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Case Histories of Moisture Monitoring in Residential Walls

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ABSTRACT: There is an unjustified concern within the building industry that the use of an exterior low water vapor permeance foam sheathing design allows an accumulation of moisture between the vapor barrier and the exterior sheathing.

In this study the authors measured the moisture content in the wood studs of seven occupied homes, in four Canadian cities, with a low water vapor permeance sheathing (extruded polystyrene), with or without a noninsulating sheathing, such as plywood, fiberboard, or chipboard, used on the exterior of the house. The degree days ranged from 4068 to 5920°C, and the relative humidity ranged from 71 to 83.5%. In all cases the actual moisture content of the studs was measured with Delmhorst moisture elements and then read with Delmhorst moisture meters. The results show a similarity in moisture concentration patterns regardless of the exterior sheathing installed. The effects of construction practices and local relative humidities are discussed.

The practical usefulness of actual moisture studies of real homes, done in a variety of climates, will be most interesting to today's architects and builders.

KEY WORDS: double vapor barriers, field studies, low permeance sheathings, moisture content, moisture research, thermal insulation

There is an unjustified concern in the building industry that the use of an exterior low water vapor permeance foam sheathing design causes accumulation of moisture between the vapor barrier and the exterior sheathing. Research done by the U.S. Department of Agriculture [*1*], Owens-Corning Fiberglass [*2*], and others [*3–5*] has shown that low permeance foam sheathings present no greater cold weather condensation hazard than the other types of sheathing studied, and therefore, the concern is unjustified.

Incorrect assumptions have led to confusion within the construction industry about the use of insulated, low water vapor permeance foam as an external sheathing on wood-frame constructed homes. In this study the authors measured the moisture content in the wood studs of seven occupied homes in four Canadian cities. Each home had a low water vapor permeance sheathing (extruded polystyrene), with or without a noninsulating sheathing, such as plywood, fiberboard, or chipboard, installed on the exterior of the house. (See Table 1 for the permeance values of common exterior sheathing materials.) Recognizing that there are many uncontrollable variables in this type of study, extreme conditions were chosen for each site. In Winnipeg, Manitoba, a high heating degree-day region using conventional construction was examined; in London, Ontario, a high interior relative humidity was studied in a moderate heating degree-day region; in Regina, Saskatchewan, an energy-efficient design was studied in a high heating degree-day region; and last, in St. John's, Newfoundland, a moderate heating degree-day region was examined in a maritime climate with a high relative humidity.

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TABLE 1—*Permeance of exterior sheathing materials.*

Product or Material	Thickness, mm	Metric, ng/Pa · s · m^2	Imperial, perm
Polyurethane (foil-faced)	25.4	1.5	0.025
Polyethylene film	(4 mil)	5.0	0.08
Exterior plywood	9.5	20.0	0.35
Extruded polystyrene	38.1	23.0	0.40
Exterior plywood	12.7	27.0	0.47
Extruded polystyrene	25.4	35.0	0.60
Building paper		58 to 290	1.0 to 5.0
Molded polystyrene	38.1	76 to 193	1.3 to 3.3
Phenolic (kraft-faced)	28.6	320	5.5
Gypsum sheathing	12.7	2330	40
Fiberboard	12.7	2330 to 5830	40 to 100
Rigid glass fiber	25.4	1750	30

The true measure of moisture performance for any building material is how well it performs against Mother Nature. It is important to understand the minimum conditions required for fungi growth when evaluating moisture content in wood stud data. Fungi growth causes wood studs to rot. This growth requires free water in cell cavities [*6*], which is present because the cell walls are already saturated. The saturation point is reached when the moisture content is within the range of 25 to 32%. Correspondingly, fungi growth requires a minimum temperature of 4°C, with the optimum temperature being about 27°C. Adequate oxygen is always present in conventional buildings; therefore, fungi growth could occur in the summer months when the weather is warm, but only if the moisture content is excessive. Moisture damage occurs when the design allows for an accumulation of moisture that results in excessive levels during the warm months when fungi are most active.

The ultimate measure of performance, then, is to ensure that the moisture content is less than 25% when the temperature is greater than 4°C.

The results showed that the moisture concentration in the wood studs was generally less than 15% in the homes studied and always less than the 25% required for fungi growth, regardless of the sheathing installed. As suggested by others [*7,8*], external relative humidity and airtightness were shown to be important variables in controlling the moisture content in wood studs. The water vapor permeance of the walls studied was shown to be an insignificant factor in controlling the moisture content in the wood stud.

Technical Setup

Instrumentation Details

Delmhorst moisture elements were installed in the wood studs during the construction of several occupied homes in Canada. The homes were located in Winnipeg, London, Regina, and St. John's. Each test site represented a specific actual condition: Winnipeg—cold winters; London—high interior relative humidity; Regina—energy-efficient design; St. John's—high exterior relative humidity. For more information on the homes chosen, see the section entitled Construction Details. The length of the studies, the amount of data collected, and the type of data collected were specific to each test site. (See Table 2 for the weather conditions.) A Delmhorst moisture meter (Model J-1) was used to collect readings, and interior wall cavity temperature corrections were according to Cech and Pfaff [*9*]. The readings were recorded in weight percentages.

TABLE 2—*Weather conditions of four locations studied.*

Location	Degree-Days, Centigrade	Average Relative Humidity, %			
		1 A.M.	7 A.M.	1 P.M.	7 P.M.
Winnipeg	5889	80	81	64	69
Regina	5920	78	80	61	65
London	4068	85	86	68	75
St. John's	4804	88	86	76	84

The electrical resistance of wood is so highly sensitive to moisture content that a change in moisture content from 7 to 20% results in a 10 000-fold decrease in resistance [*2*]. The Delmhorst moisture meter data are accurate to within 0.5 to 2.0% moisture concentration, as the actual moisture concentration varies from minimum values of 5% through the fiber saturation (25 to 32%) [*10*].

The elements were installed by drilling 6-mm-diameter holes to a depth of 12 mm at a 45° angle to the stud face. Delmhorst probes were then installed with a snug fit by forcing the plastic collar into the 6-mm hole. A more detailed investigation was conducted in St. John's, Newfoundland, where Delmhorst moisture elements were used to measure the moisture content in the stud and also the humidity at the batt/sheathing interface. Thermocouples were also installed in St. John's to measure the temperature at the batt/sheathing interface. The moisture elements were generally installed on the leeward side of the buildings near a high-relative-humidity location such as a bathroom or kitchen.

Construction Details

Winnipeg—A six-year study was conducted to examine the long-term effects of installing a low permeance foam sheathing on the exterior of a residential building. Winnipeg was chosen because the housing authorities in Canada advised that locations with cold winters would test the worst scenario. Today, all authorities in Canada agree that buildings in high-relative-humidity regions are more susceptible to moisture damage than those in the cold, dry areas in the Midwest. Each of the Winnipeg homes was built using typical 1976 construction methods (see Table 3). A vapor barrier was installed without any attempt to seal punctures or joints, it can therefore be referred to as a vapor barrier, but it cannot be considered an effective air barrier. Two Delmhorst elements were used to measure the moisture concentration in the studs in each of the four houses. The heating degree-days for Winnipeg are 5889 Celsius [*11*].

Three wall designs were included for comparison:

(*a*) traditional construction using fiberboard sheathing as a control site,
(*b*) extruded polystyrene sheathing because of the low permeability (two homes), and
(*c*) extruded polystyrene over plywood because of the low permeance combination (plywood has a lower water vapor permeability than extruded polystyrene).

The home was electrically heated.

London—A five-year study was conducted to test a high-relative-humidity building with a low permeance foam sheathing installed externally (see Table 4). High interior relative humidities placed a high moisture stress on the building structure [*12*]. An indoor pool was chosen to ensure that this high moisture stress was indeed continuously placed on the wall design. Four

TABLE 3—*Winnipeg construction details.*

Construction Detail	Home No. 1	2	3	4
Style	single story	split level	single story	split level
Heating	hot-air gas	electric forced air	oil furnace	oil furnace
Wall construction[a]	12-mm gypsum 2-mil polyethylene RSI 2.1 batts (R12) 12-mm fiberboard 1-layer paper stucco finish	12-mm gypsum 2-mil polyethylene RSI 2.1 batts (R12) 9-mm plywood RSI 1.3 (R7.5) extruded polystyrene 1-layer paper siding	12-mm gypsum 2-mil polyethylene RSI 2.1 batts (R12) RSI 1.3 (R7.5) extruded polystyrene 1-layer paper brick exterior	12-mm gypsum 2-mil polyethylene RSI 2.1 batts (R12) RSI 1.3 (R7.5) extruded polystyrene 1-layer paper brick exterior
Probe No.	1, 2	1, 2	1, 2	1, 2
Probe orientation	W, N	N, N	NE, SW	N, S
Room[b]	DR, H	H, bath	BR, K	BR, K

[a]Extruded polystyrene was installed in 600 by 2400-mm dimensions. Plywood and fiberboard were installed in 1200 by 2400-mm dimensions.
[b]DR = dining room; H = hall; bath = bathroom, BR = bedroom; K = kitchen.

TABLE 4—*London construction details.*

Construction Detail	Characteristics			
Style	home with indoor pool			
Heating	hot-air gas			
Wall construction[a]	cedar polyethylene RSI 3.5 batts (R20) RSI 1.3 (R7.5) extruded polystyrene 12-mm fiberboard building paper horizontal furring cedar siding			
Probe No.	1	2	3	4
Probe orientation	NE	NE	NW	NW
Room[b]	IP	IP	IP	IP

[a]Extruded polystyrene was installed in 600 by 2400-mm dimensions.
[b]IP = indoor pool.

Delmhorst moisture elements were used to measure the moisture concentration in the studs of the indoor pool building enclosure. The heating degree-days for London are 4068 Celsius [*11*].

Regina—A one-year study was conducted to test the effects of a properly installed interior polyethylene vapor barrier with a low permeance foam sheathing installed externally (see Table 5). An energy-efficient home was chosen with RSI 3.5 (R20) glass fiber batts and RSI 1.7 (R10) extruded polystyrene. A continuous interior polyethylene air/vapor barrier was installed (see the Discussion section for a more detailed explanation of continuous air/vapor barrier). Three Delmhorst moisture elements were used to measure the moisture concentration in the studs of the energy-efficient home chosen. The heating degree-days for Regina are 5920 Celsius [*11*].

TABLE 5—*Regina construction details.*

Construction Detail	Characteristics		
Style	split level		
Heating	gas forced air		
Wall construction[a]	12-mm gypsum polyethylene (air/vapor barrier) RSI 3.5 batts (R20) RSI 1.7 (R10) extruded polystyrene building paper siding		
Probe No.	1	2	3
Probe orientation	S	E	W
Room[b]	bath,	K	BR

[a]Extruded polystyrene was installed in 600 by 2400-mm dimensions.
[b]Bath = bathroom; K = kitchen; BR = bedroom.

Newfoundland—A one-year study was conducted to see the effects of the high relative humidities in maritime regions such as Newfoundland on walls with a low permeance foam sheathing installed externally. Since the beginning of the moisture monitoring studies in 1976, many researchers have examined the cause and effect relationship that results in moisture damage. It has been shown that the highest percentage of moisture damage occurs in the high exterior relative humidity regions such as Newfoundland or the interior of British Columbia [*7*]. This study was initiated in March 1982 in St. John's, Newfoundland, to determine the effects of low permeance sheathings in a region of this type. A single dwelling was chosen to examine the effects of three different sheathing combinations (see Table 6). The single dwelling approach was used to eliminate uncontrolled variables such as interior relative humidity and weather exposure.

The house chosen showed typical signs of interior moisture problems caused by high internal relative humidity. Condensation was found on the windows and mildew on the interior drywall. The house had an original vapor barrier installed which could not be classified as an air/vapor barrier. The wind-driven rain side of a house in St. John's faces northeast. It is considered to be the side exposed to the highest moisture stress. The moisture content in the studs was monitored, as well as the wall relative humidity and the wall temperature of the north face of the house, which was exposed to this high moisture stress. The north face was divided into three sections: chipboard sheathing over studs, extruded polystyrene sheathing over studs, and an extruded polystyrene retrofit over chipboard and studs. Delmhorst moisture elements were used to measure the moisture concentration in the studs. Other Delmhorst moisture elements were used to measure the relative humidity within the wall, and thermocouples were used to measure the temperature within the wall of each of the three sections. The measurements were taken from the middle stud section of each of the three divisions defined here (see Fig. 1 for details). The heating degree-days for St. John's are 4804 Celsius [*11*].

Results

Winnipeg

The Winnipeg study showed that the moisture concentrations in the studs with chipboard, extruded polystyrene, and extruded polystyrene over plywood cycle with the seasons (see Fig. 2). The highest moisture concentrations were found as winter progressed, and the lowest moisture

TABLE 6—*St. John's construction details.*[a]

Construction Detail	Wall Section No. 1	2	3
Style	two story	two story	two story
Heating	electric baseboard	electric baseboard	electric baseboard
Wall construction[b]	12-mm gypsum polyethylene RSI 2.1 batts (R12) 12-mm chipboard exterior siding	12-mm gypsum polyethylene RSI 2.1 batts (R12) RSI 1.3 (R7.5) extruded polystyrene exterior siding	12-mm gypsum polyethylene RSI 2.1 batts (R12) RSI 1.3 (R7.5) extruded polystyrene over 12-mm chipboard exterior siding

[a]Note that this study includes only one house.
[b]Extruded polystyrene was installed in 600 by 2400-mm dimensions.

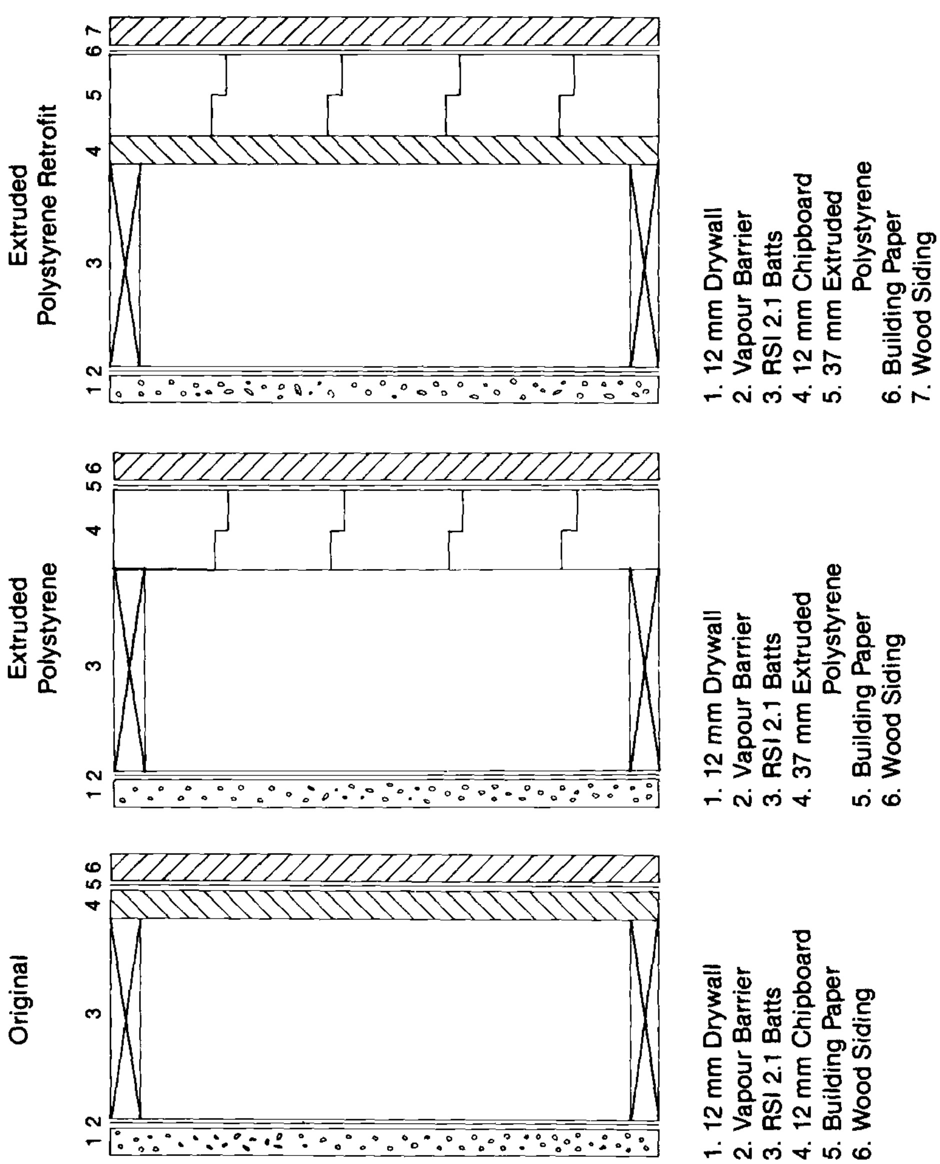

FIG. 1—*Wall construction (St. John's, Newfoundland).*

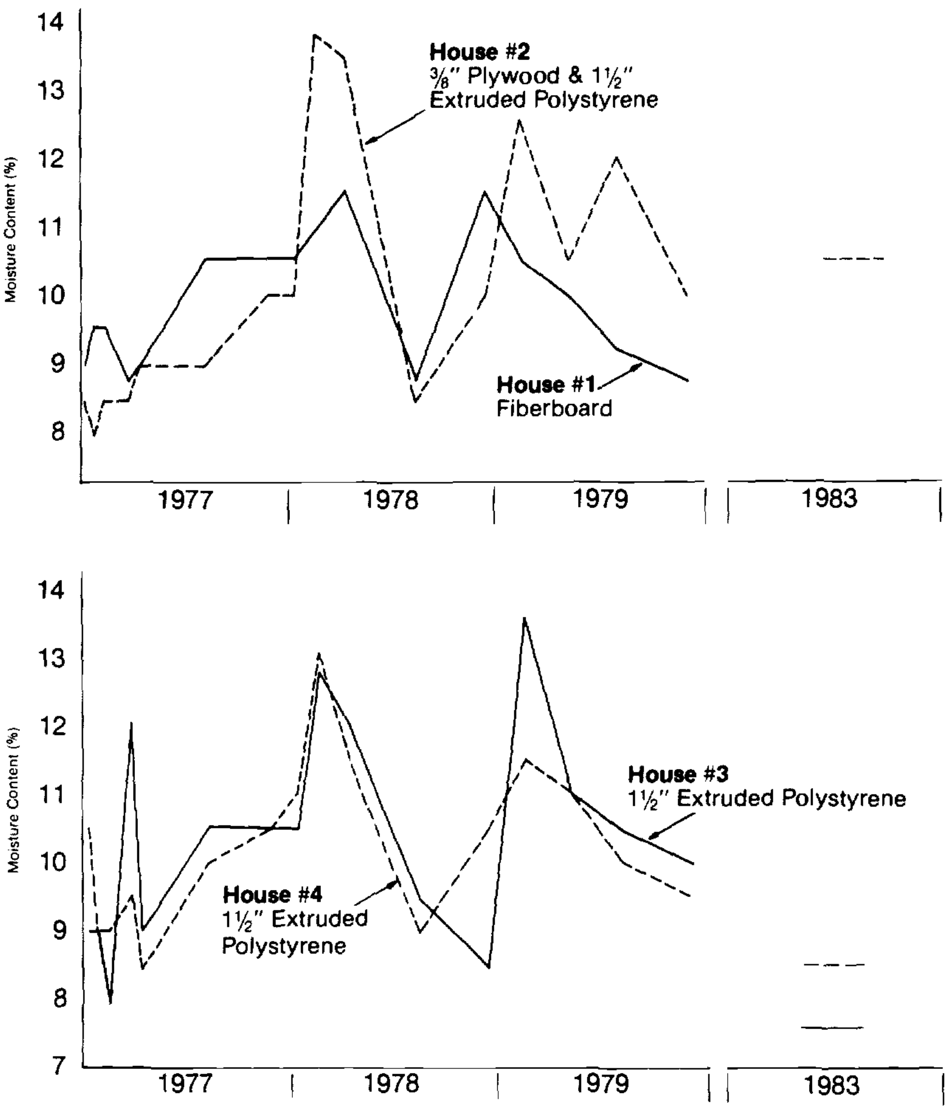

FIG. 2—*Stud moisture content versus time (Winnipeg, Manitoba).*

concentrations were found during the summer. The moisture concentrations in the studs ranged from 8 to 14%, which was well below the 25 to 32% required for fungi growth. The moisture data from the fiberboard, extruded polystyrene, or extruded polystyrene over plywood homes were generally within ±2%. Even the unvented house with electric heat and the very low permeance combination of extruded polystyrene and plywood had results comparable to those of the other test sites in Winnipeg. The results from all four houses showed no signs of an accumulation of moisture in the stud after six years. The weight percent moisture concentrations at the four test sites started at summer levels of 10, 9, 11, and 10 and ended at summer levels of 9, 11, 8, and 9, respectively. The summer moisture levels for House No. 2 increased from 1977 to 1979; however, a check in 1983 showed no increase in summer moisture from 1979 to 1983.

London

The London study was of a home with an indoor pool. Indoor pools ensure high interior relative humidities. The actual interior relative humidities were not measured. High interior relative humidities produced a higher than normal moisture stress on the wall design. The moisture concentrations in the studs ranged from 10 to 22%, which is still below the levels required for fungi growth. The results also show that the wall was able to recover from the high initial concentrations (see Table 7).

Regina

The Regina study showed that an energy-efficient house design with an air/vapor barrier installed on the warm side had moisture concentrations in the stud well below the levels required for fungi growth. The moisture concentrations in the stud ranged from 7 to 9%. These moisture concentrations were very low and did not show any signs of cycling with the seasons (see Fig. 3).

Newfoundland

The results of the Newfoundland study showed that the weather variations and the high relative humidity of this coastal region definitely affected the performance of the wall design, as can be seen in Fig. 4. The moisture concentrations of the three wall sections examined were higher than those from drier regions. The data also showed that the moisture concentrations were independent of the wall design selected.

TABLE 7—*Stud moisture content versus time, (London, Ontario).*

	Northeast		Northwest	
Date	Top Plate, %	Bottom Plate, %	Top Plate, %	Bottom Plate, %
10/78	16	18	17	19
11/78	17	19	16	22
12/78	18	15	17	20
6/79	17	11	15	13
12/79	12	10	17	16
6/82	10	11	7	10
7/83	10	10	17	17

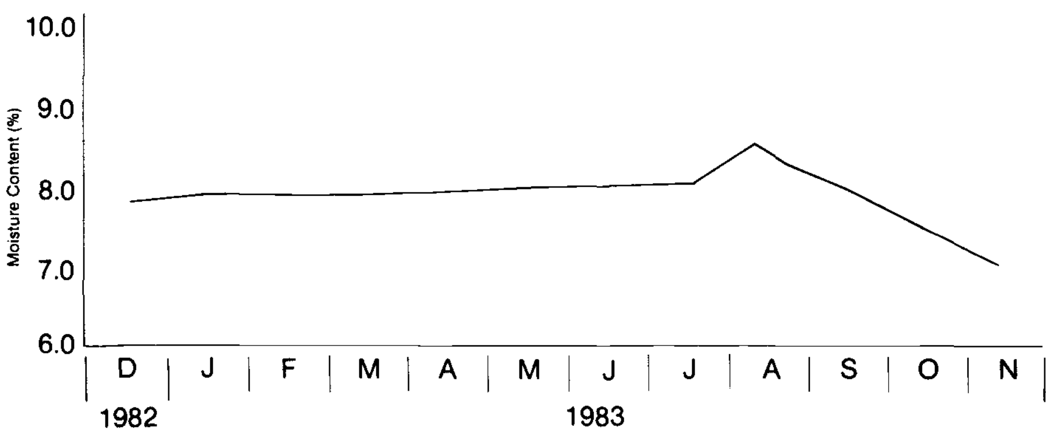

FIG. 3—*Stud moisture content versus time (Regina, Saskatchewan).*

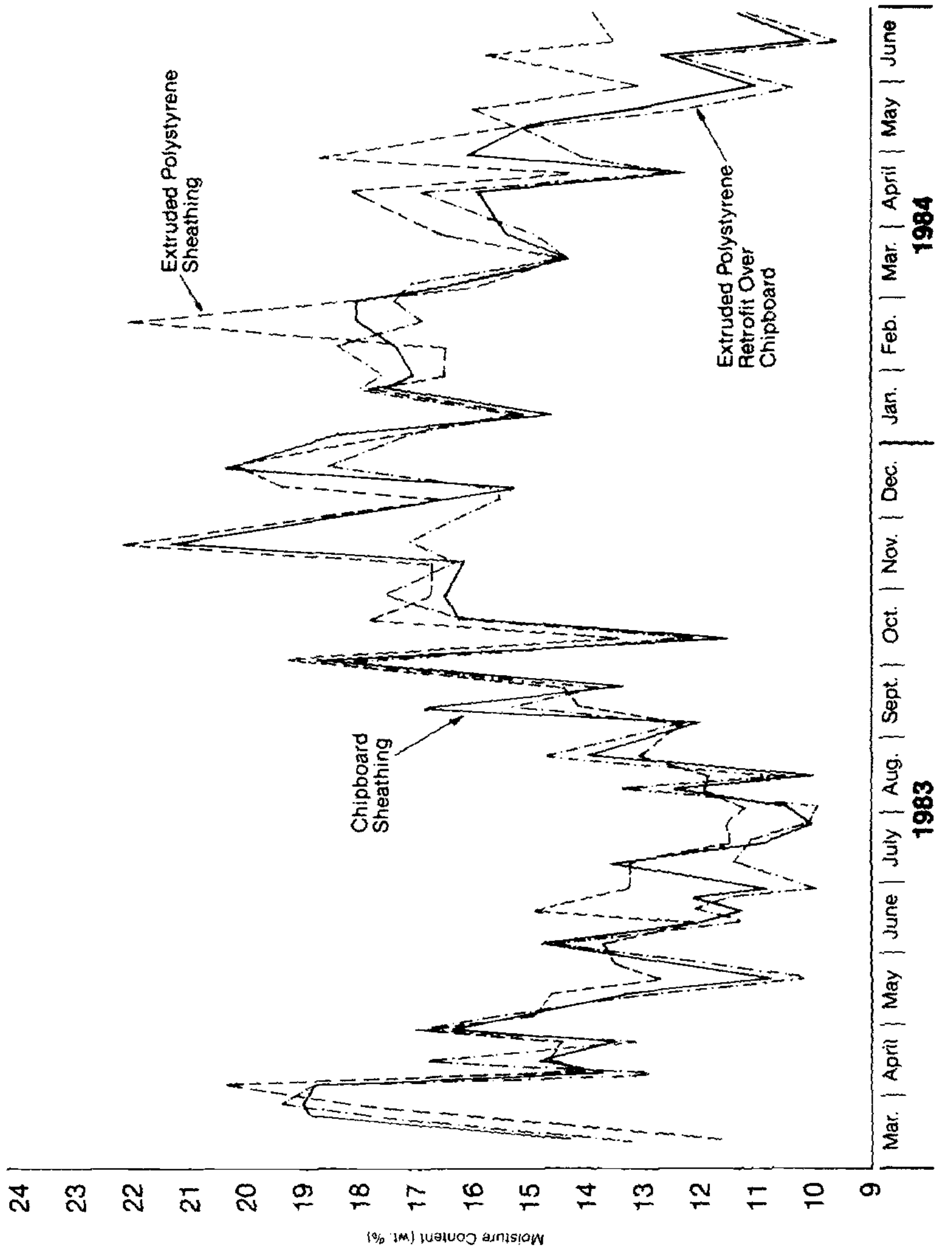

FIG. 4—*Stud moisture content versus time (St. John's, Newfoundland).*

A comparison of the data in Figs. 4 and 5 shows that the relative humidity within the wall varied daily and this, in turn, controlled the moisture concentration of the studs. The moisture concentration of the section using low permeance foam sheathing was equivalent to that of the section using higher permeance chipboard sheathing.

In Fig. 6, the temperature at the batt/sheathing interface exhibited a 3 to 6-degree-Celsius increase when low permeance foam sheathing was used in place of chipboard sheathing.

Discussion

The practice of installing low permeance foam sheathings on the exterior of a building has caused some technical people to hypothesize that moisture could accumulate between the polyethylene vapor barrier and the exterior sheathing. These problems have not materialized, and the hypothesis has remained unsupported by research or practical data. It is estimated that approximately 750 000 homes in North America have been sheathed with low permeance foam sheathings, and there has not been one documented case of moisture damage caused by low permeance foam sheathing. This practical evidence has also been supported by several research reports [*1–5*].

A point of interest found by Sherwood and substantiated in this study is that homes with an air/vapor barrier, such as the Regina home studied, control moisture cycling better than homes with only a vapor barrier. Air/vapor barriers such as the one installed in the Regina house are continuous and require special treatment at the sill plate, around the windows and doors, around electric outlets, and at the polyethylene joints. Some other designs allow for a distinction between the air barrier and the vapor barrier.

Regardless of the design and materials chosen, the importance of installing a proper air barrier to control moisture cannot be overemphasized. However, the results of this study and others [*1–5*] clearly show that normal building practices will perform satisfactorily when low water vapor permeance foam sheathings are installed externally.

In homes without an air barrier, a moisture cycling pattern can be found. It is best shown in the Winnipeg homes. The moisture content in the studs is higher in the winter and lower in the summer. The winter peaks are caused by the condensation of the moisture contained in the warm interior air, as it exfiltrates outward through the wall on the leeward side of the house.

As spring turns to summer, the warm, dry air from the exterior or the interior travels through the wall by infiltration or exfiltration, thereby drying the wood studs as the moisture content in the air reaches equilibrium with the moisture content in the wood studs.

An explanation for the excellent moisture control performance of extruded polystyrene is demonstrated in Timusk and Lischkoff [*13*]. They found that exterior insulating sheathings performed significantly better than noninsulating sheathings, when the amount of condensed water was controlled. As shown in Fig. 6, the batt/sheathing interface temperature for the walls sheathed with extruded polystyrene is 3 to 6 degrees Celsius warmer than the wall sheathed with chipboard sheathing. These warmer batt/sheathing interface temperatures can increase the capacity of air to contain moisture by over 100%, depending on the interface temperature, as shown in Fig. 7.

Conclusions

1. Extruded polystyrene used as external sheathing does not cause moisture accumulation in the wood studs.
2. Extruded polystyrene used as external sheathing will warm the batt/sheathing interface, thereby controlling the amount of condensation.

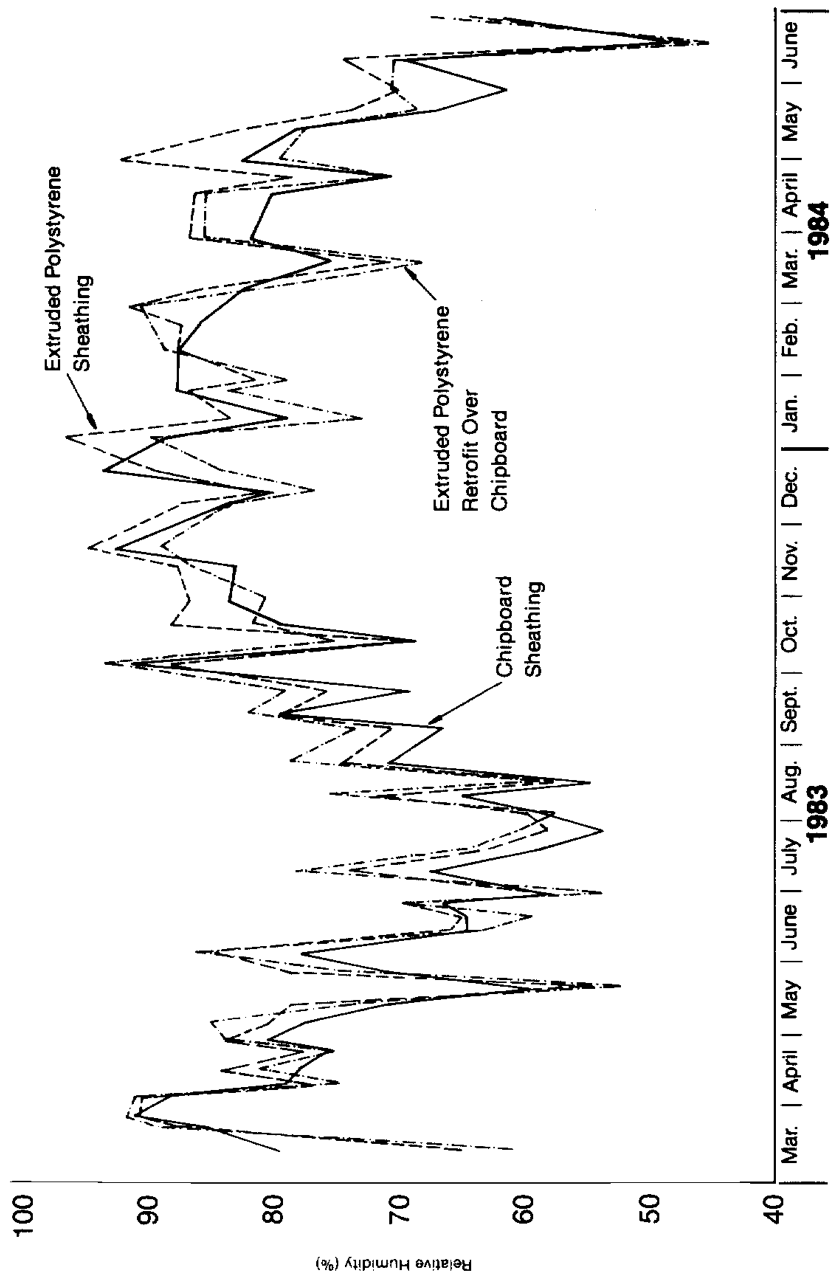

FIG. 5—Wall relative humidity versus time (St. John's, Newfoundland).

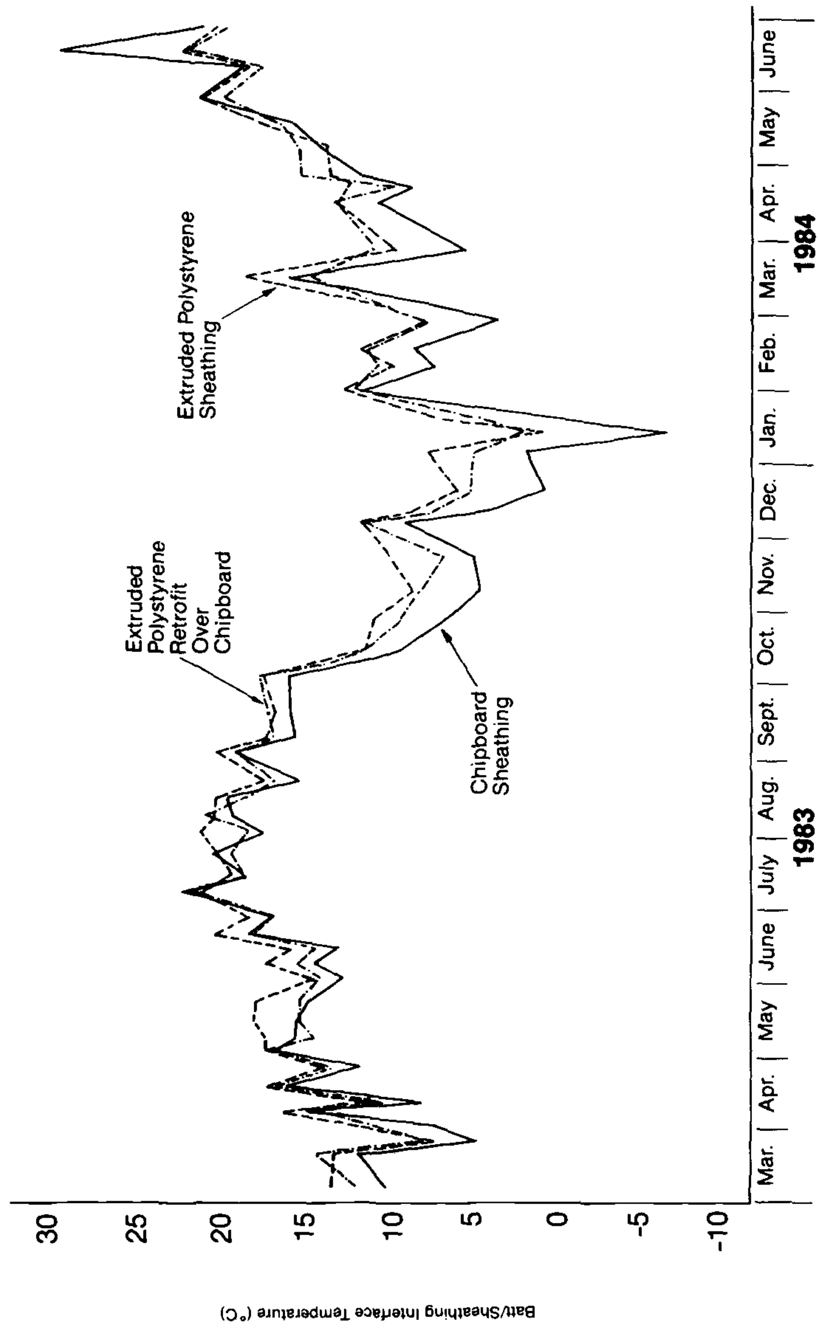

FIG. 6—*Batt/sheathing interface temperature versus time (St. John's, Newfoundland).*

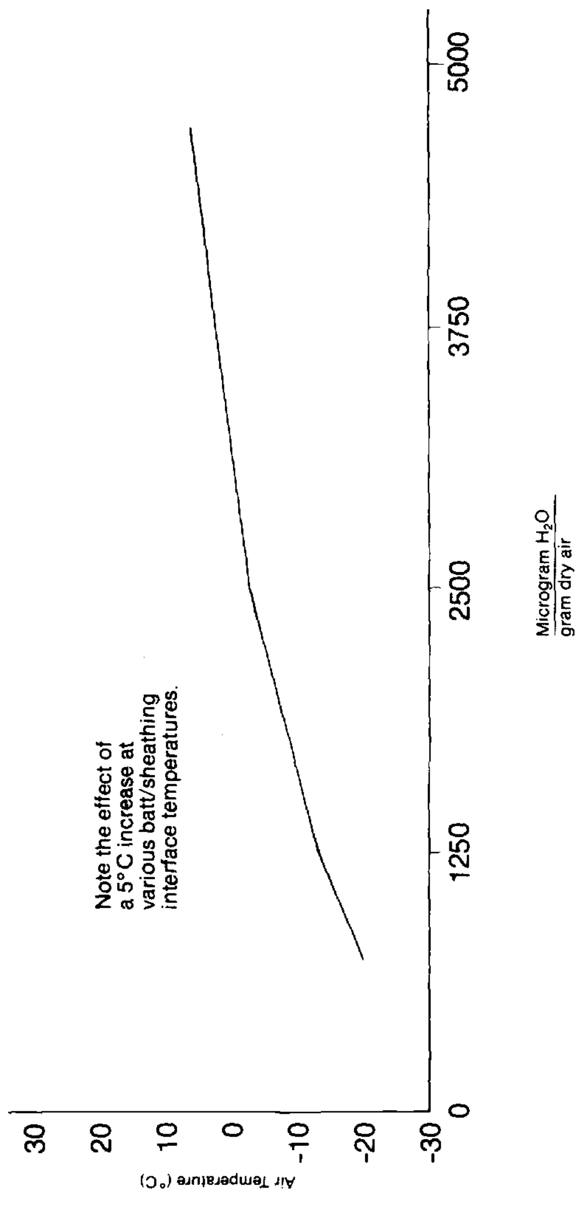

FIG. 7—*Temperature versus moisture capacity at 100% relative humidity.*

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