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Comparison of the Calculation Methods of Heating and Cooling Degree-Days in Three Different Cities in Morocco

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Abstract—*Reduction of energy consumption has become one of the main subjects of interest for most developed and developing countries. Degree-days method is a widely used method that can be utilized to estimate the heating and cooling energy requirement for a building. Several methods can be used to determine the degree-day values according to the availability of the climatic data. In the present work, heating degree-days and cooling degree-days are estimated and examined using hourly method, Ashrae method, UKMO method and Shoenau-Kehrig method. The comparison was conducted taking the hourly method as reference. Typical meteorological year of Casablanca, Marrakech and Ifrane have been used for this study.*

Keyword — *Heating degree-days, Cooling degree-days, Morocco, building.*

I. INTRODUCTION

The increase of energy consumption with each passing day places a burden on the country's economy, besides causing environmental pollution (Özkan and Onan, 2011). It has been observed that global carbon dioxide (CO2) emissions from fossil fuel combustion increased in 2013 to the new record of 35.3 billion tones (Gt) CO2, which is 0.7 Gt higher than last year's record. This moderate increase of 2% in 2013 compared to 2012 is a continuation of last year's trend and of the slowdown in the annual emissions growth (Olivier, 2014). This percentage is going to rise in the coming years as the global population continues to increase, emerging economies continue to develop, and climate changes lead to a greater demand for space heating and cooling. Buildings are intensive energy-users, their global contribution towards energy consumption has steadily increased recent years (Prakash, 2014; lin and Liu, 2015, Jraida, et al, 2016) and current predictions show that this increase is expected to triple by 2030 (Pérez-Lombard, et al, 2008). Degree-days are a tool that can be used in the assessment and analysis of weather related energy consumption in building and consequently carbon emissions due to space heating and cooling (Moreci, et al, 2016).The basic concept is that seasonal climate can be quantified by summing the average temperature difference each day over the number of days in the season. In many parts of the world several researches have been done on the subject of degree-day. In United Kingdom, Hitchin (1983) proposed a new method for the estimation of monthly degree-day values from monthly mean temperature; it was shown that it is compatible with existing methods and usable outside the UK. Based on an assumed annual normal distribution of the daily mean temperatures around the monthly mean temperature Shoenau and Kehrig (1990) presented a simple and accurate method of estimating heating and cooling degree-days to any base temperature, it was verified for four different location in the US and was shown to give highly accurate results. Buyukalaca et al (2001) determined the heating and cooling degree-days for turkey using long term recent measured data and five different base temperatures, the results presented show that both heating and cooling degree-days exhibit big fluctuations throughout Turkey. In Xinjiang, China, Jiang et al (2009) used daily data of minimum and maximum temperature of 51 stations to detect annual and seasonal variations of heating and cooling degree-days by using the Mann-Kendall trend and linear regression techniques, the results show decreasing trends in annual heating degree-days for all the stations for base temperature of 18°C and significant increasing trends in annual cooling degree-days for the base temperature of 24°C for 23 stations. Papakostas et al (2010) evaluated the annual heating and cooling degree-days for base temperature 15°C and 24°C for Athens and Thessaloniki, Greece. It is found that the heating energy demand decreases by 11.5% and 5% and the cooling energy demand increases by 26% and 10% respectively for Athens and Thessaloniki. .In UK Mourshed (2012) developed an equation for calculating degree-days by using a multiple non-linear regression of annual mean temperature data of 5511 locations around the world, the standard deviation of the monthly mean temperature and the latitude. The author provides the resulting equation of the model calculated with 18.3°C and 10°C as base temperature respectively for HDD and CDD. OrtizBeviá et al (2012) estimated trends and interannual variability in the evolution of degree-days in Spain from observations at 31 stations for the period of 1952-2005.Shin and Lok Do (2016) proposed a new CDD method using specific enthalpy values instead of dry-bulb temperature in order to predict cooling energy consumption. As a result, the comparison utilizing the enthalpy-based CDD method resulted in a percent error of approximately less than that of the temperature-based CDD method. However in Morocco, data from 37 weather stations during 10 years were used by Idchabani et al (2015) to evaluate and analyze the heating and cooling degree-days and the effect of geographical conditions using the regression approach. In the present work, heating degree-day and cooling degree-day are estimated and examined using hourly method, Ashrae method, UKMO method and Shoenau-Kehrig method. The comparison was conducted taking the hourly method as reference. Typical meteorological year of Ifrane, Casablanca and Marrakech have been used for this study.

II. METHODOLOGY

The concept of the degree-days is one of the well known and well established tools for predicting heating and cooling energy consumption in buildings (Sarak and Satman, 2003; Kaynakli, 2012; Al-Hadhrami, 2013). The predicted results can be used to make decision regarding how to minimize building energy consumption and improve overall building energy performance (Shin and Do, 2016). Several methods are used for estimating the heating and cooling degree-days depending on the availability of data.

2.1. Hourly method

The most rigorous definition of degree-time is given by equations (1) and (2). In these equations the mean daily degree hours are calculated by summing the differences between the base temperature and the hourly temperature measurements. Then the cumulative degree-hours of a day are divided by 24. The daily degree-days are then summed over the desired period t (i.e. a month, a year, etc). The hourly method presents the limitation of the hourly temperature data that cannot always be available.

$$HDD_t = \sum_{j=1}^{n}\left(\frac{1}{24}\sum_{i=1}^{24}(T_b - T_i)^+\right) \quad (1)$$

$$CDD_t = \sum_{j=1}^{n}\left(\frac{1}{24}\sum_{i=1}^{24}(Ti - T_b)^+\right) \quad (2)$$

Where n is the cumulative difference between specified temperatures in degrees over a specified time period, T_i is the outside air temperature at the i-th hour of the day and T is the base temperature. The superscript indicates that only positive values of the bracketed quantity are taken into account in the sum

2.2. ASHRAE method

In Ashrae method (ASHRAE, 2013), degree-days are calculated as the sum of the difference between mean daily temperature and base temperature. Therefore, heating degree-days (HDD) are estimated using equation (3).

$$HDD_t = \sum_{j=1}^{n}(T_b - T_{md}) \quad (3)$$

Similarly, cooling degree-days (CDD) are calculated as:

$$CDD_t = \sum_{j=1}^{n}(T_{md} - T_b) \quad (4)$$

Where n is the number of days, T_b the base temperature to which the degree-days are calculated, and T_{md} is the mean daily temperature defined as the arithmetic mean of the maximum and minimum temperatures in a given day, as shown in equation (5).

$$T_{md} = \frac{T_{max} + T_{min}}{2} \quad (5)$$

2.3. UKMO method

The UKMO method (CIBSE, 2006) was developed in 1928 by the UK Meteorological office for the calculation of degree-days.

$$HDD_d = \begin{cases} T_b - T_{md} & T_{max} \le T_b \\ \frac{1}{2}\Delta T_{min} - \frac{1}{4}\Delta T_{max} & T_{min} \prec T_b \ and\ \Delta T_{max} \prec \Delta T_{min} \\ \frac{1}{4}\Delta T_{min} & T_{max} \succ T_b \ and\ \Delta T_{max} \succ \Delta T_{min} \\ 0 & T_{min} \ge T_b \end{cases} \quad (7)$$

This method is used to calculate the degree-days using a single daily reading of maximum and minimum temperature. In order to take into account the asymmetry between the base temperature and the diurnal temperature variation four scenarios were introduced. Depending on these, daily heating degree-days and daily cooling degree-days are calculated using equation (6) and equation (7) respectively.

$$CDD_d = \begin{cases} T_{md} - T_b & T_{min} \geq T_b \\ \frac{1}{2}\Delta T_{max} - \frac{1}{4}\Delta T_{min} & T_{max} \succ T_b \text{ and } \Delta T_{max} \succ \Delta T_{min} \\ \frac{1}{4}\Delta T_{max} & T_{min} \prec T_b \text{ and } \Delta T_{max} \prec \Delta T_{min} \\ 0 & T_{max} \leq T_b \end{cases} \quad (8)$$

Where ΔTmax and ΔTmin are calculated using equation (8) and equation (9).

$$\Delta T_{max} = T_{max} - T_b \quad (8)$$

$$\Delta T_{min} = T_b - T_{min} \quad (9)$$

2.4. Schoenau and Kehrig

Schoenau and Kehrig developed one of the simple and accurate method of estimating heating and cooling degree-days to any base temperature, The only assumption made is that for every month the daily mean temperatures, T, are scattered around the monthly mean temperature with a normal distribution. The formula for calculating monthly heating degree-days is expressed as follows:

$$HDD_m = N_m S_d \left[Z_b F(Z_b) + f(Z_b) \right] \quad (10)$$

The monthly cooling degree-days CDD_m to base Tb is calculated by the same equation:

$$CDD_m = N_m S_d \left[Z_b F(Z_b) + f(Z_b) \right] \quad (11)$$

Where N_m is the number of days in the month and Z_b is the difference between monthly average temperature Tm and base temperature T_b, normalized by the standard deviation of the daily average temperature S_d:

$$Z_b = \begin{cases} \frac{T_b - T_m}{S_d}, & \text{for HDD calculations} \\ \frac{T_m - T_b}{S_d}, & \text{for CDD calculations} \end{cases} \quad (12)$$

Function f is the normal (Gaussian) probability density function with mean 0 and standard deviation 1, and function F is the equivalent cumulative normal probability function:

$$f(Z) = \frac{1}{\sqrt{2\pi}} \exp\left(\frac{-Z^2}{2} \right) \quad (13)$$

$$F(Z) = \int_{-\infty}^{Z_b} f(Z)\,dZ \quad (14)$$

III. RESULTS AND DISCUSSIONS

Heating and cooling degree-days were calculated and examined using traditional formulae and other approximate methods. Comparisons were based on calculations using hourly values from Typical Meteorological Year (TMY) data of three cities namely Ifrane (cold climate), Casablanca (mild climate) and Marrakech (hot climate). Table 1 summarizes the results of heating degree-days at 18°C base temperature and cooling degree-days at 21°C base temperature using the four methods described above. Ashare, UKMO and Shoenau-Kehrig were compared to the hourly method in order to give a percentage difference δ defined as:

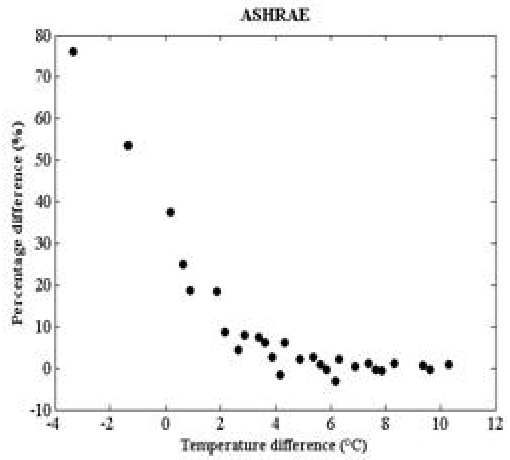
$$\delta = \frac{DD_{Hm} + DD_{Am}}{DD_{Hm}} \times 100 \quad (15)$$

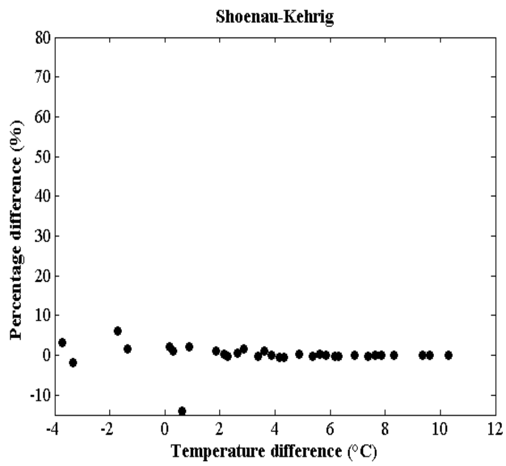
Where DDH_m is the degree-days values obtained by the hourly method and DD_{Am} the result of each of the approximate methods.

By analyzing the calculated data from the previously reported relationships, we notice that the values of degree-days vary considerably from city to city for the same base temperature. It's found that the annual heating degree-days values for Ifrane and Casablanca are higher than the annual cooling degree-days values, which means that the predominant period of the year is the heating period, subsequently, the annual heating energy consumption will be higher in these cities. However, it's seen that the annual cooling degree-days values in Marrakech are higher than those of heating degree-days; therefore, the energy consumption for cooling will be higher in this city. Besides, it's seen that Shoenau-Kehrrig method has the good performance; the heating and cooling degree-days calculated by this method agreed very closely with those calculated by the hourly method and return the lower percentage difference which is equal to 0.45% in heating degree-days and 2.15% in cooling degree-days for Ifrane, -0.23% in heating degree-days and 0.05% in cooling degree-days for Casablanca and -0.55% in heating degree-days and 0.23% in cooling degree-days for Marrakech.

Table 1- Annual HDD and CDD calculated using the models in Ifran Casablanca and Marrakech

Method	HDD	CDD	δ_{HDD}	δ_{CDD}
	Ifran			
Hourly	1906.85	516.76	-	-
ASHRAE	1725.15	376.03	9.52	27.23
UKMO	1684.97	517.44	11.63	-0.13
S-K	1898.22	505.63	0.45	2.15
Casablanca				
Hourly	1275.94	294.74	-	-
ASHRAE	1230.60	220.25	3.55	25.08
UKMO	1125.05	288.05	11.82	2.26
S-K	1279.01	294.57	-0.23	0.05
Marrakech				
Hourly	753.84	1041.73	-	-
ASHRAE	570.08	902.85	24.37	13.33
UKMO	505.12	1065.18	32.99	-2.20
S-K	758.00	1039.25	-0.55	0.23





So as to allow general comparisons to be made the percentage difference δ against ΔT_m, which represents the difference between the base temperature and the mean monthly temperature, were plotted for heating months in Casablanca. According to Figure 1, it was demonstrated that for all methods the percentage difference increases when ΔT_m is low, in other words when the base temperature is close to the external temperature. But this increase is more apparent in the case of Ashrae and UKMO methods. However when the range of mean monthly and base temperatures become significant the methods return smaller values of percentage difference.

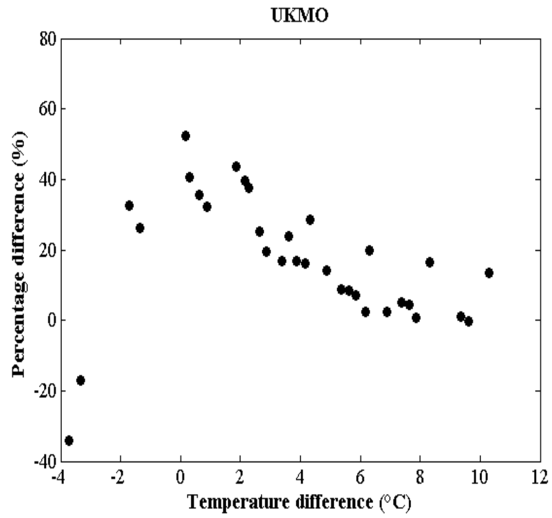


Figure 1- Percentage difference against ΔTm for heating months in Casablanca

Table 2- Annual heating degree-days for different base temperatures in the three cities

Method	HDD			
	Base temperature			
	14	16	18	20
	Ifran			
Hourly	1078.90	1465.2	1906.85	2400.5
ASHRAE	914.87	1294.8	1725.15	2209.9
UKMO	855.60	1245.5	1684.97	2125.5
S-K	1077.70	1460.7	1898.22	2389.7
	Casablanca			
Hourly	554.90	876.5	1275.94	1753.3
ASHRAE	491.10	820.5	1230.60	1708.0
UKMO	423.20	751.6	1090.77	1611.0
S-K	552.94	876.8	1279.01	1754.5
	Marrakech			
Hourly	292.96	490.4	753.84	1088.9
ASHRAE	140.78	311.4	570.08	897.31
UKMO	175.42	286.5	505.12	741.83
S-K	296.63	493.3	758.00	1090.4

Table 2 represents the yearly heating degree-days of the three cities for base temperatures of 14°C, 16°C, 18°C and 20°C and yearly cooling degree-days for base temperature of 21°C, 23°C, 25°C and 27°C. It can be discerned from the results that the selection of the base temperature is crucial as it affects significantly the annual heating and cooling degree-days. It has been found that the annual HDD increases as the base temperature increases from 14°C to 20°C, however the annual CDD decreases with the increase in base temperatures from 21°C to 27°C.This is true for all the approximate methods. Moreover, it's seen that a decrease in base temperature from 20 to 18°C lowers the heating degree-days by approximately 20.56% in Ifrane, 27.22% in Casablanca and 30.77% in Marrakech. However an increase in the base temperature from 21 to 23°C results in a reduction of approximately 32.43%, 40.01% and 27.84% in Ifrane, Casablanca and Marrakech, respectively.

Table 3 - Annual cooling degree-days for different base temperatures in the three cities

Method	CDD			
	Base temperature			
	21	23	25	27
	Ifran			
Hourly	516.76	349.16	222.39	131.60
ASHRAE	376.03	216.04	105.84	40.5
UKMO	517.44	349.41	221.82	131.16
S-K	505.63	338.01	214.52	127.67
	Casablanca			
Hourly	294.74	149.8	62.79	18.28
ASHRAE	220.25	82.75	12.20	0
UKMO	288.05	185.45	60.17	20.90
S-K	294.57	145.67	58.57	18.40
	Marrakech			
Hourly	1041.73	751.61	521.72	344.51
ASHRAE	902.85	587.41	342.95	183.73
UKMO	1065.18	760.89	522.73	347.10
S-K	1039.25	741.11	506.48	329.33

IV. CONCLUSION

The calculation of degree-days has always been a topic of focus by researchers. This paper gives an idea about the thermal needs in three different climates of Morocco and presents comparison of the traditional method (the hourly method) and the approximate methods: Ashrae method, UKMO method and Shoenau-Kehrig method using typical meteorological year of Ifrane, Casablanca and Marrakech. It's seen that the highest energy demand for heating appears in Ifran with much HDD amounts, while the highest energy demand for cooling appears in Marrakech with much CDD amounts. The results obtained show also that Shoenau-Kehrrig method has the good performance, furthermore it was observed that for all methods the percentage difference start increasing when ΔT_m is low. It has also been demonstrated that an increase of the base temperature resulted in an increase of HDD and a decrease of CDD values.

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