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Estimating Spatial Disaggregation of Urban Thermal Responsiveness on Summer Diurnal Range with a Numerical Modeling Approach in Bangkok, Thailand

Manat Srivanit and Hokao Kazunori

***Abstract*—**Facing the concern of the population to its environment and to climatic change, city planners are now considering the urban climate in their choices of planning. The urban climate, representing different urban morphologies across central Bangkok metropolitan area (BMA), are used to investigates the effects of both the composition and configuration of variables of urban morphology indicators on the summer diurnal range of urban climate, using correlation analyses and multiple linear regressions. Results show first indicate that approximately 92.6% of the variation in the average maximum daytime near-surface air temperature (T_a) was explained jointly by the two composition variables of urban morphology indicators including open space ratio (*OSR*) and floor area ratio (*FAR*). It has been possible to determine the membership of sample areas to the local climate zones (LCZs) using these urban morphology descriptors automatically computed with GIS and remote sensed data. Finally result found the temperature differences among zones of large separation, such as the city center could be respectively from 35.48±1.04ºC (*Mean±S.D.*) warmer than the outskirt of Bangkok on average for maximum daytime near surface temperature to 28.27±0.21ºC for extreme event and, can exceed as 8ºC. A spatially disaggregation of urban thermal responsiveness map would be helpful for several reasons. First, it would localize urban areas concerned by different climate behavior over summer daytime and be a good indicator of urban climate variability. Second, when overlaid with a land cover map, this map may contribute to identify possible urban management strategies to reduce heat wave effects in BMA.

***Keywords*—**Urban climate, Urban morphology, Local climate zone, Urban planning, GIS and remote sensing

I. INTRODUCTION

BANGKOK is the capital of Thailand and is among the larger cities in Asia, with an estimated unofficial population well in excess of 10 million people on the 1,576 sq.km areas. The summer period, or hot and humid season, is from March to June. At this time, temperatures in Bangkok average around 31˚C, but April have high solar intensity and longer days and thus can become quite hot, can affect a community's environment and quality of life. In addition to the effect of temperature on thermal comfort needs to be considered. For this, a psychrometric chart is used and plotted on Fig. 1 at two times of the day 6 a.m. and 4 p.m., Its was found that the summer monthly lines on the chart never cross the thermal comfort zone, especially in April, which is farthest from the thermal comfort zone; it means that the local climatic conditions always require improvement and mitigation measure for this season, so as to achieve comfort.

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Furthermore, as cities continue to grow in population and physical size, these urban–rural differences in temperature also increase as reported by long-term temperature records. Excess heat may also affect the comfort of urban dwellers and lead to greater health risks [1]. In addition, higher temperatures in urban areas increase the production of ground level ozone which has direct consequences for human health [2], [3].

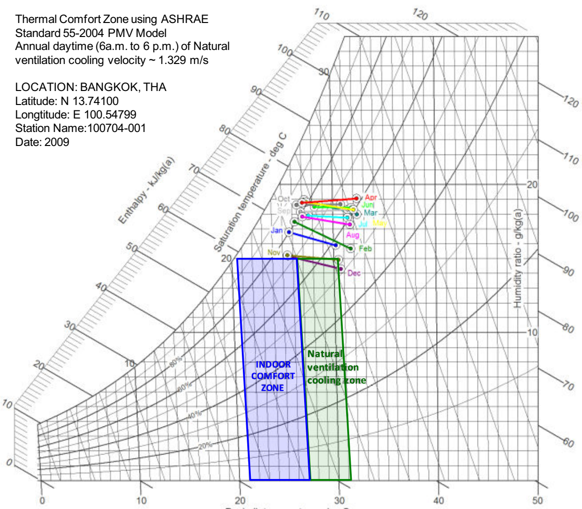

Fig. 1 Monthly daytime of Bangkok climatic conditions at two times of the day and ASHRAE Standard 55-2004 PMV Model recommended comfort zone

The thermal environment and air ventilation condition within the climate below the rooftops of buildings or the urban canopy layer (UCL) of the city are important in the analytical processes of the climatic environmental evaluation. To fully understand the phenomena, it is important to identify the key indicators in action in an urban environment that affect air dispersion. Previous researches suggest that the physical

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profile within the urban canopy layer significantly affects the physics of urban climatic environment [4], [5], [6], [7], [8], [9]. Oke [10] defined four significant controls on urban climate including urban structure (dimensions of the buildings and the spaces between them, street widths and spacing), urban cover (fractions of built-up, paved, vegetated, bare soil and water), urban fabric (construction and natural materials), and urban metabolism (heat, water, and pollutants due to human activity). These four controls, playing important roles in creating certain urban climatic environments, all are related to urban morphology.

Current priorities placed on sustainable urban development have encouraged urban planners to examine the various parameters of urban climate modeling and incorporate them into planning and design efforts. But while they may understand the importance of interactions between urban morphology and urban microclimate condition, they lack basic knowledge of urban climatology [11]. Therefore the incorporation of urban climate knowledge in the urban planning process becomes crucial. Therefore, analyzing patterns of urban thermal responsiveness on summer diurnal range in Bangkok and its relationship with urban morphology characteristics is significant to understand in order to lessen the ever worsening urban climate problem in the region.

II. Methodological And Dataset

The area under study is the urban area of Bangkok. The methodological approach based on samples surrounding meteorological ground stations of the UCL, had been conducted on April 2009 in order to better understand the effects of urban form indicators on the summer diurnal range of urban climate. The climate indicators had been assessed with 13 air temperature and relative humidity sensors network located in the city (Fig.3). For this study, a variety of sources can be used to take these measurements including the Thai meteorological department (TMD) and the Pollution control department (PCD).

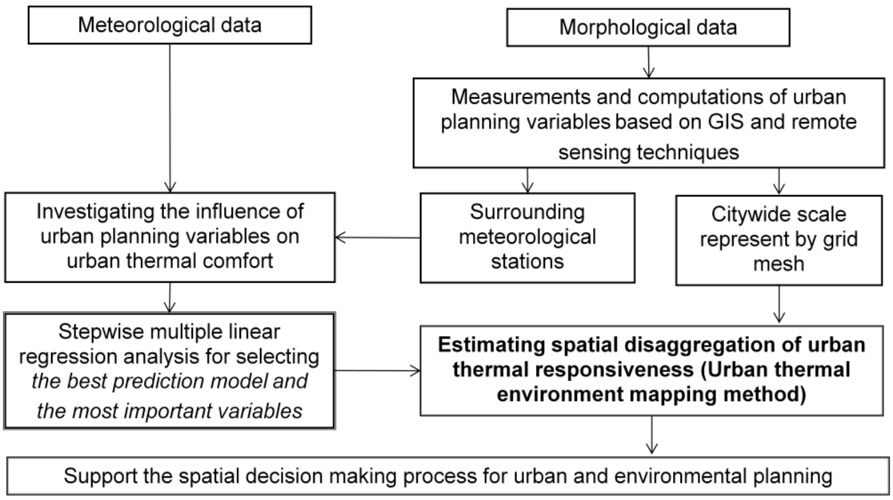

Fig. 2 the procedure and methodology of this study

This study firstly validates the influence of urban planning variable on urban thermal comfort (Fig.2). All weather station sites are essentially defined by a circle of influence (also known as source area or footprint) of the instrument which depends on its height and the characteristics of the process transporting the surface property to the sensor [10]. In this study, using the circle of influence on a temperature sensor is thought to have a radius of about 300 meters typically in stable conditions. The first objective is to automatically compute all meteorological stations, where these urban morphology indicators are using GIS and remotely sensed data and techniques within the circle of influence. Images were derived from overlaying building elevation obtained from airborne imagery and photogrammetric techniques. Identification of urban surfaces still remains a challenge because each city shows composition and structure specificities and no universal urban classification method exists [12]. The image fusion technique of an aerial orthophoto (acquired in 2009 at 1 m. resolution) with a Landsat TM image (acquired on April 25 2009, 30 m. resolution), could enhance the automated supervised object-based approach for urban canopy classification [13]. Some confusions were removed by overlaying building spatial extent as impervious surface on the classification. The maximum-likelihood classification (MLC) algorithm was applied to classify the fraction images into six classes; building coverage, impervious surface (mainly artificial structures such as pavements of roads, sidewalks, driveways and parking lots), pervious surface (including bare soil/gravel), water coverage (mainly including rivers, canals, creeks, ponds, and lakes), above green (tree canopy) and below green (grass and shrubs canopy) coverage for each surrounding meteorological stations and is based on a multi-resolution image clustering [14].Water surface and vegetation detection was optimized using Normalized Difference Vegetation Index (NDVI), and was extracted from computation of calculated from the visible and near-infrared

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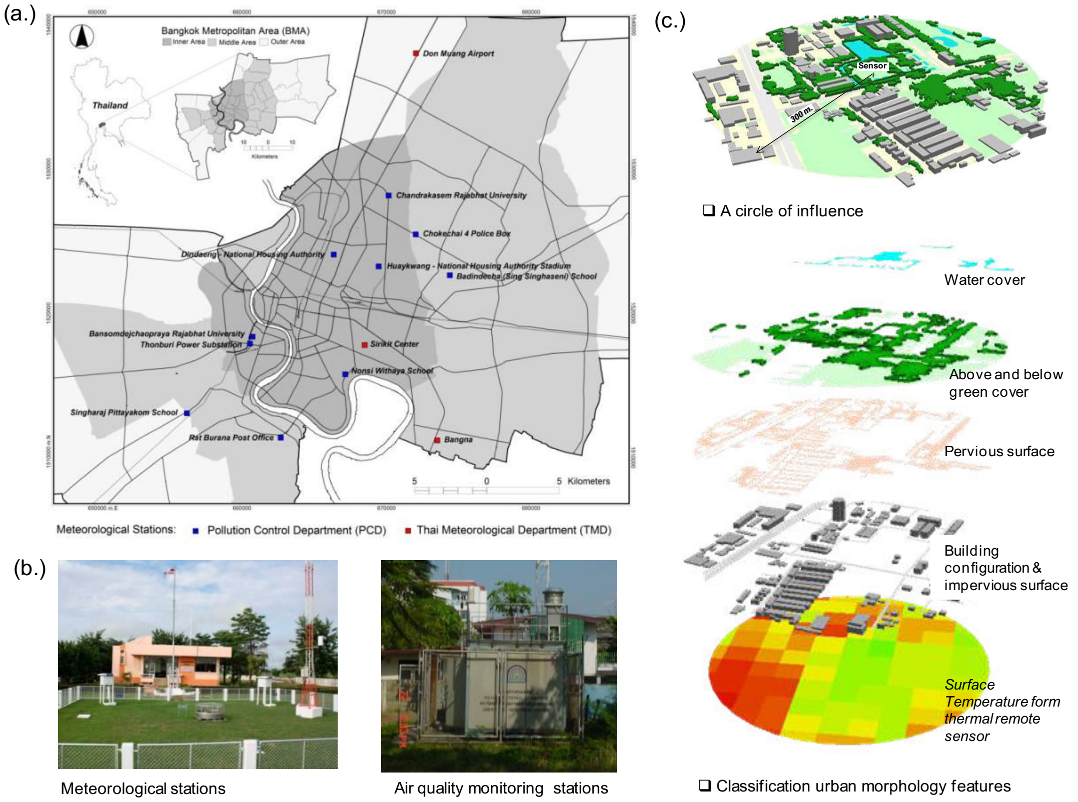
light reflected by plant to investigate vegetation cover from remote sensing imagery and then the image removed vegetation and water surface was impervious surface [15], [16], [17]. Accuracy assessment of the classification map was based on a stratified random sampling and visual assessment of the true color photography, with an overall classification accuracy of 96% being achieved. This classification is spatially limited within the circle of influence on a temperature sensor.



Figs. 3(a) Location of the Bangkok metropolitan area (BMA) and the network of meteorological stations, (b) typical of meteorological stations and (c) the circle of influence within the radius of a temperature sensor and the results of the composition and configuration of urban morphology features

This study investigates the effects of composition, whether the configuration of urban morphology features significantly affects urban climate indicators. The results from this study can enhance our understanding of how urban climate varies with changing urban morphology patterns. In addition, important insights can be provided to urban planners and natural resource managers on how to mitigate the impact of urbanization on urban climate through urban design and management. For this study, we selected the most frequently used composition variables are the percent cover of each urban canopy cover features, were calculated based on a high spatial resolution land cover classification map obtained from an object-based classification approach and the six configuration variables were used as predictor variables in the statistical analyses to examine the relationship between urban climate indicators. The major configuration of urban morphology indicators, used in this study are including;

Floor area ratio (FAR): is the ratio of the total floor area of the building to the area of the land on which it is located. It is a building density parameter used in urban planning and design disciplines. It captures the impact of vertical frictional surfaces in urban land due to high-rise built surfaces and used in urban canopy parameterisation of drag and turbulence production. On the other hand, it is a major parameter showing development intensity and refers to the intensity of activities taking place within a specified land area and obviously has implications on urban climate that reflects the number of prominent obstacles that affects air flow [8], [18], [19];

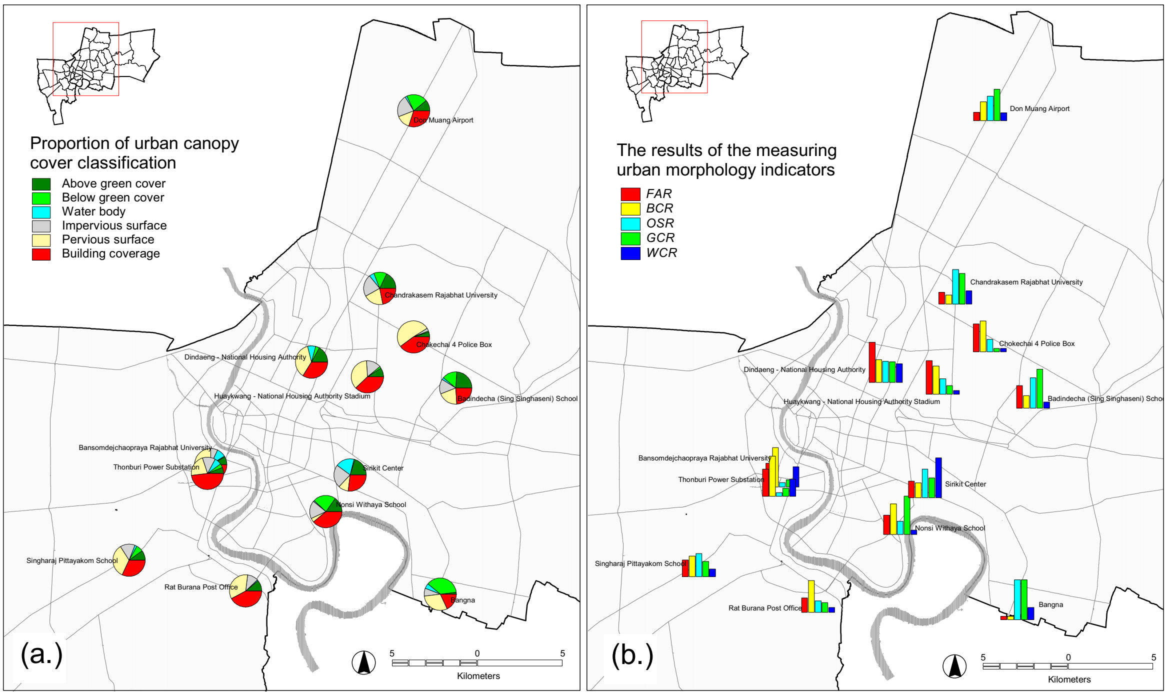
Building coverage ratio (BCR): means percentage of the total ground area of a site occupied by any building or structure as measured from the outside of its surrounding external walls. Building coverage includes exterior structures such as impervious surface mainly artificial structures such as pavements of roads, sidewalks, driveways and parking lots. Built footprints obstruct urban wind flow and increase thermal mass of urban fabric that could heat up the neighborhood [18];

Open space ratio (OSR): is the percentage of open space to the area of the land. An open-to-sky space without a roof is considered open spaces. The location, size, distribution and surface nature of open spaces could change the local environments by altering the air flow, humidity, heat balance with the urban canopy layer [20].

Green coverage ratio (GCR): is the percentage of the total area of all green spaces (including above green and below green coverage) to the area of the land. Trees and smaller plants such as shrubs, vines, grasses, and ground cover, help cool the urban environment. Thus, *GCR* is an important parameter in describing urban surface cover, which is affects urban climate such as radiation and surface temperature through shading and evapotranspiration. In the summer, generally 10 to 30 percent of the sun's energy reaches the area below a tree, with the remainder being absorbed by leaves and used for photosynthesis, and some being reflected back into the atmosphere [21] and;

Water coverage ratio (WCR): is the percentage of water coverage to the area of the land, which is an increase in the amount of cooling that normally associated with the evaporation of moisture. On the other hand, surface water bodies affects wind flow and also heat exchanges. Moreover water bodies on land such as lakes and rivers are regarded as a thermal sink for urban air pollutants [22].

Taking into the review of urban climatic studies, it is clear that different work argues differently in a different context and there is no consensus on which are the most important factors. There are also no systematic methods to determine the relationship between urban morphology. This gap of urban climatic knowledge and urban planning are where we would like to insert an effort into. This study propose the following question: Is there a relationship between urban climate concentration and urban morphology in the dense residential areas, and if there is, It is thus crucial to identify the factors amongst the many indicators available to investigate which ones are more important. A Pearson correlation was first developed to examine the strength of bivariate associations between urban climate indicators and the variables of composition and configuration of urban morphology indicators each surrounding meteorological stations. The stepwise regressions method is used to explore the relationship between urban climate indicators and the variables of composition and configuration of urban morphology indicators.



Figs. 4 Maps of (a) the proportion of urban canopy cover classification and, (b) the urban morphology indicators for each surrounding meteorological stations

Secondly, to generate an urban thermal environment map of Bangkok where effects of configuration of urban planning features on summer daytime temperature, exposure layers are together inside the GIS platform. We used grid mesh (500X500 grid cell size), the resolution is sufficient to provide information regarding urban thermal environment patterns on a local scale to calculate the most important indicators that affect the urban thermal and to estimated coefficients of a multiple linear regression model to project urban thermal responsiveness which allows the identification of the effect "hot spots". According to an urban thermal environmental map, planners and urban designers can expected comfort levels and make changes in the design at the locations where it is thermal uncomfortable.

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III. Results And Discussion

A. Classification of the composition and configuration of urban morphology features:

Results of urban morphology classifications are shown in Fig.4a. The differences in urban morphology among the thirteen meteorological stations are reflected by urban and environment planning indicators, such as *FAR*, *BCR*, *OSR*, *GCR* and *WCR* (Fig.4b). *FAR*, a major indicator of development intensity and livability has the highest value (1.425) for the core area and the lowest value (0.416) for the suburb area. The two highest *FAR* values are all located in the inner area of BMA, namely Dindaeng National Housing Authority and Huaykwang National Housing Authority Stadium; it was the low-income housing project of the Thai government.The average *GCR* value for the inner area stations about 10.84, increasing to 26.12 for the middle area stations and 38.42 for the outer area stations of BMA.Sirikit center station in the inner area has the highest values that it was containing open space of Benjakiti Park. Thus station adjacent to open space was more likely to have higher *GCR* value (20.891). It is not surprising Chokechai 4 Police Box has the lowest *GCR* value (6.104) given it has the highest building coverage.

B. Effects of the configuration of urban morphology features on summer daytime near-surface air temperature:

The correlation and regression analysis method is used to explore the relationship between the configuration of urban morphology features (*FAR, BCR, OSR, GCR, WCR*) and average maximum daytime near-surface air temperature (T_a) during the day in summer, correlation analysis was carried out on the thirteen meteorological stations. Pearson correlations between urban climate indicator and urban morphology indicators statistically significant (at 0.01 and at 0.05 level one-tailed) correlations exist can be found in Table I. The Pearson correlation coefficients show that all of the composition indicators, except *WCR*, were significantly related to T_a, with some indicators having stronger relationships with T_a than others. Composition indicators such as *FAR, BCR, OSR* and *GCR* had relatively strong relationships with T_a, while *WCR* were only weakly related to T_a. A positive coefficient for an independent variable indicates that the variable has a positive effective on T_a, or that T_a increases with the increase of the value of that variable; whereas a negative coefficient indicates T_a decreases with the increase of the value of that variable. For example, three coefficients of *FAR* and *BCR* were positive, suggesting that an increase in these variables would increase T_a. In contrast, the negative coefficients of *OSR, GCR* and *WCR* indicated that T_a would decrease with the increase of relative abundances of vegetation and water. Simple prediction model of urban climate on differences urban morphology indicators was established using linear regression analysis and scatter plot. According to the results of correlation analysis, *BCR* had the highest positive correlation with average near-surface air temperature by correlation coefficient (R^2) 0.878 and followed by *FAR* had high positive correlation with T_a by 0.471. On the other hand, *OSR* had the lowest negative correlation with T_a by 0.878 and followed by *GCR* was 0.649.Since stepwise selection of the variables allows dropping or adding variables at the various steps in either direction, it could not happen that any significant variables are dropped or non-significant variables are added in model. Therefore, a stepwise selection method was chosen, which reiterates the analysis by each parameter in turn and independently considers the inclusion or exclusion of the parameters with every step (criteria: probability-of-*F*-to-enter<=0.05, probability-of-*F*-to-remove>=0.1). The income factor with the largest probability of *F* is removed.

TABLE I

Relationships between the average maximum daytime near-surface air temperature (T_a) and urban morphology indicators aggregated for each surrounding meteorological stations obtained by single linear regression models.

Indicators	*Mean±S.D.*	*Corr. Coeff.*	*Regression analysis*		
			R-square (adjusted)	*F*	*P-value*
FAR	0.89±0.28	0.687**	0.471 (0.423)	9.810	0.010
BCR	33.69±9.15	0.937**	0.878 (0.867)	79.163	<0.001
OSR	66.12±9.20	-0.937**	0.878 (0.867)	79.169	<0.001
GCR	21.91±12.20	-0.806**	0.649 (0.617)	20.347	0.001
WCR	4.66±5.23	-0.182	0.033 (-0.055)	0.376	0.552

Note: **Correlation is significant at the 0.01 level (one-tailed)

TABLE II

The result of stepwise multiple linear regression analysis for performance urban morphology indicators that influence the summer diurnal range of the average maximum daytime near-surface air temperature by different models

Model	*Variable Entered*	R^2	*Adj.* R^2	*Std. Error of the Estimate*	*F*	*P-value*
1	*OSR*	0.878	0.867	0.312	79.163	<0.001
2	*OSR,FAR*	0.926	0.912	0.255	62.810	<0.001

Note: dependent indicator is the average maximum daytime near-surface air temperature (T_a) in summer

Table II shows the stepwise multiple linear regression results in which T_a was the dependent variable and *FAR, BCR, OSR, GCR* were used as independent variables, except *WCR* was identified as not significant and therefore removed from the analysis. It was found that Model 1 is the simplest equation included only *OSR* variable (R^2=0.878). Then the impact from *FAR* is added in Model 2, which explanation capacity is improved. By comparison with other models preformed Model 2 should be regarded as the best one, approximately 92.6% (R^2=0.926) of the variation in T_a was explained jointly by the two configuration of urban morphology variables. Thus, the T_a for the average summer daytime near-surface air temperature can be predicted from the configuration of urban morphology features of the thirteen urban meteorological stations in BMA (Eq.1, TABLE III):

$$T_a = 35.473 - 0.074OSR + 0.791FAR \quad (1)$$

TABLE III
SUMMARY RESULTS FOR MULTIPLE LINEAR REGRESSION COEFFICIENTS OF THE BEST PREDICTION MODEL FOR INVESTIGATING THE INFLUENCE ON THE SUMMER DIURNAL RANGE OF MAXIMUM DAYTIME NEAR-SURFACE AIR TEMPERATURE

Model 2	*UnStd. Coeff.*		*Std. Coeff.*	*F*	*Sig.*
	B	*Std. Error*	*Beta*		
(Constant)	35.473	0.809		43.874	<0.001
OSR	-0.074	0.009	-0.798	-7.854	<0.001
FAR	0.791	0.309	0.260	2.558	0.028

C. Estimating spatial disaggregation of urban thermal responsiveness on summer diurnal range with a numerical modeling approach

We used the estimated coefficients of the multiple linear regression model (Eq.1) to estimate urban thermal responsiveness that affect the urban thermal comfort in Bangkok area. Figs.5(a) and 5(b) shows spatial disaggregation of the most important features are open space ratio (*OSR*) and floor area ratio (*FAR*) that related thermal comfort from local climate zones (LCZs) to 500x500 m. grid cells. The current method has involved 6,620 zones for the Bangkok area. At the LCZs level, the six local climate zones highest thermal stress are located in city center of Bangkok which had thermal values higher than 35 ºC on summer diurnal range in 2009 (Figs.8 and Figs.9). The grid map shows thermal variation within a LCZ, which allows the identification of the effect “hot spots”, thermal differentiation of LCZs varies with the degree of *OSR* and *FAR* separation between zones. Result found the temperature differences among zones of large separation, such as the city center could be respectively from 35.48±1.04ºC (*Mean*±*S.D.*) warmer than the outskirt of Bangkok on average for maximum daytime near surface temperature to 28.27±0.21ºC for extreme event and, can exceed as 8 ºC. There are some hot spots identified in the grid map (Fig.7), Yaowarat (china town), Sailom, Ramkhamhaeng, Ratchaprarop are all located in the inner area of Bangkok, other LCZs of interest can also be disaggregated spatially in the same way.

A spatially disaggregation of urban thermal responsiveness of LCZ map would be helpful for several reasons. First, it would localize urban areas concerned by different climate behavior over summer daytime and be a good indicator of urban climate variability. Second, when overlaid with a land cover map, this map may contribute to identify possible urban management strategies to reduce heat wave effects in cities.

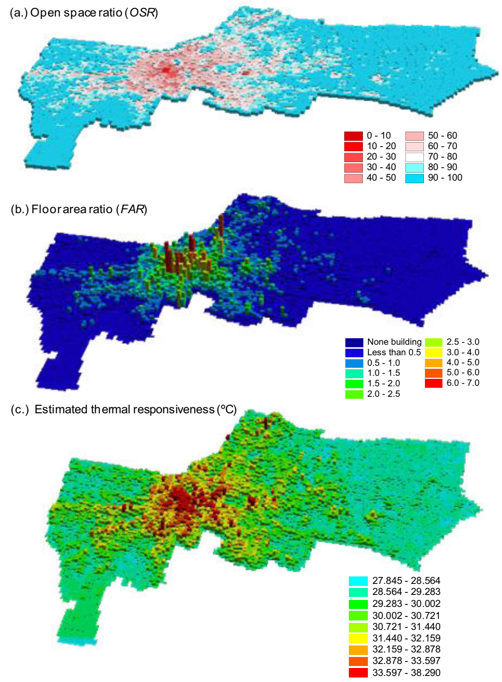

Fig. 5 Spatial patterns of (a.) floor area ratio (*FAR*), (b.) Open space ratio (*OSR*) in Bangkok area and (c.) the result of estimating thermal responsiveness of local climate zones (LCZs) with a numerical modeling approach

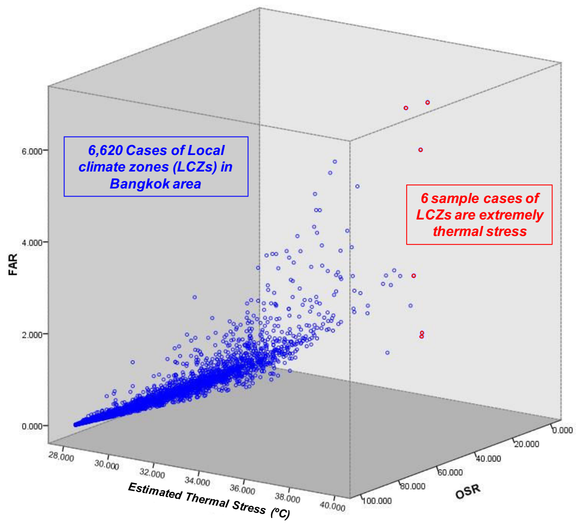

Fig. 6 Scatter plots show the variation of the average summer daytime near-surface air temperature was explained jointly by the two composition variables of urban planning indicators

IV. CONCLUSION

The results of this research indicated that both the composition and configuration of urban morphology features significantly affects the magnitude of daytime near-surface air temperature and surface temperature in summer. By explicitly describing the quantitative relationships of two urban climate indicators with the composition and configuration of urban morphology features; this research expands our scientific

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understanding of the effects of urban morphology features on urban climate indicators in urban landscapes. These results have important theoretical and management implications. Urban planners and natural resource managers attempting to mitigate the impact of urban development on urban climatology can gain insights into the importance of balancing the relative amount of various types of urban morphology features and optimizing their spatial distributions.The configuration of urban morphology features also significantly affects the average summer maximum daytime near-surface air temperature. A multiple linear regression model in this study was built to determine specific contribution of *FAR, BCR, OSR, GCR, WCR* and were used as independent variables to motivate the average near-surface air temperature which was a dependent variable rising on the daytime summer. These simple relationships between climate and urban planning indicators could help decision makers and planners to take climate adaptation into account, to ensure climate neutral development from the beginning of a planning process. It was found that approximately 92.6% of the variation in the average near-surface air temperature was explained jointly by the two composition variables including *OSR* and *FAR*. *OSR* has been identified to the most significant urban morphology indicator to affect urban thermal environment. *OSR* itself can explain 87.8% for the average daytime summer air temperature and followed by *BCR*, *CAR* and *FAR* had high positive correlation with the average daytime summer air temperature. On the other hand, *GCR* had the high negative correlation with the average daytime summer air temperature by 64.9%, except *WCR* were only weakly related.

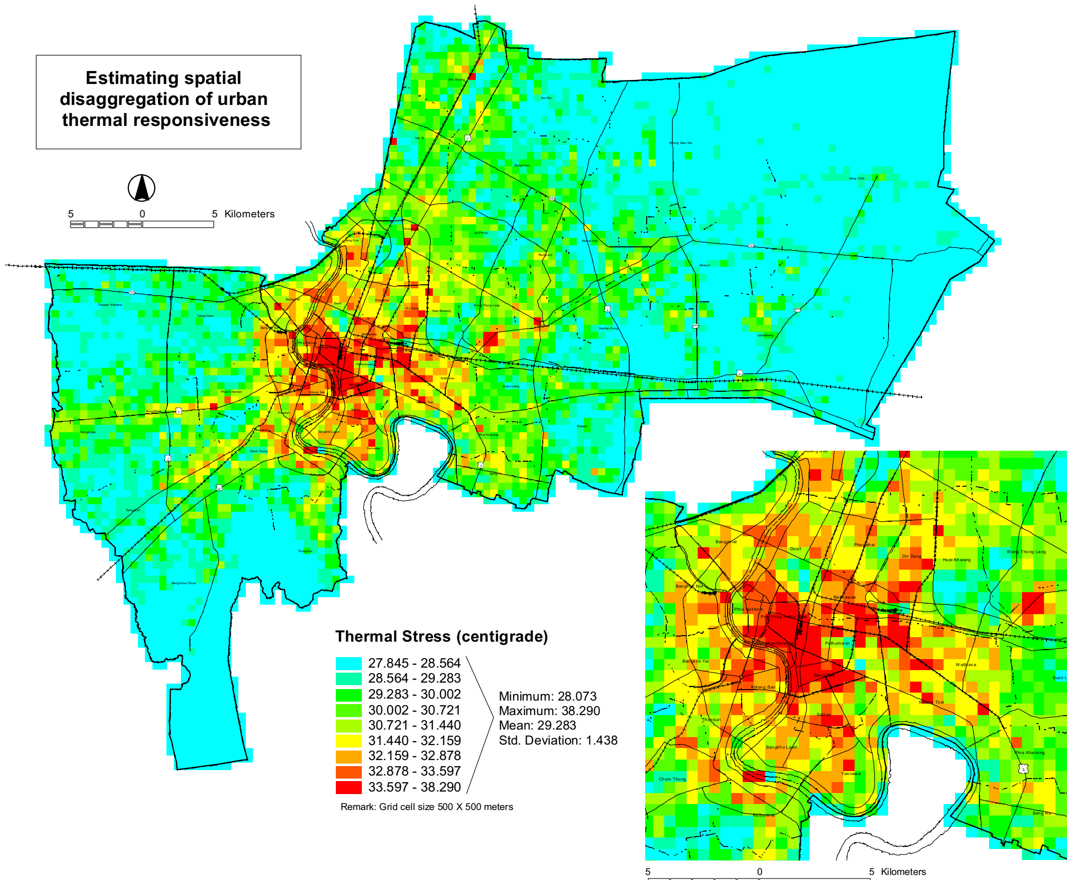

Fig. 7 Spatial disaggregation of urban thermal responsiveness on summer diurnal range in Bangkok

The average maximum daytime summer near-surface air temperature can be significantly increased or decreased by different spatial configurations of those features. This is because the spatial configuration influences obstruct urban wind flow and increase thermal mass of urban fabric that could heat up the local climate zone and, thus, affects urban climatology on the summer diurnal range. Therefore, it is our recommendation that urban planners should try to control for the effects of their composition. Vegetation management, particularly increasing tree canopy, has been considered an effective means to mitigate excess urban heat and to alleviate the thermal discomfort in the summer months for both highly urbanized areas and areas where urbanization is still in process. This approach is somewhat novel in urban climate studies because it demonstrates significant climate differences between LCZs. Quantified urban landscape descriptors have been automatically computed based on GIS and remote sensed data and techniques.

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Fig. 8 the 3D building configuration images of six sample local climate zones are extremely thermal stress

Fig. 9 the Google images of six sample local climate zones are extremely thermal stress

The most important limitation of the method in this paper is the unrecentness of GIS data and the estimates accuracy is not yet affected by the model, we would monitor human thermal comfort at different sites or representative sample of locations within Bangkok to evaluate and improve our model for estimates accuracy in the future research. The research was conducted for one region, using only one daytime thermal image to obtain surface temperature in the summer. The relationship between climate indicators and the variables of composition and configuration of urban morphology features also varies by seasons. Therefore, further studies that use multiple daytime and nighttime thermal images for different seasons are desirable. In addition, comparison studies across metropolitan areas under different climatic conditions are recommended.

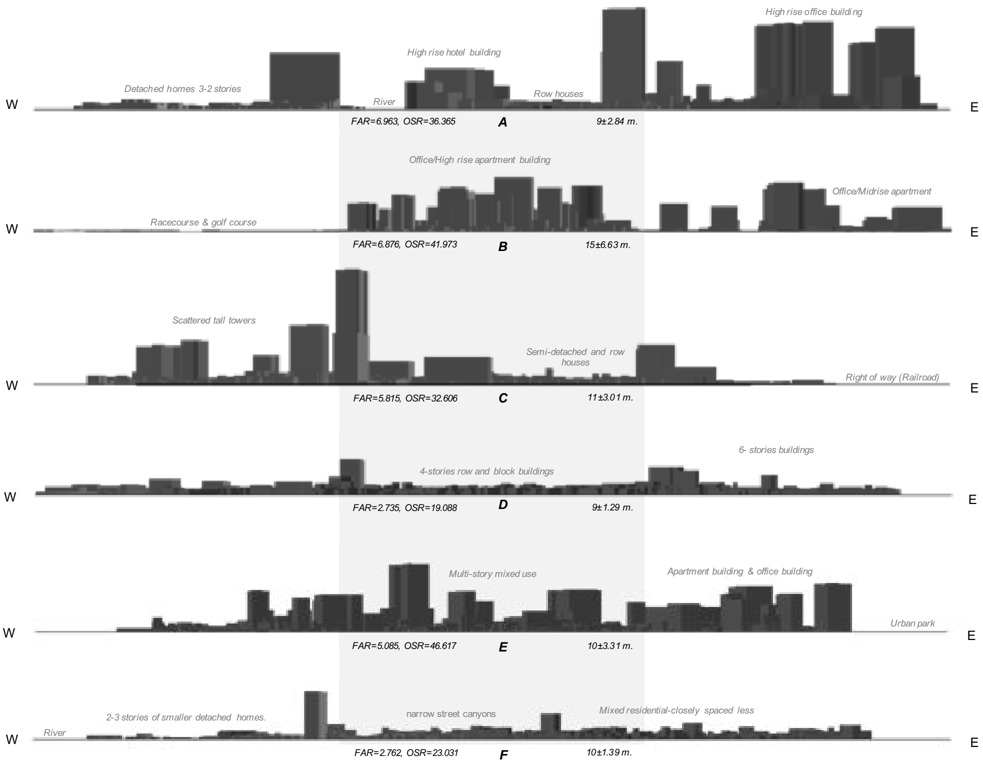

Fig. 10 Building elevation profile of six sample local climate zones are extremely thermal stress

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REFERENCES

[1] Poumadere, M.,Mays,C.,LeMer,S.,&Blong,R, "The 2003 heat wave in France: Dangerous climate change here and now. Risk Annual", 25(6), 2005, pp. 1483–1494.
[2] Akbari,H.,Rosenfeld,A.,Taha,H.,&Gartland,L, "Mitigation of summer urban heat islands to save electricity and smog. In 76th Annual American Meteorological Society Meeting Atlanta", GA, 1996.
[3] Akbari, H.,Pomerantz,M.,&Taha,H., "Cool surfaces and shade trees to reduce energy use and improve airquality in urban areas. Solar Energy", 70, 2001, pp. 295–310.
[4] Oke, T.R., "Street design and urban canopy layer climate. Energy and Buildings 11", 1988, pp.103–113.
[5] Givoni, B., "Climate Considerations in Building and Urban Design". Wiley, 1998.
[6] Clarke, A.G., Tomlin, A.S., "The atmosphere. In: Understanding Our Environment: an Introduction to Environmental Chemistry and Pollution". Royal Society of Chemistry, 1999.
[7] Chan, L.Y., Kwok, W.S., Lee, S.C., Chan, C.Y., "Spatial variation of mass concentration of roadside suspended particulate matter in metropolitan Hong Kong". Atmospheric Environment 35, 2001, pp.3167–3176.
[8] Chan, A.T., Au, W.T.W., So, E.S.P., "Strategic guidelines for street canyon geometry to achieve sustainable street air quality Part II: multiple canyons and canopies". Atmospheric Environment 37, 2003, pp.2761–2772.
[9] Kastner-Klein, P., Berkowicz, R., Britter, R.E., "The influence of street architecture on flow and dispersion in street canyons", 2004.
[10] Oke,T.R., "Initial guidance to obtain representative meteorological observations at urban sites. IOM Report No. 81, WMO=TD No. 1250", Geneva: World Meteorol Organiz http://www.wmo.ch/web/www/IMOP/publications/IOM-81/IOM-81UrbanMet Obs.pdf, 2004.
[11] Nyuk H.W., Steve K.J., Chun L.T., "Integrated urban microclimate assessment method as a sustainable urban development and urban design tool". Landscape and Urban Planning 100, 2011, pp.386-389.
[12] Baklanov, A., Mestayer, P., Clappier, A., Zilitinkevich, S., Joffre, S., Mahura, A., Nielsen, N.W., "On the parameterisation of the urban atmospheric sub-layer in meteorological models". Atmospheric Chemistry and Physics Discussions 5, 2005, pp.12119-12176.
[13] Marcelo C. C. Stabile, Inakwu O. A. Odeh, Alex B. Mcbratney. "Fusion of high-resolution aerial orthophoto with Landsat TM image for improved object-based land-use classification". Asian conference on remote sensing. http://www.a-a-r-s.org, 2009.
[14] Kurtz, C., Passat, N., Gancarski, P., Puissant, A., "Multi-resolution region-based clustering for urban analysis". International Journal of Remote Sensing 31 (22), 2010, pp.5941-5973.
[15] Tucker, C.J., Townshend, J.R.G., Goff, T.E., "African land-cover classification using satellite data". Science 227 (4685), 1985, pp.369–375.

[16] Ehrlich, D., Lambin, E.F., "Broad scale land-cover classification and inter annual climatic variability". International Journal of Remote Sensing 17 (5), 1996, pp.845–862.
[17] Y. Julien, J.A. Sobrino, J.-C. Jiménez-Mu˜noz, "Land use classification from multitemporal Landsat imagery using the Yearly Land Cover Dynamics (YLCD) method". International Journal of Applied Earth Observation and Geoinformation 13, 2011, pp.711–720.
[18] Golany, G.S., "Urban design morphology and thermal performance". Atmospheric Environment 30, 1996, pp.455–465.
[19] Theurer, W., "Typical building arrangements for urban air pollutant modeling". Atmospheric Environment 33, 1999, pp.4057–4069.
[20] Adolphe, L., "A simplified model of urban morphology: application to an analysis of the environmental performance of cities". Environment and Planning: Planning and Design 28, 2001, pp.183–200.
[21] Huang, J., H. Akbari, and H. Taha. "The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements". ASHRAE Winter Meeting, American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, Georgia, 1990.
[22] P. Edussuriya, A. Chan, A. Ye. "Urban morphology and air quality in dense residential environments in Hong Kong. Part I: District-level analysis", Atmospheric Environment, 2009, pp.1-15.