Performance of Wood-Based Siding in Energy-Efficient Homes Located in Cold Climates

R.E. Kroll, Ph.D. **K.C. Au, Ph.D.** **R.O. Gertjejansen, Ph.D.**

ABSTRACT

A test house was constructed to evaluate the performance of wood-based sidings. The exterior wall was clad with four lap and two panel sidings covering both foam and fiberboard sheathing. Moisture and thickness changes for the lap and panel sidings over different sheathing materials were compared. Moisture uptake and thickness change of lap sidings were affected by the permeability and moisture storage properties of the sheathing material and the vertical location of an opening in the vapor retarder made by an electrical receptacle in the wall cavity. The condition of the vapor retarder, intact or perforated, had little effect on the moisture and thickness change for lap sidings when installed over foam sheathing. Solid wood lap sidings (cedar and redwood) were more resilient than reconstituted wood lap sidings (hardboard and wood composite) to repeated wetting and drying cycles. Hardboard panel siding generally absorbed less moisture than plywood panel siding.

INTRODUCTION

Some energy-efficient homes in cold-climate regions have been troubled with severe exterior wall-cavity moisture problems. High levels of moisture in exterior walls can result in the premature failure of wood-based sidings and wall components (Merrill and TenWolde 1989). The failure characteristics of wood-based siding are excessive swelling, buckling, splitting between the rigid framing members, and, finally, decay. Controversy exists over the installation deficiencies of siding over insulating sheathing, particularly foil-faced polyisocyanurate foam.

Earlier studies (Lstiburek 1987; Tsongas 1991) showed that the installation of insulating (foam) sheathing is expected to reduce the drying potential of the exterior siding due to its impermeability and insulating properties. Ironically, the low heat capacity of the foam along with its high thermal resistance dramatically reduces interior or interstitial wall-cavity moisture (Tsongas 1991).

The objective of this study was to evaluate the performance of wood-based sidings installed over foam and fiberboard sheathing when exposed to typical indoor and outdoor conditions of a cold-climate environment. It is known that both thickness and moisture changes of siding on the exterior wall are influenced by the sheathing materials (foam and fiberboard), the orientation (north and south) of buildings, and the efficiency of the vapor retarder, and, therefore, those variables were evaluated in this study. Interior wall cavities were monitored with temperature and relative humidity (RH) sensors. Temperature sensors located at the siding/sheathing interface measured the effect of solar radiation on the air space behind the wood-based siding.

TECHNICAL APPROACH

Test House

A test house was constructed on the campus of a university Forestry Center in northern Minnesota (47° north latitude) where the number of heating degree- and cooling degree-days averages 9500 and 200, respectively, per year. It is a single-room structure that is 20 ft (6.1 m) long and 8 ft (2.4 m) wide, with the long axis east-west for maximum exposure of north and south walls. The north and south walls each were partitioned into 24 test sections, each 16 in. (0.4 m) wide by 4 ft (1.2 m) high, on which six types of commercial sidings were installed over the two sheathing materials with either intact or perforated vapor retarders (6x2x2=24), as shown in Figure 1. A 2 ft (0.6 m) wide plywood panel buffer surrounded the entire test wall. The east one-half of both walls had 25/32 in. (20 mm) fiberboard sheathing, while the west one-half had 1-in. (25-mm) foil-backed polyisocyanurate foam sheathing. Each wall assembly consisted of 2-in.-by-6-in. (38-mm-by-140-mm) nominal studs located 16 in. (0.40 m) on center, R-19 (RSI-3.4) fiberglass cavity insulation, and a 6-mil (0.15-mm) polyethylene vapor retarder applied directly behind the interior 0.5-in. (13-mm) gypsum wallboard. The fiberglass cavity insulation had an interior kraft paper facing that was attached to the interior edge of the studs. Both walls were divided into two levels with 2-in.-by-6-in. (38-mm-by-140-mm) lateral blocking. Thus each 16 in. (0.4 m) wide by 4 ft (1.2 m) high wall cavity was a test section where alternating cavities were fitted with electrical receptacles that perforated the vapor retarder, and the others were left intact without receptacles (Figure 1). Perforations of the wallboard and vapor retarder by the receptacles presented a potential for cold weather condensation, reportedly common in residential buildings. Table 1 and Figure 1 show the

---

R.E. Kroll is a research associate, **K.C. Au** is a post-doctoral research associate, and **R.O. Gertjejansen** is a professor in the College of Natural Resources at the University of Minnesota, St. Paul.

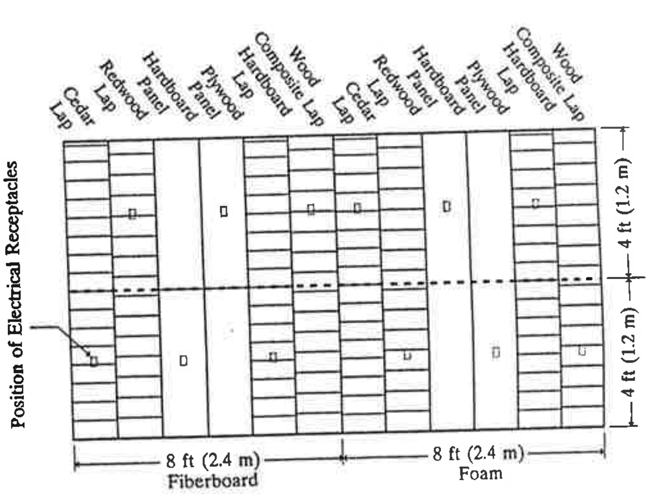

Figure 1 *Exterior view of one test wall over fiberboard and foam sheathing separated into upper and lower levels by lateral blocking (dotted line).*

TABLE 1
Location of Electrical Receptacles Behind the Foam and the Fiberboard Sheathing on the North and South Wall of the Test House

Position	Type of Siding	North Wall		South Wall	
		NE Fiberboard	NW Foam	SE Fiberboard	SW Foam
Upper Wall	Cedar Lap		X*		X
	Redwood Lap	X		X	
	Hardboard Panel		X		X
	Plywood Panel	X		X	
	Hardboard Lap		X		X
	Wood Composite Lap	X		X	
Lower Wall	Cedar Lap	X		X	
	Redwood Lap		X		X
	Hardboard Panel	X		X	
	Plywood Panel		X		X
	Hardboard Lap	X		X	
	Wood Composite Lap		X		X

* X denotes location of electrical receptacles.

location of electrical receptacles behind the respective sheathings in the test house. There was also a control fence where the same four lap and two panel sidings were installed over 4 ft (1.2 m) by 8 ft (2.4 m) by 3/4 in. (19 mm) thick oriented strandboard (OSB) sheathing, one side facing north and the other south. The purpose of the control fence was to determine the performance of wood-based sidings without the effects of wall cavity insulation and the interior environment concomitant with a test house.

Temperature and RH sensors were routed through the receptacles and placed in the upper and lower wall cavities against the interior surface of the foam or fiberboard sheathing covered with cedar bevel sidings. Temperature sensors also were located behind the cedar bevel and wood composite lap sidings on the exterior wall. The indoor temperature was recorded mechanically with a hygrothermograph, while the indoor RH was detected and recorded electronically with a sensor suspended from the ceiling. The interior of the test house was temperature and humidity controlled at 70°F (21°C) and 50% RH during the heating season and naturally ventilated during the nonheating season. Since the objective of this study was to monitor the siding performance in cold climates, temperature control in the nonheating season was regarded as less important. Also regarded as less important was the location of the electrical receptacles—one-half of them were placed in the upper wall and the other half in the lower wall. This placement unfortunately resulted in air leakage different from what was anticipated, as will be noted later.

Test Siding

Figure 1 illustrates the installation of the six commercial sidings over one test wall. The four lap sidings were cedar bevel, redwood bevel, hardboard, and wood composite. The two panel sidings were hardboard and plywood. Lengths and widths for all lap sidings were nominally 16 in. (0.4 m) and 8 in. (0.2 m). All panel sidings were nominally 16 in. (0.4 m) wide and 48 in. (1.2 m) long. Edges of all sidings were coated with a polyurethane sealant to prevent endgrain moisture diffusion. All sidings were installed on the exterior wall according to the manufacturer's recommendations. The vertical gap formed by the near juncture of adjacent sidings was closed by impressing with closed-cell polyethylene rod stock.

For the lap sidings, three thickness measurements were determined with a digital gauge along the bottom edge, along the mid-line, and 1 in. (25 mm) from the top or near the lap line (Figure 2). For the panel sidings, three thickness measurements were taken across the width at five vertical locations (Figure 2).

All hourly temperature and RH data were recorded on a microcomputer using a multichannel, programmable datalogger.

Calculation of Water Vapor Pressure

Two periods were selected representing summer and winter conditions for comparative purposes. They were

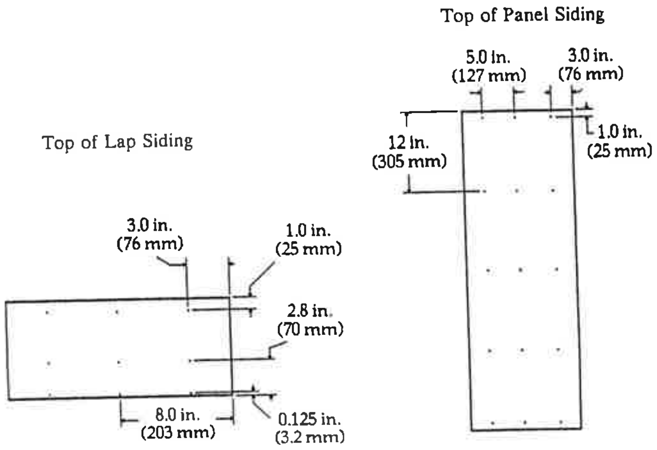

Figure 2 *Location of thickness measurements on lap and panel siding.*

August 21 through September 9, 1991, for summer and February 1 through February 20, 1992, for winter. Outdoor ambient conditions were obtained from the Cloquet weather station. Temperature and RH data were taken at 6 a.m., 2 p.m., and 10 p.m. for both periods to compute the water vapor pressure for the wall cavities and the indoor and outdoor water vapor pressure. The water vapor pressures were computed by multiplying the RH at a given temperature by the absolute vapor pressure of moist air at saturation for that temperature which was calculated using the equation from chapter 6 of the *ASHRAE Handbook* (ASHRAE 1985).

Calculation of Moisture and Thickness Change

The first thickness measurements and weights of all lap and panel sidings were taken in November 1990 after the painted sidings had been installed on the test house for six weeks. Those measurements were the basis for all future computations of moisture and thickness change. Therefore, moisture and thickness change for the measurements taken in summer (July 1991) and winter (February 1992) were computed based on the November 1990 measurements. For lap sidings, averages were used for the measurements at the bottom edge, along the mid-line, and at the top of the lap line. Averages also were used for the five locations measured on the panel sidings.

RESULTS

Water Vapor Pressure

Figure 3 shows the vapor pressures behind the lower level of fiberboard sheathing in the northeast (NEFB) and southeast (SEFB) cavities and behind the upper level of foam sheathing in the northwest (NWF) and southwest (SWF) cavities and the indoor and outdoor vapor pressures during the summer. Little difference existed between indoor and outdoor vapor pressures at 2 p.m., but indoor pressure was greater than outdoor vapor pressure at 10 p.m. and 6 a.m. Vapor pressure for SEFB showed the greatest fluctuation when measured at 6 a.m., 2 p.m., and 10 p.m. For example, the vapor pressure ranged from a high of 0.92 psi (6.34 kPa) at 2 p.m. on August 27 to a low of 0.06 psi (0.41 kPa) at 6 a.m. on September 6. This trend also manifested itself for NEFB but at a lower amplitude. In both cases, the vapor pressures peaked at 2 p.m., coinciding with the maximum solar radiation. Vapor pressures for NWF and SWF followed the cycles of the indoor vapor pressure.

During winter, indoor vapor pressure was significantly greater than outdoor vapor pressure (Figure 4). Vapor pressures for NEFB and NWF cycled between the limits of indoor and outdoor vapor pressure, which were approximately 0.20 psi (1.38 kPa) and 0.02 psi (0.14 kPa). Unlike in summer, the vapor pressure for SWF was slightly higher than SEFB and greater in magnitude than the indoor vapor pressure on February 1, 2 , 4, 8, 9, and 11.

Moisture Change (MC)

Fiberboard and foam sheathings with an intact vapor retarder were designated as tight fiberboard (TFIB) and tight foam (TFM), while those with the vapor retarder perforated by electrical receptacles were designated as loose fiberboard (LFIB) and loose foam (LFM). All lap and panel sidings on the north and south sides of the control fence were designated as control (CON) lap and panel sidings.

Figures 5a and 5b show moisture changes (MCs) for the respective lap sidings on the north and south walls for the test house and the control fence during summer. All lap sidings on the south wall had higher MCs than those on the north wall of the test house. Wood composite siding over the upper LFIB had the highest MCs of 1.96% and 4.77% on the north and south wall, respectively. MCs of cedar and redwood siding on the lower wall were lower than those of hardboard and wood composite siding on the upper wall for both the north and south walls. On the control fence, MCs for redwood siding were 2.68% and 4.40% for the north and south side, respectively, which were higher than those on the test house.

The MC pattern for winter was similar to that of summer (Figures 6a and 6b). However, MCs for redwood and wood composite siding over the upper LFIB were 9.13% and 9.63% on the north wall and 8.25% and 10.04% on the south wall, significantly higher than in summer. Lap sidings over TFM and LFM had higher MCs on the upper wall than those on the lower wall. On the control fence, lap sidings on the north side experienced slightly greater MCs than those on the south side.

Table 2 shows plywood panel siding with an opening located on the upper wall, where MCs were higher than those of hardboard panel siding with an opening on the lower wall over LFIB during summer and winter. Hardboard panel siding generally absorbed less water than plywood panel siding (Table 2).

Thickness Change (TC)

Figures 7a and 7b show thickness changes (TCs) for all lap sidings over the different sheathing materials for the test house and the control fence during the summer. All lap sidings on the south wall had higher TCs than those on the north wall of the test house. Wood composite lap siding had the highest TCs of 3.75% and 6.14% on the north and south wall, respectively, when installed over the upper loose fiberboard (LFIB). On the control fence, hardboard and wood composite siding swelled more than cedar and redwood siding on the north side. However, redwood siding had a slightly higher TC than did cedar, hardboard, or wood composite siding on the south side of the control fence (Figure 7b).

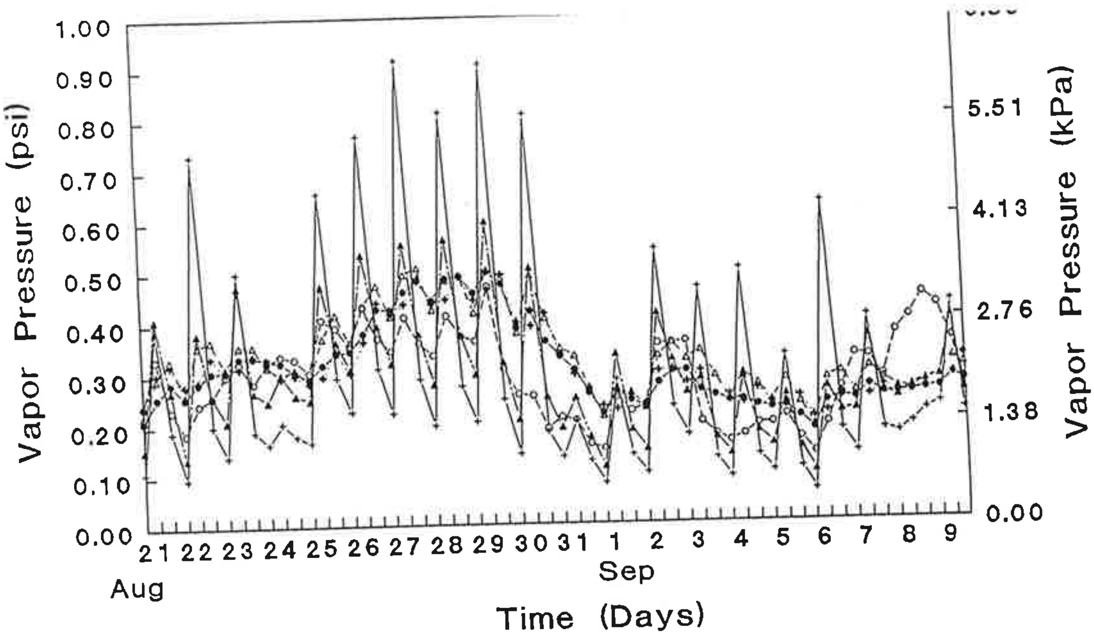

Figure 3 *Vapor pressure for test house. (Aug. 21-Sept. 9, 1991)*

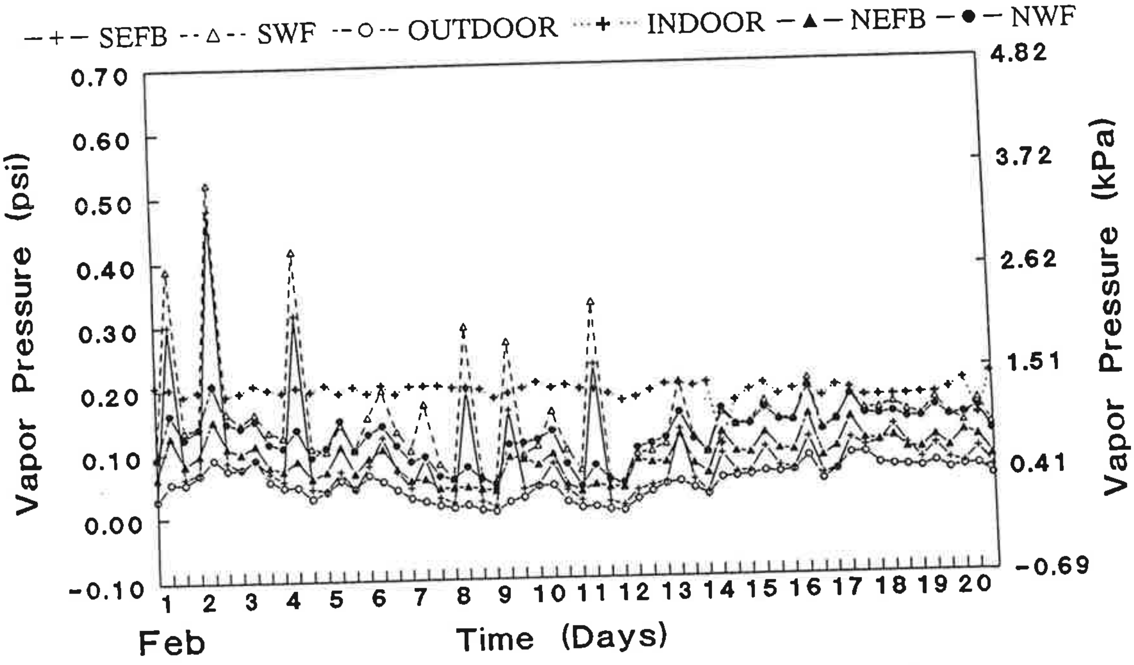

Figure 4 *Vapor pressure for test house. (Feb. 1-20, 1992)*

During the winter as in the summer, all sidings on the south wall had higher TCs than those on the north wall for the test house (Figures 8a and 8b). Wood composite lap siding had the highest TCs of 7.30% and 10.00% on the north and south wall, respectively, when installed over the upper LFIB.

The effect of position (height) on the wall could be seen when lap sidings were compared where installed over tight fiberboard (TFIB). Thus cedar siding on the upper wall had a larger TC than redwood siding on the lower wall. Hardboard siding on the upper wall also had a larger TC than wood composite siding on the lower wall (Figures 8a and 8b). Thickness change mimicked moisture change for lap sidings when installed over fiberboard with an intact vapor retarder. On the control fence, TCs for hardboard and wood composite siding were higher than those for cedar and redwood siding on the north side (Figure 8a). No significant difference existed in TCs for all lap sidings on the south side of the control fence (Figure 8b).

Table 3 shows that there was little difference in TC between plywood and hardboard panel siding on the control fence whether the comparison was in summer or winter. However, average TCs for both panel sidings on the control fence were larger than those on the test house.

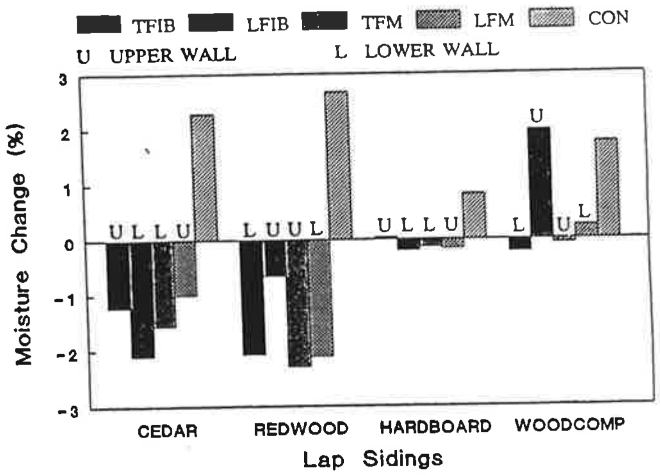

Figure 5a *MCs for lap sidings over sheathing materials (north, July 1991).*

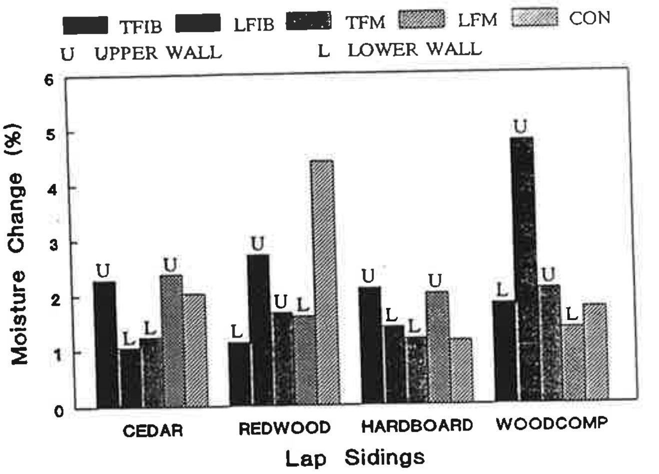

Figure 5b *MCs for lap sidings over sheathing materials (south, July 1991).*

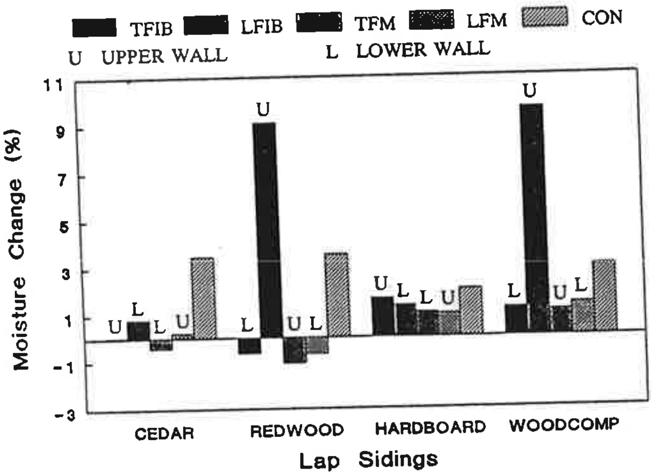

Figure 6a *MCs for lap sidings over sheathing materials (north, Feb. 1992).*

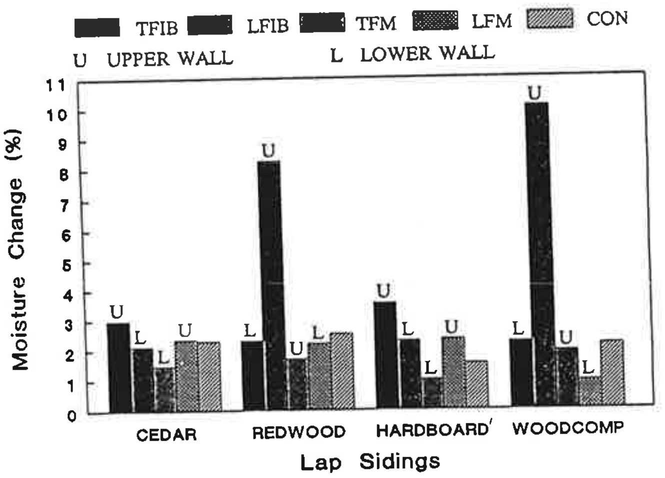

Figure 6b *MCs for lap sidings over sheathing materials (south, Feb. 1992).*

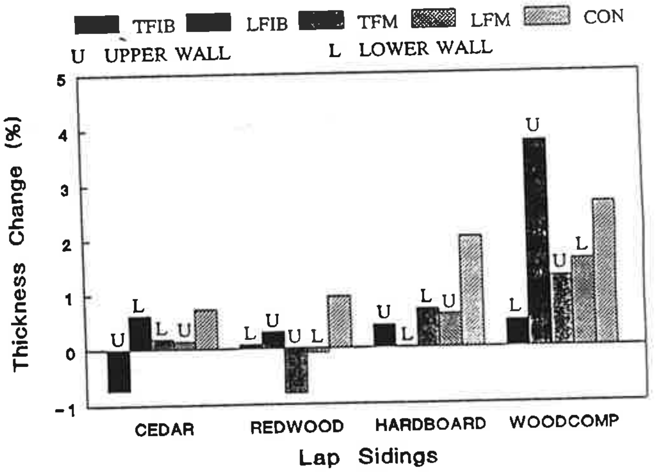

Figure 7a *TCs for lap sidings over sheathing materials (north, July 1991).*

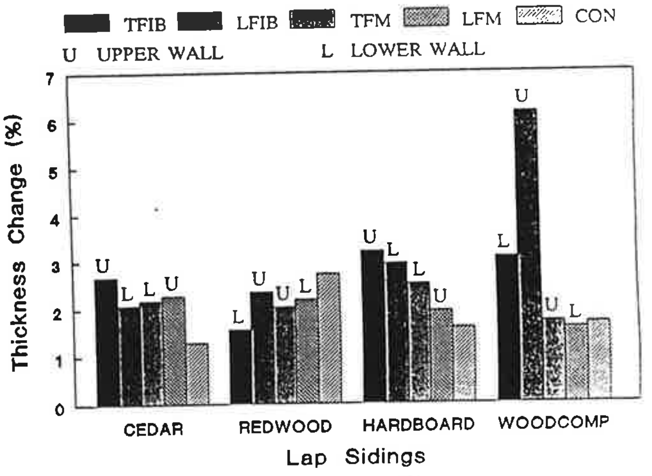

Figure 7b *TCs for lap sidings over sheathing materials (south, July 1991).*

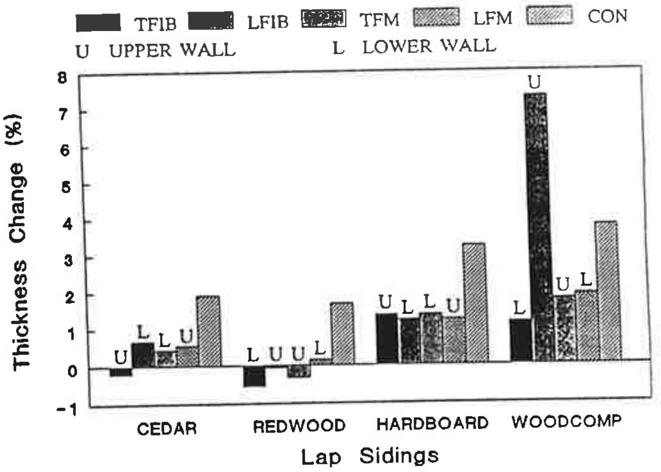

Figure 8a *TCs for lap sidings over sheathing materials (north, Feb. 1992).*

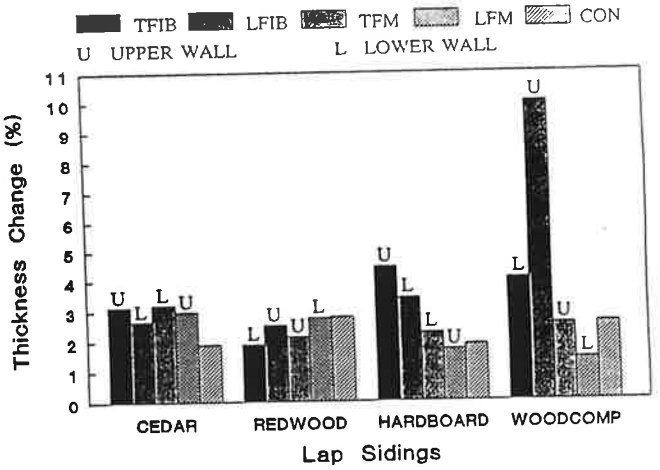

Figure 8b *TCs for lap sidings over sheathing materials (south, Feb. 1992).*

TABLE 2
Moisture Changes for Hardboard and Plywood Panel Sidings Installed over Different Sheathing Materials during Summer and Winter

Type of Sheathing Material	Moisture Change (%)			
	Summer		Winter	
	Hardboard	Plywood	Hardboard	Plywood
Tight Fiberboard	0.75(U)*	0.36(L)*	-0.70(U)	0.73(L)
Loose Fiberboard	0.39(L)	2.62(U)	4.00(L)	7.45(U)
Tight Foam	0.55(L)	1.01(U)	0.77(L)	1.59(U)
Loose Foam	0.13(U)	1.04(L)	0.93(U)	1.45(L)
Control Fence	1.25	1.59	4.15	4.30

*U and L in parentheses denote upper and lower wall, respectively.

TABLE 3
Thickness Changes for Hardboard and Plywood Panel Sidings Installed over Different Sheathing Materials during Summer and Winter

Type of Sheathing Material	Thickness Change (%)			
	Summer		Winter	
	Hardboard	Plywood	Hardboard	Plywood
Tight Fiberboard	1.39(U)*	1.15(L)*	0.83(U)	1.07(L)
Loose Fiberboard	0.23(L)	1.40(U)	1.59(L)	2.06(U)
Tight Foam	2.46(L)	2.79(U)	2.21(L)	2.09(U)
Loose Foam	0.91(U)	0.82(L)	0.97(U)	0.52(L)
Control Fence	2.93	3.05	2.29	2.59

*U and L in parentheses denote upper and lower wall, respectively.

DISCUSSION

Summer (July 1991) Data

Air movement, along with vapor diffusion, acted as the moisture transport mechanism, influencing moisture and thickness changes of exterior sidings. During the day, the solar radiation increased the temperature of the exterior surface of the siding. However, this surface evaporation would be inhibited by the impermeability of the paint, thereby creating a vapor pressure differential driving the moisture from the back of siding inward through the permeable fiberboard sheathing and into the wall cavity (Lstiburek 1987). The electrical receptacles in the stud cavities would act as openings for the vapor flow. Such openings were located above and below the neutral pressure plane on both north and south walls. The neutral pressure plane was determined to be slightly below the lateral blocking that divided the wall assemblies into two levels.

At night, the vapor pressure gradient would be reversed. The higher indoor temperature and vapor pressure would induce mass diffusion of moisture outward through the openings in the stud cavities by air leakage and vapor diffusion. Moisture then would accumulate behind the fiberboard, which had a capacity for moisture storage. The temperature of the siding could be significantly lower than ambient conditions if exposed to a clear night sky radiation (Lstiburek 1987). The coupling effects of mass diffusion and temperature gradient could result in condensation behind the back of the siding if its temperature was below the dew point.

If vapor diffusion from the back of the siding through the fiberboard was greater during the day, then the MC of the sidings behind loose fiberboard (LFIB) on the lower level should be lower than those on the upper level for both walls. This was true for redwood, cedar, wood composite, and hardboard siding when installed on the upper and lower LFIB. This can be explained by the convective movement of warm, moist interior air through the upper opening into the wall cavity. This mechanism was also responsible for the performance of siding over tight fiberboard (TFIB) on the upper level, where the MCs were generally higher than those on the lower level. Tsongas and Nelson (1991) also found that the sheathing moisture content at the top of the stud cavities was generally greater than at the bottom. MCs and TCs for plywood panel siding on the upper wall were higher than those for hardboard panel siding on the lower wall over LFIB.

TCs and MCs for hardboard and wood composite lap siding were significantly lower when installed over tight or loose foam sheathing (TFM or LFM) than when installed over tight fiberboard (TFIB) due to the impermeability and negligible moisture storage capacity of the foam sheathing. Compared to cedar and redwood sidings, hardboard and wood composite sidings had higher TCs but lower MCs on the lower wall behind both TFM and LFM. The higher TCs can be explained by the release of residual compressive stresses (springback or irreversible swelling) inherent in those products from the hotpressing manufacturing process. Repeated drying and wetting cycles also contributed to higher TCs with concomitant lower MCs.

Winter (February 1992) Data

In the heating season, the stack effect would be the mechanism behind the exfiltration of warm interior air through the receptacle openings in the upper stud cavities due to pressure differentials. Moisture then would be deposited at the interface between the sheathing and the siding. This explains why redwood and wood composite siding on the upper level over the loose fiberboard (LFIB) on the north and south walls had the highest MCs, while cedar and hardboard siding on the lower level had lower MCs. According to Sherwood (1983), moisture-laden air would condense at the sheathing-siding interface after a period of extremely cold weather. This sheathing-siding condensation was found behind the panel siding over loose fiberboard (LFIB) in the form of frost.

Furthermore, on the lap sidings, moisture movement between the back of the siding and the foam/fiberboard sheathing resulted in greater TCs on the top of the lap line and along the mid-line than at the bottom edge of the sidings. However, lap sidings over the OSB sheathing on the control fence experienced greater bottom-edge swelling than on top of the lap line and along the mid-line. Ostensibly this is the result of the capillary action of moisture, which, in turn, was held between the laps (Lstiburek and Carmody 1991). This capillary action applies to all lap sidings whether on the test house or on the control fence.

Wood composite siding made from large wood particles experienced greater TC and MC when installed over the upper loose fiberboard (LFIB) due to irreversible swelling (springback). Redwood is a relatively dimensionally stable wood species due to its high extractive content. This explains why redwood siding had a high MC but a low TC over the upper LFIB.

Generally, hardboard panel siding had lower MCs than plywood panel siding for the summer and winter seasons, which is an inherent characteristic of hardboard because of the manufacturing process. Oddly, both hardboard and plywood panel sidings had the largest average TCs but not MCs when placed over tight foam (TFM). This, however, may be due to the increased change in thickness at the edge of the two panel sidings -- one hardboard and one plywood -- which, in turn, contributed to the overall average TC for the whole panel siding.

CONCLUSIONS

Moisture uptake and thickness change of lap-type sidings were affected by the permeability and moisture storage properties of the sheathing material and the location (upper or lower) of the electrical receptacle in the wall cavity. This study showed that if an opening existed in the vapor retarder and was located on the upper wall and behind a permeable fiberboard sheathing, the siding would increase in moisture uptake and thickness change, and its performance then would be a function of the siding type. It is evident that redwood siding was dimensionally more stable than the wood-composite siding when exposed to the interior moisture movement through such an opening. For example, redwood siding absorbed/desorbed moisture and yet remained dimensionally stable, whereas wood composite siding readily absorbed more moisture, which, in turn, promoted greater change in thickness. Overall, this illustrates the importance of using an intact vapor retarder with fiberboard sheathing.

The condition of the vapor retarder, intact or perforated, had little effect on moisture and thickness change for lap siding when installed over foam sheathing. This supported the concept that when a perforated vapor retarder was used with foam sheathing, interior moisture that migrated into the wall cavity was held there and did not diffuse outward on and into the siding. Although this might enhance the overall siding performance, it poses a threat for serious deterioration of the wall cavity itself. Whether this actually occurred will be determined at the conclusion of the study in 1993 or 1994.

Hardboard panel siding generally absorbed less moisture than plywood panel siding. Plywood panel siding had a slightly larger thickness change than hardboard panel siding when installed over fiberboard sheathing with a perforated vapor retarder. However, this result was confounded by the location of the perforated vapor retarder.

ACKNOWLEDGMENTS

We acknowledge support for this project from the State of Minnesota through grant MNADM/02140-03540 from petroleum violation escrow funds. The grant was approved for funding by the Legislative Commission on Minnesota Resources. The authors also would like to extend their appreciation to the staff of Cloquet Forestry Center for their contributions toward this study and Dr. David C. Ritter, former scientist, Department of Forest Products, University of Minnesota.

REFERENCES

ASHRAE. 1985. *ASHRAE handbook - 1985 fundamentals*, chapter 6. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Lstiburek, J.W. 1987. *Applied building science*. Downsview, ON: Building Engineering Corporation.

Lstiburek, J.W., and J. Carmody. 1991. *Moisture control handbook: New, low-rise residential construction*. Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Dept. of Energy.

Merrill, J.L., and A. TenWolde. 1989. Overview of moisture-related damage in one group of Wisconsin manufactured homes. *ASHRAE Transactions* 95 (1): 405-414.

Sherwood, G.E. 1983. Condensation potential in high thermal performance walls—Cold climate. USDA For. Serv. Res. Pap. FPL 433. Madison, WI: For. Prod. Lab.

Tsongas, G.A. 1991. The effect of exterior insulating sheathing on wall moisture. In *Insulation Materials: Testing and Applications*, 2d vol., ASTM STP 1116, R.S. Graves and D.C. Wysocki, eds. Philadelphia: American Society for Testing and Materials.

Tsongas, G.A., and G.D. Nelson. 1991. A field test for correlation of air leakage and high moisture content sites in tightly built walls. *ASHRAE Transactions* 97 (1): 1-8.

USDA. 1987. *Wood handbook: Wood as an engineering material*. FPL, For. Serv., Agricultural Handbook 72. Washington, DC: U.S. Department of Agriculture.