A THERMAL ENVIRONMENT INVESTIGATION OF THE URBAN STREET CANYON IN A HOT AND HUMID CITY, TAICHUNG CITY, TAIWAN.

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Abstract

To estimate the impact of street geometry (H/W ratio), urban vegetation and building density on thermal environment in urban street canyon in hot and humid region, transect data were used to analyze the relation between three factors and air temperature in two streets in Taichung City, Taiwan. In this study, air temperature data were collected by transects on 4 different level heights (100, 200, 300, 400 cm) in two streets; meanwhile, street H/W ratio, urban vegetation and building density which were calculated by GIS data were used to represent the environment condition of 34 locations in two streets. The Analysis result shows that the air temperature in urban street canyon strongly correlated with three factors, Street H/W Ratio, Vegetation and Building Density respectively. In conclusion, this study demonstrates that increasing vegetation and decreasing building density are the important strategies to diminish the street warming and to create the comfort thermal environment in urban street canyons.

Key words: urban canyon, vegetation, building density, H/W ratio

1. INTRODUCTION

As urbanization progresses, the “heat island effect” problem is mainly aggravated because of the reduced density of green vegetation and increased building in the urban environment. Therefore, how to diminish heat island effect and to keep urban area stay in cool becomes a very important issue for urban environment researchers. Rosenfeld et al. study in alleviating the heat-island problem, believe in a three-pronged strategies beyond microclimate below trees: cool roofs, cool pavements, and vegetation for evapotranspiration (Rosenfeld et al., 1995). According to the result of one earlier study, vegetation surfaces show lower radiative temperatures around 20 K than other inanimate ones of the same color (Wilmers, 1988). The study by Shashua-Bar and Hoffman also indicated that the vegetation cooling effect in all study sites was 2.8 K, ranging from as low as 1 K in a street with heavy traffic to as high as 4 K in the smallest garden (Shashua-Bar and Hoffman, 2000). This study also demonstrated that vegetation and traffic condition have the strong influence on the temperature in the street.

On the other hand, urban geometry and thermal properties of urban surfaces have been found to be the two main parameters influencing urban climate (Oke, 1987; Oke et al., 1991). The ratio between the height of buildings (H) and the distance between them (W) influences the amount of both incoming and outgoing radiation. The nocturnal heat island has been shown to increase with H/W ratio since the net outgoing long-wave radiation decreases due to reduced sky view factor. Furthermore the more buildings the more anthropogenic heat was released from the buildings. Moreover, high thermal capacity of urban building also contributes to the heat island effect and ambient air temperature as a large part of the incoming radiation during the day is stored in building surface materials and not released until the night.

Since urban vegetation, building density and H/W ratio have a strong influence on the microclimate around buildings in the urban street, the aim of this paper is to investigate the influence of these three parameters, vegetation density (VD), building density (BD) and H/W ratio, on microclimate at street level in a hot and humid city. This is done by comparing urban canyons in two streets in Taichung City, Taiwan in winter, 2008-09. The study is base on field measurements of air temperature and GIS data.

2. METHDOLOGY

2.1. Selection of measurement sites

Taichung city (24^{o} 08’ N, 120^{o} 41’ E) is located in the middle of Taiwan (Fig. 1). The climate is characterized by hot and humid summers and cold winters. The annual average temperature is 23 °C and the annual rainfall is 1700 mm. Taichung city was chosen for this study because its weather condition and street character can represent the typical city type of Taiwan. In both streets(Fig. 2), measurement sites were chose in order to

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represent the difference in street geometry (vegetation density (VD), building density (BD) and H/W ratio) with the same orientation (East-West).

2.2. Field measurements

Transects were conducted three times throughout the day in order to measure the UHI effect over the diurnal period. The data of this study consisted of 9 transects and the use of three fixed stations in December, 2008, January and February 2009.Transects were run on December 11, 2008, January 15 and February 7 2009 during the diurnal cycle centered on 1400, 1800, and 2200 LST and over a prescribed route. All transects had been done within two hours in similar traffic condition and by the same route. The thermo recorder had been set for collecting data at 1, 2, 3, and 4 meter height. The weather condition of three measurement days is as Table 1.

2.3. Vegetation density, building density and H/W ratio calculations

In this study, on the one hand, vegetation density and building density surrounding every measuring point was evaluated using the GIS data (Fig. 3). On the other hand, the H/W ratio was calculated by equation (1) (Fig. 4).

$$H/W = (\sum Hi \times Di)/(\sum Di)/W \qquad (1)$$

Where H is the height of buildings and W is the distance between buildings (street width).

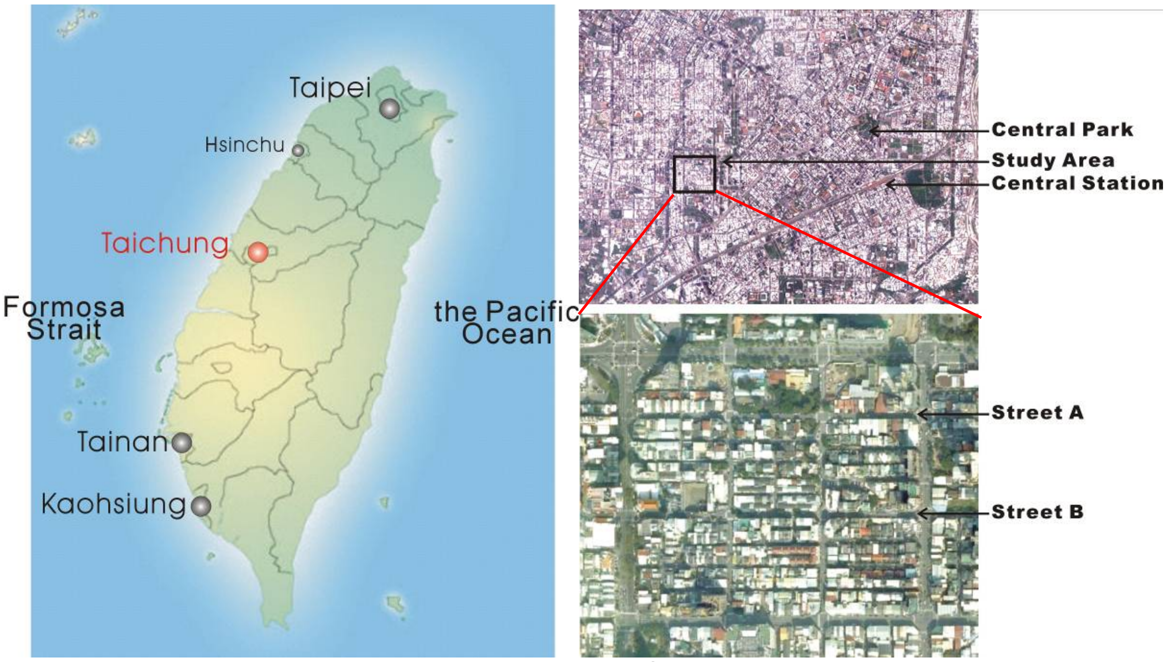


Fig.1 The location of Taichung City and study area

Fig.2 Measurement point location of two streets (●measuring points)

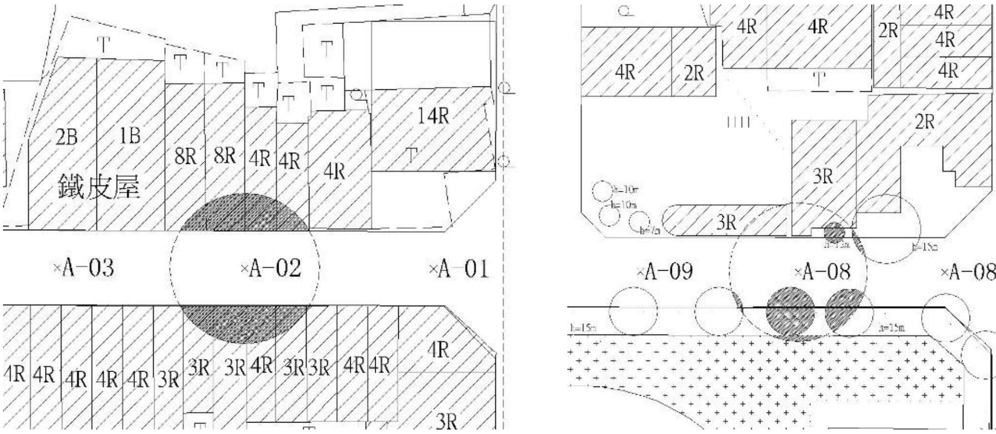
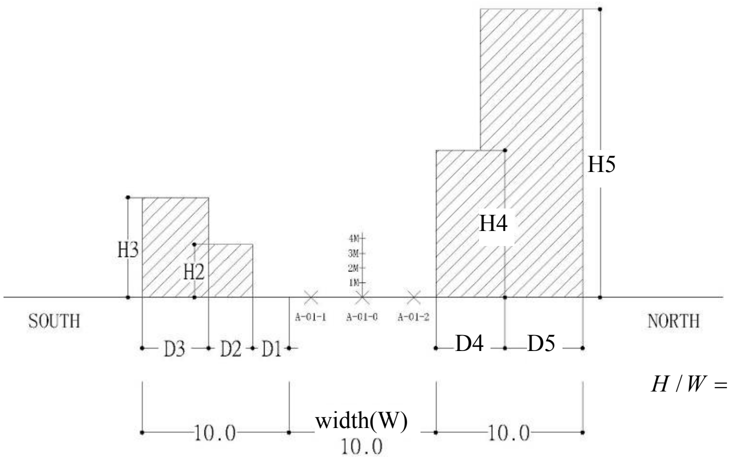


Fig.3 The calculation samples of building density (BD) (left) and vegetation density (VD) (right)



$$H / W = (\sum Hi \times Di) / (\sum Di) / W$$

Fig.4 The calculation method of H/W ratio

Table 1 The weather condition of three measuring days

	Tempe.	Dew point	RH	Wind Speed(Ave.)	Max Wind Speed(Ave.)	sunshine hours	cloudiness	Insolation
Dec. 11 2008	19.1	13.0	70.1	1.3	3.6	9.9	0.0	15.2
Jan. 15 2009	12.7	6.4	67.8	1.1	3.3	9.5	0.0	14.9
Feb. 7 2009	19.1	15.2	78.8	1.3	3.4	9.1	2.3	16.3

3. RESULT

3.1. The relationship between Air temperature and vegetation density (VD)

By day, the relationship between air temperature and vegetation density were not significant in this study, because the air temperature was strongly influenced by asphalt, sunlight, shadow and traffic. In the night, the significant coefficient correlations were found at 3 and 4 meter height both on December 11, 2008 and January 15, 2009 (Table 2 and 3). It means that even the vegetation doesn't provide evaporation to cool the ambient environment during the night; the vegetation land is still cooler than other kinds of land-covers such as concrete and asphalt.

3.2. The relationship between Air temperature and building density (BD)

In this study, after sunset, the significant coefficient correlations between air temperature and building density were found at 3 and 4 meter height both on December 11, 2008 and January 15, 2009 (Table 2 and 3). It means that building started to release heat and caused ambient air temperature high after sunset.

3.3. The relationship between Air temperature and H/W ratio

During the night, the nocturnal air temperature in urban canyon has been shown to increase with the H/W ratio since the net outgoing long-wave radiation decreases and more anthropogenic heat was released from buildings. The positive coefficient correlations between air temperature and H/W ratio showed H/W play an important role in reheat street thermal environment after sunset. The high H/W ratio situation also affects the wind fluid which may take away the heat from streets.

4. CONCLUSIONS

The results of this paper show a clear relationship between street geometry and air temperature at street level. When combining all the environmental parameters influencing thermal environment, the lowest nocturnal temperature occurred in somewhere which has low building density, H/W ratio and high vegetation density. This research is the first one of a serial urban canyon researches. For the further study, the tasks are some analyses which can find the important factors influencing street thermal environment and provide some useful strategies for improving heat island in hot and humid city, Taiwan.

Table 2 The correlation coefficient of street components and temperature on Dec. 11 2008

Sensor Height	Dec. 11 2008 14:00			Dec. 11 2008 18:00			Dec. 11 2008 22:00		
	VD	BD	H/W	VD	BD	H/W	VD	BD	H/W
1M	0.190	-0.026	-0.117	-0.227	0.000	0.065	0.024	-0.179	0.026
2M	0.237	-0.066	-0.146	-0.195	-0.023	0.100	0.001	-0.275	0.000
3M	0.043	-0.134	0.019	-0.456	0.341	**0.540**	**-0.640**	**0.556**	**0.653**
4M	0.134	-0.209	-0.038	-0.482	0.355	**0.565**	**-0.643**	**0.512**	**0.675**

Table 3 The correlation coefficient of street components and temperature on Jan. 15 2009

Sensor Height	Jan. 15 2009 14:00			Jan. 15 2009 18:00			Jan. 15 2009 22:00		
	VD	BD	H/W	VD	BD	H/W	VD	BD	H/W
1M	0.136	-0.233	0.026	-0.172	0.092	0.213	-0.322	0.232	0.267
2M	-0.049	-0.116	0.082	-0.358	0.236	0.327	-0.455	0.293	0.431
3M	-0.198	0.032	0.226	-0.410	0.253	0.464	**-0.600**	0.475	**0.619**
4M	-0.205	0.053	0.192	-0.451	0.290	0.492	**-0.638**	**0.509**	**0.582**

Table 4 The correlation coefficient of street components and temperature on Feb. 7 2009

Sensor Height	Feb. 7 2009 14:00			Feb. 7 2009 18:00			Feb. 7 2009 22:00		
	VD	BD	H/W	VD	BD	H/W	VD	BD	H/W
1M	0.222	-0.100	-0.131	-0.161	0.151	0.229	-0.074	0.147	0.163
2M	0.177	-0.047	-0.152	-0.271	0.281	0.322	-0.234	0.142	0.204
3M	0.105	-0.059	-0.144	-0.386	0.366	**0.545**	-0.222	0.210	0.250
4M	-0.011	0.041	-0.011	-0.375	0.371	0.417	-0.332	0.304	0.327

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References

Oke T.R., 1987. *Boundary layer climate*. London: Routledge.
Oke T.R., Johnson G.T., Steyn D.G., Watson I.D., 1991. Simulation of surface urban heat islands under ideal conditions at night. Part 2. Diagnosis of causation. *Boundary-Layer Meteorology*, 56, 258-339.
Rosenfeld A.H., Akbari H., Bretz S., Fishman B.L., Kurn D.M., Sailor D., Taha H., 1995. Mitigation of urban heat islands: materials, utility programs, updates, *Journal of Energy and Buildings*, 22, 255-265.
Shashua-Bar L., Hoffman M.E., 2000. Vegetation as a climatic component in the design of an urban street, *Energy and Buildings*, 31, 221-235.
Wilmers F., 1988. Effect of vegetation on urban climate and buildings, *Journal of Energy and Buildings*, 15-16, 507-514.