Evaluation of the effect of urbanization on urban thermal behaviour using urban heat island indicators: the case of the CBD of Accra.

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"Evaluation of the effect of urbanization on urban thermal behaviour using Urban Heat Island indicators – The case of the CBD of Accra"

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ABSTRACT

Various studies have shown that urban heat island (UHI) can significantly affect the local climate of the built environment. Extreme air temperatures and heat waves adversely affect people's health, their overall well-being and productivity. Tropical urban sites are constantly under the threats of the harsh urban heat island (UHI) effects – a situation which is aggravated by climate change. Several urban morphological factors can potentially modify urban climate and, consequently, the potential energy demand and supply in cities.

Since independence, Ghana has experienced a significant rise in population growth, which has culminated in the urbanisation of many of its towns. The rapid growth of Accra is attributed to rural-urban migration, natural population increase, booming economic activities, political factors among others. The influx of people into the urban areas has led to a high demand for more housing, commercial and other infrastructural developments. For Accra however, this drive has resulted in a sharp reduction in urban greenery.

Despite the obviously warm-humid climate that is prevalent in Ghana, no UHI study had previously been carried out in the country. Due to its compactness, the central business district (CBD) of Accra was chosen for the study. Through the quantification of UHI, this study aims at evaluating the effect of urbanization on the urban thermal behaviour in the CBD of Accra, with the view to developing suitable proposals that can influence current and future strategic urban design decisions meant to mitigate the negative impacts of UHI in the city.

This study employs an explanatory mixed-methods research approach. By ascertaining the presence of UHI in the city through a pilot study, the proposed research method is further improved. The quantitative study involves the collection of weather data from selected monitoring points in the city's CBD. To gain an in-depth understanding of the underlying causes of the morphological transformation the city has undergone, face-to-face semi-structured interviews with some experienced Ghanaian built environment professionals are carried out. Using a clear temperature-morphology mapping, UHI intensity dynamics within identified local climate zones are analysed. The quantitative and qualitative data sets are analysed separately and sequentially and later triangulated.

This study has shown that areas in the CBD of Accra that have large expanses of hardscapes and significantly reduced greeneries have been experiencing high UHI intensities. It is also evident that areas within deep canyons experience lower daytime temperatures compared to areas within shallow canyons; for night-time temperatures however, the opposite is the case. Upon analysing the qualitative data, other major causes of the morphological transformations that have emerged include poor enforcement of development control, non-adherence to building regulations; inadequacies in the existing building regulations; architects and building designers lacking the motivation for sustainable design etc. To adequately address the identified challenges and cushion the adverse effects of urban heat in the study area, this research ultimately recommends a holistic strategic plan that encompasses suitable environmental cooling measures and policy interventions.

Keywords: UHI, LCZ, CLUHI, central business district, building energy, climate data

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Dedication

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Researcher's publications

1. GYASI-ADDO, J. A. and BENNADJI, A. (2020). A Procedure for Assessing UHI Intensity in the Central Business District of Accra. *Journal of Scientific Research and Reports, 26(5)*, 42-61

2. GYASI-ADDO, J.A. and BENNADJI, A. 2020. Investigating the major causes of morphological transformations in the CBD of Accra and the impact on urban heat island intensity. In Scott, L. and Neilson, C.J. (eds.) *Proceedings of the 36th Association of Researchers in Construction Management (ARCOM) annual conference 2020 (ARCOM 2020),* 7-8 September 2020, [virtual conference]. Leeds: ARCOM [online], pages 566-575.

3. GYASI-ADDO, J.A. and BENNADJI, A. (2018). Working paper: Impact of urban heat island on energy efficiency of glazed multi storey office buildings in Accra*.* *Proceedings of the 34th Association of Researchers in Construction Management (ARCOM) annual conference 2020 (ARCOM 2020),* 3-5 September 2018, BELFAST.

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INTRODUCTION TO RESEARCH

1.1 Introduction

The introduction to this research study is provided by this chapter. The chapter first presents a background to the study. It then sheds light on the urban heat island phenomenon. The chapter further explains the problem statement, rationale for the study with reference to the context, aim and objectives, evidence of originality of the research, impact of the research and the research process. Subsequently, the research process and the structure of the thesis are all presented in this chapter.

1.2 Background

Over the years, urban heat island (UHI) has become a subject of importance to many cities. Extreme temperatures and heat waves have severe impacts which affect people’s health, their overall well-being and productivity (Hajat et al. 2010, Zander et al. 2018). It has been established that increasing temperature results in heat build-up which causes thermal discomfort for users of both indoor and outdoor environments (Zander et al. 2018, Xiofang et al. 2012). Furthermore, energy demand resulting from high dependence on air condition or artificial ventilation in buildings in hot environments is significantly increased. The existence of UHI in cities compounds the problems, for which reason better planning becomes very necessary.

Several researchers have indicated that extensive use of manmade materials could be the main cause (Fujita and Hirano 2012, US EPA 2015a). Urbanization has resulted in population growth in cities. Urban population growth is related to increased built-up areas and reduction in vegetation or greenery (Jusuf et al. 2007, Rajagopalan et al. 2014). Rural-urban migration brings about increased population in urban areas. As more people move to settle in the urban areas to seek employment, there is always a growing need for the development of more residential buildings, commercial buildings, and other infrastructure. Unfortunately, such physical developments, in most cases, take up much of the urban green space. Furthermore, climate change with its attendant general increase in average temperatures makes the UHI phenomenon a critical issue for the urban setting.

In view of the several adverse environmental effects of UHI, the phenomenon is deemed very important, as far as city or urban planning issues are concerned (Fujita and Hirano). Various researchers have shown that UHI affects the urban environment considerably, and therefore has the tendency to affect energy use in buildings (Fujita and Hirano 2012, Ichinose et al. 2008, Rizwan et al. 2008).

It has been estimated that by 2030, more than 61% of the world's population could become urban dwellers (Fujita and Hirano 2012). According to Berger et al. (2014), high occupancy levels in office and commercial buildings result in substantially high building energy consumption. Straube (2006) projects that over a third of global energy is used by the building industry. In warm climates, the cooling loads of large buildings are generally high.

With the country's population becoming urbanized at a fast pace, the urban areas in Ghana have become dotted with settlements with 5000 or more people (Osei et al. 2015). In the last few decades, Accra has been expanding rapidly. Despite this pace of urbanization, little or no due consideration has been given to the preservation of green spaces. It is worthy of mention that, planning control in the city might not have been as stringent as it probably ought to have been. It is thought that this situation has arisen because of weaknesses in the city's planning control regime. Ahmed and Dinye (2011) have attributed the situation to lack of enforcement of development regulations. It is important to note that, the rising cost of land in Accra has contributed to the quest for the development of large or high-density buildings in the metropolis. According to Simmons et al. (2014) and Koranteng et al. (2016), occupants of most office buildings in the urban areas in Ghana depend on artificial ventilation systems for the most part of the year, due to the warm climate that prevails. The country has over the last couple of years been grappling with interrupted power supply, and for this reason, investigating UHI which has an impact on cooling load or building energy performance becomes not only important, but very necessary.

It must be emphasized that most Ghanaians associate other local problems such as deforestation, severe drought, pollution, and flooding to changes they are experiencing, but many people do not have a clear understanding of climate change concepts (BBC WST 2010). Although Government, opinion leaders and experts are aware of the severe impacts of climate change, the issue has not yet been prioritised. Given the fast-growing population of Accra and the associated high cost of cooling loads, and the concern for vulnerable groups such as the urban poor, this study is of immense importance, as seeks to obtain empirical data on the UHI intensity dynamics present in Accra with which effective mitigation measures and strategies could be developed. To ensure effective long-term planning, and to help urban dwellers cope with heat, it is extremely important to understand the need for cities to be redesigned for people to easily adapt to increased heat (Hajat et al. 2010).

The study assesses the UHI in the central business district (CBD) of Accra with due consideration to its unique built-up characteristics and various causal factors. Findings from this study will ultimately be utilised to develop mitigation measures and planning strategies with which the heat in the city could be ameliorated. To manage the study, the UHI measurement has focussed on the central part of the city.

The study area is classified into zones based on their built-up types, and against the backdrop of the measurement procedures, suitable measurement approaches are considered. An analysis of the city’s long-term climate data and morphological transformations is done to ascertain the correlations between them. The UHI intensities obtained for the various monitoring points are also analysed within the context of their built-up types or characteristics.

To develop effective and sustainable UHI mitigation strategy for the city, the study further investigated various human factors that are believed to have contributed to the UHI formation.

1.3 Problem statement

The UHI phenomenon is known to be caused by the differences in air temperature measurements between cities or urban areas and those observed over the surrounding areas. There is barely any documentation on the quantification of UHI in the context of a tropical African country like Ghana, where its effect is perceived to be intense. Rapid urbanization of Accra and threats of global warming could escalate the adverse effect of UHI on the thermal behaviour of massive civic/commercial developments that have been springing up particularly in the last few decades. The issue of erratic power supply that has bedevilled Ghana over the past few years aggravates the problem.

Among the possible causes of UHI in the city are vegetative depletion, non-adherence to building regulations by developers, poor development control regime, lack of public awareness of benefits of green spaces, the presence of heavy vehicular traffic among others. Since the city has such challenges with its built environment, developing effective and sustainable UHI mitigation measures would require a holistic approach, instead of relying solely on quantitative assessments. A recent study by Addae and Oppelt (2019) has revealed that through human activities, the depletion of vegetation in Accra has been alarming in the last few decades.

Against this backdrop, Accra tends to present a peculiar scenario, that would require a holistic approach to identifying effective and sustainable strategies or measures that could mitigate its heat island.

1.4 Justification of the research

The urban planning process takes place in a multi-actor environment; it involves collaboration between urban designers, architects, residents, developers, professionals from various fields and other bodies or institutions. All these participants contribute to the planning process in various ways (Müller et al. 2005). In most cases, these actors use different 'language' due to their varying objectives. Processing useful results for easy interpretation from UHI studies, most of which are scientific, has often been challenging, and (Kleerekoper 2012) therefore suggests that there should be guidelines for design, basic principles, policies and examples of good practice to enhance the urban planning process.

The outcome of the study could enhance the development of remedial building design and planning strategies with which the effects of UHI in Accra could be ameliorated.

1.5 Research Aim and Objectives

The overarching aim of this study is to quantify the urban heat island (UHI) intensity in Accra with the view to developing appropriate mitigation and planning strategies to cushion the adverse effects of the urban heat.

To achieve the above aim, the following objectives are considered:

- To understand the historical developments in the urbanization of Accra and ascertain its effect on the local climate

- To explore and identify methods and procedures suitable for quantifying UHI at the city scale
- To understand the urban heat island intensity dynamics in the CBD of Accra through quantification and analysis of weather data
- To investigate and identify the main human factors that have contributed to the UHI build-up in Accra
- To identify suitable mitigation measures and planning strategies with which the effects of UHI in the CBD of Accra could be effectively cushioned

1.6 Evidence of originality

Fujita and Hirano (2012) have indicated that, impact evaluations of UHIs have been conducted in several cities however, the number of studies is still insufficient. Given that UHI is a phenomenon directly associated with local climatic change, geography, and manmade structures, conducting similar studies to assess UHIs in several other countries and cities or urban areas around the world would be of immense importance. Oke's (1984) attribution of weaknesses and research gap to the complexity of urban systems is a clear indication that location specific studies are needed to effectively mitigate the effect of UHI. The novelty in this study stems from the fact that no UHI studies have been conducted in the study area. Furthermore, there has not been any empirical study to quantify the UHI at city scale in Ghana.

1.7 Research impact

The research will help in the development of novel and suitable mitigation measures and strategies, the implementation of which could adequately cushion the effects of urban heat in Accra. Ghanaian planners, architects and policy makers will benefit from the research since it will deal specifically with a local scenario. The outcome of this research will be of immense benefit to inhabitants of the host city, planning authorities in other cities in the country, and the academic community in general. Findings from this study will also contribute positively towards global efforts to ameliorate the detrimental effects of climate change.

1.8 Research process

Considering the aim of the study, the pragmatic research stance was deemed appropriate, as it allows for the flexible use of different research methods. To achieve the aim of the study, the explanatory mixed-methods research approach was used. Dudovskiy (2018) posits that in explanatory mixed-methods research, quantitative data are first collected, while qualitative data collection is done to further explain the results of the quantitative study. It was important to first assess the urban heat island in the city. This was done by collecting weather data through field measurements and assessing the urban heat island intensity dynamics using temperature-morphology mapping. The second aspect of the study had to focus on how the city's morphological transformation has contributed to its thermal behaviour. Drawing from Oke (1984), Unger et al. (2001), and Rizwan et al. (2008b), the second aspect deals with the human factors. This was achieved through a qualitative study which involved semi-structured interviews with built environment professionals who were purposively sampled. Findings from the interviews helped the researcher gain an in-depth understanding of various critical morphological issues that need to be addressed to effectively ameliorate the thermal behaviour of the city.

Weather data from both traverse and stationary measurements were used for the analysis. Data from a two-day mobile traverse enabled the researcher to ascertain and understand the correlations between the various urban heat island intensity profiles of the different monitoring locations and their respective morphological characteristics and other possible anthropogenic factors in the different local climate zones (LCZs) in the study area. The stationary data were collected at selected spots and for at least 2 days. This made it possible to understand the urban heat island intensity pattern during both day and night.

The quantitative and qualitative data sets were analysed separately. As the researcher had gained more insights into the urban heat island profile and the main factors that account for the high temperatures in the city, a triangulation between the 2 different data sets was done.

1.9 Limitations to research scope

The research focused on a section of the CBD of Accra as the study area, due to the limited number of instruments which were available to the researcher.
Considering the poor traffic situation in certain parts of the study area such as Makola and the Tudu commercial area during the day, it was extremely difficult to record weather elements in such areas.

To enhance the level of accuracy and capture the weather data at different sites simultaneously, the researcher had to engage field assistants to conduct the mobile traverse by trekking, that is walking through urban paths. Though this approach was helpful, the extent of coverage was limited by the laborious nature of the procedure.

It was not possible to capture weather data at 3 sites during the cool-wet period, as the sensors installed there were either stolen or had become defective at the end of the campaign.

1.10 Structure of thesis

This structure of the thesis is described in this section. The thesis is composed of 8 chapters. The introduction to the research is covered in chapter 1. The background to the study, and the thesis outline are presented in this chapter.

The contextual literature is covered in chapter 2. The chapter gives background information about the study area. It briefly describes the geography of Accra and provides information on its demography, land use, historical information on the urbanization and climate of the city.

Chapter 3 deals with the main literature of the study. The chapter examines the important theoretical issues that relate to the study. It thus looks at literature on the urban heat island phenomenon to examine various causal factors. The chapter also investigates various types of urban heat island and the procedures used. The literature review allows the researcher to unearth the main research gap(s) that are particularly relevant for this study.

Chapter 4 describes the methodology used for the research. It first discusses various research philosophical viewpoints and then explains the philosophical stance that underpins this research. The data collection methods used and the rationales behind their selection are discussed. The chapter also discusses the techniques used in analysing the various sets of research data.

The quantification of urban heat island in the study is presented in chapter 5. The chapter explains the field measurement methods used in assessing the urban heat island within the canopy layer in the CBD of Accra. It also presents both daytime and night-time urban heat island profiles for dry and wet seasons, based on weather data obtained from the different local climate zones identified in the study area.

The urban heat island data presented in chapter 5 are analysed in detail in chapter 6. The chapter analyses how various morphological and climatic parameters affect the UHI profile of the study area.

Chapter 7 presents findings from the qualitative study. These data were collected through interviews. In this chapter, responses from the interviews are analysed.

Chapter 8 discusses the main results of the research. It also discusses the triangulation of findings from the quantitative and qualitative studies. The conclusions and recommendations from the study are presented in the 8th and final chapter.

The structure of this thesis is summarized in the chart in figure 1.

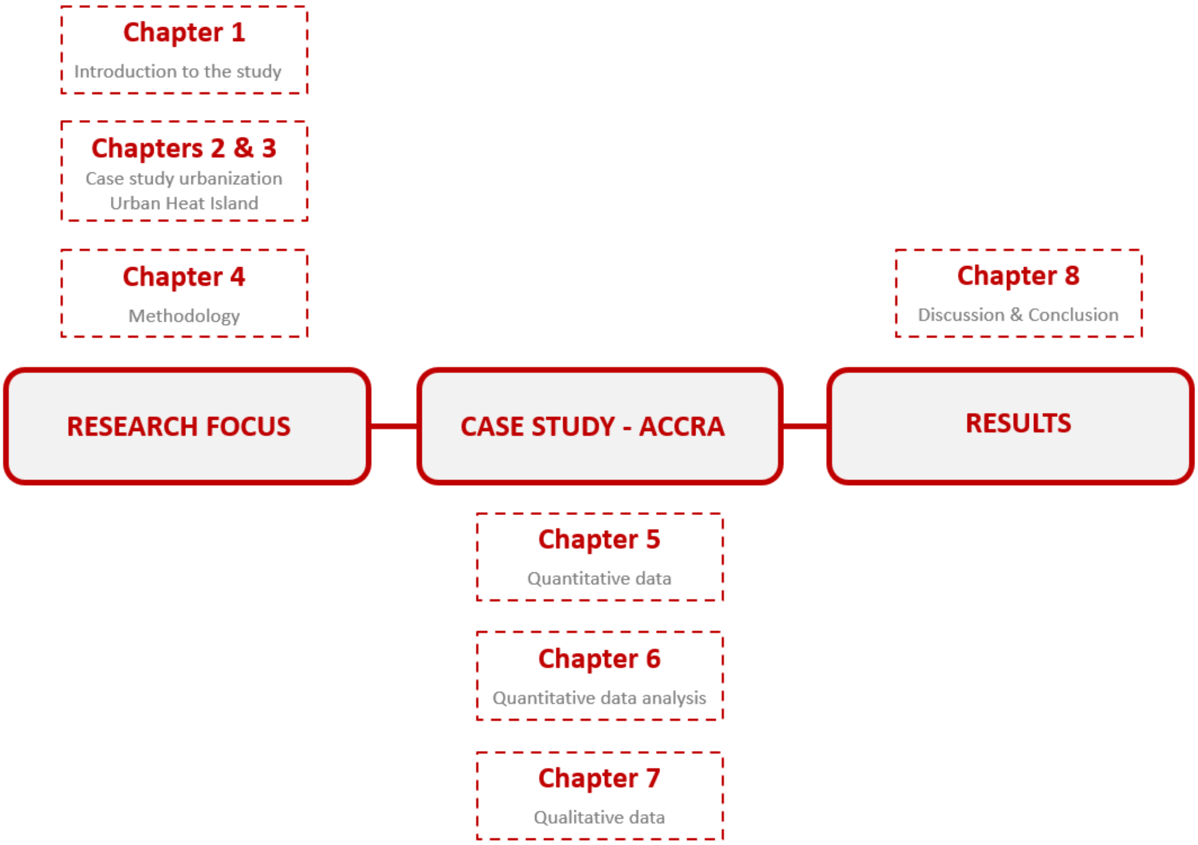

Fig 1 Structure of the thesis (Author generated)

1.11 Summary

Chapter one has presented the introduction and the context for this research. It has set the stage for the research by shedding light on the UHI phenomenon and the need to investigate it in Accra. The chapter has also explained the aim, objectives, evidence of originality and impact of the research. Finally, this chapter has presented the research process and the structure of the thesis.

As indicated in the thesis structure, the next chapter looks at the context of the study, with emphasis on the geography, demography, and historical developments in the urbanization of Accra.

Chapter 2

CONTEXT AND DEVELOPMENTS IN THE URBANIZATION OF ACCRA

2.1 Introduction

This chapter gives insights into the geography and other major issues that relate to the context of this study. The chapter begins by providing an overview of the geography of the study area. The demography, land use issues, and historical developments in the urbanization of Accra are then presented. The chapter then continues by discussing major urban planning bottlenecks the city has been facing over the years. In the last two sections of the chapter, changes in the land use pattern and the trend of the weather of Accra, based on historical data, are presented.

2.2 Study area

The study area is Accra, which is the capital city of Ghana. Ghana is in West Africa and has a population of 25 million (GSS 2014). It is located between latitudes 4.5° and 11.5° north, and between longitudes 3.5° west and 1.3° east. Ghana has a total land size of 239,460 km² and 8,520 km² of water. The country has large water bodies including the Lakes Bosomtwe and Volta, which cover an area of 3,275m². Other lakes that flood seasonally occupy another 23,350km² (EPA & UNFCCC 2011). The country shares boundaries with La Cote D'Ivoire, The Republic of Togo and Burkina Faso on the west, east and north respectively. Administratively, the country is divided into 16 regions and 260 districts. The main climatic seasons in Ghana are wet and dry. For most parts of the country, the annual temperatures are usually above 24 °C (GEPA 2001). There are two rainy seasons: from March to July and from September to October. The southern parts of the country experience the highest rainfall, with areas in the west coast receiving more than about 1940 mm each year, whilst the drier north receives a maximum of about 1230mm annually (GMA 2016). Ghana is well endowed with natural resources including gold, bauxite, diamond, timber, and cocoa, which are the country's major sources of foreign exchange. On the other hand, the country's domestic economy is mainly dependent on agriculture, which accounts for 34% of its GDP, employing about 60% of the workforce. The country has roughly twice the per capita output of the poorest countries in West Africa (EPA & UNFCCC 2011).

The location map of the study area is shown in figure 2. Accra is the political and economic capital of Ghana and at the same time, the regional capital of the Greater Accra Region. The city is on the Gulf of Guinea at latitude 5.626°N and longitude 0.1014°W (Appeaning-Addo et al. 2008). Accra covers a total land area of 139.674 km^2 (GSS 2014).

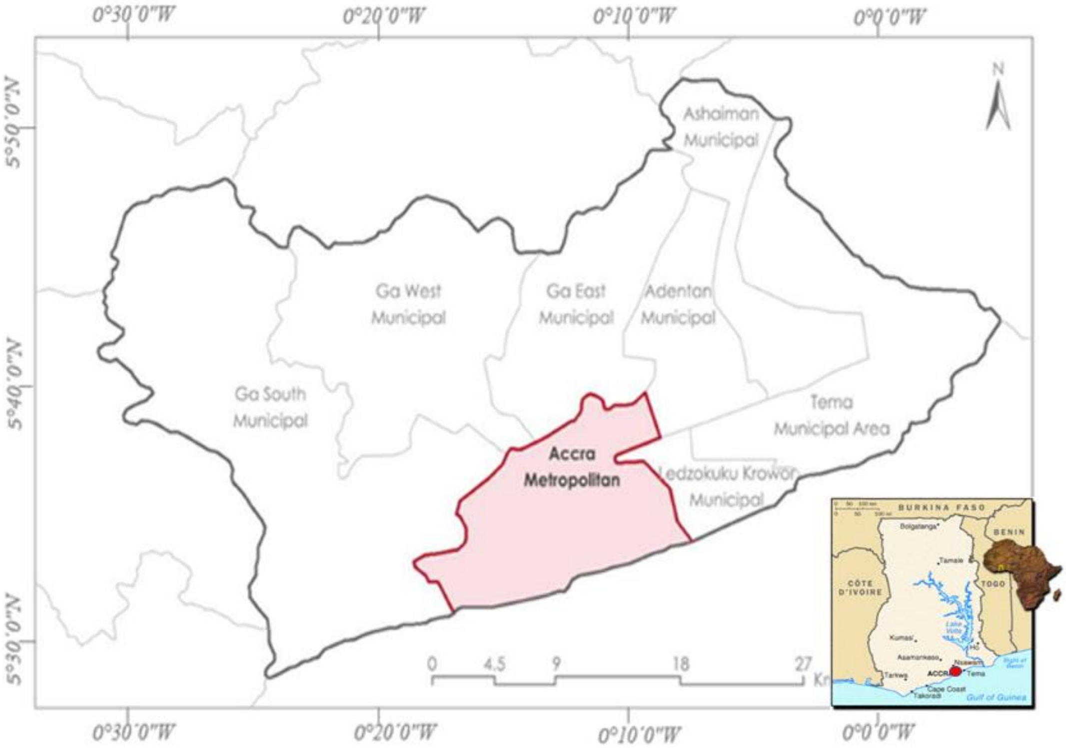

Fig 2 Map of Greater Accra Metropolitan Area showing the study area

Modified after Owusu (2013)

The geology of the city is composed of various types of hard and soft rocks, such as granite, quartz, gneiss, schist, sandstone, and shales. Due to variations in the underlying rocks, there are different types of soil in the city and these include sand, clay, humus, and silt. The organic content of the soils is generally low, which limits their productivity. This notwithstanding, it is possible to grow vegetables such as cabbages, watermelons, garden eggs, and tomatoes on the soils in the Accra area. Generally, the topography of the city is flat – with the terrain of most areas being less than 35m above sea level. The flat nature of the land, however, provides a good setting for settlement development (Bokpin et al. 2020).

There are 3 main vegetation zones in the Accra area, and these are shrub land, grassland, and coastal lands. The trees in the shrub land are mostly small and are about 5 metres tall. The grasses are short and are usually less than a metre tall. The coastal lands as described by GSS (2013), have different species which include mangroves that are mainly found in the tidal zones of estuaries, and lagoons and salt tolerant grasses found in low-lying areas of lagoons. It is worth indicating that the original vegetation in Accra has been altered by human activities. While a significant proportion of the natural vegetation in the city has been taken over by development of settlements and various infrastructure, a few greenbelts have been reserved (Bokpin et al. 2020).

Accra is in the dry equatorial climatic zone, which is characterized by two rainy seasons. The major rainy season is from April to June, while the minor rainfall period usually starts in September and ends in November. Like the rest of the country, the months between November and April are generally dry. The annual total rainfall average of the Accra area is 800mm, (Ofori-Sarpong and Annor 2001). According to Dickson and Benneh (2001), Accra records a yearly average temperature of 26.8°C. Mean monthly temperature figures for the city fall between 22°C and 32°C, with February usually being the warmest month (GMA 2016). On the average, relative humidity of the city throughout the year is about 80% (Apaa-Dankyi et al. 2012). It has been projected that the mean annual temperature of the country could increase by 0.6°C, 2.0°C and 3.9°C by the years 2020, 2050 and 2080 respectively, whilst for the same periods, the mean annual rainfall is expected to decrease by 2.8%, 10.9% and 18.6% (Antwi-Agyei 2012).

Accra is a cosmopolitan city, with a very diverse population. It could therefore be described as the melting pot of many Ghanaians and people of other foreign cultures. The population of Accra "increased from 600,000 in 1970 to 1 million in

1984 and 1.7 million in 2000" (Dionisio et al. 2010). Grant (2009) has indicated that "unlike other cities in Ghana where there are strict controls to limit uncontrolled sprawl, Accra has been expanding, thereby pushing its urban boundaries much further away from the original urban core." Experts projected Accra's population in 2007 to be 1,970,400, which was an appreciable increase of 311,463 since the 2000 census (Grant 2009).

The liberalization program introduced in Ghana in the 1990s resulted in an increase in the number of multinational establishments in Accra (Grant 2001, p. 1005). Land acquisition for development in the CBD of Accra has been highly competitive among foreign and local developers, as the city's available land has become overstretched (Grant and Yankson 2003). This has contributed to the high cost of land for infrastructural development in the CBD of Accra.

2.3 Demography and land use

The Greater Accra Region is one of the regions with very high population densities in Ghana with a population of 4.6 million as of 2016 and an estimated yearly population growth rate of 3.5% between 2000 and 2010 (Addae and Oppelt 2019). The region's population is projected to be 10.5 million by 2040 (GSS 2012). The city of Accra has an estimated population of 3 million (Rain et al. 2011). The Accra Metropolis, which covers central part of the city has a population of about 1.7 million (Owusu 2013).

Accra was originally built around a port. Its architecture ranges from large and elegant 19th Century colonial buildings to skyscrapers and apartment blocks made of concrete, glass, and steel (www.ghanaweb.com). The central and eastern parts of the CBD are characterized by formal buildings, dotted with civic and mixed-use (mainly civic-commercial) developments with a considerable number of glazed multi-storey buildings defining its skyline. Most of the newly built multi-storey edifices which many Ghanaians have regarded pleasant and modern, have been described as "glass boxes" by critics, due to the extensive use of glazing systems (Koranteng et al. 2016). In the west are extremely busy commercial areas with a major market, street shops and street vending points, though the latter have been officially outlawed. There are a few residential buildings in the CBD, most of which are official. In the country, 80% of employment is informal (Baah-Boateng and Ewusi 2013). Due to the large demand on services and infrastructure in the Accra metropolis, coupled with its resident population, the city attracts an estimated daytime population of 3.5 million and above (Owusu 2008). Unable to provide adequate formal housing and employment for its permanent resident population and migrants, informality has become the order of the day for Accra (Aba and Owusu 2018). There are hundreds of vulnerable people, most of whom are migrants who cannot afford decent accommodation and thus live and work along the major streets in the CBD, as well as other street vendors who commute from elsewhere.

2.4 Historical developments & the urbanisation of Accra

Accra developed from a series of small fishing villages and European forts into a major urban centre. It grew into a town when the British made it their colonial headquarters, having removed it from Cape Coast in 1877, following the departure of the Danes and the Dutch in 1850 and 1872 respectively (Engstrom 2013, Gillespie 2018). As Grant (2009) indicates, the British developed the city around the central business district, which was separated from the 'Native Town' by an open space. Since its early history, Accra has grown rapidly and in tandem with national and regional political-economic trends. The cocoa trade in the 19th century is believed to have resulted in wealth creation, which affected patterns of commercial land use within the city and the emerging urban system (Brand 1972a).

According to Grant & Yankson (2003), years after the country had gained independence from colonial rule in 1957, the Ridge, Airport Residential Area and Cantonment neighbourhoods (which were previously inhabited by the Europeans) are still characterised by green and well-maintained landscapes, unlike the peripheral neighbourhoods and indigenous settlements such as Teshie and Chorkor, which have seen little urban planning. Although there is a fairly good number of surviving examples of colonial buildings, by and large, the CBD has been dominated by developments that have modern or contemporary Western character (Brand 1972a).

According to Songsore (2003), following the fall of the Western Sudan trade routes, a string of coastal towns including Accra, developed to handle the new trading activities that took place between West Africa and the Europeans across the Atlantic Ocean. Accra, being one of the major coastal towns at the heart of the booming trading activities, experienced a new urban system. The urban development that was rolled out by the colonial masters in the 19th century created a social stratification and spatial segregation system that culminated in dramatic housing inequalities (Grant 2009, UN-Habitat 2010, Gillespie 2018). In effect, the colonial administrators and the Europeans inhabited the well-planned low-density areas which were properly planned with provision for good sanitation, recreation, and various spatial needs. Strict adherence to regulatory building standards were ensured and therefore, only buildings built of stone, concrete, brick, and metal roofing were permitted (GSS 2014). Due to the prevailing hot weather in Accra and Ghana in general, these well-planned low-density areas were made to have substantial greenery to make them cool and serene. Unfortunately, not much effort was made to accommodate the indigenous population in similar settlements. The indigenous population lived in unplanned areas with poor sanitation – areas described by Grant and Yankson (2003) as "mass thatched buildings arranged in a haphazard manner and separated by crooked streets. Over the years, the indigenous migrants from the rural areas also settled in the fringes or the peri-urban areas such as Nima and Accra New Town. Due to spatial segregation policies by the colonial rulers, these areas fell outside the officially planned jurisdiction of Accra and as a result were unregulated. With time, these areas developed as squatter settlements which have been difficult to regulate.

2.4.1 Urban planning in Ghana and the major bottlenecks

A plethora of planning and urban management laws have been in place in the post-independence era. The absence of clearly defined policy direction on urban development has been the bane of the myriad challenges that have confronted urban governance in post-colonial Ghana. The situation has been worsened by poor institutional coordination by key government institutions such as the ministries, the metropolitan, municipal and district assemblies, coupled with the lack of enforcement planning regulations and laws. Consequently, Accra, just like several other towns and cities in Ghana, has experienced haphazard and unplanned developments, with certain precincts being fragmented (GSS 2014).

2.4.2 Natural Increase

Natural population increase has undoubtedly accounted for the fast-urban growth Accra has experienced. The interplay between births and deaths determines the rate at which the population of any geographical area grows naturally such that, where births far exceed deaths, the population grows rapidly and in no time, may exceed the threshold population for an urban area (GSS 2014). As it has been difficult to provide official residential accommodation and commercial spaces for the large number of poor in-migrants, several illegal structures such as squatter settlements, have emerged as interstices within certain parts of the city, thereby reducing green and open spaces.

2.4.3 Changes in land use pattern of Accra

A study by Addae and Oppelt (2019) on land use pattern in the Accra area has revealed that built-up areas have been expanding at an alarming rate, taking over most of the city's open and green spaces. Through the study, it was discovered that the vegetative cover (grassland and forest) depleted substantially between 1991 and 2015. As shown in figure 3, grassland which used to be the most dominant land cover type changed from 50.5% in 1991 through 54.8% in 2000 and reduced to 46% in 2015. The same period saw the forest cover changing from 34.2% through 21.5%, before reducing drastically to 6%. It is evident from the figure that built-up areas virtually doubled in coverage from 11.8% to 20.6%

between 1991 and 2000 and again from 20.6% to 44.4% between 2000 and 2015. The study further revealed that 733 ha (i.e. 0.5% of the land cover) of the bare land transformed into built-up spaces. The water bodies did not experience any significant change within the period.

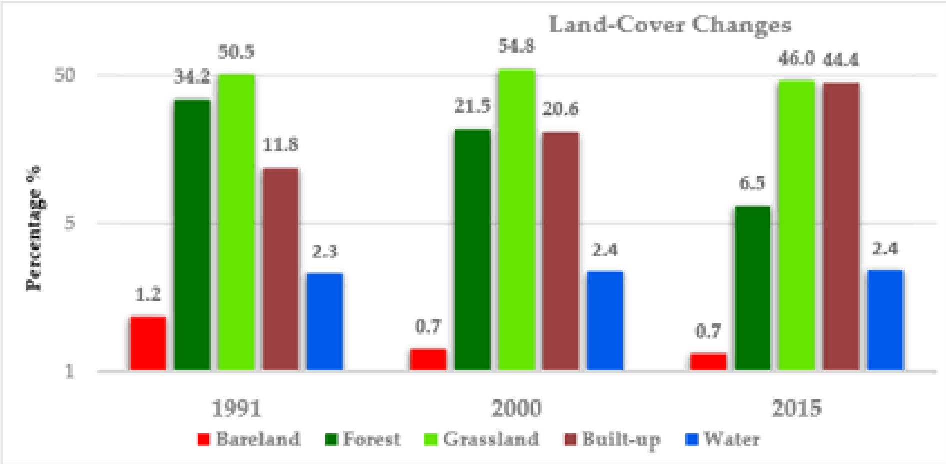

Fig 3 Land-use type percentage coverage from 1991 to 2015 (Source: Addae and Oppelt 2019)

2.5 Trend of the weather of Accra—Based on historical meteorological data of Accra

Available climate data for Accra (GMA 2017, Gyasi-Addo and Bennadji 2020) for the last 30 years indicate that the period between the latter part of October to early May constitute the warm periods. Average maximum temperatures are generally above 30°C. Since UHI is directly related to high air temperatures, this trend analysis has focused on climate/meteorological data from November to May. The historical meteorological data for Accra have shown that sometimes, the second rainy season ends in the early part of October, while the dry season commences in the latter part of the same month.

The data further show that there is a general drop in wind speed in the past 20 years, compared to the first 10 years. Temperatures within the warm months have also seen a gradual increase. Relative humidity distribution has also been quite uniform. The lowest relative humidity was recorded in January 2005, which was in the dry season. In subsequent years, the relative humidity levels increased. The graph in figure 4 shows a uniform weather pattern of Accra over the past 30 years,

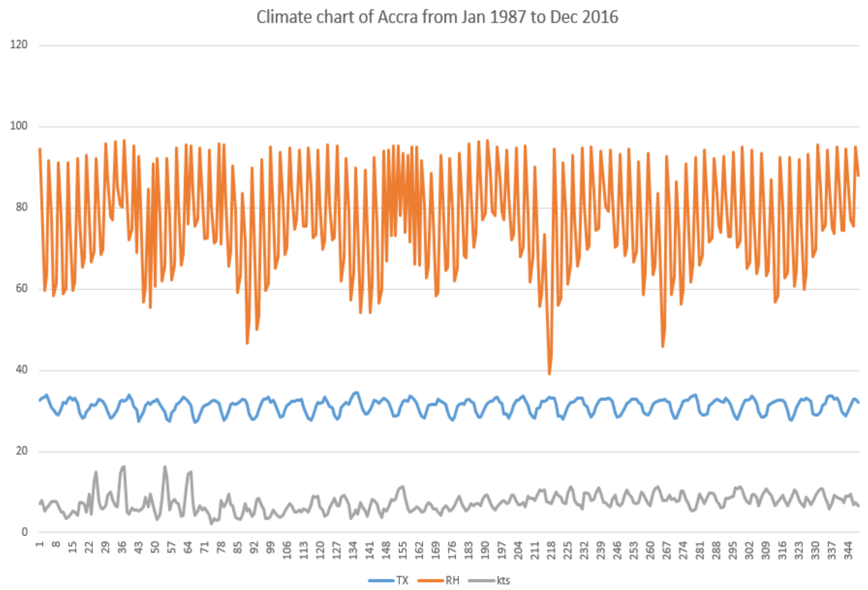

Fig 4 Accra meteorological data in from Jan. 1987 to Dec. 2016 (Source: Adapted from GMA 2017)

The data for the first 10 years (January 1987—December 1996) show that temperatures in the city between November and May months were generally high (between 27°C and 34.5°C). In the same period, wind speed was between 1 Kts and 10 Kts. High winds during the warm months occurred between December and March and that could be attributed to the northeast trade winds. Average relative humidity values between November and May within the first 10 years of the 30-year period, were between 70% and 80%, whilst the range observed in the last 5 years (2011 to 2016) was between 53.0% and 80%. From 2011 to 2016, Accra recorded temperatures between 30 and 36.1°C between the months of November and May, whilst the relative humidity range observed in the same period was between 53.0% and 80%.

Generally, there has been a rise in the high monthly average temperature values within the warm months in the last 5 years, compared to the first 5 to 10 years within the past 30 years. The relative humidity range has also dropped significantly. There has also been a drop in the wind speed after the first 5 years. It can therefore be inferred that Accra has become hotter over the past couple of decades. It is predicted that by 2030, the temperature of Ghana could increase by 2.3 °C; and in the hottest month, temperatures could increase by 8 °C (USAID 2018). This prediction means that the UHI effect in Accra could be substantial, should this trend continue.

2.6 Relationship between historical weather pattern and land use changes

The land use change analysis done by Addae and Oppelt (2019) has revealed a pattern between green cover (grassland and forest cover) and built-up coverage. As the built-up areas expanded in the given periods, the extend to greenery depleted significantly. The grassland was mostly taken over by the built-up areas, whilst the forest cover reduced into grassland.

As deduced from the values presented in table 2.1, based on Addae and Oppelt's (2019) findings, between 1991 and 2000, when the reduction of greenery (forest cover and grassland) was 13,337.2 ha, the change in built-up coverage was 13,961.6 ha. Relating this to the 30-year weather data obtained from GMA (2017), it could be inferred that the changes in the urban extent between 1991 and 2000 could have contributed to an average temperature change of 1.37°C (which was an increase of 4.6%). The period between 2000 and 2015 saw respective depletions of 23,790.5 and 13,971 ha in forest cover and grassland respectively and a corresponding average temperature increase of 0.93°C (being 2.9%). Although there were more substantial changes in the built-up coverage and depletion of greenery in the latter period, the increase in temperature in the former period was much higher. Even though the difference could be attributed to the types of urban developments that took place within the two periods, other environmental factors could not be ruled out. This phenomenon will require more detailed urban data on Accra to explain in future studies, as the historical information currently available is quite scanty. As further shown in the table, it is projected that between 2015 and 2025, the built-up area will increase by 54%, whilst the average temperature in that period could increase by 6% (being 2°C).

Table 2.1 Land use change from 1991 to 2015 and projections for 2015 to 2025.

Adapted from: Addae & Oppelt (2019) and GMA (2017)

		Area Change (ha)			**Percentage Change (%)**			**Projections for 2015-2025**	
Land Use		**1991-2000**	**2000-2015**		**1991-2000**	**2000-2015**		**Change (ha)**	**Change (%)**
Bare-land		-732.1	-77.3		-39.51	-6.9			
Forest		-20,121.40	-23,790.50		-37.08	-69.69			
Grassland		6784.2	-13,971.00		8.47	-16.08			
Urban		13,961.60	37,768.40		74.96	115.9		38,252	54.34%
Water		124.5	70.4		3.42	1.87			
		Temp. Change (℃)			**Percentage Change (%)**			**Projections for 2015-2025**	
Parameter		**1991-2000**	**2000-2015**		**1991-2000**	**2000-2015**		**Temp Change**	**Change (%)**
Temperature		1.37	0.93		4.46	2.9		2 ℃	6.05%

The changes in the urban extent in the periods 1991-2000 and 2000-2015 and the projected urban extent for the year 2025 are depicted in the land use map in figure 5.

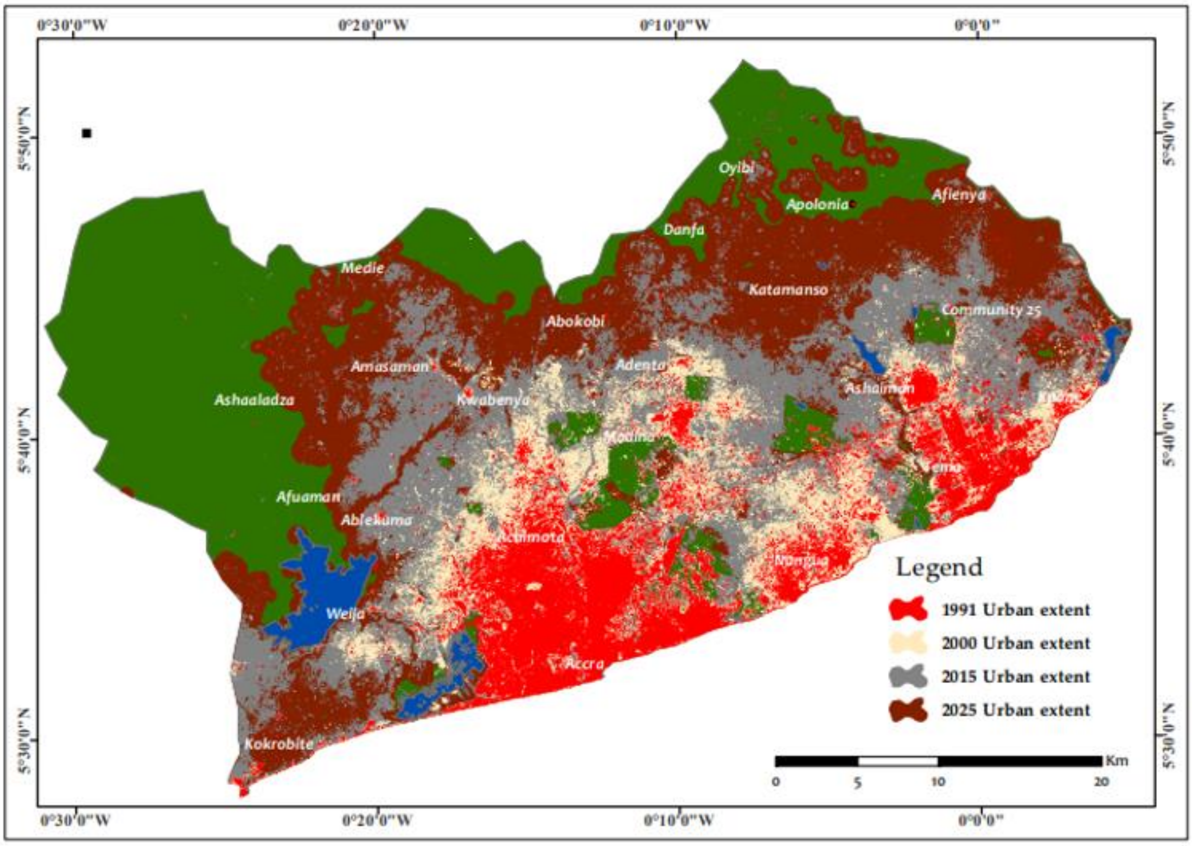

Fig 5 Changes in the urban extent of Accra between 1991 and 2015 and the projected urban extent for the year 2025. Source: Addae & Oppelt (2019)

2.7 Conclusion

Chapter 2 has presented the study context. The chapter has indicated that the study area is within the Accra Metropolis, which is in the Greater Accra Region. Accra is said to have an annual average temperature of above 24 °C. Accra developed into a big town when it was made the country's capital in 1877. It has been indicated that the urbanization of Accra started after the fall of the Western Sudan trade routes, and further expanded because of population increase, and trade liberalization policies. It has been explained in this chapter that the city has seen several huge and multi-storey buildings springing up in its central business district. It has been indicated in the chapter that unlike the city centre which was well-planned by the colonial administrators, the sprawl and consequently, haphazard developments in the peripheral areas have not been well managed, due to the absence of a well-defined urban planning policy direction.

Findings from a study by Addae and Oppelt (2019) have shown that in the past years, the city's built-up coverage has expanded significantly whilst its green cover has reduced drastically. Analysis of weather data for the same period has revealed that monthly temperatures in in the warm months (i.e. between November and May) have increased from a range of 27-34.5 °C to a range of 30-36.1 °C, whilst the relative humidity values have seen a drop from 70-80% to 53-80% in the same months. The chapter has further indicated that USAID (2018) projects the country's average monthly temperatures to increase by 2.3 °C, and the hottest month, by 8 °C by the year 2030.

To build on this contextual background, chapter 3 explores and reviews themes of the UHI phenomenon that are relevant to the study.

Chapter 3

LITERATURE REVIEW

3.1 Introduction

According to Watson and Webster (2002), reviewing literature is critical for the commencement of every meaningful research. Having presented the contextual background in the previous chapter, chapter 3 provides insights into theoretical issues that are relevant to this research. It further delves into how previous investigations into the impact of UHI on building energy have been conducted to gain a better understanding to address significant research gap(s) appropriately.

3.2 What is urban heat island?

According to Bagiorgas and Mihalakou (2016), "the UHI phenomenon exists in cities which usually have much higher air temperatures than those of their surrounding areas." Rajagopalan et al. (2014 p.159) corroborate the assertion by Oke (1982) that, UHI is caused by the reduction in vegetation which causes heat build-up in the ground and on building surfaces, resulting in higher air temperatures in the urban areas than their surroundings. According to Kolokotroni et al. (2006), urban heat island results from changes in the micro-climate of a built-up area because of drastic man-made interventions and changes to the natural environment. UHI has also been defined as the increased ambient temperature of urban areas because of warmer surfaces (Synnefa et al. 2007). It could be inferred from the foregoing that, UHI results from higher air temperatures caused by manmade changes to the natural environments with say hardscapes, that characterize heavily built-up urban areas compared to those of the less built-up surrounding areas.

3.3 Chronology of contributions to UHI study

Sundborg (1950) posits that to determine the appropriate mitigation measures against the UHI occurring in a place, it is vital to have an in-depth understanding of the local climatic variations and physical characteristics. This means, to develop effective UHI mitigation measures for a city, there is a need to have a holistic understanding of variations in climate and the overall urban context. It is established that the early research interest in city-induced climate changes arose because of a concern for human health. According to Palladio (Emmanuel 2005), to obtain street-level thermal comfort, for cold places, streets should be adequately broad, and for hot places they should be narrow with tall buildings. It has been established that studies on UHI were conducted by Howard, L. in the early 1800s (Yang et al. 2015, Mohajerani et al. 2017). After comparing the temperature records gathered at different sites outside London and a site within London, Howard (1833) posited that, "the temperature of the city is not to be considered as that of the climate; it contributes to artificial warmth, caused by its structure, by a dense population, and the use of large quantities of fuel in fires."

The first quantitative assessment of Singapore's outdoor thermal comfort was produced by Stephenson (1963), followed by Simon Nieuwolt's (1966) UHI study – probably the first to be published in English for any tropical city (Roth and Chow 2012). Nieuwolt's study involved "comparing urban air temperature observations to simultaneous readings taken at Paya Lebar Airport, then located in a predominantly rural area 10 km northeast of the city centre. The study revealed that maximum daytime temperatures were measured at the urban core (Nieuwolt 1966: 31). These laid the foundation for subsequent local urban climate studies and preceded comprehensive UHI work in the 1970s in nearby Kuala Lumpur, the capital city of Malaysia" (Roth and Chow 2012).

Landsberg (1981) gave an extensive coverage of literature on urban climate studies after about a quarter century had elapsed since the last monographic review of studies on the subject appeared in book form. The work was against the backdrop of earlier emphasis on analytical studies directed toward physical understanding of the rural-urban differences in the boundary layer.

Using a process-based approach, Oke (1982) attributes UHI formation to energy balance resulting from urbanization, which is to a large extent, affected by changes in urban morphology, cover and metabolism (Roth and Chow 2012).

Oke (1984) reviews the methods in use in urban climatology, and attributes a number of weaknesses and gaps to the great complexity of the urban climate systems, with the attendant absence of clearly defined guidelines and methods to aid architects, engineers and planners, and thus points out that, urban climatology could benefit from approaches adopted in related fields of building climatology.

From the 1990s to recent times, the focus of UHI research has been on the facilitation of better UHI measurement as well as the evaluation of mitigation options (Emmanuel, 2005). Within a decade, conferences were organized by the International Association of Urban Climate (IUAC): 1ST International Conference of Urban Climate, Planning and Building, Kyoto, Japan, 1989, 2nd Conference in Dhaka, 1993, 3rd in Essen, 1996, and 4th in Sydney, 1999, and has since been in collaboration with other interest organisations or bodies such as the International Congress of Biometeorology (de Der and Potter 1999).

Studies on the impact of UHI on the energy consumption of building and energy saving as well as mitigation measures include Santamouris (2001), Akbari (2001, 2002, 2005, 2008, 2009, 2012 etc.), Solecki (2005) and Synnefa and Santamouris (2012).

3.4 Causes of UHI

Past studies have pointed to vegetation, roads, open spaces, hardscapes among others, as factors that contribute to variations in urban climate, but the significant contributing factor to UHI has been proven to be roads (Alive 2016). US EPA (2015a) and Lowe (2016) attribute the main cause of UHI to the overuse of artificial materials, prominent among which are concrete and asphalt. According to Jusuf (2007), factors that cause the urban air temperature of cities to gradually increase include drastic reduction in greenery, low wind speed due to the presence of large buildings, and the use of hard materials for road surfaces. Land with green cover tends to lose heat faster through evapotranspiration. Eumorfopoulou and Kontoleon (2009) performed experiments on two buildings to compare the thermal behaviour of a bare wall and a green wall. Their results indicated a lower temperature on a green wall compared with a bare wall. Gill et al. (2007) conducted a study that involved the use of an energy balance model to determine the effect of green roofs on surface temperature. The study revealed that a 10%

reduction of greenery in a residential area could lead to a surface temperature increase of 7 to 8℃. Other studies (Golany 1996, Upmanis et al. 1998, Upmanis and Chen 1999, Elliason and Svensson 2003, Bottyan et al. 2005) have shown that there is a relationship between urban heat island intensity and urban morphology or the built-up ratio of a city.

Eliasson (1996) and Morris et al. (2001) have established that urban heat island intensity is inversely proportional to wind speed and amount of cloud cover. Cheung (2011) has pointed out that heat could be reduced by cloud cover in rural areas through the reduction of long wave irradiation from earth to sky, and the rate of dissipation in the urban canyon can increase with strong wind. It is evident in the foregoing that urban heat island intensity generally decreases with increasing cloud cover and wind speed.

Various studies (Levermore and Smith 2008, Kolokotroni et al. 2012) have shown that a major factor affecting UHI in London is distance from the city centre, with temperature figures increasing towards the centre.

It is evident that in addition to hardscapes, roads, buildings and other manmade materials, distance between a location and the centre of a city have significant effect on the intensity of UHI – the closer a location to the city centre, the higher the impact of UHI on it. Furthermore, drastic reduction of greenery and wind velocity in the areas with high building densities also contribute to high urban temperature build up.

Rizwan et al. (2008a) classified factors influencing urban heat island into controllable and uncontrollable. Controllable factors may be population related (for example air pollutants and anthropogenic heat) or urban design related (such as types of building materials, sky view factor and urban greenery). Rizwan et al. (2008a) further indicated that both controllable and uncontrollable factors are influenced by solar irradiance. The factors that affect urban heat island generation are depicted in figure 6.

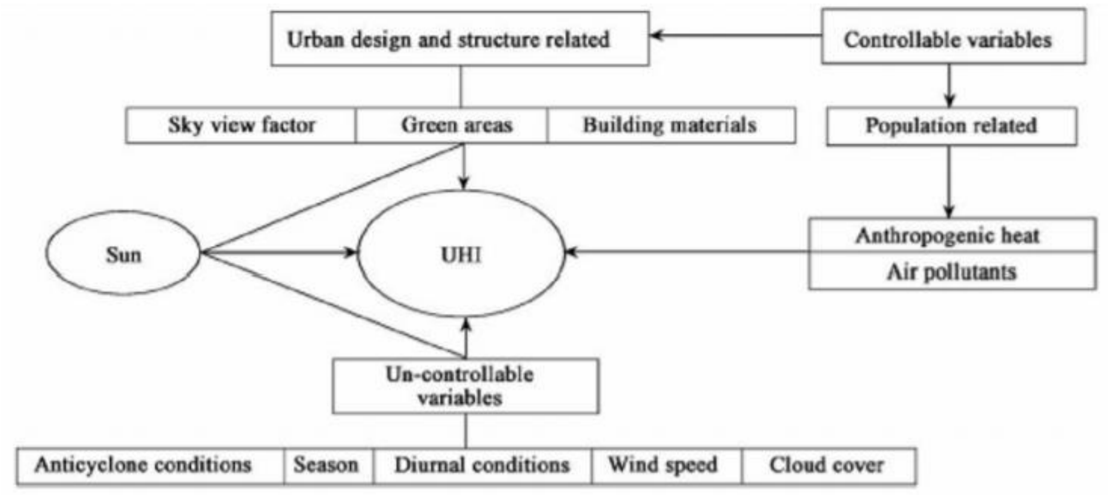

Fig 6 Factors affecting UHI generation (Source: Rizwan et al. 2008a)

Canyon geometry is among the important factors (i.e. controllable factors) that affect urban heat island. Oke (1981) expresses canyon geometry in terms of height to width ratio or sky view factor and presents the relation between UHII and urban geometry in the following equations:

$$\Delta T_{u-r} = 7.54 + 3.97\ln(H/W)$$

$$\Delta T_{u-r} = 15.27 - 13.88\psi_{sky}$$

where T is the air temperature difference between rural and urban area (i.e. urban heat island), H and W refer to the street canyon height and width respectively and ψ_{sky} is the sky view factor.

An investigation conducted by Santos et al. (2003) showed a relationship between air temperature (Ta) and sky view factor (SVF) as follows:

$$T_a = 27.75 - 2.56 \times \psi_{sky}$$

In a study by Unger (2004), the finding on the relationship between air temperature difference and SVF was summarized as follows:

$$\Delta T_{a,yea} = 5.90 - 4.620 \times \psi_{sky},$$

where $\Delta T_{a,yea}$ is the air temperature difference and ψ_{sky} is the SVF.

As presented in the literature, findings from previous research indicate that a negative or positive linear relationship exists between urban geometry (either as SVF or H/W) and urban heat island intensity. It worth indicating that the equations presented in the various studies were developed for different cities and were thus based on different conditions. It will therefore be important to investigate the relationship between SVF or H/W and the urban heat island intensity in Accra, as a single equation may not be applicable in different settings.

3.5 UHI occurrence and intensity

Santamouris (2007) has opined that UHI is caused by the differences that exist between the thermal properties of the heavily built-up urban areas and those of their surroundings. Tan and Li (2015) have indicated that the intensity of UHI varies with the characteristics of a given urban area, which could include the effects of wind tunnel. Rajagopalan et al. (2014 p.160) have categorized the factors that affect UHI occurrence and intensity into meteorological factors as well as city design. Dhalluin and Bozonnet (2015) corroborate the aforementioned factors but further extend the discourse to indicate that the geographic characteristics of an area can also impact its urban heat island. As seen in various studies, there is a wide range of factors (geographic, meteorological, anthropogenic, differences in shapes, city design etc.) affecting the occurrence and intensity of UHI. The factors revealed above underpin the need to take a holistic approach when investigating the UHI of an area.

3.5.1 Effect of meteorological factors on UHI

After investigating how UHI varies with wind speed and cloud cover, Morris et al. (2001) found that UHI intensity increases with low wind speed and clear skies. They (Morris et al. 2001) found that during summer, an increase of wind speed by 1 m/s could cause a reduction of 0.14°C in UHI intensity. Various authors (Memon and Leung 2010, Yang and Li 2011, Rajagopalan et al. 2014) consider wind speed to be an important climatic element for urban areas since it helps improve both indoor and outdoor comfort as well as building energy performance. According to Ok et al. (1996), for an urban settlement, differences in the flow pattern of wind does not only depend on weather, but also on the geometric variables that relate to the buildings. It is therefore obvious from various authors (Ok et al. 1996, Morris et al. 2001, Memon and Leung 2010, Yang and Li 2011, Rajagopalan et al. 2014) that, increase in wind speed causes reduction in UHI values and vice versa. Also, as Morris et al. (2001) have established, there is a clear association between cloud cover or clarity of the skies and urban heat island intensity.

3.5.2 Effect of city design (urban morphology) on UHI

A study conducted by Shashua-Bar et al. (2004) has revealed that urban areas with shallow and wide-open spaces could record temperatures up to about 4.7°C above those recorded in their surrounding areas or reference locations. It has also been suggested (Bourbia and Boucheriba 2010) that to mitigate the effect of UHI, both aspect ratio and street design should be incorporated into urban planning. They have also indicated that high the aspect ratio could lower the temperature of a place. Reiterating the position of Golany (1996), Rajagopalan et al. (2014) indicate that city design can affect wind circulation and speed, which could ultimately affect temperature. All the above studies point to the fact that consideration for deep open spaces in urban design could bring about a significant reduction in temperatures in urban areas. As gathered from Golany (1996) and Bourbia and Boucheriba (2010), areas with high cloud cover would require city design with considerably high street width to building height ratio to cause induced increase in wind velocity.

3.5.2.1 Urban morphological parameters

Many parameters are available for assessing the effects of urban environmental characteristics on air temperature. Various researchers (ISO 1998, Ong 2003, Song et al. 2020) have opined that although the quantification of spatial parameters is among the most important and widely used methods for describing urban morphology, the spatial indicators used in research and urban planning are not uniform.

To measure the effects of site environmental characteristics on urban heat island in a tropical environment, Jin et al. (2018) selected three categories of urban morphology parameters including land cover features, site geometry, and spatial location.

3.5.2.1.1 Influence of site or canyon geometry on temperature

The effect of site or canyon geometry on air temperature may be expressed in terms of sky view factor (SVF) or aspect ratio (AR). Sky view factor refers to the extent of openness to the sky, and it gives an indication of the amount of solar heat gain that is received by the ground surface. Aspect ratio is the mean height of building-to-width ratio of a street canyon. It gives an indication of how densely buildings are spaced with respect to their heights (Stewart and Oke, 2012, Unger, 2004). With an increase in aspect ratio and reduction in sky view factor, the loss of longwave radiation is constrained which leads to a significant increase in UHI intensity within the canopy layer (Erell et al., 2012, Stewart and Oke, 2012, Unger, 2004). According to Hien and Jusuf (2009), "sky openness" is the most important factor that affects air temperature in tropical cities. Various UHI studies have shown that during daytime, air temperature increases with increasing extent of openness to the sky, whilst less sky openness results in lower air temperatures under the effects of solar heat gain (Jin et al. 2018). On the other hand, this correlation has been seen to be negative during night-time, as areas with less sky openness experience decreased net outgoing longwave radiation, and hence higher temperatures.

Open spaces with little greenery experiences high daytime air temperature due to the high amount of heat gain that is received by the ground surface. At night, the air temperature reduces because the heat escapes into the atmosphere without any hinderance or entrapment by the surrounding buildings. On the other hand, at sites with high building densities and little vegetation, there is substantial heat accumulation due to the reduced amount of greenery which is not easily released due to the thermal capacity of the surrounding buildings. Vegetation reduces the sky openness in an urban environment. Trees reduce the level of sky openness (i.e., provide shading), thus, they cool the air temperature (Jin et al. 2018).

3.5.2.1.2 Influence of land cover parameters on temperature:

In addition to sky openness (sky view factor or aspect ratio), Jin et al. (2018) identifies building plot ratio (BPR), green plot ratio (GnPR), and percentage of pavement (PP) as the important land cover parameters that can impact a city's temperature.

Building plot ratio (BPR) is defined as the ratio of gross liveable area to the area of a site. A site with a BPR of 2:1, for instance, can have a building that has a total useable floor area that is twice that of the site (Ong 2003). Air temperatures are affected differently by land cover composition at different times of the day. Research has shown that during daytime, the correlation between temperature and BPR is negative, whilst the correlation between them during night-time is positive. It is worth indicating that there is no obvious correlation between wind speed and BPR; rather, wind speed is normally related to building composition and greenery (Jin et al. 2018).

In urban heat island studies, greenery that provides shading is usually expressed as leaf area index (LAI) which refers to the total leaf area of a plant. In simple terms, LAI can be considered as the ratio of area of leaves to that of ground that is covered. In current urban planning, the green plot ratio (GPR) metric is applied. GPR is defined as the average LAI of the greenery on site (Ong 2003). It has been shown that a 10% increase in vegetation in terms of green plot ratio could bring about a decrease of 0.3℃ in daytime temperature. During night-time, however, this relationship is mostly insignificant. On the other hand, it has been indicated that within areas that have complex urban systems, the effect of green plot ratio on air temperature is significant if the shading that is provided by vegetation is enough to mitigate the effect of solar radiation (Jin et al. 2018).

Percentage of pavement (PP) refers to the extent of coverage of paved areas within a given built-up zone. The paved surfaces in urban and suburban areas are often warmer than the less-paved surfaces in rural areas (Jin et al. 2018). Pavement is usually composed of materials with very low reflectivity or albedo. Dobos (2003) defines albedo as the fraction or percentage of incident radiation that is reflected from a surface. It plays an important role in the energy balance on the surface of the earth since it indicates the amount of solar radiation that is absorbed. According to Calkins (2012), surfaces generally absorb most of the radiation that fall on them. This heats up the component material of the pavement, and the heat is then reradiated, leading to a rise in the surrounding ambient air temperatures. In pavement structures, the main surface that affects albedo level is the topmost layer. Therefore, if heat generation is a concern, albedo should be considered in the selection of a pavement type (Ibrahim et al. (2018).

In a study at Duran, Mao et al. (2017) selected site coverage ratio (SCR), façade-to-site ratio (FSR), weighted average building height, tree coverage ratio (TCR), vegetation coverage ratio (VCR), thermal properties of building materials (mainly albedo), and the non-building sensible anthropogenic heat (mainly from traffic) as the main morphological parameters for the simulation of urban heat island. Litardo et al. (2020) define morphological parameters in terms of site coverage ratio (SCR), façade-to-site ratio (FSR), tree coverage ratio (TCR), as well as vegetation coverage ratio (VCR). Vegetation coverage ratio (VCR) can include green roofs, grassy lawns, and vine-covered walls. The site coverage ratio (SCR) is defined as the total building footprint on the site area, and it indicates the density of the buildings in an area. The façade-to-site ratio (FSR) refers to the sum of the product between the building ground perimeter and the average building height (weighted by SCR), namely the walls, by the site area. The tree coverage ratio (TCR) refers to the amount of tree coverage found in a site area (Litardo et al. 2020). The urban morphology parameters can be estimated using ArcGIS maps, Google Street View, orthophoto made available by city planning authorities, and through visits to sites in situations when imagery is not readily available. To determine the albedos of the building materials, the roofing, walls, and road materials are identified, and typical albedo values assigned for them using relevant existing literature (such as Hall 2010, Litardo et al. 2019).

Several remote sensing studies have explored the land surface composition and its implication on surface heat island. Major LCZ defining built parameters such as pervious surface fraction (PSF), impervious surface fraction (ISF), built surface fraction (BSF), sky view factor (SVF), aspect ratio and albedo (AL) were selected which explained the surface cover properties and building envelope properties.

Additional parameters that are also considered based on previous UHI study and existing urban fabric include surface albedo (AL), aspect ratio (AR), and vegetation density ratio (VDR). These have been found to be major predictors that explain UHI response (Kotharkar 2019).

3.5.2.1.3 Influence of spatial location parameters on temperature

Anthropogenic heat is measured as the heat flux density with human activity as a main source. Heat that is produced due to transportation, space heating, industrial manufacturing, and human metabolism leads to temperature variations in urban areas. As quantifying the exact heat flux is difficult, many researchers use proxy indicators to represent anthropogenic factors. These include distance to water body (DW), distance to park (DP), main streets, population density and distance to urban area or central business district (DI) (Kotharkar 2019) and the non-building sensible anthropogenic heat (mainly from traffic) as the main morphological parameters for the simulation of urban heat island (Mao et al. 2017).

Kotharkar (2019) has shown that during night-time hours, air temperature increased with increasing distance to the nearest park. However, there was no such significant relationship between air temperature and distance to park during the day. The air temperatures determined by the distance to water variable were like the variance obtained in the case of distance to park for both daytime and night-time.

3.5.3 Morphological parameters for UHI studies in tropical cities

In tropical cities with heterogeneous mix of urban surface cover, morphology, thermal and radiative properties pose the question–which built properties have a higher influence on UHI? (Kotharkar et al. 2019). For tropical UHI studies, Lithardo et al. (2020) have identified the following morphological parameters as major driving factors that characterize the intensity of urban heat island: site cover ratio (SCR), weighted building height (WBH), façade-to-site ratio (FSR), tree coverage ratio (TCR), vegetation coverage ratio (VCR), surface albedo, and traffic. These parameters are generally characterised by built-up or land cover type, green cover type, and spatial/location parameters such as distances from city centre, park, and water body.

Depending on the main aim and of a study, the definition and calculation of an indicator can vary significantly. The spatial indicators used in most studies are obtained from previous research and are usually limited by the amount of data that can be captured. Therefore, the parameters chosen for a study are by no means the exhaustive list of input variables that may be suitable for the investigation. In this vein, alternate parameters are encouraged (Song et al. 2020).

3.6 Detrimental impacts of UHI

Studies have shown that increased UHI can affect the energy use (both heating and cooling) of buildings in urban environments (Kolokotroni 2012, p.302). Fujita and Hirano (2012) assert that high building energy consumption due to the use of air conditioners is often regarded as a serious consequence of UHIs since it does not inure to efforts to curb global warming.

O'Malley et al. (2014) classifies UHI impacts into impact on humans and on micro-climate. Health issues such as stroke, thermal exhaustion, cardiovascular and other respiratory diseases are among the myriad of detrimental effects of UHI, and efforts to improve indoor comfort for building users could have negative consequences on micro-climate (Fujibe 2011, Kleerekoper et al. 2012, Pitiyanuwat 2012, O'Malley et al. 2014).

3.7 Quantification of UHI

In the first study conducted to investigate UHI in the city of Singapore (conducted by Nieuwolt in 1964), spot temperature measurements were compared with the temperature measurements gathered at a location, representative of a rural area (Nieuwolt 1966). Nieuwolt's study was found to have carried inherent errors because of time lapse, as temperature recording involved moving from one spot to another. Nichol (1994) also investigated the UHI of Singapore, using remote sensing technology. Ao and Ngo (2000) studied the UHI of Vancouver, Canada with the use of GIS. The methods used by Nichol (1994) and Ao and Ngo (2000) were employed because of the large sizes of the areas of coverage. Wong and Cheng (2005) on the other hand employed the use of mobile survey in an investigation to assess the effect of UHI on the city of Singapore.

As revealed in the above studies, several reliable methods for measuring UHI are available. From the literature, it is evident that remote sensing, mobile survey, thermal satellite image, and GIS methods are all appropriate for investigating UHI of areas with wide spatial coverage, whereas spot temperature measurements could be deemed suitable for smaller areas. Although spot temperature measurements are considered suitable for small locations, Mantey et al. (2012) point out the high cost associated with equipment acquisition and installation, and hence the limit to the number of point locations where land surface temperatures or air temperatures can be measured.

Li (2018) has posited that accurately quantifying UHI could aid the efficient assessment of possible heat risk. This would be beneficial for the management of city development and planning. UHI intensity, which is defined as the difference between the temperature of an urban setting and that of a surrounding or non-built-up area, is the well-known method of describing the quantum of the effect of UHI (Rizwan et al. 2008, Stewart 2011). Conventionally, the measurement of urban heat island intensity (UHII) is carried out at two fixed in-situ monitoring points: one in an urban area, and the other in a nearby rural environment (Yang et al. 2013, Earl et al. 2016). Similarly, as demonstrated by Stewart (2011), studying surface urban heat island intensity (SUHII) using data obtained by remote sensing is carried out over specific pixels, separately in the urban and rural settings.

Presently, it is possible to develop knowledge of a city's climate through either in-situ observations or by remote sensing (Voogt 2014). Weng and Quattrochi (2006) posit that, airborne or satellite remote sensing allows a spatially comprehensive observation of both rural and urban climates. It is very suitable to use remote sensing to measure and map surface temperatures that have effect on ambient temperature, thereby determining building thermal comfort and its effect on an urban environment (Voogt and Oke 2003). Ambient and surface temperatures could differ from each other considerably (Byrne 1979). The former is associated with the temperature of part of the surface of the earth that can vary considerably from an adjoining one, due to its composition and structure, whilst the latter is related to air temperature produced from the mixture of the heat emissions from surfaces, human activities as well as the temperature of the landscape features within the surroundings (Yan et al. 2014). Voogt and Oke (2003) have proposed that it is important to relate surface temperatures to the physical characteristics of the urban landscape. It is therefore important to relate the measurements of climate used for the monitoring of UHI and urban landscapes, so that it would be possible to generate very useful urban climatic maps which would immensely benefit planning authorities.

For varying reasons, researchers have identified various landscape classification systems for UHI or urban climate studies. According to Ren et al. (2010), "urban climate maps can be regarded as the first spatially comprehensive approach to provide information and planning recommendations that incorporate climate factors." This method involves the combination of geographic information on physical features of land, analytical climate maps and surface maps to generate urban climate maps for some specific settings. As posited by Ng (2009), improvements on those studies were realized by combining various parameters of urban morphology. Various urban climate classifications were developed to underscore the influence of the urban environment on local climate: Urban Terrain Zones (Ellefsen 1990), Urban Climate Zones (Oke 2004), Local Climate Zones (Stewart and Oke 2009a, 2009b, 2010). The benefit of these classifications is tied to their independence to definite climatic conditions. The urban climate zones (UCZs) model by Oke (2004) is of interest, as it has been included in the published guidelines of World Meteorological Organization (WMO). Through this classification, different UCZs were identified from theoretical divisions of an urban land, based on the possibility to transform the local climate. The classification however has a major limitation, as there has not been any quantification of differences between UCZ climates. This classification system has seen improvements throughout Stewart and Oke's local climate zone (LCZ) model (Stewart and Oke 2009a, 2009b, 2010). Till date, many methods used for the classification of landscape have evolved which contain several features that align with the rationale for UHI study. To study urban morphology and its effect on local climate, the LCZ developed by (Stewart and Oke 2012) is meant to define or describe cities in an exhaustive and systematic way. "There are seventeen standard LCZ classification types, composed of two subsets, namely, 10 built types and 7 land cover types. A major benefit of LCZ is the new angle of UHI that considers the variations within different LCZ classes, instead of the usual urban and rural classes" (Ren et al. 2016). The ten built types are: compact high-rise, compact mid-rise, compact low-rise, open high-rise, open mid-rise, open low-rise, lightweight low-rise, large low-rise, sparse low-rise, and heavy industry while the land cover types include dense trees, scattered trees, bush/scrub, low plants, bare rock/paved, bare soil/sand, and water (Stewart and Oke 2012).

3.8 Analytical tools for analysing climatic/UHI data sets

Various researchers (Watkins 2002, Giridharan and Kolokotroni 2009, Kolokotroni and Giridharan 2010) have used statistical packages to analyse the relationships between urban heat island and various weather parameters such as wind speed, cloud cover etc. In their study of the UHI in London, Kolokotroni and Giridharan (2010) investigated the effect of the different weather parameters in the two main seasons: summer and winter.

According to WMO (2011), most climatological processing and analyses are based on universal statistical methods since universal statistical packages are convenient computer software instruments for climate related research. It is further suggested that although several data management, analytical, and reporting tools are available in statistical packages, researchers should choose packages that have the required capabilities to manage, process, and analyse data (WMO 2011). This research therefore identified and used basic data management or statistical tools that could perform operations such as correlations, frequency tables, sorting, adding of data, arithmetic calculations, merging of data, and testing of hypothesis. The analytical tools employed could also be used to carry out many of the needs of climate analysis such as regression, variance, discriminant analysis, cluster analysis, time series analysis etc. Contained in the statistical packages are graphical tools that could be used to create, edit, and save various types of graph in specific formats of statistical packages or standard graphical formats.

An analytical process is designed to explore large sets of data with the view to identifying consistent patterns or systematic relationships among elements to validate the findings by applying any detected patterns to new subsets of data (WMO 2011). This research has employed SPSS and Microsoft excel as the main analytical tools, as they respectively contain the statistical and graphical tools deemed suitable. Drawing on Kolokotroni and Giridharan's (2010) approach, this research has considered assessing the effects of the different parameters on the UHI of Accra for both dry and wet seasons. The research has also made use of data mining to search for relationships among elements when possible relationships have not been clear.

3.9 Conclusion

In reference to various definitions by other authors, UHI is said to occur as a result of higher temperatures that are caused by artificial changes to the natural environment, usually in the form of hard surfaces that characterize the urban built environment, compared with the temperatures experienced in the rural or less built-up surroundings. The literature has indicated that various factors which affect the formation of urban heat island or heat island intensity include drastic reduction in greenery, low wind speed due to the presence of large buildings, and the use of hard materials for road surfaces (Jusuf 2007). This is consistent with the view held by Rizwan et al. (2008b) and Unger et al. (2001) that UHI develops due to the interaction between different human and environmental factors. It is further indicated in the chapter that increase in wind speed can reduce the intensity of UHI (Morris et al. 2001); however, as Ok et al. (1996) point out, the effect of wind speed to a large extent, depends on the flow pattern of wind an urban settlement or geometric make-up offers. It has become evident in this literature review that determining the main factors which contribute to the development of urban heat island in a specific setting is not very straightforward. This has underpinned the need to carry out an UHI study in Accra at a large-scale, where no such research has been done before. Against this backdrop, the study addresses the weakness and research gap which Oke (1984) has attributed to the complexity of urban systems, because of which location specific UHI studies are needed.

The chapter has indicated that UHI has detrimental impacts on human health, among which O'Malley et al. (2014) identify stroke, thermal exhaustion, and other respiratory diseases.

The chapter has also looked at various reliable methods used in the quantification of UHI at both small and large scales. It has been made evident in this chapter that to investigate UHI in areas of wide spatial coverage, remote sensing, mobile survey, and thermal satellite image as well as GIS methods are appropriate whereas spot measurements are more suitable for smaller areas. The reviewed literature in this chapter explored various landscape classification systems for UHI or urban climate studies. The chapter subsequently identified the most recognized and widely used classification system developed by Stewart and Oke (2012) based on 10 built types and 7 land cover types.

The last part of this chapter has reviewed how climatological analyses have been carried out in previous studies (Watkins 2002, Giridharan and Kolokotroni 2009, Kolokotroni and Giridharan 2010, WMO 2011). It has become evident that universal statistical methods and packages, and other convenient computer software are suitable tools for analysing climatic data and for that matter, UHI. The next chapter will discuss and justify the research methodology and methods employed for the collection of the main primary or empirical data used for the research.

CHAPTER 4

Methodology

4.1 Introduction

Through the extensive literature review done in the previous chapter, various methods, and procedures suitable for UHI studies have been identified. In this chapter, the evaluation and subsequent selection of methodological approach for the study have been enhanced by undertaking a detailed examination of various suitable and accepted methods or procedures used for UHI investigations. In choosing a suitable methodology, it was important to satisfy oneself with Dawson's five 'Ws':

- *What* the research is
- *Why* I want to do the research
- *Who* the research participants are
- *Where* the research is going to be done
- *When* the research is going to be done (Dawson 2009, p. 13).

Having considered the above, the chapter first defines *research methodology*. It then assesses various research philosophies to rationalise the methodology being chosen for the study before proceeding to discuss the method(s) and procedure(s) that will be used in collecting and analysing the data.

4.2 Methodology

Research methodology “gives a big picture of the research process such as why particular methods are chosen, while research methods refer to the various procedures, tools, or strategies with which research is carried out. Methodology could therefore be related to philosophical issues within the research process” (Giacobbi et al. 2005). Silverman (2010) posits that a methodology refers to the choices we make about cases to study, methods used in gathering data, forms of data analysis etc. in planning and undertaking a research study. Silverman further indicates that our methodology sets out how we will study any phenomenon. Dawson (2009) defines research methodology as the general principle, overall approach or the philosophy which guides a research. As seen in the above definitions, research methodology is generally related to philosophical issues and methods with which a research or study is conducted. It can be inferred from the above definitions that research methodology could be defined as the main philosophy that underpins the strategies, methods, and procedures with which a research is carried out.

The methodology of this study draws from the sequence in the layers of the research onion (Saunders et al. 2012), that is from the outer ring to the inner ring (see figure 7).

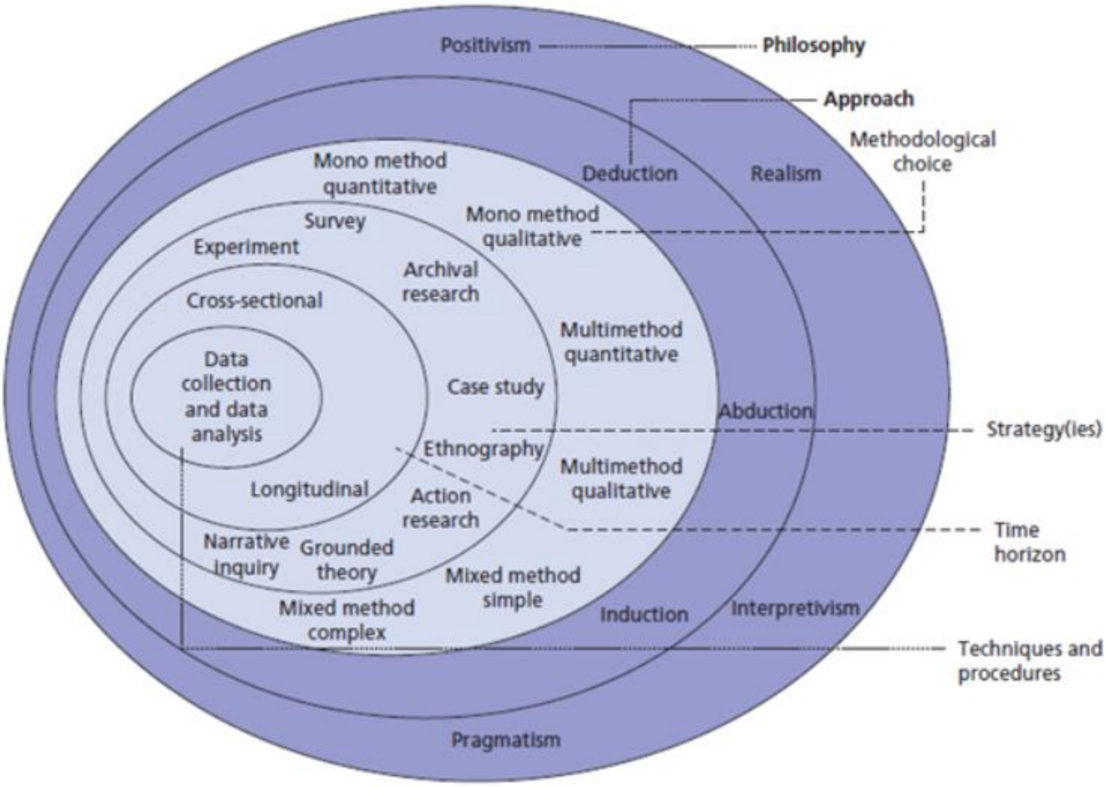

Fig 7 Research philosophy in the onion ring (Source: Saunders et al. 2012).

Following the sequence in the onion ring, this chapter first looks at the philosophy that underpins the study, following which various methodologies are explored to determine the one that is deemed most suitable. The methodology chosen is largely determined by the types of data that are needed for the study. The methodology then feeds into the research strategy that needs to be employed to collect the data. The final part of this chapter thus deals with the methods and procedures used for collecting and analysing the data.

4.3 Research Philosophy

Denscombe (2010) posits that, an approach chosen for a research defines its philosophy. Creswell and Creswell (2017) assert that individuals develop worldviews, beliefs or philosophies based on their discipline orientations, research communities, advisors and mentors, and past research experiences. Such beliefs often lead to embracing a strong qualitative, quantitative, or mixed methods approach in their research. According to Bajpai (2011), research philosophy deals with the source, nature, and development of knowledge. Dudovskiy (2018) defines research philosophy as belief about the ways in which data about a phenomenon should be collected, analysed, and used. Dudosvskiy further indicates that a research philosophy reflects a researcher's assumptions on which a research strategy is based. It could therefore be inferred from the foregoing that the philosophy chosen for a research is underpinned by the research gap it is meant to fill.

Slife and Williams (1995) posit that "although philosophical ideas remain largely hidden in research, they do influence research and it is very important to identify them." Creswell (2013) describes these philosophical ideas as worldviews, which represent a general perception about the world and the type of research which a researcher brings to a study. Various researchers have described worldviews as *paradigms* (Lincoln et al. 2011, Mertens 2010), *epistemologies and ontologies* (Crotty 1998), *phenomenology* (Byrne 2001, Saunders et al. 2009), *axiology* (Heron 1996, Saunders et al. 2009) or widely conceived *research methodologies* (Neuman 2009).

According to Dawson (2009), *epistemology* is the study of the nature of a knowledge and its relevance, and it looks at where the knowledge has come from, and how we know what we know. Moon and Blackman (2014) have posited that epistemology is concerned with all aspects of the validity, scope and methods of knowledge acquisition, and is very useful, because it influences the way researchers plan their research in their quest for knowledge discovery.

Ontology is concerned with what exists in the world, about which knowledge can be acquired. It helps researchers to be certain about what they are researching on, and is thus concerned with: (1) the 'truth claims' a researcher can make about reality, (2) the one who decides the legitimacy of what is 'real', and (3) the way in which researchers deal with different and conflicting ideas of reality (Moon and Blackman 2014).

Saunders et al. (2009) refer to *phenomenology* as the way in which humans make sense of the world around them. "Phenomenology is thought of as a study of structures that characterize consciousness and the world as we experience it. The phenomenologist's experience is from the first-person point of view, meaning, the investigator of consciousness studies their own experience by living through that experience" (Gallagher 2012).

Saunders et al. (2012) define axiology as a branch of philosophy that studies judgements about value. More specifically, axiology is associated with assessment of the extent to which a researcher's own values affect their judgments on the research they are conducting (Li 2016). From the foregoing, it could be inferred that judgments made by researchers are guided by their values.

Creswell (2017) highlights four worldviews, also known as beliefs which researchers generally bring to an inquiry: postpositivism, constructivism, transformative and pragmatism.

Postpositivist assumptions have represented the traditional form of research, and these assumptions hold true more for quantitative research than qualitative (Creswell 2017). According to Phillips and Burbules (2000), this worldview, sometimes called the scientific method, or doing science research, or postpositivsm represents the thinking after positivism and thus challenges the traditional notion of the absolute truth of knowledge. "Postpositivists hold a deterministic philosophy in which causes (probably) determine effects or outcomes, which means that problems they study reflect the need to identify and assess the causes that influence outcomes, such as those found in experiments. Knowledge developed through positivism is based on careful observation and measurement of the objective reality that exists 'out there' in the world. Positivists hold the view that there are laws or theories that need to be tested or verified and refined so that we can understand the world" (Creswell 2017). A major aspect of this study heavily relies on empirical science, which requires the collection of numerical weather data. To this end, the positivist approach must be considered to achieve some key objectives of this research.

Constructivism, often combined with interpretivism, is such a perspective, and it is typically seen as an approach to qualitative research. Social constructivists believe that individuals seek understanding of the world in which they live and work. Individuals develop subjective meanings of their experiences – meanings directed toward certain objects or things. Creswell (2017) posits that these meanings are varied and multiple, leading the researcher to look for the complexity of views rather than narrowing meanings into a few categories or ideas. The goal of the research is to rely as much as possible on the participants' views of the situation being studied. Constructivist researchers address the processes of interaction among individuals with the intent to make sense of the meaning others have about the world. In discussing constructivism, Crotty (1998) associates it with qualitative research which is largely inductive, with the inquirer generating meaning from the data collected in the field.

Proponents of the transformative worldview have always believed that postpositivism imposed strict rules and theories which did not give due consideration to matters that concern the marginalized in the society (Creswell 2017). According to Mertens (2010), a transformative worldview holds that research inquiry needs to be intertwined with politics and a political change agenda to confront social oppression at whatever levels it occurs. In transformation research, the inquirer engages the participants, which sometimes involves the designing of questions, collection, and analysis of data. Transformative research thus provides a *platform* for participants so that they can raise their awareness and advance an agenda for change to improve their lives.

Morgan (2014) indicates that pragmatism is a new paradigm that replaces the older philosophy of knowledge in which research is understood in terms of ontology, epistemology, and methodology.

Hennink et al. (2010) refer to positivist and interpretivist as the main paradigms of quantitative and qualitative research respectively. Marsh and Stocker (2010, p. 193) assert that "a positivist tends to prefer quantitative analysis in order to produce objective and generalizable findings, whereas an interpretivist is concerned with understanding, rather than explanation, and makes use of evidence based on qualitative research." According to Ponterotto and Grieger

(1999), positivism serves as the primary foundation and anchor for quantitative research. It is important to note that both positivism and interpretivism have strengths and weaknesses. The main strengths and weaknesses of the two schools of thought identified by Easterby-Smith et al. (2002) are presented in table 4.1.

Table 4.1 Strengths and weaknesses of positivism and interpretivism (Adapted from Easterby-Smith et al. 2002).

Philosophy	**Strengths**	**Weaknesses**
Positivism	Wide coverage of the range of situations Economical and fast	Not flexible Does not offer effective understanding of process
Interpretivist	Ability to understand people's meaning Adjusts to new ideas/issues as they emerge	Could be time consuming and requires substantial amount of resources Analysis and interpretation usually involving Process, pace, and end point difficult to control

"Pragmatism, on the other hand, has to do with mixed methods research, in which case inquirers freely draw from both quantitative and qualitative presuppositions in their research. This means that researchers have the freedom to choose the methods and procedures which they find suitable" (Creswell 2014). Tashakkori and Teddie (2010) posit that pragmatism underpins mixed methods studies, as it offers the researcher the opportunity to use several approaches to obtain an in-depth knowledge about an issue.

Creswell (2014) outlines the following as basis for pragmatic research:

- Pragmatism is not restricted to a single philosophical system and reality, and it applies to mixed methods research, in that, inquirers draw freely from both quantitative and qualitative assumptions when they engage in their research.

- In pragmatism, a researcher has the freedom to choose the methods, techniques, and procedures they believe would best meet the purpose of the research.
- To pragmatists, the world is not an absolute unity, and similarly, mixed methods researchers look to many approaches for collecting and analysing data rather than subscribing to only one way, say, quantitative and qualitative.
- Pragmatists believe that truth is what is workable at a given time. In mixed methods study, researchers make use of both quantitative and qualitative data in to provide the best understanding of a research problem
- The pragmatist researchers look to the *what* and *how* to research, based on the intended consequences – where they want to go with it. Mixed methods researchers need to establish a purpose for their mixing, a rationale for the reasons why quantitative and qualitative data need to be mixed in the first place.
- Pragmatism offers multiple methods, different worldviews, different assumptions, as well as different forms of data collection and analysis.

As earlier indicated in chapter 1, this study fills an important gap in UHI studies as it requires the need to understand the dynamics within a specific context. The research has adopted the pragmatist research philosophy because based on findings from the literature, assessing urban heat island intensity requires the collection of quantitative data. Second, this study seeks to investigate the main factors that have culminated in the morphological changes in the city over the years. This is against the backdrop that urban morphology can significantly affect urban heat island intensity. The second aspect of the research therefore requires qualitative data collection. To obtain both quantitative and qualitative data, the mixed research methods would have to be used. Adopting the pragmatist philosophy would therefore offer the researcher the freedom to use methodologies that would aid the collection of the two different data types needed for the study.

4.4 Approach to the inquiry - methodological choice

For this research, it is important to first carry out an empirical study, which involves the quantification of UHI in the CBD of Accra. The next step involves obtaining the opinions of some built environment professionals who are very familiar with the city and have knowledge in the UHI subject. Gathering the qualitative data helps bring to the fore, experiences, attitudes, behaviour, and above all, views of the above-mentioned professionals. It is expected that the views of the interviewees will shed more light on some of the causal factors of UHI in the city.

Mixed methods is defined as a procedure for collecting, analysing and combining both quantitative and qualitative data at some stage of the research process in a single study in order to gain a better understanding of the research problem (Tashakkori and Teddlie 2003, Creswell 2005, Ivankova et al. 2006). Ivankova et al. (2006) posit that neither quantitative nor qualitative methods can sufficiently capture the trends and details of a research situation, thus combining both methods will promote a stronger analysis. The two methods will complement each other and thus take advantage of the strengths of each.

Various researchers (Tashakkori & Teddlie 1998, Johnson et al. 2007) consider mixed method design as the combined use of both quantitative and qualitative methods in a study. Ryan et al. (2007) have on the other hand opined that studies which make use of two different quantitative or qualitative methods can be said to be using a mixed methods approach. Kumar (2014) describes a situation where different methods from a single paradigm are selected for a study as 'multiple methods' approach. This study has employed the mixed methods approach because it has used both quantitative and qualitative methods.

Depending on its objectives, a research endeavour may be classified into descriptive, correlational, explanatory, or exploratory (Kumar 2014). A descriptive study is a means of discovering new meaning and it systematically and accurately describes the facts and characteristics of a phenomenon, situation, problem, or area of interest (Dulock 1993). In a correlational study, the focus is on determining a relationship or association between two or more variables or aspects of a phenomenon (Asamoah 2014). In explanatory research, there is an effort to clarify *why* and *how* there is a relationship between two aspects of a situation or phenomenon. A study is said to be exploratory if it is undertaken with the view to exploring an area where little is known (Kumar 2014).

There are several mixed-methods research approaches for research design, but Creswell et al. (2003) focuses on three primary designs namely, convergent mixed methods, explanatory sequential mixed methods and exploratory sequential mixed methods and defines them as follows:

- In convergent mixed methods design, the researcher converges or merges quantitative and qualitative data to provide a comprehensive analysis of the research problem.
- In explanatory sequential mixed methods, the researcher first conducts quantitative research, analyses the results, and builds on the results to explain them in more detail with qualitative data. It is explanatory because the initial quantitative data results are explained further with the qualitative data and it is sequential because the initial quantitative phase is followed by the qualitative phase.
- Exploratory sequential mixed methods design is the reverse sequence from the explanatory sequential type. In this approach, the researcher first begins with a qualitative phase and later uses the data so analysed, to build into a second, that is a quantitative phase.

This study identifies with the 'mixed methods explanatory sequential design'. Kumar (2014) posits that in explanatory research, there is an effort to clarify *why* and *how* there is a relationship between two aspects of a situation or phenomenon. By employing this research design, it was possible to gain an in-depth understanding of the main causes of the heat build-up in the study area, and how those causal factors contribute to the phenomenon. Two phases are involved in this method: first, collecting and analysing quantitative data, followed by qualitative data, and these are done consecutively within a study (Ivankova et al. 2006).

In summary, postpositivism, which is associated with quantitative research, concerns itself with causal relationships (Marsh and Stocker 2010).

Constructivism, which is guided by principles of interpretivism, focuses on meaning and thus uses qualitative research to gain in-depth understanding of a phenomenon. Pragmatists have highlighted the need to freely use research methods that would best meet the goals of a study. Being an empirical research, which would ultimately be underpinned by verifiable evidence, it was deemed necessary to quantitatively collect weather data using scientifically calibrated weather instruments to assess the UHI intensity pattern in the study area. It was also realised that various sets of qualitative data: Landsat images, photographic images, and land use maps would be needed to obtain in-depth understanding of the morphological characteristics of the city and how they impact the UHI. To further get meaningful insights into the impact of the built environmental issues on the UHI dynamics, one-on-one interviews had to be conducted.

4.5 Research Strategy

Bryman (2008) defines research strategy as "a general orientation to the conduct of research." Saunders et al. (2009) have also defined research strategy as "the general plan of how the researcher will go about answering research questions." As indicated in the literature review (chapter 3), current protocols for urban heat island studies (Stewart & Oke 2012) point to the need to carry out the measurement of weather data in identified local climate zones (LCZs). It is proposed that the collection of the weather data is done by mobile and stationary surveys. The employment of spot measurements and mobile is consistent with Oke's (1984, 2006) proposal for measuring canopy layer urban heat island (CLUHI), which involves: (a) stationary field measurement and (b) mobile survey.

The collection of the qualitative data, on the other hand, is to be done through interviews. As Hennink et al. (2010) has opined, qualitative research allows the researcher to understand issues from the perspective of research participants who would be engaged. By this, the researcher will understand the meanings and interpretations of the research participants' opinions on the issues they will point out. This is meant to unearth the main factors that account for the UHI phenomenon within the context of Accra in a holistic manner.

4.6 Data collection methods and procedures

According to Smith (1989), methods refer to specific design elements and strategies for data collection, and the type of data which will be needed for a study. As already indicated, this study will depend on both quantitative and qualitative data. The research design for the study that summarizes the methodology, and the methods of data collection is presented in the flow chart in figure 8.

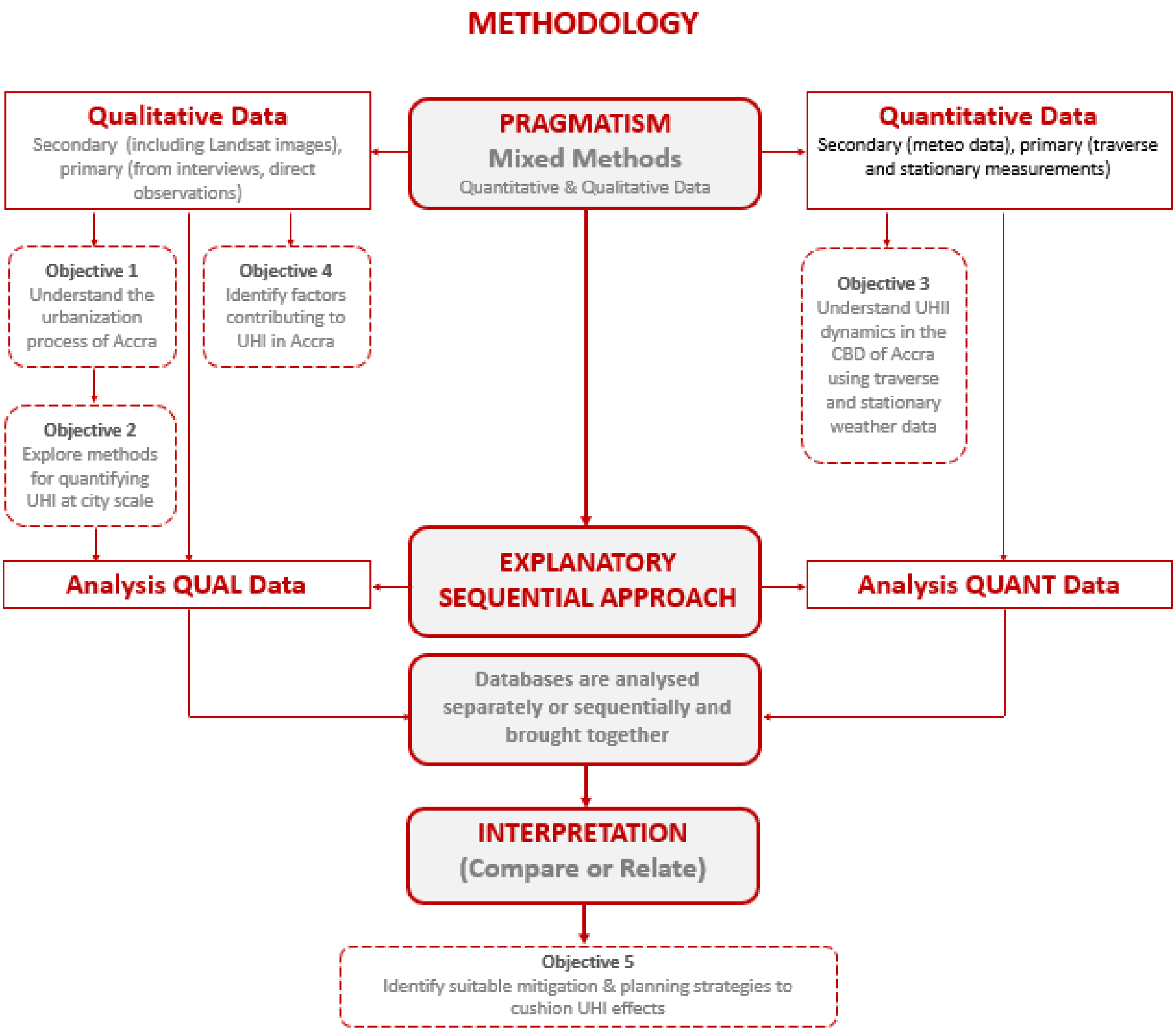

Fig 8 Flow chart depicting research methodology. Author generated

4.7 Rationale behind the selection of measurement procedure used for the collection of the weather data

Mirzraei (2015) corroborates Voogt's (2014) assertion that the resolutions of building and microclimate models within the urban canopy layer are higher, but spatially, it is impossible to extend them to cover the whole city. This is because of the complex nature of the important parameters and the associated high cost. Meso-scale models, on the other hand, are appropriate for studying the large-scale impact of the UHI; however, they are not adequately accurate in terms of providing UCL details. This points out an obvious limitation in the use of meso-scale models for CLUHI. Although the use of a satellite platform offers the advantage of wide spatial coverage, it offers a rather limited resolution. On the other hand, relying on aircraft platform for higher resolution will be expensive, as posited by Branea et al. (2016), and therefore not economically viable for this research. A major advantage of measuring air temperature for UHI analysis, and for that matter the CLUHI of the CBD of Accra, is that it is made up of a combination of heat emissions from urban surfaces, human activities, and the surrounding landscape which will give climate measurements that will be representative of the overall built-up environment under study. Since the CLUHI is to be measured in both daytime and night-time, thermal infrared satellite data that are captured during daytime when UHI is not well developed will not be appropriate; besides, that measurement does not take air temperature into consideration.

As posited by EPA (2014), CLUHI is present within the space or layer inhabited by people. Since it is also intended that the outcome of this study will benefit the assessment of both building energy efficiency and outdoor pedestrian thermal comfort, it will be prudent to take measurements within the urban canopy layer. With the area chosen for the study being within the city centre, a microclimate model is proposed, which is consistent with Mirzaei (2015), as earlier discussed. Although it is possible to use meso-scale models to investigate the effect of UHI on a large-scale, their level of accuracy is not good enough to show details of the urban canopy layer (Mirzaei 2015).

4.7.1 Procedure for Measuring Canopy Layer Urban Heat Island

CLUHI is measured through a network of sensors at standard or screen level at approximately 1.5m (Oke 1984). The design of the network of sensors considers urban and rural sites that are of interest. The sensors are to be well shaded and ventilated, and their location must respond to: (1) the main objective, (2) the sensor source area, and (3) the diversity in types of rural areas surrounding the main city.

Branea et al. (2016) identify two types of assessments that need to be made to measure the climate data of the surroundings: (1) the local scale surroundings, introducing parameters such as the urban climate zone (UCZ), the dominant land use type, the topography, the extent of land cover by vegetation, built surfaces, water and open land, the height of trees and buildings in the surroundings, the typical building materials used in construction, the traffic density and (2) the sensor heights, the surface cover, the soils and materials under cover, the building types and the roof types.

As earlier indicated, and consistent with (Oke 1984, 2006), the two main field measurement methods that are have been considered for this study include: (a) stationary field measurement and (b) mobile survey. In stationary field measurements, an area as large as a city or part of it and a surrounding location are selected for analysing UHI. A few monitoring points or stations are made distinct to represent identifiable local climate zones (LCZ) for the whole area being studied. Stationary survey therefore involves the observation of several stations in an area being studied. Parameters identified for the assessment of UHI are measured and subsequently computed to determine their effects on the various UHI intensities that are obtained. With this method, a relationship is established between various land use/land cover types or LCZs and their respective air temperatures, which can benefit future planning (Sonam et al. 2014).

Measurements done through mobile survey are to cover almost all land use types that characterize the study area (CBD of Accra) are identified. The selection of various monitoring sites or locations for the study is based on land use classification, density, vegetation, and other in-situ observations (Kruger and Tamura 2015). The selection of the route for the survey as well as the monitoring points is done taking into consideration, the different LCZs identified, accessibility, and personal safety. For the mobile traverse, a vehicle travels selected routes at a slow but steady speed. According to Sonam et al. (2014), to avoid possible variation in the weather, it is recommended that a mobile survey is completed within 1 to 1.5 hours. This conforms to WMO's official time stamp of 1 hour for the monitoring of points along mobile transects in UHI studies (Kruger and Tamura 2015). The instruments used for the measurements are weather sensors, fixed on the vehicle with insulation, which is meant to avoid or significantly minimize the effect of vehicular movements on the readings. The insulation around the instrument is also to ensure that the validity of air temperature measurements is not adversely affected by heat emissions from the body of the traverse vehicle. In addition to challenges that are associated with vehicular speed, Branea et al. (2016) indicate that there is a problem in avoiding the influences of vehicular exhaust emissions. With this method, temperature relationship between various areas could be identified, and a spatial temperature or UHI distribution map created (Sonam et al. 2014).

4.8 Data collection, analysis, and interpretation

This section presents the procedures used in collecting the data. It also explains how the various data sets are analysed and interpreted.

4.8.1 Pilot study

The essence of conducting the pilot study was to test how feasible the method selected for the data collection would be. Through the pilot study, potential challenges could be identified so that appropriate adjustments could be made for the main data collection.

This research aims at investigating the UHI intensity at the local scale and microscale, which is consistent with (Oke 1987, Salvati et al. 2017). At the local scale, the investigation covers a horizontal range of 0.5 – 10 km and within the urban canopy layer, whilst that of micro scale covers a horizontal range of 100 m – 0.5 km and at building canopy layer (Kim and Brown 2021). At both scales, weather data could be collected using weather stations mounted on mobile platforms as well as temporarily fixed weather stations.

Following Salvati et al. (2017), the assessment was done by comparing air temperature measurements at a rural or a sparsely built location on the outskirts of Accra (referred to as the reference location) with that of an area within the CBD of Accra. The pilot study was conducted in December 2017. The measurement campaign (i.e., mobile survey) was conducted in different urban canyons within the different LCZs that had been identified. The use of mobile traverse would make it possible to investigate the UHI at each monitoring location and the immediate surroundings within its LCZ (micro scale), whilst at the same time, the UHI variation between the various LCZs across the study area (i.e., local scale) could also be assessed. The mobile traverse measurements were taken at the reference location and 8 selected monitoring points within the CBD. Stationary measurements were not considered as part of the pilot, but rather for the purpose of collecting the main data, potentially safe sensor locations were explored and identified. This was because the stationary data collection procedure was not seen to be potentially challenging.

The pilot study was meant to gather both primary and secondary data. The primary data collected were weather elements: air temperature, and relative humidity. The secondary data collection in the pilot study focussed on: (1) climate data from the Ghana Meteorological Agency (GMA) over a thirty-year period (from 1987 to 2017) and (2) documentation on the urbanization of Accra the various stages of significant morphological transformations over the years. It is worth indicating that unlike the former secondary data, the latter secondary data set was not readily available.

4.8.1.1 Mobile survey in pilot study

Mobile surveys have been widely used in UHI studies (Oke and Maxwell 1975, Cardoso et al. 2017). The routes used for mobile surveys could be linear or circuitous and huge weather data could be generated within a fairly short time. It is recommended that the average vehicle speed for this type of survey should be 30 km/h, and mobile traverse should be carried out around sunset, on calm evenings under clear skies, since during that time, differences in micro and local climates are maximized (Eliasson 1996, Oke 2004, Cardoso et al. 2017).

The route used for the mobile campaign traversed 8 monitoring sites or locations in the city, namely Aviation House, Airport City, 37 Military Hospital, Jubilee House, Arko Adjei Interchange, Ridge Hospital, Ministries, and Novotel. The selection of the traverse route was informed by: (1) the need to cover LCZs that characterize the CBD of Accra and (2) traffic flow. A digital weather sensor (Eltek data logger) was mounted on four-wheel-drive vehicle to measure two weather elements (air temperature and relative humidity) across the length and breadth of the selected area in the CBD of Accra. The weather sensor was mounted on the car in such a way that there was no contact with the metallic rack. This precaution was to ensure that air temperature measurements would not be compromised by heat emitting from the roof of the car. The position of the mounted sensor was about 1.8 metres from the ground, which is consistent with Oke (2006b). Figure 9 depicts how the sensor was mounted on the vehicle. Consistent with (Oke 2004, Cardoso et al. 2017, Eliasson 1996), the vehicle was driven at a speed of about 30km/h in through the traverse route in the CBD of Accra. Several important landmarks were selected for the routes used, and the times at which they were traversed were recorded. The times recorded would be useful for correlating the selected points and the weather recordings for the development of a UHI map. Prior to the mobile traverse, weather measurements were taken at a reference location (i.e. Anyaa) which is on the outskirts of the city. Mobile traverse measurements were taken in the study area on 4 separate occasions: 26th, 28th, 29th, and 30th December 2017.

Fig 9 Vehicle-mounted weather sensor used for mobile survey in pilot study (Author generated)

For consistency, the measurements were taken around the same time of the day (between 3.00 pm and 5.00 pm). For this pilot study, the data obtained on the first day was the most reliable since that day had the smoothest traffic situation. The timing of the survey was informed by the fact that daytime UHI is pronounced during late afternoon, which is consistent with Soltani and Sharifi (2017).

For the mobile survey in the pilot study, important landmarks identified in the different LCZs were chosen as the monitoring points. Figure 10 shows the monitoring points and the route used for the mobile traverse. It is worth indicating that unlike the pilot study in which the traverse started from the reference location, in the main data collection, it was done only in the city centre.

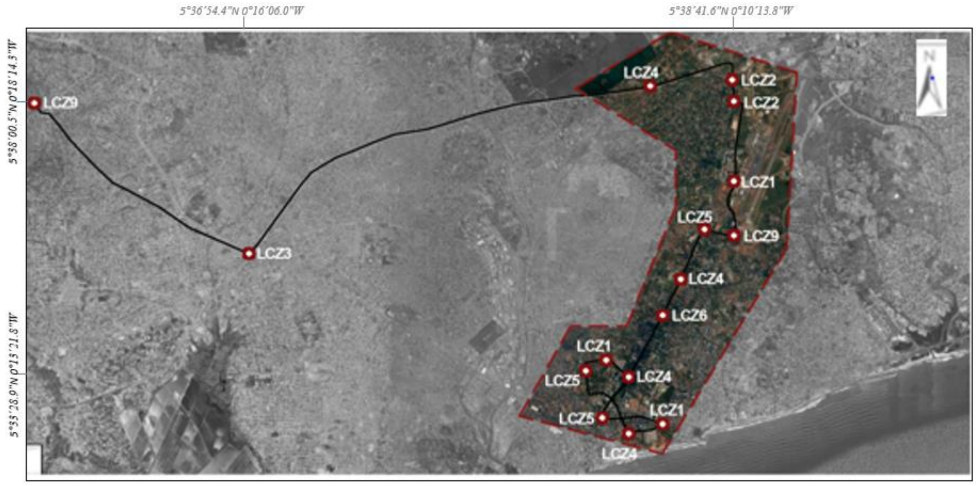

Fig 10 Map depicting traverse routes and monitoring points used for pilot study (Adapted from: Google earth)

4.8.1.2 Precaution

The weather measurements taken were tabulated against the various LCZs. To ensure data validity, outlier analysis was performed. This was meant to identify possible deviations of significance. Some deviations were noticed in the data obtained at the Accra Ridge area (LCZ5(8)). It was noticed that occasional heavy vehicular traffic in the area during the survey resulted in some outliers. Consistent with Bagade and Kotharkar (2018), the outliers had to be eliminated from the computation of inter-LCZ temperature difference.

4.8.1.3 Considerations after the pilot study

Based on the observations in the pilot study, it was seen that to avoid or minimize the effect of heat from vehicular exhaust fumes, it would be appropriate to carry out the mobile measurement campaign under good traffic conditions, that is when the vehicular traffic on the traverse route is reduced. This informed the decision to conduct the mobile survey between the hours of 15.00 and 16.00, which is a typical off-peak period in the city centre, and within which period UHI would be significant. It was also realised that a more effective way of obtaining reliable data would mean taking weather measurements at the selected monitoring locations simultaneously. This would therefore mean engaging 8 field assistants who would be designated to each monitoring location to take the measurements by trekking (i.e. on foot). Another benefit of having the 8 field assistants was that they could cover different spots within their respective designated LCZs. In view of the foregoing, carrying out the survey with a vehicle was considered as a back-up strategy.

4.8.2 Data for UHI analysis

As earlier indicated, the study makes use of both primary and secondary data. The primary data collection mainly involves direct observation using photographic recordings and measuring of weather elements. The secondary data collection focuses on (1) meteorological data from the Ghana Meteorological Agency (GMA, 2017) over a 30-year period (from 1987 to 2016), (2) Landsat images (from google earth), and (3) available data on morphological transformation in Accra over the 30-year period. The use of Landsat images and planning layouts is consistent with the recommendation by Ren et al. (2010). According to Sun (2017), climatic environment is characterized by its high randomness and uncertainty; therefore, the value of the same weather parameter at the equal moment could vary dramatically between different years. As a result of these features, simply applying the field measured values of one single calendar year as the climate condition in simulation setting is with inherent weakness and subject to be challenged for the lack of representativeness. TMY is a statistical year consisting of 12 typical meteorological months (TMM) based on field measurements spanning around 30 years. The thirty-year meteorological data obtained from the main weather station in Accra are used to generate long-term averaged data in the determination of what will be representative of TMY. Huld et al. (2018) define a typical meteorological year (TMY) as a set of meteorological data with values for every hour in a year for a given geographical location. The data are selected from hourly data in a longer period (normally 10 years or more). For each month in the year, the data have been selected from the year(s) which were considered most "typical" for that month. For instance, January might be from 2007, February from 2012 and so on, which gives an indication of typical mean annual values of various weather elements. The Landsat images aid the LCZ classification since they reveal the built-up characteristics of the study area.

4.8.3 LCZ Classification

As pointed out by Ren et al. (2016), in UHI or urban climate studies, it is important to comprehend urban morphology and its impact on local climate. The LCZ classification for this study is based on the 10 built types and 7 land cover types identified by Stewart and Oke (2012). The classification is shown in table 4.2.

Table 4.2 Classification of LCZ—after Stewart and Oke (2012)

Built Types	Land Cover Types
LCZ1—Compact high-rise	LCZ A—dense trees
LCZ2—Compact mid-rise	LCZ B—Scattered trees
LCZ3—Compact low-rise	LCZ C—Bush, scrub
LCZ4—Open high-rise	LCZ D—Low plants
LCZ5—Open mid-rise	LCZ E—Bare rock/paved
LCZ6—Open low-rise	LCZ F—Bare soil/sand
LCZ7—Lightweight low-rise	LCZ G—Water
LCZ8—Large low-rise	
LCZ9—Sparse low-rise	
LCZ10—Heavy industry	

Stewart and Oke (2012) have indicated that for sites that deviate from the standard set of classes outlined above, new subclasses representing combinations of built types, land cover types, and land properties can be created. This means that a standard LCZ type say LCZX could be assigned to a site based on the closeness of the properties of the former to those of the latter. For a site that has a predominant surface cover in addition to the building geometry, the LCZ could also be assigned a lower parent class say *a.* It has also been indicated that it is unlikely to have metadata that will match perfectly with the surface properties of one LCZ class. As such, assigning an LCZ to a site should be based on the selection of a "best-fit" class, but not necessarily based on exact match with LCZ classes (Stewart and Oke 2012). In classifying the various sites into LCZs, this research considers Oke's (2004) definitions for the 10 built types and 7 land cover types, as well as Stewart and Oke's (2012) geometric and surface cover properties for LCZs. For the purposes of geometric properties of the sites, this study makes use of aspect ratio (AR). The LCZ classification for the study area is presented in table 4.3.

Table 4.3 LCZ Classification for the study area

Sensor Location	LCZ	Aspect Ratio H/W
Airport City	LCZ1(2)	1.50
Aviation House/Glico	LCZ2(9)	0.21
Ministries (Ministry of Interior)	LCZ4(5)	0.55
The Law Courts Complex	LCZ4(5)	0.50
37 Military Hospital (Officer's Mess)	LCZ5(8)	0.11
Ridge Hospital	LCZ5(8)	0.15
Arko Adjei Int. (UDS Guest House)	LCZ6	0.30
Reference location (Anyaa)	LCZ9	N/A

The LCZ classification for the study area adopts Bechtel's method which involves the use of multiple observation data (Bechtel 2012). It thus depends on Landsat images obtained in 2016 as well as photographic recordings through direct observation. Snapshots of the LCZs identified in the reference location and the study area are shown in figure 11.

(**a**) *LCZ1(2) (Airport City)*
(b) *LCZ2(9) (Aviation House)*
(**c**) *LCZ3 (Baah Yard-Kwashieman)*
(d) *LCZ4 (The Law Courts Complex)*
(e) *LCZ4 (Advantage Place)*
(**f**) *LCZ4 (Accra City Hotel)*
(g) *LCZ4(5) (Cedi House)*
(h) *LCZ4(5) (National Theatre)*
(i) *LCZ4(5) (J.E.A Mills High Street)*
(j) *LCZ4(5) (Ministries*
(k**)** *LCZ5 (Fiesta Royale)*
(l) *LCZ5(8) (37 Military Hospital)*
(**m**) *LCZ5 (Adabraka Polyclinic)*
(**n**) *LCZ5 (Barnes Road/PWD)*
(**p**) *LCZ5(8) (Lands Commission)*
(**q**) *LCZ5(8) (Jubilee House)*
(**r**) *LCZ6) (Arko Adjei Int.)*
(**s**) *LCZ9 (Anyaa-NIC)*

Fig 11 Aerial images (snapshots) showing LCZS of the area surveyed (Source: Google earth)

A summary of the descriptions (built types) and locations of the identified LCZs in the survey area is presented in table 4.4

Table 4.4 Characteristics of identified LCZs between the reference location and the study area (using Stewart and Oke, 2012)

LCZ	Locations	Built Types
LCZ1(2)	Airport City	Compact high-rise with mid-rise
LCZ2(9)	Aviation House	Compact mid-rise with sparse low-rise
LCZ3	Awoshie Baah-Yard, Kwashieman	Compact low-rise
LCZ4	Advantage Place, Accra City Hotel/ Novotel-Movenpick	Open high-rise
LCZ4(5)	Ministries, The Law Courts Complex, Atta-Mills High Street	Open high-rise with open mid-rise
LCZ5(8)	37 Military Hospital, Jubilee House, Ridge Hospital,	Open mid-rise with large low-rise
LCZ5	Adabraka Polyclinic, Electoral Commission, PWD-Barnes Rd	Open mid-rise
LCZ6	Arko Adjei Interchange	Open low-rise
LCZ9	Anyaa-NIC	Sparse low-rise

4.9 Weather sensor used for weather data collection

The weather sensor selected for the measurement survey is the EL-USB-2 Temperature & Humidity Data Logger which is already calibrated. It is a standalone data logger which measures more than 16,000 readings over a range of -35 to +80°C (-31 to +176°F) and 0 to 100% relative humidity (RH) range. It has temperature accuracy of 0.55°C, typical (5 to 60°C); humidity accuracy of 2.25%RH typical (20 to 80%RH); internal resolutions of 0.5°C and 0.5%. The instrument has logging rates between 10 seconds and 12 hours and has immediate and delayed logging start. The logger is protected against ingress from water and dust to IP67 standard when the cap is fitted. The user can easily set up the logger and view downloaded data by plugging the data logger into the USB port of a computer and using the free EasyLog software. Data captured can then be graphed, printed, and exported to other applications for detailed analysis. It is worth stating that the main specifications of the weather sensor that have been indicated in this chapter have been sourced from the EasyLog EL-USB-2 user manual.

4.10 Collection of weather data

Since the study involved the collection of a large amount of data, a prudent as well as effective way of collecting and organizing the data was deemed important. With an internal memory of 16,382 temperature and 16,382 relative humidity readings and a battery life of 3 years, the EL-USB-2 Temperature & Humidity Data Logger had the needed features and robustness to support the collection campaign. For the mobile traverse measurements which lasted for about 30 minutes, logging interval of 10 seconds was used, since that would generate manageable data which could also be easily synchronized with the different areas that would be covered in the traverse.

The timing of the mobile traverse was done to avoid possible traffic congestion in the central business district of Accra. As indicated in chapter 4, it was also important to consider a period around sunset. Against this backdrop, the mobile traverse was carried out between 15.00 and 16.00. The mobile traverse was done at 8 different locations simultaneously. Each of the 8 monitoring locations was covered by a trekking field assistant. To avoid the effect of body temperature on the readings, the sensor was fixed to a piece of wood. The image in figure 12 depicts how the weather sensor was held by the field assistants during the survey. It was ensured that each sensor was always at an approximate height of 1.5 to

2.0 metres during the survey. Carrying out the traverse at different locations simultaneously was to ensure consistency when comparing the different weather data sets with the city’s overall weather.

Fig 12 Weather sensor held by trekking field assistant (Source: Author)

Measurements of day and night weather were done with stationary monitoring. For stationary measurements, the sensors were mounted in well-shaded areas and at 1.8 to 2.0 metres above the ground. Gartland (2008) has posited that in most cases, mobile traverse measurements last for an hour. Soltani and Sharifi (2017) argue that within an hour, microclimates could change noticeably and thus recommend a 30-minute logging time for mobile traverse measurements. The researcher settled on the 30-minute logging time in order not to unduly subject the field assistants to the adverse effects the scorching heat that prevailed.

4.11 Organization of weather data

At the end of each measurement campaign, data collected by each of the sensors was downloaded onto a laptop installed with the EL-Tek software called EL-WIN-USB 7.6 .exe. which was available on the supplier's website. The raw data that were downloaded from the data loggers were organized in spreadsheets using Microsoft Excel. The sensors recorded time, temperature, relative humidity, and dew point temperature, but for the purposes of this study, dew point temperature figures were removed from the columns created in the spreadsheet.

To accurately compare the weather data that were collected at the different monitoring locations and the reference location, all sensors were set to start and finish the recording around the same time, though not precisely, and were set to the same logging interval. The start times for the monitoring points were adjusted to the actual time recorded by the researcher, who coordinated the mobile traverse campaign.

Readings for each location were identified with the name of the location and the date(s) on which the weather data were collected. Worksheets containing the full weather data are in appendices 2 to 5. To make the large amount of weather data more manageable, averages were calculated to represent each minute of the mobile traverse. For overnight recordings that were done in the stationary measurements, averages were calculated for every hour.

4.12 Limitations of weather data collection methods

In as much as the weather data collection methods were deemed suitable, there were some inherent limitations which are presented in this section.

The use of a vehicle for the traverse would mean that it would not be possible to capture weather data across the different LCZs simultaneously. Furthermore, it had become clear from the pilot study that the presence of heavy vehicular traffic in the city centre would not promote a very smooth mobile traverse. Although this was improved when trekking field assistants were engaged in the main data collection, pedestrian safety issues resulted in some occasional interruptions during the campaign. It is worth indicating that due to security reasons, only areas that were deemed safe were monitored. Night-time traverse campaign was also avoided because of safety concerns. The number of weather sensors used was limited by the high procurement cost. Though, engaging field assistants in the traverse survey was beneficial, it meant that the extent of coverage area was limited by physical exhaustion and the harsh effect of the hot weather. Engaging trekking field assistants also meant that the researcher would not have maximum control over the accuracy of the records produced for all the 8 monitoring sites.

Security lapses at 2 monitoring sites resulted in the missing of 2 sensors during the stationary measurements in the warm-dry period. Another sensor had become defective at the end of this stationary survey during the same period, thereby limiting the amount of data that could be used for the analysis.

4.13 Collection of qualitative data

A few Ghanaian built environment professionals who live in Accra and are knowledgeable in UHI issues were purposively sampled for interview. This was to ascertain their thoughts on issues that relate to factors that affect urban heat island intensity in the city. A set of semi-structured interview questions were used so that other important information relating to the subject could be obtained. For flexibility, a semi-structured interview schedule was used, and this was in accordance with Bryman and Bell's (2004) position that "flexibility is vital for clearing inconsistencies in answers". Interview was preferred to questionnaire for this aspect of the enquiry since the response rate for the latter was seen to be *notoriously* slow in Ghana. By using interview for this study, as Kumar (2011) posits, the researcher would be able to collect in-depth information.

Prior to the interview, formal request letters were sent to each of the interviewees via email to seek their consent. The letter contained details of the research title, aim, and the relevant ethics policy. Having received positive responses to the request letters, the interviewees were each guaranteed anonymity and confidentiality in accordance with RGU research ethics policy. The interviewees were informed that the qualitative study would mainly centre on their experiences, views, and opinions on how the built-up nature of Accra has impacted the local climate, and for that matter, the UHI experienced in the core of the city. They were also informed that the interview would last between 40 and 50 minutes, and their consent was sought. The interview schedule, RGU research ethics and guidelines, and the formal request letter sent to the interviewees are in appendices 6, 7, and 8 respectively.

Through the interview, insights into how to address the identified challenges were also explored by the researcher. It was ensured that before the interviews, each participant granted the researcher permission to record.

4.14 Data Analysis

The most well-known mixing methods approach is the triangulation design, and the rationale for using it is "to obtain different but complementary data on the same topic" (Morse, 1991, p. 122, Creswell et al. 2006) to best understand the research problem. Using this model helps the researcher to arrive at valid and well-substantiated conclusions on a given phenomenon.

This research attaches high importance to both quantitative and qualitative data bases. For the analysis of this research, the convergent parallel mixed method is proposed (see figure 13). The analyses of both data bases were done sequentially, and ultimately converged during interpretation or discussion. This approach was employed, because first, the research involved the generation of a large amount of quantitative data (weather data) which could be better understood or made more meaningful after analysis. Second, the other set of data was qualitative in nature and therefore required a different method of analysis.

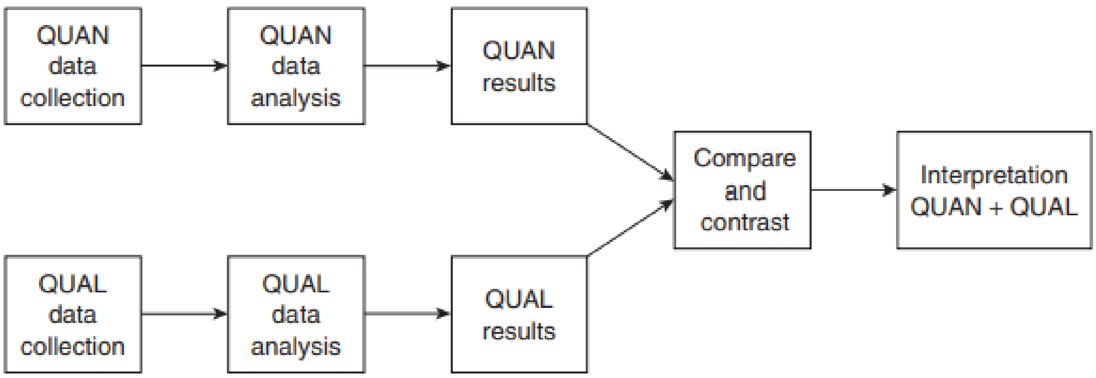

Fig 13 Triangulation Design: Convergence Model (Source: Creswell & Plano Clark 2006)

4.15 Quantitative analysis

Consistent with the recommendation by (Giridharan and Kolokotroni 2009, Kolokotroni and Giridharan 2010, WMO 2011), as earlier pointed out in 3.11, the weather data generated was analysed using universal statistical methods and a suitable computer software (i.e. excel).

For the UHI, it was important to prepare spread sheets which would indicate for each location, important climate data (temperature, humidity) and other variables such as time of reading, land use designation, surface designation, aspect ratio of immediate road/street to building(s), descriptive field notes etc. Presenting the data in graphs using excel was deemed appropriate for analysing the effects of the above-mentioned parameters on the UHII dynamics. Consistent with Dawson (2009), the use of suitable computing software for statistical analysis was considered, as it was meant to help the researcher to "explore connections among two or more variables."

4.16 Qualitative analysis

The analysis involved a "careful aggregation of the qualitative data into small number of themes" (Creswell, 2013). Guest et al. (2012) have emphasized the need to focus on the relevant data and disregard other parts of it when analysing qualitative data. Data collected through interviews were analysed by categorizing and coding various responses from each interview. Qualitative analyses were used to understand the correlation between the land use pattern of Accra and the UHI. This was achieved by comparing the land use map and the UHI map.

4.17 Conclusion

Having given an overview of how previous researchers have defined research methodology in this chapter, it has been inferred that research methodology is the main philosophy that underpins the strategies, methods, and procedures with which a research is undertaken. The chapter further explored major research philosophical worldviews including *positivism, constructivism, transformative* and *pragmatism*. Consistent with Tashakkori and Teddlie (2010), it has become evident that the pragmatist philosophical stance underpins the methodology that would suit the research, given that both numerical and qualitative data would be needed.

It is further indicated that the proposed weather data collection was done through mobile and stationary surveys. The employment of spot or stationary measurements and mobile is consistent with Oke's (1984, 2006) proposal for measuring CLUHI. This chapter also presented the research design that was employed for the research. The chapter has also elucidated the procedure that was used in carrying out the weather measurement campaign. Semi-structured interviews were deemed suitable for the qualitative data collection. Due to the challenges vehicular traffic posed, it was deemed more suitable to engage research assistants to conduct the mobile survey on foot. By engaging research assistants in the mobile survey, it would be possible to minimize the adverse effects of vehicular traffic and collect weather data from each of the monitoring sites simultaneously. Subsequently, the chapter indicates that the quantitative and qualitative data sets have been analysed separately and ultimately triangulated.

In the next chapter, results of the quantification of urban heat island intensities in the selected monitoring area in the CBD of Accra are presented.

CHAPTER 5

QUANTITATIVE ASSESSMENT OF UHI

5.1 Introduction

This chapter deals with the collection, organization, and analysis of the quantitative data (i.e. weather measurements). The procedures used for measuring the weather and the urban heat island within the canopy layer are described in the chapter. As indicated in the previous chapter, field measurements were carried out in local climate zones (LCZs) based on Stewart & Oke's (2012) classification method for collecting weather data. Weather sensors were used to carry out both mobile traverse and stationary measurements. Statistics showing the urban heat island intensity dynamics in the monitoring locations selected in the various local climate zones are presented in charts or graphs. The chapter further analyses the urban heat island intensity dynamics in the context of the different morphological characteristics present in the various LCZs and their overall or mean effect on the CBD.

5.2 Additional weather data

In addition to temperature and relative humidity, other weather parameters were seen to be of significance to the study due to their effect on urban heat island. As earlier stated in the literature review, the other weather parameters that are deemed useful for this investigation include wind speed and shortwave solar radiation and cloud cover. Since the instrument available for the measurement campaign could not record the above-mentioned parameters, the relevant data had to be obtained from Ghana Meteorological Agency Office in Accra. Unfortunately, data were available for wind speed, shortwave solar radiation, but not cloud cover. It is worthy of mention that since urban heat island is most felt under clear skies. The weather data were therefore collected on days when cloud cover was minimal to ensure that sun rays reaching the canopy layer could be maximized.

It is worthy of mention that the Meteorological Office in Accra has only one ground observation station, which is located at the Kotoka International Airport (edged yellow in figure 14). In view of this, the meteorological data could only be treated as data for the city, but not as local climate data. The eight locations in the city that were selected for the measurement campaign are also shown in the figure.

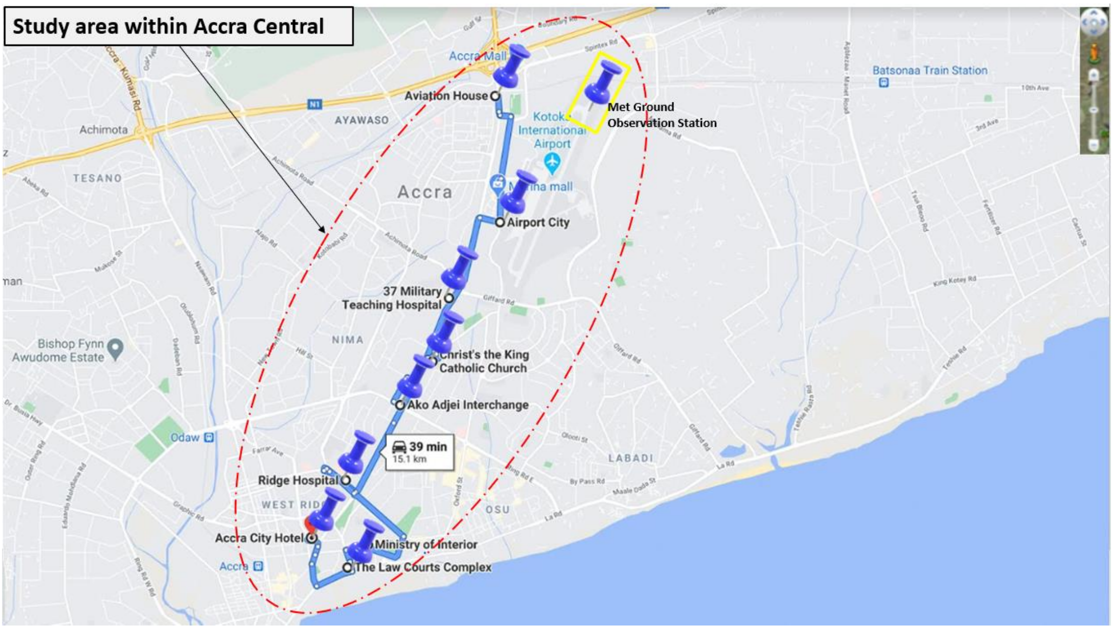

Fig 14 Locations of 8 monitoring sites and Accra Met Office's observation station (Adapted from Google earth)

For the mobile traverse, averages were calculated for each monitoring location, and those were the data used for comparing the different LCZs. To establish various correlations between the urban heat island intensities and the land use characteristics within specific local climate zones, the weather data obtained during the traverse and calculated for each minute within the 30-minute period were used.

5.3 Dynamics of Urban Heat Island Intensity at the various locations

The urban heat island intensity (UHII) for each location was obtained by subtracting the temperature of the reference location from that of the location. As indicated by Martin-Vide et al. (2015), mathematically, urban heat island intensity (UHII) is calculated as follows:

UHII = Temperature of an urban location – Temperature of rural or non-built up surroundings

From the above equation a positive result is an indication that urban heat island is present, whilst a negative result denotes the absence of urban heat island. A typical urban heat island profile is illustrated in figure 15. This study has mainly focused on the urban canyon, and the primary UHI data collected were air temperature and relative humidity. Possible correlation between air temperature, relative humidity and the other weather parameters were investigated. For specific UHII calculations, the air temperature values were used.

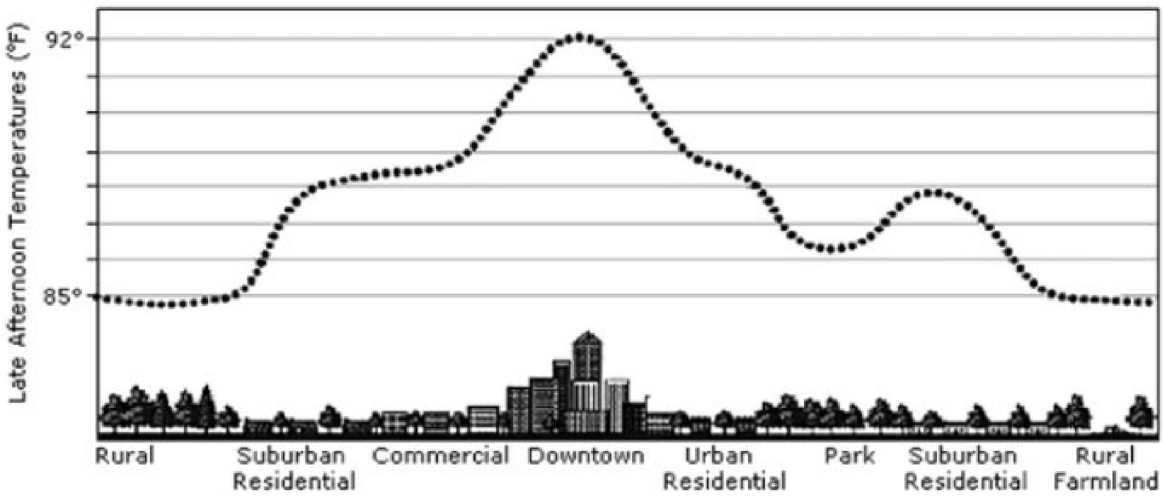

Fig 15 An urban heat island profile (Source: Frumkin 2002)

The selection of the monitoring points was based on the built-up characteristics which have varying canyon geometry. The built-up characteristics informed the creation of the local climate zones as explained in chapter 4. The main monitoring locations, their respective period of logging, and LCZs are presented in table 5.1.

Table 5.1 Monitoring sites, period of logging and LCZs

Monitoring site	Period of logging	LCZ
Airport City	30 minutes	LCZ1(2)
Aviation House	30 minutes	LCZ2(9)
Accra City Hotel	30 minutes	LCZ4
The Law Court Complex–Cedi House	30 minutes	LCZ4(5)
Jubilee House	30 minutes	LCZ5
37 Military Hospital – Lands Comm	30 minutes	LCZ5(8)
Ridge Hospital	30 minutes	LCZ5(8)
Arko Adjei	30 minutes	LCZ6
Anyaa-NIC (Reference Location)	30 minutes	LCZ9

It should be noted that at Cedi House and 37 Military Hospital, the traverse routes were extended to adjoining LCZs, as the investigation also sought to maximize coverage and to understand the UHI profile across the study area transversally. The UHII for each spot or landmark traversed was calculated based on the average temperature recorded at the minute they were traversed. The average UHII for each traverse route (i.e. monitoring site) was worked out as follows:

Average UHII = Ave. temp. – Ave. reference temp. (in the 30-minute period)

An average UHI intensity for all the 8 locations will depict the average UHII for the CBD of Accra and that was calculated as below:

$$\text{Average UHII of CBD} = \frac{\sum \text{UHII based on all sensors within 30 mins}}{\text{Number of sensors (i.e. 8)}} \quad \text{........... eq. 5.1}$$

The relevance of the average UHII of the CBD is that it represents the combined or overall effect of the individual canyon characteristics.

The traverse measurements were carried out on warm-dry days: 9th and 10th January 2019. It is worth indicating that during the cool-wet season, only stationary measurements were conducted because it was impossible to engage any trekking field assistants to carry out traverse measurements considering the high level of risk involved. Stationary weather measurements were carried out for both warm-dry and cool-wet periods. With stationary measurements, weather data for the cool wet season were collected between 29th and 31st July 2020 and that for the warm-dry season were collected between 22nd and 24th October 2020. To compare daytime and night-time UHII variations, the logging period had to be at least 24 hours. Due to the length of the stationary measurement period, a logging interval of 60 minutes was used. This was done to ensure that the amount of data collected could be managed.

Using the formula in equation 5.1, the average UHII in the CBD on both 9th and 10 January (i.e. days 1 and 2) are calculated as follows:

$$\text{Ave. UHII of on day 1} = \frac{\sum \text{UHII based on all sensors within 30 mins}}{\text{Number of sensors (8)}}$$

$$\text{Thus Ave. UHII in CBD} = \frac{(1.18+1.31+1.34+1.18+1.94+1.41+1.79+1.86)}{8}$$

Ave. UHII of CBD = **1.5**

Again, using the formula in equation 5.1, the average UHII in the CBD on day 2 (i.e. 10th January 2019) is calculated as follows:

$$\text{Ave. UHII in CBD on day 2} = \frac{\sum \text{UHII based on all sensors within 30 mins}}{\text{Number of sensors (8)}}$$

$$\text{Thus Ave. UHII in CBD} = \frac{(1.4+1+1.2+1.6+2.2+1.7+2+1.5)}{8}$$

Ave. UHII in CBD = **1.6**

5.4 Air temperature profiles of monitoring locations

The air temperature profile of the eight monitoring locations in the CBD for the surveys conducted on 9th and 10th January 2019 are presented in figures 16 and 17 respectively.

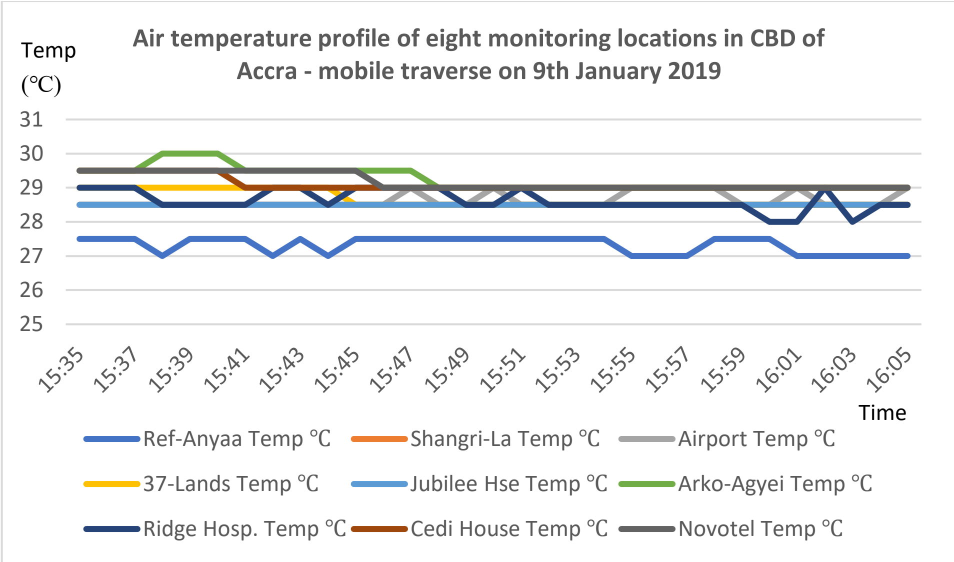

Fig 16 Air temperature profile of eight monitoring locations during mobile traverse on 9th January 2019 (Author generated)

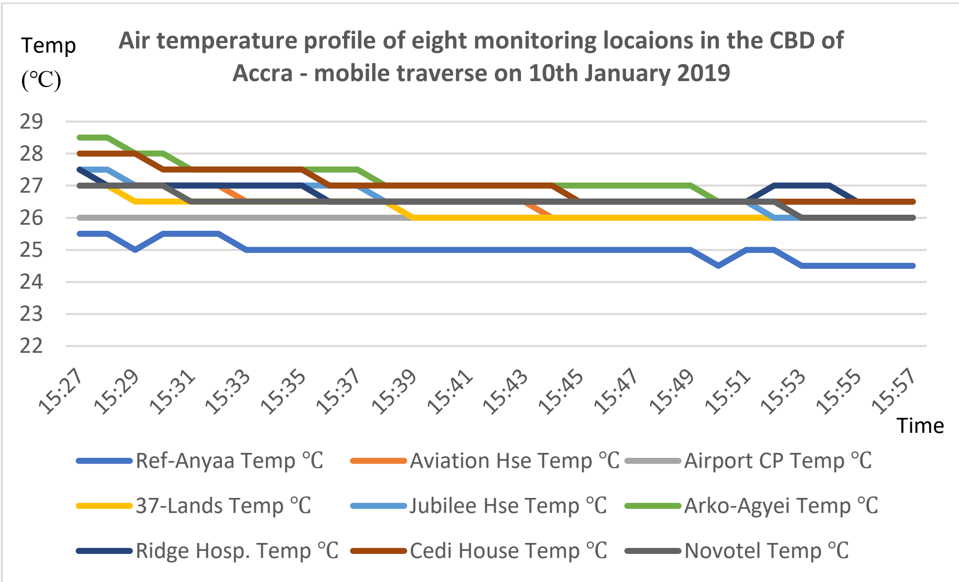

Fig 17 Air temperature profile of eight monitoring locations during mobile traverse on 10th January 2019 (Author generated)

As depicted in figures 16 and 17, the temperature profiles for both days show a significant difference between the temperature levels at the reference location and the 8 monitoring locations. On both days, a maximum UHII of 3℃ was observed at Arko Agyei. On the other hand, the minimum UHII on the 1st and 2nd days of traverse (i.e. 9th and 10th January) was 0.5℃, and this was recorded on the Ridge

Hospital – Osu and Airport City monitoring routes on the respective dates. The temperature profiles for the two different days are not the same for the same monitoring locations. This could have resulted from factors such as wind speed and direction and the possible effect of heat emission from vehicular traffic, given the busy nature of the study area. Using canyon characteristics such as aspect ratio, physical characteristics such as built-up nature, land use type, presence of vegetation, and various meteorological parameters, the urban heat island intensity dynamics observed at the various monitoring locations are presented and explained in the subsequent section.

5.5 Daytime air temperature and humidity dynamics in the different monitoring areas (LCZs)

5.5.1 Reference Location (Anyaa)

The reference location, Anyaa (LCZ9), is a sparsely built-up environment which is located on the outskirts of Accra. Buildings there are low-rise and are interspersed with substantial greenery. The image in figure 18 depicts the physical characteristics of the reference location.

Fig 18 Image showing reference location Anyaa-NIC

The graphs in figures 19 and 20 depict the weather data gathered at the reference location on days 1 and 2. The temperatures recorded on days 1 and 2 were 27 - 27.5℃ and 24.5 – 25.5℃ respectively. On both consecutive days however, the range of relative humidity values was 79.5 – 81%. The humidity level was found to be high, although the measurement was taken in the dry season.

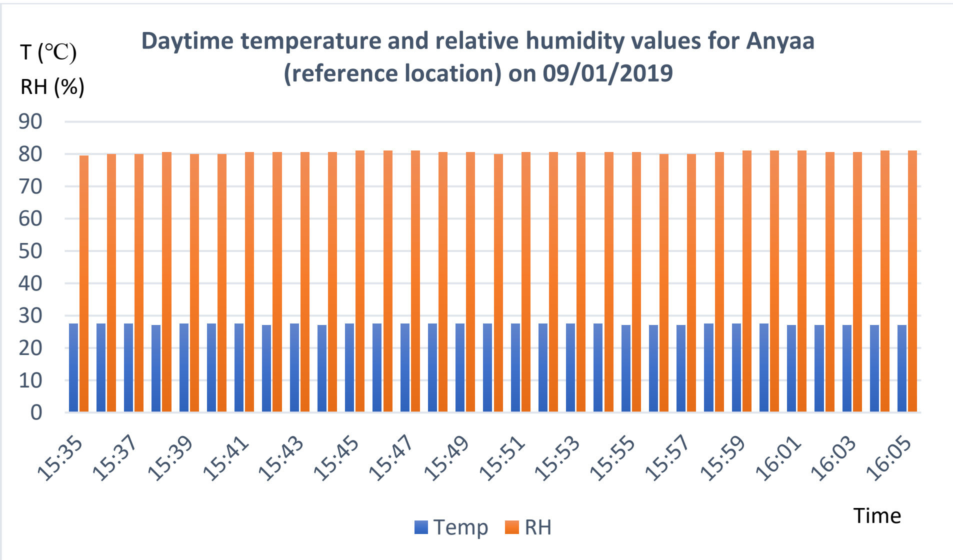

Fig 19 Graph showing temp. and RH values for Anyaa on traverse day 1 (Author generated)

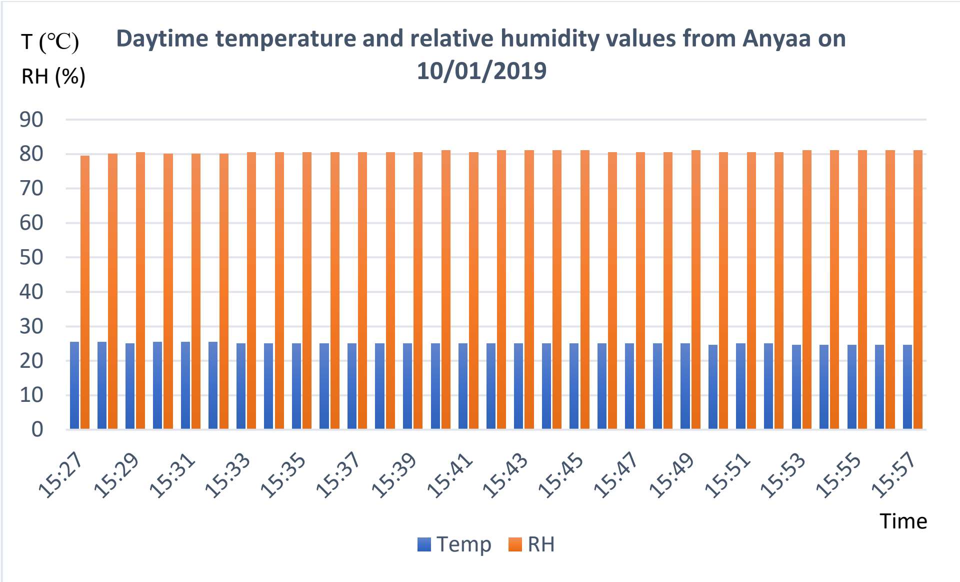

Fig 20 Graph showing temp. and RH values for Anyaa on traverse day 2 (Author generated)

5.5.2 Aviation House (Shangri-La)

Aviation House is within a compact mid-rise built-up area and thus falls under classification LCZ2(9). Located on the east of Accra, it is about a kilometre away from the main Airport Junction. The land use of the area is mainly civic and is composed of mid-rise office buildings which are between 3 and 7 floors high. There are patches of green spaces in this LCZ, but these are reduced due to the compactness of the layout or disposition of buildings. The image in figure 21 depicts the physical characteristics of the Aviation House area. Some shade trees are present along the main streets in the area, whilst the immediate surroundings or the compounds of most of the built-up spaces have sparse greenery.

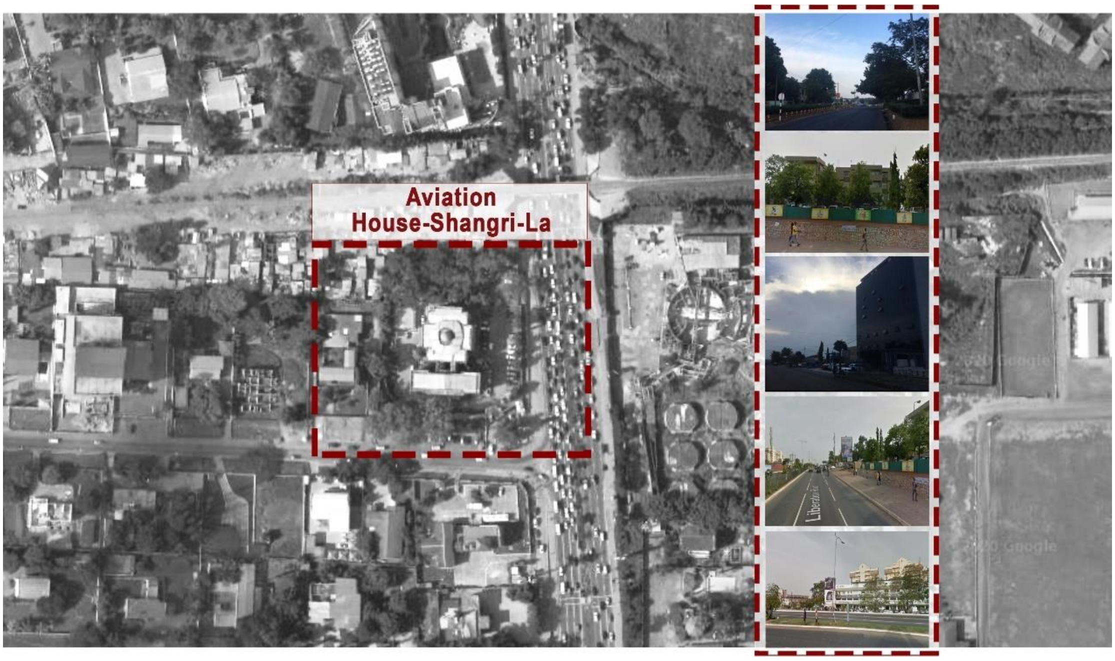

Fig 21 Image showing Aviation House area (Author generated)

The weather data gathered at the Aviation House monitoring location on days 1 and 2 are respectively depicted in figures 22 and 23. At this location, the average temperatures recorded on traverse days 1 and 2 were 28.5℃ and 26 – 27.5℃ respectively. On both consecutive days, however, relative humidity ranges were 63 – 63.5% and 60.5 – 63% respectively.

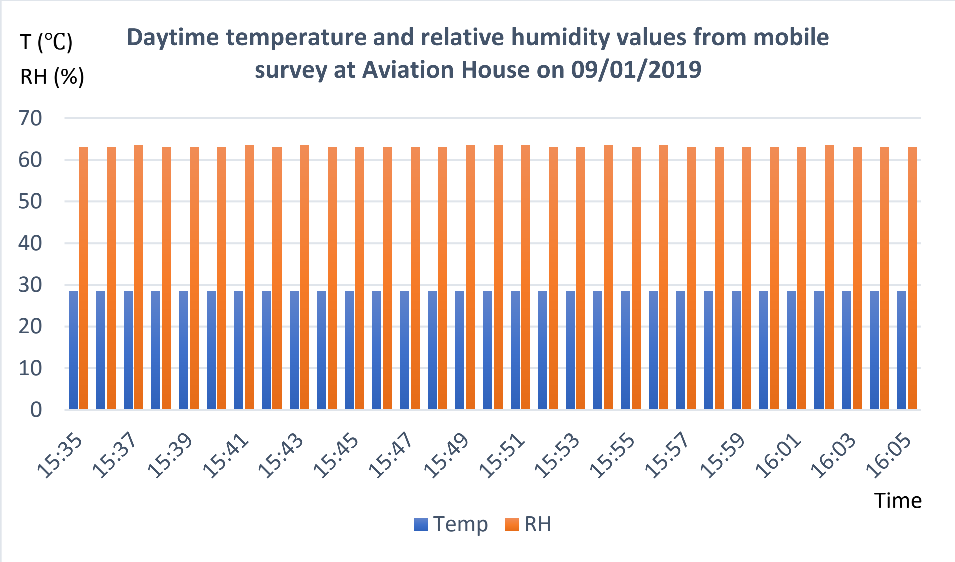

Fig 22 Graph showing temp. and RH values for Aviation House on traverse day 1 (Author generated)

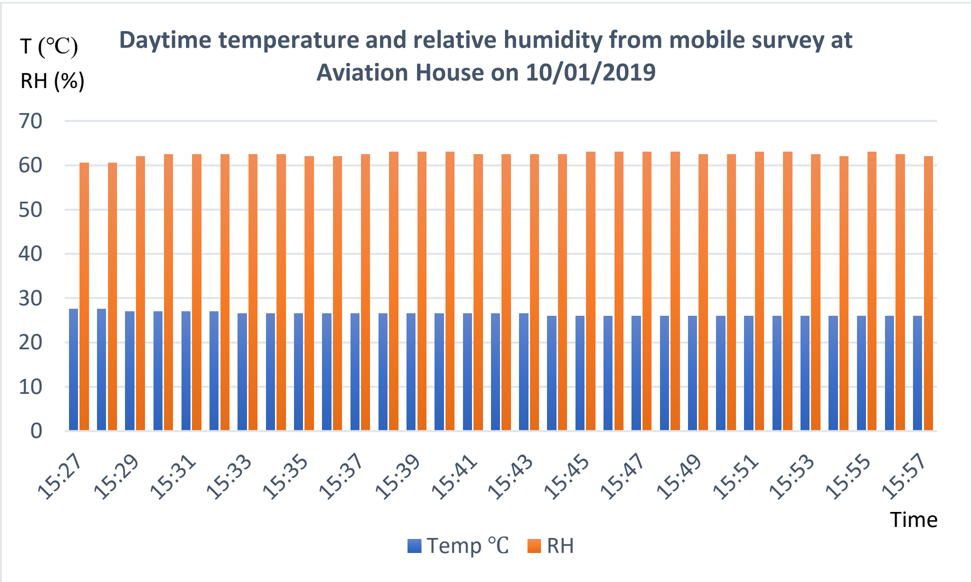

Fig 23 Graph showing temp. and RH values for Aviation House on traverse day 2 (Author generated)

5.5.2.1 UHII profile at Aviation House monitoring area

The urban heat island intensity profiles for the two days of mobile traverse at the Aviation house are depicted in the graphs in figures 24 and 25. It is worth indicating that on the second day of the traverse, the air temperature in the city was comparatively higher than that of the first day. The average daily temperatures on 9th and 10th January 2019 were 31.2℃ and 33℃ respectively.

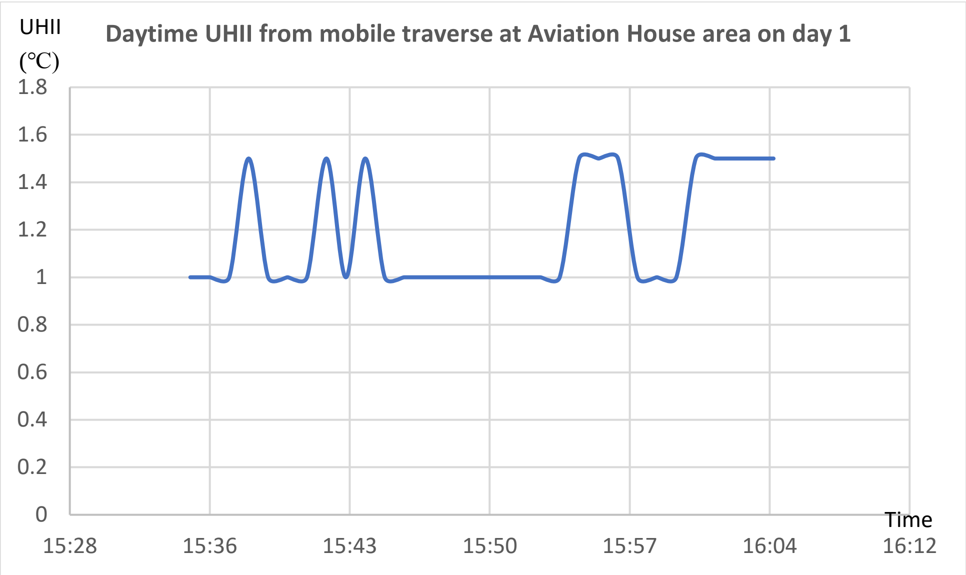

Fig 24 UHII profile for mobile traverse at Aviation House on 9th Jan 2019 (Author generated)

On the 1st day, the UHII range was between 1 and 1.5℃. In the first ten minutes of the traverse, the UHII fluctuated between 1 and 1.5℃ after about every 2 minutes. The 10th to the 20th minute showed a uniform UHII of 1℃, after which it fluctuated again between 1 and 1.5℃ at 3 to 4-minute interval. The nature of the UHII profile meant that it would be worth investigating what could have caused the variation. The areas traversed between the 10th and 20th minutes included GLICO, GHL Bank, Imperial Perking Restaurant, and the Polo Building. Having recorded the times at which the various sites were traversed, it was possible to match them with their respective UHIIs. On the 1st day, the sites that had UHII of 1℃ included Century, GHL Bank, Residence by Eagles, Kwarleyz residence, Imperial Perking Restaurant and Polo Building. The sites that had UHII of 1.5℃ included Kwarleyz Residence, GLICO, and the Aviation House.

On day 2, however, the first two minutes of the traverse showed an UHII of 2℃, after which it fell to 1.5℃. As shown in the profile depicted in figure 25, the UHII calculated for the third to the sixteenth minute remained at 1.5℃ and dropped to 1℃ on the 17th minute. From the 17th minute, the UHII remained uniform at 1℃ for 5 minutes, after which it fluctuated between 1℃ and 1.5℃ at 2 minutes intervals before flattening out at 1.5℃ in the last 4 minutes.

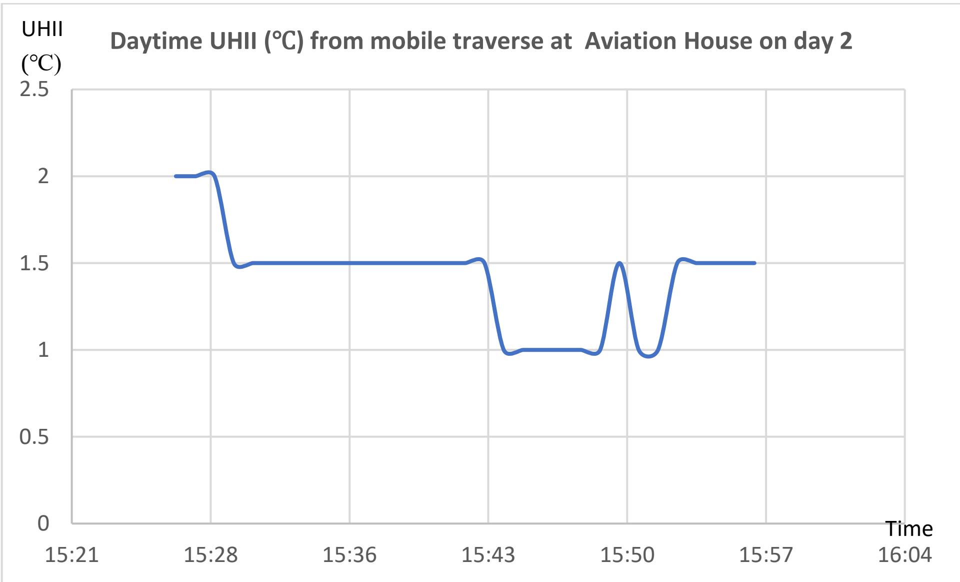

Fig 25 UHII profile for mobile traverse at Aviation House on 10th Jan 2019 (Author generated)

The areas traversed between the 3rd and 16th minutes included Kwarleyz Residence, Residence by Eagles, Airport Women's Hospital, Mustard Capital

Partners, GLICO, Bosch Company, and Airport Grande. The areas traversed between the 17th and 22nd minutes included Airport Women's Hospital, Residence by Eagles, Kwarleyz Residence, Century Aviation and GLICO.

As evident in the two graphs, for most parts of both traverse days, the UHII was between 1 and 1.5℃. On day 1, this UHII spanned the entire traverse period. On day 2, apart from the first two minutes which recorded an UHII of 2℃, the range was between 1 and 1.5℃ for the rest of the traverse period.

Mapping the times to the sites traversed revealed that Century Aviation, Airport Women's Hospital, Residence by Eagles, GHL Bank and La Chaumere had UHII of 1℃. The sites that experienced UHII of 1.5℃ were Residence by Eagles, Airport Women's Hospital, Mustard Capital, GLICO, BOSCH Office, and Airport Grande. The sites that recorded UHII of 2℃ were the Aviation House, and Kwarleyz Residence.

By comparatively analysing the data obtained for both days, it could be inferred that the areas that experienced high UHII were Aviation House, Kwarleyz Residence, GLICO, Residence by Eagles, Airport Women's Hospital, Mustard Capital, BOSCH Office and Airport Grande and the sites that experienced moderately high UHII include Residence by Eagles, GHL Bank, La Chaumere, Century, GHL Bank, Imperial Perking Restaurant, and Polo Building. The data has revealed that the Aviation House area (LCZ2(9)) could experience an UHII between 1 and 2℃ on a warm dry day. Indications of the UHIIs at the various traversed locations on days 1 and 2 are depicted in the maps in figures 26 and 27 respectively.

Fig 26 UHIIs at various locations in the Aviation House monitoring area on day 1

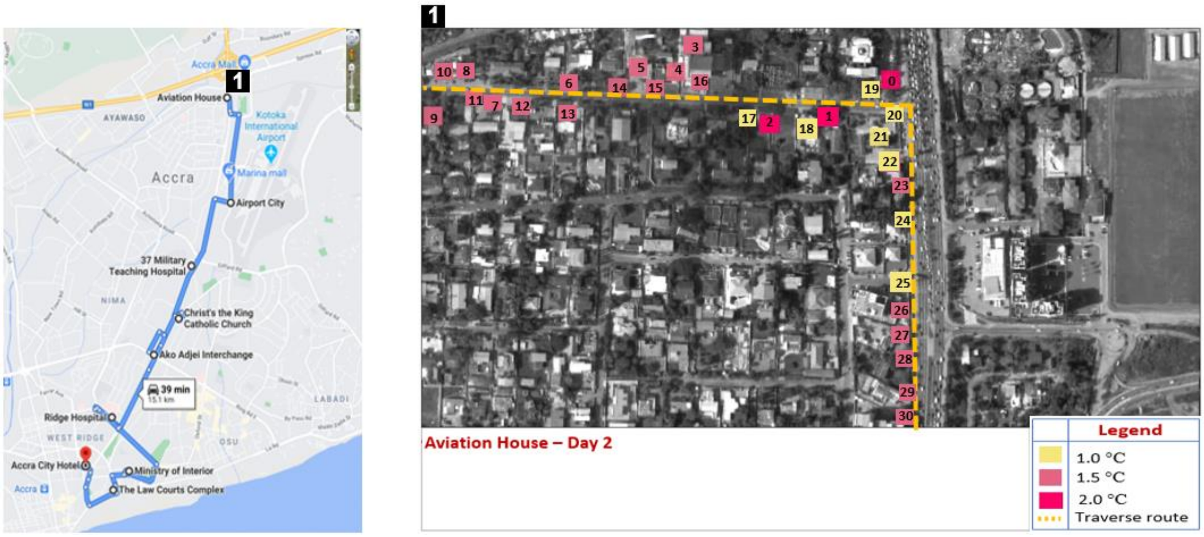

Fig 27 UHIIs at various locations in the Aviation House monitoring area on day 2

5.5.3 Airport City Park

Airport City Park is a compact high-rise built-up area and thus falls under classification LCZ1(2). Composed mainly of office and commercial facilities, the area is within the vicinity of Kotoka International Airport Accra – about half a kilometre away. Greenery is sparse in this LCZ, and most open spaces are characterized by hardscapes. Figure 28 depicts the physical characteristics of the Airport City Park.

Fig 28 Image showing the location of Airport City Park area (LCZ1) (Author generated)

The weather data gathered at the Airport City Park monitoring location on days 1 and 2 are respectively depicted in figures 29 and 30. At this monitoring location, the average temperatures recorded on days 1 and 2 were 28.5 - 29℃ and 26℃ respectively. On both consecutive days, however, relative humidity values were in the ranges of 66.5 – 67% and 65 – 67% respectively.

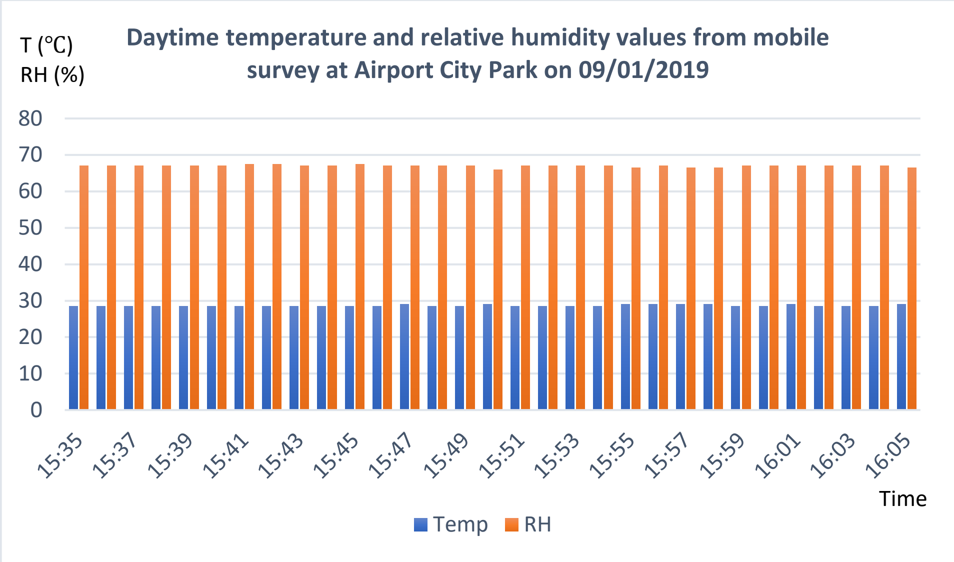

Fig 29 Graph showing temp. and RH values for Airport City on traverse day 1 (Author generated)

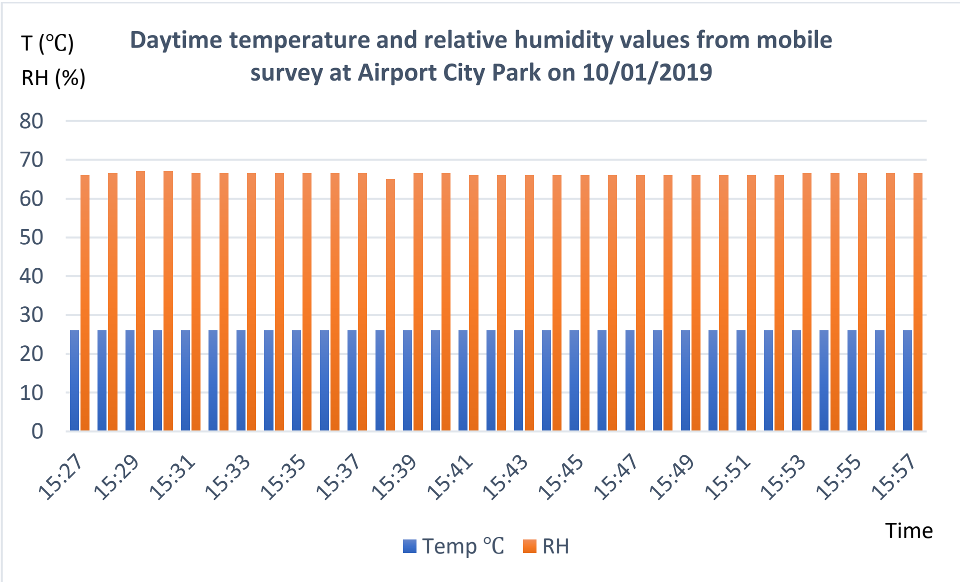

Fig 30 Graph showing temp. and RH values for Airport City on traverse day 2 (Author generated)

5.5.3.1 UHII profile at Airport City monitoring area

The graphs in figures 31 and 32 show the UHII profiles for the two days of mobile traverse at the Airport City. The average air temperature for the Airport City area based on the mobile traverse on the first day was 26℃.

On the first day of the mobile traverse, the UHII range was between 1 and 2℃. The UHII profile for the mobile traverse on the first day is presented in figure 31. The UHII fluctuated between 1 and 1.5℃ in the first 19 minutes of the traverse. It then fluctuated between 1 and 2℃ in the next 7 minutes. In the last four minutes of the traverse, the UHII range was between 1.5 and 2℃. It became evident that there were three clear UHII ranges: 1 to 1.5℃, 1 to 2℃ and 1.5 to 2℃. During the first 19 minutes of the mobile traverse, when the UHII was between 1 and 1.5℃, the sites traversed included Airport Shell Filling Station, Burger King, Bar-Sushi Restaurant, Marina Mall, Turkish Airlines, Total House Clinic, and SSNIT Emporium.

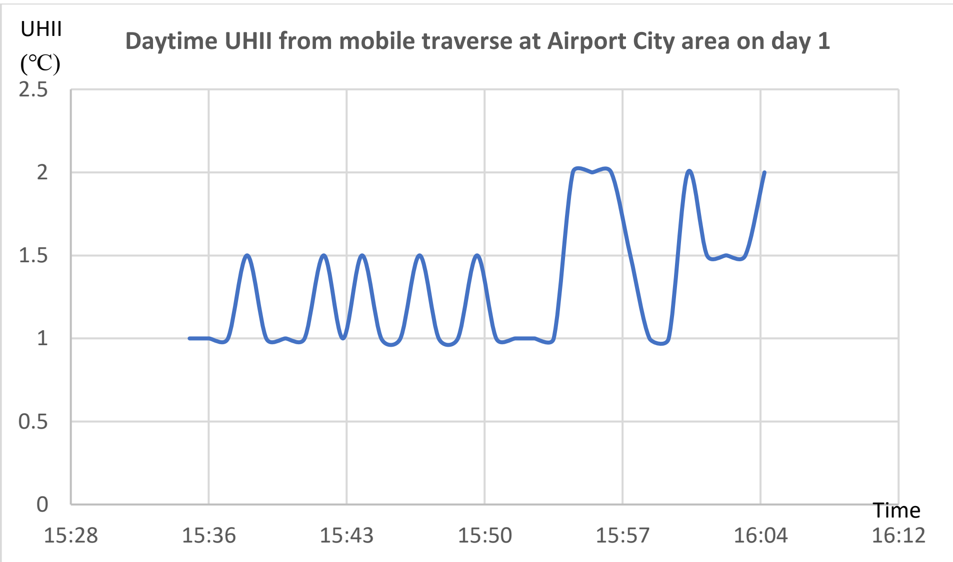

Fig 31 UHII profile for mobile traverse at Airport City on 9th Jan 2019 (Author generated)

The sites that were traversed in the next 7 minutes showed an UHII range of 1 – 2℃, and they included Société Générale Bank, Ministry of Aviation, and UNA Home Car Park. The sites covered in the last stretch of the traverse that showed an UHII between 1.5 and 2℃ included Holiday Inn and CFAO Motors. Mapping the UHIIs to the logged times showed that the sites that recorded UHII of 1℃ included Shell, Burger King, SSNIT Emporium, and Total House Clinic. The sites: Bar Sushi, Total House Clinic, Marina Mall, Turkish Airlines and Ministry of Aviation recorded UHII of 1.5℃. Société Générale Bank, UNA Home Car Park and Holiday Inn recorded UHII of 2℃.

The UHII profile for the mobile traverse conducted on the 2nd day is presented in figure 32. On that day, the UHII range was 0.5 to 1℃ in the first 6 minutes, and the sites traversed during this stretch included Shell Filling Station, Burger King, Marina Mall, and UNA Home. During the 16 minutes that followed, the UHII uniformly remained at 1℃, and the sites traversed included Turkish Airlines Office, NCA Tower, SSNIT Emporium, Marriot Hotel, Total House Clinic, Société Générale Bank, and Ministry of Aviation.

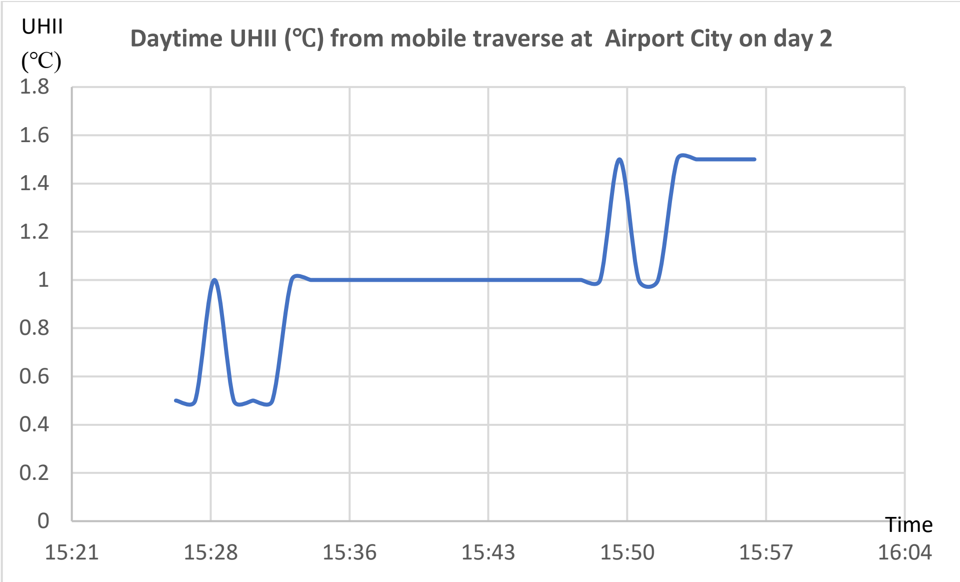

Fig 32 UHII profile for mobile traverse at Airport City on 10th Jan 2019 (Author generated)

The UHII for the last 8 minutes fluctuated between 1 and 1.5℃, and the sites traversed were the NCA building, UNA Home Car Park, and the Holiday Inn hotel. The mapping revealed that Airport Shell Filling Station and Marina Mall recorded UHII of 0.5℃. The sites that recorded UHII of 1℃ included Burger King, UNA Home, Turkish Airlines, NCA Tower, SSNIT Emporium, Marriot Hotel, and Total House Clinic. At Société Générale, Ministry of Aviation, UNA Home Car Park, and Holiday Inn, the UHII was 1.5℃.

The sites traversed on days 1 and 2, their indicative UHIIs and the routes used for the traverse are respectively depicted in the maps in figures 33 and 34. By mapping the UHII obtained for the various sites to the respective times logged during the mobile traverse for both days, it could be seen that Shell Filling Station, Burger King, Marina Mall, Bar-Sushi, Total House Clinic, SSNIT Emporium, and Turkish Airlines experienced moderate daytime urban heat island intensities (i.e. 0.5 to 1℃) compared to the other sites that were traversed in that LCZ. Sites in the LCZ which experienced comparatively high UHII (i.e. 1.5 to 2℃) included Société Générale, NCA, UNA Home, Ministry of Aviation, and Holiday Inn.

Fig 33 UHIIs at various locations within the Airport City monitoring area on day 1

Fig 34 UHIIs at various locations within the Airport City monitoring area on day 2

5.5.4 37 Military Hospital - Lands Commission

The 37 Military Hospital is within an open low-rise built-up area, that is LCZ5(8). It is located about halfway along the stretch between Jubilee House (i.e., the Presidential Palace) and the Airport City Park. The mobile traverse covered the stretch between 37 Military Hospital and Lands Commission Office. The area is mainly a military zone, and the main facilities there include a military hospital, accommodation for military officers, and some office buildings. This LCZ is characterized by a commercial area that is composed of a few shops, a small open market, and a lorry station. The military hospital and accommodation have substantial greenery, whilst the commercial areas have barely any greenery. The location and physical characteristics of the area are depicted in figure 35.

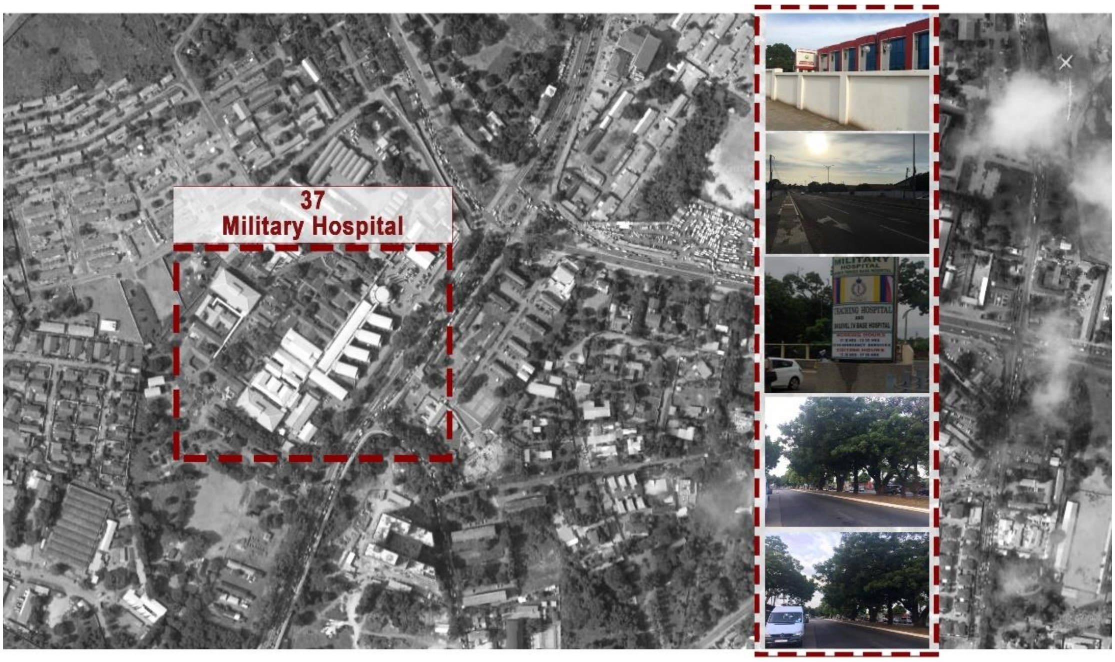

Fig 35 Image showing the 37 Military Hospital/Lands Commission area (Author generated)

The weather data gathered at the 37 Military Hospital monitoring location on days 1 and 2 are respectively depicted in figures 36 and 37. At this location, the average temperatures recorded on days 1 and 2 were 28.5 - 29℃ and 26 – 27℃ respectively. On the 2 consecutive days, relative humidity values were within 62 – 63% and 61 – 64.5% respectively.

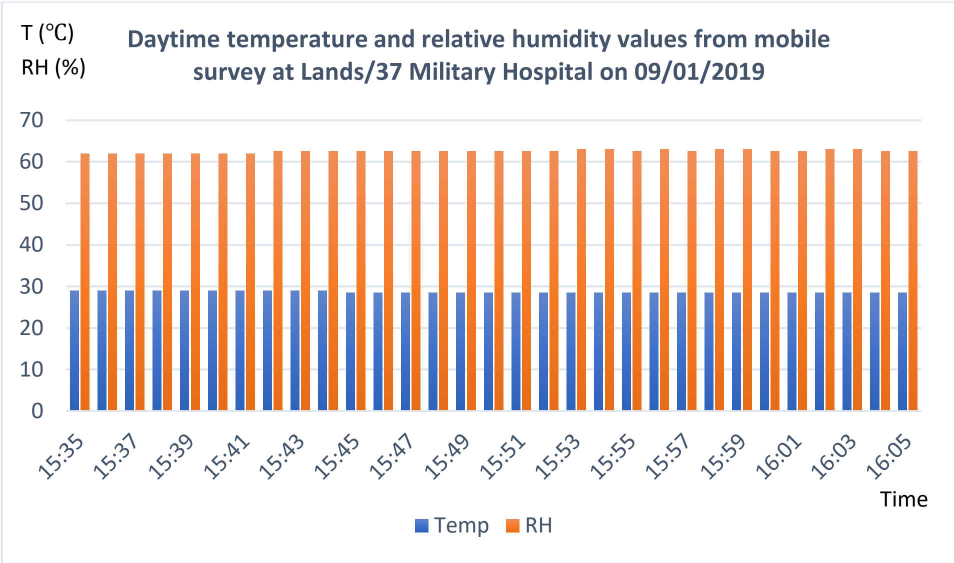

Fig 36 Graph showing temp. and RH values for 37 Hosp. on traverse day 1 (Author generated)

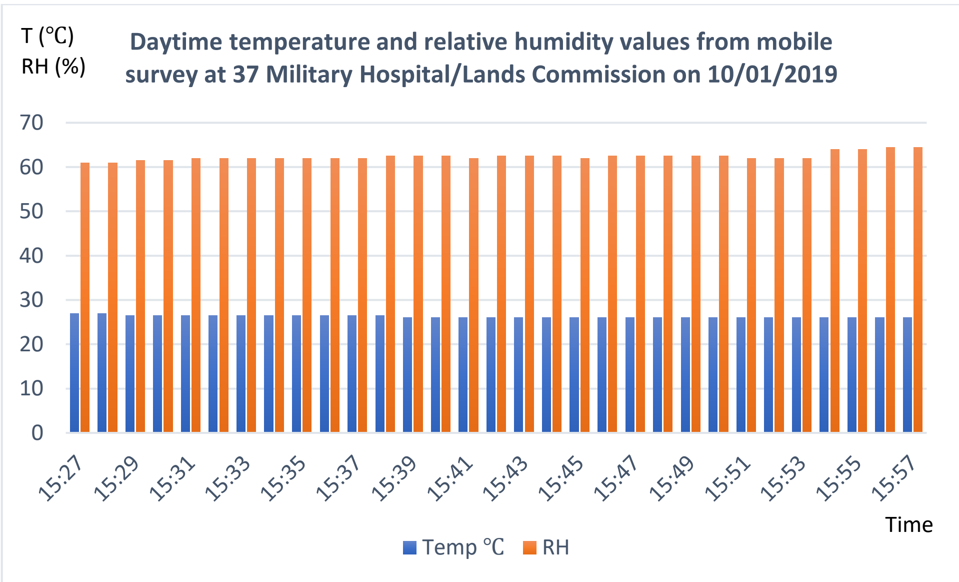

Fig 37 Graph showing temp. and RH values for 37 Hosp. on traverse day 2 (Author generated)

5.5.4.1 UHII profile for 37 Military Hospital

Figure 38 shows the UHII profile for the 1st day of the mobile traverse conducted at the 37 Military Hospital area. The UHII range for the 37 Military Hospital area, as gathered on day 1 of the mobile traverse, was between 1 and 2℃.

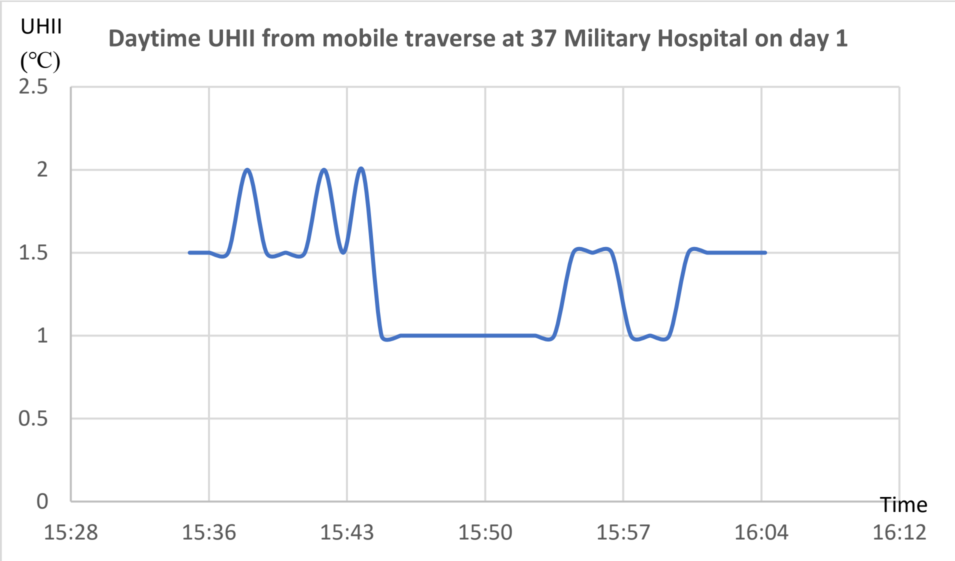

Fig 38 UHII profile for mobile traverse at 37 Military Hospital on 9th Jan 2019 (Author generated)

During the first 9 minutes of the traverse, the UHII fluctuated between 1.5 and 2℃. It then dropped to 1 during the next 9 minutes. The UHII then fluctuated between 1 and 1.5℃ in the remaining 12 minutes. The sites traversed in the entire survey were El-Wak Sports Stadium, Base Ordinance Basic School (Ghana Armed Forces), Lands Commission Office, Ghana Armed Forces Base Ordinance Depot, 37 Lorry Station, Army Officers Mess, 37 Traffic Lights, and 37 Military Hospital Main Gate/Bus Stop. Mapping the logged traverse times to the respective sites on the route, it was seen that the areas which had UHII of 1℃ included Lands Commission (Main Entrance), Ghana Armed Forces Base Ordinance, 37 Lorry Station and 37 Main Gate/Bus Stop. The sites that recorded UHII of 1.5℃ were El-

Wak Sports Stadium Gate, Army Officers' Mess, and 37 Traffic Lights. El-Wak Sports Stadium Gate and Base Ordinance Basic School experienced UHII of 2℃. The UHII profile for the mobile traverse conducted at the 37 Military Hospital area on the 2nd day is presented in figure 39.

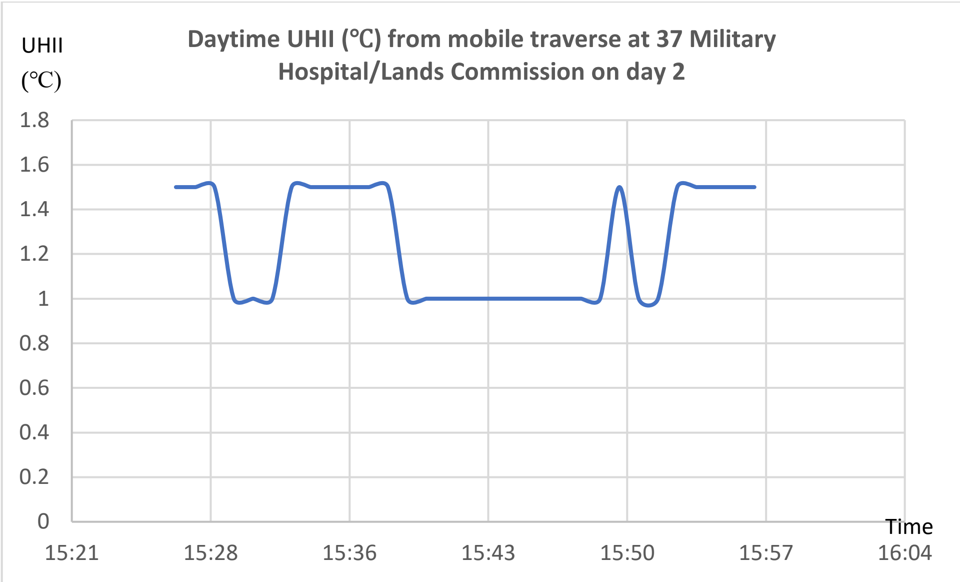

Fig 39 UHII profile for mobile traverse at 37 Military Hospital on 10th Jan 2019 (Author generated)

The UHII range for the entire mobile survey period was between 1 and 1.5℃. The traverse covered the stretch between the 37 Methodist/Presbyterian Church and the El-Wak Ports Stadium. In the first 6 minutes, the UHII fluctuated between 1 and 1.5℃. It remained at 1.5℃ from the 6th to the 11th minute and dropped to 1 a minute later. The UHII remained at 1℃ from the 12th to the 22nd minute. After the 22nd minute, it fluctuated again between 1 and 1.5℃ for 4 minutes, after which it remained at 1℃ till the end of the traverse. From the mapping, the sites that recorded UHII of 1℃ were 37 Military Hospital Main Gate, Army Officers' Mess, 37 Lorry Park, Base Ordinance Depot, Lands Commission, and Veterinary Department. The sites that recorded UHII of 1.5℃ were Methodist/Presbyterian

Church, 37 Traffic Lights, Army Officers' Mess (between 1 and 1.5), and El-Wak Stadium (Gates 1 & 3).

The sites traversed at the 37 Military Hospital area on both days, their indicative UHIIs and physical characteristics are depicted in the maps in figures 40 and 41. Data gathered on both days revealed that sites that recorded moderate UHII (of 1) included 37 Military Hospital Main Gate/Bus Stop, 37 Lorry Station, Base Ordinance Depot (Ghana Armed Forces), Lands Commission, Veterinary Department. The sites that recorded considerably high UHII (i.e. from 1.5 to 2) included Methodist/Presbyterian Church, 37 Traffic Lights, Base Ordinance School, Army Officers' Mess, and El-Wak Stadium (Gates 1 & 3).

Fig 40 UHIIs at various locations in the 37 Military Hospital area on traverse day 1

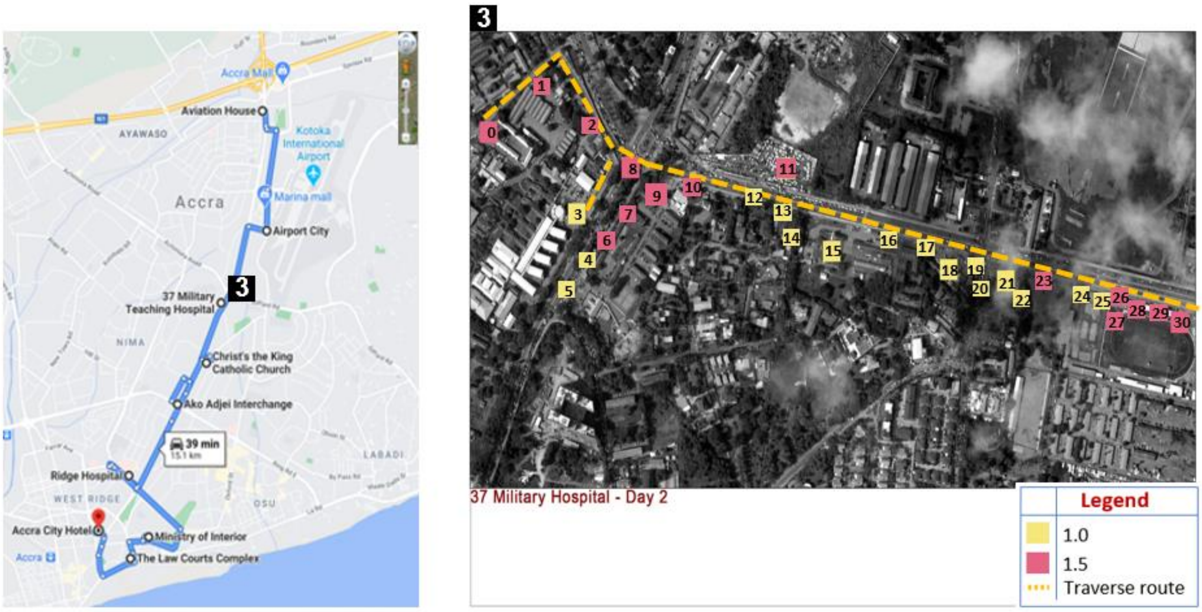

Fig 41 UHIIs at various locations in the 37 Military Hospital area on traverse day 2

5.5.5 Jubilee House

Jubilee House is the presidential palace of the government. It is within an "open mid-rise with large low-rise" built-up area, that is LCZ5(8). Located along the Liberation road, it is about a kilometre away from 37 Military Hospital. The traverse covered the Liberation road (i.e. the entrance to the Jubilee House) and the Jawaharlal Nelson road. The land use of the area is mainly civic-residential and is composed of mid-rise office buildings, official residences, and church buildings. There are substantial green spaces around most of the built-up areas, with several shade trees having been well maintained. The layout of the area is well-planned, and the buildings are adequately spaced. The image in figure 42 depicts the physical characteristics of the Jubilee House area.

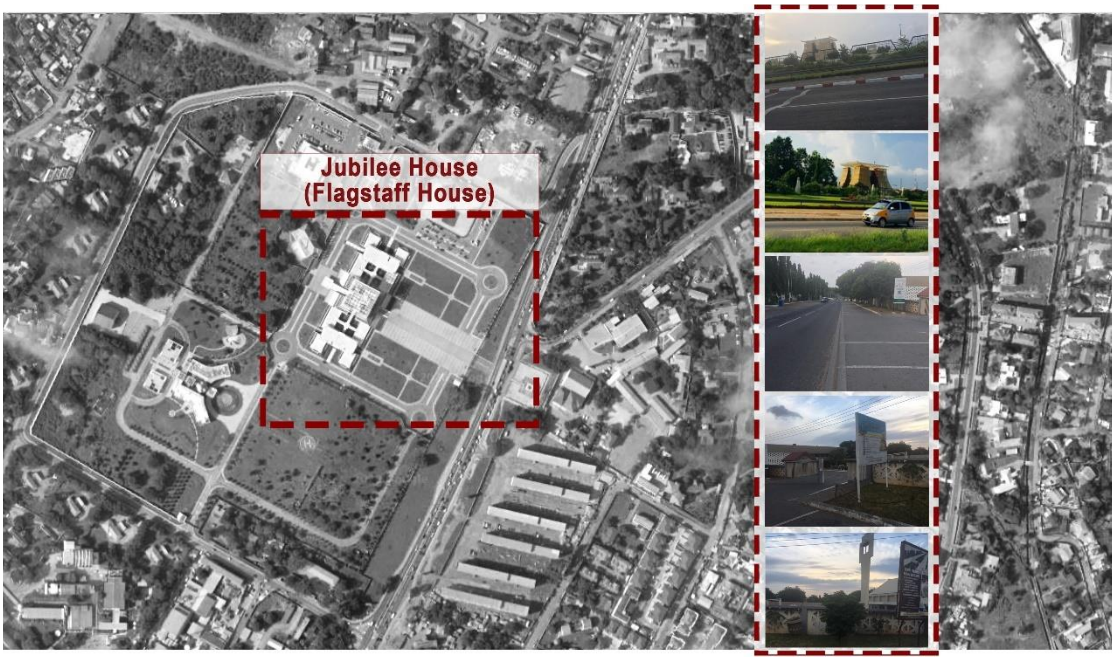

Fig 42 Image showing the location of Jubilee House monitoring area (Author generated)

The weather data gathered at the Jubilee House monitoring area on the 1st and 2nd days are respectively depicted in figures 43 and 44. In this monitoring area, the average temperatures recorded on days 1 and 2 were 28.5℃ and 26 – 27.5℃ respectively. On the two consecutive days, relative humidity values were within 62.5 – 63.5% and 60.5 – 62.5% respectively.

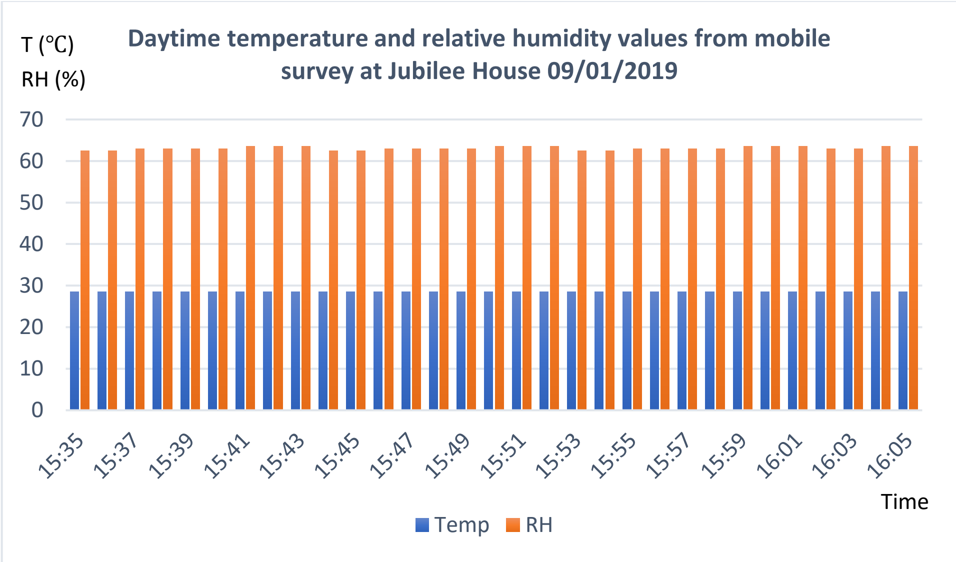

Fig 43 Graph showing temp. and RH values for Jubilee House on traverse day 1 (Author generated)

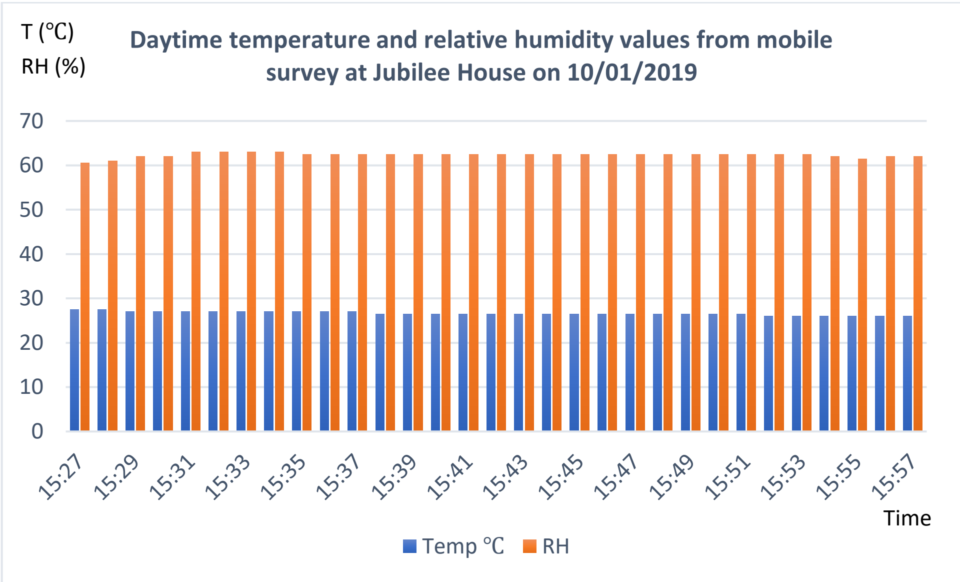

Fig 44 Graph showing temp. and RH values for Jubilee House on traverse day 2 (Author generated)

5.5.5.1 UHII profile at Jubilee House monitoring area

The UHII profile at the Jubilee House area is presented in figure 45.

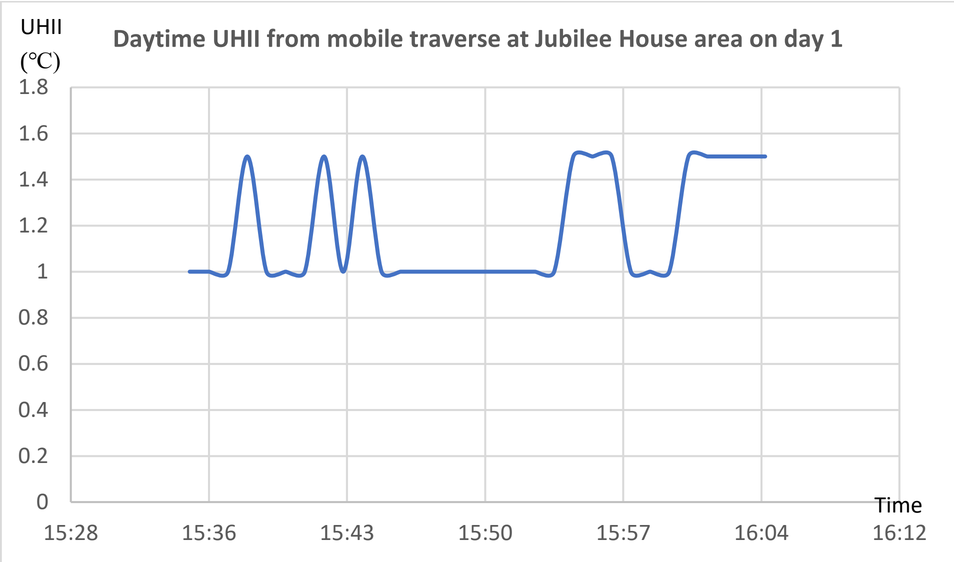

Fig 45 Graph showing UHII profile for Jubilee House on 9th Jan 2019 (Author generated)

On traverse day 1, the UHII range for the Jubilee House area was between 1 and 2℃. During the first 11 minutes of the traverse, the UHII fluctuated between 1 and 1.5℃, after which it remained at 1℃ for 9 minutes. It then fluctuated between 1 and 1.5℃ for the rest of the traverse period. The survey covered the stretch between Christ The King Catholic Church and the Office of the West Africa Examinations Council (WAEC) along the Jawaharlal Nehru Road. According to the mapping, the areas that recorded UHII of 1℃ included Christ The King Catholic Church, Cocoa Research Institute Guest House, National Development Planning Commission (NDPC) Office, Ayebea Town Houses, Furniture Works, DVLA, and Department of Parks & Gardens Head Office. The sites that recorded UHII of 1.5℃ included Residence of Canadian High Commissioner, Ghana Water Company (Revenue Collection Office), NDPC and Cocoa Research.

In figure 46 is the graph depicting the UHII profile for the mobile traverse conducted at the Jubilee House area on the 2nd day.

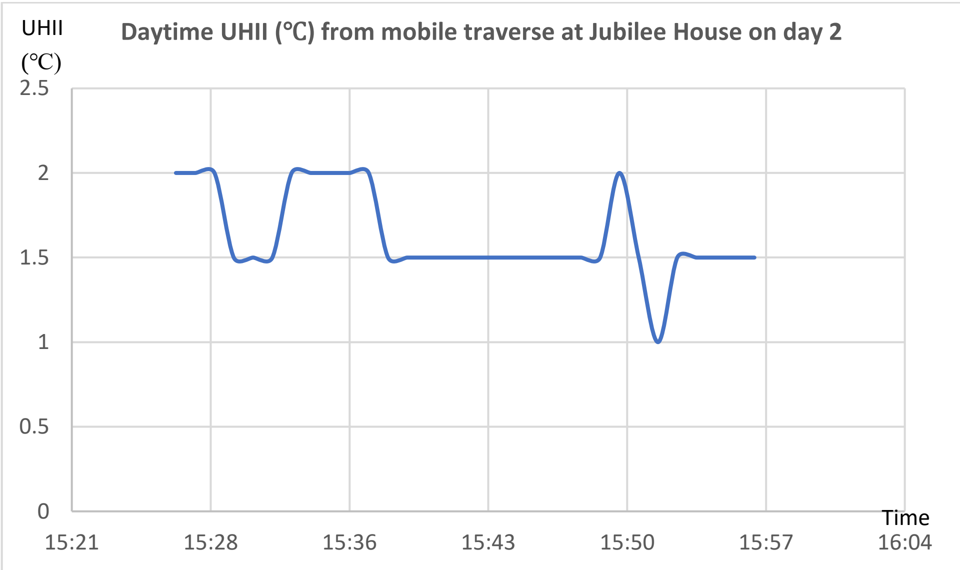

Fig 46 Graph showing UHII profile for Jubilee House on day 10th Jan 2019 (Author generated)

On day 2 of the mobile traverse, the UHII range for the entire mobile survey period was between 1.5 and 2℃. The UHII remained at 1.5℃ from the 10th to the 22nd minute, and from the 23rd minute, it increased to 2℃ for a minute. On the 25th minute, the UHII dropped sharply from 2 to 1℃. From the 26th minute to the end of the traverse, the UHII was at 1.5℃. For the 2nd day, the mapping revealed that the UHII at Christ the King was 1℃. The sites that recorded UHII of 1.5℃ were NDPC, Ayebea Townhouses, Department of Parks & Gardens (Head Office), WAEC Office, DVLA, Ghana Water Company (Revenue Collection Office), Mr. & Mrs Owusu Cane Furniture Company, and Cocoa Research Institute Guest House. UHII of 2℃ was recorded at Residence of The Canadian High Commissioner, Ghana Water Company and DVLA.

It is evident from the above that most of the sites traversed in the Jubilee House area showed low UHIIs on both days, apart from the Residence of Canadian High Commission and the DVLA Office. The route traversed at the Jubilee House area on both days, their indicative UHIIs and physical characteristics are depicted in the maps in figures 47 and 48.

Fig 47 UHIIs at various locations in the Jubilee House monitoring area on day 1 (Author generated)

Fig 48 UHIIs at various locations in the Jubilee House monitoring area on day 2 (Author generated)

5.5.6 Arko Adjei Interchange

The Arko Adjei Interchange is within an open mid-rise built-up area and thus falls under the classification LCZ6. The Arko Adjei Interchange is the intersection between Ring road and Liberation road, and it is about 500 metres from the Jubilee House. The land use of this monitoring area is civic. Apart from the presence of a high-rise office building, the area is composed mainly of well-spaced mid-rise office buildings. The traverse route used was the Ring Road East which is a dual carriageway. The surroundings of most of the developments in the area are sufficiently green. The image in figure 49 depicts the physical characteristics of the Arko Adjei Interchange area. Some shade trees are present along the main streets and around the buildings.

Fig 49 Image showing the Arko Agyei Interchange monitoring area (Author generated)

The weather data gathered at Arko Adjei Interchange monitoring location on days 1 and 2 are respectively depicted in figures 50 and 51. At this location, the average temperatures recorded on days 1 and 2 were 29 - 29℃ and 26.5 – 28.5℃ respectively. On the two consecutive days, relative humidity values were within 67.5 – 69% and 65 – 67% respectively.

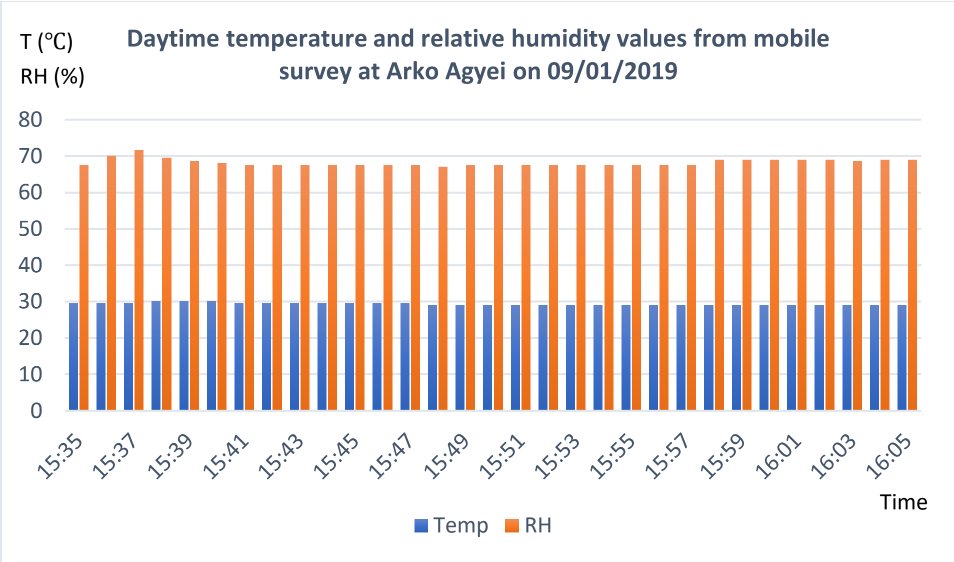

Fig 50 Graph showing temp. and RH values for Arko Adjei on traverse day 1 (Author generated)

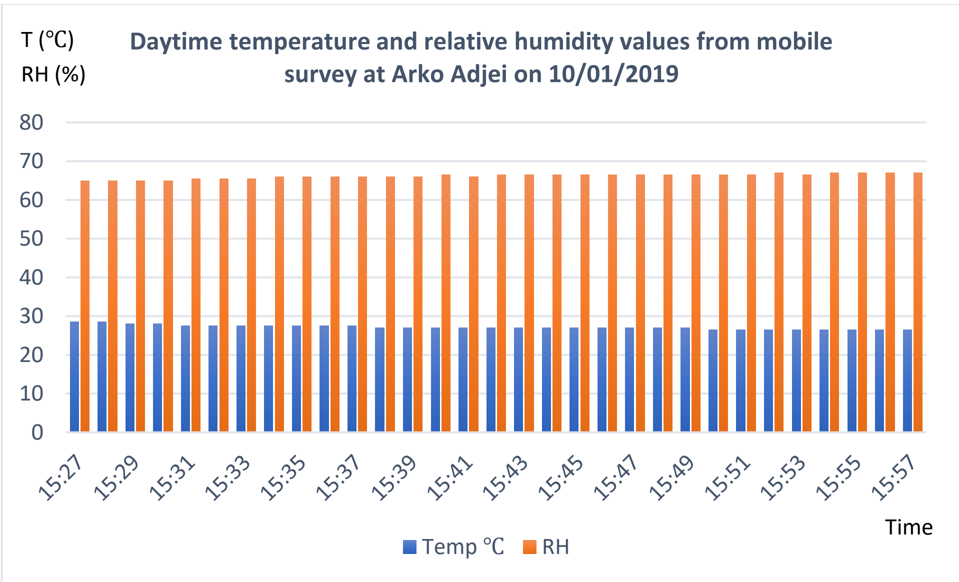

Fig 51 Graph showing temp. and RH values for Arko Agyei on traverse day 2 (Author generated)

5.5.6.1 UHII profile at Arko Adjei Interchange

On day 1 of the traverse, the UHII in the first 6 minutes was between 2 and 3℃. It fluctuated between 2 and 2.5℃ for the next 6 minutes and thereafter, dropped to 1.5℃ for 6 minutes. It fluctuated between 1.5 and 2℃ between the 19th and 26th minutes and remained at 2 in the last 4 minutes. The sites that recorded UHII of 1.5℃ included SSNIT Guest House, Police Headquarters, Independence Avenue, and GN Bank/Gold Coast Securities. UHII of 2℃ was recorded at GBC Bus Stop, Independence Avenue (Underpass), SSNIT Guest House and GN Bank/Gold Coast Securities, and at Standard Chartered Bank and Nkosuo, it was 2.5℃. For this traverse, the highest UHII (of 3℃) was recorded at Standard Chartered Bank. Figure 52 shows the UHII profile obtained through mobile traverse at Arko Adjei on day 1.

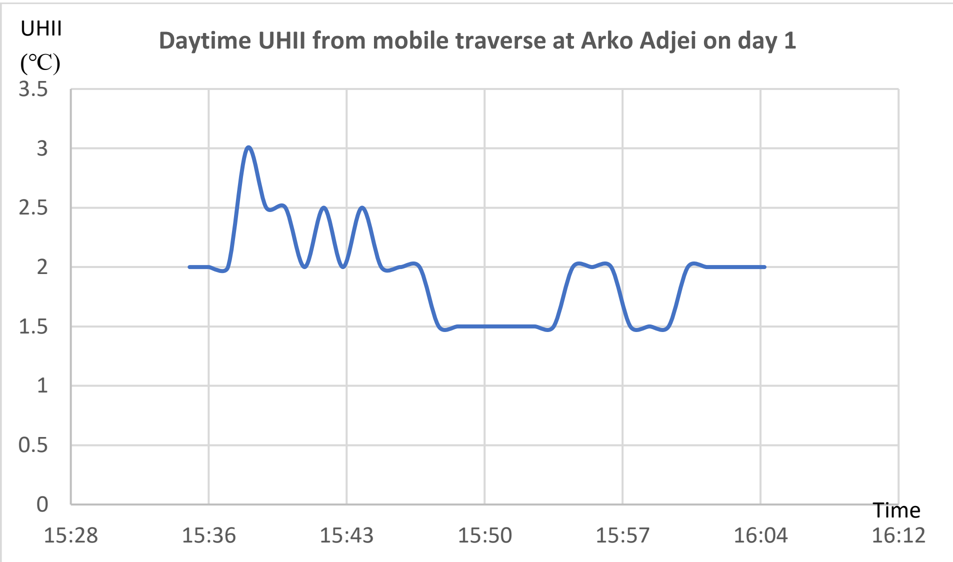

Fig 52 Graph showing UHII profile for Arko Adjei on traverse day 1 (Author generated)

The UHII profile obtained for the mobile traverse conducted at Arko Adjei on the second day is presented in figure 53.

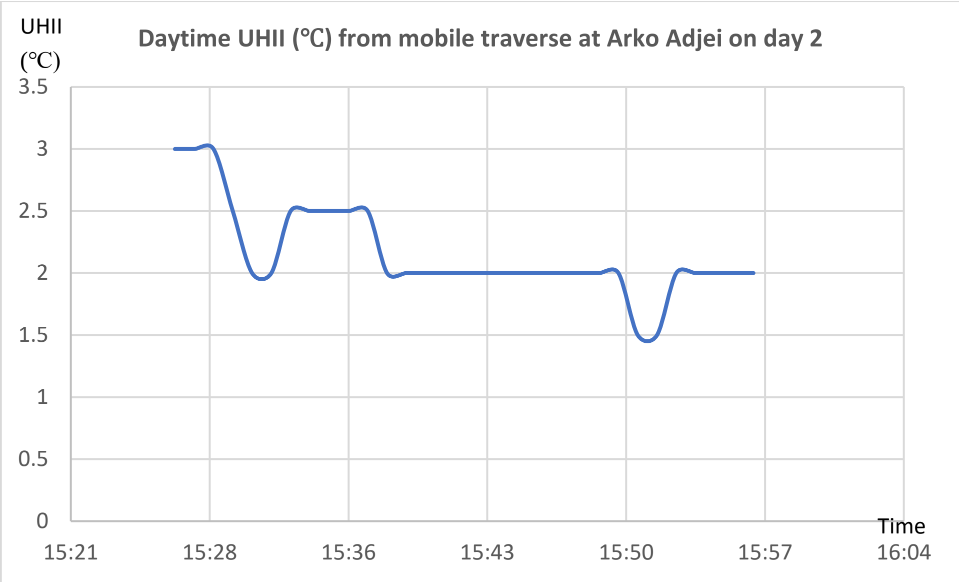

Fig 53 Graph showing UHII profile for Arko Adjei on traverse day 2 (Author generated)

On traverse day 2, the UHII was 3℃ for the first 2 mins and dropped to 2℃ by the 4th minute. It then rose to 2.5℃ in the 6th minute and remained constant for 4 minutes. By the 11th minute, the UHII had dropped to 2℃, and it remained uniform for 12 minutes before dropping to 1.5℃ in the 25th minute. The UHII rose to 2℃ in the 26th minute and remained unchanged till the end of the traverse. The only site that recorded UHII of 1.5℃ on the second day was Police Headquarters. At GBC, Independence Avenue, UDS Street, Nkosuo, SSNIT Guest House, and UNICEF, the UHII was 2℃. GN Bank and Standard Chartered Bank recorded UHII of 2.5℃. GBC Bus Stop again recorded UHII of 3℃ within the traverse period.

Analysing the data for the two days showed that in general, Police Headquarters recorded the lowest UHII (i.e. 1.5℃). The locations that generally recorded UHII of 2℃ were GN Bank, SSNIT Guest House, Independence Avenue, and UNICEF. GN Bank and Standard Chartered Bank recorded 2.5℃. Overall, the highest UHII (being 3℃) was recorded at Standard Chartered and GBC Bus Stop. The sites traversed at the Arko Adjei Interchange area on both days, their indicative UHIIs and physical characteristics are shown in the maps in figures 54 and 55.

Fig 54 UHIIs at various locations in the Arko Adjei Int. monitoring area on day 1 (Author generated)

Fig 55 UHIIs at various locations in the Arko Adjei Int. monitoring area on day 2 (Author generated)

5.5.7 Ridge Hospital

Ridge Hospital is within an open mid-rise built-up area that is LCZ5(8). It is located along the Castle Road and about 300 metres off the Liberation Road. The land use is mainly civic and generally characterized by office buildings and two hospitals. Most areas along this monitoring route have substantial greenery apart from the newly constructed Ridge Hospital. The area and its physical characteristics are depicted in figure 56.

Fig 56 Image showing the Ridge Hospital monitoring area (Author generated)

The weather data gathered at the Ridge Hospital monitoring location on days 1 and 2 are respectively depicted in figures 57 and 58. At this location, the average temperatures recorded on days 1 and 2 were 28 - 29℃ and 26.5 – 27.5℃ respectively. On the two consecutive days, relative humidity values were within 66.5 – 67.5% and 65 – 67.5% respectively.

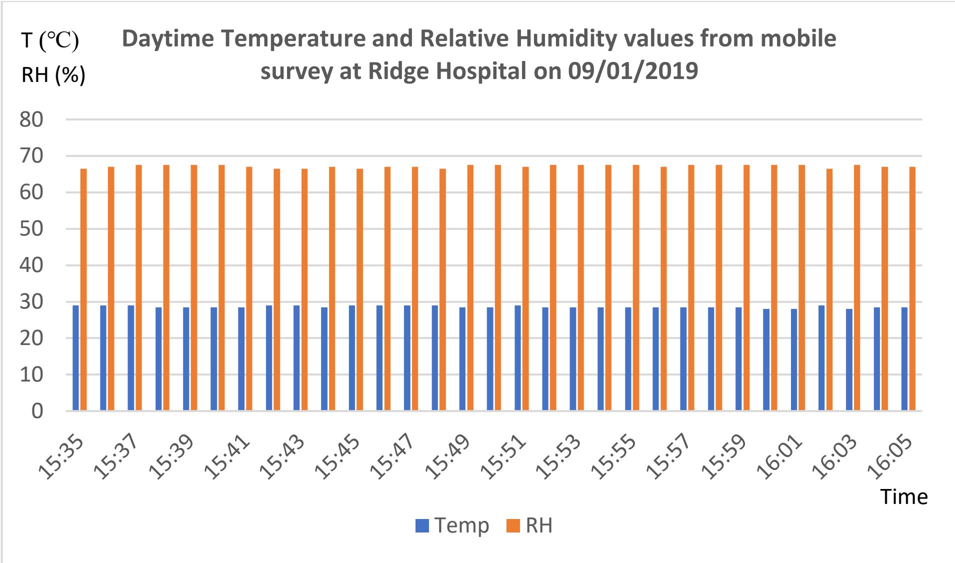

Fig 57 Graph showing temp. and RH values for Ridge Hosp. on traverse day 1 (Author generated)

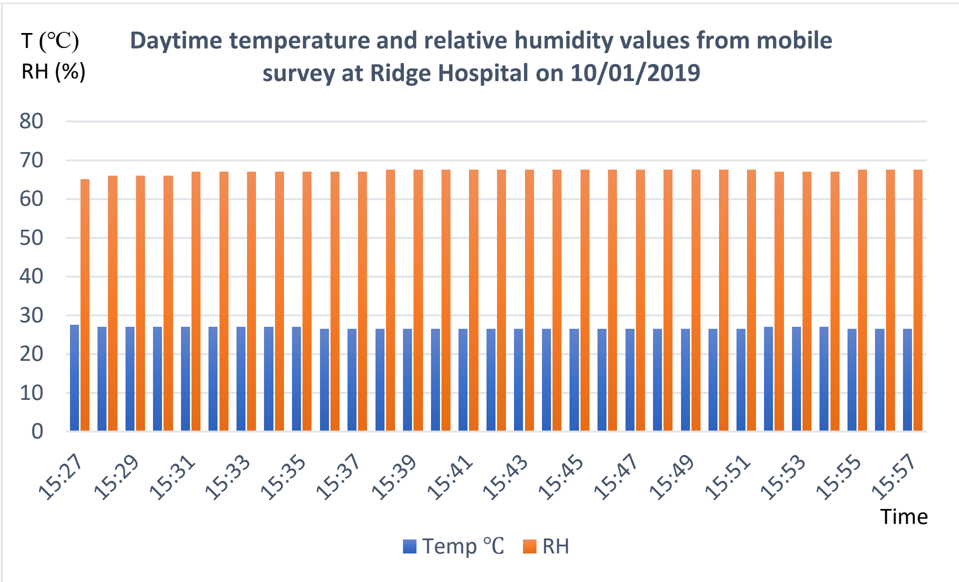

Fig 58 Graph showing temp. and RH values for Ridge Hosp. on traverse day 2 (Author generated)

5.5.7.1 UHII profile for Ridge Hospital area

The UHII profile for the mobile traverse conducted at the Ridge Hospital monitoring area on the first day is shown in figure 59.

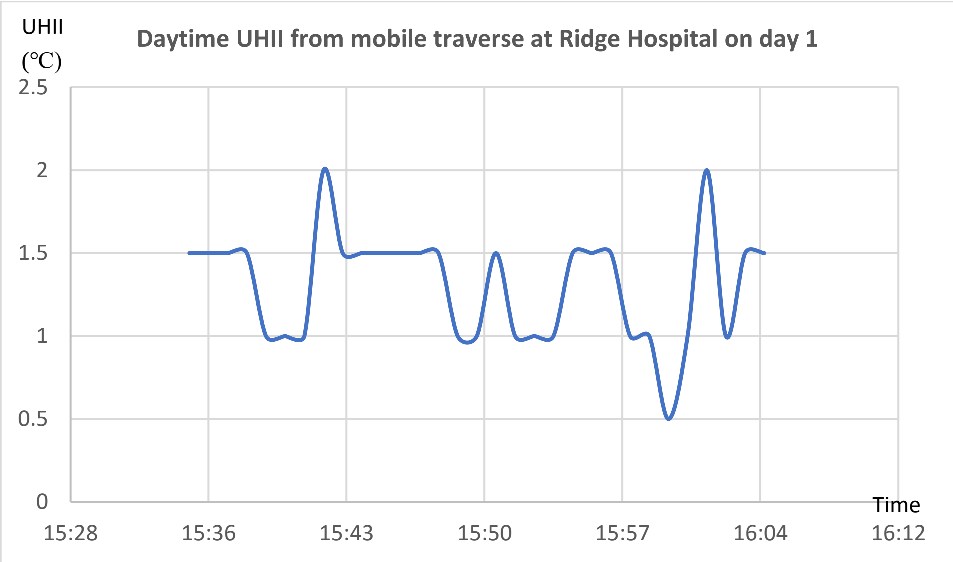

Fig 59 Graph showing UHII profile for Ridge Hospital on traverse day 1 (Author generated)

On day 1 at Ridge Hospital, the UHII was 1.5℃ during the first 3 minutes. It dropped to 1℃ in the 4th minute and then increased to 2℃ on the 7th minute. From the 8th to the 13th minute, the UHII was at 1.5℃ and it fluctuated between 1℃ and 1.5℃ from the 13th to the 23rd minute. After dropping to 0.5℃ in the 25th minute, the UHII increased sharply to 2℃ a minute later before dropping to 1℃ in the 28th minute. The last 2 minutes recorded an UHII of 1.5℃.

The mapping revealed that the UHII at the Military Cemetery was 0.5℃. The UHII at the Ridge Church Junction and the Parliament/State House was 1℃. At the Ridge Hospital, between Ridge Hosp and Ridge Roundabout, Accra International

Conference Centre the UHII was 1.5℃. The Ridge Roundabout recorded an UHII of 2℃, which was the highest for that traverse.

In figure 60 is the graph showing the UHII profile generated on the 2nd day of the mobile traverse at the Ridge Hospital area. The traverse started at the Ridge Hospital, recording an UHII of 2℃. The UHII fluctuated between 1.5 and 2℃ in the first 8 minutes and remained constant at 1.5℃ from the 9th to the 22nd minute. Between the 22nd and 24th minutes, the UHII fluctuated between 1.5 and 2℃ before increasing sharply to 2.5℃ on the 27th minutes. The last 3 minutes of the traverse recorded a UHII of 2℃.

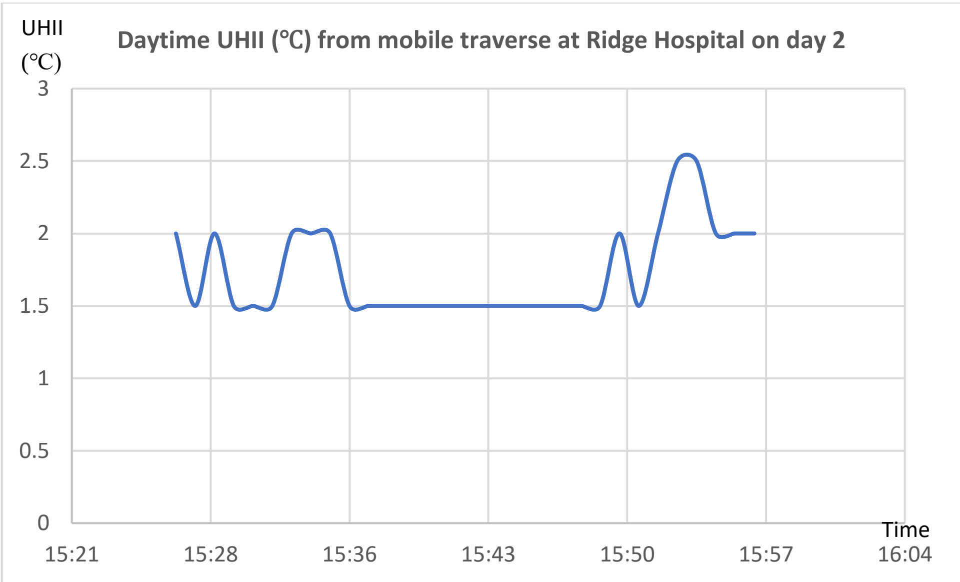

Fig 60 Graph showing UHII profile for Ridge Hospital on traverse day 2 (Author generated)

The mapping for the data gathered on day 2 for the traverse at the Ridge Hospital area showed that the UHII at Ridge Church Junction, Military Cemetery, and Parliament/State House was 1.5℃. At Ridge Hospital, Ridge Roundabout and Accra International Conference Centre, it was 2℃, while Ridge Hospital (Main Gate)/Electoral Commission recorded 2.5℃.

As evident in the UHII maps generated for the two days (figures 61 and 62), the areas around the main entrance to the Ridge Hospital, the intersection or roundabout linking Castle Road and Independence Avenue and the Accra International Conference Centre recorded significantly high UHIIs. This could have been caused by the amount of vehicular traffic and the sparseness of greenery at those areas.

Fig 61 UHIIs at various locations in the Ridge Hospital monitoring area on day 1 (Author generated)

Fig 62 UHIIs at various locations in the Ridge Hospital monitoring area on day 2 (Author generated)

5.5.8 Cedi House – The Law Courts Complex

Cedi House is at the heart of the central business district of the city and is within an "open high-rise with open mid-rise" built-up area, that is LCZ4(5). The measurement campaign for this LCZ covered the Cedi House – The Law Courts Complex stretches up to the National Lotteries building. The area is composed mainly of high-rise office buildings, with a few of them having some commercial spaces as well. Generally, the area is sparsely green, although the greenery between Accra Regional Police Station and The Law Courts Complex is quite substantial. The location and physical characteristics of the area are depicted in figures 63a and 63b.

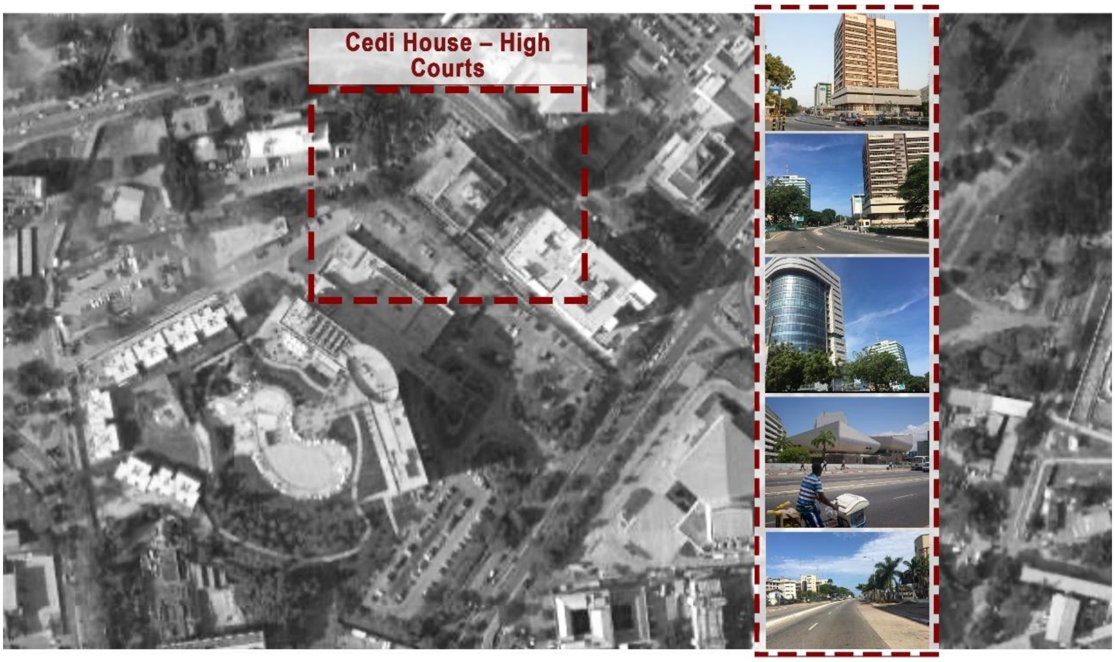

Fig 63a Image showing the Cedi House monitoring area (Author generated)

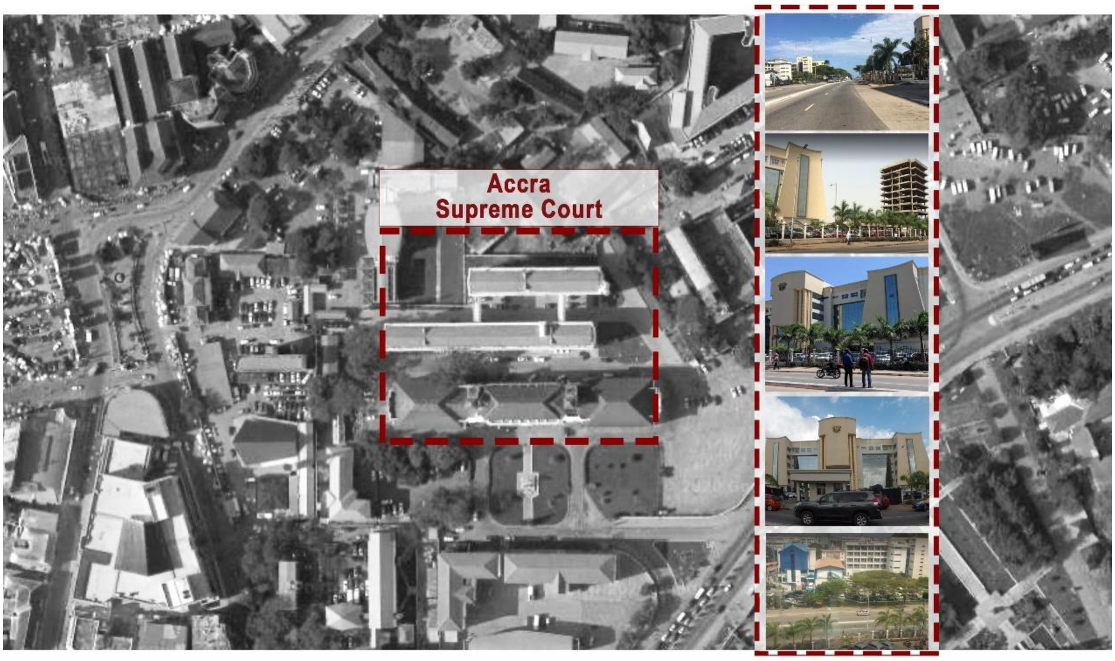

Fig 63b Image showing The Law Courts Complex monitoring area (Author generated)

The weather data gathered at Cedi House - The Law Courts Complex monitoring area on days 1 and 2 are respectively depicted in figures 64 and 65. At this location, the average temperatures recorded on days 1 and 2 were 29 – 29.5℃ and 26.5 – 28℃ respectively. On both consecutive days, relative humidity values were within 60 – 62% and 59 – 62.5% respectively.

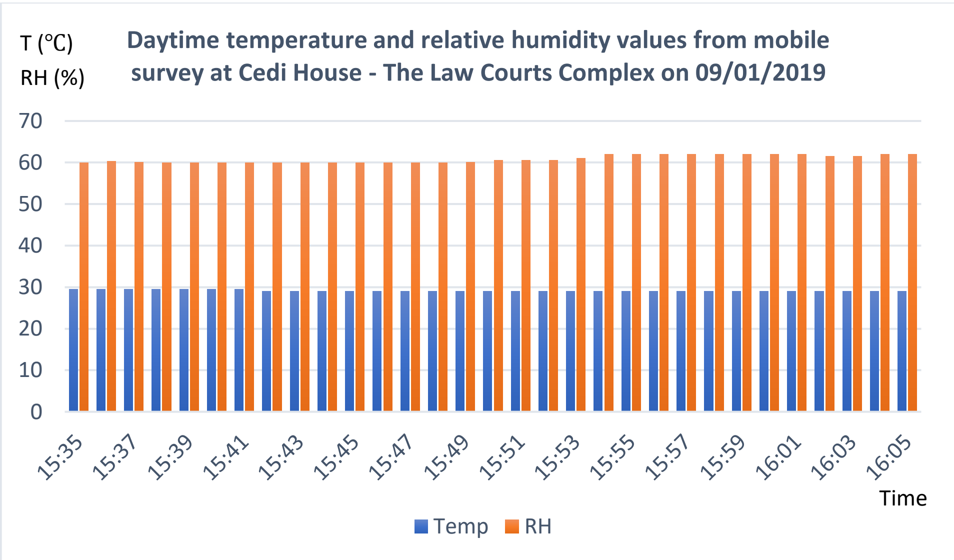

Fig 64 Graph showing temp. and RH values for Cedi House – The Law Courts Complex on traverse day 1 (Author generated)

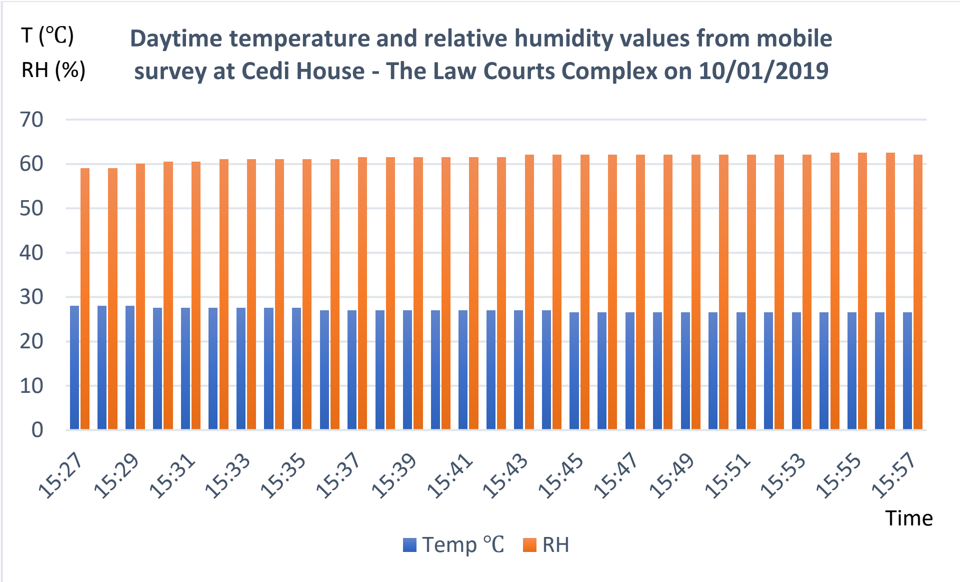

Fig 65 Graph showing temp. and RH values for Cedi House – The Law Courts Complex on traverse day 2 (Author generated)

5.5.8.1 UHII profiles for Cedi House – The Law Courts Complex area

The UHII profile for Cedi House – The Law Courts Complex monitoring area on the 1st day of the mobile traverse is presented in figure 66. On day 1 at Cedi House, the UHII range was between 2 and 2.5℃ in the first 5 minutes. Between the 5th and 11th minutes, it dropped to 1.5℃ and then fluctuated between 1.5 and 2℃. It remained at 1.5℃ from the 11th to the 19th minutes. From the 19th to the 26th minute, it fluctuated between 1.5 and 2℃ and remained at 2℃ for the last 4 minutes. From the mapping of the data gathered on day 1, it was seen that Accra Regional Police Headquarters, SSNIT Pension Tower, National Theatre and TUC recorded UHII of 1.5℃, while at Total House, Cedi House, Accra High Court Complex and NLA, it was 2℃. The main gate of the Supreme Court recorded a UHII of 2.5℃

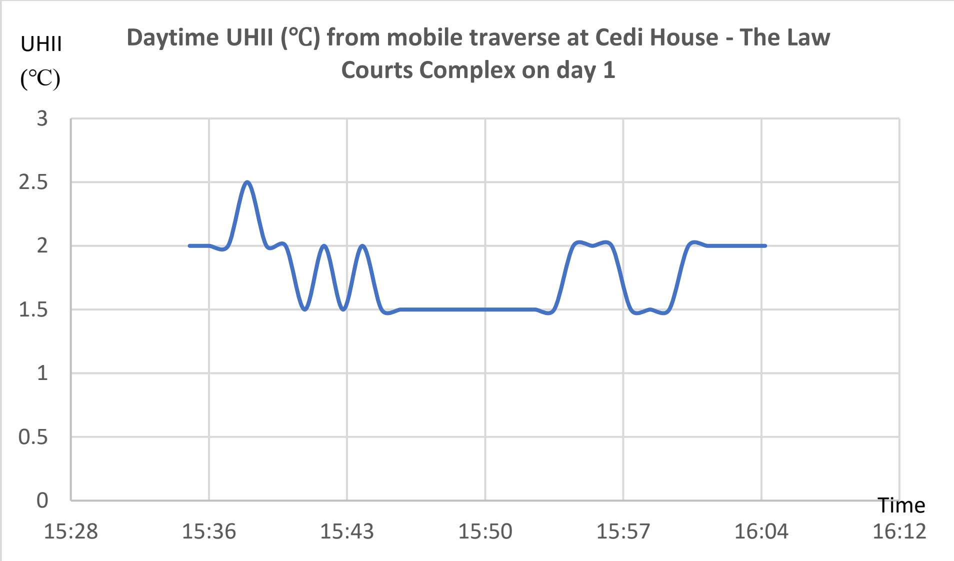

Fig 66 Graph showing UHII profile for Cedi House - The Law Courts Complex on traverse day 1 (Author generated)

In figure 67 is the graph showing the UHII profile for the mobile traverse conducted on the 2nd day at the Cedi House – The Law Courts Complex monitoring route. On the 2nd day, the traverse started at Total House with an UHII of 2.5℃. The UHII increased to 3℃ after 2 minutes and then dropped to 2℃ in the 3rd minute. Between the 3rd and 9th minutes, the UHII fluctuated between 2 and 2.5℃. From the 9th to the 17th minute, remained uniformly at 2℃ and then fluctuated between 1.5 and 2℃ in the next 9 minutes. The last 4 minutes recorded a uniform UHII of 2℃. The traverse data showed that GRA/The Law Court Complex, National Ambulance Service, and NLA recorded an UHII of 1.5℃. At World Trade Centre, Premier Tower, SSNIT Pension Tower, Greater Accra Regional Police Headquarters, State Enterprise Commission, Art Centre, and Kwame Nkrumah Mausoleum, the UHII was 2℃. The UHII increased to 2.5℃ at Total House, World Trade Centre, and National Theatre. Cedi House recorded an UHII of 3℃, which was the highest for the traverse.

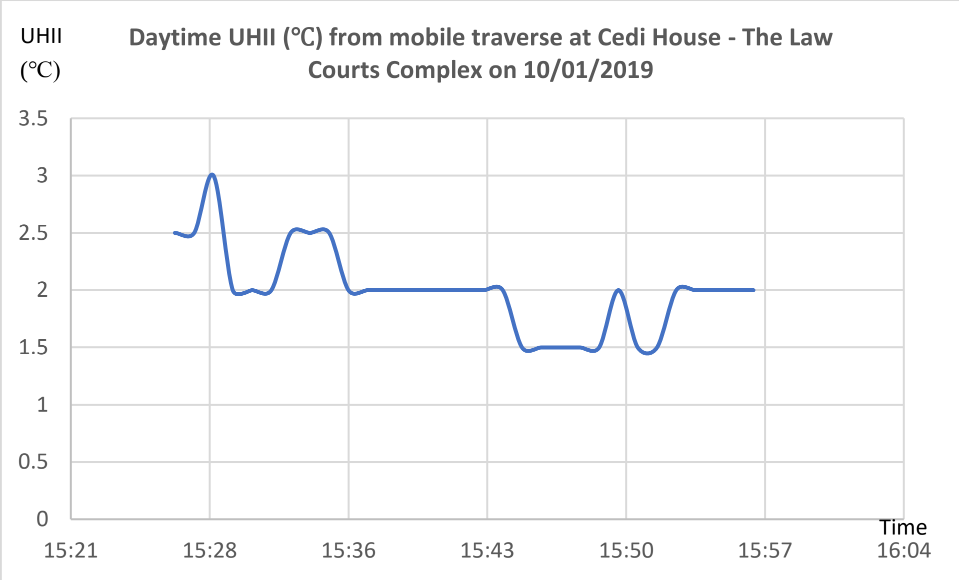

Fig 67 Graph showing UHII profile for Cedi House – The Law Courts Complex monitoring area on traverse day 2 (Author generated)

The UHII maps generated for the two days of mobile traverse at Cedi House - The Law Courts Complex monitoring area are presented in figures 68 and 69. Analysing the UHIIs profiles for both traverse days, it became evident that the sites that generally recorded low UHIIs were Greater Accra Regional Police Headquarters, Pension Tower (SSNIT), National Theatre, TUC, GRA, Accra High Courts, National Ambulance Service and NLA. The sites: Cedi House, Total House, World Trade Centre, National Theatre, Accra High Courts (Main Gate), and NLA recorded high UHIIs. Cedi House recorded the highest UHII (i.e. 3℃). It was observed that The Law Courts Complex and NLA sites recorded either high or low UHIIs on the both days. Generally, it has been observed that the sites that recorded low UHIIs were along the street corridor that faced the sea. Another observation was that, apart from the Accra High Courts Complex and NLA, the sites that recorded high UHIIs are considerably far from the sea. It would therefore be worth investigating the factors that could have contributed to the exceptions, and this would be considered subsequently in the research.

Fig 68 UHIIs at various locations in Cedi House - The Law Courts Complex monitoring area on day 1 (Author generated)

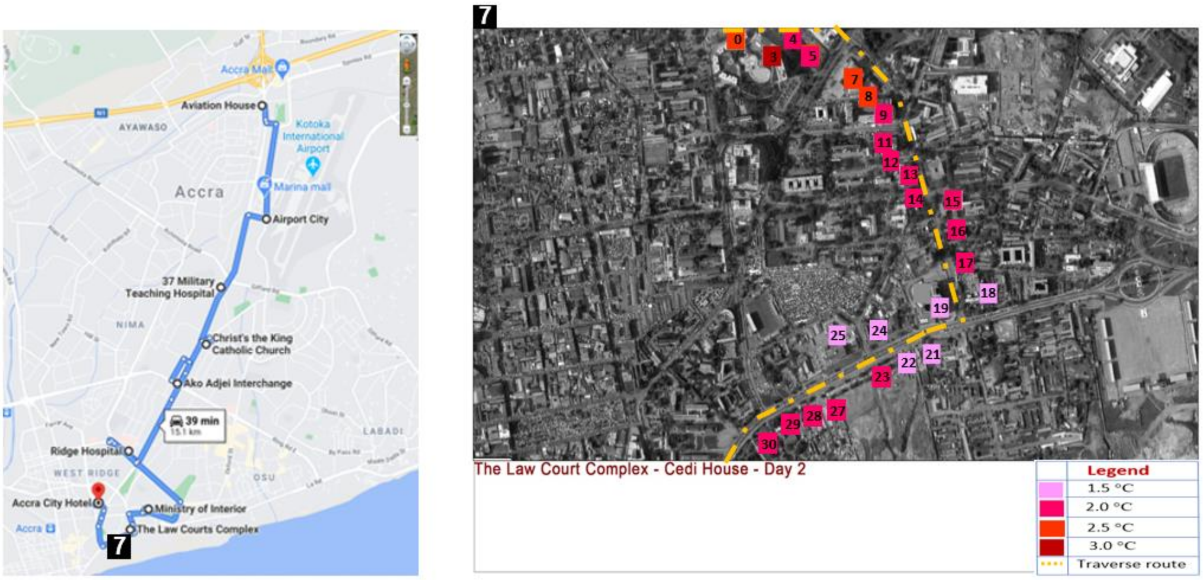

Fig 69 UHIIs at various locations in Cedi House - The Law Courts Complex monitoring area on day 2 (Author generated)

5.5.9 Accra City Hotel (Novotel)

Accra City Hotel is within an open high-rise built-up area, that is, LCZ4. It is located within the core of the CBD and in proximity to the city's busiest commercial area, the Makola market. Facilities characterizing the area are civic-commercial and are mainly composed of hotels, offices, and shops. The greenery in the area is substantial. Some of the streets are defined by avenue trees. The compounds of the hotels in the area have adequate greenery with many shade trees, whilst most of the areas with office buildings have scanty vegetative cover. The physical characteristics of the monitoring area are depicted in figure 70.

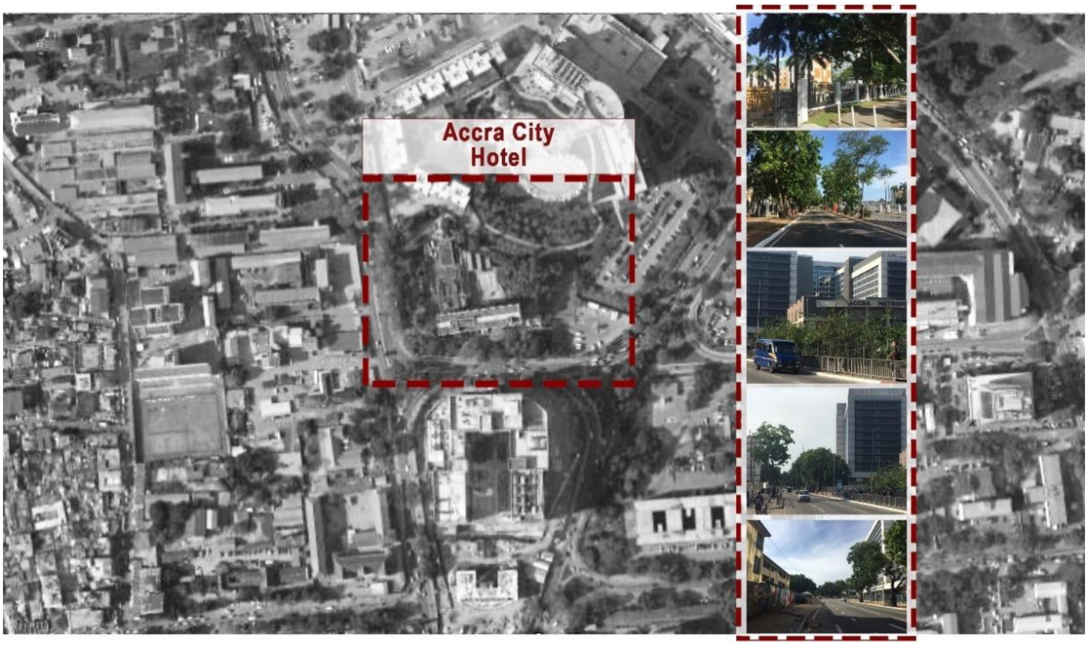

Fig 70 Image showing the Novotel – Barnes Road area

(Author generated)

The weather data gathered at the Novotel monitoring area on days 1 and 2 are respectively depicted in figures 71 and 72. At this location, the average temperatures recorded on days 1 and 2 were 29 – 29.5℃ and 26 – 27℃

respectively. On the two consecutive days, relative humidity values were within 66 – 66.5% and 65 – 67% respectively.

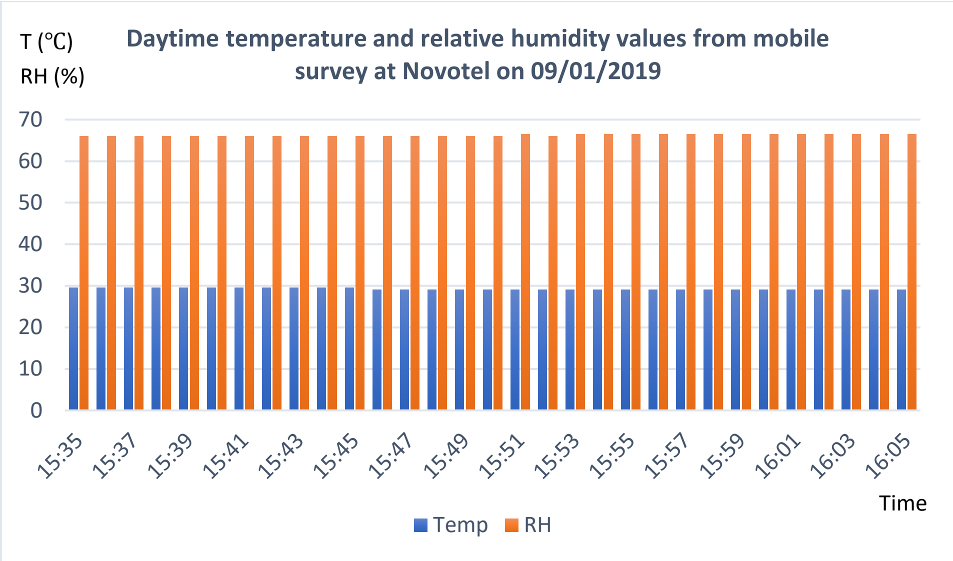

Fig 71 Graph showing temperature and RH values for Novotel on traverse day 1 (Author generated)

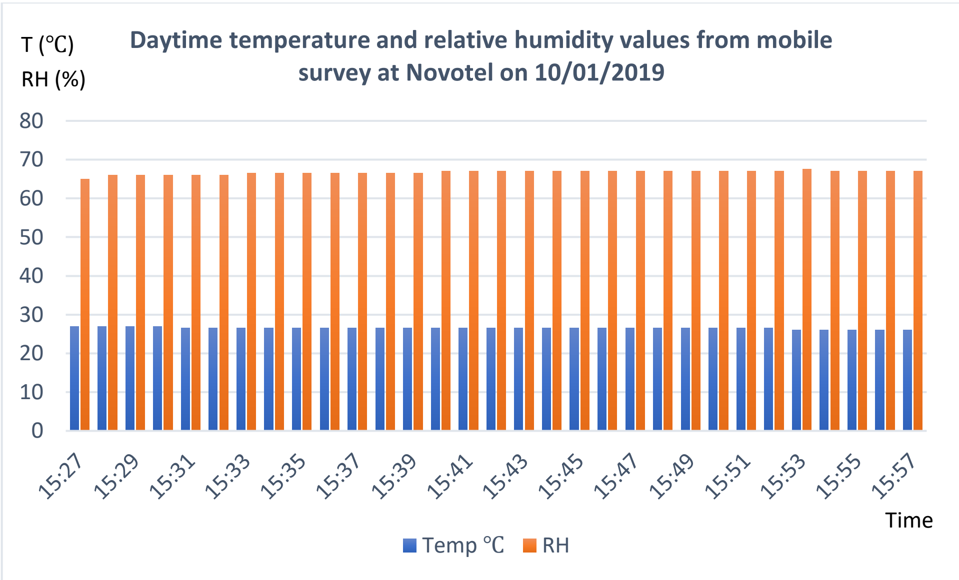

Fig 72 Graph showing temp. and RH values for Novotel on traverse day 2 (Author generated)

5.5.9.1 UHII profiles for Accra City Hotel (Novotel)

On day 1 of the traverse at Accra City Hotel (Novotel), the UHII was 2℃ during the first two minutes. It increased to 2.5 in the 3rd minute and then fluctuated between 2.5 and 2℃ for 6 minutes before dropping sharply to 1.5℃ in the 11th minute. The UHII remained at 1.5℃ from the 11th to the 19th minute after which it fluctuated between 1.5 and 2℃ till the end of the traverse. The UHII profile generated for the mobile traverse conducted at the Novotel monitoring area on the 1st day is presented in figure 73.

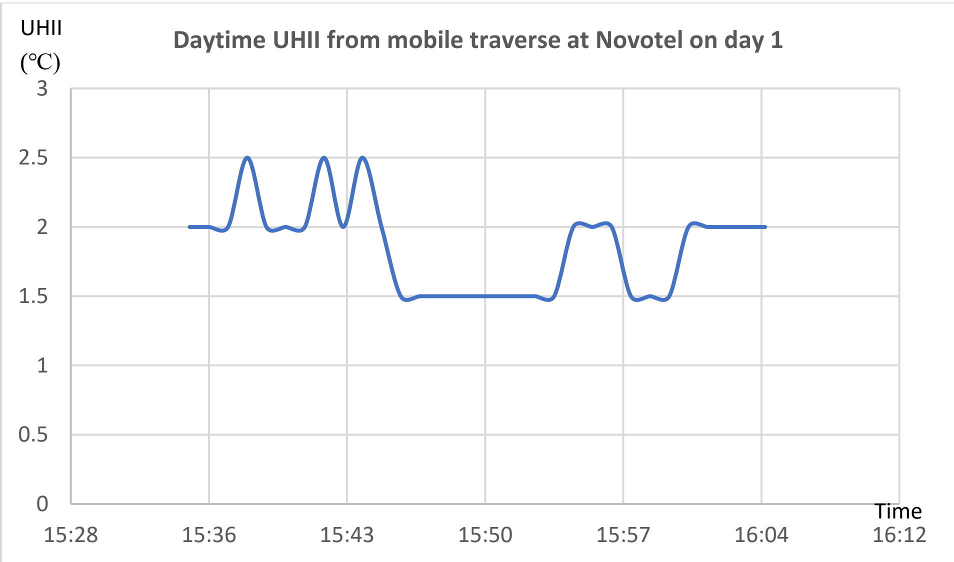

Fig 73 Graph showing UHII profile for Novotel on traverse day 1 (Author generated)

The UHII profile generated for the mobile traverse conducted at the Novotel monitoring area on the 2nd day is presented in figure 74. On traverse day 2, the UHII at the start was 1.5℃, and it increased to 2℃ in the 2nd minute. It then dropped gradually to 1℃ by the 5th minute. It increased to 1.5℃ in the 6th minute and remained constant till the 22nd minute. The UHII increased to 2℃ on the 23rd minute before dropping to 1.5℃ a minute later and thereafter, remained constant till the end of the traverse.

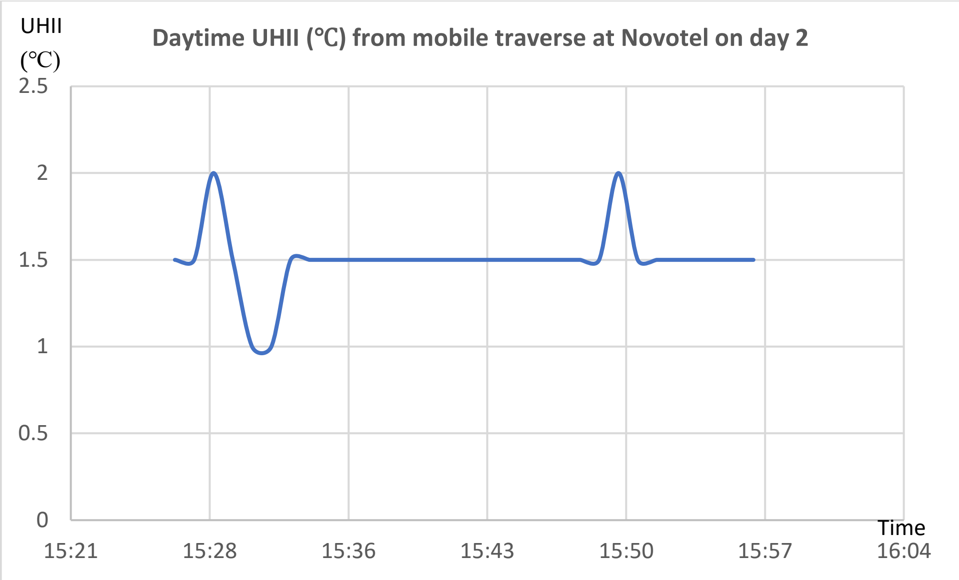

Fig 74 Graph showing UHII profile for Novotel on traverse day 2 (Author generated)

Unfortunately, the manually logged records for the traverse at the Accra City Hotel area got missing after the entire campaign, so the various UHIIs and times could not be directly mapped to the locations that were traversed. It is obvious from the two graphs that the highest UHII was recorded on day 1, and the frequency of UHII of 1.5℃ was the highest on each of the traverse days. Another observation was that there was an area with a stretch of high-rise buildings and shade trees. These canyon characteristics could have possibly reduced the daytime UHII at those locations. These factors may not be exhaustive at this stage, since several factors could account for the UHII variations noticed in the mobile traverse. In chapter 6, the effect of canyon characteristics and other parameters are more extensively investigated as part of the analysis of the data obtained from the stationary measurements, since that involves weather data for both day and night.

5.6 Summary of data for UHII profile for monitoring sites

This section presents tables showing the various monitoring locations, logging times and the indicative UHIIs. In addition, 3-D graphs depicting the UHII profiles for each day are presented.

5.6.1 Day 1 of traverse

The UHIIs obtained for each minute of the traverse period at the 8 monitoring sites on day 1 are presented in table 5.2.

Table 5.2 UHIIs obtained for 8 monitoring sites on 09/01/2019

Traverse day 1									
		Aviation Hse	**Airport City**	**37-Lands**	**Jubilee Hse**	**Arko-Agyei**	**Ridge Hosp.**	**Cedi House**	**Novotel**
Log (Min)	**Time**	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃
0	15:35	1	1	1.5	1	2	1.5	2	2
1	15:36	1	1	1.5	1	2	1.5	2	2
2	15:37	1	1	1.5	1	2	1.5	2	2
3	15:38	1.5	1.5	2	1.5	3	1.5	2.5	2.5
4	15:39	1	1	1.5	1	2.5	1	2	2
5	15:40	1	1	1.5	1	2.5	1	2	2
6	15:41	1	1	1.5	1	2	1	1.5	2
7	15:42	1.5	1.5	2	1.5	2.5	2	2	2.5
8	15:43	1	1	1.5	1	2	1.5	1.5	2
9	15:44	1.5	1.5	2	1.5	2.5	1.5	2	2.5
10	15:45	1	1	1	1	2	1.5	1.5	2
11	15:46	1	1	1	1	2	1.5	1.5	1.5
12	15:47	1	1.5	1	1	2	1.5	1.5	1.5
13	15:48	1	1	1	1	1.5	1.5	1.5	1.5
14	15:49	1	1	1	1	1.5	1	1.5	1.5
15	15:50	1	1.5	1	1	1.5	1	1.5	1.5
16	15:51	1	1	1	1	1.5	1.5	1.5	1.5
17	15:52	1	1	1	1	1.5	1	1.5	1.5
18	15:53	1	1	1	1	1.5	1	1.5	1.5
19	15:54	1	1	1	1	1.5	1	1.5	1.5
20	15:55	1.5	2	1.5	1.5	2	1.5	2	2
21	15:56	1.5	2	1.5	1.5	2	1.5	2	2
22	15:57	1.5	2	1.5	1.5	2	1.5	2	2
23	15:58	1	1.5	1	1	1.5	1	1.5	1.5
24	15:59	1	1	1	1	1.5	1	1.5	1.5
25	16:00	1	1	1	1	1.5	0.5	1.5	1.5
26	16:01	1.5	2	1.5	1.5	2	1	2	2
27	16:02	1.5	1.5	1.5	1.5	2	2	2	2
28	16:03	1.5	1.5	1.5	1.5	2	1	2	2
29	16:04	1.5	1.5	1.5	1.5	2	1.5	2	2
30	16:05	1.5	2	1.5	1.5	2	1.5	2	2

The UHII profile obtained for traverse day 1 is presented in the 3-D graph in figure 75.

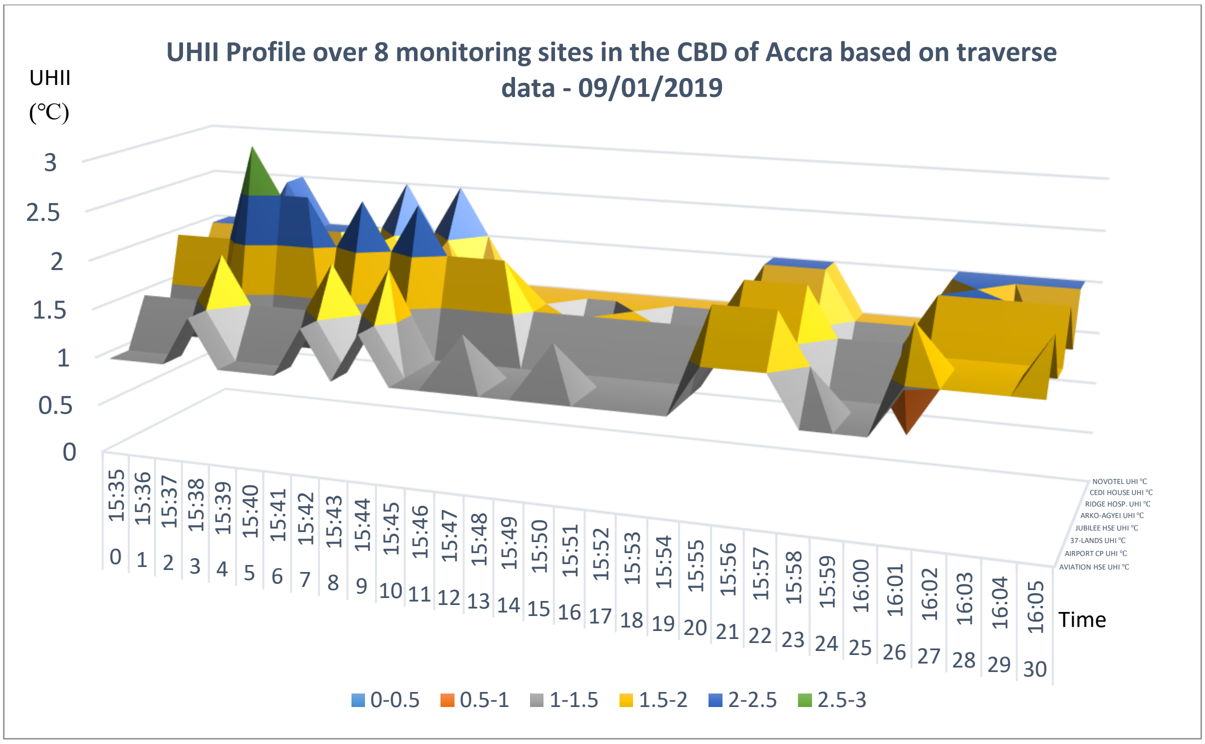

Fig 75 UHII profile over CBD of Accra on traverse day 1 (Author generated)

5.6.2 Day 2 of traverse

The UHIIs obtained for each minute of the traverse period at the 8 monitoring sites on day 2 are presented in table 5.3.

Table 5.3 UHIIs obtained for 8 monitoring sites on 10/01/2019

Traverse Day 2									
		Aviation Hse	**Airport City**	**37-Lands**	**Jubilee Hse**	**Arko-Agyei**	**Ridge Hosp.**	**Cedi House**	**Novotel**
Log (Min)	**Time**	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃
0	15:27	2	0.5	1.5	2	3	2	2.5	1.5
1	15:28	2	0.5	1.5	2	3	1.5	2.5	1.5
2	15:29	2	1	1.5	2	3	2	3	2
3	15:30	1.5	0.5	1	1.5	2.5	1.5	2	1.5
4	15:31	1.5	0.5	1	1.5	2	1.5	2	1
5	15:32	1.5	0.5	1	1.5	2	1.5	2	1
6	15:33	1.5	1	1.5	2	2.5	2	2.5	1.5
7	15:34	1.5	1	1.5	2	2.5	2	2.5	1.5
8	15:35	1.5	1	1.5	2	2.5	2	2.5	1.5
9	15:36	1.5	1	1.5	2	2.5	1.5	2	1.5
10	15:37	1.5	1	1.5	2	2.5	1.5	2	1.5
11	15:38	1.5	1	1.5	1.5	2	1.5	2	1.5
12	15:39	1.5	1	1	1.5	2	1.5	2	1.5
13	15:40	1.5	1	1	1.5	2	1.5	2	1.5
14	15:41	1.5	1	1	1.5	2	1.5	2	1.5
15	15:42	1.5	1	1	1.5	2	1.5	2	1.5
16	15:43	1.5	1	1	1.5	2	1.5	2	1.5
17	15:44	1	1	1	1.5	2	1.5	2	1.5
18	15:45	1	1	1	1.5	2	1.5	1.5	1.5
19	15:46	1	1	1	1.5	2	1.5	1.5	1.5
20	15:47	1	1	1	1.5	2	1.5	1.5	1.5
21	15:48	1	1	1	1.5	2	1.5	1.5	1.5
22	15:49	1	1	1	1.5	2	1.5	1.5	1.5
23	15:50	1.5	1.5	1.5	2	2	2	2	2
24	15:51	1	1	1	1.5	1.5	1.5	1.5	1.5
25	15:52	1	1	1	1	1.5	2	1.5	1.5
26	15:53	1.5	1.5	1.5	1.5	2	2.5	2	1.5
27	15:54	1.5	1.5	1.5	1.5	2	2.5	2	1.5
28	15:55	1.5	1.5	1.5	1.5	2	2	2	1.5
29	15:56	1.5	1.5	1.5	1.5	2	2	2	1.5
30	15:57	1.5	1.5	1.5	1.5	2	2	2	1.5

The UHII profile obtained for traverse day 2 is presented in the 3-D image in figure 76.

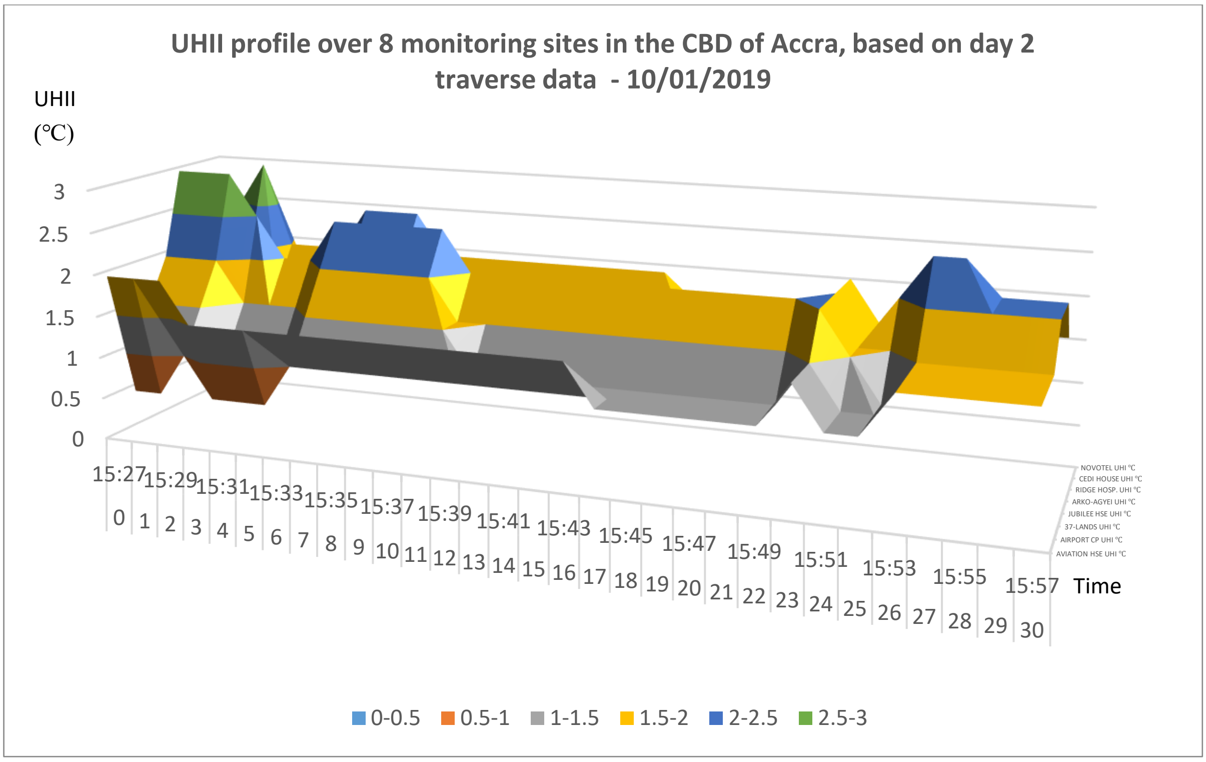

Fig 76 UHII profile over CBD of Accra on traverse day 2 (Author generated)

For traverse days 1 and 2, the UHII maps for the monitoring sites/routes and their locations in the city are consolidated and shown in appendices 1a and 1b.

5.7 Averaged UHII for a two-day mobile traverse covering eight monitoring sites in the CBD of Accra

The charts in figures 77a and 77b show the 2-day UHII averages for the 8 monitoring sites covered in the mobile traverse. The peaks of the 2 curves are consistent, giving a clear indication that Arko Adjei had the highest UHII on both days. The deviations on the 2 ends of the curve could have resulted from the slight variations in the routes traversed on the 2nd day. The second graph depicts the overall averages for the two-day period. As shown in the chart, Arko Adjei Interchange recorded the highest UHII, followed by Cedi House, Novotel, and Ridge Hospital. The 3 other sites recorded much lower UHIIs, with Airport City recording the lowest UHII. Apart from its street width and exposure to the sky, Arko Adjei Interchange is a busy intersection in terms vehicular of traffic.

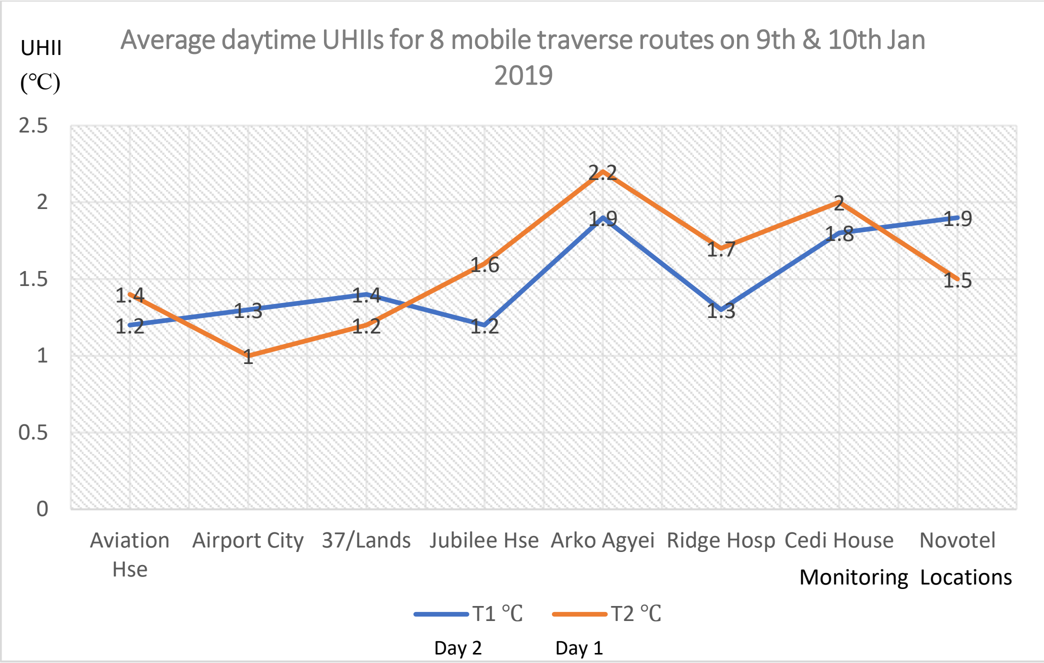

Fig 77a Graph of average daytime UHIIs for both days of traverse (Author generated)

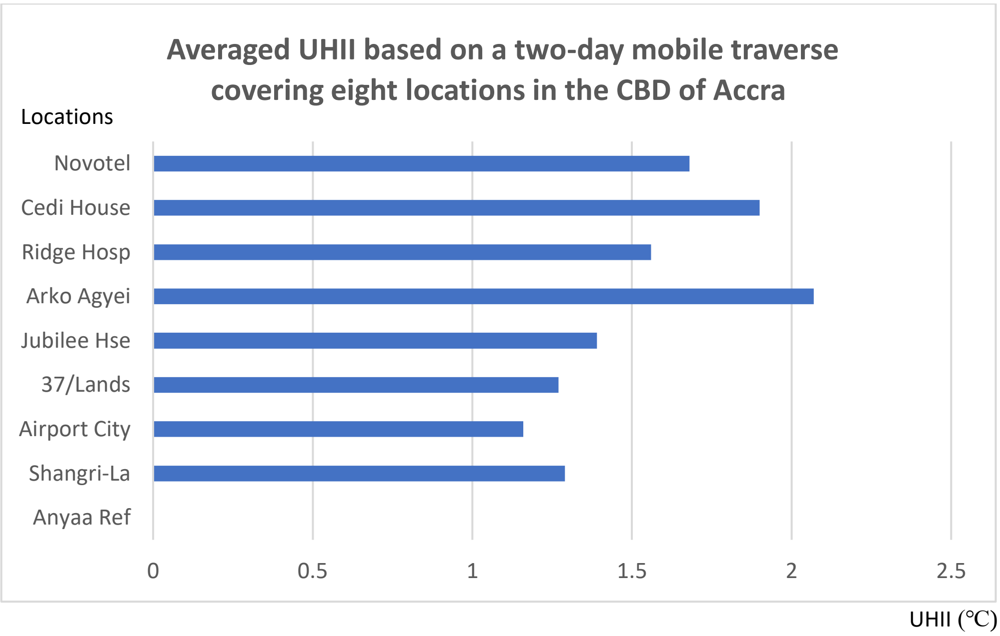

Fig 77b Graph of averaged UHIIs for 2-day traverse (Author generated)

It is worth indicating that although the data were collected on foot, it was impossible to completely avoid the effect of heat from exhausts of vehicles. The route used at Airport City (LCZ1(2)) traversed the deepest canyon among all the eight sites. Generally, it was observed that most of the routes in the monitoring sites on which higher UHIIs were recorded either had much wider streets and thus more open to the sky, characterized by heavy vehicular/pedestrian movements or had less vegetative cover. Some areas on the Aviation House (LCZ2(9)) traverse routes were either characterized by moderately deep canyons, substantial greenery, or both. The streets traversed at 37 Military Hospital and Jubilee House were wide and within shallow canyons, and most areas were well-shaded by big trees. The low UHII recorded at those places could mainly be attributed to the presence of the vegetation.

5.8 Daytime frequency distribution for 8 sites on days 1 & 2

The Frequency distribution graphs of the UHI intensities for the 8 sites for the 2 days are presented in figures 78 and 79. As shown in figure 78, on the 1st day of the mobile traverse, the UHII at most locations was 1.5, followed by UHII of 1 and 2℃. A few spots recorded UHII of 2.5℃ (with a percentage frequency of 3.23%). Only a few traversed locations recorded UHIIs below 1 or 2.5℃. As shown in figure 79, the trend of the UHII frequency distribution for the 2nd day showed a slight variation. On the 2nd day also, the UHII with the highest frequency was 1.5℃, but the percentage frequency of UHII of 2℃ was higher than that of 1℃. The 2 graphs clearly indicate that on a warm-dry day, most sites that were traversed in the study area recorded UHII between 1 and 2℃.

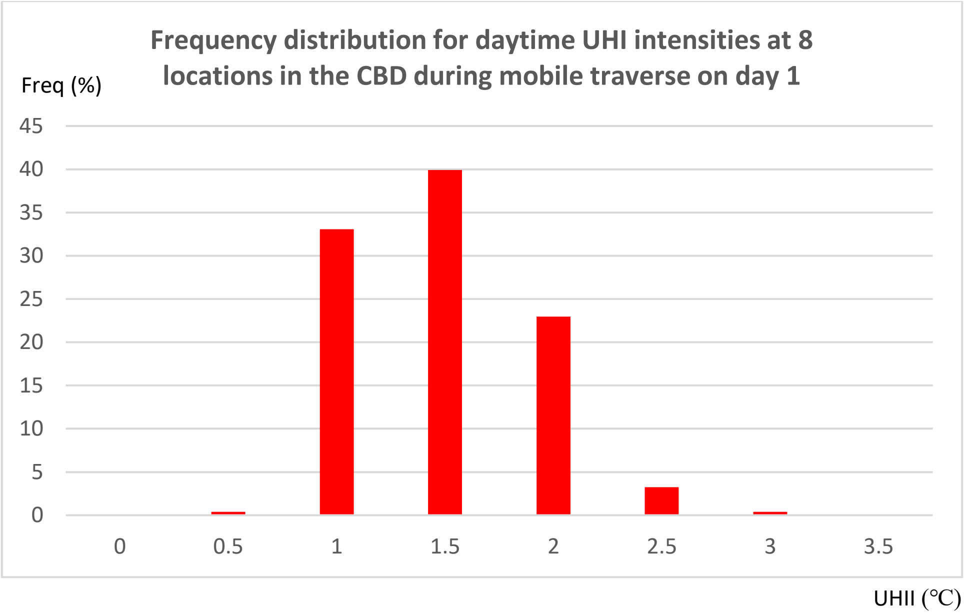

Fig 78 Frequency distribution for daytime UHII based on 1st day of traverse (Author generated)

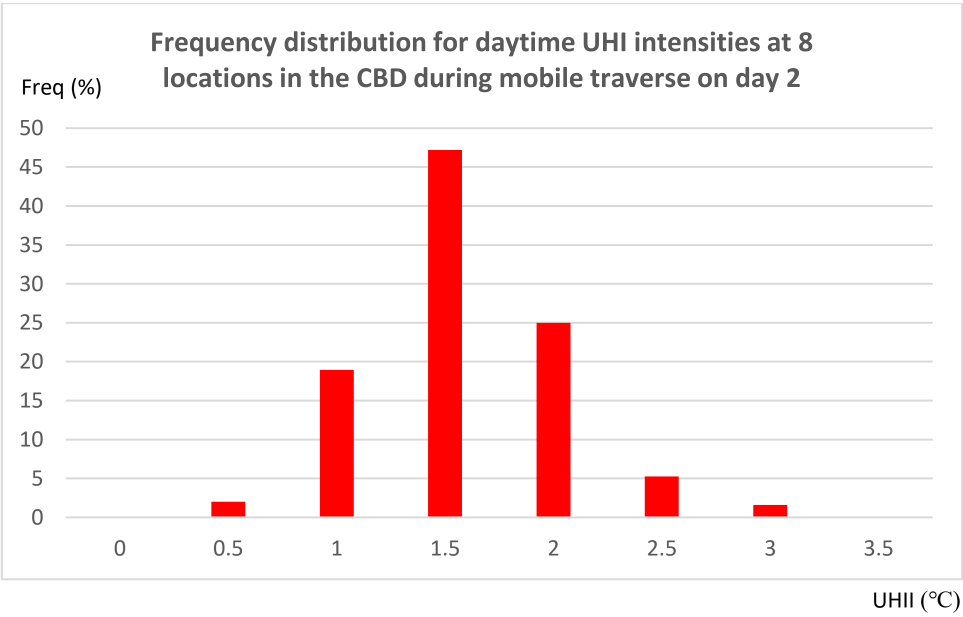

Fig 79 Frequency distribution for daytime UHII based on 2nd day of traverse (Author generated)

5.9 Mean frequency distribution for daytime UHIIs

The mean frequency distribution for daytime UHIIs over the 2-day period is presented in figure 80. The chart clearly confirms that on a typical warm day, the urban heat island intensities at most sites in the CBD of Accra generally fall between 1 and 2℃. The UHII with the highest frequency was 1.5℃ (43.55%), followed in descending order by 1℃ (26.01%), 2℃ (23.99%), 2.5℃ (4.23%), 0.5℃ (1.21%) and 3℃ (1.01%).

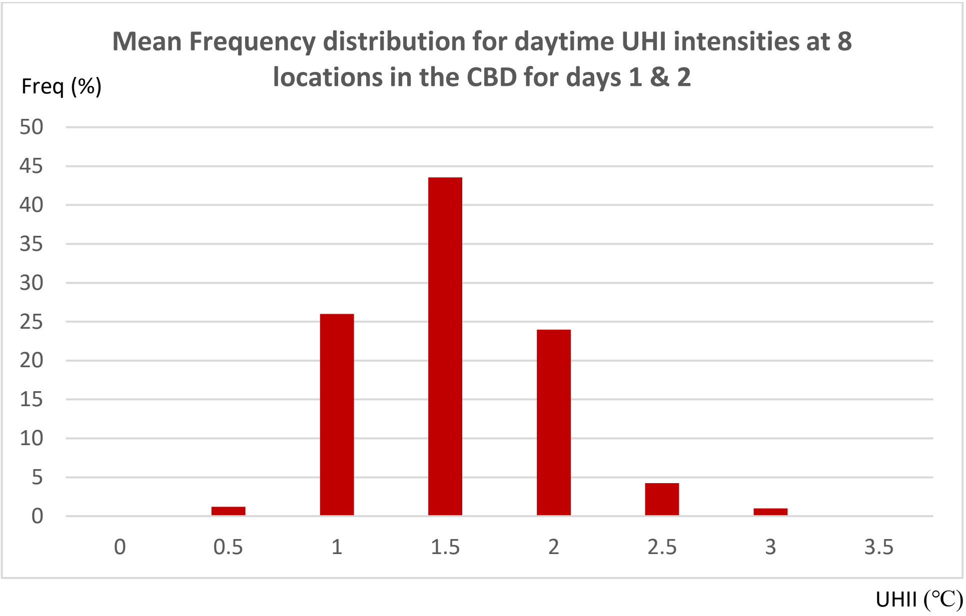

Fig 80 Mean frequency distribution for daytime UHII based on 2-day traverse (Author generated)

5.10 Cross-sectional analysis of UHII across LCZs

The colour coded data presented in table 5.4 (based on data obtained from mobile traverse 1) is used for cross sectional analysis of UHII in the different LCZs.

Table 5.4. Colour coded data for cross-sectional analysis of UHIIs in the different LCZs

			Mobile Traverse Day 1					
	LCZ2(9)	LCZ1(2)	LCZ5(8)	LCZ5(8)	LCZ5(8)	LCZ4(5)	LCZ4	LCZ6
Time	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃	UHI ℃
15:35	1	1	1.5	1	1.5	2	2	2
15:36	1	1	1.5	1	1.5	2	2	2
15:37	1	1	1.5	1	1.5	2	2	2
15:38	1.5	1.5	2	1.5	1.5	2.5	2.5	3
15:39	1	1	1.5	1	1	2	2	2.5
15:40	1	1	1.5	1	1	2	2	2.5
15:41	1	1	1.5	1	1	1.5	2	2
15:42	1.5	1.5	2	1.5	2	2	2.5	2.5
15:43	1	1	1.5	1	1.5	1.5	2	2
15:44	1.5	1.5	2	1.5	1.5	2	2.5	2.5
15:45	1	1	1	1	1.5	1.5	2	2
15:46	1	1	1	1	1.5	1.5	1.5	2
15:47	1	1.5	1	1	1.5	1.5	1.5	2
15:48	1	1	1	1	1.5	1.5	1.5	1.5
15:49	1	1	1	1	1	1.5	1.5	1.5
15:50	1	1.5	1	1	1	1.5	1.5	1.5
15:51	1	1	1	1	1.5	1.5	1.5	1.5
15:52	1	1	1	1	1	1.5	1.5	1.5
15:53	1	1	1	1	1	1.5	1.5	1.5
15:54	1	1	1	1	1	1.5	1.5	1.5
15:55	1.5	2	1.5	1.5	1.5	2	2	2
15:56	1.5	2	1.5	1.5	1.5	2	2	2
15:57	1.5	2	1.5	1.5	1.5	2	2	2
15:58	1	1.5	1	1	1	1.5	1.5	1.5
15:59	1	1	1	1	1	1.5	1.5	1.5
16:00	1	1	1	1	0.5	1.5	1.5	1.5
16:01	1.5	2	1.5	1.5	1	2	2	2
16:02	1.5	1.5	1.5	1.5	2	2	2	2
16:03	1.5	1.5	1.5	1.5	1	2	2	2
16:04	1.5	1.5	1.5	1.5	1.5	2	2	2
16:05	1.5	2	1.5	1.5	1.5	2	2	2

It is evident that LCZ2(9), LCZ1(2), LCZ5(8a), LCZ5(8b), LCZ5(8c), being Aviation House, Airport City, 37 Military Hospital-Lands Commission, Jubilee House, and Ridge Hospital monitoring sites respectively, mostly experienced UHI between 1 and 1.5℃. It must be indicated that in a few instances, LCZ1(2), LCZ5(8a), and LCZ5(8c), being Airport City, 37 Military Hospital, and Ridge Hospital respectively experienced UHI of 2℃. Monitoring sites LCZ4(5), LCZ4, and LCZ6 (Cedi House - The Law Courts Complex, Novotel, and Arko Adjei respectively) experienced UHI between 1.5 and 2.5℃. Three distinct parameters characterizing the different LCZs and based on which this cross-sectional analysis is being done are aspect ratio (AR), greenery, and vehicular traffic (i.e., anthropogenic heat).

Results from the mobile traverse show that variations in daytime UHI cannot be attributed solely to differences in geometric configurations. This is due to the fact that with the exception of Airport City i.e., LCZ1(2) which has the deepest canyon among the various LCZs, the shading provided by the LCZs with fairly deep canyons: LCZ4, LCZ4(5), and LCZ6 could not adequately or significantly reduce the intensities of their respective UHIs. Another factor is the non-uniformity of the canyon geometry and characteristics of the LCZs.

It also became evident that the presence of substantial greenery on sections of the monitoring routes in LCZ2(9), LCZ5(8a), LCZ5(8b), and LCZ5(8c) caused substantial reductions in their respective UHIIs. Although the aspect ratios of those LCZs were low (ranging between 0.11 and 0.21), to a large extent, their UHIIs were found to be significantly reduced.

Monitoring sites LCZ4, LCZ4(5), and LCZ6 being Novotel, Cedi House - The Law Courts Complex, and Arko Adjei Interchange respectively generally had UHIs between 1.5 and 2.5℃, with LCZ6 occasionally experiencing UHI of 3 which was the highest amongst those obtained for all the LCZs. It was observed during the survey that those 3 sites experienced heavy vehicular traffic. In addition, greenery at most parts of the sites was quite sparse. The high UHIIs at LCZ4, LCZ4(5), and LCZ6 could therefore be attributed to the two factors.

5.11 Results from stationary measurements

This section presents urban heat island intensities calculated for the various monitoring sites in the CBD of Accra. Stationary measurements (i.e., air temperature data) were taken from weather sensors located at Aviation House, Airport City, 37 Military Hospital, Arko Adjei Interchange, Ridge Hospital, Ministries, The Law Courts Complex, and Novotel. The reference location used for the stationary measurements was at Anyaa-NIC, same as what was used for the mobile traverse measurements. The measurements were taken during a cool-wet season and a warm-dry season. For each season, graphs are presented to show how the air temperature varied at the eight different monitoring locations. Graphs showing frequency distribution for daytime and night-time urban heat island intensities for each location are presented. The section also presents average UHII daily profile at each monitoring location for both seasons. In the cool wet season, the weather data were collected from 23:37 on 29thth July to 00:37 on 31st July 2020. The weather data for the warm dry season were collected from 23.32 on 22nd October to 00.32 on 24th October 2020.

It is worth indicating that the sky view factor for each location has been determined. The next chapter of this study assesses the effect of sky view factor on all the monitoring sites. On the other hand, not all the eight monitoring sites are within deep or typical urban canyons. Canyon effect analyses were done for 7 monitoring locations: Aviation House, Airport City, 37 Military Hospital, Arko Adjei, Ridge Hospital, Ministries and The Law Court Complex. Data for the Accra City Hotel (Novotel) could not be collected because the sensor had become defective on the day it was removed for downloading. The extents of canyon and sky view factor effects on the urban heat island intensities at each location are dealt with in chapter 7.

An indication of air temperature variation obtained from the 2-day weather measurements taken at Aviation House, Airport City, 37 Military Hospital, Arko Adjei Interchange, Ridge Hospital, Ministries, The Law Courts Complex is depicted in figure 81.

On 30th and 31st July 2020, the average wind speed in the city was between 8.4 and 8.5 m/s. Data on the cloud cover was not made available by the Ghana Meteorological Agency. Each day received 12 hours of shortwave solar radiation at varying intensities. The weather data collected from the locations showed a trend in the air temperature variation at different times between the different locations. It was observed that generally, air temperatures at all the monitoring locations started to drop between the hours of 2.00 and 6.00. Each of the monitoring locations generally experienced an increase in air temperature from 7.00 till about 15.30, after which time they began to drop again till 5.30 am. On each day, the temperature reached its peak between 11.30 and 15.30. On both days (i.e. 30th and 31st July 2020), which were typical cool days in the wet season, air temperatures were high between 6.00 and 15.30, whiles the hours between 15.30 and 6.00 recorded low temperatures. It is also evident from the graph that generally, for locations within the CBD, the coolest hours were between 20.37 and 5.37.

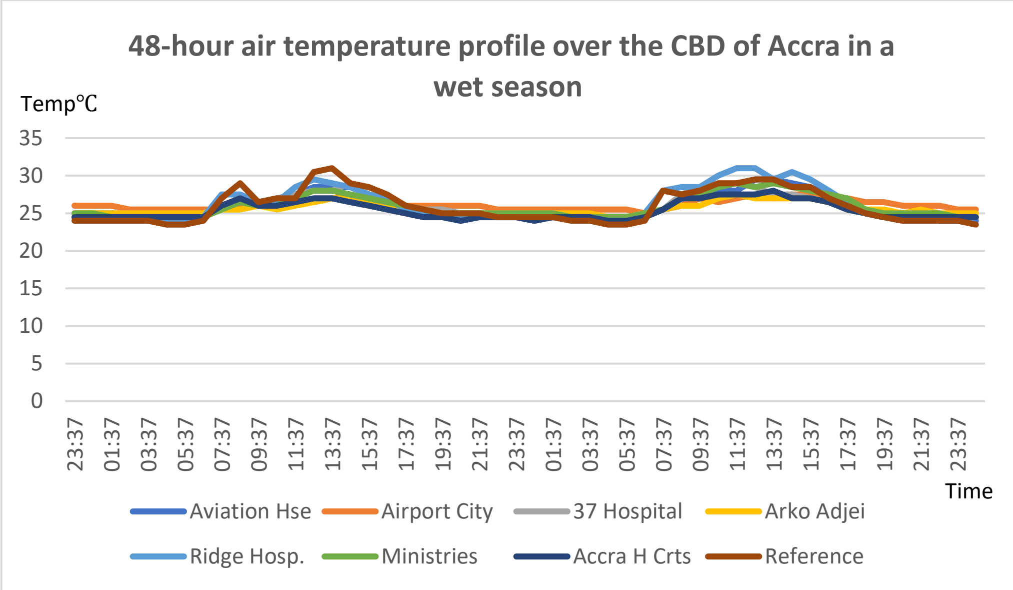

Fig 81 A 48-hour air temperature profile for 7 locations in the CBD of Accra (Author generated)

As shown in figure 81, Ridge Hospital recorded the highest temperature on both days of the survey. The peaks were recorded at 12.37 on both days (30th and 31st July) and they were 29.5 and 31℃ respectively. Accra High Courts recorded peak air temperatures of 27 and 27.5℃ on those respective days, which were the lowest amongst the peaks recorded at all the monitoring locations. On days 1 and 2, the lowest temperature (of 24℃) was recorded at 20.37 and 05.37 respectively. The graph has further revealed that in the afternoon (between 12.37 and 14.37), the reference location recorded temperatures higher than those of the monitoring locations in the CBD. At 12.37 in the afternoon of the second day (31st July) however, Ridge Hospital recorded a temperature that was 1.5 higher than that of the reference location. It is worth indicating that the Ridge Hospital monitoring site has different canyon characteristics from the other locations in the CBD. Although the Ridge Hospital area is widely open to the sky, the variation could also be attributed to reduced greenery and the presence of anthropogenic heat such as vehicular traffic that builds up near the Ridge hospital during daytime. The reference location was again observed to have recorded the lowest temperature on both days at 05.37 and 00.37. The average temperature profile based on hourly averages from the 7 monitoring locations is shown in figure 82.

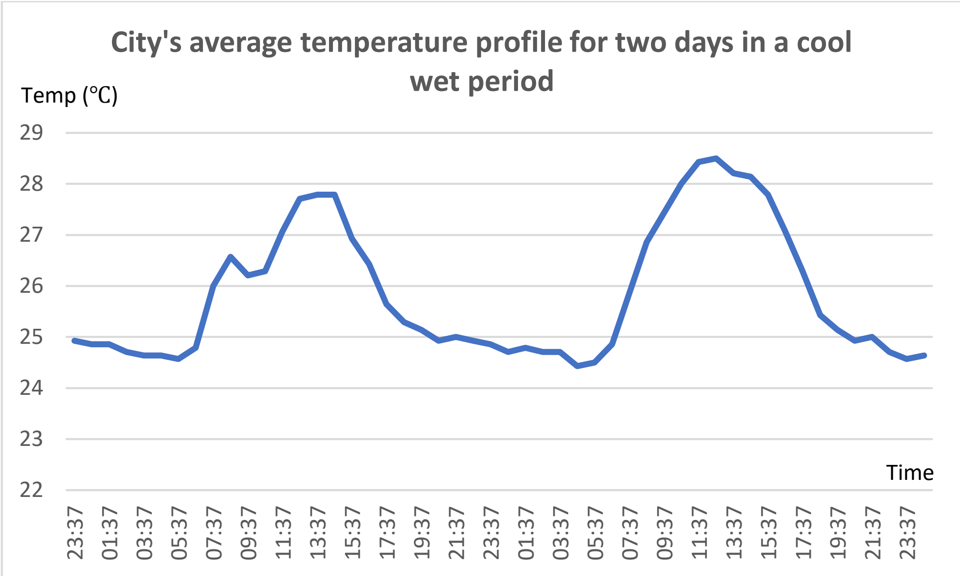

Fig 82 Graph showing average temperature profile on two days in wet season (Author generated)

5.12 Urban heat island intensities in warm-dry and cool-wet periods

This section presents the frequency distribution histograms of UHIIs based on stationary weather data collected at 7 out of the 8 main sites that were earlier selected in the study area for the mobile traverse. To reflect the two main weather seasons (being the wet and dry seasons) experienced in the country annually, histograms are presented for the weather data collected in both cool-wet and warm-dry periods.

5.12.1 Urban heat island intensities in cool-wet period

This sub-section presents the urban heat island intensities obtained for the monitoring 7 sites during the cool-wet period.

5.12.1.1 Aviation House

The daytime and night-time frequency distribution graphs for Aviation House are shown in figures 83 and 84. As depicted in the graph in figure 83, during daytime, the highest frequency of UHII at Aviation House is 25%, and it is at 0℃. It is evident that the histogram is negatively skewed, which means that in the cool wet period, urban *cool islands* are likely to develop at this location during daytime. Figure 84 on the other hand shows that the highest frequency of UHII during night-time is 50% at 0.5℃. The frequency distribution in the histogram shows that night-time UHII is higher than that of daytime. By comparing daytime and night-time UHIIs above 0℃, it is noticed that night-time UHII is more frequent than daytime UHII.

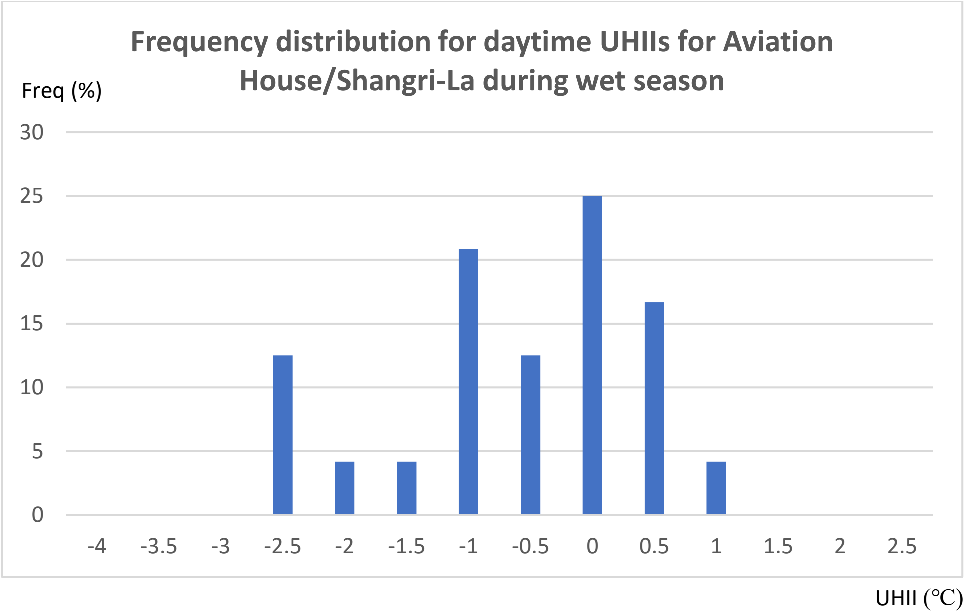

Fig 83 Daytime UHI intensities for Aviation House in a cool wet season (Author generated)

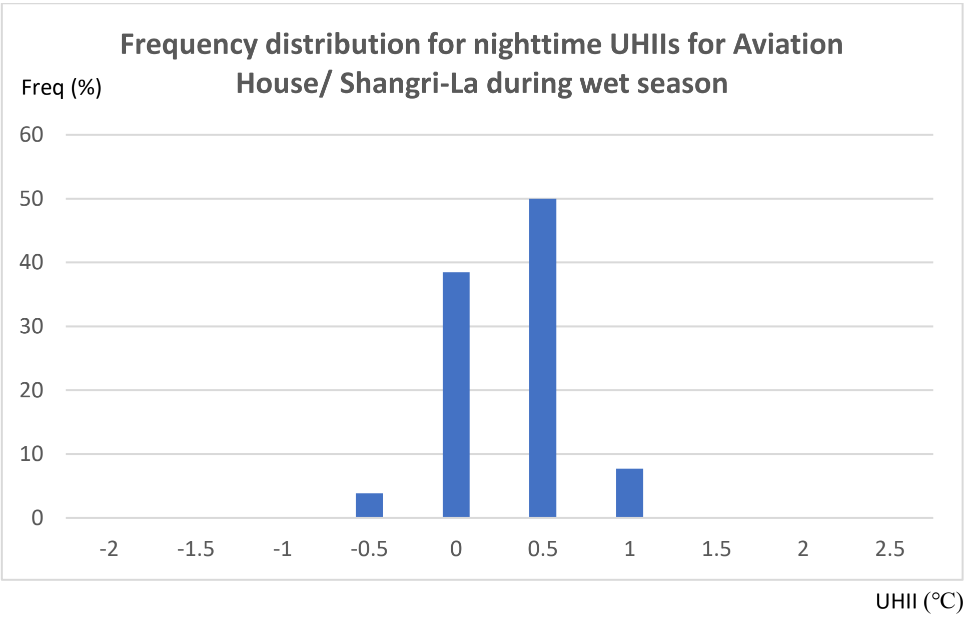

Fig 84 Night-time UHI intensities for Aviation House in a cool-wet season (Author generated)

The scatter diagram in figure 85 shows that night-time UHI is more intense between 8.37pm and 6.37am. It is also noticed that the highest UHII (i.e. 1℃) occurred between 4.47am and 6.37am.

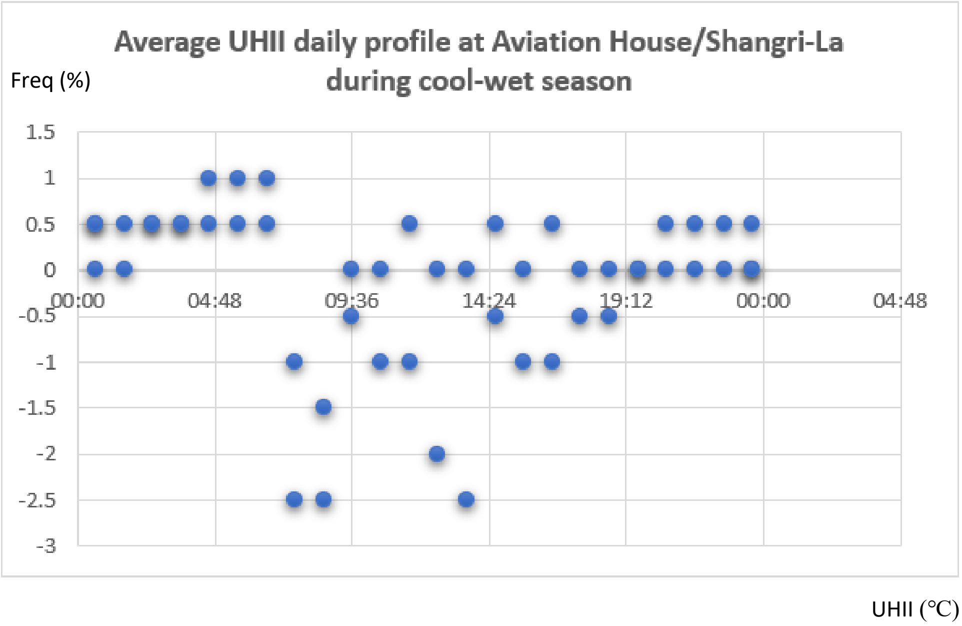

Fig 85 Average daily UHI intensity profile at Aviation House in a cool-wet season (Author generated)

5.12.1.2 Airport City

The frequency distribution histograms for daytime and night-time UHIIs at Airport City are presented in figures 86 and 87. The daytime histogram is very much skewed negatively up to -4℃. At Airport City, the highest frequency of daytime UHII is 20.83% at -1℃. With the total frequency of the negative UHIIs being 79.17%, it is evident that during daytime in the cool wet period, this monitoring site generally experiences urban cool islands. With 2℃ as the maximum and the most frequently occurring UHII (42.31%), the histogram for night-time is almost completely skewed positively, with 96.15% of UHII frequency between 0.5 and 2℃. This clearly indicates that the Airport City monitoring site experiences significantly high night-time UHII.

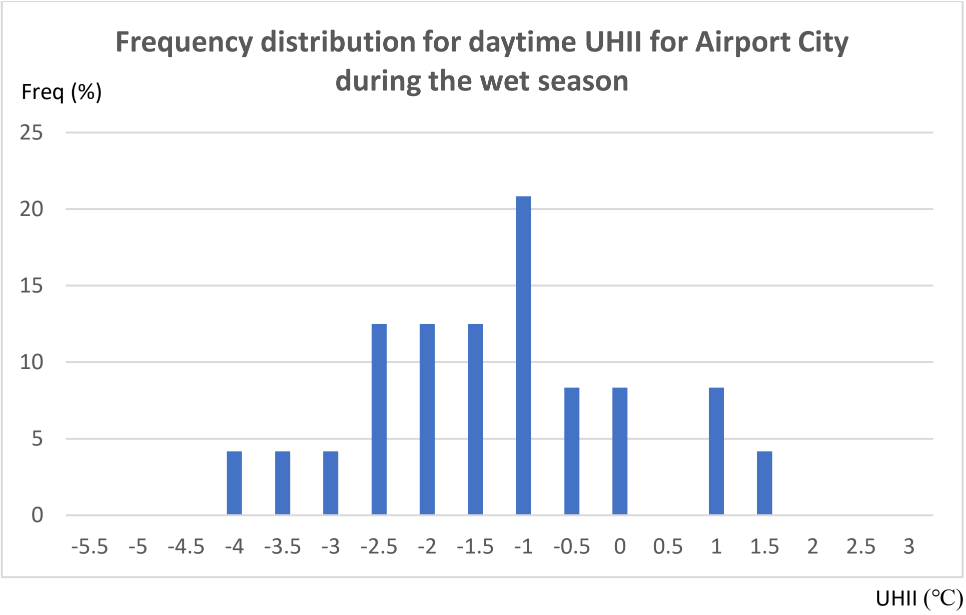

Fig 86 Daytime UHI intensities for Airport City in a cool wet season (Author generated)

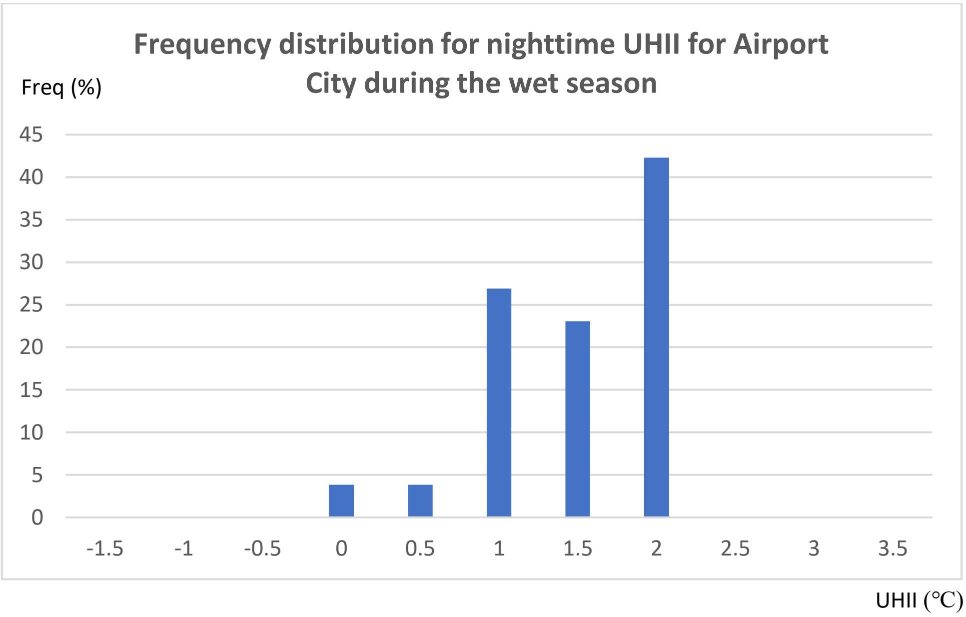

Fig 87 Night-time UHI intensities for Airport City in a cool wet season (Author generated)

The scatter diagram in figure 88 clearly shows that the UHII pattern at Airport City is like that of the Aviation House monitoring site, though with a slight variation. Daytime UHIIs are mostly below zero. The UHII starts increasing sharply after 17.30, reaching a maximum of 2℃ by 19.37. The maximum UHII remains uniform throughout the night till the early hours of the morning (i.e. around 5.30am). It has been noticed that just like Aviation House, there is a drop of 0.5℃ in the night-time UHII between the hours of 2.30 and 3.30 am at Airport City.

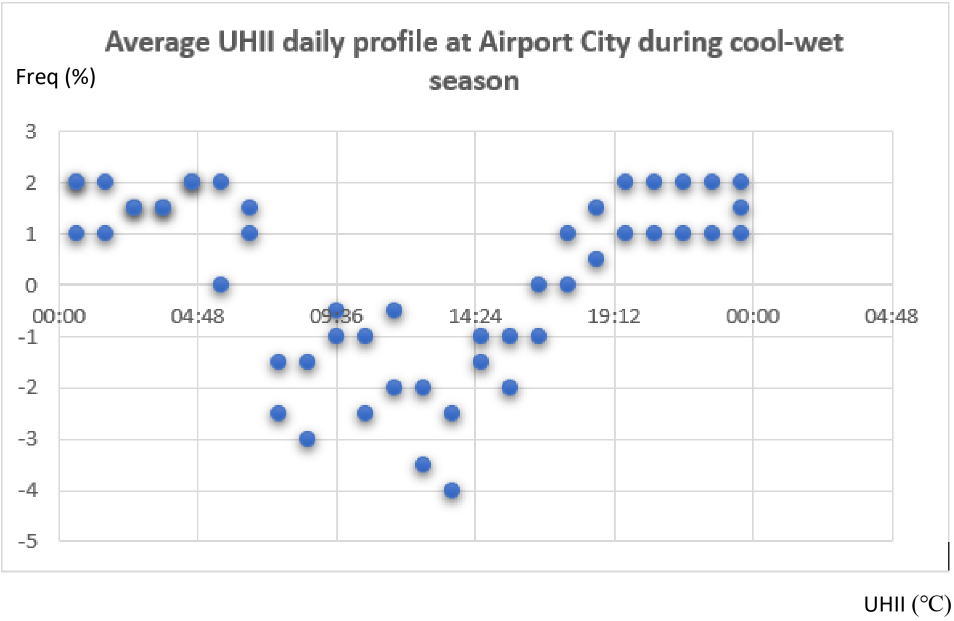

Fig 88 Average daily UHI intensity profile at Airport City in a cool-wet season (Author generated)

5.12.1.3 37 Military Hospital

The histograms depicting daytime and night-time UHII frequency distributions for 37 Military Hospital are presented in figures 89 and 90. At 37 Military Hospital, the daytime UHII frequency distribution is negatively skewed. UHII of 0℃ has the highest percentage frequency (of 29.17%), and whilst the total frequency of the positive UHIIs is 20.83%, that of the negative UHII is 50%. Although, the distribution is negatively skewed, it is worth indicating that the daytime UHII is still significant. The night-time UHII frequency distribution histogram points to an UHII range of between 0 and 1℃. The highest UHII frequency is 42.31% at 1℃. It is thus evident that the site experiences substantial UHII during night-time.

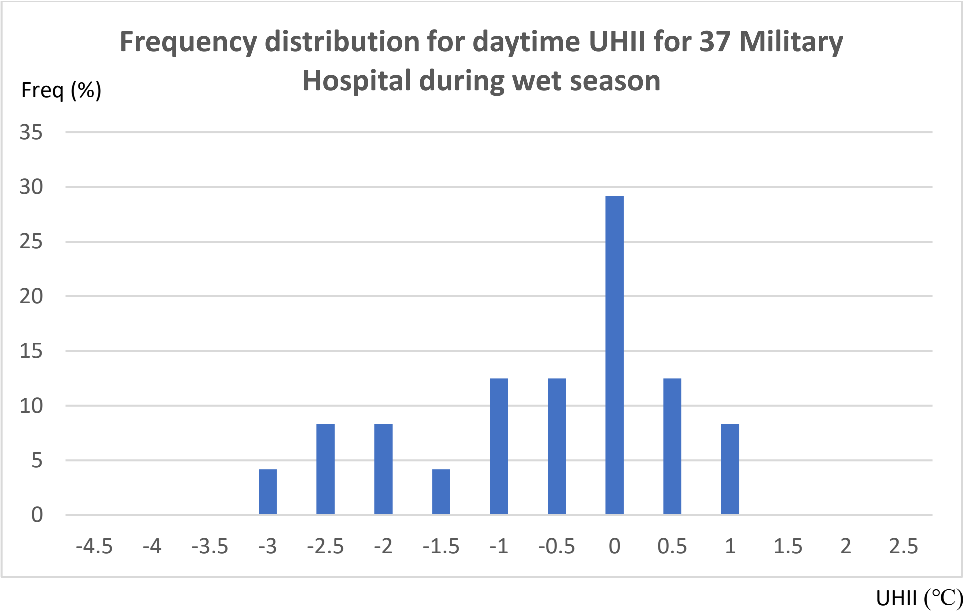

Fig 89 Daytime UHI intensities for 37 Military Hospital in a cool wet season (Author generated)

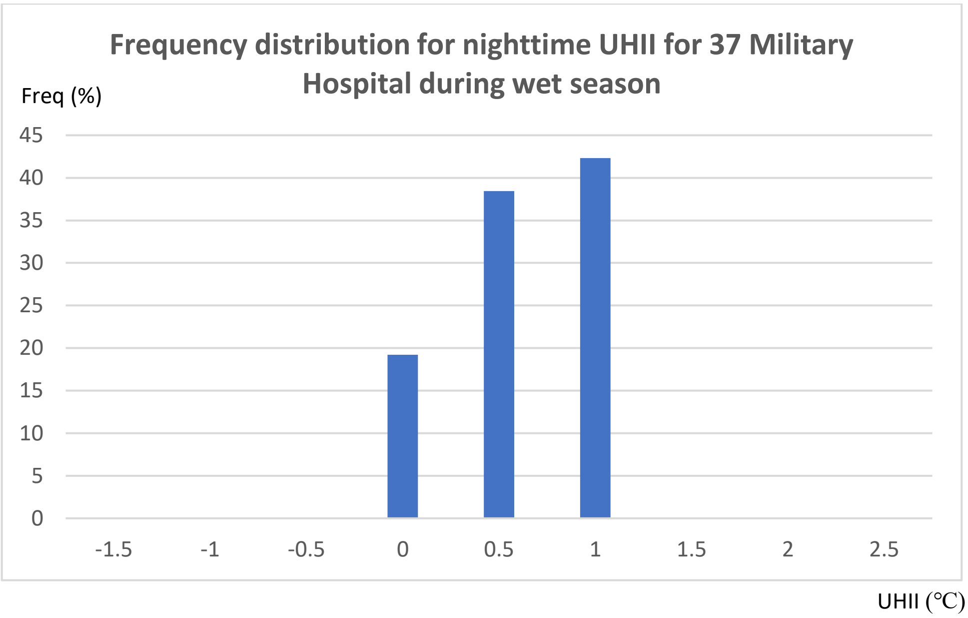

Fig 90 Night-time UHI intensities for 37 Military Hospital in a cool wet season (Author generated)

The scatter diagram in figure 91 depicts the UHII data points for both daytime and night-time for 37 Military Hospital. It is evident that during the day, UHIIs fluctuate, although they are mostly negative. This observation is further investigated in the next chapter. Night-time frequency distribution shows that the

UHI increases more significantly after 20.30pm and drops by 0.5℃ around 10.37pm and 3.37am.

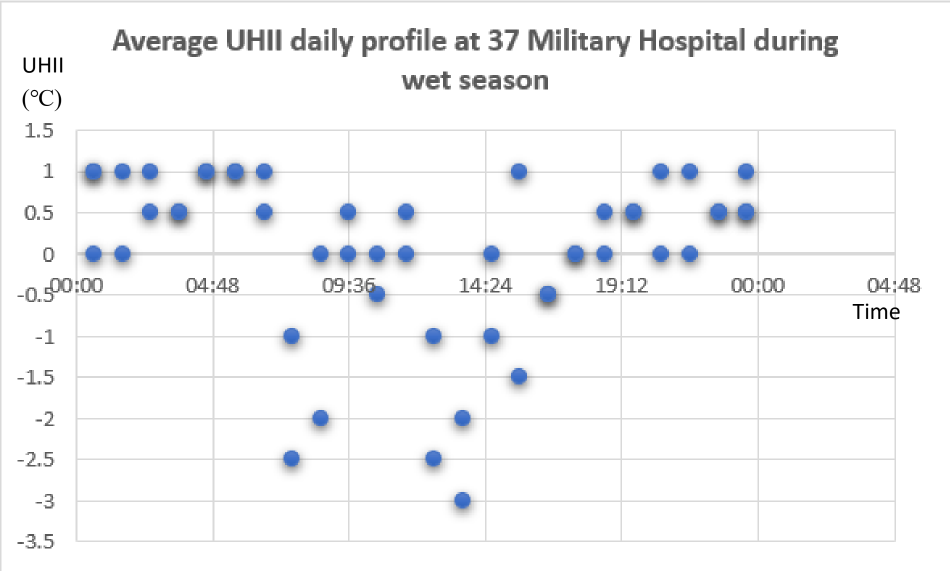

Fig 91 Average daily UHI intensity profile at 37 Military Hospital in a cool-wet season (Author generated)

5.12.1.4 Arko Adjei Interchange

The frequency distribution for daytime and night-time UHII at Arko Adjei are presented in figures 92 and 93. The histogram showing the daytime UHII distribution is skewed negatively. The highest frequency of UHII being 29.17% (at -1.5℃) during daytime is quite significant. With 87.5% of the frequency of UHII being between -0.5 and -4.0℃, it is evident that the monitoring site mostly experiences urban cool islands during the day in the cool-wet period. Like the other sites which have been discussed, the night-time UHII frequency distribution is skewed positively. At night, the highest frequency of UHII is 50% (at 1.0℃). It is noticed in the graph in figure 93 that Arko Adjei experiences a maximum night-time UHII of 1.5℃ at a frequency percentage of 15.39%. It is also evident that in the cool-wet period, night-time UHII at Arko Adjei Interchange is generally higher than those at Aviation House and 37 Military Hospital, but lower than the UHII at Airport City.

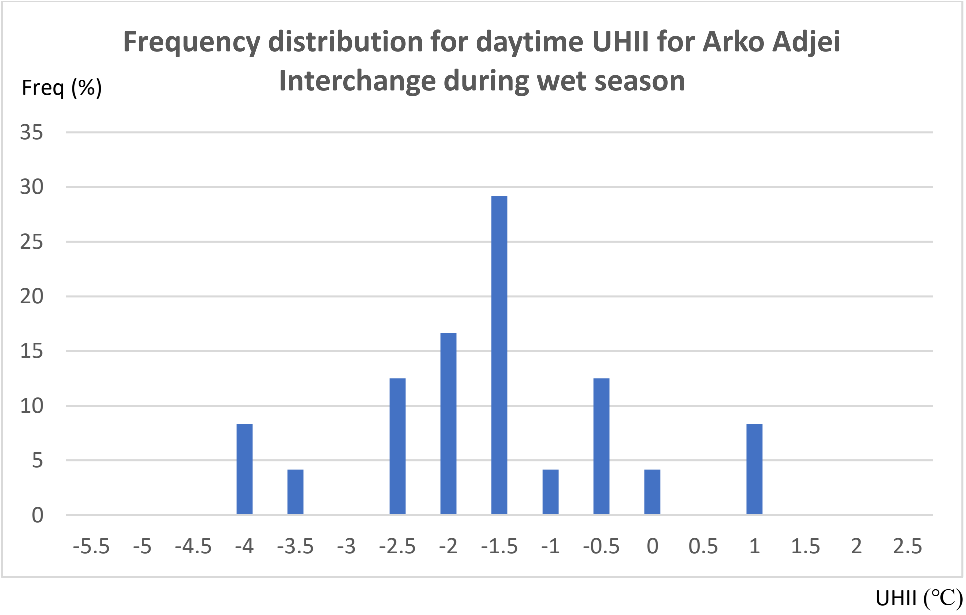

Fig 92 Daytime UHI intensities for 37 Arko Adjei Interchange in a cool-wet season (Author generated)

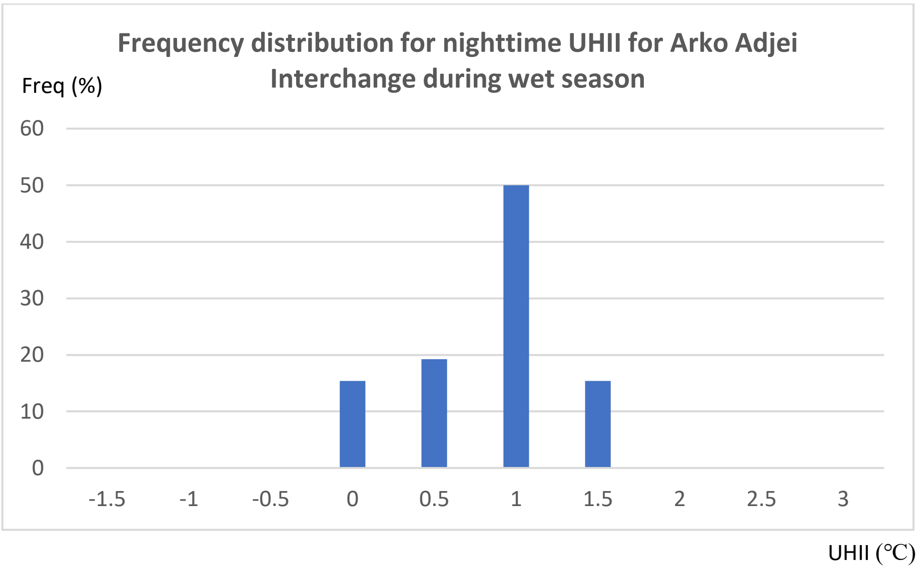

Fig 93 Night-time UHI intensities for Arko Adjei Interchange in a cool wet season (Author generated)

From the scatter diagram depicting the two-day average UHII distribution in figure 94, it is noticed that daytime UHIIs are generally below zero between the hours of 7.37 and 17.37. The UHII then increases significantly after 18.00 and reaches a maximum of 1.5℃ after 21.00. Unlike the trend noticed in the night-time UHII pattern at Airport City and 37 Military Hospital, the night-time UHII at Arko Adjei Interchange generally fluctuates between 1 and 1.5℃.

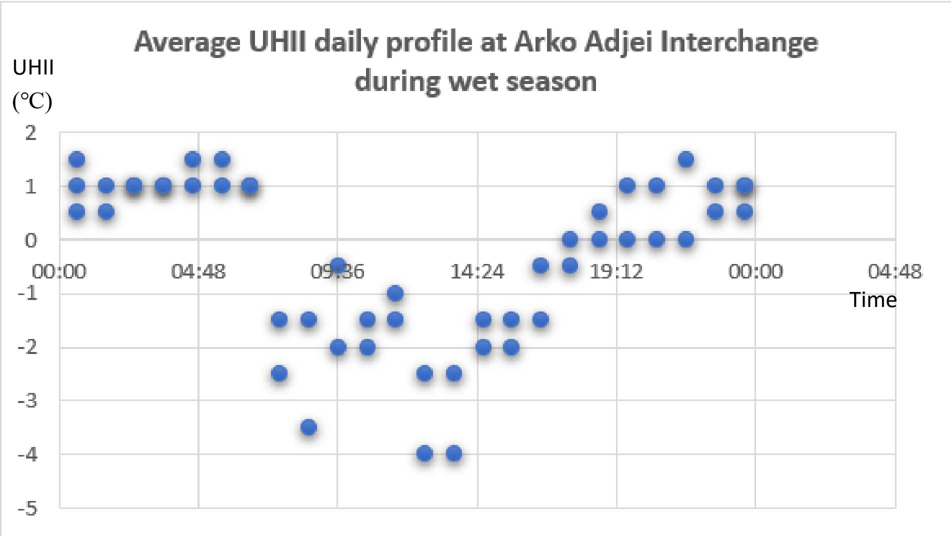

Fig 94 Average daily UHI intensity profile at Arko Adjei Interchange in a cool-wet season (Author generated)

5.12.1.5 Ridge Hospital

A look at the histogram for daytime UHII at Ridge Hospital in figure 95 clearly shows a more positively skewed frequency distribution. Secondly, on the average, daytime UHIIs at Ridge Hospital during wet-cool days are higher than those obtained for Aviation House, Airport City, 37 Hospital and Arko Adjei Interchange. The maximum daytime UHII obtained for Ridge Hospital is 2℃, which is the highest among all the sites. It is worth noting that during certain times of the day, the UHII fell below 0℃ (generally between -0.5 and -2℃). In comparison with the night-time UHIIs obtained for the 4 sites previously mentioned, Ridge Hospital had a much lower night-time UHII. Although the histogram (in figure 96) is skewed positively, a maximum night-time UHII of 1℃ with a frequency percentage of

3.85% is comparatively low. This observation means that the monitoring site receives a substantial amount of shortwave solar radiation during the day and easily loses it through longwave radiation at night. Other factors that could contribute to this pattern are further investigated in the next chapter.

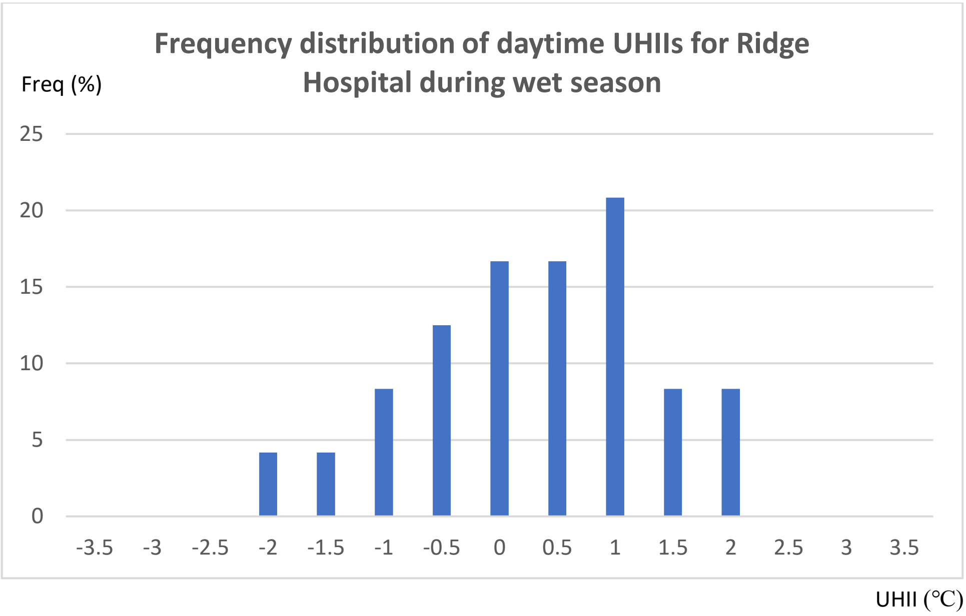

Fig 95 Daytime UHI intensities for Ridge Hospital in a cool wet season (Author generated)

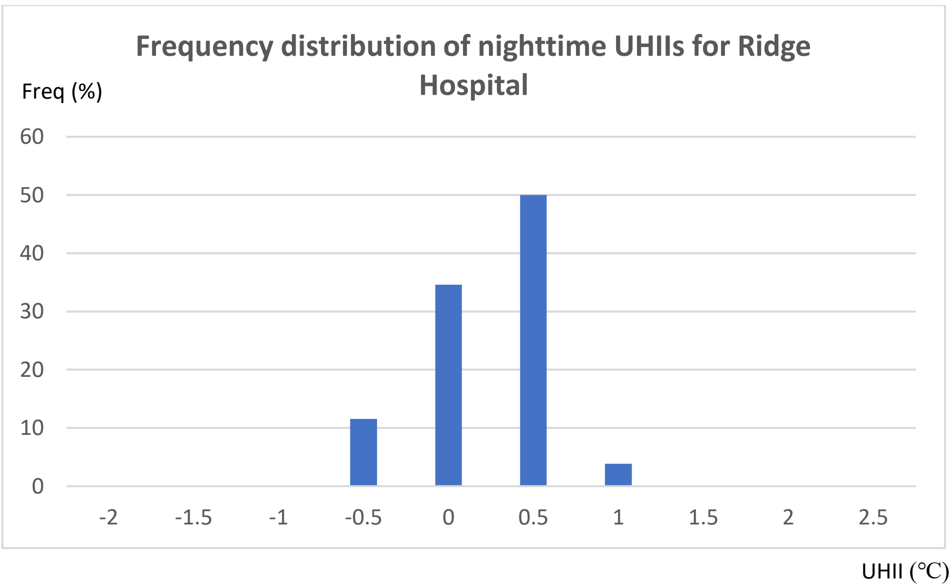

Fig 96 Night-time UHI intensities for Ridge Hospital in a cool wet season (Author generated)

The scatter diagram in figure 97 shows a clear distinction between the daytime and night-time UHII patterns. Although the daytime UHII profile points to occasional urban cool islands, between the hours of 6.37 and 16.37, the site is more likely to experience high UHIIs (i.e. from 1 to 2℃). It is also noticed that from 17.37 to 5.37 in the next morning, the UHII generally drops to 0.5℃.

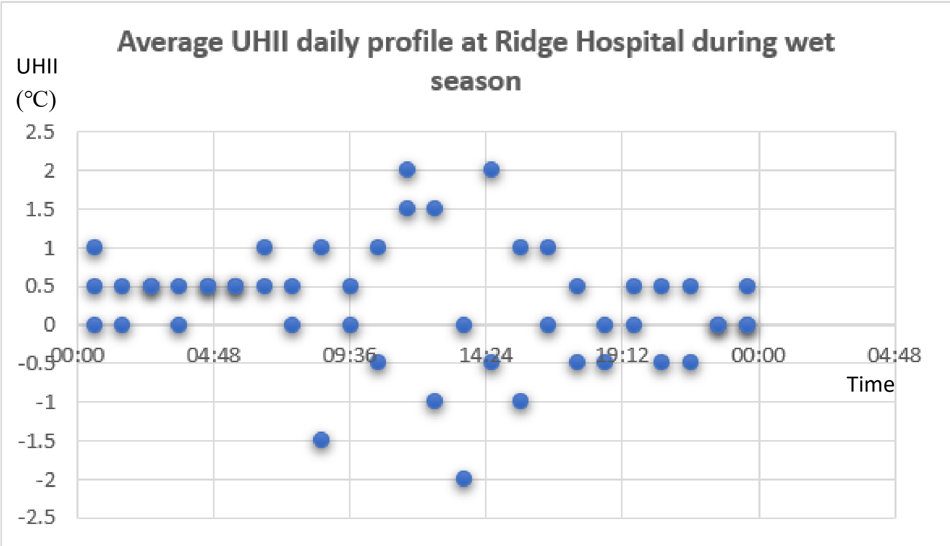

Fig 97 Average daily UHI intensity profile at Ridge Hospital in a cool-wet period (Author generated)

5.12.1.6 Ministries

Histograms depicting daytime and night-time UHII frequency distribution for the Ministries site are presented in figures 98 and 99. The histogram (in figure 98) showing the daytime UHII frequency distribution is very much skewed negatively. The pattern depicted in this figure is like that of Airport City, though the histogram for the latter showed lower UHII. The histogram shown in figure 99 indicates that Ministries generally experiences night-time UHII between 0.5 and 1℃ at frequencies of 50% and 34.61%.

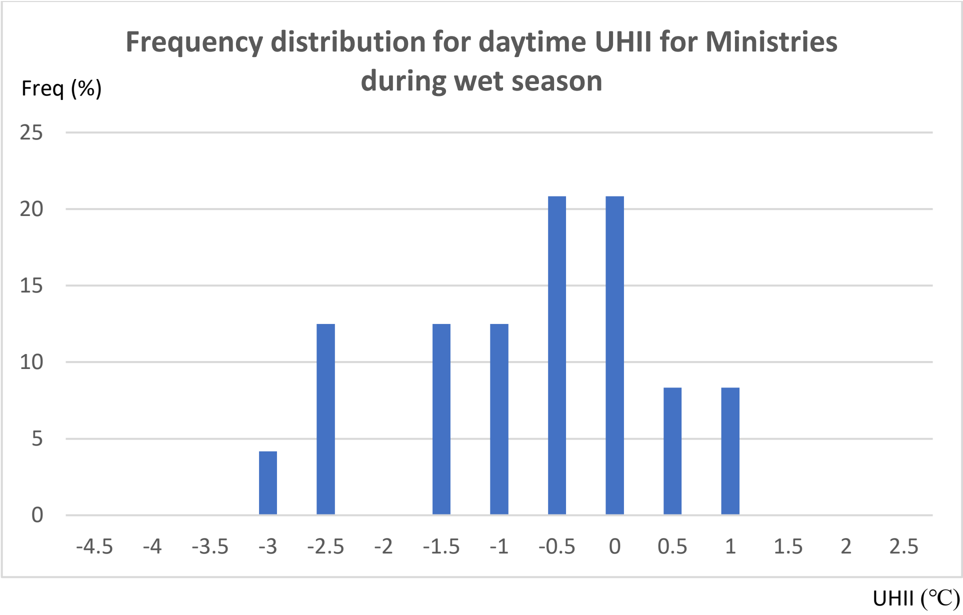

Fig 98 Daytime UHI intensities for Ministries in a cool wet season (Author generated)

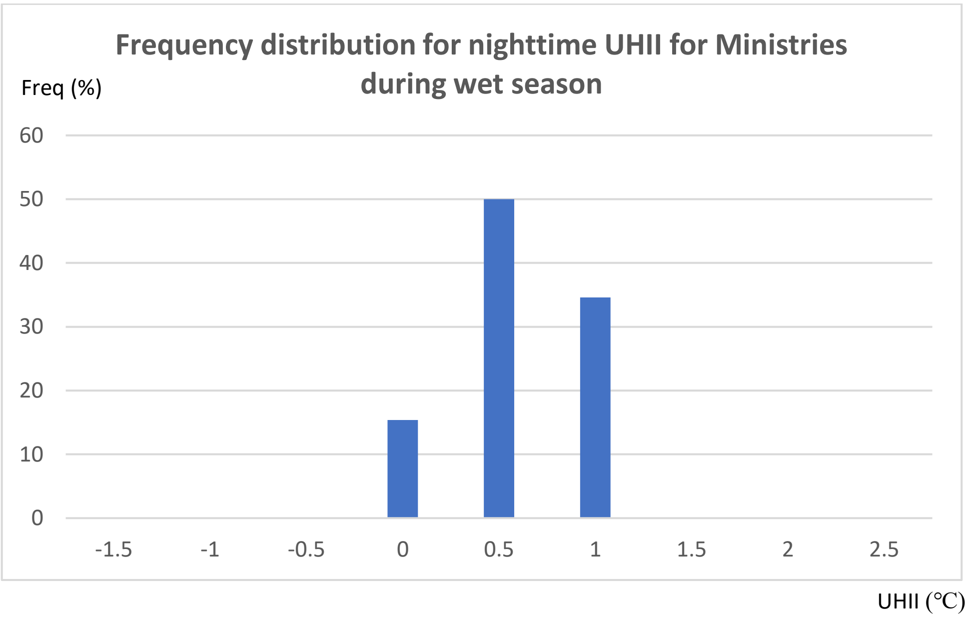

Fig 99 Night-time UHI intensities for Ministries in a cool wet season (Author generated)

From the scatter diagram in figure 100, it is evident that between the hours of 6.30 and 16.30, the site experiences low UHIIs or urban cool islands ranging between -0.5 and -3.0℃, whilst high UHIIs of up to 1℃ occur between 16.30 and

6.30. It is noticed that the night-time UHII drops to 0.5℃ between the hours of 1.30 and 3.30.

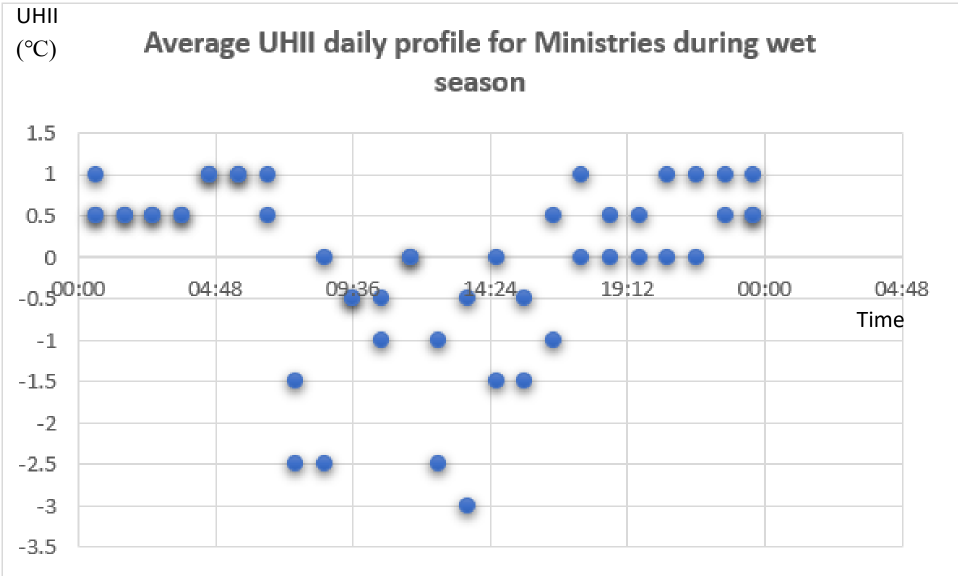

Fig 100 Average daily UHI intensity profile at Ministries in a cool-wet season (Author generated)

5.12.1.7 The Law Court Complex

The frequency distribution graphs for daytime and night-time UHIIs at The Law Court Complex shown in figures 101 and 102 respectively, reveal patterns like those depicted in the histograms for Ministries. It is noticed in figure 101 that the site frequently experiences low daytime UHIIs between -0.5 and -2.5℃. Occasionally, the daytime UHII is between -3.5 and -4℃ (both at a frequency of 4.17%). The histogram is negatively skewed and the percentage frequency for the only positive UHII (0.5℃) is 8.33%. Just as the other sites, night-time UHIIs are higher than those of daytime. Though both sites have similar morphological characteristics, figure 102 shows that night-time UHIIs at the Law Court Complex site are lower than those obtained for Ministries. It is also evident that out of the 7 monitored sites, only the Law Court Complex recorded an UHII of -1℃.

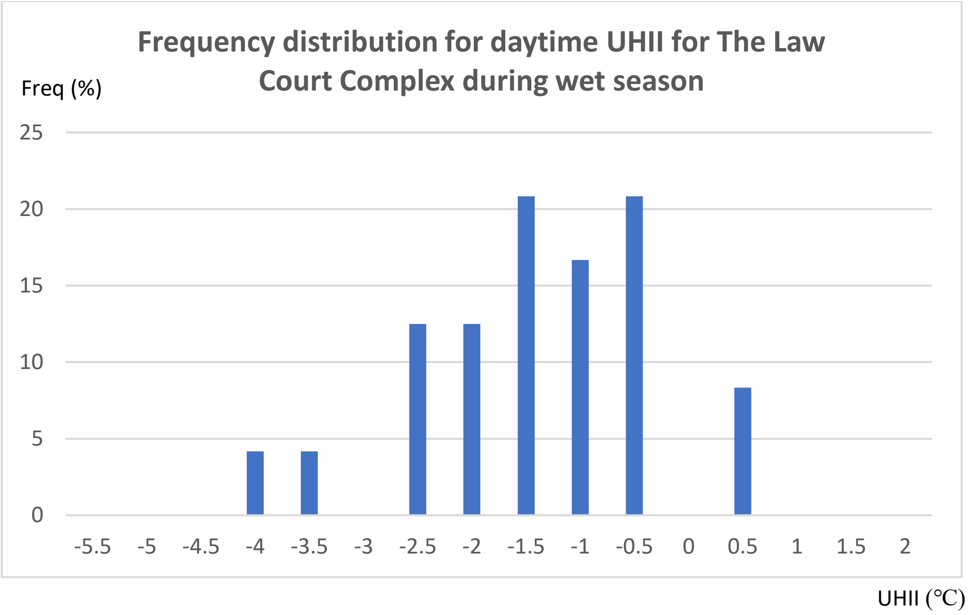

Fig 101 Daytime UHI intensities for The Law Court Complex in a cool wet season (Author generated)

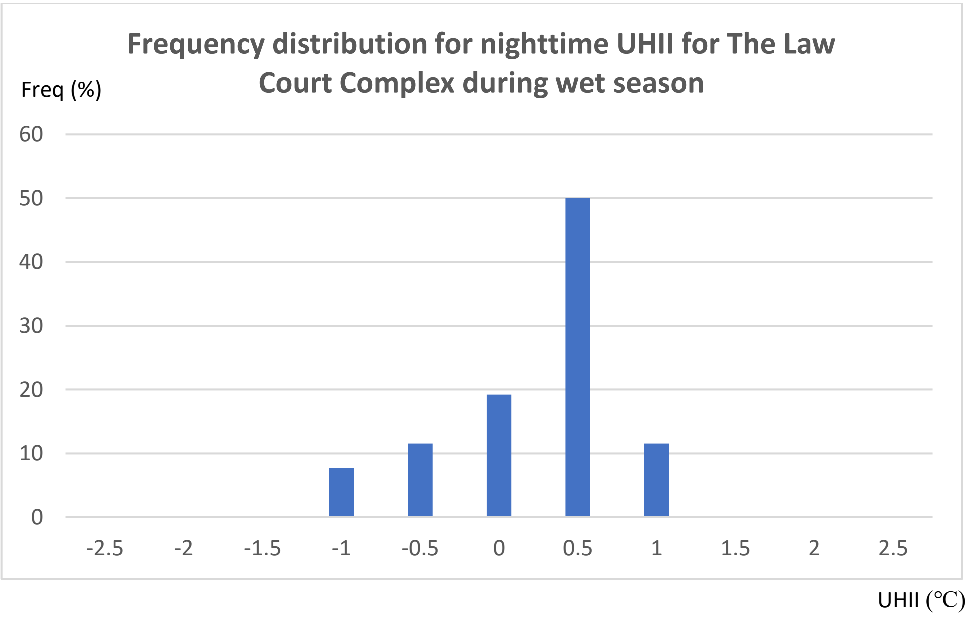

Fig 102 Night-time UHI intensities for The Law Court Complex in a cool wet season (Author generated)

It is noticed in the scatter diagram in figure 103 that The Law Court Complex site experiences urban cool islands from 6.37 to 17.37 hours, after which the UHII increases, fluctuating between 0.5 and 1.5℃ in the night.

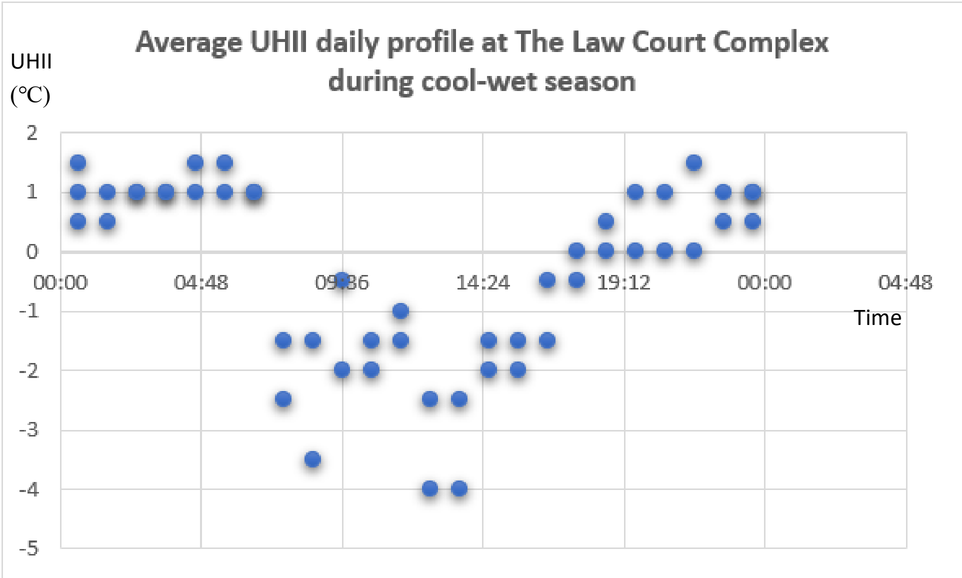

Fig 103 Average daily UHII profile at The Law Court Complex in a cool-wet period (Author generated)

5.12.2 Urban heat island intensities in warm-dry period

As done in the cool-wet period, weather data for the warm-dry period were also obtained through stationary measurements. It is worth indicating that the data collection in the warm-dry period which had originally been scheduled for March-April 2020 could not be carried out due to the onset of the covid-19 pandemic and its attendant restrictions. The data were subsequently collected in October 2020. Sensors were mounted at the 7 locations that were monitored in the cool-wet period. Unfortunately, during the warm-dry season survey, 2 sensors were stolen, and another had become defective at the end of the campaign and could not record any data as a result. In effect, weather data could only be captured at 4 sites: Aviation House, Airport City, 37 Military Hospital and Ministries.

5.12.2.1 UHIIs at Aviation House

The daytime UHIIs obtained for Aviation House were negative between 6.30 and 12.30, while positive UHIIs were obtained between 13.30 and 17.30. For this site, the highest daytime UHII (of 3℃) was recorded between 16.30 and 17.30. Although the maximum daytime UHII at Aviation House was significantly high, the UHII frequency distribution (as shown in figure 104) is slightly skewed negatively. It is evident from this site's data for the warm-dry period that both minimum and maximum UHIIs were quite substantial.

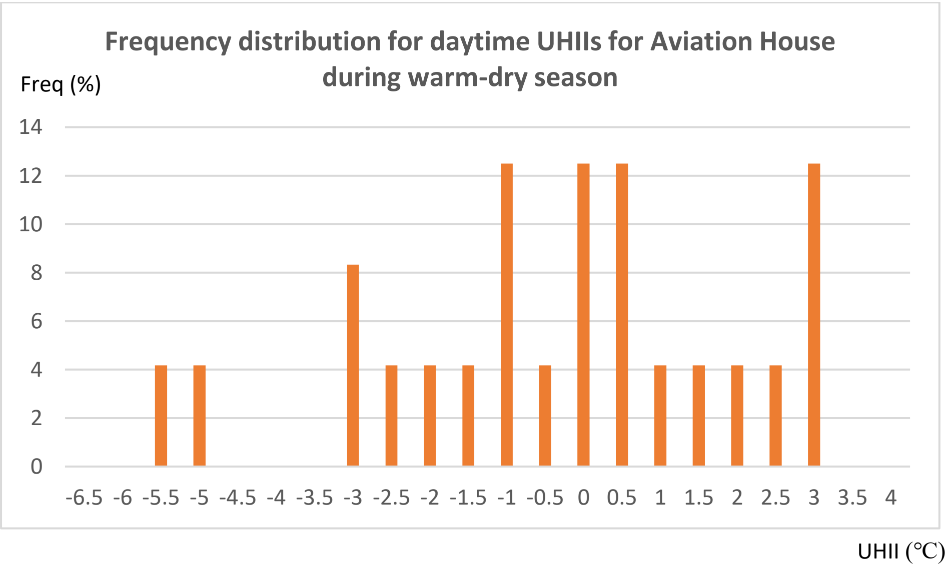

Fig 104 Daytime UHI intensities for Aviation House in a warm-dry period (Author generated)

As shown in figure 105, the night-time UHII frequency distribution graph for Aviation House during the warm-dry period is positively skewed, ranging between 1 and 2℃. It was observed that all the hourly UHIIs obtained between the hours of 18.30 and 5.30 were positive.

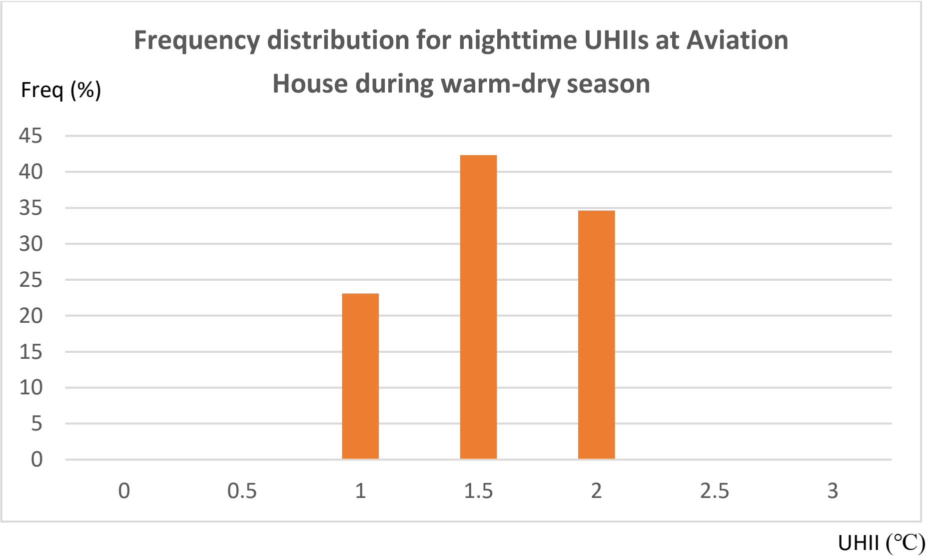

Fig 105 Night-time UHI intensities for Aviation House in a warm-dry period (Author generated)

It has been noticed that the warm-dry night UHIIs are much higher than those obtained during the cool-wet period. As shown in the scatter diagram in figure 106, the site recorded UHIIs ranging between 1 and 3℃ during late afternoon (i.e., between 14.30 and 17.30). This pattern is different from that of the cool-wet period, as the latter showed only negative daytime UHIIs.

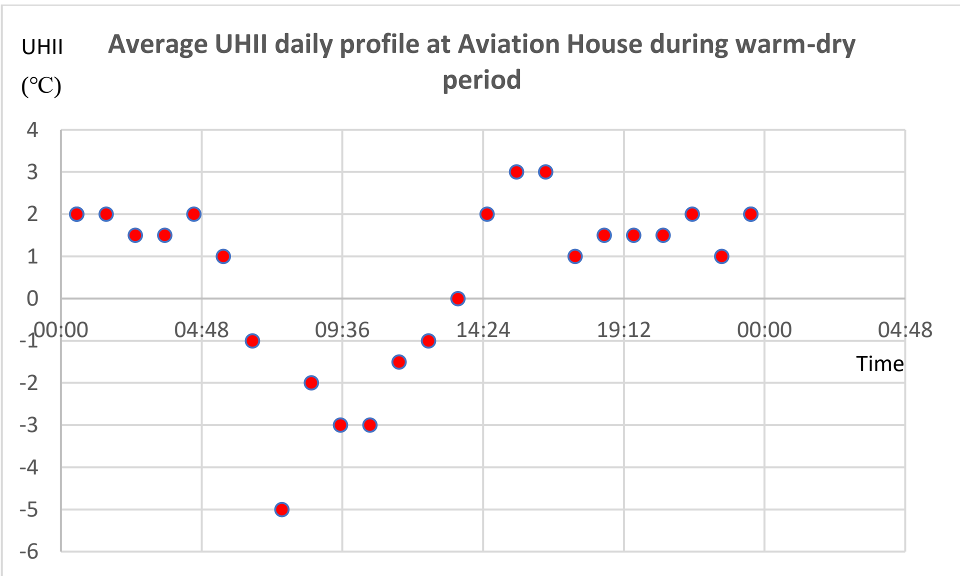

Fig 106 Average daily UHI intensity profile at Aviation House in a warm-dry period (Author generated)

5.12.2.2 UHIIs at Airport City

The UHII frequency distribution graph for daytime UHII at Airport City is presented in figure 107. Like Aviation House, all the hourly UHIIs obtained for Airport City between 6.30 and 12.30 were negative, while positive UHIIs were obtained between 15.30 and 17.30. The hourly daytime UHIIs were very low, ranging between -0.5 and -8.5℃. The highest daytime UHII obtained for this monitoring site was 2℃. Both maximum and minimum daytime UHIIs at Airport City were lower than those obtained for Aviation House. This difference could be attributed to the fact that Airport City has a much deeper canyon, and therefore it was better shaded than Aviation House.

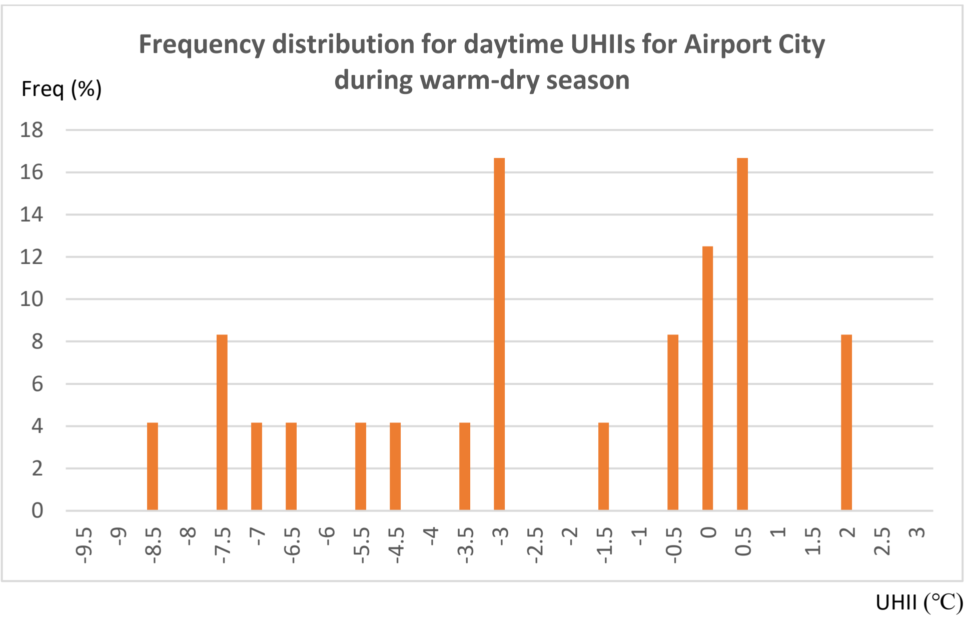

Fig 107 Daytime UHI intensities for Airport City in a warm-dry period (Author generated)

The night-time UHII frequency distribution graph for Airport City during the warm-dry period is presented in figure 108. The frequency distribution is positively skewed, with the UHII ranging between 2 and 4℃. The highest frequency was

38.46% at 3.5℃, which was very significant. In fact, all the night-time UHIIs were positive.

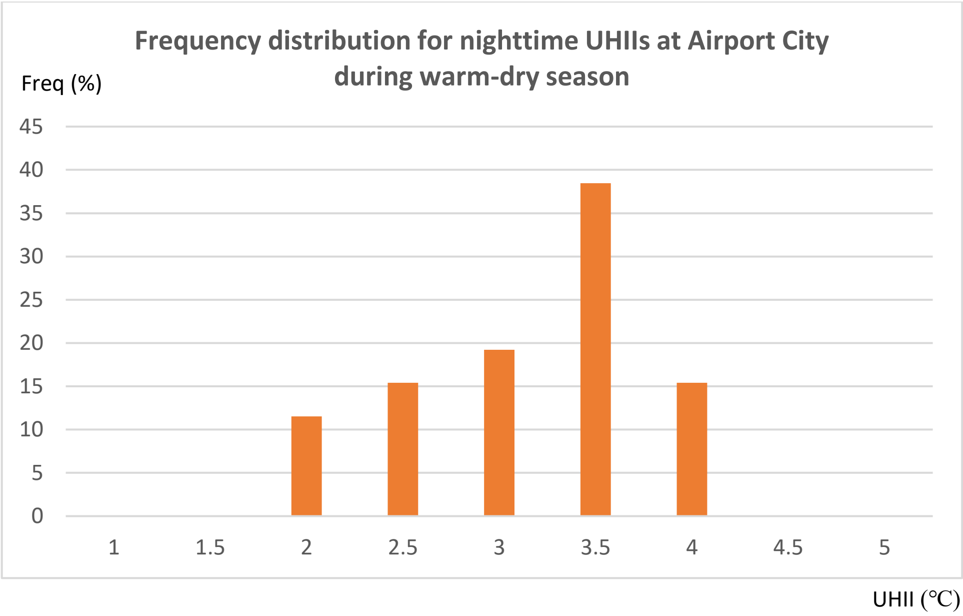

Fig 108 Night-time UHI intensities for Airport City in a warm-dry period (Author generated)

It is evident that the warm dry night UHIIs are much higher than those obtained during the cool-wet period. The scatter diagram in figure 109 shows the variations in UHII for both daytime and night-time. The scatter diagram depicts distinct daytime and night-time UHII patterns for Airport City.

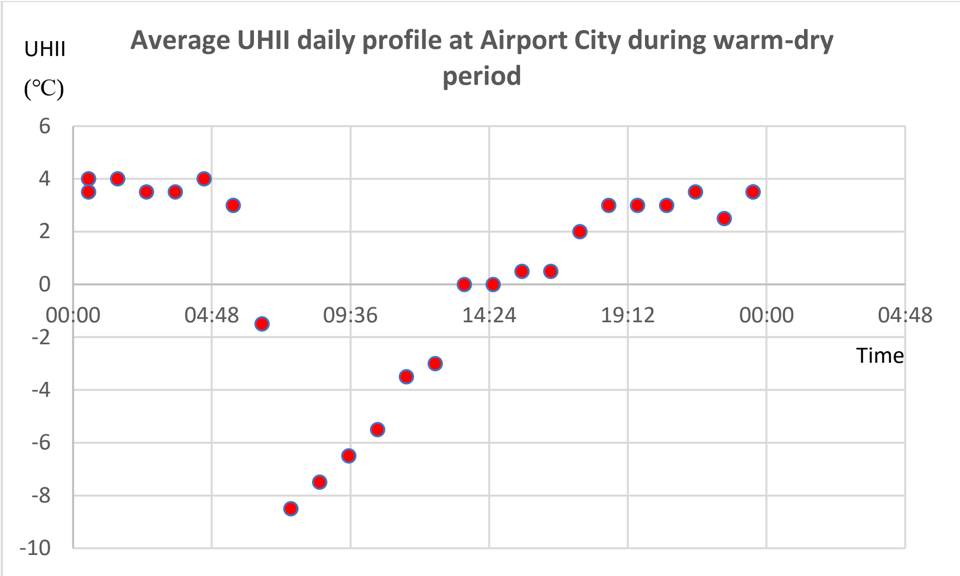

Fig 109 Average daily UHI intensity profile at Airport City in a warm-dry period (Author generated)

5.12.2.3 UHIIs at 37 Military Hospital

As evident in figure 110, the frequency distribution of daytime UHIIs at 37 Military Hospital obtained during the warm-dry period is skewed negatively. At a total percentage frequency of 66.66%, the negative UHIIs (between -0.5 and -7℃) occurred between the hours of 6.30 and 14.30. It is worth indicating that the most frequently occurring UHIIs were -2 and 0.5℃, both at 16.67%. Although the area has a shallow canyon, its daytime UHIIs were significantly reduced due to the presence of substantive greenery. The maximum daytime UHII in the warm-dry period was 2℃, which was higher than what was obtained during the cool-wet period (i.e. 1℃), but the frequency of the former was only 4.17%.

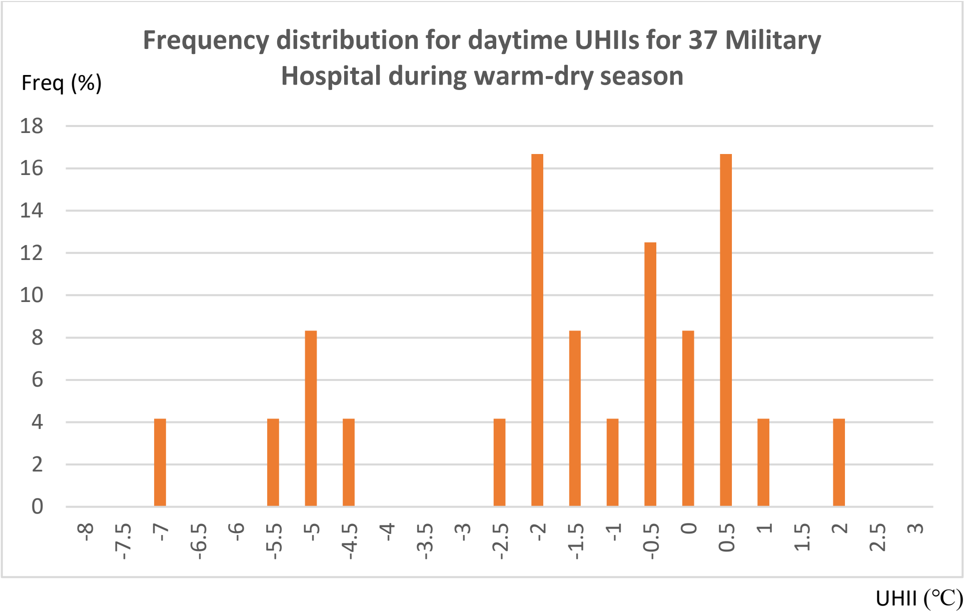

Fig 110 Daytime UHI intensities for 37 Military Hospital in a warm-dry period (Author generated)

Figure 111 shows the frequency distribution graph for night-time UHIIs at 37 Military Hospital. The UHIIs were between 1.5 and 3℃. As seen in the graph, the highest percentage frequency is 46.15%, and at UHII of 2.5℃. Although the area is quite green and has a shallow canyon, it does not appear to be cool at night due to longwave radiation that is emitted from buildings nearby and the built environment. This could also be due to the non-uniformity of the greenery in the area and as such, there are several open spaces with hard surfaces.

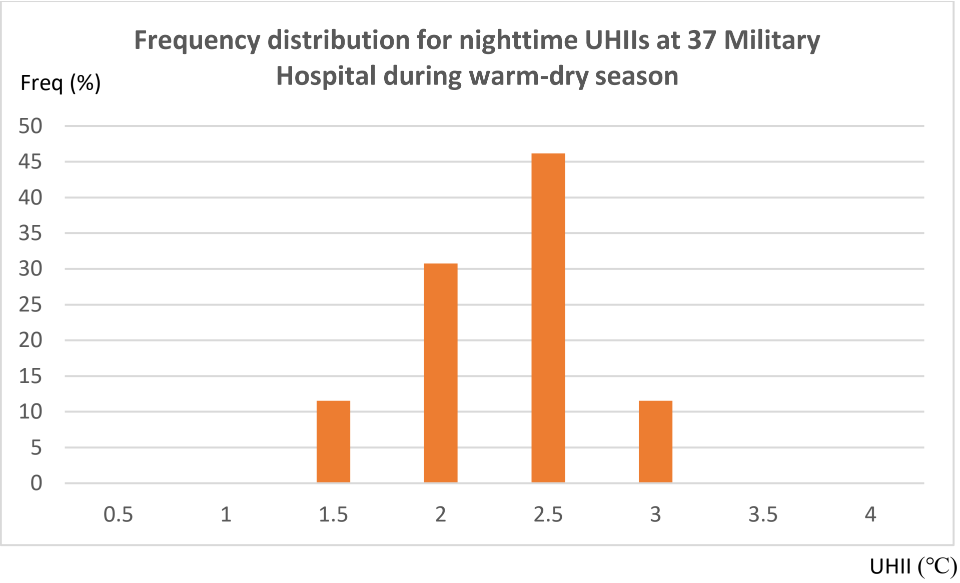

Fig 111 Night-time UHI intensities for 37 Military Hospital in a warm-dry period (Author generated)

The graph in figure 112 depicting the average UHII daily profile at 37 Military Hospital, clearly shows the UHII patterns in both daytime and night-time.

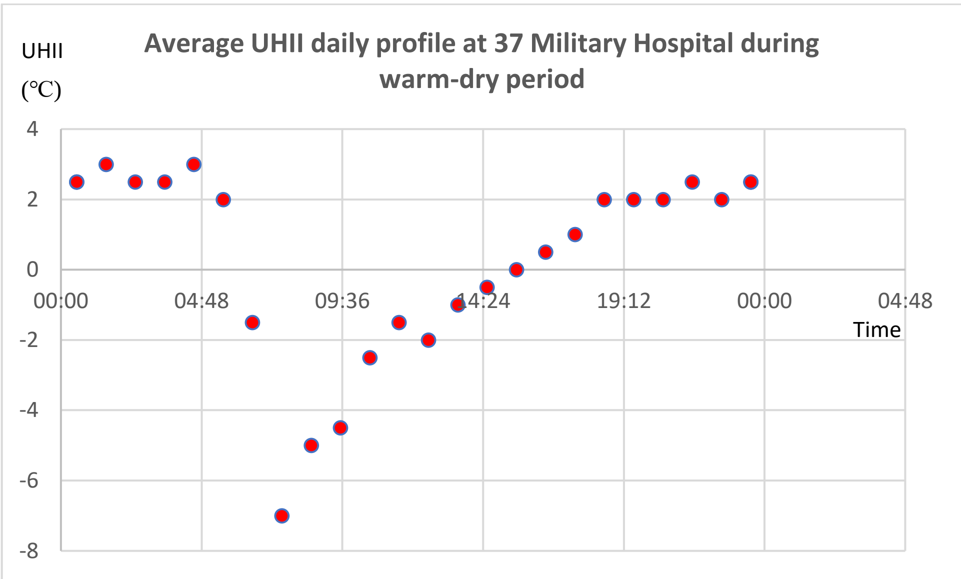

Fig 112 Average daily UHI intensity profile at 37 Military Hospital in a warm-dry period (Author generated)

5.12.2.4 UHIIs at Ministries

For Ministries, negative UHIIs (between -0.5 and -9℃) were obtained for the hours between 6.30 and 13.30, while positive UHIIs were obtained between 13.30 and 17.30. The highest daytime UHII was 1℃, and it was recorded between 14.30 and 17.30. The UHII frequency distribution (shown in figure 113) is skewed negatively. This is like that of Airport City, which also has a significantly deep canyon. As seen in the histogram, the overall percentage frequency for the positive UHIIs (0.5 to 1℃) is 32.5%.

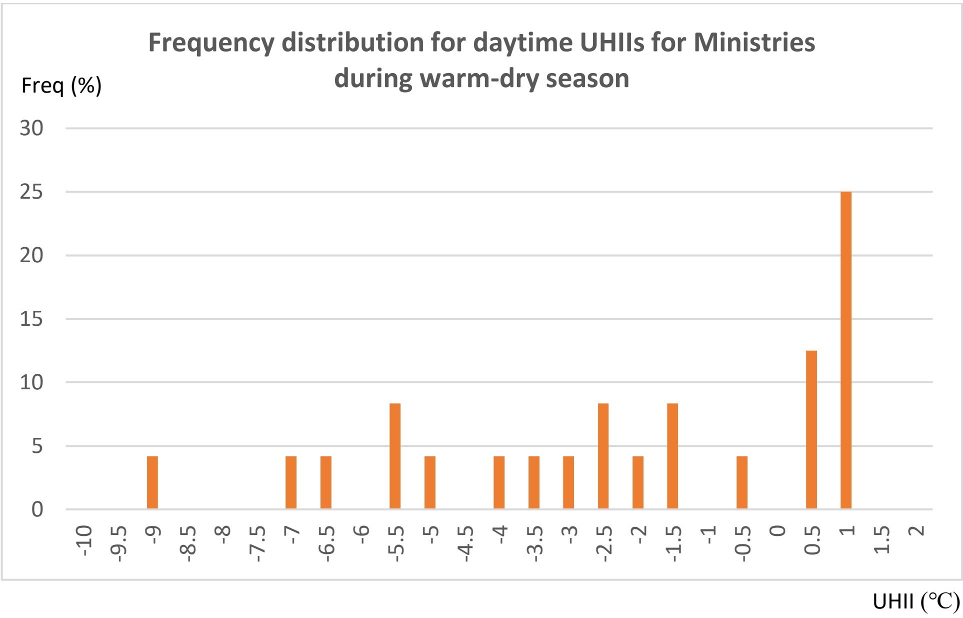

Fig 113 Daytime UHI intensities for Ministries in a warm-dry period (Author generated)

As shown in figure 114, the night-time UHII frequency distribution graph for Ministries for the warm-dry period is completely skewed positively, with moderately high UHIIs ranging between 1 and 2.5℃. The highest percentage frequency was 38.46%, at UHII of 2.

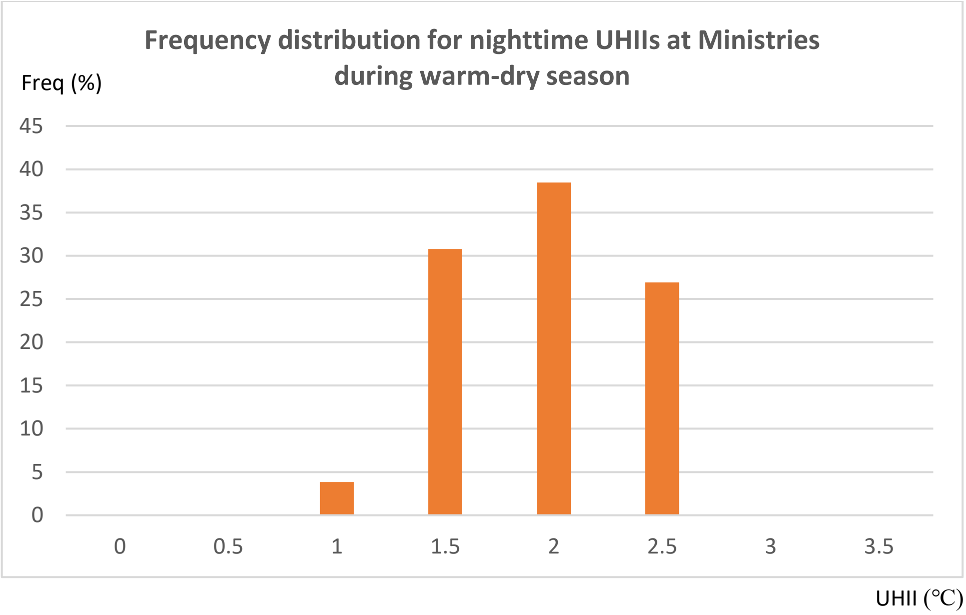

Fig 114 Night-time UHI intensities for Ministries in a warm-dry period (Author generated)

Like the 3 other sites, the night-time UHIIs in the warm-dry period are much higher than those obtained during the cool-wet period. The scatter diagram in figure 115 shows both daytime and night-time hourly variations in the UHIIs.

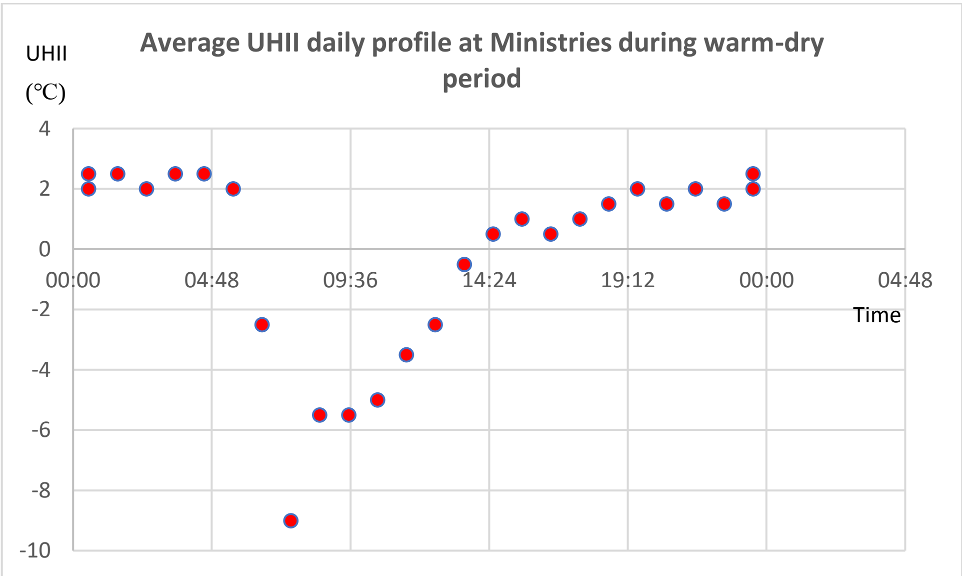

Fig 115 Average daily UHI intensity profile at Ministries in a warm-dry period (Author generated)

5.13 Day and night average UHI intensities for cool-wet and warm-dry seasons

Daytime and night-time average UHIIs for all the monitoring locations in the city obtained during the two different seasons are presented in table 5.5. During the cool-wet season, the UHI intensity averages obtained for daytime and night-time were -0.85 and 0.63℃ respectively. During the warm-dry season, the UHI intensity averages obtained for daytime and night-time were -1.71 and 2.24℃ respectively. It is evident from the table that during both cool-wet and warm-dry days the overall night-time average UHI intensities were stronger than those of daytime. The daytime average UHII on each of the cool-wet days was negative (-1.11 and -0.59℃), giving an indication that the overall temperature of the city centre during the day was comparatively lower than that of the rural reference location. During the cool-wet period, night-time UHII averages on the other hand were positive on both nights (0.54 and 0.72℃), indicating that the city centre was generally warmer than the reference location. On the warm-dry days, the daytime average UHIIs were -1.99 and -1.42℃. It is worthy of mention that during late afternoons, the city was warmer than the rural reference location. The UHIIs obtained for the two warm nights were 2.38 and 2.10, which were quite significant and much higher than those obtained during the cool-wet period. The mean standard deviation values obtained for the warm-dry period indicate that the spread of night-time UHII range (with a mean standard deviation of 0.86) was slightly wider than that of daytime (with a mean standard deviation of 0.82). On the other hand, the mean daytime standard deviation for the cool-wet period showed a larger range of UHIIs than that of night-time.

Although the city centre of Accra experienced urban heat island during both warm-dry and cool-wet seasons, night-time average UHII were much higher during former periods than the latter periods, whilst the opposite was the case for the daytime UHIIs. The high daytime temperatures recorded at the reference location could be attributed to the sparse nature of the vegetation in the centre of Accra. The vegetation is mainly grassland with shrubs and a few trees. The reference location could therefore not benefit from the cooling effect of thick vegetation and tree canopies during the day. It can also be seen that UHI effect can be most felt in the city on warm-dry nights. The variations so observed could be attributed to the effect of various morphological and climatic parameters, and these are further discussed in the next chapter.

Table 5.5 Daytime and night-time average UHIIs

	Daytime		Night-time		Day & Night Ave	
Season	Mean (℃)	SD (℃)	Mean (℃)	SD (℃)	Mean (℃)	SD (℃)
Warm-Dry (Oct)						
Day 1	-1.99	0.84	2.38	0.64	0.20	2.31
Day 2	-1.42	0.79	2.10	1.08	0.34	1.88
Ave for warm days	-1.71	0.82	2.24	0.86	0.27	2.10
Cool-Wet (July)						
Day 1	-1.11	0.50	0.54	0.39	-0.29	0.93
Day 2	-0.59	0.75	0.72	0.46	0.07	0.90
Ave for cool days	-0.85	0.63	0.63	0.43	-0.11	0.92

5.14 Conclusion

This chapter has dealt with the quantification of urban heat island in the study area. It has been indicated that the sensor used in collecting the weather data is the EL-USB-2 type which has logging rates between 10 seconds and 12 hours with immediate and delayed logging start. The chapter has indicated that for each survey, the needed data (time, temperature, and relative humidity) that were downloaded from the data loggers were organized in a spreadsheet using Microsoft Excel. Results from each survey were presented in graphs, and they depicted temperature profile, UHII profile and frequency distribution of UHII.

Results from the mobile survey indicate that in the city centre, there are significant variations in the daily heat stress levels in each LCZ due to the non-uniformity of the characteristics of each canyon. Characterized by a heavy vehicular traffic, Arko Adjei Interchange also had a deeper canyon than those of 37 Military Hospital, Ridge Hospital and Aviation House and as such recorded the highest air temperature on both traverse days. Results from the stationary surveys conducted during both cool-wet and warm dry periods have shown that canyon geometry and urban greenery have significant effects on both daytime and night-time UHII. It has been shown in this chapter that for sites with significantly deep canyons such as Airport City, night-time UHIIs were higher than daytime UHIIs, whilst the opposite was the case for sites with significantly shallow canyons such as Ridge Hospital. It has further been indicated that in the CBD of Accra, the UHI patterns for both warm-dry and cool-wet seasons were similar, except that on the average, UHIIs in the former season were much higher than in the latter. During the cool-wet season, the UHII averages obtained for daytime and night-time were -0.85

and 0.63℃ respectively, whilst in the warm-dry season, the respective UHI intensity averages obtained for daytime and night-time were -1.71 and 2.24℃.

The effects of meteorological and canyon geometrical characteristics on the UHII at the various sites are analysed in the next chapter.

CHAPTER 6

URBAN HEAT ISLAND INTENSITIES AND CAUSAL FACTORS

6.1 Introduction

This study has concentrated on urban heat island intensity calculations for warm-dry and cool-wet periods, since those are the two main weather seasons the country experiences each year. The results presented in the previous chapter have shown that in a warm climatic environment like Accra, the two different seasons (wet and dry seasons) do not necessarily present different UHII patterns. The main difference between the two seasons is that, temperature levels are comparatively low during the rainy season.

This chapter deals with factors affecting urban heat island intensity in the city of Accra. As earlier indicated in the literature (in chapter 3), the main factors that affect UHII may be related to canyon geometry or weather. Consistent with Golany (1996), Rajagopolan et al. (2014), and Bourbia and Boucheriba (2010), this study draws on the proposition that city design (street width to building height ratio), cloud cover and wind speed can affect UHII. Cheung (2011) identifies factors that affect UHI to include: 1. weather related factors such as wind speed, cloud level, total solar irradiance, rainfall and 2. canyon or morphological related factors such as canyon width, building height in canyon, distance from the city centre, extent of greenery or vegetative cover, sky view factor, road width, traffic etc. In this study, the effect of the following factors on UHII are investigated: wind speed, relative humidity, solar power at various hours, the effect of canyon width and building height (i.e. aspect ratio), the extent of greenery and distance from heat island centre. Shortwave solar power figures were used instead of sunshine hours, as data on the latter were not available for the period in which the main weather data were collected. It is also worth indicating that data on cloud levels could also not be obtained from the Ghana Meteorological Agency. This limitation notwithstanding, during the warm dry season, the researcher ensured that the stationary measurements were taken under clear skies.

The correlation between each of the above-mentioned factors and the UHI intensities at the various monitoring locations is ascertained. For each monitoring location, the correlations are calculated for the different periods or seasons during which the weather data were collected.

6.2 Effect of weather-related (meteorological) parameters on UHII

This section looks at how various meteorological parameters affected daytime and night-time UHIIs at the monitoring sites during both cool-wet and warm-dry seasons. Based on relevance and availability of data, the meteorological parameters used were solar radiation and wind speed. It is worthy of mention that data on weather parameters such as cloud cover, solar irradiance and sunshine hours were not available from the city's meteorological office.

6.2.1 Effect of shortwave solar radiation

Data on the hourly shortwave radiation reaching Accra during both cool-wet and warm-dry days were plotted against the UHIIs calculated for the various monitoring locations at the respective times. Solar radiation was 0 kilo Watt (kW) in the night, but most locations recorded UHII above 0℃. The high night-time UHIIs were caused by the emission of longwave radiation from various surfaces in the urban fabric into the atmosphere.

6.2.1.1 Effect of solar radiation on UHII during cool wet period

Generally, shortwave solar radiation affected the UHII during daytime (i.e. between 6.00 am and 6.00 pm) and the solar power levels were between 0.1 and 0.75 kW. Matching the different solar power levels to the UHIIs, it has been observed that between 6.37 and 9.37 am, some monitoring locations recorded positive UHIIs. As shown in the graph in figure 116, the 3 locations that recorded the highest night UHII (when shortwave solar power was zero) were The Law Court Complex, Aviation House, and Airport City. Their UHIIs were 1, 1.5 and 2℃ respectively. At 6.37 am, when the sun had just risen, the UHIIs at those 3 locations had dropped to 0.5, 1 and 1.5℃ respectively. At 11.37 am, when the sunshine was most intense (with shortwave solar power of 0.75 kW), majority of the monitoring locations recorded UHIIs between -1 and 1.5℃. The graph shows that when the solar power was 0.75 kW, five monitoring locations: Arko Adjei Interchange, The Law Court Complex, Ministries, 37 Military Hospital and Accra Regional Hospital recorded UHIIs of -1, -0.5, 0, 0.5 and 1.5℃ respectively. The distribution in the scatter diagram in figure 116 shows that during the cool wet period, shortwave solar radiation could generally affect daytime UHII in the city, but this effect is more significant between the hours of 10.30 am and 12.30 pm. Another important observation in the scatter diagram is that when the solar power was 0.75 kW, no monitoring location recorded an UHII below -1℃. Since UHI is generally higher in the night, the high UHII recorded in the early hours of the morning could have been partly due to the emission of longwave radiation into the atmosphere and could therefore not be solely attributed to the impact of shortwave solar radiation. This is buttressed by the fact that the 3 locations that recorded the highest UHIIs in the early hours of the morning were in LCZ1(2), LCZ2(9) and LCZ4(5) which had deeper urban canyons than the other LCZs.

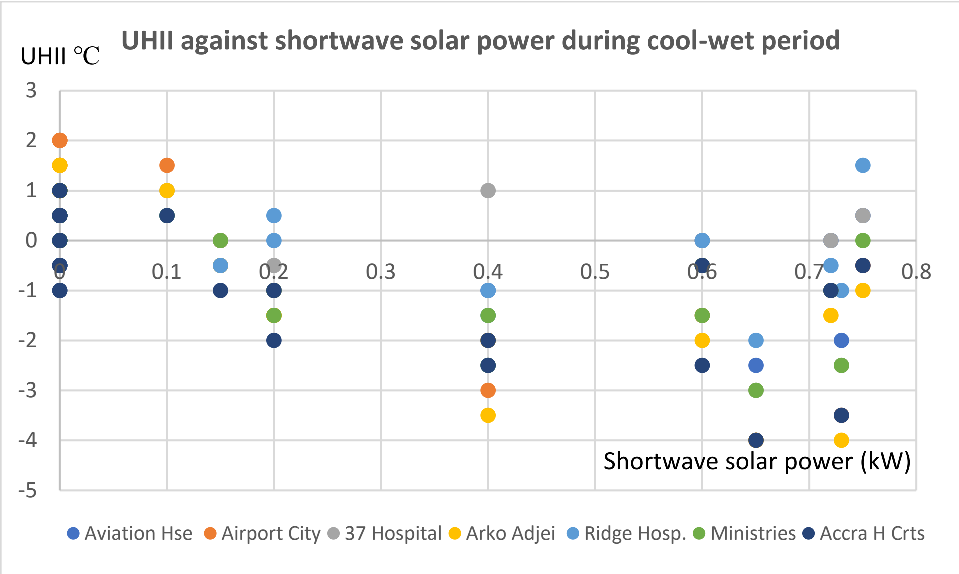

Fig 116 Effect of shortwave solar radiation on UHII on cool-wet days (Author generated)

6.2.1.2 Effect of solar radiation on UHII during warm-dry period

On the warm-dry days, shortwave solar radiation was felt in the city between 6.00am and 6.00pm. As shown in the graph in figure 117, the effect of shortwave solar radiation on the UHIIs at the 4 monitoring sites was significant between the hours of 8.30 and 14.30, when the solar power range between 0.4 and 0.71 kW. The graph also shows that the UHII at Aviation House was the most affected by the shortwave solar radiation, as it was the only site that recorded a maximum

UHII of 3℃ during daytime. It is also evident in the graph that the UHIIs at Airport City, 37 Military Hospital and Ministries, which were all negative, increased significantly between 8.30 and 14.30 when the solar power was range was between 0.4 and 0.71 kW. Within that time and solar power ranges, UHIIs at Airport City, which were the lowest during daytime in the warm-dry period, increased sharply from -7.5 to -1℃.

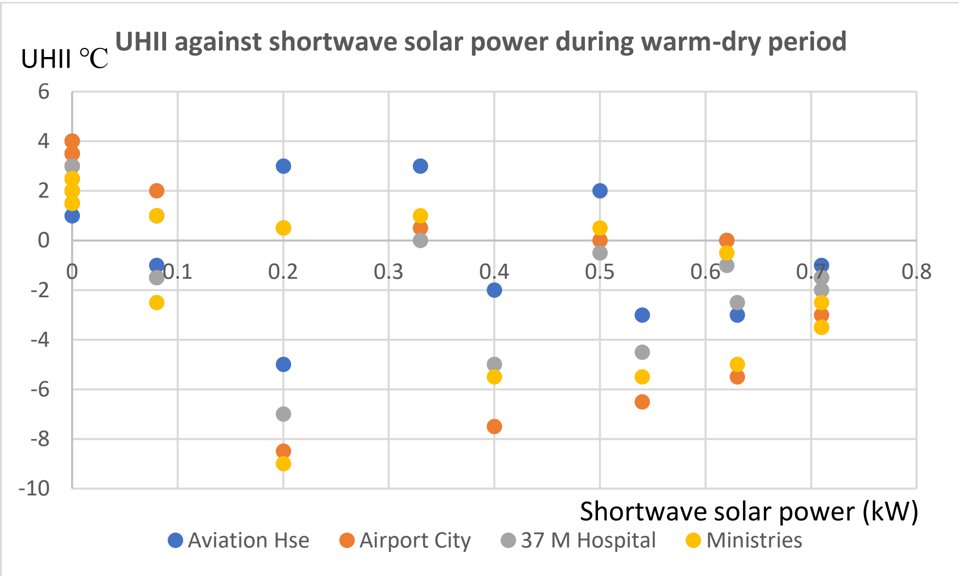

Fig 117 Graph showing effect of shortwave solar radiation on UHII on warm-dry days (Author generated)

Comparing the two graphs in figures 116 and 117 reveals that the daytime UHIIs at areas with deep canyons were comparatively lower during warm-dry periods. This could be attributed to the high temperature at the reference location during the warm-dry period and the comparatively low air temperature at the monitoring site caused by the shading within its deep canyons.

6.2.2 Effect of wind speed on UHII

As pointed out in the literature review, various researchers (Ok et al. 1996, Morris et al. 2001, Memon and Leung 2010, Yang and Li 2011, Rajagopalan et al. 2014) have posited that increase in wind speed causes reduction in UHI and vice versa. They however indicate that differences in the flow pattern of wind, as well as urban geometry can affect UHI.

To understand how the prevailing wind affected the UHII in the monitored locations, the pattern of the hourly wind speed in miles per hour (mph) recorded for Accra was analysed. It is worth indicating that the prevailing winds in the city during the wet season are the south-west monsoon winds, which originate from the Atlantic Ocean. This means that the winds come from the south western part of the country, blowing across the sea before filtering through the mainland. The hourly wind speed data for Accra on 30th and 31st July, as presented in figure 118, indicate that wind speed was lower in the night than in the day. Wind speed data available for the two days show that between 22.37 and 7.00, hourly wind speed values were between 7.3 and 7.8 mph. Daytime and early night-time hours between 7.37 and 20.37 recorded wind speed values between 8.1 and 9.9 mph. Wind speeds between the hours of 8.37 and 18.37 were particularly high (ranging between 8.4 and 9.9 mph), with 15.37 recording the highest wind speed.

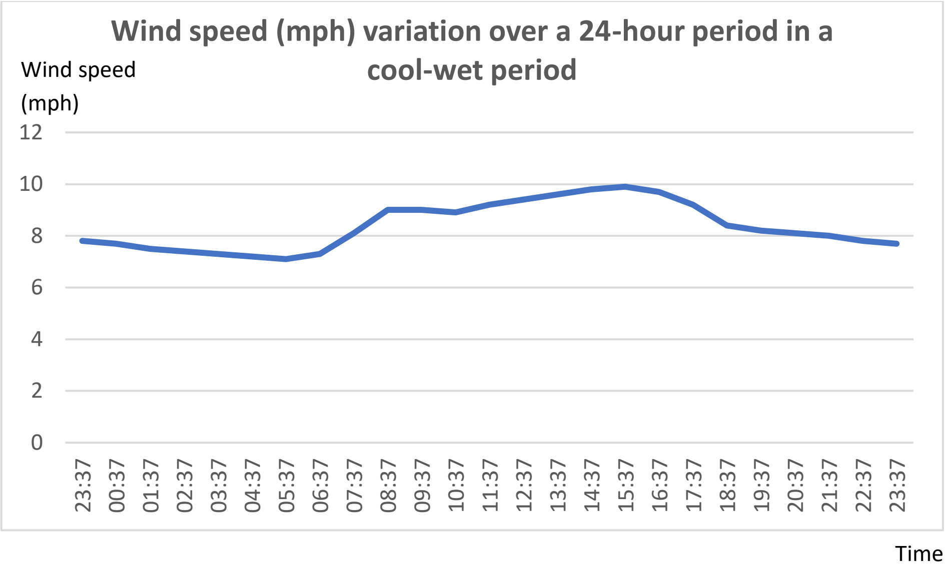

Fig 118 Graph showing hourly variation of wind speed on a cool-wet day (Author generated)

The prevailing wind in the warm-dry period was southerly, though not as strong as it was in the cool-wet period. As shown in figure 119, during the warm-dry period, the wind speed in the city varied between 5.95 and 7.2 mph, which was much lower than the wind speed range of 7.1 to 9.9 mph recorded in the cool-wet period. Like the cool-wet period, the maximum wind speed was recorded during late afternoon (at 16.30).

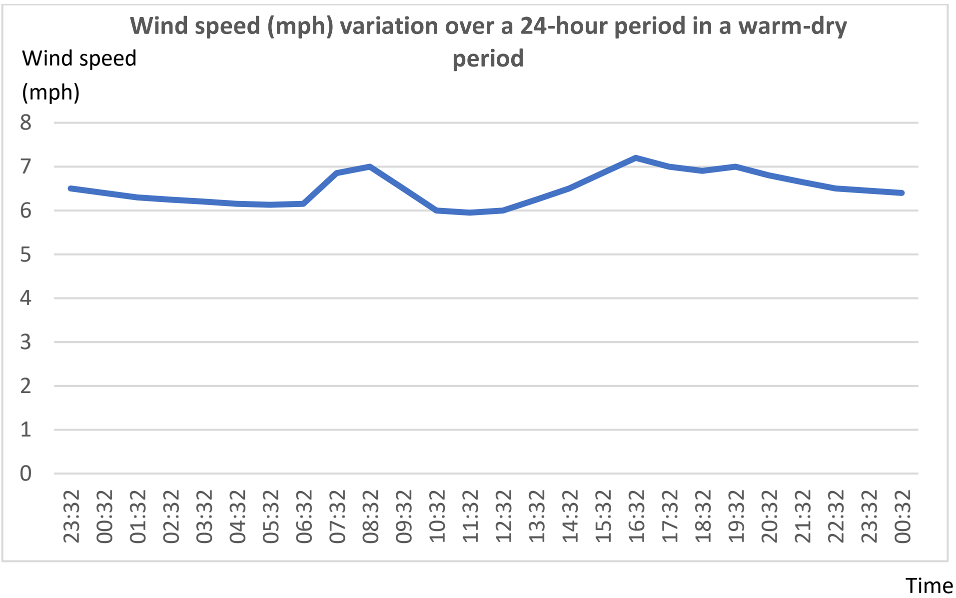

Fig 119 Graph showing hourly variation of wind speed on a warm-dry day (Author generated)

Plotting UHII against the hourly wind speed for all the 7 locations in the city has revealed that the effect of wind on UHI was most significant between the hours of 8.37 and 16.37 when the wind speed was between 9 and 9.9 mph. As shown in the graph (scatter diagram in figure 120), when the wind speed was between 9 and 9.9 mph, all the monitoring locations recorded negative UHIIs. The scatter diagram indicates that there is a correlation between the UHI and wind speed during the cool-wet period. As depicted by the regression equation (indicated on the scatter diagram), the UHII is negatively correlated with wind speed. This is an indication that as the wind speed increases, the UHII decreases. This was seen to occur when the wind speed was between 7.1 and 9.9 mph. Although other parameters could also account for the low UHIIs at a given location, it is evident from the graph that the UHII at The Law Court Complex and Ministries were the most affected by the wind speed in that range. Within the said wind speed range (i.e. between 9 and 9 mph), the UHIIs at Ministries were between -1.5 and -3℃ while The Law Courts Complex recorded UHIIs between 2- and -4℃. It is worth noting that the cool-wet seasons are mostly characterized by strong south-westerly winds which come from the sea (i.e. the Atlantic Ocean).

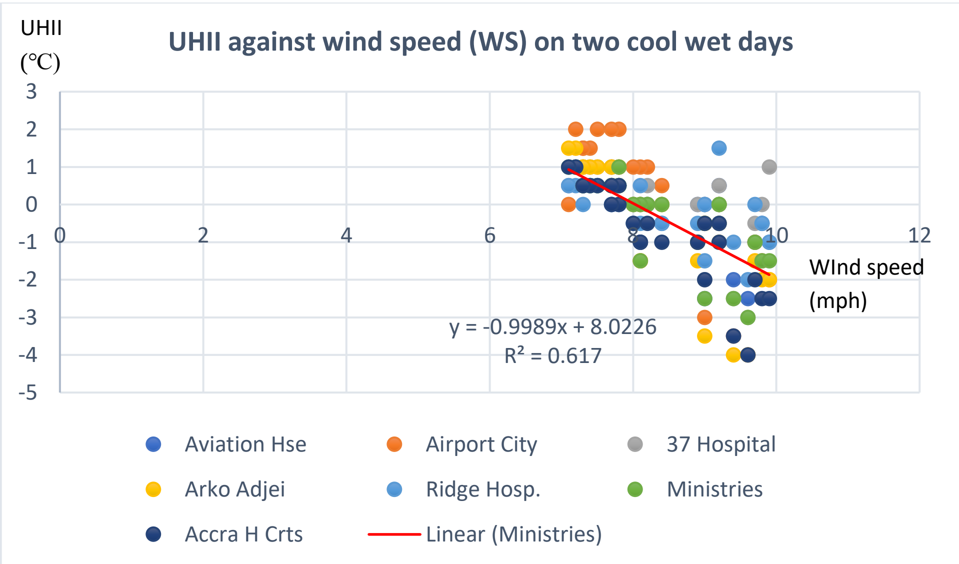

Fig 120 Effect of wind speed on UHII during cool-wet days (Author generated)

During the warm-dry period, the UHIIs at the 4 monitoring locations began to drop when the wind speed was between 6.5 and 7.2 mph. Although there was no direct correlation between the UHII and wind speed, the pattern shown in the scatter diagram in figure 121 indicates that there were marginal reductions in the UHIIs when the wind speed increased. It is worth indicating that during the warm-dry period, the effect of wind speed on the UHII in the city is significantly reduced, since the south-westerly winds are not as strong as they are in the cool-wet period. Due to the presence of the sea and hence the effect of the south-westerly winds, the harmattan winds that come from the north and characterize the warm-dry season are also not strongly felt in the city.

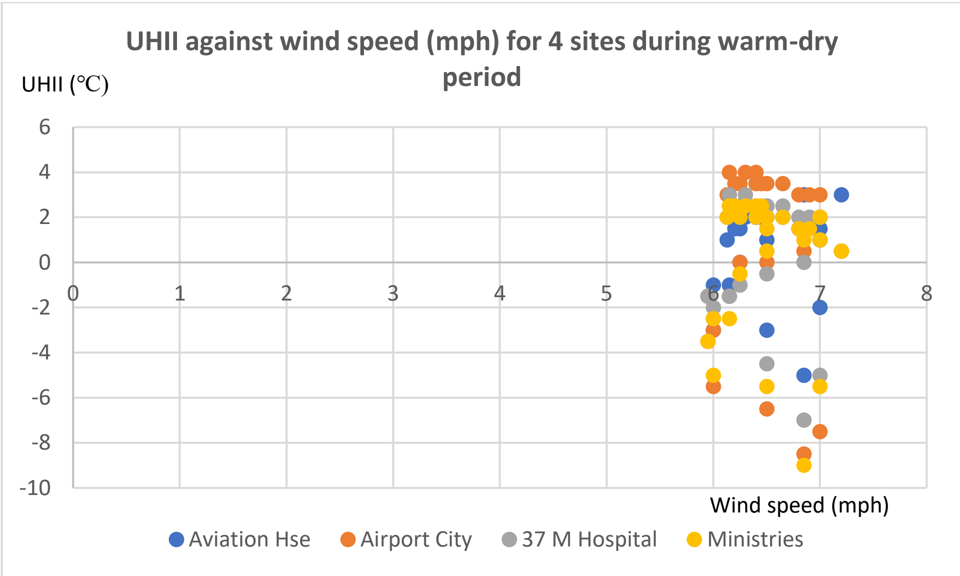

Fig 121 Effect of wind speed on UHII during warm-dry days (Author generated)

6.3 Nearness to the sea and the effect of wind

Although the UHIIs at all the other locations reduced with that wind speed range, the monitoring locations at The Law Court Complex and Ministries benefitted from their nearness to the sea as well as their orientation. The Law Courts Complex is the nearest location to the sea, followed by Ministries. The effect of the south-westerly winds on the monitoring location at The Law Courts Complex was stronger than the rest, as it was along a street corridor that was on the wind path and benefitted from unimpeded air flow and to some extent, tunnel effect. The monitoring location at Ministry of Interior was also south-facing; however, the land use pattern could not promote the same wind flow as the Law Courts Complex. The map in figure 122a shows the locations of The Law Courts Complex and Ministries with respect to the sea, wind direction. Figure 122b illustrates and how the former site (i.e., The Law Courts Complex) could be benefiting from wind tunnel effect, unlike Ministries which could be impeded by the presence of other buildings along the wind path.

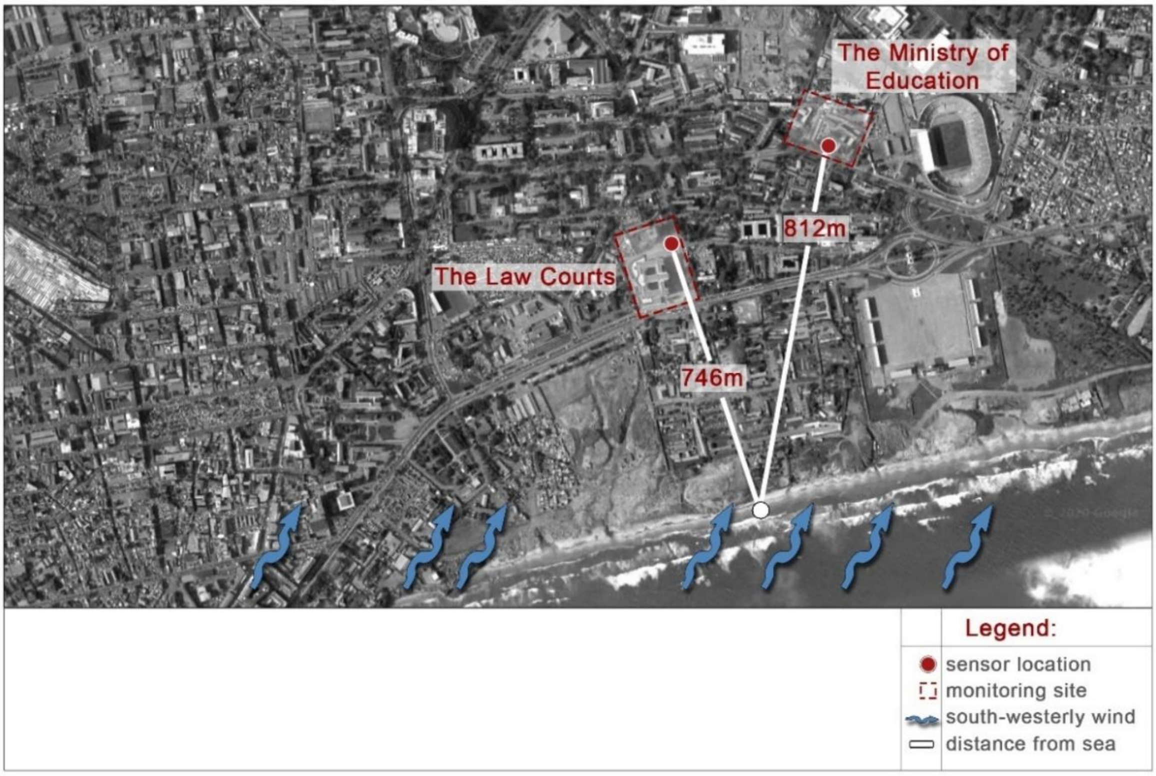

Fig 122a Map showing prevailing wind direction and nearness of The Law Courts Complex and Ministries to the sea (Author generated)

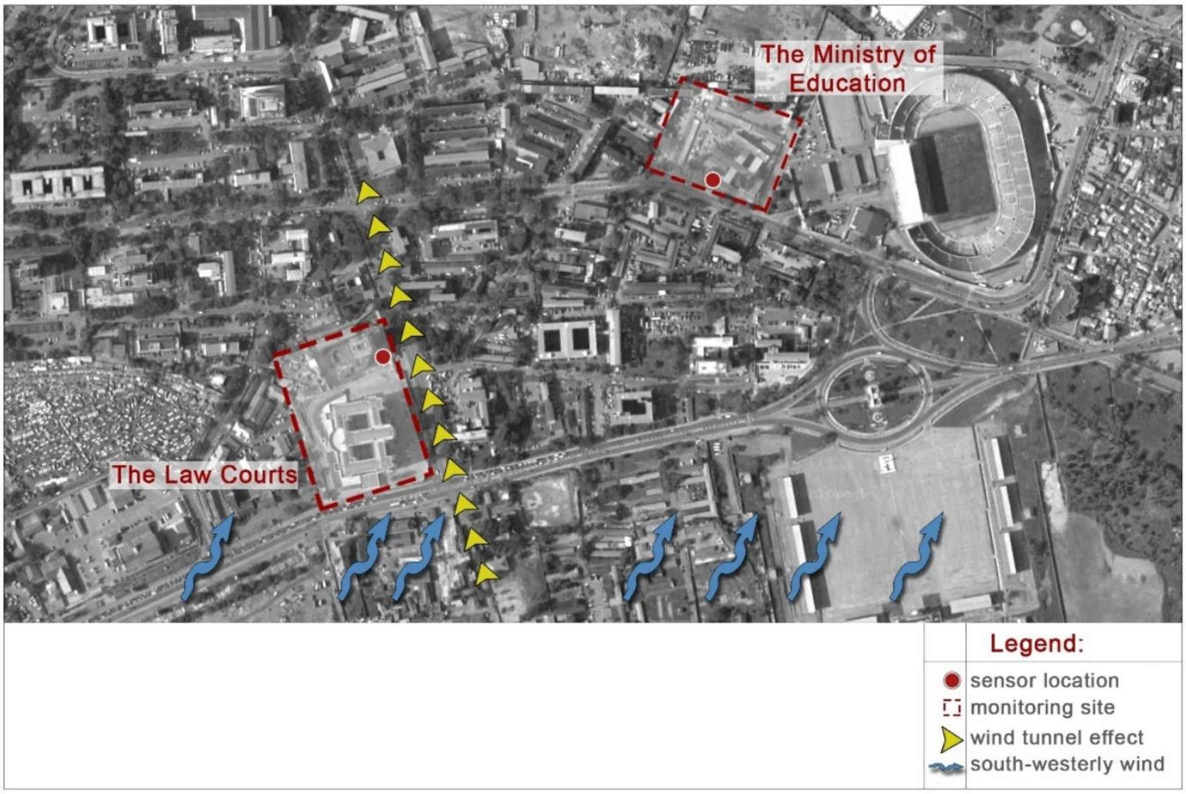

Fig 122b Map depicting proximity to sea and benefit from wind tunnel effect (Author generated)

6.4 Effect of canyon or morphological characteristics on UHII

Urban canyon geometry has been defined as aspect ratio, which refers height-width ratio, i.e H/W (Erell et al. 2011). Aspect ratio is obtained from the proportion of the mean heights of neighbouring perpendicular buildings and the average width of the space between them. Sky view factor (SVF) relates to the aspect of an urban canyon that is exposed to the sky. Zakhour (2015) asserts that a higher SVF means a smaller aspect ratio. Erell et al. (2011) has established a correlation between sky view factor and aspect ratio. The correlation is clearly depicted in figure 123a. Figure 123b also depicts how Erell (2011) demonstrates sky view factor as a function of canyon aspect ratio from a study.

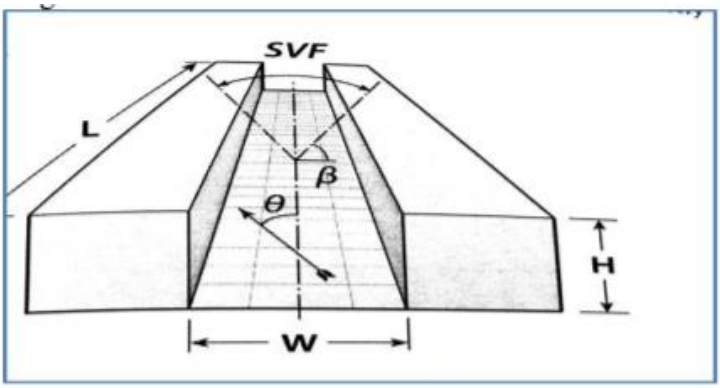

Fig 123a Symmetrical pattern of canyon (Source: Erell et al. 2011)

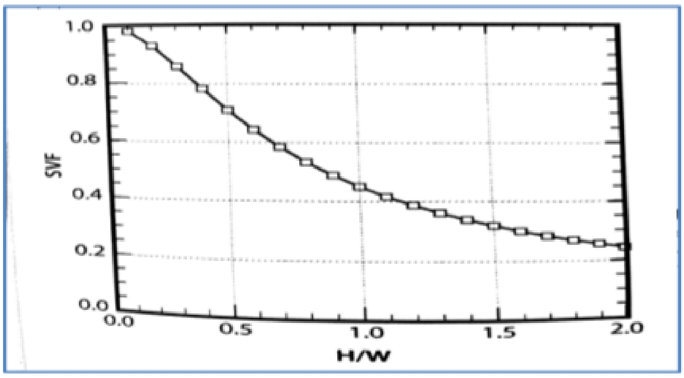

Fig 123b Sky view factor as a function of H/W (Source: Erell et al. 2011)

From the foregoing, it is evident that the effect of morphological characteristics on UHII could either be investigated using sky view factor or aspect ratio. The study area does not present complex canyon geometric characteristics, thus the effects of the morphological characteristics of the various monitoring locations on their respective UHIIs could be conveniently investigated using their aspect ratios.

Consistent with Bernard et al. (2018), this study acknowledges the large influence trees have on sky view factor and the overall canyon characteristics, but due to the complex nature of their three-dimensional shapes, representing them accurately in geographical data bases is rather complicated. Against this backdrop, this study, and for simplicity, only buildings are considered as sky obstacles in the analysis of the canyon geometry. The aspect ratio calculation is thus based only on the buildings.

It is worthy of note that most streets in the CBD of Accra do not have uniform canyon characteristics and as a result, aspect ratios calculated for various locations may to a large extent not necessarily reflect the LCZs in which they are. The selection of the monitoring locations used for this study was based on security and accessibility. Some property owners were unsure about the nature of the sensors used in measuring the weather and were therefore unwilling to permit the researcher to install them on their premises. In some instances, it was also important to get dedicated persons to ensure that the sensors were safe. In view of this challenge, it was possible to fix the sensors in the desired canyon at 7 locations which were representative of the LCZs within the study area. The locations are presented in table 6.1.

Table 6.1 Sensor locations

Sensor Location	**LCZ**	**Aspect Ratio H/W**
Airport City	LCZ1(2)	1.50
Aviation House/Glico	LCZ2(9)	0.21
Ministries (Ministry of Interior)	LCZ4(5)	0.55
The Law Courts Complex	LCZ4(5)	0.50
37 Military Hospital (Officer’s Mess)	LCZ5(8)	0.11
Ridge Hospital	LCZ5(8)	0.15
Arko Adjei Int. (UDS Guest House)	LCZ6	0.30
Reference location (Anyaa)	LCZ9	N/A

The sensor locations of the 7 monitoring sites their indicative aspect ratios and physical characteristics are presented in figures 124a to 124g.

Fig 124a Sensor location at Aviation House   Aspect ratio: 0.17

Fig 124b Sensor location at Airport City Aspect ratio: 1.5

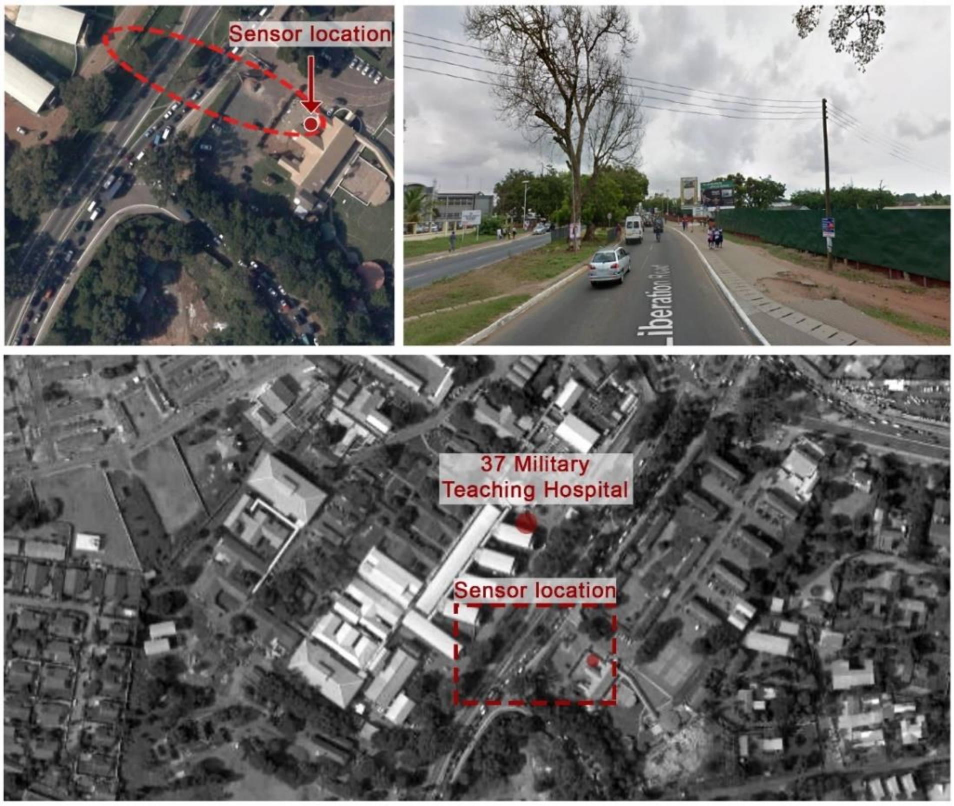

Fig 124c Sensor location at 37 Military Hospital Aspect ratio: 0.11

Fig 124d Sensor location at Arko Adjei Interchange Aspect ratio: 0.3

Fig 124e Sensor location at Ridge Hospital Aspect ratio: 0.15

Fig 124f Sensor location at Ministries Aspect ratio: 0.55

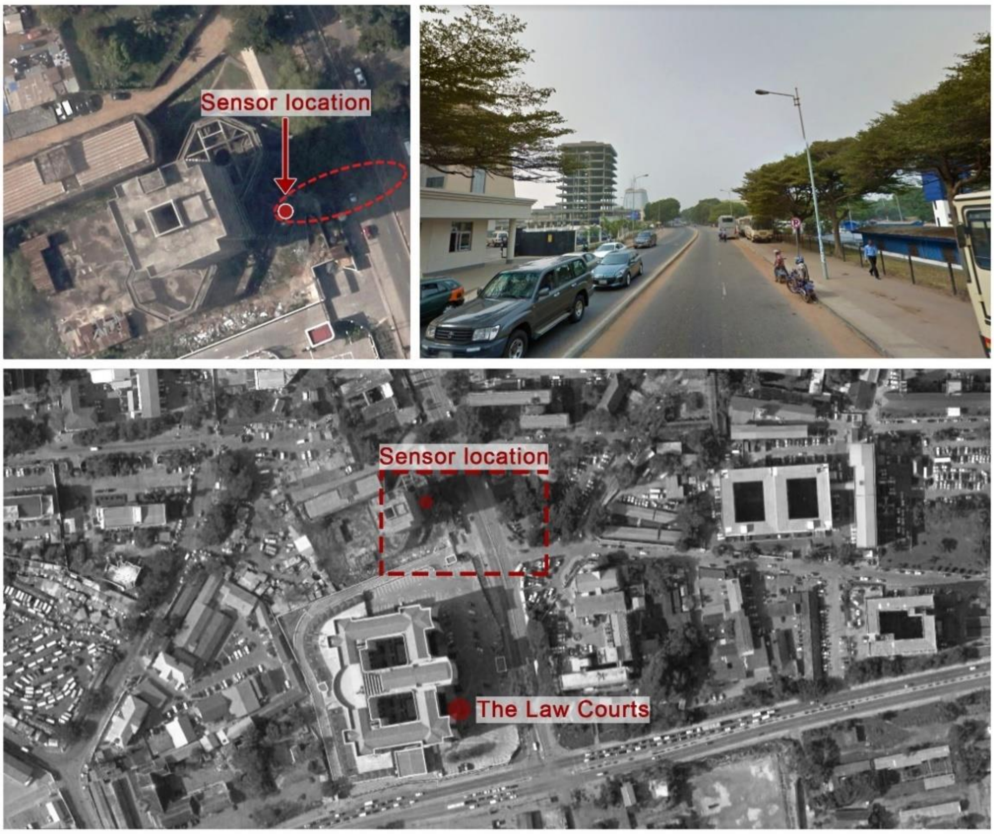

Fig 124g Sensor location at The Law Courts Complex Aspect ratio: 0.5

The graphs presented in figures 125 and 126 depict how the depths of the canyons of the various monitoring sites (in terms of aspect ratio) affected the respective UHIIs in the cool-wet period. It is evident in figure 125 that on cool-wet days, sites with deep canyons or high aspect ratios had low UHIIs, whereas the opposite was the case for sites with shallow canyons. Figure 126 shows that on the cool-wet nights, generally, areas with deep canyons had high UHIIs and vice versa. The relationship between the two variables is not uniformly proportional since the effects of other UHI causal factors could be strong at some of the monitoring sites. There are deviations in the pattern of variation at the monitoring sites: Arko Adjei, Ministries, and The Law Courts Complex.

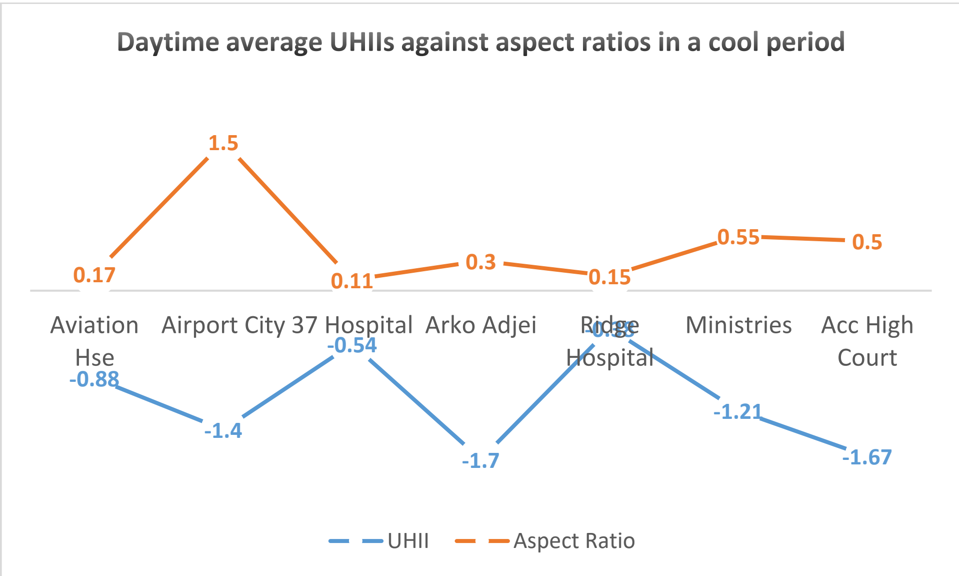

Fig 125 Graph of UHII against aspect ratio for 7 locations on a cool day (Author generated)

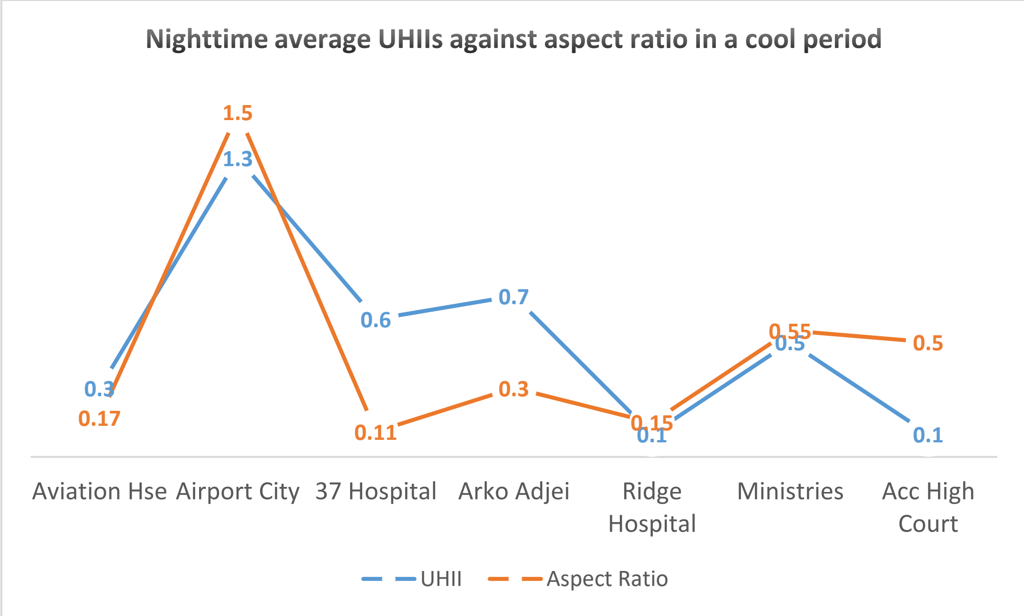

Fig 126 Graph of UHII against aspect ratio for 7 locations on a cool night (Author generated)

For the warm-dry period, graphs of daytime and night-time average UHIIs against aspect ratios for Aviation House, Airport City, 37 Military Hospital, and Ministries are presented in figures 127 and 128. Figure 127 shows that on warm days, Airport City and Ministries which had respective aspect ratios of 1.5 and 0.55 had UHIIs of -2.46 and -2.17℃. Although 37 Military Hospital had a lower aspect ratio than Aviation House, the latter had a higher UHII. This could be attributed to the fact that 37 Military Hospital was much greener due to which the amount solar radiation reaching the site during the day could have been significantly reduced.

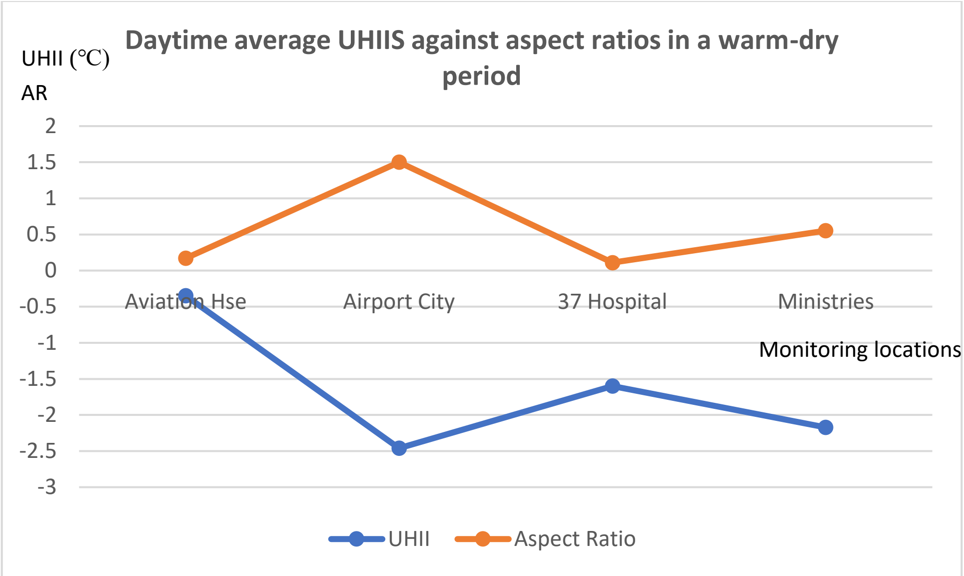

Fig 127 Graph of UHII against aspect ratio for 4 locations on a warm-dry day (Author generated)

The graph for the warm-dry nights (figure 128) shows an opposite pattern. During the warm-dry nights, UHII increased with increasing aspect ratio, apart from 37 Military Hospital.

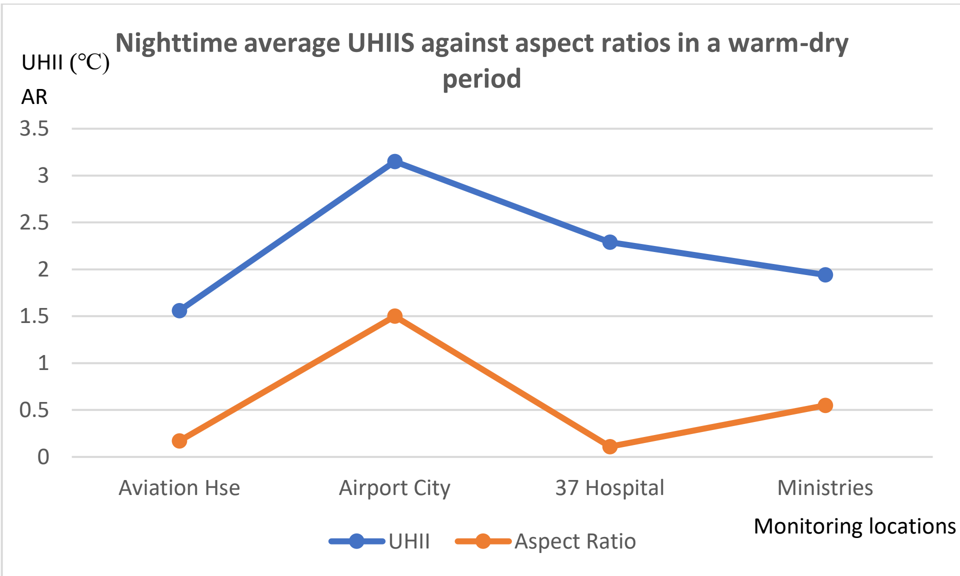

Fig 128 Graph of UHII against aspect ratio for 4 locations on a warm-dry night (Author generated)

It is obvious from the foregoing that during both cool-wet and warm-dry days, UHIIs generally decreased with increasing aspect ratio and vice versa. On the other hand, night-time UHIIs in both cool-wet and warm-dry periods generally increased with increasing aspect ratio and vice versa. Analysing the graphs for the two different periods reveals that both daytime and night-time UHIIs were higher in the warm-dry period than in the cool-wet period.

6.5 Effect of urban configuration

Studies have shown that urban configuration can affect urban heat island intensity. Through a study on UHI in Muar, Rajagopalan et al. (2014) explored the effectiveness of different urban configurations in heat island reduction. Through the investigation it was established that heat island reduction can be achieved through permeable design with an integration of tall buildings. In effect, this meant that having opened-up spaces in the city would enhance wind penetration through the buildings without entering the streets or the city grid. The presence of tall buildings would cause the wind to be drawn into the streets, thereby promoting wind flow at pedestrian level. By Venturi effect (Li et al. 2015, Rajagopalan et al. 2014), the speed of the wind that enters the tunnel created by the opened-up spaces increases. The wind gets directed up the tall buildings before flowing down to the streets or pedestrian level (at reduced speed). Various articulated geometric variations explored by Rajapogalan et al. (2014) are shown in figure 129. As illustrated in geometric variation 1, maximum ventilation is gained by placing tall buildings in the windward side.

Variation 1 Variation 2 Variation 3

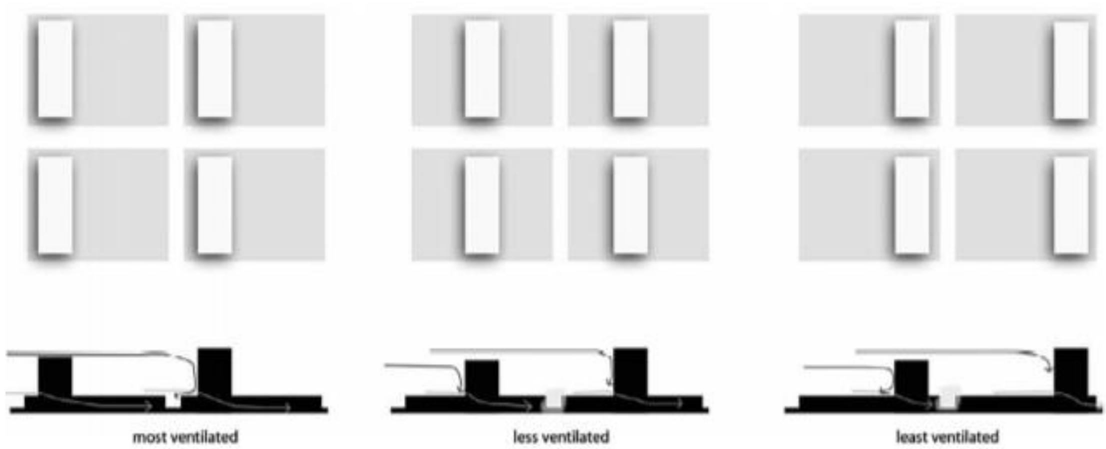

Fig 129 Articulated geometric variations (Source: Rajapogalan et al. 2014)

It could also be inferred that scattering tall buildings in an articulated geometry would result in a much higher wind flow at the pedestrian level than having them densely or compactly built together.

The configuration of the central business district of Accra is not based on a strict grid system. The planning of the study area was not based on any articulated geometry. The study area, which is in the CBD of Accra, is within one of the "planned communities" in the city. For the purposes of exclusivity, security, and privacy, most of the properties in this community (including civic and commercial properties) are walled with controlled entrances. Developments in the city centre are along the major streets or primary roads as well as secondary roads. Apart from some parts along the Arko Adjei Interchange stretch which are planned in accordance with the grid system, the layout of all the other monitoring sites or LCZs in the study area are somewhat 'amorphous' in nature. Accra presents a fan-shaped morphological configuration, with the main infrastructure spines converging on the centre, which indicates its economic and urban evolution from the harbour and more in general from the coast. The typology of the area is heterogenetic, characterized by a mixture of local and western constructions, temporary and permanent. The different construction technologies and styles of the buildings are not always adapted to the context and its conditions. The configurations of the 7 monitoring sites are presented in figure 130. It is evident that generally, the urban geometry has evolved from developments done on individual plots, but not in accordance with a consciously planned urban geometry. It should however be emphasized that a substantial number of low to mid-rise buildings have been designed and orientated north-south to take advantage of the prevailing winds in both wet and dry seasons. Due to the open nature of the geometric configurations at most of the sites, wind tunnels could be created, but the positioning of the tall buildings may not promote Venturi effect to ultimately ventilate the pedestrian level and thus mitigate the UHI.

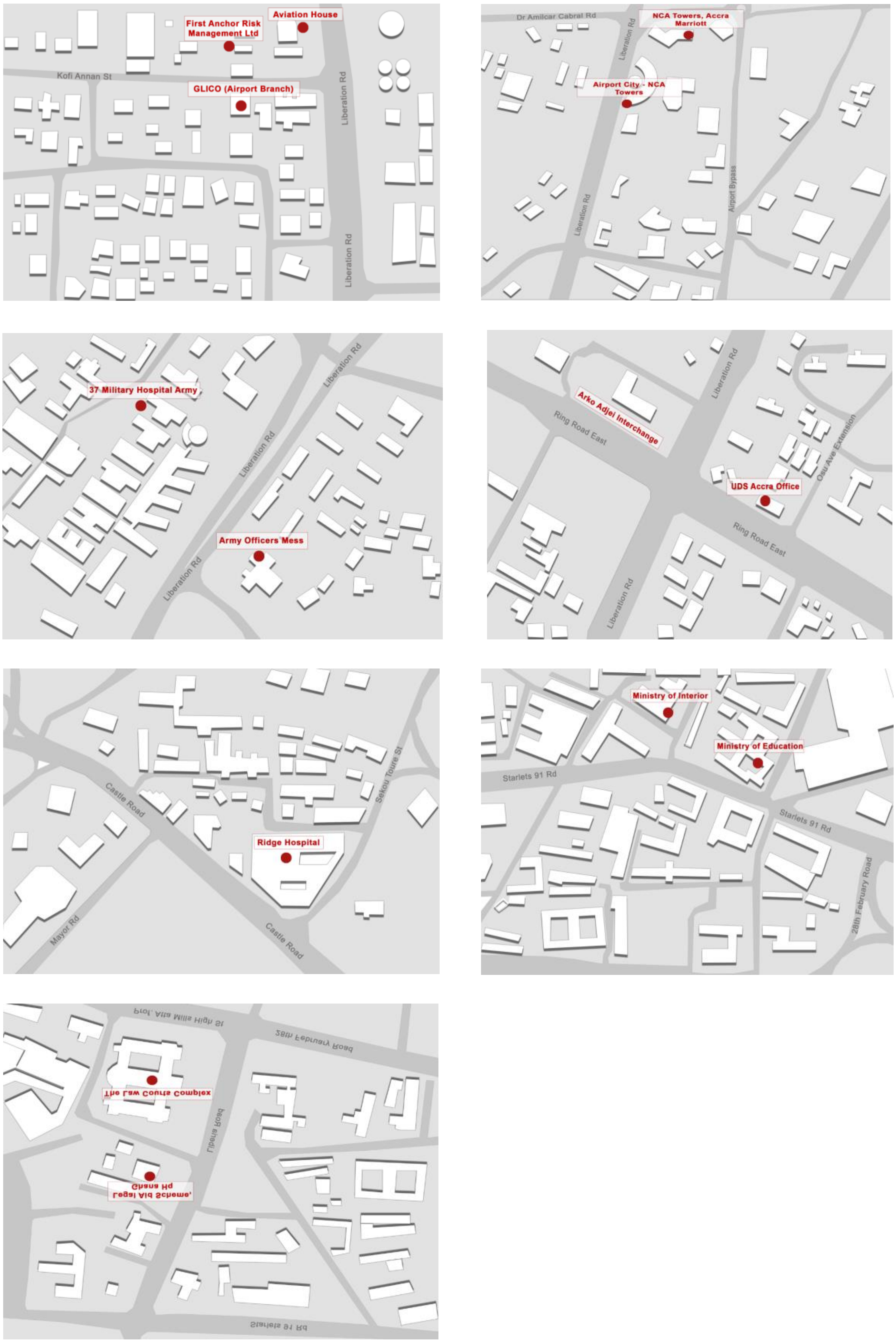

Fig 130 Configurations of 7 monitoring locations in the CBD of Accra (Adapted from Google earth)

6.6 Effect of greenery

The weather data collected from all the surveys show a clear correlation between air temperature and relative humidity. It must be emphasized however that the temperatures measured at the various sites had effect on the respective relative humidity levels, but not vice versa. The variations in relative humidity levels across the study area could also be attributed to the extent of evapotranspiration at the various monitoring sites, which could also depend on vegetative cover. Air temperature/relative humidity graph obtained based on hourly averages across the monitoring sites in 2 days the cool-wet period is presented in figure 131. It is evident from the graphs that areas with higher temperatures recorded lower relative humidity levels, whilst the opposite was the case for areas that recorded lower temperatures. In the wet period, the hottest daytime hours were between 11.30 to 14.30. During the hottest time of the day, the relative humidity and temperature at Aviation House were 71.5% and 29.5℃ respectively. The nights were cooler and the highest relative humidity figures were recorded between 12.00 and 6.30 am and during that period, the relative humidity and temperature at Aviation House were 91.5% and 24.5℃ respectively. The graph shows similar patterns across the sites in the 2-day period.

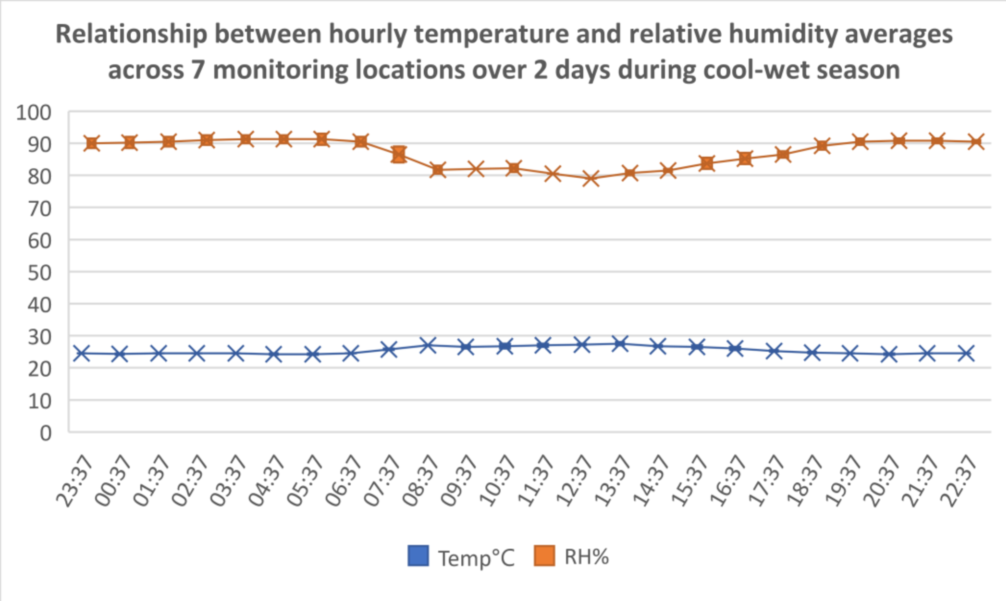

Fig 131 Graph of temperature against relative humidity across 7 monitoring locations (Author generated)

Consistent with Gill (2009), this research acknowledges the influence of urban greenery on urban temperature, however, numerical analysis of evapotranspiration based on urban morphology type (UMT) has not been considered due to the unavailability of a well-developed urban morphology map of the city of Accra. With UMT map, it would have been possible to obtain area ratios and subsequently, the evapotranspiration fraction for the green spaces in the various LCZs. This challenge notwithstanding, the effect of greenery on temperature and relative humidity could still be seen in the pattern of the graph presented in figure 131, vis-à-vis the amount of greenery present in their respective monitoring locations. Comparing the temperatures and relative humidity values obtained at 37 Military Hospital and Ridge Hospital (which are both in LCZ5(8)) at midday on 30th July, it could be seen that at Military Hospital the presence of vegetation around the sensor location could have contributed to the reduction in the air temperature. At 13.37 on that day, the relative humidity at both locations was 71.5%, however, the temperature at 37 Military Hospital was 28℃, whilst Ridge Hospital recorded 29℃. The effect of greenery on this variation is buttressed by the fact that the aspect ratio of the canyon of the sensor location at Ridge Hospital is 0.15. This is smaller than that of 37 Military Hospital, which is 0.11. It was observed in the survey that the immediate surroundings of the sensor location at 37 Military Hospital are greener than that of Ridge Hospital. Having a deeper canyon, one would have expected the latter to record a lower temperature at that time of the day than the former. A similar pattern could be observed when the weather data gathered at Ministry of Interior and The Law Courts Complex on 31st July are compared. Both locations are in LCZ4(5) but are more than 500 metres apart. The aspect ratios for the Ministry of Interior and The Law Courts Complex monitoring sites are 0.5 and 0.55 respectively, which means they are similar. The temperature and relative humidity recorded at the Law Courts Complex were 27.5℃ and 79% respectively, while those recorded at the Ministry of Interior were 28.5℃ and 73.5%. Though there are shade trees on both sites, the canyon of sensor location at the Law Complex sensor is better shaded by trees with bigger canopies than those found at the Ministry of Interior (see figures 132 and 133). Although other factors could account for the temperature variation, the higher relative humidity could be attributed to the rate of evapotranspiration at the former location. It could be inferred that the variation in the amount of vegetative cover could account for the significant differences in temperature and relative humidity at the two monitoring locations.

Fig 132 Image depicting the greenery in the street canyon at The Law Courts Complex (Adapted from Google images)

Fig 133 Image depicting the greenery in the street canyon at Ministry of Interior (Adapted from Google images)

6.7 Distance from the heat island centre

Daytime and night-time UHI maps for the 7 monitoring locations are presented in figures 134 and 135. As shown in figure 134, Ridge Hospital had the highest daytime UHII; however, this did not have any impact on the UHII at any of the nearby sites: Ministries, The Law Courts Complex, and Arko Adjei Interchange. On the other hand, the effect of distance from the night-time heat island centre on the UHII at other sites was quite significant. As evident in figure 135, the night-time heat island centre was Airport City. Although other factors could also account for the high UHII at 37 Military Hospital, its nearness to Airport City could be a major contributory factor. Another observation is that 37 Military Hospital is also near Arko Adjei Interchange, which had the second highest night-time UHII. It can be inferred that the UHII at 37 Military Hospital could have been influenced by virtue of it being sandwiched between the two heat island centres. Having recorded a high daytime UHII and given its low aspect ratio, it would have been expected that 37 Military Hospital would have recorded a rather low night-time UHII. From the foregoing, it is obvious that distance from the heat island centre could have an impact on the UHII of other monitoring locations or sites. It is believed that depending on its direction, wind can push the heat centre of the urban heat island to different areas in a city. As earlier discussed, the wind speed during the day in the wet season was high but, since daytime UHII in that period was low, there was no substantial thermal centre for the prevailing winds to push. Furthermore, the prevailing winds in that season are cool south-westerly winds which could rather reduce the UHI of the city.

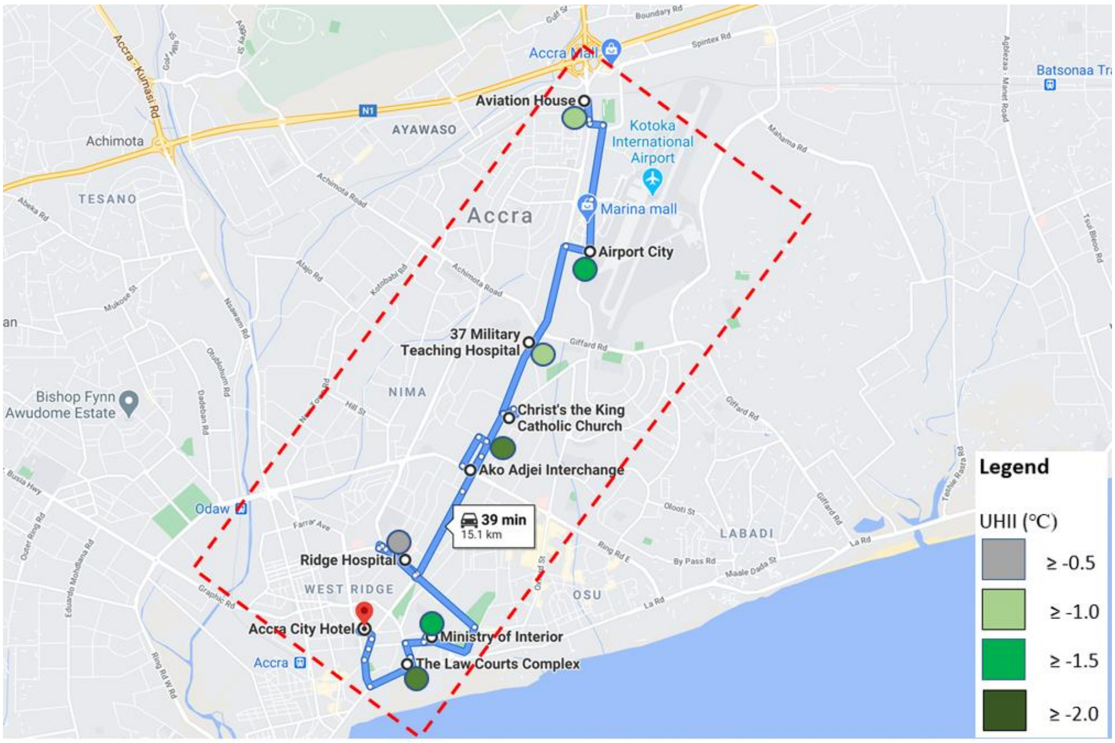

Fig 134 Daytime UHII map for 7 sites in CBD of Accra during cool-wet period

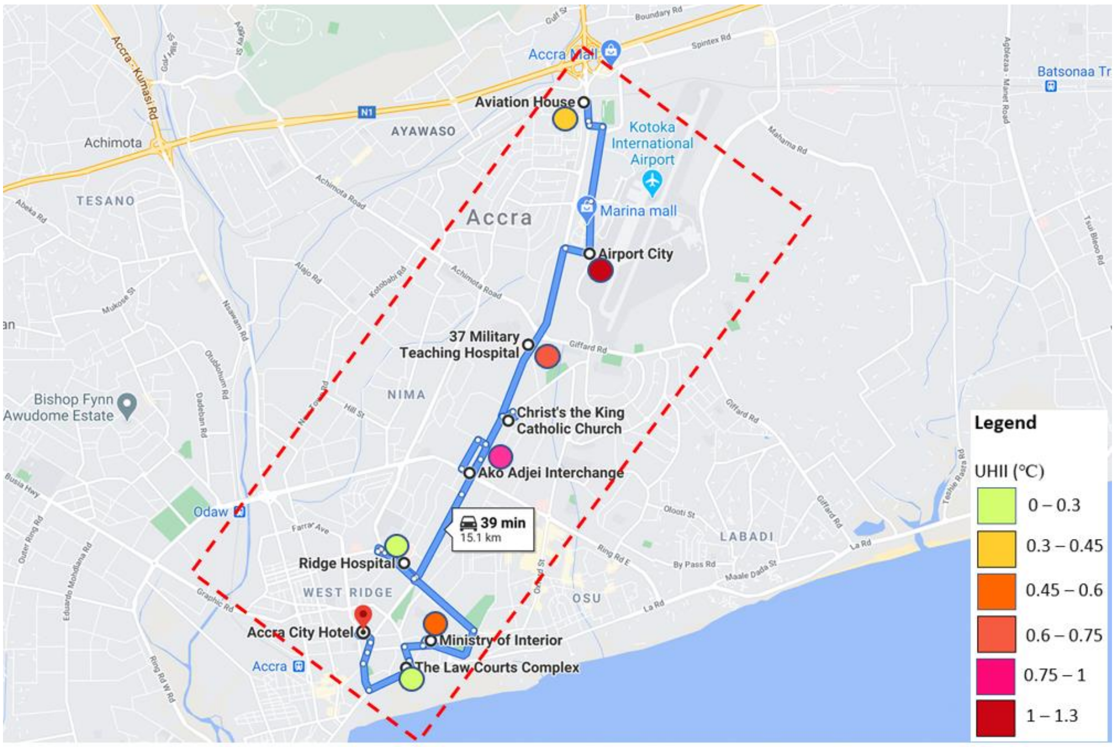

Fig 135 Night-time UHII map for 7 sites in CBD of Accra during cool-wet period

6.8 Conclusion

This chapter has dealt with factors that significantly affect the intensity of urban heat island in the CBD of Accra. The number of causal factors used for the analysis was not exhaustive, as it was mainly based on a defined scope for this research. The parameters considered were: (1) weather-related (i.e. meteorological) parameters and (2) morphological parameters.

Based on relevance and availability of data, the effects of shortwave solar radiation and wind speed on the UHII at the Aviation House, Airport City, 37 Military Hospital, Arko Adjei, Ridge Hospital, Ministries, and The Law Courts Complex monitoring sites were analysed. It is evident from the analyses that there is a negative correlation between wind speed effect and UHII in the CBD of Accra. The analyses have also shown that the effect of wind speed on UHII is more pronounced in the cool-wet period than in the warm-dry period. Analyses of the effects of urban morphological characteristics on the UHIIs at the 7 monitoring sites mentioned above have entailed canyon geometry (i.e. aspect ratio), urban configuration, greenery or vegetation, and distance from heat island centre. It has become evident that the monitoring areas in deep canyons generally experience reduced daytime UHII compared to those within shallow canyons. On the other hand, night-time UHIIs at areas within deep canyons are seen to be higher than those of areas within shallow canyons. It has also been revealed in this chapter that the geometric configurations of the various monitoring sites have not been consciously planned to maximize wind speed effect. It has been indicated that daytime UHIIs at areas with substantial greenery have been significantly reduced. The chapter has further shown that the effect of heat island centre on nearby sites is significant during night-time. The heat island centres identified are Airport City and Arko Adjei Interchange.

To gain a holistic understanding of human factors that have culminated in the transformation of Accra and the attendant development of heat waves in its CBD, results from the qualitative inquiry are presented in the next chapter.

CHAPTER 7

FINDINGS FROM QUALITATIVE STUDY

7. 1 Introduction

This chapter dwells mainly on the analysis of the qualitative data that were gathered through semi-structured interviews with experienced built environment professionals: architects, planners, and architect planners. Findings from the qualitative study are meant to shed more light on the main human factors that account for the results and analyses that were presented in chapters 5 and 6 respectively. The essence of the interviews was to gain an in-depth understanding of the extent to which the physical characteristics or the built-up nature of Accra has contributed to the presence and intensity of heat build-up or UHI in the central business district.

By conducting the interviews, it was possible to further validate the relationships between various land use and morphological parameters identified in the literature review and the UHI intensity dynamics. The interviewees gave their views on how the built environment, in terms of morphology, urban green spaces, and land use pattern have affected the local climate of the study area. The semi-structured interview schedule allowed them to shed more light on the subject, through which other relevant themes emerged. The interview schedule also offered the interviewer the opportunity to discuss suggestions on how various challenges could be addressed. It is envisaged that various suggestions offered by the participants could feed into recommendations for future land use planning remedial and UHI mitigation measures.

The chapter first provides background information about the built environment professionals who were interviewed. It then presents the analysis (content analysis) of the qualitative data collected from the interviews, which indicates the response patterns.

7.2 Interviews

Initially, five built environment professionals were purposively selected for the interview. Since one interviewee did not make himself available, the researcher had to settle on 4. The selection was based on their knowledge in the UHI phenomenon, history of morphological transformations that have occurred in Accra, and their level of professional experience. The composition of the participants was as follows: 1 architect/planners, 2 physical planners, and 1 architect. Selecting the different built environment professionals helped the researcher to obtain a rich spectrum of ideas and insights.

All the interviewees are Ghanaians who have lived and worked in Accra for 15 to 25 years and are therefore very familiar with the city's physical characteristics and historic land use issues. The description of each of the interviewees is presented in table 7.1.

Table 7.1: Detailed description of interviewees (Author generated)

Interviewee	Assigned code name	Years of Experience	Profession	Location
01	**RP/UP/01**	25-30	Physical planner	Accra
02	**RP/AP/02**	15-20	Architect planner	Accra
03	**RP/PP/03**	15-20	Physical planner	Accra
04	**RP/ARC/04**	25-30	Architect	Accra

The questions used were designed based on specific, but flexible major themes, which allowed the researcher to explore other themes that would emerge during the interview. It is worth indicating that the main themes were designed against the backdrop of earlier findings from the contextual and main literature studies, aim and objectives, observations/findings from the field measurements as well as inputs from the supervisor. During the interview, new themes emerged through follow-up questions or some responses from research participants. These new themes were later coded into sub-themes. The new or emerging themes addressed important issues or topics that were not considered under the main themes.

Consistent with Bedard and Gendron (2004), the interviewer used the first few minutes to engage the interviewee in an informal conversation with the view to creating a 'relaxed atmosphere' to promote a friendly relationship between the two. With this approach, the interviewee would respond to questions freely and without hesitation. Each interview was ended with the researcher asking the questions: (1) "In your opinion as an expert, what can be done to improve the land use map of Accra?" and (2) "What other measures do you think could be put in place to mitigate the UHI in Accra?" Those last two questions allowed the participants to recap the main land use issues discussed in the interview and further point out additional suggestions to address the challenges they had identified.

7.3 Analysis of data

The data collected through the interviews were collated in a systematic manner. The recorded data were carefully transcribed to reflect the exact responses given by the participants. It was ensured that nothing was added to or subtracted from what the interviewees had said.

To ensure that the anonymity of the interviewees is not compromised and obtain their consent to the use of their quotes in the write-up, they were each furnished with the relevant transcripts. This allowed the participants to ensure that the transcripts accurately reflected the responses they had given during the interview.

Upon receipt of approval from all the interviewees, the interview transcripts were thoroughly read by the researcher. This helped the researcher to have an in-depth comprehension of the content of the data. Having reflected and gained a clear understanding of the data, the researcher proceeded with data coding. Creswell (2015) defines coding as the process of analysing qualitative textual data by taking them apart to see their yield and thereafter, bringing them back together in a way that is worthwhile. Elliot (2018) posits that coding essentially involves indexing or mapping data to provide an overview of disparate data that helps the researcher to make sense of them in relation to their research questions; in simple terms, it could be said to be a way of tagging data that are of importance to a particular point. The coding of the qualitative data was done with NVivo. The coding was done by first identifying themes under which the data could be grouped. Vaismoradi et al. (2016) posit that themes and sub-themes convey meanings and are used as attributes, descriptors, or concepts. According to Ryan and Bernard (2003), a theme is an implicit topic that brings together, a group of repeating ideas, and it helps the researcher to study the question. The process of coding also allows for the development of new or emerging themes (i.e. sub-themes) to address topics that were not originally identified for the interview. This is consistent with the explanation by Vaismoradi et al. (2016) that each theme could have some sub-themes to derive a comprehensive view of data and bring out a pattern in the views, opinions, and experiences shared by the research participants. The sub-themes that were considered were those deemed highly significant to the respective main themes or concepts.

The final stage of the analysis entailed data interpretation. Consistent with Creswell (2009), the interpretation stage made it possible to reduce the data to a meaningful and manageable size. Following Creswell's (2015) suggestion, the researcher looked for overlaps and redundant codes to reduce the number and then collapse further into fewer themes that became the major headings used in reporting the research findings.

7.4 Presentation of findings

Findings from the qualitative study are presented under 13 main themes. Most of the findings (i.e., the first 11 themes) relate to morphological and land use issues which are believed to have affected the city's climate. Where applicable, emerging themes were captured under sub-themes. The research participants' suggestions and recommendations for land use and UHI remedial measures are elucidated in the last 2 themes. It is worth indicating that the participants' quotes that have been used in presenting the qualitative findings have not been tidied. They are as originally provided by the participants.

7.4.1 Morphological and Land Use changes

This section presents an in-depth and logical analysis of data that were obtained from the interviews regarding the research participants' views and opinions mainly on: morphological changes in Accra, land use issues in relation to urban green spaces, building regulation, enforcement of building regulations among others.

7.4.1.1 Factors contributing to rapid urban growth of Accra

This theme explores the main factors that have contributed to the rapid urban growth Accra has experienced over the past three to four decades. Based on their experiences and knowledge in the urbanisation of Accra, most of the interviewees identified rural-urban migration and natural population increase as the main factors that have accounted for the rapid growth the city has experienced. The interview question was based on the assertion earlier pointed out in the contextual literature (i.e. chapter 2) that: "high rate of urbanisation in the 21st century has had adverse effects on the microclimatic conditions, with resultant increase in urban air temperature" (Kateris et al. 2016, Salman and Baofeng 2018). Since this study is site specific and given that rate of urbanisation is relevant to UHI studies, it was deemed necessary to understand the main factors that have contributed to the rate at which Accra has expanded over the years. The rationale for the theme was also premised on the fact that the quantitative data revealed that monitoring areas with high density developments and deep canyons such as Airport City, Ministries, and The Law Courts Complex which had respective average night-time UHIIs of 1.3℃, 0.7℃, and 0.5℃ even in the cool-wet period which were comparatively higher than those obtained for the other monitoring areas.

"role of urban development in the industrialization and therefore created a migration chain from rural areas to urban areas, particularly to Accra" **RP/UP/01**

"Second, is also the population growth especially for lower income households; somehow as the fortunes of the country have improved" **RP/UP/01**

"…issue of the structural adjustment program also opening the economy of the country to foreign direct investments which have intensified economic productivity in the city" **RP/UP/01**

"…because there is the perception that Accra is the economic hub, so people from the other regions want to come to Accra and make a living" **RP/AP/02**

"…we have a lot of foreigners coming into the country, following the oil discovery. Many oil companies have moved to Accra, where they have set up their headquarters" **RP/AP/02**

"I think if you are looking at both population and the built-up area… in terms of the population growth, obviously, natural population growth" **RP/PP/03**

"…in-migration into Accra has been one of the major causes." **RP/PP/03**

"…then the uncontrolled development has led to this rapid built-up footprint" **RP/PP/03**

"One, it's due to the rural-urban migration as a result of job or employment opportunities in the urban centres" **RP/ARC/04**

It is obvious from the above that all the research participants pointed to rural-urban migration as a driver to the rapid urbanisation of Accra. Whilst 50% of the participants further pointed to natural population, another 50% opined that booming economic activities of the city following the introduction of the Structural Adjustment Program in the '90s and the discovery of oil. From the quote by **RP/PP/03,** there is a clear indication that the rapid built-up footprint the city has experienced could be attributed to uncontrolled developments. He indicated that people have just been building, and the city keeps sprawling without any green belts due to lack of development control.

7.4.1.2 Planning of Accra and its response to growth

This theme was meant to ascertain the effectiveness of the planning of Accra in response to the rate at which it has grown over the years. Research participants were expected to give their opinions either in the affirmative or negative and then provide reasons. All but one participant could not be emphatic on their assessment of the city's planning adequacy. The relevance of this theme was premised on Jusuf's (2007) attribution to city expansion as a major factor that causes the urban air temperature to gradually increase. It was therefore deemed important to gain in-depth understanding of pitfalls in planning that could have led to the high air temperatures experienced in the city.

"… so, if one looks at one perspective you could say no... if you look at the other perspective, one could say yes, it is taking account of the forces of urbanisation" **RP/UP/01**

"…the investments were not coordinated from a policy perspective; the investments were rather spread by demand, so the evolution did not follow directly, what was planned in terms of intent" **RP/UP/01**

"I think that to some extent, the planning efforts are there, but really in terms of adequacy, I think I will doubt" **RP/PP/03**

"So, in terms of adequacy, to some extent, it is ok, but if I am to judge it from a scale of 1 to 100, I might say it is up to 60%" **RP/PP/03**

It is evident from the above quotes that half of the participants believed that to some extent, there were some planning policy provisions, but the pace of urbanisation and the associated developments were not well managed.

"…the evolution has mirrored the urbanisation because it has created additional spaces. So, in terms of order of development or management of development, we have changed from single level and double volume types of development to multi-storey developments in those same spaces" **RP/UP/01**

While acknowledging that there are planning challenges, participant **RP/UP/01** further indicated in the quote above that the transformation was an expected result of urbanisation, particularly as there was a need for additional spaces to meet growing demands.

"The commercial spaces more or less overran the residential spaces almost spontaneously, and as businesses expanded and groomed, the prospects for economic growth thrived" **RP/UP/01**

"No, I don't think so. Despite the… there were certain interventions from the late '80s through mid '90s, I think they either did not do the population projections very well or there were inadequacies in the projections for retailers" **RP/ARC/04**

As indicated in the quotes above, research participants **RP/UP/01** and **RP/ARC/04** opined that projections used in planning the city centre did not adequately cater for the rapidly expanding commercial activities, and in effect, the areas earmarked for residential developments had been engulfed by commercial developments.

In the quote below, **RP/AP/02** attributes the phenomenon to lack of implementation of concrete measures by the planning authorities to contain the growth of the city after the exit of the colonial masters.

"In Accra, the colonial masters picked certain spots and designed them. The others were left to the ordinary people. Now, one of the other things is that we don't enforce laws in this country, so the ills of Accra are a layer, upon layer, upon layer, and it becomes very difficult to right the wrongs of Accra." **RP/AP/02**

7.4.1.3 Main causes of heat build-up in the CBD of Accra

Although the literature (chapter 3) has adequately dealt with generic factors that cause urban heat island, it was important to focus on the main factors that account for this specific study area. The participants demonstrated enough knowledge on this theme and of the city's fabric and were thus able to share a myriad of very useful insights, excerpts of which are captured below:
"So, we have solar radiation, we have limited areas for proper vegetation or green spaces …" **RP/UP/01**

"In the CBD, I think first and foremost, the cause will be the vegetative depletion" **RP/AP/02**

"One of the major factors is what I call *concretization* of the city. When you look at the urban landscape, for example, when you go to Airport City, you will realize that places that are not supposed to be even concrete, they have these smooth surfaced tiles" **RP/PP/03**

"The trees that are supposed to cool the environment are just being cut down left, right and centre (with impunity)" **RP/PP/03**

"One is, lack of soft landscaping or in simple terms, greenery. The CBD is predominantly hard landscaped. When you look at the parking lots for instance, it’s all pavement blocks and that reflect and do not allow absorption of the sun” **RP/ARC/04**

As seen in the above quotes, all the research participants saw vegetative depletion as a major cause of excessive heat build-up in the CBD of Accra. **RP/PP/03** and **RP/ARC/04** further indicated that vegetative depletion in the city centre could be attributed to the presence of wide expanse of hard landscape – a situation **RP/PP/03** describes as concretization.

“...the choices of building materials that have been used as the buildings have changed. In the ‘70s, everyone was using louvered windows, but in recent times, whenever there is redevelopment, the convention is the use of more restrictive materials that do not permit proper ventilation” **RP/UP/01**

“Again, if you look at the types of storey building that are coming up, the type of glazing they use reflects so much radiation …” **RP/PP/03**

“… has got to do with the massive nature or the closeness of buildings vis a vis the reflection that is brought about as a result of the glazing that is used on the façades of buildings” **RP/ARC/04**

As evident in the above quotes, most of the interviewees also raised concerns with the types of building materials that have been used for construction. Respondents **RP/PP/03** and **RP/ARC/04** made specific reference to the extensive use of glazing on many building facades in the city centre, because of which there is substantial reflection of radiation from building surfaces into the air. Respondent

RP/UP/01 bemoaned the use of glazed windows in recent times, as against the use of louvres which are more suitable for warm tropical climates.

"As the buildings have expanded, the arteries that permitted the flows of goods and services and people, have not expanded in tandem. So, the roadways, the pedestrian walkways have not expanded. The same limitations as they were in the colonial times still pertain. This situation does not allow for opportunity for greater ventilation of the spaces" **RP/UP/01**

"Everybody thinks the solution is to internally use air conditioners, so with that mind-set, and the absence of a regulator who would be pressing…" **RP/UP/01**

"it has to do with the politician not understanding or having the will." **RP/AP/02**

"…a lot of building professionals do not even understand what the building regulations are" **RP/AP/02**

The above quotes gave a clear indication that most of the interviewees believe that the building regulations are not working in the city. Whilst **RP/UP/01** opines that extensive use of air-conditioners in the country is due to the mind-set of many Ghanaians, he strongly blames it on the absence of a strong regulator. According to **RP/AP/02**, many building professionals and politicians do not even understand the provisions in the building regulations. He posited that for fear of losing votes, many politicians do not have the courage or the will to see to the effective implementation of the building regulations.

"…there is so much traffic, and fumes from the exhausts of vehicles and the associated carbon dioxide emissions also contribute to the heating of the core of the city" **RP/PP/03**

The interviewee's response as captured in the above quote was in respect of traffic congestion the city often experiences, especially during working hours. By contributing to the heating of city, the heavy vehicular traffic creates very uncomfortable situation for commuters and other users.

7.4.1.3.1 Causes of vegetative depletion

Responses to the question regarding the main causes of heat build-up in the CBD clearly revealed that vegetative depletion has been a major challenge. It was seen to be a very important phenomenon and was thus viewed as an emerging theme which had to be further elaborated. Participants **RP/AP/02** and **RP/PP/03** shed more light on the causes of vegetative depletion. Their views corroborated an earlier assertion by **RP/UP/01** regarding the indiscriminate hacking of trees by many residents of the city, who saw the presence of trees as nuisances.

"Furthermore, the cutting down of the greeneries is also a major factor. The trees that are supposed to cool the environment are just being cut down left, right and centre (with impunity)" **RP/PP/03**

"… if you acquire a plot of land, it doesn't mean that you will have to use the whole land for development; the coverage is there, the setbacks, hard landscapes, soft landscapes… all these things are essential, but you find that we don't do that in this country" **RP/AP/02**

"… around the CBD, the rich people nowadays would build; they would tile the whole compound; no infiltration, so the pavement, the tiles, the building coverage and everything" **RP/AP/02**

Respondent **RP/PP/03** buttresses the point made by **RP/UP/01** regarding the indiscriminate removal of greenery to make space for the construction of buildings and other hardscapes. From the foregoing, it is evident that the main causes of vegetative depletion in the CBD of Accra can be attributed to poor attitudes or mindset of residents and developers, non-adherence to development control regulations, and the growing penchant for paving compounds as against soft landscaping, as indicated by **RP/AP/02**. It is now common to see wide compounds of many developments in the city with hard landscape. This is because many Ghanaians believe paved areas are easy to maintain and sadly, they do not seem to appreciate the environmental cooling benefits of greenery.

7.4.1.3.2 Challenges with use of unqualified design professionals

Another theme that emerged from the responses to the question about the main causes of heat build-up in the city was in relation to the patronage of unqualified building design professionals. As presented below, this was explained in detail by research participant **RP/AP/02.**

"… we don't have professionals designing. One issue we have in the country is that… well, sometimes it's a delicate issue, so it is difficult to talk about it. We equate drafting to architecture. So, a lot of draftsmen are parading as architects" **RP/AP/02**

"The ordinary person does not understand that architecture is a site-specific issue, and the architect thinks about the exigencies of the site and comes up with solutions to that." **RP/AP/02**

"… we have the Legislative Instrument (LI) 163 of the building code which allows for draftsmen to design but to a limit… but in this country, once you give people a small room, we abuse it, that is it" **RP/AP/02**

As seen in the above quotes, **RP/AP/02** identifies three main issues. The first issue relates to the patronage of the services of draftsmen by many Ghanaians. Due to ignorance, many Ghanaians do not know the difference between a draftsman and an architect. Some prospective developers are attracted to the low fees charged by the draftsmen who parade as architects. Second, is the lack of understanding and appreciation of what the architectural profession entails and as such, they are not aware of the quality of service and advice architects could offer them. The third point raised is in connection with non-compliance with the law governing what draftsmen can do. The interviewee indicated that most draftsmen abuse the opportunity granted them by the building code and thus take up jobs solely reserved for architects.

7.4.1.3.3 Enforcement challenges with building regulations

It became evident in the interview that several references were made to building regulations enforcement challenges, particularly by **RP/AP/02** and **RP/PP/03** whilst responding to the question regarding the main causes of heat build-up in the city. The emphatic nature of the interviewees' responses gave a clear indication that poor enforcement of building regulations has to a large extent contributed to the excessive heat build-up in the core of Accra.

"The person who is issuing the permit has to be someone who understands what the issues are. In fact, some don't understand the building regulations. Others too deliberately turn a blind eye to them." **RP/AP/02**

"So, in terms of actual development control to ensure that they follow building regulations, there is a problem." **RP/PP/03**

"Considering the low salaries most of these public officials earn… some people go in for permit, but if they know they can 'pay' to get it… we don't have people who would insist that you do the right thing" **RP/AP/02**

"… we have the Legislative Instrument (LI) 163 of the building code, which allows for draftsmen to design, but to a limit… but in this country, once you give people a small room, we abuse it, that is it" **RP/AP/02**

As pointed out in the above quotes, **RP/AP/02** raised two major challenges. He indicated that some technocrats who are responsible for the issuing of building permits lack the requisite knowledge in building regulations. The interviewee further posited that in some cases, certain officials turn a blind eye to the laws when processing building permit applications, thereby allowing prospective developers to get away with several breaches of the building regulation. The interviewee also indicated that due to poor renumeration that is given to most Ghanaian public workers, many of them become easily compromised, as some developers are always ready to offer bribes to get their permit applications approved. As earlier pointed out by **RP/AP/02**, many people including unqualified design professionals take undue advantage of the weak development control regime that exists in the country in general and Accra to be specific.

7.4.1.3.4 Policy makers

Another issue of importance that came up during the interview was in connection with policy makers. As evident in the quote below, research participant **RP/AP/02** averred that many a time, politicians who are appointed to head the Works and Housing Ministry do not have enough knowledge in built environment issues. He reiterated that by not having a good understanding of the building regulations and development control laws, their appreciation of a critical subject like urban greenery and urban heat island is generally poor. Against this backdrop, the ministry tends to lack strong leadership or clear policy direction to deal with such issues. The respondent’s opinion is captured in the quote below.

“We have maybe the politician being at the Works & Housing Ministry... the deputies are politicians. They don’t have the understanding …” **RP/AP/02**

7.4.1.3.5 Problem with architecture education

It became clear during the interview that architecture education in the country had not in the past been well packaged to sufficiently equip architects to deal with issues of high urban temperatures, urban greenery, environmental cooling among others. The assertion by **RP/AP/02** is captured in the quote below.

"… majority of architects in the country were trained in KNUST… we had an issue in KNUST. I personally have an issue with KNUST, having seen what is done in both US and Ghana. Now, anthropogenic heat… does the architect even understand that?" **RP/AP/02**

7.4.1.4 Extent of changes to green spaces

The question on the above theme was meant to understand the extent of historical changes to the city's green spaces. This was done with the view to gaining an in-depth understanding of how the transformed green spaces have affected the city's climate over the years. Analysis of the historical weather data and findings from the study by Addae and Oppelt (2019) has indicated that the city's temperature over the last 30 years has increased by 2.3℃, whilst the urban extent expanded by 51,730 ha. It was therefore important to further understand the relationship between the two variables from the respondents' viewpoints. In their responses, the interviewees expressed concern over the significant reduction in greenery.

"… as far as I am concerned, it is a disaster, an absolute disaster. It is a disaster because people have treated green spaces as nuisance …" **RP/UP/01**

“In fact, it got so bad that at a certain point, President J.J. Rawlings gave an order that there should be no cutting of trees …” **RP/UP/01**

“… the green spaces you are talking about, they are being eroded. I think for the past five to seven years, it has been rapid” **RP/AP/02**

“The green space, I think is eroding if I may say, at a geometric progression. It is like, every day, something is happening… people are clearing their land …” **RP/AP/02**

“I think green spaces have changed quite massively.” **RP/PP/03**

“… we did what we call land use/land cover change analysis (for the years 1990, 2000, 2010), and we realized that when we looked at the city or the Greater Accra Region per se, there was quite a lot of greens, but the rate of reduction of these greens has been alarming” **RP/PP/03**

“I will say, the green spaces in the city have diminished drastically.” **RP/ARC/04**

The above quotes give an indication that all the interviewees generally held a strong opinion that green spaces in the city have changed drastically. In their description of the situation, respondents **RP/UP/01, RP/AP/02, RP/PP/03** and **RP/ARC/04** respectively used the phrases: “it’s a disaster”, “they are being eroded”, “have changed quite massively” and “diminished drastically”. To reinforce the gravity of the issue, interviewee **RP/UP/01** recounted a period when President J.J. Rawlings had to impose an outright ban on the cutting of trees in the inner part of Accra. Referring to a land use/land cover change analysis for the last few decades, respondent **RP/PP/03** reiterated that the rate of reduction of greenery in the city has been disturbing.

7.4.1.4.1 Main causes of changes to green spaces

In interrogating the extent of changes to green spaces, all the interviewees were asked to shed more light on the main causes of the said changes. The rich insights from the responses given were an indication that all the research participants had in-depth knowledge in issues related to the city's physical characteristics and land use.

"The considerations for green spaces have been minimal. The public awareness for green spaces has been virtually non-existent." **RP/UP/01**

"Unfortunately, we have a perverse system where people rather feel that those things are nuisances …" **RP/UP/01**

Research participant **RP/UP/01** attributed the reduction in green spaces in the city to lack of awareness on the part of the public. He indicated that this level of ignorance among the public is so endemic that most people see trees as nuisances which should not stand in the way of developments.

"I lived at Labone for a period, and I think there is a demand for mid-rise housing around Labone, Cantonments, and all that area, so the green spaces you are talking about, they are being eroded." **RP/AP/02**

“Places that are designated as open spaces are being converted into residential apartments and all that …” **RP/PP/03**

Interviewee **RP/AP/02** on the other hand, identified the demand for mid to high-density housing as a major cause of reduction in green spaces in the core of Accra, particularly around Labone and Cantonments. This point was corroborated by the view shared by **RP/PP/03**.

“We don’t have the green spaces in the first place, that is my thinking. The Ridge area used to be very beautiful, but even flood prone areas were sold to military officers, judges and the rest.” **RP/AP/02**

“… we have people who are to enforce the laws, but they are engaging in an illegal act” **RP/AP/02**

As evident in the above quotes, research participant **RP/AP/02** posits that in recent times, beautiful green spaces owned by the state have been sold to high-ranking public officials. The interviewee further indicated that the selling of the green spaces is worsened by the fact that even senior law enforcement public officials are themselves complicit.

“And one of the major contributory factors is the rural-urban migration which requires more spaces for the associated economic activities …” **RP/ARC/04**

“Number two is lack of planning or I should say, lack of implementation of planning policies.” **RP/ARC/04**

“The third one, I will see it as the citizenry not being aware of the advantages that they derive from the green spaces.” **RP/ARC/04**

In the view of interviewee **RP/ARC/04,** migration of rural dwellers to Accra means that more spaces will be required for both economic activities and residential accommodation. He also averred the lack of implementation of planning policies as a major contributory factor to the continuous depletion of greenery in the city. **RP/ARC/04** corroborated an earlier view expressed by **RP/UP/01** that lack of awareness on the part of the citizenry regarding the benefits of having green spaces in the city is a major challenge.

7.4.1.5 Significant morphological transformations

As earlier pointed out in section 2 of chapter 3 (i.e. 3.2) by various researchers (Shashua-Bar et al. 2004, Bourbia and Boucheriba 2010, Golany 1996 and Rajagopalan et al. 2014), the morphology of a city can affect the intensity of UHI present. Against this backdrop, and to gain an in-depth understanding of the UHI intensities quantified through the measurements, it was deemed very necessary to delve into the extent to which the morphology of the inner core of the city has transformed over the years. Results from the mobile survey had shown that areas along the Ridge Hospital monitoring routes which still had well-preserved colonial residential developments experienced UHIIs between 0.5 and 1.5℃, whereas areas that have seen substantial physical transformation and depleted greenery such as the Ridge Hospital premises had UHIIs between 1.5 and 2.5℃. A similar pattern had been observed on the 37 Military Hospital monitoring route, where the preserved areas (characterised by shade trees) around the main entrance to the hospital mostly had UHII of 1℃, whilst the transformed areas (with less greenery) generally had UHIIs between 1.5 and 2.0℃. In the interview, the research participants were asked to describe and share their knowledge in the significant changes that have occurred to the city's morphology over the last 3 to 4 decades.

"… it is in the ways in which the business and commercial spaces have extended. That is one of the principals… and then how that has pushed out the residential functions to the frontiers of growth and has set in motion a certain dynamic of displacement." **RP/UP/01**

"So, it was almost as if the commerce was moving outward, and then of course, it was now pushing the residential functions further and further …" **RP/UP/01**

"… in terms of the morphology, one can also see a distinction between what is native and what is internationalised, so the internationalised spaces are now emerging and distinguishing themselves from the native spaces, so the native spaces have remained the Chorkors, the Bukoms and so on." **RP/UP/01**

"Then you have the internationalised spaces such as the Airport Residential, which is now almost Airport Commercial… as there is almost no residential function; in fact, there is increasingly limited residential function …" **RP/UP/01**

"… now there has been some rezoning efforts, so we are now getting increasing numbers of vertical developments – 10-storey, 12-storey, 15-storey developments" **RP/UP/01**

"An interesting phenomenon that I have observed is that weaving into all of these complex land use patterns are small, small pockets of very low-income poor construction by slum dwellers." **RP/UP/01**

"… one could distinguish between residential areas and commercial areas. Now they have become meshed, and they have also had a thriving commercial dynamic, pushing out residential functions to the frontiers" **RP/UP/01**

As catalogued in the above quotes, interviewee **RP/UP/01** gave a vivid description of how a once residential city core with substantial greenery has over time given way to commercial spaces with depleted vegetation. From the responses given, commercial spaces have gained dominance over residential spaces, with the latter being pushed further and further out of the CBD. It was revealed that there are distinct dense modern commercial developments, with some areas dotted with a couple of temporary structures erected by slum dwellers.

"… what we call centrifugal fragmentation. Accra is sprawling, and one of the things I find interesting …I was talking initially about the housing deficit. And so, now people are moving towards Kasoa and then now people are going all the way towards Aburi-Koforidua" **RP/AP/02**

"If you are talking about morphology, it's, I don't know how to describe it… it's helter-skelter, sprawling all the way …" **RP/AP/02**

"And so, Accra itself, I term it spatial chaos. That is the term that I use… spatial chaos." **RP/AP/02**

Research participant **RP/AP/02** attributes the cause of the sprawling nature of Accra to the housing deficit which has been caused by the high in-migration and growing population. Inferring from the above quotes, the rate of expansion of the city has been very fast to the extent that it is merging into neighbouring towns which were considerably far-off, because it has not been controlled.

"… the major thing that is so obvious is the built-up footprint, because as I was saying, when you look at the land use/land cover change analysis, the built-up area of Accra was just around the core of the city, like very small, but over the years it has expanded" **RP/PP/03**

"All those places were mainly green, but now when you look at the general morphology, it is just let me say, the built-up footprint that has really transformed the whole urban landscape." **RP/PP/03**

"Cast your mind back, let's say 20 years. Most of the areas were carpet developments, maximum 2-storey and were residential. The extent of the CBD was not as vast as we see now. It was limited to a certain enclave, surrounded by a lot of residential facilities. And over the years, the retail activities have come to overtake the residential …" **RP/ARC/04**

"… and it is sprawling, I mean going everywhere and the verticality is very limited" **RP/ARC/04**

As evident in the above quotes, **RP/PP/03** and **RP/ARC/04** both aver that the small built-up area within the core of the city has over the years lost its greenery.

This position corroborates an earlier assertion by **RP/AP/02.** Research participant **RP/ARC/04** opines that nature of the sprawl stems from the fact that there has not been any conscious effort to encourage or implement verticality sufficiently in the planning of Accra.

7.4.1.6 Level of satisfaction with trend of morphological transformation

Having analysed the effects of various morphological parameters on the UHIIs obtained across the study area, it became evident that over the years developments had not been well coordinated and controlled with the view to mitigating urban heat. As seen in the quantitative analysis presented in chapter 6, no conscious efforts were made to maximize the benefits of Venturi effects through good urban configuration or appropriate street orientation. When asked about how satisfied they were with the trend of morphological changes in the city, all the research participants unanimously indicated that they were not satisfied. The quotes below indicate the responses from all the interviewees.

"As for satisfaction, I cannot say that I am satisfied… and given my peculiar background …" **RP/UP/01**

"No." **RP/AP/02**

"For the ills of Accra, you can't even count them." **RP/AP/02**

"I think when it comes to Accra, I will give it an F." **RP/AP/02**

"I wouldn't say I am that satisfied." **RP/PP/03**

"I am not satisfied at all." **RP/ARC/04**

While all the research participants were emphatic about their dissatisfaction with the trend of morphological transformation, **RP/AP/02** opined that problems of the city were numerous. He proceeded to assign a grade of F, which implied that he was extremely dissatisfied with the trend of morphological transformation the city had undergone.

7.4.1.6.1 Rationale behind level of satisfaction with trend of urban morphological transformation

While exploring the previous theme (i.e. 7.4.1.5), it was deemed important to probe and understand the various reasons given by all the research participants for their dissatisfaction with the trend of the urban morphological transformation that had occurred in Accra. Various responses given indicated that all the interviewees had in-depth knowledge about the ills associated with the city's morphology.

"This could be attributed to the fact that decidedly, nobody is focussing on how the poor are sheltered and because of that they too have to find their solutions …" **RP/UP/01**

“… without anybody coming up with any sensible approach to giving them decent housing, they will resort to criminal enterprise… or violent enterprise to get access to some decent shelter” **RP/UP/01**

“… this is where planning has broken down, because it is the role of policy and planning to device strategies so that no matter what the person’s capacity or capability is, in terms of their resource base” **RP/UP/01**

Research participant **RP/UP/01** attributed his dissatisfaction to the fact that: (1) no plans and provisions are being made to provide accommodation for the urban poor, as a result of which illegal structures will spring up and (2) planning policy implementation systems seem to be non-functional.

“Well, I personally would enumerate everything like not adhering to the building codes, not having enough building professionals, and environmental inclinations and everything …” **RP/AP/02**

“I interviewed the ministers: transportation, housing and others, and everyone admitted that we have serious issues - traffic congestion, building without permit, all those issues.” **RP/AP/02**

“… when it comes to Accra, it will be the land tenure system, I guess, ownership. These are difficult issues to talk about when it comes to Accra, because they can sell a parcel of land to many people… land guard issues etc.” **RP/AP/02**

As evident in the quotes above, research participant **RP/AP/02** cites non-adherence to the building codes, shortage of planning and relevant built environment professionals, poor road traffic system, the presence of illegal developments, and a problematic land tenure system in the city as the main reasons behind his dissatisfaction. The interviewee bemoaned the lawlessness that has surrounded land issues in Accra for several decades. Custodians of stool and family lands in the city have quite often been involved in complicated land disputes over ownership; a situation that has contributed significantly to impeding effective implementation of major planning interventions.

"… because when you look at the rate of urban sprawl and then the rate of the nature of the development control that is going on, there could be so much savings we could make going vertical and even going vertical …" **RP/PP/03**

"… unfortunately, it's just concrete, concrete and glazing everywhere which is quite poor" **RP/PP/03**

Interviewee **RP/PP/03** on the other hand, attributes his dissatisfaction with the trend of morphological transformation in the city to the uncontrolled rate of sprawl, ineffective development control regime and the over-concretization of the built-up spaces with its attendant reduction in vegetative cover.

"… because for me, it is not being done in an ordinate manner. They are haphazard developments; they are made-shift structures all within grade one offices among others …" **RP/ARC/04**

The reason given by research participant **RP/ARC/04** has to do with lack of order in the way developments have been springing up in the city, which corroborates an earlier reason given by **RP/PP/03** in relation to ineffective development control regime.

7.4.1.7 Challenges with land use plan of Accra

The purpose of the question for this theme was to ascertain the main problems confronting the implementation of the existing land use of the city. It was also meant to investigate the land use plan's inherent challenges or pitfalls. This theme was explored against the backdrop that during the mobile survey, it was observed that no serious green policies had been implemented in the land use plan of the city. For instance, no green parks artificial or water bodies were incorporated into the existing land use. Furthermore, it was noticed that several developments had over 70% of their compounds hard-landscaped, which is a contravention of the country's building regulation. The findings would provide useful insights into how to address the various problems associated with the land use plan of the city, particularly those that have adversely affected its climate.

"… there is no collaboration. That's one of the things I have seen. You can have Ministry of Roads and Highways or Feeder Roads doing their roads without considering the planner or the architect" **RP/AP/02**

"So, they would do it and put it on the shelf, and they would tell you that they have it. Yes, they have it, but the implementation is always an issue." **RP/AP/02**

Research participant **RP/AP/02** indicated that institutions that must be interested in land use planning of the city have over the years been working in isolation. He posited that the Physical and Spatial Planning sector has not been working in collaboration with the road sector, and as a result, there is no harmony in the implementation of the city's land use map. He also averred that the planning authority has been developing good land use plans over the years, but implementation has always been a challenge.

"First of all, there is the plan, like the 1991 masterplan. With the planning bit, you know, stakeholder consultations are done, but when it comes to the actual implementation on the ground, entirely different stuff is done." **RP/PP/03**

"… development control, physical development control is one, and two, budgetary allocations to even implement the plans we develop is also one of the major challenges" **RP/PP/03**

"… the level of planning education for the citizenry regarding what has been planned, so that they can also help contribute to achieving the objective of the plan is also lacking" **RP/PP/03**

"… the number of planning professionals – when you look at the MMDAs, within the Greater Accra areas, you go to some of the municipal areas and there is only one planner; even in some of the municipal assemblies, there is no planner" **RP/PP/03**

"… the planning and building inspectorate units of the assemblies are very poor in terms of physical resources to even visit the sites to check" **RP/PP/03**

From the above quotes, it is evident that interviewee **RP/PP/03** corroborated an earlier assertion by **RP/AP/02** that land use plans have always been done, but their implementation have always been problematic. **RP/AP/02** further catalogued other challenges to include lack of funding needed to effectively resource those responsible for the implementation of master or land use plans, low level of education or awareness of planning issues on the part of the citizenry, inadequate number of planning professionals working, and lack of logistics needed by the outfits mandated to implement land use plans (i.e. the municipal assemblies).

"You see the major challenges with the current settlements have to do with flooding in the sense that the storm drains due to our activities are always choked …" **RP/ARC/04**

"I talked about security in the sense that because at certain times of the evening, the retail activities close, and the place is almost always dead, and that can generate a lot of vices over there." **RP/ARC/04**

"… accommodation which is inadequate – inadequate in the sense that those who do not have places to sleep are those we can term vulnerable in the society, those low on the ladder and provision is not made for them" **RP/ARC/04**

“I would like to look at the first challenge as attitudinal. Let’s say, the way we even build, the materials we use to build, the non-adherence to the use of professionals in our developments …” **RP/ARC/04**

As captured above, interviewee **RP/ARC/04** points to the phenomenon of developments done in inordinate manner as a major challenge to the implementation of land use plan in the city. The interviewee indicated that the haphazard developments contribute to the perennial flooding experienced in the city, as in certain areas, buildings are constructed on waterways. He attributes the cause of the haphazard developments to the lack of provision of housing for the urban poor in the planning of the city. The research participant further averred that the dominance of commercial spaces has created security issues, as those spaces become dead at night, thus becoming prone to all manner of social vices. Lastly, interviewee **RP/ARC/04** views the attitude of the citizenry as a big challenge, because most residents build without recourse to the use of appropriate building materials, the adherence of building regulations, and the use of architects and other built environment professionals.

7.4.1.7.1 Causes of shortage of planners

During the interview to unearth the challenges that are associated with the land use plan, two of the interviewees mentioned the shortage of planners as a major cause. The researcher thus considered this to be an important emerging theme which needed further explanation.

As captured in the quote below, interviewee **RP/PP/03** opined that the shortage of planners was caused by lack of funding due to an IMF imposed conditionality which had barred the government from employing planners.

"… because of the IMF embargo on employment of public workers and all that, the Ministry of Finance was not releasing funds for employment. So, consistently over several years, planners were not employed" **RP/PP/03**

On his part, research participant **RP/AP/02** attributed the shortage of planners to the stalling of the spatial planning program by the country's only university, Kwame Nkrumah University of Science & Technology (KNUST) which ran it. It therefore became virtually impossible to staff all the District and Municipal Assemblies as well as the Regional Planning Offices with the right number of planners they required.

"… you would realize that for a period of almost close to 10 years (i.e. a decade) …I can't remember the specific dates in terms of year to year, but I know that they weren't offering spatial planning in KNUST …" **RP/AP/02**

7.4.1.8 Considerations for green spaces in the building regulation

As earlier indicated in 3.4, Alive's (2016) identifies greenery or vegetation among the factors that contribute to variations in urban climate. As pointed out in 3.9 by Kleerekoper (2012) and Futcher (2008), the inclusion of vegetation in urban design is an effective technique for mitigating the effect of UHI. Although the existing building regulation addresses the issue of soft landscaping, it was observed in the survey that the consideration for greenery was not appreciable enough. Against this backdrop, it became important to investigate the extent to which green spaces have been considered in the building regulations. It is intended that exploring this theme would help explain the effectiveness or otherwise of the existing regulation in the provision of environmental cooling effects in the city. Exploring this theme was meant to further deepen those for the previous theme. It is also envisaged that the findings will help the researcher to identify deficiencies and inadequacies in the existing regulations which could possibly have contributed to the high urban temperatures.

"… there are regulations on coverage, land coverage… this is 60%, so that for any development, 40% of the land space will be dedicated to landscaping" **RP/UP/01**

"It talks about all those things: green areas… to conserve areas etc. This is the new act. In fact, in the old act, which is the Act 462, which wasn't really talking about urban green spaces, I don't think that it has been specific ..." **RP/AP/02**

"… for most of it, you could say that it has captured that idea. This is because even when you are building, you are supposed to move a certain number of metres as setbacks, leave some areas as green …" **RP/PP/03**

"It is in the existing building regulation and it is 60% against 40%; 60% as the built or the coverage and 40% for landscaping (i.e. both hard and soft). That is what is in the building code. In the building regulation, I don't remember seeing any specifics." **RP/ARC/04**

As evident in the above quotes, all the research participants: **RP/UP/01, RP/AP/02, RP/PP/03** and **RP/ARC/04** indicated that green spaces have been addressed in the existing building regulations. **RP/UP/01** and **RP/ARC/04** further explained that the land space or plot that can be built is 60%, while the remaining 40% is meant for landscaping. The responses from the interviewees gave an indication that green spaces have been considered in the building regulation. Responses from the interviewees revealed that the implementation of that aspect of the building regulation has not been a success due to several reasons. The next sub-theme explores those reasons.

7.4.1.8.1 Challenges with building regulation implementation and compliance

The quotes below indicate the various views shared by the research participants on the challenges that confront effective building regulation implementation and compliance regarding green spaces.

"The laws actually exist, but nobody is respecting them." **RP/UP/01**

"People look at greenery as nuisance, so it filters through individual decision-making in terms of investing in development, it filters through policy makers who do not pay attention to, and planners …" **RP/UP/01**

"… the building code which was published in 2018 is too expensive and is thus disincentive for the general public and even some professionals to own copies" **RP/AP/02**

"… the basis or the foundation for these green spaces was mainly there, but the only challenge has been with that of the implementation regarding development control" **RP/PP/03**

"But this is not adhered to in most developments due to lack of enforcement." **RP/ARC/04**

As evident in the quotes above, interviewee **RP/UP/01** pointed out the poor attitudes of people (including those in authority) towards their appreciation and handling of green spaces and their compliance with building regulations. The interviewee's response further revealed that policy makers and planners do not put a premium on the issue of greenery in the city. Research participant **RP/AP/02** on the other hand bemoaned the fact that the current building code is not readily available to the public due to the high selling price. **RP/PP/03** saw the implementation of the relevant regulation as a huge challenge, and that was corroborated by **RP/ARC/04.**

7.4.1.9 Building regulations and sustainability

For this theme, the researcher sought to investigate the extent to which sustainable design principles are addressed by the existing building regulations. It was realised that green or sustainable design principles had hardly been applied in the design of the buildings at the Airport City which had the deepest canyon and experienced the highest UHIIs in both cool-wet and warm-dry seasons. Glazing on majority of the buildings in the LCZ was found to be extensive and in addition, green walls were missing. The use of hard surface materials for landscaping or paving was also found to be extensive at Airport City. This observation begged the question as to whether in selecting such materials, an important factor like surface albedo level was considered or not. Given that the relationships between sustainability, building energy efficiency, and UHI build-up could not be underestimated, there was a need to explore the theme. Two sub-themes further sought to ascertain from the interviewees how urban planning, urban greenery, and building energy performance are addressed under the existing building regulation regarding the issue of sustainability.

"The existing one does not… I mean the one that we have used historically has not really taken account of sustainability …" **RP/UP/01**

"… until recently that Ghana Green Building Council has been pushing the sustainable design approach and so on. So, seriously, yes, it is now emerging" **RP/UP/01**

Per his assessment (as captured in the above quote), research participant **RP/UP/01** views sustainability as an emerging phenomenon in the country which has not been addressed in the current building regulations.

"I think you will find everything in there. I made an example of… I think I made an example using an article in the building regulation dating back to the 19th century, which talks about disfigurement …" **RP/AP/02**

Research participant **RP/AP/02,** on the other hand, is of the view that sustainability has to some extent been addressed in the current building regulation, although the relevant principles have not been explicitly stated.

"The LI 1631/1636 relating to the building code is what has been introduced, but I don't think the building regulation itself has changed." **RP/PP/03**

"Yes, I think so. The building regulation covers sustainable design, and it addresses issues of urban planning and urban greenery; however, I don't think it covers building energy performance …" **RP/PP/03**

As seen in the above quotes, interviewee **RP/PP/03** explains that some aspects of sustainability such as urban planning and urban greenery have been addressed in the newly developed building code but not the existing building regulation.

"Yes, in the new one (i.e. the building code), there is a chapter, that is chapter 37, which takes care of sustainability …" **RP/ARC/04**

"Yes, the new building code makes provision for sustainability, and it covers building energy performance, energy certification, and all that." **RP/ARC/04**

As seen in the above quotes, interviewee **RP/ARC/04** corroborates the assertion by interviewees **RP/AP/02** and **RP/PP/03** that the new building code addresses issues of sustainability.

7.4.1.9.1 Building design and building energy performance

This is a sub-theme that was meant to ascertain the provisions made for building energy performance under the section of the existing building regulation that deals with sustainability. Responses from various interviewees are presented in the quotes below.

"… but when it comes to the building scale… and then the materials that have to be used …" **RP/UP/01**

"So, the part 37 of the new building code looks at two routes. So, it talks about the descriptive method and then the certification method." **RP/UP/01**

"Prior to the development of the 2018 building code, the building regulations did not necessarily spell out very specific sustainable design requirements as such, but other aspects of the regulations generally made provisions for that to some extent." **RP/AP/02**

"Regarding sustainable design rating tools or assessment, we have not had them in the past, and so the implementation has been non-existent." **RP/AP/02**

Respondent **RP/UP/01** refers to the types of building materials that are to be used to satisfy building energy efficiency requirements. In their responses, both interviewee **RP/UP/01** and **RP/AP/02** indicated that the newly developed building code addresses building energy performance and assessment or certification. Interviewee **RP/AP/02** however indicated that the implementation of building energy assessment has been non-existent, as the code was developed only recently.

7.4.1.9.2 Urban planning and urban greenery

This sub-theme was meant to explore how the existing building regulation addresses urban greenery as part of urban planning.

"On the planning scale, I don't remember any provision made for specifics, but when it comes to the building scale, it talks about the fact that 50% of the coverage should not be developed …" **RP/UP/01**

As indicated in the quotes, interviewee **RP/UP/01** asserts that the existing building regulation promotes reduction in building energy use, as it requires that 50% of a building site has to be left undeveloped but should rather be used for greenery or soft landscaping to enhance environmental cooling.

7.4.1.10 Deficiencies in the current building regulation and/or building code in terms of sustainable design

This theme was explored against the backdrop that the UHI intensity in the city is quite high, and in addition, the coverage of hardscapes on developed sites is quite extensive. This therefore begged the question as to what deficiencies might be inherent in both the building regulation and building code with respect to sustainable design, and for that matter, urban greenery. It was expected that responses from the interviewees would further deepen the findings in 7.4.1.9. The deficiencies identified by the respondents are presented below.

"… but if you look at it from the city scale, the infrastructure plan will pertain. What is the guidance on the incorporative green infrastructure zone? It is something to talk about. **RP/UP/01**

"I think that we should find a way of addressing the different built environment professionals and what their roles are." **RP/AP/02**

"… in the building code and even in land use and spatial planning, they are addressing the structural engineer, draftsman, and the architect when it comes to design… nowhere do they mention maybe a landscape architect and an urban designer …" **RP/AP/02**

In the opinion of respondent **RP/UP/01,** the building regulation does not make any specific provision for guidance on the incorporation of greenery or green infrastructure into planning at a city scale. Respondent **RP/AP/02** posited that the building regulation and the building code do not spell out the specific roles urban designers and landscape architects are to play in the design process but selectively mention the architect and the structural engineer. The respondent believes that the inclusion of such built environment professionals in the scheme of things could be very useful.

“I don’t think it has captured issues regarding the types of material used for energy savings and all that, because you know that the type of material you use affects the flux and all, energy capture and all that …” **RP/PP/03**

“… looking at the embodied energy of materials that are used in construction which the building code does not talk about. So, it does not address net zero; it does not address embodied energy” **RP/ARC/04**

“The third one is its deployment. What I mean by that is some stakeholder groups were left out of it. Specific examples include the academics, and that will trickle down to the students who will then become the future users of the code.” **RP/ARC/04**

In the opinion of respondent **RP/PP/03**, issues regarding the types of building material that are energy efficient have not been adequately addressed in the building code. Respondent **RP/ARC/04** corroborated the assertion by **RP/PP/03** by further indicating that the building code does not address the issue of embodied energy of building materials. Respondent **RP/ARC/04** also opined that the exclusion of key stakeholders such as academics in the deployment of the building code was not helpful. This was against the backdrop that as such important information could easily be disseminated to students who are prospective built environment professionals.

7.4.1.11 Effectiveness of implementation and enforcement of existing building regulations

This theme was meant to ascertain how effective the implementation and enforcement of the country's building regulation have been. Exploring this theme was informed by the haphazard nature of certain developments that were found in the study area coupled with the extent of reduction of greenery at most of the sites in comparison with the well-preserved colonial developments at Ridge. The quotes below reflect the views shared by all the four respondents.

"It is not effective, and I think it is so because of the way we handle things here in Ghana." **RP/UP/01**

"So, with regard to the public sector employees, to be honest with you, now I see them as silos. They sit there and do not do anything." **RP/UP/01**

"It is not effective. It is very difficult. For instance, it is very difficult to go for a rezoning somewhere. It is very difficult to implement it." **RP/AP/02**

"… when you look at its entirety, sometimes you would realize that even the road reservation, some of the buildings and their fence walls have gone inside and all that. So, on a scale of 1 to 10, maybe I would say, 5." **RP/PP/03**

"It is not effective, because people do their own thing …" **RP/ARC/04**

All the respondents emphatically indicated that the enforcement of building regulation has not been effective. Respondent **RP/UP/01** bemoaned the attitude of most Ghanaians and the city's development control personnel. Whilst respondent **RP/AP/02** thinks the implementation of the building regulations is challenging, respondents **RP/PP/03** and **RP/ARC/04** indicated that many buildings have been built without recourse to the building regulations.

7.4.1.11.1 Challenges with implementation and enforcement of building regulations

This sub-theme sheds light on the various building regulation enforcement challenges that were identified in the interviewees' responses.

"Advocacy, yes. The other thing too is the extent to which the code links up with curriculum. Because the people coming out of school will be the practitioners …" **RP/UP/01**

"People change the uses of the buildings anyhow, and controlling such people, most of whom are supposedly educated, is very challenging." **RP/AP/02**

"Political interference" **RP/AP/02**

"Technical know-how - the people who are supposed to address the issue, identify that this is right or wrong …" **RP/AP/02**

"… lack of commitment on the part of enforcement staff and remuneration at the assembly level - if you pay someone GHC 800 and you ask him to check building permits …" **RP/AP/02**

"We don't dwell so much on ethical and moral issues here in Ghana." **RP/AP/02**

"Funnily enough, the building code was supposed to be implemented from the day of the launch, but the necessary protocols were not put in place …" **RP/ARC/04**

"The other key challenge is: what key role does the private sector play in the implementation? Has that been defined clearly? And if it has been defined clearly, then why is that not happening?" **RP/ARC/04**

As seen in the above quotes, the respondents identified a myriad of challenges. Respondent **RP/UP/01** intimated that the building code for instance is not properly integrated into curriculum. Respondent **RP/AP/02** enumerated indiscriminate conversion of buildings, political interference, incompetence, lack of commitment on the part of enforcement officials, and disregard for professional ethics as some of the major challenges facing the implementation of building regulations in the city. Respondent **RP/ARC/04**, on the other hand, opined that the implementation of the building code was not well thought through. The respondent further identified the absence of private sector engagement in the whole implementation process as another major challenge.

7.4.1.12 Recommendations for improvement on land use and development control

This theme emanated from a follow-up question that was posed to the respondents. They had all expressed concerns about the current development control regime and land use pattern when they gave their views on the questions posed to them while exploring the themes in the two previous sections (7.4.1.10 and 7.4.1.11). Various recommendations proposed by the respondents are indicated in the following quotes.

"In terms of recommendations for land use, one is attitude, and for attitude to change, I have seen that people respond to pressure. That means that there has to be some civic action …" **RP/UP/01**

"I think of two things: changed mindset of the citizens and education as to the benefits that are derived from urban green spaces …" **RP/ARC/04**

Respondent **RP/UP/01** indicated that in terms of land use, some form of civic action may be needed, which particularly centres on attitude. This is corroborated by respondent **RP/ARC/04** who avers that for attitude to change, there should be a complete changed mindset of the citizens.

"Now in trying to promote architecture, personally, the program I want to run is to educate the ordinary Ghanaian." **RP/AP/02**

As evident in the above, respondent **RP/AP/02** corroborated a view shared by **RP/ARC/04** that there is a need to educate the ordinary Ghanaian on the benefits of urban greenery.

"… there is a classic example of participatory budget in Porto Alegre (the capital city of the state of Rio Grande do Sul in Southern Brazil), which people refer to, and where now, budgeting is not done by people in suits sitting somewhere. It is the whole community" **RP/UP/01**

"… we need a groundswell of activists who would mass up for you to get the numbers that are persuasive and are not only just protesting but are also engineering the change from the ground up" **RP/UP/01**

"Regarding the enforcement, what I said is, if they would open up and in fact, they have to do so for that third-party arrangement. When they talk about capacity which they don't have …" **RP/UP/01**

"But you see, the government must take a lead in that, help in acquiring land, get people on board to do the master plan and whatever. And the training …" **RP/AP/02**

"And the political factor; for example, it's common to hear someone say, "I am an NDC member, and I voted for NDC, so why would you demolish my house?" **RP/AP/02**

"… focus of land use planning and regulation should be more on urban greenery and urban open spaces. The greeneries that have been proposed should be implemented, and there should be more" **RP/PP/03**

"We have to reverse the concretization of the median strip (or central reservation areas) of the streets to greeneries and we should have more of green canopies on the walkways where they exist …" **RP/PP/03**

“And then again, for the rooftops that are existing, I think the urban planning, or the district assemblies should be encouraging more greening of the rooftops and even the vertical sections of the wall.” **RP/PP/03**

“I think we should encourage more mass public transit like the bus rapid system that can reduce the fumes the individual or private vehicles generate.” **RP/PP/03**

“There could even be some form of zoning so that depending on the zones, people would pay certain charges when you are entering the city.” **RP/PP/03**

“Then, once the education is done, it has to go with the planning scheme which shouldn’t sit on the shelves. It has to be implemented, so there is a need for that collaboration between the private sector and the public sector.” **RP/ARC/04**

Using Porto Allegre as an example, respondent **RP/UP/01** further proposed community engagement in planning at the local level, in which case the citizens who are key stakeholders can make useful inputs, rather than relying solely on technocrats. Both respondents **RP/UP/01** and **RP/ARC/04** believe that there is a need for a collaboration between the public sector (i.e. the planning outfits) and the private sector to achieve effective enforcement of building regulations and for that matter, development/planning control. Respondent **RP/ARC/04** indicated that engaging a third party is inevitable, since the public sector has not proven to have the needed capacity over the years. Political interference with the implementation of good planning policies and development control was identified as a major challenge by respondent **RP/AP/02**. The respondent bemoaned the lack of courage by politicians to allow the planning authorities to operate as required by law, even if punitive actions are to be taken against their supporters or allies who happen to be in breach of building regulations. Respondent **RP/PP/03** averred that land use planning and regulation should focus on (1) the provision of more greenery along the streets, open spaces, central reservation areas, rooftops and walls, (2) reduction in hardscapes or concretization, and (3) efficient public transport system to reduce vehicular traffic to the central part of the city.

7.4.1.13 Recommended UHI mitigation measures

As this research is "site specific" oriented, it was deemed very necessary to seek the views of the respondents (who are all built environment professionals) on mitigation measures that will be suitable for Accra. As captured in the quotes below, the respondents recommended different useful UHI mitigation measures.

"… we have now this principle of doing green developments vertically so, especially places where there is a tendency for radiation, due to the poor materials choices… there are these creeping plants that they allow to grow around the buildings, example, green walls and water bodies such as fountains ..." **RP/UP/01**

"… if proper storm water management is done, some of the water can actually be stored to do some of these things, and that will also reduce the floods …" **RP/UP/01**

"… there has to be an incentive. Seriously, if we say strict enforcement, there has to be an incentive somewhere to encourage people to plant trees to have green areas." **RP/AP/02**

"The other thing has to do with GIA… I think the professional body should be passionate about certain things and encourage members to learn." **RP/AP/02**

"With urban regeneration, which is like conducting a surgery, it is possible. The timing is always the issue …" **RP/AP/02**

"The Urban Land Use and Spatial Planning outfit or the district assemblies have to liaise strongly with the Energy Commission so that they can come up with policies regarding energy efficiency …" **RP/PP/03**

"The design of the buildings: we should allow for more tropical aeration, rather than using air conditioners and all that." **RP/PP/03**

"For me, I think that the issue of creating these artificial water bodies and all that in addition to more greenery could contribute to reducing that, and then where we have more concrete where there could be greenery …" **RP/PP/03**

"… so, enforcing the building code and enforcing the building regulation will bring about sanity in the built environment which will also lead to healthy open spaces." **RP/ARC/04**

As evident in the quotes above, respondents **RP/UP/01** and **RP/PP/03** suggested that there should be a strong drive for green developments, emphasizing on the need for a strict regulation of construction materials and the promotion of greenery in built-up areas. The respondent strongly recommended the use of building materials that are appropriate for warm climates, greening of walls, and the incorporation of artificial water bodies such as fountains into the urban landscape for environmental cooling. Interviewee **RP/PP/03** shared the same view. Respondent **RP/UP/01** further suggested the storing of storm water as a novel way of ensuring a year-long supply of water to the artificial water bodies. An added benefit of the storm water management system is that it can reduce flooding in the city. Regarding greenery, interviewee **RP/AP/02** held a similar view as interviewee **RP/UP/01**, but the former added that incentivizing people to plant trees in green areas could yield good results. Respondent **RP/AP/02** was also of the view that built environment professional bodies such as the Ghana Institute of Architects should spearhead the education on the UHI subject to its members and other relevant bodies. The respondent also indicated that environmental cooling strategies should be integrated into future urban regeneration schemes that will be developed for the city. As pointed out in the quotes, respondent **RP/PP/03** further averred that through a collaboration between The Urban Land Use and Spatial Planning outfit, the District Assemblies, and the Energy Commission, building energy efficiency policies could be developed. Effective implementation of such policies could ultimately result in a significant reduction in the city's anthropogenic heat. In addition, the respondent opined that the country has not managed the overdependence on artificial ventilation over the years. This stems from the fact that instead of encouraging the design of buildings that depend more on natural ventilation, based on principles of tropical architecture, many buildings in the city centre are air-conditioned. Respondent **RP/ARC/04** believed in the strict enforcement of the building code and the building regulation to sanitize the built environment and improve the city's outdoor thermal comfort.

7.5 Conclusion

This chapter has covered the qualitative inquiry of the research. It has presented the views of 4 purposively selected research participants on factors that have accounted for morphological transformations and the occurrence of excessive heat build-up in the centre of Accra. It has been indicated that a semi-structured interview schedule based on 13 main themes was used for the qualitative study. In their responses, the research participants have pointed out a myriad of problems related to: the rapid urban growth of Accra, the planning of Accra and its response to growth, heat build-up in the CBD of Accra, the extent of changes to green spaces, the trend of morphological transformation, challenges with land use plan of Accra, considerations for green spaces in the building regulation, building regulations and sustainability, deficiencies in the current building regulation, and the effectiveness of the implementation and enforcement of existing building regulations.

To improve upon the land use pattern and development control, the respondents have indicated that there is a need to: engage communities in planning at the local level, engage the private sector engagement to effectively enforce the building regulations, admonish politicians to stop interfering with the work of planning authorities, develop a more efficient transport system in the city to improve traffic flow among others. In addition, the respondents recommended UHI mitigation measures including the need for: green developments, the incorporation of artificial water bodies into the city's landscape, incentivizing people to plant more trees in the city, built environment professional bodies to lead in educating the public on the UHI subject, effective enforcement of the building code and the building regulations, etc.

The next and final chapter discusses the main findings of the study. The main conclusions and limitations of the study as well as recommendations for future studies are also presented in the final chapter.

CHAPTER 8

DISCUSSIONS & CONCLUSIONS

8.1 Introduction

This research has revealed that the CBD of Accra experiences significant urban heat island, especially during both wet and dry seasons, although the intensities obtained in the latter season are higher. The study has also shown that parameters such as wind speed, shortwave solar radiation, and morphology affect the city's climate and, for that matter, its UHI. In addition, the study has through a qualitative inquiry identified various factors (social, economic, political, administrative, etc.) that further account for the high air temperature in the city centre. This chapter discusses the main results of the study. In the discussion, the results of this study are compared with other studies to establish consistencies or differences. The chapter addresses key strengths, achievements, and major contributions of the study to academic discourse as well as benefits to relevant practitioners. It further reviews the key findings with reference to the aim and objectives and presents the main conclusions of the research. Finally, the chapter describes the limitations of the study and other areas that are worth exploring in future studies.

8.2 Discussions

This section presents the main discussions of the results of the study. It touches on the trend of the 30-year historical climate data for Accra and its future implications. It further discusses factors that have accounted for the urbanization of the city as well as the morphological transformations it has experienced over the said period. The section also discusses the main results of the quantification of UHI in the city (based on both mobile and stationary surveys) as well as findings from the qualitative study. In this discussion, key findings and how they would feed into major UHI mitigation measures and urban planning policy decisions are unearthed.

8.2.1 Historical climate data

An analysis of climate data for Accra over the last 30 years has shown that on the average, the city's temperature in the warm months (between November and May) has increased by at least 2.3°C. This finding is consistent with the temperature increase of 2°C over a thirty-year period as projected by Antwi-Agyei (2012). This implies that by the year 2050, the temperature of the city in the warm period could increase to between 32°C and 36°C, which could be alarming.

8.2.2 Urbanization of Accra and morphological transformations

As revealed in the literature, the city's fast-growing population over the years has culminated in a high demand for services and infrastructure, including the provision of formal housing for both residential and commercial purposes. The uncontrolled sprawl in the city that has pushed its frontiers away from the core (Grant 2009) is seen to have contributed to the continuous changes in the city's land cover. The high demand for infrastructure was imminent, considering the sharp increase in the city's population from 1.7 million in 2000 to 2.5 million in 2020 (Dionisio et al. 2010 and GSS 2020).

Given a reduction in grassland cover in the city from 50.5% to 46% and forest cover from 34.2% to 6% (Addae and Oppelt 2019) and an increase in the built-up area from 11.8% to 44.4% between 1991 and 2015, it could be inferred that there is a correlation between the rate of increase in built-up coverage and vegetative depletion. The drastic change means that urban greenery has barely been integrated into new developments in the city in the last couple of decades. Drawing from Jusuf's (2007) assertion, the city's increasing air temperature could to a large extent be attributed to the continuous depletion of greenery. The assertion corroborates the suggestion by previous studies (Golany 1996, Upmanis et al. 1998, Upmanis and Chen 1999, Elliason et al. 2003, Bottyan et al. 2005) that there is a strong relationship between a city's morphology or built-up ratio and urban heat island intensity. As earlier revealed in the contextual literature, Addae & Oppelt (2019) have indicated that between 1991 and 2015, the city's bare land cover reduced from 1.2% to 0.7%, whilst the built-up coverage increased from 11.8% to 44.4%. There is a clear indication that the built-up footprint of the city has increased significantly, and this has obviously culminated in the use of hard materials and the presence of hardscapes. Consistent with US EPA (2015a) and Lowe (2016), the heat island build-up in the city could be attributed to extensive use of artificial materials such as concrete and asphalt - a practice which has to be controlled with the relevant building regulation.

8.2.3 Mobile survey

Results from the two-day mobile survey (conducted on 9th and 10th January 2019) gave a clear indication that Arko Adjei Interchange was the warmest among the eight monitoring sites during daytime. The results showed that the UHIIs obtained for Cedi House, Novotel and Ridge Hospital were also high. It was also noticed that the UHIIs obtained for Aviation House, Ministries, and Airport City monitoring areas were generally low. Although the effect of vehicular traffic could not be discounted, it was noticed that monitoring sites with wide streets and high exposure to the sky had high UHIIs and vice versa. The traverse route used at the Airport City monitoring area which experienced lowest UHII had the lowest exposure to the sky (in terms of its height to width ratio) compared to the rest of the monitoring areas. As Bakarman and Chang (2015) have posited, this phenomenon is attributed to the compactness of the canyon, which prevents or minimizes deep penetration of direct solar radiation inside the canyon surfaces. Although the Cedi House area is within a compact high-rise local climate zone and, as such, had a low exposure to the sky due to heat generated by traffic congestion, the shading provided by the tall buildings could not reduce the daytime air temperature significantly. This deduction is premised on the assertion by Zhu et al. (2017) that vehicular traffic should be regarded as one of the major factors that increase the severity of UHI in big and busy cities. In effect, the average UHII obtained for the Cedi House monitoring area was as high as 1.9℃. It became evident that the Arko Adjei Interchange area which had the highest average UHII (i.e. 2.07℃) had a wide street and was characterized by a heavy vehicular traffic. Immediate to long-term measures to improve traffic flow in the city would have to be considered by the city authorities to ameliorate the effects of vehicular traffic. Similarly, the streets at Jubilee House, Ridge Hospital and 37 Military Hospital/Lands monitoring areas were wide, and with their built-up types being low to mid-rise, their canyons were shallow, and thus substantially opened to the sky. It was noticed that shading by tall buildings at Airport City, Aviation House and Novotel mitigated the daytime heat island intensities.

Wilby (2003) and Lin et al. (2011) have posited that through the process of evapotranspiration, vegetation serves as an evaporative cooling system that creates an albedo which is about 15% higher than urban surface. It was observed that the presence of substantial amount of vegetation (particularly shade trees) contributed to reduction in air temperatures, and hence the UHIIs at certain locations on the traverse routes at the 37 Military Hospital, Jubilee House, and Ridge Hospital monitoring areas. This could have accounted for the resultant averaged UHIIs of 1.27, 1.39 and 1.56℃ obtained at the 37 Military Hospital, Jubilee, and Ridge Hospital monitoring areas respectively. The finding thus corroborates the suggestion by Clay et al. (2016) and Guan et al. (2013) that green spaces or parklands can effectively mitigate the urban heat island of the CBD.

8.2.4 Stationary measurements

Results from the stationary measurements have shown that the city's average daytime UHI intensity is lower in the warm-dry period than in the cool-wet period and vice versa. A look at the average daytime UHI intensity for the warm-dry period (-1.71℃) and that of the cool wet period (-0.85℃) gives a strong indication that during warm-dry periods, daytime air temperatures are higher, and the reference locations are thus exposed to higher intensities of shortwave solar radiation. On the other hand, the city's night-time average UHI intensity for the warm-dry and cool-wet periods were 2.24 and 0.63℃ respectively. It is evident from the foregoing that in the city, night-time urban heat island intensity is higher than that of daytime. This is consistent with Gartland's (2008) observations on the characteristics of the UHI effect. Various studies (Gartland 2008, Oke 1987, Soltani and Sharifi 2017) have indicated that after long hours of exposure to solar radiation, the air temperature in the urban canopy reaches its maximum during the evening, and a dome of warm air is formed over the urban area.

8.2.5 Effects of solar radiation and wind speed on UHII

Analyses of the stationary data have shown that during the cool-wet period, the effect of shortwave solar radiation on UHII in the city is strong between late morning and early afternoon (i.e. between 10.30 am and 12.30 pm). During the warm-dry period, however, it was observed that the effect of shortwave solar radiation on UHII was significant between the hours of 8.30 and 14.30. This means that the city experienced longer hours of intense shortwave solar radiation in the warm-dry period than the cool-wet period. Although the maximum shortwave solar radiation in the cool-wet period was 0.75W whilst that of the warm-dry season was 0.71W, the maximum daytime UHII obtained during the latter period was 3℃ as against 2℃ which was obtained during the cool-wet period. At both Ridge Hospital and Aviation House where the maximum daytime UHIIs were obtained during the cool-wet and warm-dry periods respectively, the aspect ratios were low. The maximum daytime UHII at Aviation House during the cool wet season was 0.5℃ as against 3℃ which was obtained for the same site during the warm-dry season. From the foregoing, it is evident that the effect of shortwave solar radiation on daytime UHI in the city is strongly felt in canyons that are more open to the sky. Although 37 Military Hospital monitoring location had the lowest aspect ratio among the 4 sites that were monitored during the warm-dry period, it had about the same maximum daytime UHII as the other 3 sites. Despite its openness to the sky, the intensity of shortwave solar radiation reaching the 37 Military Hospital site was significantly reduced by the cooling effect of its greenery.

The effect of wind speed on the UHIIs at the various monitoring sites was more prominent in the cool-wet period when the south-westerly winds were prevalent. In both periods, daytime winds were found to be generally stronger than those of night-time. The results presented in 6.2.2 have shown that in the cool-wet and warm-dry periods, the UHIIs dropped significantly at wind speeds of 9 - 9.9 mph and 6.5 - 7.2 mph respectively. This implies that with appropriate geometric configuration, the prevailing wind could be exploited to mitigate the effects of UHI in the CBD of Accra. Previous studies (Erell et al. 2011, Rajagopalan et al. 2014) have revealed that the cooling effect of wind helps to minimize the adverse effects of heat island on microclimate and human thermal comfort. As earlier illustrated in section 5 of chapter 6, the configuration of the centre of Accra has not been consciously done to maximize the benefit of the Venturi effect.

According to He et al. (2017), wind is maximally channelled into the urban core by road segments that are parallel to the inflow direction due to lack of obstructions, whereas road segments perpendicular to the inflow direction stagnate the wind significantly. It was also noticed that the sensor at The Law Court site benefited from the effect of wind velocity since it was located along a street that is parallel to the prevailing south westerly winds. In the case of the Ministries site, wind effect on UHII was minimized, since the sensor location was along the Starlets 91 Street, which is perpendicular to the prevailing wind direction. This means that it is important to explore the relation between orientation of streets and wind direction in city planning.

8.2.6 Effects of morphological characteristics on UHII

This study was limited by the non-availability of urban morphology type map for Accra, because of which evapotranspiration could not be numerically assessed to determine ratios of green spaces in the various LCZs. This challenge notwithstanding, by analysing and matching results obtained through both mobile traverse and stationary measurements with the extent of greenery in the respective built-up types, the cooling effect of greenery on the UHII at the various locations could be seen. At 37 Military Hospital for instance, the effect of greenery on UHII was very significant. As shown in chapter 6, the 37 Military Hospital site had smaller aspect ratio (H/W) in comparison with the Ridge Hospital site, but daytime temperature at the former site was considerably lower, as it was reduced by the presence of many shade trees. It was also observed that although both Ministries and The Accra Law Courts Complex had almost the same aspect ratio, daytime and night-time UHIIs at the latter site were much lower than those obtained for the former. Of the two sites, The Accra Law Courts was seen to be much greener. This finding is consistent with Gill's (2009) assertion that urban greenery has influence on urban temperature. It is obvious that an improvement on greenery in open spaces, shallow canyons, along the streets, and in the median areas of roads could promote environmental cooling, and thus mitigate the heat island effects in the city.

The study further revealed that the night-time heat island centre could have some effect on the heat islands at other sites due to proximity. This effect could be due to the high intensity of the night-time urban heat island. This was evident in the night-time heat island map that was developed using data captured in the wet period, which covered all the 7 monitoring sites. The night-time UHII at 37 Military Hospital was seen to be high, although the site had a very shallow canyon and was expected to have easily lost longwave radiation at night. By virtue of its nearness to Airport City and Arko Adjei, which were the main heat island centres, the night-time air temperature at 37 Military Hospital was seen to have increased significantly. According to Soltani and Sharifi (2017), this phenomenon can be attributed to the occurrence of local air turbulence within the urban settings that mixes the hotter and cooler air and modifies the intensity of UHI due to land cover differences. It is worth indicating that further investigation may be needed to determine other possible causes of the high night-time UHII at the 37 Military Hospital area. This observation means that the approach to mitigate the effects of UHI in the city must be holistic. It is evident that it is not enough to provide environmental cooling elements for a selected number of areas in the city. Furthermore, the heat island map has revealed that Airport City and Arko Adjei Interchange have large expanses of hard surfaces which release substantial amount of longwave radiation at night. In both areas, the provision of effective cooling measures such as greenery on exposed hard surfaces must be considered. For deep canyons like Airport City, green walls and roofs could reduce the amount of heat that would be absorbed by the tall buildings and the flat roofs. To mitigate the UHI in both areas, it will be important to adequately shade the large expanse of hardscapes with trees. Consideration could also be given to the incorporation of water bodies such as fountains and ponds in the landscape to enhance environmental cooling.

8.2.7 Local factors and views of built environment professionals

The qualitative study identified the following as factors that have culminated in the fast rate of urbanization in the city:

- Increase in the city’s population over the years
- Rural-urban migration

The above-mentioned factors are consistent with the view held by previous researchers (Jusuf 2007, Kateris et al. 2016, Salman and Baofeng 2018) that rapid urbanisation can adversely affect a city’s microclimatic conditions and ultimately result in an increase its air temperature.

As identified in this study, other major factors that have contributed to the transformed morphology and climate of Accra include:

- Planning not done to address evolving investment spread
- Vegetative depletion due to non-adherence to building regulation, bad mindset of most developers and landowners, and poor development control regime
- Extensive use of hard building materials
- Overdependence on air conditioners in buildings
- Patronage of the services of non-qualified architects, especially draftsmen
- Lack of strong leadership or clear policy direction to deal with such issues

- Inadequacies in the curriculum of architecture education
- Selling of green spaces in the CBD to prospective developers
- Lack of intersectoral collaboration in the implementation of the city's land use map
- Absence of plans to curb the rate of sprawl of the city
- Lack of resources (both human resource and funds) to implement land use plans
- Existing building regulation not adequately addressing issues of urban greenery and sustainable design
- Planners and policy makers not putting premium on urban greenery issues
- Issues regarding energy efficient building materials not being adequately addressed in the building code.

8.2.8 Policy implications

Drawing mainly from views expressed by the research participants during the qualitative study as well as lessons from other studies, the problems stated above could be addressed through interventions that have policy implications. These policy implications are discussed in this section.

8.2.8.1 Policy makers (government)

It became evident in the qualitative study that quite often, politicians who are appointed to head relevant ministries such as the Works and Housing Ministry do not have enough knowledge in matters related to the built environment. Strong leadership and clear policy direction are needed to create a *sanitized built* *environment* that could ultimately improve the city's thermal comfort. Against this backdrop, it would be worth considering people with the requisite knowledge to head the responsible ministries.

The sale of state-owned parcels of land which were once beautiful and well-maintained green spaces in prime locations in the heart of the city needs to be revisited, as the practice has contributed to a reduction in vegetative cover. It has become obvious that planners and decision makers did not put measures in place to strategically preserve or conserve such historically greenery areas. Policy decisions should therefore factor in green conservation regulations that prospective developers of such plots would be obliged to comply with. Consistent with Soltani and Sharifi (2017), there is a need for the city's planners and decision makers to address the issue of urban heat island by prescribing minimum standards for green spaces and building types on various lot sizes as specified percentages of given block areas. Given the interest Ghanaian politicians and other high-ranking public officials have had in the sale of state lands in prime areas in the centre of Accra, urban planning professionals would need to initiate very strong advocacy to get the issue addressed.

It has been revealed in this study that in the planning of Accra, no major policies were made to address the city's possible expansion or sprawl that has resulted from rural-urban migration. As the high demand for more spaces for economic activities and residential accommodation is irreversible, the city's planners and decision makers may need to consider guidelines that could reduce building coverage so that there can be adequate areas for urban greenery. To achieve this objective, some Ghanaian built environment professionals have strongly suggested the need to encourage vertical developments in most parts of the city, especially for high-density projects. It is worth indicating that in a city like Accra, the success of such a policy also rests on its effective implementation, which requires strict enforcement of the relevant regulation. It must be indicated that an effective implementation of *verticality* in the city will make it possible to control the sprawl to a large extent. The springing up of several illegal structures in certain parts of the city has partly been attributed to lack of provisions for accommodation for the urban poor in previous plans. Given the substantial population of the informal workers and dwellers in the city's CBD, it will be important for planners and decision makers to make provision for such people in the development of future land use plans.

Urban heat island is a very important issue, which warm tropical cities must take seriously. Considering the development control architecture in Ghana, each municipality or district must be well resourced with qualified built-environment professionals, including urban planners and civil engineers. As revealed in this study, in the past, most District and Municipal Assemblies in the country failed to employ qualified built environment professionals to handle their planning and building control outfits. Although this challenge has been attributed to shortage of planners and a freeze on the employment of public sector workers (due to IMF bailout conditionalities in recent times), it could be argued that the various assembles have not shown commitment towards employing the right people over a long period. Since the country's universities have been producing many other built environment professionals including architects, surveyors, civil engineers, building technicians, etc. for several decades, the planning offices could have prioritised the employment of such professionals even long before the imposition of the IMF bailout conditionalities. Policy makers would need to ensure that the planning outfits of the Accra Metropolitan Assembly and other local authorities in the country have the right human resource capacity to handle planning and development control matters in their respective jurisdictions.

As revealed in the qualitative study, the land tenure system in the city has posed serious challenges to planning authorities and developers for many years. In Accra, just as many traditional areas in the country, land is vested in the chiefs and the various families. Due to the high demand for land in the city and competing interests of heirs, the process of land acquisition has often been characterized by disputes. The present land tenure system is quite restrictive, and thus makes it difficult for city planners to implement major planning interventions. There is therefore a need for policies to be formulated to streamline the land tenure system and the land acquisition process so that planning authorities can implement *green policies* in the city with much ease.

8.2.8.2 Planning professionals and decision makers

Although Accra had always been a busy city since the post-independence era, economic activities were said to have boomed in the 1990s. Planning professionals and decision makers who oversaw developments in the city over the years seemed to have missed the opportunity to earmark many areas as open spaces and green belts as a way of controlling sprawl. Sadly also, planners and development control officials could not ensure that the city evolved in accordance with what had originally been planned.

Planning authorities are generally supposed to have an oversight responsibility over the activities of various sectors that oversee developments. In Accra, most of the institutions that are supposed to be working in accordance with the land use plan of the city have been working in isolation. To ensure that there is harmony in the implementation of the city's land use plan, it will be important for the planning authorities to work in collaboration with all the relevant sectors to effectively coordinate their activities.

8.2.8.3 Local authority (enforcement)

'Developments in the city not directly following what was originally planned' means enforcement of planning and building regulations has not been effective over the years. The alarming rate of vegetative depletion and the concretization of parts of the city could also be attributed to poor development control regime. Both planning and development control units of the municipal assembly that is in charge of the city centre would have to ensure that developers adhere strictly to the requirements of the building regulations, for example, regarding allowable building coverage vis-a-vis the areas that are to be left for soft and hard landscaping. Effective development control should also entail strict application of the building regulations in the processing of building permits as well as periodic site inspections as required by law. After obtaining planning or building permits, many recalcitrant developers in the city tend to go contrary to the regulation when they are not checked by building inspectors.

Findings from this study suggest that planning professionals in the city need to pay attention to the regulation of building materials to ensure that they are appropriate for the prevailing (tropical) climate. This would require planners to ensure that *integrated design principles* are applied in building design so that energy efficiency would be promoted. For buildings to be energy efficient in a warm tropical city like Accra, natural ventilation and various environmental cooling principles should be encouraged as against artificial ventilation since the latter means of ventilation contributes to the generation of anthropogenic heat. Since most of the principles have been enshrined in the new building code, planners in the local authority are to ensure that architects and developers comply with them. Planning professionals in the city would also have to integrate environmental cooling strategies in future land use planning and urban regeneration schemes since that could reduce the city's climate significantly. Energy efficiency policies could also be developed through a collaboration between the city's planners and the Energy Commission.

Corruption appears to be endemic within the public sector in the country. For effective development control to be achieved, the local authority (i.e. the Accra Metropolitan Assembly) must rid itself of unscrupulous planning and inspectorate officials who become compromised, and thus allow many prospective developers to get away with breaches of the building regulations. To curb corruption practices in such an important institution, the local authorities could in consultation with government explore ways of getting the renumeration of its staff improved.

It was revealed in the qualitative study that many developers in the city have been using the services of unqualified building design professionals. This has been happening because those developers simply take undue advantage of the weak development control regime that exists in the city. People intentionally do so because in most cases, they know they can "pay their way through" without facing any sanctions. The city authorities would need to ensure that offenders are handed punitive sentences or sanctions that could be deterrent enough.

8.2.8.4 Architects and other built environment professionals

As earlier pointed out in the qualitative findings, there has been an extensive use of hard materials and glazing in the construction of buildings in the city. This phenomenon has been fuelled by the quest for modernity on the part of both building clients and architects. To give buildings modern or contemporary appeal, and in the case of civic and commercial facilities, what is termed 'corporate look', many architects have in the last few decades designed buildings with materials that are not appropriate for the local climate. Extensive use of glazing on buildings in the city results in overdependence on artificial ventilation, which eventually culminates in the release of heat into the environment. Sensitization programs would be needed to make design professionals and other built environment professionals *sustainable design oriented*.

The Ghanaian built environment professional bodies have not shown much interest in issues related to urban heat island. Moreover, a body like the Ghana Institute of Architects seems to have looked on whilst unqualified persons such as draftsmen take up jobs that are meant solely for architects. Although there is a regulator to check and curb such an illegal practice in the country, the professional body of architects should take steps to support the regulator in that regard.

The setting up of advocacy groups by the various built-environment professional bodies to achieve the above objectives would be apt.

8.2.8.5 Civic education & sensitization of the public

The study has revealed that a cross-section of the Ghanaian public needs to be educated on the urban heat island subject, the benefits of urban greenery and the need for climate responsive architecture. It is important for the citizenry to appreciate the severity of the effects of urban heat island so that they will act responsibly. It is important for the ordinary Ghanaian to see urban greenery as beneficial but not as a nuisance. When properly sensitized on the subject, the rampant cutting of trees and the extensive hard landscaping could be curbed. Against this backdrop, the planning authority should consider rolling out a civic education program on the urban heat island subject across the Accra metropolis. This civic education could be done in collaboration with other interested groups. When the citizens are well informed about such an important subject, politicians will have the courage to roll out policies that will inure to the benefits of the Ghanaian community without any fear of losing votes. Effective civic education can drive a change of mindset among the citizenry, and by and large, people will be adhering to building/development regulation.

As pointed out by some of the research participants in chapter 7, the use of unqualified built environment professionals has been quite perverse in Accra and the country in general. Whilst many Ghanaians cannot distinguish between architects and draftsmen, others have the perception that draftsmen can offer the same service as architects and at a lower fee. Due to this perception, many building clients do not patronize the services of qualified architects - an act which has often resulted in far-reaching consequences. It will therefore be important for the Ghana Institute of Architects to reach out to the public through various fora to educate them on the benefits of using qualified built environment professionals.

8.2.8.6 Curricula for trainee architects and planners

Findings from the study have shown that Ghanaian planners and architects are expected to ensure that the built environment will be comfortable for inhabitants. Given the gravity of the urban heat island issue in Accra, it is important to ensure that issues of urban temperature and environmental cooling principles are imbibed in trainee planners and architects in the built environment schools in the country. There is therefore a need for the relevant institutions to roll out repackaged curricula that will equip students to effectively handle urban heat island issues. To this end, the relevant professional bodies could explore a collaboration with the above-mentioned institutions.

8.2.9 Lessons from best practices

Various UHI mitigation strategies that have been identified and deemed suitable for tropical cities such as Duran, Hong Kong, Singapore, and Colombo: have included: (1) the adoption of land-use change with the integration of more green areas and trees in the urban environment, (2) moderate increase in vertical developments could also help in reducing the built-up surface, (3) the need to improve the albedo of pavements and roofs and to limit vehicular presence in the dense urban environments, (4) achieving a balance between horizontal and vertical dimensions for new planned areas or cities and ensuring that there is an optimized density with an open morphology of streets in order to promote enhanced natural ventilation that could prevent excessive radiation trapping, (5) the need to maintain a careful balance of urban greenery with other urban morphological parameters to achieve appreciable reductions in UHI magnitudes (Giridharan et al. 2008, Kotharkar et al. 2019, Litardo et al. 2020). Drawing from a UHI study in Adelaide, Soltani and Sharifi (2017) point to the importance of 'policy interventions' through which existing urban fabrics or landscape could be transformed towards a more liveable and sustainable future. Against this backdrop, a better understanding of causes of daily heat variations and heat stress on human participants in cities is needed to help with urban policy-making and public life management.

It is worth indicating that in addition to the insights gained from views of the research participants, this research also draws on the best practices enumerated above for the development of a holistic strategic plan for UHI mitigation.

8.2.10 Application of findings

Findings of this research comprise both UHI mitigation strategies (based on quantitative assessments) and policy implications informed largely by views of built environment professionals (based on qualitative findings). The two sets of findings can be incorporated into a major urban policy making and development process through which the city of Accra could be made sufficiently resilient to cushion the adverse effects of urban heat island.

To effectively apply the main findings of this study, it would be necessary for the responsible planning authority to set an *organizational goa*l that could address the problem of urban heat in a holistic way. This goal could be achieved by utilising both UHI mitigation measures emanating from the quantitative assessment and policy interventions that have been identified through the qualitative research. Against this backdrop, a strategic plan is proposed for the planning authority that oversees Accra to successfully achieve the said goal. Strategic planning is defined as a systematic way of planning which enlightens the future of an organization and becomes a navigation to take the right decisions with which a set target or goal could be directed to (Wilson 1998, Demir 2017). Bayraktar and Yildiz (2007) define strategic plan as the sum of operations which take an organization from its situation at a particular time to a target position.

Given the complexities of the challenges that exist in the study area, medium (1-5 years) to long-term (more than 5 years) strategic plans may be worth considering. This research proposes a strategic plan that adopts 4 key elements of Demir's (2017) strategic planning process (depicted in figure 136). This study ultimately visualises a holistic strategic plan that is presented in the flow chart in figure 137.

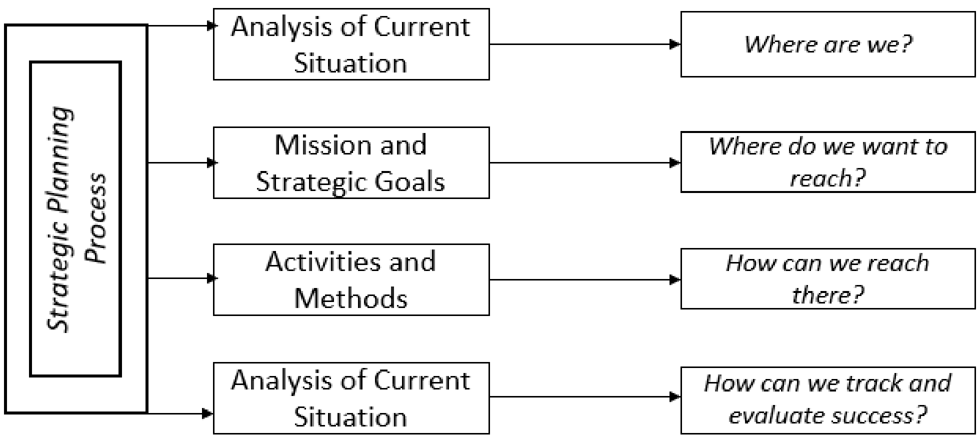

Fig 136 Flow chart of strategic planning process. Modified after Demir (2017)

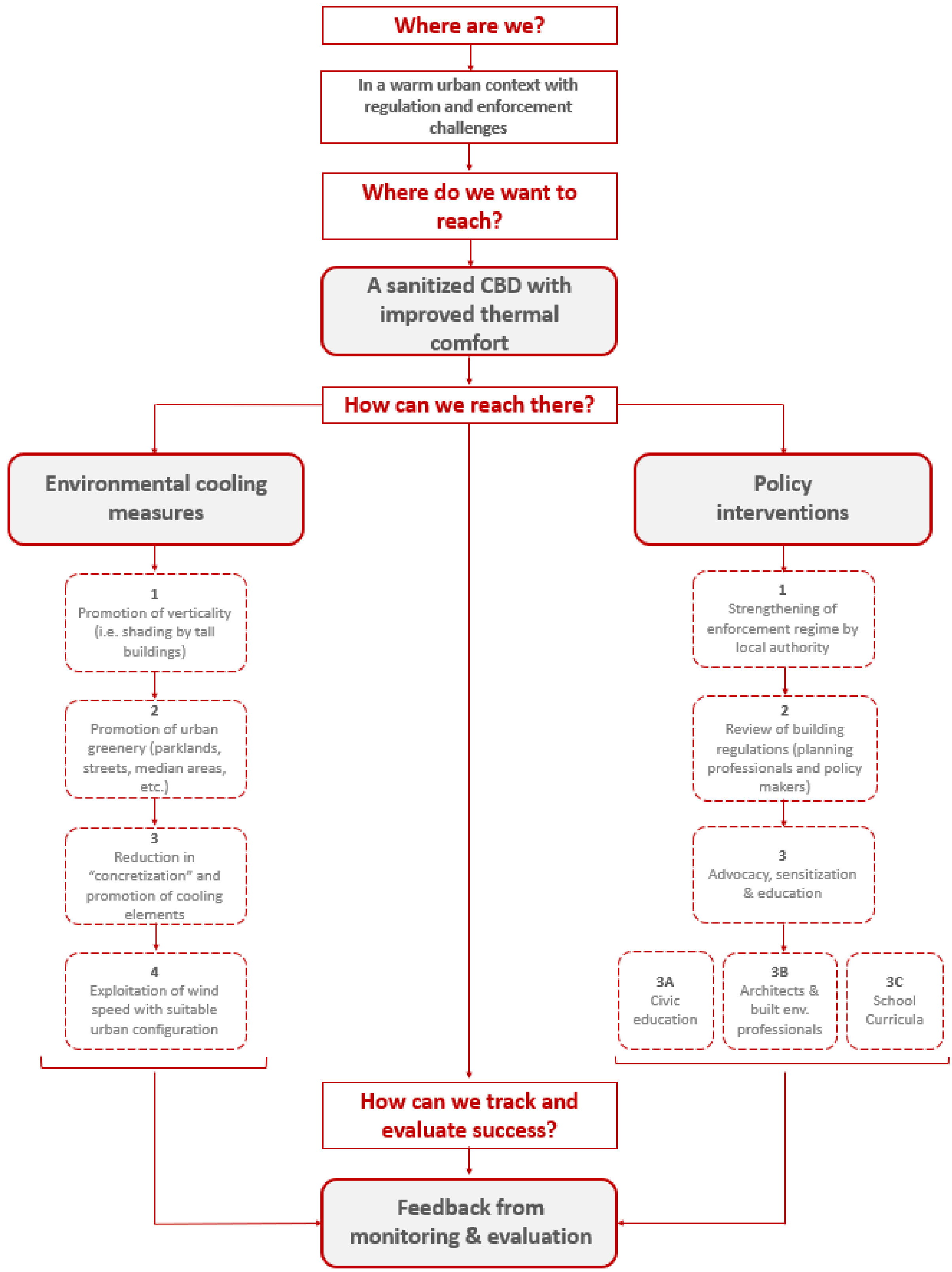

Fig 137 A visualised holistic strategic plan to mitigate UHI in the CBD of Accra (Author generated)

8.2.11 Aim and objectives revisited

The overarching aim of this study was to quantify the urban heat island (UHI) intensity in Accra with the view to developing appropriate mitigation and planning strategies to cushion the adverse effects of the urban heat. The research aim was achieved through the following objectives:

- To understand the historical developments in the urbanization of Accra and ascertain its effect on the local climate
- To explore and identify methods and procedures suitable for quantifying UHI at the city scale
- To understand the urban heat island intensity dynamics in the CBD of Accra through quantification and analysis of weather data
- To investigate and identify the main local factors that have contributed to the UHI build-up in Accra
- To identify suitable mitigation measures and planning strategies with which the effects of UHI in the CBD of Accra could be effectively cushioned

To achieve the first objective, a study was done to understand the urbanization of Accra from a historical perspective. This involved an investigation into the main factors that contributed to the urbanization of the city. It was evident that the city's expansion was catalysed by it being made the country's administrative capital during the colonial era. It was further revealed that parts of the city centre, particularly the Ridge and Cantonments areas where the European merchants and government workers mainly inhabited were well planned, unlike the peripheral areas. The well-planned areas were very green and have to a large extent remained so over the years. As pointed out by GSS (2014), the peripheral areas were not given much attention. Consequently, developments became fragmented and difficult to control for many years, as the city continued to expand due to population increase, in-migration from the rural areas, and economic boom. A further investigation (Addae and Oppelt 2019) showed that in the last 30 years, the built-up areas in Accra have quadrupled in land cover from 11.8% to 44.4%, whereas the greenery has reduced in land cover from 36% to 6%. This meant that the city’s built-up area has substantially increased in coverage. Analysis of weather data for the city in about the same period showed that the average maximum and minimum monthly temperatures in the warm months had increased by 1.6℃ and 3.0℃ respectively (GMA 2017, Gyasi-Addo & Bennadji 2020). It could be inferred in objective 1 that the city’s transformed morphology appears to have influenced its local climate over time.

The second objective explored methods and procedures that would be suitable for assessing urban heat island in the study area. To achieve this objective, uses and benefits of methods such as remote sensing, thermal satellite imaging, GIS, mobile survey, and spot measurements for investigating UHI were assessed. Considering the scale of the investigation (coupled with cost implications), mobile survey and spot measurements were deemed appropriate, and thus employed for the study. Drawing from the assertion by Rizwan et al. (2008b) and Unger et al. (2001) that UHI development is influenced by both environmental and human factors, the pragmatic research philosophy was adopted for the study. This meant that in addition to the numerical weather data that would be needed for the quantification of the UHI in the city, a qualitative inquiry would be needed to further investigate the human factors. Consistent with Creswell (2014), the pragmatic research approach offered the researcher the freedom to choose procedures (both quantitative and qualitative) that would best meet the needs of the study.

The third objective was to understand the dynamics of urban heat island intensity in the different local climate zones. This objective was achieved by statistically analysing the weather data which were collected using weather Lascar EL-USB-2-LCD weather sensors. Using excel, the different UHI profiles obtained through mobile survey and spot or stationary measurements at different seasons could be analysed. The effects of wind speed and shortwave solar radiation (meteorological parameters) as well as vegetative cover aspect ratio (morphological parameters) on the UHI intensities at the different monitoring sites were also analysed and graphically presented. The various analyses indicated that the UHII profiles obtained at the different sites in the CBD of Accra were significantly influenced by canyon geometric characteristics, the extent of exposure to shortwave solar radiation, amount of greenery present, and wind speed.

The fourth objective was to ascertain various human factors that are thought to have contributed to the worsening heat build-up in the centre of Accra. This objective was achieved through a qualitative study. To this end, 4 local built environment professionals were interviewed using a semi-structured interview schedule. Findings from the study pointed to the following as major human factors that contribute to the high urban temperature in the CBD of Accra:

- Planning not done to address evolving investment spread

- Vegetative depletion due to non-adherence to building regulation, bad mindset of most developers and landowners, and poor development control regime
- Extensive use of hard building materials
- Overdependence on air conditioners in buildings
- Patronage of the services of non-qualified architects, especially draftsmen
- Lack strong leadership or clear policy direction to deal with urban planning issues
- Inadequacies in the curriculum of architecture education
- Selling of green spaces in the CBD to developers
- Lack of intersectoral collaboration in the implementation of the city's land use map
- Absence of plans to curb rate of sprawl of the city
- Lack of resources (both human resource and funds) to implement land use plans
- Existing building regulations not adequately addressing issues of urban greenery and sustainable design
- Planners and policy makers not putting premium on urban greenery issues
- Inadequacies in the building code regarding the use of energy efficient materials

The fifth (final) objective sought to consolidate all the previous objectives to develop a holistic strategy that is suitable for mitigating urban heat island in Accra. The fifth objective thus involved the triangulation of mitigation measures that emanated from the quantitative analysis of the UHIIs as well as the qualitative analysis. Through triangulation, a major urban policymaking and development process plan (strategic plan) was proposed.

8.2.12 Research contributions

This research is a pioneering temperature monitoring study that has been carried out in Accra at a large-scale. The research addresses a new context/site which presents a unique set of problems. The study addresses the weakness and research gap which Oke (1984) has attributed to the complexity of urban systems, because of which location specific UHI studies are needed. It thus corroborates the view held by Rizwan et al. (2008b) and Unger et al. (2001) that UHI develops due to the interaction between different human and environmental factors. Determining the main factors that contribute to the development of urban heat island in a specific setting is not very straightforward. This study has thus extended the approach to the inquiry by extensively addressing human causal factors. By exploring a new context, findings from this study add to what is already known about the UHI subject.

8.3 Conclusions

This study has shown that there have been significant changes in the morphology of Accra in the last 3 to 4 decades. The study has also shown (Gyasi-Addo & Amar 2020) that Accra has experienced a change in its local climate, which has resulted in an increase of 1.6 to 3.0℃ in air temperature within the last 30 years. A comparative analysis of results from Addae & Oppelt’s (2019) study on land use changes in Accra and a study of the weather pattern of Accra (Gyasi-Addo & Amar

2020) has given an indication that the morphological changes in the city over the last 3 to 4 decades have adversely affected its climate.

Analysing the data from the mobile survey has revealed that the main factors affecting the intensity of UHI in the CBD of Accra include heat from exhausts of vehicles due to heavy vehicular traffic, the extent of exposure to the sky, the extent of shading by buildings depending on canyon depth, and the amount of green or vegetative cover present.

The study has investigated the urban heat island intensity profile in the CBD of Accra, revealing that there are variations in both daytime and night-time UHIIs in the different LCZs mainly due to the differences in their built-up or land cover types. Due to the significant differences in the canyon geometric and land cover characteristics that existed within each of the monitoring sites (or LCZs), the mobile survey conducted on a warm-dry day revealed these wide UHII variations within the respective sites: Aviation House (1 to 2℃), Airport City (0.5 to 1.5℃), 37 Military Hospital (1 to 2℃), Jubilee House (1 to 2℃), Arko Adjei Interchange (1.5 to 3℃), Ridge Hospital (0.5 to 2.5℃), The Law Courts (1.5 to 3℃), Cedi House (1 to 2℃), and Novotel (1.5 to 2.5℃). The mobile survey indicates that in the CBD of Accra, daily heat stress levels vary within walkable distances in the various LCZs. Arko Adjei Interchange recorded the highest UHII on both days of the mobile survey. Although its mobile traverse route is within a deeper canyon than those of 37 Military Hospital, Ridge Hospital and Aviation House, the presence of heavy vehicular traffic could have increased the air temperature at Arko Adjei.

The effects of meteorological and morphological parameters on the urban heat island intensity profile in the city have been assessed for both cool-wet and warm-dry seasons. The study indicates that evening and night-time UHIIs are generally higher in the warm-dry periods than in the cool-wet periods. Results from the stationary survey showed that during both warm-dry and cool-wet periods, average UHIIs across the city centre are normally higher in the evenings and nights than in the day. It is also seen that during both warm-dry and cool-wet seasons, night-time UHIIs generally drop at dawn (usually between 2.00 am and 3.00 am). The stationary survey also showed that canyon geometry and urban greenery have significant effects on both daytime and night-time UHIIs. Areas within deep canyons (i.e. with high aspect ratios) had lower daytime UHIIs due to shading by tall buildings, whereas areas within shallow canyons had higher UHIIs due to their wider exposure to the sky. The study has also indicated that night-time UHIIs are higher than daytime UHIIs for sites that are within significantly deep canyons, such as Airport City and Ministries. The deep canyons generally have huge and tall buildings which absorb a lot of shortwave solar radiation during the day, and thus tend to accumulate a lot of heat which is released as longwave radiation in the night. The rate of escape of the longwave radiation into the atmosphere is slower in the deep canyons due to their lower exposure to the atmosphere. On the other hand, areas within the shallow canyons or with lower aspect ratios such as Ridge Hospital and Aviation House generally have higher daytime UHIIs and lower night-time UHIIs, since they receive a lot of shortwave solar radiation during the day, and thus easily release it during the night. The study further reveals that at high speeds, wind can reduce the UHII in the city especially during daytime, but the present geometric configuration does not maximize this effect. The study has also indicated that reduced or lack of greenery or tree canopy correlates to higher UHII effect and vice versa. It is seen that daytime UHIIs at areas such as 37 Military Hospital and The Law Courts Complex which have substantive greenery were significantly reduced.

This study has indicated that to effectively mitigate the effects of UHI in the CBD of Accra, these measures are to be implemented: (1) the integration of urban greenery into the planning of new developments in the city, (2) effective regulation and control of the use of artificial materials in the city such as concrete and asphalt, (3) implementation of immediate to long-term measures by planning authorities to improve traffic flow in the city, and thus reduce heat emission from vehicular exhausts, (4) improvement of greenery in the shallow canyons, existing open spaces, parklands, along the roads, and median areas in the roads, (5) exploitation of the prevailing wind with the appropriate geometric configurations in future developments or regeneration schemes to improve air temperature at the pedestrian level, (6) promotion of vertical developments, (7) promotion of green walls and green roofs within the deep canyons to reduce the amount of heat that would be absorbed by tall buildings and flat roofs, and (8) adequate provision of trees at areas with large expanse of hardscapes and the incorporation of water bodies such as fountains and ponds in the landscape to enhance environmental cooling.

Given the peculiarity of the challenges noticed in the context, a qualitative study conducted has identified several human factors that have culminated in the heat build-up in the city. Based on those factors, the study visualises a *holistic strategic plan* that encompasses both suitable UHI mitigation measures and a consolidation of policies that require interventions in the following areas:

- Local authorities (enforcement)
- Planning professionals and decision makers
- Architects and other built environment professionals
- Civic education & sensitization of the public
- Curriculum for trainee architects and planners

8.4 Research limitations

Due to the challenge posed by vehicular traffic during the pilot study, in the main data collection, field assistants were engaged to undertake the mobile traverse measurements by trekking. Though the latter procedure made it possible to simultaneously obtain weather data from all the 8 different monitoring sites, there was a limit to the area each field assistant could cover. During the data collection in the warm-dry season in 2020, some weather sensors were stolen despite the safety measures that were put in place by the researcher and the field assistants, whilst another became defective. It was very difficult for the researcher to travel to Ghana to retake the stationary measurements during the warm dry season in 2020 due to the restrictions the country had imposed on international travels in the wake of the covid-19 pandemic. Furthermore, it was not feasible to send additional sensors to the field assistant to conduct a new survey, since it was obvious that there had been security lapses at the affected monitoring sites. It is also worth indicating that for the stationary measurements, it was not possible to fix a weather sensor at the Jubilee House monitoring area, since it is a security zone. Hourly data for cloud cover in the city could not be produced by the Ghana Meteorological Agency for the two seasons in which the weather data were collected, so they could not be included in the weather parameters that were used for the UHII analysis. The researcher had intended to assess land use/land cover change analysis map of Accra with the historical weather data. Unfortunately, the land use/land cover change analysis map was never made available by the Town & Country Planning outfit of the Accra Metropolitan Assembly.

8.5 Recommendations for further studies

Further studies will require the use of UMT (i.e. urban morphology type) map or details of tree canopy ratios of the city to quantitatively assess the effect of vegetation on UHI. In future studies, land use/land cover change analysis map of Accra will be needed to investigate the correlation between the transformed morphology of the city and the local climate over the last 3 to 4 decades. Findings from both studies would inform major policy decisions as well as planning interventions meant to mitigate the effects of the intense heat in the city.

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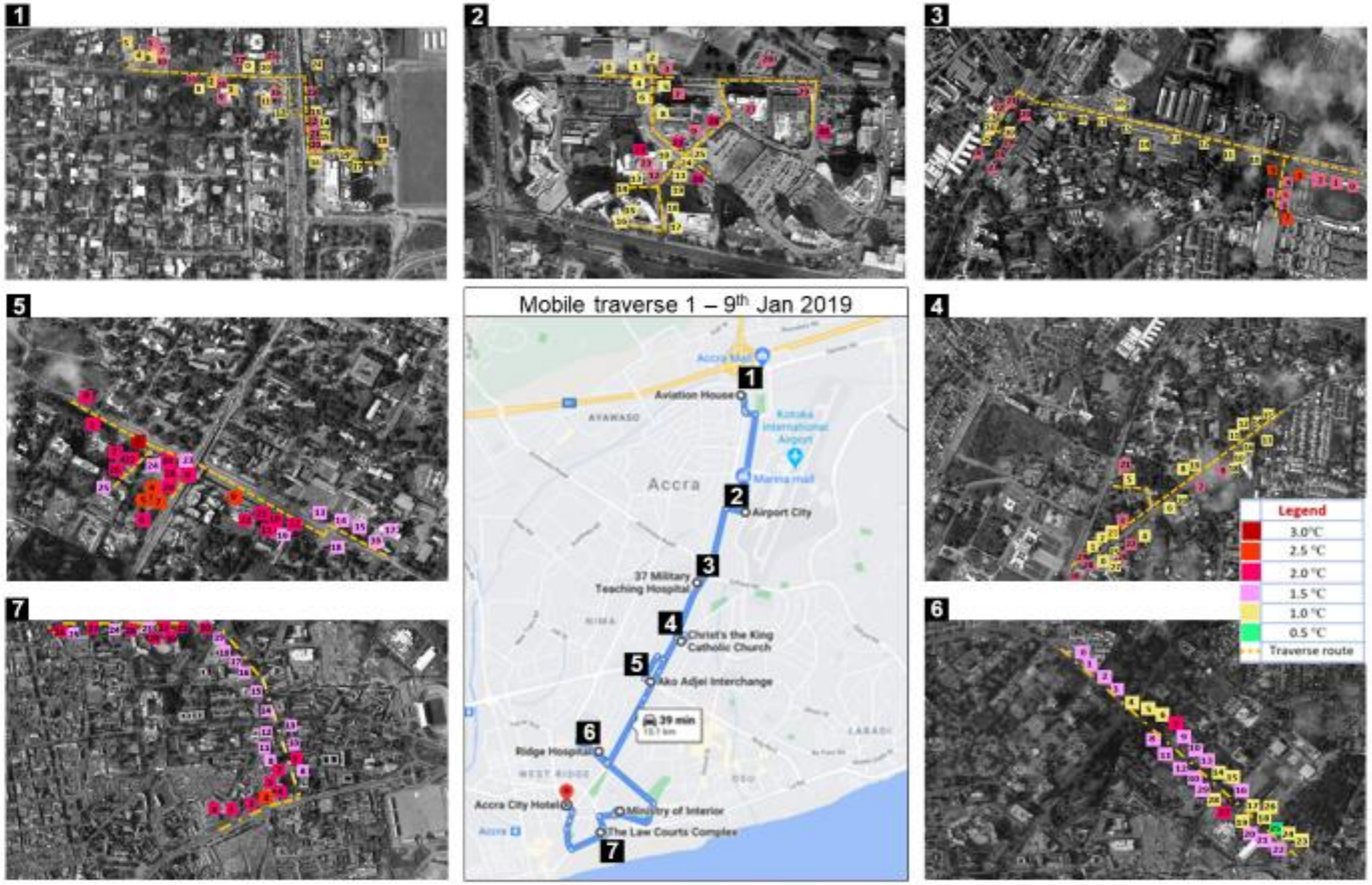
APPENDICES

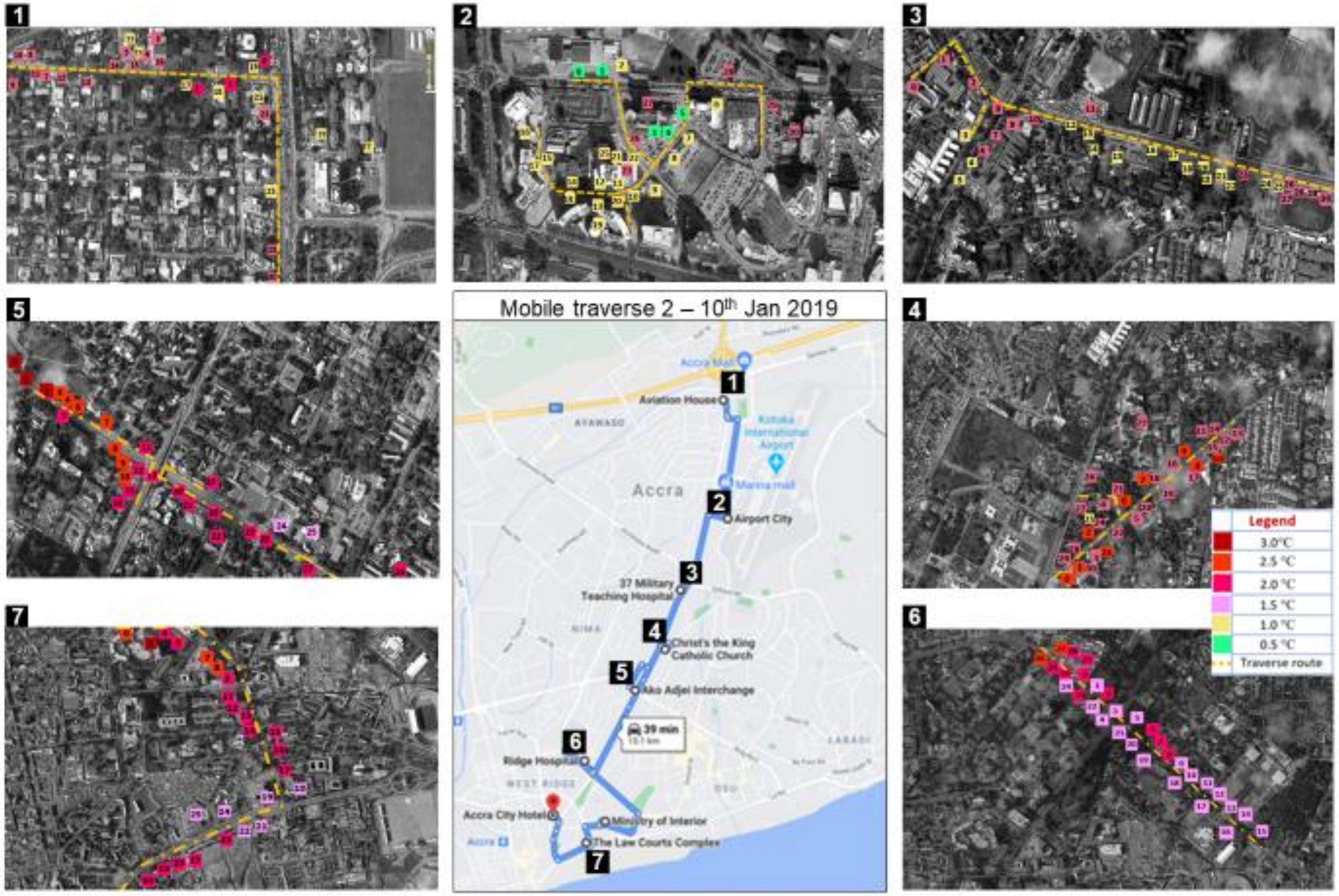
Appendix 1a

Composite UHI maps and their locations for mobile traverse on day 1



Appendix 1b

Composite UHI maps and their locations for mobile traverse on day 2



Appendix 2a

Temperature measurements from mobile traverse on day 1

Mobile Traverse Data from Eight Monitoring Locations in CBD of Accra on 09/01/2019									
Location	Ref-Anyaa	Aviation House	Airport City	37-Lands	Jubilee House	Arko-Agyei	Ridge Hospital	Cedi House	Novotel
Time	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃
15:35	27.5	28.5	28.5	29	28.5	29.5	29	29.5	29.5
15:36	27.5	28.5	28.5	29	28.5	29.5	29	29.5	29.5
15:37	27.5	28.5	28.5	29	28.5	29.5	29	29.5	29.5
15:38	27	28.5	28.5	29	28.5	30	28.5	29.5	29.5
15:39	27.5	28.5	28.5	29	28.5	30	28.5	29.5	29.5
15:40	27.5	28.5	28.5	29	28.5	30	28.5	29.5	29.5
15:41	27.5	28.5	28.5	29	28.5	29.5	28.5	29	29.5
15:42	27	28.5	28.5	29	28.5	29.5	29	29	29.5
15:43	27.5	28.5	28.5	29	28.5	29.5	29	29	29.5
15:44	27	28.5	28.5	29	28.5	29.5	28.5	29	29.5
15:45	27.5	28.5	28.5	28.5	28.5	29.5	29	29	29.5
15:46	27.5	28.5	28.5	28.5	28.5	29.5	29	29	29
15:47	27.5	28.5	29	28.5	28.5	29.5	29	29	29
15:48	27.5	28.5	28.5	28.5	28.5	29	29	29	29
15:49	27.5	28.5	28.5	28.5	28.5	29	28.5	29	29
15:50	27.5	28.5	29	28.5	28.5	29	28.5	29	29
15:51	27.5	28.5	28.5	28.5	28.5	29	29	29	29
15:52	27.5	28.5	28.5	28.5	28.5	29	28.5	29	29
15:53	27.5	28.5	28.5	28.5	28.5	29	28.5	29	29
15:54	27.5	28.5	28.5	28.5	28.5	29	28.5	29	29
15:55	27	28.5	29	28.5	28.5	29	28.5	29	29
15:56	27	28.5	29	28.5	28.5	29	28.5	29	29
15:57	27	28.5	29	28.5	28.5	29	28.5	29	29
15:58	27.5	28.5	29	28.5	28.5	29	28.5	29	29
15:59	27.5	28.5	28.5	28.5	28.5	29	28.5	29	29
16:00	27.5	28.5	28.5	28.5	28.5	29	28	29	29
16:01	27	28.5	29	28.5	28.5	29	28	29	29
16:02	27	28.5	28.5	28.5	28.5	29	29	29	29
16:03	27	28.5	28.5	28.5	28.5	29	28	29	29
16:04	27	28.5	28.5	28.5	28.5	29	28.5	29	29
16:05	27	28.5	29	28.5	28.5	29	28.5	29	29

Appendix 2b

Temperature and relative humidity measurements from mobile traverse on day 1

Ref. location on 09/01/2019				Aviation House on 09/01/2019				Airport City on 09/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:35	27.5	79.5		15:35	28.5	63		15:35	28.5	67
15:36	27.5	80		15:36	28.5	63		15:36	28.5	67
15:37	27.5	80		15:37	28.5	63.5		15:37	28.5	67
15:38	27	80.5		15:38	28.5	63		15:38	28.5	67
15:39	27.5	80		15:39	28.5	63		15:39	28.5	67
15:40	27.5	80		15:40	28.5	63		15:40	28.5	67
15:41	27.5	80.5		15:41	28.5	63.5		15:41	28.5	67.5
15:42	27	80.5		15:42	28.5	63		15:42	28.5	67.5
15:43	27.5	80.5		15:43	28.5	63.5		15:43	28.5	67
15:44	27	80.5		15:44	28.5	63		15:44	28.5	67
15:45	27.5	81		15:45	28.5	63		15:45	28.5	67.5
15:46	27.5	81		15:46	28.5	63		15:46	28.5	67
15:47	27.5	81		15:47	28.5	63		15:47	29	67
15:48	27.5	80.5		15:48	28.5	63		15:48	28.5	67
15:49	27.5	80.5		15:49	28.5	63.5		15:49	28.5	67
15:50	27.5	80		15:50	28.5	63.5		15:50	29	66
15:51	27.5	80.5		15:51	28.5	63.5		15:51	28.5	67
15:52	27.5	80.5		15:52	28.5	63		15:52	28.5	67
15:53	27.5	80.5		15:53	28.5	63		15:53	28.5	67
15:54	27.5	80.5		15:54	28.5	63.5		15:54	28.5	67
15:55	27	80.5		15:55	28.5	63		15:55	29	66.5
15:56	27	80		15:56	28.5	63.5		15:56	29	67
15:57	27	80		15:57	28.5	63		15:57	29	66.5
15:58	27.5	80.5		15:58	28.5	63		15:58	29	66.5
15:59	27.5	81		15:59	28.5	63		15:59	28.5	67
16:00	27.5	81		16:00	28.5	63		16:00	28.5	67
16:01	27	81		16:01	28.5	63		16:01	29	67
16:02	27	80.5		16:02	28.5	63.5		16:02	28.5	67
16:03	27	80.5		16:03	28.5	63		16:03	28.5	67
16:04	27	81		16:04	28.5	63		16:04	28.5	67
16:05	27	81		16:05	28.5	63		16:05	29	66.5

37 M. Hospital on 09/01/2019				Jubilee House on 09/01/2019				Arko Adjei Int. on 09/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:35	29	62		15:35	28.5	62.5		15:35	29.5	67.5
15:36	29	62		15:36	28.5	62.5		15:36	29.5	70
15:37	29	62		15:37	28.5	63		15:37	29.5	71.5
15:38	29	62		15:38	28.5	63		15:38	30	69.5
15:39	29	62		15:39	28.5	63		15:39	30	68.5
15:40	29	62		15:40	28.5	63		15:40	30	68
15:41	29	62		15:41	28.5	63.5		15:41	29.5	67.5
15:42	29	62.5		15:42	28.5	63.5		15:42	29.5	67.5
15:43	29	62.5		15:43	28.5	63.5		15:43	29.5	67.5
15:44	29	62.5		15:44	28.5	62.5		15:44	29.5	67.5
15:45	28.5	62.5		15:45	28.5	62.5		15:45	29.5	67.5
15:46	28.5	62.5		15:46	28.5	63		15:46	29.5	67.5
15:47	28.5	62.5		15:47	28.5	63		15:47	29.5	67.5
15:48	28.5	62.5		15:48	28.5	63		15:48	29	67
15:49	28.5	62.5		15:49	28.5	63		15:49	29	67.5
15:50	28.5	62.5		15:50	28.5	63.5		15:50	29	67.5
15:51	28.5	62.5		15:51	28.5	63.5		15:51	29	67.5
15:52	28.5	62.5		15:52	28.5	63.5		15:52	29	67.5
15:53	28.5	63		15:53	28.5	62.5		15:53	29	67.5
15:54	28.5	63		15:54	28.5	62.5		15:54	29	67.5
15:55	28.5	62.5		15:55	28.5	63		15:55	29	67.5
15:56	28.5	63		15:56	28.5	63		15:56	29	67.5
15:57	28.5	62.5		15:57	28.5	63		15:57	29	67.5
15:58	28.5	63		15:58	28.5	63		15:58	29	69
15:59	28.5	63		15:59	28.5	63.5		15:59	29	69
16:00	28.5	62.5		16:00	28.5	63.5		16:00	29	69
16:01	28.5	62.5		16:01	28.5	63.5		16:01	29	69
16:02	28.5	63		16:02	28.5	63		16:02	29	69
16:03	28.5	63		16:03	28.5	63		16:03	29	68.5
16:04	28.5	62.5		16:04	28.5	63.5		16:04	29	69
16:05	28.5	62.5		16:05	28.5	63.5		16:05	29	69

Ridge Hospital on 09/01/2019				Cedi House on 09/01/2019				Novotel on 09/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:35	29	66.5		15:35	29.5	60		15:35	29.5	66
15:36	29	67		15:36	29.5	60.3		15:36	29.5	66
15:37	29	67.5		15:37	29.5	60.1		15:37	29.5	66
15:38	28.5	67.5		15:38	29.5	60		15:38	29.5	66
15:39	28.5	67.5		15:39	29.5	60		15:39	29.5	66
15:40	28.5	67.5		15:40	29.5	60		15:40	29.5	66
15:41	28.5	67		15:41	29.5	60		15:41	29.5	66
15:42	29	66.5		15:42	29	60		15:42	29.5	66
15:43	29	66.5		15:43	29	60		15:43	29.5	66
15:44	28.5	67		15:44	29	60		15:44	29.5	66
15:45	29	66.5		15:45	29	60		15:45	29.5	66
15:46	29	67		15:46	29	60		15:46	29	66
15:47	29	67		15:47	29	60		15:47	29	66
15:48	29	66.5		15:48	29	60		15:48	29	66
15:49	28.5	67.5		15:49	29	60.1		15:49	29	66
15:50	28.5	67.5		15:50	29	60.5		15:50	29	66
15:51	29	67		15:51	29	60.5		15:51	29	66.5
15:52	28.5	67.5		15:52	29	60.5		15:52	29	66
15:53	28.5	67.5		15:53	29	61		15:53	29	66.5
15:54	28.5	67.5		15:54	29	62		15:54	29	66.5
15:55	28.5	67.5		15:55	29	62		15:55	29	66.5
15:56	28.5	67		15:56	29	62		15:56	29	66.5
15:57	28.5	67.5		15:57	29	62		15:57	29	66.5
15:58	28.5	67.5		15:58	29	62		15:58	29	66.5
15:59	28.5	67.5		15:59	29	62		15:59	29	66.5
16:00	28	67.5		16:00	29	62		16:00	29	66.5
16:01	28	67.5		16:01	29	62		16:01	29	66.5
16:02	29	66.5		16:02	29	61.5		16:02	29	66.5
16:03	28	67.5		16:03	29	61.5		16:03	29	66.5
16:04	28.5	67		16:04	29	62		16:04	29	66.5
16:05	28.5	67		16:05	29	62		16:05	29	66.5

Appendix 3a

Temperature measurements from mobile traverse on day 2

Mobile Traverse Data from Eight Monitoring Locations in CBD of Accra on 10/01/2019									
Location	Ref-Anyaa	Aviation Hse	Airport CP	37-Lands	Jubilee Hse	Arko-Agyei	Ridge Hosp.	Cedi House	Novotel
Time	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃	Temp ℃
15:27	25.5	27.5	26	27	27.5	28.5	27.5	28	27
15:28	25.5	27.5	26	27	27.5	28.5	27	28	27
15:29	25	27	26	26.5	27	28	27	28	27
15:30	25.5	27	26	26.5	27	28	27	27.5	27
15:31	25.5	27	26	26.5	27	27.5	27	27.5	26.5
15:32	25.5	27	26	26.5	27	27.5	27	27.5	26.5
15:33	25	26.5	26	26.5	27	27.5	27	27.5	26.5
15:34	25	26.5	26	26.5	27	27.5	27	27.5	26.5
15:35	25	26.5	26	26.5	27	27.5	27	27.5	26.5
15:36	25	26.5	26	26.5	27	27.5	26.5	27	26.5
15:37	25	26.5	26	26.5	27	27.5	26.5	27	26.5
15:38	25	26.5	26	26.5	26.5	27	26.5	27	26.5
15:39	25	26.5	26	26	26.5	27	26.5	27	26.5
15:40	25	26.5	26	26	26.5	27	26.5	27	26.5
15:41	25	26.5	26	26	26.5	27	26.5	27	26.5
15:42	25	26.5	26	26	26.5	27	26.5	27	26.5
15:43	25	26.5	26	26	26.5	27	26.5	27	26.5
15:44	25	26	26	26	26.5	27	26.5	27	26.5
15:45	25	26	26	26	26.5	27	26.5	26.5	26.5
15:46	25	26	26	26	26.5	27	26.5	26.5	26.5
15:47	25	26	26	26	26.5	27	26.5	26.5	26.5
15:48	25	26	26	26	26.5	27	26.5	26.5	26.5
15:49	25	26	26	26	26.5	27	26.5	26.5	26.5
15:50	24.5	26	26	26	26.5	26.5	26.5	26.5	26.5
15:51	25	26	26	26	26.5	26.5	26.5	26.5	26.5
15:52	25	26	26	26	26	26.5	27	26.5	26.5
15:53	24.5	26	26	26	26	26.5	27	26.5	26
15:54	24.5	26	26	26	26	26.5	27	26.5	26
15:55	24.5	26	26	26	26	26.5	26.5	26.5	26
15:56	24.5	26	26	26	26	26.5	26.5	26.5	26
15:57	24.5	26	26	26	26	26.5	26.5	26.5	26

Appendix 3b

Temperature and relative humidity measurements from mobile traverse on day 2

Ref. location on 10/01/2019				Aviation House on 10/01/2019				Airport City on 10/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:27	25.5	79.5		15:27	27.5	60.5		15:27	26	66
15:28	25.5	80		15:28	27.5	60.5		15:28	26	66.5
15:29	25	80.5		15:29	27	62		15:29	26	67
15:30	25.5	80		15:30	27	62.5		15:30	26	67
15:31	25.5	80		15:31	27	62.5		15:31	26	66.5
15:32	25.5	80		15:32	27	62.5		15:32	26	66.5
15:33	25	80.5		15:33	26.5	62.5		15:33	26	66.5
15:34	25	80.5		15:34	26.5	62.5		15:34	26	66.5
15:35	25	80.5		15:35	26.5	62		15:35	26	66.5
15:36	25	80.5		15:36	26.5	62		15:36	26	66.5
15:37	25	80.5		15:37	26.5	62.5		15:37	26	66.5
15:38	25	80.5		15:38	26.5	63		15:38	26	65
15:39	25	80.5		15:39	26.5	63		15:39	26	66.5
15:40	25	81		15:40	26.5	63		15:40	26	66.5
15:41	25	80.5		15:41	26.5	62.5		15:41	26	66
15:42	25	81		15:42	26.5	62.5		15:42	26	66
15:43	25	81		15:43	26.5	62.5		15:43	26	66
15:44	25	81		15:44	26	62.5		15:44	26	66
15:45	25	81		15:45	26	63		15:45	26	66
15:46	25	80.5		15:46	26	63		15:46	26	66
15:47	25	80.5		15:47	26	63		15:47	26	66
15:48	25	80.5		15:48	26	63		15:48	26	66
15:49	25	81		15:49	26	62.5		15:49	26	66
15:50	24.5	80.5		15:50	26	62.5		15:50	26	66
15:51	25	80.5		15:51	26	63		15:51	26	66
15:52	25	80.5		15:52	26	63		15:52	26	66
15:53	24.5	81		15:53	26	62.5		15:53	26	66.5
15:54	24.5	81		15:54	26	62		15:54	26	66.5
15:55	24.5	81		15:55	26	63		15:55	26	66.5
15:56	24.5	81		15:56	26	62.5		15:56	26	66.5
15:57	24.5	81		15:57	26	62		15:57	26	66.5

37 M. Hospital on 10/01/2019				Jubilee House on 10/01/2019				Arko Adjei on 10/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:27	27	61		15:27	27.5	60.5		15:27	28.5	65
15:28	27	61		15:28	27.5	61		15:28	28.5	65
15:29	26.5	61.5		15:29	27	62		15:29	28	65
15:30	26.5	61.5		15:30	27	62		15:30	28	65
15:31	26.5	62		15:31	27	63		15:31	27.5	65.5
15:32	26.5	62		15:32	27	63		15:32	27.5	65.5
15:33	26.5	62		15:33	27	63		15:33	27.5	65.5
15:34	26.5	62		15:34	27	63		15:34	27.5	66
15:35	26.5	62		15:35	27	62.5		15:35	27.5	66
15:36	26.5	62		15:36	27	62.5		15:36	27.5	66
15:37	26.5	62		15:37	27	62.5		15:37	27.5	66
15:38	26.5	62.5		15:38	26.5	62.5		15:38	27	66
15:39	26	62.5		15:39	26.5	62.5		15:39	27	66
15:40	26	62.5		15:40	26.5	62.5		15:40	27	66.5
15:41	26	62		15:41	26.5	62.5		15:41	27	66
15:42	26	62.5		15:42	26.5	62.5		15:42	27	66.5
15:43	26	62.5		15:43	26.5	62.5		15:43	27	66.5
15:44	26	62.5		15:44	26.5	62.5		15:44	27	66.5
15:45	26	62		15:45	26.5	62.5		15:45	27	66.5
15:46	26	62.5		15:46	26.5	62.5		15:46	27	66.5
15:47	26	62.5		15:47	26.5	62.5		15:47	27	66.5
15:48	26	62.5		15:48	26.5	62.5		15:48	27	66.5
15:49	26	62.5		15:49	26.5	62.5		15:49	27	66.5
15:50	26	62.5		15:50	26.5	62.5		15:50	26.5	66.5
15:51	26	62		15:51	26.5	62.5		15:51	26.5	66.5
15:52	26	62		15:52	26	62.5		15:52	26.5	67
15:53	26	62		15:53	26	62.5		15:53	26.5	66.5
15:54	26	64		15:54	26	62		15:54	26.5	67
15:55	26	64		15:55	26	61.5		15:55	26.5	67
15:56	26	64.5		15:56	26	62		15:56	26.5	67
15:57	26	64.5		15:57	26	62		15:57	26.5	67

Ridge Hospital on 10/01/2019				Cedi House on 10/01/2019				Novotel on 10/01/2019		
Time	Temp	RH		Time	Temp	RH		Time	Temp	RH
15:27	27.5	65		15:27	28	59		15:27	27	65
15:28	27	66		15:28	28	59		15:28	27	66
15:29	27	66		15:29	28	60		15:29	27	66
15:30	27	66		15:30	27.5	60.5		15:30	27	66
15:31	27	67		15:31	27.5	60.5		15:31	26.5	66
15:32	27	67		15:32	27.5	61		15:32	26.5	66
15:33	27	67		15:33	27.5	61		15:33	26.5	66.5
15:34	27	67		15:34	27.5	61		15:34	26.5	66.5
15:35	27	67		15:35	27.5	61		15:35	26.5	66.5
15:36	26.5	67		15:36	27	61		15:36	26.5	66.5
15:37	26.5	67		15:37	27	61.5		15:37	26.5	66.5
15:38	26.5	67.5		15:38	27	61.5		15:38	26.5	66.5
15:39	26.5	67.5		15:39	27	61.5		15:39	26.5	66.5
15:40	26.5	67.5		15:40	27	61.5		15:40	26.5	67
15:41	26.5	67.5		15:41	27	61.5		15:41	26.5	67
15:42	26.5	67.5		15:42	27	61.5		15:42	26.5	67
15:43	26.5	67.5		15:43	27	62		15:43	26.5	67
15:44	26.5	67.5		15:44	27	62		15:44	26.5	67
15:45	26.5	67.5		15:45	26.5	62		15:45	26.5	67
15:46	26.5	67.5		15:46	26.5	62		15:46	26.5	67
15:47	26.5	67.5		15:47	26.5	62		15:47	26.5	67
15:48	26.5	67.5		15:48	26.5	62		15:48	26.5	67
15:49	26.5	67.5		15:49	26.5	62		15:49	26.5	67
15:50	26.5	67.5		15:50	26.5	62		15:50	26.5	67
15:51	26.5	67.5		15:51	26.5	62		15:51	26.5	67
15:52	27	67		15:52	26.5	62		15:52	26.5	67
15:53	27	67		15:53	26.5	62		15:53	26	67.5
15:54	27	67		15:54	26.5	62.5		15:54	26	67
15:55	26.5	67.5		15:55	26.5	62.5		15:55	26	67
15:56	26.5	67.5		15:56	26.5	62.5		15:56	26	67
15:57	26.5	67.5		15:57	26.5	62		15:57	26	67

Appendix 4a

Temperature measurements from stationary survey in cool-wet period

A 48-hour air temperature profile over CBD of Accra in a cool-wet season (stationary measurements)								
Time	Aviation House	Airport City	37 Hospital	Arko Adjei	Ridge Hosp.	Ministries	The Law Courts Comp.	Ave
23:37	24.5	26	25	25	24.5	25	24.5	24.93
00:37	24.5	26	25	25	24.5	25	24.5	24.86
01:37	24.5	26	25	25	24.5	24.5	24.5	24.86
02:37	24.5	25.5	25	25	24.5	24.5	24.5	24.71
03:37	24.5	25.5	24.5	25	24	24.5	24.5	24.64
04:37	24.5	25.5	24.5	25	24	24.5	24.5	24.64
05:37	24	25.5	24.5	25	24	24.5	24.5	24.57
06:37	24.5	25.5	25	25	24.5	24.5	24.5	24.79
07:37	26	25.5	26	25.5	27.5	25.5	26	26
08:37	26.5	26	27	25.5	27.5	26.5	27	26.57
09:37	26.5	26	26.5	26	26.5	26	26	26.21
10:37	27	26	27	25.5	26.5	26	26	26.29
11:37	27.5	26.5	27.5	26	28.5	27	26.5	27.07
12:37	28.5	26.5	28	26.5	29.5	28	27	27.71
13:37	28.5	27	28	27	29	28	27	27.79
14:37	28.5	27.5	29	27	28.5	27.5	26.5	27.79
15:37	27.5	26.5	27.5	26.5	27.5	27	26	26.93
16:37	26.5	26.5	27	26	27	26.5	25.5	26.43
17:37	25.5	26	26	25.5	25.5	26	25	25.64
18:37	25	26	25.5	25.5	25	25.5	24.5	25.29
19:37	25	26	25.5	25	25	25	24.5	25.14
20:37	25	26	25	25	24.5	25	24	24.93
21:37	25	26	25	25	24.5	25	24.5	25
22:37	25	25.5	25	25	24.5	25	24.5	24.93
23:37	24.5	25.5	25	25	24.5	25	24.5	24.86
00:37	24.5	25.5	24.5	25	24.5	25	24	24.71
01:37	24.5	25.5	24.5	25	24.5	25	24.5	24.79
02:37	24.5	25.5	24.5	25	24.5	24.5	24.5	24.71
03:37	24.5	25.5	24.5	25	24.5	24.5	24.5	24.71
04:37	24	25.5	24.5	24.5	24	24.5	24	24.43
05:37	24.5	25.5	24.5	24.5	24	24.5	24	24.5
06:37	25	25	24.5	25	25	25	24.5	24.86
07:37	25.5	25.5	25.5	25.5	28	25.5	25.5	25.86
08:37	26	26	27.5	26	28.5	27	27	26.86
09:37	27.5	27	28.5	26	28.5	27.5	27	27.43
10:37	28	26.5	28.5	27	30	28.5	27.5	28
11:37	28	27	29	27.5	31	29	27.5	28.43
12:37	29.5	27.5	28.5	27	31	28.5	27.5	28.5
13:37	29.5	27	27.5	27	29.5	29	28	28.21
14:37	29	27.5	27.5	27	30.5	28.5	27	28.14
15:37	28.5	27.5	27	27	29.5	28	27	27.79
16:37	27.5	27	26.5	26.5	28	27.5	26.5	27.07
17:37	26	27	26	26	26.5	27	25.5	26.29
18:37	25	26.5	25.5	25.5	25	25.5	25	25.43
19:37	24.5	26.5	25	25.5	25	25	24.5	25.14
20:37	24.5	26	25	25	24.5	25	24.5	24.93
21:37	24.5	26	25	25.5	24.5	25	24.5	25
22:37	24	26	24.5	25	24	25	24.5	24.71
23:37	24	25.5	24.5	25	24	24.5	24.5	24.57
00:37	24	25.5	24.5	25	24.5	24.5	24.5	24.64

Appendix 4b

Temperature and relative humidity measurements from stationary survey in cool-wet period

Ref. location on 30th-31st July 2020				Aviation House on 30th-31st July 2020				Airport City on 30th-31st July 2020		
Time	Temp	RH		Time	Temp℃	RH%		Time	Temp℃	RH%
23:37	24	88		23:37	24.5	87.5		23:37	26	80.5
00:37	24	89.5		00:37	24.5	88		00:37	26	81
01:37	24	90		01:37	24.5	88.5		01:37	26	81.5
02:37	24	90.5		02:37	24.5	89		02:37	25.5	82.5
03:37	24	90.5		03:37	24.5	89.5		03:37	25.5	83.5
04:37	23.5	91.5		04:37	24.5	89		04:37	25.5	83
05:37	23.5	91.5		05:37	24	89.5		05:37	25.5	83
06:37	24	90.5		06:37	24.5	89.5		06:37	25.5	83.5
07:37	27	82.5		07:37	26	84		07:37	25.5	82.5
08:37	29	71		08:37	26.5	81		08:37	26	80
09:37	26.5	77.5		09:37	26.5	80.5		09:37	26	78.5
10:37	27	78.5		10:37	27	78.5		10:37	26	78
11:37	27	76		11:37	27.5	77		11:37	26.5	77
12:37	30.5	67		12:37	28.5	74.5		12:37	26.5	76.5
13:37	31	68		13:37	28.5	75		13:37	27	75
14:37	29	69.5		14:37	28.5	73.5		14:37	27.5	74
15:37	28.5	73		15:37	27.5	77		15:37	26.5	76.5
16:37	27.5	77.5		16:37	26.5	80.5		16:37	26.5	78.5
17:37	26	82.5		17:37	25.5	84		17:37	26	80.5
18:37	25.5	86		18:37	25	87		18:37	26	81.5
19:37	25	87.5		19:37	25	88		19:37	26	83
20:37	25	87.5		20:37	25	88		20:37	26	82.5
21:37	25	88		21:37	25	89		21:37	26	83.5
22:37	24.5	89		22:37	25	89.5		22:37	25.5	84
23:37	24.5	89		23:37	24.5	89		23:37	25.5	84
00:37	24.5	90		00:37	24.5	90.5		00:37	25.5	84.5
01:37	24.5	90.5		01:37	24.5	90.5		01:37	25.5	85
02:37	24	92		02:37	24.5	90.5		02:37	25.5	85.5
03:37	24	92.5		03:37	24.5	90.5		03:37	25.5	86
04:37	23.5	93		04:37	24	91.5		04:37	25.5	86
05:37	23.5	93		05:37	24.5	91.5		05:37	25.5	86
06:37	24	92.5		06:37	25	90.5		06:37	25	86.5
07:37	28	83		07:37	25.5	88		07:37	25.5	86.5
08:37	27.5	80		08:37	26	84.5		08:37	26	82
09:37	28	76.5		09:37	27.5	81.5		09:37	27	79.5
10:37	29	71		10:37	28	78.5		10:37	26.5	79
11:37	29	72		11:37	28	75.5		11:37	27	76
12:37	29.5	70.5		12:37	29.5	71.5		12:37	27.5	74
13:37	29.5	70		13:37	29.5	73		13:37	27	76
14:37	28.5	71		14:37	29	73.5		14:37	27.5	72.5
15:37	28.5	71		15:37	28.5	74.5		15:37	27.5	74
16:37	27	74.5		16:37	27.5	77.5		16:37	27	75
17:37	26	79.5		17:37	26	81.5		17:37	27	76.5
18:37	25	85		18:37	25	85.5		18:37	26.5	78.5
19:37	24.5	87		19:37	24.5	87.5		19:37	26.5	79.5
20:37	24	88.5		20:37	24.5	89		20:37	26	82.5
21:37	24	89		21:37	24.5	88.5		21:37	26	81.5
22:37	24	89.5		22:37	24	89		22:37	26	81
23:37	24	90		23:37	24	89.5		23:37	25.5	82
00:37	23.5	91		00:37	24	89.5		00:37	25.5	83

37 M. Hospital on 30th-31st July 2020				Arko Adjei Int. on 30th-31st July 2020				Ridge Hosp. on 30th-31st July 2020		
Time	Temp℃	RH%		Time	Temp℃	RH%		Time	Temp℃	RH%
23:37	25	82.5		23:37	25	86		23:37	24.5	86.5
00:37	25	83.5		00:37	25	86.5		00:37	24.5	87
01:37	25	83		01:37	25	87		01:37	24.5	87
02:37	25	84		02:37	25	87.5		02:37	24.5	88
03:37	24.5	84.5		03:37	25	88		03:37	24	88
04:37	24.5	84		04:37	25	87.5		04:37	24	88.5
05:37	24.5	84		05:37	25	87.5		05:37	24	88
06:37	25	83.5		06:37	25	87.5		06:37	24.5	87
07:37	26	80.5		07:37	25.5	86		07:37	27.5	79
08:37	27	75.5		08:37	25.5	83.5		08:37	27.5	77
09:37	26.5	74.5		09:37	26	82		09:37	26.5	78
10:37	27	75.5		10:37	25.5	83.5		10:37	26.5	79
11:37	27.5	72.5		11:37	26	82.5		11:37	28.5	74.5
12:37	28	72		12:37	26.5	80.5		12:37	29.5	70.5
13:37	28	71.5		13:37	27	80		13:37	29	71.5
14:37	29	69		14:37	27	79.5		14:37	28.5	73
15:37	27.5	73		15:37	26.5	82		15:37	27.5	76
16:37	27	75.5		16:37	26	83		16:37	27	78.5
17:37	26	78.5		17:37	25.5	85		17:37	25.5	83.5
18:37	25.5	82		18:37	25.5	87		18:37	25	86
19:37	25.5	83		19:37	25	88		19:37	25	86.5
20:37	25	83.5		20:37	25	88.5		20:37	24.5	87
21:37	25	84		21:37	25	88		21:37	24.5	87.5
22:37	25	84.5		22:37	25	88.5		22:37	24.5	87.5
23:37	25	85		23:37	25	89		23:37	24.5	88
00:37	24.5	86.5		00:37	25	89.5		00:37	24.5	88.5
01:37	24.5	86.5		01:37	25	89.5		01:37	24.5	89
02:37	24.5	87		02:37	25	90		02:37	24.5	89
03:37	24.5	87		03:37	25	90.5		03:37	24.5	89
04:37	24.5	87.5		04:37	24.5	90.5		04:37	24	90
05:37	24.5	87.5		05:37	24.5	90.5		05:37	24	89.5
06:37	24.5	87		06:37	25	89.5		06:37	25	88
07:37	25.5	84.5		07:37	25.5	88		07:37	28	78
08:37	27.5	76.5		08:37	26	86.5		08:37	28.5	76
09:37	28.5	72		09:37	26	85		09:37	28.5	75
10:37	28.5	70.5		10:37	27	83.5		10:37	30	70.5
11:37	29	69		11:37	27.5	81		11:37	31	68.5
12:37	28.5	69.5		12:37	27	80		12:37	31	65.5
13:37	27.5	73		13:37	27	81		13:37	29.5	71
14:37	27.5	72.5		14:37	27	79.5		14:37	30.5	67.5
15:37	27	73.5		15:37	27	79.5		15:37	29.5	70.5
16:37	26.5	76		16:37	26.5	80.5		16:37	28	73.5
17:37	26	78		17:37	26	82.5		17:37	26.5	78.5
18:37	25.5	81		18:37	25.5	86		18:37	25	83.5
19:37	25	82.5		19:37	25.5	86		19:37	25	85
20:37	25	83		20:37	25	87.5		20:37	24.5	86.5
21:37	25	83.5		21:37	25.5	86		21:37	24.5	87
22:37	24.5	83.5		22:37	25	87		22:37	24	87
23:37	24.5	84.5		23:37	25	87		23:37	24	88.5
00:37	24.5	85.5		00:37	25	87.5		00:37	24.5	88

Ministries on 30th-31st July 2020				The Law Courts on 30th-31st July 2020		
Time	Temp℃	RH%		Time	Temp℃	RH%
23:37	25	85.5		23:37	24.5	88.5
00:37	25	86		00:37	24.5	88.5
01:37	24.5	87		01:37	24.5	89
02:37	24.5	87.5		02:37	24.5	89.5
03:37	24.5	87.5		03:37	24.5	90
04:37	24.5	88		04:37	24.5	90
05:37	24.5	88		05:37	24.5	89.5
06:37	24.5	88		06:37	24.5	89
07:37	25.5	84.5		07:37	26	84
08:37	26.5	81.5		08:37	27	80.5
09:37	26	82		09:37	26	82
10:37	26	82.5		10:37	26	83.5
11:37	27	79.5		11:37	26.5	80.5
12:37	28	77		12:37	27	79
13:37	28	78		13:37	27	81.5
14:37	27.5	79		14:37	26.5	82
15:37	27	81.5		15:37	26	85.5
16:37	26.5	82.5		16:37	25.5	87
17:37	26	83.5		17:37	25	87.5
18:37	25.5	85.5		18:37	24.5	90.5
19:37	25	87		19:37	24.5	91.5
20:37	25	87		20:37	24	91.5
21:37	25	87.5		21:37	24.5	91.5
22:37	25	87.5		22:37	24.5	91
23:37	25	87.5		23:37	24.5	91.5
00:37	25	88		00:37	24	92
01:37	25	88		01:37	24.5	92
02:37	24.5	88.5		02:37	24.5	92.5
03:37	24.5	89		03:37	24.5	92.5
04:37	24.5	89		04:37	24	92.5
05:37	24.5	89.5		05:37	24	93
06:37	25	89.5		06:37	24.5	92
07:37	25.5	86.5		07:37	25.5	89
08:37	27	82.5		08:37	27	83
09:37	27.5	80.5		09:37	27	82
10:37	28.5	78		10:37	27.5	81
11:37	29	74.5		11:37	27.5	80.5
12:37	28.5	73.5		12:37	27.5	79
13:37	29	75		13:37	28	80
14:37	28.5	76		14:37	27	81
15:37	28	77		15:37	27	82
16:37	27.5	77.5		16:37	26.5	83.5
17:37	27	79		17:37	25.5	85.5
18:37	25.5	84		18:37	25	88
19:37	25	86		19:37	24.5	89.5
20:37	25	87		20:37	24.5	90
21:37	25	87.5		21:37	24.5	90
22:37	25	87.5		22:37	24.5	90
23:37	24.5	88		23:37	24.5	90
00:37	24.5	88		00:37	24.5	90

Appendix 5a

Temperature measurements from stationary survey in warm-dry period

A 48-hour temp. profile over 4 sites in the CBD of Accra in a warm-dry season					
Time	Ref	Aviation	Airport	37 M. Hosp	Ministries
23:32	25	27	28.5	27.5	27
00:32	24.5	26.5	28.5	27	27
01:32	24.5	26.5	28.5	27.5	27
02:32	24.5	26	28	27	26.5
03:32	24	25.5	27.5	26.5	26.5
04:32	23.5	25.5	27.5	26.5	26
05:32	24	25	27	26	26
06:32	28.5	27.5	27	27	26
07:32	36.5	31.5	28	29.5	27.5
08:32	36	34	28.5	31	30.5
09:32	36.5	33.5	30	32	31
10:32	36	33	30.5	33.5	31
11:32	35	33.5	31.5	33.5	31.5
12:32	34.5	33.5	31.5	32.5	32
13:32	32.5	32.5	32.5	31.5	32
14:32	31.5	33.5	31.5	31	32
15:32	30.5	33.5	31	30.5	31.5
16:32	29.5	32.5	30	30	30
17:32	27.5	28.5	29.5	28.5	28.5
18:32	26.5	28	29.5	28.5	28
19:32	26	27.5	29	28	28
20:32	26	27.5	29	28	27.5
21:32	25.5	27.5	29	28	27.5
22:32	26	27	28.5	28	27.5
23:32	25	27	28.5	27.5	27.5
00:32	25	27	28.5	27.5	27
01:32	25	26.5	28.5	27	27
02:32	24.5	26.5	28	27	26.5
03:32	24	25.5	28	26.5	26.5
04:32	24	25.5	27.5	26.5	26
05:32	23.5	25	27	26.5	26
06:32	27.5	27.5	27	27	26
07:32	31	31	28	29	27
08:32	35.5	33	28.5	30.5	28.5
09:32	33.5	32.5	29	31.5	30.5
10:32	37.5	32	30	32	31
11:32	33	33.5	30	33.5	31
12:32	34	33	31	32	32.5
13:32	32	32.5	31.5	32	32.5
14:32	31.5	33	31	31	32.5
15:32	30	33	30	30.5	31
16:32	29	31.5	29.5	29.5	30
17:32	27.5	28	29.5	29.5	28.5
18:32	26.5	28	28.5	28	28
19:32	26.5	27.5	29	28	28
20:32	26.5	27.5	28.5	28	27.5
21:32	26	27.5	28.5	28.5	27.5
22:32	25.5	27.5	28.5	28	27.5
23:32	26	27	28.5	28	27.5
00:32	26	27	28	28	27.5

Appendix 5b

Temperature and relative humidity measurements from stationary survey in cool-wet period

Ref. location on 22nd-24th Oct. 2020				Aviation Hse on 22nd-24th Oct. 2020				Airport City on 22nd-24th Oct. 2020		
Time	RH	Temp		Time	RH	Temp		Time	RH	Temp
23:32	92	25		23:32	88	27		23:32	79.5	28.5
00:32	93.5	24.5		00:32	89.5	26.5		00:32	80.5	28.5
01:32	92.5	24.5		01:32	90	26.5		01:32	81	28.5
02:32	94	24.5		02:32	90.5	26		02:32	81.5	28
03:32	94.5	24		03:32	92	25.5		03:32	82	27.5
04:32	95.5	23.5		04:32	93	25.5		04:32	83	27.5
05:32	95.5	24		05:32	93	25		05:32	84.5	27
06:32	85	28.5		06:32	86.5	27.5		06:32	84	27
07:32	61	36.5		07:32	73	31.5		07:32	80.5	28
08:32	59.5	36		08:32	65	34		08:32	77.5	28.5
09:32	58.5	36.5		09:32	66	33.5		09:32	71.5	30
10:32	54.5	36		10:32	64	33		10:32	68	30.5
11:32	59	35		11:32	64.5	33.5		11:32	66.5	31.5
12:32	59	34.5		12:32	64	33.5		12:32	66	31.5
13:32	64	32.5		13:32	67.5	32.5		13:32	66.5	32.5
14:32	68	31.5		14:32	65.5	33.5		14:32	68	31.5
15:32	70	30.5		15:32	67	33.5		15:32	71	31
16:32	76	29.5		16:32	69	32.5		16:32	72	30
17:32	83	27.5		17:32	80	28.5		17:32	76	29.5
18:32	87	26.5		18:32	83	28		18:32	76	29.5
19:32	88.5	26		19:32	84.5	27.5		19:32	77	29
20:32	89	26		20:32	85	27.5		20:32	77.5	29
21:32	90.5	25.5		21:32	86.5	27.5		21:32	78	29
22:32	90.5	26		22:32	87	27		22:32	79	28.5
23:32	92	25		23:32	87	27		23:32	78.5	28.5
00:32	92.5	25		00:32	88	27		00:32	80.5	28.5
01:32	93	25		01:32	89.5	26.5		01:32	80	28.5
02:32	93.5	24.5		02:32	89	26.5		02:32	81	28
03:32	94.5	24		03:32	91	25.5		03:32	81.5	28
04:32	95	24		04:32	92	25.5		04:32	82.5	27.5
05:32	95.5	23.5		05:32	93	25		05:32	84	27
06:32	87.5	27.5		06:32	87.5	27.5		06:32	84	27
07:32	74	31		07:32	74.5	31		07:32	80	28
08:32	61.5	35.5		08:32	67.5	33		08:32	76	28.5
09:32	65.5	33.5		09:32	67	32.5		09:32	74.5	29
10:32	54.5	37.5		10:32	69	32		10:32	72	30
11:32	65	33		11:32	65.5	33.5		11:32	71.5	30
12:32	63	34		12:32	65.5	33		12:32	68.5	31
13:32	69.5	32		13:32	68.5	32.5		13:32	69	31.5
14:32	69	31.5		14:32	67.5	33		14:32	70	31
15:32	74.5	30		15:32	68.5	33		15:32	72.5	30
16:32	76.5	29		16:32	72.5	31.5		16:32	74.5	29.5
17:32	83.5	27.5		17:32	81.5	28		17:32	76.5	29.5
18:32	86.5	26.5		18:32	83.5	28		18:32	78.5	28.5
19:32	87.5	26.5		19:32	84.5	27.5		19:32	78	29
20:32	87.5	26.5		20:32	84.5	27.5		20:32	79	28.5
21:32	89	26		21:32	86	27.5		21:32	79.5	28.5
22:32	90	25.5		22:32	85.5	27.5		22:32	79	28.5
23:32	90	26		23:32	85.5	27		23:32	78.5	28.5
00:32	90.5	26		00:32	86.5	27		00:32	80	28

37 M. Hospital on 22nd-24th Oct. 2020				**Ministries on 22nd-24th Oct. 2020**		
Time	RH	Temp		Time	RH	Temp
23:32	81	27.5		23:32	85	27
00:32	82.5	27		00:32	85.5	27
01:32	82	27.5		01:32	86	27
02:32	83	27		02:32	87	26.5
03:32	84	26.5		03:32	87.5	26.5
04:32	84	26.5		04:32	88.5	26
05:32	85	26		05:32	89	26
06:32	83	27		06:32	88	26
07:32	74.5	29.5		07:32	84.5	27.5
08:32	68.5	31		08:32	75.5	30.5
09:32	64	32		09:32	72.5	31
10:32	58.5	33.5		10:32	70	31
11:32	59	33.5		11:32	72	31.5
12:32	62.5	32.5		12:32	71.5	32
13:32	65	31.5		13:32	71	32
14:32	66.5	31		14:32	71.5	32
15:32	70.5	30.5		15:32	71	31.5
16:32	72	30		16:32	76	30
17:32	76	28.5		17:32	80	28.5
18:32	77	28.5		18:32	81	28
19:32	78.5	28		19:32	82.5	28
20:32	79	28		20:32	83	27.5
21:32	79	28		21:32	84	27.5
22:32	79.5	28		22:32	84.5	27.5
23:32	80	27.5		23:32	84.5	27.5
00:32	81.5	27.5		00:32	85.5	27
01:32	81	27		01:32	85	27
02:32	81.5	27		02:32	86.5	26.5
03:32	83	26.5		03:32	87	26.5
04:32	83.5	26.5		04:32	88	26
05:32	84	26.5		05:32	88.5	26
06:32	82	27		06:32	88.5	26
07:32	73.5	29		07:32	84.5	27
08:32	68.5	30.5		08:32	80	28.5
09:32	67	31.5		09:32	73	30.5
10:32	65	32		10:32	73.5	31
11:32	61	33.5		11:32	73.5	31
12:32	63	32		12:32	71	32.5
13:32	65.5	32		13:32	71.5	32.5
14:32	70	31		14:32	70.5	32.5
15:32	70.5	30.5		15:32	72.5	31
16:32	74	29.5		16:32	76.5	30
17:32	76.5	29.5		17:32	81	28.5
18:32	79	28		18:32	81.5	28
19:32	78.5	28		19:32	82	28
20:32	77.5	28		20:32	83	27.5
21:32	78	28.5		21:32	84	27.5
22:32	78.5	28		22:32	84.5	27.5
23:32	79	28		23:32	84.5	27.5
00:32	79.5	28		00:32	84	27.5

Appendix 6

Semi-structured interview schedule

"Evaluation of the effect of urbanization on urban thermal behaviour using Urban Heat Island indicators – The case of Accra"

Introduction

- A brief introduction to the research topic and its aim by the researcher
    - The research aim is: To quantify the urban heat island (UHI) intensity in Accra with the view to developing appropriate mitigation and planning strategies to cushion the adverse effects of the urban heat.
    - Discussion of The Urban Heat Island Phenomenon; its impacts and the need for this investigation in Accra
- Participant's specific information such as area of expertise and knowledge in UHI

Please be informed that all information collected from you for the purpose of this study will be kept strictly confidential until a release waiver is signed by you. Furthermore, no publication or reports will be produced to identify information on you without your signed consent, and after your review of the materials used.

Opening question

- What factors have contributed to the rapid urban growth of Accra over the last few decades?

- Do you think the planning of Accra, and the CBD has adequately responded to the rate of its growth? Please give reason(s) for your answer.

Factors contributing to the excessive heat build-up in the CBD of Accra

- In your opinion, what factors have contributed to the excessive heat build-up or the presence of heatwaves in the CBD of Accra?
- Please explain how each of the factors mentioned affects the city's climate.
- In your opinion, to what extent have green spaces in the city changed? What do you think have brought about those changes?

Transformation of the morphology of Accra

- What significant morphological transformation has occurred in Accra in the last couple of decades?
- Are you satisfied with the trend of urban transformation Accra has been experiencing? Please give reason(s) for your answer.
- Mention the challenges you can identify with the land use or physical planning of Accra.
- Are you satisfied with the land use planning of Accra, especially the CBD? Please give reason(s) for your answer.

Existing Building Regulation & development control regime

- Are urban green spaces covered under the building regulation of Accra? If yes, what are the requirements?

- Does the existing building regulation make provision for sustainable design? If yes, what are the provisions for: 1) Urban Planning and Urban Greenery 2) Building design and Building Energy Performance?
- What deficiencies can you identify in the current building regulation in terms of sustainable design?
- How effective is the implementation and enforcement of the existing building regulation in Accra?
- What are the main challenges confronting the effective implementation of the building regulation?

Recommendations

- In your opinion as an expert, what can be done to improve: the land use map of Accra; the existing building regulation and the enforcement or development control regime
- What other measures do you think could be put in place to mitigate the UHI in Accra?

THANK YOU

Appendix 7

RGU Research ethics and guidelines

Ethical conduct depends on:

1. Consideration of the impact of the research, including

- The potential implications of research for subjects and participants
- The potential implications of research for non-participants, and
- The uses to which research can be put

2. Guidance covering the treatment of participants, including

- informed consent
- confidentiality and anonymity (see section 3.3 below), and
- special consideration of vulnerable respondents

3. Academic considerations. Researchers are enjoined to

- Maintain research of high quality
- Display competence
- Act responsibly towards others in their field, and
- Advance their discipline

4. Guidance concerning research relationships. These include

- The responsibilities of the researcher to the body commissioning the research,
- Responsibilities to the university,
- Commitments to fellow researchers, and
- Integrity in dealing with subjects, participants, and stakeholders.

Appendix 8

Request for participation in interview

My name is James Adjei Gyasi-Addo, a research student undertaking a PhD by research with The Robert Gordon University, Aberdeen, United Kingdom. I am undertaking a research on "Evaluation of the effect of urbanization on urban thermal behaviour using Urban Heat Island indicators – The case of Accra". The purpose of this study is to quantify the urban heat island (UHI) intensity in Accra with the view to developing appropriate mitigation and planning strategies to cushion the adverse effects of the urban heat. Among others, these objectives, are being taken into consideration:

- To understand the historical developments in the urbanization of Accra and ascertain its effect on the local climate
- To investigate and identify the main local factors that have contributed to the UHI build up in Accra
- To identify suitable urban heat mitigation strategies for the CBD of Accra

The interview will be strictly conducted in accordance with the Robert Gordon University Ethics Policy, which aims at "establishing and promoting good ethical practice in the conduct of academic research", as found in the link below:

www.rgu.ac.uk/file/research-ethics-policy-pdf

The outcome of this research will be of immense benefit to policy makers, urban planners, other built-environment professionals, and inhabitants of the host city as well as the academic community. Due to your expertise in urban planning and urban climate issues, coupled with your familiarity as well as in depth knowledge in the urbanization of Accra, you have been selected to participate in this research. Your contribution to this study is very much appreciated, and please be assured that every information you provide will be treated in confidence. All data provided by you will be used anonymously and for the purpose of this research only. To confirm your interest, please contact me on mobile number +447423234130 or email address: j.gyasi-addo@rgu.ac.uk