Effect Of Different Aerogel Percentage Coating On Thermal Insulating Performance

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This paper discusses the effect of employing different percentage of aerogel powder in paint solution for thermal insulating performance. This issue has led to the development of a fresh, inventive solution that has the ability to insulate against heat, allowing for a reduction in material thickness during construction. Due to its characteristics, aerogel is a great addition to coatings that are lightweight and thermally insulating. As an additive for the created thermal coating in the current investigation, different volume of aerogel ranging from 1% to 5% have been blended. The enhanced coating was then put to an ISO-NUD microporous panel in order to observe the effects of the aerogel addition. The testing results show that employing aerogel-infused coatings or paint can help an ISO-NUD microporous panel function better as a thermal insulator based on the temperature difference between the panel's front and back surfaces. It became evident that a higher percentage of aerogel provide the better insulation. With the additional of 5% of aerogel, there was about 7% of thermal insulation enhancement that was recorded follow by the 5% of enhancement by addition of the 4% of aerogel. The additional of 3% and 2% of aerogel share almost similar level of enhancement which are about 3%. While the additional of 1% of aerogel seen unable to show significant enhancement compared to the normal paint without aerogel been infused.

Keywords: Aerogel; coatings; thermal insulator; thermal performance; microporous panel

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1. Introduction

As the world's population grows, so does the demand for homes. This causes an increase in the demand for energy by housing occupants around the world. This has caused significant concern about the building's energy consumption [1, 2]. According to the International Energy Agency's 2022 report [3] energy use in buildings increased from 115 EJ in 2010 to nearly 135 EJ in 2021, representing approximately 30% of global final energy consumption (EJ is a symbol for exajoule, a SI unit of work or energy equal to 1018 Joules). Following the lifting of Covid-19 restrictions, energy demand in buildings climbed by roughly 4% in 2021 versus 2020 (or 3% versus 2019) which is the greatest yearly increase in the recent decade. As shown in Fig. 1, electricity accounted for approximately 34% of building energy demand in 2021, up from 30% in 2010. This is mostly due to the extensive usage of electrical power for building air conditioning [4, 5], as space cooling witnessed the greatest growth in demand in 2021 across all building end uses, an increase of more than 6.5% over 2020, as shown in Fig. 2. In Malaysia, the buildings sector consumes approximately 14.3% of total energy output [6], with 80% to 90% of the people spending the majority of their time within buildings [2, 6], with cooling and lighting loads consuming the majority of the energy. Furthermore, when both direct and indirect emissions are considered, the use of air conditioners results in a very substantial carbon footprint. In 2021, approximately 19% of CO_2 emissions were attributed to the generation of electricity and heat used in buildings, with an additional 6% attributed to the manufacture of cement, steel, and aluminium used in building construction, accounting for approximately one-quarter of global energy- and process-related CO_2 emissions [3, 7]. To tackle this issue, it is necessary to develop thermal insulators that can reduce the energy consumption of the building.

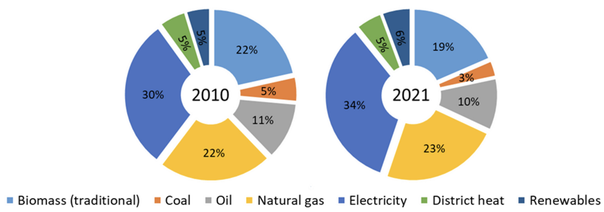

Fig. 1. Demand for energy sources from buildings in 2021 [4]

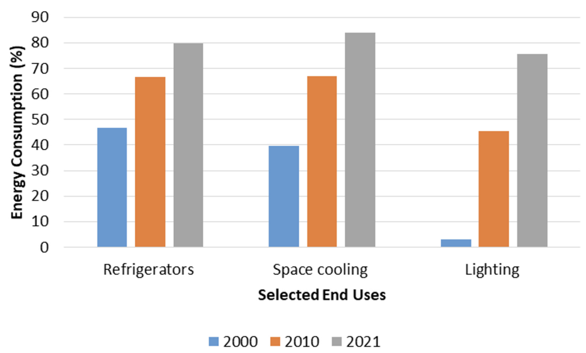

Fig. 2. Building's energy usage percentage [5]

The use of thermal insulation materials in walls and roofs is a common passive approach for lowering energy usage. Being able to limit heat exchange between the exterior and interior of a building is recognised as one of the most effective strategies to secure energy savings [8–10]. Thermal insulation materials commonly utilised include mineral wool, wood fibres, fibreglass, polypropylene nonwoven textiles, porous aramid fibres, and commercially available thermal insulating foams such as expanded polystyrene (EPS) and polyurethane (PU) foam [11, 12]. However, the thermal conductivity of these materials are higher than air (24 W/mK), limiting their insulating capability [13]. Therefore, in order to solve this issue, these material are applied in the form of sandwich structure to enhance thermal insulation performance. Kim et al. [14], which results in a very thick sandwich layer, especially when passive house or zero building standards are desired. Thick building envelopes may be a solution for today, but they are not very desirable in the long run for a variety of reasons, including but not limited to living space constraints, transport and logistics volumes, architectural and technological constraints, unsustainable material usage and existing building techniques, and so on.

This issue has led to the development of a fresh, inventive solution that has the ability to insulate against heat, allowing for a reduction in material thickness during construction. This is intended to be performed through a bottom-up approach in which macro composite materials with nanotechnology skills are combined to produce a smaller wall while maintaining thermal insulating performance. The suitability of an insulating material for this purpose depends on a variety of factors in addition to its extremely low thermal conductivity. Desirable attributes include site flexibility, mechanical strength, opacity or transparency, durability and resilience to weathering, fire protection, low risk to the environment and public health, and low cost. One such material is aerogel, a commercially accessible insulating substance in the field of nanotechnology.

Aerogel is a highly excellent material for decreasing heat conductivity, as demonstrated by the Knudsen effect [15–17]. This is due to the superiority of silica aerogel as a kinetic energy absorber, which is already thought to be superior and holds great promise for a wide range of applications ranging from cryogenic temperatures in spacecraft to high temperatures in aero engines [18]. Silica aerogels have a low density (0.003-0.5 g/cm^3), a large specific surface area (500-1200 m^2/g), strong optical transmission (90%) and porosity (80-99.8%), a low refractive index close to that of air (1.01-1.05), and wettability ranging from hydrophilic to super hydrophobic [19–22]. Because of its properties, aerogel is an excellent ingredient for lightweight and thermally insulating coatings. Reports on the use of aerogel in thermally insulating coatings for buildings, on the other hand, appear to be restricted, most likely due to the high manufacturing costs of aerogel. Aerogel application is also challenging due to poor adhesion caused by either a lack of physicochemical bonding or a mismatch in the thermal expansion coefficient between the aerogel and the substrate, which eventually results in cracking and spalling. Although putting an aerogel-based insulation may appear simple, aerogel powders are extremely difficult to deposit due to a lack of the necessary granulometric and morphological properties [23–25]. The most common way via which silica aerogel are being employed for insulation is aerogel-based blankets, which is nowadays experiencing one critical limitation such as space/thickness and weight. Due to these two constraints, it is imperative that alternative aerogel-derived solutions are proposed. This project intends to address this technological gap and remediate this problem through a stand-alone aerogel-based paint. The primary purpose of this study is to assess the boosting capacities of a micro porous thermal insulation panel with different percentages of aerogel infused coatings. These aerogel-infused coatings were created in collaboration with a paint industrial partner [26] and a Nano silica expert company [27] and they can be applied like conventional construction paint, making them incredibly practical to use. Regarding the proportion of aerogel utilised, it was anticipated that the coating with a higher percentage of aerogel would offer better insulation, indicating a lower thermal conductivity for the coating. Nevertheless, when the aerogel continues to increase in size, the thermal insulation of the mixture will eventually reach a point where it no longer improves, as a result of an excessive amount of aerogel being added.

2. Materials and methods

2.1. Materials

The aerogel used was a hydrophobic aerogel known as Aerowder, which was supplied by AEROGEL+, a subsidiary of the AeroNUD company [28]. At normal ambient temperatures and pressures of 25 °C and 1 atm, this aerogel has a bulk density of 90-100 kg/m^3 and a thermal conductivity of 0.018-0.020 W/mK. This light weight and low heat conductivity are both due to the 95% porosity, which contributes to a small particle size range of 1 μm to 15 μm and a pore size distribution of 1 nm to 50 nm.

The aerogel-infused paint was created using a paint base with the trademark name Bina UltraShield (from Bina Paint Sdn. Bhd. [26]). It is a water-based product with a solid content of 55% and a theoretical coverage of 10-12 m^2/liters at 30 microns of application thickness, depending on the substrate state. Bina UltraShield is an acrylic emulsion paint that has been specially formulated to provide additional protection for exterior walls by acting as a durable coat and protecting the wall from weather variations and fungus, making it one of the best options because the paint base is also locally produced, making it less expensive.

2.2. Aerogel Coating Preparations

To guarantee that the aerogel was properly mixed without the formation of huge lumps and to allow air absorption in the mix, the coating is formed by slowly mixing the paint base with the aerogel. As a result, the density of the coating is lowered when compared to a regular coating or paint. Furthermore, it is critical to ensure that the measured aerogel is fully mixed into the paint because the physical properties of aerogel are light weight and hydrophobic, thus it tends to stay at the top surface without being infused into the coating mixture. Aside from that, the order in which the chemicals are mixed influences the efficacy of the aerogel infusion into the paint base. Aside from that, the order in which the chemicals are mixed influences the efficacy of the aerogel infusion into the paint base. Many attempts have been made to identify the ideal formulation recipe that will result in a successful aerogel infusion.

In order to determine the best aerogel volume, the aerogel that was mixed into the coating was used at a rate ranging from 0% to 5% of the total volume of the mixture. Physically, adding 5% aerogel resulted in a somewhat thicker layer with slightly higher coating viscosity than adding less. In terms of thermal conductivity, the coating with a higher percentage of aerogel was projected to provide superior insulation, showing that the coating had a lower thermal conductivity. However, as the aerogel continues to grow, the thermal insulation of the mixture will eventually plateau. Furthermore, even if the thermal properties are the same, an abundance of aerogel may reduce the coating's binding qualities.

2.3. Sample Preparation

The created aerogel coating has the added feature of being both water resistant and permeable to water vapour. The hydrophobic feature of aerogel aids in water absorption avoidance by preventing water absorption by the incorporation of aerogel particles into the coating, which may modify the volumetric composition of the final mix. The material is substantially more breathable than standard coating and will not crack or peel in a changing climate. The aerogel-based coating will be put to ISONUD insulating panels, which have an extraordinarily low thermal conductivity and thus extremely high insulation qualities. The use of micro porous materials for thermal insulation was not a new discovery in the construction industry. ISOLEIKA, a company that has been performing different insulating products based on inorganic silicates, specially fumed silica, and different opacifiers for minimising infrared radiation, developed and manufactured a thermal insulating panel based on micro porous core with very low thermal conductivity, which means it has very high thermal insulation properties [29]. The application of an aerogel-based coating that was being developed on the surface of a panel could be a brilliant option for further reducing heat loss while also reducing the thickness of the existing panel. The current aerogel-based coating is still being developed in order to increase thermal performance while maintaining workability. Fig. 3 shows the sample of uncoated and coated ISO-NUD panel. Based on Fig. 3, based on the observation by a naked eye, the coating was observed to be able to reduce the unevenness of the panels that might be where the micro crack happens to be. This was predicted to be lowering the level of heat conductivity of the panels.

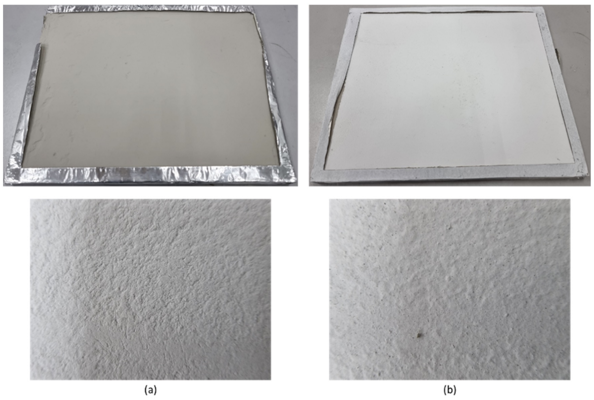

Fig. 3. The ISO-NUD panel sample, (a) Uncoated and (b) Coated

The original dimensions of the panel were 70 cm × 110 cm × 1 cm (H×W×T). However, for easier handling, the panel is separated into smaller panels with dimensions of 18 cm × 23 cm. For the current study, a total of seven ISO-NUD panels will be employed. Six panels were each coated with a different aerogel volume percentage coating and one panel was set to be baseline panel. To ensure consistency across the panel, the coating will be applied with a standard paint roller. Since the panel was cut into a more convenient size, the usage of a roller that fit the length of the panel can ensure the consistence of the applied coating. Besides that, the thickness of the coating on several point of the panel was also measure using Coating Thickness Gauge with averaged thickness 30 micrometers across all applied panels (Table 1).

2.4. Experimental Setup

The low temperature test was performed to determine how well the panel with varying aerogel percentages insulates heat from one side to the other. Because this test does not include flames or fire, a hot air gun was used to generate heat. The testing rig is divided into two sections: the test panel holder and the hot air gun holder. Fig. 4 illustrates the CAD of both structures. To ensure that the test panel holder (Fig. 4a) did not move when blown by the hot air gun, a slot type mechanism was used. The hot air gun holder (Fig. 4b) can be moved sideways so that the hot air gun's end nozzle is suitably pointed at the centre of the targeted panel to which the thermocouple was attached. Fig. 4c and Fig. 4d illustrate the real structure of the plate holder and hot air gun holder.

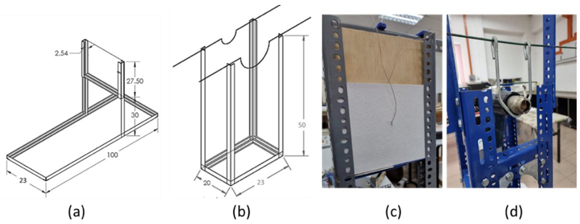

Fig. 4. The plate holder and hot air gun holder

Four thermocouples type T were used for measuring temperature in the current study. These thermocouples were connected to a data gathering system, which included a data logger and a computer desktop, to record the thermocouples' temperature history. The thermocouple will be attached to various positions, as indicated in Fig. 5, in order to capture the temperature at the defined locations, which were Gas temperature (T_g), Ambient temperature (T_a), Front surface temperature (T_1), and Back surface temperature (T_2).

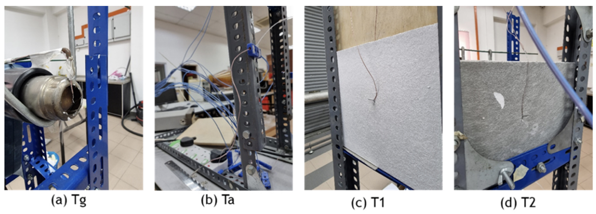

Fig. 5. Thermocouple positioning

2.5. Distance between the Gun and Panel

Since the heat source for the current study was a hot air gun, the distance between the hot air gun and the targeted plate was an important component in obtaining a more consistent heat act on the targeted surface. According to the graph in Fig. 6,a distance of one inch causes the temperature to rise faster than distances of two and three inches. Because the testing was done in an air-conditioned room, the sluggish or lower temperature between the hot air gun

Table 1. Coating Thickness measurement across the panel

Aerogel Percentage	Thickness gauge reading (Micrometres)										
	1	2	3	4	5	6	7	8	9	10	Avg.
0%	31.5	31.1	27.2	31.9	29.3	30.3	32.9	28.8	27.9	30.3	30.12
1%	30.4	28.0	29.4	27.3	32.0	31.6	30.4	33.0	31.2	28.9	30.19
2%	29.4	32.0	27.3	33.0	30.4	31.2	30.4	28.9	31.6	28.0	30.24
3%	33.1	31.3	31.7	30.5	29.5	27.4	29.0	30.5	28.1	32.1	30.27
4%	31.7	27.4	30.5	33.1	31.3	29.0	30.5	29.5	32.1	28.1	30.31
5%	29.0	31.3	31.7	32.1	33.1	28.1	27.4	30.5	30.5	29.5	30.29

Table 2. The summaries of the low temperature test

Panel	Aerogel percentage	Number of thermocouples	Distance between gun and panel	Hot air gun temperature	Test duration
ISO-NUD	0% 1% 2% 3% 4% 5%	4	1 inch (2.54 cm)	∼80 °C	∼30 minutes

and the surface temperature is due to disturbance from the surrounding air. To decrease this interference, a distance of one inch was chosen for testing. Table 2 provides summaries of the low temperature tests.

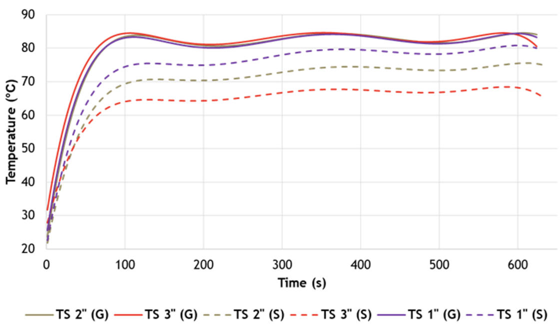

Fig. 6. Temperature histories for different distance between gun and panel

3. Results and discussion

The thermal insulation effect of the coating was measured as the temperature difference between the front and back surfaces of the target panel $T_2 - T_1 = \Delta T$. Higher temperature differences mean that the tested coating has better insulating qualities because it conducts less heat. According to Table 3, while employing the ISO-NUD panel without any coating, the panel manages to reduce heat penetration by roughly 39°C, and when coating is applied, the panel's insulating performance is increased by at least 1°C. This portrays how the presence of aerogel reduces heat conduction in the panel when coated. The heat transmission rate of the hot air gun is very slow when compared to the one without aerogel infusion. This is due to the aerogel particle structure, which is predominantly made up of pores or, more accurately, a high level of porosity that is primarily filled with air. The air within the pore has a very low thermal conductivity, which contributes to the overall thermal conductivity of the aerogel, which is between 0.018 and 0.020 W/mK, which is suitable for an insulating material.

Table 3. Temperature profile for different aerogel percentages

Sample (% Aerogel)	T_1 (°C)	T_2 (°C)	T_a (°C)	T_g (°C)	ΔT_1 (°C)
No Coating	80.31	41.28	27.01	81.28	39.03
0%	80.17	40.21	27.11	81.12	39.95
1%	80.06	40.13	26.98	81.42	39.93
2%	80.25	40.17	26.89	82.04	40.08
3%	80.06	39.90	26.96	81.38	40.16
4%	80.17	39.32	26.66	81.64	40.85
5%	80.32	38.62	26.02	81.36	41.71

However, the first several attempts at blending the aerogel from 1% to 3% appear to be no better than the baseline (Bina UltraShield) without any aerogel added. This can be described in several ways. The number of aerogel particles that act as thermal insulation over the surface area may be affected by how the aerogel is dispersed. The dispersion of the aerogel is related to the finesse of the grin which refers to the smoothness or uniformity of the finish of the system. The fineness of grind is the degree of uniformity and extent of fineness to which particles/pigments are ground in mixture. Most of the pigments and additives used in paints are processed to very fine particle sizes. This particle size ranges from 2 to 50 Microns. However, this fine size also needs to be uniformly processed to achieve a uniform dispersion and ensure the quality of dispersion in mixture. The aerogel particle's hydrophobic nature prevents it from dissolving within the coating mixture. It has simply been dispersed with a dispersing agent to avoid huge aerogel lumps from forming. As a result, the thermal conductivity of the coating may be affected in some way by how the aerogel is dispersed throughout the plate's surface. Based on the finesse test that was done separately on the coating, the result shows a consistency level of finesse across the test surface as shown in Fig. 7. From the perspective of insulating performance, the difference between the paint base and the 1% aerogel layer is almost nonexistent. This demonstrates that the aerogel particles' ability to act as thermal insulators was not brought about by their distribution within the coating mixture. Although not as much as the one with 4% and 5% of aerogel, which has recorded up to 5% and 7% of insulation enhancement respectively as shown in Fig. 8, the insulation property of the aerogel started to manifest when the aerogel percentage was further increased to 2% and 3%.

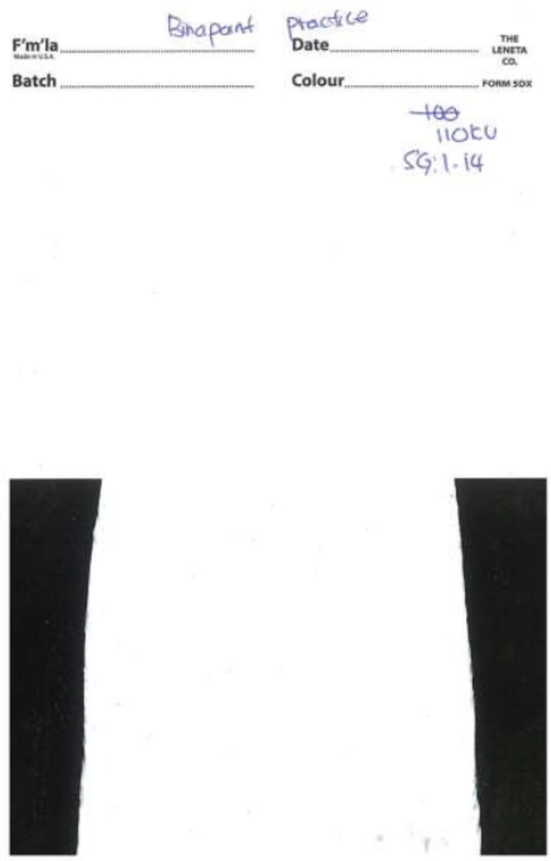

Fig. 7. Finesse test of Aerogel coating/paint

4. Conclusions

Based on the difference in temperature between the panel's front and rear surfaces, the testing results indicate that using aerogel-infused coatings or paint can assist a microporous panel called the ISO-NUD operate better as a thermal insulator. When no coating is applied to an ISO-NUD panel, heat penetration is kept to a minimum of around 39°C. However, when coating is applied, the panel's insulating performance is increased by at least about 1°C. This shows that the aerogel's presence helps to reduce the panel's ability to conduct heat when it is covered. Heat transfer from the hot air gun happens much more slowly than it does from the one without aerogel infusion. This is a result of the aerogel particle structure, which can be described as having a high amount of porosity that is primarily filled with air and has a very low thermal conductivity between 0.018 and 0.020 W/mK, the ideal range for an insulating material.

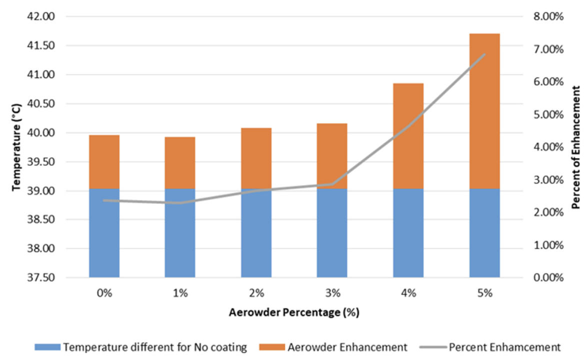

Fig. 8. Thermal Insulation enhancement of different aerogel percentage

The baseline (Bina UltraShield) without any added aerogel does not seem to be much better than the first few efforts at blending the aerogel from 1% to 3%. This can be explained by the fact that the quantity of aerogel particles that serve as thermal insulation throughout the surface area may be influenced by the distribution of the aerogel over the surface area. For instance, there is hardly any difference between the paint base and the 1% aerogel coating. This demonstrates that the aerogel particles' ability to act as thermal insulators was not brought about by their distribution within the coating mixture. The insulating property of the aerogel began to become apparent when the aerogel percentage was further increased to 2% and 3%, though not to the same extent as the ones with 4% and 5% of aerogel, which have recorded up to 5% and 7% of insulation enhancement, respectively.

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