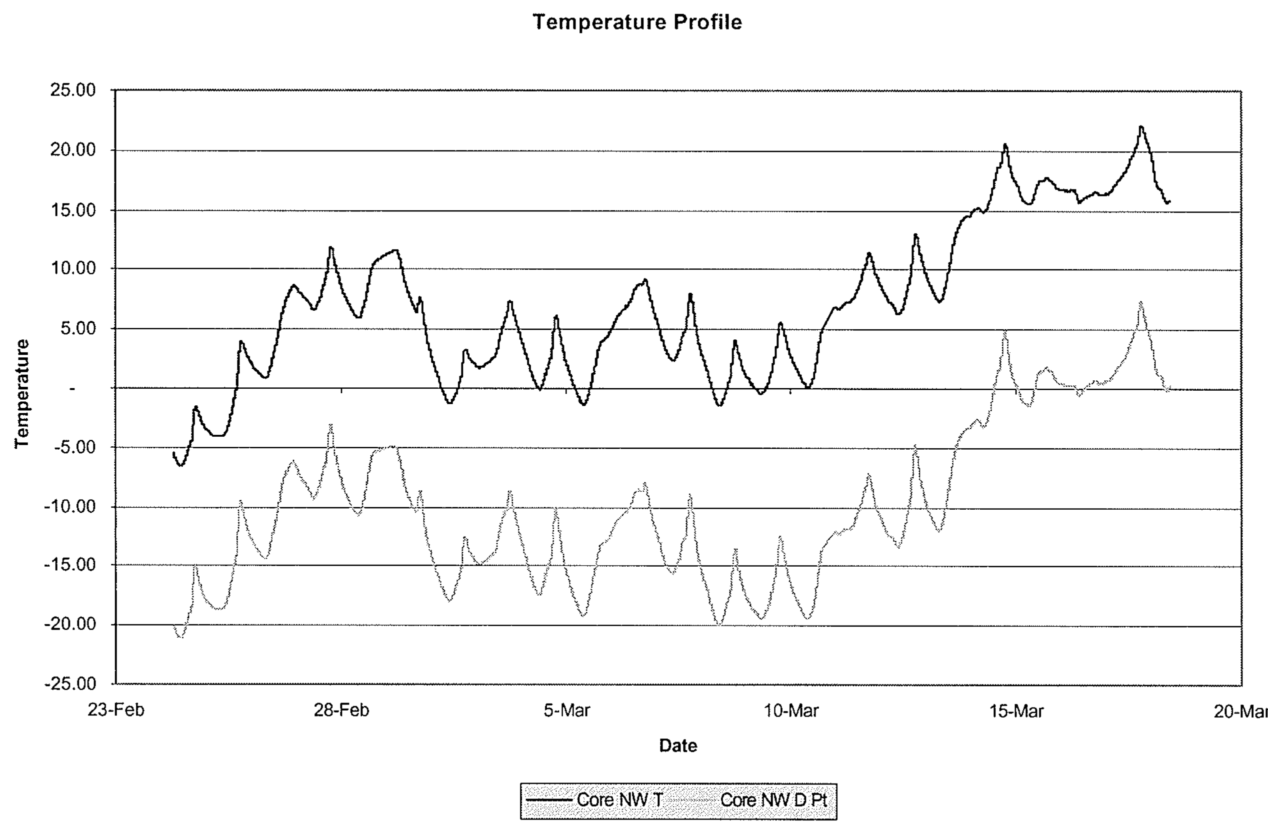


Figure 6.20: Northwest Joint Condensation Potential

7 DISCUSSION OF SMART HOUSE CONSTRUCTION

The SMART House is scheduled for construction in the summer of 2004, following the publication of this paper. Sensors will be installed and monitored over a period of two years following the completion of this project. Correlation of data will be performed, but not as part of this project.

7.1 DETECTION OF AIR LEAKAGE & CONDENSATION POTENTIAL THROUGH MONITORING

As with the Experimental House, sensors will be installed throughout the structure to determine the air leakage at various points in the structure. Joints will be targeted due to their sensitivity to failure, in particular at the roof, due to the noted potential for condensation at this location.

7.2 COMPUTER MODELLING

HOT2000 Modelling has been completed with the aid of Manitoba Hydro to determine the predicted performance of the SMART House based on test results completed to date. Based on our knowledge to date, the SMART House should meet or exceed the energy target set by the R-2000 program. Testing over the two-year period will be designed to confirm this result. Copies of the computer results are shown in Appendix N.

8 CONCLUSIONS

The following conclusions can be drawn from the experimental program.

1. Air Leakage Characteristics

- Measured results were 0.65 cm^2/m^2 for the Experimental House and the target was 0.70 cm^2/m^2. The blower door test results therefore indicate compliance with the R-2000 standard.

- Installation of sensors and monitoring of data over a three week winter period in the north wall joint, the corner southeast joint, within the west wall and at the roof joint all indicated little to no air leakage through the walls of the Experimental House.

- Infrared pictures showed minor air exfiltration at the door and window joints. This was considered normal and minor in nature for the Experimental House.

- Visual observations of the joints following one year of weathering indicated some joint failures. However, it would appear that the post-tensioning of the structure takes reliance off the caulking joint in ensuring an airtight design.

2. Window Performance

- The window for the Experimental House exceeds the requirements of the R-2000 Program.

- Visual observation of the window during testing showed extensive condensation due to the high humidity levels during testing.

- Mould growth was observed on the wooden windowsill following testing.

3. R-2000 Target Equation

- Calculations show that the energy consumption of the Experimental House exceeds the target by 69%. This is not a strong indicator of performance, however as we are outside the bounds of the model parameters.

4. Vapour Permeance

- The vapour permeance of the skin material is 0.03 ng/Pa·m^2·s, better than the NBC requirement of 45 ng/Pa·m^2·s.

5. Condensation Resistance

- The walls performed well and did not show potential for condensation.
- The wall relative humidities were not within the realm of normal health mould growth. It is therefore unlikely that mould would form if a food source were present under these conditions.
- The roof joints show potential for condensation and mould growth.

6. Durability

- The core material does not lose integrity after 30 freeze-thaw cycles in a controlled laboratory environment.
- The skin material does not lose structural integrity after long-term exposure to ultraviolet light. There is degradation of colour after a period of time.

9 RECOMMENDATIONS

The following recommendations are provided for further research into this area of study:

1. Thermal Resistance

- Obtain the thermal resistance of the skin and core material under normal operating conditions.
- After the results have been obtained, optimize the panel thickness to meet R-2000 requirements while decreasing production costs.

2. Air Leakage

- Tests indicate that the home is very airtight. Ensure adequate ventilation is provided through the heating system. This system must also be simple to use and difficult to turn off.
- Improve jointing technique to allow for thermal expansion and contraction, while addressing potential rain penetration issues.

3. Windows

- Use Fibreglass window frames where feasible to ensure the thermal expansion and contraction of the two materials are similar.
- Avoid the use of wood trim around the window.

4. Heat Capacity

- Determine the heat capacity of the materials and their effectiveness in the climate in which the houses will be constructed.

5. Determination of Condensation Resistance from Monitoring

- Perform additional testing at the roof joints to determine the extent of the condensation at this location. If necessary, re-design the joint to reduce the potential for problems.

6. Durability

- Perform additional testing to determine the long-term performance of the core material under freeze-thaw conditions.

7. Indoor Air Quality and Environmental Considerations

- Test for VOC off gassing from the panels.
- In order to meet the R-2000 indoor air quality (IAQ) and environmental requirements for the SMART House, an analysis of the requirements must be completed.

8. Additional Testing

- Perform detailed investigative joint testing, including rain penetration tests.
- Perform impact testing to determine the durability of the skin against penetration and damage.
- Determine the component thermal expansion and contraction coefficient, and design appropriate jointing material to accommodate the movement.
- Complete mould testing of panels and core material to confirm lack of food source for all known toxic moulds.

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APPENDIX A:

AMBIENTE SYSTEM DETAILS

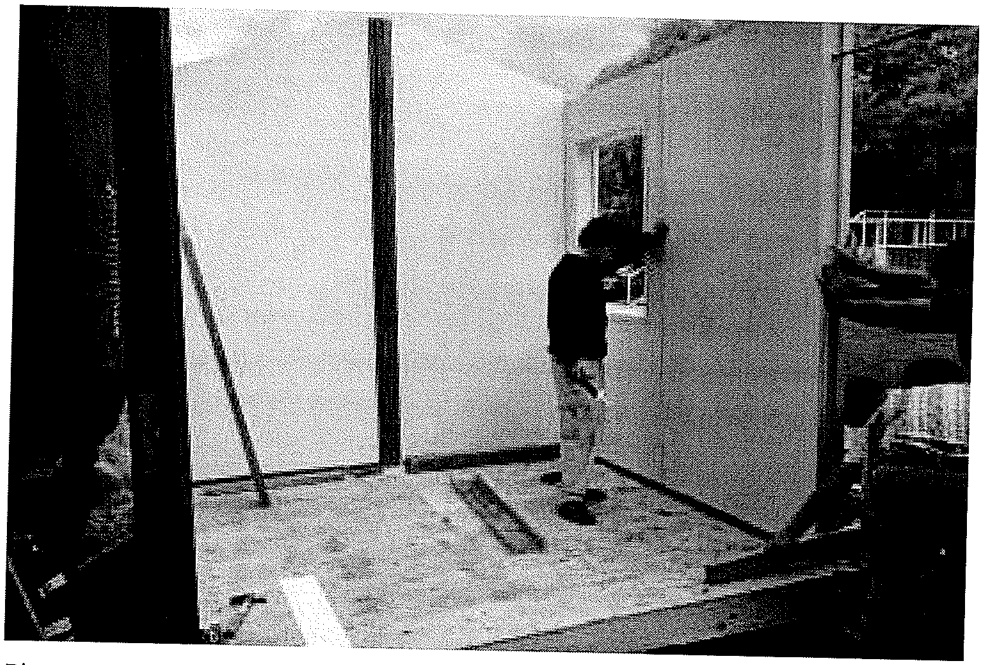


Photo 1: Installing the Third Wall

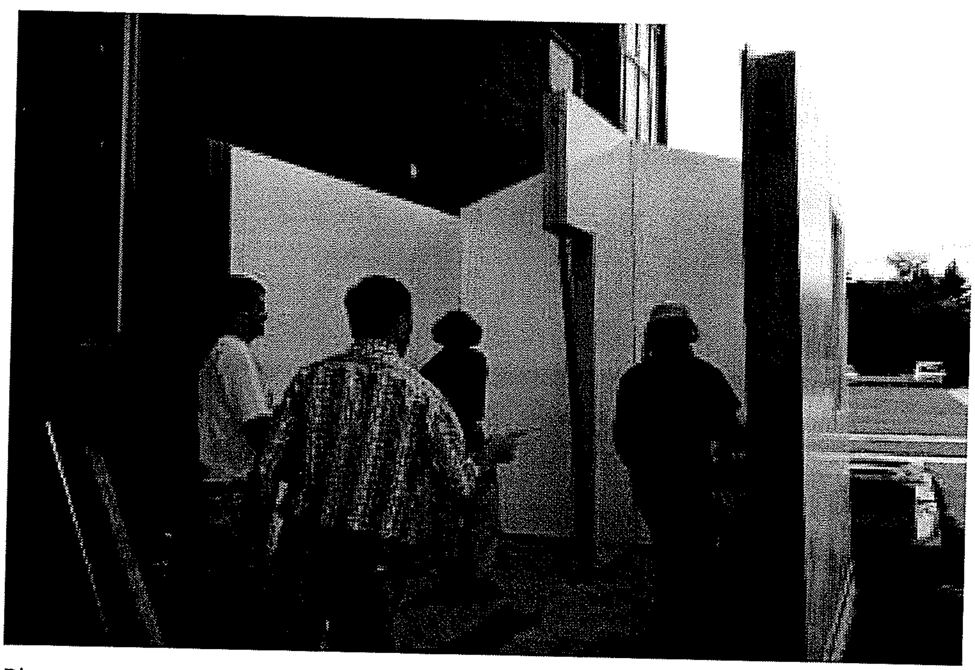


Photo 2: Installing the Partition Wall

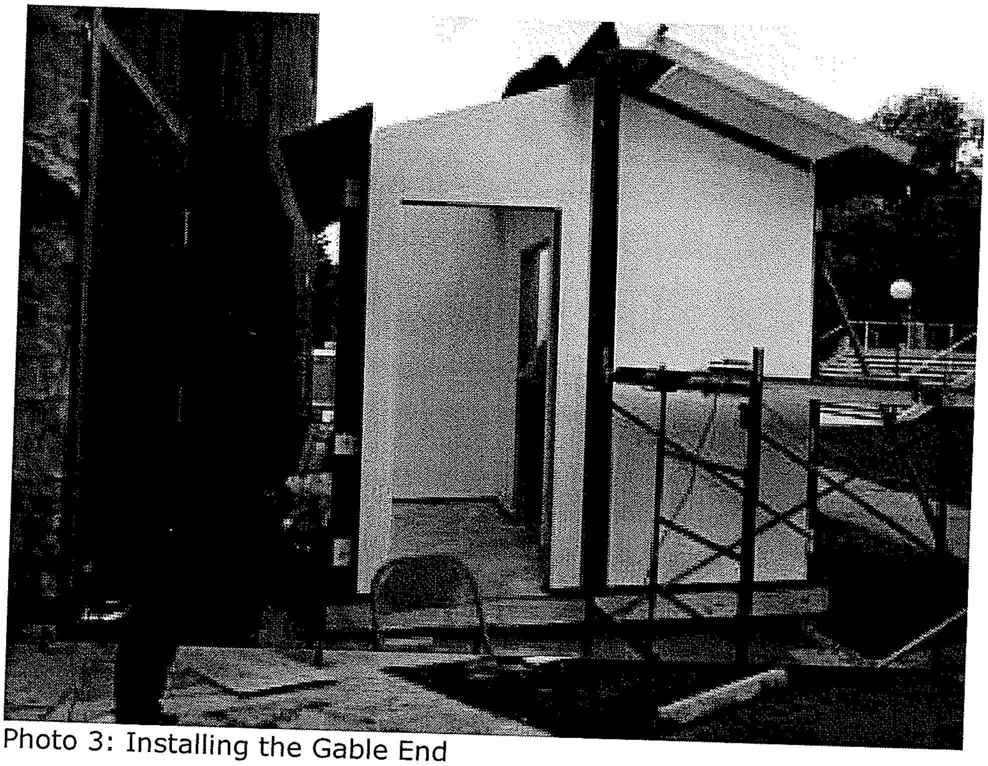


Photo 3: Installing the Gable End

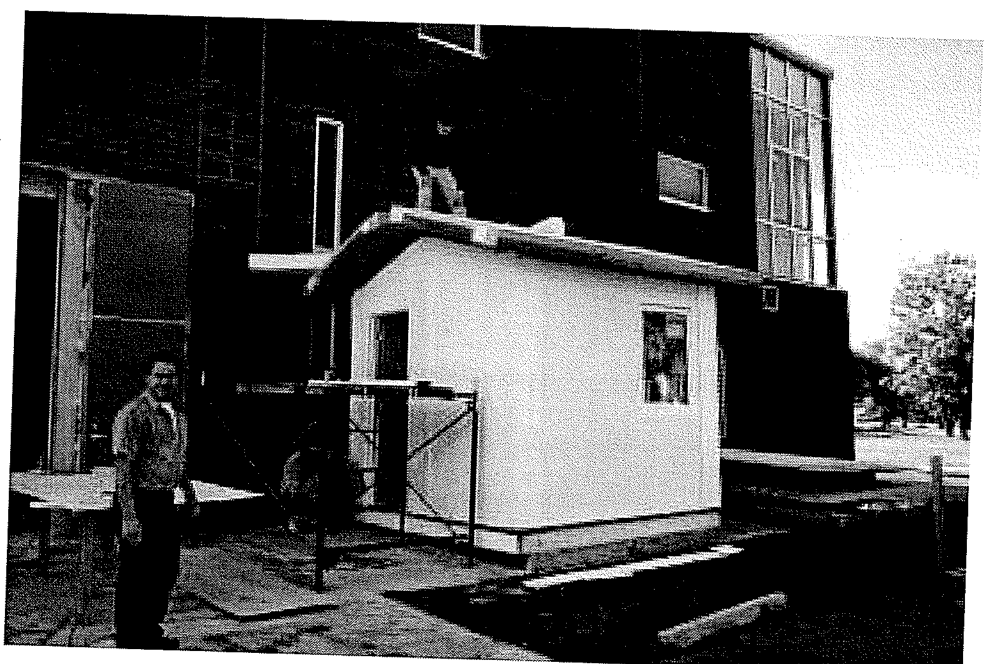


Photo 4: Installing the Roof

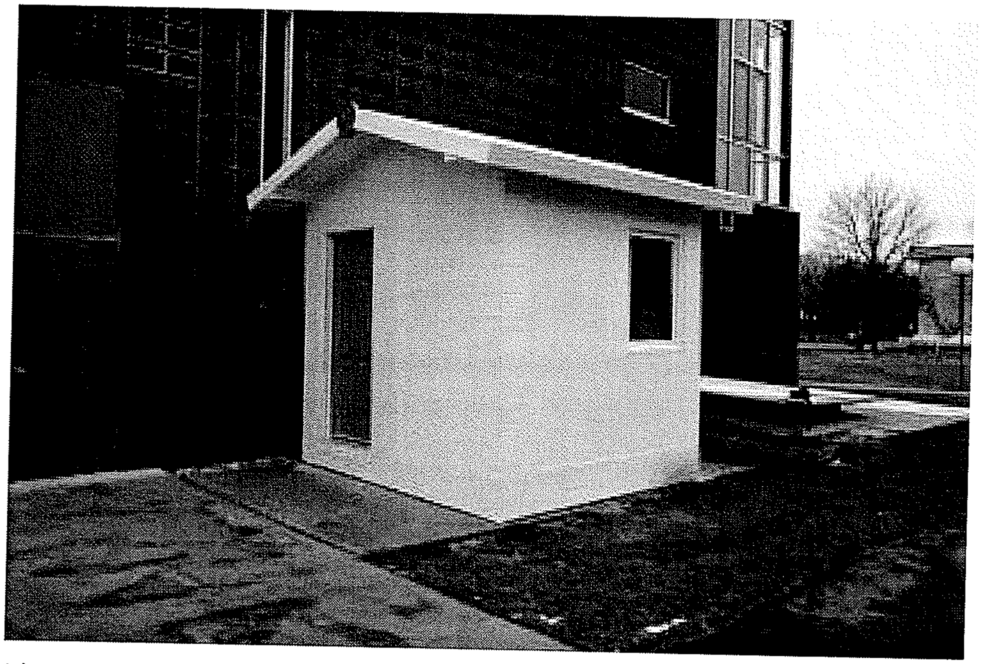
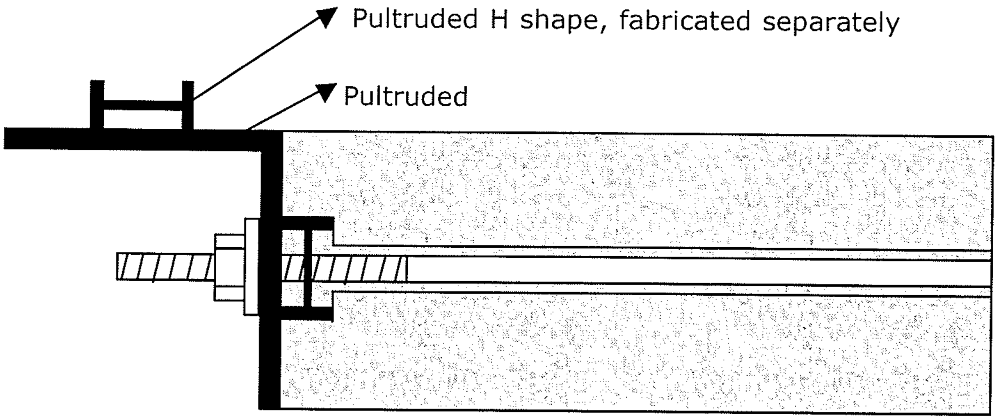
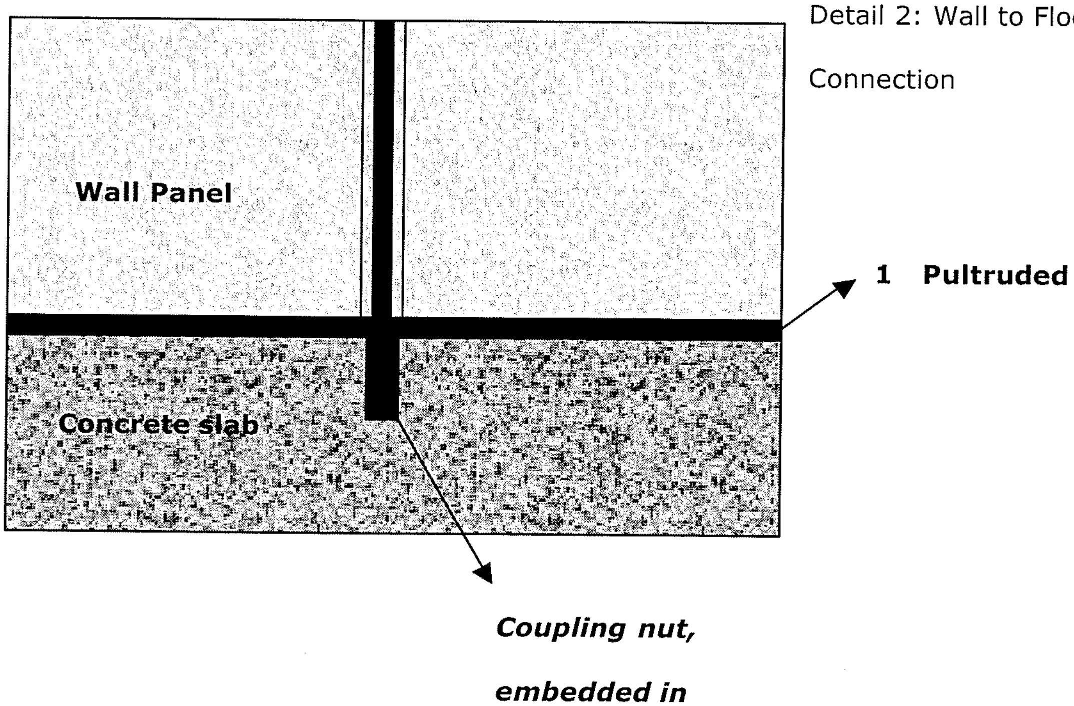


Photo 5: The Finished Experimental House

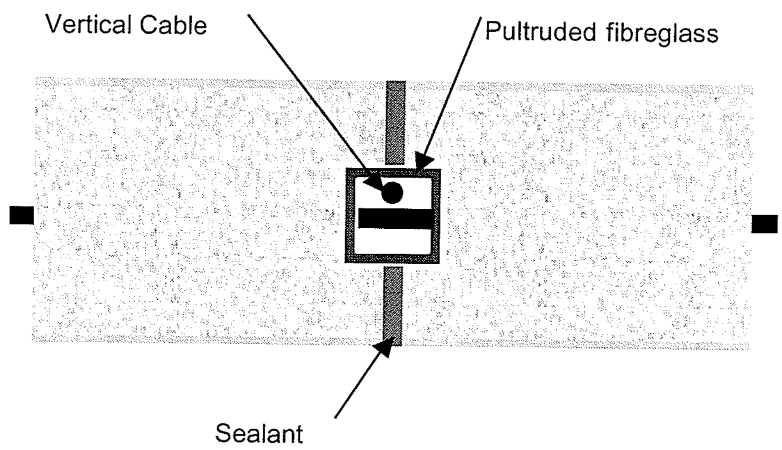


Detail 1: Corner Detail



Detail 2: Wall to Floor Connection

Panel-to-panel Joint

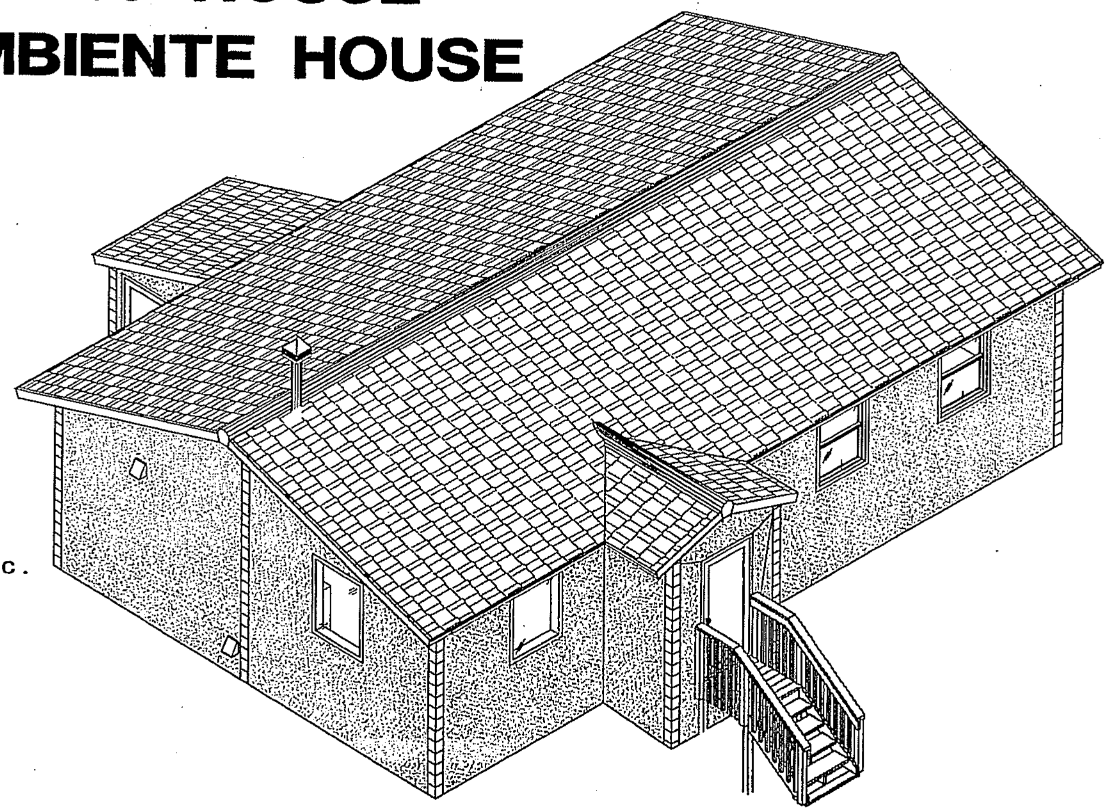


Detail 3: Panel to Panel Joint

04.02.10

UNIVERSITY
OF MANITOBA

SMART PARK DEMO HOUSE
4 BEDROOM AMBIENTE HOUSE



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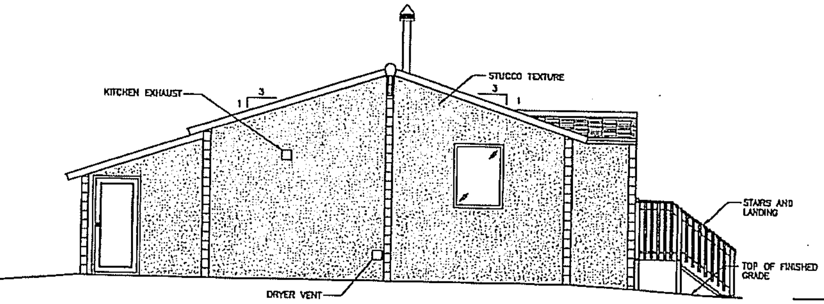
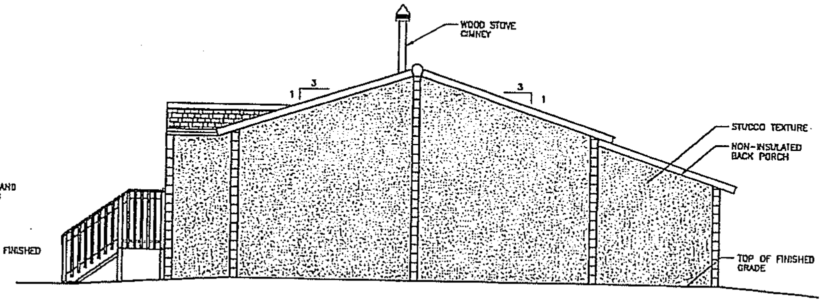


1 LEFT ELEVATION
1/4" = 1'-0"



2 RIGHT ELEVATION
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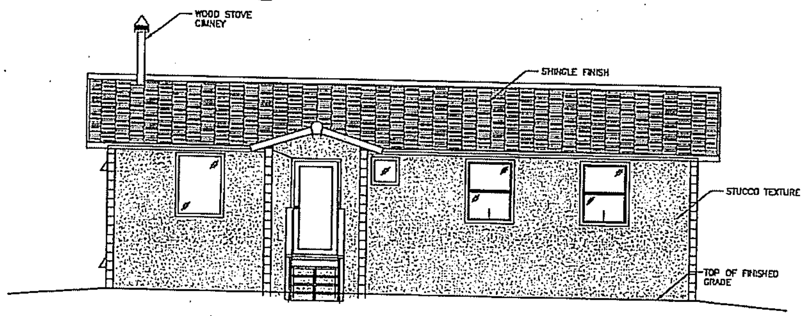

3 FRONT ELEVATION
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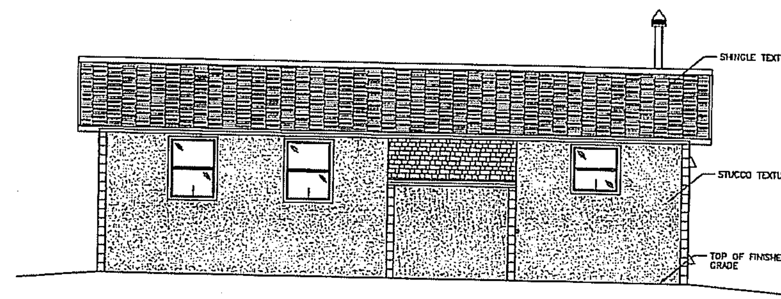

4 REAR ELEVATION
1/4" = 1'-0"

GENERAL NOTES:

1. ALL RELEVANT CSA STANDARDS, PROVINCIAL AND FEDERAL BUILDING CODES, WORKERS' COMPENSATION BOARD, AND LOCAL BYLAWS SHALL APPLY TO THIS PROJECT.
2. THE CONCRETE FOR ALL STRIP FOOTINGS SHALL BE 25 MPA AT 28 DAYS, TYPE 50 SULPHATE-RESISTANT CEMENT. MAXIMUM SLUMP 4", 1 1/2" MAXIMUM AGGREGATE, 3% TO 6% ENTRAINED AIR.
3. ALL REBAR SHALL BE NEW BILLET DEFORMED BARS GRADE 300 MPA FOR 10M, GRADE 400 MPA FOR 15M AND LARGER. ALL REBAR SHALL BE FREE OF RUST, MUD, OIL OR OTHER MATERIAL WHICH WOULD REDUCE BOND. ALL REBAR SHALL BE DETAILED AND PLACED IN ACCORDANCE WITH THE LATEST A.C.I. DETAILING MANUAL.
4. ALL DIMENSIONS AND ELEVATIONS NOTED ON THESE DRAWINGS SHALL BE VERIFIED BY THE CONTRACTOR/ OWNER PRIOR TO STARTING CONSTRUCTION. THE CONTRACTOR/ OWNER SHALL NOTIFY THE ENGINEER IMMEDIATELY UPON NOTING ANY DIMENSIONAL DISCREPANCIES.
5. HOT-DIPPED GALVANIZED NAILS SHALL BE INSTALLED IN PWF MATERIAL. STAINLESS STEEL ONLY IF STAPLES. ALL NAILING SHALL BE IN ACCORDANCE WITH TABLE NO. 7 OF THE CSA-S406 STANDARD.
6. THE DRAINAGE LAYER SHALL CONSIST OF CLEAN CRUSHED ROCK OR CLEAN GRAVEL MAXIMUM 1 1/2" DIAMETER WITH NOT MORE THAN 10% FINAL MATERIAL PASSING THROUGH A 0.12" SIEVE. EXTEND AGGREGATE MINIMUM 12" BEYOND THE EXTERIOR EDGE OF THE FOOTINGS. PLACE AGGREGATE WITH 45 MIL POLY MOISTURE BARRIER COVER OVER ENTIRE EXCAVATION.
7. UNLESS OTHERWISE NOTED ON THE CONTRACT DRAWINGS, ALL PWF STUDS SHALL BE SPEC 1 GRADE 2 OR BETTER TO THE SIZE AND SPACING AS NOTED ON THE DRAWINGS.
8. THE MATERIAL IN THE BACKFILL ZONE SHALL BE COMPRISED OF COARSE SAND OR GRAVEL INSTALLED IN MAXIMUM 12" LIFTS AND COMPACTED BY HAND TAMPING ONLY. THE TOP 12" OF BACKFILL SHALL BE COMPRISED OF IMPERVIOUS MATERIAL SLOPED AWAY FROM THE FOUNDATION WALL TO PROPERLY SHED MOISTURE AWAY FROM THE FOUNDATION SYSTEM. THE MATERIAL FOR BACKFILLING PLACED WITHIN 24" OF THE FOUNDATION SYSTEM. THE MATERIAL FOR BACKFILLING PLACED WITHIN 24" OF THE FOUNDATION WALLS SHALL BE FREE OF ALL DELETERIOUS DEBRIS, FROZEN CLUMPS, AND BOUNDERS LARGER THAN 6" IN DIAMETER. DO NOT BACKFILL UNTIL FLOOR JOISTS ARE SECURED TO WALLS.
9. HILTI NAIL OR CONCRETE NAIL PWF WALL BOTTOM PLATE TO FOOTING AT 32" O.C.
10. ALL LUMBER AND PLYWOOD THAT IS REQUIRED TO BE TREATED SHALL BE IDENTIFIED AS SUCH BY A CERTIFICATION MARK STAMPED ON THE MATERIAL THAT CONFIRMS THAT IT HAS BEEN TREATED IN CONFORMANCE WITH CSA STANDARD 080 NBC 4.2.3.2(2).

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(REMOVE WHEN DRAWING IS FINAL)

APEGM
Certificate of Authorization
Wardrop Engineering Inc.
No. 195 Expiry: April 30, 2004

1/4"=1'-0" 2 0 2 4 6ft.

NO.	DESCRIPTION	DATE	BY

REVISIONS/ISSUE

CLIENT: UNIVERSITY OF MANITOBA

WARDROP | Engineering Inc.

PROJECT NAME: SMART PARK DEMO HOUSE

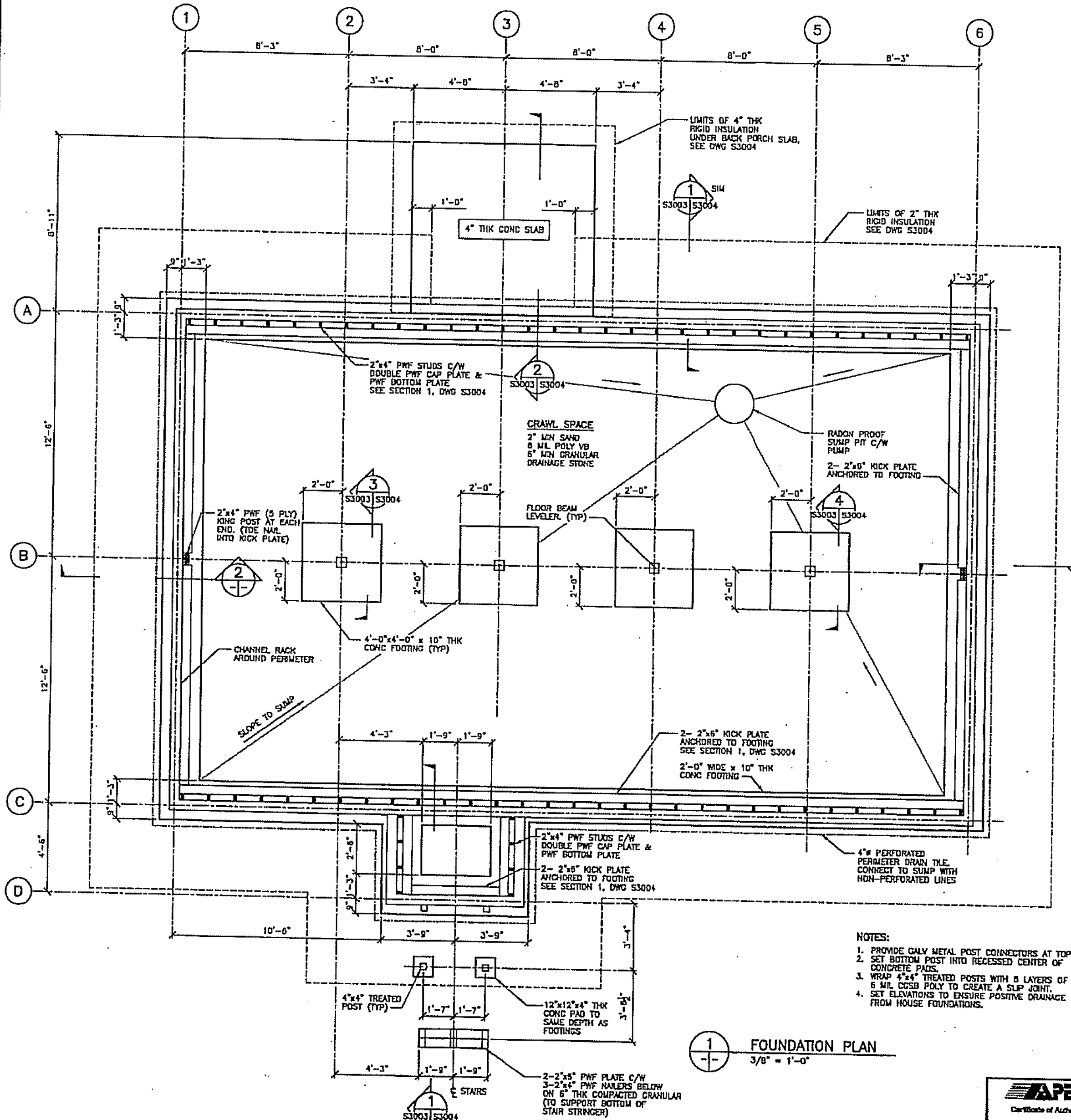
DWG. DESCRIPTION: 4 BEDROOM AMBIENTE HOUSE ELEVATIONS AND GENERAL NOTES

DESIGNED BY	DRAWN BY	CHECKED BY
R.H.W.	C.L.	RHW

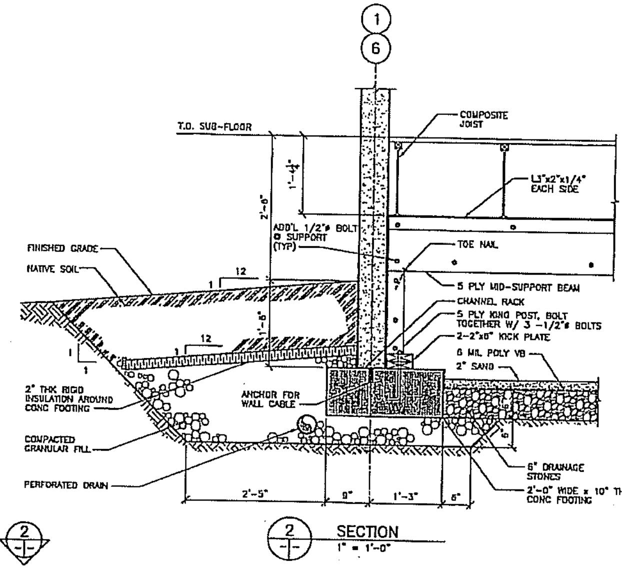
APPROVED BY:

SCALE	DATE
AS NOTED	04.01.23

DRAWING NO.	REV.
0328050100-DWG-S3002	AA



1 FOUNDATION PLAN
3/8" = 1'-0"



2 SECTION
1" = 1'-0"

NOTES:

1. PROVIDE GALV METAL POST CONNECTORS AT TOP.
2. SET BOTTOM POST INTO RECESSED CENTER OF CONCRETE PADS.
3. WRAP 4"x4" TREATED POSTS WITH 5 LAYERS OF 6 MIL CCSB POLY TO CREATE A SLIP JOINT.
4. SET ELEVATIONS TO ENSURE POSITIVE DRAINAGE FROM HOUSE FOUNDATIONS.

PRELIMINARY DRAWING ONLY
NOT TO BE USED FOR CONSTRUCTION
(REMOVE WHEN DRAWING IS FINAL)

1"=1'-0" 6 0 6 12 18in.
3/8"=1'-0" 1 0 1 2 3 4ft.

NO.	DESCRIPTION	DATE	BY

REVISIONS/ISSUE

CLIENT: UNIVERSITY OF MANITOBA

WARDROP | Engineering Inc.

PROJECT NAME: SMART PARK DEMO HOUSE

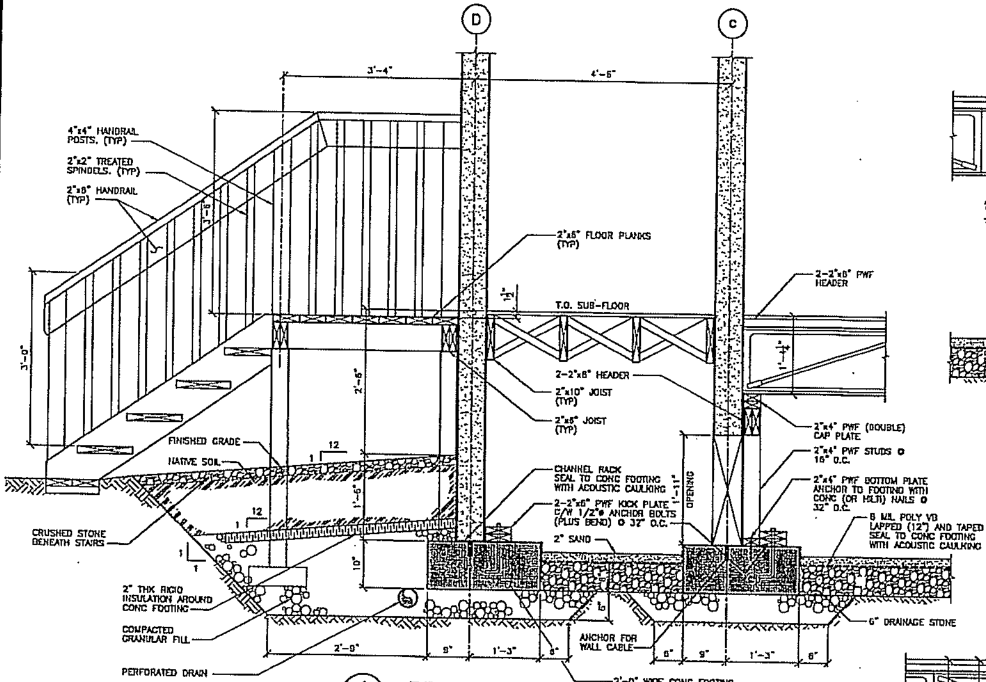
DWG. DESCRIPTION: 4 BEDROOM AMBIENTE HOUSE FOUNDATION PLAN

DESIGNED BY	DRAWN BY	CHECKED BY
R.H.W.	C.J.	

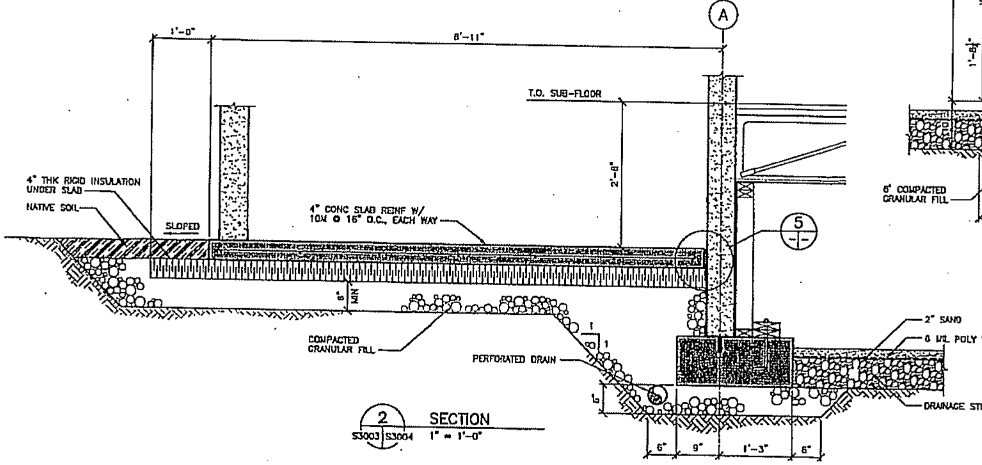
APPROVED BY:

SCALE	DATE
AS NOTED	04.01.23

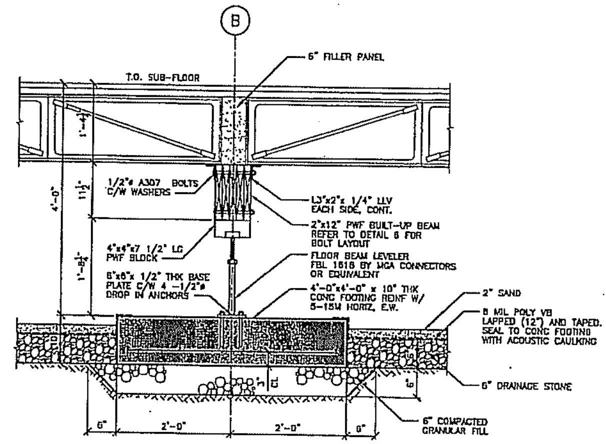
DRAWING NO.	REV.
0328050100-DWG-S3003	AA



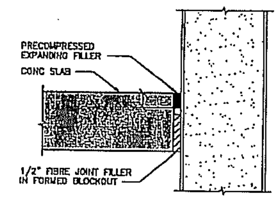
1 TYP SECTION
S3003 | S3004
1" = 1'-0"
- LOCATION OF WALL CABLE ANCHORS TO BE CONFIRMED WITH AMBIENTE



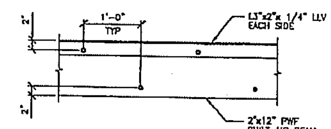
2 SECTION
S3003 | S3004
1" = 1'-0"



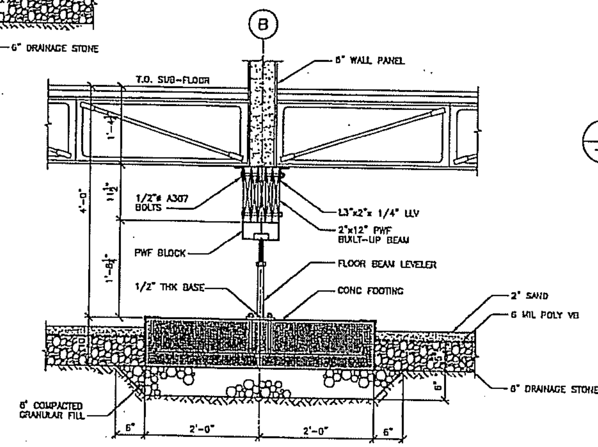
3 SECTION
S3003 | S3004
1" = 1'-0"
- PRE DRILL 5 PLY BUILT-UP BEAM FOR WALL CABLE ANCHORS



5 DETAIL
3" = 1'-0"



6 BUILT- UP BEAM BOLT LAYOUT
1" = 1'-0"
- ALL BOLTS 1/2"ø A307



4 SECTION
S3003 | S3004
1" = 1'-0"

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(REMOVE WHEN DRAWING IS FINAL)

1"=1'-0" 6 0 6 12 18in.

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No. 105 Expiry: April 30, 2004

NO.	DESCRIPTION	DATE	BY

REVISIONS/ISSUE

CLIENT: UNIVERSITY of MANITOBA

WARDROP | Engineering Inc.

PROJECT NAME: SMART PARK DEMO HOUSE

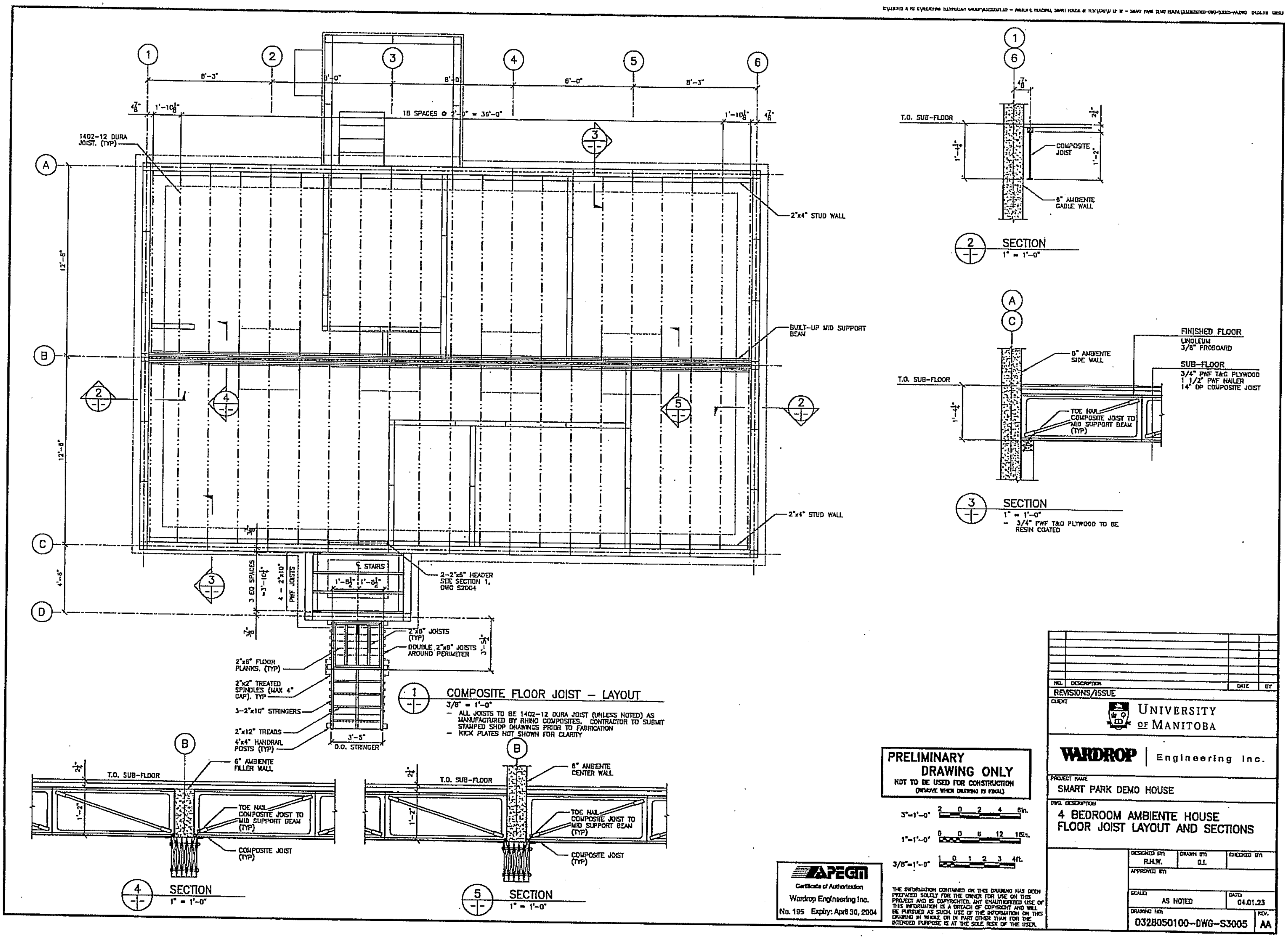
DWG. DESCRIPTION: 4 BEDROOM AMBIENTE HOUSE FOUNDATION SECTIONS

DESIGNED BY	DRAWN BY	CHECKED BY
R.H.W.	C.J.	

APPROVED BY:

SCALE	DATE
AS NOTED	04.01.23

DRAWING NO.	REV.
0328050100-DWG-S3004	AA



18 SPACES @ 2'-0" = 36'-0"
1402-12 DURA JOIST. (TYP)
2"x4" STUD WALL
BUILT-UP MID SUPPORT BEAM
2"x4" STUD WALL
2-2"x6" HEADER SEE SECTION 1, DWG S2004
STAIRS
3 EQ SPACES
4 - 2"x10" PWF JOISTS
2"x8" JOISTS (TYP)
DOUBLE 2"x8" JOISTS AROUND PERIMETER
2"x6" FLOOR PLANKS. (TYP)
2"x2" TREATED SPINDLES (MAX 4" GAP). TYP
3-2"x10" STRINGERS
2"x12" TREADS
4"x4" HANDRAIL POSTS (TYP)
3'-5" O.O. STRINGER
1 COMPOSITE FLOOR JOIST – LAYOUT
3/8" = 1'-0"
– ALL JOISTS TO BE 1402-12 DURA JOIST (UNLESS NOTED) AS MANUFACTURED BY RHINO COMPOSITES. CONTRACTOR TO SUBMIT STAMPED SHOP DRAWINGS PRIOR TO FABRICATION
– KICK PLATES NOT SHOWN FOR CLARITY
T.O. SUB-FLOOR
COMPOSITE JOIST
8" AMBIENTE GABLE WALL
2 SECTION
1" = 1'-0"
FINISHED FLOOR
LINOLEUM
3/8" PROBOARD
SUB-FLOOR
3/4" PWF T&G PLYWOOD
1 1/2" PWF NAILER
14" OP COMPOSITE JOIST
8" AMBIENTE SIDE WALL
TOE NAIL COMPOSITE JOIST TO MID SUPPORT BEAM (TYP)
3 SECTION
1" = 1'-0"
– 3/4" PWF T&G PLYWOOD TO BE RESIN COATED
6" AMBIENTE FILLER WALL
TOE NAIL COMPOSITE JOIST TO MID SUPPORT BEAM (TYP)
COMPOSITE JOIST (TYP)
4 SECTION
1" = 1'-0"
8" AMBIENTE CENTER WALL
TOE NAIL COMPOSITE JOIST TO MID SUPPORT BEAM (TYP)
COMPOSITE JOIST (TYP)
5 SECTION
1" = 1'-0"
PRELIMINARY DRAWING ONLY
NOT TO BE USED FOR CONSTRUCTION
(REMOVE WHEN DRAWING IS FINAL)
3"=1'-0"
1"=1'-0"
3/8"=1'-0"
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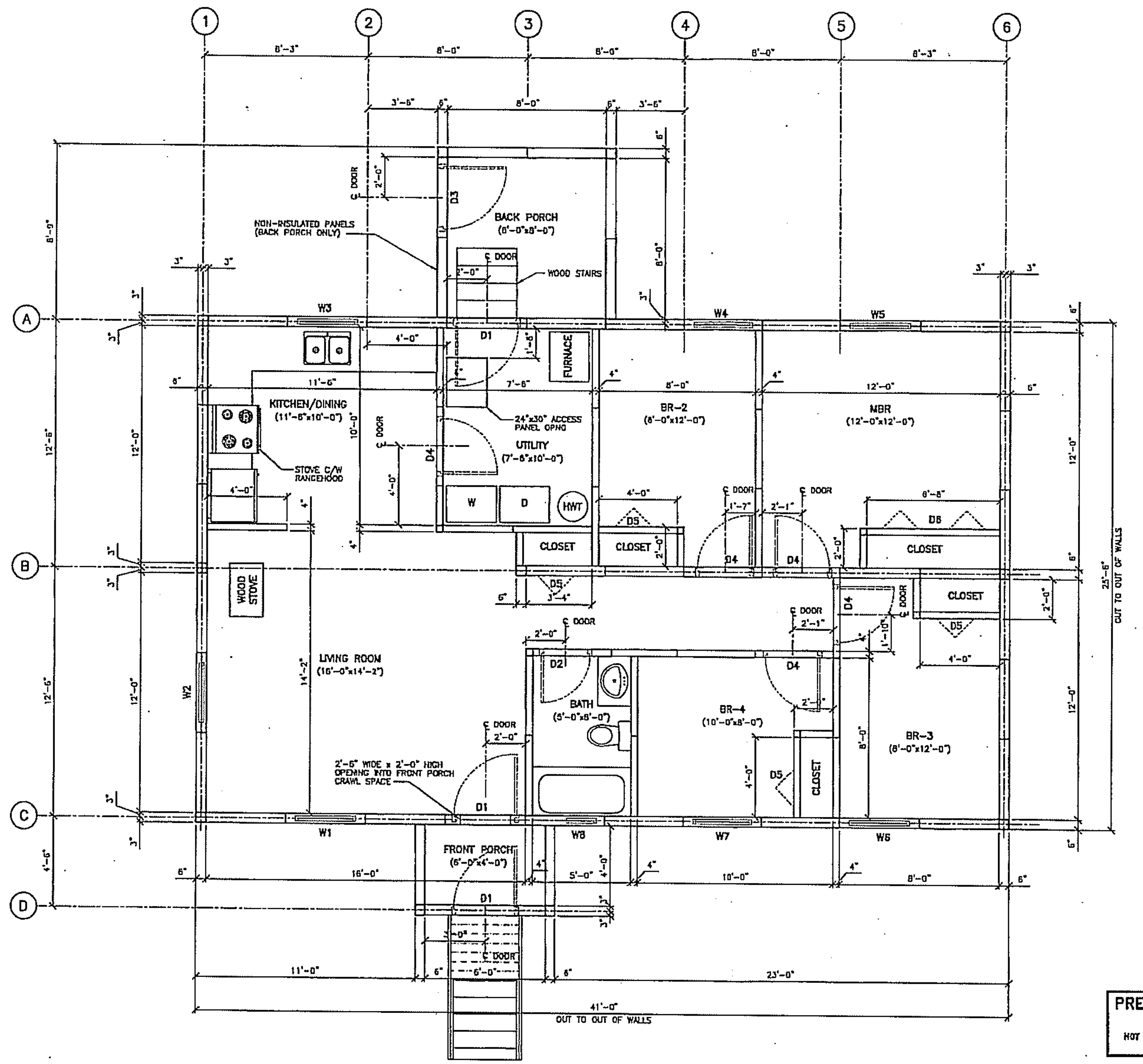
No. 195 Expiry: April 30, 2004
THE INFORMATION CONTAINED ON THIS DRAWING HAS BEEN PREPARED SOLELY FOR THE OWNER FOR USE ON THIS PROJECT AND IS COPYRIGHTED. ANY UNAUTHORIZED USE OF THIS INFORMATION IS A BREACH OF COPYRIGHT AND WILL BE PURSUED AS SUCH. USE OF THE INFORMATION ON THIS DRAWING IN WHOLE OR IN PART OTHER THAN FOR THE INTENDED PURPOSE IS AT THE SOLE RISK OF THE USER.
NO. DESCRIPTION DATE BY
REVISIONS/ISSUE
CLIENT
UNIVERSITY OF MANITOBA
WARDROP Engineering Inc.
PROJECT NAME
SMART PARK DEMO HOUSE
DWG. DESCRIPTION
4 BEDROOM AMBIENTE HOUSE
FLOOR JOIST LAYOUT AND SECTIONS
DESIGNED BY R.H.W.
DRAWN BY C.I.
CHECKED BY
APPROVED BY
SCALE AS NOTED
DATE 04.01.23
DRAWING NO. 0328050100-DWG-S3005
REV. AA



1 FLOOR PLAN
3/8" = 1'-0"

DOORS SCHEDULE						
Mk. No.	QTY	ROUGH OPENING		DOOR SIZES		DESCRIPTION
		WIDTH	HEIGHT	WIDTH	HEIGHT	
D1	3	3'-4"	6'-10"	3'-0"	6'-8"	EXTERIOR
D2	1	2'-10"	6'-10"	2'-6"	6'-8"	INTERIOR
D3	1	3'-4"	6'-10"	3'-0"	6'-8"	STORM
D4	6	3'-0"	6'-10"	2'-8"	6'-8"	INTERIOR
D5	4	2'-6"	6'-10"	2'-4"	6'-8"	BI-FOLD
D6	1	5'-2"	6'-10"	5'-0"	6'-8"	BI-FOLD

WINDOWS SCHEDULE				
Mk. No.	LOCATION	ROUGH OPENING		TYPE
		WIDTH	HEIGHT	
W1	LIVING ROOM	3'-0"	4'-0"	FIXED
W2	LIVING ROOM	3'-0"	4'-0"	FIXED
W3	KITCHEN	3'-0"	3'-0"	SASH
W4	BEDROOM 2	3'-0"	4'-0"	SASH
W5	MASTER BEDROOM	3'-0"	4'-0"	SASH
W6	BEDROOM 3	3'-0"	4'-0"	SASH
W7	BEDROOM 4	3'-0"	4'-0"	SASH
W8	BATH	1'-6"	1'-6"	FIXED

NOTE:
1. WINDOWS TO BE PVC TYPE MEETING THE REQUIREMENTS OF CSA A440. FIXED GLAZING UNITS TO HAVE AN ENERGY RATING (ER) EQUAL TO ZERO. FIXED UNITS WITH OPERABLE SASHES TO HAVE AN ER EQUAL TO -10.

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3/8"=1'-0" 1 0 1 2 3 4ft.

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No. 105 Expiry: April 30, 2004

NO.	DESCRIPTION	DATE	BY

REVISIONS/ISSUE

CLIENT: UNIVERSITY OF MANITOBA

WARDROP | Engineering Inc.

PROJECT NAME: SMART PARK DEMO HOUSE

DWG. DESCRIPTION: 4 BEDROOM AMBIENTE HOUSE FLOOR PLAN (7-UNITS)

DESIGNED BY	DRAWN BY	CHECKED BY
R.H.W.	C.L	

APPROVED BY:

SCALE: AS NOTED
DATE: 04.01.23
DRAWING NO: 0328050100-DWG-S3006
REV. AA

APPENDIX B:

MICROSCOPE PHOTOS

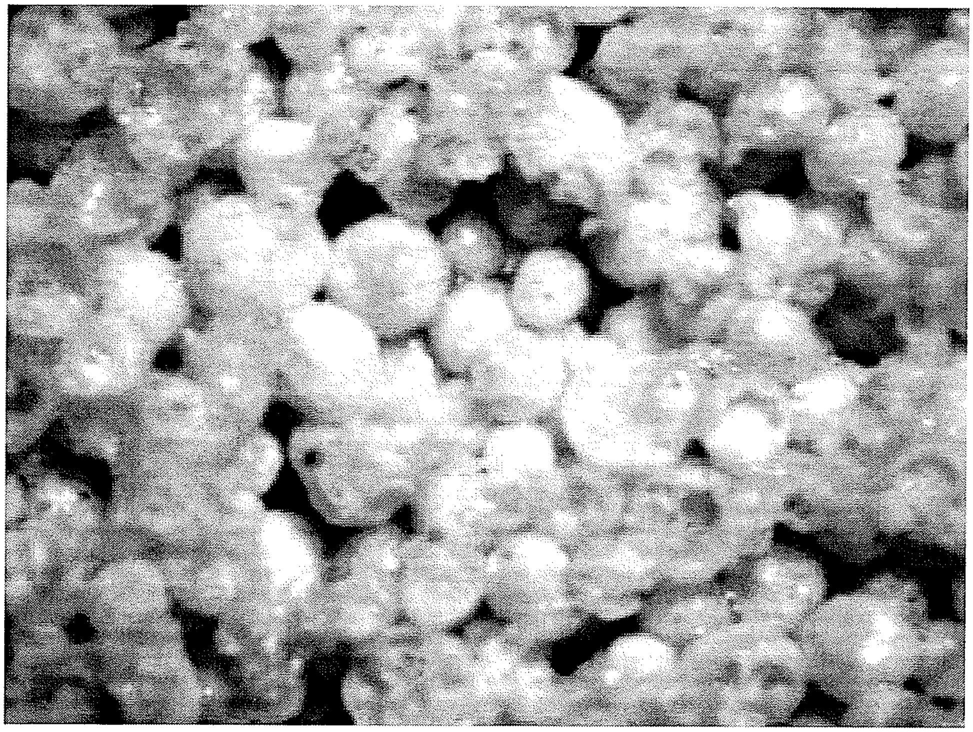


Photo 1: Ambi-Cells

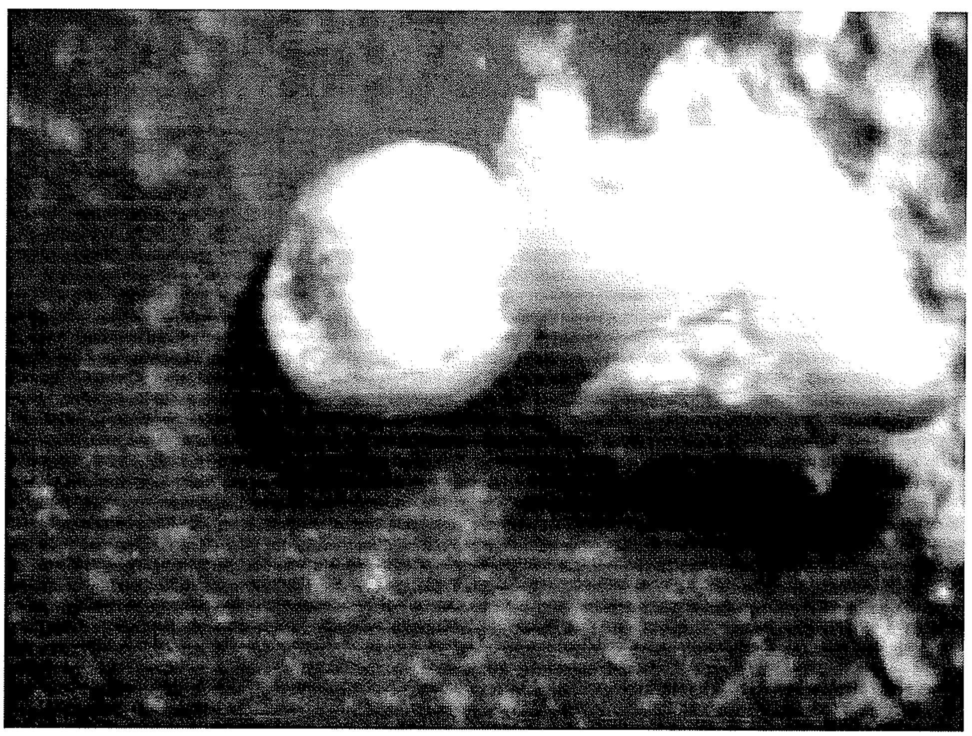


Photo 2: Single Ambi-Cell

APPENDIX C:

R-VALUE CALCULATION FOR CONVENTIONAL WOOD CONSTRUCTION

The following tables outline the calculations to determine the theoretical thermal resistance in conventional wood frame construction. The composite thermal resistance is the ratio of the quantity of each type of construction.

Table C.1: Conventional Construction Thermal Resistance at the Insulation

	Thickness (mm)	Thickness (m)	λ (W/m·K)	C (W/m²·K)	RSI
Interior Air Film				6.30	0.16
Paint					
1/2" Drywall	12.70	0.01		12.50	0.08
Polyethylene Vapour Barrier					
5-1/2" Batt Insulation	139.70	0.14	0.04	0.26	3.88
1/2" Particle Board	12.70	0.01	0.14	10.71	0.09
Stucco	12.70	0.01	0.72	56.69	0.02
Exterior Air Film				4.90	0.20
TOTAL THEORETICAL THERMAL RESISTANCE					4.43

Table C.2: Conventional Construction Thermal Resistance at the Wood Studs

	Thickness (mm)	Thickness (m)	λ (W/m·K)	C (W/m²·K)	RSI
Interior Air Film				6.30	0.16
Paint					
1/2" Drywall	12.70	0.01		12.50	0.08
Polyethylene Vapour Barrier					
5-1/2" Wood Stud	139.70	0.14	0.12	0.86	1.16
1/2" Particle Board	12.70	0.01	0.14	10.71	0.09
Stucco	12.70	0.01	0.72	56.69	0.02
Exterior Air Film				4.90	0.20
TOTAL THEORETICAL THERMAL RESISTANCE					1.72

Therefore, the composite RSI = 0.8*4.43+0.2*1.72 = 3.89 $m^2 \cdot K/W$,this is approximately equal to the value of the insulation alone (3.5 $m^2 \cdot K/W$)

APPENDIX D:

DETECTION OF AIR LEAKAGE BY MONITORING TEST PROCUDURE

Monitoring Methodology for the Detection of Air Leakage

Scope

This test method covers the methodology for the detection of air leakage of an assembly structure.

Referenced Documents

CMHC Research Report – On-Site Exterior Wall Monitoring Methods for Air Leakage, Condensation, and Rain Penetration Control Problems, 1999.

Significance and Use

The procedure described in this test method is intended to determine the qualitative amount of air leakage within the Ambiente system. The procedure is not intended to provide a quantitative measure of the amount of air leakage.

Apparatus

Temperature Sensors -- Capable of measuring between -40°C and 40°C, accurate to 0.5°C

Pressure Transducers -- Capable of measure pressure differences of up to 300 Pa, accurate to 1 Pa

Data Loggers – Capable of storing data for the entire test period (3 weeks) and recording data every 15 minute.

Sampling

Three temperature sensors and one pressure transducer will be set up at a minimum of the following:

1. One for each of the cardinal directions

2. Two in the Roof.

Identification

Mark and record the exact location of all monitoring equipment for future analysis.

Procedure

Install one sensor near the interior and one near the exterior surface of the wall. Also, install one sensor within the wall. This may be accomplished either at a joint, or by cutting out a block and reinstalling it with the sensor located within the wall.

Drill a through hole near the temperature sensors and install small tube from inside to outside. This is to be attached to the pressure transducer that will measure the pressure difference between interior and exterior. Seal all holes with caulking to reduce the potential for additional air leakage due solely to testing.

Monitor at 15 minute intervals over a minimum period of one week.

Calculation and Report

The data collected during the monitoring period should be organised in a tabular format in a computer spreadsheet program. In addition, this information should be plotted on graphs to include temperature-related information and pressure related information.

From the data obtained by the monitoring process, plot the temperature performance of the exterior walls versus time. The plot should include the indoor temperature, the outdoor temperature and the cavity temperature. From the monitored data, compute the measured temperature index for the wall at each recording interval and record in the spreadsheet.

The measured temperature index is the percentage of thermal resistance to the point that the sensor is placed within the wall from the interior.

$$T_i = {RSI_{\text{int}}}/{RSI_{total}}$$

The next step involves reducing the data to select time periods. As daytime temperatures also involve solar conditions that also effect wall temperatures, it is recommended that the analysis be completed with nighttime data only, that is from 12:00 am to 6:00 am. Using this reduced data, plot the actual temperature index versus the air pressure differences.

The actual temperature index increases with negative infiltration air pressure difference and decreases with positive air pressure difference if there is air leakage. The spread of the index change over the pressure difference range is indicative of the magnitude of the leakage problem. If the wall is air tight, the pressure difference will not induce air leakage, therefore changes in cavity temperature and the temperature index will change only nominally or not at all.

Precision and Bias

This is a qualitative test only.

APPENDIX E:

DETECTION OF CONDENSATION BY MONITORING TEST PROCEDURE

Monitoring Methodology for the Detection of Condensation

Scope

This test method covers the methodology for the detection of condensation in an assembly structure.

Referenced Documents

CMHC Research Report – On-Site Exterior Wall Monitoring Methods for Air Leakage, Condensation, and Rain Penetration Control Problems, 1999.

Significance and Use

The procedure described in this test method is intended to determine if condensation is occurring in the specific locations monitored. The procedure is not intended to provide a quantitative measure of the amount of condensation.

Apparatus

Temperature Sensors -- Capable of measuring between -40°C and 40°C, accurate to 0.5°C

Relative Humidity Sensors – Capable of measuring between -40°C and 40°C, accurate to 5%

Pressure Transducers -- Capable of measure pressure differences of up to 300 Pa, accurate to 1 Pa

Data Loggers – Capable of storing data for the entire test period (3 weeks) and recording data every 30 minutes.

Sampling

Three temperature sensors and one pressure transducer will be set up at a minimum of the following:

1. One for each joint type

2. One within the wall (not at a joint location)

Identification

Mark and record the exact location of all monitoring equipment for future analysis.

Procedure

Install one temperature sensor near the interior and one near the exterior surface of the wall. Also, install one sensor with temperature and relative humidity reading capabilities within the wall. This may be accomplished either at a joint, or by cutting out a block and reinstalling it with the sensor located within the wall. Exterior and interior relative humidities must also be taken, and their location must be within one metre of the other sensors.

Drill a through hole near the temperature sensors and install small tube from inside to outside. This is to be attached to the pressure transducer that will measure the pressure difference between interior and exterior. Seal all holes with caulking to reduce the potential for additional air leakage due solely to testing.

Monitor at 30 minute intervals over a minimum period of one week.

Calculation and Report

From the data obtained by the monitoring process, the temperature, relative humidity and air pressure difference information should be analysed and presented as follows. From the temperature and relative humidity (RH) data collected, plot the temperature and RH data of the cavity versus time. Convert the cavity temperature and RH to a dewpoint temperature and plot a third graph that compares the cavity temperature with the dewpoint temperature and the exterior temperature. Finally subtract the dewpoint temperature from the cavity temperature and present an area graph for easy viewing analysis. The solid area of this graph illustrates the difference in temperature and the duration of the difference where the dewpoint temperature of the cavity is consistently higher than the exterior. This indicates that condensation is occurring but more important that moisture is supplied constantly to the cavity throughout the monitoring period. This hypothesis can be confirmed by examining the air pressure difference across the wall.

Precision and Bias

This is a qualitative test only.

APPENDIX F:

FREEZE-THAW TEST PROCEDURE

Freeze-Thaw and Compression Test Methodology for the Ambiente Housing System

Scope

This test method covers the resistance to freezing and thawing of manufactured Ambiente housing panels. Units are tested in water.

Referenced Documents

ASTM C 1262-98: Standard Test Method for Evaluating the Freeze-Thaw Durability of Manufactured Concrete Masonry Units and Related Concrete Units

ASTM C140: Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units

Significance and Use

The procedure described in this test method is intended to determine the effects of freezing and thawing on Ambiente housing panels in the presence of water.

The procedure is not intended to provide a quantitative measure of the length of service that may be expected.

Apparatus

Freezing and Thawing Apparatus

Use the freeze-thaw apparatus owned by the University of Manitoba, located in the Durability Laboratory. The apparatus measures 3 860x406x127mm. Existing metal containers will be used house the samples. These containers measure 406x102x83mm. A 10 mm mesh shall be placed at the bottom of the containers.

Temperature Measuring Equipment

Existing temperature cycling equipment will be used. Ensure temperature can be controlled to within 1°C.

Scales

Scales for weighing full-size specimens shall have a capacity of at least 50% greater than the weight of the largest specimen tested and shall be accurate to at least 1 gram. Scales for weighing the filter paper and specimen residue shall be accurate to at least 0.2 grams.

Compression

Use test equipment in accordance with ASTM C 140 to determine the compressive strength.

Sampling

Selection of Test Specimens

Select whole units representative of the lot from which they are selected. The units shall be free from visible cracks or structural defects.

Number of Specimens

A total of forty samples are to be prepared for testing.

Identification

Mark each freezing-and-thawing specimen so that it is identifiable at any time.

Preparation of Test Specimens

Freezing-and Thawing Test Specimens

Test specimens shall consist of solid coupons saw-cut from full sized units.

One coupon shall be cut from each of five sampled units. Leave the skin attached to the top surface. Immediately following saw cutting, remove loose particles and residue from the coupon by rinsing in tap water and brushing with a soft bristle brush. Do not fully immerse coupons in water.

Place the coupons on edge on a 10 mm or coarser mesh such that there is an air space of not less than 25 mm between coupons. Allow the coupons to dry for not less than 48 hours in laboratory air at a temperature of 24°C±8°C and relative humidity of less than 80%.

Each coupon shall measure 152 mm x 76 mm x 32 mm. Only one specimen may be placed in each container to allow accurate weighing of residue.

Procedure

Specimen Conditioning

After preparation of the freezing-and-thawing test specimens, place the specimen in the container face down on the specimen supports such that the non-saw cut surface of the specimen is in contact with the specimen supports. Add a sufficient amount of water as a temperature of 16 to 27°C to the container to achieve a depth of 13 mm. Do not pour water directly onto the specimen.

After 1 hour, open the container and add water as necessary to maintain the water level at 13 mm. After another 23 hours, remove the specimen from the water and allow to drain for one minute by placing it on a 10 mm or coarser sieve, removing visible surface water with a damp cloth. Immediately weigh the specimen to the nearest 1 g and record as W_p.

Return the specimens to the container and adjust water level as required to maintain 13 mm.

Water added to the container shall be at a temperature of 16 to 27°C.

Cyclical Testing

Begin the test with a freezing cycle. Place the containers into the freezing test chamber such that each container is surrounded by a minimum air space of 13 mm on all sides. During testing the container shall be level to within 2 mm. During the freezing cycle, maintain the air temperature in the chamber at -17 ± 5°C. for a period of not less than 4 hours and not more than 5 hours. The cycle time does not include the time requires for the air temperature in the chamber to reach the prescribed temperature. Periodically at the end of a freezing cycle, open the containers and visually inspect the specimens to determine if all the water surrounding the specimen is frozen solid. If not, extend the length of freezing cycle to ensure that all water is frozen solid.

After the freezing cycle, immediately begin the thawing cycle. During the thawing cycle, maintain air temperature around the containers at 24 ± 5°C for a period of not less than 2.5 hours and not more than 96 hours. The cycle time does not include the time required for the air temperature around the specimens to reach the prescribed temperatures. Each container shall be surrounded by a minimum air space of 13 mm on all sides. Visually inspect to ensure all water is thawed prior to continuing with the freezing cycle.

One freezing-and-thawing cycle is defined as a completed freezing followed by a completed thawing.

Complete testing in accordance with Table F.1.

Rotate the location of the specimens within the freezing chamber.

Table F.1: Recording of Test Results

Sample	Volume (V_p) (lxdxh)	Weight of Sample ($W_{initial}$)	Weight of Sample (W_p)	Weight of Filter Paper (W_f)	Weight of Residue & Filter Paper (W_{f+r})	Weight of Specimen (W_{final})	Compressive Strength
1a							
1b							
1c							
1d							
1e							
2a							
2b							
2c							
2d							
2e							
3a							
3b							
3c							
3d							
3e							
4a							
4b							
4c							
4d							
4e							
5a							
5b							
5c							
5d							
5e							
6a							
6b							
6c							
6d							
6e							
7a							
7b							
7c							
7d							
7e							
8a							
8b							
8c							
8d							
8e							

1 – 0 cycles
2 – 20 cycles
3 – 25 cycles
4 – 30 cycles
5 – 0 cycles (coating)
6 – 20 cycles (coating)
7 – 25 cycles (coating)
8 – 30 cycles (coating)

Collection of Residue

Weigh to the nearest 0.2 g and record as W_f a filter paper of high wet strength and smooth surface that has come to equilibrium temperature with the lab environment. Remove a single specimen from its container. Immediately rinse the specimen with water using a squeeze bottle, being careful to collect in the specimen container the rinse water and all loose particles from the specimen. Consider any pieces that separated from the specimen as part of the residue. Pour the water from the container through the filter paper to collect the residue from the test specimen. Replace the specimen in the container. Using fingertips and a squeeze bottle, remove loose particles from all surfaces of the specimen, again being careful to collect all rinse water and loose particles in the specimen container. The top surface of the specimen shall not be immersed in water at anytime and the collected water shall not exceed 13 mm in the container. Remove the specimen from the container; pour the rinse water through the filter paper, and rinse the specimen container until all residues in the specimen container is collected on the filter paper.

Dry all the filter paper and residue collected from each specimen at 100 to 155°C for not less than 4 hours and until two successive weighing at intervals of 2 hours show an increment of loss not greater than 0.2% of the last previously determined weight. Place the filter paper and residue in a draft-free location within the laboratory for a period of two hours to allow the filter paper and residue to come to an equilibrium temperature with the laboratory environment. Weigh the filter paper and residue to the nearest 0.2 g and record as W_{f+r}. Calculate the residue weight W_r as follows:

$$W_r = W_{f+r} - W_f$$

where:

W_r = weight of residue

W_{f+r} = weight of residue and filter paper

W_f = initial weight of filter paper

At the completion of the freezing-and-thawing testing, dry each specimen at 100 to 115oC for 2 hours ± 1 hour. Weigh to the nearest 1 g the final oven dried specimen and record as W_{final}. Calculate the initial weight of the specimen as follows:

$$W_{inital} = W_{final} + W_r$$

where:

$W_{initial}$ = calculated initial weight of the specimen

W_{final} = final weight of the specimen

Test in accordance with ASTM C 140 to determine the compressive strength of each specimen.

Calculation and Report

Determine and report the average and individual weight loss for each specimen group.

Precision and Bias

Precision and bias data for freeze-and-thawing durability is not available.

APPENDIX G:

VAPOUR PERMEANCE TEST RESULTS

Vapour Permeance tests were conducted by bonding specimens on top of circular containers (81.5mm diameter) containing distilled water and measuring the time it takes for the water to evaporate through the specimen. During the tests, specimens were rotated at a constant speed, in order to ensure constant airflow on top of the specimens. (standard method CAN/CGSB-4.2 no.49, m77)

Five types of specimens were prepared:

A: Skin (3.1mm)
B: Core (18mm)
C: Core + skin (29mm)
D: Core + skin (15mm)
E: Pultruded plate (13mm)

The following table shows a sample of measurements over a week's period at controlled conditions of 21C and 65%RH.

Table G-1: Raw Test Data

Date	Time	A ($g/m^2 \cdot hr$)	B ($g/m^2 \cdot hr$)	C ($g/m^2 \cdot hr$)	D ($g/m^2 \cdot hr$)	E ($g/m^2 \cdot hr$)
Nov. 20	2:15 pm	155.032	182.750	244.143	217.963	276.402
Nov. 20	5:10 pm	155.001	181.978	244.007	217.816	276.333
Nov. 21	9:40 am	154.964	180.989	243.495	217.361	276.199
Nov. 21	4:30 pm	154.960	180.656	243.334	217.251	276.166
Nov. 22	11:40 am	154.950	179.762	243.022	217.054	276.114
Nov. 25	12:30 pm	154.914	176.348	242.686	216.703	276.031
Nov. 26	10:20 am	154.899	175.316	242.622	216.614	276.008
Nov. 27	10:20 am	154.888	174.267	242.561	216.531	275.991
Nov. 28	10:50 am	154.478	173.148	242.500	216.449	275.973

As vapour permeances are generally quoted in $ng/Pa \cdot s \cdot m^2$ Table G-2 shows the values in these units.

Table G-2: Vapour Permeances in Typical Units

	A (ng/Pa·m^2·s)	B (ng/Pa·m^2·s)	C (ng/Pa·m^2·s)	D (ng/Pa·m^2·s)	E (ng/Pa·m^2·s)
	0.654	16.281	2.868	3.100	1.455
	0.138	3.687	1.901	1.696	0.500
	0.036	2.998	1.449	0.990	0.297
	0.032	2.869	1.001	0.632	0.167
	0.030	2.883	0.284	0.296	0.070
	0.042	2.901	0.180	0.251	0.065
	0.028	2.689	0.156	0.213	0.044
	0.025	2.801	0.153	0.206	0.045
Average of Final Four Values	**0.033**	**2.822**	**0.193**	**0.241**	**0.056**

APPENDIX H:

FREEZE-THAW DURABILITY TEST RESULTS

	Sample	Volume, cm2	Winitial	Wp	Wf	Wf+r	Wr	Mean Wr	Wfinal	Comp. Strength, MPa	Mean C.Strength*	StDev	
Control	1a	334.6								1.8	1.4	0.5	
	1b	333.0								1.6			
	1c	331.8								1.5			
	1d	333.2								1.5			
	1e	329.8								0.6			0
20 Cycles	2a	334.3	195.38	224.02	1.72	2.22	0.50	0.52	194.88	1.9	1.7	0.4	
	2b	334.9	193.46	233.43	1.78	2.31	0.53		192.93	1.7			
	2c	338.6	208.31	235.25	1.69	2.38	0.69		207.62	2.2			
	2d	330.8	193.80	236.56	1.78	2.23	0.45		193.35	1.7			
	2e	339.1	184.06	249.27	1.74	2.18	0.44		183.62	1.1			20
25 Cycles	3a	334.7	187.66	236.01	1.70	2.09	0.39	0.58	187.27	1.2	1.3	0.4	
	3b	335.2	186.06	212.80	1.72	2.38	0.66		185.40	1.9			
	3c	337.2	183.21	240.81	1.71	2.23	0.52		182.69	0.9			
	3d	335.5	202.75	259.79	1.74	2.38	0.64		202.11	1.7			
	3e	331.1	188.09	251.71	1.73	2.44	0.71		187.38	1.0			25
30 Cycles	4a	328.4	187.07	260.77	1.75	2.41	0.66	0.60	186.41	0.9	1.2	0.2	
	4b	332.7	185.99	227.10	1.79	2.51	0.72		185.27	1.4			
	4c	325.6	210.56	254.90	1.73	2.32	0.59		209.97	1.5			
	4d	341.1	181.42	257.79	1.76	2.16	0.40		181.02	1.2			
	4e	335.6	190.91	248.10	1.78	2.39	0.61		190.30	1.1			30

* these values are only for comparison and should not be taken as the true compressive strentgth of the material since the size of the specimens have a significant deviation from the size specified in ASTM C140.

	Sample	Volume, cm2	Winitial	Wp	Wf	Wf+r	Wr	Mean Wr	Wfinal	Comp. Strength, MPa	Mean C.Strength*	StDev	
Control	1a'	330.8								2.1	1.8	0.3	
	1b'	332.0								2.1			
	1c'	335.6								1.7			
	1d'	333.5								1.4			
	1e'	333.9								1.7			0
20 Cycles	2a'	332.1	238.57	256.69	1.76	1.78	0.02	0.02	238.55	1.3	1.3	0.4	
	2b'	331.0	215.09	226.96	1.78	1.80	0.02		215.07	1.6			
	2c'	330.6	237.49	249.32	1.75	1.77	0.02		237.47	1.7			
	2d'	334.3	236.96	246.99	1.72	1.75	0.03		236.93	1.2			
	2e'	332.9	231.08	251.30	1.73	1.76	0.03		231.05	0.8			20
25 Cycles	3a'	331.0	237.60	241.59	1.73	1.78	0.05	0.04	237.55	1.4	1.4	0.5	
	3b'	332.4	234.41	240.75	1.74	1.77	0.03		234.38	1.0			
	3c'	333.8	229.25	230.78	1.71	1.75	0.04		229.21	0.9			
	3d'	336.1	219.41	235.41	1.72	1.76	0.04		219.37	1.5			
	3e'	330.6	236.07	239.52	1.75	1.78	0.03		236.04	2.1			25
30 Cycles	4a'	334.4	235.59	257.72	1.72	1.76	0.04	0.04	235.55	1.2	1.5	0.5	
	4b'	335.5	233.43	253.92	1.72	1.77	0.05		233.38	1.3			
	4c'	333.7	229.93	235.44	1.74	1.79	0.05		229.88	1.7			
	4d'	331.8	252.76	266.27	1.74	1.79	0.05		252.71	2.1			
	4e'	331.4	233.01	244.44	1.75	1.78	0.03		232.98	1.0			30

* these values are only for comparison and should not be taken as the true compressive strentgth of the material since the size of the specimens have a significant deviation from the size specified in ASTM C140.

APPENDIX I:

BLOWER DOOR TEST RESULTS

PROSKIW ENGINEERING Ltd.

1666 Dublin Avenu
Winnipeg, Manitob
R3H 0H

Laurie McLeod

File #146

April 16, 2003

Dear Laurie:

re: Alternative Housing For Northern Communities, Experimental House

This is to state that an airtightness test was performed on the above-noted structure, located at the University of Manitoba, on April 14, 2003. The test was conducted in accordance with CAN/CGSB-149.10 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method". The results are shown below along with some comparable airtightness data.

	Normalized Leakage Area at 10 Pa (NLA_{10})	Normalized Leakage Rate at 75 Pa (NLR_{75})
Alternative Housing For Northern Communities, Experimental House	0.65 cm^2/m^2	0.61 $l/s{\bullet}m^2$
Maximum air leakage rate permitted by the Manitoba Building Code for new houses	2.0 cm^2/m^2	
Maximum air leakage rate permitted for R-2000 houses	0.70 cm^2/m^2	
Maximum air leakage rate in the 1995 National Building Code for Part 5 buildings (not mandatory)		0.10 $l/s{\bullet}m^2$ (for relative humidities of 27% to 55%)
Typical air leakage rates for larger (Part 5), existing multi-unit residential buildings (Canada)		1.18 to 6.37 $l/s{\bullet}m^2$
Typical air leakage rates for larger (Part 5), existing office buildings (Canada)		1.44 to 4.01 $l/s{\bullet}m^2$

Phone: (204) 633-1107

Fax: (204) 632-1442

The Normalized Leakage Area at 10 Pa (NLA_{10}) is a parameter typically used to express airtightness results for residential construction while the Normalized Leakage Rate at 75 Pa (NLR_{75}) is normally used for larger buildings such as those covered under Part 5 of the 1995 National Building Code of Canada.

However, a few words of caution need to be considered when interpreting these results. Since the test house was quite small (floor area of 6 m^2, or 64 ft^2), the results are susceptible to minor inconsistencies and unintentional air leakage through the blower door assembly. Although the blower door assembly was carefully taped into place for the test, even very small extraneous leakage could have a disproportionate effect on the results. For example, as you recall, an initial test was performed with two very small holes initially left open (6 mm and about 3 mm diameter, respectively). This increased the measured air leakage, at 75 Pa, by 36%.

Thus, I would recommend that the measured test results shown above should be regarded as maximum values since testing of an equivalent, full-size structure would be less vulnerable to these types of problems and could very well give lower air leakage rates (assuming comparable levels of construction).

A qualitative examination was also performed on the structure to identify if air leakage locations could be identified. No significant sources (other than discussed above) could be found.

Also, a high pressure test was performed in which the structure was depressurized to an (arbitrary) indoor-to-outdoor differential of 153 Pascals (equivalent to a 57 km/hr wind blowing on all sides of the structure simultaneously). No damage or other effects to the structure were observed.

Yours very truly,

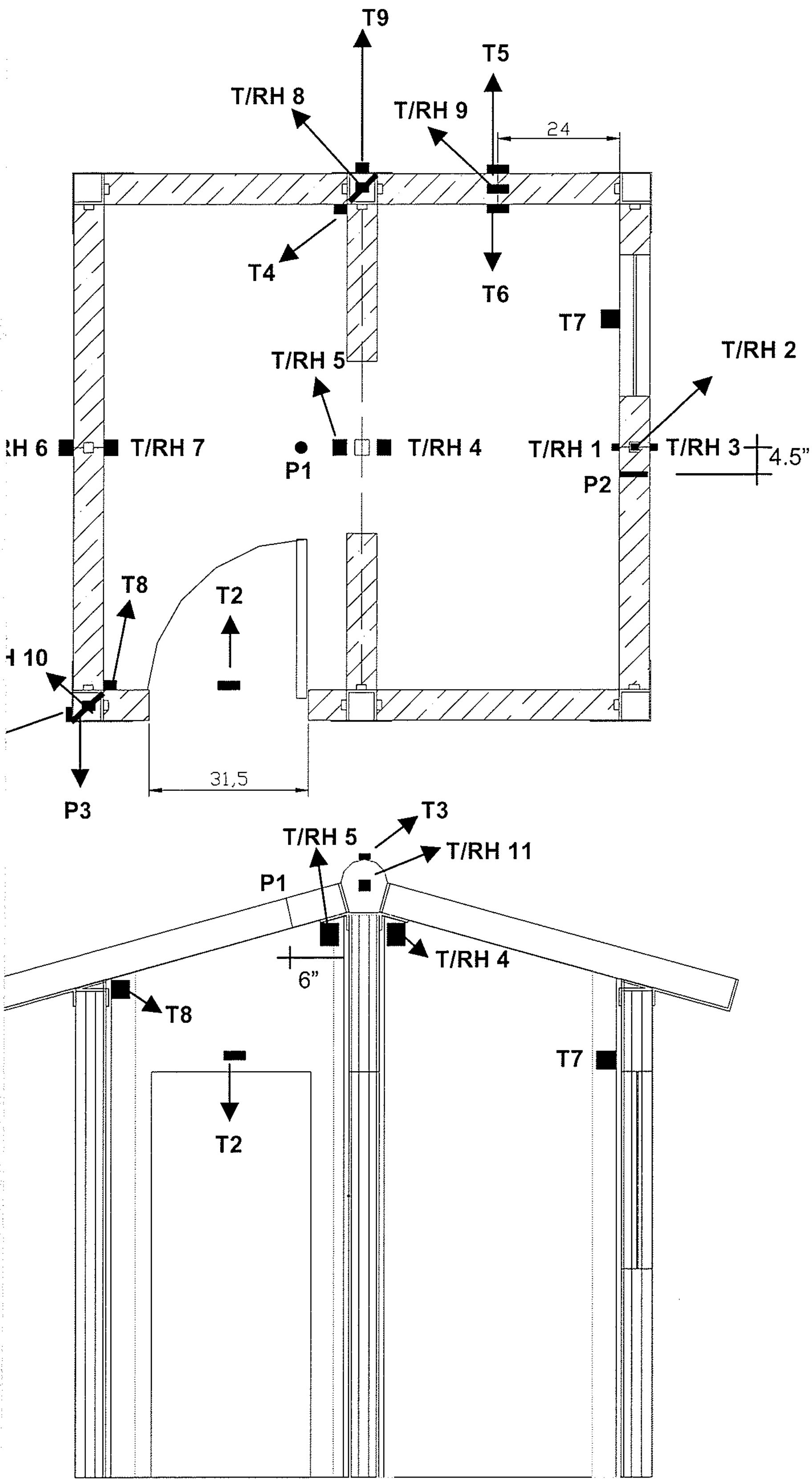
Gary Proskiw, P.Eng.
Proskiw Engineering Ltd.

APEGM
Certificate of Authorization
Proskiw Engineering Ltd.
No. 157 Expiry: April 30, 2004

PROVINCE OF MANITOBA
G. PROSKIW
REGISTERED ENGINEER

APPENDIX J:

SENSOR LOCATION & SPECIFICATIONS



Sensor	Elevation (inches)
T/RH1	48
T/RH2	48
T/RH3	48
T/RH4	96
T/RH5	96
T/RH6	48
T/RH7	48
T/RH8	48
T/RH9	48
T/RH10	48
T/RH11	108
P1	ROOF
P2	48
P3	48
T1	48
T2	80
T3	TOP
T4	48
T5	48
T6	48
T7	82
T8	94
T9	48 (inside skin)

nartReader Plus 2

ʼoduct Specifications

Type: *Four-Channel Temperature and Relative Humidity*

NERAL SMARTREADER PLUS SPECIFICATIONS

ɜ:	107 mm x 74 mm x 22 mm (4.2" x 2.9" x 0.9")
ght:	110 grams (3.75 ounces)
ɜe Material:	Noryl® plastic
tery:	3.6 volt Lithium, guaranteed for ten years
ɜolution:	12-bit (1 part in 4096)
ınting:	Magnetic backing or lock eyelet
ck Accuracy:	+/- 2 seconds per day
npling Methods:	Continuous (First-in, First-out)*, Stop When Full (Fill-then-stop) *Not available with sample rates faster than eight seconds
ɜrating Limits:	-40 to 70°C (-40 to 158°F) and 0 to 95% RH (non-condensing)
Requirements:	IBM PC or 100% compatible with at least one free serial port, 2 MB of RAM memory, and 2 MB of hard disk space
tware Requirements:	TrendReader® Standard - Windows version 3.1, 95, 98, Me, NT, 2000, or XP
nory Size:	128KB; capable of storing 87,000 12-bit readings *(Catalog #:01-0113 SRP-002-128K)*
npling Rates:	User selectable rates from 25 per second to once every eight hours (BP-101 battery pack or PS-201 power supply required for sampling rates faster than eight seconds)
nber of Channels:	Four (one for the internal temperature sensor and one for the internal RH sensor and the remaining two channels are reserved for an optional remote EH-020A probe [temperature and RH probe])

NSOR SPECIFICATIONS

nperature Sensor:	-40 to 70°C (-40 to 158°F), NTC Thermistor
ıccuracy:	+/- 0.2°C from 0 to 70°C; +/- 0.5°C from -40 to 0°C (+/- 0.36°F from 32 to 160°F; +/- 0.9°F from -40 to 32°F)
Sensor:	Capacitive thin polymer film
ıccuracy:	+/- 3% RH from 10 to 90%(-20 to 40°C [-4 to 104°F]); better than 0.04% between 25 and 60% RH at 25°C (77°F)
hod of Operation:	Changes in relative humidity cause the capacitance of the sensor to vary. SRP2 measures this value and converts the readings to a percentage of RH. The RH reading is then temperature-compensated by a simultaneously-taken temperature reading from the RH sensor's companion thermistor.

ɪ SmartReader Plus 2 is a self-contained "air-quality" logger that can be used in a e variety of applications to collect important temperature and relative humidity ɜ. The on-board RH sensor is temperature compensated permitting reliable, ʼry-free RH readings. For remote sensing, simply attach the optional EH-020A ɜrnal temperature and RH probe.

WARRANTY
Internal Battery: 10 Years
Data Logger: 3 Years

APPLICATIONS
Monitoring the transportation or storage of perishable and pharmaceutical goods, tracking "air quality", HVAC system testing and balancing, etc.

Model#:	**Cat#:**
SRP-002-128K	01-0113

Systems Inc.
84th Ave. Tel: 604-591-1128
:. Canada Toll Free: 1-800-663-7845
Fax: 604-591-2252

ACR is an ISO 9001 Registered Company
ISO9000\SPECIFICATIONS\SRP2.PDF

www.acrsystems.com
Technology Made To Measure

nartReader Plus 8

·oduct Specifications

Type: *Eight-Channel Temperature Thermistor*

NERAL SMARTREADER PLUS SPECIFICATIONS

ɜ:	107 mm x 74 mm x 22 mm (4.2" x 2.9" x 0.9")
ght:	110 grams (3.75 ounces)
ıe Material:	Noryl® plastic
tery:	3.6 volt Lithium, guaranteed for ten years
ıolution:	12-bit (1 part in 4096)
ınting:	Magnetic backing or lock eyelet
ck Accuracy:	+/- 2 seconds per day
npling Methods:	Continuous (First-in, First-out)*, Stop When Full (Fill-then-stop) *Not available with sample rates faster than eight seconds
ɜrating Limits:	-40 to 70°C (-40 to 158°F) and 0 to 95% RH (non-condensing)
Requirements:	IBM PC or 100% compatible with at least one free serial port, 2 MB of RAM memory, and 2 MB of hard disk space
tware Requirements:	TrendReader® Standard - Windows version 3.1, 95, 98, Me, NT, 2000, or XP
nory Size: *ıodels available)*	32KB; capable of storing 21,500 12-bit readings *(Catalog#: 01-0015, SRP-008)* 128KB; capable of storing 87,000 12-bit readings *(Catalog#: 01-0129, SRP-008-128K)* 1.5MB; capable of storing 1,048,000 12-bit readings *(Catalog#: 01-0158, SRP-008-1.5M)*
npling Rates:	User selectable rates from 25 per second to once every eight hours (BP-101 battery pack or PS-201 power supply required for sampling rates faster than eight seconds)
nber of Channels:	Eight (one for the internal temperatrure sensor and seven inputs for measurements of temperature, resistance, or switch status)

NSOR SPECIFICATIONS

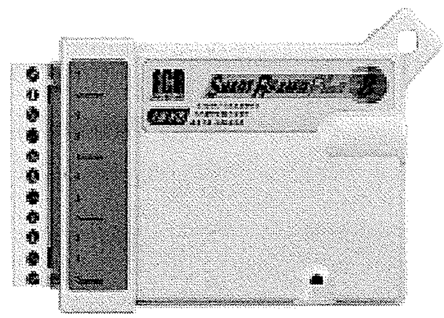
ernal Temperature Sensor: -40 to 70°C (-40 to 170°F), NTC Thermistor

Accuracy: +/- 0.2°C from 0 to 70°C; +/- 0.5°C from -40 to 0°C (+/-0.36°F from 32 to 158°F; +/-0.9°F from -40 to 32°F)

ıtional thermistor temperature probes available for remote measurements:

a) General Purpose Temperature Probe: -35 to 95°C (-30 to 200°F)
b) Low Temperature Probe: -60 to 55°C (-75° to 130°F)
c) High Temperature Probe: 10 to 170°C (50 to 335°F)
d) Oven Temperature Probe: 70 to 255°C (155 to 490°F)
e) Skin Surface Temperature Probe: 20 to 40°C (68 to 104°F)
f) Pipe Surface Temperature Probe: -35 to 95°C (-30 to 200°F)

ɜ SmartReader Plus 8 is an eight-channel temperature logger for measuring the ıperature in up to eight different locations, simultaneously (using optional ıperature probes).



WARRANTY
Internal Battery: 10 Years
Data Logger: 3 Years

APPLICATIONS
Food process verification, pharmaceutical storage, laboratories, transportation of temperature- sensitive goods, equipment run time, HVAC system testing and balancing, etc.

Model#:	Cat#:
SRP-008	01-0013
SRP-008-128K	01-0122
SRP-008-1.5M	01-0151

Systems Inc.
84th Ave. Tel: 604-591-1128
:. Canada Toll Free: 1-800-663-7845
Fax: 604-591-2252

SmartReader Plus Common Specifications

Data Loggers

i-channel
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Bit Data
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ATURES

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2 K, 128 K or
5 MB memory

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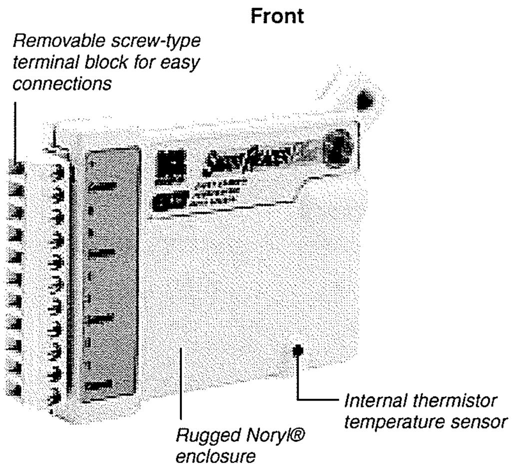
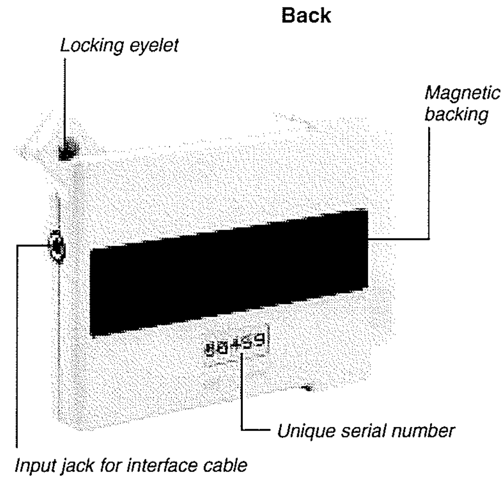




PRODUCT SPECIFICATIONS

SmartReader Plus Data Loggers share many common features. For further specifications on individual models, refer to pages 7-14.

GENERAL

Size:
107 x 74 x 22 mm. (4.2" x 2.9" x 0.9").

Weight:
110 grams (3.75 ounces).

Case Material:
Noryl® Plastic.

Operating Limits:
-40°C to 70°C (-40°F to 158°F) and 0 to 95% Relative Humidity (non-condensing).

Clock Accuracy:
+/-2 seconds per day.

Battery:
3.6 volt Lithium, 1 Amp-Hour.

Battery Life:
10 year warranty (under normal use).
Factory replaceable.

Memory Sizes:
32 K (21,500 readings). 128 K (87,000 readings) 1.5 MB (1,000,000 readings). See specific models for availability.

Sampling Methods:
1. Continuous (First-in, First-out - not available with sample rates faster than 8 seconds).
2. Stop when full (Fill-then-stop).

Sampling Rates:
User selectable rates from 25 per second to one reading every 8 hrs. (BP-101 Battery Pack or PS-201 Power Supply required for sample rates faster than 8 seconds. See Accessories section for details).

Resolution:
12 bit (1 part in 4096).

Power Consumption:
5 to 10 microamps (continuous). Factory replaceable.

PC Requirements:
IBM PC or 100% compatible running MS Windows 3.1, '95, '98, 2000, ME or NT, with at least 2 MB RAM, 2 MB of hard drive disk space and one free serial port.

Product Approvals:
Meets Part 15 for Digital Devices of the Code of Federal Regulations of the Federal Communications Commission (FCC). Meets Class A radiated and conducted emission requirements of Section 2 of the Radio Interference Regulations of Communications Canada. IEC801-2, 3, 4 and EN55011 covering ESD, RFI Immunity, EFT/Burst and Radiated Emissions respectively for the Commission of the European Communities (CE).

Resistance to X-Rays:
Tested for protection against a 160kV dose @ 5mA for 30 seconds (150mA-sec) @ 38 inches F.F.D. (about 100 times that of an airport x-ray machine). Tested for protection against Gamma Ray (equivalent to 0.137-1.38 mega volts) IR 192 - 28 curies @ 30 second exposure source to object distance 5".

INTERNAL TEMPERATURE SENSOR (COMMON ON ALL MODELS, EXCEPT MODEL 9)

Type:
Negative Temperature Coefficient Thermistor.
10,000 ohms @ 25°C (77°F).

Tolerance (sensor only):
+/-0.2°C, over the range of 0 to 70°C (+/-0.3°F over the range of 32 to 158°F).

Range:
-40 to 70°C (-40 to 158°F).

Resolution:
0.03°C (0.05°F) at 25°C (77°F). Better than 0.07°C (0.12°F) between -25°C (-13°F) and 70°C (158°F). Better than 0.13°C (0.23°F) between -40°C (-40°F) and -25°C (-13°F).

APPENDIX K:

SELECTIVE MONITORING RESULTS

Date	Interior Temperature (oC)					
	North	South	South East	North West	West	Roof
3/3/03 0:01	17.93	18.89	18.28	17.95	20.42	20.25
3/3/03 1:01	17.95	18.85	18.23	17.93	20.14	20.18
3/3/03 2:01	17.95	18.85	18.23	17.95	20.14	20.20
3/3/03 3:01	17.95	18.91	18.32	17.95	20.51	20.29
3/3/03 4:01	17.99	18.93	18.34	17.99	20.40	20.31
3/3/03 5:01	18.06	18.96	18.28	18.04	20.25	20.27
3/3/03 6:01	18.02	18.93	18.32	17.99	20.60	20.27
3/3/03 7:01	18.06	19.02	18.37	18.06	20.40	20.34
3/3/03 8:01	18.17	19.09	18.48	18.19	20.55	20.45
3/3/03 9:01	18.34	19.31	18.54	18.41	20.45	20.51
3/3/03 10:01	18.52	19.37	18.72	18.72	20.71	20.62
3/3/03 11:01	18.78	19.55	18.91	19.13	20.95	20.84
3/3/03 12:01	19.09	19.85	19.15	19.53	21.12	21.04
3/3/03 13:01	19.46	20.01	19.39	19.92	21.61	21.26
3/3/03 14:01	19.83	20.31	19.66	20.27	21.56	21.52
3/3/03 15:01	20.14	20.64	19.88	20.53	21.92	21.67
3/3/03 16:01	20.49	20.88	20.20	20.84	22.33	22.05
3/3/03 17:01	20.75	21.15	22.95	20.95	22.51	25.10
3/3/03 18:01	20.01	20.42	22.58	19.83	21.48	24.81
3/3/03 19:01	20.18	20.64	22.29	20.09	21.89	24.48
3/3/03 20:01	20.27	20.80	21.89	20.27	22.31	24.10
3/3/03 21:01	20.36	20.95	21.63	20.31	22.07	23.86
3/3/03 22:01	20.38	21.02	21.21	19.94	22.40	23.44
3/3/03 23:01	20.31	21.04	20.91	19.99	22.20	23.13

Date	Interior Relative Humidity (%) North	Interior Relative Humidity (%) South
3/3/03 0:01	76.31	72.35
3/3/03 1:01	75.31	71.55
3/3/03 2:01	74.58	70.72
3/3/03 3:01	76.59	72.54
3/3/03 4:01	75.46	71.65
3/3/03 5:01	74.74	70.93
3/3/03 6:01	76.99	73.12
3/3/03 7:01	75.86	72.03
3/3/03 8:01	74.91	71.15
3/3/03 9:01	77.25	73.26
3/3/03 10:01	75.70	72.49
3/3/03 11:01	74.87	71.89
3/3/03 12:01	77.09	74.37
3/3/03 13:01	75.95	73.63
3/3/03 14:01	74.91	73.04
3/3/03 15:01	77.16	75.19
3/3/03 16:01	75.57	74.23
3/3/03 17:01	74.44	73.17
3/3/03 18:01	62.70	61.10
3/3/03 19:01	71.35	69.44
3/3/03 20:01	72.42	70.39
3/3/03 21:01	73.01	70.86
3/3/03 22:01	73.26	70.85
3/3/03 23:01	73.24	70.60

Date	Core Temperature (oC)				
	North	South East	North West	West	Roof
3/3/03 0:01	-2.96	-8.22	1.85	-10.82	-20.19
3/3/03 1:01	-2.96	-8.19	1.77	-10.82	-19.55
3/3/03 2:01	-2.90	-8.16	1.77	-10.78	-19.16
3/3/03 3:01	-2.79	-8.03	1.82	-10.39	-18.40
3/3/03 4:01	-2.67	-7.83	1.92	-10.22	-17.94
3/3/03 5:01	-2.50	-7.74	2.05	-10.08	-17.81
3/3/03 6:01	-2.42	-7.70	2.15	-9.70	-17.31
3/3/03 7:01	-2.28	-7.74	2.31	-9.67	-16.91
3/3/03 8:01	-2.22	-7.70	2.41	-9.60	-16.22
3/3/03 9:01	-2.11	-7.93	2.54	-9.29	-15.25
3/3/03 10:01	-1.89	-7.90	2.76	-8.89	-13.76
3/3/03 11:01	-1.34	-7.29	3.19	-8.09	-12.08
3/3/03 12:01	-0.47	-6.72	3.86	-7.16	-10.04
3/3/03 13:01	0.55	-6.47	4.58	-6.53	-9.02
3/3/03 14:01	1.38	-6.34	5.19	-6.06	-8.52
3/3/03 15:01	1.95	-6.19	5.72	-6.06	-9.26
3/3/03 16:01	2.28	-6.50	6.01	-6.06	-10.71
3/3/03 17:01	2.51	-6.53	6.84	-4.61	-10.39
3/3/03 18:01	2.43	-6.09	7.34	-4.64	-11.14
3/3/03 19:01	2.05	-6.19	6.84	-5.91	-11.86
3/3/03 20:01	1.64	-6.56	6.22	-6.72	-12.12
3/3/03 21:01	1.23	-6.81	5.72	-7.54	-12.72
3/3/03 22:01	0.78	-7.29	5.21	-8.46	-14.04
3/3/03 23:01	0.23	-7.54	4.65	-9.02	-15.25

Date	Core Relative Humidity (%)				
	North	South East	North West	West	Roof
3/3/03 0:01	36.10	31.42	27.82	38.82	54.00
3/3/03 1:01	36.26	31.30	27.83	38.68	54.01
3/3/03 2:01	36.35	31.34	27.86	38.62	53.87
3/3/03 3:01	36.57	31.61	27.88	38.64	53.85
3/3/03 4:01	36.67	31.99	27.97	38.55	54.17
3/3/03 5:01	36.66	32.29	28.00	38.63	54.47
3/3/03 6:01	36.75	32.49	28.03	38.57	54.47
3/3/03 7:01	36.79	32.85	28.11	38.48	54.60
3/3/03 8:01	36.91	33.13	28.10	38.50	54.52
3/3/03 9:01	37.07	33.19	28.14	38.56	53.21
3/3/03 10:01	37.07	33.40	28.33	38.62	50.64
3/3/03 11:01	37.21	33.78	28.73	38.69	51.69
3/3/03 12:01	37.41	33.99	29.27	38.87	50.68
3/3/03 13:01	37.49	34.40	29.67	39.00	53.54
3/3/03 14:01	37.51	34.34	29.87	39.14	57.67
3/3/03 15:01	37.65	34.58	29.91	39.18	57.70
3/3/03 16:01	37.49	34.52	29.83	39.25	64.94
3/3/03 17:01	37.56	34.15	30.85	39.49	63.35
3/3/03 18:01	37.67	35.15	30.76	39.51	66.83
3/3/03 19:01	37.59	34.15	29.67	38.94	64.43
3/3/03 20:01	37.56	33.90	29.01	38.66	64.02
3/3/03 21:01	37.82	33.56	28.58	38.47	64.38
3/3/03 22:01	37.89	32.72	28.09	38.36	67.43
3/3/03 23:01	37.59	31.52	27.68	38.33	64.48

Date	Exterior Temperature (oC)				
	North	South	South East	North West	Roof
3/3/03 0:01	-20.35	-20.69	-16.47	-20.40	-21.63
3/3/03 1:01	-19.95	-20.49	-16.30	-20.15	-20.84
3/3/03 2:01	-19.65	-20.09	-16.05	-19.70	-20.30
3/3/03 3:01	-19.46	-19.89	-15.79	-19.36	-19.49
3/3/03 4:01	-19.16	-19.40	-15.41	-18.88	-18.93
3/3/03 5:01	-19.12	-19.40	-15.37	-18.64	-18.72
3/3/03 6:01	-18.83	-19.16	-15.17	-18.36	-18.29
3/3/03 7:01	-18.83	-19.11	-15.17	-18.22	-17.88
3/3/03 8:01	-17.80	-19.40	-15.13	-17.99	-17.25
3/3/03 9:01	-15.55	-19.40	-15.13	-16.90	-16.09
3/3/03 10:01	-11.02	-18.78	-13.68	-14.65	-14.35
3/3/03 11:01	-4.36	-17.13	-12.05	-11.45	-12.29
3/3/03 12:01	-0.97	-15.96	-10.92	-10.13	-10.09
3/3/03 13:01	-1.89	-15.58	-11.07	-10.95	-8.71
3/3/03 14:01	-0.72	-15.00	-10.99	-11.27	-7.87
3/3/03 15:01	-2.81	-14.88	-10.96	-11.97	-8.43
3/3/03 16:01	-4.45	-14.76	-11.21	-5.30	-10.16
3/3/03 17:01	-3.83	-14.35	-10.78	-4.66	-10.03
3/3/03 18:01	-13.28	-15.08	-11.72	-14.37	-11.12
3/3/03 19:01	-14.88	-15.96	-12.46	-15.65	-12.43
3/3/03 20:01	-15.81	-16.47	-13.02	-16.46	-13.33
3/3/03 21:01	-17.34	-17.31	-13.68	-17.71	-13.80
3/3/03 22:01	-19.02	-18.40	-14.92	-19.21	-14.85
3/3/03 23:01	-20.00	-19.06	-15.33	-20.15	-16.11

Date	Exterior Relative Humidity (%)	
	North	South
3/3/03 0:01	48.42	57.84
3/3/03 1:01	48.44	59.08
3/3/03 2:01	48.35	59.77
3/3/03 3:01	54.18	68.31
3/3/03 4:01	56.38	66.64
3/3/03 5:01	57.27	67.28
3/3/03 6:01	57.78	68.32
3/3/03 7:01	61.33	72.74
3/3/03 8:01	57.36	73.20
3/3/03 9:01	48.08	77.51
3/3/03 10:01	35.20	76.25
3/3/03 11:01	25.68	69.51
3/3/03 12:01	21.01	68.49
3/3/03 13:01	21.66	70.36
3/3/03 14:01	19.87	67.41
3/3/03 15:01	22.09	66.65
3/3/03 16:01	24.92	63.82
3/3/03 17:01	23.58	57.57
3/3/03 18:01	40.79	57.98
3/3/03 19:01	52.35	71.53
3/3/03 20:01	58.41	74.29
3/3/03 21:01	57.88	67.43
3/3/03 22:01	50.73	50.53
3/3/03 23:01	48.90	50.25

Date	Pressure (Pa)				Power Consumption
	North	South East	West	Roof	Watt-Hours
3/3/03 0:01	298.89	-298.89	1.74	2.49	931
3/3/03 1:01	298.89	-298.89	0.25	1.74	920
3/3/03 2:01	298.89	-298.89	0.00	1.25	911
3/3/03 3:01	298.89	-298.89	1.74	2.49	929
3/3/03 4:01	298.89	-298.89	1.25	1.99	917
3/3/03 5:01	298.89	-298.89	0.75	2.24	901
3/3/03 6:01	293.18	-298.89	2.24	2.74	918
3/3/03 7:01	283.71	-298.89	1.49	2.24	911
3/3/03 8:01	245.10	-298.89	1.99	2.24	927
3/3/03 9:01	248.09	-298.89	1.74	2.24	910
3/3/03 10:01	231.15	-298.89	1.49	1.99	905
3/3/03 11:01	267.77	-298.89	2.24	2.99	893
3/3/03 12:01	262.29	-298.89	1.99	2.49	907
3/3/03 13:01	4.73	-298.89	3.24	3.24	908
3/3/03 14:01	-1.25	-298.89	1.25	4.73	888
3/3/03 15:01	21.17	-298.89	1.74	2.74	891
3/3/03 16:01	30.14	-298.89	-3.74	3.24	884
3/3/03 17:01	31.14	-298.89	0.25	1.74	947
3/3/03 18:01	27.40	-298.89	2.74	0.00	881
3/3/03 19:01	19.43	-298.89	0.00	0.75	865
3/3/03 20:01	21.67	-298.89	2.24	1.74	877
3/3/03 21:01	16.69	-298.89	0.75	2.74	868
3/3/03 22:01	21.67	-298.89	0.50	-0.50	885
3/3/03 23:01	16.44	-298.89	0.00	-0.50	869

APPENDIX L:

INFRARED TEST RESULTS

INSIGHT I•N•F•R•A•R•E•D Energy Inspections Inc.
Roof Consulting & Infrared Scanning
10 Mirabelle Road
Winnipeg, Manitoba R2V 4E9
Phone (204) 253-3373
Fax (204) 338-6427

INTRODUCTION

1.1 Terms of Reference

Insight Infrared Energy Inspections Inc. was retained by Ms. Lori McLeod, to perform an Infrared scanning survey of the existing test building located in Winnipeg, MB.

1.2 Work Plan

The work plan for the survey was as follows:

- Conduct the Infrared Survey from ground level.
- Provide a brief report including thermographic principles, air temperatures and thermal images of the areas scanned.

EXAMINATION OF EXISTING CONDITIONS

2.1 Survey Conditions

The ambient outside temperature at the time of the survey was -20ºC, with the interior temperature at approximately 20ºC. The wind speed noted was 7km/h at the time of the survey.

PRINCIPLES OF THERMOGRAPHY

3. General

All objects at temperatures above absolute zero radiate energy to their surroundings. The sensor in the infrared camera absorbs radiation given off by objects in its field of view. This information is converted into a visual image, which appears on the display monitor for analysis. The thermograms included in this report provide a visual snapshot of the warm surfaces (white tones) and the cold surfaces (dark tones) noted during the scanning survey.

2.2 Interpreting Thermographic Images

Irregular thermographic patterns are called thermal anomalies and different anomalies are generally indicative of specific problems.

- **Air Leakage**

  Air leakage is the passage of air through elements of the building envelope, such as walls, windows and joints. Leakage from the interior is referred to as exfiltration.

  There are three primary mechanisms driving air through a building envelope:

  1. **Stack Effect** Stack effect is due to warm air being lighter than cool air and thus tending to rise.

  .2 **Wind Effect** Wind blowing on a building induces positive pressures on the Windward side and negative pressures on the leeward side of the building as well as eddy effects and pressure differentials at corners, at grade and at the roof. This will affect the infiltration and exfiltration characteristics of the building. Wind blowing on a building that is under positive pressure will reduce the exfiltration on the windward side and increase the exfiltration on the leeward side.

  .3 **Mechanical** Mechanical systems supply and exhaust air to and from a building. The systems are balanced in order to create positive, negative or neutral pressures in a building with respect to the interior.

The combined effect of these three mechanisms induces air movement through openings in the building envelope, such as openings in sealants or glazing gaskets.

On external thermograms exfiltrating air generally shows up as an intense bright spot at the source of the leak and a warmed zone flaring out from the leak, cooling (darkening) as it moves away.

2.3 Thermal Bridging

Thermal bridging is caused by structural components, which penetrate the insulation. As a result, conduction of heat takes place along these short circuit paths through the insulation. On external thermograms thermal bridges show up as light areas with distinct defined edges, generally in the shape of the structural components causing the bridge.

2.4 Insulation Faults

On an external scan, missing insulation shows up as light patches with distinct, well-defined edges, which generally outline the cavity not insulated. Improperly installed or damaged insulation also shows up as light patches with well defined edges which outline the areas within the cavity where the insulation is not performing it□s function. Moisture soaked insulation appears as a patchy pattern.

OBSERVATIONS

Our observations of the above building found that the general condition of the building was excellent with no appreciable heat loss noted. The structure was found to be extremely efficient in blocking the transfer of heat/cold, with the only evidence of heat loss noted confined to minor amounts around the window and door entrance. This condition would be considered normal and extremely minor in nature.

We trust that this report meets with your approval and if you have any questions please contact the writer.

Yours truly,
INSIGHT INFRARED ENERGY INSPECTIONS INC.

Mark L. Taylor
President

nsight Infrared Energy Inspections Inc.
0 Mirabelle Road
/innipeg, MB
2V 4E9

1670 - 03

JOB PHOTOGRAPH RECORD

Project: U of M

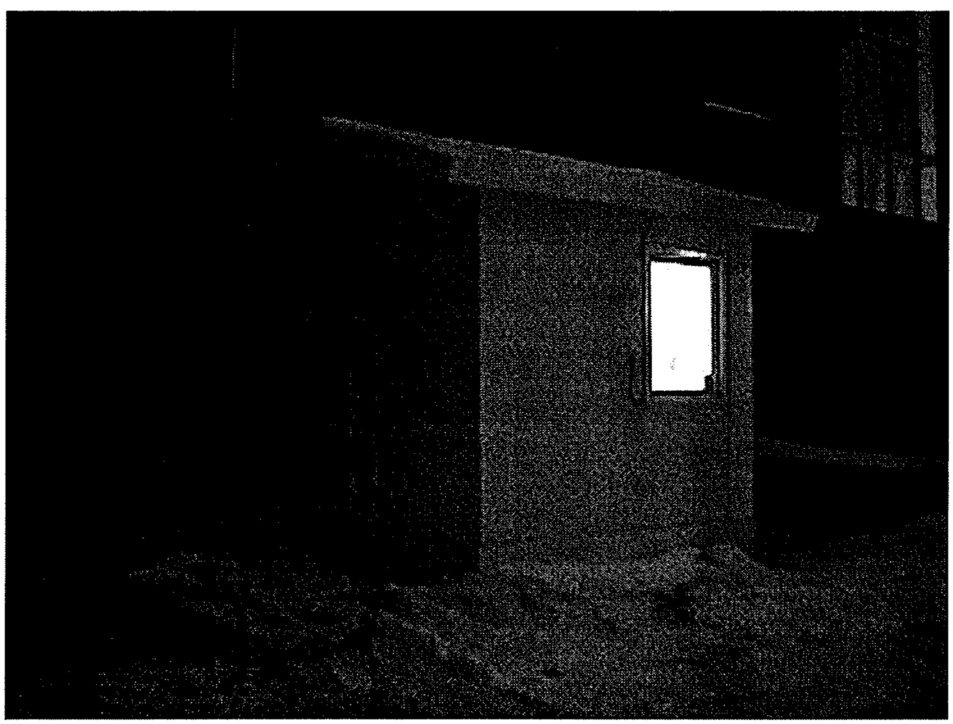
ate: February, 2003

'hoto # 1

'icture of the small test
uilding.

'hoto # 2

Real Life photograph of the
est building.



nsight Infrared Energy Inspections Inc.
0 Mirabelle Road
innipeg, MB
2V 4E9

 # 1670 - 03

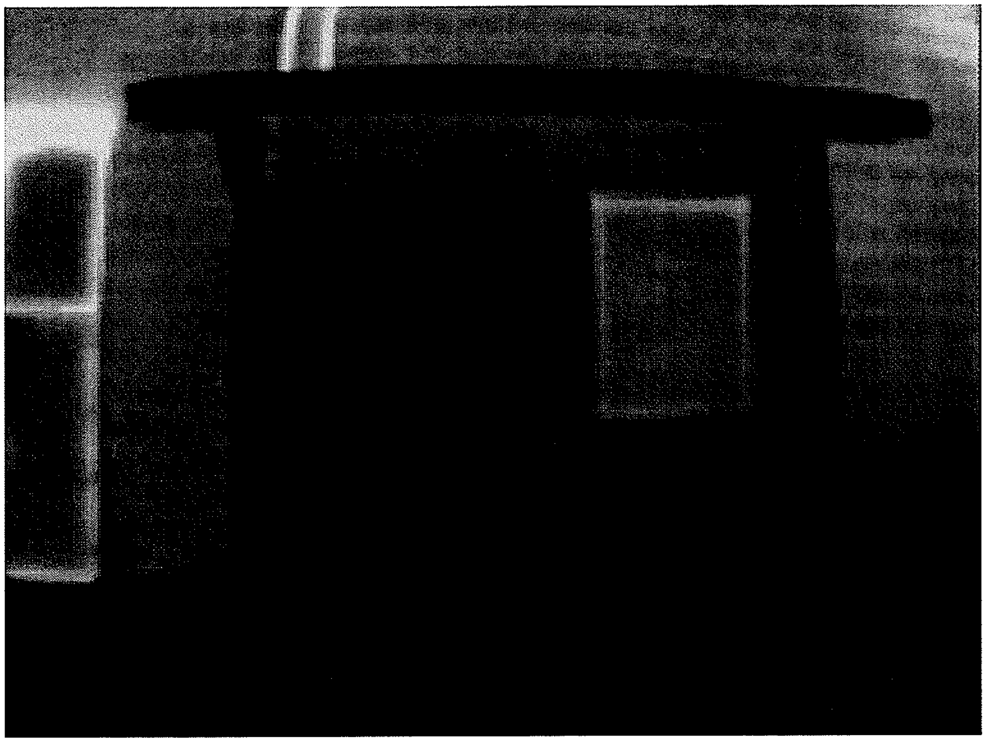
JOB PHOTOGRAPH RECORD

Project: U of M

ate: February, 2003

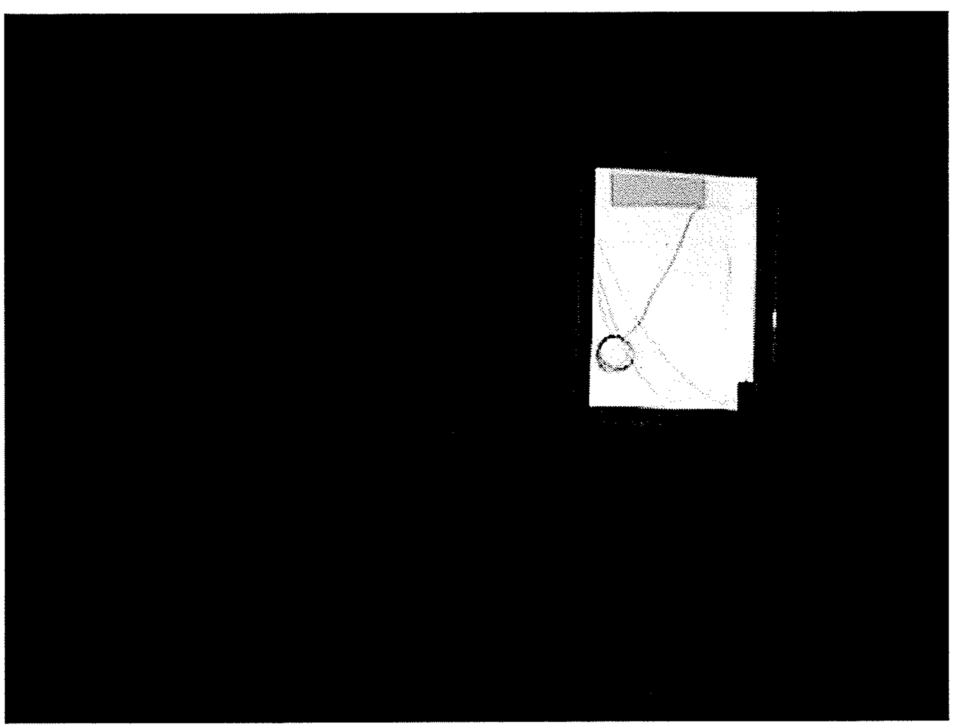
hoto # 3

icture of the North wall,
lease note no heat loss
as noted at the time of
iis survey.



hoto # 4

eal Life photograph of the
est building.



ısight Infrared Energy Inspections Inc.
) Mirabelle Road
innipeg, MB
2V 4E9

1670 - 03

JOB PHOTOGRAPH RECORD

Project: U of M

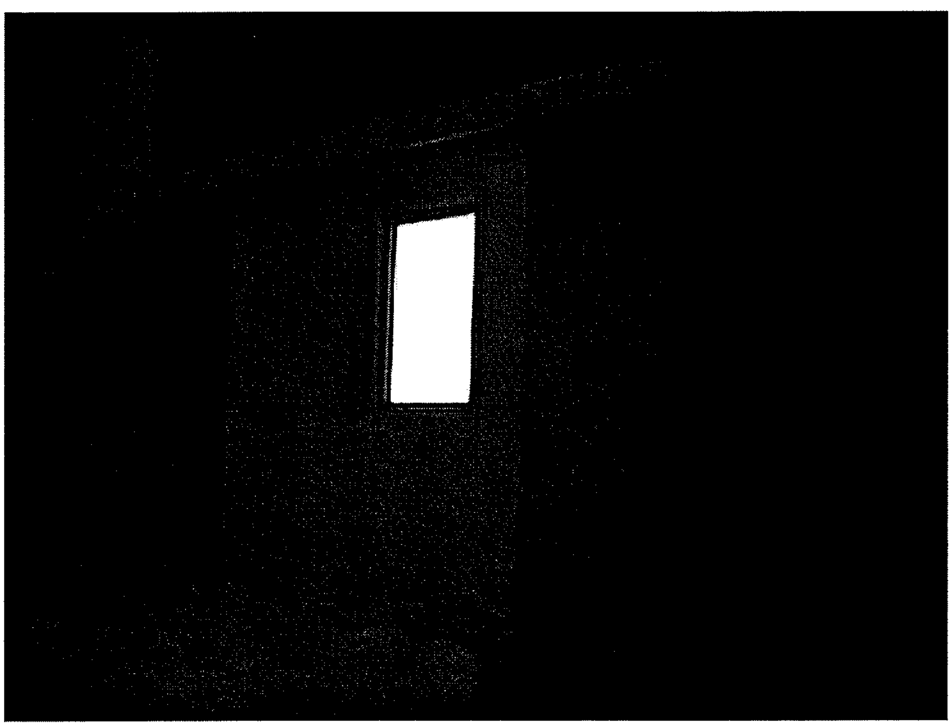
ate: February, 2003

ıoto # 5

cture of the North and
est walls of the test build-
g.

hoto # 6

eal Life photograph of the
ːst building.



ısight Infrared Energy Inspections Inc.
0 Mirabelle Road
innipeg, MB
2V 4E9

1670 - 03

JOB PHOTOGRAPH RECORD

Project: U of M

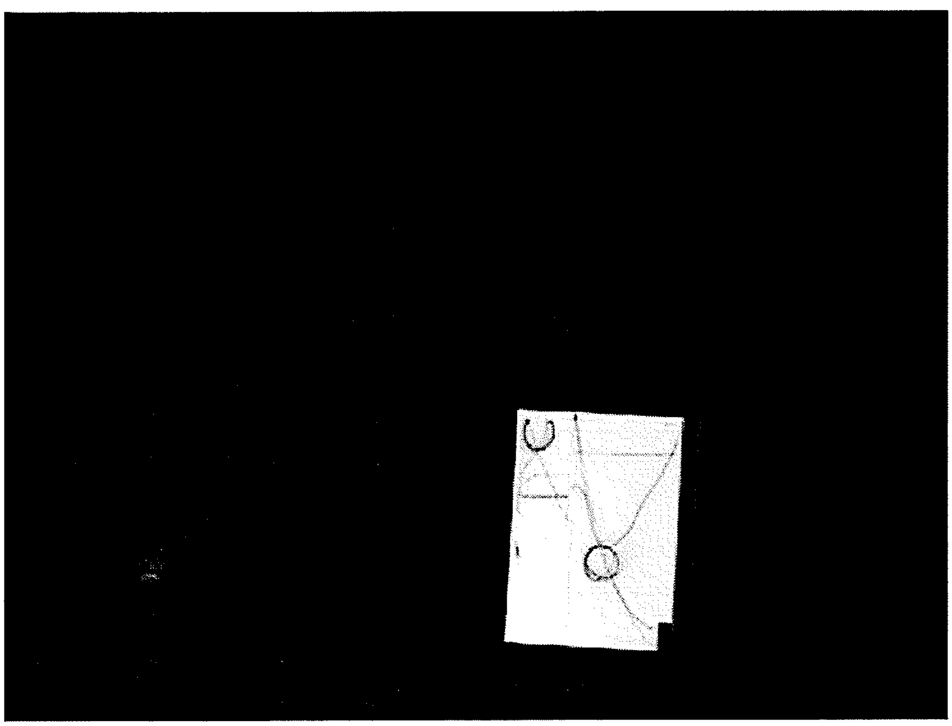
ate: February, 2003

hoto # 7

icture of the Roof Area of
ıe test building.

hoto # 8

eal Life photograph of the
:st building.



ısight Infrared Energy Inspections Inc.
0 Mirabelle Road
'innipeg, MB
2V 4E9

1670 - 03

JOB PHOTOGRAPH RECORD

Project: U of M

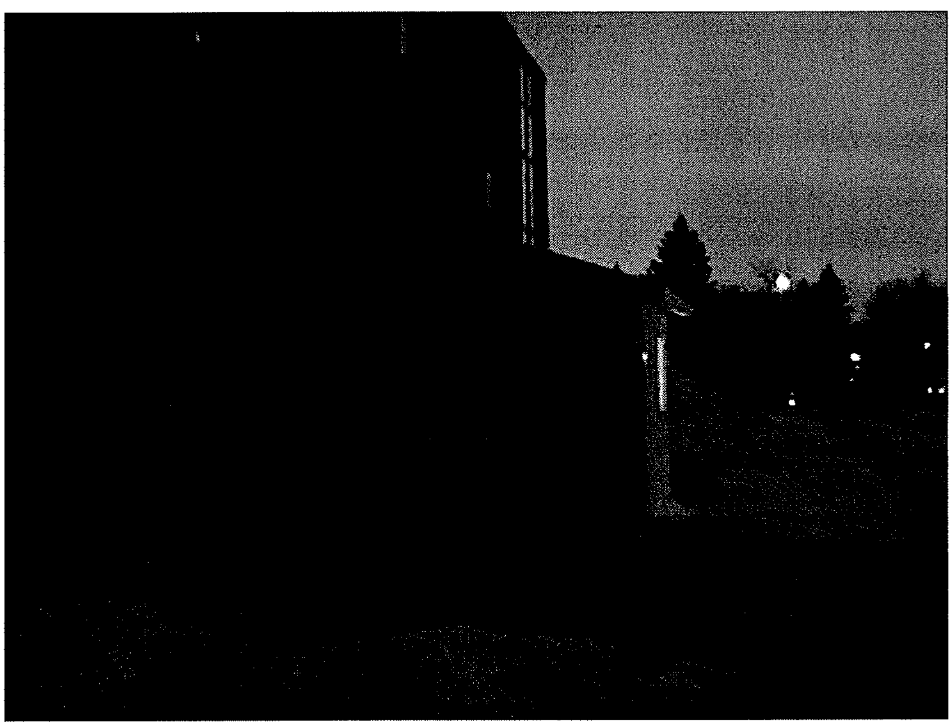
ate: February, 2003

hoto # 9

verall Picture of the test
uilding.

hoto # 10

eal Life photograph of the
ɜst building.



APPENDIX M:

WINDOW TEST RESULTS

(Provided by Manufacturer)

DUXTON
Windows & Doors

Test Report
Sovereign FG 325 Series
Casement/Awning/
Lo & Hi Profile

	Casement	Awning	Fixed
CSA Size	700 mm x 1600 mm	1000 x 1000 mm	1816 x 2020 mm
AAMA Size	27 1/2 x 63"	39 3/8 x 39 3/8"	71 1/2 x 79 1/2"

TYPE	TEST	Standard	REQUIREMENTS		RESULTS	RATING
			Test Standard	Test Criteria		
O	Air Tightness	CSA - 440	ASTM E 283	@ 75 Pascals	0.04 m3/h/m	A3
P		AAMA	ASTM E 283	@ 1.57 psf	0.01 CFM/ft2	PASS
E	Water	CSA - 440	ASTM E	at 700 Pa	No Leakage	B7
R	Tightness	AAMA	ASTM E	at 14.5 psf	No Leakage	HC-90
A	Wind Load	CSA - 440	ASTM E	at 4000 Pa	No Deformation	C4
T	Resistance	AAMA	ASTM E	at 84 psf	No Damage	HC-55
O	Forced Entry	CSA - 440	ASTM E	No Entry	No Entry	F2
R		AAMA	ASTM E	No Entry	No Entry	Grade 10
	Air Tightness	CSA - 440	ASTM E	@ 75 Pascals	0.02 m3/h/m	FIXED
F		AAMA	ASTM E	@ 1.57 psf	0.01 CFM/ft2	PASS
I	Water	CSA - 440	ASTM E	at 700 Pa	No Leakage	B7
X	Tightness	AAMA	ASTM E	at 14.5 psf	No Leakage	HC-90
E	Wind Load	CSA - 440	ASTM E	at 5000 Pa	No Deformation	C5
D	Resistance	AAMA	ASTM E	at 105 psf	No Damage	HC-70

Energy Ratings

The Thermal Performance Values, shown below, are based on products glazed with insulating glass units comprising one lite of Low-E glass, an argon filled cavity, and a double sealed aluminum spacer.

Higher performance may be achieved by using various glass coatings, inert gasses, and/or warm edge spacers.

Ratings are computer simulated in accordance with CSA-A440.2. NFRC values are interpolated from CSA A440.2 Simulations.

	Casement/Awning		Fixed - High Profile	
Performance	CSA-440.2	NFRC	CSA-440.2	NFRC
U-Value : Frame	1.43 W/m2/C	0.26 Btu/h/ft2/F	1.64 W/m2/C	0.34 Btu/h/ft2/F
U-Value : Window	1.80 W/m2/C	0.32 Btu/h/ft2/F	1.84 W/m2/C	0.33 Btu/h/ft2/F
SHGC	0.49	0.49	0.63	0.63

Note: The reader is cautioned that test results should be used for comparison purposes only. Results are size and installation dependent. In-Service performance can be significantly different from those shown.

*AAMA Results are extrapolated form Canadian Test Results

APPENDIX N:

PARAMETRIC VARIABLES AND RESULTS OF HOT2000 MODELLING

HOT2000

Natural Resources CANADA
Version 9.01

File: Pauingassi - Laurie1.HSE
Application Type: R-2000

Weather Data for WINNIPEG, MANITOBA

Builder Code:

Data Entry by: Laurie McLeod
Date of entry: 9/12/2003
Company: University of Manitoba

Client name:
Street address:

City:
Postal code:

Region:
Telephone:

GENERAL HOUSE CHARACTERISTICS

House type: Single detached
Number of storeys: One storey
Plan shape: Rectangular
Front orientation: Northeast
Year House Built: 2003
Wall colour:
Absorptivity:
Roof colour: Medium brown
Absorptivity: 0.84
Soil Condition: Normal conductivity (dry sand, loam, clay)
Water Table Level: Normal (7-10m/23-33ft)

House Thermal Mass Level: (B) Medium, wood frame

Effective mass fraction 1.000

Occupants :
2 Adults for 50.0% of the time
2 Children for 50.0% of the time
0 Infants for 0.0% of the time

Sensible Internal Heat Gain From Occupants: 2.40 kWh/day

HOUSE TEMPERATURES

Heating Temperatures

Main Floor:	21.0 °C
Basement:	19.0 °C
Crawl Space:	15.0
Calculated Crawl Space:	16.8
TEMP. Rise from 21.0 °C:	2.8 °C

Indoor design temperatures for equipment sizing

Heating:	22.0 °C
Cooling:	24.0 °C

WINDOW CHARACTERISTICS

Label	Location	#	Overhang Width (m)	Header Height (m)	Tilt deg	Curtain Factor	Shutter (RSI)
Southeast							
Window - 8	Wall - 2	1	0.41	0.61	90.0	1.00	0.00
Window - 9	Wall - 2	1	0.41	1.22	90.0	1.00	0.00
Northeast							
Window - 1	Wall - 2	1	0.41	0.15	90.0	1.00	0.00
Window - 2	Wall - 3	1	0.41	0.15	90.0	1.00	0.00
Window - 3	Wall - 4	1	0.41	0.15	90.0	1.00	0.00
Window - 4	Wall - 5	1	0.41	0.15	90.0	1.00	0.00
Southwest							
Window - 5	Wall - 6	1	0.41	0.15	90.0	1.00	0.00
Window - 6	Wall - 7	1	0.41	0.15	90.0	1.00	0.00
Window - 7	Wall - 1	1	0.41	0.15	90.0	1.00	0.00

Label	Type	#	Window Width (m)	Window Height (m)	Total Area (m^2)	Window RSI	SHGC
Southeast							
Window - 8	313p4	1	0.91	1.22	1.11	0.723	0.3508
Window - 9	313p4	1	0.91	1.22	1.11	0.723	0.3508
Northeast							
Window - 1	313p4	1	0.91	1.22	1.11	0.723	0.3508
Window - 2	313p4	1	0.46	0.46	0.21	0.570	0.2342
Window - 3	313c4	1	0.91	1.22	1.11	0.723	0.3508
Window - 4	313c4	1	0.91	1.22	1.11	0.723	0.3508
Southwest							

Window - 5	313c4	1	0.91	1.22	1.11	0.723	0.3508
Window - 6	313c4	1	0.91	1.22	1.11	0.723	0.3508
Window - 7	313c4	1	0.91	0.91	0.84	0.699	0.3367

WINDOW CODE SCHEDULE

Name	Internal Code	Description (Glazings, Coatings, Fill, Spacer, Type, Frame)
313p4	313214	Triple/triple with 1 coat, Low-E .04 (soft), 13 mm Argon, Insulating, Hinged, Vinyl, ER* = -11.59, Eff. RSI= 0.45

* Window Standard Energy Rating estimated for assumed dimensions, and Air tightness type: CSA - A1; Leakage rate = 2.790 m^3/hr/m

BUILDING PARAMETER DETAILS

CEILING COMPONENTS

	Construction Type	Code Type	Roof Slope	Heel Ht.(m)	Section Area (m^2)	R. Value (RSI)
Ceiling - 1	Cathedral	User specified	4.0/12	0.17	13.46	5.28
Ceiling - 2	Cathedral	User specified	4.0/12	0.17	19.58	5.28
Ceiling - 3	Cathedral	User specified	4.0/12	0.17	5.99	5.28
Ceiling - 4	Cathedral	User specified	4.0/12	0.17	12.39	5.28
Ceiling - 5	Cathedral	User specified	4.0/12	0.17	10.00	5.28
Ceiling - 6	Cathedral	User specified	4.0/12	0.17	14.38	5.28
Ceiling - 7	Cathedral	User specified	4.0/12	0.17	10.00	5.28
Ceiling - 8	Cathedral	User specified	4.0/12	0.17	9.38	5.28

MAIN WALL COMPONENTS

Label	Lintel Type	Fac. Dir	Number of Corn.	Number of Inter.	Height (m)	Perim. (m)	Area (m^2)	R. Value (RSI)
Wall - 1 Type: User specified	N/A	N/A	1	0	2.44	8.23	20.07	5.28
Wall - 2 Type: User specified	N/A	N/A	1	0	2.44	9.63	23.49	5.28
Wall - 3 Type: User specified	N/A	N/A	0	0	2.44	1.52	3.72	5.28
Wall - 4 Type: User specified	N/A	N/A	0	0	2.44	3.15	7.68	5.28
Wall - 5 Type: User specified	N/A	N/A	1	0	2.44	7.19	17.54	5.28
Wall - 6 Type: User specified	N/A	N/A	1	0	2.44	8.31	20.25	5.28
Wall - 7 Type: User specified	N/A	N/A	0	0	2.44	2.54	6.20	5.28
Wall - 8								

Type: User specified	N/A	N/A	0	0	2.44	2.39	5.82	5.28

DOORS

Label	Type	Height (m)	Width (m)	Gross Area (m^2)	R. Value (RSI)
Door - 1 Loc: Wall - 2	Steel polyurethane core	2.07	1.02	2.10	1.14
Door - 2 Loc: Wall - 8	Steel polyurethane core	2.07	1.02	2.10	1.14

FOUNDATIONS

Foundation Name: Crawlspace - 1
Foundation Type: Crawl space
Data Type: Library

Volume: 115.7 m^3
Ventilation Type: Closed
Thermal Break R-Value: 0.00 RSI
Skirt R-value: 0.00 RSI

Total Wall Height: 1.27 m
Floor Length: 12.19 m

Rectangular
Floor Width: 7.47 m

Wall type: User specified — **R-Value** 5.28 RSI
Number of Corners: 4
Lintel Type: N/A
Added to slab type : N/A — **R-value :** 1.32 RSI
Floors above found.: User specified — **R-value :** 0.65 RSI

Roof Cavity Inputs

Gable Ends — **Total Area:** m^2
Sheathing Material — RSI
Exterior Material: — RSI

Sloped Roof — **Total Area:** 0.00 m^2
Sheathing Material Plywood/Part. bd 12.7 mm (1/2 in) — 0.11 RSI
Exterior Material: Asphalt shingles — 0.08 RSI

Total Cavity Volume: 0.0 m^3 — **Ventilation Rate:** 0.50 ACH/hr

Added To Slab

Name	Code	Description (Framing, Spacing, Insulation, Int., Sheathing)
38 mm XTPS IV (1	00A00	None, 305 mm (12 in), 38 mm XTPS IV (1.5 in), None, None

BUILDING ASSEMBLY DETAILS

Label	Construction Code	Nominal (RSI)	System (RSI)	Effective (RSI)

BUILDING PARAMETERS SUMMARY

ZONE 1 : Above Grade

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Ceiling	95.19	95.19	5.28	8049.75	14.43
Main Walls	104.76	91.71	5.28	9934.91	17.81
Doors	4.21	4.21	1.14	2196.36	3.94
Southeast Windows	2.23	2.23	0.72	1836.19	3.29
Northeast Windows	3.55	3.55	0.71	2972.42	5.33
Southwest Windows	3.07	3.07	0.72	2548.20	4.57
		ZONE 1 Totals:		27537.84	49.35

ZONE 2 : Basement

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Below grade foundation	0.00	0.00	-	0.00	0.00
		ZONE 2 Totals:		0.00	0.00

ZONE 3: Crawl Space Foundation

Component	Area m^2 Gross	Area m^2 Net	Effective (RSI)	Heat Loss MJ	% Annual Heat Loss
Foundation	141.02	141.02	-	20417.71	36.59
		ZONE 3 Totals:		20417.71	36.59

Ventilation

House Volume	Air Change	Heat Loss MJ	% Annual Heat Loss
393.13 m^3	0.242 ACH	7840.460	14.05

AIR LEAKAGE AND VENTILATION

Building Envelope Surface Area: 340.97 m^2

Air Tightness Level is

Terrain Description	**Height**	**m**
@ Weather Station : Open flat terrain, grass	Anemometer	10.0
@ Building site : Suburban, forest	Bldg. Eaves	3.0

Local Shielding:	**Walls:**	Very heavy
	Flue :	Light

Leakage Fractions- Ceiling: 0.200 **Walls:** 0.500 **Floors:** 0.300

Estimated Equivalent Leakage Area @ 0.00:	149.78 cm2
Normalized Leakage Area @ 10 Pa:	0.4393 cm2/m2
Estimated Airflow to cause a 5 Pa Pressure Difference:	10 L/s
Estimated Airflow to cause a 10 Pa Pressure Difference:	15 L/s
ELA used to calculate Estimated Airflows:	59.91 cm2

F326 VENTILATION REQUIREMENTS

Kitchen, Living Room, Dining Room	3 rooms @ 15.0 L/s: 15.0 L/s
Bedroom	1 rooms @ 10.0 L/s: 10.0 L/s
Bedroom	3 rooms @ 15.0 L/s: 15.0 L/s
Bathroom	1 rooms @ 5.0 L/s: 5.0 L/s
Basement Rooms	: 0.0 L/s

CENTRAL VENTILATION SYSTEM

System Type:	HRV
Manufacturer:	Lifebreath
Model Number:	155 Max

Fan and Preheater Power at 0.0 °C:	57 Watts
Fan and Preheater Power at -25.0 °C:	57 Watts
Preheater Capacity:	0 Watts
Sensible Heat Recovery Efficiency at 0.0 °C	67%
Sensible Heat Recovery Efficiency at -25.0 °C	70%
Total Heat Recovery Efficency in Cooling Mode	28%

Low Temperature Ventilation Reduction: 0%

Low Temperature Ventilation Reduction: Airflow Adjustment (0%)

Vented combustion appliance depressurization limit: 5.00 Pa.

Ventilation Supply Duct

Location:	Main floor	**Type:**	Flexible
Length:	1.5 m	**Diameter:**	152.4 mm
Insulation:	0.7 RSI	**Sealing Characteristics:**	Sealed

Ventilation Exhaust Duct

Location:	Main floor	**Type:**	Flexible
Length:	1.5 m	**Diameter:**	152.4 mm
Insulation:	0.7 RSI	**Sealing Characteristics:**	Sealed

Operating schedule for

Month	% of Time	Added Vent. Rate (L/s)	Month	% of Time	Add Ra
Jan	85.23	24.32	Jul	0.00	
Feb	87.32	24.92	Aug	0.00	
Mar	91.73	26.18	Sep	0.00	
Apr	97.99	27.96	Oct	100.00	
May	0.00	0.00	Nov	93.74	
Jun	0.00	0.00	Dec	88.21	

AIR LEAKAGE AND VENTILATION SUMMARY

F326 Required continous ventilation:	45.000 L/s (0.58 ACH)
Central Ventilation Supply Rate ():	28.536 L/s (0.37 ACH)
Total house ventilation is Balanced	
Gross Air Leakage and Ventilation Energy Load:	19665.354 MJ
Seasonal Heat Recovery Ventilator Efficiency:	66.353 %
Estimated Ventilation Electrical Load: Heating Hours:	959.405 MJ
Estimated Ventilation Electrical Load: Non-Heating Hours:	2.996 MJ
Net Air Leakage and Ventilation Load:	8320.163 MJ

ROOM-BY-ROOM DESIGN HEATING AND COOLING LOADS SUMMARY

Room Name	Floor Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)	Ventilation Flow Heating (L/s)	Ventilation Flow Cooling (L/s)
BR2	9	697	225	18	16
BR3	9	863	170	22	12
BR4	12	840	152	21	11
MBR	14	1125	259	28	19
bath	6	382	29	10	2
kitchen - dining	13	1079	667	27	48
living	19	1752	887	44	64
utility	9	671	31	17	2
Crawlspace - 1	91	0	0	0	0
Whole house	91	7410	2421	187	175
Latent cooling	-	-	810	-	-
Totals	91	7410	3231	187	175

ROOM-BY-ROOM DESIGN HEATING AND COOLING LOAD DETAILS

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR2					
C:Ceiling - 7	5.28	10.0	10.0	104	40
W:Wall - 7	5.28	6.2	5.1	53	7
-G:Window - 6	0.72	1.1	1.1	85	144
Crawlspace - 1	0.65	91.0	91.0	127	-33
Total Loss/Gain	-	-	-	242	191
Air Change	-	-	-	201	67
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	697	225
Air Flow Rate (L/s)	-	-	-	18	16

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR3					
C:Ceiling - 5	5.28	10.0	10.0	104	40
W:Wall - 5	5.28	17.5	16.4	171	24
-G:Window - 4	0.72	1.1	1.1	85	89
Crawlspace - 1	0.65	91.0	91.0	127	-33
Total Loss/Gain	-	-	-	360	152
Air Change	-	-	-	249	51
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	863	170
Air Flow Rate (L/s)	-	-	-	22	12

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR4					
C:Ceiling - 4	5.28	12.4	12.4	129	49

ROOM-BY-ROOM DESIGN HEATING AND COOLING LOADS SUMMARY

Room Name	Floor Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)	Ventilation Flow Heating (L/s)	Ventilation Flow Cooling (L/s)
BR2	9	697	225	18	16
BR3	9	863	170	22	12
BR4	12	840	152	21	11
MBR	14	1125	259	28	19
bath	6	382	29	10	2
kitchen - dining	13	1079	667	27	48
living	19	1752	887	44	64
utility	9	671	31	17	2
Crawlspace - 1	91	0	0	0	0
Whole house	91	7410	2421	187	175
Latent cooling	-	-	810	-	-
Totals	91	7410	3231	187	175

ROOM-BY-ROOM DESIGN HEATING AND COOLING LOAD DETAILS

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR2					
C:Ceiling - 7	5.28	10.0	10.0	104	40
W:Wall - 7	5.28	6.2	5.1	53	7
-G:Window - 6	0.72	1.1	1.1	85	144
Crawlspace - 1	0.65	91.0	91.0	127	-33
Total Loss/Gain	-	-	-	242	191
Air Change	-	-	-	201	67
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	697	225
Air Flow Rate (L/s)	-	-	-	18	16

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR3					
C:Ceiling - 5	5.28	10.0	10.0	104	40
W:Wall - 5	5.28	17.5	16.4	171	24
-G:Window - 4	0.72	1.1	1.1	85	89
Crawlspace - 1	0.65	91.0	91.0	127	-33
Total Loss/Gain	-	-	-	360	152
Air Change	-	-	-	249	51
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	863	170
Air Flow Rate (L/s)	-	-	-	22	12

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
BR4					
C:Ceiling - 4	5.28	12.4	12.4	129	49

W:Wall - 4	5.28	7.7	6.6	68	10
-G:Window - 3	0.72	1.1	1.1	85	89
Crawlspace - 1	0.65	91.0	91.0	158	-41
Total Loss/Gain	-	-	-	282	148
Air Change	-	-	-	242	45
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	840	152
Air Flow Rate (L/s)	-	-	-	21	11

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
MBR					
C:Ceiling - 6	5.28	14.4	14.4	150	57
W:Wall - 6	5.28	20.3	19.1	199	28
-G:Window - 5	0.72	1.1	1.1	85	144
Crawlspace - 1	0.65	91.0	91.0	184	-47
Total Loss/Gain	-	-	-	434	229
Air Change	-	-	-	324	77
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	1125	259
Air Flow Rate (L/s)	-	-	-	28	19

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
bath					
C:Ceiling - 3	5.28	6.0	6.0	62	24
W:Wall - 3	5.28	3.7	3.5	37	5
-G:Window - 2	0.57	0.2	0.2	20	11
Crawlspace - 1	0.65	91.0	91.0	77	-20
Total Loss/Gain	-	-	-	119	40
Air Change	-	-	-	110	9
Internal Gain: People	-	-	-	-	0

Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	382	29
Air Flow Rate (L/s)	-	-	-	10	2

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
kitchen - dining					
C:Ceiling - 1	5.28	13.5	13.5	140	54
W:Wall - 1	5.28	20.1	19.2	200	28
-G:Window - 7	0.70	0.8	0.8	66	104
Crawlspace - 1	0.65	91.0	91.0	181	-47
Total Loss/Gain	-	-	-	406	185
Air Change	-	-	-	311	59
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	470
Total Room Load	-	-	-	1079	667
Air Flow Rate (L/s)	-	-	-	27	48

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
living					
C:Ceiling - 2	5.28	19.6	19.6	204	78
W:Wall - 2	5.28	23.5	18.0	188	26
-G:Window - 8	0.72	1.1	1.1	85	144
-G:Window - 9	0.72	1.1	1.1	85	144
-G:Window - 1	0.72	1.1	1.1	85	89
-D:Door - 1	1.14	2.1	2.1	102	10
Crawlspace - 1	0.65	91.0	91.0	250	-64
Total Loss/Gain	-	-	-	748	491
Air Change	-	-	-	505	181
Internal Gain: People	-	-	-	-	280
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	1752	887
Air Flow Rate (L/s)	-	-	-	44	64

Room Component	R-Value	Gross Area (m^2)	Net Area (m^2)	Heating Load (Watts)	Cooling Load (Watts)
utility					
C:Ceiling - 8	5.28	9.4	9.4	98	37
W:Wall - 8	5.28	5.8	3.7	39	5
-D:Door - 2	1.14	2.1	2.1	102	10
Crawlspace - 1	0.65	91.0	91.0	120	-31
Total Loss/Gain	-	-	-	238	53
Air Change	-	-	-	193	9
Internal Gain: People	-	-	-	-	0
Internal Gain: Appliances	-	-	-	-	0
Total Room Load	-	-	-	671	31
Air Flow Rate (L/s)	-	-	-	17	2

SPACE HEATING SYSTEM

Primary Heating Fuel: Electricity
Equipment: Forced air furnace
Manufacturer:
Model:
Calculated* Output Capacity: 7.50 kW
* Design Heat loss X 1.00 + 0.5 kW
Steady State Efficiency: 100.00 %
Fan Mode : Auto
Low Speed Fan Power 0 watts
High Speed Fan Power 146 watts

DOMESTIC WATER HEATING SYSTEM

Primary Water Heating Fuel: Electricity
Water Heating Equipment: Conserver tank
Energy Factor: 0.90
Manufactuer:
Model:

Tank Capacity = 189.12 Litres
Tank Loacation: Main floor
Tank Blanket Insulation 0.00 RSI

ANNUAL SPACE HEATING SUMMARY

Design Heat Loss at -33.00 °C (18.85 Watts / m3): 7409.66 Watts
Including credit for HRV (10.19 Watts / m3): 4006.99
Gross Space Heat Loss: 55796.01 MJ

Usable Internal Gains: 23596.10 MJ
Usable Internal Gains Fraction: 42.29 %
Usable Solar Gains: 5469.61 MJ
Usable Solar Gains Fraction: 9.80 %
Auxilary Energy Required: 29872.39 MJ

Space Heating System Load: 29872.39 MJ
Furnace/Boiler Seasonal efficiency: 100.00 %
Furnace/Boiler Annual Energy Consumption: 29303.89 MJ

ANNUAL DOMESTIC WATER HEATING SUMMARY

Daily Hot Water Consumption:	225.00 Litres
Hot Water Temperature:	55.00 °C
Estimated Domestic Water Heating Load:	17065.10 MJ
Primary Domestic Water Heating Energy Consumption:	18730.42 MJ
Primary System Seasonal Efficiency:	91.11%

BASE LOADS SUMMARY

	kwh/day	**Annual kWh**
Interior Lighting	3.00	1095.00
Appliances	14.00	5110.00
Other	3.00	547.50
Exterior Use	4.00	1460.00
HVAC Fans		
HRV/Exhaust	0.73	267.33
Space Heating	0.43	157.92
Space Cooling	0.00	0.00
Total Average Electrical Load	25.17	9185.25

FAN OPERATION SUMMARY (kWh)

Hours	**HRV/Exhaust Fans**	**Space Heating**	**Space Cooling**
Heating	266.50	157.92	0.00
Neither	0.83	0.00	0.00
Cooling	0.00	0.00	0.00
Total	267.33	157.92	0.00

R-2000 HOME PROGRAM ENERGY CONSUMPTION SUMMARY REPORT

Estimated Annual Space Heating Energy Consumption	= 29872.39 MJ	= 8297.89 kWh
Ventilator Electrical Consumption: Heating Hours	= 959.41 MJ	= 266.50 kWh
Estimated Annual DHW Heating Energy Consumption	= 18730.42 MJ	= 5202.89 kWh
ESTIMATED ANNUAL SPACE + DHW ENERGY CONSUMPTION	= 49562.21 MJ	= 13767.28 kWh
ANNUAL R-2000 SPACE + DHW ENERGY CONSUMPTION TARGET	= 53887.16 MJ	= 14968.66 kWh

Estimated Greenhouse Gas Emissions 240.87 kg/year

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY

Fuel	Space Heating	Space Cooling	DHW Heating	Appliance	Total
Electricity (kWh)	8564.38	0.00	5202.89	8760.83	22528.11

ESTIMATED ANNUAL FUEL CONSUMPTION COSTS

Fuel Costs Library = C:\PROGRA~1\STDLIBS\FuelLib.FLC

RATE	Electricity (WpgHyd97)	Natural Gas (WpgGas98)	Oil (Ottawa97)	Propane (Ottawa97)	Wood ($70/Cord)	Total
$	1250.47	0.00	0.00	0.00	0.00	1250.47

MONTHLY ENERGY PROFILE

Month	Energy Load (MJ)	Internal Gains (MJ)	Solar Gains (MJ)	Aux. Energy (MJ)	HRV Eff. %
Jan	9864.9	2460.4	605.8	7552.6	67.4
Feb	8227.9	2217.4	729.5	5867.3	66.9
Mar	7269.8	2460.3	976.7	4258.5	66.2
Apr	4524.1	2389.9	721.8	1569.6	65.8
May	2711.3	2089.8	621.5	0.0	0.0
Jun	1287.9	1216.9	71.1	0.0	0.0
Jul	786.7	777.7	9.0	0.0	0.0
Aug	978.8	955.5	23.3	0.0	0.0
Sep	2007.9	1726.5	281.4	0.0	0.0
Oct	3750.6	2411.9	505.0	926.3	65.8
Nov	6000.1	2414.7	440.8	3493.5	65.8
Dec	8543.9	2475.1	483.8	6204.7	66.8
Ann	55954.0	23596.1	5469.6	29872.4	66.4

FOUNDATION ENERGY PROFILE

	Heat Loss (MJ)				
Month	Crawl Space	Slab	Basement	Walkout	Total
Jan	2898.0	0.0	0.0	0.0	2898.0
Feb	2563.6	0.0	0.0	0.0	2563.6
Mar	2462.3	0.0	0.0	0.0	2462.3
Apr	1841.5	0.0	0.0	0.0	1841.5
May	1432.8	0.0	0.0	0.0	1432.8
Jun	1002.4	0.0	0.0	0.0	1002.4
Jul	789.3	0.0	0.0	0.0	789.3
Aug	769.4	0.0	0.0	0.0	769.4
Sep	980.7	0.0	0.0	0.0	980.7
Oct	1364.3	0.0	0.0	0.0	1364.3
Nov	1835.3	0.0	0.0	0.0	1835.3
Dec	2478.1	0.0	0.0	0.0	2478.1
Ann	20417.7	0.0	0.0	0.0	20417.7

FOUNDATION TEMPERATURES & VENTILATION PROFILE

	Temperature (Deg °C)			Air Change Rate		Heat Loss
Month	Crawl Space	Basement	Walkout	Natural	Total	(MJ

Jan	15.0	0.0	0.0	0.1	0.4	1665.0
Feb	15.0	0.0	0.0	0.1	0.4	1355.0
Mar	15.1	0.0	0.0	0.1	0.4	1145.2
Apr	15.9	0.0	0.0	0.0	0.4	605.5
May	17.2	0.0	0.0	0.0	0.0	89.1
Jun	18.2	0.0	0.0	0.0	0.0	25.8
Jul	18.9	0.0	0.0	0.0	0.0	11.1
Aug	18.9	0.0	0.0	0.0	0.0	19.5
Sep	18.3	0.0	0.0	0.0	0.0	66.1
Oct	17.4	0.0	0.0	0.0	0.4	491.2
Nov	15.9	0.0	0.0	0.1	0.4	938.9
Dec	15.1	0.0	0.0	0.1	0.4	1428.2
Ann	16.8	0.0	0.0	0.0	0.0	7840.5

SPACE HEATING SYSTEM PERFORMANCE

Month	Space Heating Load (MJ)	Furnace Input (MJ)	Pilot Light (MJ)	Indoor Fans (MJ)	Heat Pump Input (MJ)	Total Input (MJ)	System Cop
Jan	7552.6	7408.8	0.0	143.7	0.0	7552.6	1.0
Feb	5867.3	5755.7	0.0	111.7	0.0	5867.3	1.0
Mar	4258.5	4177.4	0.0	81.0	0.0	4258.5	1.0
Apr	1569.6	1539.7	0.0	29.9	0.0	1569.6	1.0
May	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oct	926.3	908.6	0.0	17.6	0.0	926.3	1.0
Nov	3493.5	3427.0	0.0	66.5	0.0	3493.5	1.0
Dec	6204.7	6086.7	0.0	118.1	0.0	6204.7	1.0
Ann	29872.4	29303.9	0.0	568.5	0.0	29872.4	1.0

MONTHLY ESTIMATED ENERGY CONSUMPTION BY DEVICE (MJ)

Month	Space Heating		DHW Heating		Lights &	HRV &	Air
	Primary	Secondary	Primary	Secondary	Appliances	FANS	Conditioner
Jan	7408.8	0.0	1684.8	0.0	0.0	274.0	0.0
Feb	5755.6	0.0	1534.8	0.0	0.0	232.2	0.0

Mar	4177.4	0.0	1684.8	0.0	0.0	221.3	0.0
Apr	1539.7	0.0	1592.2	0.0	0.0	174.8	0.0
May	0.0	0.0	1591.4	0.0	0.0	0.0	0.0
Jun	0.0	0.0	1487.9	0.0	0.0	0.0	0.0
Jul	0.0	0.0	1498.1	0.0	0.0	0.0	0.0
Aug	0.0	0.0	1483.6	0.0	0.0	0.0	0.0
Sep	0.0	0.0	1449.7	0.0	0.0	0.0	0.0
Oct	908.6	0.0	1537.5	0.0	0.0	170.5	0.0
Nov	3427.0	0.0	1540.1	0.0	0.0	205.2	0.0
Dec	6086.7	0.0	1645.4	0.0	0.0	252.9	0.0
Ann	29303.9	0.0	18730.4	0.0	282.8	1530.9	0.0

ESTIMATED FUEL COSTS (Dollars)

Month	Electricity	Natural Gas	Oil	Propane	Wood	Total
Jan	180.0	0.0	0.0	0.0	0.0	180.0
Feb	149.8	0.0	0.0	0.0	0.0	149.8
Mar	132.9	0.0	0.0	0.0	0.0	132.9
Apr	91.9	0.0	0.0	0.0	0.0	91.9
May	68.5	0.0	0.0	0.0	0.0	68.5
Jun	65.8	0.0	0.0	0.0	0.0	65.8
Jul	67.2	0.0	0.0	0.0	0.0	67.2
Aug	67.0	0.0	0.0	0.0	0.0	67.0
Sep	65.3	0.0	0.0	0.0	0.0	65.3
Oct	83.2	0.0	0.0	0.0	0.0	83.2
Nov	118.6	0.0	0.0	0.0	0.0	118.6
Dec	160.2	0.0	0.0	0.0	0.0	160.2
Ann	1250.5	0.0	0.0	0.0	0.0	1250.5

The calculated heat losses and energy consumptions are only estimates, based upon the data entered and assumptions within the program. Actual energy consumption and heat losses will be influenced by construction practices, localized weather, equipment characteristics and the lifestyle of the occupants.