Experimental Evaluations of Building Surface and Indoor Temperature Reducing Effect of the Thermal Insulation Coatings

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Abstract
This paper presents a comparative study on thermal insulation coatings and their effect on lowering building surface and indoor temperatures. At first, eight reflective coatings from international market, Wakkanai Siliceous Shale (WSS) mortar coated and an uncoated concrete blocks were experimented for comparison. The study reveals that lighter coatings have higher albedo and lower heat flux which can reduce the surface temperature up to 6.9°C than the uncoated one. Next, periodic experimentation was conducted and from the results WSS particle coating was found to be the best to lower the indoor surface temperature (5.8°C). This study can support in choosing more appropriate coatings for building envelopes and contribute to the reduction of heat island effect.

1. Introduction
The continuous growth and careless development of the urban environment has a major impact on the urban microclimate. Among the causes that contribute to the heat island effect, surface properties, i.e. roughness coefficient and solar reflectivity play a very important role [1]. Applying the high reflective coating has found effective in reducing surface temperature specially during daytime [2]. Another alternative to moderate envelope temperature is using the moisture adsorption and evaporation capabilities of porous materials.

The objective of this study is to propose a sustainable alternative to moderate wall temperature. Thermal performance of the samples was investigated by steady state & periodic experiments. The spectral reflectance and albedo of the samples were measured to further investigate the relationship with the temperature difference and albedo.

2. Steady State Experiment

2.1. Description of the selected coatings
Eight reflective external surfaces coatings and 5mm WSS mortar (WSS 44.04%, Ca(OH)₂ 44.05%, Binder 10.5%, MC 0.88% and Viniron 0.44%) were applied on 30cmX30cmX5.5cm concrete blocks and experimented. An uncoated concrete block was also studied as reference. The specifications and albedo measured by pyranometer of selected samples are presented in Table-1. The pictures are shown in Figure-1.

2.2. Experimental site and Methods
A high stability controlled air temperature and relative humidity (RH) environment chamber (W2700 X H2400mm X D2400mm) was used to carry out the experiment. Chamber 1 was set as outdoor climate condition with 30°C temperature and 75% RH. Chamber 2 was set as indoor climate with 26°C temperature and 60% RH. The thermal performance of the samples was measured in the chamber for six hours to achieve the steady state. The basic experimental setup is shown in Figure-2. Equipments used in the experiment are listed in Table 2. Instantaneous values were measured and saved on a data logger every 10 seconds. Comparative
temperature measurement of the outdoor surface was also made with an infrared camera with 10 minute interval. During the experimental period, wind velocity was controlled between 0.6 to 0.7 m/s by one fan in each chamber. Two halogen lamps (Promate, 500W) were placed 1.5m away and approximately at 45° angle with a radiation of around 750 W/m².

2.3. Experimental results and discussion
2.3.1. Temperature and heat flux

**Figure-3(a)- 3(d)** show temperatures measured from 5 different depth of S1, S6, S3 and S10. It shows the temperatures reach steady state approximately within four hours and remain stable onwards. The comparison of outdoor and indoor temperatures and inner heat flux are given in **Figure-4**. The minimum values of the outdoor surface temperature were observed S5 and S9. The minimum value of inner surface was found 29.1°C for dirt resistant white coating (S6) and synthetic resin silver spray (S9). It shows the S5 and S9 have the lower heat flux which results to a cooler inner surface. However, when the outdoor surface measurements from thermocouples were compared with those taken from an infrared camera, very small differences were observed. The thermal image and the temperatures recorded by the camera after 6 hour are shown in **Figure- 5**.

2.3.2. Albedo

As shown in **Figure-6**, the white coatings with the higher reflectance are S5, S6 and S8 that can reflect a major part of the light and also appear to stay cooler. A simple relationship of the heat flux difference and albedo difference calculated by pyranometer and spectroradiometer was presented in **Figure-7(a) and 7(b)**. Both show a trend of increase in the difference of heat flux with the increase of the difference of albedo.

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**Table-2** Description of the instruments

<table>
<thead>
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<th>No</th>
<th>Measured Value</th>
<th>Measurement point</th>
<th>Apparatus</th>
<th>Specification</th>
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<td>2</td>
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<td>Relative humidity</td>
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<td>5</td>
<td>Solar radiation</td>
<td>Outdoor pyranometer</td>
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<td>Wind velocity</td>
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**Figure-4** Thermal performance comparison from steady state experiment

**Figure-5** Thermal image of steady state experiment [°C]
3. Periodic experiment

Temperature changes under actual weather conditions involve several factors, for example, variation of temperature and relative humidity from day to night time, and solar radiation. Therefore, periodic experiment was introduced to include these important factors of climatic boundary conditions.

3.1. Materials and methods

The materials measured in the steady state experiment were again used to investigate their performance in the periodic experiment. 3 different sizes of WSS particle (mixed with 12% binder and 5% WSS paint) were included in this section. Figure-8 shows S11 (1.12-2.8mm), S12 (2.8-5.6mm) and S13 (5.6-9.52mm). In one cycle (24 h) of the experiment, the environment of the chamber was set to simulate the weather conditions corresponding to one day. Two cycles, a total of 48 h, were carried out for each material.

The environmental conditions of the left chamber were changed in three stages: (i) at the first 6 h, air temperature and RH were kept constant at 20°C and 85% respectively and the lamps were turned off. (ii) From the 6th to 18th hour air temperatures and RH was maintained to 35°C and 75%. During these hours, three lamps were turned on sequentially at 2.5 hour interval to simulate solar radiation at approximately 650 W/m². (iii) At the last stage, all the lamps were turned off and air temperature and relative humidity were changed to 20°C and 85% respectively. Right chamber was kept in a constant condition of 26°C temperature and 60% RH throughout the whole cycle. Wind velocity in both chambers was maintained constantly at 6-6.5 m/s at every cycle.

3.2. Results and discussion

Figure-9(a)-(c) show temperatures measured at different depth of uncoated, white painted and WSS mortar applied concrete block. Figure-10 compares the indoor surface temperature change for all materials for two continuous cycles. The estimated outdoor and indoor temperature and heat flux for each coating sample (except S11) are given in Figure-11. Thermal images and the temperatures recorded by the camera at pick sunlight hour (13th hour) are shown in Figure-12.

3.3. Comparison of the thermal performance

The maximum temperature during the pick sunshine hour was calculated and compared. It shows, the white coloured coatings in general have the ability to reduce
the surface temperature. The minimum value for outdoor surface was found for white uneven thermal barrier coating (S5), which can reduce the temperature up to 7.9°C than the uncoated concrete. S7, S6 and S8 reduce 6.4, 6.6 and 6.7°C respectively. The minimum inner surface temperature value was found for WSS particle (L) which can reduce 5.8°C than the uncoated concrete. Si2 and Si3 showed the two lowermost heat flow rate (76.3 & 81.2 W/m²) which is almost one third of the heat flow rate of uncoated concrete.

4. Conclusion
The first experiment shows that, uneven white coating, dirt resistant white coating and silver spray have higher reflectance and lead to considerable surface temperature reduction. WSS mortar didn't show that much effectiveness in this case. But in the periodic experiment WSS particle coating was found to be a better solution to reduce indoor temperature compared to the thermal insulation paints. This phenomenon occurs because the particles of siliceous shale are comprised of a lot of mesopores which could lead to high capability to keep surface moisture from vapor adsorption, especially during night time. Figure-13 shows that WSS can absorb vapor at a ratio of approximately 290 mg of water per gram of dry material. During daylight hours latent heat is released from evaporation and helps lowering surface temperature. The hygroscopic behavior of WSS can play an important role in buildings, as they have an influence on moisture content by extracting moisture from air.

5. Future work
Periodic experiment of S11 is not finished yet. After the periodic experiment, the performance of porous materials in terms of moisture transfer and the ratio of moisture and rainwater absorption quantity to evaporation quantity will be introduced. Numerical evaluation of simultaneous heat and moisture effect will also be studied. Further research regarding the point of investment including the labor and maintenance cost of thermal insulation paint, WSS mortar and particle coating and a thin layer of insulation material on inside wall will be done to compare and find the best solution for indoor thermal cooling.

Reference