Urban Open Space Pavement Design to Reduce Heat Island for Developing Eco-city in Hot Humid Zone

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Abstract

Climate pattern affects urban thermal effect of local microclimate which directly relating to urban heat island effect, however their impacts are different according to its climate zone. For instant, the urban heat island effect causes only minor problem in the city of temperate climate zone, but it does cause a serious problem in the city locates in hot climate zone due to higher and longer elevated temperature will increase more energy consumption for air-conditioners and space uncomfortable. In an urban area, open space such as parking lots and public plaza are very common, and their pavement materials and construction design will affect urban microclimate eventually. It is the reason urban open space paving design become a very important issue for developing an eco-city in the hot humid zone and need to study their impacts.

This paper studies four kinds of urban open space pavement designs in Taiwan, mainly car parking lot and urban public plaza. The pavement designs selected are permeable brick with grass paving, permeable RC paving, and asphalt paving. The field measurement are conducted during summer season and in daytime, and thermal parameters of temperature, humidity, and weather condition of the day are collected. By using this data a comparison and analysis are worked out and a proposed urban open space pavement design concept and a strategy for developing an eco-city of hot humid zone is concluded and suggested.

Keywords

urban heat island, microclimate, pavement, heat effect, hot humid zone

1. Introduction

Greenery and water are widely considered as the key elements of microclimate mitigation for building an eco-city, due to their advantage to decrease the problem of urban heat island, by using them into urban plaza space designs. Proven by some studies, urban heat island effect will cause 6% higher electricity consumption of air conditioners when an urban area in hot humid zone experiences 1℃ higher temperature, however it will cause only 3.6% higher electricity consumption in the temperate zone. Consequently, to decrease urban temperature 1℃ in hot humid zone will bring more energy saving as well as less carbon emission. In recent years, cost for electricity has been sky rocketing that once again alerts people to reduce the electricity bill for the air conditioners, especially for the people in Taiwan since it is in a typical hot humid climate area. This research is looking for further understanding to the ground surface pavement designs in urban area and their heat effect quantitatively through field experiment of real cases. As a result, a more detailed assessment factors should be identified, which will be used as a reference basis to develop ground surface improvement strategies and policies of minimizing urban heat island problem in order to become an eco-city.

2. Theory and Approach

2.1 Heat Effect in Hot Humid City

Hot humid zone on the Earth locates the area between latitude 30°N and 30°S, where experiences longer summer season about 6 months to 4 months with daytime temperature usually over 30℃ or even 35℃. The area latitude over 40°N or 40°S as temperate zone experiences only 2 months daytime temperature over 30℃ in summer time. Basically the uncomfortable condition of higher temperature in urban area intensified by the heat effect of urban heat island increases the negative impact on city in the hot humid zone, and this situation seldom happens to the city in the cold zone. As a conclusion, from the thermal comfort viewpoint, the change of urban ambient temperature and heat effect influenced by the urban heat island, will cause more worse negative impact to human body comfort as well as building air conditioning system power consumption in the hot humid zone. However the negative impact will be minor in the temperate zone and the impact becomes positive effect in the cold zone due to energy saving for less building heating needed. As a consequence, the impacts and

problems caused by open space heat effect due to the urban island during summer time in the hot humid zone are more serious and critical that needs to pay more attention about the factors relating to urban heat island. Besides, a proper design principle and strategy to rectify the drawback of current ground surface situation should be proposed.

According to a past study, it shows that in hot humid zone the average temperature in urban city is 4~5℃ higher than that in rural area because of the urban heat island, however it also expresses that some particular spots of the city only 1~2℃ higher than in rural area. This means that there are different microclimate among sub-areas in an urban area that is decided by the local elements of pavement, soil, vegetation, water body, topography, and landform. So that a proper design and arrangement to these elements is able to mitigate the microclimate of urban sub-area that might give an opportunity to reduce the disadvantage of heat effect caused by the urban heat island.

In fact, the pavement material, soil, vegetation, water body, landform, and topography of urban site are usually not designed regarding to the environment effect that results in the ground surface shrinkage of soil size and increased impermeable surface paving in urban area year after year. It seems the problems of space heat effect change due to more impermeable surface were seldom discussed and studied in the past. In addition to that, the reduced area size for vegetation or using less shading vegetation in urban city was also not much discussed in term of space heat effect. The same situation exists about water body which were eventually filled by foreign soil or covered with concrete slabs that changes the heat effect of the urban sub-area and that was overlooked. All these make the urban heat island effect more and more serious. Therefore, in hot humid zone how much the urban heat island is affected by the urban ground surface improper designs changing urban original condition of ground soil, vegetation, and water body into artificial pavements is still not well clear. The artificial pavement will have negative impact on urban heat mitigation so that it is urgent to understanding, so its effective solution to deal with this problem. To response to this need, the ground surface design approach of open space in urban area and its local heat effect should be taken into account and a further study.

2.2 Environmental Heat Effect Factors

The total heat in an urban context come from the heat of solar radiation, vehicle exhausted air, heat produced by air conditioners, and heat generated from kitchen stove. All these heats are absorbed by the materials inside the urban spaces, and accumulate in the urban area that result in higher daytime temperature in the urban area than in the

rural area, same in the nighttime because of poor local ventilation effect due to dense high-rise building towers. Among them, the solar radiation heats the ground surface and building envelope much more than other heat sources, so that the ground surface heat effect caused by the solar radiation has a very apparent cause effect relation. Based on the principle of energy preservation, the heat balance formula used for urban ground surface is as following.

R=P+LE+A……(1)

where, R: net radiation heat; P: convection heat; LE: evaporation and condensation balanced heat; A: ground surface conduction heat.

Take a daytime urban area situation for example. When the solar radiation reaches to the urban ground surface, it increases the total heat of the ground surface, but the natural wind will take part of heat away by convection. If the ground surface is water contented, part of heat will be taken away through evaporation by latent heat depending upon the amount of water volume. The rest heat of ground surface will be taken away through heat conduction of surface material into soil or earth beneath. See Fig.1. The rest heat keeping inside the ground surface becomes environmental heating energy which heats up the local temperature that change the heat effect of local microclimate. The natural wind, ground surface water, and surface material are considered as microclimate mitigation factors of local thermal environment.

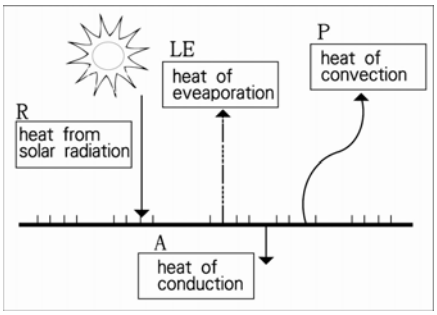


Fig. 1 Urban Environmental Solar Heat and Microclimate Mitigation Elements

The convection heat P in the formula (1) will not be included for further study due to natural wind having less relationship with ground surface design, so that the formula (1) could be simplified as R=LE+A for analyzing the heat effect. The evaporation and condensation balanced heat LE is defined as formula（2）.

LE=539 kcal/kg × G, ……(2)

where, G: water evaporated (kg)= θ ×a×(Xs-X); θ : evaporation coefficient (kg/㎡ · h)=25+19V; V: velocity of air above the water surface (m/s); a : water surface area (㎡); Xs : humidity ratio in saturated air at the same temperature as the water surface (kg/kg); X : humidity ratio in the air (kg/kg).

The ground surface conduction heat A is defined as formula （3）.

A=K×a×△T/d……(3)

where, K: thermal conductivity (W/m·k); a: total area of conducting surface (㎡); △T : temperature difference (℃); d: thickness of conducting surface (m).

There are three kinds of ground surface pavement commonly used for urban open space, i.e., brick with grass planted paving, asphalt paving, and RC slab paving. In order to calculate the net radiation heat for pavements, their physical heat reaction characteristics should be realized such as heat conductivity, evaporation, and reflectivityas Table 1.

Table 1 Reflectivity, Conductivity, and Heat Evaporation of Selected Pavements

Type of Pavement	Reflectivity (Albedo)	Heat Conductivity (W/m · k)	Heat Evaporation of water (kcal/kg)
RC Brick with Grass Planted	Grass: 0.26 RC Brick: 0.30	Grass: 0.05 RC Brick: 1.7	Grass & Soil: 539
Poured RC Slab	0.30	1.7	Venting Cavities:539
Asphalt Slab	0.13	0.75	—

Due to the reflectivity of ground surface material, part or solar radiation heat is not likely absorbed by the ground surface easily. The reflectivity of grass is 0.26 and RC is 0.3, the total amount of heat absorbed by each of them is about the same. Because that, the heat conductivity of grass surface is very low as 1/30 than to that of RC, and high heat evaporation of water in the surface, the grass planted brick surface pavement will perform lower heat to rise environment temperature rapidly during daytime in summer season. On the other hand, because of lower reflectivity, lower heat conductivity, and no heat evaporation capacity, the asphalt pavement seems have a very high environment temperature rising potential and serious heat effect impact.

Assuming there is 500 ㎡ ground surface paved with grass planted brick which is 1/4 size covering with grass and 3/4 size covering with RC bricks, the heat released by grass through water evaporation will be 90.8kW×1/4=22.7kw, and by RC brick through conductivity will be 1.8kW×3/4＝1.35kW. So that, the total heat released by grass planted brick pavement will be 24.05kW, neglecting other heat release conditions.

Again assuming there is 500 ㎡ ground surface paved with poured RC slab, without water evaporation condition, the total heat released by RC slab will be only 1.8kW through conduction. Based on this theoretical analysis, it is obvious that grass planted brick pavement with low heat storage will lower ambient temperature during all the daytime even in the noon, and cooling down quickly at the night time coming.

On the other hand, due to better heat conductivity, poured RC slab pavement will transfer the heat more quickly into ground soil that slows down the speed of air temperature rising up in the morning and noon. However the heat transfer of paving will reverse to return the heat to air that slows down the air cooling effect at the time of late afternoon.

2.3 Experiment Establishing

2.3.1 Experiment Objectives

This research conduct a general survey to collect the popularly used ground surface material and construction method of large size open space in an urban area, and conduct a field measurement of environment heat effect of these ground surfaces during the summer daytime. The first main objectives of this experiment is to assure that local microclimate will be affected differently according to different ground surface material and its work method and their linkage to form the urban heat island as a city environmental issue. The second main objectives of the experiment is to understand the impact of heat effect factors, such as air temperature based on the physics of the ground surface material which will be used to compare and verify the relationship between heat effect and paving material. The third main objectives is to review the difference among surface materials seeking a proper way to minimize urban area heat effect of negative impact, and try to select an appropriate ground surface material with correct design approach as well as the strategy to cool down urban heat island for rebuilding an eco-city in the hot humid zone.

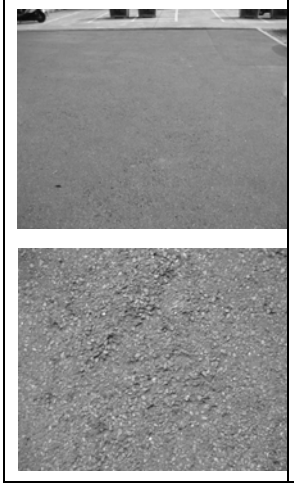
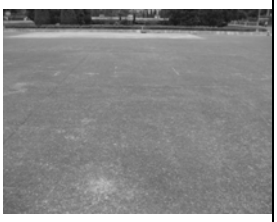
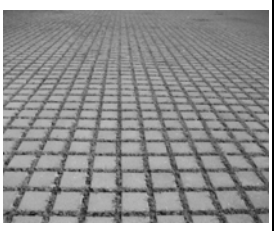
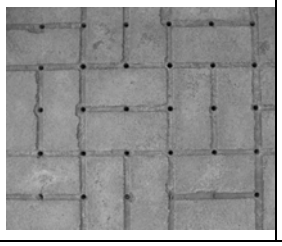
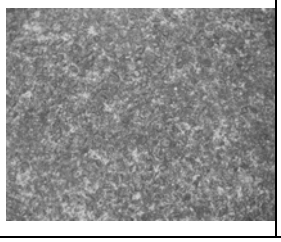
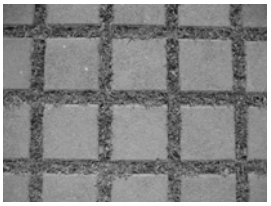
2.3.2 Experiment Plan Designing

In order to analyze local heat effect of urban open space area caused by ground surface element, four kinds of ground surface pavement are focused as study cases for further field measurements. Four study cases and their material and construction method are shown as in Table 2.

These four cases selected for field measurement are all located at Taipei area of Taiwan, due to its high population and dense buildings that pretty much reflect the common situation of an urban with heat island effect in hot humid zone.

The size of the cases for field measurement all excesses 400 ㎡ and the shape of the site closes to square. All the field measurements are conducted from morning to late afternoon during summer months of July and August, and in sunny days.

Table 2 Experimental Cases of the Ground Surface Pavement

Case A	Case B	Case C	Case D
asphalt pavement	RC with 2% venting holes pavement	RC with gravel cavities pavement	brick with grass planted pavement
			
			

3. Study Results

3.1 Field Measurement Statistic

All the measured results of the air temperature for the selected 4 different pavements is filed and compared to the temperature provided by Taiwan government's weather data of Taipei as reference temperature. Fig. 2, Fig. 3, Fig. 4, and Fig. 5 are showing the temperature difference of field measuring and reference for the ground surface of the cases, i. e., asphalt pavement, RC pavement with venting holes, graveled RC pavement, and grass planted brick pavement respectively. From the comparisons, it implies that the temperature variation between the field measurement temperature and the reference temperature are relatively different among these four cases.

3.2 Analysis and Comparison

The cross comparison of temperature differences between field measure and the reference temperature from government's weather data for these four cases is shown in

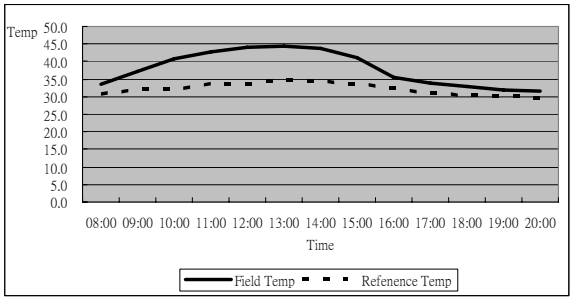


Fig. 2 Case A Temperature Variation

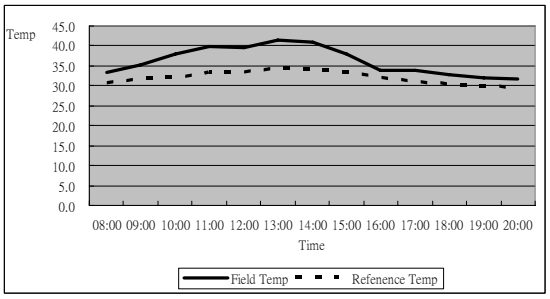


Fig. 3 Case B Temperature Variation

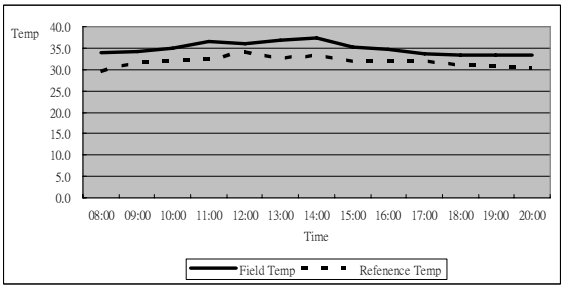


Fig. 4 Case C Temperature Variation

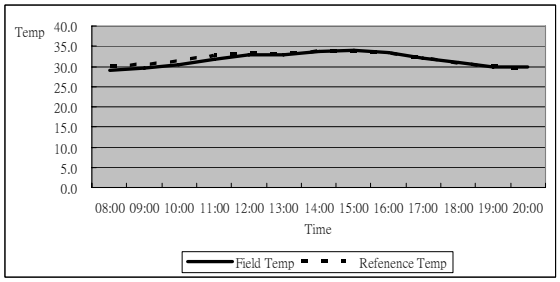


Fig. 5 Case D Temperature Variation

Fig. 6. It shows that case A of asphalt pavement is 10.6℃ as the largest difference, and case B of RC with venting holes paving is 7.0℃, case C of RC with graveled cavities pavement is 4.1℃, and case D of brick with grass planted pavement is only 0.4℃. It also shows that the time duration of the temperature difference exceeding 4℃ is 7 hours at the case A, 6 hours at the case B, 4 hours at case C, and 0 hour at the case D. The analysis also shows that at case C the temperature difference still over 3℃ higher than other cases only 2.1℃~ 0.4℃ in late afternoon.

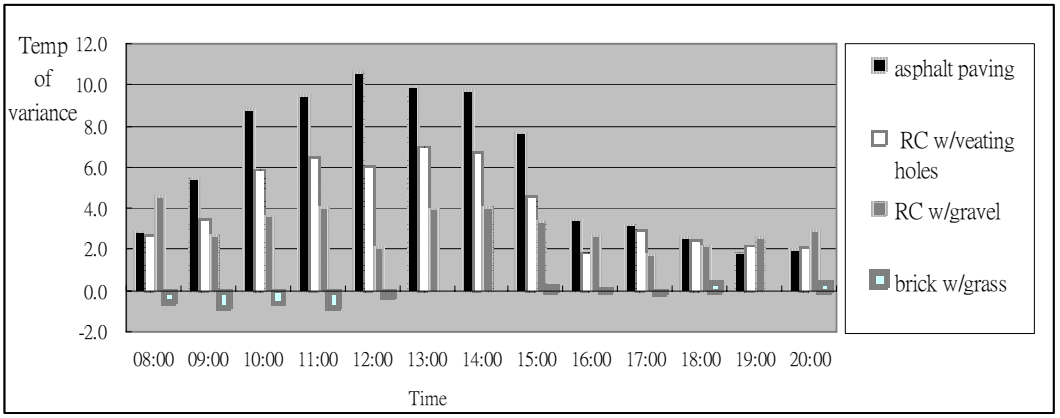


Fig. 6 Temperature Difference Between Field Measures and Reference of the Cases

3.3 Discussion

Based on the analysis results, the material and construction method selected for urban open space ground surface, either plaza pavement or parking lot pavement, will create

local heat effect differently. From the different heat effect appeared among the cases, it infers that the brick with grass planted pavement material and construction method keeps the daytime temperature stable with minimal variance due to its large evaporation capacity, which adds urban heat island effect very low.

The surface material of urban space with high reflectivity, such as RC material, the percentage of absorbed solar heat is lower, same as its heat storage, This hind of surface material has lower effect for temperature rising, therefore has lower impact to add urban heat island effect during the daytime in summer season .

Because of higher heat conductivity for RC materials, it tends to transfer the ground surface heat into earth easily that will slow down the temperature rising of local environment. However RC material will also delay the temperature cool down due to the heat storage in the earth back to the ground surface at afternoon that will prolong the heat island effect existing locally.

The comments about material and construction method of ground surface pavement relating to urban heat island for this analysis are as below.

(1) Any ground surface paving materials and construction with good water content capacity and evaporation capacity due to its small impact to the heat effect of local temperature that could avoid adding urban heat island effect, should treat as key element and the best design choice for urban space pavement.
(2) In the hot humid climate zone, ground surface paving materials with high reflectivity could minimize the latitude of temperature rising and time duration of higher temperature, are the best design element for ground surface paving to cool down urban heat island effect.
(3) Ground surface material with low heat conductivity, such as asphalt pavement, will heat up the local temperature quickly and largely is not a good material for reducing urban heat island effect. However the material with high heat conductivity, such as RC pavement, will slow down the heat island effect building up in the noon, but it will also lasting local high temperature situation so that prolong the urban heat island effect.
(4) Different types of material will change heat effect of local environment quite differently however the way of construction method will also impact the heat effect but only in minor. Consequently, surface material selection is much more important than the method of construction to reduce the urban heat island effect.
(5) From the study result, asphalt pavement shows its relation building up urban heat island effect very significantly and becomes a negative impact to eco-city, so that a

design change is needed for urban open space ground surface paving especially in hot humid climate zone.

4. Conclusion and suggestion

4.1 Conclusion

To reduce the impact of global warming and climate change crisis, many hot humid cities like as in Taiwan begin move to develop strategy of eco-city and green building instead traditional city planning and luxury building design. It is urgent to design urban element to mitigate their hot temperature of urban heat island in summer daytime.

Large size open spaces in urban area usually cover certain percentage of city area, and they are still increasing. However the ground surface paving design of these open spaces still considers only regarding to its using duration and visual aspect, and does not know how to response the UHI. From the result of this research, it shows that to develop eco-city with lower heat island effect, the heat effect from different ground surface paving material and method needs take into account as important design factors.

By through this theory study, and heat effect analysis of ground surface pavement from the field measurement of real cases, and cross comparison results, some important findings and primary conclusions are brought out as followings.

(1) Among these ground surface pavements, brick with grass planting performs near 0 ℃ temperature difference because it possesses good permeable, water evaporation, high reflectivity, and low heat conductivity that together give the best example for cooling down urban heat island effect. The second example is RC pavement which performs around 5℃ higher local temperature than other area that add the urban heat island effect modestly because of poor permeable, few water evaporation if rains, high reflectivity, high heat conductivity. The worst example is asphalt pavement which appears over 10℃ local temperature higher than rest area that becomes a key element to form the significant urban heat island effect, due to very weak heat control features such as no water permeable, no water evaporation, low reflectivity, and low heat conductivity.

(2) The ground surface pavement of asphalt material will prolong the duration of local high temperature and give the highest heat effect of temperature difference, so it is the biggest negative element to control the urban heat island effect. On the other hand, the RC pavement will low down the local hot temperature difference at the

noon, but prolong the time needing for cooling down in return.

4.2 Suggestion

(1) To find out the solution to urban heat island cooling down, actually the ground surface pavement material and construction design for urban open space is a key factor. For example of car parking lot, it is better not to use asphalt as long as possible, and to use brick pavement with grass planting as much as possible. The grass planted brick is also good to urban local flood control.
(2) To improve the current situation of urban overheat, ground surface paving design using of asphalt deteriorates the urban heat island problem should be rectified as much as possible. Private sector and public sector should work together to set up a low UHI ground surface paving design specification as well as its evaluation system to speed up the process to resolve the UHI problem.
(3) New investment of developing new urban ground surface paving materials which possess ecological, permeable, economical, and esthetic characteristic, and the construction methods is needed and important that provides slow heating-up, quick cooling-down, smaller altitude of temperature fluctuation during solar radiation.

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