IMPACT OF URBAN CONFIGURATIONS ON MICROCLIMATE AND THERMAL COMFORT IN RESIDENTIAL AREA OF KUALA LUMPUR

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To My Beloved Family;
Abd. Rachni (alm), Suniaty Kad,
Windi Wiguna and Hebby Wilanda

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All praise to be to Allah, the Most Gracious and the Most Merciful, for His Blessing, Love, and Guidance. A Salute upon Prophet Muhammad (Peace Be Upon Him), His family and all His companions.

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ABSTRACT

The increase of vertical development causes the modification of urban microclimates and higher intensity of Urban Heat Island (UHI). Scholars emphasise that urban configuration is one of the major factors that influences this issue. Current studies on the relationship of urban configurations and urban climate mainly focus on the urban canyon. Furthermore, there is lack of focus on the impact of urban configurations on both microclimate and thermal comfort. Therefore, this study investigated the impact of urban configurations on the mitigation of UHI and the balance between microclimate and thermal comfort, called Climatically Responsive Urban Configuration (CRUC) in Kuala Lumpur. Four urban configurations, namely: Courtyard, U, Courtyard Canyon and Canyon were investigated using ENVI-met simulation. The urban configurations were simulated according to the value of Sky View Factor (SVF). Besides, these urban configurations were set according to two canyon directions; East – West and North – South in two empirical sites situated in Kuala Lumpur. The results showed that the urban configurations have impact on both microclimate and thermal comfort. This is an indication that the increase of SVF in urban configurations could mitigate the intensity of the UHI. Enclosed urban configurations such as the Courtyard and Courtyard Canyon complied with the concept of CRUC in the setting of East – West canyon direction, whereas urban configurations with canyon features for Canyon and Courtyard Canyon are recommended in the setting of North – South canyon direction. The finding emphasised that in Kuala Lumpur climatic context, the high intensity of the solar radiation is the main influential factor in UHI mitigation and forming the CRUC. It is recommended that urban planners avoid East-West canyon direction in strategising the impact of urban configurations on microclimate and thermal comfort.

ABSTRAK

Peningkatan pembangunan secara menegak menyebabkan berlaku perubahan iklim mikro bandar dan Pulau Haba Bandar (UHI) yang berintensiti tinggi. Pakar menekankan bahawa konfigurasi bandar merupakan salah satu faktor utama yang mempengaruhi isu ini. Kajian sedia ada tentang hubungan konfigurasi bandar dan iklim bandar secara umumnya memberi tumpuan kepada ngarai dalam bandar. Di samping itu, terdapat kekurangan tumpuan terhadap kesan konfigurasi bandar di kedua-dua iklim-mikro dan keselesaan haba. Oleh itu, kajian ini mengkaji kesan konfigurasi bandar pada pengurangan UHI dan keseimbangan antara iklim-mikro dan keselesaan haba, yang dikenali sebagai Konfigurasi Bandar yang Responsif Iklim (CRUC) di Kuala Lumpur. Empat konfigurasi bandar, iaitu: 'Courtyard', 'U', 'Courtyard Canyon' dan 'Canyon' telah dikaji dengan menggunakan simulasi ENVI-met. Model konfigurasi bandar telah disimulasikan mengikut nilai Faktor Pandangan Langit (SVF). Selain itu, konfigurasi bandar ini telah ditetapkan mengikut dua arah ngarai; Timur - Barat dan Utara - Selatan di dua tapak sekitar Kuala Lumpur. Hasil kajian menunjukkan bahawa konfigurasi bandar mempunyai kesan terhadap kedua-dua iklim-mikro dan keselesaan haba. Ini menunjukkan bahawa peningkatan SVF dalam konfigurasi bandar boleh mengurangkan intensiti UHI. Konfigurasi bandar tertutup seperti 'Courtyard' dan 'Courtyard Canyon' mematuhi konsep CRUC dalam arah ngarai Timur – Barat, manakala konfigurasi bandar dengan ciri-ciri ngarai untuk 'Canyon' dan 'Courtyard Canyon' dicadangkan dalam arah ngarai Utara - Selatan. Hasil kajian ini menekankan bahawa dalam konteks iklim Kuala Lumpur, keamatan tinggi radiasi solar merupakan faktor utama yang mempengaruhi dalam pengurangan UHI dan membentuk CRUC. Dapatan ini mencadangkan agar para perancang bandar mengelakkan arah ngarai Timur – Barat dalam mengatur strategi kesan konfigurasi bandar di iklim-mikro dan keselesaan haba.

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LIST OF ABBREVIATIONS

CBD	-	Central Business District
CRUC	-	Climatically Responsive Urban Configuration
EPA	-	Environmental Protection Agency
FAR	-	Floor Area Ratio
FBTS	-	Flat Bandar Tasik Selatan
H/W	-	Height to Width
L/W	-	Length to Width
PET	-	Physiological Equivalent Temperature
PMV	-	Predicted Mean Vote
RBL	-	Rural Boundary Layer
RH	-	Relative Humidity
RSME	-	Root Squared Mean Error
SET	-	Standard Effective Temperature
SM	-	Surya Magna
SVF	-	Sky View Factor
Ta	-	Air Temperature
Tmrt	-	Mean Radiant Temperature
To	-	Operative Temperature
Ts	-	Surface Temperature
TS	-	Thermal Sensation
UHI	-	Urban Heat Island
UBL	-	Urban Boundary Layer
UCL	-	Urban Canopy Layer
UPL	-	Urban Plume Layer

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The relationship between climate and urban development has been an inseparable part in city sustainability framework. The climate change as the results of rapid human activities brings the new topic to the contemporary urban planning and design. Definitely, it is due to the fact that the climate change has threatened the urban area. The climate change mitigation and adaptation is a global agenda that is still facing scientific challenge (Masson et al., 2014). Therefore, the climate change mitigation agenda still becomes a continuing conceptual topic to the city planners and scholars. Carter et al. (2015) points out three roles of city as the central position in the adaptation agenda. Firstly, the urbanisation as the result of the population growth, secondly, the city development that creates modification of urban microclimates and thirdly the urban social issues which more relate to the urban governance.

The modification of urban microclimate that leads to the phenomena of Urban Heat Island (UHI) and thermal discomfort is a real threat to high-density cities. The issues of Urban Heat Island (UHI) as the direct impact of modification of urban microclimate and urban thermal discomfort are mainly discussed in the current urban climatology studies, as they are more technical topic to the adaptation agenda. The modification of urban microclimate and thermal comfort are stressed to be significantly influenced by the configuration of urban surface. The ongoing discussion on the relationship between the urban configurations on the urban microclimate and thermal comfort does not seem to form a solid conclusion to the adaptation agenda, as there is still gap of argument within the discussion. The climatic variables, variation of the climate regions, the expansion in physical feature of urban design and planning, the causes of the microclimate modification and the effective strategies to the adaptation agenda are among the gaps that leave space to explore. Particularly, current studies are still lacking the review on the relationship of urban configurations and urban microclimate as well as thermal comfort in Kuala Lumpur, Malaysia context, which is the case of this study. Therefore, the following discussion elaborates this concern as the introduction of this study.

The explosion of population is an ongoing issue in fast growing countries. According to projection by United Nations (2011), from 2011 to 2050, the global population will increase by 2.3 billion passing from 7 billion to 9.3 billion. It is also stated in the report that while the global population grows, the rapid urbanisation trend will follow. The urbanisation trend is the transformation of urban development expansion through population measure, which is concentrated within the urban areas. It has become a global phenomenon, which the population living in urban area is projected to gain 6.25 billion from 3.63 billion in 2011 to 2050, while the population living in rural area will decrease from 3.34 billion to 3.05 billion for the same period. Economic growth and urbanisation that overcome both developing and developed countries have attracted the migration of people from rural to urban area. This indicates that proportion of the population is definitely moving to concentrate on the urban area, which some of them are megacities. United Nation reported that the number of megacities is projected significantly increases to 37 in 2025, while 1 out of 7 to 8 living in urban areas will live in megacities which occupies 8 % of the global population.

There will be no exception for Malaysia. As fast growing country with big cites, Malaysia has generated urbanisation that rises from 54.3 % to 65.4 % from 1991 to 2000 (Federal Department of Town and Country Planning Peninsular Malaysia, 2006) and it is projected that it will reach 75 % by 2020. Kuala Lumpur and Putrajaya as the administrative center are reported with 100 per cent level in urbanisation, followed by Selangor and Pulau Pinang with 91.4 % and 90.8 % urbanisation level (Department of Statistic Malaysia, 2010). As occurs in other fast growing countries, Malaysian population is concentrated in urban areas while the rural population decreases started from 1990 to 2030 (Figure 1.1). The data projects that 80 % of the Malaysian population live in cities by 2030 (Jali et al., 2006), while 90 % Malaysians are projected to live in cities by 2050 (United Nations, 2009; Yuen, et al., 2006; Mazlan, 2014). The projection presents that the contrast trend between the urban and rural area shows the urge of urban planning concern on the urban development. This trend indicates that the urban areas are expanding to sub-urban; Kuala Lumpur area as the capital of Malaysia clearly presents this trend (Department of Statistic of Malaysia, 2010). Figure 1.2 illustrates Kuala Lumpur urban expansion from 1895 to 1990, which presents rapid expansion over almost a decade. As a result, the increase of city expansion emerges the number of new cities in sub-city or rural area. As reported by Mazlan (2014), the number of towns in Malaysia increased from 72 to 228 from 1980 to 2010 (Figure 1.3).

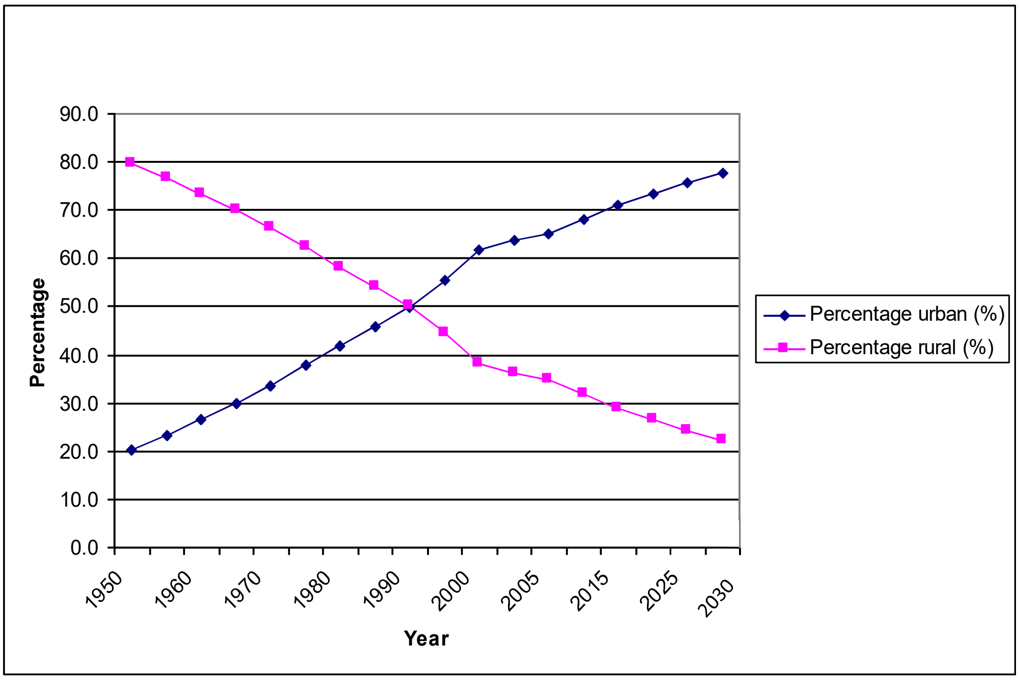
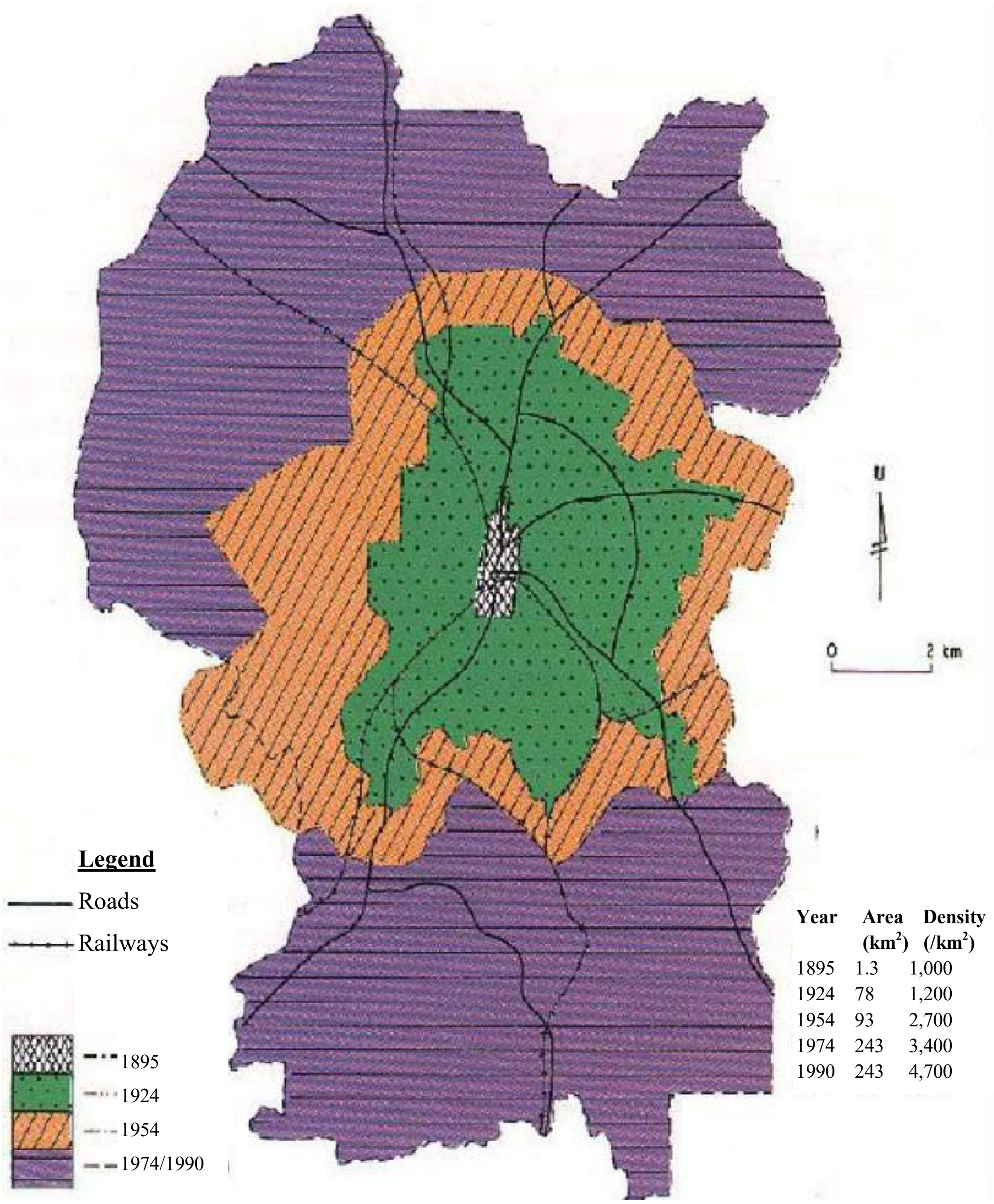


Figure 1.1: Trend of Malaysian Urban and Rural Population from 1950 to 2030 (projected)

Source: Jali et al. (2006)



Year	Area (km^2)	Density ($/km^2$)
1895	1.3	1,000
1924	78	1,200
1954	93	2,700
1974	243	3,400
1990	243	4,700

Figure 1.2: Kuala Lumpur City Expansion from Year 1895 to 1990

Source: Kuala Lumpur City Hall (2000)

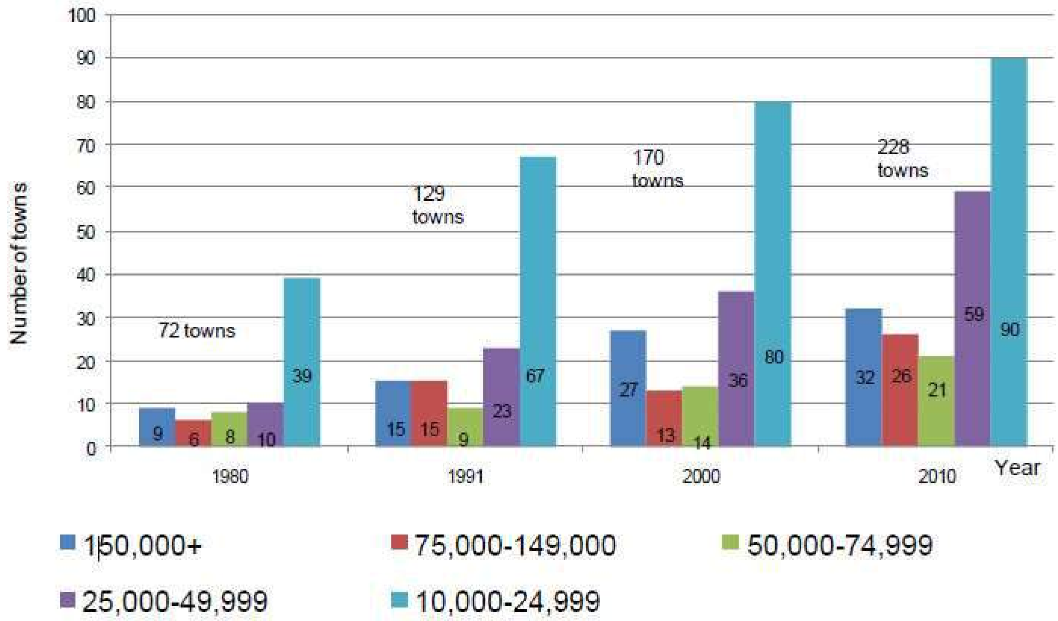


Figure 1.3: Increase of Number of Towns in Malaysia between 1990 to 2010

Source: Mazlan (2014)

This trend will continue as Malaysia is projected as one of the Asian countries with the high rate of urbanisation in 2030 (Roberts and Kanaley, 2006). It creates on-going urban threats such as social problem, environmental damages, and economic issues. One of the obvious problems starts from the space issue in urban area. When urban areas rapidly expand and create new sub towns, fast migration of rural to urban and urban to urban will occur that consequently will drive urban area to lacking of space. The space issue becomes phenomena that generates the rising the value of space in urban area, especially in city center. The land demand and price rise significantly, as well as the property price (Mukiibi, 2009). As the result of the urban spaces are transformed into high-rise buildings and skyscrapers. Emporis (2012) reported that dense city population causes the emerge of high-rise buildings in most of big or mega cities in the world. This trend is also indicated emerges in most of big cities in Asian countries with the rapid economic development, including Kuala Lumpur (Ernst and Young, 2012). Most of populated and urbanised big cities in Malaysia grow with the rapid high-rise buildings (See Table 1.1). The data presents that among the big cities with high rate of population and urbanisation, the number of high-rise buildings Kuala Lumpur leads the as the highest density.

Table 1.1: High-Rise Buildings of Big Cities in Malaysia

Cities	Population (Million)	Urbanisation (%)	Number of High-Rise Buildings
Kuala Lumpur	1,627,172	100	787
George Town	1,520,143	90.5	197
Johor Bahru	3,233,434	71.9	39

Source: Adapted from Emporis (2012) and Statistic Department of Malaysia (2010)

The evolution of urban development shows the planning strategies to adapt to the emerge of high-rise buildings in the dense urban area. Earlier review (Yola et al., 2013) highlights that the high-density vertical urban expansion has been transformed into different concept of urban configuration. Different key concepts of vertical urban development were proposed. The examples were grid city proposed by Corbusier (1929), sustainable vertical city (Foo and Yuen, 1999), vertical core and sub city clusters (Lachman Kataria, 2010), future skyscrapers city (Al-Kodmany and Ali, 2013), vertical garden city (Abel, 2011), and vertical theory of urban design (Yeang, 2012).

The review pointed out that all concepts aim to apply the sustainability. Each concept is applied into different scenario and objective of vertical urban development. Coubusier (1929) proposed 'towers in the park' (Figure 1.4) that transformed the urban development into the high-rise instead of building out. This grid city concept influenced the urban planning trends especially the current massive housing development. However, Yola et al. (2013) in earlier study highlights that there is no current fixed standard provided to regulate the configuration of vertical urban development.

The vertical urban development is reported to be responsible to the contribution of the urban microclimate modification. Buildings and pedestrians are blocked from the direct sunlight and urban wind due to the obstruction of urban blocks. The high-rise buildings shade urban spaces and the surrounding buildings. The concrete walls and pavement surface absorbs radiation and releases the nocturnal heat creates the temperature increase in the urban area. The urban temperature increase is called the Urban Heat Island (UHI), where urban area is warmer compared to the surrounding rural area during nighttime.

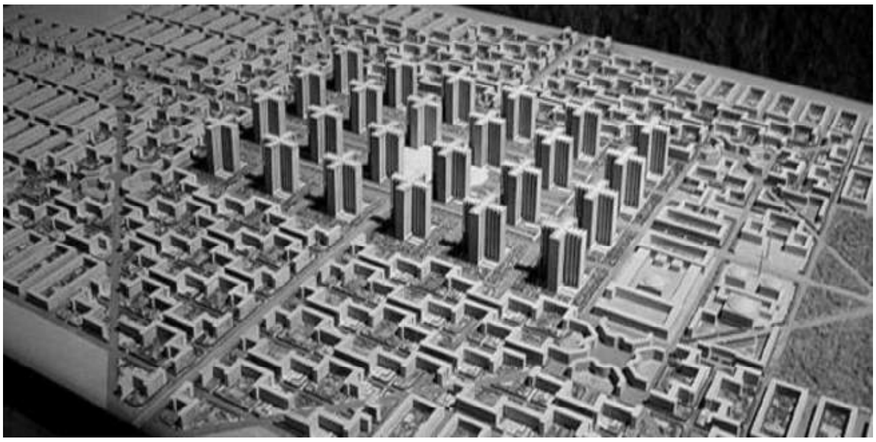


Figure 1.4: Grid City Concept by Le Corbusier
Source: Corbusier (1929)

Urban temperature increase has been also rapidly rising in Kuala Lumpur (Sani, 1984; Wai et al., 2005; Elsayed, 2006). Sani (1984), the pioneer in Urban Heat Island (UHI) study in Malaysia reported that the Urban Heat Island (UHI) could reach up to 1.7 ºC to 2 ºC in new residential area in Kuala Lumpur. Figure 1.5 presents the Urban Heat Island (UHI) in Kuala Lumpur and Petaling Jaya area between February 1972 to September 1980 (Sani, 1984). Later study conducted by Elsayed (2006) reported that the intensity of Urban Heat Island (UHI) in Kuala Lumpur increased from 4 ºC in 1985 to 5.5 ºC in 2004 (see Figure 1.6). Further latest studies still indicate that the Urban Heat Island (UHI) increases significantly in Kuala Lumpur (Shahmohamadi et al., 2011, Yusuf et al., 2014; Shaharuddin, 2014; Hashim, 2014; Ooi et all., 2017). These reports indicate that the issue of Urban Heat Island (UHI) increase is the real threat to resolve in the Kuala Lumpur climate adapting agenda.

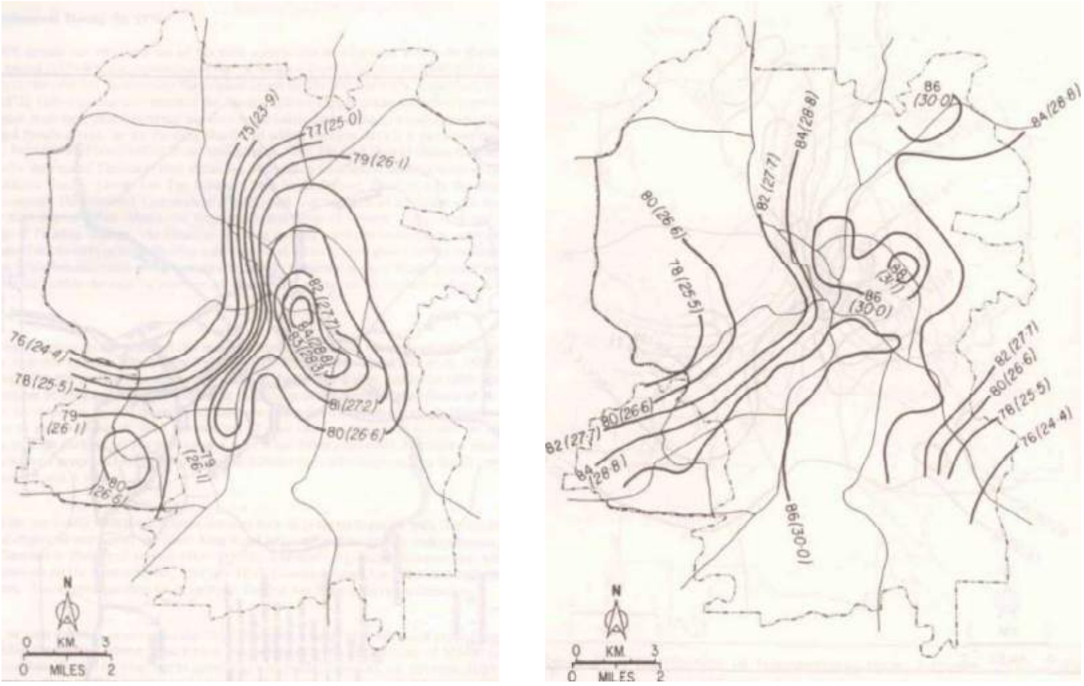


Figure 1.5: Kuala Lumpur Temperature Distribution taken between 9 pm to 10 pm on 1972 (left) and 1980 (right), Isotherm numbered in °F (°C in bracket) Source: Sani (1984)

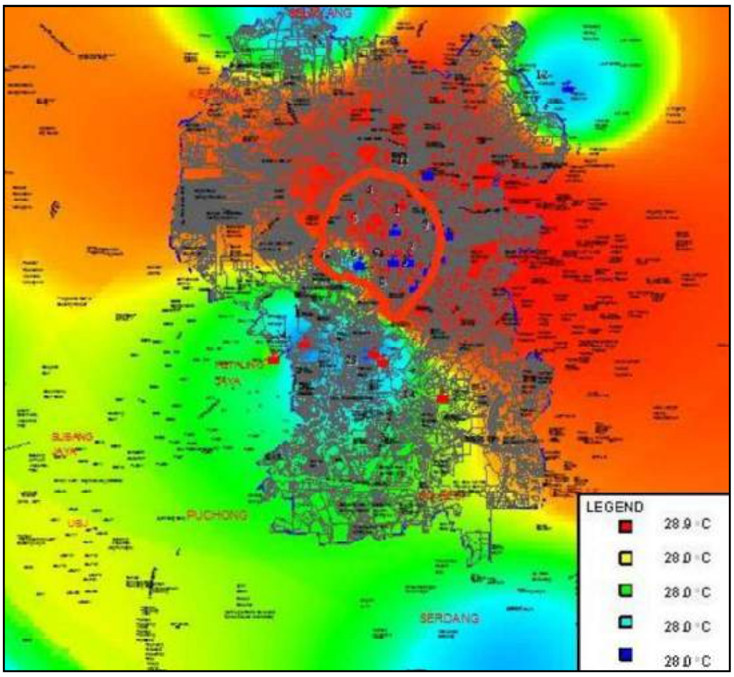


Figure 1.6: Kuala Lumpur Urban Heat Island (UHI) Image in 2004
Source: Elsayed (2006)

Although it is claimed to be safe for human health (Elsayed, 2006) the Urban Heat Island (UHI) intensity increase in Kuala Lumpur causes consequences to environment and living environment. Hashim et al. (2007) stressed that the rainfall increased 6 % and there was an increase of heat and land surface (Takeuchi, 2010 and Shaharuddin et al., 2006) in Malaysian urban areas like Kuala Lumpur due to the rising measure of Urban Heat Island (UHI). As projected by Malaysian Meterology Department (2010), the annual temperature anomaly will increase around 2.8 ºC from 2001 to 2099 while it is also followed by the rainfall trend that also increases significantly. This phenomenon also influences the urban thermal comfort.

Thermal comfort is a subjective expression towards environmental factors (ANSI/ASHRAE Standard 55, 2013). Studies reported that the temperature and other urban microclimate modification significantly influenced the pedestrian volume and activities (Taleghani et al., 2015; Aultman-Hall et al., 2009). The increase of heat stress in the city was reported to affect the urban thermal comfort of the indoor and outdoor environment (Honjo, 2009), urban dwellers' satisfaction towards open space (Makaremi, et al., 2012; Yang et al., 2012; Latini et al, 2010), the psychology of the urban dwellers (Matzarakis and Amelung, 2008 and Makaremi et al., 2012) and pollutant dispersion and CO_2 emission (Moonen et al., 2012).

As a result, the thermal discomfort issue requires the adjustment of the indoor or outdoor environment. Cooling load demand is one of the consequences caused for indoor part of the building. Increase of cooling load due to temperature increase in tropical regions mainly occurs in commercial and residential buildings (Lundgren and Kjellstorm, 2013), where the building occupants would use air conditioning to reach indoor thermal comfort. Every degree of temperature increase demands increase in energy demand and air conditioning cost (Lundgren and Kjellstorm, 2013; Moonen et al., 2012; Yau and Pean, 2011; Aebischer et al., 2007; Fung et al, 2006). Liao et al. (2015) reported that every degree increase of mean ambient temperature results in up to 14.2 % increment of cooling loads in an air-conditioned typical flat.

This discussion shows that the Urban Heat Island (UHI) as the result of modification of urban microclimate majorly influences the urban thermal comfort and energy efficiency. Therefore, the relationship of urban microclimate and Urban Heat Island (UHI) with the urban thermal comfort and energy efficiency is the concern in this study.

Studies emphasise that the increase of Urban Heat Island (UHI) is the impact of the heat released from the surface materials (building and road, roof and pavement albedo and emissivity, surface cover), anthropogenic heat and lacking of evapotranspiration (Haider, 1997; Sailor, D.J., 2011; Chen et al., 2011; Lin and Zhao, 2012; Chung et al., 2015). However, Urban Heat Island (UHI) is discussed in recent literatures as an obvious impact of urban development. Urban Heat Island (UHI) as part of urban energy balance system is an heat circle mainly driven by solar radiation in hot and humid regions (Djen et al., 1994; Terjung, 2005; Rizwan et al., 2008; EPA, 2013). Heat and solar radiation are the major features that drive urban energy balance system (illustrated in Figure 1.7). The heat that mainly generated by the human activities are the anthropogenic, sensible and latent heat.

Besides the heat energy, the short wave solar radiation is released to the sky in daytime. Short wave radiation is the reflected radiation from the urban surface. However, the trapped heat is stored in the urban spaces as long wave radiation. In this context, the stored heat is mainly influenced by the configuration of urban surface. The long wave radiation is normally trapped in the urban spaces between the tall buildings. This scenario explains the high intensity of Urban Heat Island (UHI) that occurs in dense urban area.

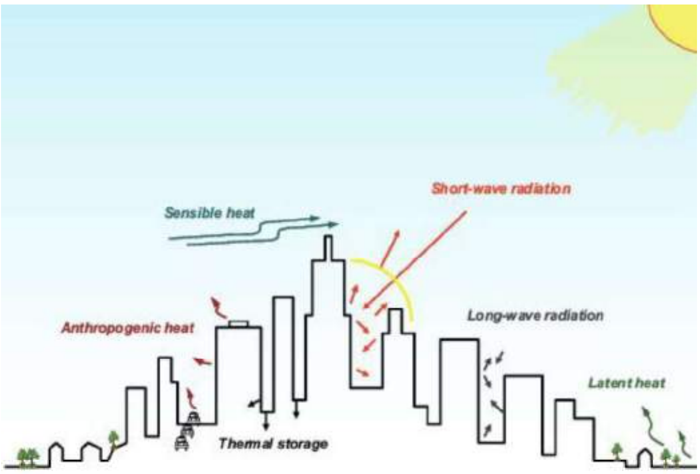


Figure 1.7: Heat and Solar Radiation Circle in Urban Energy Balance System
Source: US Environmental Protection Agency (2013)

The study on strong relation of Urban Heat Island (UHI) or urban microclimate and urban configurations has been justified from various perspectives. Urban configuration studies discuss how urban configurations can be strategise in order to modify the impact of solar radiation. Some of them are urban fabric and geometry (Martin and March, 1972; Shashua-Bar et al., 2004; Johansson, 2006; Hamaina et al., 2012), urban space structure (Hagen et al., 2014), building shape and orientation (Ling et al., 2007; Gerber and Lin, 2013) and roof shapes and forms (Xie et al., 2005).

Besides the role of solar radiation, urban ventilation is also emphasised contributing to modification of urban energy balance system. Building arrangement planning and canyon effect are the example of the strategies in order to maximise the urban ventilation (Nunez and Oke, 1977; Oke, 1987; Oke, 1988; Elhanas, M. M., 2003, Emmanuel, 2005, Emmanuel, 2007; Yuan and Edward, 2012; Lim and Ooka, 2014). Studies elaborated that urban wind could perform as urban ventilation in order to minimise the absorbed and stored heat from the urban surface as well as naturally ventilate the indoor environment. Oke (1987 and 1988) outlined the behaviour of airflow within different geometry of urban canyons. It emphasised that the building height and the distance between buildings influences the flow of the urban ventilation.

On the other hand, improper planning and design of urban configuration results in high intensity of the Urban Heat Island (UHI) and thermal discomfort. In short, the climatically unresponsive urban configuration (with the major characteristic of Urban Heat Island (UHI), thermal discomfort and high cooling load are mainly caused by rapid population and urbanisation, urban expansion and lack of land issues which extend the urban into vertical development (refer to Figure 1.8). In tropical countries like Malaysia, urban configuration modification is reported to be the effective alternative in modifying solar radiation and urban wind (Emmanuel, 2007; Giannopoulou et al, 2010; Rajagopalan and Jamei, 2014). The strategising of the urban configurations is suggested to urban planners and designers in order to go towards the climate friendly urban development.

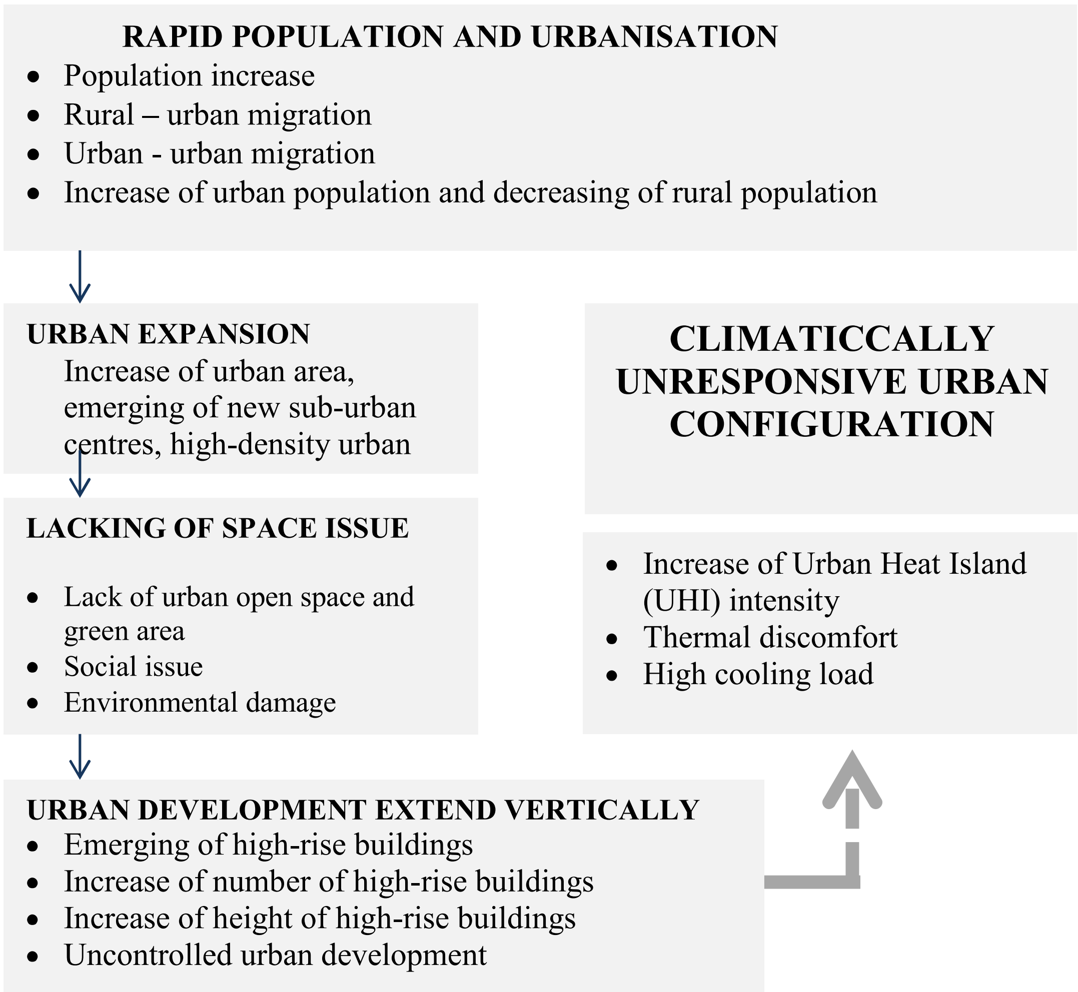


Figure 1.8: Causes of Climatically Unresponsive Urban Configuration

1.2 Problem Statement

Urban Heat Island (UHI) has been discussed as a real threat to city sustainability but enhancing long-term climate change (Solecki, et al, 2004; Weverberg et al., 2008; Corburn, 2009; David, P.E., 2010; Oleson, 2012). The temperature increase will not only demand for energy consumption but also for developing the significant pattern of climate change that contributes to global warming. If the trend of significant pattern of climate change continues, the future of earth will not only face the energy crisis, but also extreme damage of climate and environment (IPCC, 2007; U.S. Global Change Research Program Report, 2009; U.S. Environmental Protection Agency, 2012). Lack of detail awareness and knowledge of urban planners and designers towards the imperative of mitigation strategy of Urban Heat Island (UHI) contributes to the trend of moving away from city sustainability. Therefore, current literatures concern on the Urban Heat Island (UHI) mitigation strategies to apply in urban planning and development, although there is still no fixed framework regulate the strategy as a global policy.

Building passive design, urban configuration ratio, open space, street ratio, and suggested technology are part of the proposed strategies highlighted. The literatures stress that it is imperative to avoid segregation between Urban Heat Island (UHI) mitigation strategies and city sustainability. However, this study closely looks into the issue that it is not only the lacking of the awareness of the urban planners and designers on the climate friendly urban configurations, but also urban thermal comfort. Urban microclimate strongly relates to thermal comfort. However, the importance of considering thermal comfort seems to be frequently discussed separately from urban microclimate on urban configuration study and Urban Heat Island (UHI) mitigation strategy.

Although literatures investigate both urban microclimate and thermal comfort (Dalman and Saleh, 2012; Yahia, 2012; Perera et al, 2012; Adunola, 2014; Van Hove, 2015), very few studies aim to specifically explain the significance of Urban Heat Island (UHI) mitigation strategies from the perspective of both variables. Urban microclimate and thermal comfort have strong relationship, however, each variable aims to achieve different objectives. As discussed earlier, Urban Heat Island (UHI) mitigation strategy is a concerned agenda of urban planners and designers towards minimising significant climate change effect. The other way, maximising thermal comfort aims to meet the needs of acceptable level of environment for human in doing their activities.

For example, high-rise courtyard residential blocks could generate different urban microclimate compared to surrounding open area. Like other outdoor urban spaces, courtyard open space in between the high-rise urban blocks functions as the center point of social interaction among the residents (Marcus, C. and Francis, 1998; Glaeser and Sacerdote, 2000; Goncalves and Umakoshi, 2010; Farida, 2013). As it is outdoor, the social interaction will depend on the urban microclimate level (Givonni, 1998; Nikolopoulou and Lykoudis, 2007; Bruse, 2009; Brown, 2010; Erell et al, 2011; Andreou, 2013). This scenario also happens for indoor environment, the effect of building shading will influence the natural ventilation and daylighting penetration into the building (Givoni, 1998; Okeil, 2004; Ismail and Wan Moh Rani, 2014; Vartholomaios, 2015). Indoor thermal discomfort causes the increase of the energy demand for cooling load. On the other hand, the consequences of the choice of urban configuration influence the energy consumption. Thus, this study stresses the discussed problem of the uncontrolled climatically unresponsive urban configuration that leads the development to the consequences of city unsustainability; increase of Urban Heat Island (UHI), thermal discomfort and energy efficiency (illustrated in Figure 1.9).

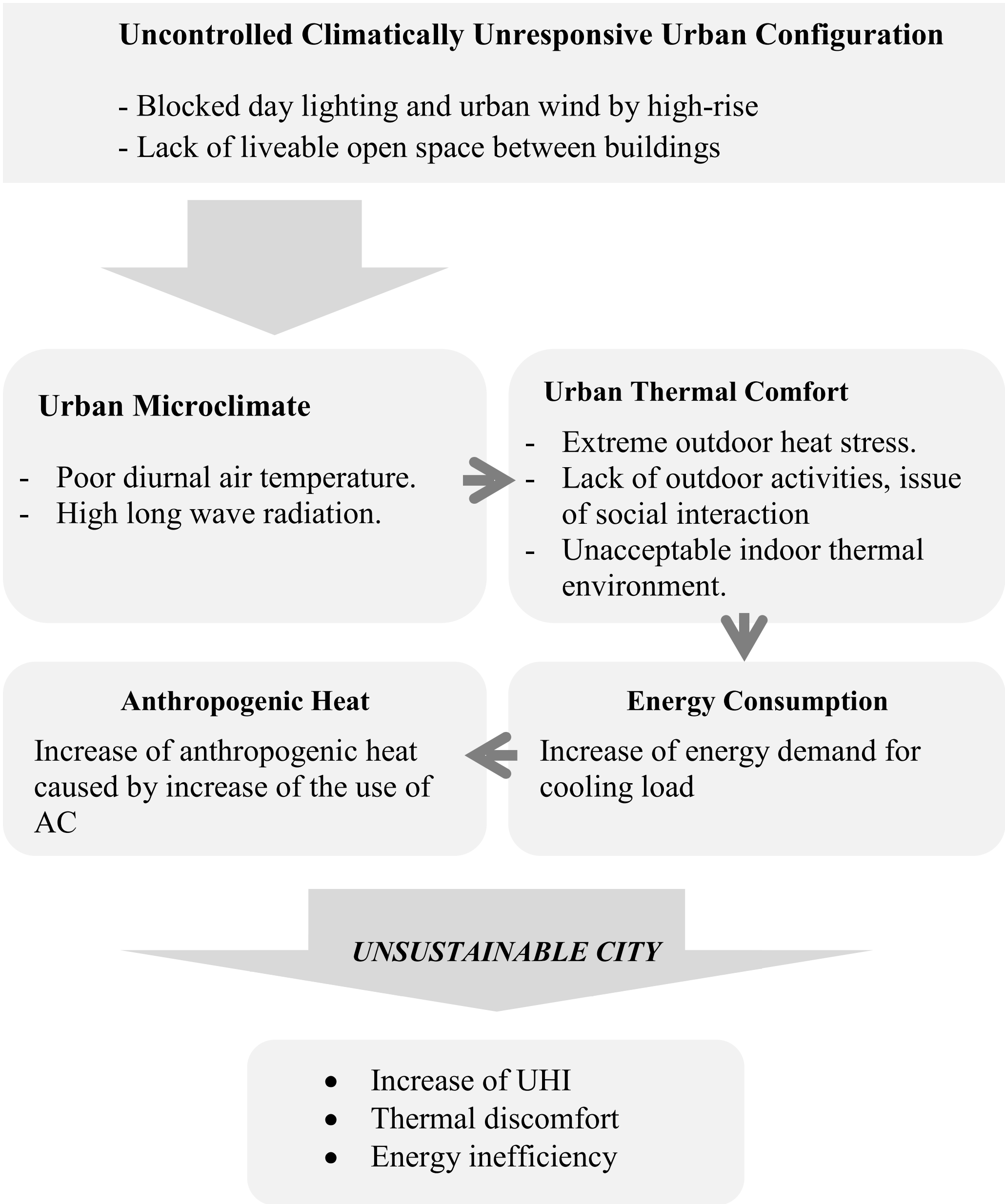


Figure 1.9: Climatically Unresponsive Urban Configuration and Consequences of Unsustainable City

1.3 Research Gap

The current studies on the relationship between the urban configuration, the urban microclimate and thermal comfort are dominated by the investigation on urban canyon or urban street canyon. Linear space, which normally covers building row that forms the urban canyon, is mainly influenced by Height to Width (H/W) aspect ratio and Sky View Factor (SVF). Table 1.2 summarises the review on the development of studies on the relationship of urban configuration with climate. It shows that pioneer studies (1970 – 1990) covered lesser climate variables and climate region. The studies were also conducted mostly on urban canyon instead of other types of urban configurations. Later studies (1990 – 2010) were performed with more climate variables in various configuration or types of buildings. Latest studies conducted between 2010 and 2015 were done with more choices of configuration, climate feature and climate regions. However, the studies investigation were mostly focused on climate variable, while this study specifically investigates the impact of more option of urban configurations on the holistic climate features in the context of Kuala Lumpur.

Furthermore, this study justifies that urban spaces is not only about urban canyon that is frequently used for street use. Other open space that is meant to accommodate city dwellers' outdoor social activities seems to be overlooked. For example, shared courtyard in between residential high-rise is always functioned for residents' outdoor activities, as the vertical living space does not offer much open space. The occupant needs this shared open space either day or nighttime. It also needed as thermal comfort besides the suitable urban microclimate as the space. Besides, the configuration between the open space and the buildings will also influence the indoor day light and ventilation. This highlights the need of investigating both urban microclimate and thermal comfort, which is not comprehensively discussed for urban street canyon as it used by pedestrians and cars instead of residents.

Table 1.2: Matrix of Research Gap

Researcher, Year	**Investigated Research Scenario and Variables**																		
	Region / study area			Building Use				Types of Investigated Urban Configurations			Physical Design Consideration				Climatic Research Variables		Climatic Research Output		
	Low-Mid Latitude	Tropical	Malaysia	Residential	Commercial	High Density	Numerous /Not specified	Various configuration	Urban /street canyon	Open space	Height to Width	Configuration layout	Sky View Factor	Orientation	Solar Radiation	Urban Wind	Urban Heat Island	Urban microclimate	Thermal comfort
1970-1990																			
Hotchkiss & Harlow,1973	√						√		√		√					√	√	√	
Martin and March, 1975	√						√	√				√			√				
Hawkes, 1981	√					√		√			√				√			√	
Gupta, 1984		√					√	√			√	√	√	√	√			√	
Sani, 1984			√				√										√	√	
Mayer and Hoppe, 1986	√						√		√					√	√				√
Oke, 1987/1988	√						√		√		√		√	√	√	√	√	√	√
Remarks	Pioneer Studies. More focus on the case research, less variables (mostly on solar radiation), cover mostly urban street canyon or undefined various configuration, and studies in low/mid latitude region.																		
1990-2010																			
Dabberdt & Hoydish,1991	√						√	√	√		√	√		√		√		√	
Pearlmutter et al., 1999	√						√		√		√			√	√				√
Goh and Chang, 1999		√		√							√						√		
Elhanas, 2003	√						√		√		√		√	√	√	√	√	√	
Assimakopoulus et al, 2003	√						√		√		√	√				√		√	
Xie et al, 2005	√					√			√			√		√	√	√		√	
AliToudert and Mayer, 2006	√						√		√		√		√	√	√	√			√
Elsayed, 2006			√				√										√	√	
Johansson, E., 2006			√				√		√		√				√				√
Ling et al, 2007			√			√					√	√		√	√				
Li et al., 2009	√			√		√		√			√	√			√				√
Bruse, 2009	√				√					√		√		√	√			√	√
Remarks	The climatic variables are more various, studies on more types of configurations or case buildings, cover more regions of study area																		

2010-2015																			
Ng, 2010		√				√			√		√		√	√	√			√	
Hachem et al, 2011	√			√				√				√			√			√	
Erell, 2011	√						√		√		√		√	√	√	√	√	√	
Kruger et al., 2011		√					√		√	√	√		√	√		√		√	
Harahap et al, 2011			√	√				√				√		√		√			√
Dalman et al, 2011		√		√					√									√	√
Makaremi et al., 2012			√		√					√						√			√
Zhang et al., 2012		√				√		√			√	√							
Yang et al, 2013	√			√		√						√				√			√
Ndetto and Matzarakis, 2013		√					√		√		√			√					√
Almhafdy et al., 2013			√		√					√	√	√		√	√			√	
Cardenas-Jiron et al., 2014	√					√	√		√	√	√			√	√			√	
Qaid and Ossen, 2014			√		√	√			√		√		√	√	√	√		√	
El-Deeb, 2014		√		√		√				√	√	√						√	
Ismail & Rani, 2014			√	√								√				√			√
Remarks	Studies are more focused, have more variables (however, most of studies focus on specific either urban microclimates or thermal comfort, lacking of concern of both), more region of study area (more studies are conducted in tropical region), however, none studies on impact of urban configurations on both microclimate and thermal comfort in Malaysia/Kuala Lumpur), more theories derived.																		
This study (2017)		√	√	√		√		√				√	√	√	√	√	√	√	√
Remarks	Study on more options of urban configuration (not only canyon), focus on balance of urban microclimate, thermal comfort, and energy consumption), study conducted in Kuala Lumpur context.																		

However, there are very few studies elaborating this need in detail. Urban configuration naturally creates various geometry and urban spaces instead of only linear space like urban canyon. This study finds out that beside Height to Width (H/W) aspect ratio, Sky View Factor (SVF) and canyon orientation; the urban configurations will strongly influence the urban microclimate. Different urban configurations can influence various variables such as different behavior of urban wind, solar radiation angle, existence of daylighting obstruction, building shadow, especially when it covers high rises. Gupta (2013) showed example of the study that different urban configuration resulted in different urban microclimate (Figure 1.10). However, the concept of this investigation needs further analysis on more option of urban configurations rather than canyon space as both urban microclimate and thermal comfort have to be holistically assessed in order to achieve the balance of both needs.

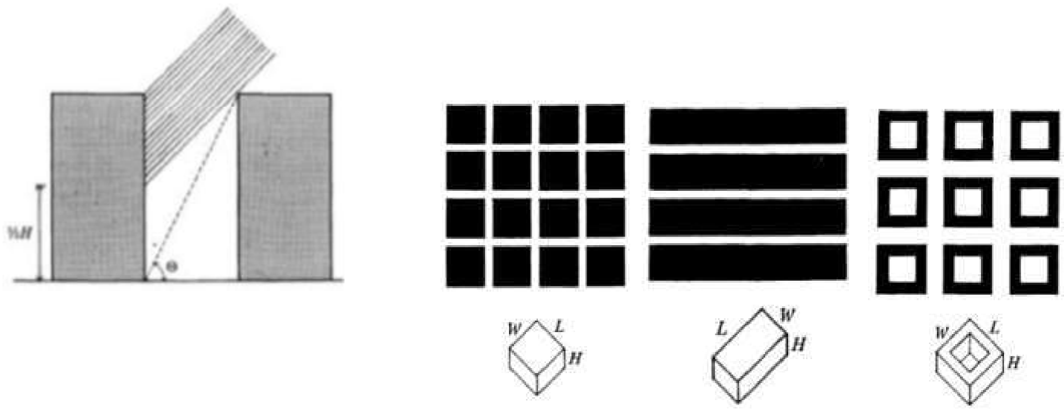


Figure 1.10: Building Shading and Angle of Solar Radiation Obstruction (Left) and Different Scenario of Urban Configuration Layouts (Right)
Source: Gupta (2013)

The scenario of this study to meeting the both variables aims to achieve the city sustainability framework. Environmental, social, and economic consideration cannot be segregated. In this case, climatic modification represents environmental, thermal comfort represents social factor and energy consumption represents the economic feature. Urban microclimate modification influences thermal comfort that will affect the demand of energy efficiency. The urban configuration fulfills the balance of these three components. A suitable diurnal microclimates and mitigation of Urban Heat Island (UHI) will create better thermal comfort in outdoor urban spaces.

A better thermal comfort encourages outdoor social activities within urban spaces or particularly residential open spaces. Better outdoor thermal comfort for more social activities will also reduce the cooling load because it will use less indoor spaces. Lesser use of air conditioning will also reduce the anthropogenic heat generated by the air conditioning; therefore, the urban microclimate will also improve. The interrelationship among these three variables; urban microclimate, thermal comfort and energy efficiency creates the balance which in this study is called as a concept of Climatically Responsive Urban Consideration (CRUC). A further justification of this concept is discussed in Chapter 3.

1.4 Research Aim

This research aims to investigate the relationship of urban configurations with microclimate and thermal comfort. Specifically, it investigates the impact of the urban configurations on both urban microclimate and thermal comfort. It seeks to investigate urban configuration to strategise the Urban Heat Island (UHI) mitigation and propose the scenario of Climatically Responsive Urban Configuration (CRUC).

1.5 Research Objectives

The research objectives of this study are:

1) To investigate the impact of urban configurations on the Urban Heat Island (UHI).
2) To identify the urban configuration that is best for Kuala Lumpur microclimate and thermal comfort context.
3) To propose the Climatically Responsive Urban Configuration (CRUC) scenarios in both canyon directions of East – West and North - South.

1.6 Research Questions

The research questions of this research are:

1. Do urban configurations influence nocturnal air temperature?
   a. If yes, what is the recommended urban configuration that mitigates the nocturnal air temperature?
   b. If yes, what are the influencing factors?

2. Do urban configurations influence air temperature (T_a) and mean radiant temperature (T_{mrt})?
   a. If yes, what is the recommended urban configuration that complies with the concept of Climatically Responsive Urban Configuration (CRUC)?
   b. If yes, what are the influencing factors?

1.7 Research Hypothesis

The research hypothesis of this study is as follow:

H_0: Urban configurations do not have impact on Urban Heat Island (UHI), urban microclimate and thermal comfort.

H_1: Urban configurations have impact on Urban Heat Island (UHI), urban microclimate and thermal comfort.

The hypothesis of this study is that urban configurations create impact on the Urban Heat Island (UHI), urban microclimate and thermal comfort. The different urban configuration results in different behavior of solar radiation and wind flow. Figure 1.11 presents the surface area affected by solar radiation, while the windward and leeward flow depends on the block configuration arrangement. Wind plays significant role on thermal comfort as it influences the human body response towards the air temperature and behaves as urban ventilation as it moves the stagnant heat to release to other points. Therefore, urban canyon would benefit this character in order to reduce heat from longwave radiation as it functions as wind tunnel in the canyon space.

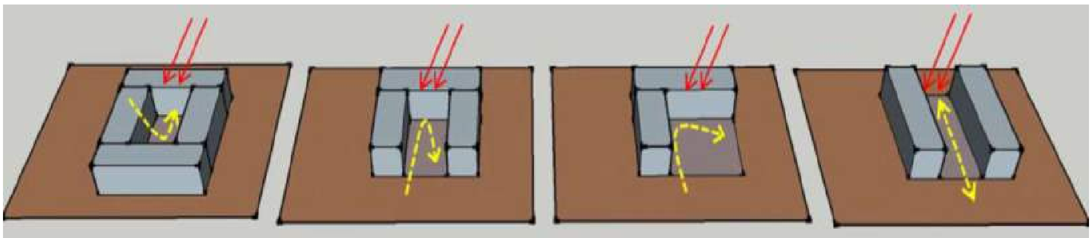


Figure 1.11: Solar Radiation (red) and Air Flow (yellow) Scenario on Different Urban Configurations

However, air velocity in Kuala Lumpur context is very low sometimes it reaches almost zero m/s in certain location in the dense city area due to the vertical obstruction by high-rise buildings. This phenomenon would indirectly influences the long wave mitigation through the urban wind. Solar radiation will be the major factor in determining the urban microclimate and thermal comfort modification. Therefore, this study stresses that the shading affect from urban block would dominate the cause of maximum level of short and longwave radiation.

1.8 Research Scope

This study was performed by using the ENVI-met computer simulation as the main analysis of the urban - climatic variables, and the empirical field observation as the validation of the computer simulation. The simulation and empirical study were set in the in Kuala Lumpur, as this study focused on investigating the urban climate in the hot and humid region. The investigated models were high-rise urban configurations. The direction of the canyons was set parallel and perpendicular to the sun path, which is East – West and North - South. It is based on the empirical urban configuration; Courtyard Canyon in the two sites; Flat Bandar Tasik Selatan (FBTS) and Surya Magna (SM). The simulated urban configuration models were Courtyard, U, Courtyard Canyon and Canyon. It was arranged by the increase of the Sky View Factor (SVF). However, the Height to Width (H/W) aspect ratio of the urban configuration models remained constant, according to the empirical urban configuration from the two sites. The details of the investigated urban configurations are further discussed in Chapter 3 and Chapter 4.

Both urban microclimate and thermal comfort were investigated in this study. The urban microclimate variables were solar radiation (with the details of short wave and long wave radiation), surface temperature, air velocity, air humidity and air temperature (T_a), while the thermal comfort variable was mean radiant temperature (T_{mrt}). The investigated climatic variables were limited to outdoor. However, to investigate the research objectives, this study focused the analysis on air temperature (T_a) as the indicator of outdoor urban microclimates and mean radiant temperature (T_{mrt}) as the indicator of outdoor thermal comfort. However, solar radiation (with short wave and long wave radiation) and air velocity were mainly assessed to investigate the urban microclimate and the thermal comfort. The nocturnal air temperature (T_a) was the Urban Heat Island (UHI) investigated variable in this study. The simulated and observed climate data in this study was limited to the receptor data located at the centre of the open space of the urban configuration.

1.9 Research Significance

This study scientifically elaborates the significant impact of urban configuration on both urban microclimate and thermal comfort, which can be used in architecture, urban design, and urban planning field. It suggests urban planners and designers the awareness of applying the Climatically Responsive Urban Configuration (CRUC) in planning and design the process of urban development. It also stresses that the holistic consideration achieving maximum Urban Heat Island

(UHI) mitigation strategy and urban thermal comfort is an inseparable stage of achieving city sustainability framework.

Furthermore, the finding of this study can lead to urban design guidelines on urban configuration in high-density residential area at Kuala Lumpur regulated by local authority. The physical planning guideline on suitable urban configuration incorporated with Height to Width (H/W) aspect ratio and Sky View Factor (SVF) can be proposed. Lastly, the finding of this study can be used by the climatology researcher as reference to current literature on Urban Heat Island (UHI) or climate change and global warming mitigation strategies. Integrated and holistic strategies and policies result in a comprehensive outcome.

1.10 Thesis Structure

This thesis is elaborated into seven chapters; the content is summarised in Figure 1.12. Chapter 1 justifies the imperative of urban configuration study on urban microclimate and thermal comfort and the need of investigation on integration of urban microclimate and thermal comfort towards city sustainability. The issue of poor diurnal and increase of nocturnal air temperature or long wave radiation contributes to outdoor social activities and Urban Heat Island (UHI) is emphasised in the research problem statement. The need of comprehensive literatures on the urban configurations rather than just urban canyon in high-density residential blocks and the balance of urban microclimate, thermal comfort and energy consumption are illustrated in the research gap. This chapter also presents research objectives, research questions, research hypothesis, research scope, research contribution and thesis structure.

Literature review is discussed in Chapter 2 and Chapter 3. Chapter 2 reviews the concepts of urban surface energy budget, urban microclimates and thermal comfort, Malaysia climatic context, and the review of ENVI-met simulation as the reliable approach to use in this study. Chapter 3 reviews the concept of Climatically

Responsive Urban Configuration (CRUC) and urban canyon features, which include Height to Width (H/W) aspect ratio, Sky View Factor (SVF) and urban canyon direction.

Chapter 4 describes the detail of the methodology of the study. It elaborates the investigated urban configuration models, introduction of site profiles (in two settings of canyon directions); East –West and North – South canyon direction, data collection and analysis (ENVI-met simulation). This chapter also presents ENVI-met validation through the comparison with empirical study in two sites.

Chapter 5 and Chapter 6 illustrate the detail simulation result analysis of the impact of urban configurations on Urban Heat Island (UHI), urban microclimate and thermal comfort in two settings of East –West and North – South canyon direction. The results on the Research Objectives 1 on the impact of urban configurations on the Urban Heat Island (UHI) and Research Objective 2 and 3 on the impact of urban configuration on both air temperature (T_a) and mean radiant temperature (T_{mrt}) are elaborated in this chapter.

Chapter 7 presents the conclusion that answers the Research Objectives, Research Questions and Research Hypothesis. It emphasises the recommended urban configuration that mitigates the Urban Heat Island (UHI) and complies with the concept of Climatically Responsive Urban Configuration (CRUC). Recommendation, Further Study and Research Contribution are also presented in this chapter.

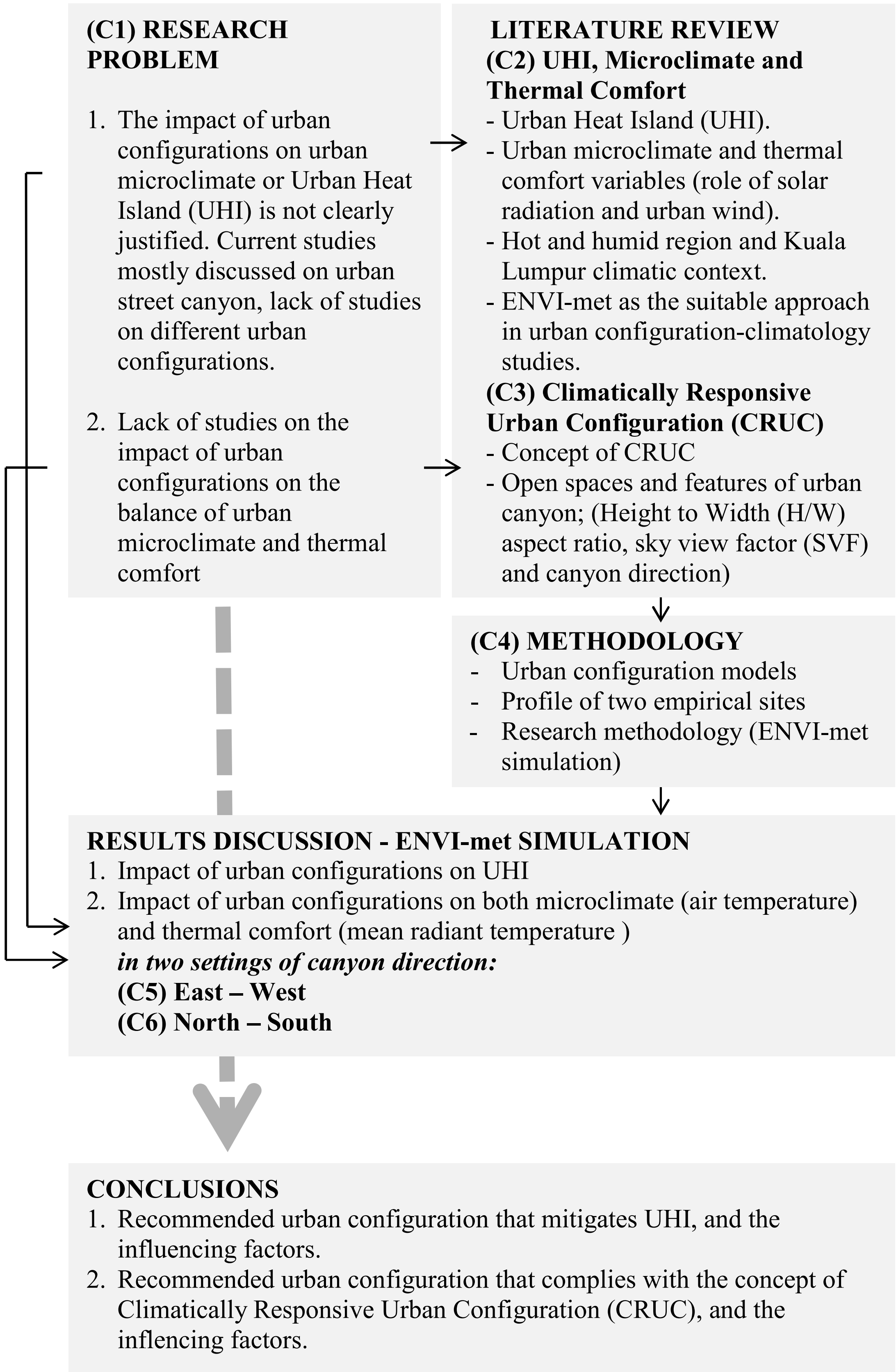


Figure 1.12: Thesis Structure

1.11 Chapter Summary

This chapter highlights that the increase of high-rise buildings which modifies the urban configuration contributes to the increase of Urban Heat Island (UHI), thermal discomfort and energy efficiency. This study emphasises that this scenario is called the climatic unresponsive urban configuration. The review highlights that the Urban Heat Island (UHI) is a real threat to the urban area as it creates the urban thermal discomfort and increase of energy demand. The current studies on the relationship of urban configurations and climate mostly investigate urban canyon, while other types of urban configuration are left unanswered. Therefore, this study aims to investigate the impact of urban configurations on the Urban Heat Island (UHI) mitigation and investigation on the urban configurations that complies with the Climatically Responsive Urban Configuration (CRUC) concept, which in this context is the balance between the microclimate and thermal comfort. The integration approach of investigating urban microclimate and thermal comfort aims to minimise energy consumption.

The hypothesis of this study is the urban configurations have impact on mitigation of Urban Heat Island (UHI) and the balance of the urban microclimate and thermal comfort. The modification of solar radiation is the main variable to justify the hypothesis, as the solar radiation intensity is very high throughout the year in Kuala Lumpur context. The concept of Climatically Responsive Urban Configuration (CRUC) is highlighted as the concern in this study which is expected to fulfil the gap in the current urban climatology issue and climatic adapting agenda. The finding of this study can be applied by the urban planners and designers to strategise the residential urban configurations in both existing and new development. The next discussion is the literature review to justify the concept of two fundamentals in this study; urban climate and configuration. The following chapter is the review on the Urban Heat Island (UHI), microclimate and thermal comfort, which mainly review the mitigation of the Urban Heat Island (UHI), climatic variables used in this study, and the review of the computer simulation as the reliable approach to use in this study.

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