Exploring the Urban Heat Island (UHI) Effect in Port Louis, Mauritius

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Abstract

Although many methods for heat island study have been developed, there is little attempt to link the findings to actual and hypothetical scenarios of urban developments which would help to mitigate the UHI in cities. The aim of this paper is to analyze the UHI at two sites with similar geometries within Mauritius, with emphasis on the difference in ambient air temperature. The measurements of these parameters contributing to heat island formation over the urban areas of Port Louis and Plaisance were established from mathematical relationships between them. The mathematical models were then tabulated to show the temperature rise emanating from Urban Heat Island in Port Louis.

Keywords: Urban Heat Island, Port Louis, Urbanisation, Energy management

1. INTRODUCTION

Pursuing economic prosperity, cities around the world have been acting as focal points of government, production, trade, knowledge, innovation and rising productivity. Thus, urbanisation has been responding to accommodate not only the core of the economy but also the rising population increase. Driven by the concentration of investment and employment opportunities in urban areas, UNPD highlights that this developmental trend has various impacts on our urban fabric, namely: environmental contamination stemming from traffic congestion, the concentration of industry, and inadequate waste disposal systems (Undp, 2008). Urban Heat Island (UHI) is one of the most serious issue from the rise in temperature due to artificial land cover and anthropogenic heat (Y. Hirano and T. Fujita, 2012) and at this rate of urbanization and global population increase, the problem of UHI may become a more important issue than global warming because the rate of urban warming may be greater.

Urban areas generally have higher solar radiation absorption and a greater thermal capacity and conductivity because of being covered with buildings, roads and other impervious surfaces. Heat is stored during the day and released during night. Therefore, urban areas tend to experience a relatively higher temperature compared to the surrounding rural areas (Fig. 1). This thermal difference, in conjunction with waste heat release from urban houses, transportation and industry, contribute to the development of UHI (Q. Weng and S. Yang, 2004). Urban climatologists have long been interested in the differences in observed ambient air temperature between cities and their surrounding lower density rural regions (H. E. Landsberg, 1981, William D. Solecki et al., 2004). The UHI effect is not restricted to large metropolitan areas; in fact, it has been detected in cities with population less than 10,000 people (T. R. Karl et al., 1988).

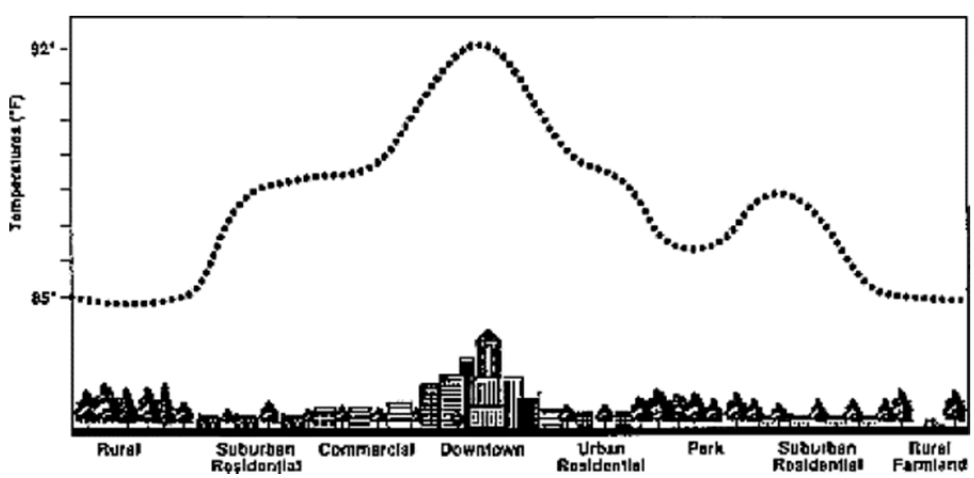

Fig. 1. A general urban heat island profile.

An UHI is a phenomenon of local temperature change, and its shape, location, and intensity vary depending on the time and season. Therefore, to save energy by UHI mitigation, it is crucial to select appropriate measures that are suitable for each area in relation to its spatial distribution (Y. Hirano and T. Fujita, 2012). On the Mauritian context, the capital city, Port Louis, currently accommodates 137,608 inhabitants over and area of 46.7km2. While having seen a massive development boost over the last century, there have been no documented works about the impacts of UHI on the local context. The global community states that the adverse effects of UHI includes the deterioration of living environment, elevation in ground-level ozone (A. H. Rosenfeld et al., 1998), increase in energy consumption by air conditioners (P. Droege, 2008, S. Konopacki and H. Akbari, 2002)and even increase in mortality rates (S. A. Changnon et al., 1996). It is very important to consider this facet as energy saving is intimately connected with countermeasures against global warming.

Against this backdrop, the objective of this paper is to study the relationship between temperature difference by using meteorological data from an urban and rural site in Mauritius. We produce recommendations to achieve energy savings during summer and also identify areas where further research is warranted in order to quantify the UHI phenomenon in Mauritius.

2. METHODOLOGY

National meteorological data was used to estimate the atmospheric Urban Heat Island Intensity in Port Louis and a rural site, as spatially diverse air temperatures are present in urban and rural areas (Nina Schwarz et al., 2012). Following a common method (D. O. Lee, 1992, P. I. Figuerola and N. A. Mazzeo, 1998, Y. Charabi and A. Bakhit, 2011, E. Vardoulakis et al., 2013), the UHI Intensity was achieved by comparing the recorded temperature yearlong between two sites;

$$\text{UHI: } \Delta T(u\text{-}r)$$

[where u is urban and r is rural]

The location of sites played a key role in determining the UHI. As the elevation of a site greatly impacts its temperature, it was important to consider areas of, or almost, the same elevation from sea level. Table 1 shows a list of available meteorological stations from which temperature data are recorded around the island of Mauritius (Meteomauritius, 2013) and their elevation from sea level (Googleearth, 2013).

Area	Type	Population	Elevation (feet)
Grand Baie	Rural	11,910	36
Port Louis	Urban	137,608	220
Vacoas	Urban	105,559	1319
Rose Hill	Urban	103,098	1012
Quatre Bornes	Urban	90,810	1005
Curepipe	Urban	84,967	1433
Rose Belle	rural	12,619	815
Flic en Flac	Rural	2,010	62
Flacq	Rural	140,294	432
Plaisance	Rural	15,753	206

Table 1. Areas in Mauritius with available meteorological data

As no stations were identified in forestry areas on the same elevation as Port Louis (Fig 2(a)), where no UHI would be observed, Plaisance (Fig 2(b)) was chosen as being the next best alternative scenario. This is further emphasized as both sites, Port Louis and Plaisance are geographically close to the shore and both subjected to cooling by water evaporation, a factor of which is known to affect ambient air temperature (E. D. Freitas et al., 2007, E. A. Hathway and S. Sharples, 2012).

Fig 2(a) Port Louis

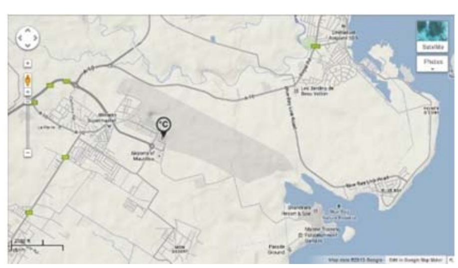

Fig 2(b) Plaisance

In the analysis of long-term trends, it is important that observation sites offer a continuous record and be subject to as little change as possible, either through relocation, or by changes in the immediate surroundings such as the encroachment of built-up areas. The use of single sites to represent the heterogeneous nature of the city climate is always subject to reservations, but the consistency of the record must be balanced against this (D. O. Lee, 1992).

In Port Louis the choice of such sites are rather limited, but data gathered from a personal weather station located at Latitude S 20° 10' 03" and Longitude E 57° 31' 10" was used to represent temperatures within the city. However, the meteorological station is not located into the city's Central Business District (CBD), which might hold the maximum UHII. As access to portable data sensors, to be installed closer to the CBD, were unavailable for this study, the real magnitude of the urban-rural temperature difference will be underestimated at this site. The station sits on an antenna fixed on the roof of a two storey building and thus corresponds with the World Meteorological Organisation's (WMO) specifications requiring a height of more than 1.5 metres. For Plaisance, temperature recordings are taken from the airport located in the region. The sensors are also in accordance with the WMO. Airports are known to be areas prone to having a higher UHII due to heat emanating from engines and its wide artificial land cover (L. A. Baker et al., 2002) but the area is prone to higher wind speeds than Port Louis. Research done by Vardoulakis (E. Vardoulakis et al., 2013) shows that high wind speed may reduce UHI or even tends to eliminate it. Thus it is assumed that the wind factor might compensate the UHII that may occur from the airport terminal.

The distribution of energy patterns in summer for Port Louis resulting from UHI was then studied in order to quantify the energy spent for powering mechanical cooling due to UHI.

3. FINDINGS

There is a well-identified diurnal cycle in the urban heat island, largely a reflection of differences between rates of cooling and heating for urban and rural

surfaces as they respond to the solar cycle. The magnitude of the UHI varies with season as well, in response to seasonal changes in the strength of isolation, state of atmosphere, surface characteristics and urban activities (B. Ackerman, 1985). The meteorological data for July 2012 till June 2013 was used for this study.
The data logger in Port Louis recorded data at irregular intervals which generated numerous records per hour which resulted in over 100,000 data fields. The data were then averaged and filtered in an hourly format for ease of comparison. On rare occasions where missing data were identified, those fields were replaced by the mean of the previous and subsequent values.

As predicted temperatures from the urban site were higher than the rural one. The data comparisons from both sites reveal a mean yearly UHI Intensity of 1.9°C ± 0.2°C in Port Louis. Mauritius has two seasons per year and collected processed data, represented by Fig 3, indicates that the monthly average value of $\Delta T(u\text{-}r)_{mean}$ seems to be higher in cool months with an intensity of 2.4°C ± 0.2°C and slightly lower in warm months with an mean intensity of 1.5°C± 0.3°C. The highest averaged monthly UHI observed was in August with a value of 3.4°C ± 0.2°C and the lowest was 1.3°C ± 0.3°C occurring in April. Cool months are defined as those from May through October, and warm months those from November through April.

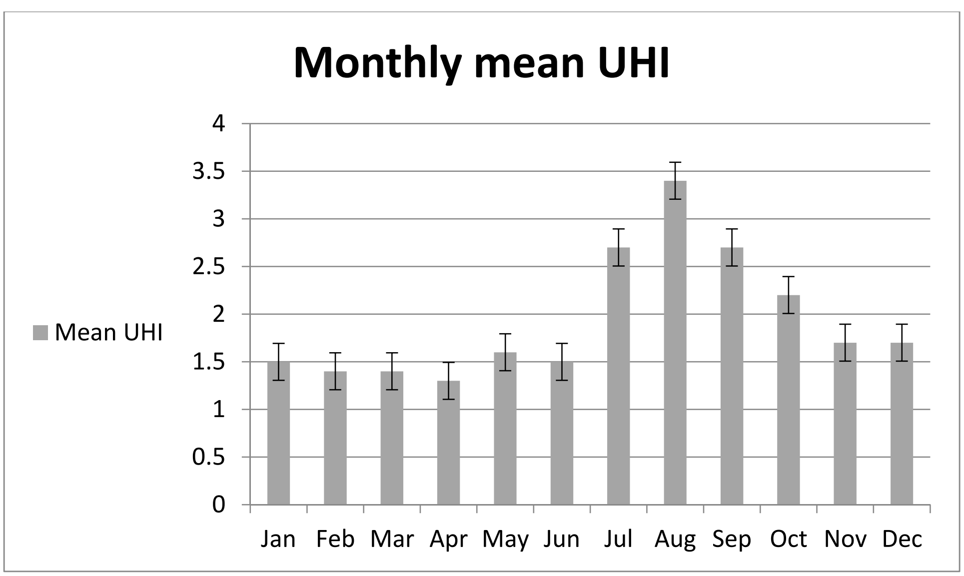

Fig 3. Monthly mean UHI trend.

Since the UHI observed could be from the ratio of the anthropogenic heat released resulting from solar radiation, one can infer that a part of the heat island is anthropogenic. In consideration of the research on the anthropogenic origin of the heat island, another periodic fluctuation was studied, namely the weekly variation of the urban heat island. The daily values of $\Delta T(u\text{-}r)_{\mathrm{mean}}$ from the dataset are grouped according to the weekdays. The amount of data under these conditions amounted to a full year and subsequently divided into only cool and warm month categories. Figure 4 shows the average values of $\Delta T(u\text{-}r)_{\mathrm{mean}}$ depending on the day of the week.

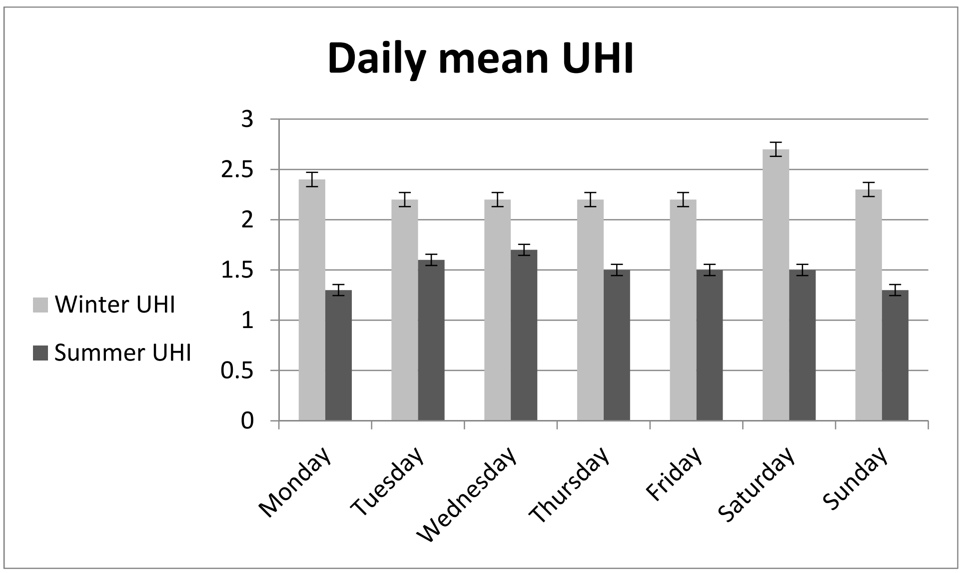

Fig 4. Daily mean UHI.

The observed trend, as shown in Fig 5, shows that the estimated differences resulting in a maximum UHI for a typical day, for both seasons, is mainly a nocturnal effect; occurring during the night to early morning, from midnight until sunrise. In comparison to this, the temperature difference during the day seems to be less pronounced. For daytime UHI, maximum values were recorded during peak hours from 06:00-09:00 and from 13:00-16:00. Compared with values from summer, UHI in winter seems to be highest at any given point.

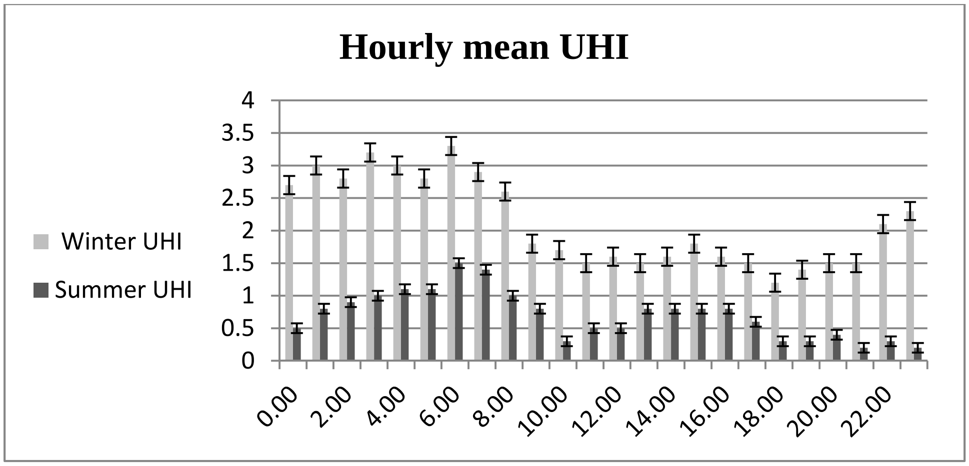

Fig 5. Hourly mean UHI for a day.

In cool months, the average $\Delta T(u\text{-}r)_{\text{mean}}$ diminished 0.7°C between Saturday and Sunday. This is understood because the UHI decreases when there is less vehicular and commercial activity. In warm months the same trend was observed but with slightly less difference. The weekly variation can be caused by the low activity all day Sunday and a weaker $\Delta T(u\text{-}r)_{\text{mean}}$ early on Monday morning compared to other mornings, especially in warm months. The highest UHI a single day was 5.8°C ± 0.1°C and was observed during Winter in the month of September where the difference between wind speeds at the two sites affected the values $\Delta T(u\text{-}r)_{\text{mean.}}$ The island is relatively small to travel from one point to another, therefore, vehicular transportation registered only in the city cannot be taken into consideration for evaluation of UHI. Port Louis accommodates nearly 300, 000 commuters every day, which represents nearly a quarter of the population of the island. At this point, there is a need for further research in order to understand the motives of travel and their relationship to the city. The fall in UHI for Thursdays are understandable as there is no commercial activity in the afternoon in Port Louis. As for the rise of UHI on Saturdays compared to Fridays, this can be linked to commercial activity and equestrianism. The country's centralized horse racing track is found in the city's core and certainly helps in increasing significantly the amount of transportation and activity in one particular spot. In order to study in more detail the effect of anthropogenic heat, the average hourly value of the heat island was compared for each weekday, using the data of the selected days, classified in cool and warm months. In this way, more than 30 values were obtained for each hour of each day.

The weekly variation in the heat island during the warm months is presented in Figure 6(a) and that of winter in Figure 6(b). A time gradient of difference in temperature changes more slowly around 09:00 to 23:00 for both seasons. During early hours between Friday and Sunday in winter, a rapid increase of the urban heat island occurred when compared to other days. This trend differs in summer where there seem to be a more smooth transition in temperatures to other days. Despite the fact that the differences in the isopleths are not important between Sunday and weekdays, it is possible to see an isopleth averaging 3.5°C ± 0.1°C in the first hours on Saturday and Sunday in winter which is higher than on the other days. Another trend is observed where UHI seems to be lower during sunset for both seasons. Friday to Sunday seems to record lowest UHI during that instance in warm months while the trend alternates in cool months where the lowest UHI values are observed on Thursdays.

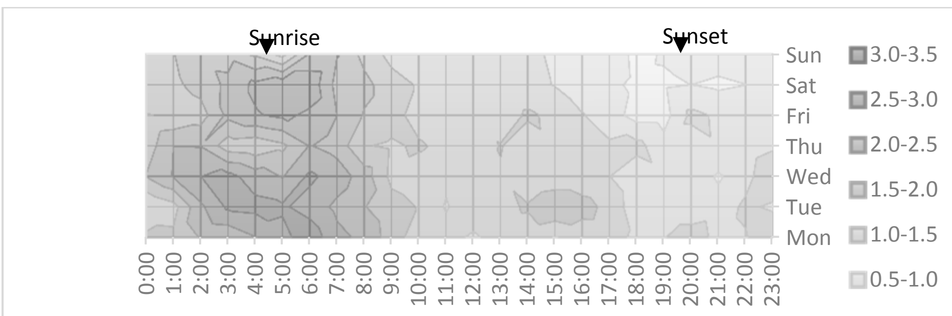

Fig 6(a) Summer UHI

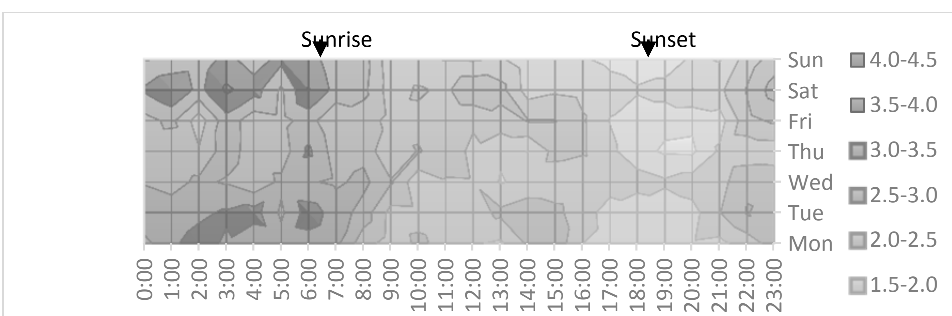

Fig 6(b) Winter UHI

The heat island behavior may be explained as resulted of two factors. The first mechanism, the anthropogenic heat production would be based on the fuel and electric consumption for human activities (heating, traffic, etc.) especially in winter. Building heating during the day and the hours after sunset is an important factor in the increase of the temperature in the city. Therefore, minor commercial and industrial activity on weekends would produce a smaller heating of the city and a smaller value of the heat island.

4. CONCLUSION

This study notes a UHI of 1.9°C per month in Port Louis, with the highest monthly average in August with a value of 3.4°C, and lowest in April with a value of 1.3°C. On an hourly basis, the highest value is observed from 06:00 t0 09:00 and from 13:00-16:00, and the highest UHI on a single day was observed at 5.8°C in winter. On a wider local perspective, we need to stress towards an energy management focused on art and science in order to achieve more with less energy (M. K. Elahee, 2011). Architecture and urbanism cannot complain of a logical deficiency as whether on a conceptual level or firmly grounded in reality, the built environment interferes with society and with our planet, thus contributing to the transformation of the world. Such transformation should be closely monitored and channeled (Z. Allam, 2012). As such, in times of fast urbanization and population increase, we need to properly align our resources and intelligence in both design and technology in order to create sustainable approaches towards planning the new African city.

5. RECOMMENDATIONS

Numerous studies have reported the successful applied measures on mitigating urban heat island effects whether being in economical or ecological facets. Those could broadly be categorized as: (1) related to reducing anthropogenic heat release (e.g. switching off of air conditioning); (2) Betterment in roofing designs (e.g. Green roofs, roof spray cooling, reflective roofs etc.); (3) other design factors (e.g. Humidification, increased albedo, photovoltaic canopies etc.) (A. M. Rizwan et al., 2008).

It seems that the planting and vegetation is the most widely applied mitigation measure which could achieve huge energy savings through temperature reduction of the area (Yukihiro Kikegawa et al., 2006, Y. Ashie et al., 1999). It was reported in a study conducted by (R. A. Spronken-Smith et al., 2000)that parks could help control temperatures through an evaporation of more than 300% as compared to its surrounding. The mitigating measures, however, are not limited to planting and vegetation only but also covers other design aspects with diversifying benefits. An example is the study conducted by (M. Kolokotroni et al., 2006) who estimated that an optimized office building in an urban area could reduce 10% cooling energy demand through proper ventilation. (A. Urano et al., 1999) reported that anthropogenic heat release has greater potential for modifying the day time thermal environment and wider buildings are better than small tall pencil buildings. Furthermore, it has been also been found that the urban configuration on the whole is one of the primary factors affecting temperature variation in the city (D. Taleb and B. Abu-Hijleh, 2013). However UHI mitigation strategies does not limit to urban scale as the works of Taha (H. Taha et al., 1999) emphasizes the choice of materials with a low solar reflective index as he reports that low values of surface-albedo could achieve temperature reductions and peak electric energy savings. As UHI also impacts the comfort level of pedestrians and reduces ozone formation (H. Huang et al., 2005 & Arthur H. Rosenfelda et al., 1998), It is important to address this issue from a cross disciplinary perspective and engage into further contextual research to address the matter on a local level.

6. FURTHER RESEARCH

This paper served as a first and foremost evaluation of the atmospheric UHI phenomenon on the capital city of Mauritius. As the contribution of urban-induced warming relative to mid- and end-of-century climate change illustrates strong dependence on built environment expansion scenarios and emissions pathways (M. Georgescu et al., 2013), it is imperative that a developing nation, portraying itself as a leader of the African world, undertakes further research on urban heat island for a better urban design that would align towards sustainable development practices. In order to quantify UHI on a microcosmic level, it is essential to conduct further investigation on various parameters such as spatial developmental patterns and trends, statistical analysis, wind patterns, thermal imagery & ground surface temperature and heat absorbance & reflectance of materials. Furthermore it will be essential to quantify the energy consumption due to UHI in the cities in Mauritius. Due to the consequences of UHI on the energy consumption and human discomfort due to temperature rise, indulging in those research areas would be primordial in order to devise detailed mitigation strategies for UHI on the local context to achieve both energy savings and societal benefits. In this respect, funding allocation is highly recommended for this topic.

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