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Modified Degree-Hour Calculation Method

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1. Introduction

A wide variety of building energy analysis methods are currently available to HVAC engineers and range from simple to sophisticated. The simplest methods involve the largest number of simplifying assumptions and therefore tend to be the least accurate. The most sophisticated methods involve the fewest assumptions and thus can provide the most accurate results. Generally, methods for building energy analysis can be given at three categories as follows:

- Single Measure Methods (example: Equivalent Full Load Hours)
- Simplified Multiple Measure Methods (example: Bin Method)
- Detailed Multiple Measure Methods (example: Hour by Hour)

Detailed Multiple Measure Method provides the most accurate results. In detailed Multiple Measure Method, energy calculations are on hour-by-hour basis. Within the detailed multiplemeasure categories are two major sub-categories worth discussing: The Reduced Hour-By-Hour Method and 8760 Hour-By-Hour Method. When consider the detailed methods, it is very difficult to find actual hourly weather data for each place. Also, detailed methods take much time for calculation [1]. The most detailed methods simulate the hourly dynamic heat transfer process inside the building envelope as well as the dynamic behavior of the heating system and the equipment. They are based on thermodynamic principles and solved numerically by using the initial and boundary conditions in addition to the geometry of the building. These procedures account for the influence of many factors such as weather, internal heat gains, building thermal inertia, solar gains, control system, etc., which may significantly vary with time. These methods are defined to be dynamic and they require hourly weather temperature data [2]. Dynamic methods are more detailed and usually require hourly calculations over the whole year for an accurate analysis of the annual load and the energy consumption [2-5].

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Forecasting the total or monthly energy requirement for cooling or heating purposes requires the determination of cooling or heating load profiles, for which identification of the two main external factors are necessary namely; the mean outdoor temperature probability distribution and the heat gain from sunlight. Monthly outdoor temperature probability distribution is very important input data for determining monthly heating and cooling degree-hour. It is known that degree-hour values are calculated simply by summing up the differences between the hourly dry-bulb temperatures and a standard reference temperature (base temperature). Outdoor temperature distribution and reference (base) temperature directly affect the heating or cooling load. Reference temperatures for heating in building applications vary from country to country. For instance, in the UK, heating degree-hour values are based on an outside dry bulb temperature of 15.5 °C, while Australia uses 18°C and the United States uses 18.3°C. After estimating the probable outdoor temperature distribution, the total cooling or heating degree-hours values are calculated.

Probability density functions are successfully applied in wind, solar, and hydrogen energy production as well as the outdoor temperature analyses and as such, they are commonly preferred by many researchers [6-13] for energy analyses in the literature. Coskun [13] applied this technique to outdoor temperature and proposed a new approach for degree-hours calculation. He used the sinusoidal function to specify the outdoor temperature probability distribution. Many scientists [14-20] focused on the total cooling/heating degree hours and degree-days values for different countries. In some studies, a constant base temperature method is employed to predict the cooling/heating degree-hours. In the literature, only a few studies are available that focus on both constant and variable base temperatures. More recently, hourly building energy simulations increasingly replaced the simplified load calculation methods such as the degree-days and degree-hours approaches. These simulations provide several advantages over such kinds of simplified methods during the design stage, including the ability to explore the equilibrium state of applying a large number of different combinations (or packages) of energy conservation measures and to account for any dynamic behavior such as the thermal energy storage in the structure itself. However, simplified models and methods are still preferred in practice over these sophisticated building energy simulation programs. In Turkey, people are generally in favor of using less complicated methods [21].

In this study, a modified degree-hours calculation method is developed to obtain more accurate results and then applied to four cities in Turkey.

2. Calculation method and new function

Coskun [13] proposed a sinusoidal function to estimate the probability density distribution of the outdoor temperatures. The proposed sinusoidal function is given by the equation below:

$$H_{T_{out}} = a + b \cdot Cos(c \cdot T_{out} + d) \tag{1}$$

where, a, b, c and d are the model parameters, T_{out} denotes the outdoor temperature in °C and $H_{T_{out}}$ gives the hours lapsed in a month at a temperature of T_{out} degrees. After estimation of the temperature probability density distribution, heating and cooling degree-hours were calculated using the equations below;

$$HDH_{Total} = \sum_{n=s}^{k} H_n \cdot (T_{Base} - T_n) \tag{2}$$

$$CDH_{Total} = \sum_{n=s}^{k} H_n \cdot (T_n - T_{Base}) \tag{3}$$

Temperature 'k' and 's' denotes the temperature limits of the function. HDH_{Total} and CDH_{Total} indicate the total heating and cooling degree-hour values for a chosen month, respectively. T_{Base} is a reference indoor temperature for both heating or cooling.

2.1 New modeling functions

In this study, two new functions are proposed. The proposed new functions are given by the equations below:

$$H_{T_{out}} = f \cdot e^{\left[\frac{-(T_{out} - g)^2}{2 \cdot h^2}\right]} \tag{4}$$

$$H_{T_{out}} = e^{\left[k + \frac{m}{T_{out}} + n \cdot \ln(T_{out})\right]} \tag{5}$$

where, f, h, g, k, m and n are the new model parameters, which are determined according to mean outdoor temperature probability density distribution, whose determination is explained detail in Section 3 below.

3. Determination of mean outdoor temperature probability density distribution

We calculated both temperature probability distribution and time elapsed in a month for any temperature interval of 1 °C. In the calculation, hourly dry-bulb outdoor temperature data, based on the last 32 years and recorded by the Turkish State Meteorological Station, were used. In this study, the general trend was tried to be obtained in one formulation. The outdoor temperature distribution frequency exhibits different characteristics in each year and month. Nevertheless, the mean outdoor temperature probability density distribution for each month can be determined by using the long term actual data for the past temperatures, which can be utilized as a reference distribution for degree-hours calculations. It was observed that outdoor temperature has a random fluctuation on general trend. In this study, the mean outdoor temperature probability density distribution was taken as a reference distribution for the modified degree-hours calculation method. Fig. 1 is given to illustrate the fluctuation of actual outdoor temperature frequency distributions for 32 years.

4. Results and discussion

The modified degree-hours calculation method was applied to four cities in Turkey. The model parameters are determined and given in Table 1. Analysis results show that the two new functions result in higher accuracy for the summer season. Therefore, the three functions are incorporated into a modified degree-hours calculation method in this study.

The two functions proposed in this study were also applied to a case study to demonstrate its accuracy. The province of Adana was chosen for this purpose. The actual outdoor temperature probability density distribution and the two functions are shown in Fig. 2 for the month of May. As it can be seen from Fig. 2, the new functions displayed better performance for cooling degree-hours calculations for the summer season. Also, actual and model outdoor temperature probability density distributions for six months were given in Fig. 3 for Adana.

Adana		Months											
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Model parameters	a	32.80	25.36	25.75	-	-	-	-	-	-	-	-	-
	b	36.37	28.30	29.35	-	-	-	-	-	-	-	-	-
	c	0.28	0.24	0.22	-	-	-	-	-	-	-	-	-
	d	-2.79	-2.61	-3.13	-	-	-	-	-	-	-	-	-
	f	-	-	-	64.87	-	-	-	-	-	-	59.48	73.53
	g	-	-	-	17.36	-	-	-	-	-	-	15.19	11.16
	h	-	-	-	4.44	-	-	-	-	-	-	4.84	4.04
	k	-	-	-	-	83.856	149.445	261.517	261.733	137.124	71.657	-	-
	m	-	-	-	-	-404.1	-858.3	-1652.7	-1668.4	-794.0	-340.7	-	-
	n	-	-	-	-	-19.87	-34.46	-59.45	-59.35	-31.45	-16.88	-	-
Temperature limits		0.5	0.5	2.5	5.5	11.5	15.5	17.5	17.5	13.5	9.5	1.5	-1.5
		19.5	21.5	25.5	33.5	39.5	40.5	43.5	43.5	41.5	38.5	30.5	24.5

Balıkesir		Months											
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Model parameters	a	-	-	-	-	-	24.11	-	-	-	-	-	24.00
	b	-	-	-	-	-	24.28	-	-	-	-	-	30.26
	c	-	-	-	-	-	0.21	-	-	-	-	-	0.21
	d	-	-	-	-	-	-4.66	-	-	-	-	-	-1.69
	f	67.07	53.76	60.37	51.70	-	-	-	-	53.81	62.06	60.80	-
	g	4.85	5.48	7.62	12.67	-	-	-	-	20.67	15.35	10.60	-
	h	4.43	4.99	4.92	5.57	-	-	-	-	5.36	4.79	4.73	-
	k	-	-	-	-	42.664	-	104.903	106.627	-	-	-	-
	m	-	-	-	-	-162.4	-	-566.7	-571.2	-	-	-	-
	n	-	-	-	-	-10.28	-	-24.29	-24.77	-	-	-	-
Temperature limits		-8.5	-10.5	-7.5	3.5	5.5	8.5	11.5	11.5	6.5	1.5	-3.5	-3.5
		20.5	22.5	26.5	32.5	37.5	35.5	40.5	40.5	36.5	32.5	27.5	19.5

Antalya		Months											
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Model parameters	f	71.70	61.35	66.30	66.10	63.15	58.40	-	-	-	-	61.79	71.50
	g	10.24	10.77	12.90	16.20	20.51	25.38	-	-	-	-	14.72	11.34
	h	4.16	4.39	4.49	4.36	4.72	4.94	-	-	-	-	4.68	4.17
	k	-	-	-	-	-	-	165.897	157.934	101.845	65.237	-	-
	m	-	-	-	-	-	-	-1034.5	-975.4	-557.6	-290.3	-	-
	n	-	-	-	-	-	-	-37.45	-35.7	-23.46	-15.58	-	-
Temperature limits		-1.5	-1.5	0.5	4.5	8.5	12.5	17.5	17.5	14.5	9.5	3.5	0.5
		21.5	22.5	26.5	30.5	36.5	40.5	44.5	44.5	39.5	37.5	29.5	23.5

Ankara		Months											
		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Model parameters	f	60.96	51.50	51.90	54.17	52.80	49.98	50.18	50.45	48.08	55.00	53.65	64.80
	g	1.04	2.14	6.00	10.95	15.56	19.52	23.09	22.98	18.56	12.66	6.65	2.15
	h	4.89	5.23	5.75	5.33	5.65	5.83	5.99	6.00	6.09	5.44	5.40	4.60
Temperature limits		-12.5	-12.5	-9.5	-3.5	0.5	6.5	8.5	10.5	5.5	-0.5	-6.5	-10.5
		14.5	16.5	21.5	25.5	31.5	34.5	37.5	38.5	33.5	29.5	21.5	15.5

Table 1. Monthly model parameters for the four cities.

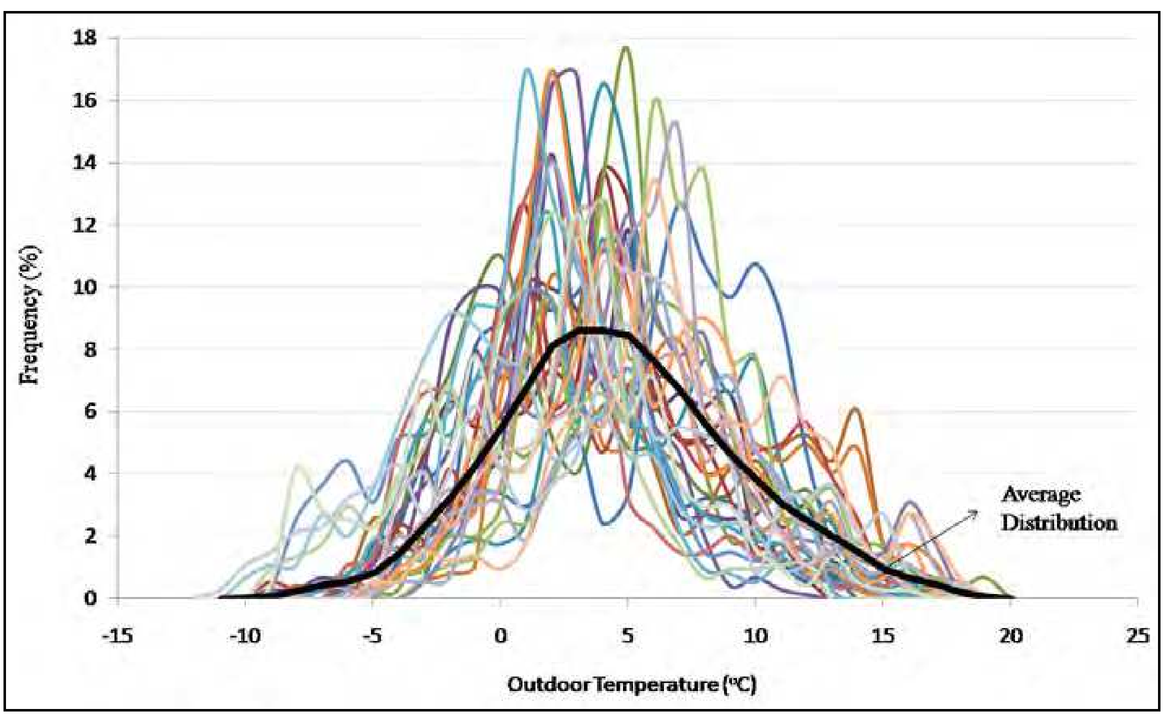

Fig. 1. Actual and mean outdoor temperature frequency distributions for Balikesir during the month of January

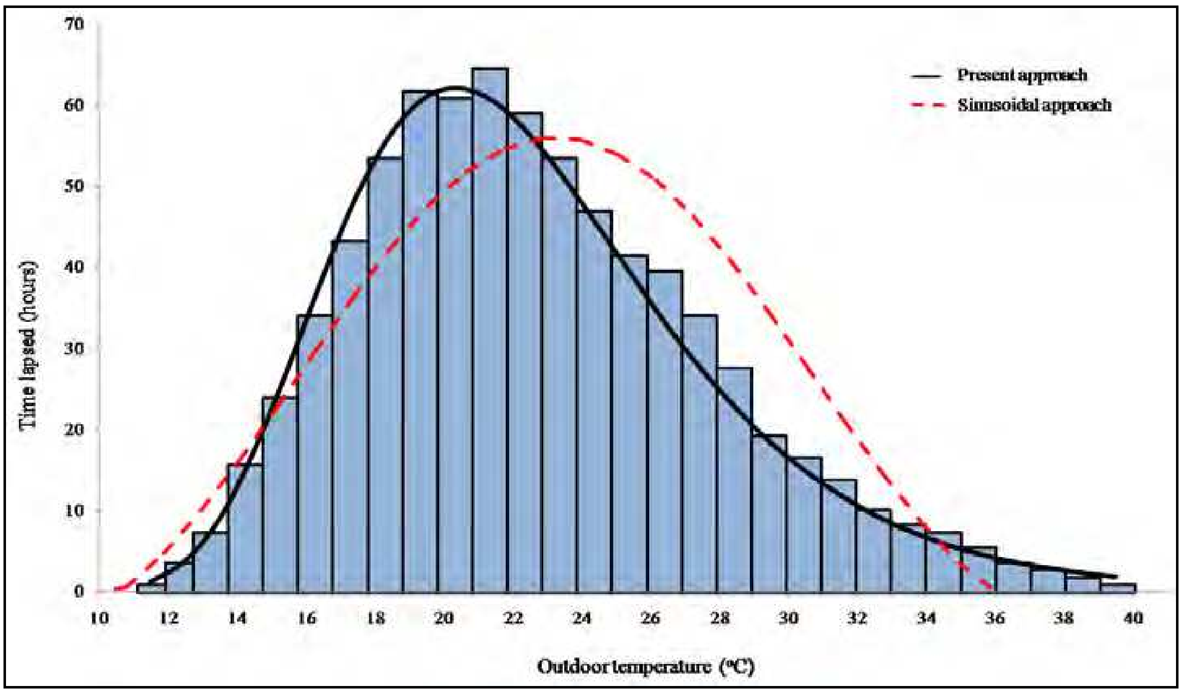

Fig. 2. Outdoor temperature probability density distribution for May

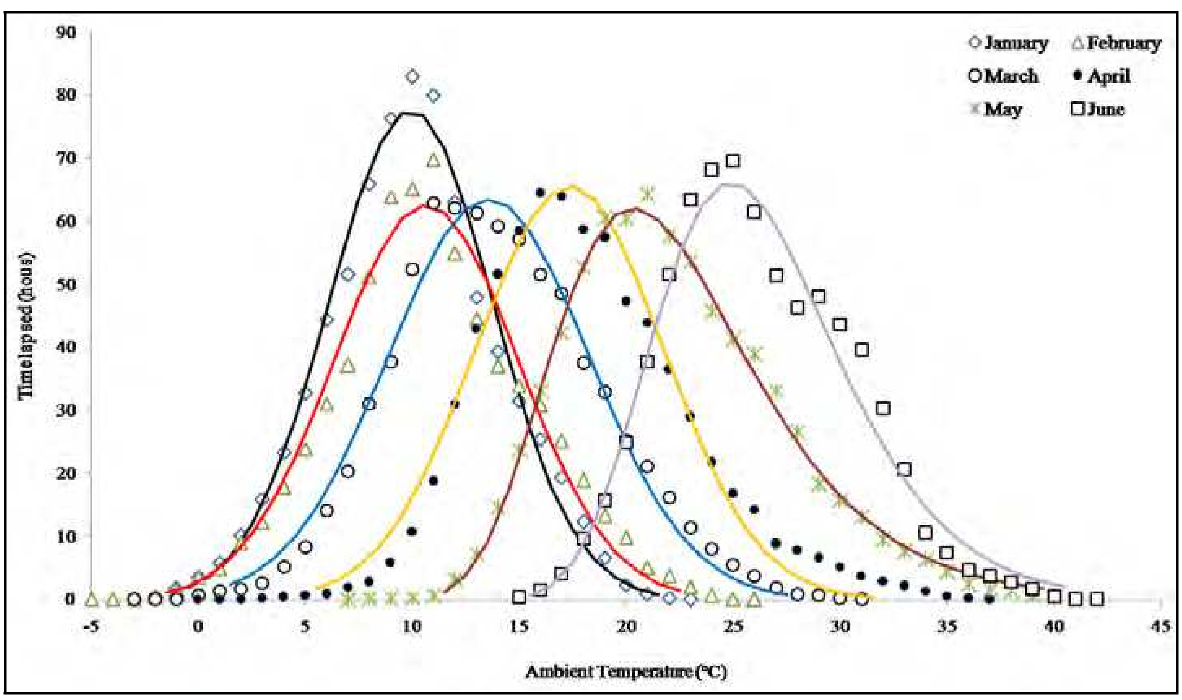

Fig. 3. Outdoor temperature probability density distribution for six months

5. Conclusions

Results of the analysis show that one function is not sufficient for determining the accurate outdoor temperature distribution during the year. In this regard, two new functions were proposed and added to the existing calculation procedure. As a result, the modified degree-hours calculation method obtains more accurate results for each month by using all three outdoor temperature distribution functions. The main advantages of the approach can be listed as follows:

- Outdoor temperature distribution for each month can be determined precisely by using the modified degree-hours calculation method. Probable heating and cooling degree-hours value can be calculated by using probable outdoor temperature distribution for each month.
- Heating and cooling degree-hour values can be calculated for each month with respect to any chosen base temperature.
- The user can easily calculate the time elapsed in a month for temperatures below or above any chosen level of outdoor reference temperature.

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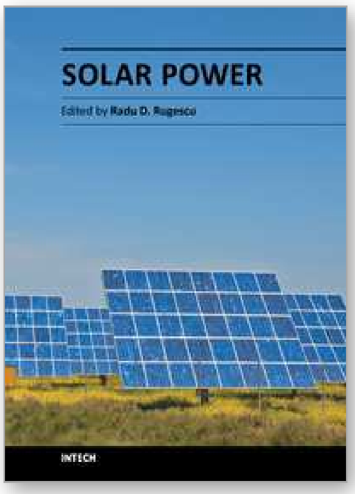

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A wide variety of detail regarding genuine and proprietary research from distinguished authors is presented, ranging from new means of evaluation of the local solar irradiance to the manufacturing technology of photovoltaic cells. Also included is the topic of biotechnology based on solar energy and electricity generation onboard space vehicles in an optimised manner with possible transfer to the Earth. The graphical material supports the presentation, transforming the reading into a pleasant and instructive labor for any interested specialist or student.