Ventilation and Wall Research House

W. Maref, PhD
Member ASHRAE

B. Ouazia, PhD

J. Reardon, PhD
Member ASHRAE

M. Rousseau

ABSTRACT

Nowadays numerical tools for 2D- or 3D-heat transfer are readily available to the building professional to calculate the thermal transmittance of thermal bridges. However, designers need appropriate limits to compare the predicted performance and decide on the necessity to improve the detailing. This paper presents a methodology to develop such limiting values. First the influence of thermal bridge geometry and insulation thickness on the linear transmittance is analyzed. Then the 2D-transmission heat loss resulting from all joints encountered in five typical masonry dwelling designs is quantified. The distribution of the heat loss over different components (junctions with roof, window, foundation, etc.) is presented. Finally limits for the linear thermal transmittance are developed in order to minimize 2D-transmission heat loss. The limiting values differ as a function of thermal bridge geometry and take account of the technical feasibility of the requirements.

INTRODUCTION

NRC-IRC took a big step forward over the past year with the completion of upgrades to the Institute's two-storey research house. This new addition to NRC-IRC's full-scale facilities complements other NRC-IRC experimental facilities in many ways. It has borrowed and refined some of their best experimental features, while offering the opportunity for wholesale redesign and adaptation of the interior and the envelope of the house for purposes of investigating technologies that can potentially redefine the house's performance altogether. This facility has the potential to investigate and improve the indoor air quality, comfort, durability and energy efficiency of housing.

The research house (Figure 1) is very flexible and can be reconfigured to allow different kinds of experiments. Changes to the facility include a fully zoned hydronic radiant floor heating system and also zone-controlled forced-air heating and cooling systems. These systems can be run one at a time, or in combination (hybrid) to investigate whether some types of rooms are better served by one type of heating and ventilating system or another.

The research house facility is also equipped with a fully zoned automated tracer gas dosing & sampling system with multiple tracer gas capability and two automated 3-D indoor environment measurement systems.

Given the emphasis on zone control, some partitions were taken down and new rooms added, resulting in a totally redefined interior layout, which allows for a more in-depth investigation of the impacts of the different systems. In addition, a section of one exterior wall was replaced with a test-bay that can accommodate samples of several different wall systems side-by-side, with each system fully instrumented and monitored.

The recent upgrades enable research on topics that highlight the interrelated nature of the indoor environment and envelope performance, allowing researchers to investigate the influence of the heating and cooling system or the air circulation approach, on both comfort conditions in the rooms and the hygrothermal performance of the building envelope.

If, for example, a heating system results in uneven distribution of heating in the rooms of the house, researchers will be able to quantify in a single experiment the impacts on occu-

W. Maref *is an associate researcher officer and manager of the Field Exposure of Walls Facility,* ***B. Ouazia*** *is an associate researcher officer and manager of the Ventilation and Wall Research House,* ***J. Reardon*** *is a senior researcher officer, and* ***M. Rousseau*** *is a research council officer and co-manager of the FEWF at the Institute for Research in Construction, National Research Council Canada.*

Figure 1 NRC-IRC ventilation and wall research house located in Ottawa (Canada).

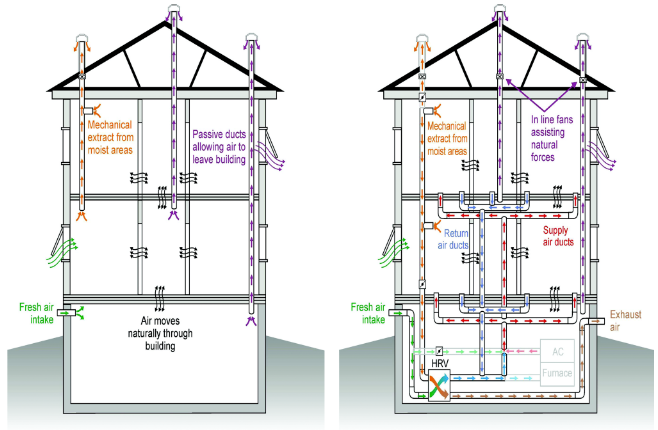

Figure 2 Hybrid ventilation—both mechanically-assisted natural ventilation and passive-supplemented mechanical ventilation.

pant comfort and wall moisture performance. As another example: in the case of high indoor humidity conditions which could result in envelope interior surface condensation and mould growth, one heating system might be shown to deliver more comfortable living conditions while also reducing condensation and risk of mould growth. Both examples point to the capabilities of this facility, which are expected to be of special interest to component manufacturers and builders who want to offer a complete performance package to their clients.

Using the new facility, NRC-IRC's Indoor Environment and Building Envelope and Structure Programs are jointly initiating research projects that integrate indoor climate and building envelope performance, and that will holistically assess heat, air and moisture transfers amongst the outside, the enclosure, the indoor air and the HVAC systems. There are three on-going research projects in the research house:

Hybrid ventilation using mechanical assistance to supplement natural ventilation when required, by incorporating combinations of mechanical air exchange and passive ventilation openings in the basement walls and flues.

Hybrid heating, which incorporates a combination of zone-controlled hydronic radiant floor heating and zone-controlled forced-air heating to achieve optimal air-circulation for a particular room depending on its use.

Hygrothermal performance of exterior wall assemblies that have different wall construction techniques, insulation systems and air-and vapor-barrier approaches.

This presentation gives an overview of these projects and some experimental results and analysis for the first year of operation.

HYBRID VENTILATION

NRC-IRC is using the upgraded test facility to study combinations of natural and mechanical ventilation. This project provides the opportunity to ensure that innovative hybrid ventilation strategies will be suitable for houses, with or without the good indoor air distribution provided by forced-air heating. This is important because ventilation and air-conditioning can account for 30% to 50% of residential energy consumption in Canadian homes and each can have a direct impact on occupants' health and comfort.

Natural ventilation may result in too little or too much fresh air exchange, and may waste energy spent in heating or cooling a space. Mechanical ventilation is easily controlled and enables heat recovery and air cleaning/filtration but it consumes electrical energy and thereby promotes greenhouse gas emissions. Hybrid ventilation, combining the advantages of both natural and mechanical ventilation, may offer a way to reduce the energy used for building ventilation.

This project is evaluating innovative hybrid ventilation strategies (Figure 2) for single-family residential buildings in terms of meeting building code requirements and indoor air quality standards, as well as achieving occupant satisfaction and energy efficiency. A first step in this investigation is an assessment of the natural ventilation rates typical in existing Canadian houses.

The experiments are assessing several hybrid strategies in terms of air exchange rates and distribution, energy consumption and thermal comfort for a full range of weather conditions. The experimental process employs and evaluates intelligent control systems that automatically switch between natural and mechanical ventilation modes and modulate fan speeds and/or vent openings to ensure a steady ventilation rate and adequate interior distribution of the supply air.

The experimental approach of this project is the comparison monitoring, for a wide range of weather conditions, of: air exchange, air distribution, impact on house energy consumption, moisture levels and IAQ achieved by: (a) mechanical ventilation alone, (b) natural ventilation alone, and (c) hybrid ventilation—both mechanically-assisted natural ventilation and passive-supplemented mechanical ventilation.

This research project has the potential to establish practical hybrid ventilation strategies for houses that reduce energy consumption and peak electric load, and improve ventilation and comfort. The study results are expected to lay the foundation for further development of residential strategies for free cooling, as well as for applications in commercial buildings.

Hybrid Heating

The majority of new houses built in Canada are equipped with combustion-fired, forced-air heating systems. Although there have been many improvements to forced-air systems in the past three decades, this may not be the most energy-efficient way to deliver thermal comfort to occupants. NRC-IRC is using the upgraded Ventilation Research House to see if further improvements can be gained by combining the best features of hydronic radiant floor heating and forced-air heating. This research is being conducted in parallel with a project investigating residential hybrid ventilation systems, taking both indoor air circulation and quality into consideration.

Hydronic radiant floor heating provides the comfort of a warm floor, and in some ways, is a more energy-efficient means of delivering thermal comfort due to the much greater heat capacity of water compared to air. Also, radiant heating may allow a reduction in indoor air temperature without compromising comfort, thereby reducing heat losses by conduction through walls and windows. However, radiant floor heating (Figure 3), on its own, does nothing to provide adequate air distribution, so supplementary ventilation schemes are needed.

Hybrid heating systems combining radiant floor and forced-air heating may provide improved thermal comfort and greater energy efficiency for the house overall. Both the forced-air and the hydronic radiant floor heating systems in the research house are fully zoned. This allows an assessment of the performance of various combinations of forced-air and radiant floor heating. These experiments are taking place during the 2007–2008 heating and shoulder seasons.

Several system approaches are available for radiant floor heating. This project is using a low-mass, fast-response system type consisting of insulated EPS floor panels with integrated aluminum top skin formed with grooves spaced on 15 cm (6 in.) centers into which is snapped 13 mm (0.5 in.) diameter BPEX tubing.

The experimental approach of this project is to compare the two heat delivery systems: hydronic radiant floor heating and forced-air heating. Methods of investigation involve:

- Comparing total energy consumption for whole house heating by the forced-air and radiant systems individually.
- Assessing thermal comfort quality delivered by each heating system individually.
- Determining energy required by each system's components to deliver the thermal comfort achieved.

This research is expected to provide a comprehensive evaluation of the comparative energy and comfort benefits of hybrid approaches (Figure 4) to home heating and could reduce energy consumption and greenhouse gas emissions. The project's results will also help the industry and consumers make better heating-system choices for both renovations and new construction.

Thermal Comfort Requirements

The achievement of thermal comfort conditions in buildings is important to satisfy occupants. The international standards ISO 7726 and ASHRAE Standard 55-2004 define for various types of indoor spaces the values of parameters affecting the thermal comfort. The standards recommend an optimal indoor temperature of 23°C, with an acceptable range of 20–24°C in winter, and 23–26°C in summer. The relative humidity

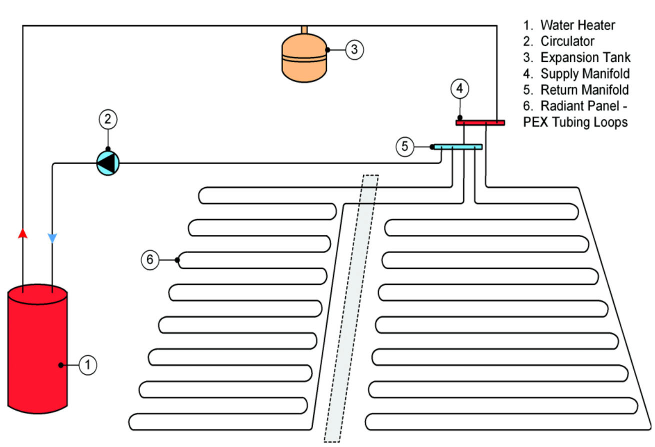

Figure 3 *Hydronic radiant floor heating system.*

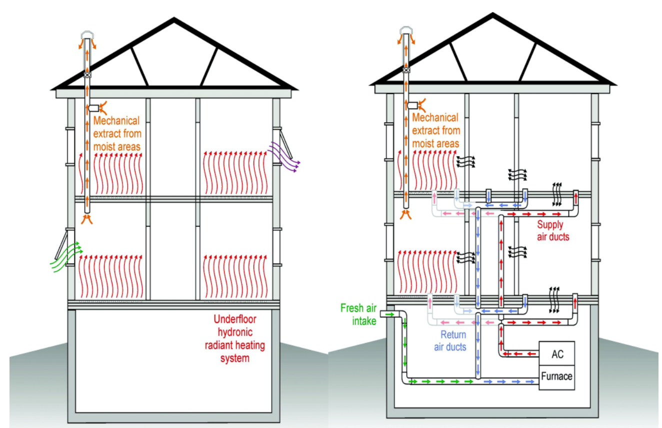

Figure 4 *Hybrid heating system combining radiant floor and forced-air heating.*

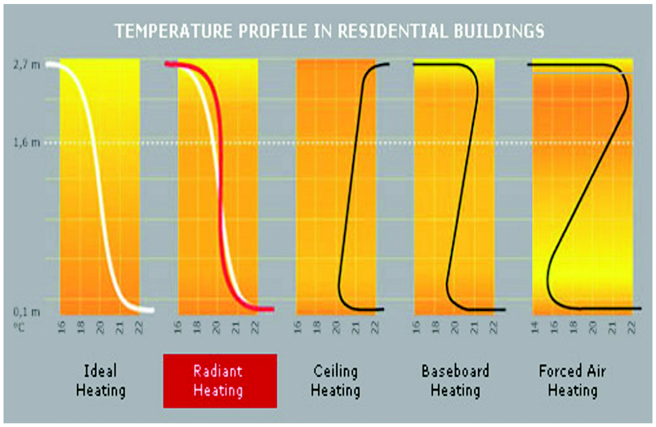

Figure 5 *Vertical temperature profiles for various heating modes (courtesy of Roth Canada).*

should be between 50 and 60% and, to prevent draft, the air velocity near a seated person should be less than 0.15 m/s.

In IRC's Indoor Environment Research Program, some studies regarding thermal comfort conditions are performed in the Ventilation and Wall research house facility. One aspect of the hybrid heating research aims to evaluate thermal comfort parameters in two identical rooms simultaneously, one room heated by forced-air and the other room heated by hydronic radiant floor heating. One of the main features of radiant floor heating is the claimed uniform temperature conditions from floor to ceiling compared to the less uniform vertical temperature profile for convective systems (see Figure 5). Thermal comfort standards recommend that the air temperature difference between ankle and head heights be limited to no more than 3 K, for sedentary persons to be comfortable.

Automated 3-D Indoor Environment Measurement Systems

Two automated 3-D indoor environment measurement systems have been developed to measure the spatial distribution of thermal environment parameters. Each apparatus permits the computer-controlled movement of measurement sensors in three-dimensional (3-D) space for automated continuous monitoring. The automated apparatus, of robotic construction (Figure 6), permits movement in five directions: three linear (along longitudinal, lateral and vertical axes) and two rotational (pitch and yaw). Here the one rotational degree of freedom for the robot is that around the vertical axis and is termed yaw. To allow measurement sensor(s) to be moved close into the corners of the room, an "arm" on the vertical carriage can be rotated about a horizontal axis facilitating a "pitch", the second rotational degree of freedom. It is therefore possible for these robots to reach any location in their respective rooms.

The vertical carriage has on one side the "arm" that can carry up to five sensors (e.g., air and mean radiant temperatures, plane radiant asymmetry, air velocity and relative

Figure 6 *Computer-controlled 3-D system to measure spatially distributed indoor environment parameters.*

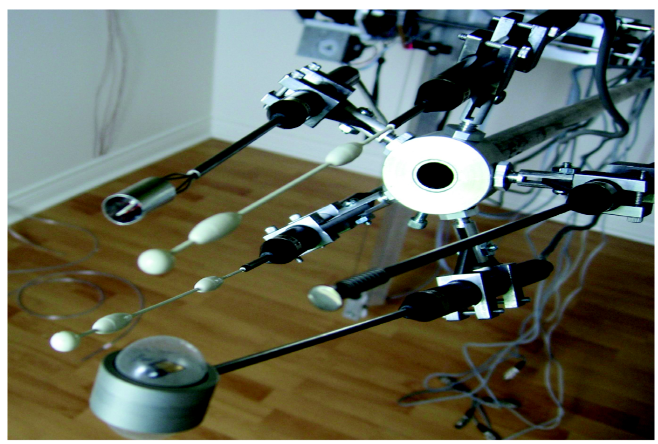

Figure 7 *Sensors: relative humidity, air speed, dry bulb, mean radiant and operative temperatures.*

humidity) as shown in Figure 7 for detailed location measures. On its other side an infrared camera (Figure 8) can be mounted, with focus control, for thermographic surveys of surface temperature distributions.

FIELD EXPOSURE OF WALLS FACILITY

The facility consists of a test opening measuring 4.8 m wide by 2.1 m high on the first floor of the west façade of the

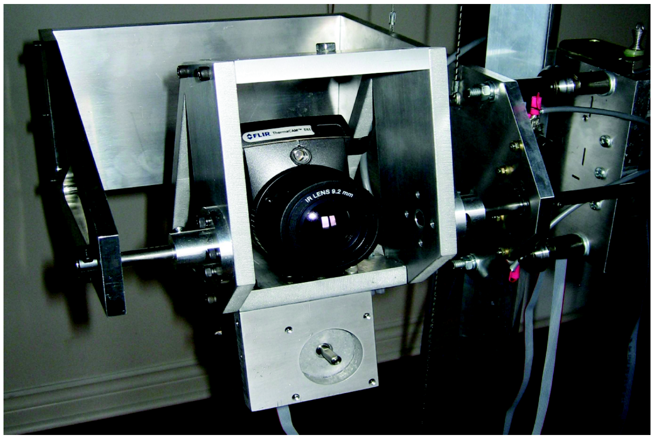

Figure 8 *Infrared camera for thermographic surveys of surface temperatures.*

Figure 9 *New test facility for assessing field performance of innovative wall and window systems.*

research house located on the NRC campus in Ottawa, Ontario, Canada (Figure 9). Several test specimens separated from each other by thermal and air flow masks can be inserted side-by-side into the test opening. The specimens are exposed to the natural outdoor climate conditions, and to a controlled indoor climate. Sophisticated instrumentation and data acquisition systems, appropriate for long-term field monitoring of the hygrothermal response of the wall or window system are used by the research team to meet the objectives of a project. An indoor controlled chamber can be installed over the interior face of one or more specimens to apply precisely controlled temperature, relative humidity and air pressure conditions as required by a project to provide the base-case scenario as well as challenging conditions for the hygrothermal response of the test specimen assembly.

OBJECTIVES

The new Field Exposure of Wall Facility (FEWF) complements other NRC-IRC laboratory and numerical modeling capabilities (*hyg*IRC 1D and 2D) to investigate heat, air and moisture transfer across the building envelope to assist the building industry in developing integrated solutions (Figure 10).

The wall testing capability of the upgraded research house will be used to assess innovative wall assemblies and windows relative to variable indoor conditions over multiple seasons, to support the following objectives:

- Characterize the heat, air and moisture response of exterior walls and windows exposed to naturally varying outdoor climate and to controlled indoor conditions of temperature, relative humidity and air pressure defined by occupancy and HVAC systems
- Help advance building science and provide guidance on sustainable design of wall and window assemblies
- Field benchmark IRC numerical models hygIRC 1D and 2D

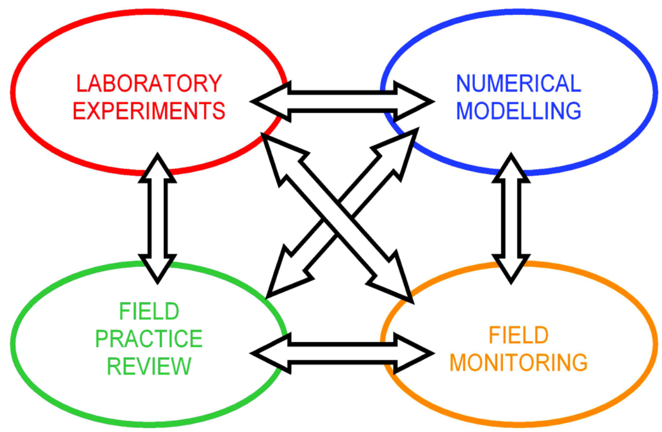

Figure 10 *The new Field Exposure of Wall Facility (FEWF) complements NRC-IRC modeling research tools.*

- Investigate the interaction between the building envelope and the indoor environment (e.g., issues of thermal comfort and air quality)

2006–2007 RESEARCH PROGRAM

Experiments with three identical test specimens of traditional 2 × 6 wood-frame wall construction were conducted until spring 2007 to benchmark the facility and commission the data acquisition system (Figure 11).

During the winter months of 2006–7, the test specimens were subjected to indoor relative humidity and air exfiltration to examine the condensation potential in different layers of the assemblies and to yield valuable information on the systems' strengths and weaknesses. At some time during the testing period, specific "deficiencies" (i.e., cracks) were introduced in the air/vapor barriers of two of the three specimens to characterize the response of the wall in terms of condensation potential and moisture content of moisture-sensitive materials.

With the coming of spring, researchers monitored the drying potential of the test specimens. In summer 2007, the research team dismantled the specimens to examine the materials for signs of deterioration, and the next series of specimens were installed.

Figure 11 *Three wall specimens being instrumented in preparation for field monitoring in fall 2006 and winter 2006–2007.*

Wall Test Specimens

Three identical traditional construction wall specimens were set up for monitoring in fall 2006, winter 2007 and spring 2007 (Table 1 and Figure 12) with the aim of commissioning the facility and the instrumentation and assessing the reproducibility of the side-by-side test specimen exposure. The specimens were considered to be reference walls, as they represent the traditional approach to low-rise residential construction in Canada. The 6-mil polyethylene film barrier is the designated air/vapor barrier of the assembly.

Experimental Design

Three identical wall systems of traditional 2x6 wood-frame construction were exposed to natural outdoor conditions (Ottawa) occurring in fall, winter and spring in this first year of the experiment. During the course of the experiment, the three wall systems were tested against high indoor relative humidity (50%) and air exfiltration level (5 Pa) on indirect air leakage path to explore condensation potential in different layers of the walls, and to assess the strengths and weaknesses of each system.

Table 1. Description of the Specimens—Year 1 (FY06/07)

	Int. finish	VB and ABS	Insulation	Framing	Sheathing Board	Sheathing Membrane	Siding
W1 W2 W3	Painted gypsum board, 12 mm	6 mil poly	R-20 glass fiber batts	2 × 6 at 16 in. spacing for center cavity	OSB, 12 mm installed with horizontal 6 mm gap in the middle stud cavity	Spunbonded polyolefin housewrap	Horizontal vinyl siding

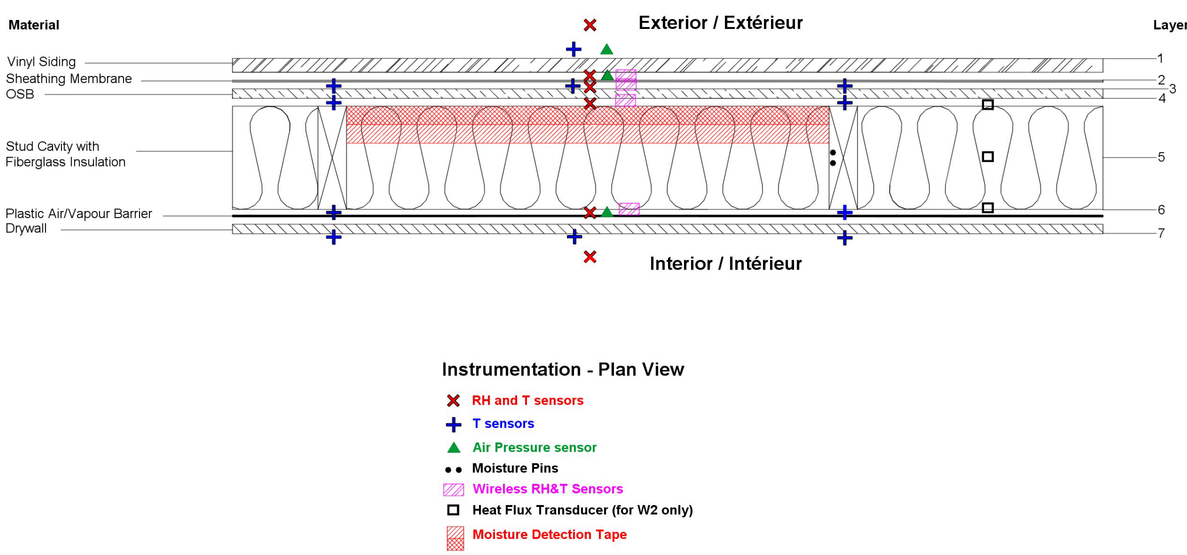

Figure 12 *All 2006-07 test specimens' composition and layout of the instrumentation.*

The experiment was set up in four steps over fall, winter and spring:

1. *Step I (Oct, Nov and Dec 06)*: the test specimens were installed as is and exposed to "natural" indoor operating conditions.
2. *Step II (Jan 07):* openings were made in the polyethylene plastic (the air/vapor barrier) of W2 and W3 specimens. This was likely to induce a mass flow exchange mechanism between indoors and outdoors, as there was a similar opening at mid-height in the exterior sheathing. The indoor chamber was maintained at 21°C and 50%RH and at 5 Pascals pressurization.
3. *Step III (Feb 07):* the size of the opening in the polyethylene was reduced by half. The indoor conditions remained the same as in Step II.

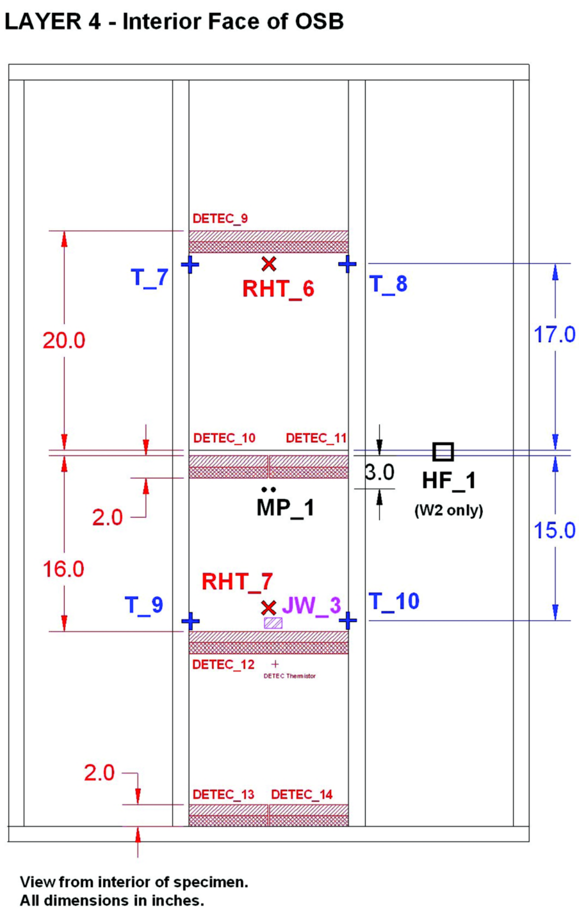

Figure 13 *Elevation of the layout of the instrumentation on the inside face of the OSB sheathing of W3 specimen (the one specimen with a heat flux transducer, HF-1). T = thermocouple, RHT = RH and T sensor, MP = moisture pins, JW = innovative wireless RH and T sensor, and Detec = detection strip for water detection and moisture content.*

4. *Step IV (Feb-May07)* was similar to Step III, with the difference being that the outdoor conditions gradually changed from severe winter to milder springtime.

Instrumentation and Measurements

The wall specimens were monitored for hygrothermal response in several layers of the assembly. Temperature, relative humidity, air pressure and moisture content (in wood-based materials) were measured in the middle stud cavity of each specimen and at different heights and different layers (Figures 12 and 13). Traditional and innovative sensor technologies were in place for comparison purposes. Infrared thermography scans and air leakage rate testing were carried out at critical steps of the experimental program.

Indoor Climatic Chamber

Part of the objectives of the first year of testing at the FEWF included investigating the effects of an increase of indoor humidity on moisture content of wood-based materials. To this purpose, a chamber was constructed to introduce high humidity and increased pressure conditions on the indoor side of two of the specimens (Figure 14). The third specimen was exposed to regular indoor conditions as a control.

RESULTS

The analysis will be done to provide the building industry with practical information related to energy efficiency, potential for condensation and deterioration.

This field monitoring will enhance our understanding of the comparative hygrothermal response of different wall assemblies (variations in properties and with/without deficiencies) exposed to dynamic natural annual fluctuations of Ottawa outdoor climate and to different sets of controlled indoor conditions.

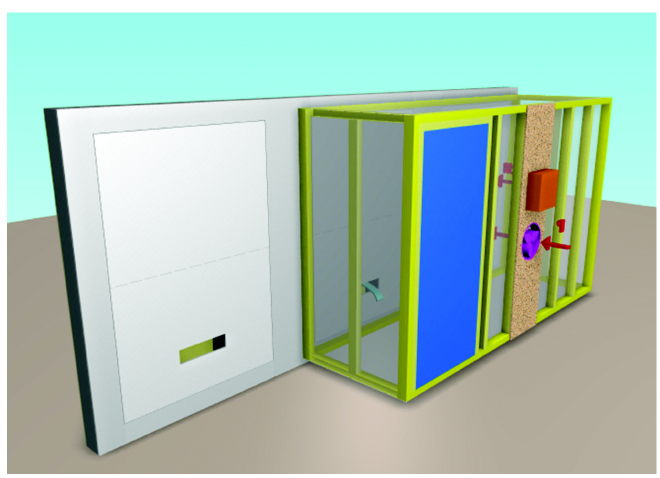

Figure 14 *Schematic of the indoor climatic chamber enclosing two of the three specimens*

Data is being collected at the time of the publication of this paper and researchers will be able to present results at the conference.

Future Plans

Researchers expect to advance building envelope science and performance assessment in the following areas:

- Innovative coatings and membranes that perform multiple hygrothermal functions at different times of the year (e.g. smart vapor barriers).
- Vapor barrier, air barrier and heat flow control strategies to achieve minimal wetting and maximal drying of wall assemblies over cycles of seasonal loading.
- Traditional or innovative insulation systems designed to provide thermal resistance and other functions (e.g., insulations that also act as vapor and/or air barriers).
- Innovative wall or wall/window configurations designed for temperature and humidity control.
- Development of multi-disciplinary projects to investigate the interaction between the building envelope and the indoor environment

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