Effect of Furring Orientation on Thermal Response of Wall Assemblies with Low Emissivity Material and Furred-Airspace

Hamed H. Saber[*] and Wahid Maref

Institute for Research in Construction, National Research Council Canada
Bldg. M-24, 1200 Montreal Road, Ottawa, Ontario, Canada K1A 0R6
http://irc.nrc-cnrc.gc.ca/irccontents.html

ABSTRACT

In wall systems, airspaces can contribute in obtaining a higher thermal resistance, if a reflective material such as foil with low emissivity is installed on one side or the other of a Furred-Airspace Assembly. In this paper, the present model, hygIRC-C, was used to investigate the steady-state thermal performance of wall specimens that incorporate foil bonded to expanded polystyrene (EPS) foam in a furred-assembly having airspace next to the foil. In order to investigate the effect of the furring orientation on the wall thermal performance, the furring was installed horizontally and/or vertically. Also, a reference wall similar to these walls but with no furring was considered. For the reference wall and wall with horizontal furring, the 2D version of the present model is suitable to model these wall assemblies. However, for wall with vertical furring, the 3D version of the present model was used in order to capture the 3D effect of the thermal bridges due to the vertical furring on the energy transport and momentum transport in the wall system. Consideration was given to investigate the effect the foil emissivity and outdoor temperature on the contribution of the FAA on the thermal performance of the wall systems. Results showed that the thermal resistance (R-value) of the reference wall (no furring) is greater than the wall systems with furring. Also, results showed that the contribution of the FAA to the R-value of wall system with vertical furring is higher than that for wall system 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 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 hygIRC-2D model that was previously developed at NRC-IRC [1-2], and test results in a number of projects. In the case of accounting for heat, air and moisture transport, the 2D version of the present model was 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 hygIRC-2D model [1-2] and the experimental measurements (within ±5%) [3]. Recently, the 2D version of 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].

---

[*] Corresponding Author (hamed.saber@nrc-cnrc.gc.ca)

In the case of accounting for heat and air transport (no moisture transport), the 3D version of the present model was used to conduct numerical simulations for different full-scale wall assemblies in order to predict the effective thermal resistance (R-value) with and without air leakage [6]. These walls incorporated different types of insulations. The predicted R-values for these walls were in good agreement (within ± 5%) with the measured R-values in the Guarded Hot Box (GHB) [6-8]. Also, the present model was benchmarked and used to assess the dynamic heat transmission characteristics through Insulating Concrete Form (ICF) wall specimens [9-10]. The results showed that the model predictions were in good agreement with experimental data [10].

Currently, reflective thermal insulation is being used in home attics, flat and sloped roofs, and wall systems [11]. In addition to reflective insulations, there are a number of thermal insulations that can be used in conjunction with reflective insulation assemblies in the building envelope. 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, enclosed airspace contributes to the overall R-value of a system whether or not a reflective surface is installed in the system, but the reflective surface augments the thermal resistance of that airspace. Within an enclosed airspace, which is a transparent medium, there are three modes of heat transfer: conduction, convection and radiation (see [13-18] for more details). The contribution of the enclosed airspace in roofing or wall systems to their R-values depends [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.

Within opaque materials, no thermal radiation is transmitted through these materials. Any surface of these materials that faces a transparent medium (airspace in this study) absorbs and emits long-wave thermal radiation (e.g. surfaces of wood furring and drywall in furred-airspace assembly [13-16]). The amount of radiative heat transfer by this surface depends on its temperature and emissivity. Most of construction materials have a surface emissivity of 0.9 (ASHRAE 2009 [19]).

The present model was extensively used to quantify the contribution of the reflective insulation on the thermal performance (R-values and energy savings) of above-grade, and above- and below-grade wall systems with Furred-Airspace Assembly (FAA) [13-16]. The present model was benchmarked against the test data obtained using GHB (in accordance of 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 fibre batt insulation and a foil bonded to wood fibreboard installed in a furred-airspace assembly (the foil was facing the airspace and 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 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 indicted earlier, the reflective insulations can also be used in home attics, and flat and sloped roofs. In these types of applications, 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 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 bonded 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 inch x 8 inch x 1 inch) was created in the center of EPS layer (12 inch x 12 inch x 1 inch), 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 objective of this study is to conduct a parametric study using the present model 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, and
- Investigate the effect of foil emissivity and outdoor temperature on the R-value of wall specimens.

WALL SPECIMENS, BOUNDARY CONDITIONS AND ASSUMPTIONS

In order to quantify the contribution of the reflective insulation to the wall R-values, three wall specimens were considered in this study. The first wall specimen (reference wall which is a theoretical wall assembly for comparison purposes, see Figure 1a) consisted of two layers of foil faced EPS insulation (25.4 mm thick) and gypsum board (12.7 mm thick). The two layers were separated by airspace (25.4 mm thick) where the foil faces the airspace. A top and bottom plates were used (each 64 mm height x 25.4 thick) to form enclosed airspace. The height of the wall specimen is 2,400 mm. To investigate the effect of furring orientation on the R-value, two other wall specimens were considered. These two walls are identical to the reference wall but with four furring (with the same dimensions as the top and bottom plates) that are installed horizontally for one wall (Figure 1b) and vertically for the other wall (Figure 1c). The center-to-center of the furring is 467.2 mm.

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 1c), the three-dimensional effect of thermal bridging due to the vertical furring affects both the energy transport through the wall system and the momentum transport of the air inside the enclosed airspace. This three-dimensional effect was captured using the 3D capabilities of the present model.

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]. To investigate the effect of foil emissivity on the thermal performance of different wall specimens, a wide range of foil emissivity was considered in this study (0.0 – 0.9). The foil emissivity can increase due to: (a) oxidation of the foil, and accumulation of dust and/or vapor condensation on the surface of the foil. For example, Cook et al. [23] 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.

The boundary conditions on the top and bottom surfaces of all wall specimens are adiabatic and sealed (i.e. no heat and mass transfer). 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 1c), the left and right surfaces of this module were subjected adiabatic condition (due to symmetry). 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/m^{2}K [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^{o}C and 8.29 W/m^{2}K, 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, 0.09 and 0.159 W/(mK), respectively. The 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 effect R-value 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 1 for the case of foil emissivity of 0.05, temperature difference between the indoor and outdoor is 15°C (21°C and 6°C for the indoor and outdoor temperatures, respectively). Figure 2a 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 3 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 3). For the purpose of comparison, Figure 4a 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.

Owing to the temperature differential across the enclosed airspace, a buoyancy-driven flow develops in the airspace. Figure 2 and Figure 3 show that a convection loop due to mono-cellular airflow with one vortex cell is developed in each enclosed airspace for all wall specimens. There are a number of parameters that affect the thermal performance of wall with and without furring, namely:
- Stronger convection current in the enclosed airspace occurs in the case of wall specimens with no furring and with vertical furring (one convection loop) than in the case of wall specimen 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 2a), which is higher than that in wall specimen with horizontal furring (53 mm/s, Figure 2b).
- 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 3), which is higher than that for wall with no furring (89 mm/s, Figure 2b). However, the maximum downward velocities of these walls were approximately the same (89 mm/s, see Figure 2b and Figure 3). Except for the portion of the enclosed airspace close to the vertical furring (~33 mm out of the furring), Figure 4a (wall with no furring) and Figure 4b

4

(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.

- Due to installing furring in the wall specimen, 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 due to 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. Figure 5a shows 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 for, respectively. As shown in this figure, the effective R-value of wall with vertical furring is 9.5% (7.826 ft^{2}hr^{o}F/BTU, only one convection loop along the height of the wall) higher than wall with horizontal furring (7.148 ft^{2}hr^{o}F/BTU, five convection loops along the height of the wall). By comparing the R-value of walls with no furring (8.347 ft^{2}hr^{o}F/BTU) and with furring, the horizontal furring caused a reduction in the effective R-value by 16.8%, while the vertical furring caused a reduction in the R-value by 6.7%.

The R-value of both EPS layer (25.4 mm thick) and gypsum layer (12.7 mm thick) is 4.574 ft^{2}hr^{o}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 5b. 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 ft^{2}hr^{o}F/BTU, respectively. 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 deferential across the wall system as shown next.

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

In order to quantify the effect of foil emissivity on the thermal performance and account for the possibility of dust 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 system or the foil surface is completely covered by dust or liquid water due to vapor condensation. Also, a foil emissivity of zero means that no thermal radiation is emitted from the surface (i.e. purely reflective surface). Figure 6 shows an example for the effect of foil emissivity on the effective R-value of wall specimens with horizontal and vertical furring (see Figure 1) 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 tend to converge as the foil emissivity approaches to 0.9 Figure 6a). In this case, the R-value of the wall specimen with vertical furring (5.701 ft^2hr^oF/BTU) is only 0.9% higher than that for wall specimen with horizontal furring (5.649 ft^2hr^oF/BTU). As shown Figure 6b, 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 ft^2hr^oF/BTU) is 2.88 times that with foil emissivity of 0.9 (1.127 ft^2hr^oF/BTU). 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 ft^2hr^oF/BTU) is 2.39 times that with foil emissivity of 0.9 (1.075 ft^2hr^oF/BTU). 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.

Effect of outdoor temperature on the R-value

Because the temperature differential across the wall system (ΔT) affects the rate of heat transfer by convection and radiation inside the FAA, numerical simulations were carried out to investigate the effect of the outdoor temperature on the effective R-value of a wall system. As an example, the wall specimen with horizontal furring (Figure 1a) 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 7. 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 (ΔT = 36°C, R-value = 6.742 ft^2hr^oF/BTU) to 15°C (ΔT = 6°C, R-value = 7.647 ft^2hr^oF/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 systems 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 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 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 greater than that for wall specimen with horizontal furring. In the case of no foil installed in the wall system (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 system affects the rate of heat transfer by convection and radiation inside the Furred-Airspace Assembly (FAA), results showed that the
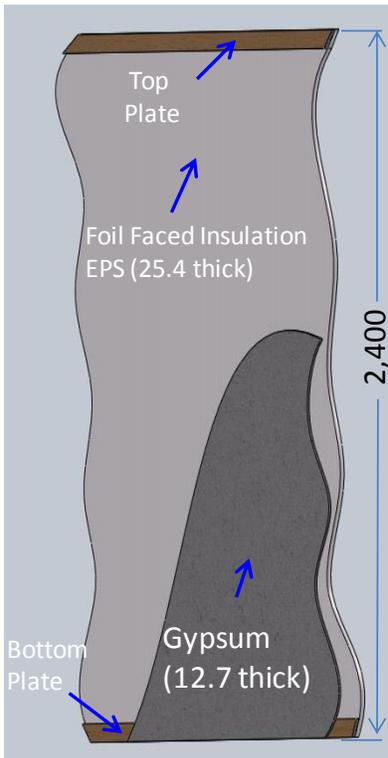
6

outdoor temperature has a significant effect on the contribution of the FAA to the effective R-value of wall system.
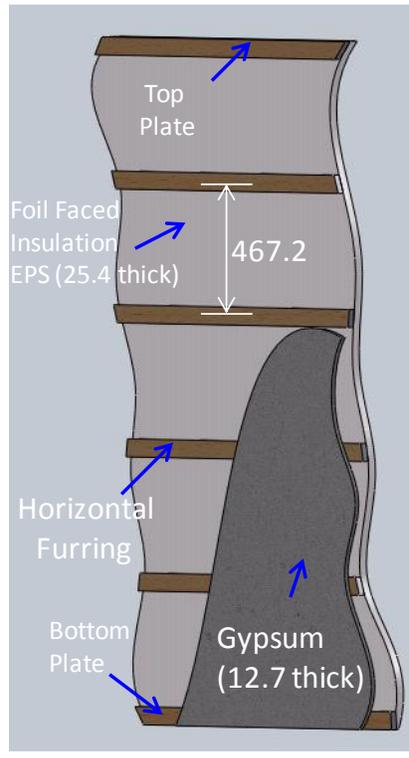
REFERENCES

1. W. Maref, M.K. Kumaran, M.A. Lacasse, M.C. Swinton, D. van Reenen, "Laboratory Measurements and Benchmarking of an Advanced Hygrothermal Model", Proceedings of the 12th International Heat Transfer Conference (Grenoble, France, August 18, 2002), pp. 117-122, October 01, 2002 (NRCC-43054).
2. W. Maref, M.A. Lacasse, M.K. Kumaran, M.C. Swinton, "Benchmarking of the Advanced Hygrothermal Model-hygIRC with Mid-Scale Experiments", eSim 2002 Proceedings (University of Concordia, Montreal, September 12, 2002), pp. 171-176, October 01, 2002 (NRCC-43970).
3. H.H. Saber, W. Maref, M.A. Lacasse, M.C. Swinton, K. Kumaran, "Benchmarking of Hygrothermal Model against Measurements of Drying of Full-Scale Wall Assemblies", 2010 International Conference on Building Envelope Systems and Technologies, ICBEST 2010, Vancouver, British Colombia Canada, June 27-30, 2010**,** pp. 369-377.
4. H.H. Saber, M.C. Swinton, P. Kalinger, and R.M. Paroli, "Hygrothermal Simulations of Cool Reflective and Conventional Roofs", 2011 NRCA International Roofing Symposium, Emerging Technologies and Roof System Performance, held in Sept. 7-9, 2011, Washington D.C., USA.
5. H.H. Saber, M.C. Swinton, P. Kalinger, and R.M. Paroli, "Long-Term Hygrothermal Performance of White and Black Roofs in North American Climates", Journal of Building and Environment, in press, October 2011.
6. A.H. Elmahdy, W. Maref, M.C. Swinton, H.H. Saber, R. Glazer, "Development of Energy Ratings for Insulated Wall Assemblies", 2009 Building Envelope Symposium (San Diego, CA. 2009-10-26) pp. 21-30, 2009.
7. H.H. Saber, W. Maref, A.H. Elmahdy, M.C. Swinton, R. Glazer, "3D Thermal Model for Predicting the Thermal Resistances of Spray Polyurethane Foam Wall Assemblies", Building XI Conference, December 5-9, 2010, Clearwater Beach, Florida, USA.
8. H.H. Saber, W. Maref, H. Elmahdy, M.C. Swinton, R. Glazer, "3D Heat and Air Transport Model for Predicting the Thermal Resistances of Insulated Wall Assemblies", International Journal of Building Performance Simulation, (http://dx.doi.org/10.1080/19401493.2010.532568), First published on: 24 January 2011 (iFirst), pp. 1-17.
9. M.M Armstrong., H.H. Saber, W. Maref, M.Z. Rousseau, G. Ganapathy, and M.C. Swinton, "Field Energy Performance of an Insulating Concrete Form (ICF) Wall", 13th Canadian Conference on Building Science and Technology (13th CCBST) conference, held in May 10-13, 2011, Winnipeg, Canada.
10. H.H. Saber, W. Maref, M. Armstrong, M.C. Swinton, M.Z. Rousseau, G. Gnanamurugan, "Benchmarking 3D Thermal Model against Field Measurement on the Thermal Response of an Insulating Concrete Form (ICF) Wall in Cold Climate", Building XI Conference, December 5-9, 2010, Clearwater Beach, Florida, USA.
11. C. Craven, C. and R. Garber-Slaght, Product Test: Reflective Insulation in Cold Climates, Technical Report Number TR 2011-01, Cold Climate Housing Research Center (CCHRC), Fairbanks, AK 99708, www.cchrc.org, April 12, 2011.
12. Reflective Insulation Manufacturers Association International (RIMA-I). (2002). Reflective Insulation, Radiant Barriers and Radiation Control Coatings. Olathe, KS: RIMA-I.
13. H.H. Saber, M.C. Swinton, "Determining through Numerical Modeling the Effective Thermal Resistance of a Foundation Wall System with Low Emissivity Material and Furred–Airspace", 2010 International Conference on Building Envelope Systems and

Technologies, ICBEST 2010, Vancouver, British Colombia, Canada, June 27-30, 2010, pp. 247-257.

14. H.H. Saber, W. Maref, M.C. Swinton, and C. St-Onge, "Thermal Analysis of above-Grade Wall Assembly with Low Emissivity Materials and Furred-Airspace," *Journal of Building and Environment,* volume 46, issue 7, pp. 1403-1414, 2011 (doi:10.1016/j.buildenv.2011.01.009).

15. H.H. Saber, W. Maref and M.C. Swinton, "Numerical Investigation of Thermal Response of Basement Wall Systems with Low Emissivity Material and Furred – Airspace", 13th Canadian Conference on Building Science and Technology (13th CCBST) Conference, held in May 10 – 13, 2011 in Winnipeg, Manitoba, Canada.

16. H.H. Saber, W. Maref, and M.C. Swinton, "Thermal Response of Basement Wall Systems with Low Emissivity Material and Furred Airspace", *Journal of Building Physics*, Published online in 5 August 2011, DOI: 10.1177/1744259111411652, The online version of this article can be found at: http://jen.sagepub.com/content/early/2011/07/30/1744259111411652.

17. H.H. Saber, W. Maref, G. Sherrer, M.C. Swinton, "Numerical Modelling and Experimental Investigations of Thermal Performance of Reflective Insulations", submitted to the Journal of Building Physics, October, 2011.

18. H.H Saber "Investigation of Thermal Performance of Reflective Insulations for Different Applications" submitted to the Journal of Building and Environment, October 2011.

19. ASHRAE (2009). Chapter 25. *Thermal and Water Vapor Transmission Data*. ASHRAE Handbook – Fundamentals. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc.

20. Air- Ins inc, Performance Evaluation of Enermax Product Tested For CCMC Evaluation Purposes as per CCMC Technical Guide Master Format 07 21 31.04, Confidential Test Report Prepared for Products of Canada Corp., AS-00202-C, August 17th, 2009.

21. ASTM. 2006. ASTM C 1363, Standard Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus, 2006 Annual Book of ASTM Standards 04.06:717–59, www.astm.org.

22. ASTM. 2003, ASTM C-518, Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus, Annual Book of Standards, 04.06, 153-164, American Society for Testing and Materials, Philadelphia, Pa, www.astm.org.

23. J.C. Cook, D.W. Yarbrough, and K.E. Wilkes, "Contamination of Reflective Foils in Horizontal Applications and the Effect on Thermal Performance", ASHRAE Transactions, Vol. 95, Part 2, 677-381, 1989.
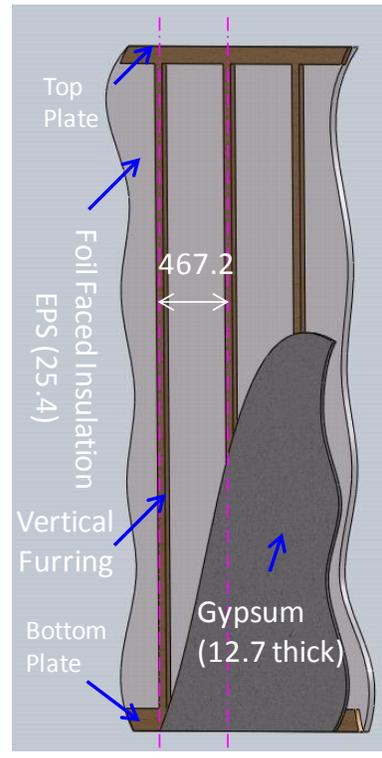
(a) Wall with no Furring (Reference)   **(b) Wall with Horizontal Furring**   **(c) Wall with Vertical Furring**

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

All dimensions are in mm

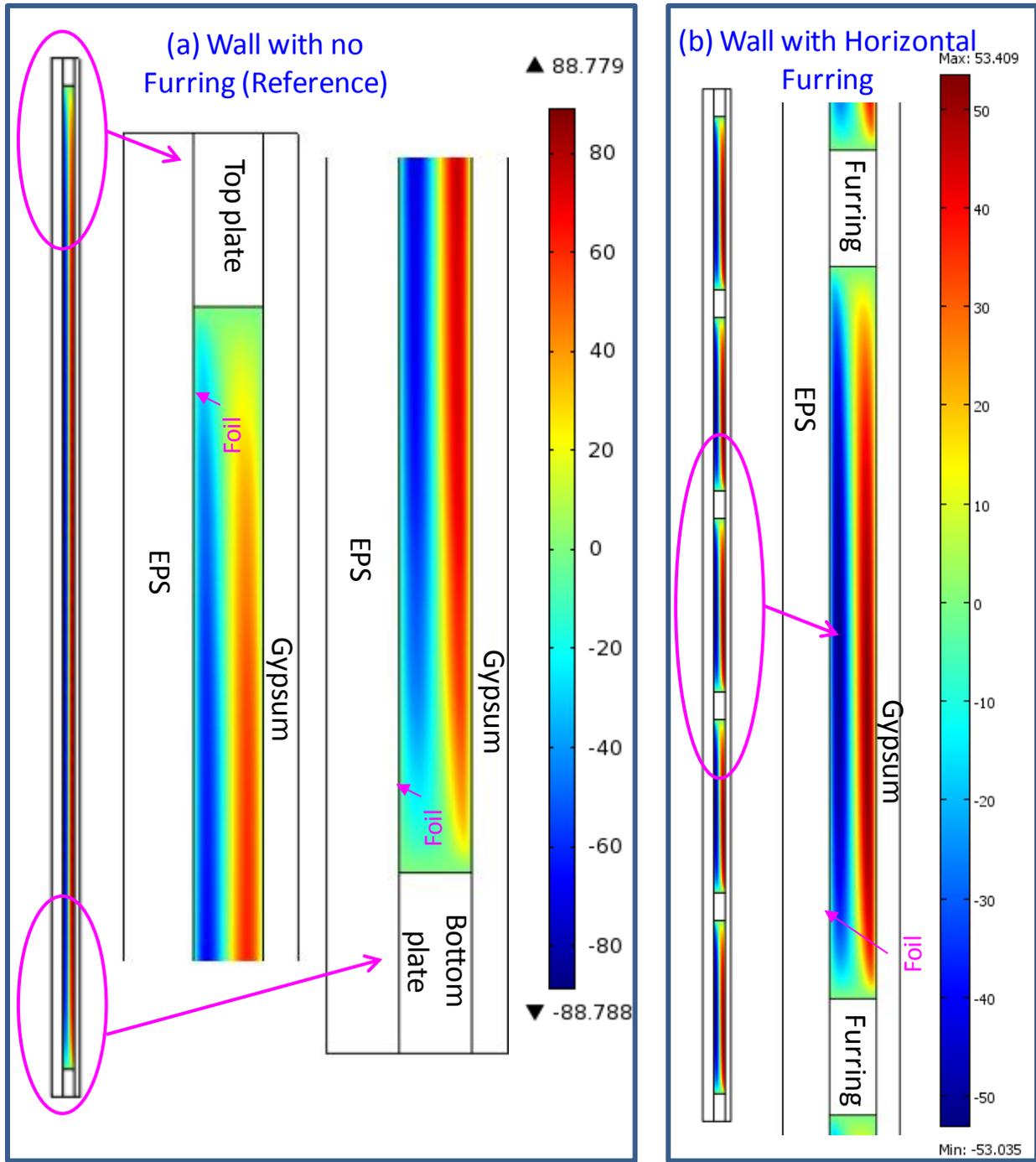**Figure 1.** Wall specimens with no furring, horizontal furring and vertical furring

Figure 2. Vertical velocity contours (in mm/s) for wall with no furring and horizontal furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05)
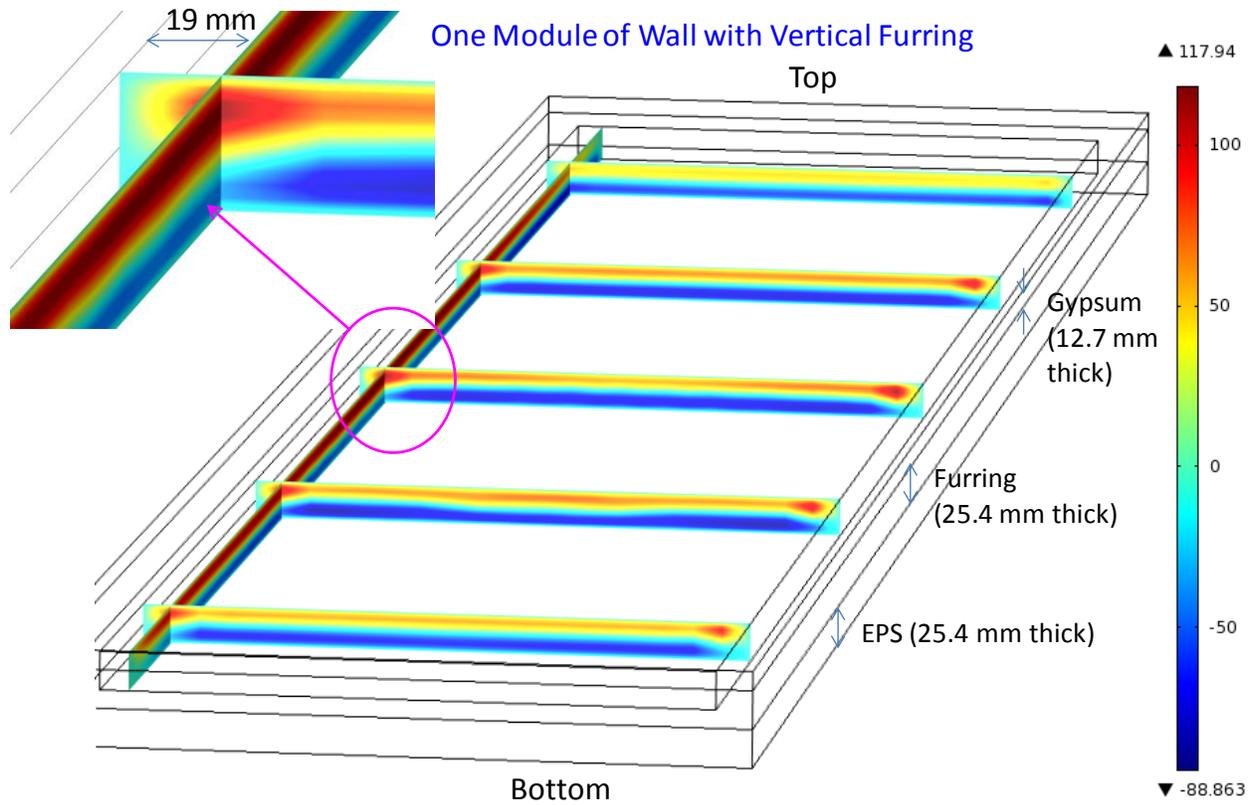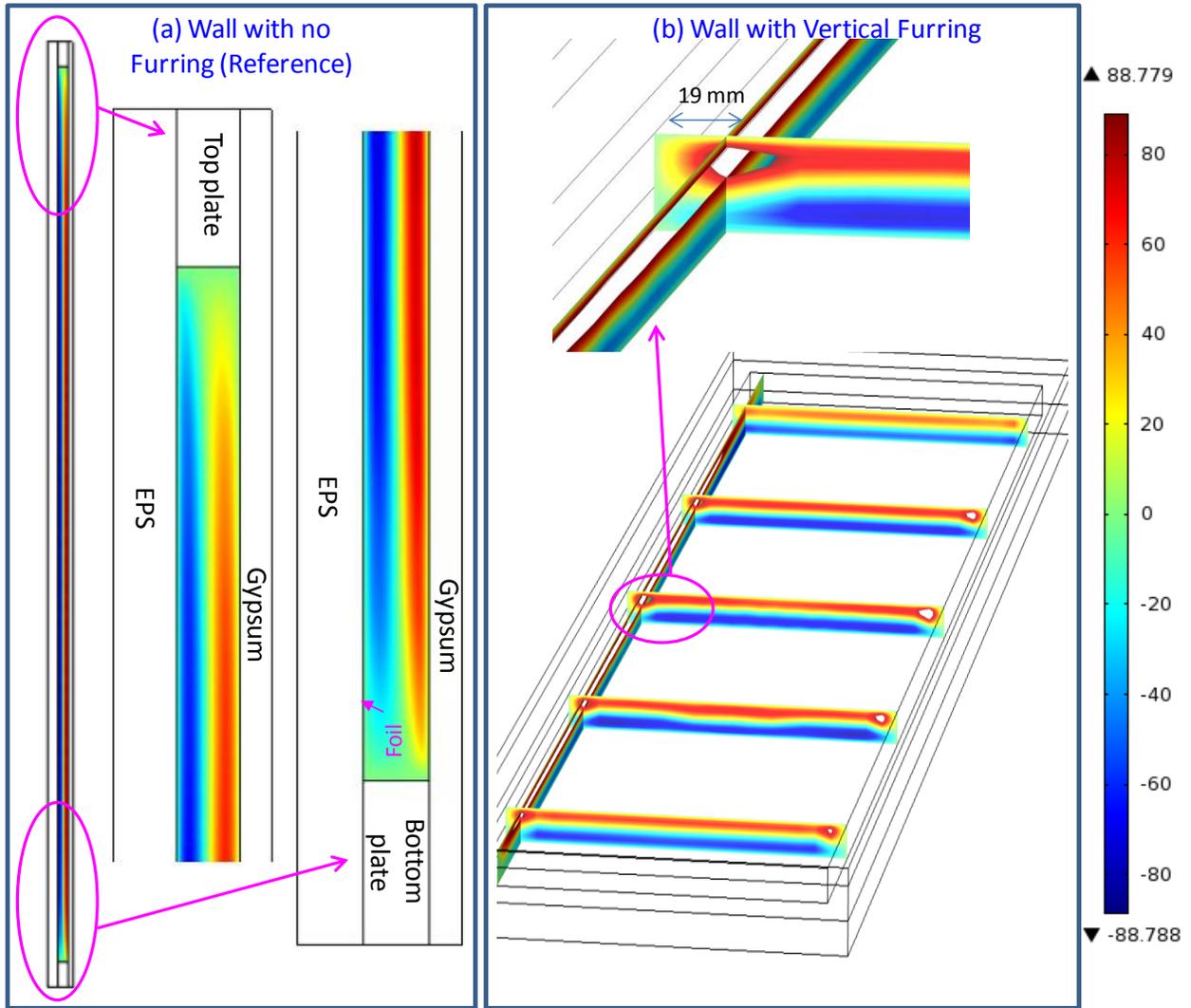
Figure 3. Vertical velocity contours (in mm/s) for wall with vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05)
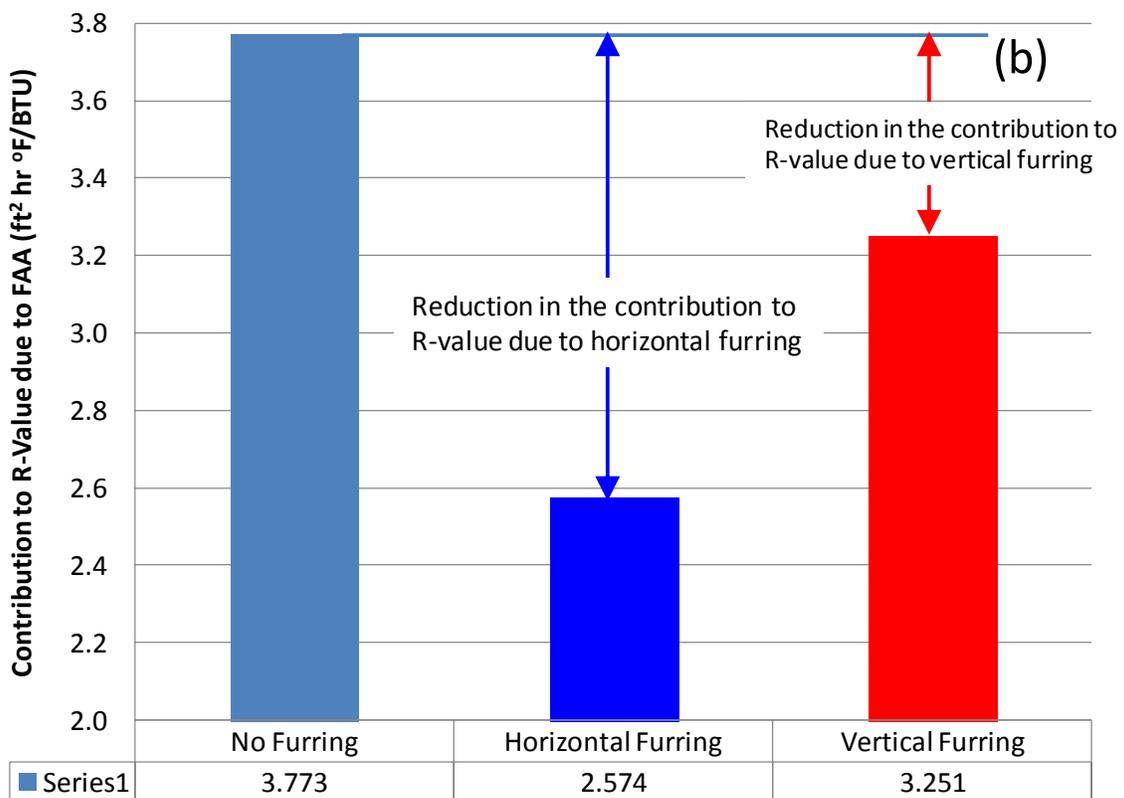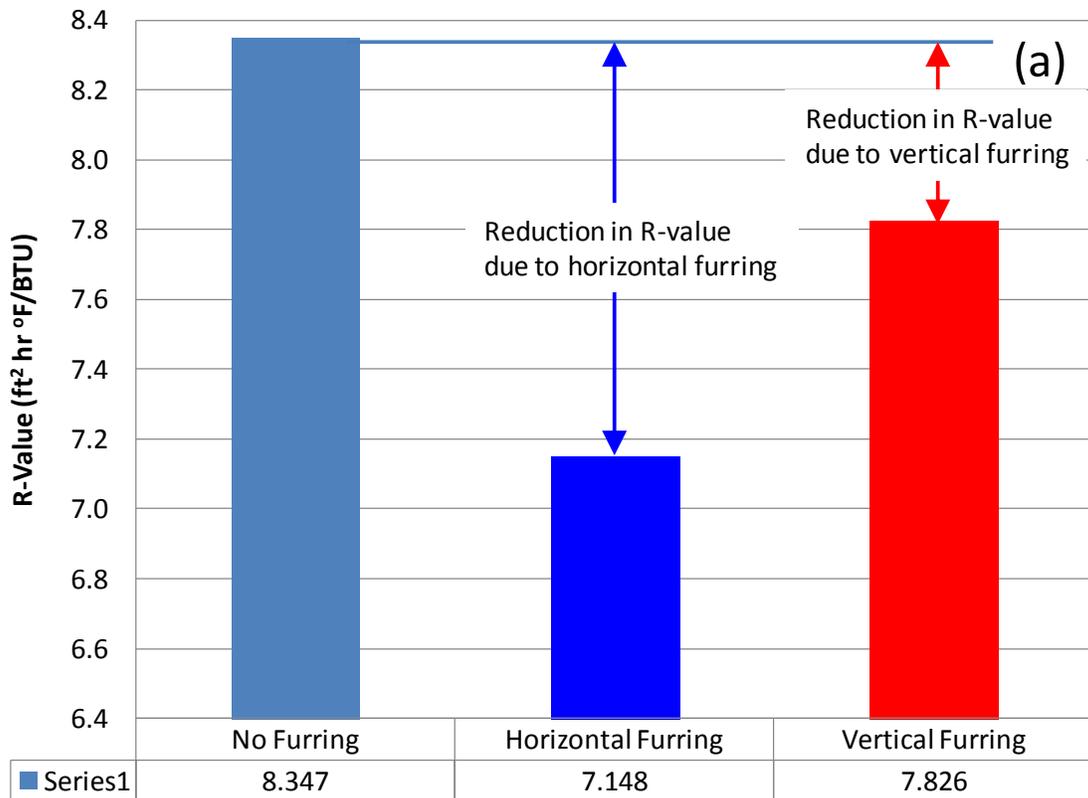
Figure 4. Vertical velocity contours (in mm/s) for wall with no furring and vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C, foil emissivity = 0.05)

Figure 5. 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)
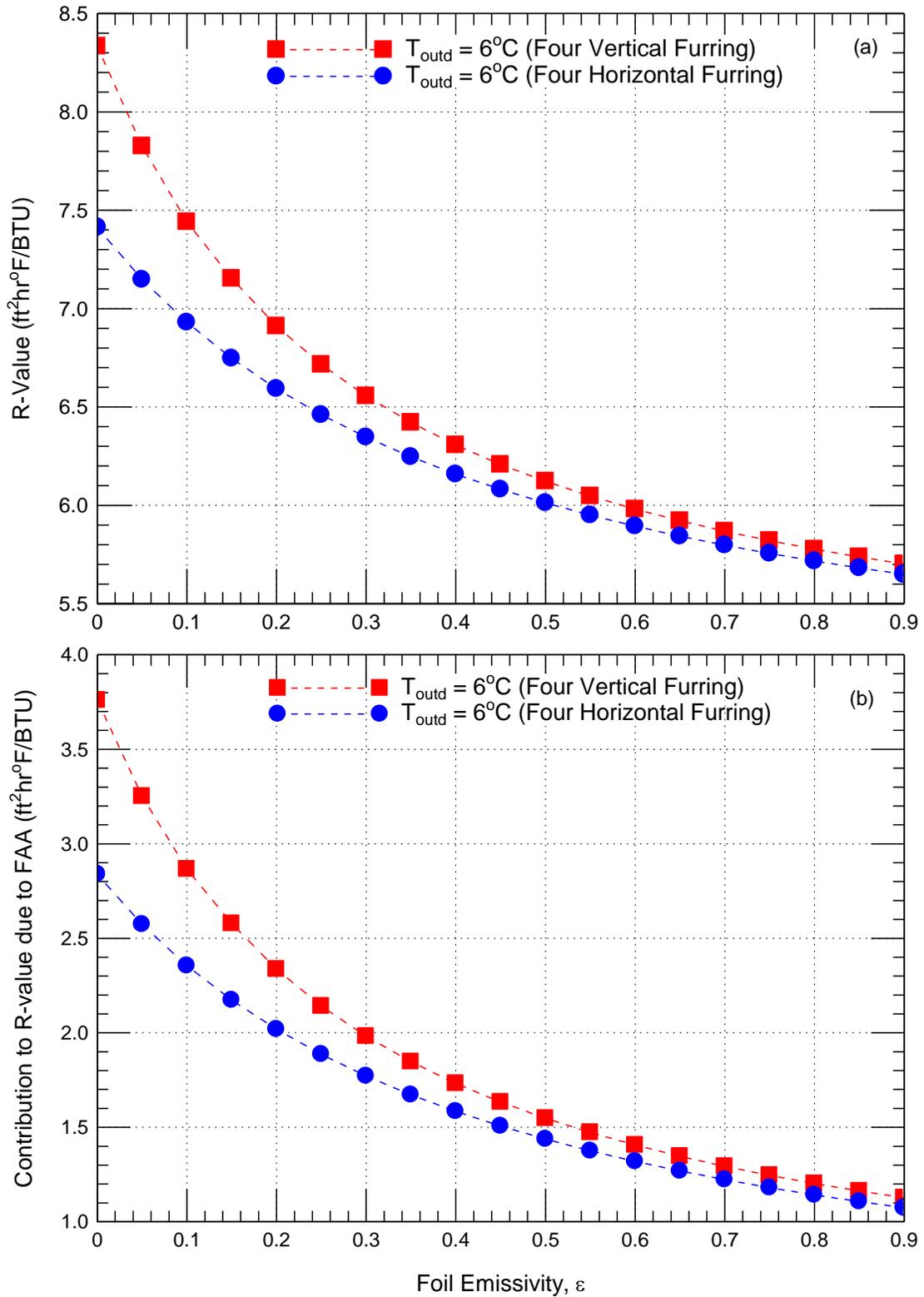
Figure 6. Effect of foil emissivity on the R-value of wall specimens with horizontal and vertical furring (indoor temperature = 21°C, outdoor temperature = 6°C)
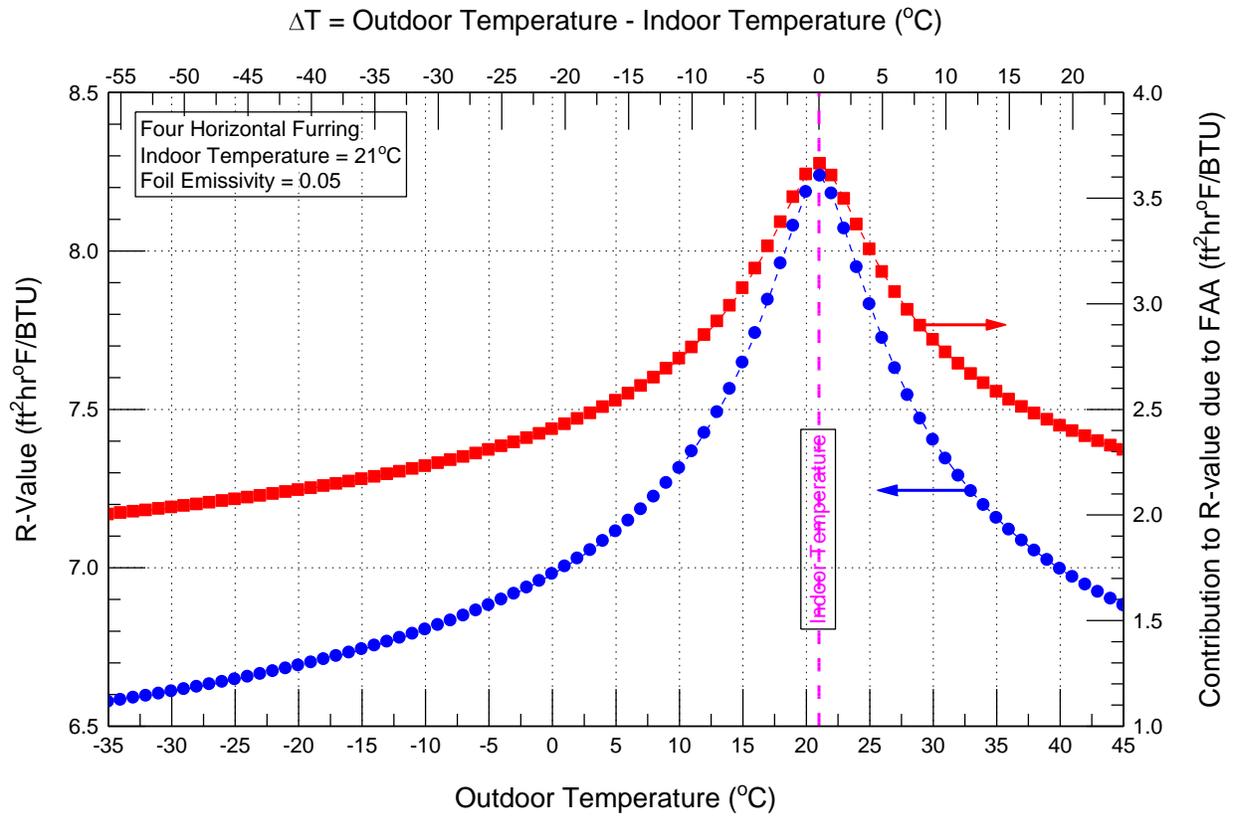
Figure 7. Effect of outdoor temperature on the R-value of wall specimen with horizontal furring (indoor temperature = 21°C, foil emissivity = 0.05)