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OVERVIEW OF URBAN HEAT ISLAND (UHI) PHENOMENON TOWARDS HUMAN THERMAL COMFORT

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Abstract

Urban Heat Island (UHI) is expected to be a disastrous challenge to human in the following decade as a result of continuous urbanization without appropriate planning and design. The impacts of UHI are even getting worse due to large population density with improper building design especially in dense metropolitan cities. A lot of research has been carried out for UHI phenomenon both in tropical and seasonal climates. There are many factors contributing to the formation of UHI phenomenon that includes increasing rate of urbanization and population density, uncontrollable factors and controllable factors. In a fundamental study, a prolonged exposure to heat impact will significantly contribute to human discomfort and health problems resulting in heat-related illness. The cases of heat related deaths, such as heat strokes, are due to the result of climate changes and further the problem of heat waves will increase year by year. Since the consequences of UHI are considered to be more significant, the severity of the problem should be critically examined and carefully reported. Many research efforts have been implemented for making conceptual design and also a wide range of literature is available for continuing the mitigation strategies. Therefore, this study is emphasized on the critical investigation of the features, factors and impacts of UHI towards evaluating human safety and thermal comfort. Future research direction should also be encompassed on the design and planning parameters as well as assessment of climate change risks and vulnerability for reducing the effects of urban heat island onto human health and safety.

Keywords: heat related illness, human safety, thermal comfort, urban heat island

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1. Introduction

In line with economic and population growth, rapid urbanization and industrialization is expected to take place in order to improve our material lives and comfort. As city grows, the area covered by city is also expanding and the natural ground surface is being changed to an artificial surface. This will increase the amount of heat storage during sunny days. The hot city phenomenon has far-reaching consequences for environmental sustainability and it is believed that it has significant impact on human health. The urban city temperature is higher when compared to the surrounding rural or suburban areas

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(green area) which are referred to as the Urban Heat Island (UHI) phenomenon (Livingstone, 2006; Voogt, 2004).

A UHI is recognized as a climatic phenomenon in which urban areas have higher air temperature than their surrounding rural area as a result of anthropogenic modification of land surfaces, urban expansion, population growth, energy use, and its consequent generation of waste heat which causes alarming effects in many metropolitan areas (Ghazanfari et al., 2009; Kolololtsa et al., 2009; Kolokotroni and Giridharan, 2008; Shahmohamadi et al., 2011). The difference in absorbed energy is due to the use of massive construction materials like asphalt, concrete and other construction materials that in terms of low albedo effect creates significant temperature difference between cities and neighboring areas (Ghazanfari et al., 2009).

Mostly, researchers have only discussed the impact of UHI based on the anthropogenic factors rather than 'albedo' effects (Sailor, 2011; Shahmohamadi et al., 2011; Zhou et al., 2011). According to Kolokotroni and Giridharan (2008), the most critical variables that determine the day time and nocturnal air temperature is the surface albedo that influences the absorption and reflection of the solar radiation. A high surface albedo reduces the energy usage and positively influences the environmental assessment, especially on roofing system (Susca et al., 2011). Taha et al. (1988) also indicate that the albedo modification of construction or materials used in making buildings have the potential for reducing cooling energy as well as UHI effects. Discomfort and inconvenience to the urban population due to higher temperature will definitely place the urban population at greater risk in terms of increased morbidity and mortality (Shahmohamadi et al., 2011). There are numerous cases being reported for heat stroke which is coming from climate change and heat wave that is increasing from year after year as reported by Mueller and Colgate (2011) from National Centre for Catastrophic Sports Injury which reports heat-related death and proven to have doubled from 1975 to 2011.

In order to distinguish the thermal behavior of different construction materials, thermal mannequin was developed at least half a century ago to enhance the understanding of relationship between the human body and surrounding environment (Gao and Niu, 2005). This paper reviews the basic concept on the generation and mitigation of thermal behavior that leads to UHI. It summarizes the most relevant findings from previous researchers on the related discussion, presenting previous and latest research methods, methodologies and tools that are used for understanding the adverse effects of thermal behavior to human thermal comfort in the most convenient way and discussing the aspects of potential future research areas. Besides that, various factors and their importance in the formation of UHI and its relationship to the thermal behaviour at built environment and heat wave had also been discussed and described. At last, the impacts of UHI in relation to the human health and heat related illness, together with the research areas on the applications of different methods and tools for mitigation of UHI in terms of human thermal comfort are also covered.

2. Formation of UHI phenomenon

The progressive replacement of natural landscape to artificial building structure has lead to the development of UHI formation. The global solar radiation is gradually reduced due to the absorption and scattering of radiation by the built environment. UHI mainly develops in metropolitan areas which contain higher percentage of water resistance, non reflective surfaces and low percentage of vegetated land covers. The different reasons for the UHI phenomenon to occur which will be discussed below.

2.1. Urbanization

The rapid urbanization has transformed current environment from natural vegetation to engineered structures. This has increased the thermal-storage capacity due to the retention and emittance of solar heat, resulting in the significant urban heated society when compared to the adjacent rural areas; known as urban heat island (UHI) effects (Ghazanfari et al., 2009; Golden, 2004; Luber and McGeehin, 2008; Weng, 2003; Zhang et al., 2009). The Urban Heat Island phenomenon mostly appears in growing cities than in the developing countries due to the parallel growth of urbanisation and population density (Ghazanfari et al., 2009; Xie and Zhou, 2015).

The main consequence of this population shift is due to extreme changes in land use that gradually replaces the pre-existing natural landscape (Golden, 2004). It is clear that the population density is positively correlated with the urbanisation and city size and also its temperature gradients (Hua et al., 2008; Hughes, 2006). The energy demand also tends to be higher at the urban centre as a result of the higher population density (Che-Ani et al., 2009). A case study of warming effects as a result of urbanisation has been performed in China. It demonstrated that adverse UHI effect happened in the region with rapid industrial and economic development especially in the northern part of China and was found to be weaker in the areas of coastal city (Hua et al., 2008). Dasimah et al. (2009) reported that Malaysia has been undergoing rapid urbanisation and development of new townships and as a result there is a heavy migration of rural people. Malaysia can be classified as one of the most advanced developing countries which are currently experiencing significant urbanization (Takeuchi et al., 2010). Most cities in Malaysia experience hot-humid climate all the year round in parallel to increasing rate of urbanization and population density. The consequences of the UHI phenomenon will directly impact human safety and health.

2.2. Thermal behaviour of urban built environment

The thermal behavior of various urban surfaces play an important role because this is directly integrated with UHI phenomenon and environmental aspects such as heat stress and air pollution (Chudnovskym et al., 2004). In urban areas most of the surface materials have higher adsorbed energy with low albedo effects. The impervious surface properties of roads, streets, roofs, walls, lawns, landscape and parking lots will enhance higher absorption ability of the construction materials (Ghazanfari et al., 2009; Golden, 2004; Taha et al., 1988). This heat will be adsorbed, stored and then re-emitted to the surrounding urban air at night time causing a high temperature difference between urban and rural area. Moreover, there are many other factors that contribute to the formation of UHI. Rizwan et al. (2008) categorized them as controllable and uncontrollable factors (Fig. 1).

The uncontrollable factor includes the temporary effect variables, such as air speed and cloud cover which occur naturally in the existing environment. On the other hand, controllable factors include permanent effect variables such as green areas, building material and sky view factor as well as cyclic effect variables such as solar radiation and anthropogenic heat sources. Due to rapid urbanization, urban areas have become the source of anthropogenic carbon dioxide emissions where global solar radiation is scattered and easily absorbed onto the surface materials. Addition of anthropogenic heat and air pollutants including the cooling and heating of buildings, manufacturing, transportation and lighting will also contribute to environmental heat, instantly and directly. Wind speed and direction in the urban canopy layer decreased mainly due to the roughness of the city and has substantial impacts on UHI intensity.

According to the study of Kolokotsa et al. (2009) in Hania, Greece, wind pattern of Northern wind pushed the hot spot away from the coastal area while Western winds reduced urban temperature by natural urban ventilation because due to the orientation of main streets. Therefore, street canyon geometries and orientations will result in significant influence on the street thermal environment and thermal comfort (Amirtham and Devadas, 2007). Besides that, a decrease in sky view (brighter sun shine) will also result in high heat storage between the building structures.

Impermeable surface materials like building and pavement quickly shed precipitation into catchment basins which could reduce surface moisture and evapo-transpiration. Furthermore, the thermal properties of urban construction materials contribute to the formation of UHI phenomenon. Urban materials of higher specific heat capacity will adsorb and retain solar radiation as well as reduce the solar reflectance. This will ensure heat storage in urban cities is higher, which will end up with higher surrounding temperature.

During daytime, it is believed that asphalt paved roads and roof tops are the dominant warm urban elements in the urban environment (Chudnovsky et al., 2004). In addition, the accumulation of daytime heat storage in thermal mass will cause nocturnal UHI intensity to reach up to 1.3ºC within an estate and 0.4ºC between estates but these values are still low compared to the daytime UHI intensity in the case study of Belchers, Wah Fu-1 and Wah Fu-2 (Giridharan et al., 2005). Therefore, the urban design should be considered as a fundamental element in mitigation of Urban Heat Island (UHI) effect.

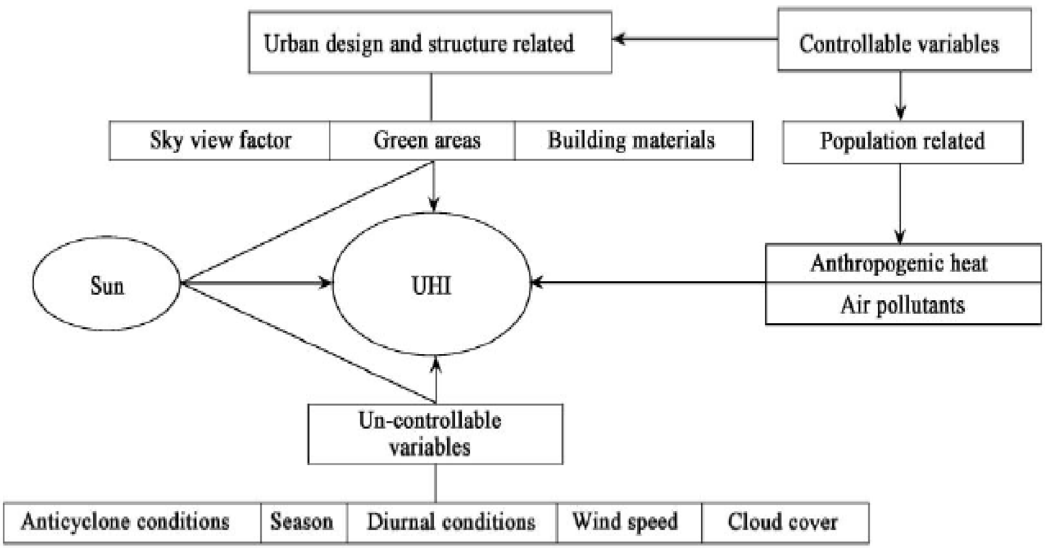

Fig. 1. Generation of Urban Heat Island (UHI)(adapted upon: Rizwan et al., 2008)

3. Previous studies on the UHI phenomenon

In recent years the UHI phenomenon has become one of the most growing environmental problems in the urban areas due to the land cover, urbanisation and population density (Sarkar, 2004). UHI can be assessed by applying thermal remote sensing to perform land cover classifications and thermal behaviour of various urban surfaces which varies in response to the surface energy balance (Chudnovsky et al., 2004; Voogt and Oke, 2003). Besides that, UHI detection can also be performed using fixed-station or meteorological station and car-traverse measurement to detect UHI intensity and the air temperature in the regions (Kolokotsa et al., 2009; Saaroni et al., 2000). Pongracz et al. (2006) and Zhou et al. (2011) had integrated remotely sensed data (MODIS) and meteorological observations to observe daily maximum day and night time UHI intensity. Furthermore, Zhou et al. (2011) using support vector machine (SVM) regression technique to predict maximum night time UHI intensity (MNUHII) based on surface characteristic of materials, climatic as well as meteorological conditions. Numerical models with a set of empirical equations can be used to determine the relationship between maximum UHI intensity and factors - factors that contribute towards the formation of UHI (Montavez et al., 2008).

Several research studies have been performed on the UHI phenomenon. The UHI intensity differs between seasonal climate and tropical cities. In the seasonal climate, the UHI are strongest in the summer or winter season. According to Liu et al. (2007) and Papanastasiou and Kittas (2012), the UHI intensity is positively correlated with solar radiation and relative humidity during summer while on the other hand it is negatively correlated with wind speed and relative humidity during winter. However, for tropical cities, it also exhibits a seasonal variation in the intensity of UHI due to the dry and wet season during the year. Table 1 shows the UHI intensity in several selected urban cities where these cities are characterized by higher population density and vast human features in comparison to areas surrounding it, based on UHI studies.

In Malaysia, there are only a few UHI study investigation being carried out at the urban cities of Kuala Lumpur area, Selangor, Pulau Pinang and Johor Bahru as shown in Table 1.

This implies that the urbanization that took place in most of the urban areas, to some extent, plays quite a significant role in changing the urban air temperature patterns (Takeuchi et al., 2010). In summary, there are other studies of UHI in various urban centers based on seasonal and tropical climate (Table 1).

Table 1. General Urban Heat Island studies at various urban areas based on seasonal and tropical climatic conditions

Reference	***Location (urban areas)***	***UHI intensity***
Tropical climate		
Lim (1980)	Georgetown, Penang	4°C
Zainab (1980)	Johor Bahru, Johor	3°C
Sham (1984))	Kuala Lumpur-Petaling Jaya	7°C
Sham (1986)	Several urban centers in the Klang Valley	2 - 5°C
Sham (1987)	Kuala Lumpur	4.4 – 5°C
Shaharuddin (1992)	Urban parks in Kuala Lumpur	3 - 5°C
Sin and Chan (2004)	Georgetown, Air Hitam, Bandar Bayan Baru and Bayan Lepas	2 - 6°C
Priyadarsini et al. (2008)	Singapore: central business district (CBD)	4°C
Kubota and Ossen (2009)	Johor bahru City: Rainy day, Sunny day	2°C, 4°C
Mohan et al. (2009)	Delhi	Daytime: 7.6°C Nocturnal: 8.3°C
Jongtanom et al. (2011)	Bangkok, Chiang Mai and Songkhla, Thailand	2.24°C, 2.73°C, 2.42°C (Daily) 1.06°C, 2.73°C, 2.70°C (monthly)
Seasonal Climate		
Saaroni et al. (2000)	Tel-Aviv, Israel	3 - 5°C
Kim and Baik (2002)	Seoul, Korea	3.4°C
Pongracz et al. (2006)	Hungarian cities (Summer)	1 - 6°C
Kolokotroni and Giridharan (2008)	London (summer)	Daytime: 8.9°C (semi urban) Nocturnal: 8.6°C (urban)
Kolokotsa et al. (2009)	Hania, Crete (summer)	8°C
Devadas and Lilly (2009)	Chennai, India	Summer: 2.48°C Winter: 3.35°C
Hara et al. (2011)	Tokyo metropolitan areas (winter)	2 - 3°C
Papanastasiou and Kittas (2012)	Volos, Greece (summer, winter)	3.1°C, 3.4°C
Dobrovolny et al. (2012)	Brno, Czech Republic	Summer midday: 2.5°C Night-time: 1 - 1.5°C

From the UHI intensity observation for tropical and seasonal climate, it shows that urban areas in tropical climate exhibit higher UHI intensity since the average air temperature is high all throughout the year. The UHI intensity (Table 1) refers to the difference between urban and rural air temperature.

4. UHI impact

The UHI phenomenon has added effects on the heat wave intensity and exacerbates the impact of heated society on thermal comfort and heat related mortality. The heat related mortality is the most serious health outcome due to UHI effects. However, mortality data reflect only on extreme health events. So, it can be assumed that thermal comfort conditions are likewise significant predictors of morbidity and general for human well-being.

4.1. Human thermal comfort

Basically, thermal comfort can be defined as the physiological interval where the human can operate or tolerate the environment. It is the condition which human body expresses satisfaction with the thermal environment (ASHRAE Standard 55P, 2003). There are a number of standards used to evaluate comfort conditions, such as ISO7730 based on Fanger's predicted mean vote (PMV) equation and ASHRAE Std 55 (Nicol and Humphreys, 2002). There are seven ISO sensation scale for determining thermal comfort in the human body which is used by PMV: hot, warm, slightly warmer, neutral, slightly cooler, cool and cold. Thermal comfort basically is affected by heat conduction, convection, radiation and evaporative heat loss. Physical variables or parameters such as air temperature, relative humidity, water vapour pressure, wind speed, mean radiation temperature, worn clothing and the activities of the person will take into account for the measurement of human thermal comfort in the hot and humid environment (Cheng et al., 2012; Rahola et al., 2009; Tsutsumi et al., 2007).

On the other hand, the air temperature and humidity are among the most important parameters to evaluate thermal comfort especially in hot and humid countries for indoor thermal comfort (Al-Homoud et al., 2009). The ASHRAE guidelines recommend about 68 to 74°F or 20 to 23°C in the winter and 72 to 80°F or 22 to 27°C in the summer and a relative humidity (RH) of 30 to 60 % to maintain a comfortable level. Humphreys and Nicol (2000) discovered that the comfort temperature is linearly related to the mean outdoor temperature which is derived from the monthly mean daily maximum and minimum temperature from the comfort surveys for free running building. The expression of the comfort temperature is Eq. (1):

$$T_c = 0.54T_o + 12.9 \quad (1)$$

where: T_o is mean outdoor temperature and is expressed in [°C].

Thus, Table 2 summarizes the previous research studies carried out for determining the thermal comfort evaluation.

Table 2. Previous research studies in determining thermal comfort evaluation

References	***Field of study***	***Findings***
Makaremi et al. (2012)	• Quantitative field study in outdoor spaces to investigate human thermal comfort conditions during hot and humid tropical climate of Malaysia. • Thermal condition in outdoor space - measurement of parameters related. • Thermal perception - questionnaire survey (local and international student).	• The thermal comfort Index (PET) was higher than the comfort range defined for tropical climate (PET < 30°C) in the selected outdoor space. • Psychological adaptation influence thermal sensation of individuals. Local respondents have higher tolerance with the local climate compared with foreign respondents.
Nilsson and Holmer (2003)	• Develop and analyze computational models such as Computational Fluid Dynamics (CFD) and thermal manikin methods for thermal comfort evaluation in different working place environment.	• The results from both calculations and measurements show a relatively good agreement with the measurements made in the real environment. • Thermal evaluation enables engineers to perform better design and construction process.
McGuffin et al. (2002)	• Thermal comfort evaluation of passengers in vehicles. • Predictive tools used - psychological model (Human thermal comfort), physiological model (human thermal system) and thermal manikin (real vehicle testing).	• Developing the predictive model for thermal comfort sensation/perception (skin and core temperature). • Developing NREL Human Thermal Model (finite element model) - consists of human-tissue system, thermoregulatory system and clothing model. • Thermal manikin is incorporate with finite element models to perform as true human response such as heat transfer and sweat rates.

Noor Hanita Abdul majid (2004)	• Evaluation of microclimate conditions (plazas adjacent to tall buildings - PATB) in urban spaces. • Determination of thermal comfort based on PATB orientation and geometry.	• Among the orientation, the combined diagonal position of Northwest-southeast and Northeast-Southwest show higher comfort vote. • The plaza located underneath a tall building is the best geometry in this assessment.
Wong et al. (2002)	• Evaluation of thermal comfort perception in naturally ventilated public housing in Singapore. • Investigation of the influence of sessions of the day, building height and flat types on thermal perception and whether it meets ASHRAE standard-55's 80% acceptability criteria.	• The occupants are satisfied/feel comfortable with their thermal environment. • The percentage thermal acceptability (indoor environment) is higher on the top floor levels than on the low and middle floor levels respectively. • Based on the thermal comfort between flat type, maisonette units have a higher comfort level than a three-room unit and a four-room unit (Bedford scale).
Conceicao et al. (2009)	• Thermal comfort evaluation by using numerical model - simulate buildings thermal responses for different passive solutions in kindergarten (summer). • Thermal comfort level is evaluated using PMV (predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) - ISO 7730 • The numerical model includes the analysis of the application of a new roof in the top of the kindergarten, external pyramidal opaque trees placed in front to the windows - facing West and East and horizontal shading devices placed above the windows level - facing south.	• The application of new roof and the horizontal shading devices are thermally efficient while the external pyramidal opaque trees are not. • This numerical model can be used as thermal solutions in the actual kindergarten to improve the occupant's thermal comfort level and the energy savings in the future.
Nilsson (2007)	• Developing new comfort evaluation method and new numerical thermal manikin (CFD) based on the combination of thermal manikin measurements and human experiments.	• The results show that the CFD simulations give good prediction, similar to real life measurements on how humans perceive the different environments. • The CFD calculations had no problem in simulating and produced reasonable results in relatively homogeneous climate (the office case), but need to be further developed for more complicated climate situations (cabin case).

Thus, frequent exposure to the heated environment will contribute to a decrease in thermal comfort and thus will increase prevalence of heat related illness. These thermal comfort and sensation in these extreme environments are complicated in terms of physiological and psychological responses from the human body. Therefore, investigation should be made to correlate the physical and psychological factors of the human body within the microclimate environment for further development and improvement of human thermal comfort evaluation.

There is a better understanding between the inter relationship of urban climate, outdoors space use and health. The focus should be to reflect healthy planning strategies and climate change adaption planning (McKenzie, 2009). It is understood that UHI occurring in metropolitan areas is more significant and will therefore cause a higher incidence of heat-related morbidity and mortality. Henry (2002) investigated the potential impacts of climate change on human health commissioned by Climate Change Central, a non-profit organization empowered by the government of Alberta to study and take suitable action on climate change. The study discusses health impacts associated with thermal extremes, air pollution, and climate change and is followed by implication for public policy. As a result, continuous exposure to heat can cause illness and death to humans.

4.2. Heat related illness

Heat illness is the one that is brought about by the combination of hot weather and physical activity which is known to occur during, e.g. military training, physical labor, organized team sports and amateur sporting events (Wallace et al., 2007). These illnesses arise during a disruption in the regulation of body temperature because heat input from the environment and body metabolism is the increased relative to the heat output from the skin via radiation, evaporation, and convection (Grubenhoff et al., 2007). The heat illness includes heat exhaustion, heat cramps, heat rash and the heat stroke (Occupational Safety and Health Administration, OSHA, 1999). Heat illness, especially heat stroke, occurs when the body temperature regulation fails and the body temperature rises to critical levels (Occupational Safety and Health Administration, OSHA, 1999). Heat Stroke is the life-threatening heat disorder if immediate professional medical treatment is not obtained. There are many extreme hot weather incidents which can cause discomfort in human body. In the worst case scenario they can lead to more heat-illness casualties such as heat stroke. Cases of heat related deaths, such as heat stroke results from climate change and heat waves, are becoming increasingly common from year to year. For example in Japan, the number of deaths due to heat stroke increased to 904 people in 2007 when a heat wave occurred in summer with peak temperature of 40.9°C (Ohba et al., 2010). The number of deaths due to heat stroke in Japan is shown in (Fig. 2). Besides that, the latest case reported by Mueller and Colgate (2011) from the National Center for Catastrophic Sports Injury is that the heat-related deaths have more than doubled since 1975 (Table. 3). It could be explained that the outdoor thermal comfort is getting more threatened in the recent year of 2006 - 2011 because of increased outdoor temperature due to urbanization and human activities.

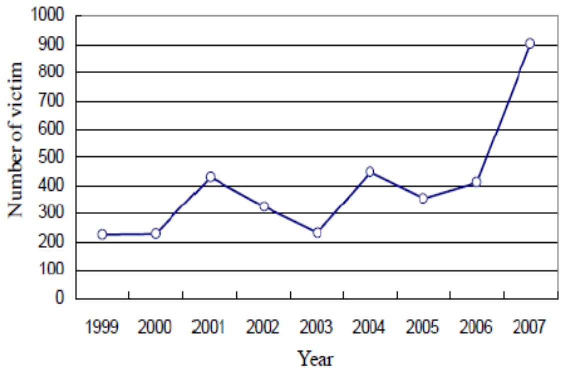

Fig. 2. The annual number of deaths due to heat stroke in Japan (adapted upon: Ohba et al., 2010)

Table 3. Heat Stroke Fatalities from National Center for Catastrophic Sport Injury, 1975 - 2011 (Mueller and Colgate, 2011)

Year	*Total*
1975 - 1980	9
1981 - 1985	8
1986 - 1990	6
1991 - 1995	5
1996 - 2000	14
2001 - 2005	8
2006 - 2011	25

Furthermore, as in United States, the Centres for Disease Control and Prevention reported 8015 deaths due to excessive heat exposure from 1979 - 2003 and approximately 334 deaths occur per year (Helman, 2010). According to Nelson et al. (2011), there were around 54,983 patients treated in U.S emergency departments for exertional heat-related injuries from 1997 to 2006. There was 133.5% increase in the number of exertional heat-related injuries, from 3192 in 1997 to 7452 in 2006. So, people living in the United States may suffer from heat related deaths during prolonged and unrelenting heat waves every year especially in summer. For example, in the heat wave of 1995, Chicago officials reported approximately 437 heat related deaths as the temperature and humidity reached historical peaks (Naughton et al., 2002). In the heat wave of August 2003, thousands of elderly, living in predominately urban areas in France, Italy, and other European countries, died because of heat stroke (Bailes and Reeve, 2007). Besides that, the incident reported nearly 15,000 people died from the heat-related illness in Paris during a very hot summer of 2003 due to the failure of buildings to attenuate internal air temperature (Kershaw et al., 2010).

In addition, the incidences of heat stroke in Saudi Arabia varies from 22 to 250 cases per 100,000 population, whereas, the incidences of heat exhaustion in contrast ranges from 450 to more than 1800 cases per 100,000 population (Bouchama and Knochel, 2002). Piver et al. (1999) assessed the impacts of both air temperature and air pollution variables in Tokyo, Japan. The study is based on determining the daily number of heat stroke emergency transport cases per million residents according to gender and three age groups for the months of July and August in 1980 till 1995. The result indicates that the number of heat stroke emergency transport cases per million residents was greater for males than for females who are in the same age group.

4.3. Heat wave

Heat waves are usually associated with prolonged high daily average temperature, maximum and minimum temperature, relative humidity, and air pollutant concentrations. Heat waves may occur as a result of increased surface air temperature. Therefore, it is important to determine the extent to which some or all of these climate and air pollutant variables contribute to heat-related morbidity, particularly heat stroke. From the cases reported above, most of the heat-related fatalities happen in developing countries where the urbanization rate is at a much higher level. However in Malaysia, although there are not many cases reported from the related agencies, heat-related illnesses are still at the top concern for the people who are mostly exposed to the heat condition. Therefore, it is important to report the cases of heat-related fatalities to the related medical agencies or organizations so that people will be alerted and some prevention strategies can be implemented.

According to Chew and Abdul Latif (2010), temperatures above 41.6 to 42°C are considered to be the critical thermal maximum for humans to tolerate for 45 minutes upto eight hours. Extreme temperatures above 49°C may result in near immediate cell death due to protein denaturation and interruption of critical cellular process in the cellular level. Exposure to prolonged extreme heat is a significant public health problem and becomes the main cause of weather - related mortality (Luber and McGeehin, 2008). Therefore, heat-related morbidity and mortality are among the primary health concerns that are expected to increase as a function of climate change. Hence, additional research is needed to provide a stronger theoretical framework for health-based scenarios, including better understanding of building structures, urban planning air temperature, air pollution and the potential nature of changing variability of heat and the exposure–response relationship. With these approaches, it is hoped that valuable information can be provided to aid public health and environmental authorities in planning and communicating the risks of climate change to the public (Kinney et al., 2008) .

5. Mitigation and prevention strategies

In the UHI phenomenon, the temperature increases in the urban environment, leading to an increasing frequency of heat waves and duration of hot spells (Santamouris et al., 2011). It has added effects on the heat wave intensity, which may exacerbate the impact of heated society on heat related mortality where it is the most serious health outcome due to UHI effects. Therefore, most of the metropolitan cities nowadays suffer from the negative impacts of warming climate. According to National Aeronautics and Space Administration (NASA)'s Goddard Institute for Space Studies (GISS), the global temperature in 2011 was 0.92°F (0.51°C) warmer than the global temperature in the mid-20th century (NASA, 2012). In U.S. it is reported that, the average temperature was 53.8°F (12.11°C) which is 1.0°F (-17.2°C) above the 20th century average (National Oceanic and Atmospheric Administration, NOAA, 2012). The comfort ability and well-being of the urban populations during summer time will become increasingly compromised under the future scenario of climate change and urbanization. Therefore, mitigation and prevention strategies should be implemented to keep people away from heat and discomfort.

The thermal comfort of human can be categorized for different urban structures such as street canyon and availability of vegetation as investigated by Mayer and Hoppe (1987). In short, the cooling of urban environment should be a top priority for urban planners and authorities in order to alter the urban microclimate by modifying its heat absorption and emission.

These efforts can be executed by urban greening through increasing vegetation, the use of high-reflectivity materials, and avoiding canyon street design by increasing openness to allow cooling winds especially for the newly developing areas or township. Besides that, it is also found that optimal urban geometry can minimize solar absorption as one of the energy efficient design for building performance. This can be proved by comparing deep and shallow street canyon on outdoor thermal comfort where it was shown that deep canyon is considerably cooler than shallow one during continuous measurement in hot season (Johansson, 2006; Johansson and Emmanuel, 2006.). The design consideration in terms of building orientation is being discussed where it shows that building should be oriented to provide maximum natural ventilation and minimum solar gain by the blockage of direct sunlight (Al-Tamimi et al., 2011). Buildings itself can provide improved comfort ability and higher level of sustainability by taking advantage of exemplary facade, glazing and ventilation designs present inside the building (Smith and Levermore, 2008).

Besides the concept of designing low energy and sustainable buildings, thermal comfort can also be increased by acclimation concept. The comfort thermal survey by Dear and Leow (1990), Wijewardane and Jayasinghe (2008) and Lin (2009) indicates that increasing comfort temperature limits the response shown to the actual human response and the design requirements for outdoor public spaces in hot and humid region can be explained as the processes of physiological acclimation and perceptual habituation (Cao et al., 2011; Zhang et al., 2010). Various mitigation strategies in building materials have been developed, for example, cool roofs, green roofs and cool pavements. The characteristics of each technology used for reducing the urban heat island phenomenon have been comprehensively examined by many researchers (Takebayashi et al., 2011). The efforts of these researchers in investigating the urban surface temperature to enhance human thermal comfort have been summarized in (Table. 4).

Table 4. Historical research for the investigation of urban surface temperature

References	***Research Areas***	***Finding***
Sakakibara (1996)	• Numerical investigation of the effect of urban canyon geometry on thermal environment by using parking lot model and urban canyon model.	• Urban canyon absorb more heat in the daytime and release more at night than parking lots. • The canyon wall at north building and the street floor absorb more heat during daytime, while the canyon wall at south building absorbs more in the morning • The surface temperature at the centre of the canyon street (H/W ratio = 0.71) is higher than that when H/W=2.04, but drops at noon due to shadowing.
Synnefa et al. (2005_	• Investigation of the thermal performance of reflective coatings to lower ambient temperature	• Appropriate reflective coating can reduce surface temperature (white coloured coatings

	and surface temperature of buildings.	have better solar reflectance than aluminium-pigmented coatings).
Hazlini Dzinun et al. (2011)	• Analysis of the thermal behaviour of vertical facade building (brick, concrete, granite and tiles) with the mechanism of heat flux.	• Granite is 2.7 times more heated than brick wall. • Granite, concrete and brick increase surface temperature and exhibit high absorption.
Asaeda and Ca (1996)	• Heat storage for various types of pavement materials on a summer day - observed on heat flux at the air/ground interface.	• Asphalt is highly heated and release substantial amount of heat at night. • Lower heat conductivity (asphalt) hotter at daytime while high heat conductivity (black-top concrete) is hotter at night.
Akbari et al. (2008)	• Study on pavements and roofs - reducing urban albedo which will result in less absorption of direct solar radiation.	• By using cool roofs and cool pavements - increase albedo by 0.1. • It is estimated that a negative forcing of 4.4 x 10^{-2} W/m^2 is equivalent to offsetting 44 Gt of emitted CO_2.
Santamouris et al. (2011)	• Review on the development and assessment of cool materials for buildings and urban structures in terms of solar reflectance and infrared emittance.	• White materials exhibit very high reflectivity and emissivity compared to natural materials like white marble and white mosaic. • Cool coloured material using near infrared reflective pigments show higher reflectivity than conventional materials of same colour. • Incorporation of nano-materials and with dynamic optical characteristics as third and fourth phase shows reduction in surface temperature.
Synnefa et al. (2006)	• Investigation of the performance of prototype cool coloured coatings using near infrared reflective colour pigments and compared with conventional pigmented coatings to increase surface albedo - improve outdoor thermal comfort.	• Cool coloured coatings reflect large part of solar energy that arrive as infrared radiation rather than absorb it. • Maximum difference between the solar reflectance is 22 with temperature difference of 10.2°C. • Increase albedo by feasible 0.45 can decrease air temperature by 1.6°C.
Synnefa et al. (2007)	• Investigation of the indoor thermal comfort conditions of residential buildings by using cool roof coatings. Indoor thermal comfort conditions were improved by decreasing the hour of discomfort by 9 -100% and max temperature in non air-conditioned residential buildings by 1.2 - 3.3°C.	• Cool coloured coatings containing infrared reflective pigments have higher solar reflectance values than standard coatings. • Cool coloured coatings have lower surface temperature than colour-matched conventionally pigmented coatings.
Amirtham and Devadas (2007)	• Study on the impacts of built environment (street geometries/orientation) on the outdoor thermal comfort conditions in the hot humid city of Chennai, India.	• Shallow urban canyon warmer than deeper one due to shading effects, reduction in solar penetration and reduced sky view factor in deeper urban canyon. • Street with N-S orientation provides better thermal comfort than E-W orientation.
Chia et al. (2007)	• Examination of geometric shape of building (square and circle) and building orientation towards the total solar insolation received by tall buildings.	• The most optimum shape of building in minimising total solar insolation is circular shape with W/L ratio 1:1. • The square shape with W/L ratio 1:1 (north-south orientation) receives the lowest annual total solar insolation. • The highest amount of solar insolation is received on east-orientated wall, followed by the south-, west- and north-orientated walls respectively.
Synnefa et al. (2009)	• Analysis of solar spectral properties and thermal performance of colour and thin layered asphalt in comparison to conventional black asphalt.	• Five colour thin layer asphalt demonstrated higher solar reflectance values and lower surface temperature when compared to conventional black asphalt as same with the simulation result from CFD where average air temperature can decrease by 5°C. • Maximum temperature difference for off-white sample was 12°C.
Rashid et al. (2010)	• Evaluation on thermal performance of green roof on residential building in Bangladesh.	• Green application on buildings causes lower indoor temperature than ambient temperature

		and tends to reduce energy consumption for passive cooling load. • Maximum indoor and outdoor temperature difference was 6.8°C.
Gago et al. (2013)	• A review article that provides recent research on the urban heat island and the mitigation strategies to overcome its adverse effects.	• The mitigation strategies for the urban heat island effect had been analyzed in terms of urban greenery and building materials such as parks and green areas, trees and vegetation, green roof, albedo, pavement. • The planning strategies also clearly reflects on how urban design can be modified to reduce solar radiation adsorption and improve the air flow within the urban street canyon.

The significant effect on thermal comfort can be extended into surrounding neighbourhoods; to some extent the parks must be large and contain adequate amount of shading trees to block out direct solar radiation (Vanos et al., 2011).

In his study Yilmaz et al. (2007), found that soil surface was the most advantageous surface while asphalt concrete surface was the least favourable feature.

Thus, the effort of modifying the urban environment is significant by increasing the area of vegetation spaces and albedo directly or indirectly brings some benefits and contributions to the community. Planting trees in cities will reduce the CO2 concentration directly by natural photosynthesis and indirectly from cooling energy (Akbari et al., 2001).

In hot climate regions, the effect of evapo-transpiration from green areas is significant on urban climate which has a marked effect on human comfort (McKenzie, 2009). The impact of shade trees, cool roofs and cool pavement could be significant on energy use and air quality in an urban area (Fig. 3).

The Urban climate change and the harmful effects from the impacts of Urban Heat Islands especially for human thermal comfort, human health, energy use and environmental quality will directly affect the quality of our life. This situation enables some mitigations of UHI to achieve the sustainable cities. Mitigation of UHI including maintaining sufficient open space and increased vegetation cover, applying 'cool' surface materials, restricting street canyon height to width ratios, designing orientation of buildings with regards to wind direction, improving energy efficiency, and promote low carbon emission (Akbari et al., 2008; Amirtham and Devadas, 2007; Holmes and Hacker, 2007; Rosenthal et al., 2008; Santamouris, et al., 2011; Su et al., 2010; Synnefa et al., 2009). 'Cool' materials can be characterized by high solar reflectance and infrared emittance value resulting from lower surface temperature.

Among the mitigation strategies, the green areas or green vegetation on roofs and buildings is very important on microclimates and enhancing human thermal comfort and health. It is due to their capacity in minimising solar radiation and albedo effects by providing shade and improving air pollution through filtering and providing natural ventilation and vertical air mixing (McKenzie, 2009). Furthermore, prevention strategies can be incorporated in the decision tools for example, web-based program and computer based decision tools to estimate the heat-related health effects and provide necessary information to choose the best strategies (O'Neill, 2009). Once UHI reduction is achieved due to the suitable mitigation measures, people may enjoy more quality and healthy life.

6. Discussion

The literature provides the information that development is a non-stop and ever going process and in turn gently affects the environment. Since development is a proof of improvement in leading to more comfortable life, there is no reason to terminate it. However, civilization can be an awareness to preserve the human-highly-depended environment. Therefore, various mitigation as well as risk prevention and management strategies concerning the urban heat island (UHI) phenomenon are aimed to be implemented in urban cities.

Mitigation strategies are intended for the developed cities, whereas prevention strategies are needed for developing cities. As mentioned, the formation of UHI is the environmental warmth due to heat accumulated and generated by various urban conditions especially at night.

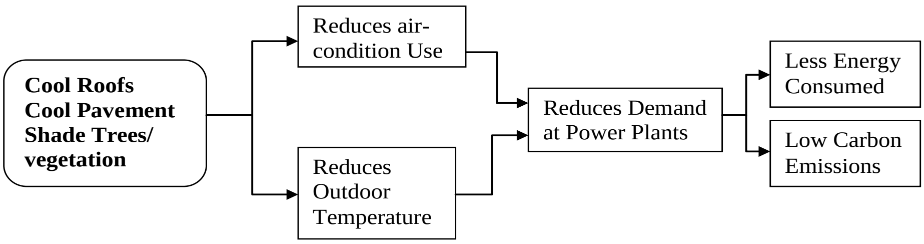

Fig. 3. Impact of tree shade, cool roofs, and cool pavements on energy use and air quality (Akbari et al., 2001)

Urban area is the region surrounding a city with the existence of high population density and vast human features in comparing to the areas surrounding it. The highest UHI intensity always happened at the representative urban cities for the country with the highest population density and compacted built environment; example, Kuala Lumpur, Delhi and London. As the rapid urbanization propagating, various heat generations from the urban fabric had created the formation of UHI such as thermal behavior of surface materials, anthropogenic heat, urban geometry and orientation which had raised serious attention to the occupants in cities.

Based on previous research, heat generated by the anthropogenic heat sources and solar radiation are the main sources of heat in the cities. The anthropogenic heat and solar radiation had instantly and directly impacted towards the urban fabrics and caused heat adsorption or accumulation within the built environment. The heat emitted to the surrounding will indirectly cause raise in air temperature. Besides that, with the aid of incorrect design for the urban street geometry and orientation, it will decrease the sky view factor and block the pathway for the wind flows which will further fasten the formation of UHI. For prevention strategies, the designer and planner should give more thoughtful ideas for urban design in the development of cities to prevent UHI effect.

UHI intensity observation for seasonal and tropical climate showed that urban areas in tropical climate exhibit higher UHI intensity than seasonal climate. In seasonal country, it only experiences high temperature during summer; while, for the tropical climate, it exhibits higher air temperature and humid throughout the year where heat loss due to evaporation is hardly to happen if the relative humidity of the surrounding environment is lower at daytime (Beggs, 2002). The existence of UHI intensity critically contributes to higher thermal discomfort. As reported, the comfortable temperature for human is ranging from 22.5°C to 25.5°C (Yau, 2008) and the tolerance limit for highest temperature is from 35°C to 40°C (CCOHS, 2008). Since health impacts are highly associated with the thermal heat, regular exposure to the thermal environment will increase human discomfort level and increase the prevalence of heat illness if exposed to it continuously. According to the heat stroke cases reported in Malaysia, there were 17,909 stroke victims were admitted to government hospitals throughout the country and 3,245 of them were fatal and yet this figure is expected to exceed 25,000 every year by 2020 (Krishnamoorthy, 2007). In view to the facts, the mitigation and prevention strategies from all the parties must be proposed in order to reduce the effects from UHI phenomenon to preserve human thermal comfort and improve energy consumption (Huynh and Eckert, 2012).

The mitigation strategies to obtain thermal comfort as discussed can be categorized into urban greenery, urban building surface materials, urban geometry and orientation. Urban geometry and orientation can be the most effective and immediate strategies by restricting street canyon height to width ratios and designing orientation of buildings which will directly create natural ventilation and blockage of sunlight. Urban ventilation and shading effects directly affect human thermal comfort in outdoor spaces when compared to cool surface materials. Urban ventilation can immediately neutralize the thermal environment to the acceptable level through the wind flow within the street canyon; while the shading effects can reduce direct solar gain towards human. Suitable street canyon height to width ratios and orientation of buildings can provide an appropriate pathway for the wind flow as well as minimize the solar absorption created by the shading effects to obtain comfortable condition for thermal comfort. Apart from this, cool surface materials exhibit high solar reflectance and infrared emittance values resulting in lower surface temperature which may indirectly affect human thermal comfort by low heat emitting from the building surface. In summary, urban ventilation and shade from direct solar radiation have quicker outcome to provide a comfortable condition for human thermal comfort in outdoor spaces than cool surface materials.

In the current dominant research trend, UHI affects data: solar radiation, wind speed, relative humidity and ambient temperature were collected from the field tests and further analyzed to determine human thermal comfort. The direct method of exposing human body to direct sunlight or outdoor environment is discouraged due to the induction of death and health problem consequently. Therefore, in combination with these mitigation efforts, the development of thermal mannequin can be handy as a representative of human simulation model in the future study to investigate the occurrence of UHI and to evaluate thermal comfort in microclimate conditions (Cheong et al., 2006; Nilsson, 2007; Nilsson and Holmer, 2003). According to the past literature of thermal mannequin, it has been used for indoor and outdoor environment measurement with the goal of providing a better and more realistic simulation of the human body (Holmer, 2004). Thermal mannequin in operation can simulate human sweating and provide valuable information about evaporation heat exchange and capable of predicting human thermal response to hot and cold environments for it to be used in practical applications (Haslam, 1989; Holmer, 2004; Wang et al., 2009). Since the development of thermal mannequin is getting more and more attention, it is possible to include the combination of human factors such as physiological mechanism of thermoregulation by fabricating thermal mannequin, thermal sensation by questionnaire survey and meteorological data by quantitative field studies with the thermal comfort indexes like discomfort index, Physiological Equivalent Temperature (PET) and Predicted mean Vote (PMV) to precisely evaluate human thermal comfort in outdoor environment (Djongyang et al., 2010).

For future study, it is recommended to concentrate especially on the determination of anthropogenic heat sources and solar radiation in order to significantly reduce the UHI effects. Simulation is one of the alternatives to perform a parametric study to minimize the formation of UHI. A reliable design approach should be provided with massive research for preventing UHI formation. However, for developed cities, thermal mannequin is one of the direct methods to investigate the impacts and factors that contribute to the UHI effects. Suggested mitigation strategies should be applied to the developed cities once the factors and impacts are identified. By applying these actions, it will minimize the risk of health problem induced by UHI.

7. Conclusions

It can be concluded that UHI is mainly caused by direct solar radiation intensity, anthropogenic heat and then followed by the thermal behaviour of surface materials. This variable of factor covers the design and planning parameters which are complex but essential. As a result, the temperature increases due to UHI phenomenon has added effects on the thermal comfort and heat-related illness such as heat stroke which is a serious health outcome due to UHI effects.

Therefore, more research is needed to achieve sufficient mitigation benefits. Assessment of climate change risks and vulnerability is essential in order to inform and implement appropriate mitigation strategies. This is to ensure human quality of life by achieving thermal comfort level and to reduce the heat-related illness especially heat stroke which may cause increasing rate of mortality.

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