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Computer Simulation as an Alternative Approach in Climatically Responsive Urban Configuration Study

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Urban microclimate is a significant parameter to urban climatology, as it forms urban heat island, thermal comfort, and energy demand. Studies on the climatically responsive urban configuration commonly conducted through the empirical and physical modelling approach. However, in this context recently, computer simulation as numerical modelling approach has been broadly applied by scholars. Besides overcoming the limitation of time, spaces and cost, computer simulation offers an effective solution to perform hypothetical studies. As a new approach over empirical and physical modelling approach, scholars frequently perform a comparison of both computer simulation and field observation approach. It shows that even though the computer simulation has been commonly used, but the validation is still questioned. This paper presents not only the comparison of computer simulation with observation data but also empirical model equations. The hypothetical urban configurations situated in Kuala Lumpur City were simulated by using ENVI-met V. 3.1 microclimatic model. Two empirical model equations of maximum urban heat island developed by Oke were used to compare with computer simulation. A 24-h air temperature data is presented for the simulation and field observation comparison. The results indicate the significant correlation between the two comparisons. This study verifies and strengthens the validation of the computer simulation as a reliable approach in urban configuration and microclimate studies.

1. Introduction

Climate change and global warming have become the real threat to the current living environment. The global temperatures increases that have reached 0.6 ºC in last 100 y (NOAA, 2016) present that the continuity of this issue portrays a significant future impact on society and environment. Built environment is no exception. The high-density urban development generates a night temperature increase in urban which is called urban heat island (UHI) that could reach up to 5 – 6 ºC (Lauwaet et al., 2015). As the result, the UHI causes the thermal discomfort, air pollution and increase of energy demand (Gartland, 2008). As the UHI is a broad issue and discussion in urban climatology studies, there are various approaches developed by planners and designers. Oke (1982), one of the pioneers in UHI studies stressed that studies on UHI causes include observation, theoretical and modelling approach. Modelling approach, as the concern of this paper, is categorised into three model; empirical, physical, and numerical. Those models were adapted in different studies, depends on the purposes. Empirical model is frequently applied to overcome physical experimental issues (Saavedra et al., 2013). Computer simulation emerges as the current trend of assessment tools among varies areas including built environment (Nimlyat et al., 2014). Nimlyat et al. (2014) stressed that the innovation of computer technology offers the holistic assessment. As the new approach in urban climatology studies, the validity of computer simulation seems always to be underpinned (Ali et al., 2015).

Earlier study (Yola and Siong, 2015) highlights that the validation studies aim to clarify the limitation of computer simulation and uncertain accuracy of the simulation models. However, the validation studies are always performed to confirm the accuracy of the computer simulation with the field observation that is set to the setting of the particular study (Witlox et al., 2013). Therefore, this paper justifies further the gap in the

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significance and barriers not only between the computer simulation and the field observation approach but also formulated empirical equations.

2. Climatically responsive urban configuration

The temperature increases as the result of the modification of urban microclimate generate direct impact on thermal comfort (Radhi et al., 2015) and energy demand for cooling load (Kalz et al., 2014). The urban configuration is discussed as the most influenced factor to impact the three major roles of urban energy budget studies (Erell et al., 2011). The urban microclimate, thermal comfort and energy consumption are interconnected by the physical attributes in built environment (Ng, 2010) which in this study is called climatically responsive urban configuration. In general, climatically responsive urban configuration is the urban configuration strategy in achieving the sustainability by holistically considering the climatic feature. There are diverse of approaches applied by scholars in investigating relationship between urban climatology and urban configuration. UHI is the major study in this context. The major approaches in UHI study; empirical, physical model and numerical are reviewed in this paper.
Empirical modelling or mathematical equation as the main approach used in earlier UHI studies was derived based on the statistical field observation. The findings from the empirical modelling lead to formulating the new equation models. One of the pioneer studies on UHI by Oke (1981) has generated empirical mathematical Eq(1) and Eq(2) which are the fundamental concept used by the scholars in investigating the outdoor microclimate. The equations formulate that the maximum expected UHI to be influenced by the Height to Width (H/W) aspect ratio and Sky View Factor (SVF) in urban canyon configuration (Givoni, 1998). These equations justify that high H/W aspect ratio and small SVF contributes to maximum UHI. As the equations are widely used in urban climatology studies, this paper applies them to compare the computer simulation with the empirical modelling. However, these equations were formulated by investigating urban canyon configuration. Therefore, this paper aims to explore the equations on other urban configurations.

$$dT_{max} = 7.45 + 3.97 \times \ln (H/W) \tag{1}$$

$$dT_{max} = 15.27 - 13.88 \times SVF \tag{2}$$

The physical modelling represents the design attributes of existing or hypothetical scenario to predict their thermal behavior. Scale model approach offers planners and designers to overcome the limitation of field observation, such as time, accessibility, and spaces. Numerical modelling is the mathematical models that formulate the computer simulation. It complies and improves the earlier applied approaches of empirical and physical modelling. Due to these benefits, nowadays planners and designers tend to apply the numerical modelling over other two approaches (Elnabawi et al., 2015) as it has been reported to be a feasible tool to have a more flexible, accurate and valid assessment. Furthermore, earlier studies also stressed that computer simulation is a suitable method and tool for analyzing the correlation between the climatic variables and physical design (Yola and Siong, 2014). However, as validation of the computer simulation method is always performed by comparing two approaches in the current study setting, this study compares the computer simulation with both physical and empirical modelling.

3. ENVI-met computer simulation and empirical model of urban configuration

This study investigates the impact of urban configuration on outdoor urban microclimate by comparing empirical modelling, physical and numerical modelling. This paper clarifies the significant correlation of these approaches in investigating urban climatology and urban configuration. The study performs two stages of the investigation, which are the comparison of the computer simulation study with the empirical Eq(1) and Eq(2) and the comparison of the simulation study with the physical modelling. The simulation and field observation were set in in Kuala Lumpur city center (3º 8’ N 101º 41’ E), Malaysia, which is situated in a hot and humid region. This location was considered as Kuala Lumpur city center represent the urban setting which mostly influenced by complex UHI and thermal comfort. The outdoor simulation was performed by ENVI-met V3.1 3D microclimate simulation. Besides the canyon (I I), two other hypothetical building configurations were investigated; semi-enclosed (⊔) and courtyard (☐). The Height to Width (H/W) aspect ratio of 1 : 1, 2 : 1 and 3 : 1 as shown in Figure 1. This paper investigates the air temperature as the main microclimate and UHI features. The 24-h receptor data was taken at the ground level (0 m) of the outdoor spaces of the urban blocks. The simulation and field observation were set on 15 March 2015. The initial temperature was 300 K, the wind direction was 225 (SW), relative humidity was at 83 %, and roof and wall albedo was 0.5 and 0.3. The field observation data was also taken by using Air Velocity Logger.

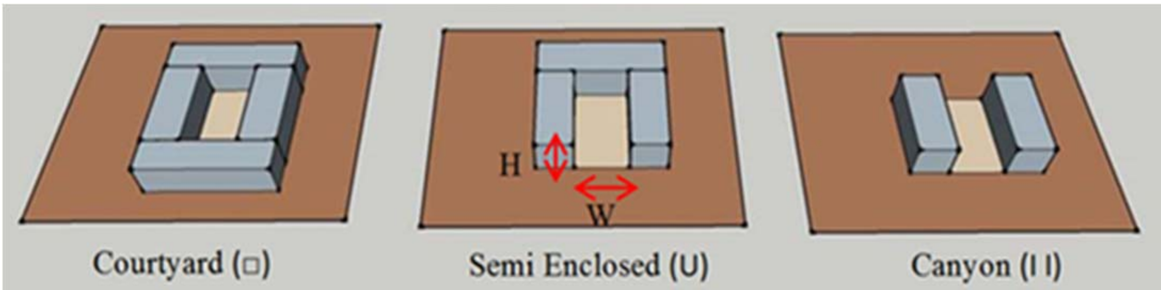

Figure 1: Case study urban configurations: courtyard, semi-enclosed and canyon

4. Results and discussion

The comparison result of air temperature data extracted from the empirical models (Eq(1) and Eq(2)) and the simulation indicates the identical trend (Table 1). The empirical equations show that the higher Height to Width (H/W) ratio and the smaller sky view factor (SVF) result in the higher temperature. Scientifically, this result is also confirmed by the simulation result. It shows the smaller night temperature drop occurs in a higher Height to Width (H/W) aspect ratio and smaller sky view factor (SVF) which indicates the expected maximum night temperature that contributes to Urban Heat Island (UHI) as formulated by the two equations. Besides to verifying the validity of the computer simulation approach over the empirical equations for this study, the results also prove that both approaches are reliable to investigate the modified configuration of urban canyon spaces.

Table 1: Data comparison of empirical model and simulation

Urban Configuration	Height to Width (H/W) Aspect Ratio	Sky View Factor (SVF)	Expected Maximum Temperature (dT_{max}) from Empirical Models by Oke (ºC)		Night Temperature Drop (Envi-met Simulated Temperature) (ºC)
			Eq (1) H/W Model	Eq(2) SVF Model	
Courtyard (□)	1 : 1	0.324	7.45	10.77	2.92
Semi Enclosed (⊔)	1 : 1	0.426	7.45	9.36	3.22
Canyon (I I)	1 : 1	0.519	7.45	8.07	3.65
Courtyard (□)	2 : 1	0.185	10.20	12.70	1.95
Semi Enclosed (⊔)	2 : 1	0.336	10.20	10.61	1.84
Canyon (I I)	2 : 1	0.395	10.20	9.79	2.81
Courtyard (□)	3 : 1	0.111	11.81	13.73	1.37
Semi Enclosed (⊔)	3 : 1	0.284	11.81	11.33	1.26
Canyon (I I)	3 : 1	0.327	11.81	10.73	2.37

The validation of this simulation study was also compared with the field observation result. The results indicate that the field observation and the simulation show the identical trend (Figure 2 and Figure 3). The regression analysis (Figure 4) indicates the very strong correlation between the two approaches (R^2 = 0.76 to 0.94). However, the gap between observed and simulated data shows that there were existing external factors influencing the field observation data such as surrounding environment and the variety of building materials that were not covered in the simulation due to its limitation. The strong correlation (R^2 = 0.76 to 0.94) between the two approaches and the identical results in Table 1 proves that the numerical approach signifies the both empirical and physical modelling approaches in the architectural thermal response.

As the result, the comparison data characteristics and trend in this study justify that the computer simulation approach as a trend in thermal response studies is a reliable approach when compared to the empirical modelling. Compared to the field observation approach which basically generates the raw data that requires further analysis, the computer simulation elaborates the detail, comprehensive and scientific analysis aspect of the climatic features. The validation of computer simulation (ENVI-met V. 3.1.) as a form of numerical modelling is scientifically reliable to not only physical modelling but also empirical modelling. This study offers a reference that ENVI-met V. 3.1 is a valid tool to study the relationship between urban configuration and microclimates. Furthermore, this study also verifies that ENVI-met V. 3.1 is a reliable tool to simulate varies of urban configurations that were not justified in the earlier empirical modelling.

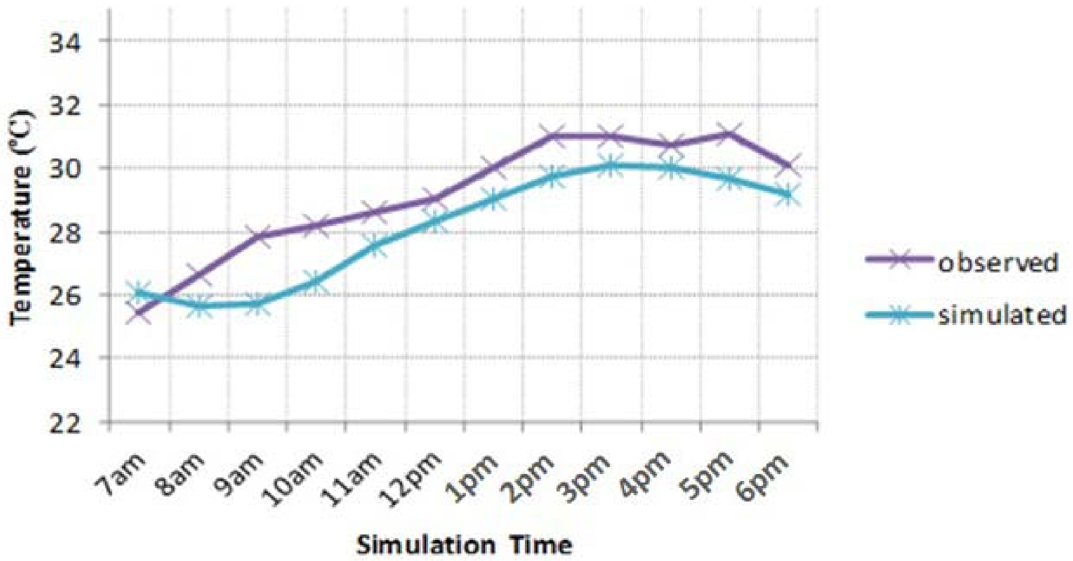

Figure 2: Comparison of observed and simulated day-time air temperature

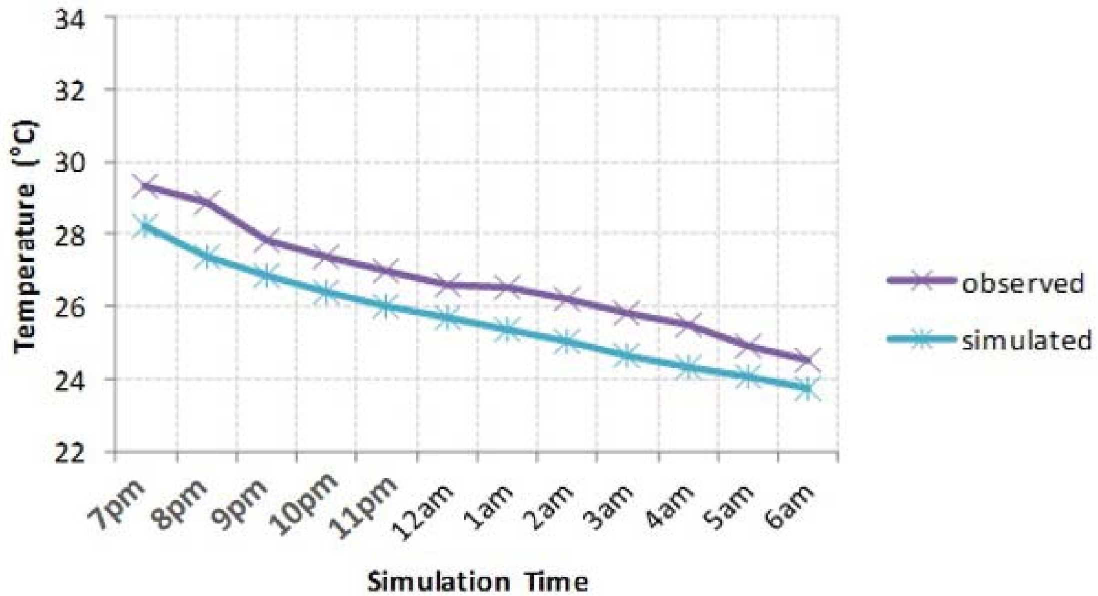

Figure 3: Comparison of observed and simulated night-time air temperature

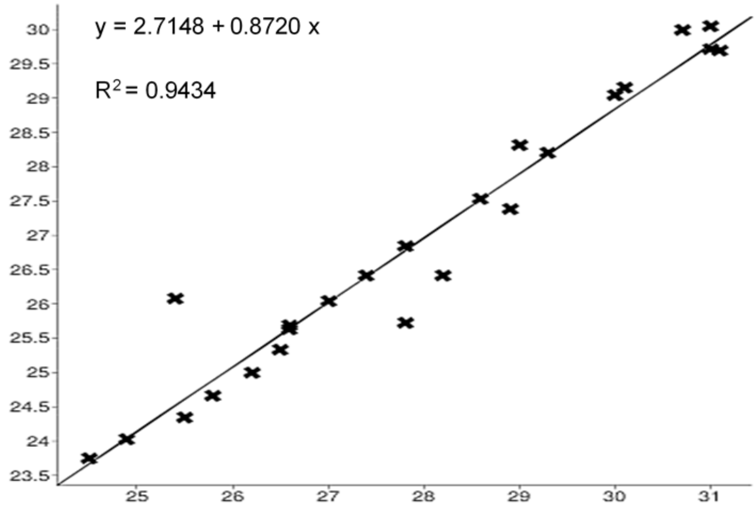

Figure 4: Regression analysis of observed and simulated air temperature data

5. Conclusion

This study scientifically justifies that computer simulation is a reliable tool to climatically responsive urban configuration study. The validation proves that the numerical modelling is effective and reliable approach to physical and empirical modelling. Furthermore, this study also scientifically justifies that computer simulation also eliminates the barriers of the field observation which offers to extend the scope of the study. In this study, computer simulation presents the analysis of more alternatives urban configuration instead of limited to one configuration as formulated in the empirical equations. The findings show that with the innovation of technology, the computer simulation offers the great flexibility for scholars to research more design alternatives with effective time, site, cost, and climate issues which are the likely challenge for the empirical and physical modelling approach. This significance approach assists them in decision making during the planning and design process. However, this study does not limit planners and designers to apply only the computer simulation approach in their design process, as under certain circumstances, field observation would still be recommended.

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