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Impact of Climate Change on Heating and Cooling Energy consumption in Sulaimani city/ Iraq- Kurdistan Region

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Abstraic:

The objective of this study is to analyze the changes in annual, minimum and maximum temperatures due to global warming phenomena during period (1973-2015) in Sulaimani city and its impact on energy consumption on the heating and cooling to get comfort degree for residents in Sulaimani city.

The Microsoft Excel-2010 analysis Toolpak which provides statistical analysis tools were used to discern the mean annual trends. Results show that there is difference in change of temperature over the forty-two years study period, the average annual temperature that the average annual temperature in Sulaimani city increased by (0.0716 C˚/ y) in summer time while at July during the period increase by the rate (0.1844 C˚/ y) in winter time at January, The linear trend analysis for the monthly maximum temperature for January and July for period (1973-2015) is shown in figure (5), the trend analysis cleared the rate of increase in January (0.1777 C˚/ y) and in July (0.0606 C˚/ y), also the trend analysis of monthly minimum temperature for the same period shows rate of increase in temperatures, January (0.1751 C˚/ y) and July (0.0667 C˚/ y), for minimum temperature than maximum temperature (about 0.751 C˚).

By using data of daily electricity consumption and temperature for the period 1973-2015 in Sulaimani, the variation of energy consumption and the correlations between energy consumption and temperature are analyzed. In order to determine the months of need for cooling and months for heating in Sulaimani city, the temperature (18.33 C˚) was essentially taken as the thermal threshold for heating and (23.89 C˚) as the thermal threshold for cooling.

For the period of 1973-2015, the annual CDD and HDD of Sulaimani are calculated and a linear trend analysis shows that in warm months (April to October), the CDD would increase at a rate of ( ) while in cold months (C˚ d) November to March) the HDD would decrease at a rate of (C˚d). A positive relationship was obtained between high temperatures and the amount of energy use in cooling while the linear relationship and discontinuities emerge in cold seasons.

Introduction

Climate change impacts are expected throughout the energy system, through the demand side, the balance of heating and cooling demand patterns is changing due to rising temperatures, (Ebinger and Vergara, 2011).
Increased concentration of atmospheric greenhouse gases (GHG) due to massive industrialization and widespread use of fossil fuels in the last century has changed the global energy balance (Wentz et al., 2007).
several studies reported that the Earth's temperature has increased by 0.74 °C in the last hundred years (1906–2005); the increase became much significant after 1970, with a rate of 0.15 °C/ decade according to the Intergovernmental Panel on Climate Change (IPCC) in 2008, (IPCC, 2013). Changes in temperature cause increase in the energy consumption around the world, these changes in temperature get involved in temperature extremes and the minimum (Song et al., 2014; Matiu et al., 2016).
Amongst various climatic factors, which may affect the energy consumption, temperature is the most dominant one (Yan, 1998).
Temperature is an important climatic component in the spatial expansion of cities, because spatial expansion reflects the most use of building materials like Stones, concrete blocks, and these materials are known for their high temperature absorption, and this process adds to the temperature of the air.
The majority of thermal energy added to the environment of the city is the product of various human activities within cities and studies indicate the impact of the rise in the population in urban temperatures, multiplied by ten times the city temperature rises one degree Celsius. In addition to these factors global climate change added degrees to the urban environment in general, which causes of increasing energy for cooling and heating operations.
In this paper we study the climate change in Sulaimani city through the increase of temperature for the period (1973-2015) and study the impact of this increase on energy consumption for a better energy management.
In the first part of this study the historical temperature record from 1973-2015 studied and the statistical analysis were conducted on the data.
In this paper we study the climate change in Sulaimani city through the increase of temperature for the period (1973-2015) and study the impact of this increase on energy consumption for a better energy management.
In the first part of this study the relationship between temperature and electricity consumption are investigated. Based on this relationship, the base temperatures for cooling and heating demand are derived.
In the following sections, relationships between the energy consumption and two climatic indices, namely cooling degree-days (CDD) and heating degree-days
(HDD), are used to investigate the correlation with energy consumption in hot and cold months, respectively. With CDD, the climate influence on the cooling energy consumption is assessed and with HDD the heating requirement is estimated. Finally, by applying the future projection of temperature data, the trend in CDD and HDD for 2011{2050 are predicted.

2-Study area and climate:

The astronomical position is one of the most important factors determining the Sulaymani city climate fall within the climate of Mediterranean region, which is characterized by high temperatures in the summer, the mean temperature in the summer reach 33.27 C˚ in June which is the hottest months. The winter is characterized by decrease in temperature and cold, the mean temperature reaching about 6.66 C˚ in January which is one of the coldest months.
Average amount of rain falling annually in Sulaimani city is about (638 mm).

Figure (1): Location of the studied area

3-Data:

In this study, the daily and monthly mean temperature data from 1973 to 2015 were obtained from the Sulaimani metrological Climate Center (SMCC) (853 m. a.s.l). Since 2001, another meteorological observation stations have been established in Bakrajo area (BMCC) (Fig.2). The two stations provide daily, hourly and even more detailed meteorological observations.

Figure (2): SMCC and BMCC location map

In this study, the researcher used the inductive and analytical method in the analysis of temporal variation of the average annual temperature and the maximum and minimum temperature for all 43 years and their positive and negative deviations during the study period using the Microsoft Excel-2010 analysis Toolpak which provides statistical analysis tools, these tools uses the appropriate statistical or engineering macro functions to calculate and display the results in an output.
Table (1, 2, 3 and 4) shows the annual mean temperature at Sulaimani metrological Climate Center for the period 1973 to 2015.

Table (1): annual mean temperature for Sulaimani for the period (1973-1985)

Months	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.
Jan.	1.6	2.6	5.3	5.4	1.9	6.4	6	3.6	6.8	4.5	1.6	7.6	8.1
Feb.	8.3	3.9	5	3.9	10.4	9.1	9.9	6.3	7.4	2.8	5	8.7	4.1
Mar.	10.3	10.3	10.1	7.9	12.9	11.8	10.8	11	11.5	8.9	9.3	12.1	8.6
Apr.	14.6	14.1	18.4	14.5	15.8	15.7	17.1	16	15	17.2	15.8	16.5	17.1
May.	21.6	23.3	20.7	19.9	22.2	22.7	22.4	17.8	20	22.4	22.3	20.1	24
Jun.	27.1	29.1	28.9	28	28.3	27.1	28	29.7	28.1	28.3	27.7	29.6	28.9
Jul.	30.9	31.8	32	30.6	31.5	33.1	31.7	34.5	31.2	30.6	31.8	34.1	28.9
Aug.	33.3	30.3	31.5	32	32.5	30.9	33	32.4	31.5	30.5	30.6	30	33.4
Sep.	28.2	26.6	22.8	25.9	21.8	27.6	30.7	26.8	28.8	28.3	27.3	28.6	28.5
Oct.	23.6	23.2	19.8	19.5	18.9	22.7	21.7	20.9	22.2	18	21.2	21	22
Nov.	11.5	14.3	13	15.1	13.2	9.8	15.8	13.8	12.4	9.8	15.6	12.3	15.7
Dec.	7.3	6.5	5.4	9.7	7.5	8.4	6.9	8.9	9.9	5.1	8.4	5.8	7.3
Total	18.2	18	17.7	17.7	18	18.7	19.5	18.4	18.73	17.2	18.05	18.87	18.88

Table (2): annual mean temperature for Sulaimani for the period (1986-1997)

Months	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.
Jan.	7	8	5.4	2.1	4.6	3.025	1.4	4.9	8.8	8.7	6.5	6.9
Feb.	8.4	10.4	6.6	6.1	5.9	4.4	2.8	6.3	6	9.4	8.6	4.9
Mar.	11.6	8.4	10	12	13.1	7.8	2.4	11.4	13.4	12.6	9.8	8.4
Apr.	17.6	15.7	16.3	20.7	16.9	16.2	15.4	15.4	17	15.6	16.6	15.4
May.	20.7	24.2	22.8	24.6	23.2	21.48	19.7	19.5	23.6	23.9	25	23.2
Jun.	27.6	29.3	26.2	28.6	28.7	27.28	25.8	28	25.7	28.5	28.4	29.4
Jul.	34.2	32.5	32.5	34	33.8	32.85	31.9	33.5	32.6	33.4	34.6	31.8
Aug.	33.6	31.9	37.3	32.1	30.7	30.68	30.6	32.5	32	31.4	32.8	31.3
Sep.	31	32.2	27.9	26.8	27.8	27.48	27.1	27.9	29.4	30.2	27.8	26.8
Oct.	22.4	19.1	21.1	22.9	21.3	21.7	21.8	22.2	23.5	21.3	20.6	21.3
Nov.	11.4	14.5	12	13.5	16.4	15.1	12.2	11.3	12	13.3	15.7	14.3
Dec.	6.8	7.7	7.8	8.2	7.9	6.25	5.6	9.6	4.4	7.3	11.1	8.7
Total	19.36	19.49	18.83	19.3	19.19	17.85	16.39	18.54	19.03	19.63	19.79	18.53

Table (3): annual mean temperature for Sulaimani for the period (1998-2009)

Months	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.	Av.
Jan.	4.1	9.1	5.4	7.1	5.2	7.2	7.4	6.2	5.3	5.7	3.1	6.8
Feb.	6.5	9.4	7	8.1	9	6.3	7.1	6.4	8.3	8.6	7.2	9.9
Mar.	11.1	13.3	10.4	14.7	13.6	9.7	14.6	11.7	14.2	11.8	16.6	12.0
Apr.	17.9	18.2	18.4	17.8	14.9	16.9	16.1	18.8	19.2	15.2	21.5	16.0
May.	23.3	25.4	23.9	22.9	22.5	23.9	21	23.7	23.7	25.6	23.9	23.9
Jun.	31.4	30.3	29.9	29.5	29.1	29.2	28.8	29.5	31.1	30.5	30.0	29.9
Jul.	33.8	22.8	35.8	33.4	32.6	32.4	32.5	34.5	32.3	32.9	33.4	32.4
Aug.	35.2	34.2	32.9	33.1	31.2	33.4	31.5	32.9	35.1	33.0	34.7	31.6
Sep.	28.8	27.8	27.7	28.3	28.1	27.3	29	28	28.3	29.4	28.9	26.2
Oct.	23	22.9	19.9	22.3	23.4	23.3	23	21.5	22.4	24.1	22.1	22.5
Nov.	18.2	13.2	13.4	13.1	14.6	13.2	12.1	14.3	12.7	15.0	14.1	13.2
Dec.	13.3	10.3	8.4	8.7	6.4	8	6.9	11.5	7.2	8.7	9.4	9.8
Total	20.55	19.74	19.43	19.92	19.22	19.23	19.17	19.92	19.98	20.04	20.41	19.52

Table (4): annual mean temperature for Sulaimani for the period (2010-2015)

Months	2010 Av.	2011 Av.	2012 Av.	2013 Av.	2014 Av.	2015 Av.
Jan.	10.3	6.6	6.05	7.45	7.7	7.6
Feb.	10.3	8	6.9	10.3	9.05	9.7
Mar.	14.8	12.7	9.25	13.85	13.4	12.85
Apr.	17.5	17.2	19.65	27	17.7	17.05
May.	23.2	22.85	24.75	23.55	24.55	24.55
Jun.	31.1	30.05	30.65	30.05	30	25.1
Jul.	33.8	34	33.5	33.2	33.4	34.8
Aug.	34.6	32.75	33.45	32.65	33.85	34.65
Sep.	30.7	27.9	29.35	27.25	28.2	30.45
Oct.	23.3	20.7	23.2	20.85	21.45	22.7
Nov.	17.0	10.75	15.6	14.85	13.2	13.3
Dec.	11.7	9.15	9.55	6.95	10.4	7.95
Total	21.52	19.39	20.16	20.66	20.24	20.06

4-Average monthly and annual temperature trends in Sulaimani city:

After comparing the average monthly and annual temperature values to assess the average monthly and annual trends of the temperature in the study area and to analyze these thermal variations in the light of temperature values, these results show us:

1- The lowest monthly temperature averages were recorded during the first period (1973-1975) in January (3.2 C˚) as shown in table (5).
2- The highest monthly temperature averages were recorded during the fifth period (2006-2015) in July and August (33.6 C˚) as shown in table (5).

Table (5): annual mean temperature for Sulaimani for 1973-2015

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	ave
1973-1975	3.2	5.7	10.2	15.7	21.9	25.7	31.6	31.7	27.4	22.2	12.9	6.4	17.9
1976-1985	5.2	6.8	10.5	16.1	21.3	28.4	31.8	31.5	27.4	20.8	13.4	7.8	18.4
1986-1995	5.7	6.9	10.5	16.7	22.5	27.6	33.2	32.5	28.9	21.7	13.0	7.3	18.9
1996-2005	6.5	7.3	11.7	17.1	23.5	29.6	32.4	32.9	28.0	22.1	14.2	9.3	19.6
2006-5015	6.7	8.8	12.2	18.0	24.1	30.3	33.6	33.6	28.7	22.3	14.0	9.1	20.1
ave	5.4	7.1	11.0	16.7	22.6	28.3	32.5	32.4	28.1	21.8	13.5	8.0	19.0

3- The monthly averages of temperature in the period (1986-1995) and the period (2006-2015) shows an increase in temperature in all the months of the year, in compare with the rest average data, figure (3).

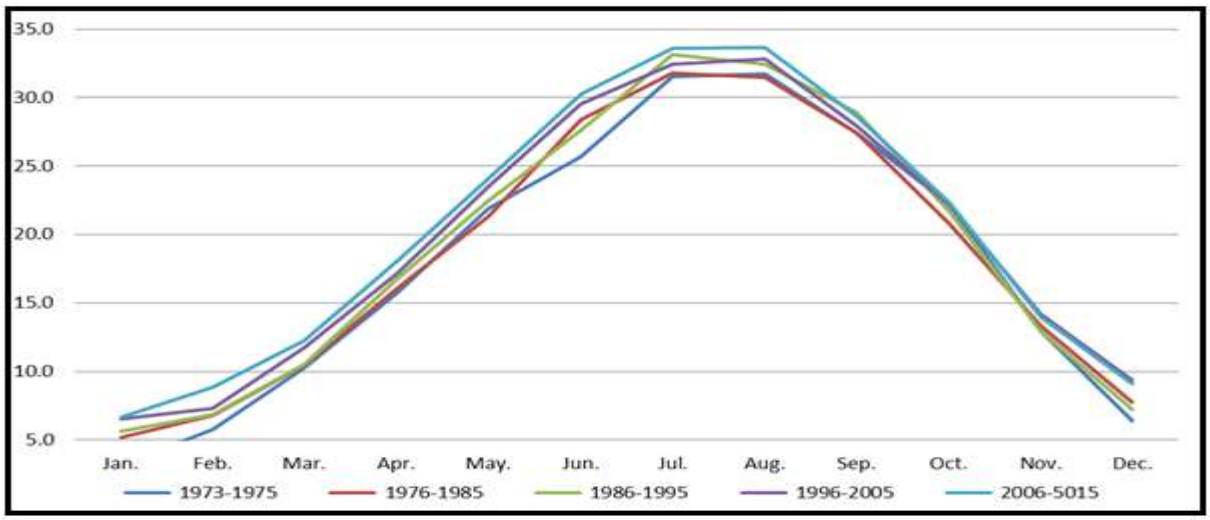


Figure (3): Monthly temperature averages from (1973-2015)

To ascertain the trends of temperature change of Sulaimani city during 1973-2015 the mean annual and maximum with minimum temperature during winter and summer the data subdivided into seasons, this is to know whether certain seasons show consistently higher or lower temperature trends than others, The results obtained for the seasons are shown in Table (6), which clearly indicate that temperature trends over the studied period are not consistent between sea-sons. The comparison between these two seasons was estimated by taking the maximum and minimum temperature and annual rate for the months of January and July of (1973-2015),

Table (6): Maximum, Minimum and annual temperature rate for January and July from 1973 to 2015.

The linear trend analysis shows that the average annual temperature in Sulaimani city increased by (0.0716 C˚/ y) in summer time at July during the period (1973-2015) and (0.1844 C˚/ y) in winter time at January during the **same**

Months		1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Ave	Jan.	1.6	2.6	5.3	5.4	1.9	6.4	6.0	3.6	6.8	4.5	1.6	7.6	8.1	7.0	8.0	5.4	2.1	4.6	3.0	1.4	4.9	8.8
	Jul.	30.9	31.8	32.0	30.6	31.5	33.1	31.7	34.5	31.2	30.6	31.8	34.1	28.9	34.2	32.5	32.5	34.0	33.8	32.9	31.9	33.5	32.6
Max	Jan.	6.2	5.7	9.3	9.5	5.3	10.5	9.8	6.7	10.8	8.9	5.1	12.1	12.6	11.2	13.2	8.7	6.2	8.2	6.3	4.4	8.8	12.5
	Jul.	37.8	38.3	38.7	36.8	37.9	39.4	38.6	41.4	35.3	37.6	38.8	40.9	33.8	41.3	38.2	37.9	41.3	40.2	39.8	39.4	39.9	38.8
Min	Jan.	-2.9	-0.4	1.3	1.3	-1.5	2.4	2.3	0.6	2.8	0.2	-1.9	3.1	3.7	2.8	2.8	2.1	-1.9	1.0	-0.3	-1.5	1.1	5.1
	Jul.	24.1	25.4	25.3	24.4	25.2	26.8	24.9	27.6	27.2	23.7	24.8	27.3	24.1	27.2	26.8	27.2	26.7	27.4	25.9	24.4	27.2	26.4
Months		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	total Ave
Ave	Jan.	8.7	6.5	6.9	4.1	9.1	5.4	7.1	5.2	7.2	7.4	6.2	5.3	5.7	3.1	6.8	10.3	6.6	6.1	7.5	7.7	7.6	5.4
	Jul.	33.4	34.6	31.8	33.8	22.8	35.8	33.4	32.6	32.4	32.5	34.5	32.3	32.9	33.4	32.4	33.8	34.0	33.5	33.2	33.4	34.8	32.5
Max	Jan.	12.9	10.0	10.8	7.6	13.2	9.3	11.4	8.8	11.1	10.8	10.0	9.1	9.8	7.1	11.8	14.3	10.7	10.3	11.7	12.0	12.2	9.7
	Jul.	38.4	40.5	38.2	40.6	28.0	41.8	39.3	38.0	38.9	38.8	40.8	38.6	38.8	39.9	38.5	40.6	40.7	39.9	40.4	40.2	42.5	39.0
Min	Jan.	4.6	3.1	3.0	0.7	5.0	1.6	2.8	1.7	3.4	4.0	2.5	1.6	1.5	-1.0	1.9	6.3	2.5	1.8	3.2	3.4	3.0	1.8
	Jul.	28.4	28.7	25.4	27.0	17.6	29.9	27.5	27.3	26.3	26.2	28.3	26.1	26.9	26.9	26.4	27.0	27.3	27.1	26.0	26.6	27.1	26.3

period (1973-2015), from this we observe that in the cold season the increase in the annual average temperature was higher compared to the warm as shown in Figure (3).

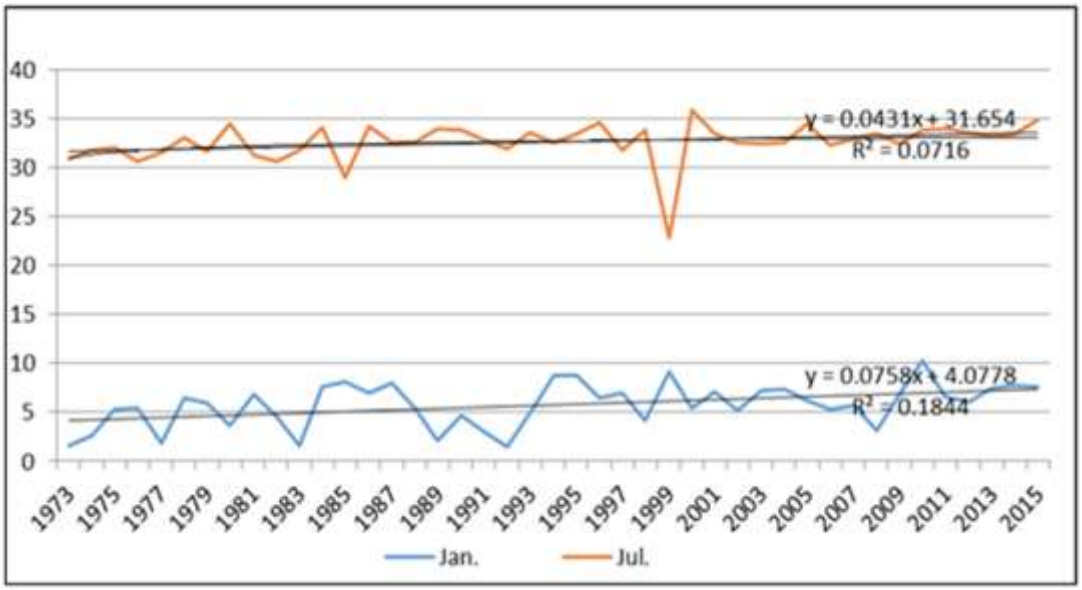


Fig (4): Average annual temperature trend in Sulaimani city during (1973-2015)

The linear trend analysis for the monthly maximum temperature for January and July for period (1973-2015) is shown in figure (5), the trend analysis cleared the rate of increase in January (0.1777 C˚/ y) and in July (0.0606 C˚/ y), also the trend analysis of monthly minimum temperature for the same period shows rate of increase in temperatures, January (0.1751 C˚/ y) and July (0.0667 C˚/ y), figure (6).

It is note that the most significant trends in all clusters are found in winter and summer, but a definite trend of warming occurs in winter season, this is in line with global expectations of a global temperature increase in winter (Hansenet al., 2010).

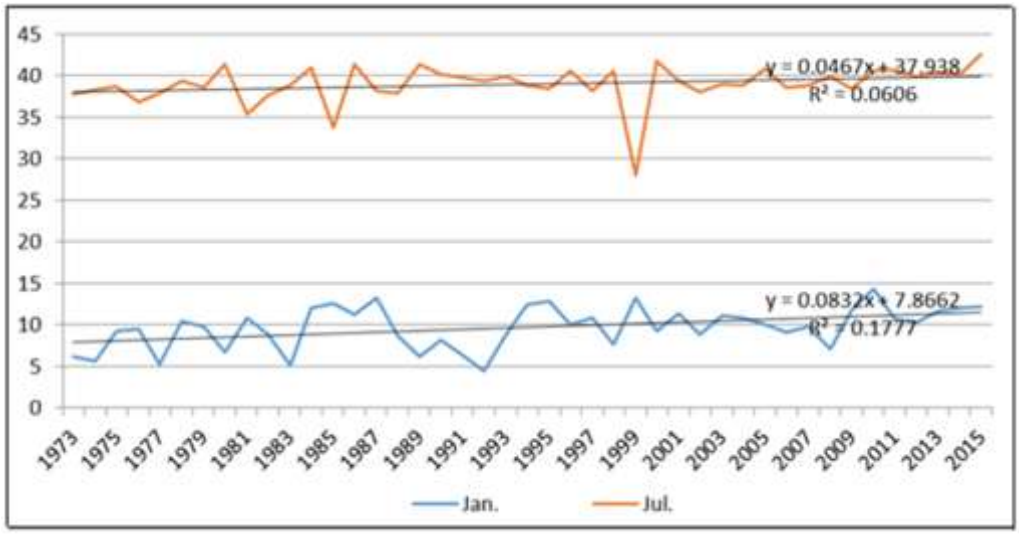


Fig (5): Maximum temperature trend in Sulaimani city during (1973-2015)

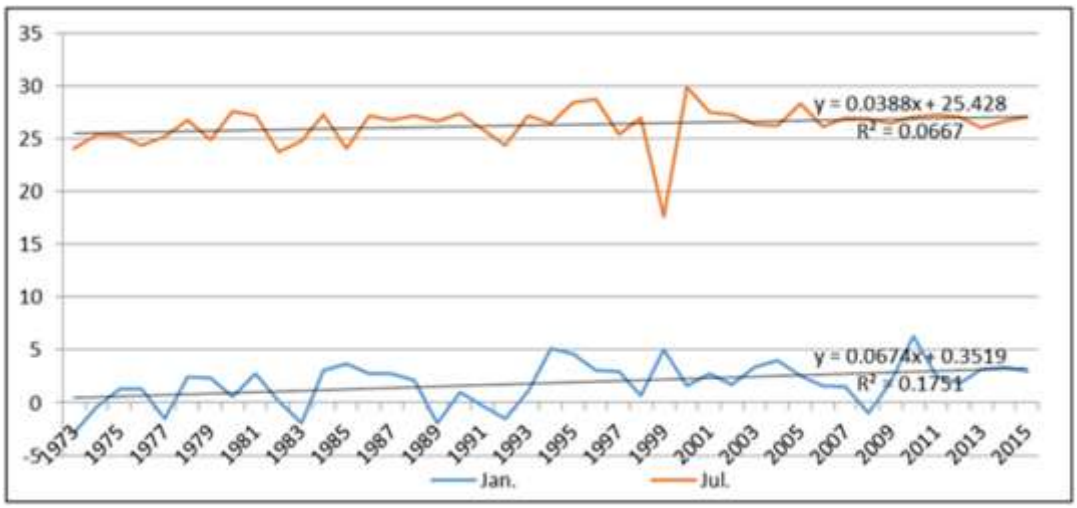


Figure (6): Minimum temperature trend in Sulaimani city during (1973-2015)

5-Analysis of the correlation between temperature and power consumption:
The temperature is one of the most effective climatic elements on human activity has damaged the first civilizations of humans in areas that did not need the heating and cooling.
The temperature data required for the assessment of heating and cooling changes due to climate changes can be summarized in terms of Heating Degree Days (HDD) and Cooling Degree Days (CDD); they affect the amount of electricity consumption and used these arithmetic equations:

$$Hdd = \frac{(18.33 - Tmax) + (18.33 - T\,min)}{2}$$

$$Cdd = \frac{(Tmax - 23.89) + (T\,min - 23.89)}{2}$$

For each month of the year, daily temperature values are collected to get the monthly values of CDD and HDD and finally the annual values of CDD and HDD estimated (Moustris et al, 205). In order to determine the months of need for cooling and months for heating in Sulaimani city, the temperature (18.33 C˚) was essentially taken as the thermal threshold for heating and (23.89 C˚) as the thermal threshold for cooling. This choice was based on researches (Roshan & Grab, 2012; Omidvar et al, 2016).
The result of the CDD and HDD values is shown in table (7) below:
Table (7): Annual CDD and HDD values for Sulaimani city during (1973-2015)

The amount of annual accumulated temperature per month was calculated and should be reduced in more than thermal threshold to create a perfect atmosphere to suit human comfort. The need for heating for three months December, January and February of Sulaimani station was calculated either as the need for cooling that extended to seven points for the

year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
hdd	3533.9	3629.7	3604.9	3541.4	3210.2	3130.6	2935.1	3271.4	3042.0	4396.2	3574.0	3143.8	3181.9	3141.7	3015.7
cdd	1962.2	1866.4	1782.1	1573.9	1719.2	1904.8	2006.3	1933.6	1747.8	1610.8	1767.7	1942.7	1891.4	2195.1	2131.4
year	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	
hdd	3360.4	3145.8	3036.2	3755.7	4460.3	3272.8	3101.7	2791.4	2833.9	3286.8	2813.6	2403.1	3127.2	2671.7	
cdd	2218.0	2247.3	2027.9	1843.6	1591.1	1888.3	1959.3	1948.2	2181.4	1823.9	2523.9	1858.1	2202.9	2115.8	
year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	
hdd	2881.7	3027.2	2950.7	2759.2	2840.5	2838.6	2646.2	2705.9	2073.2	3004.0	2866.1	2474.4	2592.8	2792.4	
cdd	1931.0	2089.6	1908.5	2178.4	2313.8	2291.1	2366.8	1946.1	2451.6	2105.6	2351.0	2333.7	2284.5	2294.1	

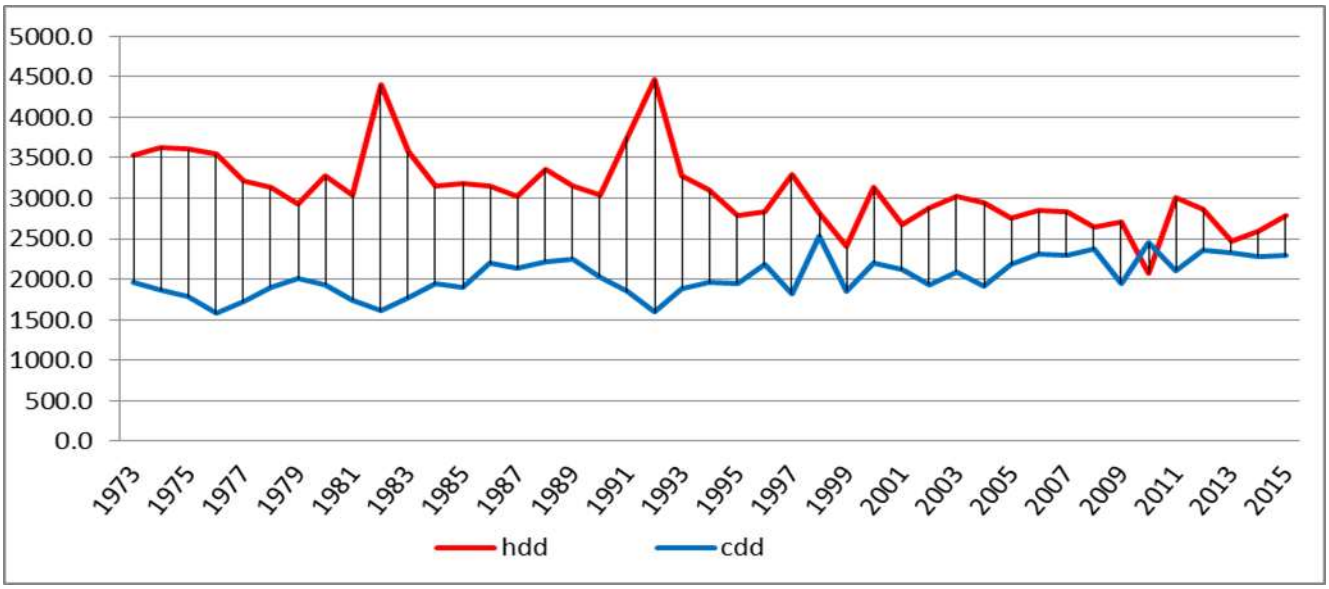
Sulaimani station, May, June, July, August, September and October.

the table shows that the city of Sulaimani city needs cooling and heating operations throughout the year and the heating process in the retreat with the increase in temperatures in the cold seasons up to (3- 4 C˚)degrees of temperature, where we show from the values (HDD and CDD) that the largest value of heat accumulating heating was In 1982 and 1992, where the value of (HDD) was 4396 and 4496, and the lowest value of (HDD) recorded in 2010, amounted to 2073 degrees of aggregate temperature and contrary to this, the cumulative temperature of cooling(CDD) operations has increased significantly, recorded the highest value in the year 2010 were reached (2451) while in 1976 it recorded a value of (1573).

For the period of 1973-2015, the annual CDD and HDD of Sulaimani are calculated and a linear trend analysis, Figure 8, shows that in warm months (April to October), the CDD would increase at a rate of ( ) while in cold months (C˚ d) November to March) the HDD would decrease at a rate of (C˚ d) as shown in figure (7) .

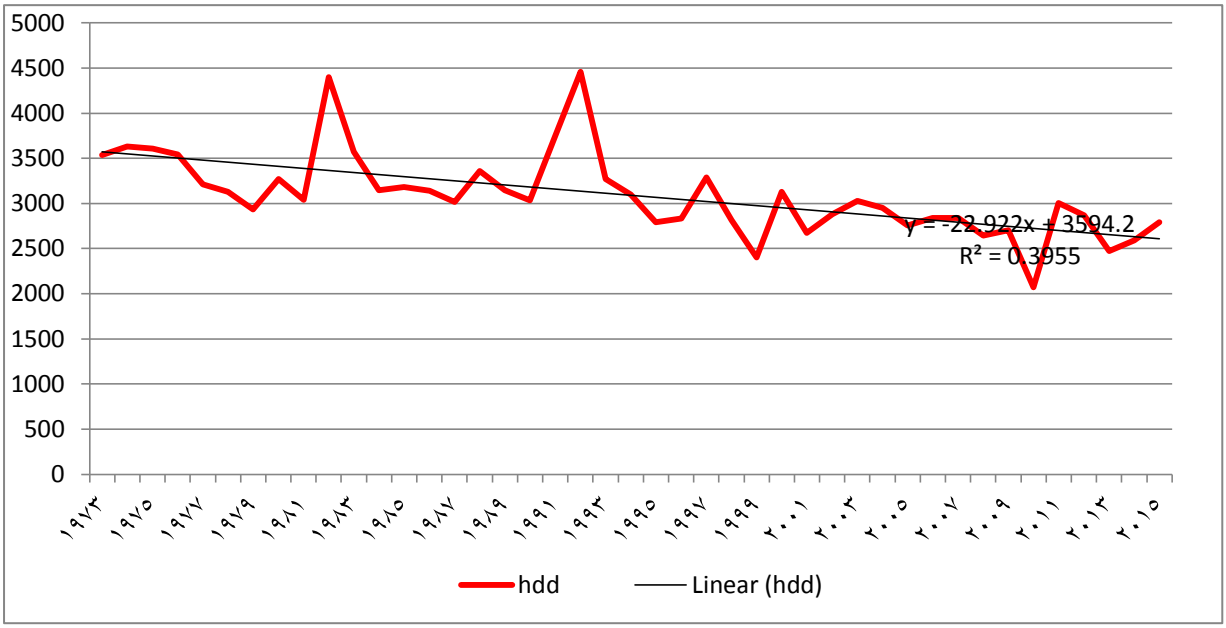
Figure (7): Annual HDD and CDD trend in Sulaimani city during (1973-2015)

Electrical energy in the province, which should be used to compensate for the low heat when the temperature is below the thermal threshold and when above and as above shown that the need for cooling in the study area more than the need for



heating by about twice as shown in the figure .

Figure (7): Annual HDD trend in Sulaimani city during (1973-2015)



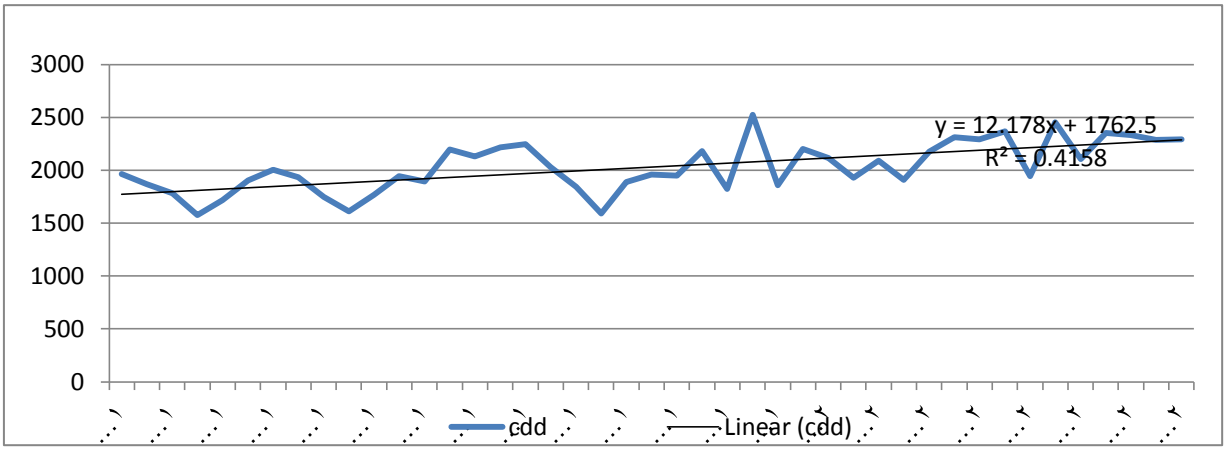
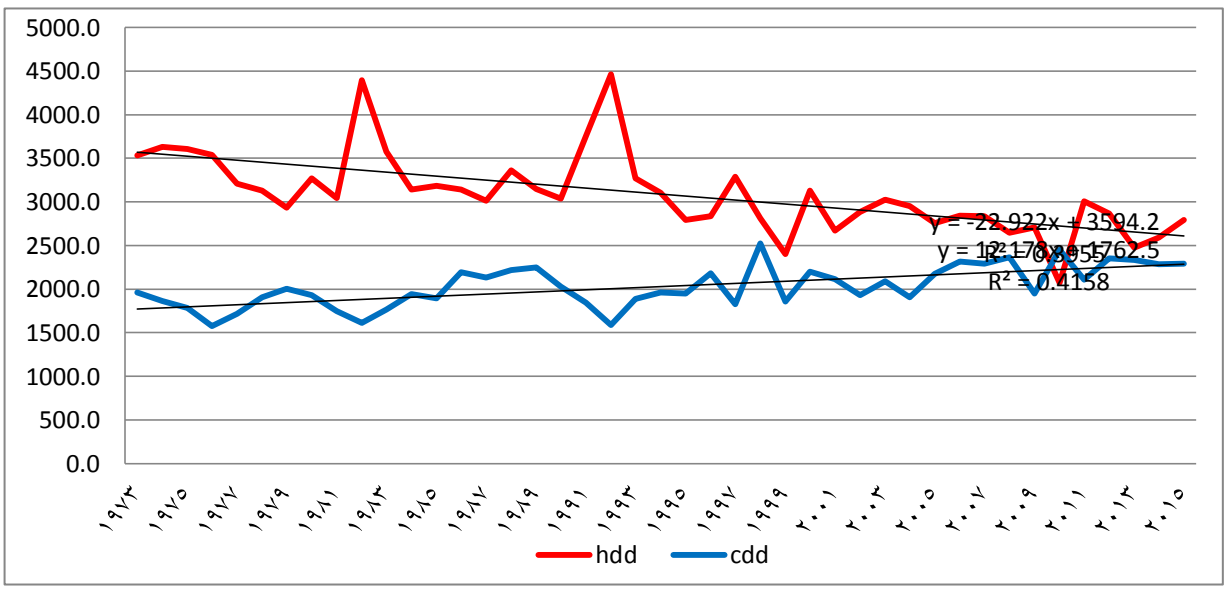


Figure (8): Annual CDD trend in Sulaimani city during (1973-2015)

Figure (8): Annual CDD trend in Sulaimani city during (1973-2015)
Figure (9): Annual HDD and CDD trend in Sulaimani city during (1973-2015)



6- Conclusions:

In this paper, the average monthly and annual temperature trends in Sulaimani city for the period (1973-2015) analyzed. The annual and monthly averages of temperature in the period (1973-2015) show an increase in temperature in all the months of the year.

The mean annual and maximum with minimum temperature during winter and summer data subdivided into seasons, the results clearly indicate that temperature trends over the studied period are not consistent between seasons.

The linear trend analysis shows that the average annual temperature in Sulaimani city increased by (0.0716 C˚/ y) in summer time and (0.1844 C˚/ y) in winter time, from this we observe that in the cold season the increase in the annual average temperature was higher compared to the warm seasons.

Correlation between temperature and energy consumption analyzed, the relationship between energy consumption and daily mean temperature in the study area analyzed through the definition of the base temperature of CDD and HDD in warm months and cold months.

The relationship between energy consumption and daily mean temperature in Sulaimani was analyzed through the definition of the base temperature of CDD and HDD in warm months and cold months.

Energy demand shows significant seasonal variations. The linear trend analysis shows that the annual heating degree days (HDD) decreased by (0.3955 ˚C d) between the periods 1973–2015 while the annual cooling degree days (CDD) increased by (0.4158 ˚C d) between the periods 1973–2015.

\ The trend of a decreasing number of HDD and an increasing number of CDD is in line with the increasing trend in mean temperature in Sulaimani city, and this is due to the effect of global warming and local urbanization

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