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Thermal Performance of Wall Assemblies with Low Emissivity

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ABSTRACT

In wall systems, airspaces can increase thermal resistance if a reflective material such as foil with low emissivity is installed in a Furred-Airspace Assembly (FAA). In this paper, the present model, hygIRC-C, was used to investigate the steady-state thermal resistance of wall assemblies that incorporate foil adhered to expanded polystyrene (EPS) foam in a furred-assembly. To investigate the effect of the furring orientation, the furring was installed horizontally and vertically and compared to walls with no furring. For wall with vertical furring, the 3D version of the present model was used to capture the 3D effect of the thermal bridges. Because the foil emissivity can be affected by dust accumulation and/or water vapor condensation on the foil surface, consideration was given to investigate the effect of both varying foil emissivity and outdoor temperature on the thermal performance of the various wall specimens. Results showed that the thermal resistance (R-value) of the reference wall (no furring) is greater than the wall specimens with furring. Also, results showed that the contribution of the FAA to the R-value of wall specimen with vertical furring is higher than that for wall specimen with horizontal furring.

Keywords: Reflective insulation, Furred-Airspace Assembly (FAA), low emissivity material, thermal modelling, thermal resistance, R-value, airflow, heat transfer by convection, conduction and radiation.

INTRODUCTION

The present 2D and 3D proprietary IRC hygrothermal model, hygIRC-C, was used to predict the thermal and hygrothermal performance of different roofing and wall systems. This model was benchmarked against the previously developed model [1-2], and experimental results in number of projects. The 2D version of the present model was also used to predict the drying rate of a number of full-scale wall assemblies subjected to different exterior and interior boundary conditions [1]. The results showed that the predictions of the present model were in good agreement with the experimental measurements (within $\pm 5\%$) [3]. Recently, the 2D version of the present model was used to conduct hydrothermal simulations in order to investigate the moisture accumulation over time as well as energy use of reflective and non-reflective roofing systems, subjected to different climatic conditions of North America [4, 5].

Omitting moisture transport, the 3D version of the present model was also used to conduct numerical simulations for different full-scale wall assemblies to predict the effective thermal resistance (R-value) under conditions of air leakage [6]. These walls incorporated different

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types of insulations. The predicted R-values for these walls were in good agreement (within $\pm 5\%$) with the measured R-values in the Guarded Hot Box (GHB) [6-8]. Furthermore, the present model was benchmarked and used to assess the dynamic heat transmission characteristics through Insulating Concrete Form (ICF) wall specimens [9-10] and compared with experimental data [10].

Currently, reflective thermal insulation is being used in home attics, flat and sloped roofs, and wall systems [11]. There are a number of thermal insulations that can be used in conjunction with reflective insulation assemblies in building envelopes. According to the Reflective Insulation Manufacturers Association International (RIMA-I), reflective insulation is defined as *“thermal insulation consisting of one or more low-emittance surfaces, bounding one or more enclosed air spaces”* [12]. As will be shown in this study, an enclosed airspace contributes to the overall R-value of a system whether or not a reflective surface is installed, but the reflective surface augments the thermal resistance of that airspace. As shown in Figure 1, within an enclosed airspace, which is a transparent medium, there are three modes of heat transfer: conduction, convection and radiation (see [13-18]). The direction of the convection loop shown in Figure 1b represents the case of indoor temperature higher than the outdoor temperature.

Any surface of opaque materials that faces a transparent medium (enclosed airspace in this study) absorbs and emits long-wave thermal radiation [13-16] where the amount of radiant heat transfer depends on temperature and emissivity of this surface. Most of construction materials have a surface emissivity of 0.9 (ASHRAE 2009 [19]).

The present model was benchmarked against the test data obtained using GHB (in accordance with ASTM C-1363 test method [20-21]) for a full-scale above-grade wall system (8' x 8') consisting of 2"x6" wood frame construction with stud cavities filled with friction-fit glass fiber batt insulation and a foil adhered to wood fiberboard installed in a furred-airspace assembly (the foil was facing the interior finishes). Results showed that the predicted R-value of this wall system was in good agreement with the measured value [14].

The present model was used to conduct a parametric study in order to investigate the effect of low emissivity of foil laminated to XPS foam when used within a FAA [13]. Also, it was used to investigate the effect of outdoor and indoor conditions on the steady-state and transient thermal performance of a foundation wall system (including the above-grade and below-grade portions of the wall) having FAA that also incorporates a low emissivity material (foil) [15-16].

In the previous studies described above [13-16], the orientation of the enclosed airspace was vertical. As indicated earlier, the reflective insulations can also be used in home attics, and flat and sloped roofs. In these types of applications, the enclosed airspace would have a zero or non-zero slope with a horizontal surface. Recently, a number of tests were conducted for different types of reflective insulations using the ASTM C-518 test method [22] with a heat flow meter that accommodates product samples up to 12" in width and length, and thickness up to 4" [11, 17]. In these tests, sample stacks with different type of reflective insulations were placed horizontally between the upper cold plate and lower hot plate of the heat flow meter. Each sample stack consisted of three layers. The upper layer (12" width x 12" length x 1" or 2" thick) made of reflective insulation (foil adhered to the bottom surface). The bottom layer made of gypsum (12" x 12" x 1/2") [11] or EPS (12" x 12" x 1") [17]. To quantify the thermal resistance added to the samples by creating a reflective insulation component, an air cavity (8" x 8" x 1") was created in the center of EPS layer (12" x 12" x 1"), which was placed between the upper and lower layers. The present model was benchmarked against these test data [17].

Thereafter, it was used to investigate the contribution of reflective insulations to the R-value for specimens with different inclination angles, different directions of heat flow through the specimens, and a wide range of foil emissivity [18].

The contribution of the airspace in roofing or wall systems to their R-values depends on [17-18]:

- (a) The emissivity of all surfaces bounded the airspace.
- (b) Size and orientation of the airspace.
- (c) Direction of heat transfer through the airspace.
- (d) Temperatures of all surfaces of the airspace.
- (e) Air infiltration in the case of un-sealed airspace.

The case of an air cavity with openings (un-sealed airspace) exposed to the exterior of wall systems would be subjected to air infiltration, which can affect the R-value of the wall systems. An example of this application is exterior polyisocyanurate insulation with foil facing the vinyl siding. The effect of air infiltration on the R-value of wall systems is not addressed in this study. This effect will be investigated in a future study.

The objective of this study is to conduct a parametric study using the present model that was previously benchmarked in order to:

- Quantify the contribution of the reflective insulation to the R-value of wall specimens with Furred-Airspace Assembly (FAA),
- Determine the effect of furring orientation on the R-value of wall specimens,
- Investigate the effect of installing foil on the two opposite sides of the vertical faces of the enclosed airspace (see the “Case-two foils” described next), and
- Investigate the effect of varying foil emissivity and outdoor temperature on the R-value of wall specimens.

NUMERICAL SIMULATIONS

Wall specimens

Three wall types were analyzed. The reference wall, Figure 2a, consisted of three layers: (a) foil faced EPS insulation (25.4 mm thick), (b) enclosed air gap (25.4 mm thick) and (c) gypsum board (12.7 mm thick). The height of the wall specimen is 2,400 mm. Test walls are identical to the reference wall but with furring that are installed horizontally for one wall (Figure 2b) and vertically for the other wall (Figure 2c). The center-to-center distance of the horizontal and vertical furring is 467.2 mm.

Considerations are given to quantify the contribution of installing foil on the gypsum board that faces the airspace on the effective R-values for the three wall specimens shown in Figure 2a, b, c. Two cases are considered in this study (see Figure 1):

- Case-one foil: foil facing the airspace is adhered to EPS layer only [23], and
- Case-two foils: foil facing the airspace is adhered on both EPS layer and gypsum board.

The “Case-one foil” above was investigated in a recent study by Saber and Maref [23]. The results of that study are compared with the results of the “Case-two foils” in this study. The 2D version of the present model is suitable for predicting the thermal performance of the reference wall (no furring) and wall specimen with horizontal furring. However, for the wall specimen with vertical furring (Figure 2c), the three-dimensional effect of thermal bridging caused by the

vertical furring affects both the energy transport through the wall specimen and the air movement inside the enclosed airspace and requires the three-dimensional version of the present model.

Assumptions

It was assumed that all material layers are in perfect contact (i.e. the interfacial thermal resistances between all material layers were neglected). The emissivity of all surfaces bounded the airspace (gypsum board, top and bottom plates and furring) except the foil was taken equal to 0.9 [19]. The foil emissivity can increase with time because of (a) oxidation of the foil, (b) accumulation of dust on the foil and/or, (c) water vapor condensation on the foil. For example, Cook et al. [24] conducted experiments to investigate the effect of accumulation of dust on the emissivity on horizontal foil faces. That study showed that the emissivity of foil faces increases significantly as dust accumulates from an initial value of under 0.05 to an apparent asymptote ranging from 0.67 to 0.85, depending on the type of dust. However, the rate of dust accumulation on the foil faces with time may be affected by the foil orientation. Since we do not know the degree of cleanness of the foil and the degree of connectivity between the air gap and the exterior or interior air to investigate the effect of foil emissivity on the thermal performance, we considered a wide range of foil emissivity from 0 to 0.9 for both “Case-one foil” and “Case-two foils” (see Figure 1b). When the foil emissivity is known for a given wall system, the respective wall R-value can be obtained from the graphs presented later in this paper (e.g. see Figure 7 and Figure 8).

The results obtained in this study represent only the case when the airspace (25.4 mm thick) is completely sealed (i.e. zero air infiltration). However, in some applications (e.g. exterior polyisocyanurate insulation with foil facing under vinyl siding that generally uses vertical furring), the airspace has opening where air infiltration takes place inside the airspace. The effect of air infiltration in these applications on the R-values of wall systems will be addressed in future publications.

Surface-to-surface R-Value of wall specimen

The objective of this study is to determine the R-value of different wall specimens, subjected to different conditions. The surface-to-surface R-value is determined as:

$$R - Value = \Delta T / q''_{avg} . \quad (1)$$

Note that the air-to-air R-value can be easily determined after adding the reciprocal of the outdoor and indoor film coefficients ($1/h_{outd} + 1/h_{ind}$) to the LHS of Eq. (1). ΔT in Eq. (1) is the surface-to-surface temperature difference across the wall specimen, which is calculated by performing the following numerical integrations as:

$$\Delta T = abs \left(\frac{1}{A_{outd, surf}} \int_{A_{outd, surf}} T_{outd, surf} \bullet dA - \frac{1}{A_{ind, surf}} \int_{A_{ind, surf}} T_{ind, surf} \bullet dA \right) \quad (2)$$

where:

$T_{out, surf}$ and $T_{ind, surf}$ are the local temperatures of the outdoor and indoor surfaces, and $A_{out, surf}$ and $A_{ind, surf}$ are the areas of the outdoor and indoor surfaces of the wall specimen, which are equal in this study (A_{surf}) (see Figure 2).

In Eq. (1), q''_{avg} is the average heat flux that represents to the actual heat passing through the whole wall specimen ($q''_{avg} = Q_{actual} / A_{surf}$). The average heat fluxes on the outdoor and indoor surfaces ($q''_{outd, avg}$ and $q''_{ind, avg}$) are calculated as:

$$q''_{outd, avg} = \frac{1}{A_{outd, surf}} \int_{A_{outd, surf}} q''_{n, outd, surf} \bullet dA, \text{ and } q''_{ind, avg} = \frac{1}{A_{ind, surf}} \int_{A_{ind, surf}} q''_{n, ind, surf} \bullet dA, \quad (3)$$

where: $q''_{n, outd, surf}$ and $q''_{n, ind, surf}$ are the local normal heat fluxes on the outdoor and indoor surfaces of the wall specimen. In the case of allowing for the side heat losses from the top and bottom surfaces of the wall specimen (Figure 2), the $q''_{outd, avg}$ and $q''_{ind, avg}$ given by Eq. (3) are not equal. In this case, neither $q''_{outd, avg}$ nor $q''_{ind, avg}$ represents the actual heat passing through the whole wall specimen. In order to calculate the R-value using Eq. (1), however, the side heat losses from the top and bottom surfaces of the wall specimen should be eliminated. This can be achieved by applying adiabatic boundary condition on these surfaces. Consequently, q''_{avg} in Eq. (1) which represents the actual heat passing through the whole wall specimen is equal to $q''_{outd, avg}$ and $q''_{ind, avg}$ (due to energy conservation). Similarly, in the case of conducting experiments to measure the R-value of a specimen by using one of the standard test methods (e.g. ASTM C-518 [22] or ASTM C-1363 [21]), the side heat losses from the specimen must be minimized in order to accurately measuring its R-value.

Boundary conditions

The boundary conditions on the top and bottom surfaces of all wall specimens shown in Figure 2 are adiabatic (i.e. no side heat losses). As indicated earlier, applying adiabatic condition on these surfaces permits calculating the surface-to-surface R-value of the wall specimens using Eq. (1). Since only one module of the wall specimen with vertical furring was modeled (half width of the furring on the left, enclosed airspace, and half width of the furring on the right, see Figure 2c), the left and right surfaces of this module are subjected to a symmetry condition.

The exterior surface of the EPS layer is subjected to convective boundary condition with different air temperature and heat transfer coefficient of 34.0 W/m²K [21]. Similarly, the interior surface of the gypsum board is subjected to a convective boundary condition with constant air temperature and heat transfer coefficient of 21.0°C and 8.29 W/m²K, respectively [21]. In this study, all numerical simulations were conducted when the thermal conductivity of EPS, furring (including the top and bottom plates), and gypsum board were 0.035 W/(mK), 0.09 W/(mK) and 0.159 W/(mK), respectively. All R-values reported in this paper are surface-to-surface R-values. In the next section, the effect of furring orientation, foil emissivity, and the outdoor temperature on the effective R-values of different wall specimens are discussed.

RESULTS AND DISCUSSIONS

To investigate the effect of the furring and its orientation on the R-value, numerical simulations were conducted for the wall specimens shown in Figure 2 for the case of foil emissivity of 0.05, and temperature difference between the indoor and outdoor of 15°C (21°C and 6°C for the indoor and outdoor temperatures, respectively). The numerical simulations were conducted when foil facing the airspace is installed on EPS layer only (Case-one foil), and when foil facing the airspace is installed on both EPS layer and gypsum board (Case-two foils) (see Figure 1b).

For the “Case-one foil”, Figure 3a and b shows the vertical velocity distributions in the enclosed airspace of wall specimens with no furring and with horizontal furring, respectively. For wall specimen with vertical furring, Figure 4 shows the vertical velocity distribution in the enclosed airspace through five horizontal slices (uniformly distributed along the wall height) and one vertical slice (19 mm out from the vertical furring, see the insert in Figure 4). For the purpose of comparison, Figure 5a and b show the vertical velocity distributions in the enclosed airspace using the same scale of the contour lines for the wall specimens with no furring and with vertical furring, respectively.

The temperature differential across the enclosed airspace causes a buoyancy-driven flow in the airspace. Figure 3 and Figure 4 show that a convection loop due to mono-cellular airflow with one vortex cell is developed in each of the enclosed airspaces. There are a number of parameters that affect the thermal performance of wall with and without furring, namely:

- Stronger convection currents in the enclosed airspace occur in the walls with no furring and with vertical furring (one convection loop) than for wall with horizontal furring (5 convection loops). For example the maximum upward/downward air velocity in wall specimen with no furring is 89 mm/s (Figure 3a), which is higher than that in wall specimen with horizontal furring (53 mm/s, Figure 3b).
- Due to the effect of thermal bridging of the vertical furring, the maximum upward velocity was 118 mm/s and occurs close to the furring (~19 mm out from the furring, Figure 4), which is higher than that for wall with no furring (89 mm/s, Figure 3b). However, the maximum downward velocities of these walls were approximately the same (89 mm/s, see Figure 3b and Figure 4). Except for the portion of the enclosed airspace close to the vertical furring (~33 mm out of the furring), Figure 5a (wall with no furring) and Figure 5b (wall with vertical furring) show that the vertical velocity distributions within the enclosed airspace are approximately the same for both walls.
- More convection loops in the Furred-Airspace Assembly (FAA) along the height of wall specimen (one loop in wall with no furring and vertical furring, five loops in wall with horizontal furring) would enhance its thermal conductance (i.e. resulting in lower R-value). In a previous study [18], it was shown that more convection loops even with lower air velocity resulted in lower R-value.
- Because of installing furring in the wall, the surface area of low emissivity surface facing the enclosed airspace (foil) decreases. In other words, the surface area of high emissivity surfaces (emissivity = 0.9) of the enclosed airspace increases. As such, the rate of heat transfer by radiation through the FAA would be higher in the case of wall with furring than that with no furring. This leads to more reduction in the R-value for the wall with furring.
- A reduction in the R-value occurs due to the thermal bridges of the top and bottom plates of both walls with and without furring. However, for walls with vertical and horizontal furring, more reduction in the R-value would take place due to the thermal bridges of the furring.

The interactive and coupled effects of the different parameters described above resulted in lower R-value for wall specimens with horizontal and vertical furring than that with no furring.

For the “Case-one foil” and “Case-two foils”, Figure 6a and Table 1 show an example for the comparison between the effective R-value for wall specimens with and without furring in the case of foil emissivity of 0.05 and the indoor and outdoor temperatures of 21°C and 6°C, respectively. As shown in this figure, the effective R-value of wall with vertical furring is higher by 9.5% and 11.4% for the “Case-one foil” and “Case-two foils”, respectively (Case-one foil: 7.826 ft²hr°F/BTU, Case-two foils: 8.180 ft²hr°F/BTU, only one convection loop along the height of the wall) than wall with horizontal furring (Case-one foil: 7.148 ft²hr°F/BTU, Case-two foils: 7.344 ft²hr°F/BTU, five convection loops along the height of the wall). By comparing the R-value of walls with no furring (Case-one foil: 8.347 ft²hr°F/BTU, Case-two foils: 8.730 ft²hr°F/BTU) and with furring, the horizontal furring caused a reduction in the effective R-value by 16.8% and 18.9% for the “Case-one foil” and “Case-two foils”, respectively; while the vertical furring caused a reduction in the R-value by ~6.7% for both “Case-one foil” and “Case-two foils” (see Table 1).

The R-value of both EPS layer (25.4 mm thick) and gypsum layer (12.7 mm thick) is 4.574 ft²hr°F/BTU. The contribution to the effective R-values due to FAA (top and bottom plates, furring and airspace) for different wall specimens was obtained by subtracting the R-value of EPS and gypsum layers from the effective R-values of the wall specimens. This contribution is shown in Figure 6b and Table 1. Note that in the case of wall without reflective film (i.e. emissivity of all surfaces bounded the airspace = 0.9 [19]) and without furring, the predicted effective R-value was 5.622 ft²hr°F/BTU. In this case, the sealed airspace (25.4 mm thick) contributed to the effective R-value by 1.048 ft²hr°F/BTU. However, when the foil emissivity equal 0.05 for the walls with no furring, horizontal furring and vertical furring, the FAA contributed to the effective R-values by 3.773, 2.574 and 3.251 ft²hr°F/BTU, respectively, for the “Case-one foil”, and by 4.156, 2.770 and 3.605 ft²hr°F/BTU, respectively, for the “Case-two foils”.

As expected, the R-values for the three wall specimens in the “Case-two foils” is higher than that in the “Case-one foil”. As shown in Figure 6b and Table 1, the contributions of the FAA to the R-values in the “Case-two foils” are higher than that in the “Case-one foil” by 0.383 ft²hr°F/BTU, 0.196 ft²hr°F/BTU, and 0.354 ft²hr°F/BTU (i.e. 10.2%, 7.6% and 10.9% higher) for wall with no furring, horizontal furring and vertical furring, respectively. Furthermore, for a given wall configuration, the contribution to the effective R-value due to FAA depends not only on the foil emissivity but also on the temperature differential across the wall specimen as shown next.

Effect of furring orientation and foil emissivity on the R-value

To quantify the effect of foil emissivity on the thermal performance and account for the possibility of dust accumulation and/or vapor condensation on it, numerical simulations were conducted for a range of foil emissivity of 0.0 – 0.9. A foil emissivity of 0.9 represents the case of no foil installed in the wall specimen or the foil surface is completely covered by dust or liquid water due to vapor condensation. As indicted earlier, the emissivity of horizontal foil faces can significantly increase as dust accumulates from an initial value of under 0.05 to an apparent asymptote ranging from 0.67 to 0.85 depending on the type of dust [24] (these values might not be the same for a vertical foil orientation). Also, a foil emissivity of zero means that no thermal radiation is emitted from the surface (i.e. purely reflective surface).

For the “Case-one foil”, Figure 7 shows an example for the effect of foil emissivity on the effective R-value of wall specimens with horizontal and vertical furring (see Figure 2) when the temperature difference between the indoor and outdoor is 15°C (indoor temperature = 21°C, outdoor temperature = 6°C). For all values of foil emissivity, this figure shows that the effective R-value of wall with vertical furring is always higher than that for wall with horizontal furring. As indicated earlier, for a foil emissivity of 0.05, the R-value of wall with vertical furring is 9.5% higher than that for wall with horizontal furring.

In the case of no foil installed in the wall specimens or the surface of the foil is covered by dust and/or liquid water due to condensation (foil emissivity = 0.9), the furring orientation has insignificant effect on the effective R-value (i.e. resultant lines in Figure 7a tend to converge as the foil emissivity approaches to 0.9). In this case, the R-value of the wall specimen with vertical furring is only ~0.9% higher than that for wall specimen with horizontal furring. As shown in Figure 7b for the “Case-one foil”, in the case of vertical furring, the contribution of the FAA to the effective R-value of wall specimen with foil emissivity of 0.05 (3.251 ft²hr°F/BTU) is 2.88 times that with foil emissivity of 0.9. In the case of horizontal furring, however, the contribution of the FAA to the R-value of wall with foil emissivity of 0.05 (2.574 ft²hr°F/BTU) is 2.39 times that with foil emissivity of 0.9. Because the foil emissivity has a significant effect on the thermal performance, accurate energy calculations for wall systems with reflective insulations, subjected to different climate conditions, requires performing hygrothermal simulations instead of thermal simulations in order to investigate whether or not vapor condensation occurs on the surface of the foil.

Comparison of R-values for “Case-one foil” and “Case-two foils”

For a wide range of foil emissivity (0.0 – 0.9) when the temperature difference between the indoor and outdoor is 15°C (indoor temperature = 21°C, outdoor temperature = 6°C), Figure 8a and Figure 8b show comparisons between the R-values for the “Case-one foil” and “Case-two foils” (see Figure 1 for the definition of these cases) of wall specimens with horizontal and vertical furring, respectively. As shown in these figures for a given foil emissivity, the difference between the R-values of “Case-one foil” and “Case-two foils” represents the contribution to the R-value due to installing foil on the gypsum board that faces the enclosed airspace. For a foil emissivity of 0.9 (i.e. no foil installed in the wall specimens), the R-values of both “Case-one foil” and “Case-two foils” are the same.

For a theoretical foil emissivity of 0.0 (i.e. purely reflective surface), the surface-to-surface thermal radiations takes place on the surfaces of wood (top and bottom plates and furring) and gypsum that face the enclosed airspace for the “Case-one foil”, and on the surfaces of wood only for the “Case-two foils”, resulting in more heat transfer rate by radiation for “Case-one foil” than that for “Case-two foils”. Consequently, for foil emissivity of 0.0, the predicted R-values for the “Case-two foils” are higher than that for the “Case-one foil” by 0.086 ft²hr°F/BTU and 0.182 ft²hr°F/BTU for the wall specimens with horizontal and vertical furring, respectively.

The difference between the R-values for the “Case-one foil” and “Case-two foils” (i.e. contribution to R-value due to installing foil on gypsum) are shown in Figure 9 for the wall specimens with horizontal and vertical furring. As shown in this figure, as the foil emissivity increases, this difference increases and reaches its peak value. Further increase in the foil emissivity results in a decrease in the contribution to R-value due to installing foil on gypsum (reaching 0.0 at foil emissivity of 0.9). The highest contribution to the R-value due to installing

foil on gypsum occurs at foil emissivity of 0.2 (0.499 ft²hr°F/BTU) for wall specimen with vertical furring, and at foil emissivity of 0.25 (0.340 ft²hr°F/BTU) for wall specimen with vertical furring.

Effect of outdoor temperature on the R-value

Because the temperature differential across the wall specimen (ΔT) affects the rate of heat transfer by convection and radiation inside the FAA, numerical simulations were carried out for the “Case-one foil” to investigate the effect of varying the outdoor temperature on the effective R-value of a wall specimen. As an example, the wall specimen with horizontal furring (Figure 2b) was selected to conduct these simulations in the case of foil emissivity of 0.05 and indoor temperature of 21°C. The obtained results are shown in Figure 10. As shown in this figure, the highest effective R-value occurred as ΔT approaches to zero. A higher ΔT causes a higher rate of heat transfer by both convection and radiation inside the FAA, resulting in a lower R-value. For example, increasing the outdoor temperature from -15°C ($\Delta T = 36^\circ\text{C}$, R-value = 6.742 ft²hr°F/BTU) to 15°C ($\Delta T = 6^\circ\text{C}$, R-value = 7.647 ft²hr°F/BTU) resulted in an increase of the effective R-value and the contribution of the FAA to the R-value by 13.4% and 41.7%, respectively.

SUMMARY AND CONCLUSIONS

Numerical simulations were conducted to quantify the contribution of the reflective insulation on the thermal performance of wall specimens for wide ranges of foil emissivity and outdoor temperatures. Three wall specimens were considered in this study. The first wall (reference wall) consisted of two layers of foil faced EPS insulation and gypsum board, which were separated by enclosed airspace where the foil faces the enclosed airspace. To investigate the effect of furring orientation on the R-value, two other wall specimens were considered. These two walls were identical to the reference wall but with four furring that were installed horizontally and vertically. The numerical simulations were conducted for a wide range of foil emissivity (0.0 – 0.9) to cover the possibility of dust accumulation and/or water vapour condensations on the surface of the foil. In addition to installing foil on the EPS surface, considerations were given to investigate the contribution to the R-value of wall specimens due to installing foil on the surface of gypsum as well. The 2D version of the present model was used for the wall specimens with no furring and with horizontal furring, and the 3D version of the present model was used for the wall specimen with vertical furring.

Results showed that in the case of low foil emissivity, the R-value of wall specimen with vertical furring is higher than that for wall specimen with horizontal furring. In the case of no foil installed in the wall specimen (i.e. foil emissivity = 0.9), the R-values of wall specimen with vertical furring is slightly higher than that with horizontal furring. Because the temperature differential across the wall specimen affects the rate of heat transfer by convection and radiation inside the Furred-Airspace Assembly (FAA), results showed that the outdoor temperature has a significant effect on the contribution of the FAA to the effective R-value of wall specimen. Also, results showed that the contribution to the R-values of wall specimens due to installing foil on the surface of gypsum depends on the foil emissivity.

This work can assist architects and building designers to estimate the contribution to the R-values due to installing FAA in wall systems with different furring orientations, foil emissivities,

and environmental conditions. A future work is recommended in order to cover different applications of the reflective insulations including the effect of air infiltration that use actual R-value of insulation under different climatic conditions so as to avoid over sizing the heating and cooling equipments.

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Table 1. Comparison between R-values of wall specimens with and without furring for the “Case-one foil” and “Case-two foils” (indoor temperature = 21°C, outdoor temperature = 6°C, and foil emissivity = 0.05 for all wall specimens)

Wall specimen with	R-Value (ft ² hr °F/BTU)		Contribution to R-value due to FAA (ft ² hr °F/BTU)		Reduction in R-value due to Furring (%) [#]		Increase in R-value due to installing foil on gypsum (%)	Increase in the contribution to R-value due to installing foil on gypsum (%)
	Case-one foil	Case-two foils	Case-one foil	Case-two foils	Case-one foil	Case-two foils		
No furring	8.347	8.730	3.773	4.156	0	0	4.6	10.2
Horizontal furring	7.148	7.344	2.574	2.770	16.8	18.9	2.7	7.6
Vertical furring	7.826	8.180	3.251	3.605	6.7	6.7	4.5	10.9

[#] Wall with no furring is a reference wall

Figure 1. A schematic of vertical cross-section of wall specimen with four horizontal furring showing the modes of heat transfer inside the enclosed airspace (Note: the drawing in Figure 1b is not to scale)

(a) Wall with no Furring (Reference)

(b) Wall with Horizontal Furring

(c) Wall with Vertical Furring

Top Plate, Bottom Plate, Horizontal furring, and Vertical Furring are 25.4 thick X 64 height

All dimensions are in mm

Figure 2. Wall specimens with (a) no furring, (b) horizontal furring and (c) vertical furring

Figure 3. Vertical velocity contours (in mm/s) for wall with (a) no furring and (b) horizontal furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05, Case-one foil: foil adhered to EPS only)

Figure 4. Vertical velocity contours (in mm/s) for wall with vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05, Case-one foil: foil adhered to EPS only)

Figure 5. Vertical velocity contours (in mm/s) for wall with (a) no furring and (b) vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05, Case-one foil: foil adhered to EPS only)

Figure 6. Effect of no furring and furring orientation on the R-value (indoor temperature = 21°C, outdoor temperature = 6°C, and foil emissivity = 0.05 for all wall specimens)

Figure 7. Effect of foil emissivity on the R-value of wall with horizontal and vertical furring (indoor temperature = 21°C , outdoor temperature = 6°C , Case-one foil: foil adhered to EPS only)

Figure 8. Comparison of the R-values for the “Case-one foil” and “Case-two foils” of walls with horizontal and vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C)

Figure 9. Contribution to R-value due to installing foil on the gypsum for walls with horizontal and vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C)

Figure 10. Effect of outdoor temperature on the R-value of wall specimen with horizontal furring (indoor temperature = 21°C , foil emissivity = 0.05, Case-one foil: foil adhered to EPS only)