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A MODEL OF THE MOISTURE BALANCE IN THE OUTER PORTION OF WOOD FRAME WALLS

By:
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Introduction

Because of a strong economic need for improvement in the durability of wood frame walls in damp climates, several recent field and experimental investigations of wood frame wall performance have been undertaken that have yielded results not readily usable by the building design industry. Although scientists have been investigating the migration of moisture within walls for several decades, the type of hard design information needed to improve performance is not available. This demonstrated lack of availability of design guidelines led the Canada Mortgage and Housing Corporation to commission a research program aimed at prediction of moisture performance. The program, which has lead to the model summarized in this paper, is still in progress. A more detailed description of the model and the findings of this research program is available from the Canada Mortgage and Housing Corporation in Ottawa, Canada.

Objective

The objective of the study was to provide a computer model of the portion of a wood frame wall, from the sheathing outwards that could be used as a tool for furthering the understanding of the physical processes involved in wetting and drying and for the improvement of wall durability.

Model Description

The basic heat, moisture and air movement mechanisms were analyzed at the beginning of the project to determine if the model could be reduced from a general three dimensional model to something more compact. It was determined that a two dimensional section through the wall could be modelled that would illustrate all the basic properties necessary. The conditions could be varied in such a model to represent any vertical section of a wall.

The model was further simplified with, what we consider, little loss in generality by dividing the two dimensional wall section into a vertical stack of one dimensional horizontal heat and moisture flow wall model elements joined by a one dimensional vertical airflow model which represents the airspace behind the siding. Figure 1 illustrates this arrangement. This physical arrangement within the wall is used with two scalar field models which are temperature and moisture content and the vector field model of air velocity.

The word element in this context refers to the one-dimensional flow model in the vertical stack of models. Each one-dimensional element is modelled by a series of layers consisting of the various building materials within the wall. A location within the wall can therefore be uniquely specified by its element number (vertical direction) and its layer number (horizontal direction).

In studying the process of heat and moisture flow through the wall, it was found that sufficient accuracy could be attained by allowing heat transfer as well as moisture transfer by diffusion and capillary action to act one dimensionally, with variations in wall performance being accounted for by the number of one dimensional models stacked vertically to represent the wall. There are some processes, however, that do not fit well into this one dimensional approach. Airflow in the airspace behind the siding is one such process. This was handled by producing a vertical airflow model of the airspace which could interact with any or all of the heat and moisture flow models.

In addition to the airflow, water drainage provides vertical movement of moisture. Drainage was handled by allowing surface layers to be saturated to a maximum beyond which any additional moisture would become a source on the next lower element.

Air leakage has been treated as a series of source/sink pairs with a sink in any particular layer of any particular element in the stack being tied to a source in any other layer of any other model element. This provides a method of modelling more or less complicated flow paths whose driving potential is the pressure difference across the wall.

Types of Results

The model in its present form has been used to generate two different forms of results. Several runs have been made using steady-state inputs to generate distributions within the wall for fixed conditions. These runs illustrate the basic performance of the wall to give an understanding of wall behaviour in general.

The second set of runs gives hourly time histories of various parameters for an extended period, using hourly weather data. These time histories demonstrate the long term response of the wall to real weather given an initial high moisture content. These results illustrate the use of the model as a design tool to determine the reliability of given wall constructions.

The running of the program requires a "wall" file which describes the wall in terms of materials, thicknesses, opening dimensions etc. Table 1 is an example of the wall file. The first line of Table 1 is simply a title that gives a brief description of the wall. The reference to Halifax south wall indicates that the pre-processed hourly weather data is for a south facing wall located in Halifax. The appropriate data file is specified within the table. A prompt in the program asks if weather data is to be used. If not, it asks for a set of fixed weather conditions, and ignores the weather data file, named in the table.

The material properties are specified by numbers from a materials database shown in Appendix A. Those properties are handbook values subject to modification if desired.

The conditions shown in Table 1 have been chosen as the benchmark wall. Changes from the benchmark wall that have been made for each run are shown on each of Figures 2 to 10. Any parameter not mentioned on a figure is the same as that given in Table 1. Note that the wall height has been set to 6m on the base wall, making each of the 9 elements 67 cm tall. The effect of a change in wall height is also investigated. Also shown on the figures are the weather conditions used for the steady-state runs.

One of the purposes of the study was to investigate the effect of the installation of vertical furring strips, commonly called strapping, beneath horizontal siding. This creates an airspace between the siding and the sheathing material. The amount of airflow within this airspace, and its communication with outdoors could have a large effect on the ability of the wall to dry. For this reason the gap between horizontal siding elements, referred to here as simply the gap, the width of opening at the top of the airspace, referred to as the top opening, and the airspace thickness created by the strapping have been used as parameters in the study.

Discussion of Results

Figures 2, 3 and 4 are drying data selected and grouped to show the effect of wall type under different weather conditions.

Using these three graphs, one can judge the general performance of a wall construction compared to other constructions. For example, in this case, the base wall condition (strapping, top opening, 1mm gap) appears to be the best in two of the three weather conditions. In the third case, wider siding gaps appear better. In this comparison, the wall with no strapping and no top opening appears to be the worst. This type of comparison is good for grading performance of construction types, but does not help to judge the adequacy of any wall type or assist in material selection.

Figure 5 compares the drying rate of the sheathing with two different sheathing paper permeabilities. This is accomplished by changing the thickness of the paper from 0.5mm to 1.5mm. As Figure 5 shows, the drying rate to the outdoors is very dependent upon building paper permeability. The ratio of permeabilities shown is 3:1. It is not uncommon for roofing felt to be used in place of building paper, which is thirty times more resistive to vapour than sheathing paper.

All of Figures 2 to 5 show data for a 2 storey wall of 6 metres in height. To investigate the effect that height has on drying, the base wall was altered to a height of 2 metres. A comparison of drying rates for the 2 and 6 metre walls under three different weather conditions is shown in Figure 6. The wind pressure distribution was kept the same for both wall heights. It can be seen that there is little difference except when there is high incident solar radiation. In that case, the drying rate is significantly higher for the taller wall.

Figures 7 to 10 are time histories of moisture content in layer 10 (sheathing) at the top, middle and bottom of the wall. The weather data used was taken from weather data tapes for Halifax, 1974. Figures 7 and 8 represent a wall with 20mm strapping while Figures 9 and 10 represent a wall without strapping. By comparison of Figures 7 and 9 or Figures 8 and 10, the effect of strapping can be seen. The walls have initially 88% moisture content by weight and are allowed to dry without moisture input other than from the outside air.

As a method of comparison, the time required to reach 30% could be used. This is shown on the figures. From this comparison we find that the unstrapped wall takes from 28% to 133% longer to reach 30% moisture content than the strapped wall. A similar comparison between north and south walls shows that north facing walls take from 15% to 30% longer than south facing walls to dry to 30%.

The graphs also show that in the strapped wall, the top dries as quickly as the bottom. In the case of the unstrapped walls, however, the top takes from 66% to 79% longer to dry than the bottom. This indicates that for the condition shown, the drying profile that is most prevalent must be something like those shown on Figures 2 and 4 which are both no wind, convection cases. We must note here that the higher drying rate near the bottom is due to the fact that outside air is entering at the bottom and rising to the top. This situation would be drastically altered if the lower gaps were sealed or if exterior wetting and drainage had come into effect.

Conclusions

The development of a computer model has proven to be an efficient method of assembling available information and presenting it in a manner that directs further work with a minimum of duplication. The focus of work now in progress is the refinement of the model, the assembly of airflow and drainage coefficients, unavailable from the literature and the validation of the model through laboratory and field investigations.

The model has been demonstrated in its two different operational modes. These are:

1) Grading the relative performance of different wall constructions under standard conditions; and

2) Grading the relative long term performance of different wall constructions in the presence of real weather conditions.

Results to date show that provision of ventilation paths behind siding enhances the wall's drying capability. Both free and forced convection are important factors in wall drying.

TABLE 1
WALL CONSTRUCTION FILE

HALIFAX SOUTH WALL: 20mm AIR SPACE, 20mm OPENING AT THE TOP, 3 ITERATIONS

NUMBER OF ELEMENTS UP THE WALL (NV) AND LAYERS THROUGH THE WALL (NE) 9, 12

SELECTION OF MATERIALS FOR EACH LAYER (SEE PROPERTIES DATABASE FOR #) 1, 15, 16, 16, 16, 4, 5, 4, 6, 7, 8, 9

THICKNESS OF EACH LAYER (m)
1,0.002, 0.005, 0.005, 0.005, 0.002, 0.02, 0.002, 0.0005, 0.005, 0.095,1

WALL HEIGHT (m), WALL LENGTH (m)
6, 9

SIDING GAP CHARACTERISTICS: WIDTH (m), FLOW PATH LENGTH (m), FLOW EXPONENT 0.001, 0.01, 0.9

TOP OPENING CHARACTERISTICS: WIDTH (m), FLOW PATH LENGTH (m), FLOW EXPONENT 0.020, 0.02, 0.8

AIR SPACE CHARACTERISTICS: NUMBER OF THE LAYER, FLOW EXPONENT
7, 0.8

WIND PRESSURE COEFFICIENTS FROM BOTTOM TO TOP (9 elements + UPPERMOST OPENING) 0.1, 0.2, 0.3, 0.4, 0.5, 0.5, 0.4, 0.3, 0.2, 0.1

WALL ORIENTATION (DEGREES FROM NORTH): N:360, E:90, S:180, W:270 180

NAME OF THE WEATHER DATA FILE (INCLUDE THE DRIVE SPEC: e.g. A:DWEATH.SOU) A:HAL.SOU

MOISTURE SOURCE STRENGTH IN kg/hr, & LOCATION: LAYER # & ELEMENT NUMBER 0, 7, 3

SIMULATION START AND END (DAY OF YEAR) 1,365

NUMBER OF ITERATIONS BETWEEN THE 3 MAJOR SUB MODELS 3

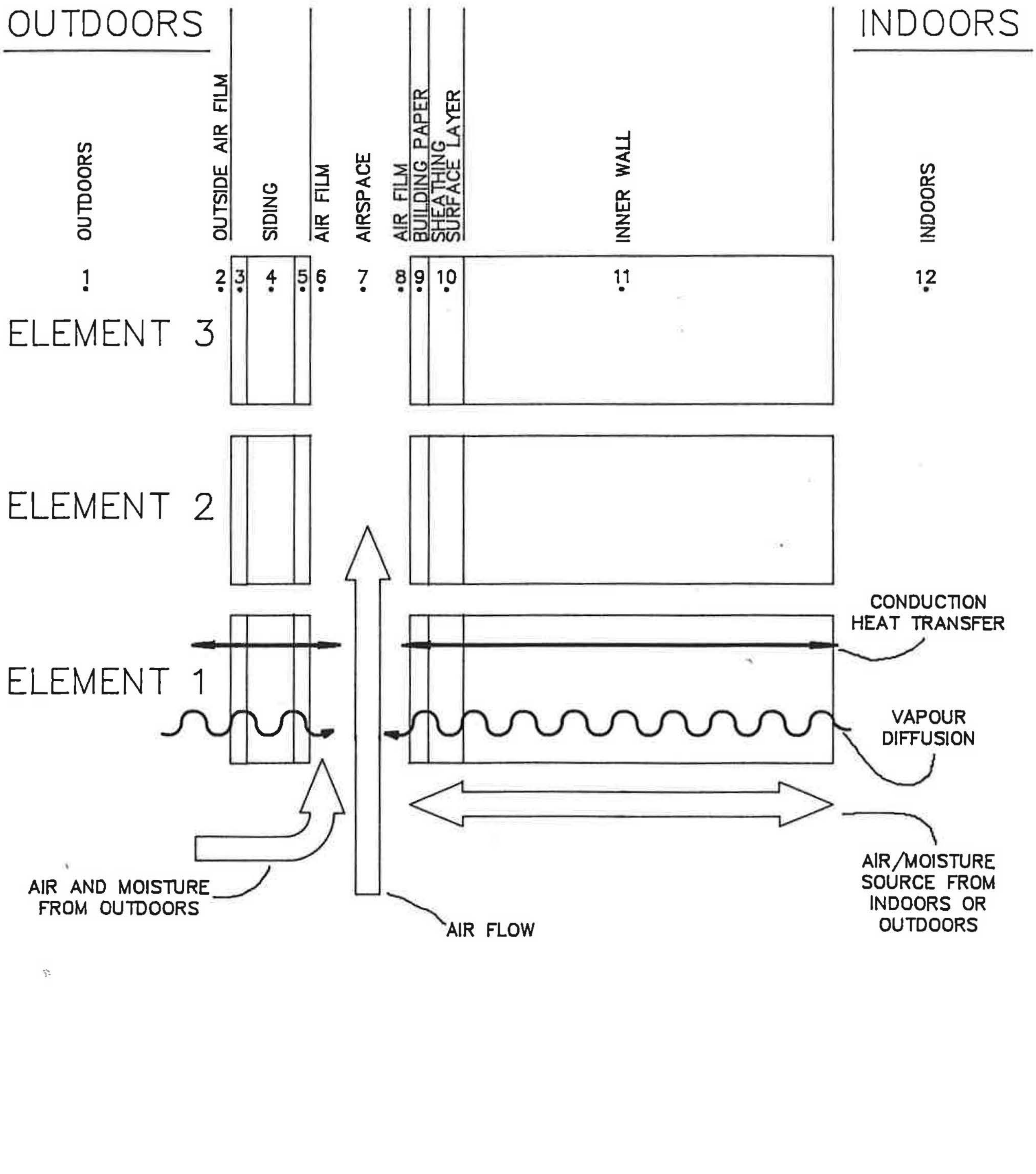
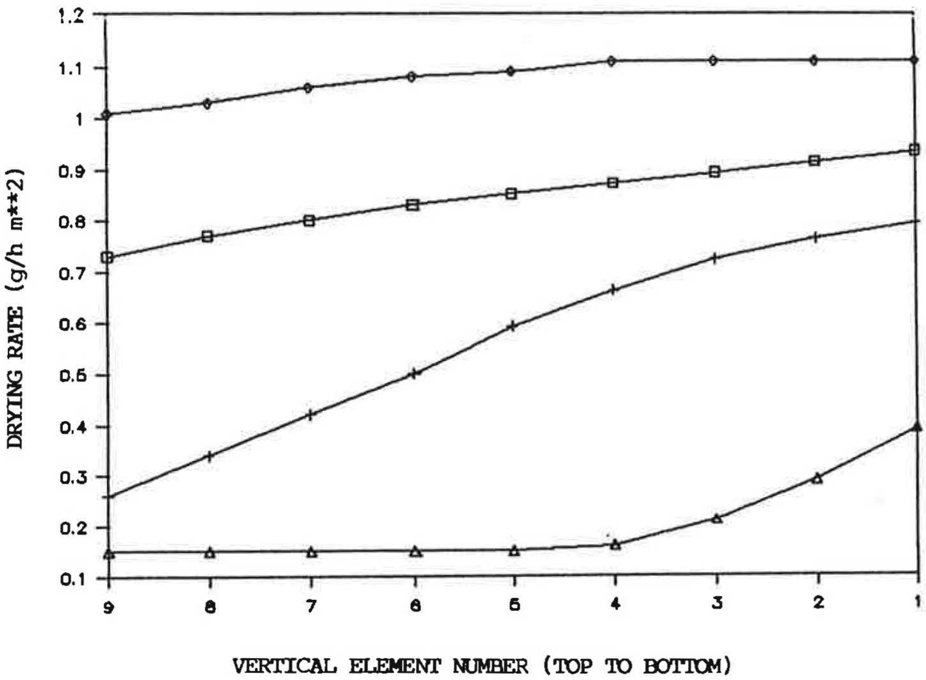


FIGURE 1
MODEL SCHEMATIC

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar Radiation(W/m^2): 0



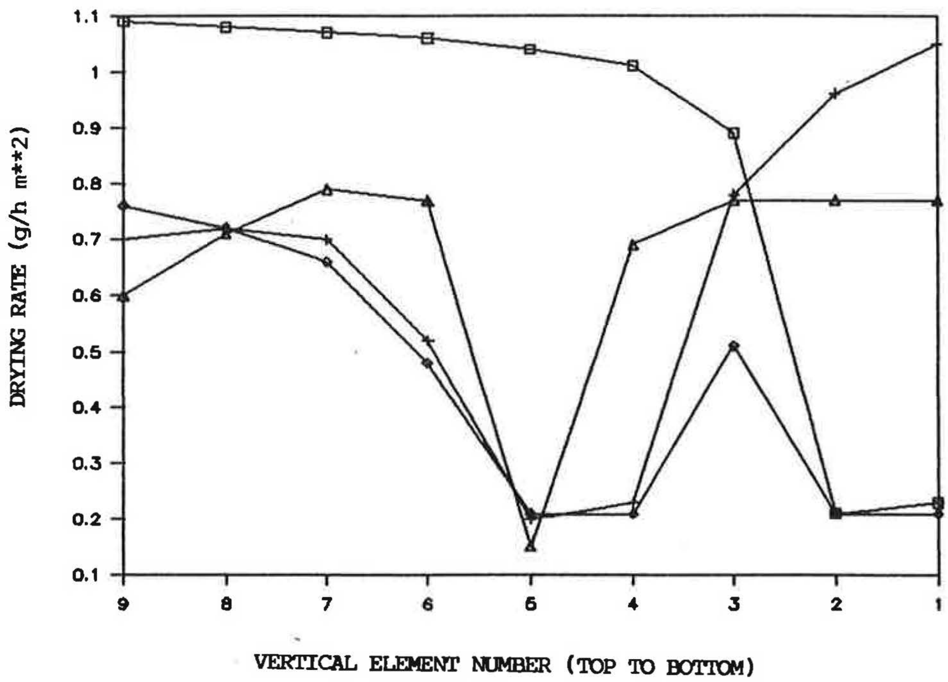
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◊	20	20	3	0.5
Δ	3	1	1	0.5

FIGURE 2
COMPARISON OF DRYING RATES
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 20

Solar
Radiation(W/m^2): 0



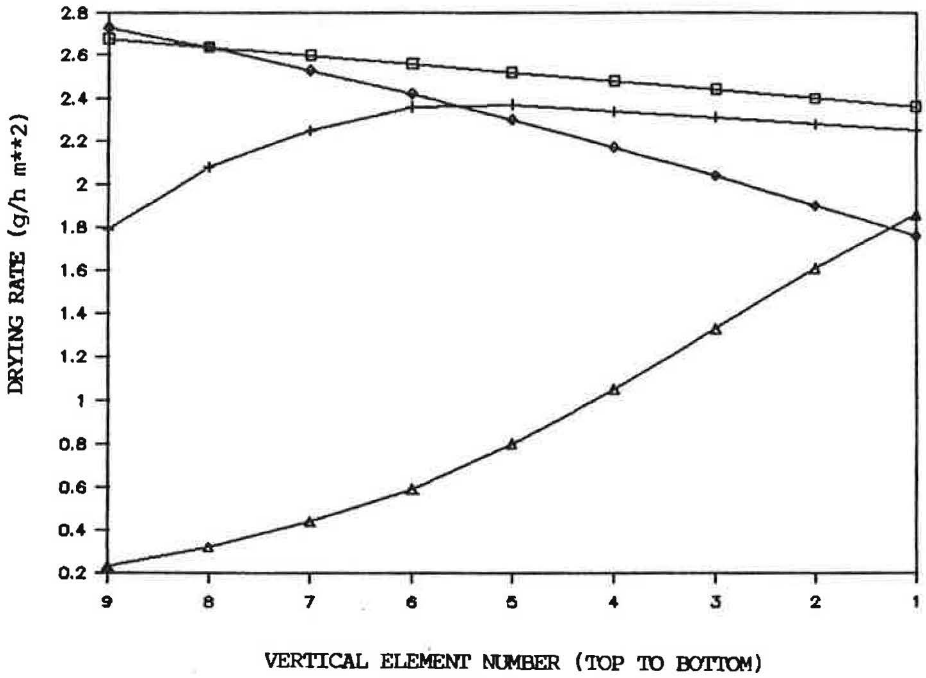
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◊	20	20	3	0.5
Δ	3	1	1	0.5

FIGURE 3
COMPARISON OF DRYING RATES
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar
Radiation(W/m^2):1000



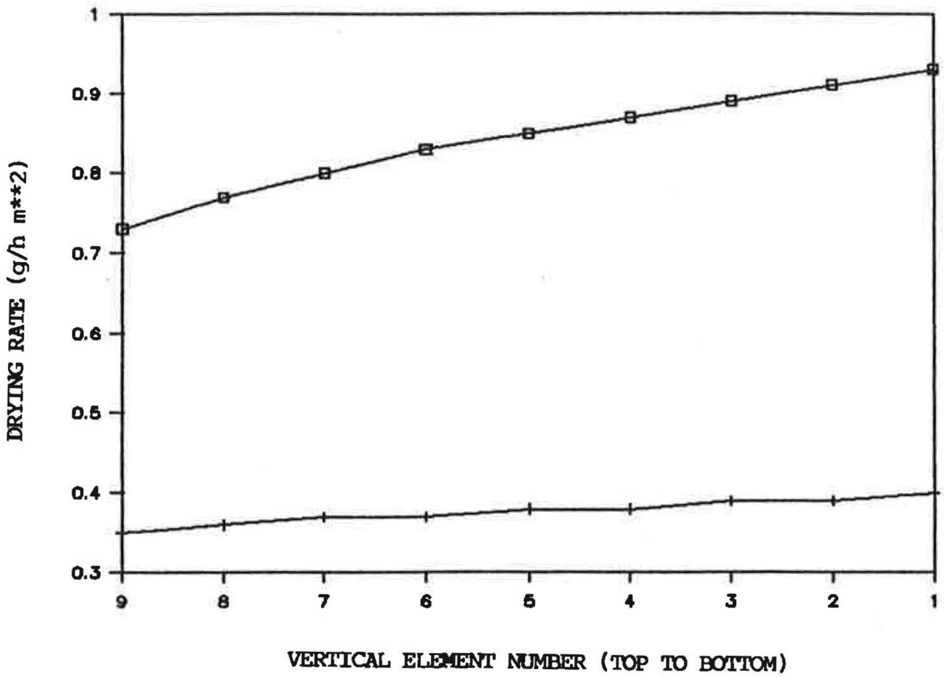
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◇	20	20	3	0.5
Δ	3	1	1	0.5

FIGURE 4
COMPARISON OF DRYING RATES
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar Radiation(W/m^2): 0

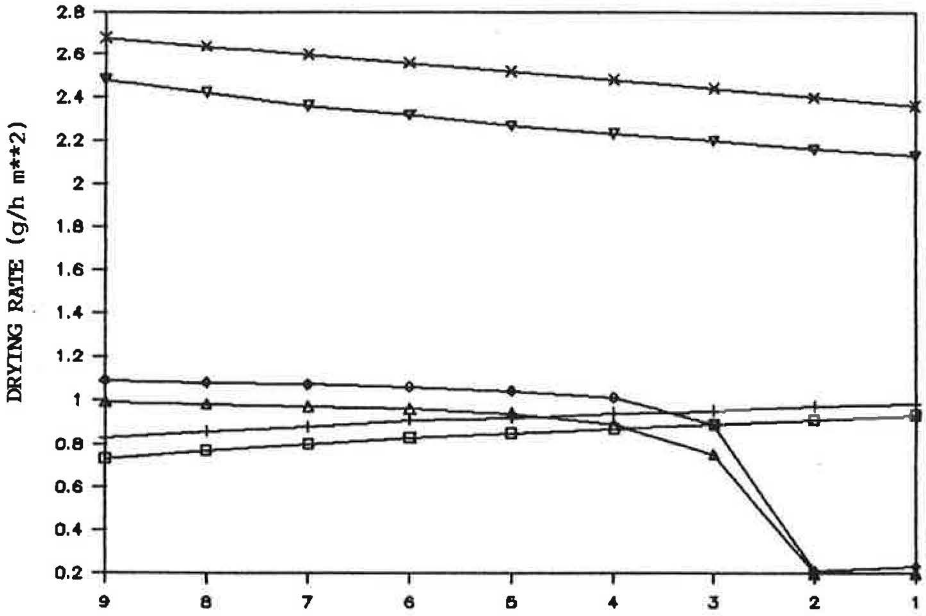


SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	20	1	1.5

FIGURE 5
COMPARISON OF DRYING RATES FOR TWO DIFFERENT SHEATHING PAPER THICKNESSES

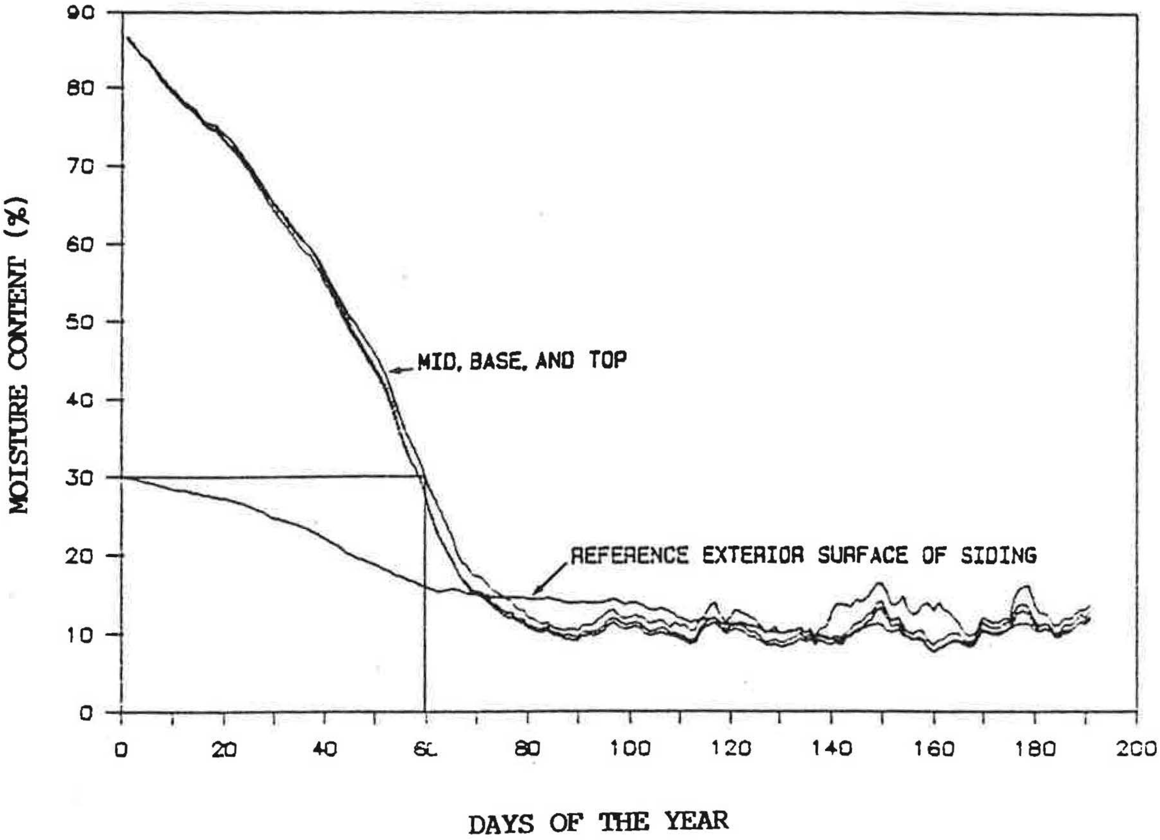
WALL PROPERTIES

Top Opening: 20 mm
Airspace Thickness: 20 mm
Gap Width: 1 mm
Sheathing Paper Thickness: 0.5 mm



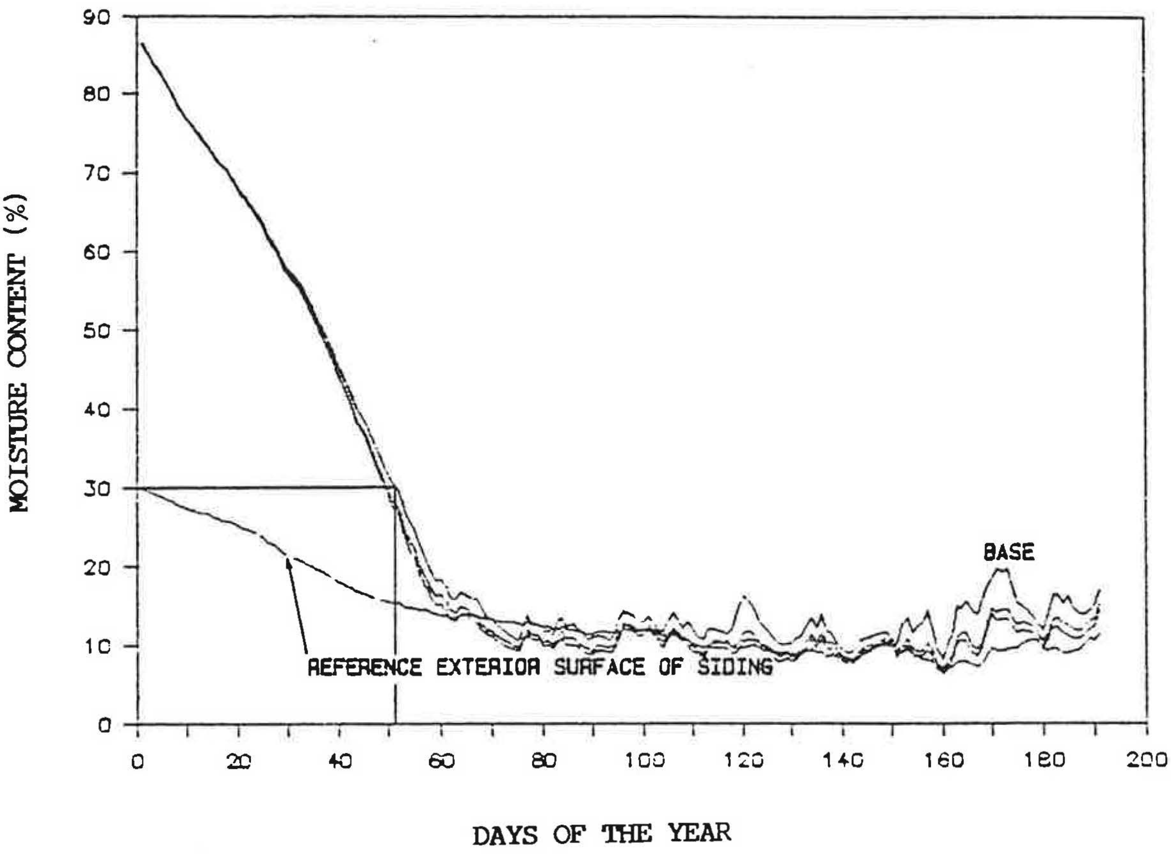
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)	WALL HEIGHT (m)
□	0	-10	0	6
+	0	-10	0	2
◊	20	-10	0	6
Δ	20	-10	0	2
X	0	-10	1000	6
∇	0	-10	1000	2

FIGURE 6
COMPARISON OF DRYING RATES AT LAYER 10
FOR TWO DIFFERENT WALL HEIGHTS



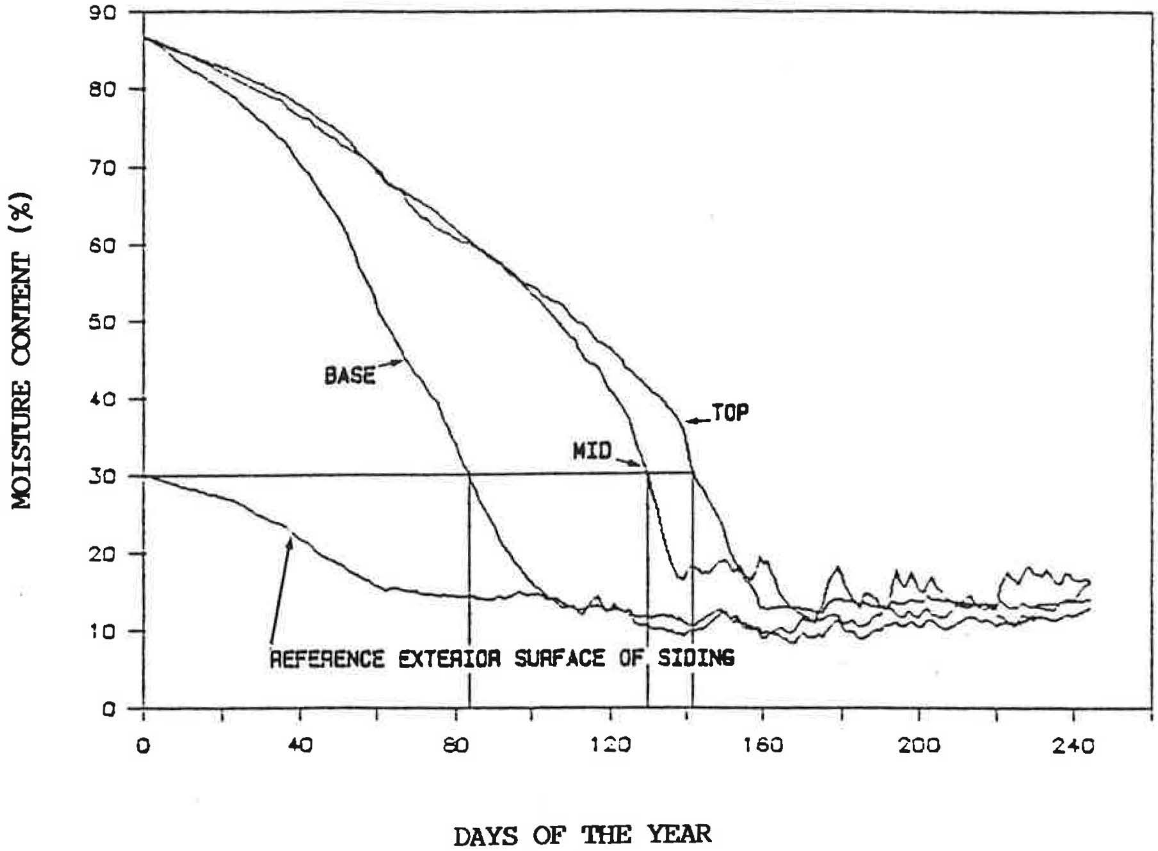
HALIFAX - north facing,with strapping

FIGURE 7
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



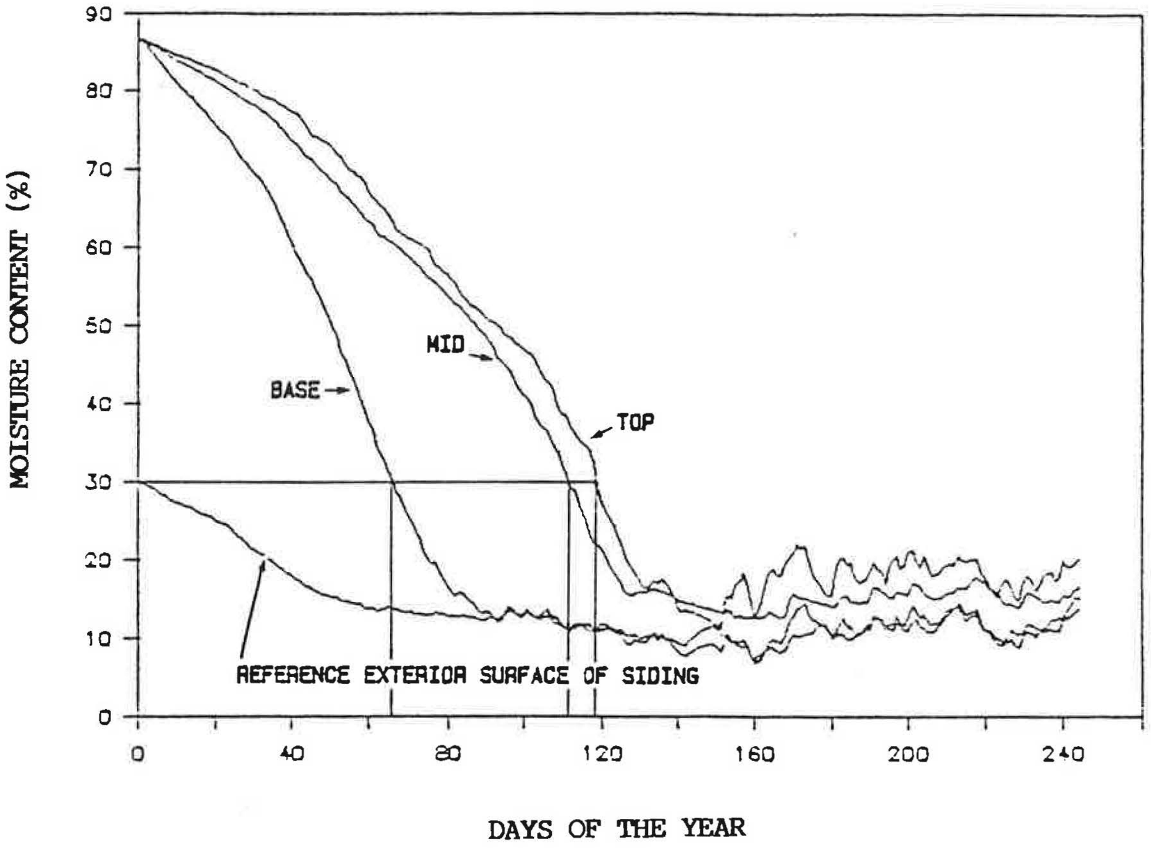
HALIFAX - south facing,with strapping

FIGURE 8
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



HALIFAX - north facing,without strapping

FIGURE 9
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



HALIFAX - south facing,without strapping

FIGURE 10
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE

APPENDIX A

MATERIALS DATABASE

PROPERTIES OF MATERIALS COMMONLY FOUND IN WALLS 03-14-1986

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RECORD NO. 1
 NAME                                             : OUTDOOR AIR
 DENSITY (Kg/m3)                                  : 1.21
 HEAT CAPACITY   (W.s)/(Kg.K)                     : 1005
 THERMAL RESISTIVITY   ((m2.C)/W)/m               : 0
 DIFFUSION RESISTIVITY   ((Pa.m2.s)/Kg)/m         : 5.7E9
 GAS CONSTANT   (Pa.m3)/(Kg.K)                    : 287.055
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)             : 1

RECORD NO. 2
 NAME                                             : WATER VAPOUR
 DENSITY (Kg/m3)                                  : .598
 HEAT CAPACITY   (W.s)/(Kg.K)                     : 2050
 THERMAL RESISTIVITY   ((m2.C)/W)/m               : 18.
 DIFFUSION RESISTIVITY   ((Pa.m2.s)/Kg)/m         : 0
 GAS CONSTANT   (Pa.m3)/(Kg.K)                    : 461.52
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)             : 1

RECORD NO. 3
 NAME                                             : LIQUID WATER
 DENSITY (Kg/m3)                                  : 998
 HEAT CAPACITY   (W.s)/(Kg.K)                     : 4180
 THERMAL RESISTIVITY   ((m2.C)/W)/m               : 1.66
 DIFFUSION RESISTIVITY   ((Pa.m2.s)/Kg)/m         : 0
 GAS CONSTANT   (Pa.m3)/(Kg.K)                    : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)             : 2

RECORD NO. 4
 NAME                                             : INTERIOR AIR FILM
 DENSITY (Kg/m3)                                  : 1.21
 HEAT CAPACITY   (W.s)/(Kg.K)                     : 1005
 THERMAL RESISTIVITY   ((m2.C)/W)/m               : 20
 DIFFUSION RESISTIVITY   ((Pa.m2.s)/Kg)/m         : 5.7E9
 GAS CONSTANT   (Pa.m3)/(Kg.K)                    : 287.055
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)             : 1

RECORD NO. 5
 NAME                                             : AIR SPACE
 DENSITY (Kg/m3)                                  : 1.21
 HEAT CAPACITY   (W.s)/(Kg.K)                     : 1005
 THERMAL RESISTIVITY   ((m2.C)/W)/m               : 5
 DIFFUSION RESISTIVITY   ((Pa.m2.s)/Kg)/m         : 5.7E9
 GAS CONSTANT   (Pa.m3)/(Kg.K)                    : 287.055
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)             : 1
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03-14-1986

RECORD NO. 6

NAME	: SHEATHING PAPER
DENSITY (Kg/m3)	: 210
HEAT CAPACITY (W.s)/(Kg.K)	: 1200
THERMAL RESISTIVITY ((m2.C)/W)/m	: 10
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 1.7E12
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 4

RECORD NO. 7

NAME	: FIBREBOARD SHEATHING
DENSITY (Kg/m3)	: 352
HEAT CAPACITY (W.s)/(Kg.K)	: 1300
THERMAL RESISTIVITY ((m2.C)/W)/m	: 16.5
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 20E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 8

NAME	: INNER WALL
DENSITY (Kg/m3)	: 80
HEAT CAPACITY (W.s)/(Kg.K)	: 725
THERMAL RESISTIVITY ((m2.C)/W)/m	: 20
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3200E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 9

NAME	: INDOOR AIR
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 0
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 10

NAME	: PLYWOOD(DOUGLAS FIR)
DENSITY (Kg/m3)	: 544
HEAT CAPACITY (W.s)/(Kg.K)	: 1220
THERMAL RESISTIVITY ((m2.C)/W)/m	: 8.7
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3906E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 11

NAME	: PARTICLE BOARD
DENSITY (Kg/m3)	: 800
HEAT CAPACITY (W.s)/(Kg.K)	: 1300
THERMAL RESISTIVITY ((m2.C)/W)/m	: 7.4
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3900E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 12

NAME	: SEMI-RIGID FIBREGLASS
DENSITY (Kg/m3)	: 100
HEAT CAPACITY (W.s)/(Kg.K)	: 960
THERMAL RESISTIVITY ((m2.C)/W)/m	: 30.5
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.9E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

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RECORD NO. 13
 NAME                                               : FIBERBOARD SIDING
 DENSITY (Kg/m3)                                    : 800
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 1300
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 10.7
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 503E9
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 3

RECORD NO. 14
 NAME                                               : METAL SIDING
 DENSITY (Kg/m3)                                    : 2740
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 896
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : .004
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 1E20
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 4

RECORD NO. 15
 NAME                                               : EXTERIOR AIR FILM
 DENSITY (Kg/m3)                                    : 1.21
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 1005
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 15
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 5.7E9
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 287.055
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 1

RECORD NO. 16
 NAME                                               : WOOD-BASED SIDING
 DENSITY (Kg/m3)                                    : 544
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 1170
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 11.9
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 800E9
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 3

RECORD NO. 17
 NAME                                               : GLASS FIBER INSULATION
 DENSITY (Kg/m3)                                    : 25
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 657
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 26
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 5.9E9
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 1

RECORD NO. 18
 NAME                                               : WOOD STUD
 DENSITY (Kg/m3)                                    : 430
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 1200
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 9.1
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 800E9
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 3

RECORD NO. 19
 NAME                                               : POLYETHYLENE
 DENSITY (Kg/m3)                                    : 0
 HEAT CAPACITY  (W.s)/(Kg.K)                        : 0
 THERMAL RESISTIVITY  ((m2.C)/W)/m                  : 0
 DIFFUSION RESISTIVITY  ((Pa.m2.s)/Kg)/m            : 2.1E15
 GAS CONSTANT  (Pa.m3)/(Kg.K)                       : 0
 CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)               : 4
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