Experimental study on performance of outdoor ground materials in aspect of surface temperature by constant field experiment in subtropical climate city

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Abstract. In order to create a comfortable building thermal environment, it is important to study the outdoor ground materials performance. In this article, we carried out a constant field experiment in Guangzhou, China, studying on the variations of the surface temperature of three common outdoor building materials: concrete, pavement and grass. We put the equipment on six experiment points respectively to measure the ground surface temperature constantly. The result shows that because of the specific heat capacity, both concrete and pavement have an obvious time delay during their temperature decrease when the grass ground has almost no time delay. And when in the same conditions (exposed to sunlight all day), the material with a low specific heat capacity has a more sensitive variation in temperature. The lower the specific capacity is, the steeper the variation trend of the surface temperature will be. So compared with concrete, the pavement brick ground with a low specific heat capacity has a higher surface temperature in daytime and a lower temperature in the late night time. When in different conditions (different time exposed to sunlight), the temperature value is proportional to the time exposed to the sunlight between the same materials. The concrete exposed to sunlight all day has the highest temperature when the shaded one has the lowest. This experiment reveals that both specific heat capacity and the exposed time to sunlight has a strong influence on the surface temperature of outdoor materials. In subtropical region, the materials with a higher specific heat capacity and a less time exposed to sunlight may be more beneficial to the building thermal environment.

1. Introduction
The outdoor thermal environment has become increasingly important on building design. The thermal comfort experience has a directly influence on how much time people spend out the room, especially in hot or cold region, which indirectly effects people’s physical health. What’s more, according to the Report of the Development of the International Energy in 2017, the proportion of primary energy consumption in China is up to 62%, so if people can spend more time out the house, kinds of energy consumption such as air conditioning, lighting or warm heating can be reduced, which can make contributions to the reduction of world energy. A great attention has been paid on how to create a suitable outdoor thermal environment.
As for how to improve the outdoor thermal environment, various kinds of experiments have been done. Ryozo Ooka et al studied the thermal environment of apartment block in Shenzhen through simulation and field measurement [1]. Uehara Kiyoshi et al carried out the wind-tunnel experiments in order to improve the natural ventilation of a street-canyon [2]. Akira Hoyano et al clarified characteristics of the summer thermal environment in an actual membrane structure by field measurements and simulations [3]. Xi et al had done some researches mainly on the influence of human-built elements and the outdoor thermal environment and thermal environment of piloti [4-7].

Besides the studies above, there are also a lot studies on the specific factors which can influence the building thermal environment. Yue et al revealed that the urban water landscape has some effects on the thermal environment [8]. Somsak Chaiyapinunt et al had invested different types of glass window to study the influence of it on the thermal comfort and heat transmission [9]. Elisa et al studied on the roof and presented an assessment of the effectiveness of cool and green roof on order to improve the thermal comfort [10]. Mohamad et al studied the thermal performance of a special wall aiming at examining the energy behavior of the buildings’ multi-layer exterior wall structures [11].

As for materials, many studies related to its effect on the outdoor thermal environment, have been done. But studying on the property of material itself is few in number, let alone the specific data or any constant field experiment. This paper has studied on the performance of ground materials itself via a constant field experiment and present a set of specific data, which offers good references for researchers in further research.

2. Methodology

2.1. Experiment points

The experiment is conducted in the campus of South China University of Technology, Guangzhou. Guangzhou is located in the subtropical region where the winter is short, summer is long. So it is important to study the summer outdoor thermal environment to satisfy the outdoor experience. Because of the typical subtropical climate, the sunlight there is really strong, ground materials receive more solar radiation which can directly influence the ground surface temperature. So it is reasonable to choose Guangzhou city as the experiment site.

In order to compare the different materials performance, six measurement points have been chosen (figure 1). As is shown in the picture, both point 1, 2, 3, 5 are concrete ground. Point 1 is located on an open square where can receive the sunlight all day. Point 2 is located under a piloti shaded from the sun all day. Point 3 is located in building block which is shaded only in the early morning. Point 5 is located under a piloti and only can be exposed to sunlight half the day. And point 4 is pavement brick ground located near a river where can be exposed to sun all day. Point 6 is the grass ground located on an open square, 500 meters far away from other 5 points, exposed to sun all day.

![Experiment site](image)

**Figure 1.** Experiment sites.

2.2. Experiment method

The experiment lasted for 2 whole days, starting on 9:00 am, 4th July, 2009. The equipment is BES-02.
BES-02 is a kind of temperature and humidity collection recorder which can measure the temperature and humidity simultaneously. You can use the computer to preset parameters such as the time to start or to end the measurement. And when the measurement is over, you can download the measure data through PC. As for the experiment method, we put the equipment on each measurement point respectively to measure the temperature at almost the same time. The surface temperature data of all points is constant during the experiment. In order to exclude the interference of the radiation influence, all sensors were covered by the same materials of the experiment ground. Then a piece of sliver paper was put on it. For example, from point 1 to point 5, the sensors were covered by cement powder and the sensor in point 6 were covered by grass (figure 2). This method to exclude the interference of the radiation influence has been used in many studies such as the experiment held in Guangzhou by Xi [6]. The more specific information about the equipment can be seen in table 1 below.

![Figure 2. View of experiment.](image)

Table 1. Information of the equipment.

| Equipment | Production Place | Operating system | Measurement range | Measurement accuracy |
|-----------|------------------|------------------|-------------------|----------------------|
| BES-02    | China            | Windows2000/XP   | -30°C-50°C        | ≤0.5℃               |

![Figure 3. Environment data.](image)

(a) temperature and humidity  
(b) mean radiation temperature

3. Experiment analysis

What is shown in figure 3 is the simultaneous air temperature and humidity of point 1 in two days and
the mean radiation temperature of point 1 in 5th July. The mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure [12]. MRT is an important factor to estimate the building thermal environment. We can see it from the picture that the temperature in Guangzhou can reach almost 40°C in summer. The humidity of it is also high, the peak value is almost 80%. That is all because Guangzhou is in the typical subtropical climate zone where the temperature and humidity there are usually high. So just as the picture shown below, the value of mean radiation temperature of point 1 is large.

The specific heat capacity values of three materials can be found in table 2 below. We can see that the specific heat capacity of pavement brick is a little bit lower than concrete.

| Material          | Specific heat capacity (J/kgK) |
|-------------------|--------------------------------|
| Pavement brick    | 840                            |
| Concrete          | 880                            |
| Grass             | 850                            |

All the measured ground temperature was plotted in figure 4. As is shown in figure 4, when compared with the other side of the peak line, all the human-made materials have a time delay when their temperature begins to decrease. Because point 2 is shaded from the sunlight all day, so the temperature fluctuations of it are very small but it still can be found. And compared with the human-made materials, point 6 (grass surface) almost has no time delay.

![Figure 4. Surface temperature of all measured points.](image)

For a more intuitive comparison, we take out point 1, point 4 and point 6 into one picture (figure 5) to compare the surface temperature of three different kind of materials when they are in the same conditions (exposed to sunlight all day). We can see it clearly from the picture that the material with a low specific heat capacity has a more sensitive variation in temperature. Both the trend of temperature variations and the temperature value of the three points are different. The pavement brick with a lower specific capacity (840 J/kgK) has a higher value and a steeper variation trend than the concrete. What’s more, compared with other two points, point 6 has a faster increasing temperature and a relatively stable variation trend.

To compare the temperature variations of the same materials in different conditions (the time exposed to sunlight is different), we make point 2 (under piloti, without any direct sunlight) as the standard. As is shown in figure 6, though the specific heat capacity of the three points is the same, the value of temperature is different which is because the different time exposed to sunlight. Point 2 (shaded...
all day) has the lowest temperature value when point 1 (exposed all day) has the highest. Point 3 (shaded in the early morning) is a little bit lower than point 1. As for point 3, shaded half the day, has the middle temperature value and an earlier temperature decreasing.

![Figure 5. Surface temperature of point 1, 4, 6.]

![Figure 6. Standardized temperature value of point 1, 3, 5.]

4. Experiment conclusions
This work studied the surface temperature variations of three common building materials. The result shows that both the specific heat capacity and the exposure to the sunlight have a strong influence on materials’ surface temperature. Because of the specific heat capacity, all the human-made materials (concrete, pavement brick) have a time delay. According to the experiment data, the material with a low specific heat capacity has a more sensitive variation in temperature. Compared with the concrete (exposed all day), the pavement brick (exposed all day) has a higher temperature in daytime and a lower temperature in late night time. And the variation trend of it is much steeper. Besides, the time exposed to the sunlight has a strong influence on the value of surface temperature. For the same materials, the temperature value is proportional to the time exposed to the sunlight which is showed clearly between all the concrete points. What’s more, compared with other two materials, the grass ground has almost no time delay and shows a relatively stable variation trend of temperature. That might be an advantage to building a comfortable thermal environment in subtropical region.

The result of this study hopes to have a good influence on the designers on how to use the materials properly in outdoor design. Especially in subtropical region, the materials with a higher specific heat
capacity may be more beneficial to the building thermal environment. And in order to get a lower temperature, designers should reduce the time of the materials exposed to the sunlight through designing method.

This experiment was held in Guangzhou, a typical subtropical region. The specific heat capacity and the exposure to sunlight are two major factors that we considered which can influence the surface temperature of the ground. However, besides the two aspects, there are many other factors that also have a strong influence on ground surface temperature such as the convective, conductive and radiation heat transfer. So the present work of this article is a little bit objective to some extent and more studies should be done in the future.

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