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Calculation and Modelling of Cooling Degree-Hours for Some Iraqi Cities

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Abstract: The current study dealt with the calculation and modeling of cooling degree-hours for some Iraqi cities, represented by Mosul city as a model for the Northern cities, Baghdad as a model for the central cities and Basra as a model for the Southern cities. This research was based on previous actual dry-bulb temperature data recorded over the previous 10 years. These data were used to calculate the actual values of the cooling degree-hours for different base temperatures ranging from 14-28°C to cover all cooling application requirement data. In turn, these data were used to obtain the appropriate mathematical model which can be used to calculate cooling degree-hours values from any base temperature with a small error rate ranging from 0-4% over the Summer months for all locations. And after the success of the developed model in three studied cities which represented three different climatic pattern regions in Iraq, developed model can be used as a general model to predicate the cooling degree-hours for any location in Iraq at any base temperature after knowing the mean value and the standard deviation of the dry-bulb temperature for the concerned location.

Key words: Cooling degree-hours, degree-days, model, cooling load and dry-bulb temperature, climatic, temperatures ranging

INTRODUCTION

Heating and air-conditioning application rank first in the building sector energy bill in many countries of the world (Ahmad *et al*., 2016; Ozel, 2011). In Iraq, the building sector consumes a large proportion of locally produced electricity energy and most of this energy spent on heating and cooling application (Electricity, 2018). As the national electricity energy mix in Iraq depend on 70-80% fossil oil, so, the extensive using of this energy led to increasing the emissions of carbon dioxide from 52.8-98.8 million tons over the past 20 years (Anonymous, 2013). Therefore, any reduction in this energy requirement in the conditioned spaces is a reduction of fossil fuel usage for electricity production and hence, a considerable reduction in total greenhouse gas emissions. Generally, the main purpose of heating and cooling equipment in the buildings is to overcome the outside climate effect on conditioned space resulting from the temperature difference between conditioned space and outside air. As a result of the temperature difference, heat transfer from the hot to the cold region through the building envelope depending on the laws of nature. Therefore, knowing the amount and duration of the temperature difference is very important for Heating, Ventilation and Air Conditioning (HVAC) engineers to select the proper elements for building envelope and HVAC equipment which will save more energy, money and greenhouse gas emissions during the building lifespan. Therefore, the concept of connecting temperature difference with the time has appeared under the name of degree days or degree hour temperature difference depending on the temperature difference calculation resolution. Degree days represent the positive cumulative temperature difference between the base temperature (T_b) and daily mean outside air temperature while degree hours represent the positive cumulative temperature difference between the base temperature and the hourly outside air temperature (Mourshed, 2012). The base temperature in the degree-days or degree-hours concept refers to the temperature at which the conditioned space becomes in thermal equilibrium with the outside. In other words, for the specified value of the indoor air temperature for conditioned space, i.e., set point temperature, the total heat loss from the space is equal to the heat gain from Sun, occupants, lights, equipment, etc. (Kreider *et al*., 1994). Even though the degree-days are more common than the degree-hours due to the lack of hourly temperature data at a particular location but the latest is accurate. Today, degree-days or degree-hours become well known and important climatic indicator used HVAC industry and agricultural applications. In HVAC engineering field, degree-days represent an important parameter in the calculation of optimum thermal insulation

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thickness, life cycle cost, sizing heating and cooling equipment's, environmental impacts of the HVAC system and building energy management. Due to the importance of this value in many industrial sectors and the specificity of this value for each particular site, there are many research studies in the literature that calculate, guess and model this value for different geographic locations. There are many study researches in the literature that calculated degree-days value for a variety of distinct geographies from actual metrological data for different base temperatures.

These include, among others (Al-Hadhrami, 2013) for Saudi Arabia (Dombayci, 2009) for Turkey, (Arguez and Applequist, 2013) for the United States (Shi *et al*., 2016) for China (De Rosa *et al*., 2015) for Italy, Pallavi *et al*. Borah *et al*. (2015) for India, Badescu and Zamfir (1999) for Matzarakis and Balafoutis (2004) for Greece, Erosat (Eurostat, 2014) for selected European countries. And other researches attempt to find and develop mathematical models to predict degree-days values depend on some metrologic variables like seasonal maximum and minimum air temperature, seasonal average air temperature, stander deviation of air temperature etc. In this regard, Kolokotroni *et al*. (2010) describe a method to predicate future air temperature in London depending on historic measured air temperatures data. The prediction model is based on an Artificial Neural Network (ANN) modeling. The predicted air temperatures are used to compute heating and cooling degree-hours for many discreet locations in London. The validity of the model was tested using metrological data measured after 8 years from conducting the research; it was found that site-specific hourly air temperature prediction provides acceptable accuracy. Thevenard (2011) examines several methods for calculating heating and cooling degree-days to any base temperature by relying on temperature statistics such as the monthly mean temperature and the standard deviation of daily average temperature. It is found that the method developed by Schoenau and Kehrig works best and is usually able to estimate monthly heating and cooling degree-days to with variation within 3°C/day of their true value (in a root-mean-square error sense). Adigun and Olorunmaiye (2005) developed a mathematical model to compute cooling degree-days for Southern Nigeria. The model takes a statistical approach in terms of the Probability Density Function (PDF) and Cumulative Distribution Function (CDF) based on beta distribution. Oktay *et al*. (2011) developed a method depend on daily maximum and minimum temperature in prediction the daily outdoor temperature fluctuation which was used later in daily and monthly cooling degree-hours calculation. The validity of the developed model is tested by calculating the cooling degree-hours for 58 cities in different geographical regions of Turkey and compares them with the published data for the same cities. It becomes clear from the previously that the degree-days play an important role in energy estimations and analysis that are worth to be investigated. Therefore, there is a great effort from researchers and countries to calculate, model and update the values continuously in order to keep pace with the climate changes facing the world. The lack of Iraqi cities data between the scientific research conducted in this field and databases prepared in this regard (ASHRAE, 2009; Atalla *et al*., 2018) was the main motivation to conduct this research. The main aim of the present research is to calculate cooling degree-hours for three main Iraqi cities falling in different geographical locations. Mosul is selected as a model from northern cities Baghdad as a model of middle cities and Basra as a model of southern cities. The cooling degree-hours for different base temperature calculated depended on historic metrological data recorded at each hour during the past 10 years ago (2006-2015). Furthermore, the current research sought to find a comprehensive mathematical model that can be used to estimate approximate cooling degree-hours values in most Iraqi cities for different base temperatures depending on some climatic statistical information.

MATERIALS AND METHODS

Weather data: The accuracy of degree-days or degree-hours calculations depends on the pattern of recording and archiving weather data. The data which is recorded every hour of the year gives more accurate results than daily or monthly rates for the same duration. In Iraq, so far, weather data is still manually recorded and kept in logs as daily average data. This is due to successive wars, international sanctions and the economic embargo imposed on it which prevented the entry of new weather station equipment to Iraq which read and archive weather data in digital data form to facilitate dealing with them. For this reason, the present research depended on the hourly weather data recorded by the well-known weather station (Wunderground) during the past 10 years (2006-2015) for Mosul, Baghdad and Basra. To verify the accuracy of the data, the dry bulb air temperatures recorded by Wunderground weather station is compared with the monthly mean temperatures recorded by the Iraqi Meteorological Organization and Seismology (Transportation) for each city. The results of the comparison showed a significant convergence between the data, we were able to use these data in our current research.

Cooling degree-hours calculation: The value of CDH for a certain location can be calculated from hourly recorded dry bulb temperature data using the expression:

$$CDH_a = \sum_{i=1}^{N} f(T) \quad (1)$$

$$f(T) = T\text{-}T_b \text{ if } T > T_b \quad (2a)$$

$$f(T) = 0 \text{ if } T \le T_b \quad (2b)$$

Where:
- T = Hourly dry-bulb Temperature in °C
- T_b = Base Temperature in °C
- N = Number of hours in the period over which CDH is calculated

Theoretical background of mathematical modeling: Since, the CDH represent the positive cumulative temperature difference between the outside dry-bulb and base temperature over a given period of time. So, the mathematical model of CDH associated with a certain base temperature can be found, if the mathematical model of the cumulative distribution function of the dry-bulb temperature known using the following mathematical expression (Erbs, 1984):

$$CDH_c = N(T_{max}\text{-}T_b)\text{-}\int_{T_b}^{T_{max}} NQ(T)dT \quad (3)$$

Where:
- T_{max} = Maximum Temperature during the time period
- $Q(T)$ = Cumulative Distribution Function (CDF) of dry-bulb temperature

Due to the difference in the temperature range during the months of the year as well as the difference from certain location to another, so, normalizing the variable (T) to non-dimensional scale variable (h) using the following expression will be very helpful in finding a general model for CDH_c:

$$h = \frac{T\text{-}\overline{T}}{\sigma\sqrt{N}} \quad (4)$$

Where:
- $\overline{T}$ = Mean Temperature during the time period
- σ = Standard deviation of dry-bulb temperature

The advantage of using non-dimensional scale variable (h) in place of Temperature (T) is that symmetric distribution curves become centered on the same value of the independent variable and also the range of independent variable required to encompass the measured data is nearly the same for different months and different locations. By changing the independent variable to (h) the Eq. 3 becomes:

$$CDH_c = \sigma N^{1.5}\left[(h_{max}\text{-}h_b)\text{-}\int_{h_b}^{h_{max}} Q(h)dh\right] \quad (5)$$

The Eq. 5 can be applicable, if the mathematical expression for CDF which can be obtained from long-term weather data for certain cities.

Analysis of data and model development: Hourly dry-bulb temperature data for Mosul (Latitude 33, 23°N, Longitude 44, 23°W), Baghdad (Latitude 36, 32°N, Longitude 43, 15°W) and Basra (Latitude 30, 57°N, Longitude 44, 23°W) for 10 years (2006-2015) were obtained from Wunderground weather station sorted and analyzed using Microsoft Excel Software (MicroSoft, 2013). The data for the particular month of the year was saved in one file with separate columns for all the 10 years. As the dry-bulb temperature data did not follow any of statically known distribution, so, the CDF of dry-bulb temperature cannot be found easily and it must be treated as a special case. For this reason, the following procedure conducted in this research to find a proper mathematical expression that can express the CDF of the dry-bulb temperature. The procedure started by estimating histogram (bin diagram) for each month separately with a bin width of 1°C. In this diagram, the horizontal axis represents the bin (dry-bulb temperature scale) and the vertical axis represents the total number of hours that the bin value frequent during the month. In the next step, the number of hours in each bin was divided by 10 (the number of years of data used) to get the average bin data for each month. To convert the bin data to discrete probability density data the number of hours in each bin of the monthly average bin data is divided by the total number of hours in the months which is equal to 24 (hours of the day)×(number of days in the month). The probability density data were used to generate discrete cumulative distribution data for each month. The average temperature and standard deviation for each month were also found. The abscissae (T) of the cumulative distribution data for each month changed to non-dimensional scale variable (h) using Eq. 4. At the end of these steps, the cumulative distribution data for dry-bulb temperature for each month became to look like the diagram as shown in Fig. 1.

The CDF of the data set represents the mathematical expression that can express the curve which passes through bins data. The obtained data gives an indicator that the curves can be modeled by using S curve functions. For this reason, hypobaric tan function form used to develop the model of CDF. The model form was chosen as:

$$Q(h) = a+b\left[\tanh\left(c\times h\right)\right] \quad (6)$$

where, a, b and c are curve fitting constants and can be estimated from long-term dry-bulb temperature data. The value of the constants a-c is optioned depending dry-bulb temperature values by using try and error method. The prorate value of these constant is found to be as (a = 0.5) (b = 0.5) and (c = 28.5) that fit our data. By compensating the constant values in Eq. 6 the CDF Model becomes:

$$Q(h) = 0.5+0.5\left[\tanh\left(28.5\times h\right)\right] \quad (7)$$

Substituting Eq. 7 in 5 and integrating by taking h_{max} equal to Eq. 1, the model of CDH become:

$$CDH_c \quad N^{1.5} \; \frac{\ln(\cosh(28.5 \quad h_b))}{} \; - \frac{h_b}{} + 0.0122 \quad (8)$$

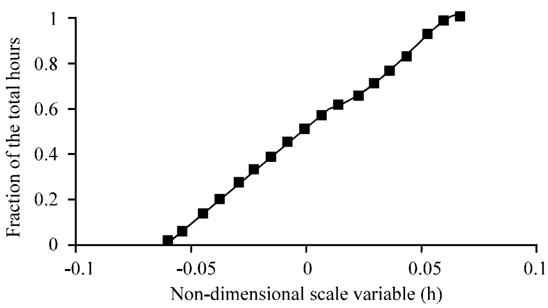

Fig. 1: Dry-bulb temperature cumulative distribution data for Baghdad during July

Where:

$$h_b = \frac{T_b - \overline{T}}{\sigma\sqrt{N}}$$

The value of hmax in Eq. 5 is taken equal to (1) because of that all the data of the cumulative distribution data represented in Eq. 6 lies between (-1) and (1) for all values of non-dimensional scale variable (h). So, h_{max} can be taken any number equal to or >1 (Myers *et al*., 2016).

Validation of predicated CDH_c data: The validity of the predicated CDH_c obtained from Eq. 9 is checked with the actual data CDH_a obtained from Eq. 1 by calculating the percentage of error between the two values following this expression:

$$\text{Error} = \frac{\left|CDH_a - CDH_c\right|}{CDH_a}\times 100\% \quad (9)$$

RESULTS AND DISCUSSION

In the present research, the actual cooling degree-hours is calculated depending on 10 years hourly recorded dry-bulb temperature for three main sites in Iraq namely Mosul, Baghdad and Basra which are locating in deferent geographical and climatically locations (Table 1). According to the monthly mean temperature, we are investigating the Summer season in Iraq starts with the beginning of April to the end of October. For this reason, the 10 years average hourly dry-bulb temperature is used in Eq. 1 to calculate CDH_a for 14 different base

Table 1: Actual CDH values

	Statistical values			Base Temperature values (T_b)														
Months	$\overline{T}$	σ	City	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
April	18.9	5.5	Mosul	3723	3160	2661	2156	1687	1288	968	709	512	364	255	168	112	91	64
	24.3	5.2	Baghdad	7399	6679	5961	5252	4560	3902	3289	2731	2230	1752	1338	990	722	497	340
	26.4	4.5	Basra	8806	8088	7366	6648	5934	5230	4544	3901	3313	2719	2169	1672	1266	919	648
May	25.5	5.5	Mosul	8436	7693	6957	6265	5561	4907	4287	3617	3002	2561	2064	1606	1223	913	668
	30.3	4.6	Baghdad	12158	11414	10670	9926	9182	8438	7694	6950	6212	5490	4789	4124	3506	2945	2441
	32.8	4.6	Basra	13986	13242	12498	11754	11010	10266	9522	8778	8034	7290	6550	5823	5121	4451	3834
Jun	32	5.4	Mosul	12921	12201	11481	10761	10041	9321	8602	7885	7170	6469	5791	5139	4531	3963	3336
	35.1	4.7	Baghdad	15178	14458	13738	13018	12298	11578	10858	10138	9418	8698	7978	7258	6538	5818	5115
	36.4	5.7	Basra	16159	15439	14719	13999	13279	12559	11839	11119	10399	9679	8959	8239	7519	6800	6094
July	35.2	5.4	Mosul	15742	14998	14254	13510	12766	12022	11278	10534	9791	9048	8307	7569	6840	6124	5440
	37.2	4.7	Baghdad	17230	16486	15472	14998	14254	13510	12766	12022	11278	10534	9790	9045	8302	7557	6814
	37.8	6.1	Basra	17713	16969	16225	15482	14739	13996	13253	12511	11770	11030	10291	9555	8822	8093	7370
August	34.6	5.3	Mosul	15308	14564	13820	13076	12332	11588	10844	10100	9356	8612	7868	7124	6388	5675	5004
	37.1	4.9	Baghdad	17195	16451	15707	14963	14219	13475	12731	11987	11243	10499	9755	9011	8267	7523	6779
	37.1	6.5	Basra	17149	16405	15661	14917	14173	13429	12685	11941	11197	10453	9709	8965	8221	7482	6768
September	29.4	5.8	Mosul	11013	10293	9573	8853	8133	7416	6706	6007	5338	4707	4115	3501	2903	2379	2002
	32.6	5.1	Baghdad	13426	12706	11986	11266	10546	9826	9106	8386	7666	6947	6235	5539	4871	4241	3659
	32.8	6.9	Basra	13524	12804	12084	11364	10644	9924	9204	8484	7772	7081	6423	5802	5219	4677	4071
October	22	5.1	Mosul	6009	5308	4631	3988	3397	2780	2224	1729	1310	978	712	514	362	272	193
	29	5.0	Baghdad	11006	10306	9906	9106	8407	7626	6906	6186	5466	4747	4045	3379	2747	2171	1667
	27.5	6.0	Basra	10074	9330	8586	7843	7108	6381	5680	5018	4405	3852	3355	2907	2399	1929	1570

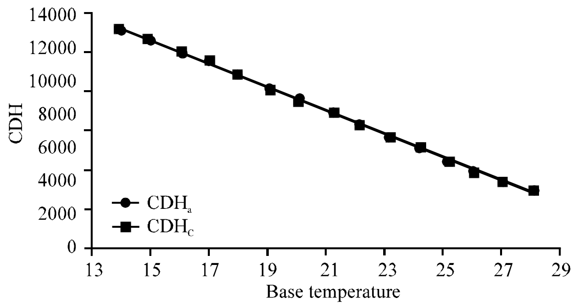

Fig. 2: Mosul CDH_a and CDH_c during Jun

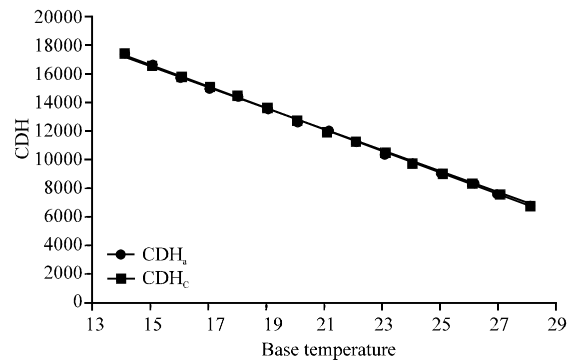

Fig. 3: Baghdad CDH_a and CDH_c during August

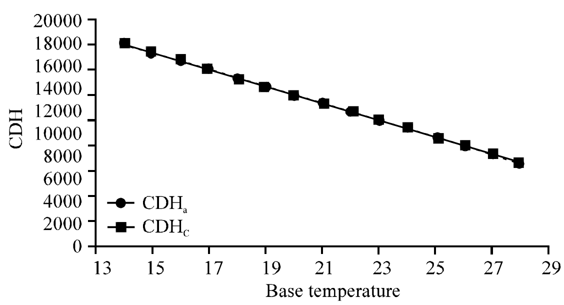

Fig. 4: Basra CDH_a and CDH_c during July

temperature starting from 14-28°C to cover all HVAC application data requirement. The CDH_a was illustrated in table form for all sites instead of graphical representation because it is more helpful in this type of research to get the required value exactly, Table 1. The CDH_a values show that the Basra city has great CDH values for all base temperatures and followed by Baghdad and Mosul (Fig. 2-4). The developed model represented by Eq. 9 is used to predicate the CDH of the same base temperatures for the same cities depending on the statistical values which are illustrated in the Table 1. The results showed that the percentage of error between the actual values (CDH_a) and predicted values of (CDH_c) ranging between 0-4% when $(\bar{T}+2 \geq T_b > 14)$ which is represent a good convergence between the actual and predicted values. The graphical representation of actual and predicted values of CDH for each site in different summer months illustrated in Fig. 2-4. This result confirmed the validity of the developed model to predicate cooling degree-hours for any base tempera-ture falling between $(\bar{T}+2 \geq T_b > 14)$ and after the success of the developed model in three cities that were under study which represented three different climatic pattern regions in Iraq this model can be used as a general model to predicate the cooling degree-hours for any location in Iraq at any base temperature after knowing the mean value and the standard deviation of the dry-bulb temperature for the concerned location.

CONCLUSION

The cooling degree-hours represent an approximate method to estimate the cooling energy required in a given application. There are many important decisions in HVAC engineering that are based on this method like optimum insulation thickness, HVAC equipment size, HVAC equipment's operation and maintenance cost and environmental analysis regarding energy utilizing in conditioned spaces. For this reason, this values must be updated from time to time in order to cope with climate change in the world. The calculated values of cooling degree-hours for many Iraqi cities gave the following impressions:

The Southern regions of Iraq are warmer than the Northern and Northern regions. Using efficient HVAC equipment and selecting proper building envelop material in the Southern regions of Iraq will play an important role in energy conservation and environmental impact reduction resulting from energy uses in conditioned spaces. All the regions in Iraq have the same temperature distribution pattern but differing in the daily temperature range.

REFERENCES

ASHRAE, 2009. ASHRAE Handbook Fundamentals. American Society of Heating Refrigeration and Air-Conditioning Engineering, Atlanta.

Adigun, O.J. and J.A. Olorunmaiye, 2005. Modeling of cooling degree-days for Southern Nigeria using beta distribution. Lautech J. Eng. Technol., 3: 1-7.

Ahmad, M.W., M. Mourshed, D. Mundow, M. Sisinni and Y. Rezgui, 2016. Building energy metering and environmental monitoring: A state-of-the-art review and directions for future research. Energy Build., 120: 85-102.

Al-Hadhrami, L.M., 2013. Comprehensive review of cooling and heating degree days characteristics over Kingdom of Saudi Arabia. Renewable Sustainable Energy Rev., 27: 305-314.

Anonymous, 2013. Report of environmental state in Iraq. International Maritime Organization (IMO), Iraq, Jordan.

Anonymous, 2019. Iraqi meteorological organization and seismology. Ministry of Transportation of Ontario, Toronto, Canada. http://www.meteoseism.gov.iq/

Arguez, A. and S. Applequist, 2013. A harmonic approach for calculating daily temperature normals constrained by homogenized monthly temperature normals. J. Atmos. Oceanic Technol., 30: 1259-1265.

Atalla, T., S. Gualdi and A. Lanza, 2018. A global degree days database for energy-related applications. Energy, 143: 1048-1055.

Badescu, V. and E. Zamfir, 1999. Degree-days, degree-hours and ambient temperature bin data from monthly-average temperatures (Romania). Energy Conver. Manage., 40: 885-900.

Borah, P., M.K. Singh and S. Mahapatra, 2015. Estimation of degree-days for different climatic zones of North-East India. Sustain. Cities Soc., 14: 70-81.

De Rosa, M., V. Bianco, F. Scarpa and L.A. Tagliafico, 2015. Historical trends and current state of heating and cooling degree days in Italy. Energy Conver. Manage., 90: 323-335.

Dombayci, O.A., 2009. Degree-days maps of Turkey for various base temperatures. Energy, 34: 1807-1812.

Electricity, I.M.O., 2018. Statistical data of the ministry of electricity. Independent Electricity Market Operator (IMO), Iraq.

Erbs, D.G., 1984. Models and applications for weather statistics related to building heating and cooling loads. Ph.D Thesis, University of Wisconsin-Madison, Madison, Wisconsin.

Eurostat, 2014. Energy statistics-cooling and heating degree days (nrg_chdd). Eurostat Inc., Luxembourg city, Europe. https://ec.europa.eu/eurostat/cache/metadat a/fr/nrg_chdd_esms.htm

Kolokotroni, M., M. Davies, B. Croxford, S. Bhuiyan and A. Mavrogianni, 2010. A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island: Case-study of London. Solar Energy, 84: 2246-2255.

Kreider, J.F. A. Rabl and P. Curtiss, 1994. Heating and Cooling of Buildings: Design for Efficiency. 2nd Edn., McGraw-Hill Education, New York, USA., ISBN:9780078347764, Pages: 890.

Matzarakis, A. and C. Balafoutis, 2004. Heating degree-days over Greece as index of energy consumption. Int. J. Climatol., 24: 1817-1828.

Mourshed, M., 2012. Relationship between annual mean temperature and degree-days. Energy Build., 54: 418-425.

Myers, R.H., S.L. Myers, R.E. Walpole and K. Ye, 2016. Probability & Statistics for Engineers and Scientists. 9th Edn., Pearson Education Limited, London, England, UK., ISBN:9781292161365, Pages: 816.

Oktay, Z., C. Coskun and I. Dincer, 2011. A new approach for predicting cooling degree-hours and energy requirements in buildings. Energy, 36: 4855-4863.

Ozel, M., 2011. Thermal performance and optimum insulation thickness of building walls with different structure materials. Appl. Therm. Eng., 31: 3854-3863.

Shi, Y., X. Gao, Y. Xu, F. Giorgi and D. Chen, 2016. Effects of climate change on heating and cooling degree days and potential energy demand in the household sector of China. Clim. Res., 67: 135-149.

Thevenard, D., 2011. Methods for estimating heating and cooling degree-days to any base temperature. ASHRAE. Trans., 117: 884-891.