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Temperature Cooling and Warming Rates in Three Different Built Environments within Nairobi City, Kenya

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Urban canyon, urban park, and suburban surface air temperature data for hot-wet, hot-dry, cool-dry, and warm-wet periods in Nairobi city were analyzed to detect differences in the cooling and warming rates. Measurement of temperature for thirty continuous days was done at each of the three sites for each of the above periods. The cooling and warming rates were computed on an hourly basis beginning at 6.00 P.M., the approximate time of sunset. The results of the study showed that the largest cooling and warming rates were generally experienced during the hot-dry period while the lowest during the cool-dry period. Cooling and warming rates were also found to be the highest at the suburban site and the lowest at the urban canyon site. The differences in the conditions of the built environment at the three sites could explain the cause of the differential cooling and warming rates. The study recommends proper planning of the built environment to ameliorate the problem of excessive nocturnal heat loads within the built environment.

1. Introduction

Urban geometry is one of the major factors leading to the modification of urban climate. Specifically, urban geometry that relates to the urban canopy layer (UCL) influences aspects such as increased substrate heat storage due to greater thermal admittance of surface materials and decreased latent heat fluxes arising from the replacement of soil and vegetated surfaces with impervious material [1–5]. It also leads to increase in solar radiation absorption due to lower albedo of urban materials and reduced wind speeds caused by the aerodynamically rougher urban fabric [6]. There is also the release of anthropogenic heat from domestic, commercial, industrial and transport energy sources and increased atmospheric radiation absorption from green house gases [4, 6, 7].

This paper examines the thermal behaviour of both the urban and suburban landscapes as a possible cause of the differences in the urban heat island within Nairobi city. The study proposes that the structure and composition of the urban canopy as well as the density of the built-up

environment are significant factors in explaining the intensity of the modification of urban climate.

2. Study Area

The study was carried out in the larger Nairobi area including the city centre, extending from longitude $1^{\circ}15'S$ to $1^{\circ}25'S$ and latitude $36^{\circ}40'E$ and $37^{\circ}05'E$. The area extends from the Kikuyu highlands in the west to the Athi-Kapiti plains in east, covering approximately 690 square kilometers (Figure 1). Nairobi has a diversified physical environment, with altitude ranging from an average of 1400 metres above sea level in the east to approximately 1900 metres above sea level in the west. The topography, which is fairly rugged and diverse, slopes eastwards and is drained by rivers that flow from west to east across the city centre. It has also significant effects on the climate and vegetation. The western part of Nairobi, which was originally covered by forest, and the eastern part, covered by grassland, have been modified by the growth and expansion of the city [8]. However, there are still remnants of the original vegetation in these areas. During the census

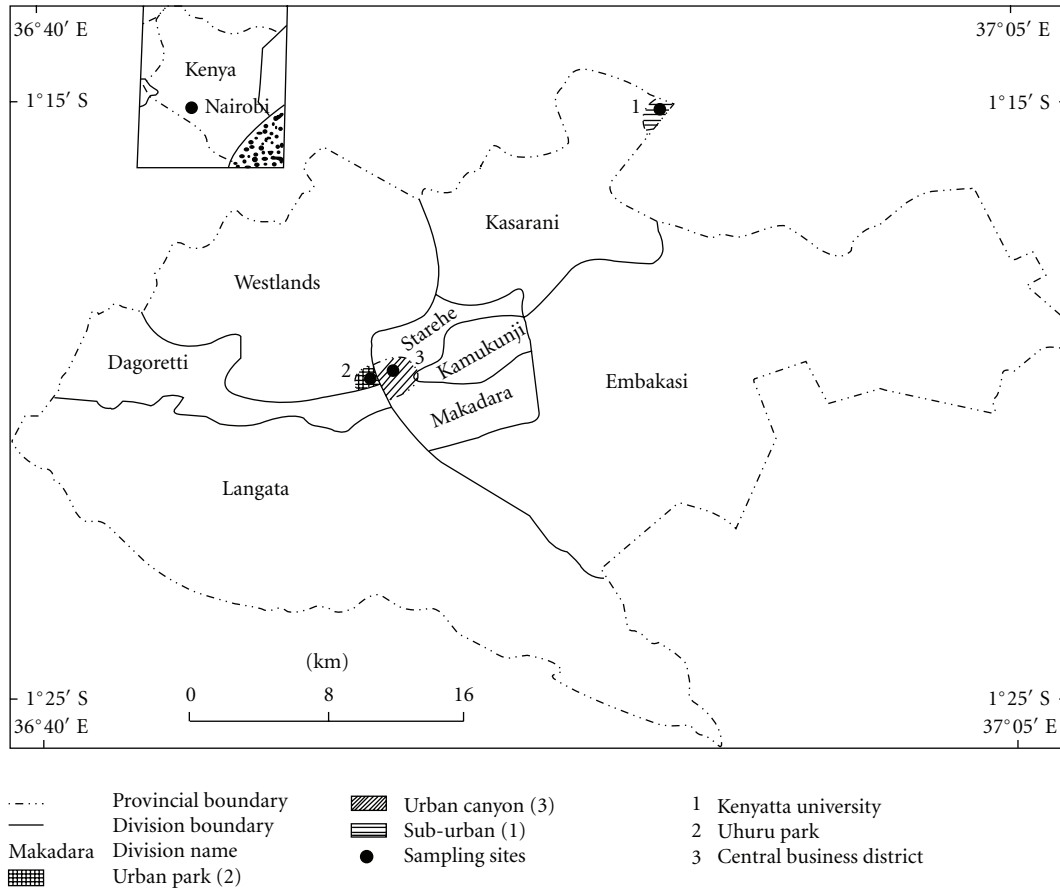


FIGURE 1: Study area showing the sampled sites.

of 1999, the population of Nairobi currently stands at over 3 million people, with an urban population growth rate of about 5 percent per annum [9].

The city centre of Nairobi lies on the foot of the Kikuyu highlands but areas in all directions have become built up during the past forty years. It consists of mainly high rise densely built up area with very low sky view factor (SVF) of canyons. The building structure of the suburban residential areas varies considerably depending on the social status, but in unplanned residential areas, dense blocks of multistorey buildings are common. The well-planned residential areas have green and open spaces compared with the inner city.

3. Data

Data from three purposefully sampled observation sites were used for the analyses presented in this paper. The three sites were Agakhan Walk (urban canyon), Uhuru Park (urban park), and Kenyatta University (suburban). They are located in areas of similar landscape morphology, that is, relatively flat areas consisting mainly of clay soils. However, in addition to differences in building geometry, the three sites have differences in thermal properties, as the urban park and suburban measurement screens were located on grass while

the urban canyon consisted of asphalt and bricks. The urban canyon observation screen was located in the middle of the city centre on a paved pedestrian walk with a canyon SVF of about 0.4, while the urban park was located in an open park with trees, grass, and an open recreational water reservoir. The suburban station situated about 20 KM north east of the city centre at Kenyatta University was sited in an environment that resembles a rural site. Low building structures surrounded the measurement screen with very high SVF.

All the recording and measuring instruments used in this study were calibrated and standardized at the Kenya Meteorological Department (KMD) at the instruments' workshop before being taken to their respective sites for use. They included thermohygrographs type NG5538 to record temperature and dry-bulb thermometers type 1/C BS 692 to countercheck the accuracy of thermohygrographs. The measurements were done at screen level.

Data for surface air temperature for the three sites were continuously recorded and collected for a period of 30 days in the year 2007 for the months of February/March (hot-dry), April/May (hot-wet), July/August (cool-dry), and October/November (warm-wet). The four stated periods coincide with the four climatic subseasons of Nairobi.

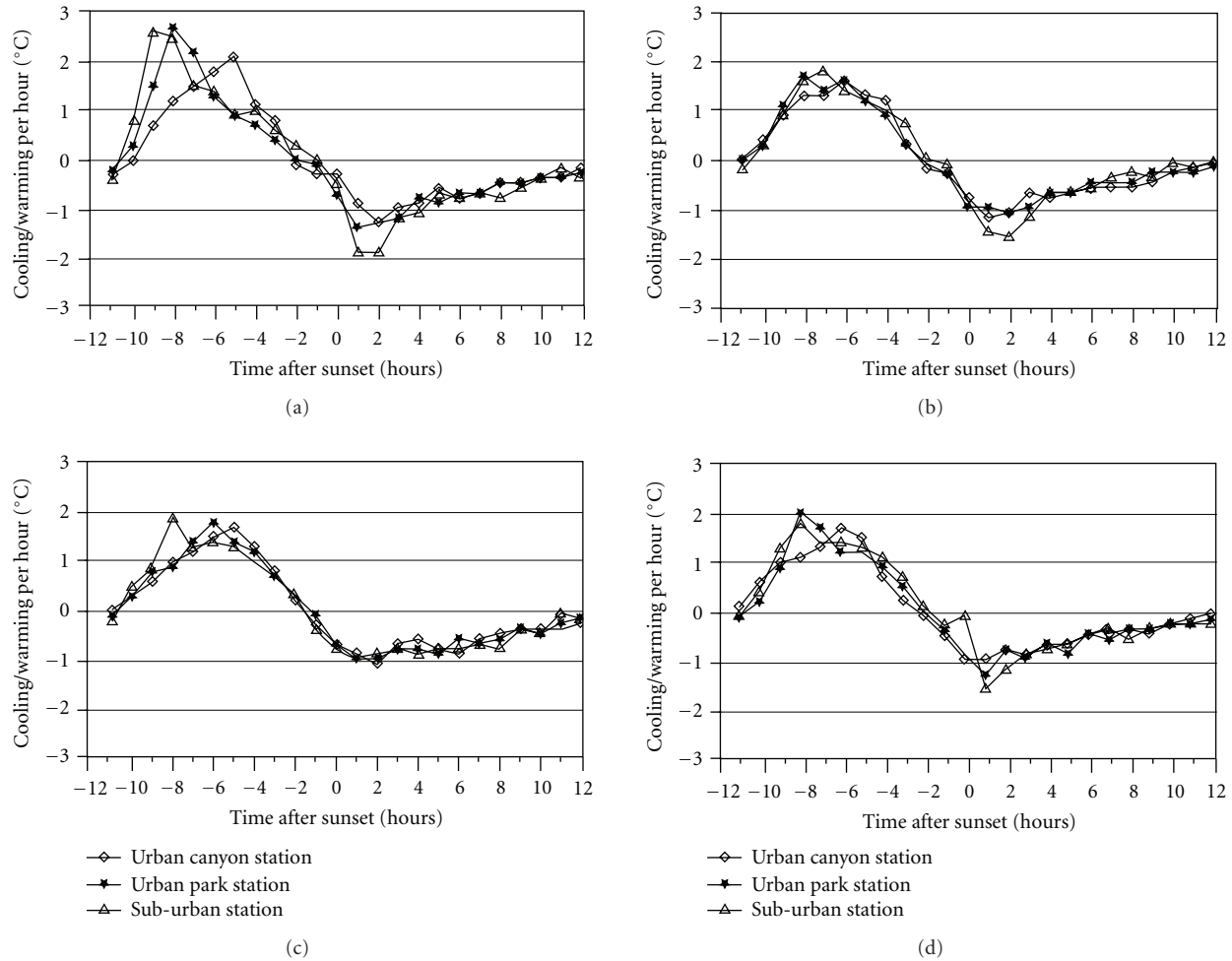


FIGURE 2: Hourly cooling and warming rates at three sites in Nairobi during different periods of the year.

The temperature data were collected on a weekly basis. This was because the recording instruments and charts used in the study were designed to record continuously for a period of one week. For every observation period of 30 days, the instruments were initially set on a Friday at 9.00 A.M. until the following Monday at 9.00 A.M. This period of three days was meant to check the accuracy of the instruments and make adjustments where necessary. Thereafter, until the end of each observation period, the instruments were cleaned and the charts replaced after every week on a Monday at 9.00 A.M. The data were extracted from the weekly recording charts at one-hour interval.

3.1. Data Analysis. To compute the temperature cooling and warming rates at each of the three sites, the beginning time at sunset was taken as 6.00 P.M. (18 hours local time or 1500 GMT). This time was assigned a value of zero on the horizontal scale. On the positive side of the scale, the time at 7.00 P.M. (19 hours local time or 1600 GMT) was assigned a value of 1 hour after sunset, the next hour a value of 2 hours after sunset, and so on up to a value of 12 hours after sunset. On the negative side of the scale, the hour before 6.00 P.M.,

that is, 5.00 P.M. was assigned a value of -1 , the next hour before 5.00 P.M. a value of -2 , and so on up to -11 hours before sunset.

Starting at 0 (time of sunset), the cooling and warming rates at each hour were computed [10]. This computation was done by subtracting the temperature value at 7.00 P.M. from the preceding one at 6.00 P.M., at 8.00 P.M. from at 7.00 P.M., at 9.00 P.M. from at 8.00 P.M., and so on until reaching the temperature value at 5.00 P.M. The cooling and warming rates were then plotted against time after and before sunset. This was done for each of the observation periods at each of the three sites. The results were presented using graphs and tables.

4. Results and Discussions

The differences in the cooling and warming rates between the three sites, urban canyon, urban park, and suburban are shown in Figures 2(a) to 2(d). In all the four periods, warming took place during the day and cooling during the night. However, both the warming and cooling rates were influenced by the conditions around the station and the

TABLE 1: Highest cooling rates ($^{\circ}\text{C/hr}$) after sunset for three sites in Nairobi city.

Site	Period	Site type	Cooling rates ($^{\circ}\text{C}$)	Hours after sunset
Agakhan Walk	Feb-Mar	Urban Canyon	-1.3	2
Uhuru Park		Urban Park	-1.4	1
Kenyatta University		Suburban	-1.9	1
Agakhan Walk	Apr-May	Urban Canyon	-1.2	1
Uhuru Park		Urban Park	-1.1	2
Kenyatta University		Suburban	-1.6	2
Agakhan Walk	Jul-Aug	Urban Canyon	-1.1	2
Uhuru Park		Urban Park	-1.0	2
Kenyatta University		Suburban	-1.0	1
Agakhan Walk	Oct-Nov	Urban Canyon	-1.0	0
Uhuru Park		Urban Park	-1.3	1
Kenyatta University		Suburban	-1.6	1

TABLE 2: Highest warming ($^{\circ}\text{C/hr}$) rates before sunset for three sites in Nairobi city.

Site	Period	Site type	Warming rates ($^{\circ}\text{C}$)	Hours before sunset
Agakhan Walk	Feb-Mar	Urban Canyon	2.1	5
Uhuru Park		Urban Park	2.7	8
Kenyatta University		Suburban	2.6	9
Agakhan Walk	Apr-May	Urban Canyon	1.6	6
Uhuru Park		Urban Park	1.7	8
Kenyatta University		Suburban	1.8	7
Agakhan Walk	Jul-Aug	Urban Canyon	1.7	5
Uhuru Park		Urban Park	1.8	6
Kenyatta University		Suburban	1.9	8
Agakhan Walk	Oct-Nov	Urban Canyon	1.7	6
Uhuru Park		Urban Park	1.7	7
Kenyatta University		Suburban	1.8	8

season of the year. In all the three sites, the cooling rates were largest from 1 hour before until 3 hours after sunset, with a maximum at 1 to 2 hours after sunset (Table 1). The warming rates were largest from 9 hours to 4 hours before sunset, with a maximum at 5 to 9 hours before sunset (Table 2). The largest cooling and warming rates were experienced during the dry-hot period of February-March (Figure 2(a)), whereas the lowest cooling and warming rates were experienced during the cool-dry period of July-August (Figure 2(c)). The rainfall periods of April-May (Figure 2(b)) and October-November (Figure 2 (d)) experienced moderate cooling and warming rates. Thus during the hot-dry period, higher cooling and warming rates explain the development of extreme urban heat island condition in Nairobi city.

Table 1 shows the highest cooling rates for each site after sunset. The highest cooling rates were experienced at the suburban site in February-March period, whereas the lowest at the urban site during the October-November period. The urban park site experienced moderate cooling rates throughout, suggestive of the moderating influence of the park on urban temperatures. The reduced cooling rates at the urban canyon site are likely to be caused by the urban geometry, which causes increased heat absorption by the

urban fabric and consequently leads to higher nocturnal minimum temperature, and eventually the development of the urban heat island [3, 11, 12]. The highest difference in the cooling rates between the urban canyon site and the suburban site was -0.6°C per hour experienced during the February-March and October-November periods (Table 1). These were also the periods when the urban heat island was found to be highest in Nairobi [8].

Table 2 shows that the warming rates are highest at the suburban site and lowest at the urban canyon site during the four periods of study. The highest difference in the warming rates between the two was 0.5°C per hour experienced during the hot-dry February-March period. Again, during all the four periods of study, the urban canyon site warmed more slowly than the suburban site (Table 2). For instance, during the February-March period, the suburban site recorded the highest warming rate 4 hours earlier than the urban canyon site (Table 2). The fast warm-up at the suburban site compared to the canyon site can be attributed to the faster release of terrestrial radiation compared to the slower release experienced in the urban atmosphere. It may also be attributed to the presence of shadows and low sky view factor (SVF) at the urban station [11].

5. Conclusion

The thermal behaviour of the three urban landscapes showed noticeable differences in their cooling and warming rates over the four different climatic periods of Nairobi city. The largest cooling and warming rates were generally found during the hot-dry period while the lowest during the cool-dry period. Except for the cool-dry period, all the remaining three periods had the urban canyon and the urban park sites record lower cooling rates than the suburban site. The highest cooling rates were recorded at the suburban site while the lowest at the urban canyon site. The reduced cooling rates at the urban canyon site were attributed to increased heat absorption by the urban fabric, which was lacking at the suburban site. The warming rates were found to be higher at the suburban site compared to the urban canyon site. This could be attributed to faster emittance of long-wave radiation at the suburban site compared to the urban canyon site where there is more heat absorption and storage, with less emittance and lower SVF [1, 6]. Generally the urban park site showed relatively moderate cooling and warming rates, a fact that was attributed to the moderating effects of park vegetation. Therefore, to reduce excessive nocturnal heat loads and increase nocturnal cooling, built environment should have adequate open and green spaces, which will enhance air circulation and less radiation absorption during the day.

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