Contribution to the Heat Budget in Nairobi-Metro Area by the Anthropogenic Heat Component

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(Manuscript received 16 November 2007, in final form 07 February 2008)

ABSTRACT

This study quantifies the ejected waste heat from artificial supplies comprising road transport and industrial, commercial, domestic and metabolic heating activities which may enhance the urban temperatures in Nairobi metro area, taking into account the energy intensity of a given activity and the level of the activity, considering expended fossil and biofuels, electrical energy consumption and human metabolism. Translation of linear source strengths to area averages from the road transport sector yields about 4% of the total anthropogenic energy over the city. The contribution from the road sector is likely to rise to 10.8 W m^{-2} in 2029 as the City expands. The industrial/commercial sector contributes up to 35.5 W m^{-2} or 57% of the total anthropogenic energy, and could increase to 284 W m^{-2} by 2029 due to industrialization and economic growth. Domestic utilities account for up to 13 W m^{-2}, which is 21% of the total anthropogenic energy. Depending on the activity engaged in, human metabolism contributes up to 11.4 W m^{-2}, which is about 18% of the total anthropogenic energy supplies. The sum total area-averaged anthropogenic energy consumption over the city centre is currently small, constituting about 11 to 18% of the global radiation for the warmer and colder seasons, respectively. Notably, only a part of this energy is released into the atmosphere as waste heat as most is used for the intended purposes. If the current trends of rising population, increased motor vehicle density and enhanced industrialization persist, the anthropogenic waste heat ejection would be large enough to alter the heat balance of the study area appreciably in future by 2030.

Key words: Waste heat; energy intensity; gross calorific value; urban heat island effect

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1. INTRODUCTION

Urban settings differ markedly from rural areas with regard to their impact on the environment. Outstanding among these is the way urban environments inadvertently modify the microclimate of cities and their immediate surroundings. The urban heat island (UHI) effect, together with urban dynamics, govern microclimates in urban settings. The UHI effect depends, to an extent, on the anthropogenic waste heat emission, whose accurate representation in dynamical modelling is important in assessing the influence of cities on microclimates. This component has not been quantified to any extent within the Equatorial region, which is the goal of this study.

Studies to establish the influence of urban environments on microclimatic elements like temperature, airflow, humidity, convection and rainfall have focussed on the role played by the urban geometry, aerodynamic roughness, reflectivity, and thermal characteristics on these elements (Oke, 1987; Changnon, 1992; Opijah and Mukabana, 2004). More recently, there has been growing interest in the role of the anthropogenic warming intensity on weather and climate (e.g., Ichinose, 2001; Sailor, 2003; Offerle *et al*, 2005) and on socioeconomic life, including health (Manu, *et al*, 2006; EPA).

At the urban scale, waste heat from anthropogenic sources is undoubtedly an active component in producing or exacerbating the urban heat island phenomenon and has the potential to change weather/climate at the site and urban levels, and beyond (e.g. Pielke, 1984; Changnon, 1992). Studies have indicated that anthropogenic heat can be as much as one-third of that received from solar energy (Sailor, 2004). Garnett and Bach (1965) estimated waste heat of about one-third of the net radiation balance, or one-fifth of the total radiation received for Sheffield, England for 1952. In greater London, for 1971, McGoldrick (1980) found daily waste heat of between 0 and 5 Wm^{-2}.

A number of authors (e.g., Nakamura 1966, and Okoola 1980) have reported a distinct UHI phenomenon over the City of Nairobi. King`uyu (2004) reported a significant increasing trend in maximum temperature of 0.2°C per decade at Dagoretti Corner.

What proportion of the heat energy in the City of Nairobi is due to anthropogenic heating, and is this energy in sufficient quantities to influence the heat budget and boundary layer fluxes in the tropical African city? This study seeks to assess the current status of the anthropogenic heat component relative to the overall heat budget in the Nairobi urban milieu, and its projected contribution to the heat budget in future.

2. SURFACE ENERGY BUDGET IN AN URBAN ENVIRONMENT

The net quantity of energy in an urban surface layer comprises contributions from radiation, convection and conduction, the balance of which results in the ground surface equilibrium temperature. In the atmosphere, the transfer of heat is essentially by radiation and convection. The radiative heat transfer is defined in terms of the net radiation, Q_N. Convection involves the transfer of heat by turbulent eddies and comprises sensible, Q_H, and evaporative, Q_E, heat fluxes; molecular transfer (i.e., conduction) is negligible in the atmosphere.

Conversely, substrate transfer of heat by convection and radiation are negligible; the transfer here is primarily by conduction in the form of ground heat flux, Q_G.

Partitioning these forcing terms and including the energy stored in a “parcel” of atmosphere, Q_s, yields (1), where positive and negative signs denote a transfer from and to the ground surface, respectively. The heat balance equation in the surface layer has been discussed in detail by various authors including Oke (1987), Pielke (1984), Garratt, (1992), and George and Becker (2003).

$$Q_N = Q_H + Q_E - Q_G + Q_s \qquad (1)$$

The net radiation, Q_N is the vectorial sum of the down-welling direct shortwave radiation, diffuse irradiance and the outgoing and incoming long wave radiative flux divergences. Q_H and Q_E are generally parameterized using the bulk aerodynamic formulation, while Q_G is computed using a rate equation of temperature.

In an urban environment, there are significant modifiers to the heat budget statement occasioned by the natural cycle of cooling and heating, in terms of the urban fabric, water surfaces and vegetation, and waste heat discharge, Q_F, which generates energy as a by-product that directly heats the atmosphere.

These processes decrease the down-welling solar shortwave radiative flux, increase the upwelling infrared radiation and increase the storage term, Q_s. The term Q_F comprises all anthropogenic processes involving energy consumption, including ventilation systems, industrial processes, internal combustion engines, domestic utilities and metabolism. Q_s is

Figure 1: The roads network in the Nairobi CBD and its position in Kenya and Africa (www. worldmaps.com

substantially modified by, but is not equivalent to, Q_F. Q_F is not normally quantified using parameterization techniques, and needs to be estimated.

Quantification of the anthropogenic heat emission, Q_F, term in this study is based on the premise that this quantity is the arithmetic sum of the heat from vehicular emissions, Q_v, industrial/commercial activities, Q_i, domestic utilities, Q_d and human metabolism, Q_m (2).

$$Q_F = Q_v + Q_i + Q_d + Q_m \tag{2}$$

The chemical equation (3) shows how fuel (e.g., CH_2O) combines with oxygen (O_2) to give carbon dioxide (CO_2) and water (H_2O) thereby evolving heat energy. When the final water molecule (H_2O) is gaseous, the heat evolved is called the *net calorific value*, otherwise it is the *gross calorific value* (GCV). *GVC* is sometimes called the *heat of combustion*.

Energy use from any given activity is the product of the energy intensity and the level of activity (e.g., Harrison and McGoldrick, 1981). This is divided by the area of activity to give the corresponding energy intensity over a given time level. For Q_v, the energy intensity is the energy consumed per kilometre, while the level of activity is the distance travelled by a motor vehicle.

Qv is, therefore, obtained from Equation 4 where N, D, E and A represent the number of uniformly spaced vehicles on a roadway, the distance of the roadway, the energy use per kilometre per vehicle and the cross-sectional area of the roadway, respectively (Grimmond, 1992).

$$Q_v = NDE/A \tag{4}$$

Let us assume that an ordinary vehicle, on average, consumes one litre of gasoline in 10.4 km. Using the typical GCV of petrol of 34 MJ l^{-1} (Twidell and Weir, 1986), this translates to 3264

Light trucks (mini-buses and pick-ups) consume 30-40% more fuel than cars (IPCC, 1995), which translates to about 8 km per litre. Buses and large commercial vehicles use diesel which has a GCV of 38 MJ l^{-1} (Twidell and Weir, 1986), corresponding to 4750 J km^{-1} (38 MJ l^{-1} X 0.125 l km^{-1}). Road transport accounts for over 80% of the total transport energy consumed in most countries in Africa (IPCC, 1995).

Industrial/commercial, Q_i, and Domestic, Q_d components are generally termed as the *building sector*. Q_i, is estimated using (5) where I is Gross calorific value (energy intensity) and C is the energy consumption (the level of activity); A is the area involved. The industrial/commercial sector, for all intents and purposes, is driven by electricity, although the actual energy evolved is a function of the efficiency of the appliances used; fuel consumption in this sector is negligible.

$$Q_i = IC/A \tag{5}$$

Indoor fuels comprise crop fuels (especially wood), crop residues (e.g., rice husks, bagasse, etc), secondary biofuels (e.g., charcoal, ethanol, methanol, biogas), and fossil fuels including kerosene, diesoline and petrol (Twidell and Weir, 1986). Wood fuel is used in a clandestine way, being due to countrywide deforestation; its usage is difficult to quantify. Crop residues are not used commonly within the city. Charcoal is used in many homesteads, as is kerosene. The gross calorific values of the common fuels in Nairobi are given in Table 1. Q_d is obtained from (6) where E is the energy intensity per household (GCV) and H is the number of households; A is the area of the residential district.

$$Q_d = HE/A \tag{6}$$

Equation 7 gives the contribution to the heat budget arising from metabolism as the product of the metabolic rate, M, (i.e., the energy intensity) and population density, P, (i.e., the level of activity).

$$Q_m = PM/A \tag{7}$$

3. THE STUDY SITE

The central business district (CBD) of Nairobi (Fig. 1) is located at longitude 36°49' E and latitude 1°18' S at an average height above mean sea level (MSL) of 1670 m. The total built-up space of Nairobi City covers an area of approximately 100 square kilometres and consists of a rapidly expanding commercial/administrative CBD, an industrial area, cover an area of about 12.25 km^2. The City lies within a wider area forming the Province of Nairobi with an area of about 696 km^2 bounded by latitudes 1°12' S to 1°27' S and longitudes 36°40' E to 37°06' E. A sizeable proportion of this area is a national park.

The city of Nairobi is a major socio-economic centre in eastern and central Africa that has undergone elaborate phase changes in its growth and development since its inception in 1901. There is evident continuing growth in commercial and industrial production, the construction sector, infrastructural facilities, motorized transportation and population. The population of Nairobi City is projected to reach nearly 8 million people by the year 2029, which is envisaged to be accompanied by compounded energy use needs and anthropogenic heat release in the city. These phase changes have had appreciable effects on the region's ecologic and environmental stability.

As for the rest of the country, the four-season climate over Nairobi is governed to a large extent by monsoonal synoptic flows, which are determined by the migratory drift of the ITCZ. By virtue of its altitude, Nairobi has fairly low average temperatures compared to other tropical cities within the same zone. Although the diurnal range of temperature is approximately 12°C, the annual range is small, ~4°C (Fig. 2).

The dry north-easterly monsoon is associated with warm, cloud-free conditions reaching ~26°C in February.

The fairly moist, diffluent and subsiding south-easterlies/south-west monsoons between May and September are characterized by dry and cool conditions. The lowest mean minimum temperatures (~10°C in July) is due to the prevailing cloudiness (about 8 hours per day) and cold air incursions from the Southern Hemisphere winter at this time. Transition rainy periods (mid-March-April-May and October-November-December) experience a strong component of moist, easterly flow patterns at low levels. Studies show that anthropogenic heat is a function of weather/climate (e.g., Ichinose, 1999).

Figure 3 shows the spatial variation of maximum and minimum temperature and relative humidity for a case study done in July, 1997 at some selected stations across the City, whose altitudes are also given. This period, within the cool dry season, was envisaged to vividly display the anthropogenic effects on the observed meteorological conditions. The CBD (Basilica),

Table 1: Total Categorised Domestic Heating Estimates per Day for Buruburu (Middle Income) Residential Estate in Nairobi. Brackets show values for Mukuru (low income) estate. Gross Calorific values are taken from Twindell

Energy-Source	Average Monthly Estimate	Gross Calorific Value	Net Energy Consumption ($W\ m^{-2}$)
LPG (Methane)	54,363 kg	55 kJ kg^{-1}	2.31
Kerosene	16,274 (18,900) l	37 MJ l^{-1}	0.46 (0.54)
Charcoal	53,848 (53400) kg	32 MJ kg^{-1}	1.33 (1.32)
Firewood	(2,365 kg)	16 MJ kg^{-1}	0.03
Electricity	1,463 kWh	—	4.06

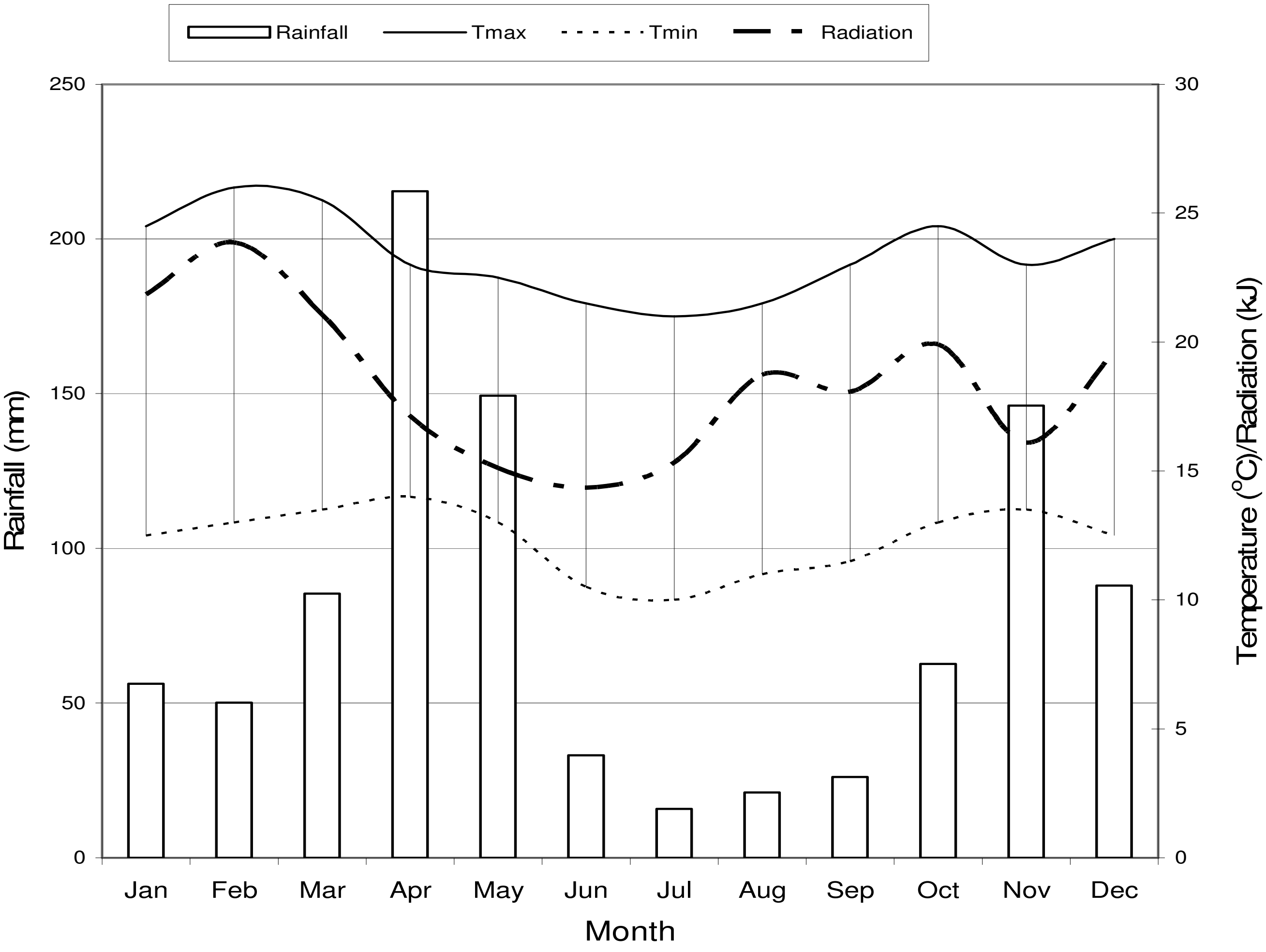

Figure 2: The monthly mean rainfall (mm), maximum and minimum temperatures (T_{max} and T_{min}, ℃), and radiation intensity (kJ) in Nairobi, Kenya (data from the Kenya Meteorological Department).

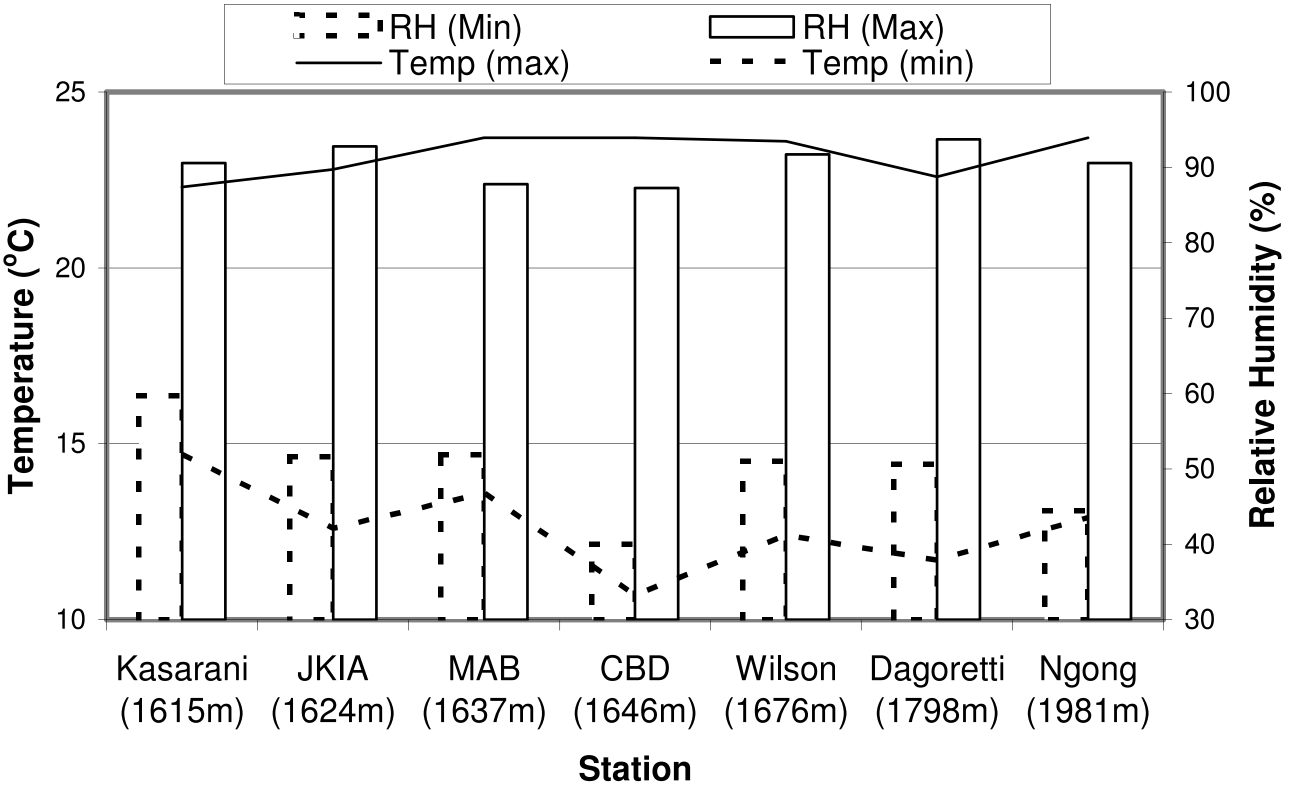

Figure 3:Spatial variation of maximum and minimum temperature (Temp °C) and relative humidity (RH %) for July, 1997 at selected stations within Nairobi area. Brackets show the height above MSL (See appendix)

Wilson and MAB stations are considered as urban stations; the rest are more rural.

The temperature and humidity patterns shown may be attributed to both topographical (especially altitude) influences and anthropogenic factors. The lower minimum and maximum relative humidity at Basilica than the surrounding stations may be attributed partly to reduced vegetative cover and fewer open water surfaces over the city centre (Grimmond, 1992). The higher altitude stations had lower temperatures. The urban heat island effect is also evident: The city centre had higher maximum temperatures due to heat captured and radiated by impervious, higher mass, surface layers with higher capacity to absorb and store heat. The magnitude of the UHI of +1°C is smaller than that reported by Okoola (1980). Minimum (morning) temperatures occur at the city centre, with an UHI of -1°C, attributed to the wind chill factor due to channelling of air. This is unlike at MAB and Wilson, the other “urban” stations that had higher minimum temperatures by about +1°C. Evidently, the influence of waste heat at this time is small. Notably, the times of occurrence of maximum and minimum temperature and relative humidity at the stations were staggered.

4. ESTIMATED ANTHROPOGENIC HEAT COMPONENT IN NAIROBI METRO AREA

The waste heat energy emission source strengths in Nairobi metro area for a state of restricted heat advection (i.e., an atmosphere at rest) and uniform horizontal diffusion of heat are discussed below.

4.1 Estimated Contribution from the Transport Sector

About 15% of the mobile population in Nairobi use non-motorised transport, 25% use private motorised transport and 50% use public transport and taxi (IPCC, 1995)

Figure 4 shows the number of national car sales in Kenya will quadruple the current status supposing an exponential trend up to the year 2030. Figure 5 shows emission of 297 MJ km^{-1} for cars, 12 MJ km^{-1} for light goods vehicles, 5 MJ km^{-1} for heavy goods vehicles and 20 MJ km^{-1} for buses and coaches; giving the total energy per kilometre arising from the vehicular load at the emission point source of approximately 335 MJ km^{-1}. City council counts were used.

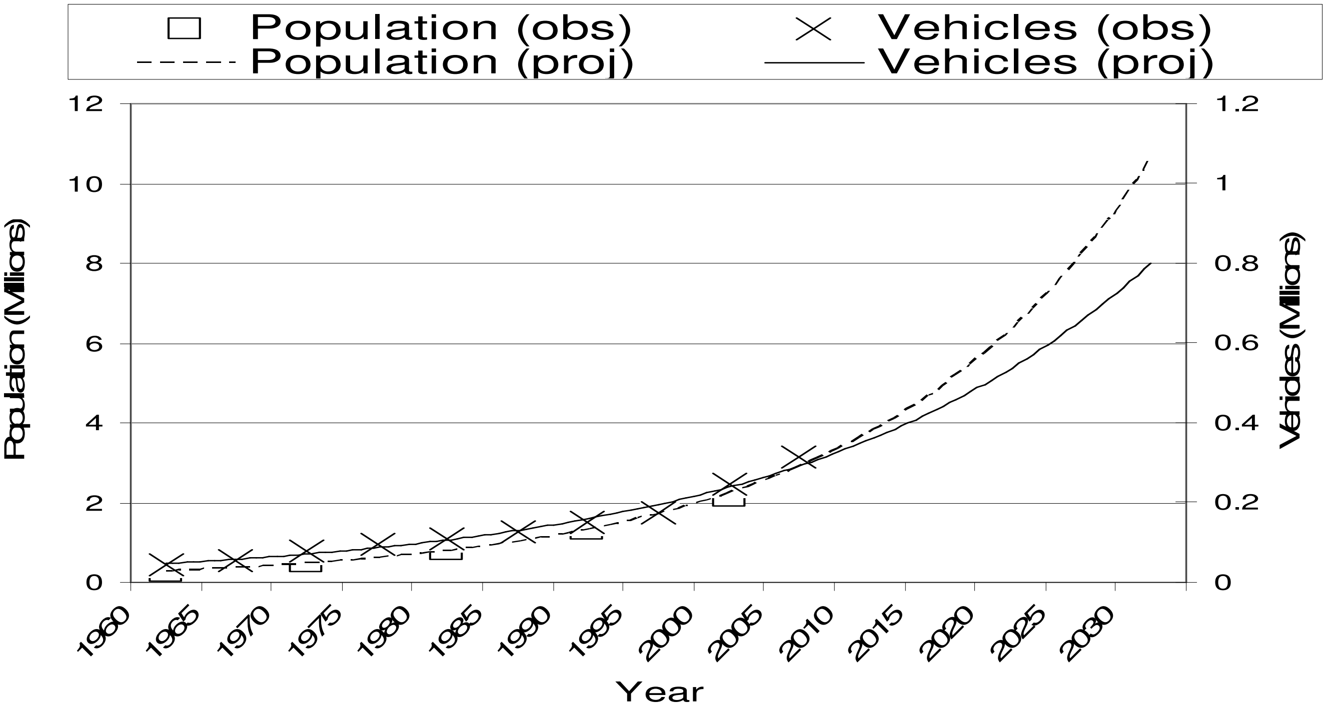

Figure 4: The number of cars registered in Nairobi (crosses) and the forecasted exponential trend up to the year 2030 (solid). Also shown is the observed population of Nairobi Province (squares) and its projected exponential growth (dashed) up to the year 2030

Supposing that each vehicle traverses the CBD, in the process travelling a distance of 3½ km, the total energy emitted by these vehicles is 1,174 MJ (i.e., 335 MJ km^{-1} X 3½ km). When this energy is distributed over the CBD, this energy amounts to about 96 J m^{-2} (i.e., 1,173 MJ X 12.25 km^{2}). The energy released by a vehicle moving at a speed of 60 km h^{-1} is therefore 0.46 W m^{-2} (96 J m^{-2} X 3½ minutes). Suppose further that the vehicles are moving at a uniform typical speed at the CBD of 10 km h^{-1}; the vehicles will take 6 times longer releasing 2.7 W m^{-2}. This quantity corresponds to about 0.5% (warmer season) to 0.8% (colder season) of the total global radiation (Fig. 2). In reality, vehicles move more slowly because of poor road conditions and traffic jams; hence the energy released is likely to surpass the value obtained above. The emitted "waste" heat energy is large at the actual point source, but decreases away from the road with very little reaching the open spaces in the city.

Basing on the exponential trend, this energy will quadruple, reaching a value of 10.8 W m^{-2}, which translates to about 2.0% (warmer season) to 3.3% (colder season) of the total global radiation. The low vehicular emissions arise from the translation of linear source strengths into areal averages so as to determine the net amount over the entire city centre.

4.2 Estimated Contribution from Industrial and Commercial Activities

Kenya is set to become an industrialized nation by the year 2030, as per Government targets.

Figure 6 shows the trend of total national fuel sales comprising liquefied petroleum gas (LPG, 2%), motor spirit (21%), illuminating kerosene (14%), light diesel (37%), heavy diesel (2%) and fuel oil (24%) between 1989 and 2004. LPG and kerosene are for the most part used domestically; kerosene is a supplement for charcoal; motor spirit and light diesel are primarily used in the transport sector; fuel oil is essentially used for electricity generation (CBS, 1998). Only heavy diesel is used for industrial production. If all this energy were used at Nairobi's industrial area, which is not the case, it would contribute just 0.1 W m^{-2}, which is a measly 0.03% of the global radiation (Fig. 2) and which is within the margin of error in radiation measurements.

Figure 7 shows the partitioning of electricity in Nairobi, of which about 67.8% is used in the industrial/commercial sector (Fig. 8). Distributing this energy over the industrial area, the electrical energy consumed is in the order of 35.5 W m^{-2}. This translates to between 6.4% and 10.7% of the global radiation in the warmer and colder seasons, respectively.

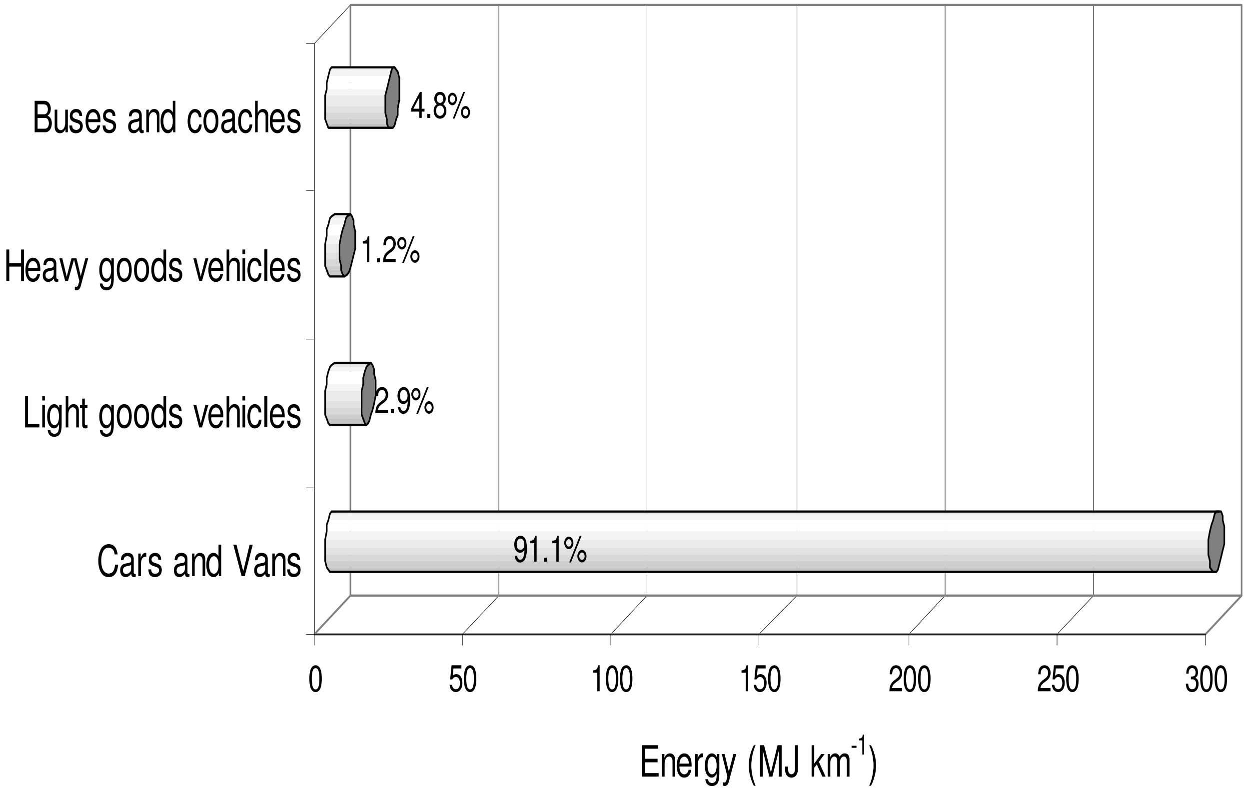

Figure 5:Total vehicular energy consumption per kilometre (MJ km^{-1}) and total categorised vehicle population (%) on major roads in the main business district of Nairobi.

Highly variable causative factors (national economy, climate variability and global aspects) occasion the trend in the consumption of electricity and fuel. By 2029, the waste energy from an exponential trend in the electricity consumption in the city will increase by approximately eight times. The corresponding exponential increase in fuel consumption nationally will be double the current amount.

4.3 Estimated Contribution from the Domestic Sector

The domestic sector includes individual households, institutions and eateries. Energy sources for domestic purposes include electricity (mainly hydroelectric power), charcoal, firewood, LPG and kerosene. Energy is mostly used for lighting, ironing, cooking and heating water. This energy is a function of weather, population, income, and GDP.

Table 1 illustrates the energy consumption at two types of residential estates in Nairobi using averaged systematically randomly sampled data for schools, colleges, hotels and households, averaged over an area of one square kilometre. The middle income residential estate (Buruburu), which is a fairly good representation of the scenario at the CBD, consumed energy of 8.19 W m^{-2} in the period considered, corresponding to between 1.5 and 2.5% of the global radiation for the warmer and colder seasons, respectively (Fig. 2).

Figure 8 shows that about 25.5% of all electricity sold in Nairobi city is used for domestic purposes; a paltry 0.5% is used for lighting streets. It is interesting to note that spreading this domestic load, in the tune of 470 MWh, over the entire province of 696 km^2 amounts to 1.9 W m^{-2}, which is just 0.3 and 0.6% of the global radiation for the warmer and colder seasons, respectively. However, spreading it over the built up space (100 km^2) amounts to 13 W m^{-2}, which is 2.4% of the global radiation in the warm season and 3.9% in the cold season.

Assuming that the economic class structure remains in the same proportion as it is currently, the energy demand will quadruple by 2029. It is worth noting that the current electrical energy demand in the City has not been fully met by the Kenya Electricity Generating company.

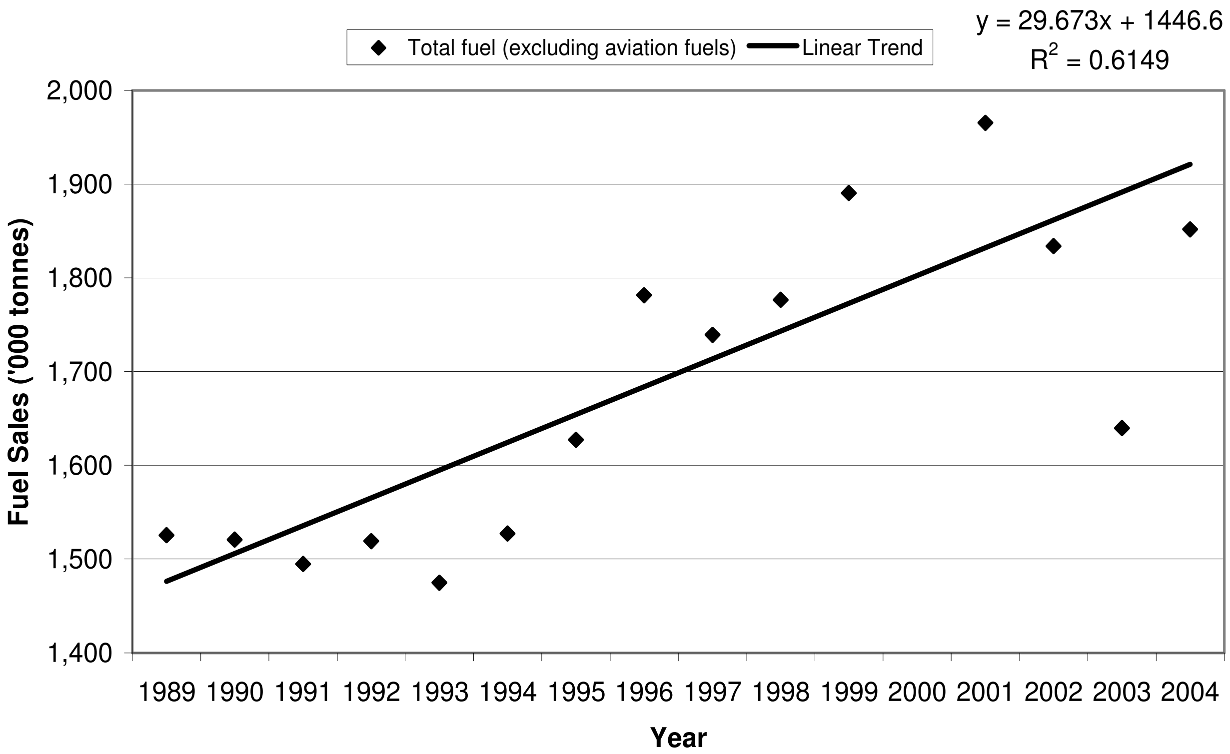

Figure 6: The observed trend of the total fuel sales (excluding aviation spirit and jet/turbo fuel) in Kenya from 1989 to 2004. The trend line equation and coefficient of determination (R^2) are indicated.

4.4 Estimated Contribution from Human Metabolism

The population of Nairobi has risen from about 250,000 people in 1960 to over 2.14 million in 1999 residing in about 649000 households, of whom 54% are male (CBS 2000); the population may quadruple to reach 8 million inhabitants in 2029 if the current trend continues.

Only a minority of the population lives within the City centre. One million folk, by conservative estimates, work in the metro area but live outside the Province. Most of the populace are poor folk, living on less than one US dollar a day. The population density over Nairobi in 1999 of 3,709 persons per square kilometre (CBS, 2000), translates to over 45,000 people residing at the City centre (i.e., 3709 X 12.25 km^2). The metabolic levels used here are by Givoni (1969).

If 150,000 people engage in basal metabolism at the CBD, considering the density imbalances over the City, they would emit anywhere between 10.5 MW and 12.2 MW (i.e., 150,000 X 69.8W and 81.5W). Spreading this energy over the CBD (12 km^2) gives the nighttime energy density of between 0.9 and 1 W m^{-2}. This is between 0.2 and 0.3 % of the global radiation in the warm and cold seasons, respectively (Fig. 2), which is within the sphere of instrumental error.

One million people engaged in light work at the CBD in Nairobi would generate through metabolism between 8.6 and 9.5 W m^{-2} of energy (i.e., 1000000 X 104.8 and 116.4 W spread over 12.25 km^2), which is between 1.6 and 2.9% of the global radiation in the warm and cold seasons, respectively. When involved in sedentary activity, these figures go up to 9.5 and 11.4 W m^{-2} (i.e., 1,000,000 X 116.4 and 139.7 W spread over 12.25 km^2), which translates to between 2.9 and 3.4 % of the global radiation in the warm and cold seasons, respectively. The 15% of the working population in Nairobi who walk or cycle to work (IPCC, 1995) generate during their mobility between 3.0 and 6.8 W m^{-2} (150,000 X 244.4 and 558.7 W) which is between 0.5 and 2.1% of the global radiation.

The metabolic heat component will quadruple by the year 2029 as the population escalates to between 38 Wm^{-2} and 45.6 W m^{-2}. Most of the metabolic energy is used in performing body functions (e.g., muscle movement and organ activity) and only a small fraction of this eventually escapes to the atmosphere as “waste” heat.

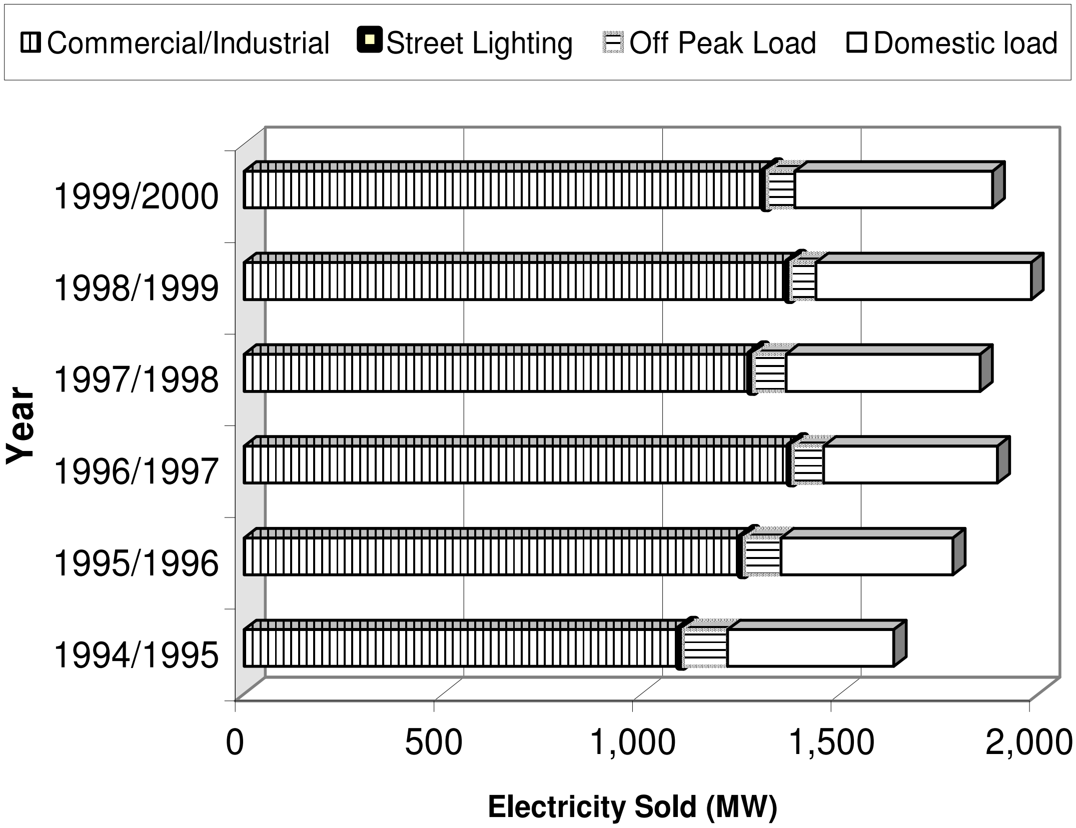

Figure 7: The distribution of electricity utilities sold in Nairobi area region between 1994 and 2000 (Kenya Power and Lighting component).

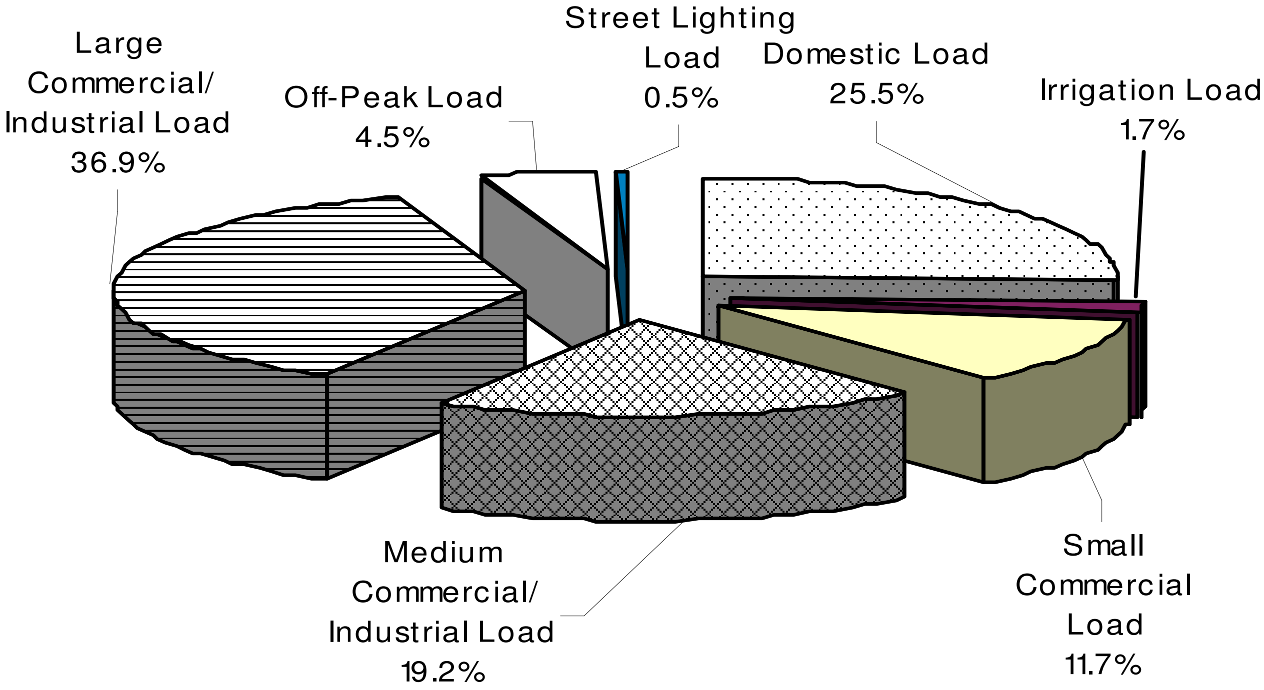

Figure 8: The distribution of electricity sold in Nairobi area region in 1997 (Source: Kenya Power and Lighting Company).

5. SUMMARY AND CONCLUSIONS

The growth and development of Nairobi with respect to the demographic, economic, industrial, infrastructural structures, and the built environment, have favoured an increase in the demand for anthropogenic energy sources, which have swelled the waste heat released into the atmosphere.

This study has shown that the road transport sector yields just about 2.7 W m^{-2} (1.0% of the global radiation); this sector contributes about 4% of the total anthropogenic energy over the City. The contribution from the road sector is likely to rise to 10.8 W m^{-2}, or 3% of the global radiation in 2029 as the City expands. The contribution to the heat budget arising from fuel consumption in the industrial/commercial sector is insignificant. Nonetheless, this sector contributes up to 35.5 W m^{-2} from electrical energy consumption, (6.4% and 10.7% of the global radiation). This energy constitutes 57% of the total anthropogenic energy. This energy will increase by eight times to 284 W m^{-2} by 2029 if the current exponential trend persists. Domestic utilities account for up to 13 W m^{-2}, which is 21% of the total anthropogenic energy, corresponding to between 1.5% and 3.9% of the global radiation for the warmer and colder seasons, respectively. If this energy quadruples by 2029 as projected, it will constitute between 6% and 12% of the global radiation. Human metabolism contributes between 1 and 11.4 W m^{-2}, depending on the activity engaged in, the latter constituting about 3% of the global radiation, and 18% of the total energy. By 2029, this amount will increase fourfold to up to 14% of the global amount. During basal metabolism, the respective contributions from the transport, industrial/commercial, domestic and human metabolism sectors are currently 5%, 68%, 25%, and 2% of the total anthropogenic energy.

The total anthropogenic energy consumption is currently in the tune of 61 Wm^{-2}, or 11% of the global radiation during the warm season and 19% in the cool season. This energy is smaller than that reported for developed countries in temperate latitudes; it is less than the summer (400 Wm^{-2}) and winter (1590 Wm^{-2}) reported for Tokyo (Ichinose *et al,* 1999). The projected increase of the anthropogenic heat component to 393 Wm^{-2} in 2029 if the current demographic, vehicular, and industrial/commercial trends persist, would be substantial. The deduced implication is that this heat would appreciably alter the heat balance of the study area in future particularly during the “cool-dry” season. Anthropogenic heating is also likely to aggravate the temperature rise over the City due to global warming in future.

Acknowledgements: The authors wish to express their gratitude to the staff at the Kenya Meteorological Department, the Nairobi City Council of Nairobi, and the Central Bureau of Statistics of Kenya.

Appendix: The stations considered in Figure 3 were Kasarani (at 1615 m MSL, and 1°13'S 36°53'E, 12 km NE of the city centre), Jomo Kenyatta International Airport (JKIA, at 1624 m MSL and 1°19'S 36°55'E, 12 km SE of downtown), and Moi Air Base (MAB, at 1646 m MSL and 1°16'S 36°52'E, 4 km ENE of the city centre). Others were city centre (1°17'S 36°49'E, 1646m MSL, Basilica grounds), Wilson (1°19'S 36°49'E, 4 km south of the city at 1676m MSL), Dagoretti (1°18'S 36°45'E, 8 km west of the city centre at 1798m MSL) and Ngong (1°23'S 36°40'E, 20 km SW of the city centre at 1981m MSL).

REFERENCES

CBS (Central Bureau of Statistics), 1998. *Kenya Economic Survey*, Central Bureau of Statistics, Statistical Abstracts, 1998.

CBS (Central Bureau of Statistics), 2000. *Kenya Economic Survey*, Central Bureau of Statistics, Statistical Abstracts, 2000.

Changnon, S.A., 1992. Inadvertent weather modification in urban areas: Lessons for global climate change. *Bulletin of American Meteorological Society,* **73**, 619- 627 pp.

EPA (US Environmental Protection Agency,): http://www.epa.gov/heatisland/about/healthenv.html

Garnett, A. and Bach, W., 1965. An estimation of the ratio of artificial heat generation to natural radiation heat in Sheffield. *Monthly Weather Rev*iew, **93**, 383-385 pp.

Garratt, J.R., 1992. *The Atmospheric Boundary Layer*. Cambridge Univ. Press.

George, L. A. and Becker, W.G., 2003. Investigating the urban heat island effect with a collaborative inquiry project. *Journal of Geoscience Education,* **51 (2)**, 237-243 pp.

Givoni, B., 1969. *Man, Climate and Architecture*. Elsevier Publ. Co.

Grimmond, C.S.B., 1992. The suburban energy balance: Methodological considerations and results for a mid-latitude west city under winter and spring conditions. *International Journal of Climatology*, **12**, no 5, 481-497 pp.

Harrison, R., and McGoldrick, B., 1981. Mapping artificial heat release in Great Britain. *Atmospheric Environment*, **15**, 667-674 pp.

Ichinose, T., 2001, Regional warming related with land use change during Past 135 years in Japan. In *Present and Future of Modeling Global Environmental Change: Toward Integrated Modeling*, Eds., T. Matsuno and H. Kida. 433–440 pp. © by TERRAPUB, 2001.

Ichinose T., Shimodozono, K., Hanaki, K., 1999. Impact of anthropogenic heat on urban climate in Tokyo. *Atmospheric Environment,* **33,** 3897-3909 pp.

IPCC, 1995. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate change: Scientific-Technical Analyses*. [Watson, R.T., Zinyowera, M.C., Moss, R.H., Dokken, D.J. (eds.)], Cambridge Univ. Press. Cambridge. UK. 681-708 pp.

King'uyu, S. M., 2000. The urban climate of Nairobi. *M.Sc. Thesis*, Univ. of Nairobi.

Manu, A., Twumasi, Y.A., and Coleman, T.L., 2006. Is it the result of global warming or urbanization? The rise in air temperature in two cities in Ghana. In *Promoting Land Administration and Good Governance.* 5th FIG Regional Conference. Accra, Ghana, March 8-11, 2006. 1-14 pp

McGoldrich, 1980. Artificial heat release from greater London, 1971. *Physics Divisum Energy Workshop Rept.* **No. 20**, 32 pp. Dept. of Physical Sciences, Sunderland Polytechnic, Sunderland.

Nakamura, K., 1966. The city temperature of Nairobi. *Journal of Geography of Japan*, **75**, 316-317 pp.

Offerle, B., Grimmond, C. S. B. and Fortuniak, K., 2005. Heat storage and anthropogenic heat flux in relation to the energy balance of a central European city centre. *International Jounal of Climatology,* **25**, 1405–1419 pp. (Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/joc. 1198)

Oke, T.R., 1987. *Boundary Layer Climates,* Methuen, London. (2nd Ed.).

Okoola, R.E., 1980. The Nairobi heat island. *Kenya Journal of Science and Tech*nology, 1, 53-65 pp.

Opijah, F.J. and Mukabana, J.R., 2004. On the influence of urbanization on the water budget in Nairobi: A numerical study. *Geojournal.* **61**. 121 – 129 pp.

Pielke, R.A., 1984. *Mesoscale Meteorological Modelling*, Academic Press.

Sailor, D.J., 2003, *Streamlined mesoscale modeling of air temperature impacts of heat island mitigation strategies*. Project Report. Mechanical Engineering, Portland State University, Portland, OR, 1-31 pp

Sailor, D. J, 2004. An anthropogenic heating database for major US cities. USA. *Atmospheric Environment,* **38**, (17) 2737-2748 pp.

Twindell, J., and Weir, T., 1986. *Renewable Energy Resources*. E. and F.N. Spon Ltd. London, NY.