A comparison of diurnal variation of pavement albedo between vertical and horizontal surfaces under tropical climatic condition of Thailand

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Abstract. Albedo is an important indicator of radiation reflectance of pavement surfaces for the building envelope and on the ground level, and their resultant impacts on human comfort and the urban environment in outdoor spaces. Usually, albedo is generally accepted only for horizontal surfaces. This study developed an experimental test set-up for the albedo measurement system with pyranometers and automatic meteorological data acquisition system, which used it to conduct field measurements of albedo on horizontal and vertical surfaces of the used concrete block. The results show that albedo measured on a horizontal surface is not proportional to irradiance on a vertical surface. The albedo value between the two surfaces depend upon time of day, and the horizontal surface also received significantly more incident solar radiation than the vertical surface during all but the central hours of the day, while at reflected solar radiation on vertical irradiances were less than the horizontal. These results can help reduce the uncertainty in understanding and evaluating the thermal behaviour of the building and environmental impacts of pavement surfaces with different albedos in the outdoor urban space.

1. Introduction
The most climatic condition of Thailand is tropical savanna climate that corresponds to the Köppen climate classification categories "Aw" in the northern hemisphere [1]. Moreover, a large percentage of Thailand’s urban areas is covered with a high density of pavement and increasing in the pavement surfaces, which are contribute to significantly creation of the surface urban heat island (UHI) by solar radiation [2,3]. When the pavement is exposed to the solar energy emitted by the sun ray, some of total solar radiation on pavement surface is reflected back into the air, and some is absorbed by the pavement, which will lead to temperature rise in the surface pavement and higher temperatures of urban area than that of rural area [4,5]. In the northern hemisphere, the winter sun (November, December, January) rises in the southeast, transits the celestial meridian at a low angle in the south (more than 43° above the southern horizon in the tropics), and then sets in the southwest. A vertical surface facing south of building is effective for capturing solar thermal energy [6], and the sun ray is a major factor in the heat gain of buildings which can create thermal effects on urban environment.
Thus, albedo (or solar reflectivity) is an indicator of the reflecting power of a surface and a key thermal characteristic, which defined as the ratio of the reflected solar radiation to the incident solar radiation at the surface [7], and is generally accepted only for horizontal surfaces [8]. An albedo of 0 means no reflecting power of a perfectly black surface (none reflected, all absorbed), an albedo of 1 means perfect reflection off a perfectly white surface [9]. Incident irradiance on a non-horizontal surface (from any surface position of vertical or inclined) from a variety of incident angles may cause the reflectivity can change. Assumptions about the reflectivity of a vertical surface are frequently made for a variety of wall surfaces usually found in urban buildings. In this work, the relation between albedos on a horizontal surface, and that on vertical surface facing directly south of the used concrete blocks (the whole measurement system is shown in figure 1), has been investigated under ideal conditions throughout a single day with a diurnal range of zenith angles and also to examine diurnal changes in albedo.

2. Research Methodology
Reflectance measurements on vertical and horizontal surfaces was measured throughout a cloudless day (24 January 2020, as in the winter time in the northern hemisphere) at 7th floor rooftop of the Faculty of Architecture and Planning building at Thammasat University (Rangsit Campus) (14.06° N, 100.61° E), using a dual-pyranometer is composed of two S-LIB-M003 silicon pyranometer sensors with a measurement range of 0 to 1280 W/m² over a spectral range of 300 to 1100 nm and HOBO automatic meteorological data acquisition system (as shown in figure 1(c)), and measure distance of 40 cm from base of the sensor to sample. Two types of concrete blocks were applied on two-frame substrate of wood comprises a horizontal and vertical frames with 1.2x1.2 m, which is the reference material for comparison (figure 1(a), 1(b)). The climatic data (including air temperature, relative humidity, wind speed and direction) during the measurement period were also monitored using a nearby HOBO weather station. During the measurement day of January 24th 2020, temperature daily highs to be around 35 °C with humidity averages just under 90%, prevailing wind are mostly south direction. The climatic conditions on an experimental day in this study is summarized in figure 2(a). To ensure that the measurement location had the efficiency surface solar radiation under clear sky condition as that obtained by using the 180° fisheye lens to take a test point image. This study calculated the sky view factor (SVF) value in RayMan Software, as the percentage of level of sky clearness at a measurement point. As shown in figure 2(b), it is expressed as a 9.2% value of the horizon limitation, representing the measurement location located at the relatively open area. The sun path diagram shows the sun rise in the southeast and sets in the southwest. At noon, it looms in the middle of the horizon and directly south.
Figure 1. Illustration of (a) two types of used concrete blocks with different size, and (b) installation of a dual-pyranometer to measure incoming and reflected solar irradiance of pavement, (c) which can be recorded together automatically using a data logger.

Figure 2. (a) The climatic conditions on an experimental day, and (b) sun path diagram and the SVF percentage of the measurement location in January 24th, 2020.

3. Results and Discussion

3.1. Diurnal-albedo due to surface types
The measured albedos are illustrated in figure 3 on all surfaces using a boxplot, gives an even clearer illustration of this variation of albedo across these two surfaces. The results show that a horizontal surface, which is facing directly south, has lower albedo than a vertical surface with the diurnal-mean albedo are 0.43 and 0.45, respectively. The relatively low albedo of horizontal surface will absorb more incident solar radiation, and produce a high temperature. In contrast, a vertical surface generally has a higher albedo, which will reflect more incident solar radiation and produce a lower pavement temperature.

| Statistics of diurnal-albedo | South facing vertical surface | Horizontal surface |
|-----------------------------|-------------------------------|--------------------|
| Mean                        | 0.45                          | 0.43               |
| SD                          | 0.06                          | 0.05               |
| Median                      | 0.46                          | 0.44               |
| Min                         | 0.34                          | 0.26               |
| Max                         | 0.61                          | 0.48               |
| Max-Min                     | 0.28                          | 0.22               |

Figure 3. Boxplot and summary statistics showing the surface variations of diurnal-albedo of concrete blocks measured on January 24th, 2020.

3.2. Effect of solar radiation intensity on diurnal-albedo
The incident and reflected radiation of the concrete block pavement surfaces were measured respectively on January 24th, 2020. The results of radiation at every ten minute were shown in figure 4. It can be
clearly seen that the incident solar radiation intensity fluctuated violently even within ten minutes on both vertical and horizontal surfaces. As expected, the incident solar radiation at the vertical surface (calculated between the local sunrise (6:45 am) and sunset (6:19 pm) times) ranging from 13 W/m² to 568 W/m² is much lower than that at the horizontal surface ranging from 24 W/m² to 852 W/m². However, the reflected radiation measured at the vertical surface is in the range of 9 W/m² to 244 W/m², which is close to the reflected radiation measured at the horizontal surface ranging from 8 W/m² to 368 W/m². This implies that the incident angle has effect on the measured albedo. In the case of horizontal surface is plotted in figure 4(b), a higher albedo will be given on the early morning or late afternoon, and relatively constant around the middle of the day (11:00 am to 3:00 pm).

Measured albedo changes over time during day on a south facing vertical surface, it is high in the early morning and then lead to a continuous decline in the late afternoon when there is a low incident angle of solar radiation as in the early morning (see figure 4(a)). The position of the early morning sun means that direct solar radiation is positioned to fall more directly on the south facing vertical surface, causing maximum reflection of the incident solar radiation to the detector for a south facing orientation. The decrease in diurnal-albedo value is due to the change in sun azimuth from morning to afternoon, where the direct solar radiation falling on the vertical surface has decreased due to the westerly progression of the sun through the sky. This was also observed by Webb et al. [10] and Turner et al. [8] when investigating irradiances falling on vertical surfaces in the southern hemisphere.

![Figure 4](image_url)

**Figure 4.** Diurnal variation of solar reflectivity on concrete blocks in January 24th, 2020 for (a) south facing vertical and (b) horizontal surfaces.

4. Conclusion
An experimental test set-up for the albedo measurements presented in this study are for a single day in winter time in the northern hemisphere at Thailand. The diurnal variation of albedo determined from the dual-pyranometer measurements on vertical and horizontal surfaces is analysed. The results illustrate the changing nature of albedo on a south facing vertical surface compared to that of a horizontal surface. The study found that the sun have higher incident solar radiation at large albedo on a horizontal surface of concrete blocks than a south facing vertical surface. The south facing receives comparatively little radiation at Thailand location. It may be because when the position of the sun is to the south it is also very close to the zenith position (the winter month of January), thus a vertical surface is far from normal to the direct beam [11,12]. These results take on a stronger connotation if extended to other seasons of Thailand. Additionally, a further study will be to perform a sensitivity analysis of the albedo enhancement of selected surfaces to reveal a more accurate assessment of urban climate of Thailand.

The measurement system in this study can be applied quantitatively to other pavement surfacing materials and conditions, but by studying what happens in these ideal conditions a more general qualitative pattern of albedos can be inferred and applied to other situations [13,14]. However, additional simulations need to be carried out to investigate the combined effects of simultaneously increasing
albedo of pavements and other building façade materials on urban climate and building energy use, and their impacts on human thermal comfort [15,16,17,18].

5. References
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