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Executive Summary of Research Contributions Related to Moisture Management of Exterior Wall Systems (MEWS) - Modeling, Experiments, and Benchmarking

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Executive Summary of Research Contributions Related to Moisture Management of Exterior Wall Systems (MEWS) – Modeling, Experiments, and Benchmarking

Maref, W.; Lacasse, M.A.; Booth, D.G.

IRC-RR-127

December 2002

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IMPORTANT NOTICE TO READERS

The main emphasis of the MEWS project was to predict the hygrothermal responses of several wall assemblies that are exposed to North American climate loads, and a range of water leakage loads. Researchers used a method based on both laboratory experimentation and 2-D modeling with IRC's benchmarked model, hygIRC. This method introduced built-in detailing deficiencies that allowed water leakage into the stud cavity - both in the laboratory test specimens and in the virtual (modeling) "specimens"- for the purpose of investigating water entry rates into the stud cavity and the drying potential of the wall assemblies under different climate loads. Since the project was a first step in investigating a range of wall hygrothermal responses in a parametric analysis, no field study of building characteristics was performed to confirm inputs such as water entry rates and outputs such as wall response in a given climate. Rather, ranges from 'no water entry and no response' to 'too much water entry and too wet for too long' were investigated.

Also, for the sake of convenience, the project used the generic cladding systems (e.g., stucco, masonry, EIFS, and wood and vinyl siding) for labeling and reporting the results on all wall assemblies examined in the study. However, when reading the MEWS publications, the reader must bear in mind that the reported results are more closely related to the nature of the deliberately introduced deficiencies (allowing wetting of the stud cavity) and the construction details of the wall systems investigated (allowing wetting/drying of the assembly) than to the generic cladding systems themselves. As a general rule, the reader must assume, unless told otherwise, that the nature of the deficiencies and the water entry rates into the stud cavity were different for each of the seventeen wall specimens tested as well as for each of the four types of wall assemblies investigated in the modeling study. For this reason, simply comparing the order of magnitude of results between different cladding systems would take the results out of context and likely lead to erroneous conclusions.



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Executive Summary of Research Contributions Related to Moisture Management of Exterior Wall System (MEWS)– Modeling, Experiments and Benchmarking

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Report from Task 6A-2 and Task 7 of MEWS Project

Task 7 - Benchmarking of IRC's Advanced Hygrothermal Model- hygIRC – Final report – T7-10

Dr. Wahid Maref, Dr. Michael Lacasse and Daniel Booth

December 2002

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MEWS PROJECT REPORT T7- 10: December 2002

TASK 7 - BENCHMARKING EXERCISE OF hygIRC- FINAL REPORT T7- 10

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Executive Summary of Research Contributions Related to Moisture Management of Exterior Wall System (MEWS)– Modeling, Experiments and Benchmarking

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INTRODUCTION

Background - context

Uncontrolled moisture accumulation in a building envelope reduces the structural integrity of its components through a combination of mechanical, chemical and biological degradation. Damage induced by moisture ingress includes rotting of wood studs and wood-based sheathing, as well as other detrimental effects such as efflorescence and spalling of masonry, and rusting of fastening mechanisms. Over the past decade, a significant number of low-rise wood-frame residential buildings have been plagued with water penetration problems related to uncontrolled moisture accumulation in the building envelope. In the majority of cases, the reported problems are in coastal areas such as lower mainland of BC, Maritime Provinces and eastern US. Effective moisture control is essential for an acceptable service life of building envelope. Effective moisture control implies both, minimising moisture ingress to prevent ingress of moisture into the inner most fabric of the wall assemblies, and redirection of moisture to the exterior. The principal objective is not to allow any component within the system to stay 'too wet' for 'too long'. The challenge would be to qualify and quantify what is considered "too wet" and "too long"?

To address the above challenges, the Institute of Research in Construction (IRC), other industry groups, and stakeholders have established the Moisture Management on Exterior Walls Systems (MEWS) consortium. The objective of MEWS is to determine the minimum characteristics and levels of performance of various wall elements in handling rainwater ingress depending on the surface environment of the wall assembly. Experimental work has been conducted, both at mid-scale and full-scale levels in order to validate the results obtained through the Advanced Hygrothermal Model hygroIRC. Such models allowed the prediction of hygrothermal effect on various wall assemblies at any desired environment conditions, and contribute to control moisture in building envelope.

Validation of hygrothermal models

Building envelope components and structure were developed through traditions and generations of experience, but far too often new building materials and construction practices are introduced without proper understanding of their hygrothermal behaviour. This can be done using the results of laboratory and field experiments or calculations. Whereas laboratory and field experiments are often too selective and rather slow; calculation methods can readily represent a variety of changing boundary conditions and result in much faster analysis. With rapid advances in computer technology and development of numerical methods, many computer models for hygrothermal

calculations were developed during the past decade. Depending upon the complexity of the problem under consideration, such models can be based on very simple, one-dimensional, steady state methods or on very complex, two-dimensional, transient methods.

The Advanced Hygrothermal Model hygIRC (Maref & al, 2002a, 2002b) was used as preliminary analytical tool to conduct parametric studies to assess the hygrothermal performance of various wall assemblies subjected to different climatic conditions. hygIRC presently uses hygrothermal property data derived from small-scale test results undertaken by Kumaran (1996) and subsequently updated in recent years. It has been previously demonstrated that results obtained from these small-scale tests and those derived from the use of hygIRC are in close agreement (Kumaran & Wang 1999).

In this series of simulations hygIRC was implemented to assess the drying rate of two wall components: OSB sheathing and sheathing membrane. The drying rates of several different OSB sheathing and membranes combinations were assessed in a series of experiments and the results were subsequently used to help benchmark hygIRC.

hygIRC – Advanced hygrothermal simulation model

The current version of the advanced hygrothermal model that is used at IRC is called hygIRC [Maref et al, 2002a, Maref et al, 2002b, Kumaran, 2002] which is an enhanced version of the model Latenite [Salonvaara and Karagiozis, 1994, Karagiozis & al., 1995, Karagiozis and Kumaran, 1997]. hygIRC is built around well-known heat, air and moisture transport equations (Fourier's law of heat conduction, Fick's law of diffusion of matter and Darcy's law of fluid flow as well as Navier-Stokes equations) and corresponding equations that define the conservation of energy, mass and momentum.

The model simulates the response of each element to the changing environmental conditions on either side of the envelope on an hourly basis. This produces information on the temperature and relative humidity distributions within the wall assembly and the changes in these with time. The data can be sampled at any desired time interval and visualised using post-processing graphic software. Reviewing the output in this manner readily permits identifying locations within the assembly that may be subjected to high moisture conditions over prolonged periods of time. As well, it permits a rapid assessment of the extent to which the simulation may emulate experimental results.

EXPERIMENTAL APPROACH

Objectives, scope and method

The series of experiments have been conducted to gather data on the hygrothermal behaviour of full-scale wood-frame wall assemblies and wall components when subjected to steady and transient state climatic conditions such that the results could be used to evaluate the expected performance and predictive capabilities of hygIRC.

hygIRC uses the hygrothermal property data derived from the test results undertaken in the laboratory on small-scale specimens, i.e. specimens having dimensions of 300 x 300-mm. A considerable amount of experimental work has already been completed towards assessing the hygrothermal properties of most building materials used in wood-frame construction. From this work an extensive database of hygrothermal material

properties has been developed and is used by hygIRC [e.g., MEWS Task 3 (2002)]. It has been readily demonstrated that results obtained from these small-scale tests and those derived from the use of hygIRC are in close agreement and as such, it is expected that hygIRC can adequately duplicate and help predict hygrothermal behaviour of wall components when subjecting the components to simulated climatic conditions.

The objectives of the work were:

- To measure the overall hygrothermal behaviour of wood-based layers in wood-frame construction when subjected to steady and transient state hygrothermal conditions in a controlled laboratory environment.
- To validate the model prediction of the drying rate of wood-based components.

The scope of the work consisted of:

- Determining the overall hygrothermal behaviour of wood-frame wall components and assemblies under controlled laboratory conditions. Measurable total moisture contents were recorded and compared to that derived from using hygIRC.
- Conducting full-scale experiments on wall assemblies having dimensions of 2.43x2.43-m.

The wall components that were evaluated, were those typically used in the fabrication of the respective wall assemblies being proposed for evaluation; the list of components and their respective hygrothermal properties are those taken from the material database as developed by Kumaran et al [e.g., MEWS Task 3 (2002)]. Measurable hygrothermal effects included measuring changes in moisture content of materials and changes in weight of wall components or assemblies over time. Comparison and analysis from experimental results were then compared to those obtained from simulations using hygIRC [Maref & al, 2002].

Method

To achieve the objectives, the experimental work consisted of testing both mid-scale and full-scale experiments. As well, in order to verify experimental results and develop a basis for validation of hygIRC, extensive use of the model was made.

An overview of the different stages used in the evaluation program is provided in Figure 1. In the first step the drying process of mid-scale test specimens (0.8-m x 1.0-m) was monitored over time. The advantage of testing these specimens was to establish data acquisition protocols and determine the wetting procedure for wood components.

The mid-scale series included not only OSB sheathing but also combinations of OSB in contact with different water resistive barrier (WRB) materials or other materials for which an understanding of the hygrothermal response was essential for proper assessment of the overall response of the walls.

A full-scale test series was made of wall assemblies having dimensions of 2.43 x 2.43-m. The test was carried out in controlled laboratory conditions over a period of time sufficiently long as to permit quantifying gravimetrically, the change, and rate of change, in the total moisture content (drying) of critical wall assembly components. The experimental results were compared to those predicted by hygIRC model and were reported by Maref & al [2002a, 2002b & 2003].

The full-scale tests were preceded in a series of steps, each step comprised of evaluating the hygrothermal response of a full-scale specimen to specified laboratory controlled conditions. The initial step consisted of determining the response of a single sheet of OSB to specified conditions whereas each subsequent step had an increased level of complexity in regard to the number of assembly components being modelled and for which data was to be reconciled with the experiment.

This step-wise approach permitted gaining a better understanding of the relative contribution of each component to key hygrothermal effects. In this way, complex assemblies of components were analysed and their hygrothermal response to steady or transient state climatic conditions characterised in relation to that simulated using hygIRC.

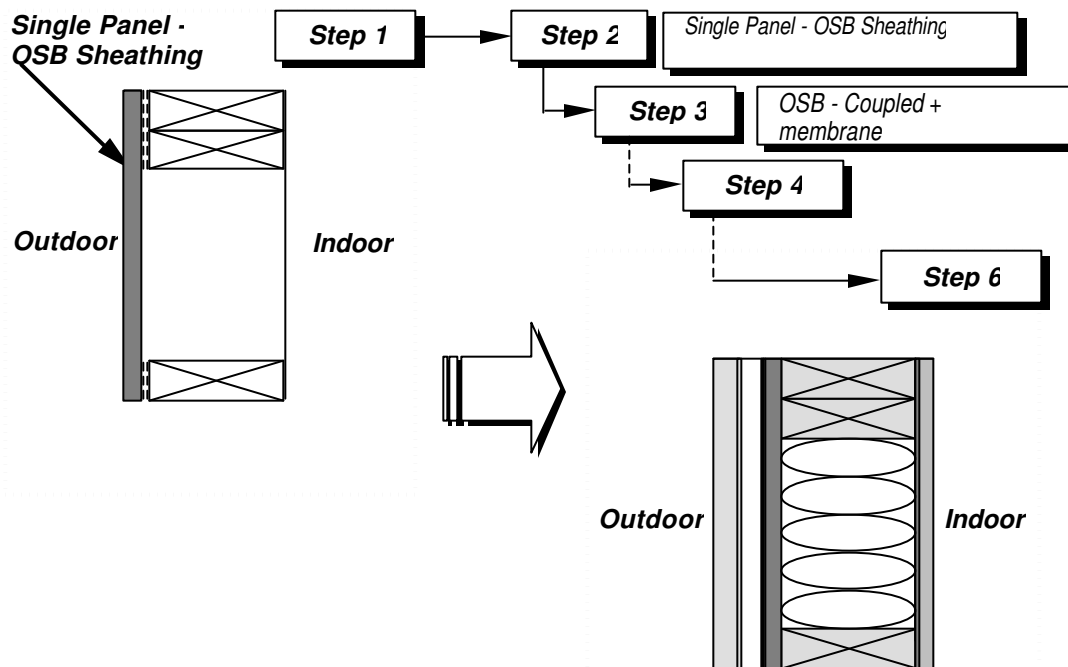


Figure 1 – Step-wise approach for experimental stages to evaluate hygIRC

Equipment, materials and specimen assemblies

A detail of the test equipment used in these tests is provided in MEWS Technical Reports T6-01-R1 to T6-01-R4 [Maref and al].

MATERIALS

The relevant physical properties of the materials used in both mid- and full-scale experimental sets are provided in Table 1. The first set of mid-scale experiments included an OSB having 9.5-mm thickness whereas all subsequent experimental sets, either mid- or full-scale, used an OSB of greater thickness (11.5-mm). The thinner board in the initial set was used such that drying times could be minimized and the subsequent set started as soon as possible. The relevant hygrothermal characteristics of both of these materials are provided in MEWS Technical reports T3-01 to T3-18 (for specific details refer to list of reports included in references).

SPECIMEN ASSEMBLIES

The material components and initial exposure conditions of the different test specimens for both mid- and full-scale tests are provided in Tables 2 and 3, respectively. Three sets of specimens were assessed in the mid-scale tests (Table 2) whereas four sets of full-scale specimens were evaluated in this latter test series (Table 3).

Table 1 – Description of test materials and relevant properties

Item No.	Component	Description	Characteristic Properties	
			Density (kg/m ³)	Thickness (mm)
1	Sheathing	OSB-1	650	9.5
2	Sheathing	OSB-2	650	11.5
3	Membrane	IV	800	0.35
4	Membrane	III	870	0.23
5	Membrane	II	810	0.21
6	Membrane	X	670	0.10
7	Membrane	VII	464	0.14
8	Membrane	V	715	0.72
9	Membrane	I	288	0.30

Table 2 –Mid-scale experimental sets and related material combinations and test conditions

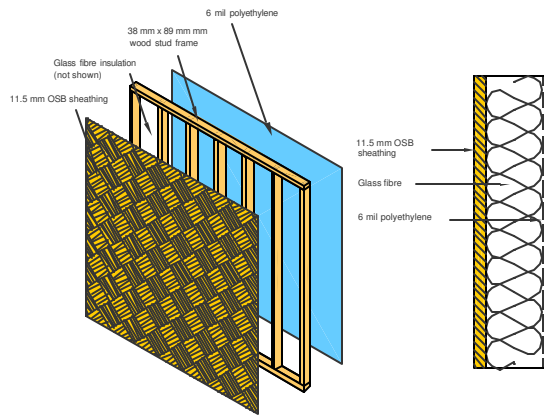
Set	Spec. No.	Materials	Conditions
1	1	Wet OSB	Climatic chamber
	2	Dry OSB+ Wet OSB+ Dry OSB (perfect contact)	
2	1	Wet OSB	Climatic chamber + EEEF (Environmental Envelope Exposure Facility)
	2	IV* + Wet OSB + IV	
	3	III + Wet OSB + III	
	4	II + Wet OSB + II	
	5	X + Wet OSB + X	
	6	VII + Wet OSB + VII	
	7	XI + Wet OSB + XI	
	8	V + Wet OSB + V	
	9	I + Wet OSB + I	
3	1	VII + Wet OSB + VII	EEEF
	2	III + Wet OSB + III	
	3	V + Wet OSB + V	
	4	Wet OSB	
	5	Wet OSB	
	6	Wet OSB	
	7	VII + Wet OSB + VII	
	8	III + Wet OSB + III	
	9	V + Wet OSB + V	

* refers to the type of water resistive barrier (WRB) – sheathing membrane

Full scale wall specimens

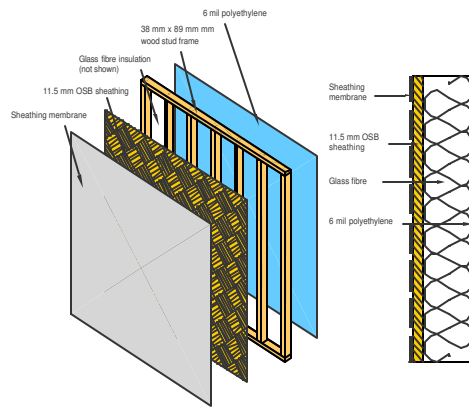
A schematic is provided in Figure 2 that depicts the various components of each of the 4 experimental sets evaluated in full-scale tests. A brief description of each is provided below a summary of which is given in Table 3.

Experiment Set 1



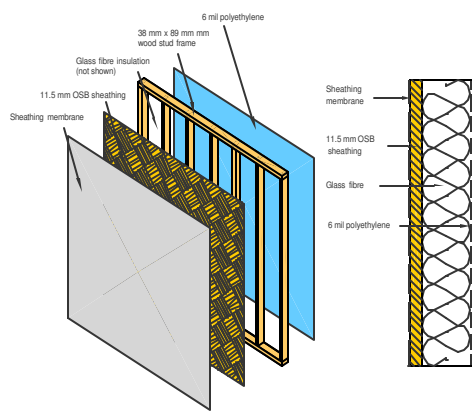
(a) Set 1

Experiment Set 2



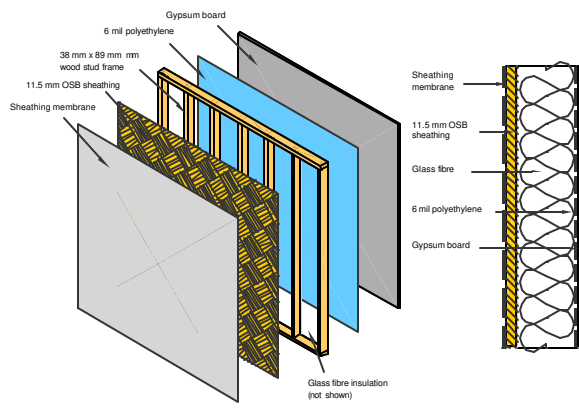
(b) Set 2

Experiment Set 3



(c) Set 3

Experiment Set 4



(d) Set 4

Figure 2 – Configuration of full-scale wall assembly specimens: Sets 1 to 4.

EXPERIMENT SET 1

Experimental Set 1 consisted of evaluating the hygrothermal properties of a single sheet of OSB that was de-coupled from the wood frame assembly, this being achieved by coating the wood frame with a lacquer. Fiberglass insulation was added in the cavities between the studs of the assembly. A single sheet of polyethylene was installed on the interior side of the assembly (laboratory conditions) (see Figure 2 (a)).

EXPERIMENT SET 2

Experimental Set 2 consisted of evaluating the hygrothermal properties of a single sheet of OSB that, again, was de-coupled from the wood frame assembly, this being achieved by coating the wood frame with a lacquer. A sheathing membrane (no. VII; Table 2) was installed on the OSB sheathing board, fiberglass insulation was added in the cavities between the studs of the assembly and, as in Set 1, a single sheet of polyethylene was installed on the opposite side of the assembly (laboratory conditions) (see Figure 2 (b)).

EXPERIMENT SET 3

Experimental Set 3 consisted of evaluating the hygrothermal properties of a single sheet of OSB that is de-coupled from the wood frame assembly. A sheathing membrane (no. IV; Table 2) was installed on the OSB sheathing board, fiberglass insulation was added in the cavities between the studs of the assembly and, as in Set 1, a single sheet of polyethylene was installed on the opposite side of the assembly (laboratory conditions) (Figure 2 ©).

EXPERIMENT SET 4

Experimental Set 4 consisted of evaluating the hygrothermal properties of a single sheet of OSB that is de-coupled from the wood frame assembly. A sheathing membrane (no. IV; table 2) was installed on the OSB sheathing board Insulation was added in the cavities between the studs of the assembly, a single sheet of polyethylene was installed on the opposite side of the assembly and, a dry wall (see Figure 2 (d)).

Table 3 – Full-scale experimental sets, related test materials combinations conditions

Set No.	Materials	Conditions
1	Wet OSB + Insulation + Polyethylene	EEEEF
2	VII* + Wet OSB + Insulation + Polyethylene	
3	IV + Wet OSB + Insulation + Polyethylene	
4	IV + Wet OSB + Insulation + Polyethylene + Dry wall	

** Refers to the type of water resistive barrier (WRB) – sheathing membrane

NOMINAL RESULTS FROM BENCHMARKING TRIALS

Results from trials on mid-scale specimens

Nominal results and discussion

Simulations were performed using hygroIRC to estimate the drying response of several specimens. Results from simulation and experimental drying of OSB sheathing alone exposed to the surrounding environmental conditions within the climatic chamber EEEF (Environmental Exposure Envelope Facility) are plotted in Figure 3. In this experiment, the initial MC of the OSB was measured at 61% and this was set as an initial condition for the simulation. As can be observed in this figure, the equilibrium moisture content (EMC) is achieved after 21 days (5% MC); the simulation is nominally in good

agreement with the experimental data. Noticeable differences exist during the first four days. However, it must be acknowledged that the overall agreement between the experimental and simulated drying curves is excellent in terms of the drying times as well as the shape of the drying curve derived from these experimental sets.

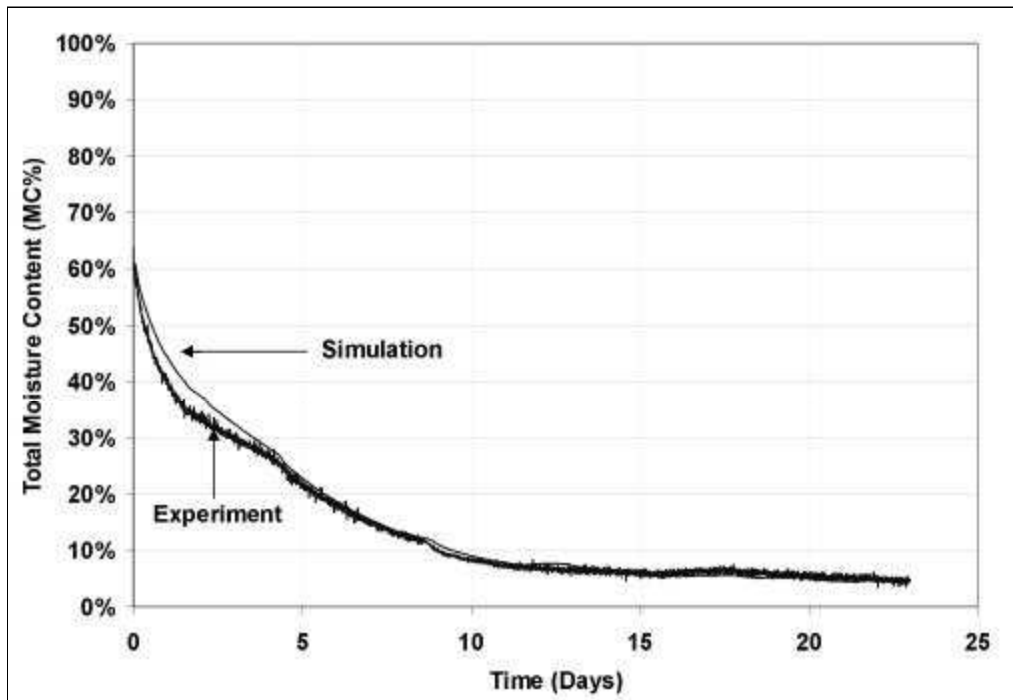


Figure 3– Comparison of simulated and measured drying results of OSB layer (Set 2- Spec 1)

Results from trials on full-scale wall assemblies

General description of test specimen

The nominal size of full-scale specimens was 2.43 x 2.43-m with the structural components comprised of two panels of 7/16-in. (11.5-mm) OSB sheathing placed on a 38 x 89-mm (2 x 4-in.) wood stud frame, having vertical studs centred every 406-mm (16-in.). The single layer of OSB sheathing was attached to, but de-coupled from, the structural wood frame, the de-coupling being achieved by coating the wood frame with a water impervious lacquer. A spun-bonded polyolefin sheathing membrane was used as water resistive barrier and applied to the sheathing board. Glass fibre insulation was placed within the wood frame in the cavities between the studs, and on the opposite side of the frame, a single sheet of polyethylene (6 mil) was installed as vapor barrier. A double top plate was used in the assembly of the test frame to which a steel cleat was bolted to accommodate connection to the transverse beam on the weighing system.

As an example of results obtained from all of the experimental series presented in this report, those obtained from evaluating the hygrothermal properties of a single sheet of

OSB that, again, was de-coupled from the wood frame assembly, this being achieved by coating the wood frame with a lacquer. A sheathing membrane (VII) was installed on the OSB sheathing board, fiberglass insulation was added in the cavities between the studs of the assembly and a single sheet of polyethylene was installed on the opposite side of the assembly (laboratory conditions).

RESULTS AND DISCUSSION

Figure 4 shows a comparison between simulated and total measured MC of OSB derived from experimental results. The initial total MC for both boards in the assembly, as described in the previous section, is ca. 51 %. After 33 days a value of 16% MC is attained. These results indicate a very good agreement between the results obtained from simulation and those derived from experiment. In fact, the greatest difference between the simulated and the experimental results after 33 days is not more than 1.4 % MC.

No adjustments to the model were made to minimise the differences between results from simulation and those of the experiment. However, differences between results may be due to a number of factors the most significant are thought to be related to the manner in which the simulation at the surface of the OSB sheathing was implemented in the program. Specifically, the simulation assumes that there is perfect contact between the membrane and the sheathing board. In fact, in the real system, there always exists some interstitial space between these components. The net effect of this assumption is that the drying rate of the sheathing board in the simulation is decreased and this in-turn under estimates the loss in moisture content over time, as is shown in Figure 3.

In general, the simulations were able to adequately predict the time required for the OSB sheathing to reach equilibrium moisture content; essentially, hygIRC is clearly able to mimic the drying process in this wall assembly. In each of the experimental steps so far reported, simulation results have shown very good agreement with those derived from experiment. Indeed, the greatest difference evident when comparing the results derived from simulation and those obtained from experiment are ca. 5%.

A number of such types of experiments have been made in the stepwise approach to help validate hygIRC, results of which are provided in the report attached to this summary.

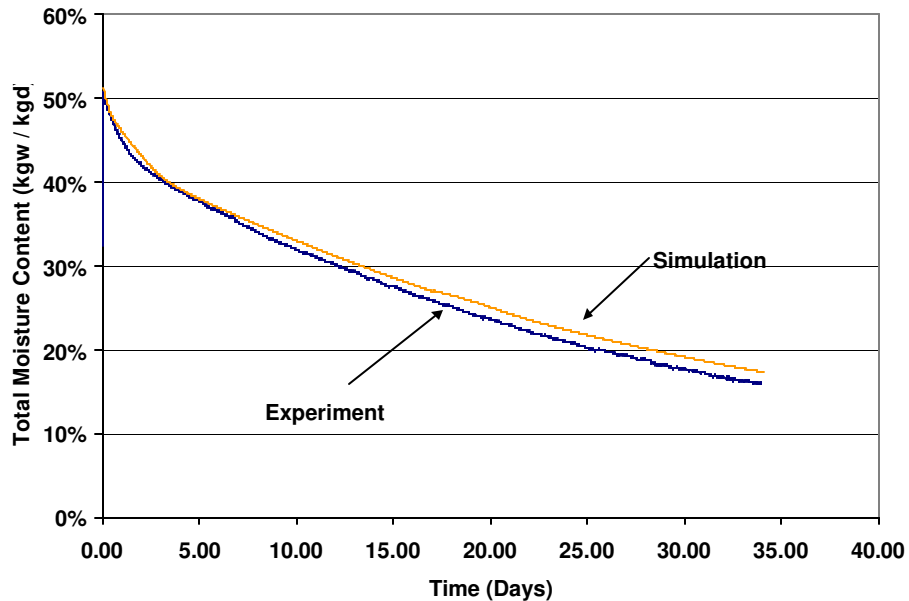


Figure 4— Comparison of experiment and simulated drying results in terms of total MC (%) of OSB sheathing wall components (Set 1)

CONCLUDING REMARKS

hygIRC has been used in the MEWS project as the primarily analytical tool to conduct a parametric study to assess the hygrothermal performance of various wall assembly types subjected to different North American climatic conditions.

The overall agreement between experimental and simulated results is very good in terms of the shape of the drying curve and the time taken to reach equilibrium moisture content. A mean set of material properties alone is used in this preliminary investigation. Other material property data on hand at the Institute suggests that the properties can vary within a range.

This results obtained in these experiments further enhance confidence towards the implementation of hygIRC in undertaking broader parametric studies.

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