

# Climate change and its role in forecasting energy demand in buildings: A case study of Douala City, Cameroon

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The foremost role of a building is to assure the comfort of its occupants. The thermal comfort of a building depends on the outdoor climate and requires a demand in energy for heating and cooling. In this paper, demand of energy (heating/cooling) in the buildings is discussed in Douala, Cameroon. Daily data of the last 40 years coming from five weather stations of Cameroon have been studied. Some forecasts have been carried out with 14 GCM models, associated to three future climate scenarios B1, A2, and A1B. However, only INCM3 of General Circulation Model (GCM) and A2 scenario was used. Energy demand in buildings is valued by HDD (heating degree day) and CDD (cooling degree day) indices. Obtained results show that the temperature evolves more quickly in dry season than in rainy season in Douala. Climate rise indicates an increasing demand of energy in the buildings for cooling. Global Douala heating shows a definite effect on outdoor comfort. From 2045 to 2075, the demand of energy for cooling will be superior to 50%. The total demand in energy for heating in the buildings is estimated to be 67.882 kcal from 1970 to 2000 and will be around 67.774 kcal from 2013 to 2043.

## 1. Introduction

Development of a country is tightly related to a good definition of its energy policy. Energy locates at the center of the economy of a nation. With the boom of construction industry since the 1970s, the surface area of public buildings has experienced a high rate of increase in Cameroon. Energy efficiency of public buildings becomes a key factor affecting the economic and environmental development in Africa and in the entire world. The access to shapes of modern energy brings advantages for the human well-being and the economic development. These modern energies include electricity,

LPG, natural gas, and solar energy. They are more efficient and cleaner and facilitate better conditions of life (Bas *et al.* 2012). Housing and industry remain two sectors where energy consumption has increased rapidly during recent decades in many countries. The most important objective of a building is to provide its inhabitants with a comfortable indoor climate in the respect of energy efficiency. On the other hand, the industrial decision-makers are always in search of techniques allowing them to produce more, while consuming less energy. Many works proved that more than 2.3 billion people count on wood or charcoal for cooking and heating of buildings (Goldemberg 2000; IEA 2010). More

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than 70% of this population depending on this traditional energy type stays in Africa. In Europe and in Asia, several laws are established and applied concerning the use of modern energies and electrification (Sorda *et al.* 2010; Chen and Chen 2011; Toan *et al.* 2011; Roshan *et al.* 2012; Shen *et al.* 2012; Detert and Kotani 2013; Raphael and Heffron 2013). Africa remains as the continent where no sophisticated policy is defined in energy (production and consumption). Today, climate change consequences are one of the main problems of the world (Roshan *et al.* 2012). The impacts of climate change are now more visible. Various surveys conducted at the regional level in different continents show that this phenomenon is progressing. Different emission scenarios provided by the Intergovernmental Panel on Climate Change (IPCC) show that the impacts of climate change will touch all sectors and more particularly natural resources (IPCC 2001, 2007). The vulnerability of African countries in exposure to climate change results from their narrow dependence on sectors sensitive to climate. According to IPCC, 80% of the world needs in energy are covered currently by fossil fuels. The estimates show that oil, natural gas, and coal have at most 47, 67, and 160 years of conventional reserves, respectively. Around 77% of total greenhouse gases emitted by human activities are constituted of CO<sub>2</sub>, 74% of which come from the combustion of fossil fuels. The average sea level has risen from 1.8 mm/year for 1961 to 3.1 mm/year for 1993, due to thermal expansion and melting of glaciers (IPCC 2007). Implications of climate change in consumption of energy in building sectors are visible today, especially in Africa. For some years, the imbalance persisted between the energy offer and demand, during the period of low water in Cameroon. The Cameroon government wrote down lately in the new law on energy, a chapter dedicated to renewable energies notably for what are the facilitation and the guarantee of acquisition of productions. Cameroon, is the second-most forest occupied region in Africa with an area of about 21 million hectares as estimated in 2006 (MINFOF et FAO 2005). 98% of the poor households still use firewood as their main source of energy (MINEE 2004). Cameroon has considerable resources in hydroelectricity. The reserves of natural gas are estimated to be about 186 billion m<sup>3</sup>. Second hydroelectric potential in subSaharan Africa with an amount of 19.7 GW is attributed to Cameroon. Sunshine average is of 4.9 kWh/m<sup>2</sup>/j, but its exploitation remains weak. According to recent studies, wind potential of Cameroon is not negligible and is economically exploitable in the regions of west and north. The law n°2011/022 of December 14, 2011 governing the electricity sector in Cameroon dedicates the support of the state

to the promoters of renewable energies, notably in its articles 63–67 (ARSEL 2013). Degree-day methods are simple, yet efficient and fairly reliable for quantifying the heating and cooling energy demands in a building. The severity of a climate can be characterized concisely in terms of degree-days. Globally, the need for heating and cooling according to the definition is the addition or subtraction of temperature daily means from a definite threshold in a definite period of the year and it is expressed in terms of degree-days. The choice of Douala City as the study area is not made at random; its proximity to the sea constantly results in flooding streets in rainy seasons. Douala is the most industrialized city in central Africa and at the same time the city most affected by the climatic change in Cameroon. The methodology used in this research is described in detail in the survey of Christenson *et al.* (2006).

## 2. Materials and methods

### 2.1 Study area

The study area is constituted of five climatic zones. This study was carried out in a warm zone in sub-Saharan Africa (Cameroon). Cameroon stretches in length from 2 to 13 degree of North latitude, and spreads in large from 9 to 16 degree of East longitude. It covers 475,442 km<sup>2</sup> of area and presents various climatic nuances summarizing all bioclimates of African continent. This diversity is simplified by the distribution of different climatic nuances: in north of 6th parallel, the dry tropical climate dominates; while in the south, equatorial climate becomes more and more humid towards the coastline and Mount Cameroon. Cameroon is divided into three climatic zones, namely, the Sudanese, the Sudano–Sahelian, and the equatorial regions. Cameroon is characterized by an equatorial climate with two main seasons of equal amplitudes: a long rainy season from mid-March to mid-November (8 months) and a short dry season from mid-November to mid-March (4 months). The study was conducted in the equatorial city of Douala.

Douala is the economic capital of Cameroon, the main business centre, and one of the largest cities in the country. It is the most industrialized city in central Africa. It is proven that the industries, the cars, and the buildings emit more than 60% of the total CO<sub>2</sub> in the atmosphere. Douala's port is the main place of entry of cars not only in Cameroon, but also in Chad, and in Republic of central Africa (RCA). This city is located on the Atlantic Ocean coast, from 4° to 4°4'N of latitude and from 9°40' to 9°48'E of longitude, with an area

of nearly 210 km<sup>2</sup>. Climate in Douala is tropical wet and hot, characterised by temperatures between 18° and 34°C, accompanied by heavy precipitation, especially during the rainy season from June to October. The air almost always records 99% relative humidity during the rainy season, and about 80% during the dry season from October to May.

## 2.2 Climatic data

Outdoor daily data of the last 40 years of temperature (minimum and maximum), precipitation and sunshine was taken in five meteorological stations within the study area. Some outdoor data are given in table 1.

The various data are measured from 3 to 10 m in height from the ground and with a frequency of 10–15 min. In selected weather stations, data like the relative and absolute humidity, wind speed, and evaporation are also available. The mentioned stations are selected because their administrative staff was qualified, measuring devices were reliable and also installed in a place far from any type of hindrance. Measurement errors on the temperature and relative humidity are estimated to be  $\pm 0.1^\circ\text{C}$  and 1%, respectively.

## 2.3 Climate change models

In the present research, 14 GCM models and three scenarios have been used (B1, A2, A1B). The most significant input of these models is the rate of emission of greenhouse gases in the future eras. However, a precise final determination is not possible. Accordingly, different emission scenarios with a variety of gas qualities in future have been offered. On the other hand, to define the effect of global warming by means of the rise in global temperature, it was necessary to employ a LARS-WG model. LARS-WG is one of the most well-known meteorological stochastic data-generating models used for generation of the quantities of rainfall, solar radiation, and daily maximum and minimum temperatures in both present and future climates of a meteorological station (Racsco *et al.* 1991; Semenov and Barrow 2002). The first version of the above-mentioned model was invented as a tool for statistical exponential microscaling in Budapest in 1990 (Racsco *et al.* 1991). In a LARS-WG model, some complex statistical distributions are used for modelling of meteorological

variables. Fourier's series estimates the temperature. Daily maximum and minimum temperatures are simulated as stochastic processes with daily standard deviations and means, depending on dry or wet conditions of the relevant day (Orosa *et al.* 2014). In this assessment, Douala's temperature data in the time intervals of 1970–2000, were chosen as the basic data and temperature changes for the years 1985–2005 were studied based on the proposed scenario, so that the proper model accords with the experimental data of temperature in the proposed years. After testing the best model with Pearson correlation coefficient, the changes in Douala's temperature components were predicted in the worldwide heating bed for the periods 2013–2043 and 2045–2075. Based upon these changes, the degree day index values were calculated and compared with those in the past and present periods.

## 2.4 Calculation of heating and cooling degree-days

Degree-day methods are simple, yet efficient and fairly reliable for quantifying the heating and cooling energy demands in a building. Estimations are accurate if the internal temperature, thermal gains, and building properties are relatively constant. The severity of a climate can be characterized concisely in terms of degree-days. According to a recent survey carried out in Douala by Kameni *et al.* (2014), it has been found that the temperature of human comfort varies following the seasons. The threshold temperatures vary for different conditions and as a general rule, the range of 19°–25°C is proposed for human comfort.

In order to estimate the amount of cooling needed in an N-day definite period, equation (1) was used.

$$\text{CDD} = \sum (T - \theta_2), \quad \theta_2 = 25. \quad (1)$$

In equation (1), the CDD is the required amount of cooling and  $T$ , the daily mean temperature. The temperature threshold  $\theta_2$  considered for Douala is 25°C.

In order to calculate the need of  $\theta_2$  to heating, equation (2) must be employed.

$$\text{HDD} = \sum (\theta_1 - T), \quad \theta_1 = 19. \quad (2)$$

In this equation, HDD is the need for heating on the basis of degree-day;  $T$  and  $\theta_1$  have the same

Table 1. Physical measured data for Douala City.

Temperature (°C)			Relative humidity (%)			Precipitation (mm)
Maximum	Minimum	Mean	Maximum	Minimum	Mean	Mean
33.4	17.3	26.2	100	49	62	215.7

concept as in the previous equation and regarding Douala's conditions 19°C has been chosen as the temperature threshold.

The heating degree-days (HDD) and cooling degree-days (CDD) can be defined in accordance with (SIA Standard 1982; McCarthy *et al.* 2001; ASHRAE 2009) the equations (3) and (5):

$$\text{HDD}(\theta_i, \theta_{\text{th}}) = m_k \sum_{k=1}^n = 1(\theta_i - \theta_{e,k}) \quad (3)$$

where  $\theta_i$  is the internal temperature,  $\theta_{e,k}$  the daily mean external temperature,  $\theta_{\text{th}}$  the threshold temperature for heating, and  $k$  is the day number in the year.

In this sense, the annual heating demand of a building  $Q_h$  may be written as equation (4):

$$Q_h = K_{\text{tot}} \text{HDD} - \eta Q_s \quad (4)$$

where  $K_{\text{tot}}$  is the total thermal loss due to transmission and infiltration,  $Q_s$  is the internal heat source and solar gain and  $\eta$  is an efficiency to factor in the share of  $Q_s$  that serves to reduce heating demand.

In equation (5),  $\theta_{\text{tc}}$  is the threshold temperature for cooling:

$$\text{CDD}(\theta_{\text{tc}}) = m_k \sum_k^n = 1(\theta_{e,k} - \theta_{\text{tc}}). \quad (5)$$

Finally, it is interesting to note that, if building properties are assumed to be constant, the cooling energy demand is proportional to the number of CDD.

### 3. Results and discussion

#### 3.1 Standard deviation of temperature

An analysis between the different daily values of temperature shows that during the period from

1970 to 2000, standard deviation between minimal temperatures varied from 0.6 to 1.4. On the other hand, standard deviation between the maximal different values of temperature varied from 1.1 to 1.9 (figure 1). These different standard deviations explain the real effect of temperature on outdoor climate and the comfort of the middle. Standard deviation value is not the same during different months of the study period. In January, standard deviation is nearly the same for the maximal and minimum temperatures. In March, standard deviation is of 1.37 in agreement with the minimal temperatures and 1.85 according to the maximum temperatures. In August, standard deviation decreases up to 0.65 (minimum temperatures), but increases up to 1.6 (maximum temperatures). On the other hand, in December, standard deviation value increases up to 1.0 according to minimum temperatures and decreases up to 1.2 according to the maximum temperatures. These different uncertain variations of temperature can explain the effect of heating and cooling of buildings in different periods of the year.

#### 3.2 Climatic change predictions

After a meticulous analysis of daily temperature data of the last 40 years, coming from five synoptic stations concerning Douala's city and validation of GCM model, the forecast of linear evolution of temperature has been made. As the reference, the year 1984 (average temperature in dry season 26.9°C and average temperature in rainy season 25.7°C) is considered. Figures 2–5 show different linear variations of temperature.

Figure 2 shows the linear evolution of average outdoor temperature from January to April between 1977 and 2040. February is the month where the temperature increases the most (0.071°C). In March, the temperature varies by 0.053°C every

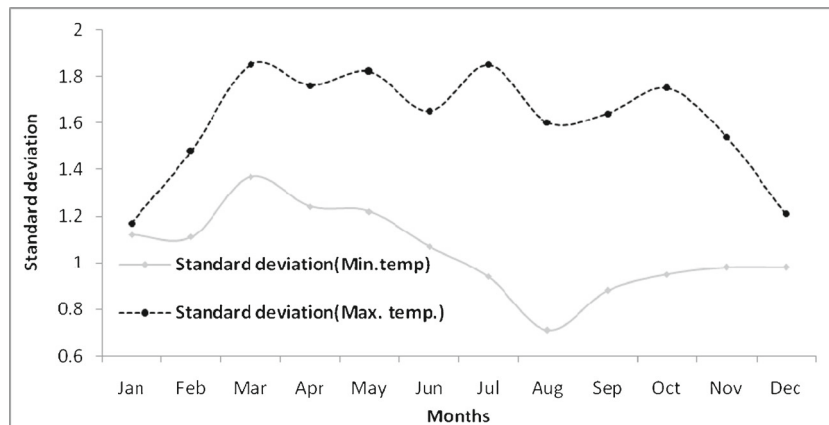


Figure 1. Standard deviation of temperature during the period from 1970 to 2000.

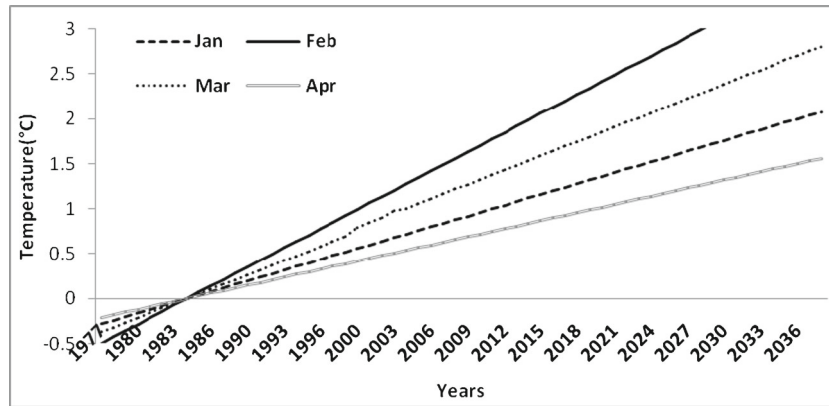


Figure 2. Monthly temperature increment from January to April (1977–2045).

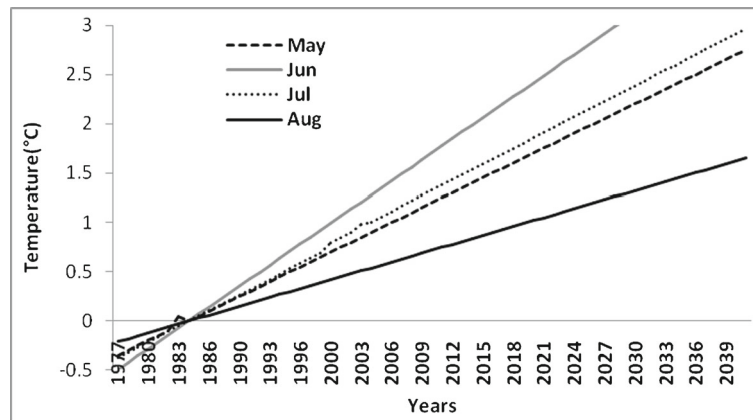


Figure 3. Monthly temperature increment from May to August (1977–2042).

year. In April, despite the heating of Douala City, the increase of temperature is distinctly moderate in comparison with the first three months ( $0.03^{\circ}\text{C}$ ). These different variations of temperature prove that the climate change plays a remarkable role. The average temperature that was of  $25.7^{\circ}\text{C}$  in April 1984 becomes  $27.2^{\circ}\text{C}$  in April 2039. The average temperature of  $26.9^{\circ}\text{C}$  in January 1984 becomes  $29.3^{\circ}\text{C}$  in 2047. Figure 3 shows the variation of temperature from May to August. A linear variation of  $0.072^{\circ}\text{C}$  is observed in June of different studied years, while a variation of  $0.029^{\circ}\text{C}$  is observed in August. In May, the temperature varies  $0.05^{\circ}$  and by  $0.053^{\circ}\text{C}$  in July. The temperature in August 1984 ( $26.2^{\circ}\text{C}$ ) will be  $27.5^{\circ}\text{C}$  in August 2040. The temperature increases more in June ( $0.043^{\circ}\text{C}$ ), in May ( $0.021^{\circ}\text{C}$ ) and in July ( $0.024^{\circ}\text{C}$ ) compared to August. The temperature trend from September to December is shown in figure 4. In this figure, it is observed that the monthly temperature varies more in December ( $+0.154^{\circ}\text{C}$ ), but slightly in October ( $0.03^{\circ}\text{C}$ ). The increase

of the temperature is moderate in September ( $0.04^{\circ}\text{C}$ ).

In figure 5, it is seen that the temperature varies more in hot period than in humid period. The following equations have been established after analysis of the evolution of different temperatures:

$$\Delta t_{\text{Wet}} = 0.032 \cdot \theta \quad (6)$$

$$\Delta t_{\text{Dry}} = 0.048 \cdot \theta \quad (7)$$

where  $\Delta t$  is the mean seasonal temperature increment ( $^{\circ}\text{C}$ ) and  $\theta$  is the time (years).

During the next 30 years, the maximal temperature of Douala will reach  $38.8^{\circ}\text{C}$ . According to IPCC (McCarthy *et al.* 2001; Kont *et al.* 2003; Wesker 2013), it is likely that the climate change will have a certain number of irreversible impacts. If the temperature increases by  $3.5^{\circ}\text{C}$ , the model foresees that from 40 to 70% of recorded kinds could disappear from the surface of the globe.

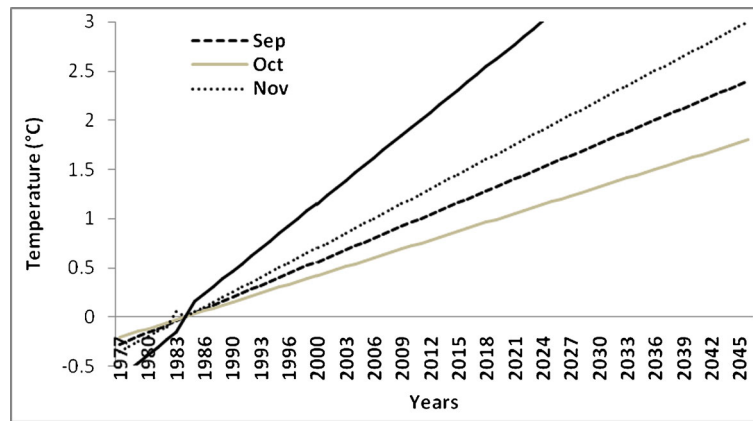


Figure 4. Monthly temperature increment from September to December (1977–2045).

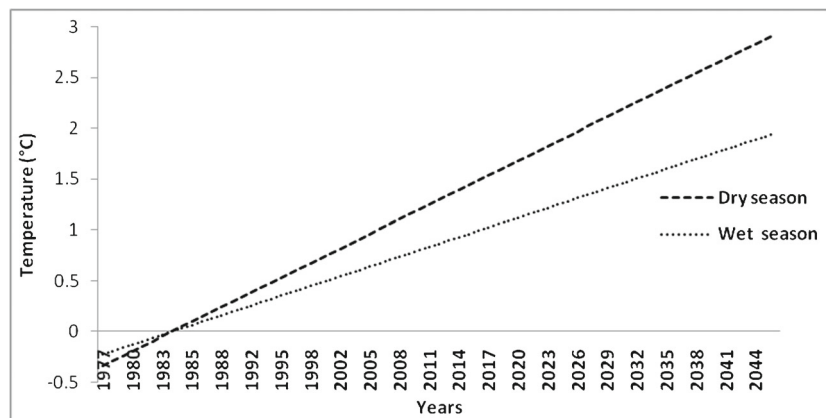


Figure 5. Annual temperature increment.

### 3.3 The correlation of results in real and simulated data

Different forecasts on the climate change for Douala City have been achieved by using 14 GCM models, associated with three scenarios (A2, B1 and A1B). As shown in figure 6, the highest correlation coefficient value between the temporal series of real and simulated data with  $r = 0.91$ , relates to INCM3 model (SRA2). Therefore, it is better to use the simulated results of INCM3 model in order to simulate the temperature components.

### 3.4 Energy demand in buildings

This part of research includes the study on Douala's buildings' need for cooling and heating energy for the three time periods of past, present, and future. The past time scale is related to the data from 1970 to 2000, the present time scale includes the data from 2013 up to 2043, and the future includes the time period from 2045 to 2075.

Results concerning the heating energy in buildings (figure 7) show that August, with an average of

5375.5 degree days had the highest rate in comparison with other months in the different periods. In February where the average heating energy during the different periods is of 4732.5 degree days, the slowest rate is observed. The yearly average rate of heating energy in Douala's buildings during the three periods is 2092.7 degree days. On the other hand, the results also indicate that heating energy in the buildings is unsteady and depends on the period of the year. In October of every period, for example, this energy is 5370, 5301, and 5346, respectively for the periods (1970–2000, 2013–2043, and 2045–2075). Whereas with an average of 5203 degree days in November, this energy falls by 133 degree days compared to the average of the next month. This fall is normal because the outdoor climate of the city is slightly humid in October. 5328 degree days is the total value of heating energy used for the period 1970–2000 in December. A reduction of 4.5 and 57 degree days on this energy allow to get heating energy in December 2013–2043 and 2045–2075, respectively. In the past period (1970–2000), the total maximum cooling energy is obtained in February with an

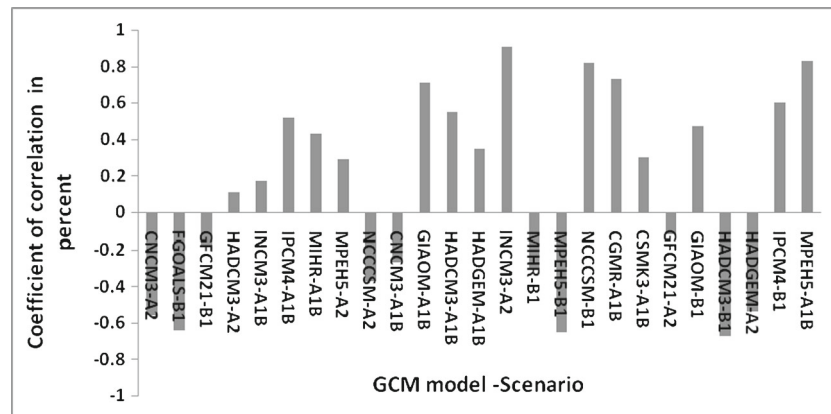


Figure 6. The correlation coefficient values between the real and simulated data series of temperature for the study period 1970–2000.

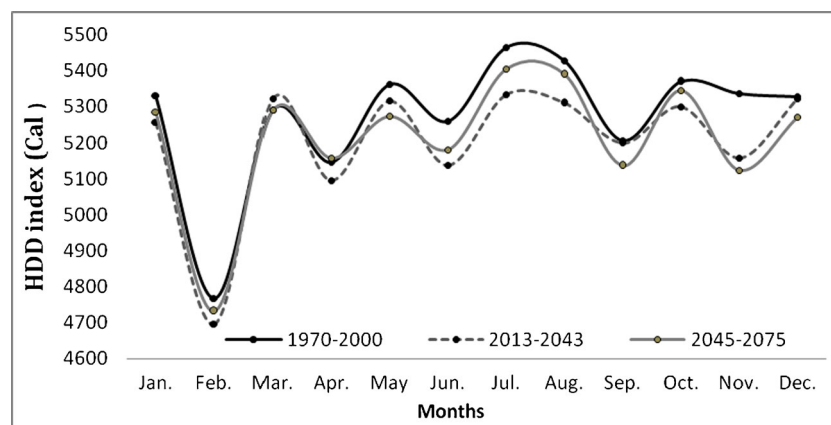


Figure 7. Calculation of the monthly average HDD index during the three study periods.

amount of 2600 degree days (figure 8). In August and September, no energy is used for cooling of buildings. In October, a total of 600 degree days is used for cooling. The increase in outdoor heat rate requires a strong demand of cooling energy, it explains why in December, cooling energy increases up to 2055 degree days during the same period. In the present period (2013–2043), maximum cooling energy is obtained in March (3679.5 degree days). This cooling energy decreases linearly between May and July and a minimum value is obtained in August (1009.5 degree days). From this month, an increasing demand for the cooling energy is observed until December (3049.5 degree days). In the future (2045–2075), a maximum of total cooling energy is obtained in February (3475.5 degree days) then, a minimum is obtained in August (1132.5 degree days). An analysis of general averages of total cooling energy in all three periods indicates that the demand in energy is stronger in dry seasons (January, February, March, April, May, November, and December). Figure 9 shows the total heating and cooling energy during the three periods. It is observed that in the period 1970–2000, heating

energy is 67882 degree days while cooling energy is 21589 degree days. From 2013 to 2043, heating and cooling energy are 67774 and 30861 degree days, respectively. Between 2045 and 2075, heating energy is 67874 degree days whereas cooling energy is 30945. Analysis of these data shows that heating energy demand in the buildings is more in the period 1970–2000 and less in the period between 2045 and 2075. On the other hand, the cooling energy demand is more in the future between 2045 and 2075 and less elevated from 1970 to 2000. Such a result is not surprising, because the more warm it is, the more cooling energy demand is developed.

Figures 10–12 show the daily average of cooling and heating energy of Douala during the three considered periods (1970–2000, 2013–2043, and 2045–2075). The months are chosen according to their average sunshine, monthly total precipitation and especially the variation of temperature. Figure 10 shows the daily average of CDD and HDD indices for hot month (February 1998), warm month (March 2000), slightly warm month (November 1995), slightly cool month (September 1995), cool

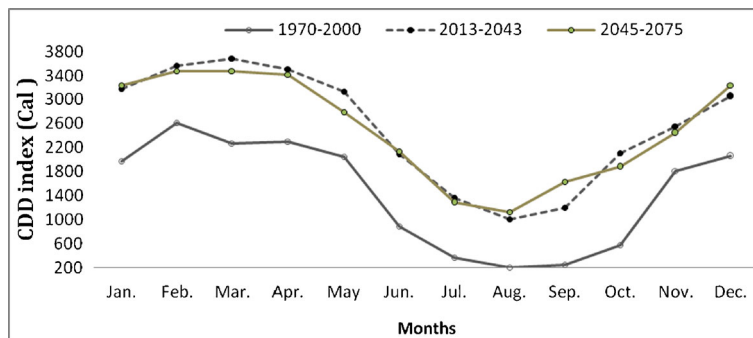


Figure 8. Calculation of the monthly average CDD index during the three study periods.

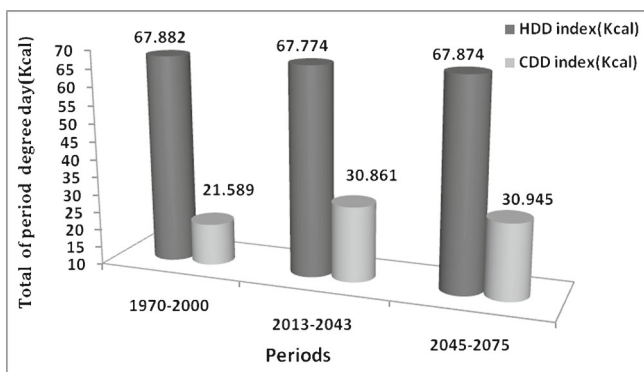


Figure 9. Calculation of the monthly average CDD and HDD indices during the three study periods.

month (July 1981), and cold month (August 1991) during 1970–2000 period. For temperatures varying between 23.7° and 36.5°C (standard deviation of 1.42), corresponding to an average sunshine  $S = 5.73$  kWh/m<sup>2</sup>/j and total precipitation  $P = 7.9$  mm (figure 10a), the cooling energy demand of buildings is 38.09 degree days with a daily average of 5.44 degree days. The energy demand for heating in the buildings is very weak (0.98 degree day). For temperatures varying between 20.0° and 36.3°C ( $SD = 0.98$ ) at  $S = 4.98$  kWh/m<sup>2</sup>/j and  $P = 228.8$  mm (figure 10b), the cooling and heating energy demand is 37.89 and 1.5 degree days, respectively. In figure 10(c), it is shown that for temperatures ranged between 21.0° and 32.5°C ( $SD = 0.77$ ), the cooling energy demand is 14.29 degree days at  $S=4.61$  kWh/m<sup>2</sup>/j and  $P=156.0$  mm. Furthermore, the heating energy is estimated to be 3.4 degree days in the same range. In agreement with figure 10(d), it is observed that for temperatures ranged between 19.6° and 31.5°C ( $SD = 0.59$ ), at  $S = 3.94$  kWh/m<sup>2</sup>/j and  $P = 715.0$  mm, cooling energy demand is estimated at 7.17 degree days, while heating energy is 49.18 degree days. In cool period (figure 10e), at temperatures ranged between 19.5° and 29.7°C ( $SD = 0.65$ ), at  $S=4.03$  kWh/m<sup>2</sup>/j and  $P = 1207.9$  mm,

3.37 degree days is estimated for cooling energy, while 39.51 degree days is attributed to heating energy demand. Finally, for temperatures varying between 19.1° and 29.1°C ( $SD = 0.54$ ), at  $S = 3.98$  kWh/m<sup>2</sup>/j and  $P = 1081.2$  mm, heating and cooling energy demands are 39.92 and 0.7 degree days, respectively. These different results show that cooling energy demand in the buildings is more elevated when temperature and sunshine increase. A weak heating energy is used in the buildings in hot and warm months.

Figure 11 shows the daily average of CDD and HDD indices for hot month (March 2043), warm month (February 2040), slightly warm month (November 2022), slightly cool month (October 2014), cool month (September 2018), and cold month (August 2015) during 2013–2043 period. In figure 11(a), for temperatures varying between 23.3° and 36.9°C ( $SD=1.05$ ), at  $S=5.76$  kWh/m<sup>2</sup>/j and  $P=190.7$  mm, 30.41 degree days is estimated as cooling energy demand, while 0.05 degree day is determined to be heating energy demand. At  $S=5.88$  kWh/m<sup>2</sup>/j and  $P=38.04$  mm, for temperatures varying between 23.1° and 35.9°C ( $SD = 0.97$ ), cooling and heating energy is estimated at 29.31 and 0.98 degree days, respectively (figure 11b). This energy has increased by 0.93 degree day compared to previous month. In figure 11(c), it is observed that at  $S = 4.71$  kWh/m<sup>2</sup>/j and  $P=238.9$  mm and for temperatures varying between 21.8° and 33.2°C ( $SD=0.68$ ), 18.81 and 6.19 degree days are reported as cooling and heating energy, respectively. In figure 11(d), for temperatures ranging between 20.5° and 33.0°C ( $SD=0.99$ ), at  $S = 4.40$  kWh/m<sup>2</sup>/j and  $P=157.2$  mm, heating energy is estimated at 54.27 degree days, while cooling energy demand is 15.96 degree days. During cool month (figure 11e), heating energy increases up to 57.97 degree days and cooling energy decreases to 12.23 degree days, at temperatures between 19.9° and 32.1°C ( $SD=0.38$ ). On the other hand, in figure 11(f), at  $S=3.23$  kWh/m<sup>2</sup>/j and  $P= 444.8$  mm, for the temperatures varying between 18.8°



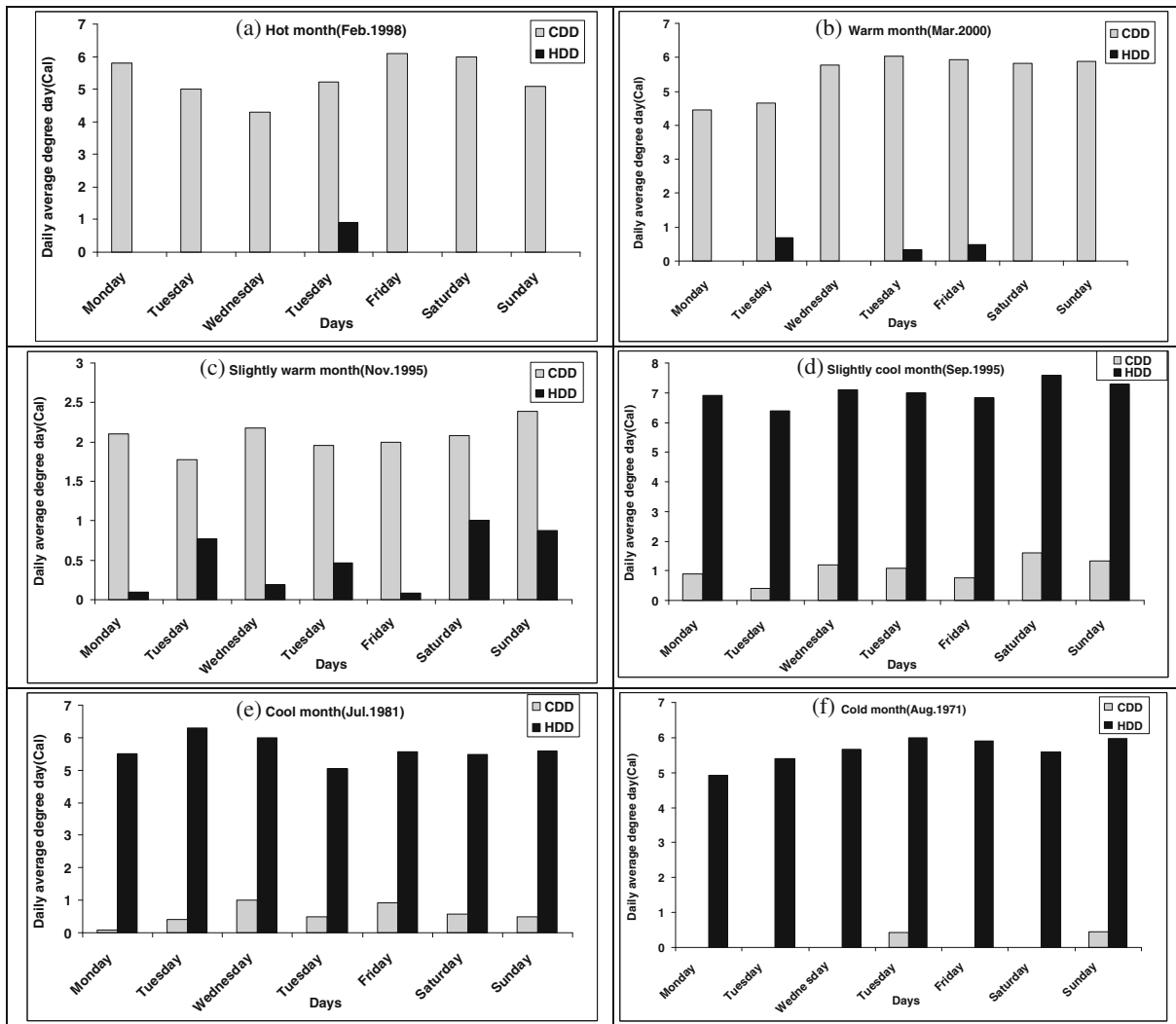


Figure 10. Daily average of CDD and HDD indices for Douala City during the period 1970–2000.

and  $29.9^{\circ}\text{C}$  ( $\text{SD}=0.76$ ), 49.33 and 7.31 degree days, have been detected for heating and cooling energy demand, respectively. A detailed analysis of different energy demands shows that cooling energy increases around 19% during this period. This result is not astonishing, nor surprising, if we bear in mind the global heating trend in this city. This heating is characterized by alarming increase of temperature, especially in dry season.

Figure 12 shows the daily average of CDD and HDD indices for hot month (February 2075), warm month (January 2071), slightly warm month (June 2055), slightly cool month (July 2045), cool month (September 2050), and cold month (August 2046) during 2045–2075 period. In figure 12(a), for temperatures varying between  $23.3^{\circ}$  and  $37.9^{\circ}\text{C}$  ( $\text{SD}=1.1$ ), at  $S=6.21\text{ kWh/m}^2/\text{j}$  and  $P=13.2\text{ mm}$ , cooling energy demand is 36.7 degree days, while 0.03 degree day is estimated to be heating energy demand. In figure 12(b), it is observed that for

temperatures varying between  $21.7^{\circ}$  and  $36.8^{\circ}\text{C}$  ( $\text{SD}=0.99$ ), heating and cooling energy are 1.85 and 34.47 degree days, respectively. For temperatures varying between  $20.7^{\circ}$  and  $34.5^{\circ}\text{C}$  ( $\text{SD}=0.56$ ), at  $S=4.78\text{ kWh/m}^2/\text{j}$  and  $P=232.7\text{ mm}$ , cooling energy demand decreases to 17.42 degree days, while heating energy increases to 8.68 degree days (figure 12c). In figure 12(d), 52.48 and 10.09 degree days are respectively heating and cooling energy demands at  $S=3.87\text{ kWh/m}^2/\text{j}$  and  $P=621.5\text{ mm}$  for temperatures classified between  $21.1^{\circ}$  and  $31.6^{\circ}\text{C}$  ( $\text{SD}=1.12$ ). 53.06 and 11.06 degree days are detected as heating and cooling energy for temperatures between  $21.9^{\circ}$  and  $31.5^{\circ}\text{C}$  ( $\text{SD}=0.78$ ) (figure 12e). In figure 12(f), for temperatures between  $19.1^{\circ}$  and  $29.8^{\circ}\text{C}$  ( $\text{SD}=0.91$ ), at  $S=2.92\text{ kWh/m}^2/\text{j}$  and  $P=1350.0\text{ mm}$ , cooling energy is estimated at 7.95 degree days while heating energy is fixed at 46.35 degree days. The analysis of different energy values shows that contrary to the results of 1976–1995 (Roberts 2008; Delfani *et al.* 2010),

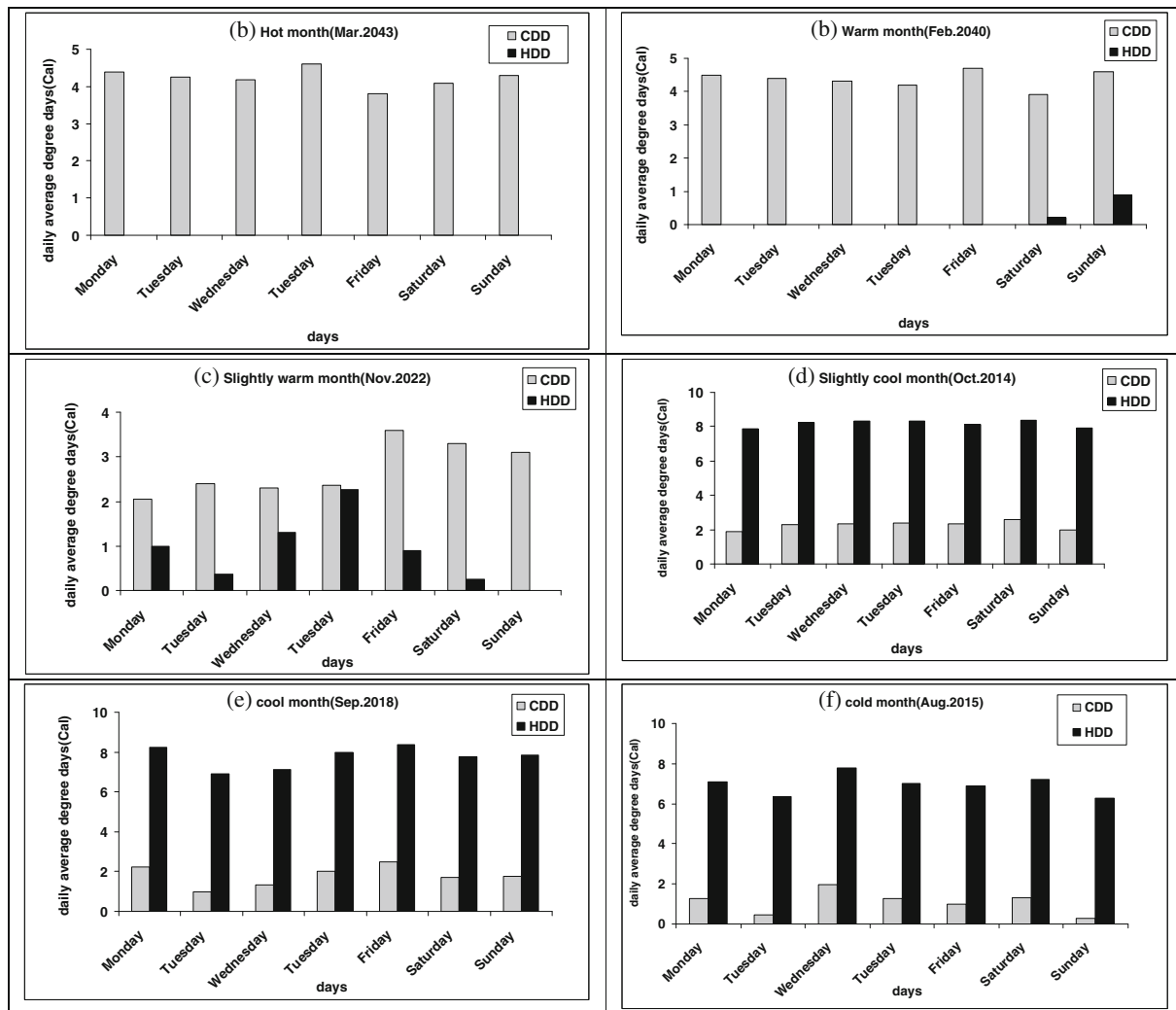


Figure 11. Daily average of CDD and HDD indices for Douala City during the period 2013–2043.

the cooling energy demand increases 19.7% (2013–2043) and around 50% between 2045 and 2075.

This heating and cooling energy demand is more current in the Douala's modern buildings. These different modern habitats have varied geometrical forms with different layers (glass, wood, etc.). These materials are mostly imported with physical and chemical characteristics rather than modified at countries of origin. In Douala's traditional buildings, heating and cooling energy demand is very weak. These kinds of building are comfortable during all the seasons (dry and rainy seasons). More than 80% of energy consummate in these buildings come from biomass, while in the modern buildings, electric energy is most used (Kameni *et al.* 2014). Nowadays, buildings are one of the greatest energy consumers. In the entire world, 30–40% of the total primary energy is used in buildings (Farshid 2013). In 2011, for example, 41.6% of produced energy in USA has been

consumed in the buildings, on the other hand, 34% and 22% have been consumed respectively in Canada and in Brasilia. An increase of 0.4°C, of temperature during the 10 next years, found in this study, is not very amazing, in view of the present heating of the city.

This value confirms the results of several researchers focussed on global warming. The works of Delfani *et al.* (2010), show that the earth area temperature will increase from 1.4° to 5.8°C, in one decade. Cooling energy demands in Douala City will increase more than ever. This is, in part, due to indoor warming and rising of the urban population. Buildings of European and American styles are seen more and more in this city. Today, climate change is one of the main problems of the entire world, with fatal consequences, which humans have to face (e.g., desertification in north Africa, threat of disappearance of lake Tchad in central Africa, flooding in England and France, great tempest in USA, etc.).

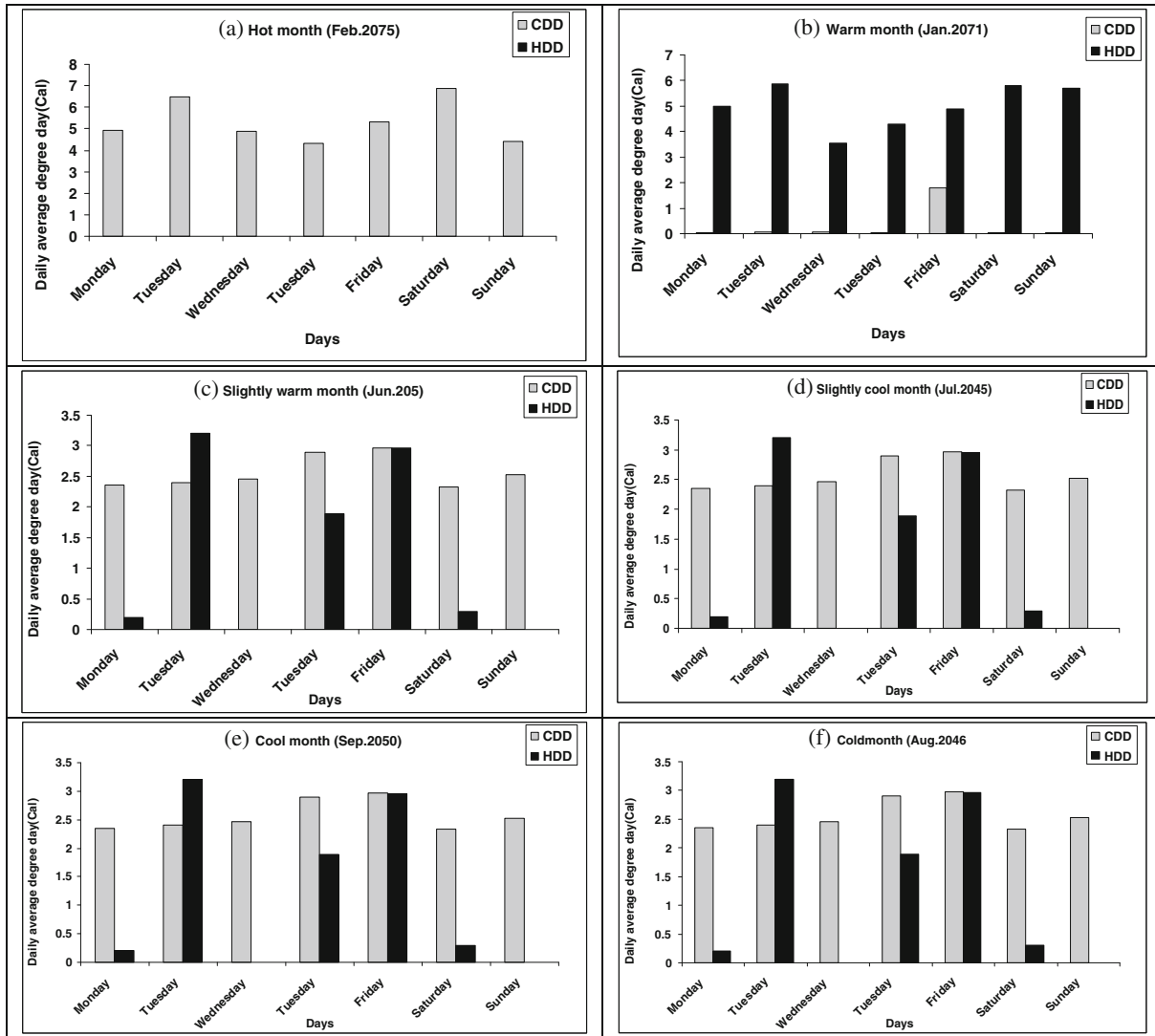


Figure 12. Daily average of CDD and HDD indices for Douala City during the period 2045–2075.

Figures 2–5 show that the temperature in Douala City has not changed in the same manner. It changes in May by  $0.021^{\circ}\text{C}$ , by  $0.024^{\circ}\text{C}$  in July, by  $0.029^{\circ}\text{C}$  in August, by  $0.071^{\circ}\text{C}$  in February, etc. This confirms the results of Luterbacher *et al.* (2004), who show that the rising temperature changes the function of seasons. The average heating energy demand in the buildings of Douala City is 2.262 kcal/year in 1970–2000 and of 2.259 kcal/year, in 2013–2043 period. On the other hand, average cooling energy demand is 0.718 kcal/year in 1970–2000, 1.028 kcal/year in 2013–2043, and 1.072 kcal/year in 2045–2075. An analysis of those different averages shows that heating energy demands decrease every year, whereas, cooling energy demands increase every year. These results are not surprising, because temperature increases every year. Earth warming requires a big cooling energy demand in the habitats. Cooling energy demands will be 1032 degree days in

2075, this value is 89.89% similar to the results found by Roshan *et al.* (2012), which is 1148 degree days in the same year in Iran. Energy demand also varies depending on the month of the year according to the different seasons, as does the air temperature. During different periods, the cooling energy demands for the hot month is 38.09, 30.41 and 36.7 degree days respectively during 1970–2000, 2013–2043, and 2045–2075 periods, whereas the heating energy demands in the same periods are respectively 0.98, 0.05 and 0.03 degree days. It is concluded that heating energy used in the buildings in a hot month is very low. Statistical analysis of the precedent results shows that cooling energy demand increases by 6.29 degree days from 2013–2043 to 2045–2075, whereas heating energy demand decreases by 0.093 degree days from 1970–2000 to 2045–2075. On the other hand, cooling energy demands in the cold month is 0.7, 7.31 and 7.95 degree days respectively in

1970–2000, 2013–2043 and 2045–2075 periods, whereas heating energy demand in the same periods are respectively, 39.92, 49.33, and 46.35 degree days. An analysis of these results shows that cooling energy demand increases to 7.25 degree days from 1970 to 2075, heating energy demand increases to 9.41 degree days from 1970 until 2043 and then decreases to 2.98 degree days from 2043 to 2075.

99.1% of the energy demand is used in hot month (February 1998) as cooling energy, compared to cold month (August 1971) in 1970–2000 period, alone 1.8% of energy demand is used in hot month as heating energy compared to cold month in the same period. On the other hand, 75.96% of the energy demand is used in hot month (March 2043) as cooling energy, compared to cold month (August 2015) from 2013 to 2043, whereas 99.98% of the energy demand is used in the cold month as heating energy compared to warm month during the same period. Finally, 75.33% of the energy demand is used in hot month (February 2075) as cooling energy, compared to cold month (August 2046) of 2045–2075 period, only 0.2% energy demand is used in the hot month as heating energy compared to energy used in the cold month in the same period. Many laws are enacted by the Cameroon government with respect to standard construction, but none of these laws have been implemented by architects and other specialists in the design of buildings. Enormous progress must be made by the occupants in the field of energy efficiency to reduce energy demand in the residential sector. Use of local materials, such as construction tools, must be implemented by Douala's population to reduce energy demand.

#### 4. Conclusion

In this research, a survey has been carried out to value heating and cooling energy demand in Douala city buildings. The effects of climate change are visible, especially in Africa where the flooding increases in the coastal cities. No nation will be saved of its consequences, if nothing is done to fight against the big curse of this century. Several terms are recommended to fight against the climate change, but then they linger to be put in place. Being located within the Congo water basin, considered as the second valuable biosphere reserve after Amazonia, Cameroon could remarkably contribute to the reduction of CO<sub>2</sub> emission in the atmosphere.

Thanks to CDD (Cooling degree day) and HDD (Heating degree day) indices, energy demand has been evaluated. Forecast on the evolution of temperature of Douala City has been studied by

making use of 14 GCM models within three scenarios (B1, A2, and A1B). The INCM3 model (SRA2) has been adopted to forecast the climate and the energy demand in buildings. The first role of a building is to assure a comfortable environment for its occupants. Thermal comfort of buildings is necessary for inhabitant's health and productivity. The outdoor climate affects the indoor comfort of buildings and implies a spreading consumption of energy for heating/cooling of buildings. The alarming elevation of temperature necessitates increasing cooling energy demand in buildings. Results show that the temperature increases faster in dry season (0.048°C/year) rather than in rainy season (0.032°C/year). The increasing trend of temperature would have the potential to augment cooling energy demand up to more than 50% by 2075 in comparison with today. A study covering all regions of Cameroon will be able to orient the population about the heating country and the increasing demand for cooling energy in buildings.

#### References

- ASHRAE Fundamentals Handbook 2009 Energy Estimating and Modeling Methods; SI edn, American Society of Heating, Refrigerating, and Air-conditioning Engineers, Atlanta, GA, Chapter 19.
- Agence de régulation du secteur de l'électricité (ARSEL). [www.arsel.cm](http://www.arsel.cm) (Decembre 2013).
- Bas J, Ruijven van, Schers J, Detlef P and Vuuren V 2012 Model-based scenarios for rural electrification in developing countries; *Energy* **38** 386–397.
- Chen Z M and Chen G Q 2011 An overview of energy consumption of the globalized world economy; *Energy Policy* **39** 5920–5928.
- Climate Change 2001 Working Group I. The Scientific Basis 2001 [http://www.grida.no/publications/other/ipcc%5Ftar/?src=/CLIMATE/IPCC\\_TAR/WG1/042.htm](http://www.grida.no/publications/other/ipcc%5Ftar/?src=/CLIMATE/IPCC_TAR/WG1/042.htm).
- Christenson M, Manz H and Gyalistras D 2006 Climate warming impact on degree-days and building energy demand in Switzerland; *Energy Conversion and Management* **47** 671–686.
- Delfani S, Karami M and Pasharshahri H 2010 The effects of climate change on energy consumption of cooling systems in Tehran; *Energy and Buildings* **42** 1952–1957.
- Detert N and Kotani K 2013 Real options approach to renewable energy investments in Mongolia; *Energy Policy* **56** 136–150.
- Farshid Bagheri, Vahab Mokarizadeha and Mohsen Jabbar 2013 Developing energy performance label for office buildings in Iran; *Energy and Buildings* **61** 116–124.
- IEA World energy outlook 2010 Paris: International Energy Agency.
- IPCC 2001 Technical Summary. Climate Change; In: Impacts, Adaptation and Vulnerability, A Report of Working Group II of the Intergovernmental Panel on Climate Change (eds) McCarthy J J, Canziani O F, Leary N A, Dokken D J, White K S, Cambridge University Press, Cambridge.
- IPCC 2007 The physical science basis; In: Contribution of Working Group I to the Fourth Assessment Report of

- the Intergovernmental Panel on Climate Change (eds) Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K B, Tignor M and Miller H L, Cambridge University Press, Cambridge.
- Goldemberg J 2000 World energy assessment, energy and the challenge of sustainability; UNDP, New York.
- Kameni N, Tchinda R and Orosa J A 2014 Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon: A questionnaire-based statistical study; *Applied Energy* **114** 687–699.
- Kont A, Jaagus J and Aunap R 2003 Climate change scenario and the effect of sea-level rise for Estonia; *Global Planet. Change* **36** 1–15.
- Luterbacher J, Dietrich D, Xoplaki E, Grosjean M and Wanner H 2004 European seasonal and annual temperature variability, trends and extremes since 1500; *Science* **303** 1499–1503.
- MINFOF et FAO 2005 Evaluation, des ressources forestières du Cameroun.
- MINEE 2004 Etude du marché de GPL, Cameroun.
- McCarthy J J, Canziani O F, Leary N A and Dokken D J 2001 IPCC Technical Summary. Climate Change; In: Impacts, Adaptation and Vulnerability, A Report of Working Group II of the Intergovernmental Panel on Climate Change, Cambridge University Press.
- Orosa A, Roshan G R and Negahban S 2014 Climate change effect on outdoor ambiances in Iranian cities; *Environ. Monit. Assess.* **186** 1889–1898.
- Racsco P, Szeidl L and Semenov M 1991 A serial approach to local stochastic weather models; *Ecological Modeling* **57** 27–41.
- Roshan G R, Orosa J A and Nasrabadi T 2012 Simulation of climate change impact on energy consumption in buildings, case study of Iran; *Energy Policy* **49** 731–739.
- Raphael J and Heffron F 2013 The application of contrast explanation to energy policy research: UK nuclear energy policy 2002–2012; *Energy Policy* **55** 602–616.
- Roberts S 2008 Effects of climate change on the built environment; *Energy Policy* **36** 4552–4557.
- Semenov M A and Barrow E M 2002 LARS-WG a stochastic weather generator for use in climate impact studies; User's manual. Version 3.0. <http://www.rothamsted.ac.uk/mas-models/download/LARS-WG-Manual.pdf>.
- Sorda G, Banse M and Kemfert C 2010 An overview of biofuel policies across the world; *Energy Policy* **38** 6977–6988.
- Shen L, Gao T M and Cheng X 2012 China's coal policy since 1979: A brief overview; *Energy Policy* **40** 274–281.
- SIA Standard 381/3 1982 Heating Degree-Days in Switzerland; Swiss Association of Engineers and Architects (in German), Zurich, Switzerland.
- Toan P K, Bao N M and Dieu N H 2011 Energy supply, demand, and policy in Vietnam, with future projections; *Energy Policy* **39** 6814–6826.
- Wesker E 2013 Climate Change; a summary of some present knowledge and theories; [http://www.euronet.nl/users/e\\_wesker/climate.html](http://www.euronet.nl/users/e_wesker/climate.html).