EFFECTS OF ROAD GEOMETRY AND ROADSIDE TREES ON URBAN ROAD THERMAL PERFORMANCE IN PENANG

By

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TABLE OF CONTENTS

CHAPTER FIVE: RESULT AND ANALYSIS :

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF ABBREVIATIONS

AT (a)	Air Temperature (afternoon)
AT (m)	Air Temperature (morning)
AT (n)	Air Temperature (night)
AVE	Average Variance Extracted
LAI	Leaf Area Index
PLS	Smart Partial Least Squares
RO	Road Orientation
RW	Road Width
SEM	Structural Equation Modeling
SHI	Surface Heat Island
ST (a)	Surface Temperature (afternoon)
ST (m)	Surface Temperature (morning)
ST (n)	Surface Temperature (night)
SUHIs	Surface Urban Heat Island Intensity
TH	Tree Height
TP	Tree Position than road orientation
UBLs	Urban Heat Islands of Boundary Layer
UCLs	Urban Heat Islands of Canopy Layer
UHI	Urban Heat Island
UHII	Urban Heat Island Intensity
VIF	Variance Inflation Factor

LIST OF APPENDICES

KESAN GEOMETRI JALAN DAN POKOK-POKOK BERSEBELAHAN KE ATAS PERILAKU TERMAL JALAN BANDAR DI PULAU PINANG

ABSTRAK

Penyelidikan ini merupakan kajian tentang kesan sifat fizikal jalan dan pokok bersebelahan jalan terhadap perilaku termal jalan di Pulau Pinang Malaysia; iaitu di kawasan tropika dengan keamatan radiasi solar yang tinggi. Pembolehubah dari jalan bandar yang dikaji termasuk kelebaran dan orientasi jalan. Manakala ciri-ciri fizikal pokok bersebelahan jalan yang dikaji adalah lokasi pokok, ketinggian pokok, ketumpatan kanopi dan jarak pokok dari tepian jalan. Metodologi kajian adalah kuantitatif melalui ukuran-ukuran kajian lapangan untuk menilai perilaku termal jalan. Kajian mengukur suhu permukaan dan suhu udara di atas permukaan jalan mengikut objektif dan hipotesis kajian. Dapatan kajian menampakkan kesan yang signifikan ciri-ciri jalan dan pokok terhadap suhu permukaan dan suhu udara. Berdasarkan orientasi jalan dan kelebaran, arah Barat Laut – Tenggara jalan lebar mempunyai purata suhu permukaan tertinggi. Walaubagaimanapun, jalan yang berorientasi Utara Selatan dengan ciri sempit memberikan iklim mikro jalan yang lebih baik. Pokok yang tinggi dengan ketumpatan kanopi memberikan kesan yang paling signifikan terhadap pengurangan suhu permukaan dengan memberikan kualiti peneduhan. Hasil kajian juga mendapati perbezaan yang ketara perilaku termal jalan di antara jalan dengan pokok dan jalan tanpa pokok. Akhir sekali, kesimpulan dari potensi kesan penyejukan dengan adanya pokok bersebelahan jalan dan ciri-ciri jalan dapat diterapkan sebagai garispanduan rekabentuk jalan bandar untuk modifikasi iklim mikro jalan di kawasan bandar ber iklim tropika.

EFFECTS OF ROAD GEOMETRY AND ROADSIDE TREES ON URBAN ROAD THERMAL PERFORMANCE IN PENANG

ABSTRACT

This research investigates the effects of the physical road characteristics and roadside tree features on the road thermal performance in Penang, Malaysia; located in tropical region where there is high solar radiation intensity. The variables of urban road features studied include road width and road orientation. Accordingly, the effects of physical properties of roadside tree takes to accounts, including tree position, tree height, canopy density and tree distance from the road edges. The research methodology is quantitative in nature via fieldwork measurements to assess the road thermal performance. The study measures road surface temperature and air temperature above road surface in accordance with research objectives and hypotheses. The research findings illustrated the significant effects of road and tree characteristics on road surface temperature and air temperature. Based on road orientation and width, North West-South East wide roads had the highest average surface temperatures. However, North-South oriented narrow roads provide a better urban road microclimate. Moreover, tall trees with dense canopy had the most significant effect on road surface temperature reduction by providing high quality shade. The results also revealed remarkable differences of road thermal performance between road with trees and without trees. Finally, the conclusion from the potential cooling effects of roadside trees and road characteristics on the road thermal performance can be implemented as a guideline of urban road design in modification road microclimate in urban tropical region.

CHAPTER ONE

INTRODUCTION

1.1 Research Background

Nowadays, massive urban areas are occupied by fabricating surfaces such as asphalt imposed significant undesirable changes in the landscape and natural ecosystem. Consequently, man-made urbanized developments altered the climatic characteristics of urban areas negatively.

Such environmental changes have direct and indirect effects on the local climate of urban areas, specifically resulting in temperature alteration, which is referred to as, Urban Heat Island or UHI (Landsberg, 1981, Emmanuel, 2005, Gartland, 2008, McCarthy et al., 2010). The effect of UHI was explored extensively over the world (Oke, 1973, 1978, 1988; Streutker, 2003b; Tran, 2006; Gartland, 2008). Different scales can be formed from the heat islands, such as around a single structure, a vegetative canopy, or throughout a city. The main cause of this phenomenon is the urban surface changes in which vegetation is replaced by paved surfaces, such as surfaced roads and buildings that effectively store short-wave radiation (Barnes et al., 2001; Jin et al., 2005; Stathopoulou & Cartalis, 2009).

Heat islands appear in various different ways, including diurnal and seasonal variations of temperature ranges. UHI effects can be mentioned in temperate climate regions only during the summer season. However, tropical cities experience increased urban heat island effects because of their location in hot areas (Taha, 1997; Yague et al., 1991; Swaid et al., 1993; Santamouris et al., 2001; Synnefa et al, 2006; Burkart et al., 2011).

Singapore was one of the earliest tropical cities that the urban heat island effects were studied by Nieuwolt (1966). Since 1972, Sham (1973, 1986 &1990/91) was a pioneer to investigate heat island effects in Malaysia over a two-decade period. He estimated significantly the difference in air temperature in large urban areas by contrasting with rural surrounding areas. Although many studies were conducted in some urban zones on urban heat island intensity (Elsayed, 2006, 2007, 2012; Shaharuddin, 2007; Rajagopalan et al., 2014), still more researches are needed in order to investigate the causes of this phenomenon and its effects on urban environment in city areas.

Because paved road surfaces are one of the factors affecting urban heat islands, numerous studies were carried out on the thermal behavior of fabric surfaces in the urban environment (Akbari et al., 1999; Rose et al., 2003, Streutker, 2003b; Anak Guntor et al., 2013). Besides, as roads can be an intersection between structural and urban scales, it affects the inside and outside microclimates by discharging heat transfers through material surfaces to the surrounding area, which elevates the outdoor and indoor temperatures (Carnielo & Zinzi, 2013; Weller & Thornes, 2001). In tropical cities, the fundamental issue of road design is not only to protect it from tropical climate conditions in general, but also from the high levels of solar radiation intensity in the long period of the day (Ali-Toudert & Mayer, 2006). Accordingly, road climatology is essentially concerned with investigating the variables that impact the air and road surface temperature along a road (Postgård & Lindqvist, 2001).

On the other hand, to mitigate UHI, trees contribute to the urban microclimate amelioration with a reduction of air temperature by evaporative and shading cooling (Bernatzky, 1982; Givoni, 1994; Santamouris, 2007; Chang et al., 2007). As road surfaces absorb a high level of solar radiation, roadside trees provide shade, avoiding exposure to direct solar radiation (Chow & Roth, 2006). These studies provided useful quantitative data on urban green spaces as a design factor to offset the elevated ambient temperatures in tropical and non-tropical cities (Jauregui, 1991; Miller, 1996; Bourbia & Awbi, 2000; Bourbia & Awbi, 2004).

As Penang is located in a tropical region and due to an extensive expansion of highways and roads, it is provided to study on the urban roads of Penang affecting urban microclimate. This research chooses Georgetown as a case study to focus on a microscale evaluation of road characteristics and their roadside trees. In doing so, this study assesses the relationship between road surface temperature and air temperature above road surfaces with respect to the characteristics of roads and roadside trees.

1.2 Problem Statement

Despite many studies on how urban surfaces contribute to the formation of urban heat islands and the role of urban vegetated surfaces in reducing these heat islands, few researchers entered into specific details of road characteristics and tree features affecting surface temperature and ambient temperature. This lack of research is considered to be more in tropical regions because of the fact that trees can have a major role in reducing road surface temperature in these areas.

Reduced vegetation and increased impervious urban surface materials led to a reduction in the amount of shaded areas over urban spaces, and therefore intercepted solar radiation areas would be reduced. Due to additional solar radiation absorption, such phenomena occur in relationship to an increase in the surface temperature and then ambient temperature (Oke, 1978; Gartland, 2008; Shahmohamadi et al., 2011; Reed, 2013).

Szokolay (2008) described that the tropical region is one of the hardest climates to compromise through urban designs. Although Malaysia is characterized by high temperature affected by the heat island due to the reduction of green areas which is continuing for urban development. By 2013, the Malaysian road network length was improved up to 145000 km (Malaysia Transport Stats, 2013). Despite these improvements, the roads created the majority of the environmental impacts, such as increasing urban temperature that was impressed by the occupant thermal satisfaction and the human health condition (Elsayed, 2012; Rajagopalan et al., 2014).

As a reduction of urban green spaces, roadside trees are often the first to be sacrificed for infrastructural developments, such as road widening, especially in fast growing cities. Urban planners and managers have often undervalued potential role of urban vegetation and trees in mitigation of ambient temperature (Escobedo et al., 2011). City managers are concerned about the possible hazards posed by roadside trees due to traffic management and pedestrian safety, and often unwilling to spend money on the maintenance and renewal of trees on city roads (Pauleit, 2003; Dumbaugh, 2005). Roadside trees are also a stressful issue due to their proximity to atmospheric pollutants, poor drainage, inhospitable soil, and lack of space for growth (Ware, 1994; Jim, 1999; Thaiutsa et al., 2008).

Although some researches were conducted on the relationship between urban surface temperature and air temperature (Voogt & Oke, 2003; Hartz et al., 2006; Lindberg, 2007; García-Cueto et al., 2007), more are still required in order to assess the relationship between road surface temperature and air temperature above road surfaces. Furthermore, there is a lack of studies related to the relationship between road characteristics and road surface temperature, in particular with regard to roadside tree characteristics.

The current study focuses on the combined effects of both geometric road characteristic and roadside tree physical features on road surface temperature and air temperature and thereby on the urban microclimate. The research seeks to provide some preliminary results concerning road and roadside tree characteristic in reducing road surface temperatures using simplified assumptions, and to discuss some implications of potential strategies for road surface temperature mitigation, resulting in urban microclimate modification.

1.3 Research Objectives

This research contributes to characterize the urban road features that affect road surface temperature and the role of roadside trees in reducing surface temperature, resulting on the roads surrounding microclimate. To accomplish the objective, exploratory analyses are completed, utilizing during the day and night of the road surface temperature and air temperature above the road surface with respect to roadside tree characteristics. For achieving the purposes, the following objectives are provided:

1. To assess the effects of geometric road characteristics such as road orientation and road width on road surface temperature.

2. To assess the effects of roadside tree physical features on road surface temperature, including the tree position in relation to the road orientation, tree height, tree canopy density and distance of the tree from road edges.

3. To assess the relationship between road surface and air temperatures above the road surface level.

1.4 Research Questions

This study is conducted to answer the research questions based on the research objectives discussed above:

1. What are the effects of geometric roads characteristics such as roads orientation and roads width on road surface temperature?

2. What are the effects of roadside trees physical characteristics on road surface temperature, namely tree position in relation to the road orientation, tree height, tree canopy density and distance of the trees from road edges?

3. How is the relationship between road-surface and road-air temperatures above the road surface level?

1.5 Research Hypotheses

1. There is a relationship between road geometric characteristics and road surface temperature that can affect urban road thermal performances.

H1a: Roads orientation is related to the road surface temperature.

H1b: Roads width is related to the road surface temperature.

2. There is a relationship between physical characteristics of roadside tree and road surface temperature that can affect road thermal performances.

H2a: Position of the roadside tree in relation to road edges orientation is related to the road surface temperature.

H2b: Height of the tree is related to the road surface temperature.

H2c: Canopy density (Leaf Area Index) of the roadside tree is related to the road surface temperature.

H2d: Distance of the roadside tree from road edges is related to the road surface temperature.

3. There is a relationship between the road-surface temperature and road-air temperatures above the road surface that can be affected urban road microclimate.

H3a: Road surface temperature is related to road-air temperatures above the road surface.

1.6 Scope and Limitation of the Research

This research focuses on the combined effects of roadside trees features and road characteristics on road surface temperature and air temperature above the road surface to improve the road surrounding microclimate through surface and air temperature reduction in Georgetown, Penang, Malaysia. The focus of the research is on the urban roads, not including the roads nearby high-rise buildings or the roads affected by building shadows for better understanding of the tree characteristics effects specifically on road surface and air temperature. The limitation of the study was to not continuously measuring 24 hours due to security and safety reason, therefore it was measured from 8 am to 11 pm. Also, due to investigation of study on surface and air temperature, relative humidity and solar radiation were not on measuring scope. The scope of this research and the overall framework of the study are presented in Figure 1.1.

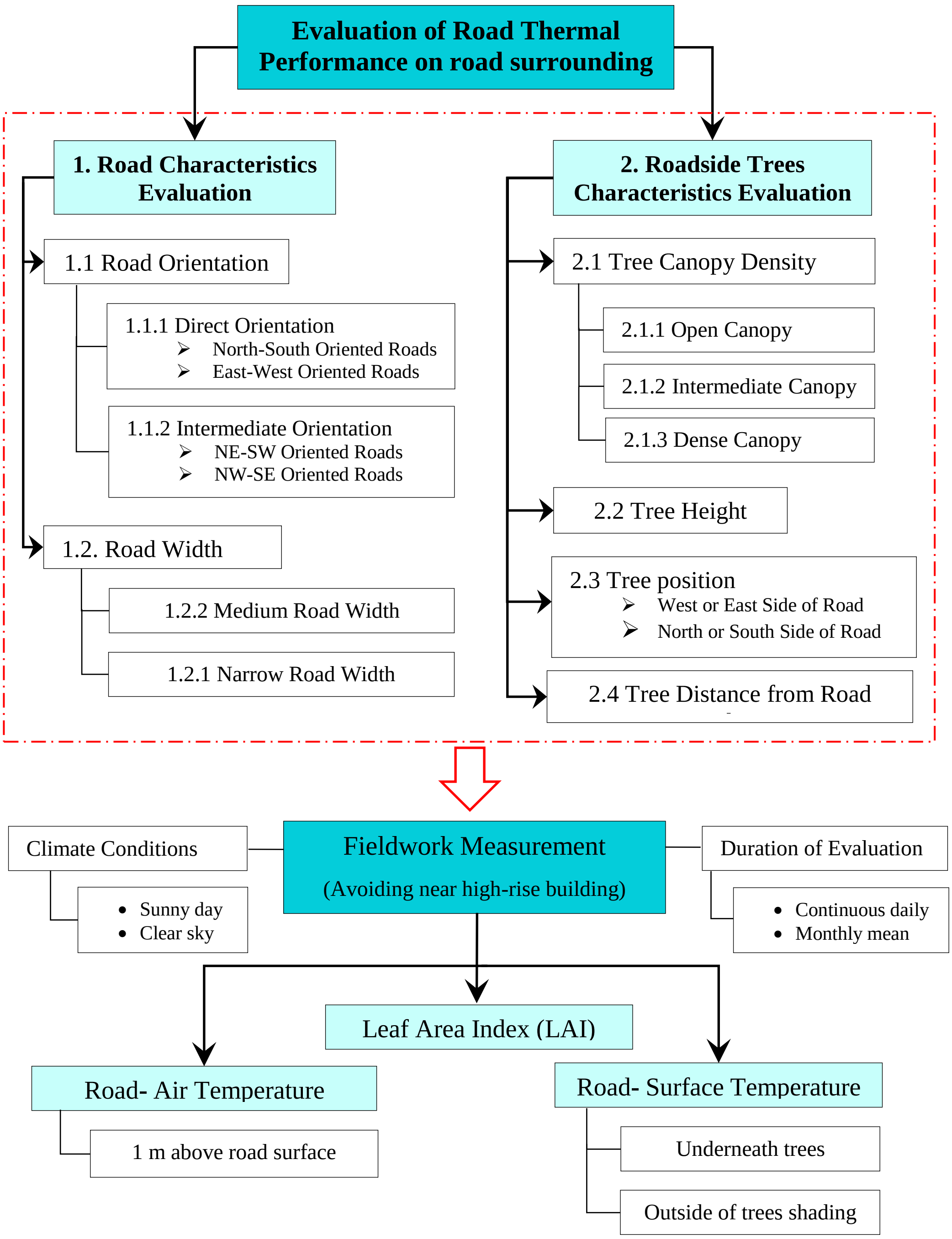

Figure1.1. Scope and overall framework of the study

This research concentrates on measurement of road surface temperature and air surface temperature above the road surface during the day and at night. Road surface and air temperatures are measured at the height of one meter above the road surface level under the trees and outside of the shading provided by trees exposed to the sun. To this end, desired features of the road geometric characteristic such as various widths and orientations are taken into account. Meanwhile, roadside trees characteristics, including tree position, tree height, canopy density and distance of the tree from road edge are considered. Each road includes some segments (i.e., small or large) and a series of experimental spots. For collecting data, the sunny days, clear sky and less wind is intended.

1.7 Research methodology

In order to achieve the research objectives, fieldwork measurement was designed to survey road thermal performances and their impact on urban road microclimate.

Quantitative research methods were selected to analyze fieldwork measurements data based on real cases of urban roads in real climate conditions. Two groups of raw data, namely road thermal performance data (surface and air temperature) and roadside trees aspect data were obtained from four different urban roads case studies. Descriptive statistics were used to describe the research findings based on probabilistic arguments via two analysis techniques: descriptive statistical techniques using excel, and structural equation modeling (SEM) techniques using smart partial least squares (PLS).

1.8 Chapters Organization

This research consists of seven chapters namely, introduction, literature review, methodology, research findings, discussion and conclusion and recommendations.

Chapter one commences with an overview of the research background, following by statement of the problems. This is followed by the research objectives of the study and the research questions and hypothesis. The limitation and scope of the study are described. The chapter ends with chapter organization section.

Chapter two is the literature sections that is substructure of this research. It begins with an introduction of urbanization and urban heat island phenomenon. It continues to explain urban road characteristics and their impacts on road surrounding environment. Later, the research discusses the effects of trees on urban microclimate.

Chapter three presents the research methodology which is used in this study. Quantitative research with fieldwork measurements is conducted based on real case studies in the roads site of the research scope. Descriptive statistical techniques using excel and structural equation modeling (SEM) techniques using smart partial least squares (PLS) are selected to analyze research findings.

Chapter four presents the pilot study results prior to the actual field measurements to determine the appropriate measurement spots and duration.

Chapter five explains the research findings and results from fieldwork measurement data based on research objectives and hypotheses with excel and PLS.

Chapter six discusses the results of the research and correlate findings with previous related researches. It focuses on road surface temperature variations according to the road and roadside characteristics impacts.

Chapter seven concludes the research results and recommends some suggestions for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter introduces the study area generally according to previous researches. It begins with introduction of rapid urban development and population growth as the difficulties of modern urban societies. It is continued with an explanation of the urban heat island (UHI) phenomenon and related studies of urban heat island are presented. The highlight of this chapter is to introduce urban roads as multimodal transportation corridors and serve. The effect of roads on the surrounding environment and contribution to increase air temperature are discussed. Later on, trees and roadside trees with their specifications are presented which is investigated the effects of trees on the urban microclimate. The last part of this chapter presents the research flowchart, resulting from the literature review.

2.2 Urbanization

2.2.1. Rapid Urbanization Development

Rapid world urbanization in metropolises has been remarkably increased owing to the socio-economic factors of modernization to achieve human-scale development (Huang, 2008).

Up to 61% of the global population is expected to live in metropolitan areas by 2030 especially in Asian cities (Tran et al, 2006; Rajagopalan et al, 2014). Although urbanization provides better lives and comfort, the immoderate and unexpected growth of urbanization led to unpleasant side effects worldwide such as global warming and air pollution (Rizwan et al., 2008; Mirzaei, 2010).

Without reasonable planning of the urbanization process will subsume to continue environmental issues which are causing the urban environment to be deteriorated (Priyadarsini et al; 2008). Besides, urbanization growth has changed the city landscape with more artificial urban surfaces and less greenery with a consequent increase in urban heat island (Oke, 1982; Owen et al, 1998). Increasing of urban paved surfaces is related to urbanization and population growth (Stankowski, 1972). As metropolises continued to increase demographically and physically, the temperature difference between urban and rural areas will be increased (Tran et al., 2006). Since rapid urbanization has caused a faster rate of the change to be continued, it is needed to recognize the impacts of urban development.

2.2.2 World Population and Cities Growth

In the early of the 20^{th} century, only one tenth of the world population lived in the cities. During that century, a substantial percentage of the global population moved to larger cities to live (Santamouris et al, 2001). At present, sixty million people are moving into the major cities each year (UNEPTIE, 2010).

Refer to thousands of years, global population reached the first billion by 1800 and 130 years later, another billion was added to the universe. The total global population was three billion in 1960 whereas with the passage of time 80 million has been added to world population each year (DeSA, U.N., 2001). It is anticipated by the United Nations that the urban population will be reached to 5.1 billion people by 2025. The Table 2.1 shows the tendency of population increase in different regions.

Table 2.1: Percentage of population living in urban areas by regions

Source: DeSA, U. N. (2013)

Percentage of population living in urban areas	**1950**	**1965**	**1980**	**1995**	**2010**
Africa	14.6%	20.7%	27.3%	34.9%	43.6%
Asia	17.4%	22.4%	26.7%	34.7%	43.6%
Latin America and the Caribbean	41.4%	53.4%	64.9%	73.4%	78.6%
Rest of the World	55.3%	64.1%	70.5%	74.2%	78.0%

Rapid population growth and urbanization had a dramatic effect on cities size and numbers. By 2015, there should be 560 cities worldwide with residents in the city areas of over one million in which 21 of them are mega cities with people over eight million (DeSA, U. N., 2013).

Table 2.2: Distribution of large cities by regions

Source: DeSA, U.N. (2001)

Region **Number of Cities**	**1800**	**1900**	**1950**	**2000**
Africa	-	-	2	27
Asia	1	4	26	126
Latin America and the Caribbean	-	-	7	38
Rest of the World	1	13	45	102

The urban growth, including an increase in the number and size involves notable changes in the urban landscape with less greenery affecting the urban microclimate and urban ecosystem.

2.2.3 Malaysian Urbanization Development

Malaysia has experienced urban space transformations since 1970 up to present. Not only numbers of cities have been increased, but also urban centers capacities have improved outward to the suburbs boundaries. Totally, the current population of Malaysia has reached to almost 30,268,000 increasing slightly from 2013. This made Malaysia as the 42nd most populated countries worldwide (DeSA, U. N., 2013). Population distribution to the various states is shown in the Table 2.3.

Table 2.3: Ranking Census statistics Malaysia 2010 for megacities

Source: Swee-Hock (2015)

Rate	State	Population
1	Johor	3,200000
2	Sabah	3,120000
3	Perak	2,250000
4	Kuala Lumpur	1,620000
5	Penang	1,520000
6	Kelantan	1,450000

In Malaysia, the rates of annual growth of urban population are high because of two reasons: rural to urban migrations and urban to urban movements (Table 2.4).

Table 2.4: Population of Kuala Lumpur and Georgetown in 1980-2010

Source: Department of Statistics, Malaysia (1983, 1995, 2001, 2011)

Year	Total Population	
	Kuala Lumpur	Georgetown
1980	937,000	250,000
1991	1,145,000	219,000
2000	1,297,000	180,000
2010	1,627,000	198,000

As the Malaysian urban population has been increased, the number of urban centers reached from 8 to 170 till 2010. The number of big cities with a population of 200,000 increased from 2 to 17 in 2010. Apart from the growing number of large cities, cities with less than 25,000 people reached from 6 in 1911 to 82 in 2010.

It should be noted that the increasing urbanization in Malaysia has provided environmental problems notably such as urban heat island.

2.2.4 Urban Heat Island

2.2.4(a) Definition of Urban Heat Island

An urban heat island (UHI) is a metropolitan region or city which is remarkably hotter than its surrounding countryside or rural areas due to human activities (Hinkel et al., 2003). UHI is one of the most recognized forms of microclimate change systems referred to as a dome of increased air temperatures in urbanized areas (Christensen, 2005; Park, 2007). It can be occurred noticeably during the winter and summer in which temperature differences normally are higher during the day. The UHI intensity (HUII) depends on population, city size, and industrial development together with physical design, geographical climate and meteorological weather conditions (Oke et al., 1991). It further appears when there is less wind, which depends on many characteristics such as topography, regional wind speed, and urban morphology (Souza et al., 2004). This phenomenon was authenticated firstly over 150 years by Howard (1833) in London; although he was not who named this phenomenon. Since heat islands have been investigated in many of the mega cities worldwide, it has been documented in most of these major cities around the world (Voogt 2004). Urban heat islands intensity has obtained increasing concern due to the rapid changes from natural green surfaces to artificial paved surfaces with a high percentage of heat absorption by urban surface structures and buildings (Oke, 1987).

2.2.4(b) Causes of Urban Heat Island

The urban heat island is affected by several controllable and uncontrollable variables which are categorized into three groups (Figure 2.1): permanent variables such as greenery, material and sky view factor; temporary variables like wind and cloud; and cyclic variables such as solar radiation (Rizwan et al., 2008). Solar radiations will warm the ambient temperature directly and indirectly. Solar heat is absorbed and stored in the form of thermal energy by urban materials during the day and then released to the environment after sunset. The low sky view can reduce heat storage extent in materials (Giridharan et al., 2004). Vaporization is important in rural energy balance because of large latent heat of water, which is less into cites due to the lack of urban greenery (Kondoh & Nishiyama, 2000). Many investigations have reported that wind and cloud have a negative correlation to the UHI (Morris et al., 2001; Kim & Baik, 2002).

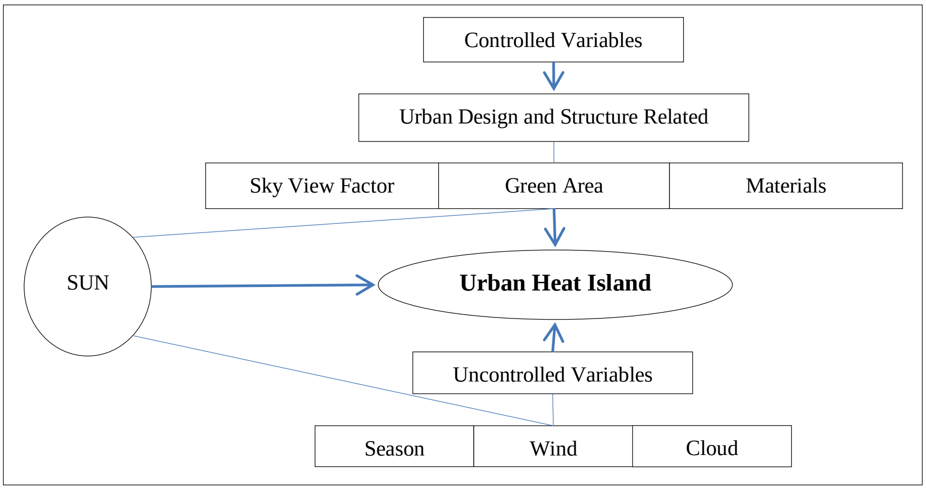

Figure 2.1 Generation of Urban Heat Island (UHI)

Source: Rizwan et al. (2008).

Yet, more studies are needed to investigate the degree of influence of various temporary and permanent factors on urban heat island.

2.2.4(c) Different Types of Urban Heat Island

Recognition of the variety of urban heat island can contribute to understanding this phenomenon, which is identified through its location and height in an urban environment. The urban heat island was classified by Oke (1995) and then simplified by Roth (2002) that offered two types of UHIs including air temperature UHI and Surface Temperature UHI (Table 2.5).

Table 2.5: Classification scheme of Urban Heat Island

Source: Oke (1995); Roth (2002)

UHI Types	Location
1. Air Temperature UHI:	
1.1. Meso- Scale: Boundary Layer UHI:	Vertical Column of Air above Average Building Height
1.2. Micro- Scale: Canopy Layer UHI:	Between Building and below Building Rooftop
2. Surface Temperature UHI	Land/ Ground Surfaces

The urban heat island is generally measured from air temperature and surface or skin temperature through various procedures. Although these two methods measure two different quantities, surface temperature and air temperature are often entirely similar. However, in under certain situation, they perform unique and specific actions. The Figure 2.2 indicates the differences of surface temperature and air temperature at day and night. Surface and atmospheric temperatures vary over different land use areas. Surface temperatures vary more than air temperatures during the day, but they both are fairly similar at night.

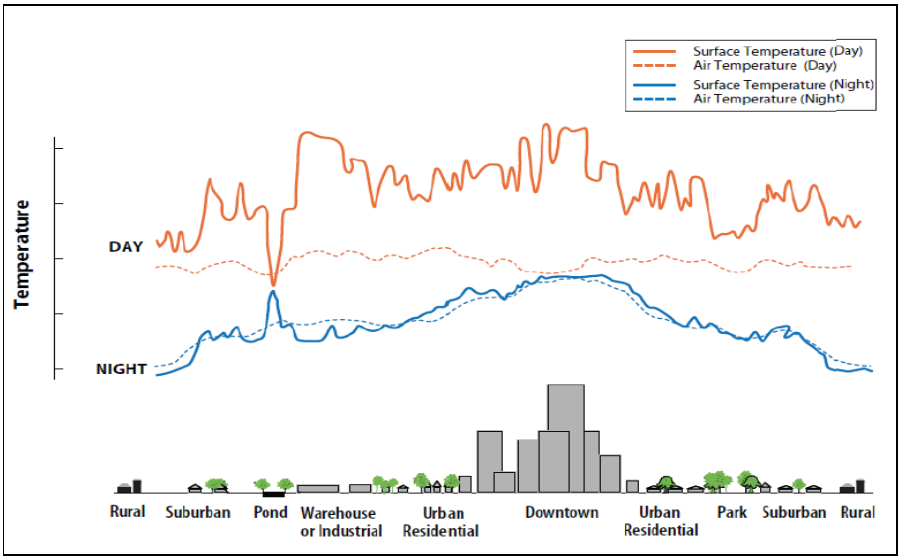

Figure 2.2 Variations between Surface and Air Temperature

Source: Voogt (2004)

Researchers examining air temperatures are either studying the mesoscale details of UHI, which are referred to as Boundary Layer Urban Heat Islands (UBLs), and the microscale details, which are referred to as Canopy Layer Urban Heat Islands (UCLs). At the mesoscale, the UBL research focuses on the vertical column of air above the average building heights. At the micro-scale, the UCL research focuses on the surface layer, which is the area between buildings and below the building rooftop. However, the predominant type of analysis taking place focuses on UCLs and therefore, UCLs are most commonly associated with the UHI effect. The following Figure 2.3 shows a view of the urban heat island in various types and scales which can be a dome above of the city in mesoscale or a sublayer in microscale. Air Temperature UHI and Surface temperature UHI is described in the following sections.

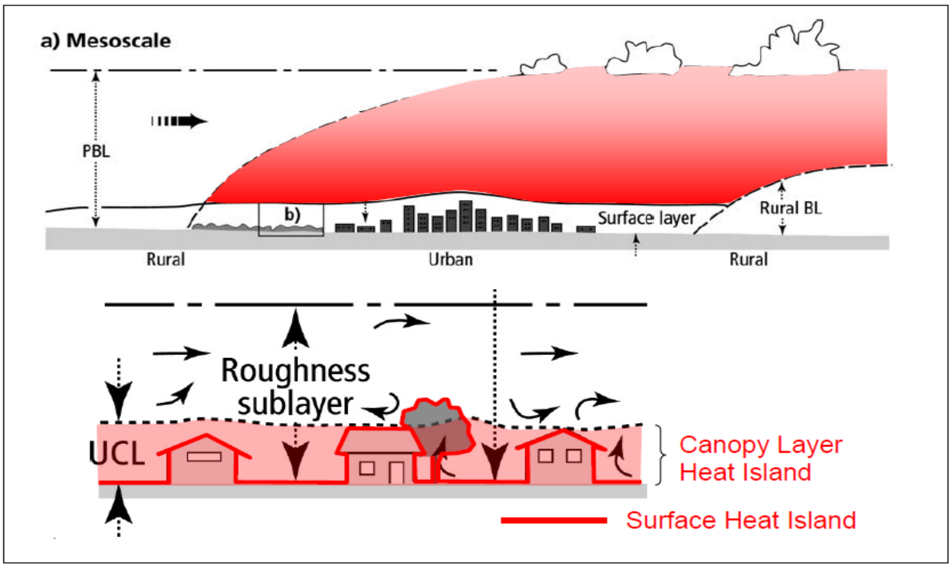

Figure 2.3: Types of urban heat islands

Source: Roth (2002)

Air temperature can be measured through the use of weather station networks or automobile transects and surface temperature is measured through the use of satellite remote sensing or surface thermometer. Each type of measurement can be used in special situations with their advantage and disadvantage. The advantage of in situ data is long data recording and high temporal resolution while are poor in spatial resolution. Unlike, there is a higher spatial distribution in satellite remote sensing data, whereas short data recording and low temporal resolution.

i: Air Temperature UHI

As mentioned above, Air temperature UHIs are categorized into two different types according to the understanding urban canopy and atmospheric system (Oke, 1973). The urban boundary layer (UBL) refers to an overall atmospheric system which expands above cities and the urban canopy layer (UCL) is from ground level up to the average height of the building roofs. Intelligibly, the majority of the climatic impacts is mainly felt in the urban canopy layer (Emmanuel 2005). Based on the UHI definition, air temperature in urban areas should be higher than that of surrounding rural places while its intensity can be varied in different location throughout the day and night (Wong & Yu, 2005; Gartland, 2008). The small differences between rural air temperature and urban air temperature are in the early morning; however, it increases during the day when urban surfaces heat up and consequently release into the ambient (Gartland, 2008). To monitor air temperature UHI, fixed weather stations and mobile traverses are used (Sham, 1990, 91; Magee et al, 1999; Unger, 200l; Kim & Baik, 2005; Wong & Yu, 2005; Giridharan et a1., 2007).

The simplest method of measuring air temperature UHI is comparison of fixed station data together. There are three different ways to use data from fixed stations: firstly, comparing two weather stations data in urban and rural areas; secondly, analyzing multiple station data to investigate a two-dimensional impacts region; thirdly, studying historical data to assess heat island over time as a region developments (Gartland, 2008).

Through a mobile traverse, air temperature UHI can be monitored which is known as an economical method. To obtain the air temperature data, weather instrumentation moves throughout the city and stops in the desired locations to collect data. For traveling into the city, it can be walked or cycled between specific locations or used a car to cover extensive areas (Spronken-Smith & Oke 1998; Stewart, 2000; Wong &Yu, 2005).

ii: Surface Temperature UHI

Surface temperature UHI is higher in the cities with more buildings and paved surfaces which can be reached to highest peak after solar noon (Roth, 2002; Emmanuel, 2005). Urban surfaces are heated by solar radiations during these hours, reaching to 50 °C hotter than air temperature (Gartland, 2008).

Surface characteristics affect Surface Heat Island (SHI) (Voogt, 2004). Sunlight is more readily absorbed by dark surfaces in comparison to lighter and moist surfaces or shaded surfaces. The SHI is positive during the day and night times; nevertheless the values are normally greater in the day hours. Due to the effects of solar radiation, green areas have been known to prevent increased surface temperatures (Klok et al., 2012). Past studies in the Phoenix region of Arizona have identified that urban paved surfaces like roads and highways modify urban temperatures. The significant results regarding to the UHI and a variety of surface temperatures have shown to be related to pavement material types with consideration to location and surrounding landscapes (Golden & Kaloush, 2006). Elsayed (2012) argues that there are many factors combined to warm cities especially, in Kuala Lumpur; however, the main factor is urban fabric. The vegetation, crops and soil of the countryside are replaced in the urban surfaces by bricks, concrete, steel, asphalt and glass. Thus, compared to the rural area, the city is generally a drier, denser, consisting more rigid surfaces. As a result, the thermal properties for these two surfaces areas became significantly different. Adams and Smith (2014) claimed that the of role vegetation cover plays in influencing surface and air temperature. They found trees and other vegetation can reduce surface temperatures because they intercept solar radiation and provide shading on surfaces. Consequently, vegetation covers directly modify surface temperatures and thus the air temperature. Kleerekoper et al. (2012) offered a strategy for increasing urban green spaces in four different types of application of vegetation in urban areas: urban forests, road trees, private green in gardens and green roofs.