HYGROTHERMAL PERFORMANCE ASSESSMENT OF ICF WALLS WITH DIFFERENT MOISTURE CONTROL STRATEGIES AND WALL DESIGNS

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ABSTRACT

The initial high moisture content of concrete and the low vapor permeability of insulation layers on both sides of the concrete complicate the drying process of Insulated Concrete Forms (ICF). In order to facilitate the moisture transport and enhance the drying process, different moisture control strategies and wall designs can be implemented. The application of an air and vapor barrier is one of the most common moisture control strategies. In this paper, the impact of vapor permeance of an air and vapor barriers on the hygrothermal performance of an ICF wall in three different cold and wet climates is examined using a validated Heat-Air-Moisture transfer model. The hygrothermal performance of an ICF wall assembly with different types of barriers and locations in the wall system for several wall designs is investigated. Results indicate that a smaller thickness of insulation on the outside facilitates removing the moisture towards the outside and installing low permeance air/vapor barrier systems on the outside prohibits drying and drives the moisture to the inside. Our findings also show that with the proper selection of insulation thickness and vapor control strategy moisture-related problems can be avoided.

KEYWORDS

hygrothermal performance, vapor and air barrier membranes, building envelope, passive energy-saving, insulated concrete form walls

1. INTRODUCTION

North American residential and commercial buildings consume a considerable amount of their national energy demands. The US Energy Information Agency (EIA) reported residential and commercial buildings consumed 41.6% of the total energy consumption in 2014[1].

According to Natural Resources Canada [2], Canadian buildings consume about one-third of the national energy supply while being responsible for 28% of the total Greenhouse Gas Emissions (GHG) and Canadians spent $50.8 billion in energy purchases in 2009. About two-thirds of the residential and half of the commercial and institutional buildings' energy use is for space conditioning to mitigate the heat and air flow through building envelope components.

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In the last decade, Insulated Concrete Form (ICF) walls have come to be featured as one of the most energy efficient wall systems in the construction industry. (ICF's are hollow expanded polystyrene (EPS) or extruded polystyrene (XPS) blocks into which concrete is poured to form walls. Buildings with ICFs can be designed as passive energy-saving houses and buildings and are expected to reduce demanding energy needs and the consumption of hydrocarbon energy resources.

In North America, residences, apartments and multi-family buildings' structures have used ICF walls in the last decade. For instance, in the City of Waterloo, ON, (Population 100,000) approximately 80 mid-rise student residences, apartments, and multi-family buildings have been constructed with ICFs [3].

Studying the thermal performance and the energy efficiency of an ICF wall system has been an interesting subject for several researchers [4–7]. However, not many findings are reported regarding the hygrothermal performance of ICF walls. Space gaps/voids generally can be created between the foam and the surface of the concrete that affects both the energy and hygrothermal performance of the walls and can be inspected using ground penetrating radar [8, 9].

Gajda et al. [10, 11] from the Portland Cement Association studied the potential of moisture problems in ICF walls through laboratory experimentation and simulation tools. Their study incorporates building ICF wall sections and monitoring their drying process for one-year followed by dismembering the wall system to study moisture related distress. Their findings showed no moisture damage. Based on a steady-state water vapor diffusion analysis, they recommend implementing interior vapor retarders for climates with 7000+ heating degree-days, base 65°F (HDD65).

Understanding the moisture transport in ICF walls is crucial especially when considering the significantly high initial moisture content of the concrete coupled with the relatively low vapor open insulation layers on both sides which make its drying process slower. In addition, implementing ICF walls without proper study of the moisture content inside the ICF components could cause moisture related problems such as thermal and moisture performance degradations, mold growth and its related occupant health risks, and an increase in maintenance and repair expenses.

An air barrier system is one of the critical layers in the building envelope assembly that helps to reduce energy consumption by reducing any unintentional airflow through building envelope components. In addition to reducing energy loss it also helps to avert moisture damage on building envelope components and enhance thermal comfort. Based on the vapor permeability of an air barrier, it can be classified as a vapor open air barrier or an air and vapor barrier. However, a vapor barrier based moisture control strategy requires critical care because some moisture control strategies, which are intended to keeping water vapor out, could end up blocking the intended moisture removal approach [12].

There are two types of school of thought on barrier applications in ICF walls. The first one is that the insulation foams in either side of the concrete can serve as a barrier and hence there is no need to have either vapor or air barriers [13, 14]. The second is that the moisture accumulated in in the concrete will move towards the inside [10, 11] and, additionally, during the wet season the insulation foam might not provide a good shield to keep moisture outside.

This study aims to investigate the hygrothermal performance of ICF walls with two types of membranes (vapor open and closed) and different types of ICF wall designs using a benchmarked heat-air-moisture (HAM) model called *HAMFit* [15–17]. The moisture management potential of the systems, more specifically the effects of these membranes on the moisture control strategy of ICF walls is investigated.

The *HAMFit* model is capable of simulating transient thermal and moisture responses of building envelope components for time varying boundary conditions. To represent wet and cold climate conditions, the annual weather data for three Canadian Cities (Vancouver, BC; Halifax, NS; and Winnipeg, MB) were used. In addition to the outdoor boundary conditions, the positions of the membranes in the ICF wall are considered as important parameters to study the effects of vapor permeance and the location of air membrane on the hygrothermal performance of an ICF wall. In this study, various ICF wall designs with different thicknesses of insulating forms (EPS) and interior finishes are considered. Through this exhaustive study, the hygrothermal performance of the wall systems is characterized and presented.

2. MATHEMATICAL MODEL AND DESCRIPTION OF *HAMFIT*

The *HAMFit* model simultaneously solves the three interdependent transport phenomena of heat, air and moisture in a building component. The mathematical model comprises a set of partial differential equations (PDEs) that govern the individual flows. The corresponding governing equations are shown below:

$$\theta \frac{\partial \varnothing}{\partial t} = \nabla \cdot \left(D_{\phi} \nabla \varnothing + D_{t} \nabla T \right) - \nabla \cdot \left(D_{t} \rho_{w} \vec{g} + \rho_{a} \vec{u} C_{c} \hat{P} \varnothing \right) \tag{1}$$

where $D_{\phi} = \left(+ D_{t} \frac{\rho_{w} R T}{M \varnothing} \right)$, $\mathrm{D}_{r} = \left(\delta_{r} \frac{\widehat{\partial P}}{\partial T} + D_{t} \frac{\rho_{w} R}{M} \ln(\varnothing) \right)$ and $C_{c} = \frac{0.622}{P_{\mathrm{atm}}}$

Heat balance

$$\rho_{w} C_{P\mathrm{eff}} \frac{\partial T}{\partial t} + \nabla \cdot (\vec{u} T) \rho_{a} \left(C_{pa} + \omega C_{pr} \right) + \nabla \cdot \left(\lambda_{\mathrm{eff}} \nabla T \right) = \dot{m}_{c} h_{fg} + \dot{m}_{c} \left(Cp_{v} - Cp_{l} \right) + \dot{Q}_{s} \tag{2}$$

where $C_{P\mathrm{eff}} = Cv_{m} + y_{l} C_{Pl}$ and $\dot{m}_{c} = \nabla \cdot \left(\delta_{v} \nabla P_{v} \right) - \rho_{a} \nabla \cdot (\vec{u} \omega)$

Air mass balance

$$\nabla \cdot \left(\rho_{a} \vec{u} \right) = 0 \tag{3}$$

Momentum balance (Darcy equation)

$$\vec{u} = \frac{k_{a}}{\eta} \nabla P \tag{4}$$

$$-\nabla \cdot \left(\rho_{a} \frac{k_{a}}{\eta} \nabla P \right) = 0 \tag{5}$$

where: ρ_w: density of water (kg/m^3), ρ_a : density of air (kg/m^3), θ : sorption capacity (kg/m^3), $\varnothing$: relative humidity, $\vec{u}$: air velocity (m/s), $\dot{m}$: mass flow rate of dry air (kg/s), h_{fg} : latent heat of evaporation/ condensation (J/kg), $\widehat{P}$: saturated vapour pressure (Pa), δ_v : vapour permeability (s), ω : humidity ratio (kg/kg air), k_a : air permeability (m^2), η : dynamic viscosity (kg/ms)

The governing partial differential equations (PDEs) of the three transport phenomena (Equation 1, Equation 2 and Equation 5) are coupled and solved simultaneously for temperature, relative humidity and pressure using a finite-element-based software called COMSOL Multiphysics 5.1. The *HAMFit* model accommodates non-linear transfer and storage properties of materials, moisture transfer by vapor diffusion, capillary liquid water transport and convective heat and moisture transfer through multi-layered porous media. The transient HAM model is successfully benchmarked against published test cases [15, 17]. The test cases are comprised of an analytical verification, comparisons with other models and validation of simulation results with experimental data.

The building envelope model is developed under the following assumptions. The fluid (air, water vapor and liquid water) in the pores and the local solid matrix are in thermal equilibrium. The general gas law defines the thermodynamic state of the air, water vapor and the water vapor-air mixture in the pores. The contact surfaces between two adjacent layers are assumed to be in perfect contact; consequently, the profiles of vapor pressure, suction pressure and temperature are continuous at the interface. More detailed information on the development and application of the *HAMFit* model can be found in Tariku [16].

3. ICF WALL SYSTEMS CONSIDERED IN THE STUDY

The main components of an ICF wall comprise a rigid insulation (EPS) on either side of the concrete. The thickness of the insulations on the interior and exterior seldom varies. However, based on the indoor and outdoor climate, the insulation thickness on the interior and exterior side of the concrete can be varied to enhance moisture transport and avoid moisture related problems.

As part of the moisture control strategy in this study, two types of membranes are used: a vapor and air barrier (from here onwards referred to Membrane A) and a vapor open air barrier membrane (Membrane B).Various configurations with different combinations of exterior insulation, concrete and interior insulation thicknesses and locations of vapor and air control layers are examined. Figure 1 shows a typical rain screen ICF wall design consisting of (from exterior to interior components): Cladding (19 mm Stucco), 10 mm air gap (rain screen wall systems), Membrane (Membrane 'A' or 'B') posted on the exterior or interior side of the ICF wall, Exterior EPS insulation (50 mm or 100 mm), Concrete (150 mm or 200 mm), Interior EPS insulation (50 mm or 100 mm) and Interior finishing (13 mm gypsum wallboard with or without paint.)

3.1 Material properties

The physical and transport properties of the materials used are determined with serious care to determine the optimum moisture control strategy. This scheme is characterized by air and vapor barriers' location and permeance value. In this study the basic material properties required for the input file of *HAMFit* are obtained from the ASHRAE research report [18].

Seven sets of material properties are required for *HAMFit* simulation, including dry density, thermal conductivity, heat capacity, sorption and water retention characteristics, such as water absorption coefficient, vapor permeability and Liquid permeability. Table 1 shows the basic material properties of the ICF wall components used.

3.2 Boundary Conditions

ICF walls are commonly built with a similar wall control strategy regardless of variations in climatic condition. In this study, three geographic locations are considered to study the climatic

FIGURE 1. Typical ICF wall components and locations of a membrane.

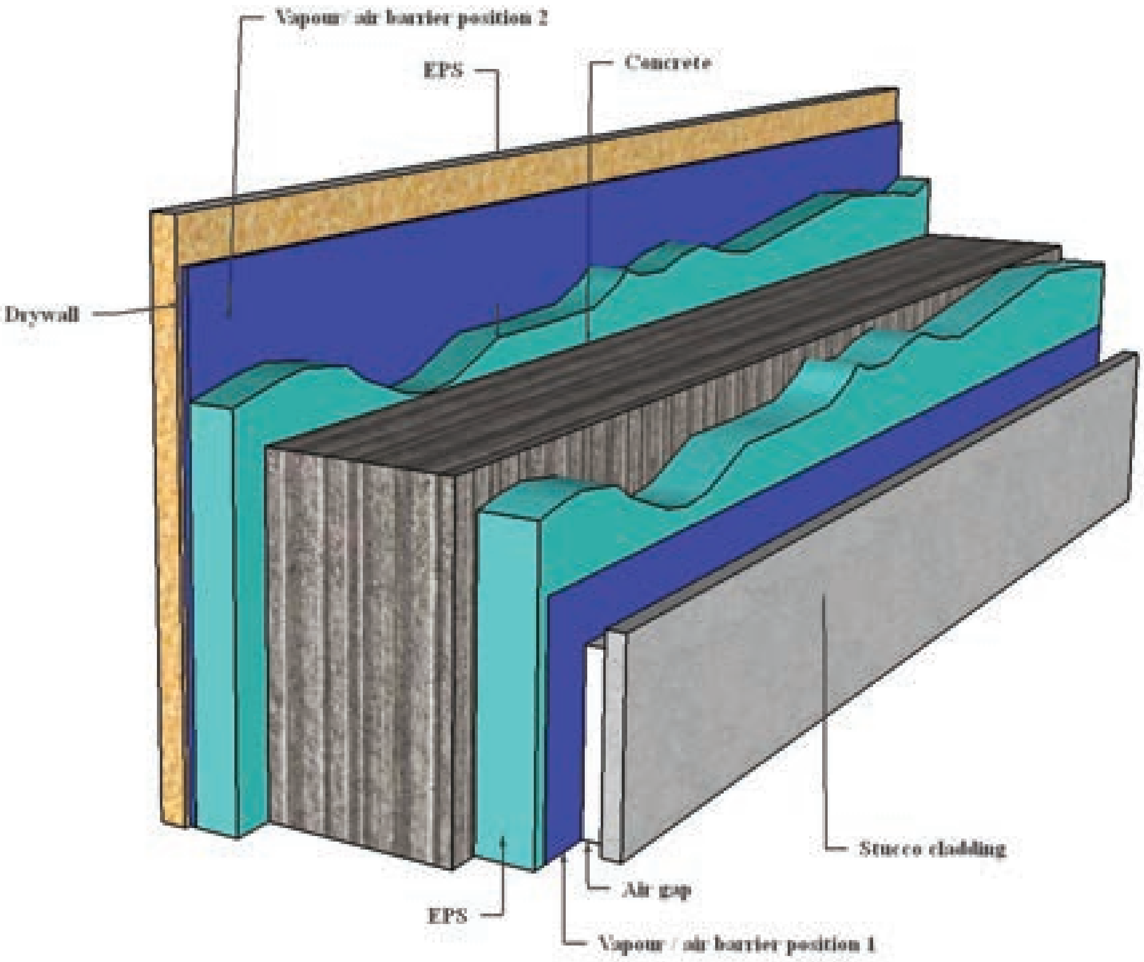


TABLE 1. Basic material properties of the ICF wall components.

Material	Density [Kg/m^3]	Thermal Conductivity [W/(m.K)]	Heat Capacity [J/(kg.K)]
Concrete	2200	1.210	840
EPS	30	0.040	1500
coated Gypsum board	690	0.198	690
Stucco	1985	0.409	840
Membrane	840	0.159	0

effects on the vapor/air barrier performance in ICF walls. The geographic locations are selected based on the drying and wetting potentials of the respective climate conditions, expressed by a moisture index (MI), and considering cold and mild temperature climates [19]. The selected locations (i) Halifax (NS), (ii) Vancouver (BC), and (iii) Winnipeg (MB) and their respective moisture index and wall orientation is shown in Table 2. The wall orientation in each location is selected to represent a wall facing the highest wind driven rain load for the selected wet and average year.

The exterior climatic conditions required for *HAMFit* simulations have seven major weather components: hourly temperature, relative humidity, wind speed, wind direction, rainfall, solar radiation and cloud cover (to estimate long-wave heat exchange with the sky). These weather conditions are taken from Environment Canada weather data and processed for *HAMFit* simulations.

The indoor condition for the residential building is set in accordance with ASHRAE 160P intermediate model as shown in Equation 6 [20].

$$p_i = p_{o,24\text{h}} + \frac{c\dot{m}}{Q} \tag{6}$$

where p_i = indoor vapor pressure, $p_{o,24\text{h}}$ = 24-hour running average outdoor vapor pressure, c = 1.36 × 105 Pa·m^3/kg, $\dot{m}$ = design moisture generation rate, Q = design ventilation rate. The indoor air temperature is set at 21°C and by assuming the building as airtight, according to ASHRAE 160P, 0.1 ACH is used to calculate the design ventilation rate.

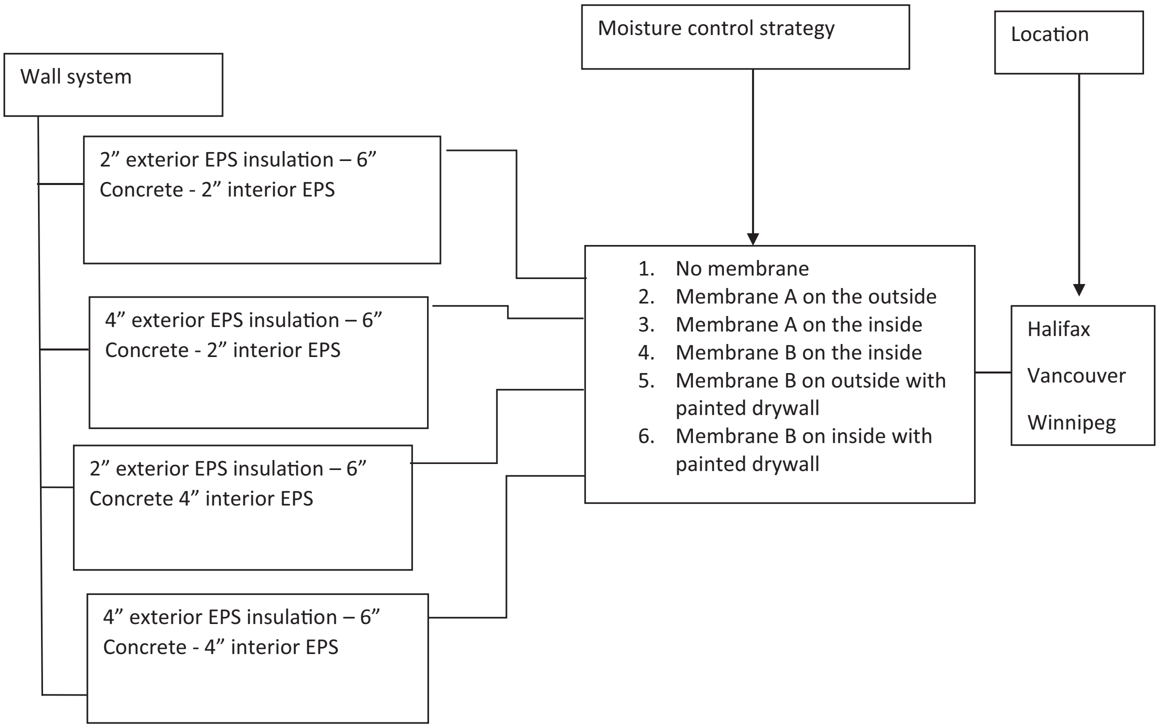
3.3 ICF wall design parameters

The primary objective of this study is to investigate the hygrothermal responses of ICF wall systems with vapor and air barrier membranes. To achieve this, a parametric analysis was performed and the results were assessed on the basis of the year long-term moisture response of various versions of ICF wall assemblies when exposed to the different interior and exterior climatic conditions. Hence, the five parameters investigated in this study are (i) the variation of membranes' location (installed on the outside of the exterior insulation and between interior insulation and drywall); (ii) exterior insulation thickness; (iii) concrete thickness; (iv) interior insulation thickness; and (v) variation in exterior and interior climatic conditions. The second, third and fourth parameters refers to size variation on the EPS and concrete thickness and their consequent effect on the concrete drying potentials. Figure 2 shows a matrix of different combinations of ICF wall parameters considered.

TABLE 2. Moisture Index for Three Locations.

Location	Moisture Index	Classification w.r.t Moisture Loading	Orientation
Halifax(NS)	1.15	High	East
Vancouver (BC)	1.09	High	East
Winnipeg (MB)	0.86	Low	North

FIGURE 2. Basic Combinations of ICF wall parameters.



Four different wall systems each with six different moisture control strategy in three different geographical locations provides 72 ICF wall parameters.

4. SIMULATION RESULTS AND ANALYSIS

In this study, four different insulation thicknesses and a 6-inch concrete core are used as base simulation configurations. The insulation thickness is varied between 2 inches and 4 inches on either side. In order to enhance the moisture control strategy, Membrane A (an air and vapor membrane) and Membrane B (vapor open, air membrane) are placed at different positions in the ICF assembly and the performance is assessed and compared with one another and to the base case of an ICF wall with neither air nor vapor membrane.

The results section is categorized as preliminary simulation, the impact of vapor permeance of air/ vapor barriers on ICF wall performance, the impact of wall design and impact of climatic conditions on ICF wall performance.

4.1 Preliminary simulation to determine the initial conditions

As in one of the common practices in ICF wall construction, the wall is allowed to cure for 28 days before the other components (membrane, drywall and stucco) are attached to it. In order to find out the relative humidity and temperature values, a fully wet concrete (> 99%) and an EPS insulation from the shelf (= 50% RH) are simulated with outdoor boundary condition in both faces for 28 days. The temperature and the RH values of the 28th day are used as initial conditions for the EPS and concrete materials in the main simulation. The results of the preliminary simulations are used as an initial condition for the main modeling task. One year of simulation is performed for each run (see combinations of parameters, Figure 2). The simulation start date was chosen to be July 1 so as to provide a favorable drying period for the freshly built ICF wall systems.

4.2 Impact of vapor permeance of air barriers on ICF wall Hygrothermal performance

Considering the number of ICF wall parameters investigated in this study, it is difficult to present temperature and relative humidity profiles for all scenarios. Instead, in the next subsection (4.2.1), a representative case is presented. In subsection 4.2.2 the relative humidity values on the drywall and near the outer side of exterior insulation for the different moisture control strategies are compared. Finally, the overall moisture content of the concrete throughout the year is plotted and used as a parameter to recommend an optimum moisture control strategy.

The hygrothermal response of a typical wall of design with 2” exterior EPS insulation, 6” Concrete and 4” interior EPS for the city of Halifax is presented below.

Six probes (points of interest) are used to calculate the relative humidity and temperature values throughout a year on an hourly basis. The selected locations are

1. Near exterior face of the stucco cladding
2. Near the outer face of exterior insulation
3. Exterior face of the concrete
4. Interior face of the concrete
5. Near inner face of the interior insulation
6. Inner face of the gypsum board

The locations of the probes are shown in the schematic diagram, Figure 3.

Temperature and relative humidity results of an ICF wall design with thicknesses of 2-inch interior and 4-inch exterior insulations and are presented below. The simulation is a one-year simulation which starts on July 1st.

In this study six different cases of moisture control strategies are used to study the Impact of vapor permeance of air barriers on ICF wall performance, as shown in Table 3. The performance of these strategies is studied for three different climates and four types of different wall designs.

In Case 1 no air and vapor membranes are used on either side. This model serves as a base case to compare the performance of other models with membranes. Figure 3 shows relative humidity and temperature measuring probes locations.

The relative humidity and temperature values at different wall components for the wall design of 2”-exterior insulation, 6”-concrete and 4”-interior insulation for Halifax weather climate are shown in Figure 4. The exterior side of the concrete dries faster than the interior side of the concrete. This effect is also similar to exterior insulation in comparison to the interior

FIGURE 3. Probe locations for RH and temperature calculation.

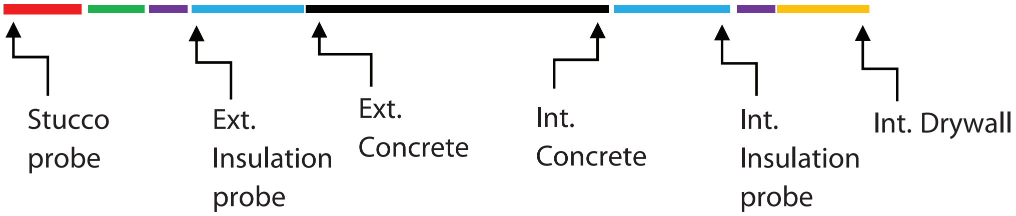


TABLE 3. Types of moisture control strategies.

Moisture control strategy case number	Air and Vapor membrane location	Drywall paint
1 (base case)	No Membrane	NO
2	Membrane A at interior	NO
3	Membrane A at exterior	NO
4	Membrane B at exterior	NO
5	Membrane B at Exterior	Yes
6	Membrane B at Interior	Yes

Key: Membrane A = air and vapor barrier membrane
Membrane B = air barrier membrane

insulation. This is mainly due to solar gain and the outdoor mass transfer coefficient is higher in comparison to the indoor mass transfer coefficient. The RH value on the stucco mainly depends on the outside weather condition. The drywall keeps a relatively low RH value throughout the year. The temperature plot in figure 4 (b) shows that the exterior part of the wall remains colder in most of the year. Whereas, the concrete maintains a relatively similar temperature difference throughout the whole concrete width.

In Case 2, the vapor and air barrier membrane (Membrane A) is located on the inside part of the EPS insulation and the drywall. Results show that Membrane A slows the drying of the interior concrete and interior EPS. The interior side of the concrete remains highly wet throughout the year. The interior insulation has a high relative humidity (> 85%) during the warm season in comparison to the exterior insulation. This is because the exterior insulation is exposed to solar driven drying. The relative humidity of the drywall remains low throughout the simulation time.

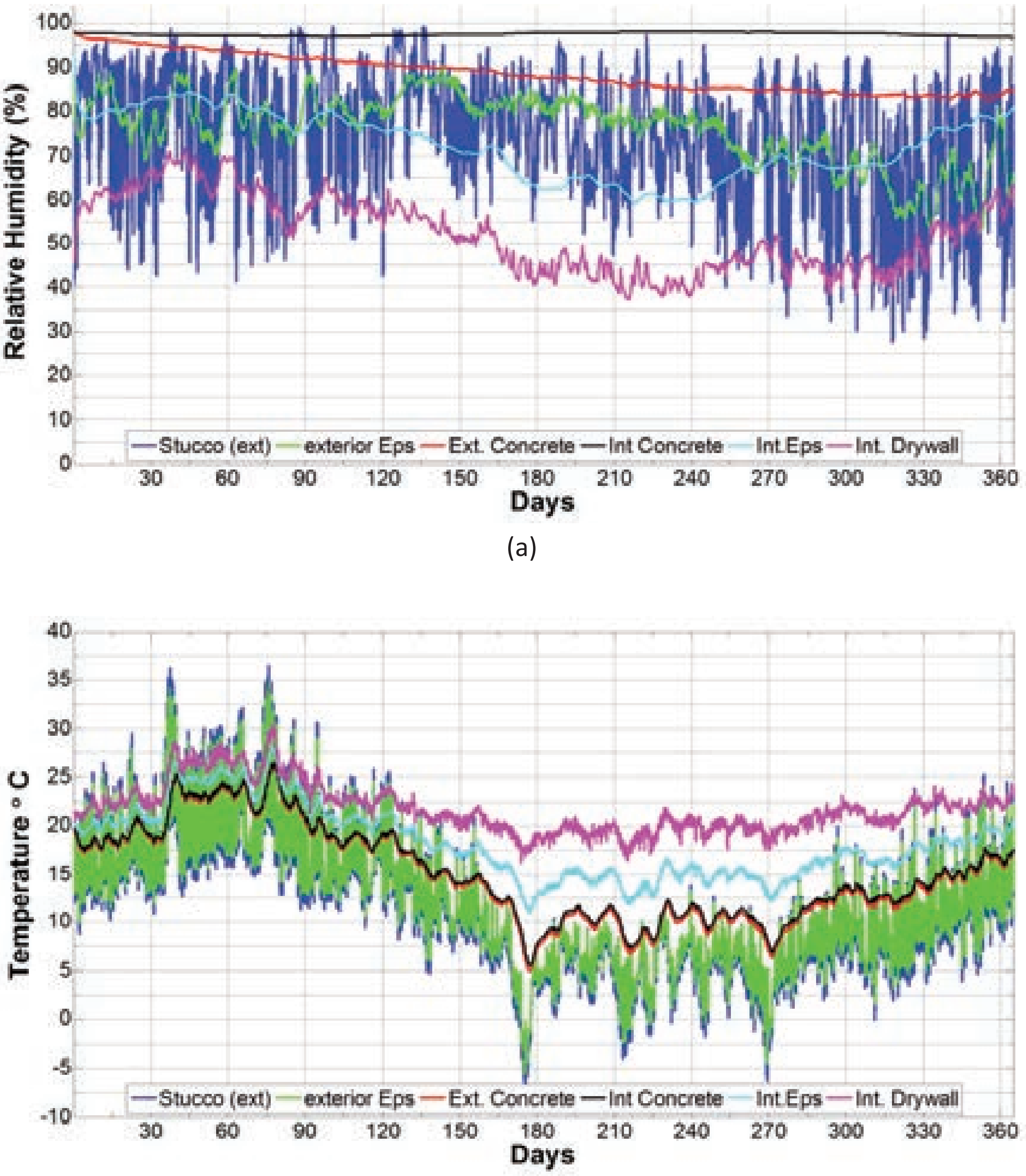
The air and vapor membrane (Membrane A) is placed on the outer face of exterior EPS insulation in Case 3. This strategy prohibits the moisture transport to the outside and forces the exterior side of insulation to sustain a 100% RH value during most of the time. The RH value of the concrete remains constant along the width, and its drying process is found to be minimal. It is reasonable to assume this effect leads the ICF wall to dry towards the inside and increase the moisture content of the inside wall systems and the gypsum board over time.

In Case 4, where an air barrier (Membrane B) is placed on the outer face of the exterior EPS insulation, the concrete has shown a trend of drying to the outside. The relative humidity of the exterior EPS reaches its highest value during the winter.

In Case 5 an air barrier is placed on the outer face of the exterior EPS insulation and the drywall is painted. The paint helps to lower the indoor mass transfer coefficient, which in turn lowers the drywall relative humidity. The RH value during the cold season becomes higher for the exterior insulation. The concrete's drying to the outside increases through time and the exterior parts of the concrete dry faster.

In Case 6, an air barrier is placed in between the interior EPS insulation and the painted drywall. In this case, where the drywall is painted and the air barrier (Membrane B) is located

FIGURE 4 (A) AND (B). The computed relative humidity and temperature values for ICF wall with no membrane respectively.



(a)

(b)

on the inside, results similar to Case 2 occur, which is that the vapor and air barrier membrane (membrane A) is located on the inside. A similar outcome of the slow drying of the interior concrete and interior EPS is observed. The interior side of the concrete remains highly wet throughout the year (RH value is greater than 90%). The interior insulation has a high relative humidity during the warm season as compared with exterior insulation. The relative humidity of the drywall remains low throughout the simulation time.

In order to find out the optimum moisture control strategy in ICF walls using an air and vapor barrier membrane, the relative humidity values on the end of exterior insulation (outside face of the exterior EPS) for all cases considered (case 1 to 6) are compared.

The modeling results show, due to solar gain on the outside face of the ICF wall and a higher mass transfer coefficient of the outdoor environment, that the moisture tends to dry out towards outside. The outer face of the exterior insulation holds higher moisture content if the control strategy is not performing well. Comparing the relative humidity at the end of exterior insulation gives a good picture of which control strategy scenario is performing better than remaining procedures. In addition to the RH values on exterior insulation, the total moisture content of concrete within a year under different moisture mitigation strategies is also investigated and shown.

4.2.1 ICF Wall with 4”-Exterior Insulation-6” Concrete-4” Interior Insulation

Figure 5 (a) and (b) shows the relative humidity values on the inside of the interior EPS and at the end of external EPS insulation for 4” exterior Insulation 6” Concrete 4” interior insulation design. The Interior EPS accumulates a higher value of RH in Case 2. Case 5 and Case 6 have similar RH values most of the time. With the exception of Case 2, the RH value of the interior EPS did not reach a critical value (stayed below 90%). The RH value of the exterior insulation probe on case 3 is 100% most of the time and a similar result is also observed for the other ICF wall designs analyzed.

The moisture content of the concrete in Cases 1, 4, 5 and 6 are similar and 7 kg/m^3 moisture is removed from the concrete. As shown in Figure 6, Case 3 is the strategy with the minimum moisture reduction results.

4.2.2 ICF wall with 2” Exterior Insulation-6” Concrete-4” Interior Insulation

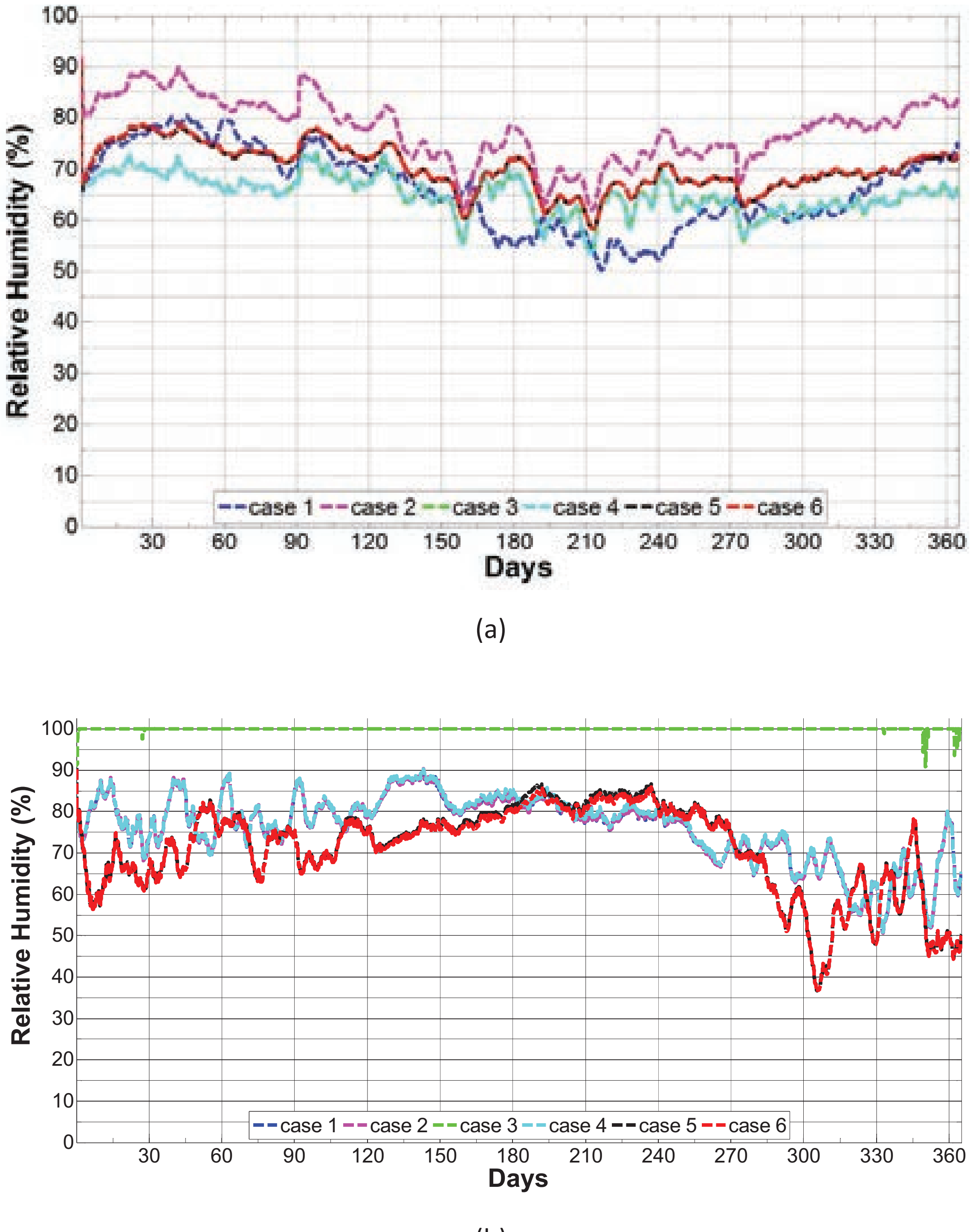
Figure 7 shows the relative humidity value at the end of external EPS insulation probes. Figure 8 shows the total moisture content of a concrete under different cases. The relative humidity of the drywall in all cases remains below 80% due to a larger insulation thickness used on the inside. The RH value on the outer face of exterior insulation is 100% through most of the year when membrane A is located on the outside. Similarly, when membrane B is located on the outside, the RH value reaches 100% on two separate occasions during winter.

As shown in Figure 8, Case 3 (where Membrane A is located on the outside) has only managed 5 kg/m^3 of moisture removal by the end of the year. Case 1 (no barrier used in the assembly), on the other hand, is a strategy where the highest moisture removal is observed: a loss of 12.5 kg/m^3.

4.2.3 ICF Wall with 2” Exterior Insulation 6”Concrete 2” Interior Insulation

Figure 9 shows the relative humidity value at the end of external EPS insulation. Figure 10 shows the total moisture content of a concrete under different cases of the same wall design. For an ICF wall with 2” insulation thickness on either side of the concrete, the drywall RH value for

FIGURE 5 (A) AND (B). Relative Humidity (RH) values on the interior side of EPS and at the external face of EPS respectively.



(a)

(b)

FIGURE 6. Moisture content of concrete.

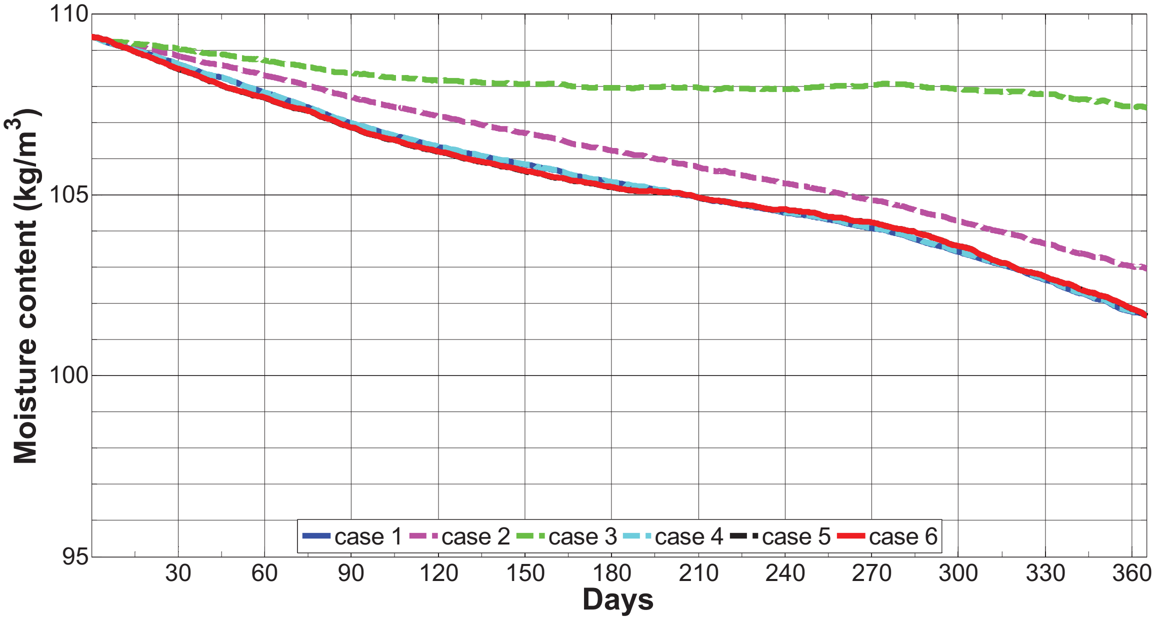
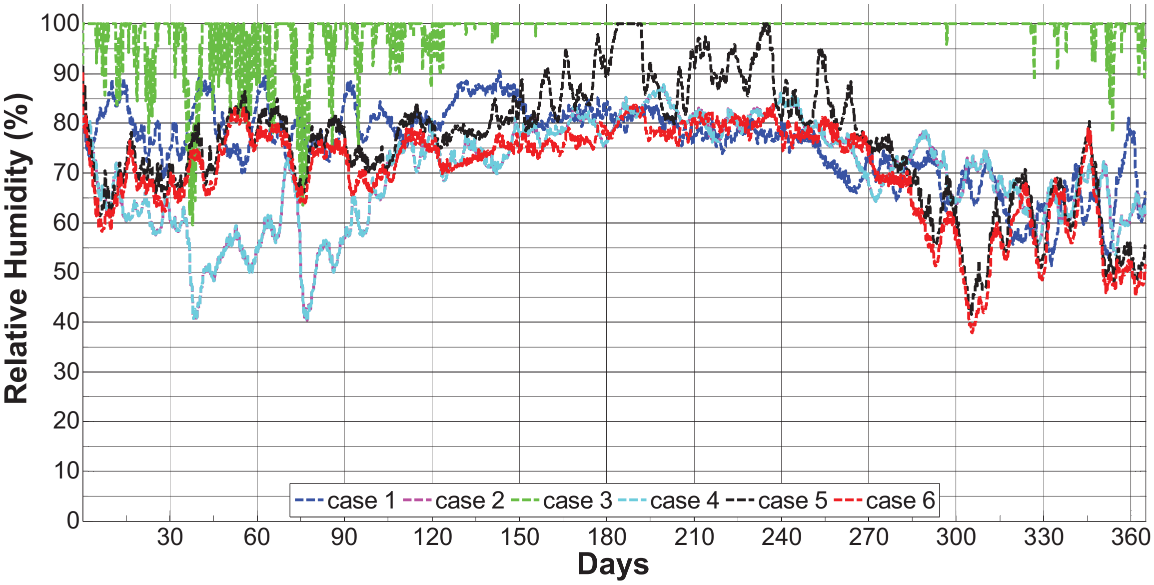


FIGURE 7. Relative Humidity (RH) value at the front face of external EPS respectively.



Case 1 (no membrane) and Case 4 (Membrane B on the exterior side) fluctuates as the moisture dries towards both inside and outside, and it is also affected by an outdoor weather condition.

The RH value of the outbound face of the exterior EPS is a minimum for Cases of 1, 2 and 6 for which there is either no membrane, membrane A is located on the inside, or Membrane B is located inside. Cases 4 and 5 (membrane B is located on the outside) resulted in a relatively high RH value during the cold season. Case 3 (where membrane A is located on the outside),

FIGURE 8. Moisture content of a concrete.

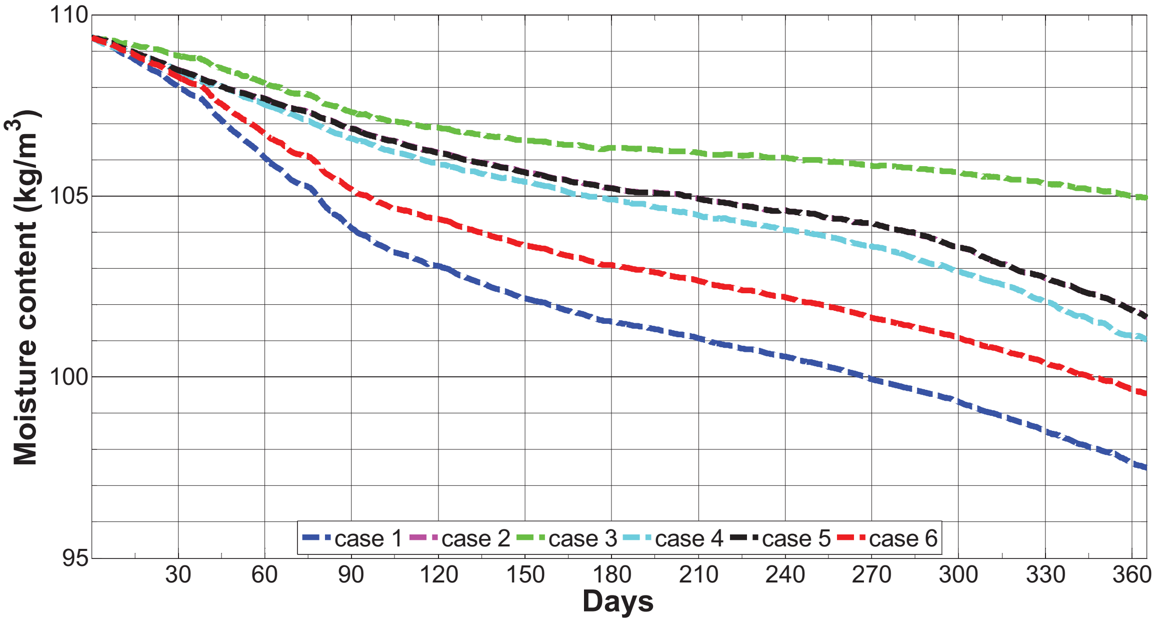
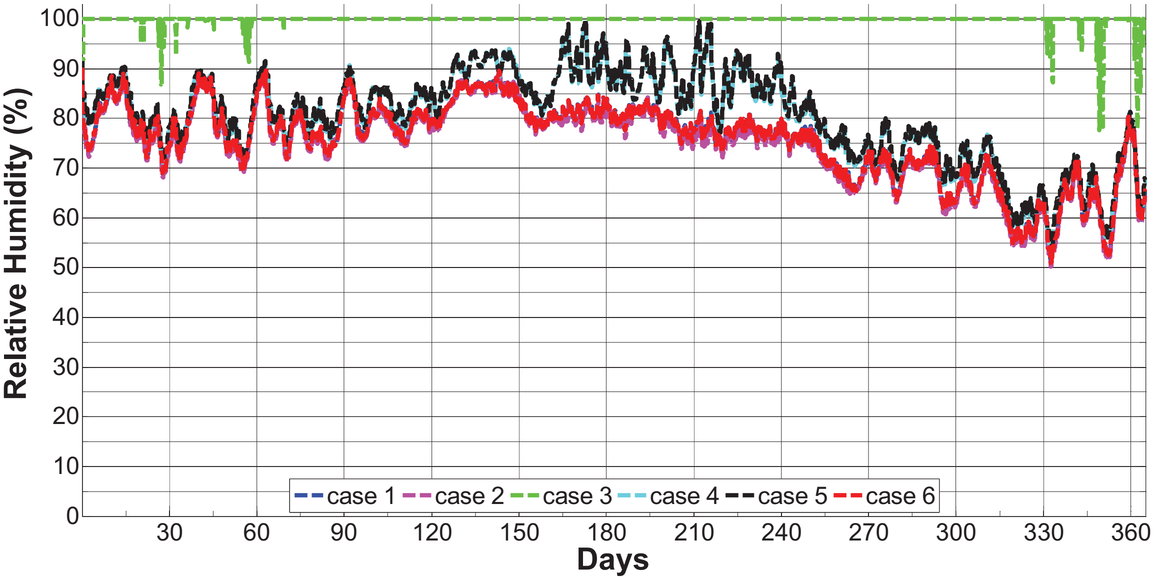


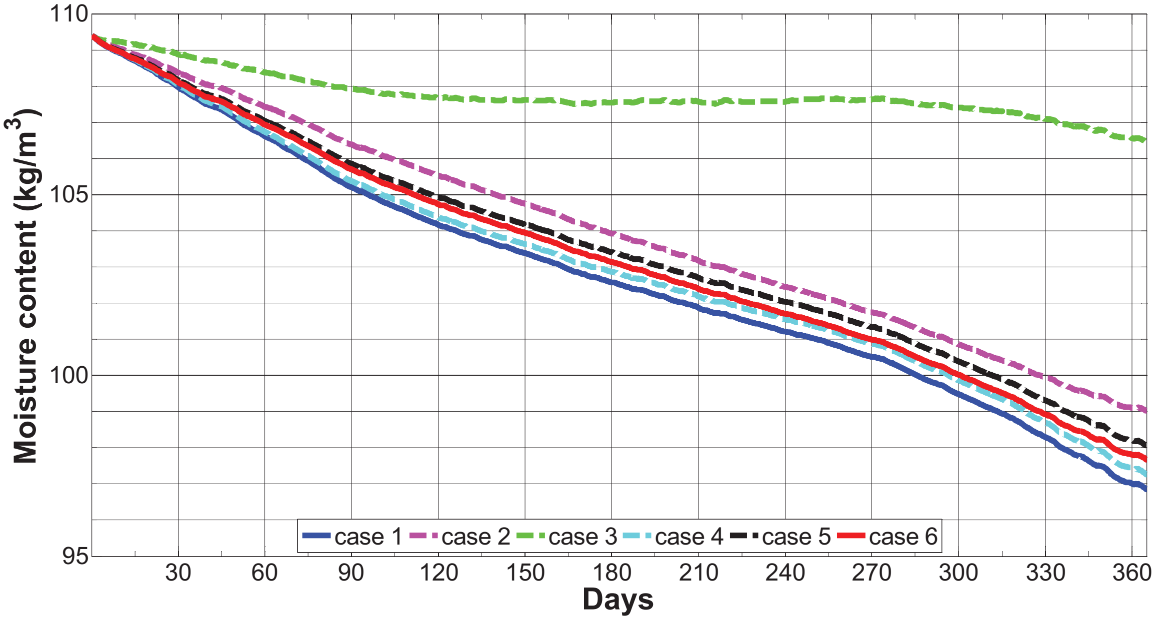
FIGURE 9. The relative humidity value at the exterior face of external EPS respectively.



on the other hand, maintains the highest RH value almost throughout the year, and it is preventing the drying process of the moisture.

As shown in Figure 10, Case 3 has the slowest drying process of the concrete moisture. Case 1, when there is no membrane, 9 kg/m^3 of moisture is removed from the concrete. Cases 4, 5 and 6 facilitate an average of 8 kg/m^3 moisture removal. Case 3 has seen the least amount of moisture drying.

FIGURE 10. Moisture content of concrete.



4.2.4 ICF Wall with 4″-Exterior Insulation-6″Concrete—2″ Interior Insulation

Figure 11 shows the relative humidity value at the end of external EPS insulation. Figure 12 shows the total moisture content of a concrete under different cases. The drywall moisture reaches a critical value (> 80%) for Case 3 and Case 4 for a short period of time. For the other wall designs, the drywall RH value can be considered safe or performing well. The RH value

FIGURE 11. Relative Humidity (RH) value at the front face of external EPS respectively.

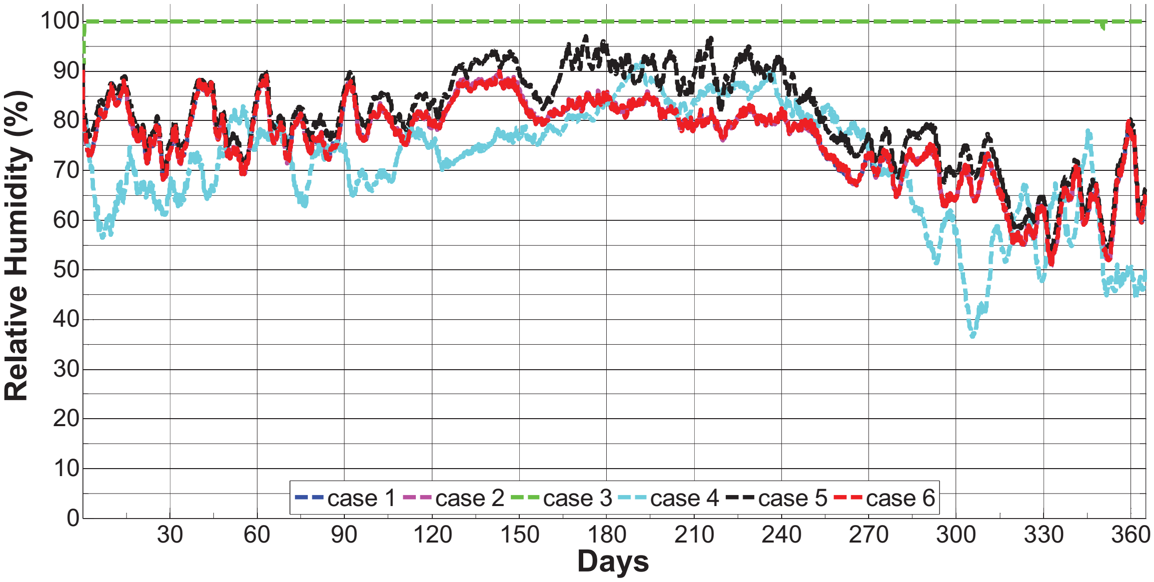
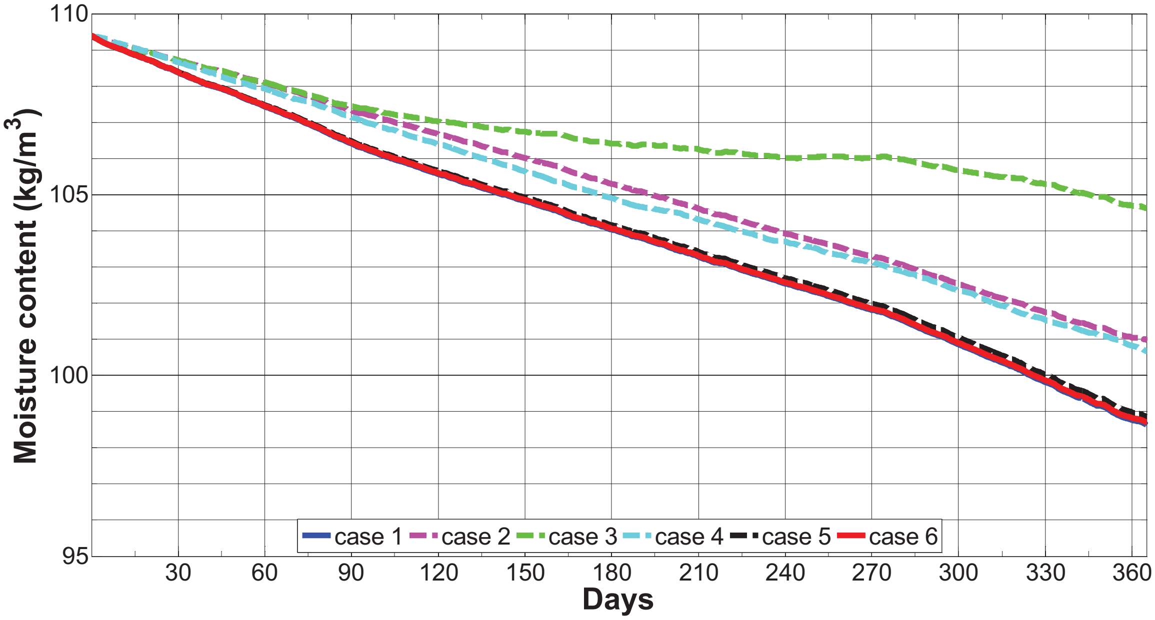


FIGURE 12. Moisture content of concrete.



of the exterior insulation probe on Case 3 is 100% most of the time. The RH value of Case 5 reaches the highest value during the cold season.

Figure 12 shows the concrete in Case 1, Case 5 and Case 6 lost about 9 kg/ m^3 of moisture. The concrete in Case 3 lost the minimum amount of moisture, 4.5 kg/ m^3.

4.3 Impact of Climatic Conditions on ICF Wall Hygrothermal Performance

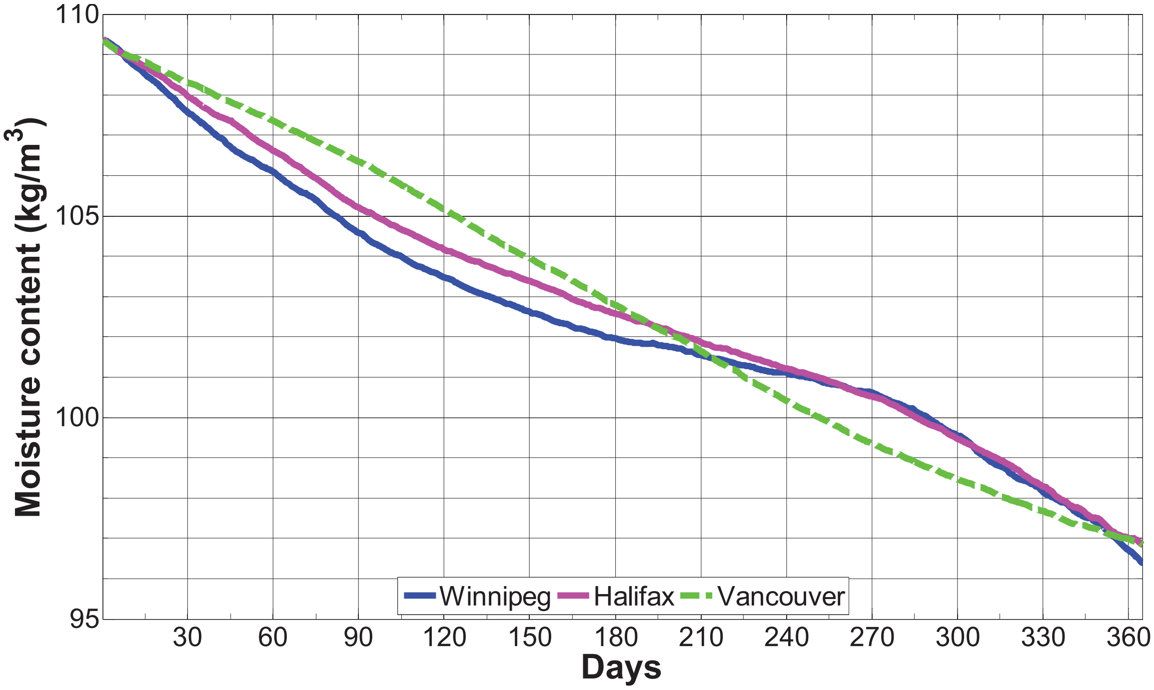
In addition to Halifax, two other Canadian locations are used to study the hygrothermal performance of ICF walls with Membrane A and B. Vancouver, BC, and Winnipeg, MB, are used to represent wet and a cold climates respectively.

The wall design used for the Winnipeg climate does not have a rain screen air gap between the exterior EPS and the cladding. The moisture index value of Winnipeg is low (0.86), which is the reason behind this type of wall design selection. This design has both favorable and adverse effects on moisture control strategy. During summer, the concrete dries faster, whereas, the exterior EPS gets wet during the cold season.

Figure 13 shows the concrete's moisture content in the three different locations, the concrete used in the colder and less wet climate (Winnipeg) dries quickly during the summer season (the days in the graph start on July 1st). This is mainly due to the wall being designed without a rain screen. Since the exterior EPS is directly attached to the cladding, the moisture transport is accelerated. However, during the winter, the drying process is slower as external moisture is driven to the wall. Mild and wet climates (as shown in Vancouver) show a relatively constant drying process throughout the year. The drying process of the ICF concrete in Halifax (a city with the highest moisture index in this study) has slowed during the cold season, even though a rain screen is implemented in the wall design.

The exterior insulation is fully wet during most of the cold season. Similar to Halifax in Case 3, where membrane A is located on the outside, the exterior EPS is fully wet throughout the year in both the Vancouver and Winnipeg cases.

FIGURE 13. Moisture content of concrete under three different climates.



The RH value at different probes for the Vancouver climate shows a similar trend to the city of Halifax results. Our findings show: (i) ICF walls with painted drywall regulates the RH value on the drywall, (ii) when Membrane A is located on the outside blocks drying to the outside, (iii) the exterior EPS RH value increases during cold season for cases in which there is no membrane used on the outside.

Generally, in all cases, unless the moisture transport is blocked with a vapor impermeable membrane on the outside, the concrete moisture tends to dry to the outside. This phenomenon helps to maintain drywall and indoor RH at low values. The moisture in the concrete dries slowly in Case 3, where Membrane A is posted on the outside of the ICF component. Case 2, where Membrane A is located on the inside, has the second slowest drying but it helps to maintain the drywall and the indoor RH value at a minimum. The concrete moisture dries at a higher rate when there is no membrane in the ICF wall system.

4. CONCLUSION

The moisture performance of ICF walls with vapor and air barrier membrane (membrane A) and Membrane B (with 20 perm permeance) have been investigated for three cities using computer modelling. The effects of membrane type, membrane location, wall design (insulation and concrete thickness), and drywall paint on moisture transport were studied. Results show that ICF walls with no membrane are the fastest drying walls. Walls with membrane B located on the inside face of ICF exhibited the second most rapid moisture removal from the concrete. Membrane A's location has the most significant effect on moisture transport. Walls with membrane A located on the inside helped the drywall from getting wet, but the moisture transport exiting the concrete is slower and one directional which is towards the outside.

Locating Membrane A on the outside face of the ICF forced the wall to stay wet. We predict this practice eventually drives the moisture towards the inside and creates a critical moisture content on the drywall.

The wall design varies based on the size of the insulation and concrete thicknesses. Four types of wall designs are considered in this study. Increasing the thickness of the EPS on either side of the concrete slows the concrete drying process. Thus the 2-6-2 wall design dries fast. A 4” EPS insulation on the interior side of concrete helped the drywall from getting wet. However, 4” insulation in front of the concrete slowed the moisture transport towards the outside and generally had a negative impact on the moisture removal strategy.

The drywall paint slowed the moisture migration towards the inside. The ICF walls with painted drywall have a lower RH value on the drywall in comparison to unpainted drywalls. In cases where Membrane B is located on the inside (Case 4) and the drywall is painted (Case 6) results in a similar moisture removal amount to Case 2, where membrane A is located on the inside. This shows membrane A can be effectively replaced by membrane B with a painted drywall.

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