Proceedings of the International Conference on Heat Transfer and Fluid Flow
Prague, Czech Republic, August 11-12, 2014
Paper No. 167

Hygrothermal Performance of Reflective Roof Insulation

Gerson H. dos Santos
UniversidadeTecnológica Federal do Paraná – UTFPR
Mechanical Engineering Graduate Program – 84016-260 – Ponta Grossa, Brazil
gsantos@utfpr.edu.br

Nathan Mendes
Pontifícia Universidade Católica do Paraná - PUCPR
Mechanical Engineering Graduate Program – 80215-901 – Curitiba, Brazil
nathan.mendes@pucpr.br

Abstract-Building envelopes play an important role on energy consumption and on thermal comfort in the building sector. In this context, the use of thermal insulation in roofs has been progressively increased in the last few years especially in emerging countries. However, in the literature, the combined heat and mass transport through roof sheets (concrete) and rafters (timber) is barely explored. Therefore, a mathematical model considering the combined two-dimensional heat, air and moisture transport through unsaturated roof is presented. In the porous domain, the differential governing equations are based on driving potentials of temperature, moist air pressure and water vapor pressure gradients, while, in the air domain, a lumped approach is considered for modeling the heat and mass transfer through the cavity between the roof sheet and insulation. The multi-reflective effect in the cavity has been also considered. In the results section, comparisons in terms of heat fluxes at the internal boundary for the roof will be presented and discussed.

Keywords**:** Reflective insulation, Roof performance, Porous media.

1. Introduction

Residential and commercial buildings worldwide are responsible for energy consumption that varies from 40 to 50%. According to the US Department of Energy, only residential buildings are responsible for 22% of the total energy use in the country, from which 45% are due heating and cooling systems. In Brazil, residential and commercial buildings are responsible for about 45% of the total consumption of electricity, which progressively motivates energy conservation studies for promoting building energy efficiency.

In this context, several research works have been carried out to identify the energy savings potential of building envelope insulation, including the use of reflective roof insulation coatings (Al-Sanea, 2002; Suehrcke *et al.*, 2008; Belusko *et al.*, 2011; Saber *et al.*,2012; D'Orazio *et al.*, 2012).

In the studies presented in the literature, the reflective effects of insulation coatings were presented, however, an analysis including heat and mass transport in roof sheets (concrete) and rafters (timber) is barely explored. The presence of moisture implies an additional latent heat transport that may cause discrepancies on the indoor air temperature and humidity values. Despite the importance, building envelope mathematical models are limited, mainly when air- and vapor-permeable cavities are considered within the building walls and roofs.

In this way, a mathematical model considering the combined two-dimensional heat, air and moisture transport through unsaturated porous elements to analyze the hygrothermal performance of roofs with reflective insulation is presented. The roof configuration analyzed is usually adopted in Brazil (Fig. 1) and a reflective insulation coating is placed underneath the roof to decrease the downward heat flux.

The model is based on driving potentials of temperature, air pressure and water vapor pressure gradients for consolidated porous material. The solution of the sets of governing equations has been simultaneously obtained using the MTDMA (MultiTriDiagonal-Matrix Algorithm) for the three potentials, avoiding numerical divergence caused by the evaluation of coupled terms from previous iteration values (Mendes, et al., 2002). A lumped approach for energy and water vapor balances is used to calculate the cavity air temperature and relative humidity. The multi-reflective effects inside the cavity and the loss by long-wave radiation in the external boundary are considered. In the results section, comparisons in terms of heat fluxes at the internal boundary as well as temperatures and humidity relative profiles for the roof will be presented and discussed.

2. Mathematical Model

The model for the porous media domain has been elaborated considering the differential governing equations for moisture, air and energy balances. For the air cavity domain, a lumped approach for energy and water vapor balances has been considered (Fig. 1). The mathematical model is presented thoroughly in Santos and Mendes (2009).

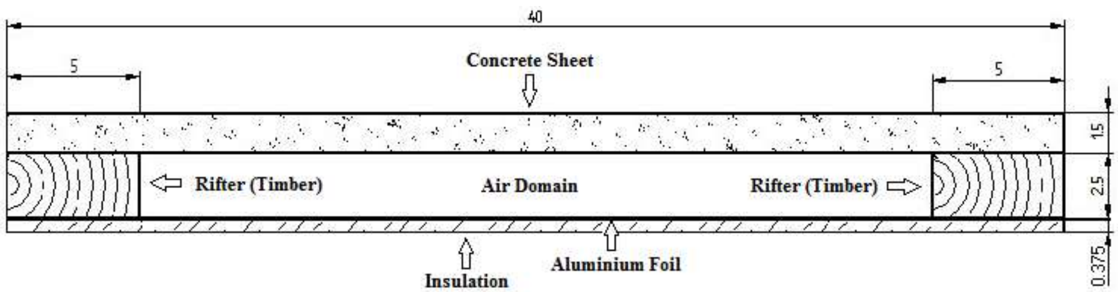

Fig. 1. Physical domain and dimensions (cm) of the roof.

The solution of the balance equations has been obtained through a fully-implicit central-difference scheme for the discretization using the finite-volume method (Patankar, 1980) and the MTDMA to simultaneously solve the three set of equations. In the air cavity domain, a hybrid method called semi-analytical has been used in order to speed up simulations (Santos and Mendes, 2004).

3. Simulation Procedure

The roof has been represented by two different configurations. In the first case, the roof has been considered with a concrete sheet (1.5 cm), rifter timber (2.5 cm) and a reflective insulation, as shown in Fig. 2. The hygrothermal properties have been obtained from the benchmark of the European project HAMSTAD (Hagentoft, 2002) for insulation, from Künzel et al. (2008) for concrete and from IEA Annex 14 Report (IEA, 1991) for timber. The internal emissivity was considered of 0.9 (concrete sheet and timber) and 0.1 for the aluminium foil. In the second configuration, only the reflective insulation was removed.

A regular 2-D mesh (2.5 mm²) for the discretization using the finite-volume method and a 60-s time step have been applied for all simulations.

In the air cavity domain, except in the stagnation region (next internal corner), an average convective heat transfer coefficient of 1.5 W/m²K has been adopted. In the internal cavity corner region, the air has been considered stagnant and an equivalent conductive heat transfer resistance between the air and the internal surface control volumes of 0.5 W/m²K has been considered.

The external and internal convective water vapor transfer coefficients are calculated by Lewis's relation for each control volume.

As external boundary conditions, the lower surface was exposed to air at 24°C and 50 % of relative humidity (conditioned environment). At the upper surface, sinusoidal variations of temperature during the day between 25 ºC and 35 ºC and of relative humidity between 70 % and 90 % have been considered. A sinusoidal variation of solar radiation also was adopted with 800 W/m² of peak value at noon. Constant convective heat transfer coefficients of 3 and 10 W/m²K have been used at the internal and external surfaces. The other surfaces were considered adiabatic and impermeable. Solar absorptivity of 0.6 and long-wave emissivity of 0.9 have been used for the concrete sheet. The Swinbank (1963) sky temperature correlation has been used in this work. Gas (moist air) pressure has been considered constant at all surfaces.

4. Results

Heat fluxes at the internal roof surfaces is presented in Fig. 2. A reduction of 40 % on the peak value is observed when the reflective insulation coating is applied underneath the roof. The effect of the aluminium foil has been also verified, contrasting values of long-wave emissivity of 0.9 for the insulation and 0.1 for the aluminium foil. The indoor latent heat flux is negligible when the reflective insulation is used due to aluminium foil to be impermeable. On the other hand, when the reflective insulation is removed, an additional heat gain is observed due to mass transport. In this case, an increase of 10 % in the heat flux is reported in the Fig. 2.

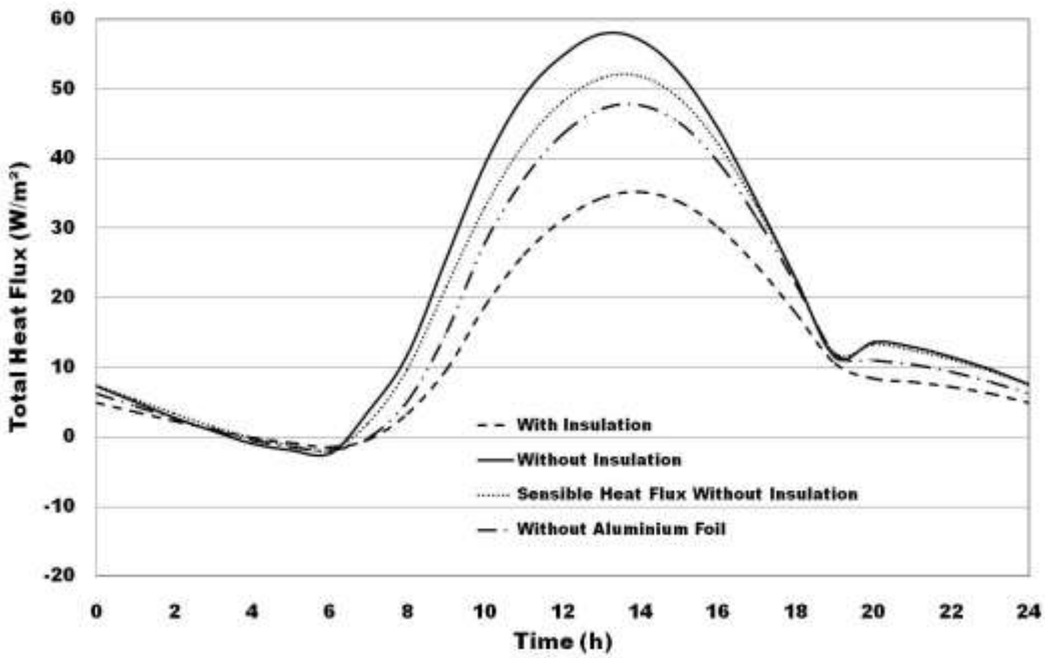

Fig. 2. Heat fluxes at the internal roof surface.

5. Conclusion

In this work, the hygrothermal performance of the reflective roof insulation was verified. A mathematical model considering the combined two-dimensional heat, air and moisture transport through unsaturated roof was utilized. The results showed that the reflective insulation is important to improve energy saving and passive cooling strategies to limit the electrical consumption in hot and moderate climates. The multi-reflective effect of the aluminium foil also was verified. For thin insulation, it plays an important role. The results also presented that moisture in building porous elements can imply an additional mechanism of transport, affecting the building hygrothermal performance.

For further work, indoor conditions will be used as a result of integration with a whole-building simulation code in order to verify the impact on the building energy consumption and condensation risks.

Acknowledgements

The authors thank CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico - of the Secretary for Science and Technology of Brazil - and Fundação Araucária by financial support.

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