Journal of Scientific Research & Reports

26(5): 42-61, 2020; Article no.JSRR.57318
ISSN: 2320-0227

A Procedure for Assessing UHI Intensity in the Central Business District of Accra

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Authors' contributions

This work was carried out in collaboration between both authors. Author JGA designed the study, gathered all the data, wrote and proofread the entire draft of the manuscript. Author AB assisted with the setting up of the weather sensors used as well as the structure and proofreading of the draft of the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2020/v26i530259
Editor(s):
(1) Dr. Karl Kingsley, University of Nevada, USA.
Reviewers:
(1) Antipas T. S. Massawe, University of Dar Es Salaam, Tanzania.
(2) Ionac Nicoleta, University of Bucharest, Romania.
Complete Peer review History: http://www.sdiarticle4.com/review-history/57318

Original Research Article

Received 09 April 2020
Accepted 15 June 2020
Published 20 June 2020

ABSTRACT

Aim: The study aims at developing a procedure or method for assessing Urban Heat Island (UHI) in the CBD.
Study Design: Mobile traverse.
Place and Duration of Study: The Scott Sutherland School, Robert Gordon University, Garthdee road, Aberdeen, between December 2018 and September 2019.
Methodology: It entails a review of various UHI types and the methods for measuring them, thereby considering method(s) that would be highly suitable. Weather data measurements are taken by mobile traverse, with a sensor mounted at a level of 1.5 m above the ground. Reference data were recorded at a monitoring point outside Accra. In the study, the dynamics of the UHI intensities within the various local climate zones are analysed. Various analytical approaches are explored for further investigation into the trends in the climatic variations and possible impact of the morphological changes in the urban fabric.
Results: Recordings at: Anyaa-NIC, Kwashieman, Jubilee House, Supreme Court, Ministries, National Theatre, Advantage Place, Ridge Hospital and Electoral Commission showed negative deviations between −1 and −2°C from the city's long-term average temperature. It was noticed that

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at Advantage Place, which is in open high-rise (LCZ4) development area, the presence of big trees showed lower UHI intensity in comparison with the intensities observed at Jubilee House and Novotel which both belong to the same local climate zone (LCZ).

Conclusion: This study reveals the presence of UHI in Accra and highlights the importance of using the LCZ classification system. It also highlights the high impact of urbanization on the local climate of the city.

Keywords: Urban heat island; local climate zone; canopy layer urban heat island; central business district; climate data.

1. INTRODUCTION

Over the years, urban heat island (UHI) has become a subject of importance to many cities. Extreme temperatures and heat waves have always had severe impact on people's health, their overall well-being and productivity [1,2]. In addition, increasing temperature results in heat build-up which causes thermal discomfort for users of both indoor and outdoor environments [2,3]. Furthermore, energy demand resulting from high dependence on air condition or artificial ventilation in buildings in hot environments is quite significant. The existence of UHI in cities generally worsens the problem, for which reason better planning becomes very necessary.

Several researchers have indicated that extensive use of manmade materials could be the main cause of UHI [4,5]. Urbanization has resulted in population growth in the cities. Urban population growth is related to increased built-up areas and reduction in vegetation or greenery [6,7]. 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 increase in average temperatures makes the UHI phenomenon a critical issue for urban settings in the tropics.

In view of the many adverse environmental effects of UHI, the phenomenon is deemed very important, as far as city or urban planning issues are concerned [4]. Various researchers have shown that UHI affects the urban environment considerably, and therefore has the tendency to affect energy use in buildings [4,8,9].

It has been estimated that more than 61% of the world's population could become urban dwellers [4]. According to Berger et al. [10], high occupancy levels in office and commercial buildings result in substantially high building energy consumption. Straube [11] projects that over a third of global energy is used by the building industry. The cooling loads of large buildings in warm climates are generally high.

With the country's population becoming urbanized at a fast pace, the urban areas in Ghana have become dotted with settlements of 5000 or more people [12]. 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 [13] 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 Simons et al. [14] and Koranteng et al. [15], 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 [16]. 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 which could barely be borne by the urban poor, this study is of immense importance, as seeks to obtain empirical data on the UHI intensity dynamics present in Accra. With findings from the study, 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 [1].

The overarching aim of this study is to develop a suitable procedure to assess the UHI of Accra, with due consideration to its unique built-up characteristics. To manage the study, the UHI measurement has focussed on the central part of the city. The ultimate purpose of this study is to quantify UHI intensities in Accra, using the heavily built-up CBD as the study area. Data from this study could be subsequently used for building energy performance projections. Furthermore, the outcome of the study could enhance the development of appropriate remedial building design and planning proposals or strategies. In developing a suitable procedure for the study area, various UHI types and their respective measurement procedures are reviewed. The study area is grouped into zones based on their built-up types, and against the backdrop of the measurement procedures, suitable measurement approaches are considered. Results from the campaign are compared with long-term weather averages to ascertain if there are correlations between them. The UHI intensities at the various monitoring points are also analysed within the context of their built-up types or characteristics.

1.1 Literature

Bagiorgas and Mihalakou [17] posit that urban heat island is present in cities that usually record considerably higher temperatures in comparison with the temperatures of their surrounding areas. The assertion by Oke [18] is corroborated by Rajagopolan, Lim and Jamei [7] that, heat build-up in hard surfaces (i.e., on the ground and buildings) is caused by reduction in green spaces or vegetation, and this results in UHI. The phenomenon is also defined as the situation where there is a considerable rise in the ambient temperature of an urban environment, because of the presence of warmer surfaces [19]. From the foregoing, it can be inferred that changes to the natural environment brought about by human interventions, especially construction activities and reduction in urban green spaces to a large extent, contribute to high temperature build-up in urban areas and hence the development of UHI.

According to Rajagopalan, Lim and Jamei [7], the occurrence of UHI could be affected by climatic factors as well as city planning or design. The factors mentioned above have been corroborated by Dhalluin and Bozonnet [20], who further assert that, an area’s geographic characteristics can also affect the intensity of its UHI. From the above studies, it is evident that the occurrence and intensity of UHI are mainly influenced by geographical, meteorological, and anthropogenic characteristics, as well as the design and shape of a city.

Several researchers have investigated UHI in areas of wide coverage using remote sensing; thermal satellite image and GIS methods [21,22,23]. For small areas, spot temperature measurements are recommended [23]. Aduah, Mantey and Tagoe [24] have indicated that despite the suitability of spot measurements for small areas, the high cost of procurement and installation of the needed equipment limits the number of points which can be monitored.

Li [25] 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 [9,26]. 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 [27,28]. Similarly, as demonstrated by Stewart [26], 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 [29]. Weng and Quattrochi [30] 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 [31]. Ambient and surface temperatures could differ from each other considerably [32]. 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 [33]. Voogt and Oke [31] 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 the planning authorities.

For varying reasons, researchers have identified various landscape classification systems for UHI or urban climate studies. According to Ren, Ng and Katzschner [34], "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 [35], improvement 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 [36]; Urban Climate Zones [37]; Local Climate Zones [38,39,40]. The benefit of these classifications is tied to their independence to definite climatic conditions. The urban climate zones (UCZs) model by Oke [37] 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 improvement throughout Stewart and Oke's local climate zone (LCZ) model [38,39,40]. Till date, many methods used for the classification of landscape have evolved which contain several features that align with the rationale for UHI study. For the purpose of studying urban morphology and its effect on local climate, the LCZ developed by Stewart and Oke [41] 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 [42]. The LCZ classification system is shown in Table 1.

1.2 Study Area

Ghana has a total population of over 25 million [43] and is found on the west coast of Africa. On the east, it shares a boundary with The Republic of Togo, and on the west and north, with La Cote D'Ivoire and Burkina Faso respectively. Ghana has 16 regions and 212 districts [44]. The country basically experiences wet and dry seasons. In general, the country records average annual temperatures above 24°C [45]. Fig. 1 is the location map of the study area.

For Accra, average monthly temperatures are usually between 22 and 32°C and the month of February is usually the warmest [47].

Table 1. 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	

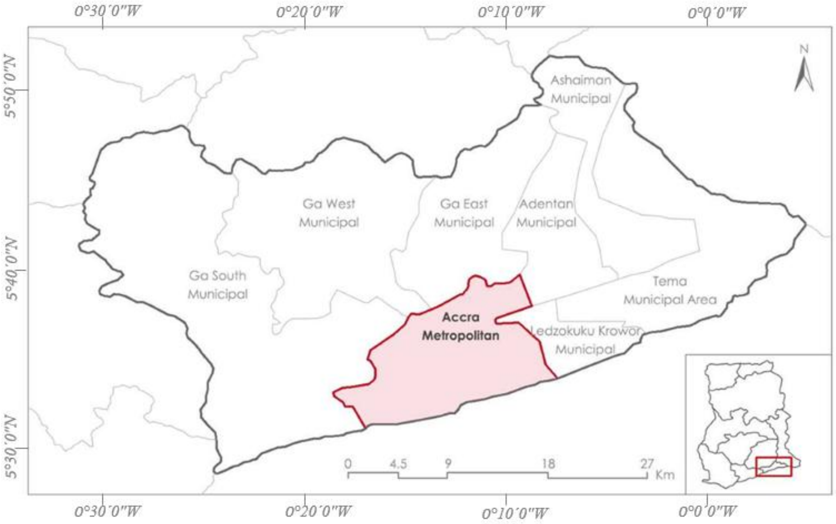

Fig. 1. Map of greater accra metropolitan area showing the study area; modified after [46]

An obvious impact following the introduction of the liberalization program in the country during the 1990s was the boom in the establishment of multinational businesses in Accra. Currently, the city hosts the head offices of almost 700 companies [48]. To a large extent, this has contributed to the significant appreciation in the value of land needed for infrastructural development in the city, especially within the CBD. Dotted in the CBD are several large commercial and multi-storey office buildings, most of which are highly glazed. Accra has been experiencing substantial urban growth and globalization, and the associated increase in economic opportunities in the city has culminated in land cover and land use change [49,50].

1.2.1 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 [51]. Currently, the Accra Metropolis has a population of about 1.7 million [46]. The population is projected to be 10.5 million by 2040 [52]. The central and eastern parts of the CBD are characterized by formal buildings, dotted with civic and mixed-use (mainly civic-commercial) developments. In the west are extremely busy commercial areas with a major market, street shops and street vending points, though the latter has been officially outlawed. There are few residential buildings in the CBD, most of which are official. In the country, 80% of employment is informal [53]. Due to the large demand on services and infrastructure in the Accra metropolis, coupled with addition to its resident population, the city attracts an estimated daytime population of 3.5 million and above [54]. 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 [55]. 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. DATA AND METHODS

2.1 Data Types

This study utilises primary and secondary data. The primary data were collected using photographic recordings and directly measuring the weather elements. The needed secondary data comprise: 1) 30-year weather data compiled by the Meteorological Agency of Ghana for [47], 2) Available planning layouts of Accra for the past 30 years, 3) Historic Landsat images and 4) Spatial distribution of vulnerable people in the Accra Metropolis. The use of Landsat images and planning layouts was consistent with the recommendation by Ren et al. [34]. The Landsat images would aid the LCZ classification, since they would reveal the built-up characteristics of the study area. According to Sun, Li and Xiao [56], "climatic environment is characterized by its high randomness and uncertainty, therefore, value of the same weather parameter at the equal moment could vary dramatically between different years. Because 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. The invention of typical meteorological year (TMY) thus provides a solution to this challenge and has been broadly accepted within the near decade. TMY is a statistical year consisting of 12 typical meteorological months (TMM) based on field measurement ranging over decades—usually around 30 years." The 30-year meteorological data from the main weather station in Accra would be used to generate long-term averaged data that will be representative of TMY. Huld et al. [57] define a typical meteorological year (TMY) as a set of compiled weather data which contains hourly values in a year for an area. The values are selected from hourly data over a long period, usually 10 years or beyond. For every month in the year, the selection is based on data which are the most "typical" and reflective of the month. For example, January data could be selected from 2005, February from 2010 and so forth, which indicate typical mean annual values of various weather elements.

2.2 Trend of the Weather of Accra—Based on Historic Meteorological Data of Accra

Available climate data from GMA's [47] weather station in Accra for the last 30 years indicate that November, latter part of December and then from January till May constitute the warm periods. Average maximum temperatures are generally above 30 degrees Celsius. Since UHI is directly related to high air temperatures, the research focuses on climate/meteorological data from November to May.

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 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 ranged 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 five years, compared to the first five to ten years within the past thirty years. The relative humidity range has also dropped significantly. There has also been a drop in the wind speed after the first five 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 [58]. This prediction means that the UHI effect in Accra could be substantial, should this trend continue.

2.3 Local Climate Zone (LCZ) Classification

As pointed out by Ren et al. [42], in UHI studies, it is important to comprehend the morphology of an urban setting and how it impacts on local climate. As shown previously in Table 1, the classification system used for this investigation is based on the ten built types defined by Stewart and Oke [41]. For this study, the classification has employed Bechtel's method which makes use of multiple observation data [59]. It relies on current Landsat images and aerial photographic images. Fig. 2 shows snapshots of the LCZs defined for the entire study area.

Table 2 shows a summary of the locations and the respective built types of the identified LCZs in the study area.

2.4 Rationale for Selection of Measurement Procedure/Method

Mirzraei [60] corroborates Voogt's [29] 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. [61] 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 which is 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 [62], CLUHI is present within the space or layer inhabited by people. Since it is also intended that the outcome of this study ultimately benefits the assessment of UHI impact on building energy efficiency, it will be prudent to carry out measurements within the urban canopy. With the area chosen for the study being within the city centre, a microclimate model is proposed, which is consistent with [60], as earlier discussed.

In assessing the effect of UHI intensity on the energy efficiency of buildings, it is important to take into consideration, solar gains through the adiabatic surfaces of the reference building(s) and other urban morphological features, example, the proportion of visible sky above an observation. In view of this, conducting the measurement within the 'height' of the urban canopy layer is deemed appropriate.

Mirzaei [60] posits: "the interaction of a building with its surrounding environment in the surface layer is the basis of the development of microclimate models (MCM), which are widely employed by building scientists and architects. In principle, solar radiation and surface convection from the buildings' surfaces can be included in such models. Investigation of the large-scale UHI variation of a city is broadly adopted in urban climatology and meteorology fields, and this is mostly analyzed using meso-scale (MM) tools." Although it is possible to use meso-scale models for investigating the effect of UHI on a large-scale, their level of accuracy is not good enough to show details of the urban canopy layer [60].

2.5 Procedure for Measuring Canopy Layer Urban Heat Island

CLUHI is measured through a network of sensors at standard or screen level at approximately 1.5 m [63]. 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:

- the main objective;
- the sensor source area;
- the diversity in types of rural areas surrounding the main city.

Branea et al. [61] identify two types of assessments that need to be made to measure the climate data of the surroundings and they are:

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;

2. The sensor heights, the surface cover, the soils and materials under cover, the building types and the roof types.

Two main field measurement methods are proposed for CLUHI and they include: a) Stationary field measurement and b) Mobile survey [63,64].

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 land uses for the whole area being studied. Stationary survey therefore involves the observation of several stations in an area that is being studied. Parameters identified for the assessment of UHI are measured and subsequently computed to determine the intensity. With this method, a relationship is established between the land use/land cover and the ambient temperature of the area which can benefit future planning [65].

(**a**) *LCZ1 (Airport City)* (**b**) *LCZ1 (National Theatre)* (**c**) *LCZ1 (Cedi House)*

(**d**) *LCZ2 (Shangri La)* (**e**) *LCZ3 (Baah Yard-Kwashieman)* (**f**) *LCZ4 (Jubilee House)*

(**g**) *LCZ4 (Advantage Place)* (**h**) *LCZ4 (Accra City Hotel)* (**i**) *LCZ4 (J.E.A Mills High Street)*

(**j**) *LCZ4 (Supreme Ct-Public Lib)* (**k**) *LCZ4 (Ministries-Ind. Sq.)* (**l**) *LCZ5 (Fiesta Royale)*

(**m**) *LCZ5 (37 Military Hospital)* (**n**) *LCZ5 (Adabraka Polyclinic)* (**p**) *LCZ5 (PWD-Barnes Road)*

(**q**) *LCZ6 (Arko Agyei Interchange)* (**r**) *LCZ6 (Anyaa)* (**s**) *LCZ9 (Lands Commission)*

Fig. 2. Aerial images (snapshots) showing lczs of the area surveyed; source: Google earth

Table 2. LCZs identified in the study area—based on [41]

LCZ	Locations	Built Types
LCZ1	Airport City, National Theatre, Cedi House	Compact high-rise
LCZ2	Shangri-la Hotel	Compact mid-rise
LCZ3	Awoshie Baah-Yard, Kwashieman	Compact low-rise
LCZ4	Jubilee House, Advantage Place, Accra City Hotel/ Novotel-Movenpick, Atta-Mills High Street, Supreme Court-Public library, Independence Square-Ministries	Open high-rise
LCZ5	37 Military Hospital, Ridge Hospital, Adabraka Polyclinic, Electoral Commission, PWD-Barnes Rd.	Open mid-rise
LCZ6	Arko Agyei Interchange, Anyaa	Open low-rise
LCZ9	Lands Commission, Anyaa-NIC	Sparse low-rise

Measurements done by mobile survey are to cover almost all types of land uses that are identified. The selection of various monitoring points/stations for the study is based on a combination of land use classification, density, vegetation and other in-situ observations [66]. The selection of the route for the survey as well as the monitoring points, is done taking into consideration, the different LCZs identified. For the mobile traverse, a vehicle travels selected routes at a slow but steady speed. According to [65], to avoid possible variation in the weather, it is recommended that a mobile survey is completed within 1 h or 1.5 h. This conforms to WMO's official time stamp of 1 h for the monitoring of points along mobile transects in UHI studies [66]. 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 related to the speed of the vehicle, Branea et al. [61] indicate that there is a problem in avoiding the effect of vehicle exhaust emissions. With this method, the relationship between temperature and various areas could be identified, and a spatial distribution map for the climatic parameters, created [65].

2.6 Data Acquisition through a Pilot Study

In this study, it is intended to investigate the UHI intensity at both local scale and micro scale—consistent with [67,68]. Following [68], the assessment was done by comparing air temperature measurements from a non-built or a sparsely built location on the outskirts of Accra (i.e., reference location) with that of an area within the CBD of Accra. The measurement campaign (mobile survey) was conducted in different urban canyons within the different LCZs identified on 31st March 2018, which was a warm and dry day. The day recorded no rainfall, and it experienced variable wind directions. Other meteorological data recorded on the day were: wind speed of 6 Kts; sunshine hours of 7.3; minimum and maximum temperatures of 25.5 and 33 degrees Celsius respectively, and minimum and maximum relative humidity values of 60 and 86 percent respectively. The measurements carried out covered the reference location and the selected monitoring points within the CBD.

2.7 Mobile Survey

Mobile surveys have been widely used in UHI investigations [69,70]. The routes used for mobile surveys could be linear or circuitous and huge weather data could be generated within a fairly short time. Various studies have recommended that the average vehicular speed for this type of survey should be 30 km/h, and mobile traverse should be carried out shortly after sunset, on calm evenings with clear sky, since during that time, differences in micro and local climate are maximized [37,70,71]. For the mobile survey, important landmarks identified in the different LCZs were chosen as the monitoring points. Fig. 3 shows a mapping of the routes used.

An Eltek data logger (i.e. a weather sensor) was fixed on the roof rack of a vehicle. It was ensured that the sensor was mounted about 30 cm above the car with a horizontal offset of 30 cm. Using a sport utility vehicle (SUV) vehicle with a roof rack made it possible to position the sensor within the recommended height of 1.8–2.0 m above the ground. Preventing contact between the sensor and the metallic roof was a precautionary measure put in place to enhance the reliability of the air temperature that would be measured.

Fig. 3. Map depicting traverse routes and monitoring points; adapted from google earth

The mobile traverse covered several parts of the survey area. It started from a sparsely built area near Anyaa and moved through Awoshie, a compact low-rise area, then through Tetteh-Quarshie Interchange to Accra Airport City Park which is a compact high- rise area. The measuring campaign for the CBD started from Airport City Park and covered: Lands Commission Head Office, 37 Military Hospital, Arko Agyei Interchange, Cedi House, Movenpick-Novotel, PWD-Barnes Road, Supreme Court-Public Library, Atta-Mills High Street, Independence Square, Ministries, Advantage Place (Ecobank Building), Electoral Commission Head Office, and Accra Regional Hospital (Ridge Hospital).

2.8 Precaution

The weather measurements taken were recorded for the various LCZs. To ensure that the data collected were valid and reliable, it was deemed very necessary to perform outlier analysis. This was meant to identify possible deviations of significance. A few deviations were noticed in the data obtained at the Accra Ridge area (LCZ5). It was noticed that there was an occasional heavy vehicular traffic in that area during the survey. The heat accompanying vehicle exhaust fumes in the heavy traffic could have possibly caused some of the outliers. In view of this, such measurements (considered as outliers) had to be eliminated from the computation of inter-LCZ temperature difference, and this is consistent with [72].

3. RESULTS, DISCUSSION, LIMITATIONS AND FURTHER STUDIES

3.1 Results from Mobile Traverse

Fig. 4 depicts mobile traverse measurements taken between the reference location and the CBD of Accra.

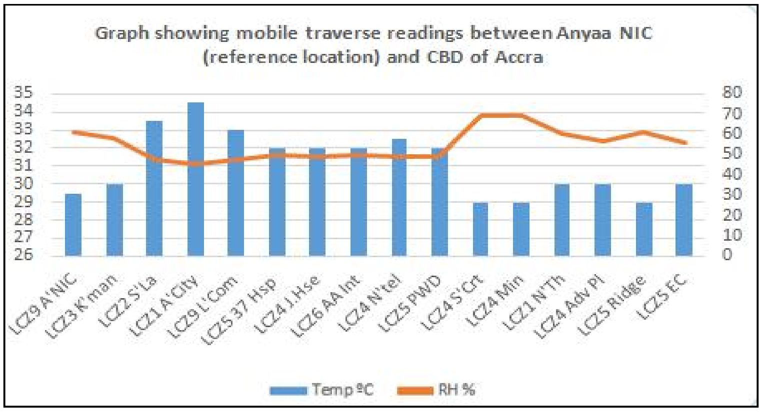

Fig. 4. Graph of traverse data between anyaa and the CBD of accra. (Author generated)

At Anyaa-NIC, which is the reference location (in LCZ9), the average air temperature (Temp°C) and the relative humidity (RH%) were 29.5°C and 61% respectively. The temperature increased by 0.5°C whilst the relative humidity dropped by 3% after a ten-minute drive into Kwashieman (in LCZ3). The relative humidity further dropped by 10.5% upon reaching Shangri-La Hotel, which is within LCZ2 and in proximity to the Kotoka International Airport. At Shangri-La, the air temperature had increased to 33.5°C, which meant that there was a significant increase of +3.5°C from Kwashieman. The second phase of the mobile traverse covered monitoring points within the core of the CBD. The areas covered were: Airport City (LCZ1), Lands Commission (LCZ9), 37 Military Hospital (LCZ5), Jubilee House (LCZ4), Arko Agyei Interchange (LCZ6), Novotel Hotel (LCZ4), PWD (LCZ5), Supreme Court (LCZ4), Ministries (LCZ4), National Theatre (LCZ1), Advantage Place (LCZ4), Ridge Hospital (LCZ5) and the Electoral Commission Head Office (LCZ5). There were significant variations in the temperature and relative humidity values that were recorded at the various points or LCZs. Using the average temperature recorded at the reference location (i.e. 29.5°C), the urban heat island intensity (UHII) levels obtained for the various monitored locations have been plotted against the actual air temperature and relative humidity values, and these are depicted in Fig. 5. The urban heat island intensity (UHII) for each location is the difference between the location's average temperature and the reference location's average temperature measured during the traverse period.

3.1.1 Analysis of accra's meteorological data for 1987–2016

As UHI is associated with air temperature magnitudes, this study dwells on climate or meteorological data available for the period between November and May. The city's meteorological data obtained for the period between 1987 and 1996 (GMA 2017) indicate that between January and December, temperatures were generally between 27°C and 34°C. The period between the months of November and May recorded temperatures ranging from 30°C to 36.1°C, and relative humidity from 53.0% to 80%.

A year's customised meteorological dataset also referred to as TMY, is meant to represent the climatic conditions that are typical of a place over a long period [73]. The most common method of computing TMY for solar energy conversion systems which was proposed by the Sandia National Laboratory [74], has been modified by several researchers and clearly outlined by Wilcox and Marion [75]. The TMY dataset is composed of meteorological data obtained for 12 calendar months and selected from various years from long-term records and linked together to form a complete year, with the consistency of all the different meteorological variables being kept. "The selection of the typical months in the long-term dataset is based on specific weighted

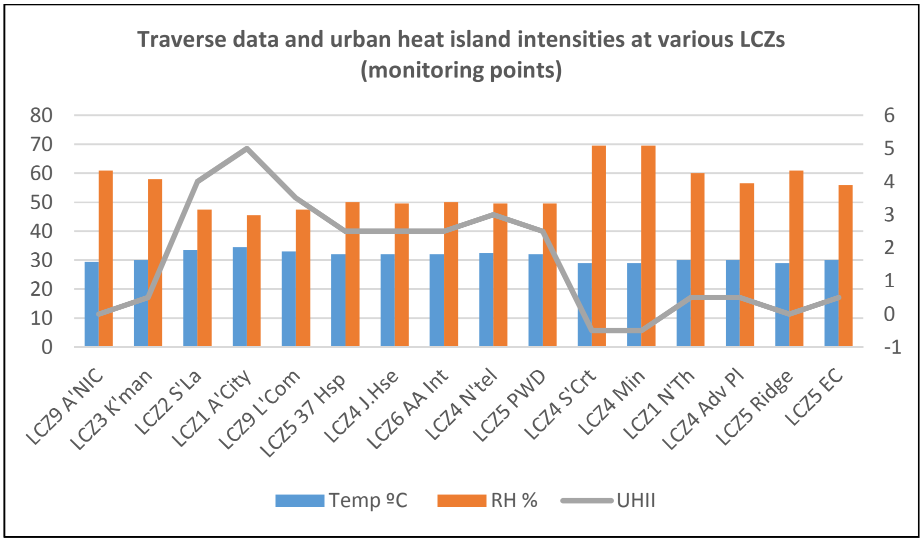

Fig. 5 Graph depicting the relationship between traverse data and UHII
(Author generated)

combination of the global, diffuse horizontal and direct normal irradiances, air temperature, wind speed and relative humidity" [73]. TMY has some weaknesses, the most important of which is the fact that its data lacks information on extraordinary scenarios. TMY data are said to be at the 50th percentile of the full distribution of possibilities; TMY data are mainly developed from modelled data sets and the component that is actually measured is only about 2% [76].

TMY data have generally been used as reference figures or benchmarks for analysing the extent of UHI intensity in various months. In analysing the long-term meteorological data for this study, the emphasis is on air temperature, relative humidity and wind speed. Pusat, Ekmekci and Akkoyunlu [77] have established a strong agreement between long-term averaged temperature data sets and TMY. This means long-term averaged climate data can be reliable for the projection of UHI intensities in a city. Long-term average weather data, which will be representative of the climatic conditions of Accra were determined using the typical monthly climate data averages for the last 10 out of the 30-year period (see Table 3). The city's morphology has transformed significantly over the years, so using data for the last 10 years would be more reliable than using data for the entire 30-year period. This is also consistent with Renne's [76] assertion that weather data extracted from a minimum of 10 years can be used for long-term average weather calculations.

Using the typical monthly climate data averages in Table 3, the long-term averaged temperature (TX), relative humidity (RH) and wind speed (Kts) values obtained are 31°C, 74.52% and 8.49 m/s respectively. Fig. 6 is a graph depicting the typical average monthly climate data shown in Table 3. The average monthly maximum climate data depicted in the graph have been calculated using daily maximum data for the ten-year period. The graph shows that temperature and humidity are inversely proportional. It also shows that the warm periods (November to May) have comparatively lower humidity levels, whilst the opposite is the case for the cooler periods, which are generally between June and September. It must be noted however that, May falls within the warm period, but is associated with high humidity levels and is usually the month in which the rainy season begins.

3.1.2 Traverse data and long-term averages

Fig. 7 depicts various temperature deviations at the monitoring points from the long-term averaged temperature. As shown in the graph, temperatures obtained at the monitoring points at: Shangri La (LCZ2), Airport City (LCZ1), Lands Commission (LCZ9), 37 Military Hospital (LCZ5), Arko-Agyei Interchange (LCZ6), Novotel Hotel (LCZ4), and PWD (LCZ5) show positive deviations between 1 and 3.5 °C. On the other hand, monitoring points: Anyaa-NIC (LCZ9), Kwashieman (LCZ3), Jubilee House (LCZ4), Supreme Court (LCZ4), Ministries (LCZ4), National Theatre (LCZ1), Advantage Place (LCZ4), Ridge Hospital (LCZ5) and Electoral Commission (LCZ5) show negative deviations ranging from −1 to −2 °C. It could be seen that apart from the monitoring points at LCZ2, LCZ3 and LCZ5, different monitoring points within same LCZs showed distinct variations.

Table 3. Typical monthly climate data averages (temperature, humidity and air speed) obtained from 2007 to 2016. adapted from [47]

Month m/s	Ave Max Temp. °C (TX)	Ave Max. Relative Humidity (RH) %	Average Max Wind Speed (KTS) m/s
January	32.79	66.97	7.37
February	32.88	72.42	8.74
March	32.76	73.16	8.69
April	31.91	75.35	8.07
May	32.11	76.77	8.06
June	29.54	79.78	8.8
July	29.13	77.88	10.16
August	29.3	77.11	9.94
September	30.14	76.41	9.2
October	31.35	73.1	8.48
November	32.2	71.54	7.1
December	32.4	73,71	7.25

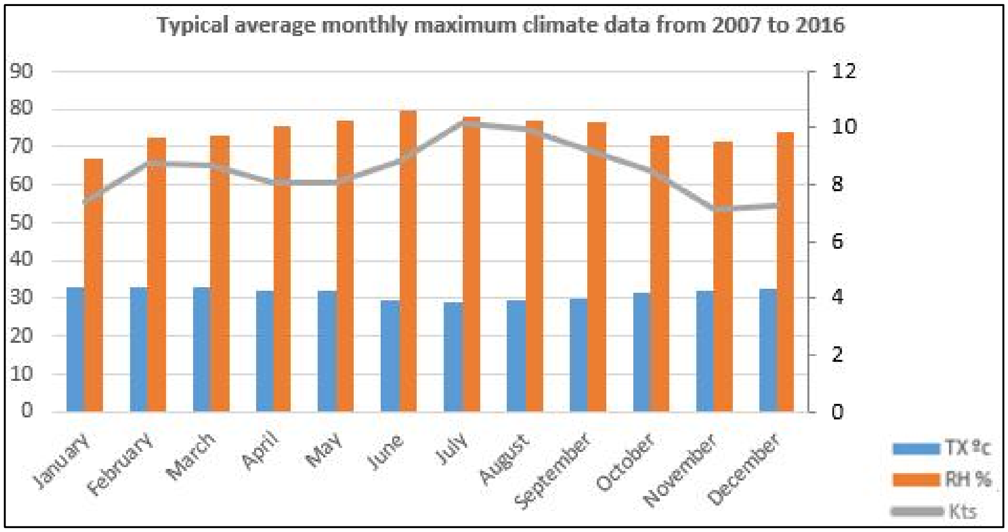

Fig. 6. Graph depicting typical average monthly maximum climate data from 2007 to 2016.
(Author generated)

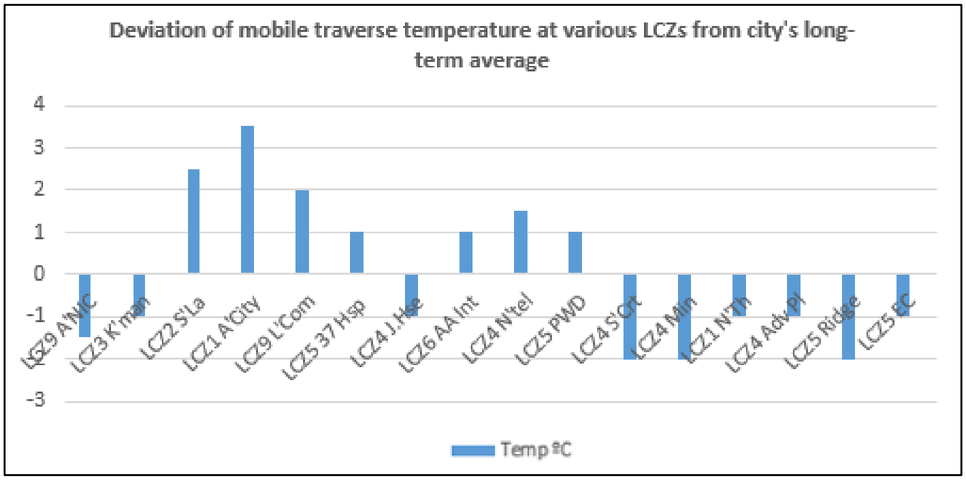

Fig. 7. Graph depicting deviation of mobile traverse temperature at various LCZs from City's. long-term average
(Author generated)

It can be seen from Fig. 8 that there is generally a correlation between the temperature and relative humidity values. Monitoring points with low temperature deviations from the long-term average show high corresponding humidity deviations. Further investigations will be required to explain these significant observations.

3.1.3 Relationship between UHI effect and spatial distribution of vulnerable groups

In the CBD of Accra, UHI affects residents, visitors, workers in both formal and informal sectors and motorists in several ways. The presence of heat waves affects indoor thermal comfort for occupants and users of residential, civic and commercial buildings and as such increases their cooling loads. Motorists who do not have air condition in their vehicles as well as commuters who patronize public transport are all affected by the excessive heat. The presence of heavy vehicular traffic during the day worsens the situation. The vulnerable groups mainly comprise street vendors, head porters, beggars and street children as well as other migrant workers who do not have formal accommodation or shelter. The street vendors and beggars are normally found around Fiesta Royale Dzorwulu, Airport City Park, 37 Military Hospital and the stretch between World Trade Centre and

Movenpick Ambassador Hotel. The stretches between Makola Market, Rawlings Park, Barnes Road (PWD) and Attah Mills High Street are the busiest, and they are the areas where several migrant workers live and work. Fig. 9 depicts the areas where the vulnerable groups are found. During the survey, those areas recorded daytime temperatures between 30 and 34 °C. It is worth indicating that the map in Fig. 9 was generated based on field observations and not actual statistical data; the latter was neither readily available nor within the scope of this study.

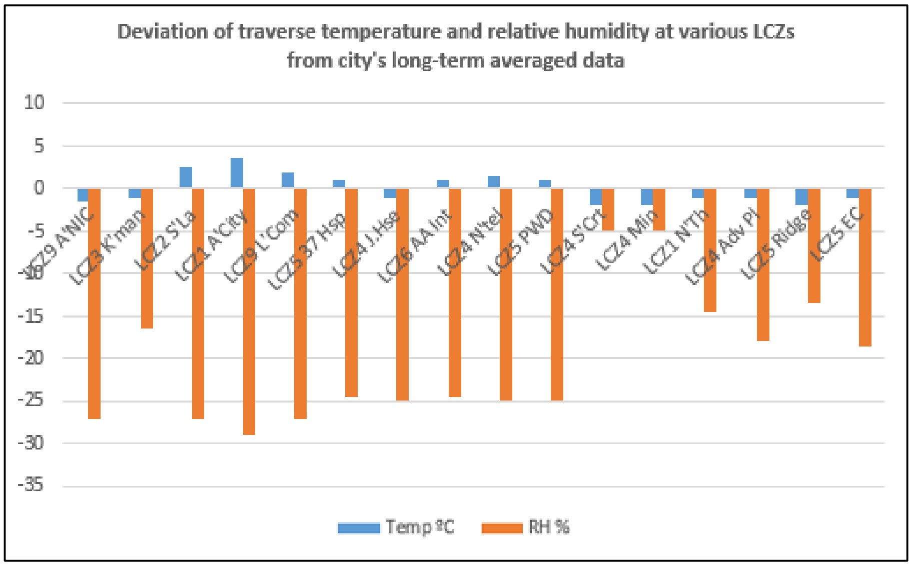

Fig. 8. Graph depicting traverse temperature and relative humidity at various LCZs from. City's long-term averaged data

(Author generated)

Fig. 9. Spatial distribution of vulnerable groups. (a) Spatial map showing areas of vulnerable groups (b) Street vending around Rawlings Park [78] (c) Heavy traffic off Barnes road [79] (d) Commuters waiting for public transport under the sun [79]

3.2 Discussion of Results

The historic climate data have clearly shown that the climate of Accra has changed significantly over the years. The consequences of climate change imply that the high temperatures experienced in Accra could get worse if the current situation remains unchecked.

The temperatures recorded at Shangri-La (LCZ2) and Airport City (LCZ1) were found to be higher by 0.5°C and 1.5°C respectively than the city's maximum temperature, as provided by the Ghana Meteorological Agency. It is worth indicating that the city's weather station is located at the Kotoka International Airport, which is near both Shangri-La and Airport City park. Both Shangri-La and Airport City area are dotted with huge multi-storey buildings, but with sparse vegetation. Most of the buildings found there are for civic or civic-commercial use and are highly glazed—typical of the 'modern Ghanaian corporate look'. From Airport City Park (LCZ1) to PWD (LCZ5), the temperature had dropped from 34.5°C to 32°C, though the latter location is within the inner core of the CBD. On the other hand, the relative humidity had increased by 4% for the same traverse. It is worth mentioning that in contrast to the presence of wide expanse of hard surfaces in the Airport City Park area (LCZ1), there are many big shade trees and substantial soft landscape in the PWD area (LCZ5) as well as certain parts of the CBD. Consistent with [80], the amount of vegetation in each local climate zone obviously contributed to the level of humidity present. The mobile traverse measurements also revealed that the areas that recorded higher temperatures had low relative humidity levels. On the other hand, areas with substantial greenery in most cases, recorded comparatively lower temperatures and higher relative humidity levels.

Results from monitoring points: Anyaa-NIC (LCZ9), Kwashieman (LCZ3), Jubilee House (LCZ4), Supreme Court (LCZ4), Ministries (LCZ4), National Theatre (LCZ1), Advantage Place (LCZ4), Ridge Hospital (LCZ5) and Electoral Commission (LCZ5) showed negative deviations from the city's long-term average temperature, ranging from −1 to −2 °C. As shown in the graph in Fig. 4, the temperatures recorded in those areas were much lower than the city's maximum temperature of 33°C. It could be seen that apart from the monitoring points at LCZ2, LCZ3 and LCZ5, different monitoring points within same LCZs showed distinct variations.

It was noticed that at Advantage Place, which is in an open high-rise (LCZ4) development area, the presence of big trees showed lower UHI intensity in comparison with the intensities observed at Jubilee House and Novotel, both of which belong to the same LCZ. The shade trees with high foliage densities served as friendly environmental elements due to their cooling effect, compared with grass or lawns, which had less cooling impact. This is consistent with [80].

Oke [81] and Bernard et al. [82] have all demonstrated that street canyons with high aspect ratios could benefit from reduced UHI intensity. Although the regional climate and the type of built environment could also impact UHI intensity, it was observed that narrow street canyons had not been implemented in the planning of the study area. In further studies, it would be worth investigating how sky view factor (SVF) affects UHI intensities at the different monitoring points.

It was observed in the mobile survey that heavy vehicular traffic caused outliers in the measurements at certain busy areas. The data in the outliers were deemed unreliable and were therefore not used. The heavy and sometimes chaotic traffic situation, as pointed out by Haddad and Aouachria [83], contributed to the heat build-up in the busy areas. It was obvious that effective traffic management and decongestion strategies had not been implemented.

It was also noticed that despite the nearness of the core of the CBD to the sea, land use pattern could hardly enhance the filtering of sea breeze into the urban corridors, hence the minimal impact of wind on the intensity of UHI there.

3.3 Limitations and Recommendations for Improvements in Procedure

Only three locations were earmarked for the stationary survey because of the limited number of sensors that were available; as a result, it was not possible to carry out both mobile traverse and stationary survey concurrently. This means that for effective or simultaneous survey, more weather sensors will be required. Additional field assistants will have to be engaged in the mobile survey, so that the selected monitoring points in the different local climate zones could be covered simultaneously and more extensively. Due to the traffic situation in certain parts of the study area, engaging additional field assistants will reduce the time needed to complete the campaign, possibly by trekking. This approach would enhance the validity of the data, since measurements could be taken at all the monitoring points simultaneously.

It was also noticed that the outliers identified were caused by the presence of heavy vehicular traffic. Heat from the exhausts of the vehicles had significant effect on the measurements in those instances. To minimize such outliers, future campaign should be done during a period when traffic is minimal. Conducting the mobile survey with both field or trekking assistants and a vehicle would be very useful, since the data set from each mode could be used to validate the other.

As with night SUHI, CLUHI is most felt when conditions are stable, with the highest intensity associated with heavily built-up urban core [84]. This means that UHI is more intense between sunset and sunrise. Extending the mobile campaign into the evening and through the night would be necessary, however, since a few areas in some of the LCZs in that part of the city are security zones in the night, the requisite clearance or permission may have to be sought and where necessary, adequate safety measures put in place to facilitate subsequent measurements.

3.4 Further Studies

It would be useful to ascertain how the morphology of the city, particularly the study area, impacts the canopy urban heat island intensity. Chandler [85] asserts that: “cities with an orderly pattern, like the street grid have a much greater urban heat island effect than those with a more disorderly pattern.” Salvati, Roura and Cecere [68] have shown how sky view factor relates to CLUHI. From the foregoing therefore, it would be useful to ascertain how the morphology of the city, particularly the study area, impacts the canopy UHI intensity.

An extensive study of land use and land cover plans or maps of the CBD of Accra over the last 30 to 40-year period would reveal the pattern of transformations in its built-up nature. This could be compared with the 30-year climate pattern to ascertain the extent to which it has been affected by changes to the built environment.

4. CONCLUSIONS

Following a review of various types of UHI, as well as measurement procedures and protocols, and against the backdrop of the built-up nature and scale of the area under investigation, a critical appraisal gave credence to CLUHI measurement by mobile traverse.

This study has revealed that UHI exists in the city. It has also highlighted the relevance of employing the LCZ system of classification in undertaking the study to assess the intensity of UHI in the CBD of Accra. It also highlights the effect of urbanization on the local climate of the city. It is evident from the study that daytime temperatures of densely developed areas in the city (especially LCZ1 and LCZ2) are considerably higher in comparison with those of open and sparse low-rise areas (i.e., LCZ6 and LCZ9). From the study, there is an indication that built-up areas in the CBD which have substantial vegetation are cooler than those with little or no vegetation, especially the LCZ1 areas.

Having identified challenges such as inadequate number of sensors, the presence of heavy vehicular traffic during the day, and the inability to take measurements simultaneously at several monitoring points, various mitigating measures have been proposed to improve future campaigns.

It has been proposed that comparisons between the weather data obtained at the different LCZs, the 30 to 40-year meteorological data, as well as historic land use plans of the study area could shed light upon any identifiable trends and correlations.

It is envisaged that through this study, various planning and design skill sets aimed at developing or enhancing strategies meant to improve thermal comfort, could ultimately be proposed. Through this research lapses or weaknesses in critical aspects of the city’s building and planning regulations could be identified, based on which effective UHI mitigation measures and strategies could be proposed.

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to Central University, Ghana for financially supporting this research. Much gratitude also goes to The Scott Sutherland School of Architecture and Built Environment, Robert Gordon University, for providing the weather instruments used for the research. Finally, the authors wish to thank Patrick Okai Aboagye and Daniel Addo for assisting with the mobile survey.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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