Hygrothermal Analysis of Magnesium Oxide as Structural Insulated Sheathing

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ABSTRACT – Moisture performance of Structural Insulated Sheathing (SIS) was simulated for 15 climate locations representing all North American climate zones. Analyses employed common wall types and a proprietary SIS panel integrating magnesium oxide as the sheathing component. Simulation outcomes revealed a highly effective and adaptable enclosure system. Its performance is linked to a complement of material properties offering high water resistance and exceptional vapor control.

INTRODUCTION

The term Structural Insulated Sheathing (SIS) represents manufactured composite panels having an outer fastener-base and an inner insulation layer. As with conventional sheathing, SIS panels are designed to resist lateral forces in framed wall construction. They differ by also resisting dead and live loads of cladding materials without the need for stud or substructure attachment. Panels may further integrate factory-applied Air and Water Barriers (AWBs) to offer continuous structural and barrier systems.

The SIS panel has traditionally utilized plywood or oriented strand board as its nail-base or fastener-base component. More recently, magnesium oxide (MgO) has emerged as a sheathing alternative. Magnesium oxide panels are rigid boards formed from the hydration of MgO with magnesium salts – typically either magnesium chloride ($MgCl_2$) or magnesium sulfate ($MgSo_4$). Slurries also contain proprietary additives as well as fillers such as wood, perlite, and sand. Mixtures are cast with embedded mesh scrims and cured similarly to other cementitious materials.

When compared to wood-based products, MgO panels offer significant improvements in fire resistance, structural performance, and overall durability [1-3]. Furthermore, MgO panels exhibit greater mold resistance and remain dimensionally stable when exposed to moisture.

The SIS system is seen largely as a structural advancement in wall design. It also offers important benefits in hygrothermal performance. Most notably, the sheathing and drainage plane are rejoined with the rainscreen cavity where historically this interface has done the greatest good and where sensibly it should exist. This repositioning aids in assembly drying. The insulation layer is now protected from the exterior environment. And since the outboard sheathing serves as the fastener-base, there is no need for cladding attachment systems that would otherwise bridge the insulation. The thermal control layer is therefore truly continuous and is demonstrably more efficient – even when compared to thermally-isolated attachment systems (4). Dewpoints are also managed by the panel's foam insulation, diminishing the sheathing's role as a hygric intermediary. This reduces the need for interior vapor retarders, which greatly simplifies wall design.

This study examines hygrothermal performance of walls configured with a proprietary MgO-based SIS panel. Using rigorous climate conditions, I demonstrate how a single enclosure system accommodates all North American climates while remaining attentive to minimum R-value standards. I further discuss the role of each panel component in offering a synergy in climate-based design.

METHODS

Wall Assemblies

Modeled walls incorporated configurations and material properties of the ArmorWall Plus SIS system (DuPont™ Performance Building Solutions). This proprietary panel consists of fluid-based polyurethane insulation that is pressure-fused to the back side of magnesium oxide boards. The AWB is factory-applied and is characterized here as an acrylic coating.

One-dimensional illustrations of the evaluated wall types are shown in Figure 1 and further described in Table 1. Wall A represents the base wall type that relies on the panel itself as the sole insulation layer. In this configuration, the 5-1/2-inch stud cavity remains empty. Wall B denotes a hybrid 1-hour fire-rated assembly whereby the 5-1/2-inch stud cavity is filled with mineral wool batts. Lastly, Wall C represents the same assembly as Wall B but with the stud cavity reduced to 3-1/2 inches. Each wall type is shown with a 2-inch SIS panel. Actual simulations employed panel thicknesses that varied based on climate, minimum R-value requirements, and the product's standard panel dimensions (Table 2).

Hygrothermal Simulations

Simulations were performed using WUFI® Pro 6.6, a hygrothermal analysis tool developed jointly by the Fraunhofer Institute for Building Physics and Oak Ridge National Laboratory. The software's capabilities include one-dimensional analysis of coupled heat and moisture transfer under real-world climate conditions [5]. Except where noted, analyses were performed in accordance with the WUFI User Manual [6, 7] and ASHRAE 160-2016 [8].

Building Orientation, Height and Rain Loading

Analyses reflect north-facing orientation with an inclination of 90 degrees. Rain loading was calculated according to ASHRAE Standard 160 utilizing the building height range of >33 ft - <66 ft. Corresponding exposure and deposition factors were 1.2 and 0.5, respectively.

Surface Transfer Coefficients.

Exterior surfaces reflected the wind-dependent option with a coating permeance of 10.9. Absorptivity and emissivity values were designated as 0.5 and 0.9, respectively. Interior surfaces utilized a surface transfer coefficient of 1.41 Btu/hr ft^2 °F and a user-defined permeance of 8.0.

Calculation Periods

Simulations were performed for 10-year periods with start and end dates of October 1. Results reflect Year One plotted for a single continuous year with start and end dates conforming to seasons in the northern hemisphere.

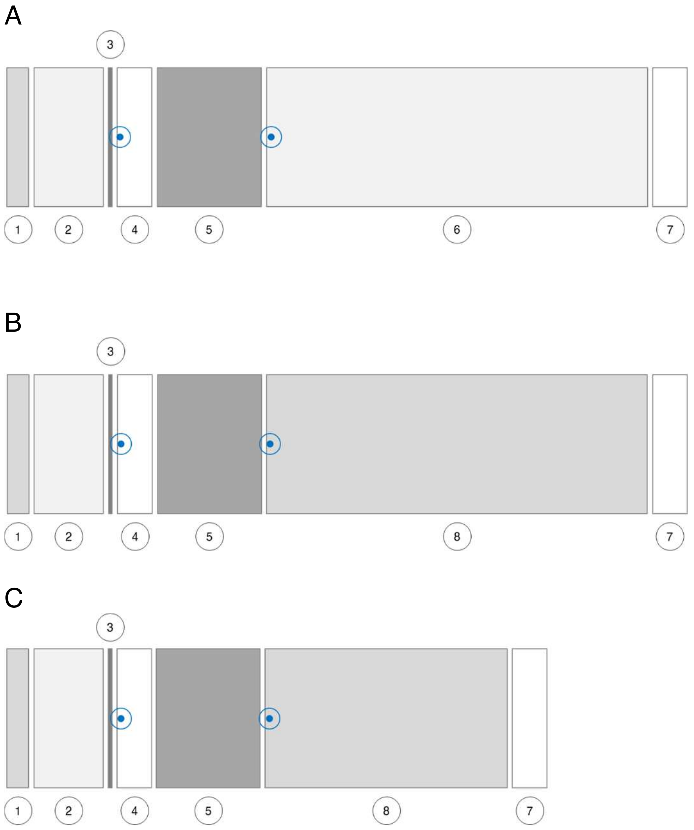


Fig. 1. Simulated wall types. Assembly components are described in Table 1. Primary monitoring positions are shown for the outer layers of the MgO sheathing and stud cavity component (⊙)

Table 1. Wall components and layer thicknesses.

Component	WUFI Material	Thickness (in)
Cladding (1)	Fiber Cement Sheathing Board	0.314
Rainscreen Cavity (2)	Air[1]	1.0
AWB (3)	DuPont™ ArmorSeal Plus Coating	0.0078
MgO Board (4)	DuPont™ ArmorBoard	0.5
Panel Insulation (5)	DuPont™ ArmorWall Polyurethane Foam Insulation	1.5 – 3.25
Empty Stud Cavity (6)	Air[1]	5.5
Batt-Filled Stud Cavity (8)	Mineral Wool	3.5 or 5.5
Interior Gypsum Panel (7)	Interior Gypsum Board	0.625

[1] Air layers represent air without additional moisture capacity. This approach yields more realistic results for improved evaluation.

Table 2. Exterior climates and corresponding SIS panel thicknesses for each wall type.

Climate Zone	Location	SIS Panel Thickness[1]		
		C.I. Only (A)	5-1/2” Studs (B)	3-1/2” Studs (C)
1A	Miami, FL	2	2	2
2A	Houston, TX	2	2	2
2B	Phoenix, AZ	2	2	2
3A	Atlanta, GA	2	2	2
3B	Las Vegas, NV	2	2	2
3C	San Francisco, CA	2	2	2
4A	Kansas City, MO	2.75	2	2
4B	Albuquerque, NM	2.75	2	2
4C	Seattle, WA	2.75	2	2
5A	Boston, MA	3.75	2.75	2.75
5B	Boulder, CO	3.75	2.75	2.75
6A	Minneapolis, MN	3.75	2.75	2.75
6B	Billings, MT	3.75	2.75	2.75
7	Intl. Falls, MN	3.75	2.75	2.75
8	Fairbanks, AK	-	3.75	3.75

[1] 2 inches = R-10; 2.75 inches = R-15; 3.75 inches = R-21

Materials

Material properties and hygric functions for the ArmorWall SIS system were determined by a third-party testing laboratory. These data are planned for inclusion into the WUFI® materials database pending future updates. Properties for the remaining materials were selected from the WUFI® 6.6 database as summarized in Table 3.

Moisture and Air Change Sources

A default value of 1% was assumed for water penetration beyond the exterior cladding. This value represents the wind driven rain fraction and is deposited on the exterior surface of the AWB. Free water saturation was selected as the source term cut-off to reflect the AWB’s low water absorption properties. An air change rate 10 air changes per hour was assigned to the rainscreen air cavity.

Climates

Exterior climates were assigned ASHRAE Year 1 datasets for the 15 climate locations in accordance with ASHRAE RP 1325 (Table 2). These Year 1 data represent severe weather years based on performance outcomes from measured 10-year periods [9].

Interior conditions were derived from corresponding exterior climates using the algorithm specified by ASHRAE Standard 160 [8]. Analyses assumed air-conditioning, dehumidification, and the default set points for temperature and relative humidity. Interior climates further reflected moisture generation rates of 1 lb/hour. Air exchange rates were defined as air-tight construction with a building volume of 100,000 ft^3.

Moisture Performance Evaluation

Performance evaluation utilized relative humidity as a function of surface temperature in accordance with ASHRAE Standard 160-2016. Two monitoring positions served in performance evaluation. The first included the outer layer of the MgO board (0.004 in). The second employed the outer layer of the stud cavity air or the mineral wool batt (0.08-0.11 in). Both monitoring positions reflected surfaces associated with the highest hourly relative humidity within the greater wall assemblies.

Selected monitoring positions represented ‘medium resistant’ sensitivity classes based on ASHRAE 160-2016. However, for this evaluation, the stud cavity monitoring position was treated as a ‘sensitive’ class to account for possible adjacency to wood studs in real-world three-dimensional assemblies. A more stringent criterion of 80% relative humidity was therefore used in evaluating stud cavity components. Mold-resistant MgO panels reflected a higher value of 85%.

Table 3. Basic material properties of wall components[1].

Material	ρ^2 (lb/ft^3)	Φ (ft^3/ft^3)	Cp (Btu/lbF)	k (Btu/hftF)	μ (Perm in)
Fiber Cement Sheathing Board	86.1	0.479	0.201	0.142	0.13
Air[3] (rainscreen cavity)	0.081	1.0	0.239	0.089	253.0
DuPont™ ArmorSeal Plus Coating	8.12	0.001	0.549	1.3	0.023
DuPont™ ArmorBoard	71.98	0.65	0.203	0.092	5.2
DuPont™ ArmorWall Polyurethane Foam	3.6	0.991	0.351	0.012	0.56
Air[3] (stud cavity)	0.081	1.0	0.239	0.499	1,430
Mineral Wool	39.0	0.706	0.203	0.0208	120
Interior Gypsum Board	39.0	0.706	0.208	0.092	18.3

[1] Properties do not reflect hygric functions. [2] Density (ρ), Porosity (Φ) Specific Heat Capacity (Cp), Thermal Conductivity (k), and Permeability (μ). [3] Air properties represent the WUFI designation as ‘air without additional moisture capacity’.

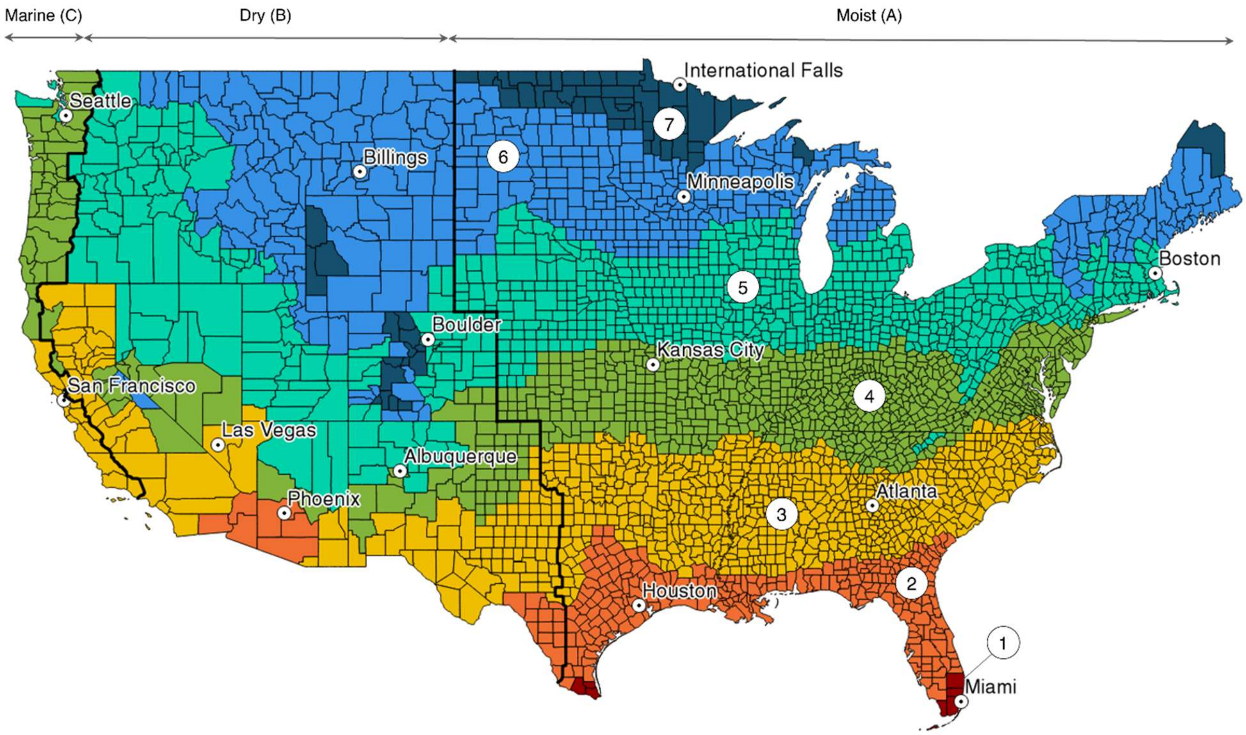


FIG. 2. Climate locations and ASHRAE climate zones.

RESULTS & DISCUSSION

Simulation results represent Year One of each 10-year calculation period (Figs. 3-8). For greater clarity, these data are plotted as 7-day moving averages for each wall type and monitoring position. Climate locations are further differentiated based on corresponding climate zones.

The predicted outcomes demonstrate quality performance for all wall type variants in all climate locations. In each case, simulations showed no evidence of moisture accumulation within the SIS panel or greater wall assembly. Predicted conditions were also well below the essential factors necessary for mold growth – arguably the most stringent of performance criteria. Furthermore, hourly outcomes met the evaluation criteria of 80% and 85% relative humidity for the respective monitoring positions. Evaluations based on raw hourly outcomes are considerably more rigorous than those typically adopted by industry practices, including ASHRAE Standard 160.

It should be noted that peak moisture conditions at the outer layer of the MgO board were always higher than those at the panel-stud cavity interface. With few exceptions, these conditions corresponded to colder exterior temperatures associated with late fall, winter, and early spring. Although relative humidity was maintained below the criterion of 85%, it is still relevant to consider relative humidity as a function of surface temperature (10). Still, in all instances, these co-dependent factors yielded conditions ill-suited for moisture accumulation and mold growth.

The Effect of Climate

Modeled assemblies incorporated panel thicknesses corresponding to minimum R-value requirements for the respective climate zones. These requirements are based largely on temperature and, more specifically, on heating degree days. Therefore, it is not surprising to see differences in predicted outcomes vary as a function of longitude, not latitude. In other words, wall moisture reflected differences in climate regimes where dry climates exhibited lower relative humidity as compared to moist climates. With minimum R-values addressed, rainfall and exterior humidity become greater determinants of wall performance. This relationship held true regardless of climate zone or general wall type.

The Effect of Stud Cavity Conditions

The findings showed that stud-cavity conditions had notable effects on wall performance. This is best illustrated by comparing plots conveying the stud-cavity monitoring position (Figs. 4, 6, 8). Such differences were expected as stud cavity insulation, by its very nature, reduces heat transfer to panel interfaces. This region of the wall therefore stays cooler, increasing relative humidity where batt insulation meets the back side of the SIS panel.

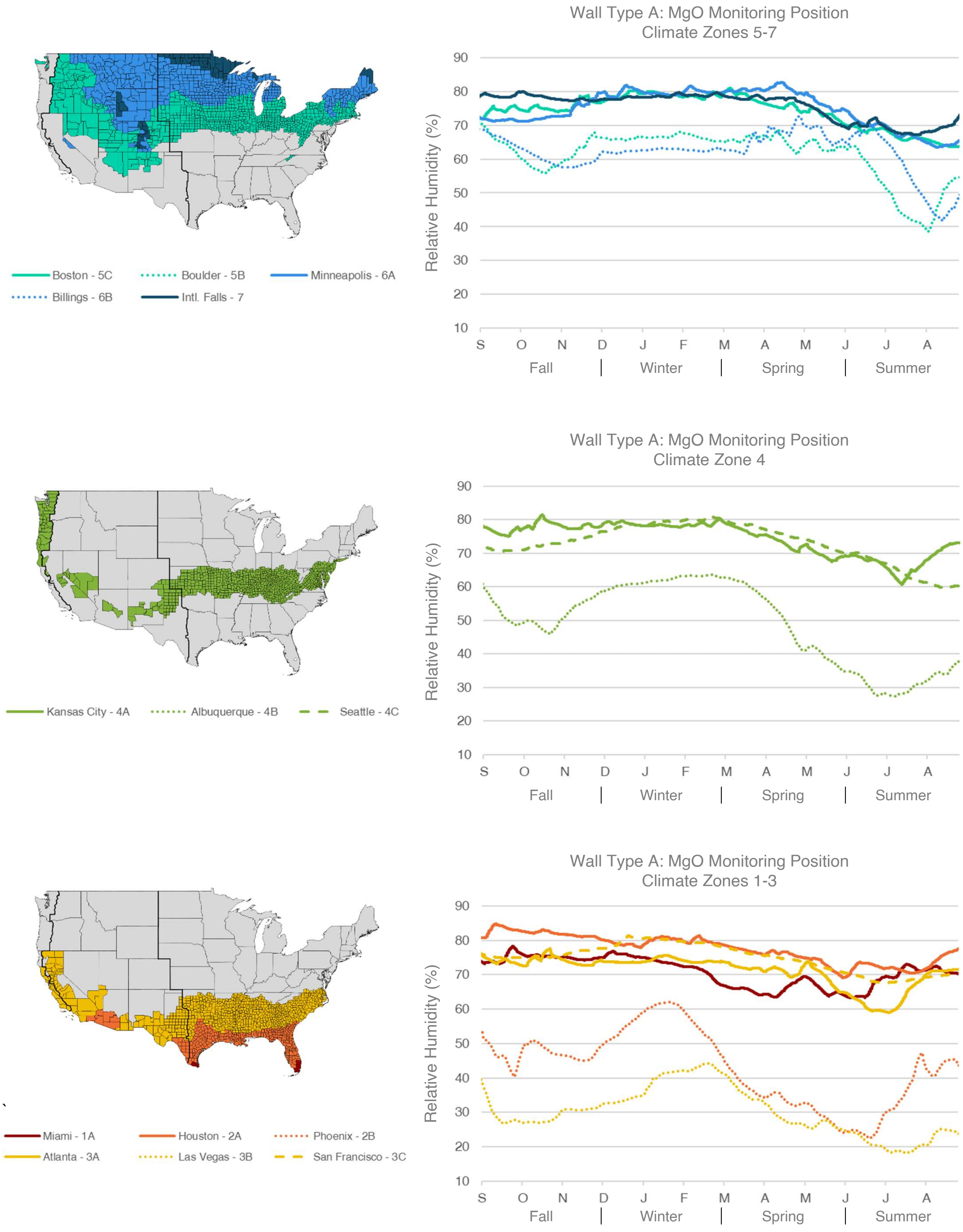


Fig. 3. Wall Type A: Relative humidity for Year 1 at the MgO monitoring position.

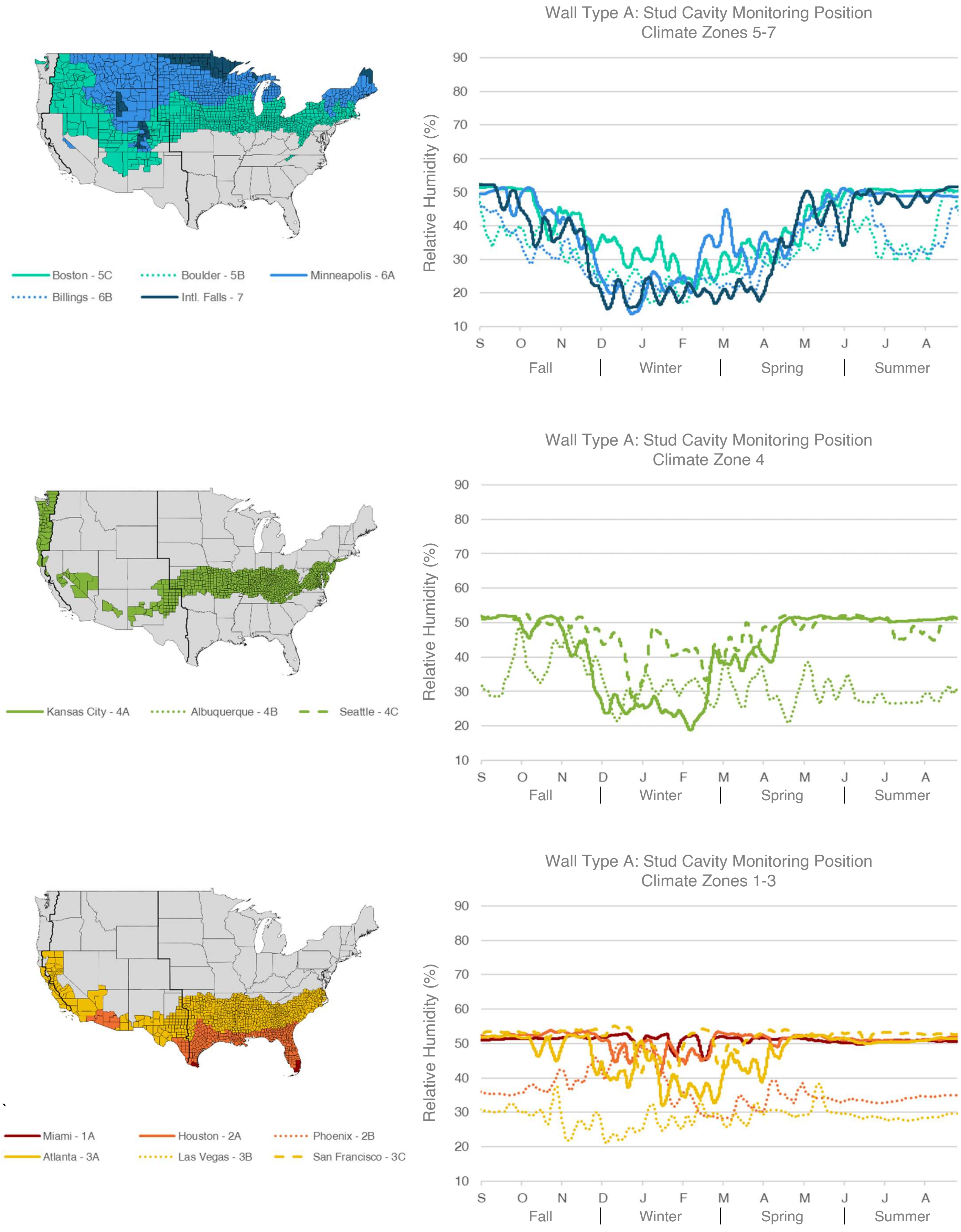
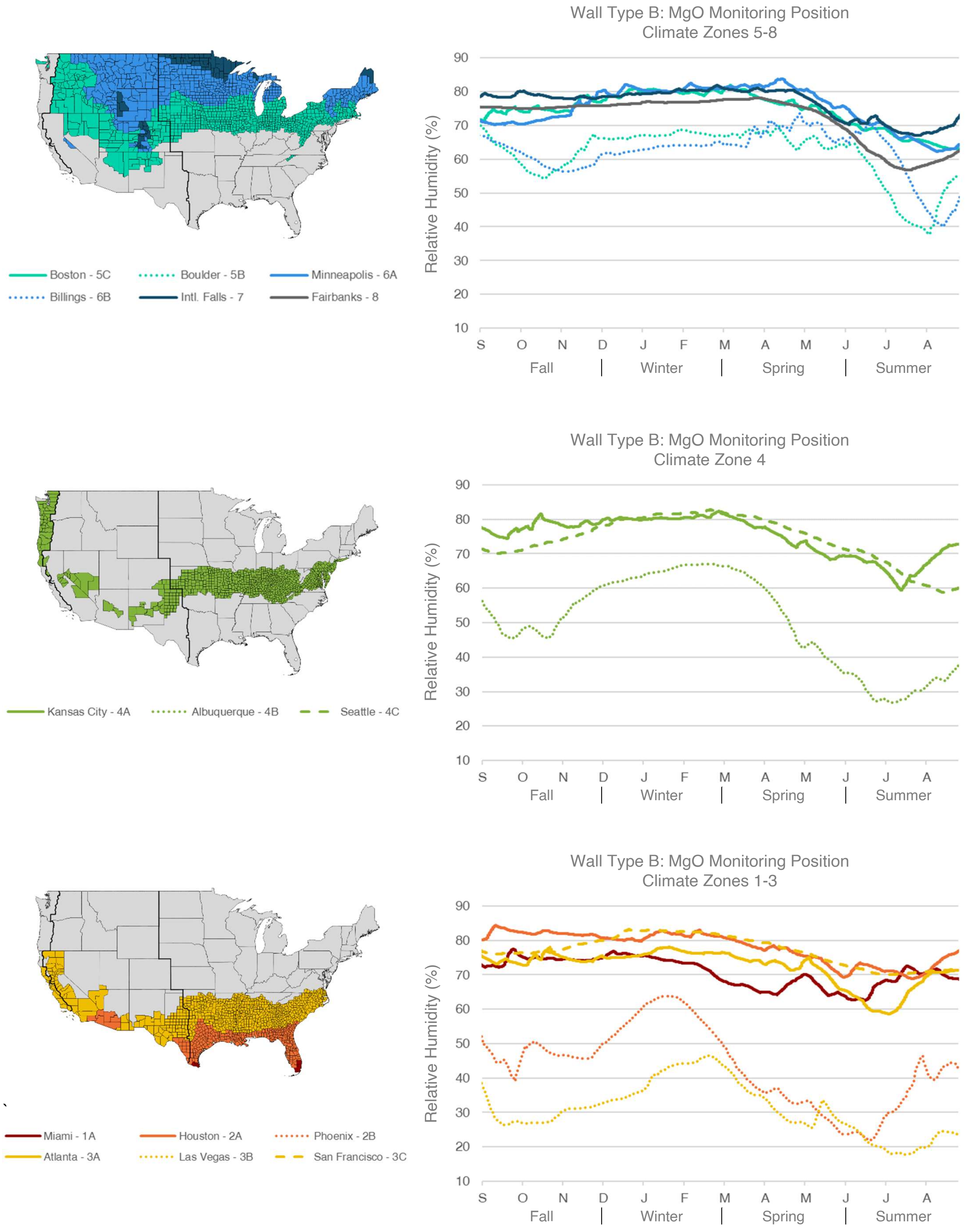


Fig. 4. Wall Type A: Relative humidity for Year One at the stud cavity monitoring position.



Wall Type B: MgO Monitoring Position
Climate Zones 5-8

Wall Type B: MgO Monitoring Position
Climate Zone 4

Wall Type B: MgO Monitoring Position
Climate Zones 1-3

Fig. 5. Wall Type B: Relative humidity for Year One at the MgO monitoring position.

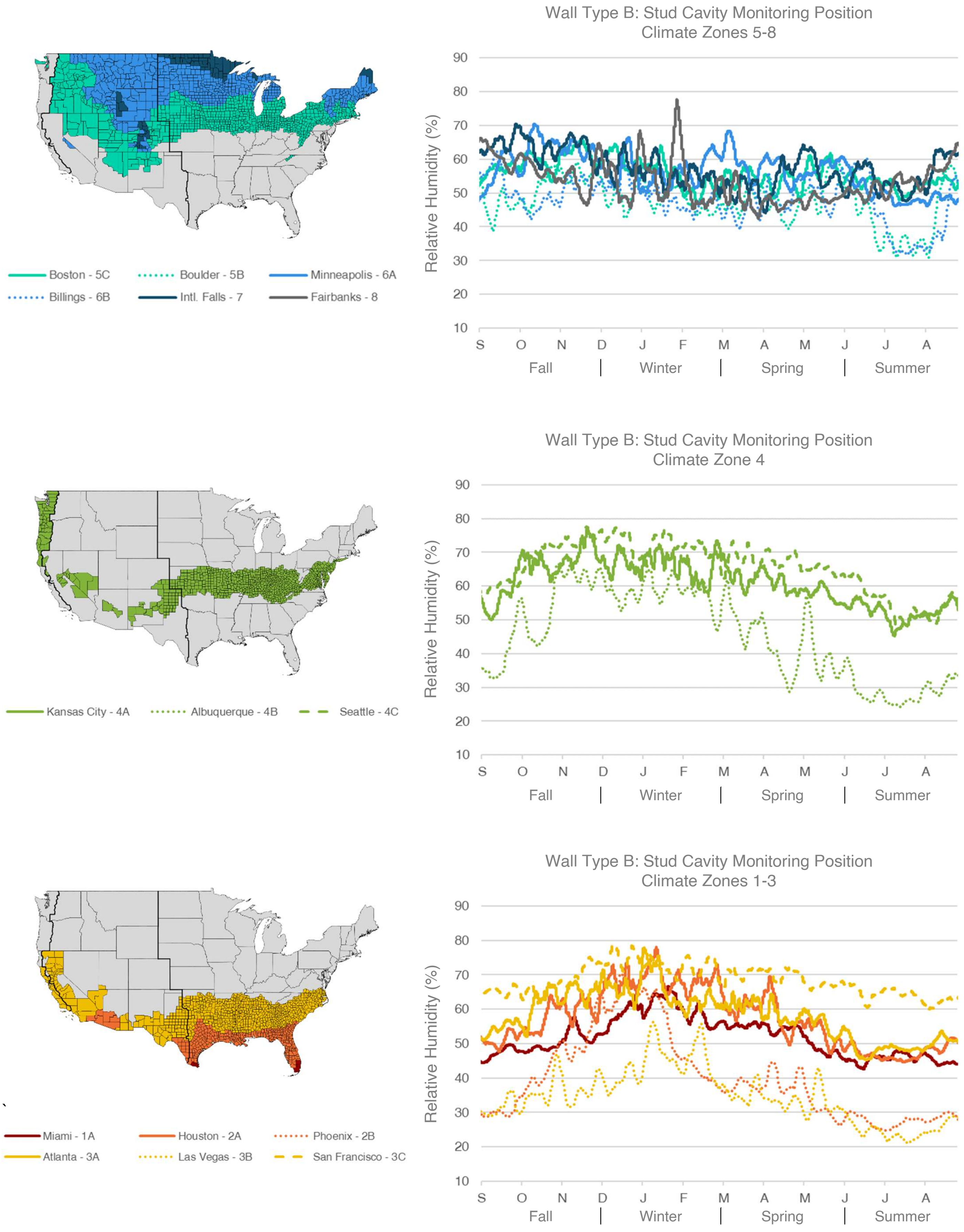


Fig. 6. Wall Type B: Relative humidity for Year One at the stud cavity monitoring position.

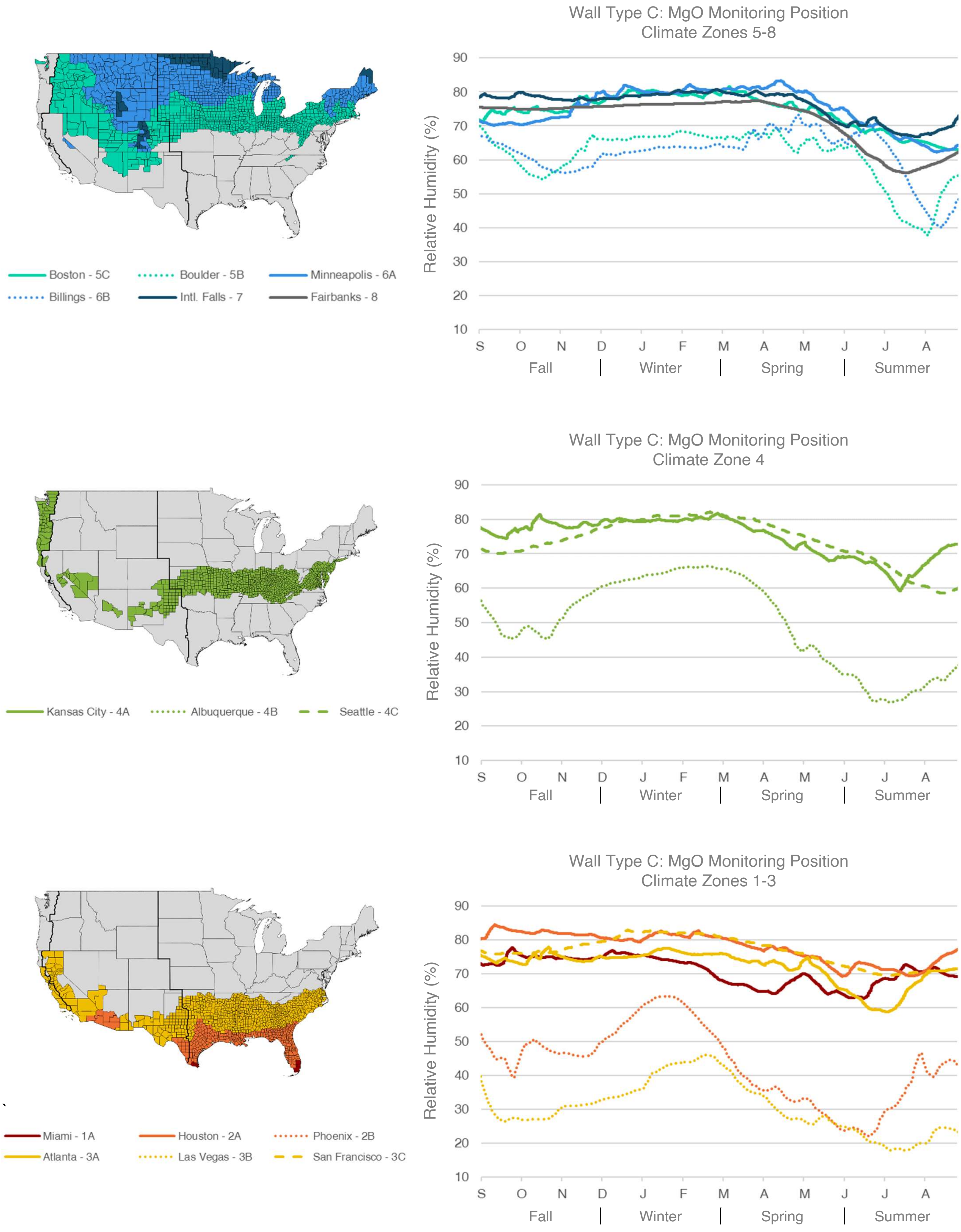


Fig. 7. Wall Type C: Relative humidity for Year One at the MgO monitoring position.

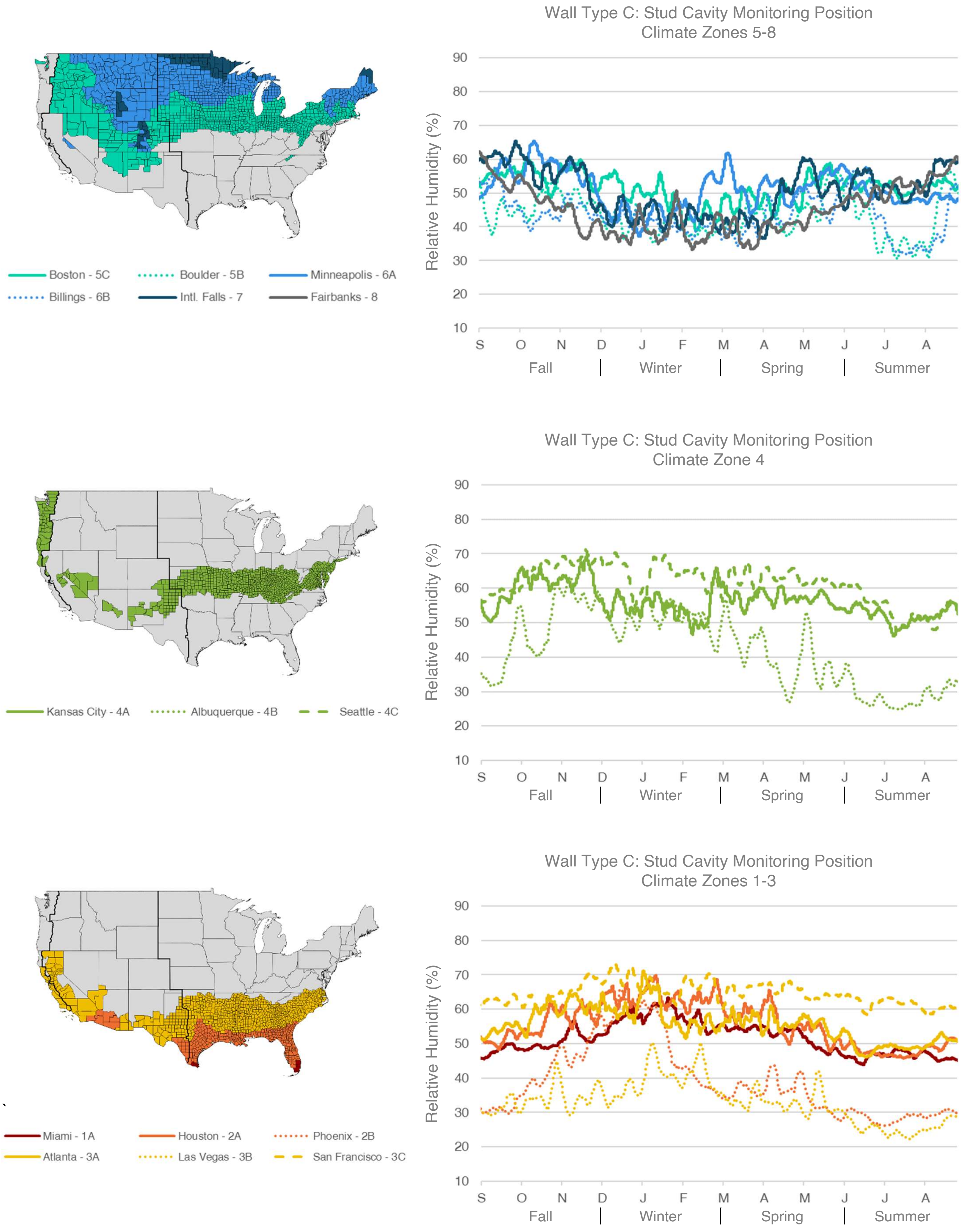


Fig. 8. Wall Type C: Relative humidity for Year One at the stud cavity monitoring position.

Notwithstanding these effects, relative humidity at panel-batt interfaces remained below the more stringent threshold of 80% – the critical relative humidity necessary for mold growth [7, 10]. Although polyurethane foam represents a more resistant sensitivity class, the 80% criterion was adopted to account for possible adjacency with wood studs. A highly conservative approach was therefore assumed, especially when considering that real-world, three-dimensional assemblies have much higher moisture storage capacities.

Variations in stud cavity size showed similar differences in simulated outcomes. These results were also expected as additional insulation serves to further isolate the panel-batt interface. Relative humidity increases accordingly. Assuming minimum panel thickness and a stud cavity of 3-1/2 inches, the outboard-to-inboard insulation ratio shifts from 30:70 to a more favorable 40:60. At maximum panel thickness, the ratio is improved from 50:50 for 5-1/2-inch cavities to 60:40 for 3-1/2-inch cavities.

The ideal wall configuration is one that relies solely on exterior insulation. This is true for any wall. However, when the cavity is filled, whether for thermal performance or fire rating, one may do so safely without concern for deleterious effects.

Vapor Retarders

Interior vapor retarders were omitted to demonstrate a simpler climate-based design. The findings show quite definitively that vapor retarders are not necessary, regardless of climate zone. Indeed, under most interior conditions, moisture generation rates are simply too low to pose risks. Water vapor is also managed by the panel's ability to safely store moisture while remaining vapor-permeable in both directions.

If desired, vapor retarders may be safely incorporated for applications in Climate Zones 5-8. Moreover, they may be necessary for interior climates having moisture loads that differ from those adopted here.

How The SIS Panel Works

The ArmorWall SIS system represents a composite panel in which the outboard AWB and inboard insulation form high-bond interfaces with their MgO substrate. Unlike conventional approaches for continuous insultation, the sheathing and AWB are brought forward of the insulation. This alone offers real advantages by reuniting the rainscreen with the primary drainage plane. The stud cavity now interfaces with the insulation, eliminating the sheathing from a position prone to dewpoints and moisture accumulation.

Beyond the obvious benefits of layer sequencing, advantages are also gained from novel materials. Each offers properties ideally suited for their placement while being uniquely designed to complement the next. Though the panel represents a unitized system, the resulting synergy is best understood by examining key attributes of its individual parts.

The Air & Water Barrier

The system's AWB consists of an acrylic coating having moisture-dependent vapor permeance (Fig. 9). As relative humidity increases, the coating's perm value increases to over 30 perms at 90% relative humidity. This function partly accounts for the conditions predicted at the outer MgO layer where the steep change in permeability coincides with 75 to 85% relative humidity. Beyond this range, the panel dries to the exterior or interior, depending upon prevailing vapor gradients.

While the AWB remains vapor open, it still exhibits low water absorption and very high resistance to bulk water – characteristics supported by my own experimental studies. These combined attributes are truly ideal for multi-climate design where conditions may be unknown or subject to change. Indeed, the primary purpose of any AWB is to protect the assembly from intruding air and bulk water. Its secondary role is a supporting one, to manage vapor transport. In this case, the AWB serves both functions.

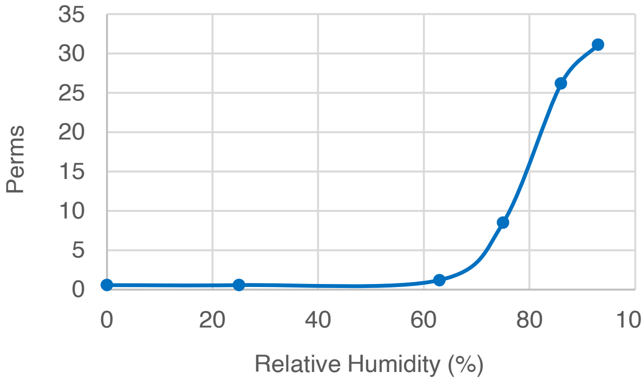


Fig. 9. Moisture-dependent permeability of the DuPont™ ArmorSeal Plus Coating.

The MgO

Magnesium oxide is a mineral-based cementitious material. When compared to wood-based panels, it is considerably less vulnerable to physical and biological degradation. And unlike wood, it is dimensionally stable when exposed to moisture. This durability is its primary attribute and the basis for performance under higher moisture loads.

The board is also hygroscopic and vapor permeable. These features aid in moisture transport and subsequent release to its interfacing components and beyond. For example, the board's moisture sorption curve depicts its ability to store and transport water at increasing relative humidity (Fig. 10). The steepest portion of this curve corresponds to increasing permeability of the board's coating (Fig. 9). Hygroscopicity of the MgO is therefore complimented by the vapor permeance of its coating. As a result, moisture is safely stored, transferred, and released in response to prevailing vapor gradients.

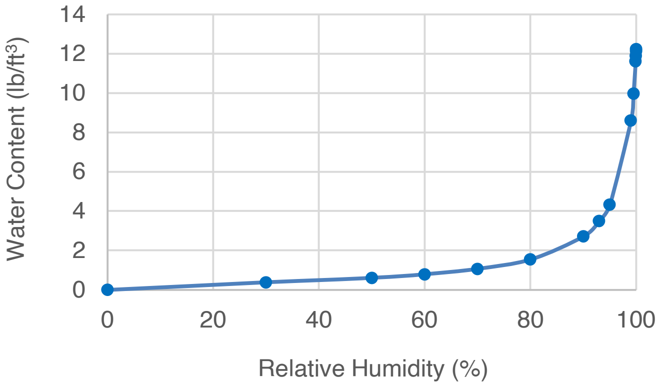


Fig. 10. Moisture storage function of the DuPont™ ArmorBoard MgO.

Further benefit is gained by its ability to safely store and release moisture without adverse effects such as weeping, a phenomenon observed in MgO panels having flawed magnesium-to-chloride ratios. In such scenarios, moisture adsorption leads to leaching of mineral salts – a condition implicated in metal corrosion and MgO degradation [11]. With proper chloride ratios, this defect of weeping is entirely avoided. Ongoing studies of the ArmorWall MgO board support this conclusion. My work also shows a board having consistently favorable free chlorides and an absence of weeping under moisture extremes.

The Insulation

The panel's polyurethane insulation is liquid-applied and pressure-fused to the back side of the MgO board. This provides an extremely uniform and durable bond that interfaces with the MgO at the surface pore level. Furthermore, this process prevents interstitial voids typically associated with spraying and laminating. The pressure-fused foam has an R-value of 6.5 per inch, which is greater than that of polystyrene and conventional spray-applied polyurethanes.

Although the insulation is semi-impermeable, it remains moderately hygroscopic. It therefore serves in moisture storage and bi-directional vapor transport. As with other foams, the insulation should not be viewed as a discrete vapor barrier. Instead, it represents a matrix of vapor-permeable cells where moisture at any given pore is freely exchanged with that of the adjacent. This attribute is complemented by those of the MgO and AWB coating – the former being more highly hygroscopic and the latter having an ideal moisture-dependent permeance. This synergy alleviates the need for interior vapor retarders under typical interior moisture loads.

SUMMARY

These analyses offer unique insights into the hygrothermal workings of a MgO-based SIS system. For the first time, its advantages are seen across all climate zones using common wall types and recognized climate extremes. My findings show an elegant system that retains a high level of adaptability while remaining profoundly simple. The system's intent as a structural advancement is now discernably matched by its attributes in climate-based design.

This study also reveals a complement of very specific components that, when brought together, offer a truer, simpler solution to persisting hygrothermal problems. These challenges center around the fundamental roles of modern enclosure systems: air/water resistance, vapor management, and true insulation continuity.

As demonstrated here, the SIS concept, and specifically the ArmorWall Plus system, addresses the needs of modern enclosures. It does so by simplifying the assembly and repositioning wall components to better align with proven rainscreen practices. These needs are not met by merely cobbling together pieces and parts. Instead, they reflect a comprehensive whole; one that is designed and tested as such – in ways that exceed the status quo. Further benefits are gained with novel materials having hygric functions that turn potential limitations into system strengths. Component interfaces become unitized to aid in both form and function. Above all, the system is inherently and demonstrably durable.

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