Activity 3 (continued): Advanced Moisture Model Results

The following presents the results from the ORNL MOISTURE-EXPERT hygrothermal model (Karagiozis, 2001), which was used for a parametric analysis of the performance of permeable wall systems without mechanical ventilation. A series of 2-D simulations were performed. The 2-D simulations allowed us to determine the hygrothermal performance of the walls with the influence of infiltration/exfiltration air dynamics. In these 2-D simulations, the influence of air flow through the wall system was evaluated as a function of hourly wind pressures.

To reiterate, the tested wall sections were as follows (with the defining characteristics in parentheses):

Wall 1. "Standard" Wall (polyethylene vapor retarder)

½" Gypsum wallboard w. 1 coat latex paint, 6 mil polyethylene vapor retarder, 2x6 studs w. R-19 unfaced fiberglass batt insulation, OSB, housewrap, vinyl siding.

Wall 2. Permeable Wall A (no polyethylene vapor retarder)

½" Gypsum wallboard w. 1 coat latex paint, 2x6 studs w. R-19 unfaced fiberglass batt insulation, OSB, housewrap, vinyl siding.

Wall 3. Permeable Wall B (no polyethylene vapor retarder, vented rainscreen battens)

½" Gypsum wallboard w. 1 coat latex paint, 2x6 studs w. R-19 unfaced fiberglass batt insulation, Fiberboard , housewrap, 1x4 battens installed vertically over studs with 3/4" air space, wood siding (back primed).

Wall 4. Modified Permeable Wall B (no polyethylene, vented rainscreen battens, EPS interior)

½" Gypsum wallboard w. 1 coat latex paint, ½" expanded polystyrene board (EPS), 2x6 studs w. R-19 unfaced fiberglass batt insulation, Fiberboard, housewrap, 1x4 battens installed vertically over studs with 3/4" air space, wood siding (back primed).

Below is a summary of the available results, with the wall assembly types and investigated parameters.

Figure	Wall	Location	Moisture Rate	Comments
3a.1	1	Int'l Falls	High	Airtight wall
3a.2	1	Int'l Falls	Low	0, +3, & -3 Pa
3a.3	1	Int'l Falls	High	0, +3, & -3 Pa
3a.4	1	Minneapolis	Low	0, +3, & -3 Pa
3a.5	1	Minneapolis	High	0, +3, & -3 Pa
3a.6	2	Int'l Falls	High	Airtight wall
3a.7	2	Int'l Falls	Low	0, +3, & -3 Pa
3a.8	2	Int'l Falls	High	0, +3, & -3 Pa
3a.9	2	Minneapolis	Low	0, +3, & -3 Pa
3a.10	2	Minneapolis	High	0, +3, & -3 Pa
3a.11	3	Int'l Falls	Low	0, +3, & -3 Pa
3a.12	3	Int'l Falls	High	0, +3, & -3 Pa
3a.13	3	Minneapolis	Low	0, +3, & -3 Pa
3a.14	3	Minneapolis	High	0, +3, & -3 Pa
3a.15	4	Int'l Falls	Low	0, +3, & -3 Pa
3a.16	4	Int'l Falls	High	0, +3, & -3 Pa
3a.17	4	Minneapolis	Low	0, +3, & -3 Pa
3a.18	4	Minneapolis	High	0, +3, & -3 Pa
3a.19	4	n/a	n/a	2D schematic
3a.20	4	n/a	Low	2D T distribution, -3 Pa
3a.21	4	n/a	Low	2D RH distribution, -3 Pa
3a.22	4	n/a	High	2D T distribution, -3 Pa
3a.23	4	n/a	High	2D RH distribution, -3 Pa
3a.24	1	n/a	High	2D T distribution, -3 Pa
3a.25	1	n/a	High	2D RH distribution, -3 Pa

In the graphs showing moisture content for OSB (in kg), a line has been added which is approximately equivalent to a moisture content of either 15% for OSB or 12 % for Fiberboard. As will be explained later, this is one of the critical threshold values for mold growth.

Wall 1: "Standard" Wall (polyethylene vapor retarder)

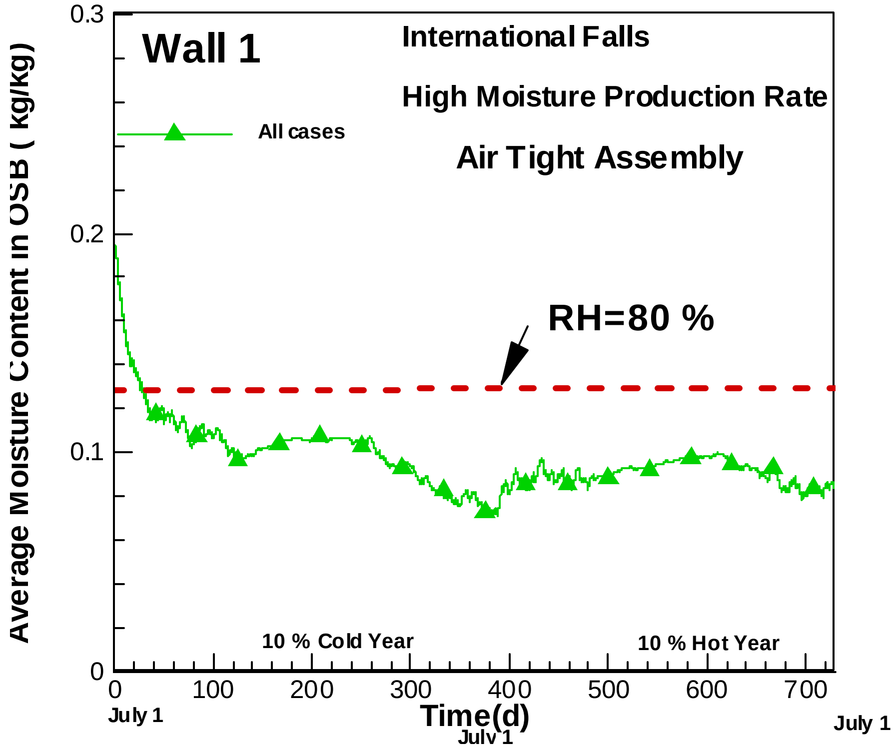


Figure 3a.1: Wall 1, International Falls, High Moisture Production, Airtight Wall

This wall assembly was first run with a high airtightness value, which could represent an airtight drywall assembly (ADA), and/or a well-sealed polyethylene vapor barrier. This is shown above in the response of moisture content to pressure: all three pressures (+3, 0, and –3 Pa) collapse on the same curve. This case would be representative of the case with only vapor diffusion through the assembly. It should note that Wall 1 dries out to lower than 80% equilibrium moisture content in less than 30 days.

As can be seen by the moisture content measurements, the hygrothermal performance of this wall is excellent: the MC quickly declines from the starting 19%, and only rises to ~10% during the following year.

In the following figures, results are presented for Wall 1 accounting for the influence of air flow.

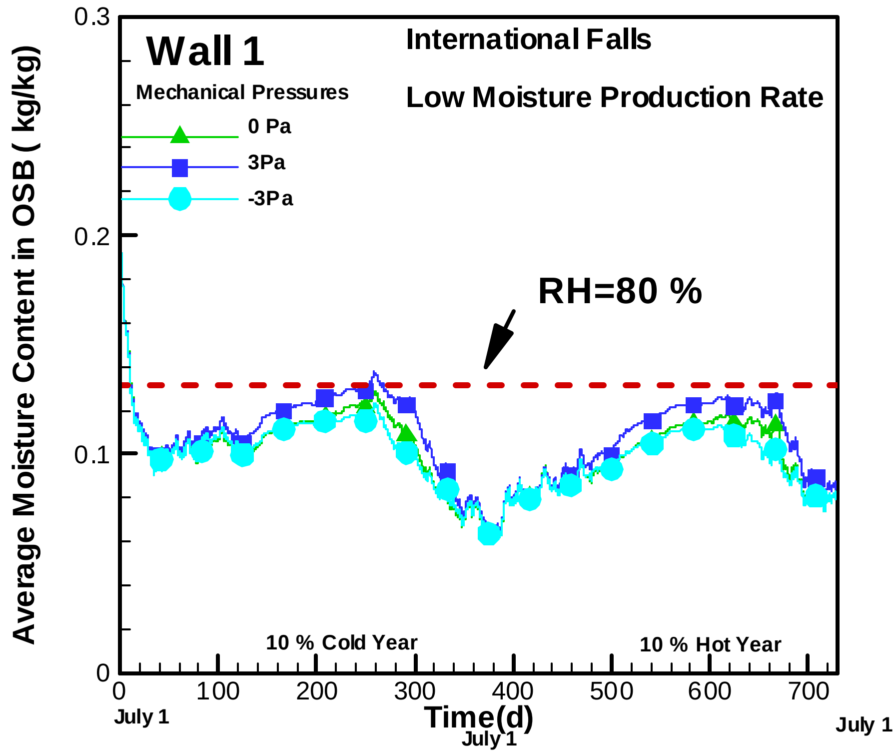


Figure 3a.2: Wall 1, International Falls, Low Moisture Production, 0, +3, & -3 Pa

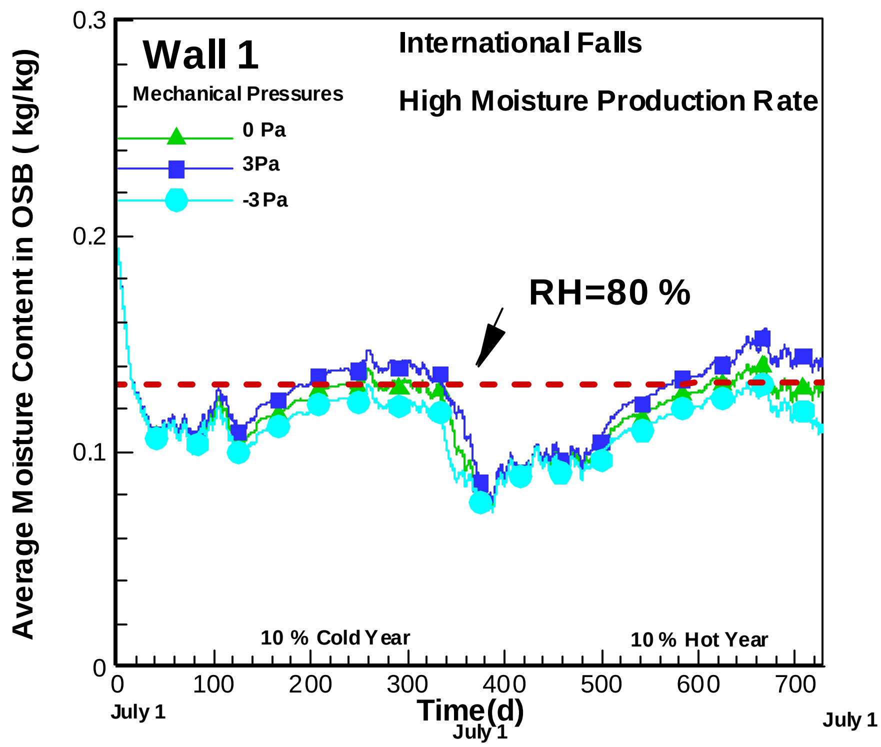


Figure 3a.3: Wall 1, International Falls, High Moisture Production, 0, +3, & -3 Pa

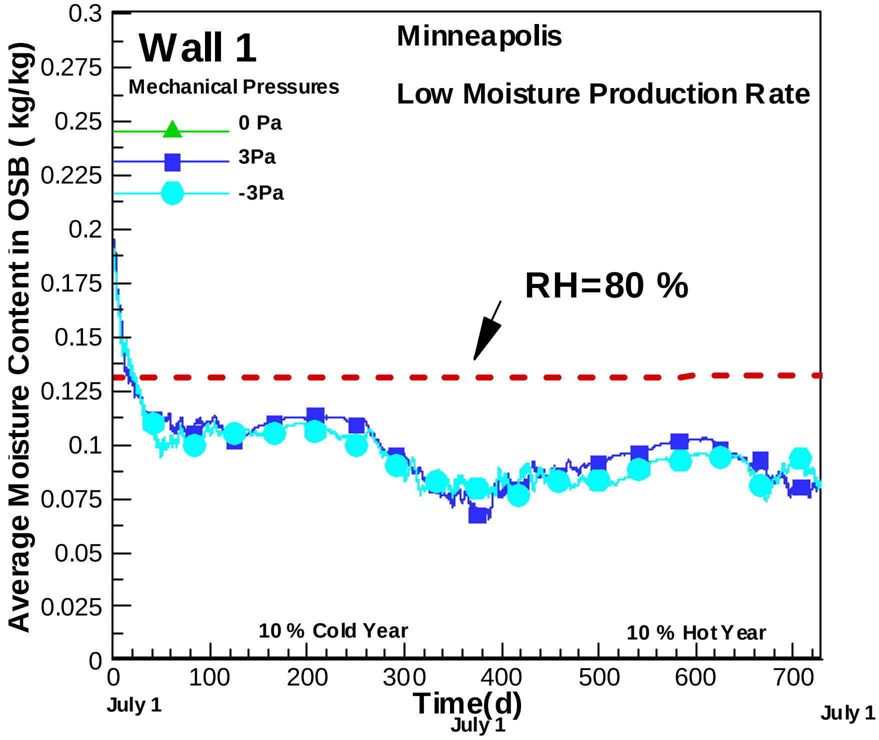


Figure 3a.4: Wall 1, Minneapolis , Low Moisture Production, 0, +3, & -3 Pa

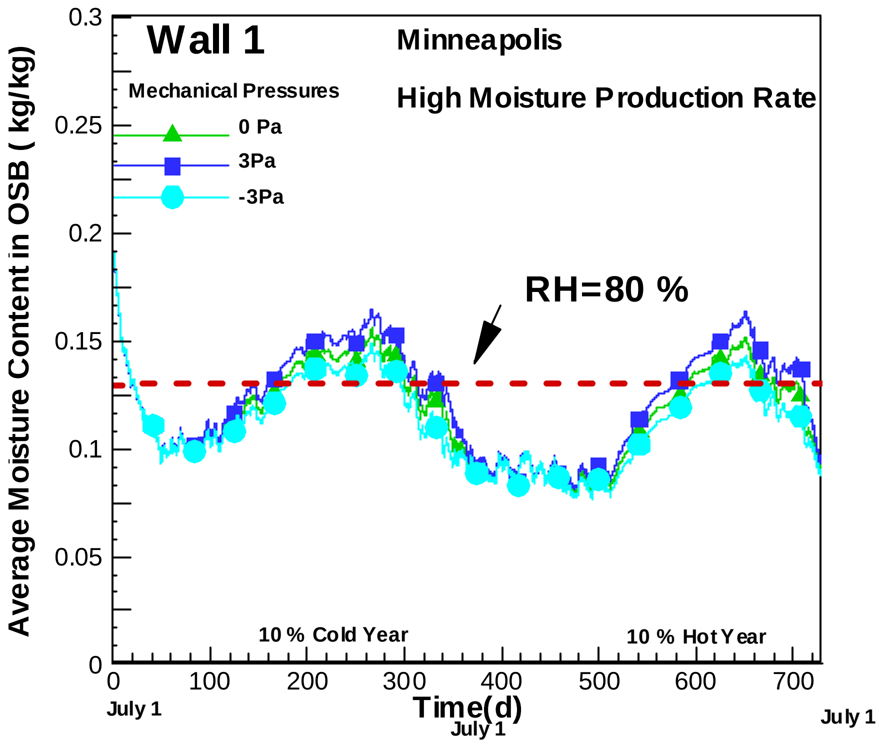


Figure 3a.5: Wall 1, Minneapolis, High Moisture Production, 0, +3, & -3 Pa

Wall 2: Permeable Wall A (no polyethylene vapor retarder) Results

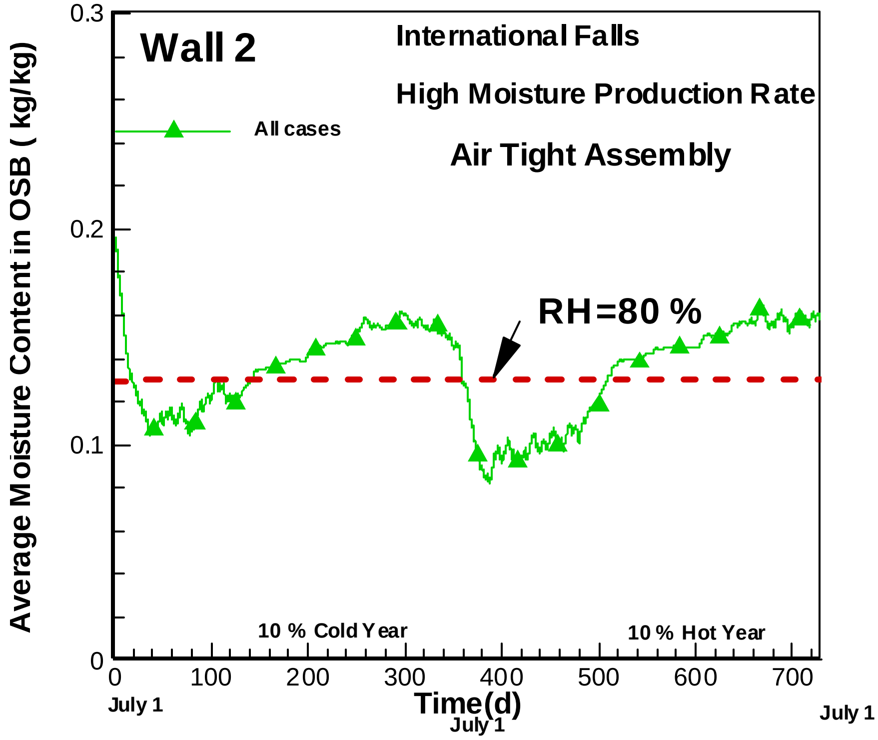


Figure 3a.6: Wall 2, International Falls, High Moisture Production, Airtight Wall

Similar to Figure 3a.1, this plot shows the sheathing MC for Wall 2 (similar to Wall 1, but without polyethylene vapor retarder). It shows much higher moisture content readings during the winter than Wall 1 (although plots during the summer season are similar).

The following are plots for Wall 2 (in Minneapolis and International Falls) accounting for airflow.

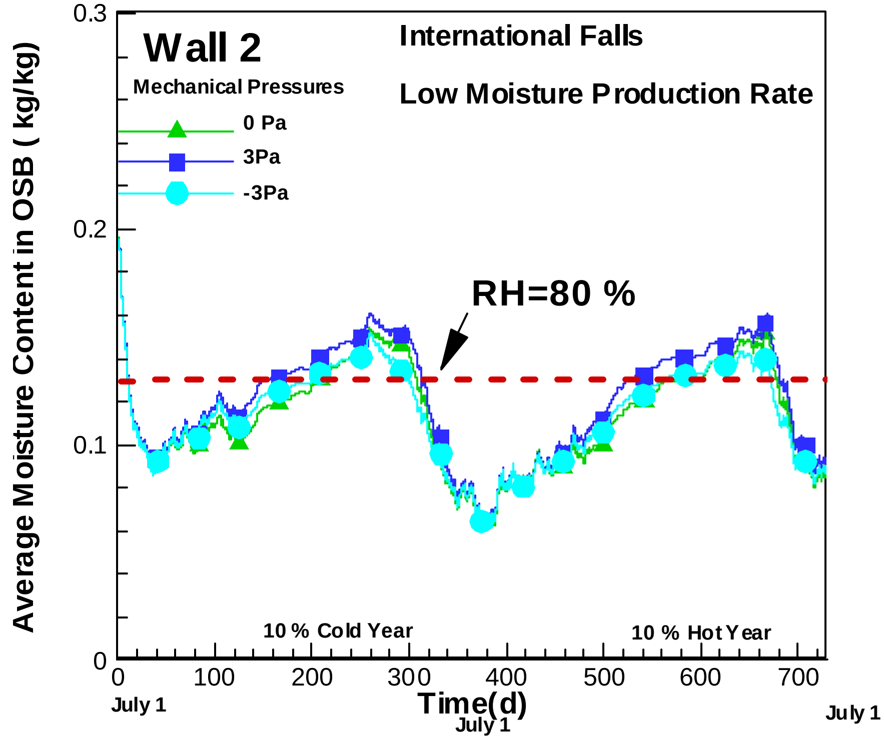


Figure 3a.7: Wall 2, International Falls, Low Moisture Production, 0, +3, & -3 Pa

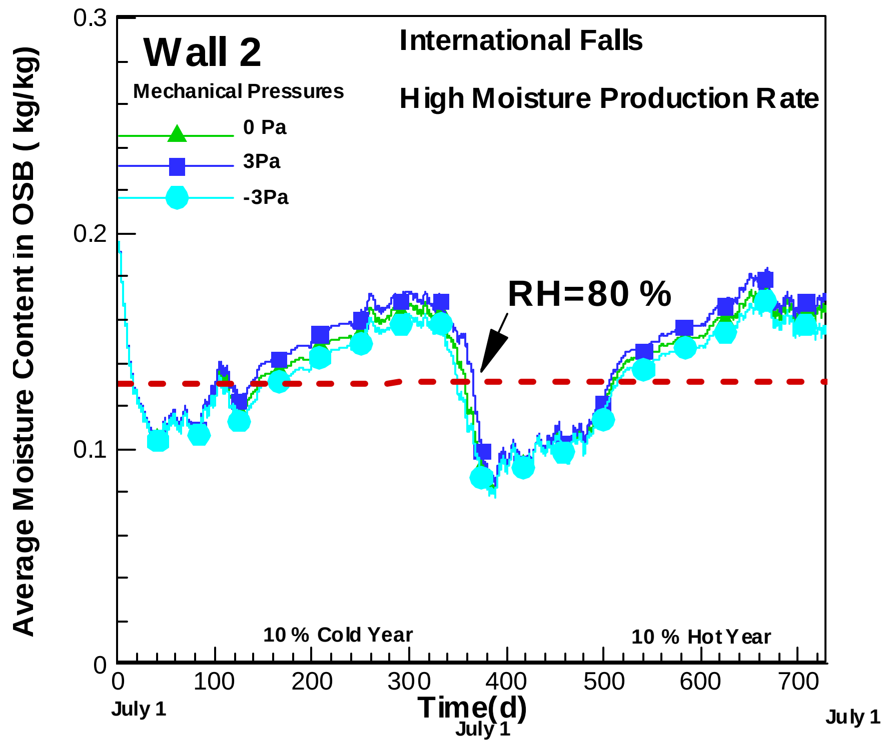


Figure 3a.8: Wall 2, International Falls, High Moisture Production, 0, +3, & -3 Pa

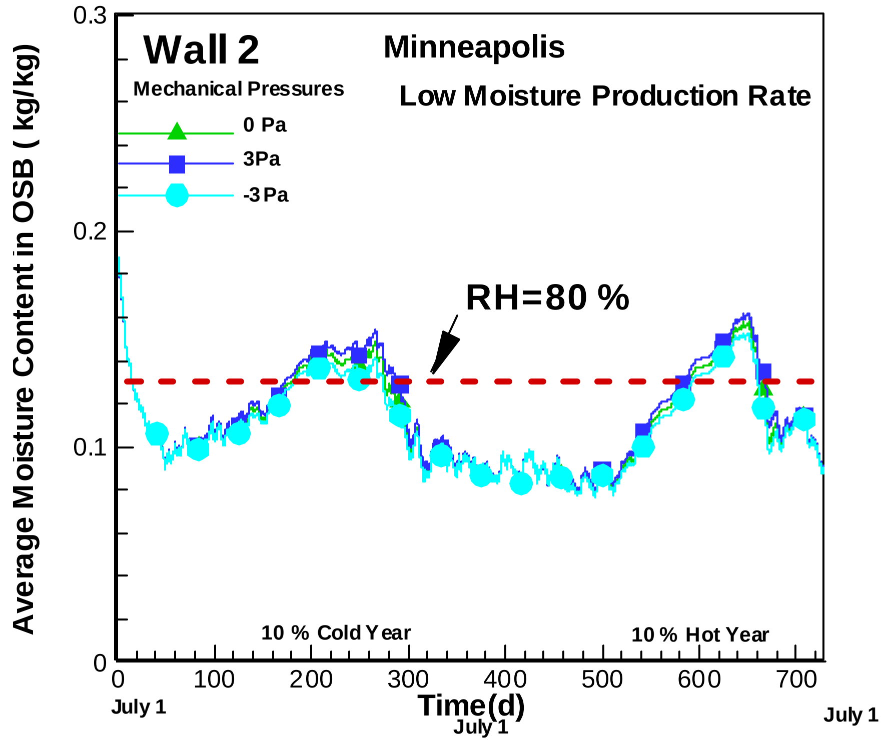


Figure 3a.9: Wall 2, Minneapolis , Low Moisture Production, 0, +3, & -3 Pa

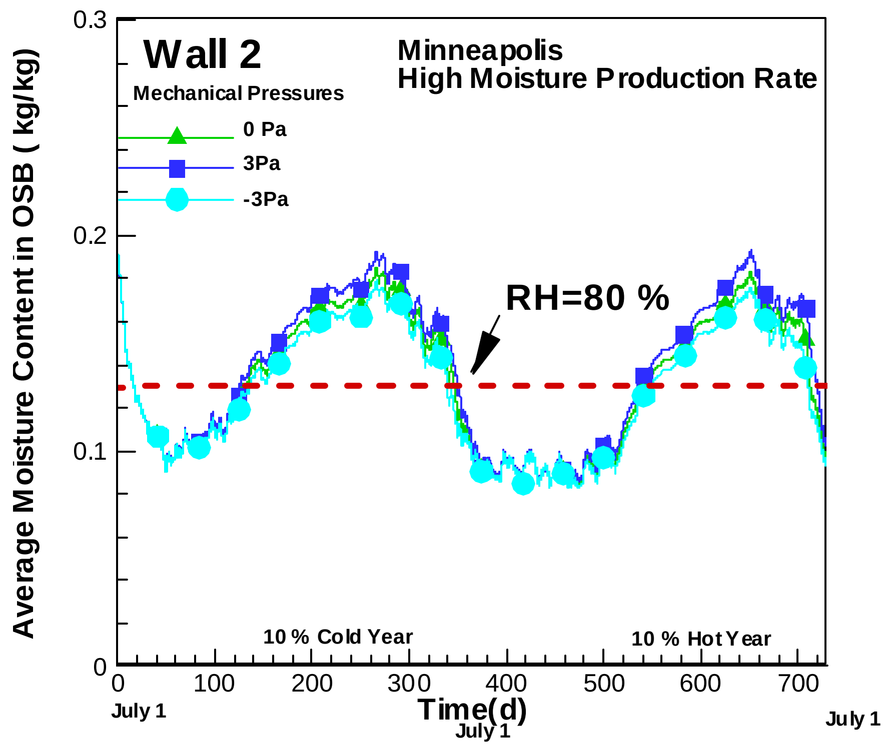


Figure 3a.10: Wall 2, Minneapolis , High Moisture Production, 0, +3, & -3 Pa

Wall 3: Permeable Wall B (no PE vapor retarder, vented rainscreen battens) Results

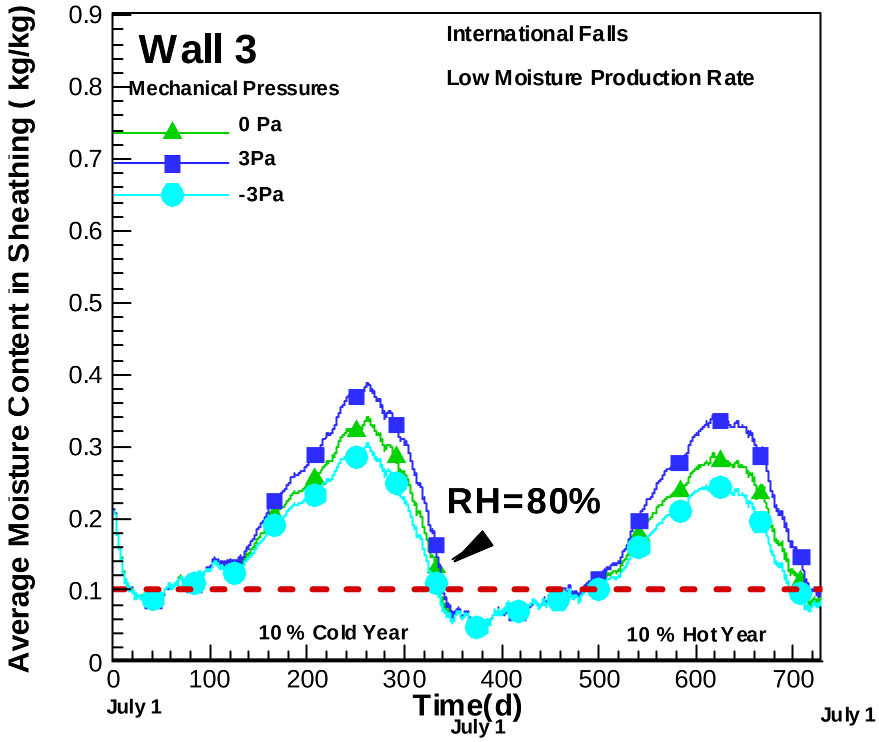
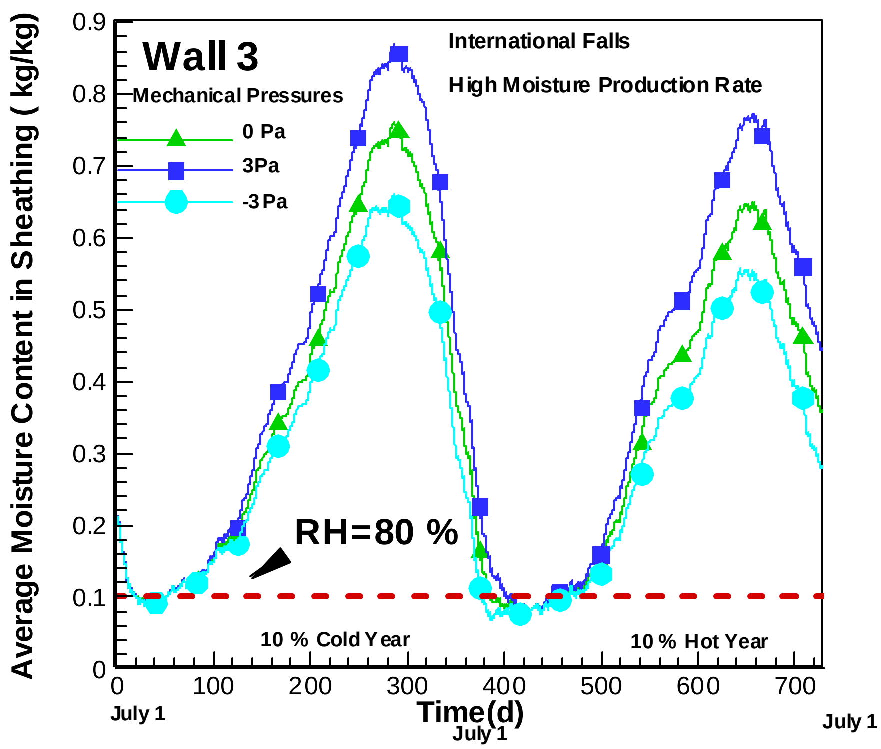


Figure 3a.11: Wall 3, International Falls, Low Moisture Production, 0, +3, & -3 Pa



(b)

Figure 3a.12: Wall 3, International Falls, High Moisture Production, 0, +3, & -3 Pa

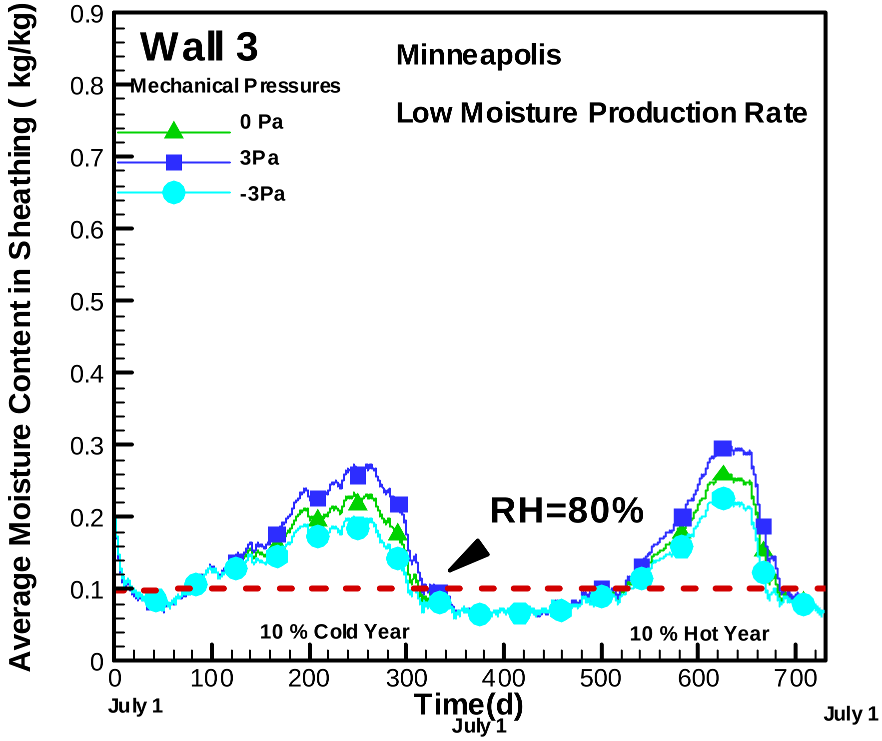
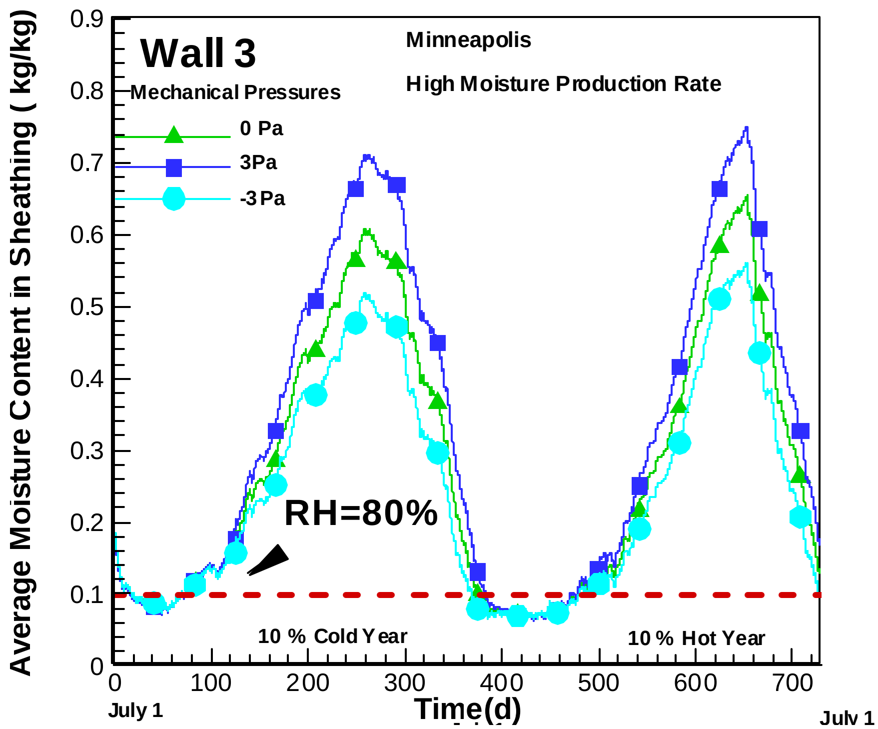


Figure 3a.13: Wall 3, Minneapolis, Low Moisture Production, 0, +3, & -3 Pa



(b)

Figure 3a.14: Wall 3, Minneapolis, High Moisture Production, 0, +3, & -3 Pa

Wall 4: Modified Permeable Wall B (no PE, vented rainscreen battens, EPS) Results

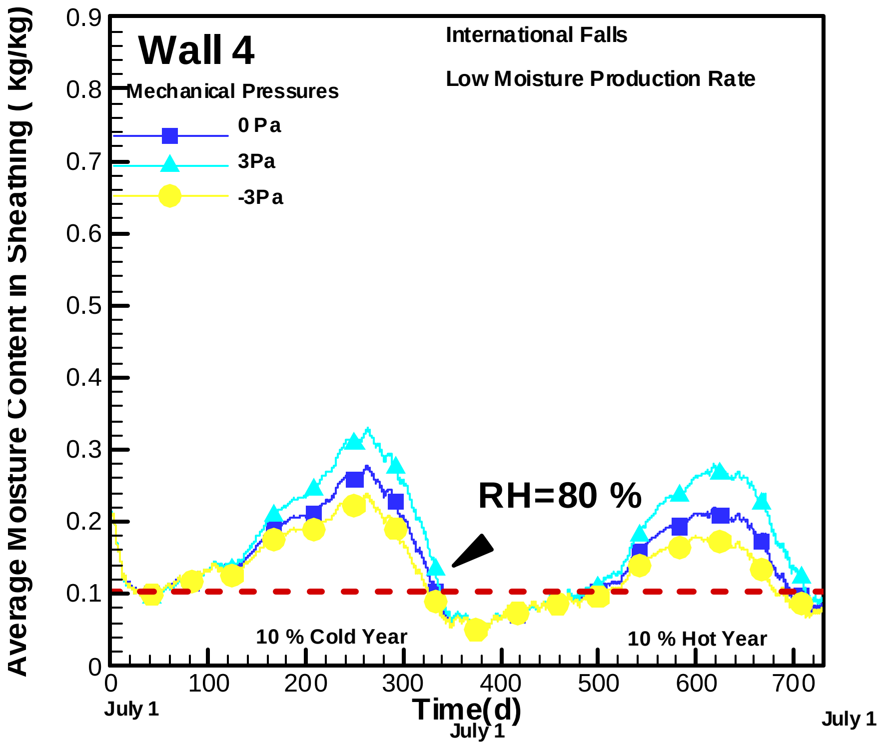
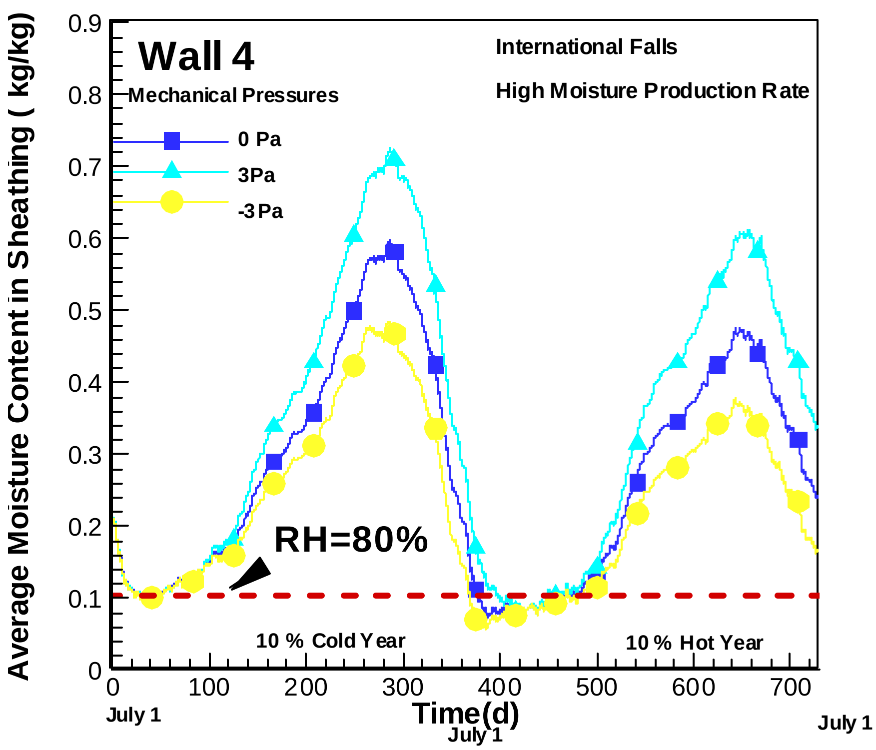


Figure 3a.15: Wall 4, International Falls, Low Moisture Production, 0, +3, & -3 Pa



(b)

Figure 3a.16: Wall 4, International Falls, High Moisture Production, 0, +3, & -3 Pa

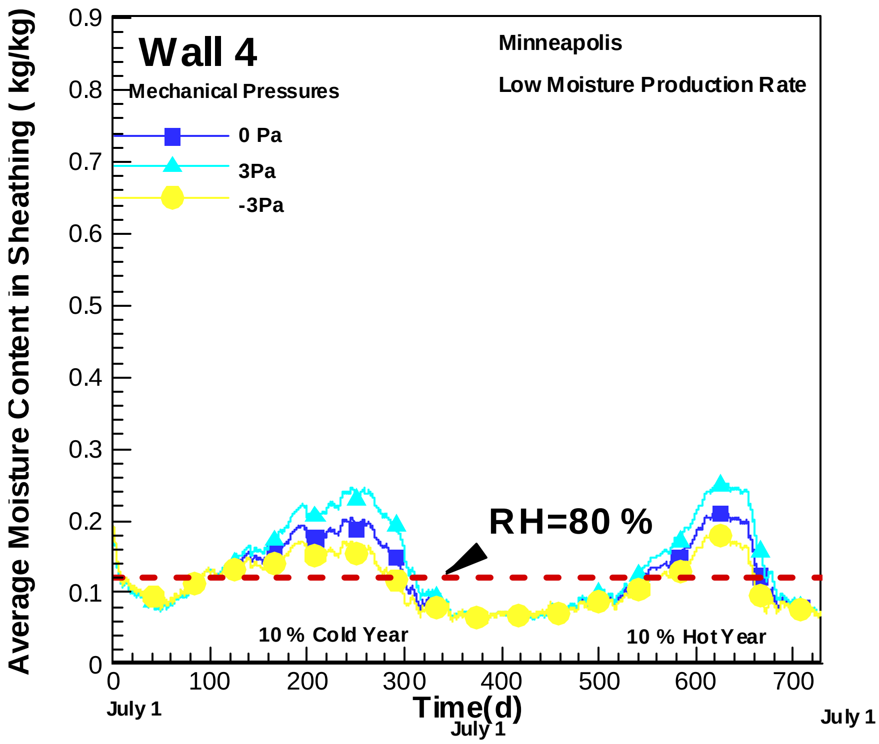
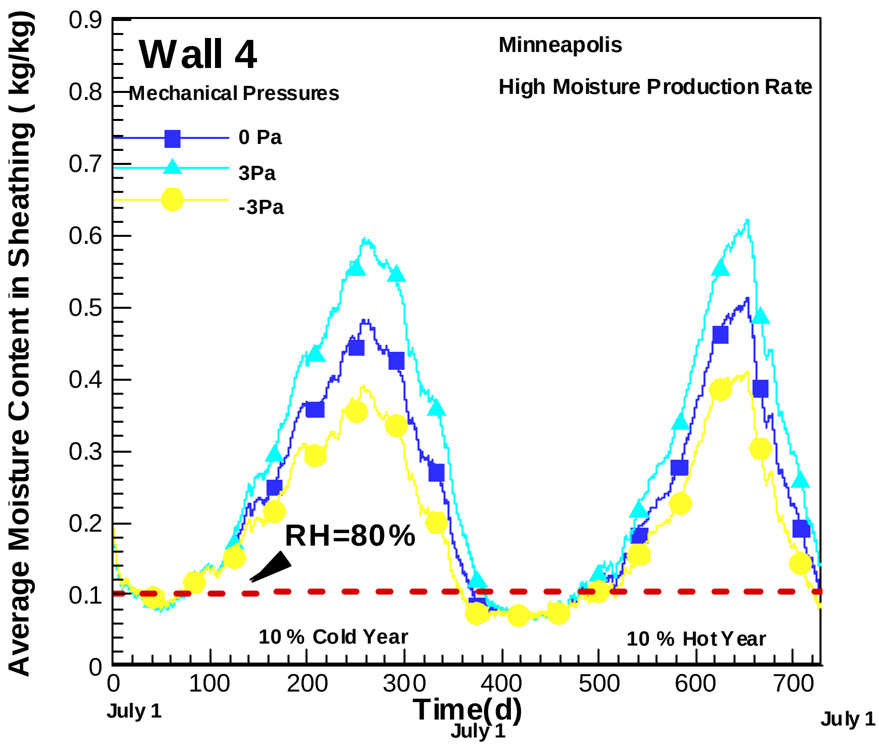


Figure 3a.17: Wall 4, Minneapolis, Low Moisture Production, 0, +3, & -3 Pa



(b)

Figure 3a.18: Wall 4, Minneapolis, High Moisture Production, 0, +3, & -3 Pa

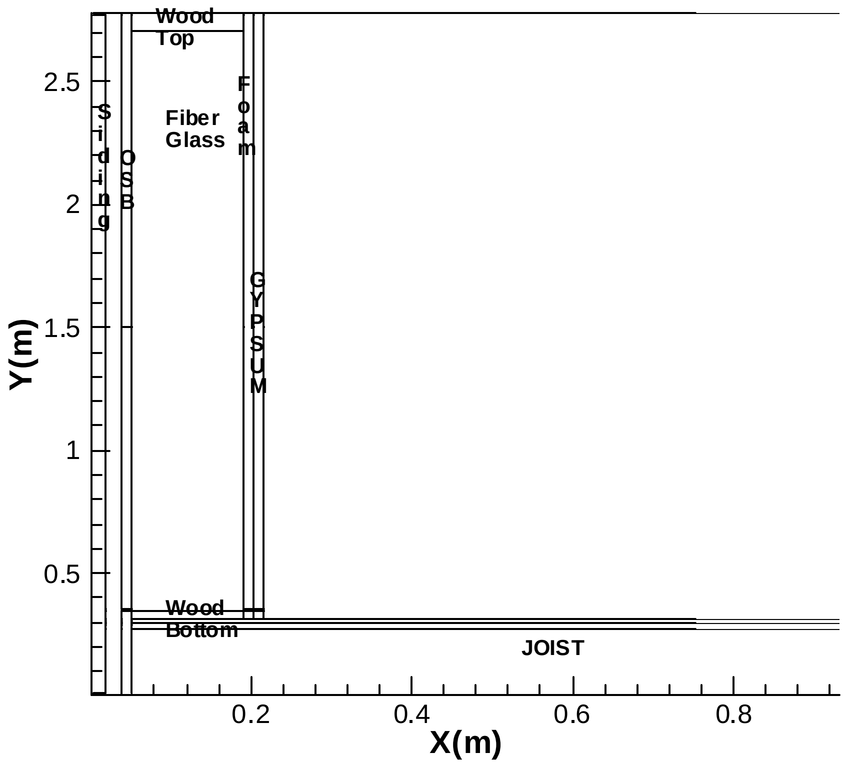


Figure 3a.19: Wall 4 2-dimensional schematic layout

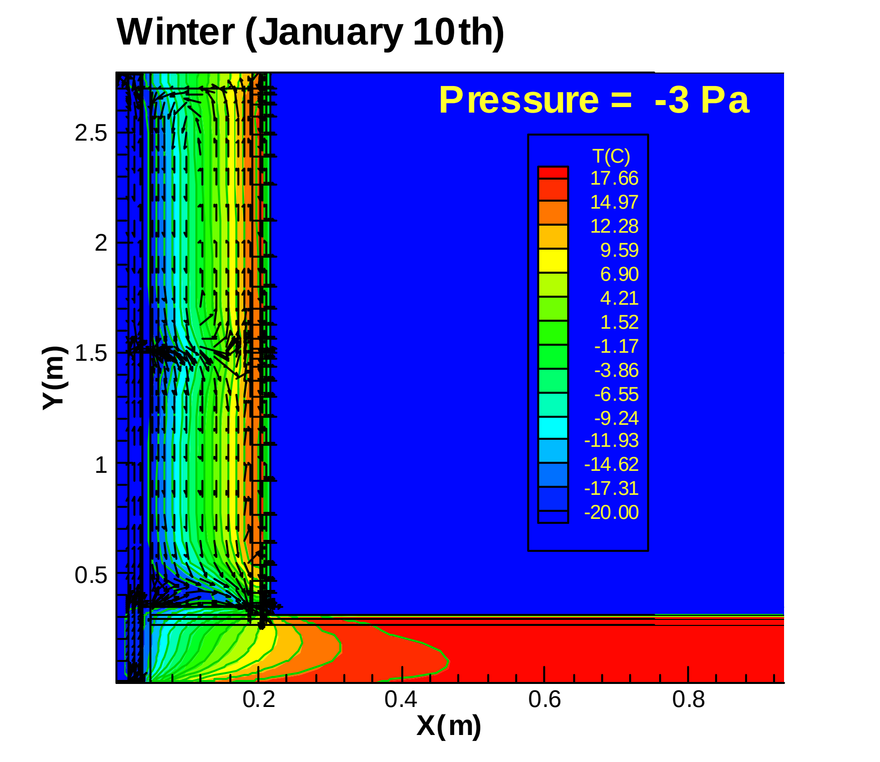


Figure 3a.20: 2D temperature distribution for Wall 4, -3 Pa, low moisture rate

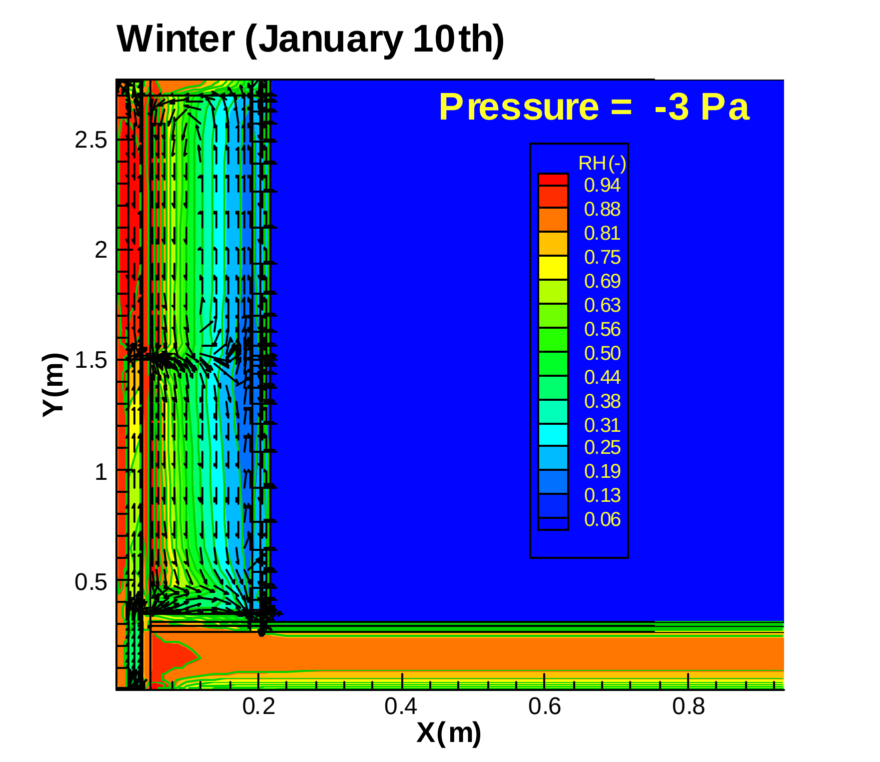


Figure 3a.21: 2D relative humidity distribution for Wall 4, -3 Pa, low moisture rate

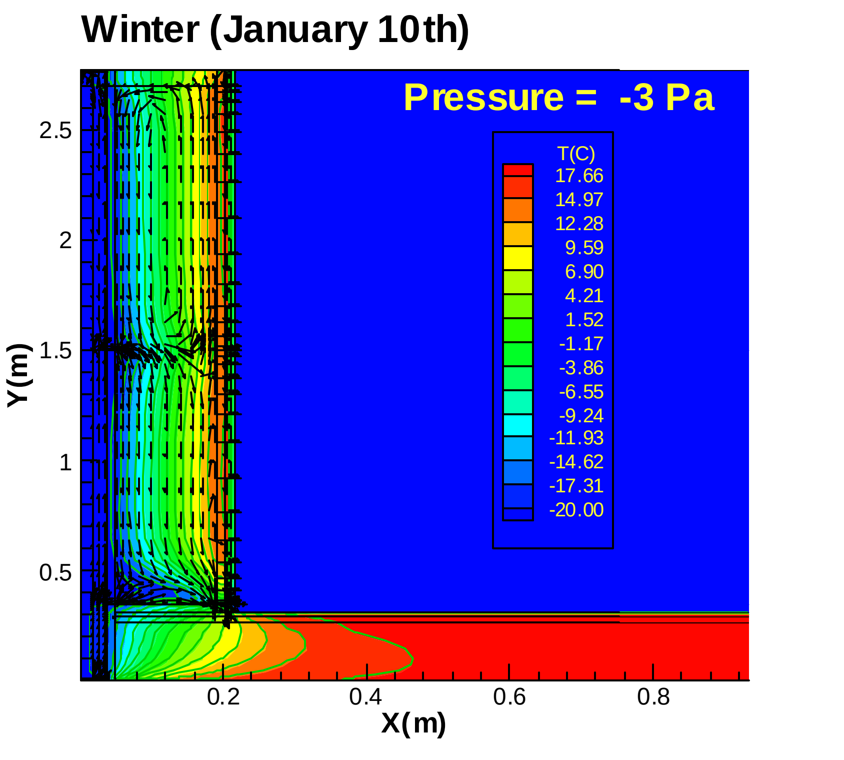


Figure 3a.22: 2D temperature distribution for Wall 4, -3 Pa, high moisture rate

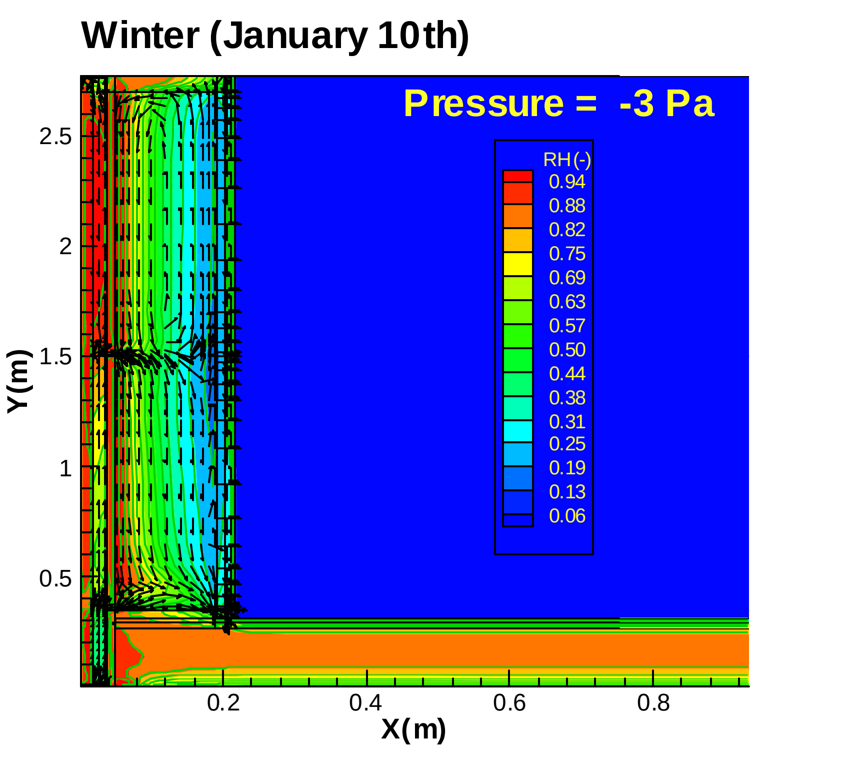


Figure 3a.23: 2D relative humidity distribution for Wall 4, -3 Pa, high moisture rate

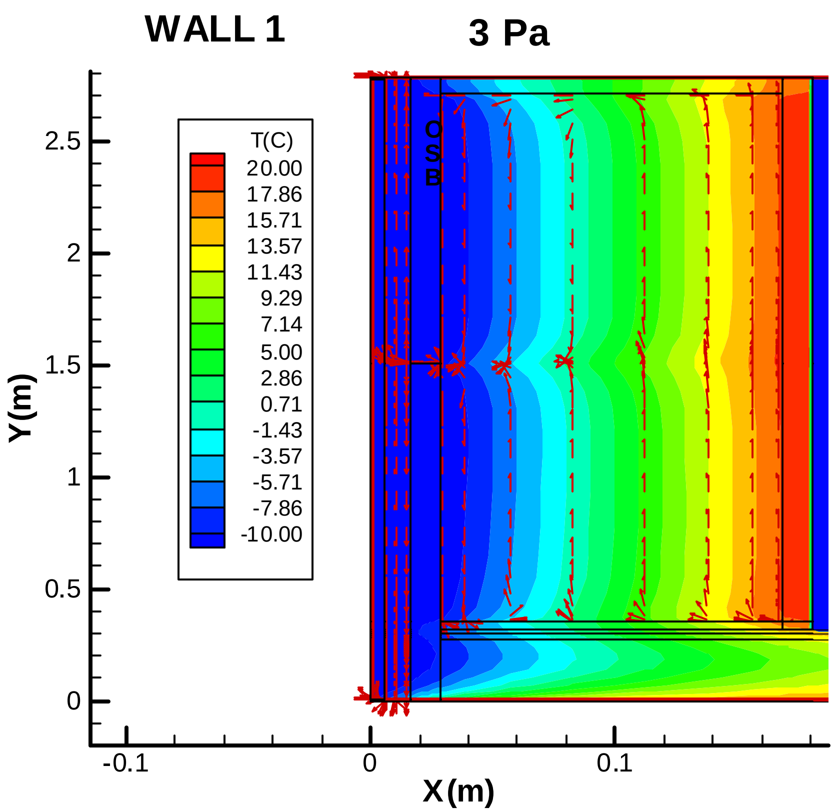


Figure 3a.24: 2D temperature distribution for Wall 1, -3 Pa, high moisture rate

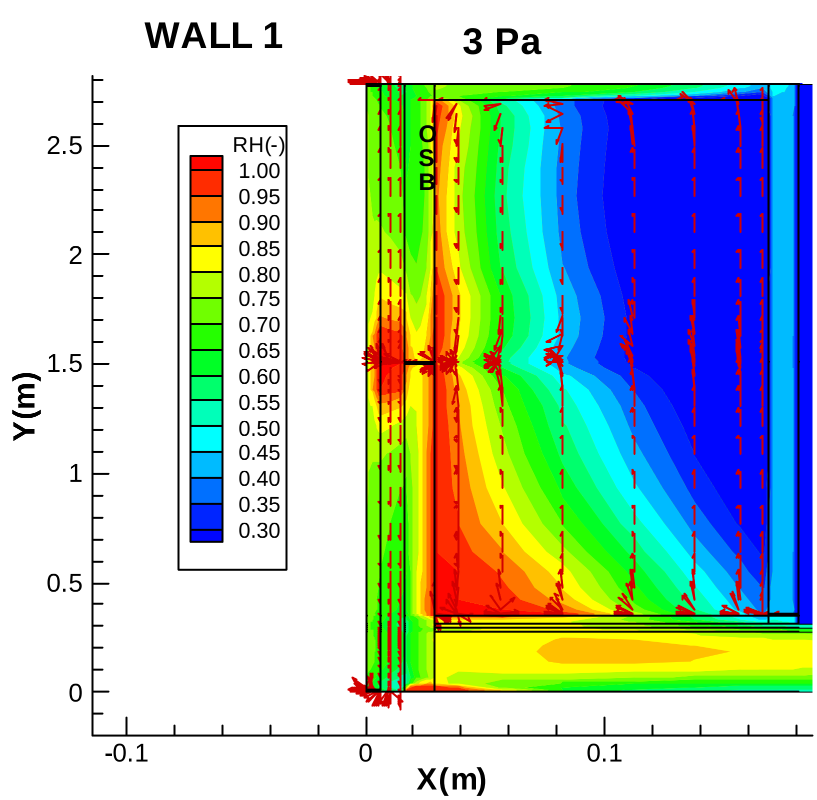


Figure 3a.25: 2D relative humidity distribution for Wall 1, -3 Pa, high moisture rate

Interpretation of Graphs

Moisture content measurements are shown for the simulated Wall Assemblies 1, thru 4. The most directly comparable metric, as well as the most significant for wall performance, is the moisture content of the wall sheathing. All wall assemblies were started at ~19% MC by weight: higher than the typical “shipped” MC of a manufactured wood product (typically 3-5% range). Some moisture adsorption on the jobsite was assumed before building dry-in (as per typical construction), as well as due to equilibration with framing lumber of a higher MC. However, the OSB was not intentionally “loaded” with an exceptionally high starting moisture content. Again, no water intrusion was simulated for the hygrothermal performance analysis for all walls.

The critical moisture contents for wall performance are as follows:

- Below 13%: little chance of mold growth; target MC (OSB)
- Below 10%: little chance of mold growth; target MC (Fiberboard)
- 10%/13% or higher: mold growth (surface phenomenon) may occur
- 20-28%: mold growth is assured and wood decay is possible
- 28% or higher: decay of wood products likely

The 13% (OSB) and 10% (Fiberboard) moisture contents were based on equilibrium MC data at given relative humidities (ASTM, 2001). This source shows a moisture content of 0.128 kg/kg at 80% RH for OSB, and 0.096 kg/kg for Fiberboard.

From the results it is evident that some differences in hygrothermal performance are found when comparing Minneapolis vs. International Falls locations. It is clear that International Falls is colder during the winter and that moisture accumulation is higher because of this.

This difference is shown on the sheathing moisture content graphs; in Wall 1, the MC quickly declines from the starting 19% MC, and only rises to ~10% during the following year. In Walls 2, 3 and 4, even under low moisture generation conditions, there are considerable periods with moisture content over 13%. In Wall 3, peaks are ~27% and ~30% (for a +3 Pa pressurization) for the two years (cold and warm, consecutively) in the low interior moisture cases. In Wall 4, the corresponding peaks are ~24% and ~25%. Wall 4 has slightly better performance due to the addition of EPS (white beadboard) foam on the interior; it decreases the moisture permeance of the interior surface (compared to painted drywall), resulting in les moisture transmission into the assembly. However, both of these walls have unacceptable overall performance.

In Appendix A, for each simulated case, a mold growth index was calculated using the temperature, relative humidity, and moisture content spatial and temporal distributions. From this data the mold growth index was calculated for a location very close to the opening in the OSB boards. This location was chosen as the highest accumulation was observed in that region. The risk for mold growth can be estimated and compared using these approaches, rather than examining just the moisture content data.

Sensitivity Study of Data

Dynamic conditions (hourly values) were used in the course of the simulations. Several of the parameters were changed over the course of these simulations, including interior moisture generation rates, outdoor weather years (hot or cold), and mechanically induced pressures.

Low and high moisture generation rates (1.8 & 4.4 gal/day, respectively) can be compared, for instance, in Figures 3a.2 and 3a.3 (or any low-high pairing). The moisture content of the OSB and the Fiberboard is increased by having higher moisture generation rates indoors: the lower generation rate has a peak MC (depending on air pressure differential) that is substantially lower than the one for higher generation rates.

The outdoor weather years can be compared sequentially in Figures 3a.2 through 3a.18. The 10% percentile cold year shows greater moisture content: the OSB or Fiberboard is a colder condensing surface (causing more accumulation), and the thermal moisture drive (?T) is higher, assuming a relatively constant indoor temperature. Basically, given that 10% hot and cold years are shown, they can be considered boundary conditions for the majority (80%) of the weather that will be experienced, based on historical data.

Three pressures were used: +3 Pa, 0 Pa, and –3 Pa. These pressures also provide reasonable boundary conditions for the operation of ventilation systems, as well as consistent pressure differentials caused by mechanical system operation. The moisture content was always elevated in the +3 Pa condition (compared to 0 Pa), due to air-transported moisture (due to exfiltration) into the wall cavity. Likewise, the –3 Pa condition reduced the moisture content.

From the mold growth index data in Appendix A, the results clearly show the significant influence of both interior moisture loads (low and high) and the interior vapor control strategies (e.g. polyethylene vs. painted drywall).

It is also interesting to observe the behavior of the choice of the exterior sheathing. The Fiberboard sheathing is at least 10 times more vapor permeable at very high relative humidities (OSB: 6.38 x 10^{-12} kg/m·s·Pa, compared to 6.15 x 10^{-11} kg/m·s·Pa for Fiberboard). At a relative humidity of 80% the moisture content of OSB is 0.128 kg/kg, and for fiberboard, at 0.096 kg/kg. At much higher relative humidities (e.g., 99%), the OSB and Fiberboard moisture contents are 0.445 kg/kg and 0.853 kg/kg respectively. The liquid diffusivity is also approximately 10 times higher for fiberboard than OSB. As vapor diffuses from the inside space, any accompanying air–transported moisture enters the stud insulation space. Moisture may then accumulate in the insulation space, or move in the exterior sheathing. Depending on the thermal and moisture properties of the wall system, a redistribution of the total moisture occurs. This makes the comparison of these two sheathing boards very complex, in terms of moisture content, or even relative humidities.

Using a mold growth index helps resolve this issue. In the cases with an interior vapor retarder (Wall 1), moisture flow due to diffusion is restricted. The mold growth indexes clearly shows lower risk for mold to occur. When high interior moisture loads are used, then the risk becomes greater. The mold growth index also shows that it does not remain high throughout the year, even for the high interior moisture load case, but reduces to zero during the swing seasons. In Wall 2 cases, low risk for mold growth exists only for the low interior moisture load case, and much higher risk exist than for Wall 1 for the high interior moisture load cases. The cases with fiberboard (Wall 3 and Wall 4) show lower maximum risk values than Wall 2, but prolonged mold growth risk conditions.

It is important to note that the vapor drive and thermal effects have a much stronger effect on the moisture content than air-transported moisture in these simulations. Part of this is due to comparing a very strong thermal drive (Winter design T = -23° F; ? T˜93° F) with a relatively weak pressure difference (3 Pa). However, note that in this two-dimensional simulation, the air infiltration is diffused over the assembly as a slot ("line"), as opposed to being concentrated at a single location (hole, or "point"). The latter situation is the typical scenario for air transported moisture-based sheathing damage, with the affected area being localized close to the hole.

Appendix B shows some of the more interesting plots of relative hygrothermal wall performance. They plot moisture content of either sheathing or insulation over the course of two years in the International Falls weather location. A positive pressurization (+3 Pa) is acting in all cases, for 33% of the day.

Figure B.1 compares high and low moisture generation rates, as well as the effect of the polyethylene vapor barrier (Wall 1 vs. Wall 2). Note that moisture generation rate is a more dominant variable (for the given variation of parameters) than the wall construction.

Figures B.2 and B.3 show insulation and sheathing MC (respectively), comparing Walls 1 through 4. Walls 2, 3, and 4 have no interior vapor retarder (polyethylene). It shows the hygric redistribution in the wall assembly when different components are used. Although Walls 3 and 4 (Fiberboard sheathing) shows low amounts of water in the insulation (Figure B2), there is much more water in the Fiberboard than in the OSB (Walls 3 and 4 vs. Walls 1 and 2). More water is therefore stored in the Fiberboard than the OSB.

Figures B.4 and B.5 compare Walls 1 and 2, plotting water content in the insulation and in the sheathing. Specifically, these plots compare the effects of moisture diffusion and airflow. For instance, in Figure B4, the difference between Wall 2 airtight & Wall 2 +3 Pa (magenta & green peaks) shows the effect of airtightness (in a wall with no vapor barrier). The increased moisture content due to air-transported moisture is quite noticeable. A similar comparison can be seen comparing Wall 1 airtight & Wall 1 +3 Pa (yellow and blue).

The effect of diffusion can be isolated by comparing Wall 1 airtight and Wall 2 airtight (yellow and pink): this compares two airtight walls with and without a polyethylene vapor diffusion retarder. Also, comparing Wall 2 airtight and Wall 1 +3 Pa (pink and blue) shows that for these parameters, the effect of adding airflow to a wall with a vapor barrier, and the effect of omitting the vapor barrier from an airtight wall are roughly comparable.

List of Figures