THE EFFECT OF PERMEABLE PAVEMENT USE ON AIR TEMPERATURE OF SURROUNDING BUILDING

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ABSTRACT

This paper describe how permeable pavement effects day time and night time thermal environment during summer in subtropical Taiwan. The experiment was carried out on one type of conventional pavement (dense grade asphalt concrete/DGAC) and three types of permeable pavements (permeable asphalt pavement/PAC, concrete, grass block/ GB, and permeable interlocking concrete block/PICB) used 2012 data on summer time (June-September). The result shows that there were surface temperature differencesamong the four types of pavement, particularly during at noon. The use ofpermeable asphalt pavement decreasesthe temperature up to 0.571°C, and up to 10.042°C, and 8.402°C when using GB and PICB, respectively.During the night, there was no difference between DGAC and PAC, while the GB and PICB decreased up to 6.265°C and 5.521°C, respectively.The result also shows that pavement surface temperature affects outdoor and indoor temperature particularly on the 1st and 2nd floor.

Keywords: *permeable pavement, traditional pavement, air temperature, CFD simulation, Design Builder*

INTRODUCTION

The urbanization process increases artificial surfaces and less natural vegetation, decreases the albedo, increases metabolic heat and resulting in heat island effect(Ferguson,2005). Pavements are considered to be the one contributing factor to the Urban Heat Island (UHI).

Permeable pavements are recommended as a strategy to mitigate heat island effect by cooling the environment. When wet, permeable pavement can lower temperature through evaporative cooling (Lin, 2013). When dry, the larger voids in permeable pavement increase the available surface area. This condition may limit heat transfer to the lower pavement structure and soils, keeping heat at the pavement’s surface (and increasing daytime surface temperatures), but reducing bulk heat storage (reducing release of heat at nighttime). **Figure 1** illustrates the comparison between permeable and traditional pavements. In general, there are three types of permeable pavement that commonly used on the field: permeable asphalt concrete pavement, pervious concrete pavement, and permeable interlocking concrete pavers.

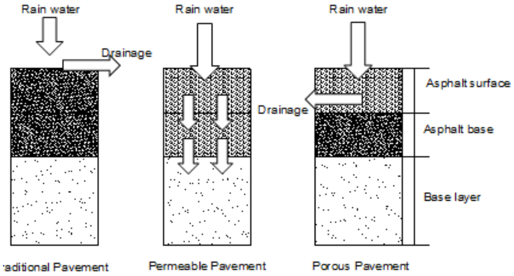

Figure 1. Comparison between permeable and traditional pavements (Lin, 2003)

Weather factors like wind speed, air temperature, relative humidity, and irradiation affect the pavement temperature. The different weather condition on day time and night time results in different pavement behavior during day time and night time.

This research examines the effect of permeable pavements and traditional pavement behavior on day time and night time during hot summer for achieving better outdoor and indoor thermal environments in Taiwan. Due to the differences between urban and suburban areas in Taiwan, the percentage of impervious area cause of the heat island effect. Therefore, this study helps to clarify the effect of pavement on the microclimate of outdoor and indoor environments, and help in releasing the heat island effect in the future.

METHODOLOGY

This study used three types of permeable pavements (PAC, GB, PICB)which were measured and compared with traditional pavement (DGAC). Site measurement was conducted to collect meteorological and pavement surface temperature data.

Permeable pavement experimental area in the Ministry of Economic Affairs Water Resources Agency, Xindian, New Taipei City, Taiwan was used to collect data for permeable pavement and dense grade asphalt surface temperature, also meteorological data (air temperature, relative humidity, wind velocity, and irradiance) of the area. Easy weather station, thermocouple, and data logger were installed on the site (**Figure 2**). The data was taken for 2012 summer time (June-September).

Other measurements were conducted at Civil Engineering Building, National Central University (NCU), Jhongli, Taiwan to obtain actual data of pavement, wall, roof surface temperature, and meteorological data of NCU.T-type thermocouple, easy weather station, and data logger were installed on the site (**Figure 3**).

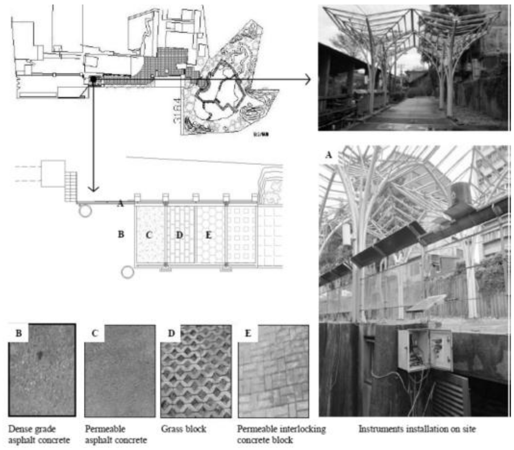

Figure 2. Photo and site plan of the permeable pavement experimental area in Xindian

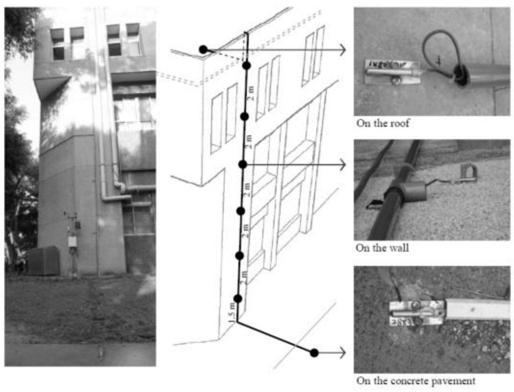

Figure 3. Installation of measurement instruments on Civil Engineering building

This study used one daily maximum temperature from NCU site measurement to represent the hottest temperature of the year.

Correlation analysis was used to examine the correlation between variables and multiple regression was used to develop the pavement surface temperature model. The model along with meteorological data from NCU was used to approximate the surface temperature of permeable pavement when it is being utilized around NCU main library building. The impact of permeable pavement surface temperature on outdoor and indoor air temperature was investigated using Computational Fluid Dynamics (CFD) simulation in *DesignBuilder* software. Simple model of building blocks, as seen in **Figure 4**, is made with size 25m x 50m with height 3.96m for each floor and consist of 8 blocks represents 8 floors of the real building. Pavement area around building is designed to be 60m x 80m.

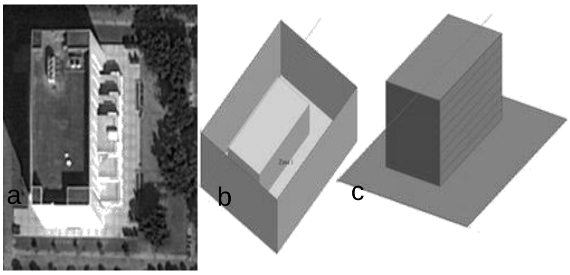

Figure 4. Picture of NCU main library (a) Building Model for CFD outdoor simulation(b) building model for cfd indoor simulation (c)

Table 1 indicates the geometric characteristics of the pavements and the corresponding thermal properties. Materials for each layer of pavement are chosen from DesignBuilder data library based on its thermal conductivity. Due to DesignBuilder limitation, the thickness of soil is made only 0.5 m, and others were based on the original pavement thickness.

Outdoor and indoor temperatures affect thermal comfort. Improve thermal comfort important to decrease sick building syndrome symptoms, and improve work performance.

Table 1. Pavement materials setting for CFD analysis in DesignBuilder

Type	*Layer*	*Thickness*	*conductivity*	*Reflectivity*
DGAC	1. Asphalt	0.1	1.2	0.1
	2. Gravel	0.25	0.36	
	3. Soil-earth common	0.5	1.28	
	4. Gravel	0.1	0.36	
PAC	1. Asphalt	0.1	0.8	0.13
	2. Gravel	0.25	0.36	
	3. Soil-earth common	0.5	1.28	
	5. Gravel	0.1	0.36	
GB	1. Soil-earth, gravel	0.08	1.6	0.22
	2. Loosefill/powders-sand	0.04	1.74	
	3. Gravel	0.25	0.36	
	4. Soil-earth common	0.5	1.28	
	5. Gravel	0.1	0.36	
PI	1. Concrete	0.08	0.69	0.2
	2. Loosefill/powders-sand	0.04	1.74	
	3. Gravel	0.25	0.36	
	4. Soil-earth common	0.5	1.28	
	5. Gravel	0.1	0.36	

Comfort index calculation established by Central Weather Bureau Taiwan. Air temperature and dew point temperature should be the indicators of outdoor thermal comfort.Comfort index equation is as follows (Lee, 2012):

$$CI = T - 0.55\left[1 - \frac{exp\left(\frac{17.269\,Td}{Td + 237.3}\right)}{exp\left(\frac{17.269T}{T + 237.3}\right)}\right](T - 14)$$

Where:
CI = comfort index,
T = air temperature,
Td= dew-point temperature
Definition of the comfort index values are presented in **Table 3**.

Table 2. Comfort index values and definition

Comfort index	Definition
≤ 10	Very cold
11-15	Cold
16-19	Cool
20-26	Comfortable
27-30	Hot and humid
≥31	Prone to heatstroke

RESULTS AND DISCUSSIONS

Site measurement data analysis

Surface temperature and air temperature responds is represented in the changing of solar irradiance as seen as **Figure 5**. Solar irradiance presents the radiation power on a surface. It is associated with surface and air temperature. Irradiance pattern was different at daytime and night time. Irradiance increased after sunrise, and peaked in midday around 12:00-14.00, after that, it decreased steadily until midnight around 02:00-04.00. Therefore data will cluster into day time and night time by looking irradiance value. Day time include time from sunrise (irradiance >10 W/m^2) until sunset (irradiance <10 W/m^2) and night time from sunset until the next sunrise.

The correlation analysis between weather data (wind speed, wind direction, relative humidity, and air temperature) and irradiance showed that all weather factors except wind direction has relationship with surface temperature. Therefore, these variables were then used for surface temperature model building. Surface temperature prediction for four types of pavement was established using meteorological data from National Central University measurement. Surface temperature prediction for day time used meteorological data on July 20th, 2012 at 13:30 as the maximum daily temperature in summertime (wind speed = 0.815m/s, air temperature = 37.406, RH = 81.492, irr = 923.932), and for night time used meteorological data on August 17th, 2012 in 00:50 as the minimum daily temperature in summertime(wind speed = 6.843m/s, air temperature = 24.467, RH = 91.15, irr = 7.022).

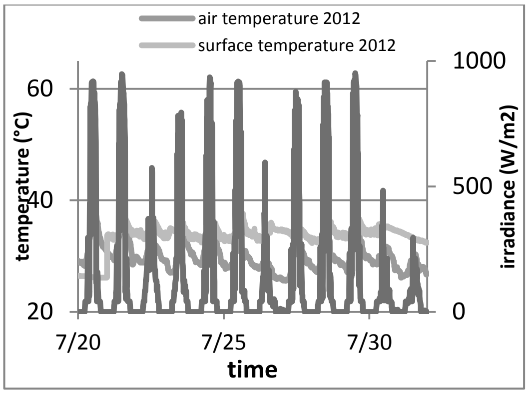

Figure 5. Temperature and irradiance profile

Table 3. Day time pavement surface temperature prediction on 20th July 2012, 13:30

	Surface temp. model	*S.temp (°C)*
DGAC	y=-104.726-5.367x1+1.091x2 +1.409x3 +0.01x4	53.369
PAC	y=-118.011-3.893x1+1.136x2 +1.596x3 +0.01x4	52.798
GB	y=-58.523-3.220x1+0.827x2 +0.867x3 +0.01x4	43.327
PICB	y=-34.177-4.923x1+1.121x2 +0.321x3 +0.017x4	44.967

At daytime, as shown in **Table 3** DGAC has the highest temperature, followed by PAC and PI, while GB has the lowest temperature. In night time, however, PAC has the highest temperature due to thermal conductivity, followed by DGAC and PI. GB still has the lowest temperature.

Table 4. Night time pavement surface temperature prediction on August 17th 2012 in 00:50

	Surface temp. model	*S.temp. (°C)*
DGAC	y=-447.393-1.798x1+0.881x2 +5.155x3 +0.010x4	31.807
PAC	y=-102.054-3.659x1+1.141x2 +1.440x3 +0.107x4	31.832
GB	y=-255.839-0.211x1+0.666x2 +2.924x3 -0.001x4	25.542
PICB	y=-174.410-0.400x1+1.050x2 +1.950 x3 -0.000x4	26.286

This results same with surface temperature pattern from Xindian Permeable Pavement Experiment Area. This surface temperature will be used to predict the outdoor and indoor wall temperature.

Effect of Pavement Surface Temperature on Outdoor Wall Temperature

The outdoor surface temperature of a building envelope component depends on ambient air temperature and surface transfer, absorption of short-wave radiation from the sun, and emission/absorption of long-wave radiation (Kehrer,2006).

Simulation was done by CFD analysis in DesignBuilder program. Meteorological data and pavement surface temperature prediction for 4 types of pavement from regression analysis on **Table 3 and 4**.

Wall temperature was different in every different wall height. The wall temperature was affected due to conduction. The 1st floor temperature was higher particularly in the day time. The 2nd floor temperature was lower because of the influence of surface temperature decrease on 2nd floor. While the 3rd to 6th floor temperature was higher with the increasing of wall height. The 7th and 8th floor have highest temperature at day time and lowest on the night due to the influence of the roof.

Effect of Pavement Surface Temperature on Indoor Wall Temperature

Different from outdoor wall temperature, indoor air temperature almost the same in all floor for 4 types of pavement in day time and night time.

From the simulation analysis it was found that the hottest air temperature is in the middle of the room, as shown in **Figure 7**. Maximum indoor air temperature was decreasing by the increase of wall height. But indoor wall temperature increased with the increasing of the wall height.

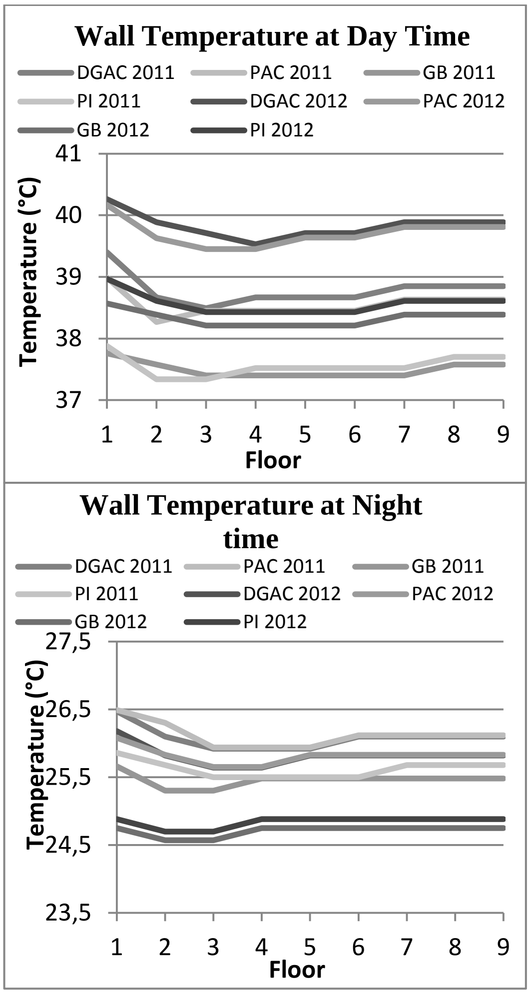

Figure 6. Outdoor Wall Temperature on Day Time and Night Time

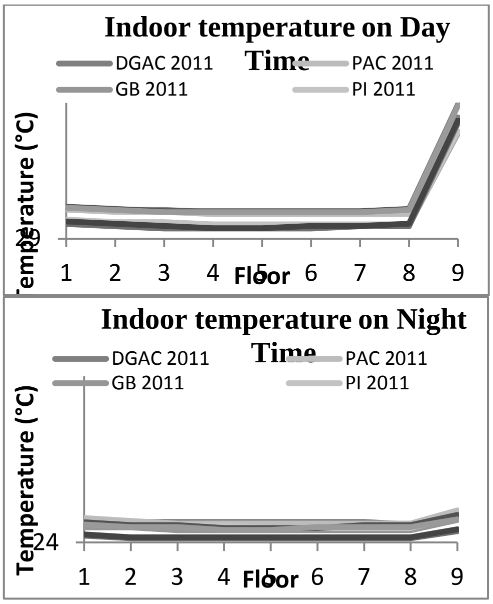

Figure 7. Indoor Wall Temperature on Night Time and Day Time withPavement Surface Temperature Effect

The Pavement Surface Temperature also affects the building temperature, particularly on the 1st floor and 2nd floor. In day time, DGAC caused the highest temperature, followed by PAC, PI and GB. While at night time, PAC caused the highest temperature for lower and high floor, followed by DGAC, PI and GB. Indoor air temperature differences for all pavement types are just about 1°C.

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

a) Surface temperature difference between four types of pavement was high at noon. DGAC is the highest (53.369°C), followed by PAC (52.798°C), PI (44.967°C), and GB (43.327°C).
b) At night all of types of pavement share almost the same temperature. The differences only vary around 1°C.
c) Wall temperature was different in every different wall height. Surfaces influence the wall temperature because of conduction especially for 1stand 2nd floors.
d) Indoor air temperature also follows the pattern of pavement surface temperature and outdoor wall temperature. Pavement Surface Temperature affects the lower floor. 1st floor and 2nd floor, but the differences between all types of pavements vary around 1°C.

Recommendations

a) This study simulates using 4 types of pavement, recommended to also simulate using real proportion of pavement and vegetation around building.
b) The presence of trees around building influences the distribution of incoming solar radiation in the wall. It is necessary to investigate tree effect to the building and pavement surface temperature and the shading effect due to trees.

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