Simulation of the Thermal Performance of a Novel Green Building Insulation Material

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Abstract: Globally it has been estimated that the building sector accounts for 25-40% of primary energy use which translates to as much as 60% of total electricity generation. Also, about 30 – 40% of greenhouse gas emission and the same percentage of solid waste production are attributed to the construction and operation of buildings. Thus, there are many initiatives toward green building technology.

In this paper, reduction in space cooling requirements, which is the top energy consumer in the building sector, is considered via the use of insulation materials made from recycled industrial wastes. In this study, the materials chosen are geopolymers. Geopolymers are a class of inorganic polymers formed by alkali activation of alumina-silicate materials. These alumina-silicate materials, aside from other sources, are available from industrial wastes and by-products such as fly ash from coal-fired power plants, and slag or waste materials from iron and metal production. Aside from being processed industrial waste, the process itself of geopolymer synthesis has been shown to have much smaller CO_2 emissions.

This study compares the thermal performance of a conventional material-based insulation system with novel insulation material-based (geopolymers) through the use of ANSYS simulation software. The simulation is implemented on the same building design (physical structure) and conditions.

Keywords: Green building materials, insulation, geopolymers, building simulation, carbon emissions

1. INTRODUCTION

1.1 Overview

Heat that crosses the building envelope is a major contributor to the air conditioning load. In the Philippines where the ambient conditions are generally warmer than the desired indoor conditions, heat enters the building and must be transferred from the colder inside to the warmer outside via an air conditioning system to maintain the desired colder indoor conditions. This process of transferring heat from low temperature interior to high temperature exterior of the building is an energy consuming operation. This energy consumed (in the form of electricity) is the space cooling energy that takes up a major chunk of total electric power generation.

Insulation can improve a building's energy efficiency by either keeping heat inside the building or outside the building, depending on the season and how the space is conditioned. In cold weather, the insulation will keep heat inside the building and in warm weather; it can reduce the wall heat transmission into the building.

However, the use of insulation also involves economic, health and environmental issues.

Conventional insulation materials used in the building and construction sector are produced or taken directly from natural resources. Due to depletion of resources, costs increase (Saygili and Baykal, 2011). The manufacture and utilization of these thermal insulation materials such as fiberglass, mineral wool or polyurethane foams can be hazardous to human health (Panyakaew and Fotios, 2011). Thus the demand for ecological insulation materials is growing dramatically (Zach et al., 2012).

As geopolymers that are formed from industrial waste such as fly ash and rice hull ash may fall in the category of ecological materials, it is considered in this study if such geopolymers can be functional substitutes for these conventional materials.

1.2 What are Geopolymers?

Geopolymers are formed from the reaction between alumino-silicate oxides and alkali metal silicate solutions under highly alkaline conditions yielding amorphous to semi-crystalline three-dimensional polymeric structures, which consist of Si–O–Al bonds (Davidovits, 1991; Barbosa et al., 2000).

Geopolymers are the synthetic equivalents of natural tecto-alumino silicates. The geopolymerization process is similar to the thermosetting of organic polymers where silicon and aluminum atoms form molecules that are chemically and structurally comparable to those of natural rocks. For this reason, these materials are termed as "geopolymers" (Davidovits, 1994). Thus new products from this process exhibit the best properties of rock-forming elements, i.e., hardness, chemical stability and longevity (Davidovits, 1994; Kumar et al., 2007).

Specific formulation of geopolymers has been shown to have comparable if not better technical properties than the conventional ordinary Portland cement (OPC). And, as it can be synthesized from industrial wastes such as blast furnace slag and coal ash with as much as 80% less greenhouse gases than OPC and at much lower temperatures (<100^{o}C), the possibilities for sustainable manufacture makes it a very attractive alternative to OPC (Davidovits, 1994; Kumar et al., 2007).

1.3 Green Building and Green Building Materials

According to GBCA (Green Building Council of Australia), a building is considered to be a green building when it incorporates design, construction and operational practices that significantly reduce or eliminate its negative impact on the environment and its occupants. Thus, the construction and operation of green building will make use of materials to enhance this "green" characteristic.

Franzoni (2011) defined green building materials as

- sustainable during their whole life-cycle and
- not hazardous to human health.

However, together with the 'greenness' characteristic, these materials must also satisfy requirements set by national laws, national/international standards, and codes of practice, such as

- mechanical properties (for structural materials), such as strength, stiffness, etc.
- thermal performance, in order to achieve a satisfactory energy behavior during the operating phase

2. METHODOLOGY

The performance of geopolymers as a "green" building insulation material was evaluated via simulation using ANSYS for a simple residential building structure. The residential building structure contains the following parts:

(1) a roof constructed from galvanized iron (6 mm thick) and with foam insulation (50 mm thick)
(2) a window that is made from glass
(3) a door that is made from hard wood, and
(4) walls

The reference wall thickness is 165 mm (6.5 in) of OPC-based concrete. Composite wall configurations having a certain thickness of geopolymer sandwiched between layers of OPC-based concrete are evaluated. The thicknesses of the geopolymer layer in the composite walls are determined such that the composite wall has the same effective compressive strength as the reference concrete wall.

The properties of geopolymers were obtained from samples formed using mixtures of coal fly ash, coal bottom ash and rice hulls ash activated using an alkali mixture of sodium hydroxide and water glass.

For the properties of geopolymers, the following were used:

Thermal conductivity,
0.258 to 0.615 W/m-K
Density,
830 to 1550 kg/m³
Compressive strength,
5 to 15 MPa

The specific values used in the simulation are k = 0.258 W/m-K, density = 830 kg/m³, and the mean value of compressive strength of 10 MPa.

For the properties of the reference concrete (considered for residential building applications), the following (NRMCA; ACI 122R-02, 2002) were used:

Thermal conductivity, *1.67 W/m-K*
Density, *2400 kg/m³*
Compressive strength, *17 MPa*

In the simulation using ANSYS, convection was considered on the external and internal wall and roof surfaces of the simple residential building. Radiation was considered on the outer surface of the roof exposed to direct sunlight. A floor temperature of 22°C (295K) is established while an indoor air temperature of 24°C (297K) was considered to simulate an air-conditioned interior. In addition, an outdoor air temperature of 38°C (311K) was considered representing typical summer conditions in the Philippines. A uniform film coefficient value of 1.5 $Wm^{-2} K^{-1}$ was used for air. Also, an emissivity value of 0.6 was used throughout the simulation.

3. RESULTS AND DISCUSSION

Sample simulation results are shown in Figures 1 and 2 (temperature distribution) and Figures 3 and 4 (heat flux). In these figures, the temperature distribution and heat fluxes are seen to decrease with increasing thicknesses of the geopolymer layer.

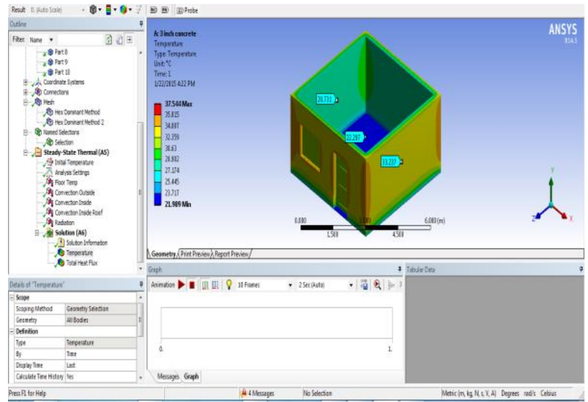

Fig. 1. Temperature distribution using 75 mm thick concrete wall with 150 mm thick geopolymer insulation

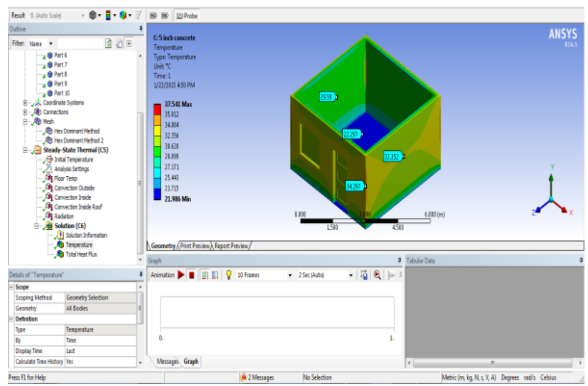

Fig. 2. Temperature distribution using 125 mm thick concrete with 65 mm thick geopolymer insulation

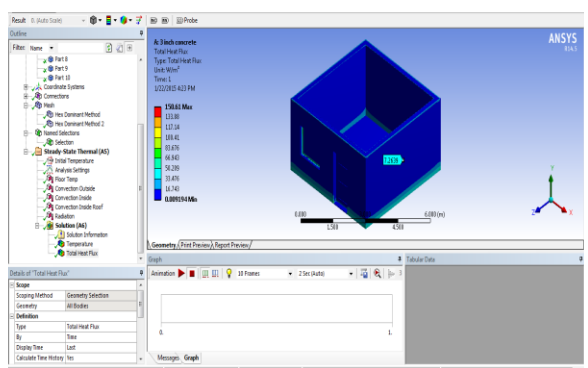

Fig. 3. Heat flux across a 75 mm thick concrete wall with 150 mm thick geopolymer insulation

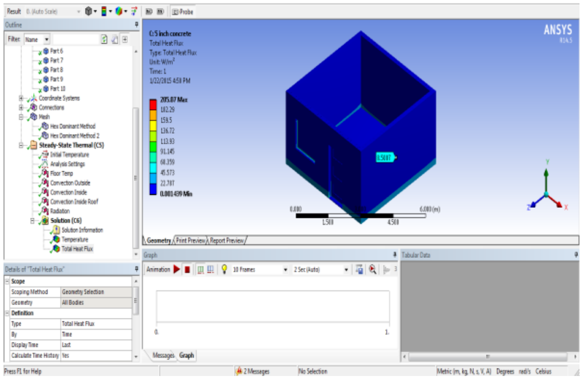

Fig.4. Heat flux across a 125 mm thick concrete wall with 65 mm thick geopolymer insulation

A summary of these simulation results is given in Table 1.

Table 1. Results of simulation on different wall configurations.

	Thickness, mm		Surface temperature, °C		Wall Den-sity, kg/m³	Heat Flux, W/m²
	Con-crete	Geopo-lymer	In-side Wall	Out-side Wall		
1	165	0	30.4	31.4	2400	9.97
2	125	65	29.6	32.4	1870	8.50
3	100	105	29.1	32.8	1591	7.73
4	75	150	28.7	33.2	1356	7.26
5	0	280	27.9	34.1	830	5.79

From Table 1, it can be seen that the wall configurations that include a geopolymer layer has better insulation performance. This insulation effectiveness increases as the thickness of the geopolymer layer increases as evidenced by the decreasing inside wall temperature (Figure 5) and decreasing heat flux (Figure 6).

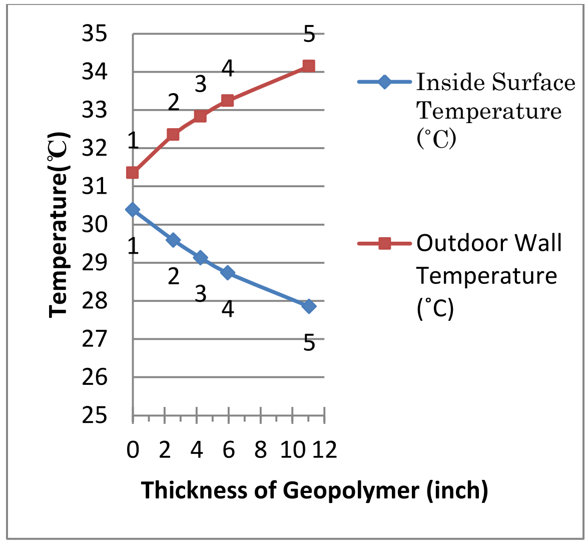

Fig. 5. Wall surface temperature vs. thickness of geopolymer layer

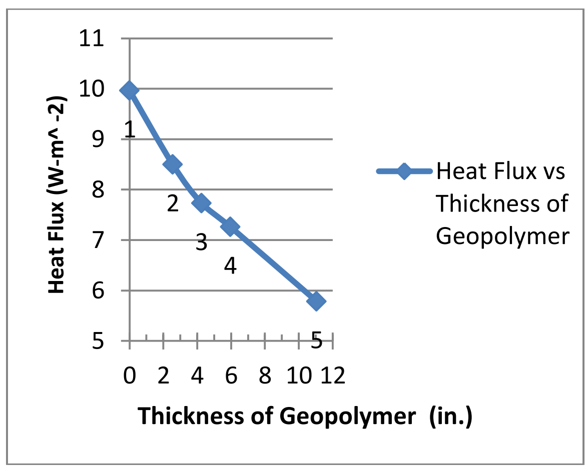

Fig. 6. Heat flux across the wall vs. thickness of geopolymer layer

From the above results, it can be determined that a 15% reduction in building heat gain is achieved with a 65 mm layer of geopolymer relative to the pure OPC-based concrete wall. This increases to as much as 42% reduction with a pure geopolymer wall of the same load (weight carrying) capacity.

Further, the average wall density of the composite wall decreases from 2400 kg/m³ for the 165 mm thick reference wall (pure OPC-based concrete) to 830 kg/m³ for the 280 mm thick pure geopolymer wall. For a unit wall area, this translates to 396 kg/m^2 for the reference wall to 232 kg/m^2 for the pure geopolymer wall. Thus, even as combined wall thickness increases, there is a 41% reduction in weight. As thermal storage in building walls is directly proportional to the weight of the walls, there will be an associated decrease in thermal storage.

Also, even as the combined (composite) wall thickness increases and thus more volume of materials are needed, the increase in volume corresponds to the geopolymer layer while the volume of OPC used actually decreases. Thus the more expensive OPC combined or replaced with the cheaper geopolymer presents a comparable if not more economical option.

4. CONCLUSIONS

Based on the results of the simulations and the analysis presented above, the geopolymers, with characteristics used in this study, show potential as practical alternative insulation materials for residential structures.

As a result of their low thermal conductivity, low density, and relatively high strength, their use as an insulation (or combined insulation and structural material) lead to reduced wall gain load and thermal storage, thus lower air conditioning load and thus cooling costs.

Lastly, the geopolymer insulation based structure would also comply with the green building materials definition specified above. It reduces the negative impact on the environment and at the same time, it also utilizes resources efficiently.

In summary, as far as this study is concerned, the use of geopolymers as an alternative building insulation material presents the following potentials:

1. lower costs of space cooling
2. lower materials cost
3. environmental benefits

5. ACKNOWLEDGEMENTS

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