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Reflective insulations for hot–humid climates

Abstract

Reflective insulation systems (RIS) are generally described as *enclosed reflective air spaces*. RIS provide resistance to heat flow across enclosed airspaces with low–emittance surfaces on at least one of the surfaces perpendicular to the direction of heat flow. The low–emittance surface is typically provided by aluminum foils or metalized films that have thermal emittances in the range 0.03 to 0.05. The low emittance significantly reduces the transfer of heat from the warm side to the cool side of the enclosed air space. Steady–state heat transfer between large parallel planes bounding an enclosed has been thoroughly described in the literature[1–4] and consensus standards have been published.[5–7] In most cases, part of the heat transfer across an enclosed air space will be due to free convection which on the orientation of the air space. The greatest convective contribution occurs when the heat flow direction is upward (lower surface is hot) and the least convective contribution occurs when the heat flow direction is downward (upper surface is hot). In hot–humid climates, the dominate heat flow direction across roof assemblies is downward from the building roof. This is the optimum orientation for RIS. RIS performance is characterized by a thermal resistance or R–value (often RSI when SI units are used). RSI values measured in laboratories are for steady–state, one dimensional heat flow. RSI values with units m^2. K/W have the same meaning and use as RSI values for mass insulations such as mineral fiber of cellular plastic insulations.

Keywords: reflective insulation, radiant barriers, thermal radiation, field test, thermal resistance

Volume 3 Issue 2 - 2018

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Received: December 16, 2017 | **Published:** March 21, 2018

Steady–state performance of RIS

The steady–state performance of RIS combines heat transfer by radiation, conduction and convection as shown by the Eqns. 1 and 2 that contain temperature difference, ΔT (K), and heat flux, q (W/m^2), and the distance across the air space, L. The convective component is introduced by the dimensionless number Nu, Eqn. 3, the ratio of heat low by convection and conduction to heat flow by conduction that is calculated using Fourier's Law. Nu values which depend on the heat flow direction are obtained from measured values for Q_{TOTAL}. Heat flow by radiation is readily calculated from Eqn. 4, the Stefan–Boltzmann Equation with an effective emittance, E, derived from the emittances of the hot and cold surfaces, ε_{HOT} and ε_{COLD}. Table 1 contains calculated RSI for a 50mm enclosed air space

$$RIS = \frac{\Delta T}{q_{TOTAL}} \qquad (1)$$

$$Q_{TOTAL} = Q_{RAD} + Q_{COND} + Q_{CONV} \qquad (2)$$

$$Nu = \left(Q_{TOTAL} - Q_{PA\Delta}\right) / \left(\lambda_a \bullet \frac{\Delta T}{L}\right) \qquad (3)$$

$$q_{RAD} = E.\left(5.67.10^{-8}\right) \bullet \left(T^4_{HOT} - T^4_{COLD}\right) \qquad (4)$$

$$1/E = \frac{1}{\varepsilon_{HOT}} + \frac{1}{\varepsilon_{COLD}} - 1 \qquad (5)$$

with E=0.03, T_{hot} =313.15 K (40°C), and ΔT=15 K. E equal to 0.03 is representative of an air space with an aluminum foil surface on one of the surfaces perpendicular to the heat flow direction. Nu values are determined from measurements of Q_{TOTAL}. The single example in Table 1 is intended to show the strong dependence of RSI for an enclosed reflective air space (RIS) on heat–flow direction that favors the use of RSI as part of roof assemblies in regions where the dominant heat–flow direction is downward.

Table 1 RSI for a 50mm enclosed reflective air space

Heat Flow Direction	UP	45° Up	Horizontal	45° Down	Down
RSI (m^2·K/W)	1.24	0.65	0.49	0.42	0.36

RIS in buildings

Heat transfer in buildings is not a steady–state phenomenon and regions available for insulation are not always bounded by parallel surfaces. There is, therefore, motivation for in–situ measurements of thermal performance. Specific locations in a building can be evaluated used portable equipment that measures heat flux.[8,9] Field studies in which structures in a climate of interest are instrumented to measure heat flows and temperatures differences provide data for performance of actual buildings.[10] Transient field data are used to determine time–average RSI for an insulation assembly or region of a building involve using analysis illustrated by Eqn. 6. Successful use of Eqn. 6 usually involves filtering of input data to delete extraneous spikes caused by near zero ΔT or erratic environmental conditions.

$$RSI_{ave} = \left(\frac{1}{t_2 - t_1}\right) \bullet \int_{t_1}^{t_2} \left(\frac{q(t)}{\text{Ä}T(t)}\right) dt \approx \left(\frac{1}{n}\right) \bullet \sum \left(\frac{q}{\text{Ä}T}\right)_i \qquad (6)$$

A field study example

Figure 1 is a photograph of small buildings used to determine thermal performance of selected roof assembly insulations including

MOJ Eco Environ Sci. 2018;3(2):69‒70.

RIS. The data collection strategy suggested by Eqn. 6 was used to determine RSI for RIS located in Malaysia, a hot–humid region of the world. Heat flux and temperature difference obtained from the test units over an extended period of time were used to calculated RSI values for typical reflective insulation assemblies. Table 2 contains examples of time–average RSI obtained from field data described above. The space in the test units between the roof and ceiling in divided into two regions in some cases. An enclosed air space between the roof tiles and insulation is separated from the rest of the attic space by the reflective insulation. If no space is indicated, then the insulation is installed close or in contact with the roofing material. The reflective insulation used in this research included fabric with low–emittance surface material (Fab/Foil), polyethylene bubble pack insulation with aluminum foil facers (PE BP/foil), and 50 mm rock wool batts (RW) with nominal RSI 1.39. The results in Table 2 show that attic space insulated with RIS compare favorably with attics Insulated with mineral fiber insulation. The highest result was observed with a combination rock wool and a low emittance surface fabric forming an enclosed reflective air space. Additional results are contained in paper by Khar San Teh et al.[10]

Table 2 Time–average RSI derived from field measurements

Roof Type	Air Space (mm)	Insulation	RSI ($m^2 \cdot K/W$)
Concrete tile	50	none	0.4
		PE BP/foil	2.69
		Fab/foil	2.16
Metal deck	None	RW	1.61
		RW+Fab/foil	2.77
		PE BP	2.02

Figure 1 Photograph of small test units equipped for RSI measurement.

Summary

Geographical regions characterized as hot and humid result in downward heat from roof surfaces to building interior spaces. RIS provide their optimum thermal resistance for this type of heat flow. In many cases, in–situ thermal measurements are needed to determine thermal insulation performance for configurations and conditions that differ significant from the laboratory conditions used to label thermal insulations. A project designed to obtain in–situ thermal resistances has been described and examples of data that have been obtained have be disclosed. Thermal resistance reduces heat loads and utility cost when air conditioning is used to create comfortable indoor conditions. Thermal insulation improves comfort for occupants when air conditioning is not available

Acknowledgements

The authors extend thanks to San Miguel Yamamura Woven Products, Air Keroh, Malaysia and R&D Service, Inc, Cookeville, TN, USA for encouragement and support for this research. Special acknowledgement and appreciation to Mr. Kah Wei Yam and Dr. Patrick Suok Tee Loi of San Miguel for their expertise and assistance.

Conflict of interest

The authors do not have potential conflicts of interest regarding the research, authors, or publication of this paper.

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Citation: Yarbrough DW, The KS, Lim CH, et al. Reflective insulations for hot–humid climates. *MOJ Eco Environ Sci.* 2018;3(2):69–70. DOI: 10.15406/mojes.2018.03.00069