Effect of pavements albedo on long-term outdoor thermal comfort

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Abstract

The outdoor thermal environment is impacted by the built environment, e.g. anthropogenic heat, evaporation and evapotranspiration of plants, shading by trees and man-made objects, and ground surface covering, such as natural grass and artificial pavement. Due to the albedo of pavements affect the quantity of global radiation reflected to the sky, the pavement with low albedo value is one of the main factor causes the high air temperature and thermal uncomfortable for human beings. Therefore, this research focus on 4 different pavements, i.e. grass, interlocking blocks, concrete and asphalt, located in university campus, measuring the albedo value and other thermal physical parameters. The net radiation is measured by CNR1 with up and down side short- and long-wave radiation. The field experiments are conducted in different season and the albedo value of each pavement are calculated. Meanwhile, the long-term thermal comfort is calculated in the RayMan model which has been calibrated with the local climate. The analytical result indicated that the low albedo pavement (i.e. asphalt) contribute longer period for hot hours (PET > 42 °C) than the high albedo ones (i.e. grass). The result could be applicable in the design of outdoor environment for the mitigation of urban heat island and improvement of human's thermal comfort.

1. Introduction

Outdoor thermal environment factors, such as air temperature, air humidity, wind speed, and solar radiation, affect evaluations of thermal comfort, e.g. thermal perception, preference and satisfaction. Studies conducted in temperate regions showed that many people visit outdoor urban spaces when the thermal conditions is high in both winter and summer (Nikolopoulou et al. 2001; Thorsson et al. 2004; Thorsson et al. 2007). However, research conducted in hot and humid regions indicated that few people visit squares or other public spaces when the thermal index is high (Lin 2009). The largest numbers of people visit squares when the thermal condition is close to their thermal comfort range. Therefore, outdoor thermal environments affect evaluations of thermal comfort and usage of outdoor spaces; the degree of impact varies with the thermal requirements of people in different climatic regions.

In general, outdoor thermal environment is impacted by the built environment, e.g. anthropogenic heat, evaporation and evapotranspiration of plants, shading by trees and man-made objects (Lin et al. 2010), and ground surface covering, such as natural grass and artificial pavement. Due to the albedo of pavements affect the quantity of solar radiation reflected to the sky, the pavement with low albedo value is one of the main factor cause the high air temperature and thermal uncomfortable for human beings.

Previous studies have generally performed field experiments on only a few days to investigate how pavement affect thermal environment. However, such experimental results merely elucidate the characteristic measured (or simulated) on a particular day and may not represent annual thermal conditions. On the other hand, tolerance of outdoor

thermal environments also varies for people in different climates, and they have different thermal perception given by the same thermal environment (Nikolopoulou and Lykoudis 2006; Lin and Matzarakis 2008). Therefore, one must discuss long-term thermal comfort based on the thermal requirements and characteristics of local residents.
The aim of the research is to realize the albedo value of some popular ground surface by field experiment. The long term thermal comfort is then calculated and the threshold of each thermal perception in Taiwan is then applied to understand the effect of pavement on long-term thermal comfort of for local people.

2. Method

2.1 Field measurement

This research focus on 4 different pavements, i.e. grass, bricks (red), concrete (gray) and asphalt (black), located in at the National Formosa University (NFU) campus in Taiwan. The physical microclimate parameters, i.e. air temperature, relative humidity, globe temperature, wind velocity/direction, direct/reflect short- and long-wave solar radiation. All the parameters are collected in a one-minute interval from 8:00 to 17:00 through the conducted day. The albedo value is calculated by the proportion of reflected short-wave solar radiation over long-wave radiation.

Fig. 1: The instrumentation of the filed experiments

2.2 Assessment of Outdoor Thermal Comfort

Several indices integrating thermal environmental factors and heat balance of the human body are applied for accessing thermal comfort. As PET is already included in the VDI

(German Association of Engineers) guideline 3787 (VDI 1998) for human biometeorological evaluation of climates in urban and regional planning, and has been employed in several studies of outdoor thermal comfort (Andrade and Alcoforado 2007; Oliveira and Andrade 2007; Thorsson et al. 2007). PET was adopted as the primary thermal index in this study. PET is estimated using the RayMan model, which has been used in urban built-up area with complex shading patterns and generated accurate predictions of thermal environments (Matzarakis et al. 1999; Gulyas et al. 2006; Lin et al. 2006; Matzarakis et al. 2007)

2.3 Thermal sensation classifications for locals

To account the subjective thermal perceptions under different PETs, one must define the PET ranges in which local people feel comfortable, i.e., the "thermal comfort range" for the PET. To estimate the thermal comfort range of Taiwan's residents, this study uses the data from an outdoor field study that conducted 1644 interviews in Taiwan (Hwang and Lin 2007; Lin and Matzarakis 2008). Table 1 is the thermal sensation classifications for Taiwan, combined with classifications for people living in Western/middle European climates (Matzarakis and Mayer 1996)

Table 1: Thermal sensation and PET classes for Taiwan and Western/Middle European classes. (Source: Lin and Matzarakis, 2008 Matzarakis and Mayer, 1996)

Thermal sensation	PET range for Taiwan **(°C PET)**	PET range for Western/middle European **(°C PET)**
very cold		
	14	**4**
Cold		
	18	**8**
Cool		
	22	**13**
Slightly cool		
	26	**18**
Neutral		
	30	**23**
Slightly warm		
	34	**29**
Warm		
	38	**35**
Hot		
	42	**41**
Very hot		

2.4 Long-term thermal comfort evaluations for different pavements

After validation of the RayMan model, long-term meteorological data from weather stations are imported into the model with each albedo settings for predicting long-term variations in thermal environmental conditions and thermal indices. The meteorological data applied in this study were from the nearest weather station, which is located in Chiayi. Hourly data for the 10-year period of 1998–2007 were selected. The parameters imported into the RayMan model were the air temperature, air humidity, wind speed and mean cloud cover. The albedo value for each pavement is obtained by the field experiment.

3. Results and discussion

3.1 Mean albedo value of each pavement

Fig. 2 is the mean albedo value of 3-5 field experiments for each pavement. The grass (albedo=0.177) have the highest value among the four pavement while the asphalt (albedo=0.087) have the smallest.

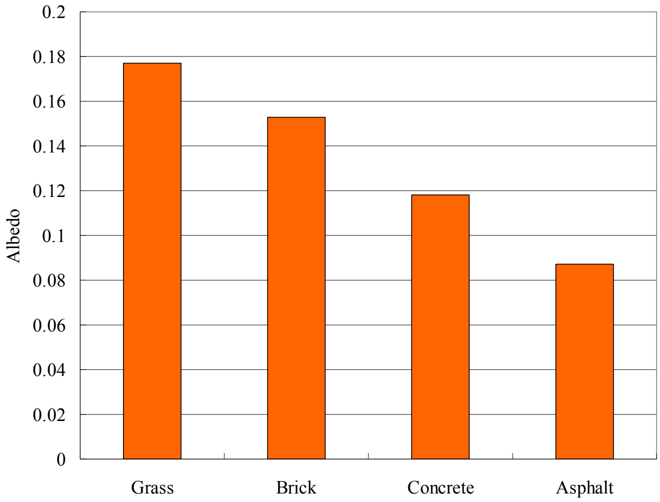
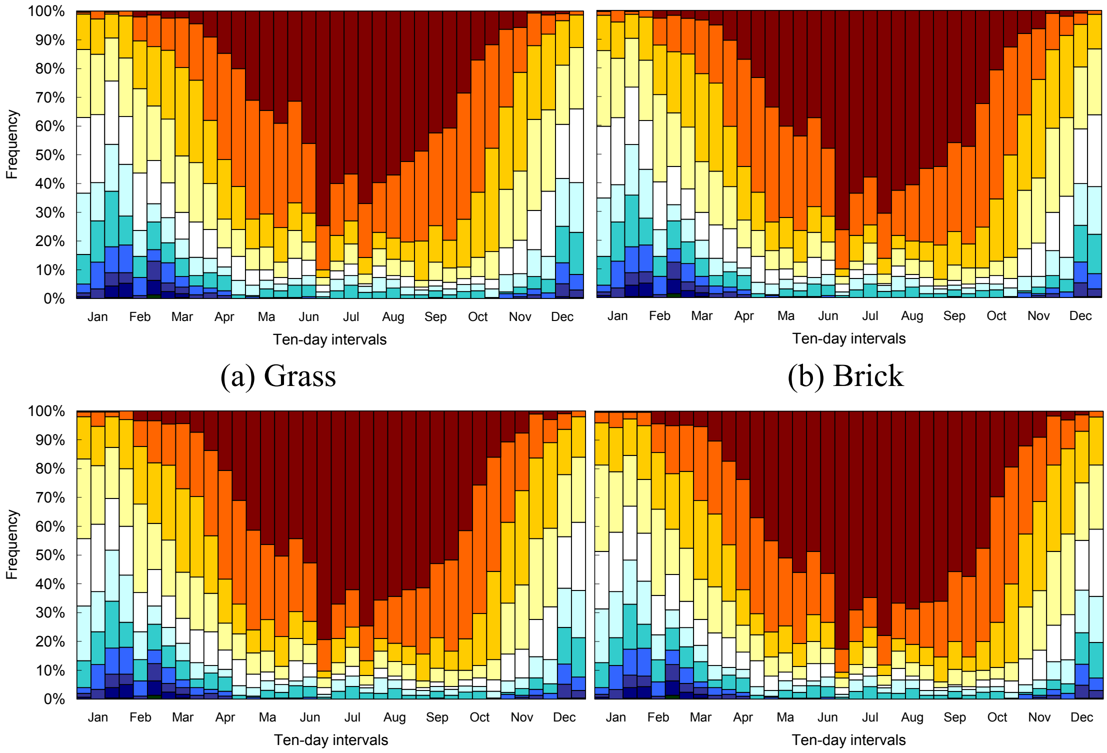


Fig. 2: Mean albedo value of each pavement

3.2 Frequencies and of long-term thermal comfort

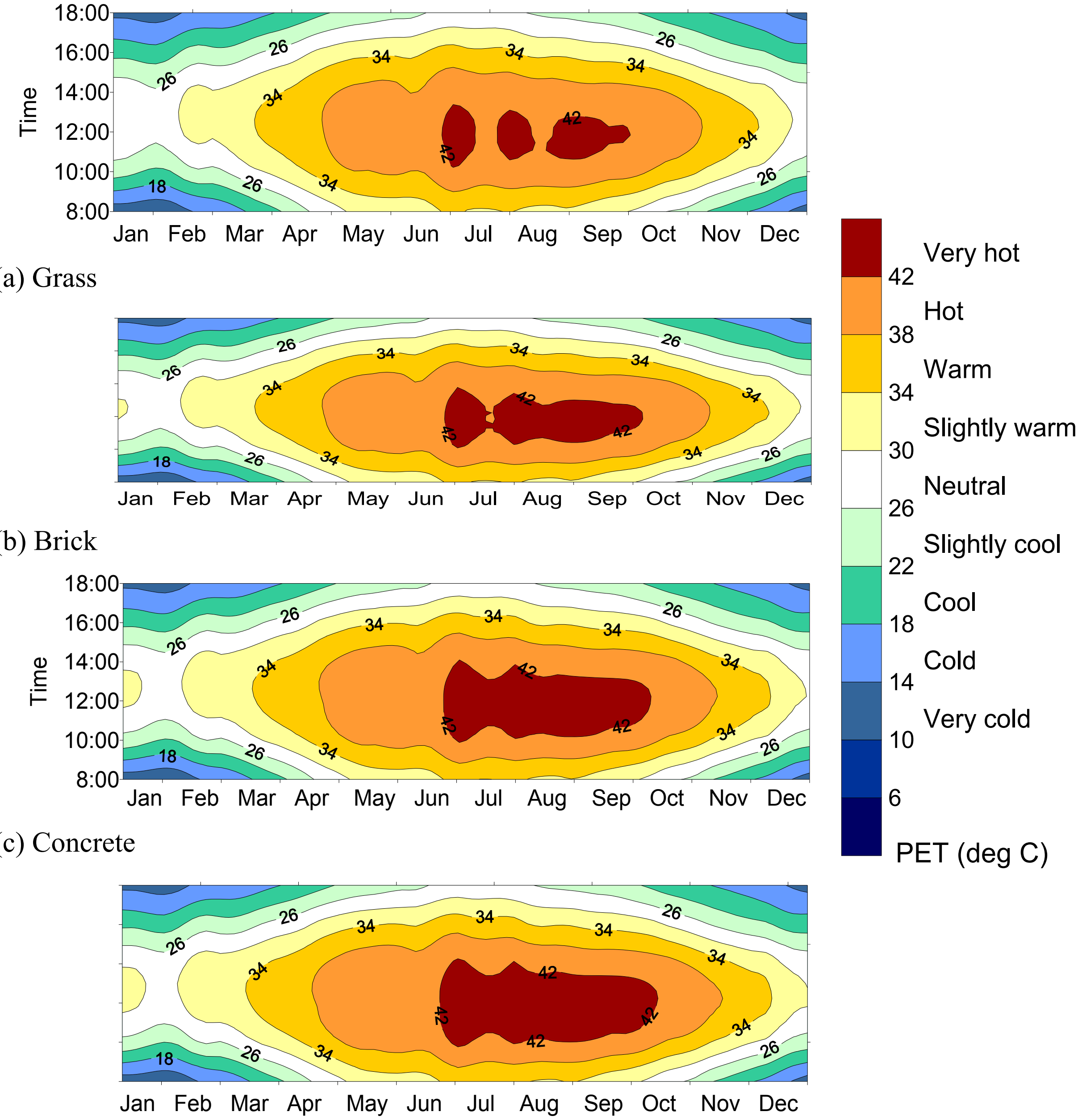
Figures 3 show modelled PET frequency distribution graphs for each pavement in the noon (10:00–14:00) during 1998–2007 at 10-day intervals. Owing to that the frequency maps are almost the same while 24 hour data of each day is presented among the pavements; only the noon time data, i.e. 10:00–14:00 are displayed in this figure. As shown in fig 3, however, the results still almost the same for each pavement. Slightly differences occur in the frequencies of PET > 42 °C (very hot) among each pavement. Asphalt have the highest frequencies of PET > 42 °C while grass have the relative low frequencies.



(a) Grass (b) Brick

(c) Concrete (d) Asphalt

Fig. 3: Estimation of annual PET frequencies at 10:00-14:00 during 1998-2007



(a) Grass

(b) Brick

(c) Concrete

(d) Asphalt

Fig. 4: Estimation of annual PET contour maps at 8:00 - 18:00 during 1998-2007

3.3 Annual distribution long-term thermal comfort

From figure 4, it is more obvious to find the differences among each pavement. The area of PET>42 are largest for asphalt while the grass got the smallest PET>42 area. The comparative results indicate that the albedo value indeed affect the long-term thermal comfort, especially for the high temperature conditions.

4. Conclusions

This study conducted field experiment on four types of pavements to obtain the albedo value through the measurement. Although the estimated long-term frequencies of PET are similar for each pavements, the significant differences exist among the occurrence of PET>42, i.e. very hot condition for Taiwanese people. The results indicate that high albedo pavement (or ground covering), i.e. grass, and will help to mitigate the hot condition. The results are also helpful for the outdoor environment design for the increased problem of urban heat island and global warming.

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