Computational simulation of the temperature distribution of aerogel–based coated and uncoated multi–layer panels for thermal insulation

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Abstract. A computational simulation is developed to study the temperature distribution of two types of multi–layer panels, one of which utilizes an aerogel–based coating. The simulation considers properties such as layer thickness, thermal conductivity, specific heat and density of the materials. From a set of materials, a multi–layer is geometrically modeled to perform the simulation. The results obtained indicate the temperature distribution across the different layers of materials and evidence the presence of the aerogel material with respect to the uncoated model. This research aims to visualize the effect of whether or not having a special coating can benefit the thermal distribution in the panel, hence, the thermal control within enclosures and architectural structures.

1. Introduction

Various types of materials are being implemented to enhance thermal conditions within enclosures and architectural structures. One of the biggest costs that have to be considered in structural design is the thermal control in closed spaces, since these costs correspond to most of the energy consumption of buildings through wall thermal losses [1]. Even though there are various options of insulating coatings, there are few materials that out–stand in all of the thermo–physical properties needed to achieve an appropriate function as a thermal insulator [2]. Therefore, the development of new materials that are able to comply with the current needs of building insulation have been carried out, being aerogel–based materials some of the most promising for this task [3].

Kyriakidis et al [4] carried out comparisons through numerical modelling in which radiation within traditional and contemporary walling was studied. Also, both micro structural [5, 6] and composite panel studies [3, 7] have been made, both in which aerogel has been found to perform better subjected to various thermal conditions in comparison to different insulating materials alternatives.

In the present study, a comparison between an aerogel–coated and uncoated multi–layer panel was developed by means of computational simulations. Both panels, aerogel–coated and uncoated were evaluated through an external condition of a fixed 45 °C temperature.
2. Methodology

2.1. Layer properties and simulation conditions

The computational simulations were made on two multi–layer panels where the benefit of whether having or not an aerogel–based coating was studied by each sample’s temperature distributions through the various layers of materials. The materials’ sequence that make up the multi–layers was similar to those proposed in [8] and [9] and whose properties can be seen in Table 1. To evaluate the thermal conductivity of the multi–layer panels, a surface temperature of 45 °C was considered in the aerogel and concrete layers for the coated and uncoated cases, respectively.

Table 1: Thermo–physical properties of the multi–layer panel [8]

| Material                 | Thickness (cm) | Thermal conductivity (W/(mK)) | Specific heat (J/(kgK)) | Density (kg/m³) |
|--------------------------|----------------|-------------------------------|-------------------------|-----------------|
| Plaster (inside layer)   | 1.3            | 0.32                          | 800                     | 790             |
| Glass Wool               | 16             | 0.041                         | 840                     | 12              |
| Concrete                 | 25             | 2.1                           | 800                     | 2400            |
| Aerogel–based coating    | 4              | 0.027                         | 1100                    | 200             |

2.2. Mathematical modelling

The heat transfer equation in steady–state regime was established to model the thermo–conductive behavior through all of the layers of material that were implemented. The mathematical model is as proposed by Ángel, Suárez and Niño in [5],

\[ k_c \nabla^2 T = -\rho h \in \Omega^2 \quad (1) \]

Where \( T \) corresponds to the temperature of the material on a specific point, \( k_c \) is the thermal conductivity of the aerogel SiO\(_2\) which takes values between 13–20 mW/(mK), or each layer’s thermal conductivity and \( \rho h \) is the rate of heat generation or accumulation of internal energy within the material.

And the heat flow conditions or temperature that is applied over the external surface can be described through:

\[ k_a \frac{\partial T}{\partial x} = h_c (T - T_\infty) \in \Omega^2 \quad (2) \]

\[ T \in \partial \Omega \quad (3) \]

Where \( \partial T/\partial x \) is the heat flow due to convection through the boundaries, \( h_c \) is the convective coefficient of the fluid to which the surface is exposed, \( k_a \) is the thermal conductivity of air in W/mK, \( T \) is the temperature along the boundary and \( T_\infty \) is the ambient temperature.

2.3. Geometrical and numerical modelling

A panel of 600×700 cm and of thickness as specified in Table 1, was developed. The aerogel–coated and uncoated panels are presented in Figure 1.
Figure 1: Geometrical modelling of the multi-layer uncoated panel.

The numerical meshing of both panels was developed through hexahedral elements for each one of the layers, implementing finite element methods for the solution of the differential equations that describe the behavior of both composite panels [10]. The meshing of the multi-layer panels is shown in Figure 2.

Figure 2: Multi-layer panel meshing

3. Results and discussion
The temperature distribution of the aerogel-based coating panel can be seen in Figure 3. Here, most of the layers have a constant temperature of around 30 °C and most of the heat exchange appears to happen in the outer layers, these being the aerogel and part of the concrete; where the biggest temperature differences occur, specially in the aerogel layer. The latter is due to the low thermal conductivity and high porosity of the aerogel material, which have been previously reported [11, 12] to be the major causes of its effectiveness retaining the energy that is trying to be conducted through the different layers. Also, within the aerogel layer there are some areas that have a greater temperature than the rest, this may be due to the heat transfer that may be easier to occur in certain directions rather than the others.
In Figure 4 the temperature distribution of the uncoated panel can be seen. There is a greater area with a variable temperature, which corresponds to the concrete layer; nevertheless, the adjacent layers have a slight increase in temperature too. In general, there are greater temperature variations through the entire layers which clearly evidences the absence of aerogel. Although the temperature values are lower than in the aerogel–coated case, there are more temperature fluctuations.

4. Conclusions

Being thermal control one of the biggest costs that have to be taken into account for structural design, efforts have to be made in the understanding of the behavior of new insulating material alternatives. A computational simulation was made in which the ability of energy retention of aerogel was shown in comparison to a conventional multi–layer wall. Aerogel proved to make a difference in keeping a constant temperature through the entirety of the layers. A greater temperature was obtained in the over all aerogel–coated multi–layer relative to the uncoated multi–layer.

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