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Analysis of perlite and pumice based building insulation materials

Serdar Celik [a,*], Roxana Family [b], M. Pinar Menguc [b]

[a] Southern Illinois University Edwardsville, Edwardsville, IL 62026, USA
[b] Ozyegin University, Cekmekoy, Istanbul 34794, Turkey

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ABSTRACT

Insulation panels composed of perlite, pumice, and cement were fabricated. Perlite and pumice were used to achieve high thermal resistance, and low density. Experimentation was conducted for determining *R*-values of perlite-pumice-cement (PPC) panels at different moisture content values. Dry and moist sample panels were tested with and without soil and moss at the top where the one with the soil and plant coupling represents a green roof. Reverse heat leak method was used in determination of the *R*-values of the samples. Verification of theory was achieved via experimentation with an acceptable error range. Thermal diffusivity values of the developed samples were measured using flash method.

1. Introduction

About 40% of the energy consumed by any building is for maintaining the desired indoors air condition [1]. This fact underlines the importance of energy-efficient air-conditioning systems along with effective building insulation. Design expectations from a well-designed building insulation material are high thermal and acoustic resistances, low flammability, light weight, resistance to water and being cost effective [2]. A lot of efficient materials have been introduced for the insulation of walls to sustain thermal efficiency and cost effective. Some of them are foam blankets, spray on foam developed by NASA, polyurethane foam, aerogels, and fiber glass [3]. Perlite and pumice are two materials that have the potential to satisfy all major expected characteristics from insulation materials. Perlite is an amorphous aluminosilicate volcanic glass that can be utilized as a raw material in geopolymerization technology [4]. It contains 2–5% combined water that expands 10–30 times of its original volume when heated to temperatures in a range of 760–1150 °C. Volatilization of the combined water during the shock heat treatment expands the hot, softened ore into foam that solidifies into a lightweight, cellular aggregate with bulk densities ranging between 80 and 240 kg/m^3. The resulting product can be used in industrial and construction-related applications because of its thermal insulation, noise reduction, porosity, light weight, non-flammability, and non-toxicity [5].

Topcu and Isikdag [6] studied high heat resistant bricks made by mixing perlite and clay at ratios in the range of 5–50%. The results showed that the optimal replacement ratios were 24% for heat conductivity and 31% for shrinkage. Use of pumice in insulation materials is also becoming popular. Increasing utilization of lightweight materials in civil structuring applications is the reason that makes pumice a popular raw material [7]. Pumice consists of a group of materials having a similar origin and physical structure, such as pumice, volcanic cinders, scoria and volcanic tuff. It has high strength-to-weight ratio, low sound transmission characteristics, and low thermal conductivity. These properties make it desirable for use as an additive for lightweight bricks, blocks and aggregate for concrete and plaster [8].

For the green roof scenario, tests were conducted with the developed samples under vegetation layer. Thermal analysis of green roofs is different than the analyses performed on rigid, inorganic building materials. Studies should account for heat transfer and evapotranspiration phenomenon occurring at the plant layer. Sailor [9] focused on designing process of green roofs by using a program developed by the U.S. Department of Energy. For the energy budgeting, FASST (fast all season soil strength model), developed by Frankenstein and Koenig [10] was employed. Niachou et al. [11] studied the thermal performance of green roofs, with emphasis on the color of the plants used. Celik et al. [12,13] conducted energy savings analyses on green roof systems employing various growth media and plant coupling combinations. In these studies, growth media were composed of inorganic rocks such as pumice, haydite, arkalyte, lava, and furnace bottom ash.

* Corresponding author.
E-mail address: scelik@siue.edu (S. Celik).

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Nomenclature

C_f	bulk transfer coefficient
$I_l^{\downarrow}$	net longwave radiation, Wm^{-2}
$I_s^{\downarrow}$	net shortwave radiation, Wm^{-2}
k	thermal conductivity, $Wm^{-1}K^{-1}$
LAI	leaf area index
r''	surface wetness factor
R	thermal resistance, m^2KW^{-1}
t	time, s
U	dimensionless temperature
W_{af}	wind speed within foliage, ms^{-1}
Y	mass fraction

Greek symbols

α	thermal diffusivity, m^2s^{-1}
α_f	surface albedo at foliage
ε_g	emissivity of soil
ε_f	emissivity of foliage
θ	moisture content, m^3m^{-3}
ρ_a	density of air, kgm^{-3}
ρ_f	density of foliage, kgm^{-3}
σ_f	foliage cover ratio
φ	porosity, m^3m^{-3}
ω	dimensionless time

Moisture content of building materials plays a significant role in thermal resistance of these layers. Hence the porosity and water content of the tested samples should be accounted for in the theoretical analysis. Sarwar and Majumdar [14] examined two-phase composite porous media model for thermal conductivity with inert materials. Effects of porosity, water content and presence of inert material absorbed in pores were analyzed. Dos Santos and de Sylos Cintra [15] studied the effect of moisture on the thermal conductivity of porous ceramic materials, suggesting a numerical model of the energy equation employing numerical integration. Shabbir et al. [16] investigated the thermo-physical properties of consolidated porous rocks focusing on thermal conductivity, thermal diffusivity and heat capacity of these formations while Garboczi and Bentz [17] conducted a similar analysis on transport properties of concrete. Win-Jin and Cheng [18] conducted an analytical solution to coupled heat and moisture diffusion transfer in porous materials. Laplace transformation implemented with coupled partial differential equation and boundary condition was reduced to an ordinary equation by introducing a transformation function. Temperature and moisture distributions in the transform domain for the solution were obtained.

Determination of R-value for these materials is important for quantification of insulative properties. Reverse heat leak method (RHLM) is one of the reliable techniques, which is a major thermal testing method extensively used in the refrigeration industry to test U values of refrigerators [19]. Numerous studies [20–23] exist on employing RHLM. While the technique is same, different types of heating elements for simulating the heat load is being used in these studies.

This study involves design and fabrication of new building insulation materials along with R-value determination tests conducted on the samples prepared in the lab, using the RHLM. Experimental and theoretical analyses are conducted on both dry and moist samples with or without plant layer on top, where the plant layer simulates a green roof application employing moss as the vegetation.

2. Experimentation

Experimental analysis includes R-value testing, microscopy, and thermal diffusivity measurements. R-value testing was conducted using reverse heat leak method which requires an insulation chamber. This chamber was made of extruded polystyrene (XPS) with the top wall being the test surface for retrieving the R-values of the fabricated prototype panels. The setup also includes a heat load and a data acquisition system which is composed of thermocouples, a multiplexer and a data logger. A schematic of the experimental setup is given in Fig. 1.

For measuring temperatures of surfaces, inside air, and ambient air; eighteen T-type thermocouples were calibrated and placed at selected locations Temperatures were measured on both the inner and outer surfaces of each face of the box. Fig. 2 illustrates the reference box made of XPS, along with the heat load (10.5 W light bulb) and thermocouples.

All thermocouples measuring surface temperatures were covered with $2 \times 2 \times 0.5\ cm^3$ XPS foam to isolate the thermocouple tips from the surrounding affects. Inside air temperature was measured at two levels (at one quarter and three quarters of the inner height) within the box, to get an average inside temperature. Outside air temperature was measured at four sides of the box. The test box was placed on a hollow galvanized steel stand to ensure that the bottom surface is also completely exposed to outside air. To block the flow of heat through the metal stand, XPS

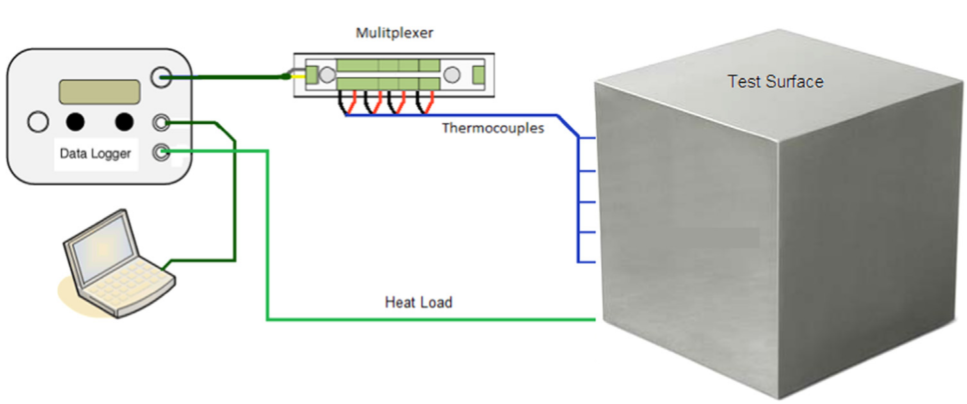

Fig. 1. Schematic of the experimental setup.