Energy 36 (2011) 4855–4863

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A new approach for predicting cooling degree-hours and energy requirements in buildings

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ARTICLE INFO

Article history:
Received 23 November 2010
Received in revised form
12 May 2011
Accepted 15 May 2011
Available online 22 June 2011

Keywords:
Degree-hours
Cooling
Cooling load
Building
Energy analysis
Dimensionless temperature variation coefficient

ABSTRACT

This study develops a novel approach to predict the outdoor temperature fluctuations during daytime as a dimensionless temperature variation coefficient. In this approach, the daily outdoor temperature trend is established by using the daily maximum and minimum temperatures. A case study is performed to calculate the cooling degree-hours for 58 cities in different geographical regions of Turkey as a case study for the present approach. The results are then compared with the published data. The other advantage of this approach is that it allows the prediction of monthly cooling degree-hours for buildings.

1. Introduction

During summer seasons, electricity consumption drastically increases for cooling and air-conditioning applications and affects the peak electricity demand. Forecasting the total electricity consumption for cooling requires determination of the cooling load profile, for which the identification of the two main external factors is required, namely the daily or hourly average outdoor temperatures and the heat gain from sunlight. The reliable data for daily average outdoor temperatures can be obtained from many sources. Nevertheless, accessing accurate information on the hourly outdoor temperatures is much more difficult. In order to overcome this obstacle, several studies, e.g., [1–9] have been undertaken to analyze the outdoor temperatures by using degree-hour/day values in order to predict the heating and cooling energy requirements for buildings. In some studies, a constant base temperature method is employed to predict the cooling degree-hours. In the literature, there are only a few studies, focusing on both constant and variable base temperatures. Monthly cooling loads and their profiles cannot be predicted from the total cooling degree-hour values. Clearly, each month displays a particular outdoor temperature distribution and cooling degree-hours values. Hence, the probable hourly temperature distribution must be established to address such differentials in the distributions. Probability density functions are successfully applied in wind, solar energy, hydrogen production and outdoor temperature analyses and as such, they are commonly preferred by many researchers [9–13] for energy analyses.

During the past several decades, hundreds of building energy programs have been developed, enhanced and put into practice. The core tools in the building energy field are the whole-building energy simulation programs, which provide users with a number of key building performance indicators such as energy use and demand, temperature, humidity, and the related costs [14]. More recently, hourly building energy simulations have increasingly replaced the simplified load calculation methods such as the degree-day and degree-hour 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 dynamic behavior such as the thermal energy storage in the

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doi:10.1016/j.energy.2011.05.022

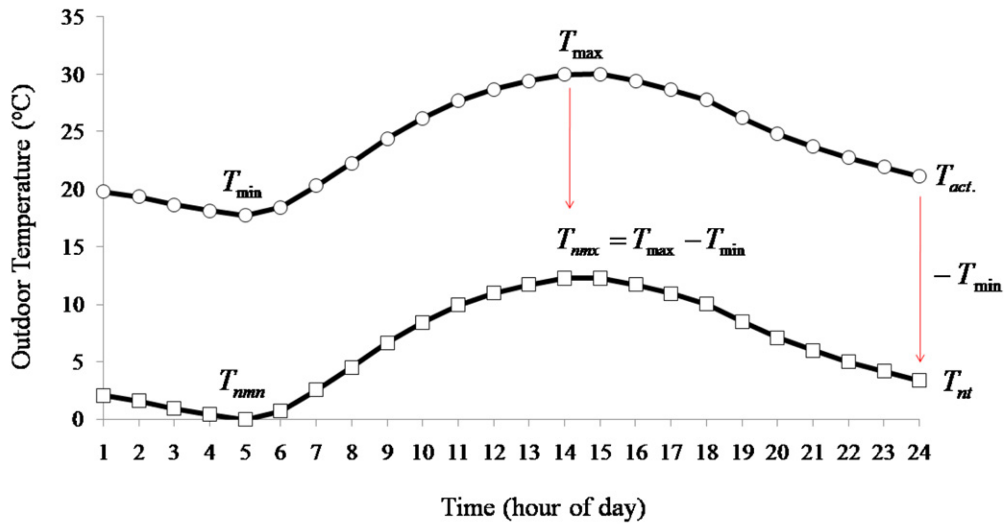


Fig. 1. Distribution of actual and new actual temperatures.

structure itself. However, simplified models and methods are preferred over these sophisticated building energy simulation programs. In Turkey, people are in favor of using less complicated methods.

In this study, a novel method is proposed to estimate both monthly outdoor temperature trends and cooling degree-hours. In this regard, the data for 58 cities in Turkey are considered and utilized for study and compared with the results of the present method. A new parameter namely, the dimensionless temperature variation coefficient (Z) is introduced.

2. Models for the estimation of cooling degree-hours

Zhang et al. [15] provide a model to estimate the cooling degree-hours by using daily average temperatures and solar radiation as parameters. In their study, model parameters were calculated for 22 cities in China, and hence the relationship between cooling degree-hours and the average temperature was investigated. Also, it was observed that there is a weak positive correlation between cooling degree-hours and daily solar radiation, which was thereby included as another parameter along with the average temperature in predicting cooling degree-hours. Zhang [16] also established a method for converting cooling degree-hours for a specific base temperature to another base for China. Coskun [9] demonstrated the probability density distribution for outdoor temperatures and determined heating and cooling degree-hour values by using his distribution.

3. Model development

3.1. Model description

The main objective of this study is to quantify the variation of outdoor temperature change during daytime as a dimensionless number between 0 and 1. In this regard, a new approach is proposed to estimate the dimensionless temperature distribution during course of the day. In this approach, the daily minimum temperature value is subtracted from each outdoor temperature, in effect creating a new temperature curve. Consequently, the minimum temperature in this obtained curve equals to zero. For the next step, all the temperature values on the new curve are divided by a new maximum temperature, which yields values of 1

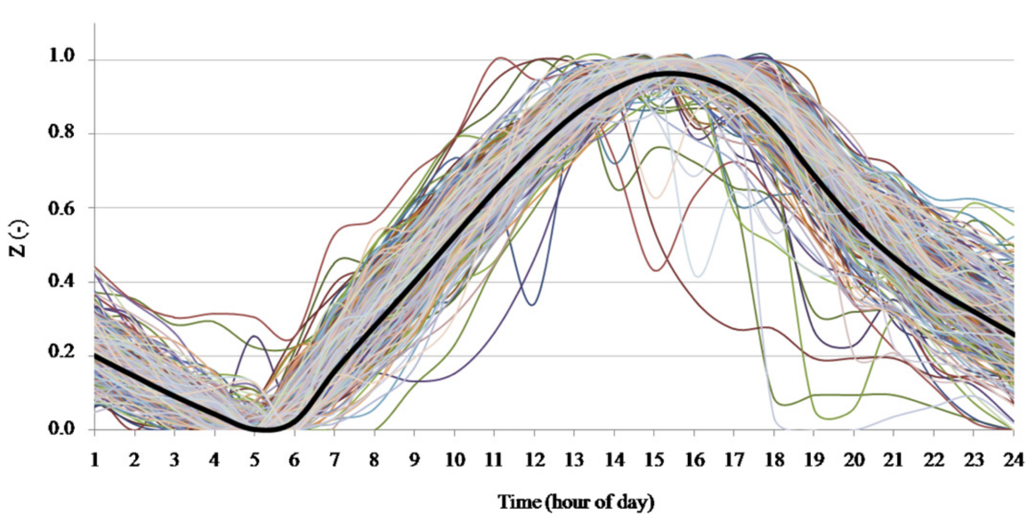


Fig. 2. Actual and monthly average Z-curve for Denizli in July.

and 0 values as maximum and minimum points along the curve, respectively. This dimensionless temperature variation becomes the *Z*-curve. This parameter makes it possible to define the variation in outdoor temperature change without referring to a specified unit like degree Celsius (°C). The actual and the transformed temperature curves are shown in Fig. 1. Therefore, the corresponding equations are given as

$$T_{nt} = T_{act} - T_{min} \quad (1)$$

$$T_{nmx} = T_{max} - T_{min} \quad (2)$$

where T_{nt} and T_{nmx} denote the new temperature and the new maximum temperature.

The dimensionless temperature variation coefficient (Z) is then calculated by

$$Z = \frac{T_{nt}}{T_{nmx}} \quad (3)$$

Using Eqs. (1–3), the actual temperature distribution can be determined as

$$T_{act} = (T_{max} - T_{min})\cdot Z + T_{min} \quad (4)$$

Here, Z was determined for each day during the time period of 1975–2007 (11,680 days) for each of Turkish cities. Actual hourly dry-bulb outdoor temperature data are taken from the Turkish State Meteorological Service for 58 cities in Turkey. After the calculation of dimensionless temperature variation coefficient for each day, the monthly average dimensionless temperature variation coefficient curve (*Z*-curve) is illustrated for each city. A sample demonstration for the actual and monthly average *Z*-curve is displayed for Denizli for the month of July in Fig. 2. It is found out that average *Z*-curve during the cooling season exhibits a similar distribution with the actual distribution curve. The average *Z*-curve for cooling season is calculated by the monthly *Z*-curves for the cities. This plotted curve is named as the average dimensionless temperature variation coefficient curve for the cooling season ($Z_{cooling}$ curve). After determining the $Z_{cooling}$ curve for each city, similar trends are categorized under the same group. Instead of presenting the $Z_{cooling}$ curve for each city, we categorize a total of 58 cities into six groups as given in Table 1. The variations of temperature coefficients for these six groups are shown in Fig. 3. Analyzing the coefficients data, it is found out that no meaningful correlation exists between the variations in $Z_{cooling}$ curves and the climatic zones. Thus, it can be explained that climatic zones in Turkey bear no significant effect on grouping of the $Z_{cooling}$ curves.

3.2. Estimation of cooling degree-hours from the Z

One needs to know the daily maximum and minimum temperatures in order to make use of the dimensionless temperature variation coefficient (Z). Two main parameters, namely the average maximum and minimum outdoor temperatures, are then employed to simplify the approach. The average maximum and minimum outdoor temperatures for each city are provided in the Turkish State Meteorological Service's web site [17]. In this study, these average maximum and minimum outdoor temperatures are used in the calculations. Then, the monthly average outdoor temperature curve is estimated using the $Z_{cooling}$ curve. This profile is employed to represent the midline for the outdoor temperature. Next, the outdoor temperature distribution is estimated for each hour of each day from the 32-year temperature data. Afterward, the hourly outdoor temperature variation gap and the hourly outdoor temperature distribution density are estimated. Thus, this distribution is divided into ten sections with equal durations based on the hours of the day. The number of sections is chosen to be ten particularly for the purposes of simplifying the calculation. Alternatively, a different number of equal sections above ten could be

Table 1
Cooling degree-hours for six groups ($T_{base} = 24$ °C).

Groups/Cities	Cooling degree-hour		Difference (%)
	Ref. [5]	Present approach	
1. Group			
Balikesir	5827	5794	−0.6
Mersin	9746	9491	−2.6
2. Group			
Adiyaman	16,598	16,416	−1.1
Aksaray	4648	4579	−1.4
Bilecik	2748	2803	2.0
Kirikkale	4880	4917	0.8
Kirklareli	4707	4759	1.1
Ordu	1861	1878	0.9
Samsun	1458	1463	0.3
S. Urfa	19,418	19,607	0.9
Trabzon	1369	1408	2.9
3. Group			
Afyon	3005	3006	0.1
Antalya	10,175	10,168	−0.1
Tekirdag	2124	2144	0.9
Yalova	2980	3084	3.5
4. Group			
Bartin	2335	2302	−1.4
Denizli	9676	9797	1.3
Diyarbakir	14,750	14,924	1.2
Edirne	5696	5774	1.4
Izmir	9854	9828	−0.3
Kastamonu	1954	1937	−0.9
Mardin	12,417	12,401	−0.1
Nevsehir	2234	2203	−1.4
Tunceli	8568	8632	0.8
Tokat	3485	3488	0.1
Usak	4217	4131	−2.0
5. Group			
Ankara	3513	3503	−0.3
Bursa	4733	4653	−1.7
Batman	16,416	16,343	−0.5
Canakkale	4361	4443	1.9
Corum	2813	2815	−0.1
Eskisehir	2740	2822	3.0
Isparta	3816	3829	0.3
Kirsehir	3268	3163	−3.2
Kutahya	2171	2292	5.6
Kocaeli	3512	3513	0.1
Manisa	11,225	11,121	−0.9
Mugla	7925	7783	−1.8
6. Group			
Adana	12,995	13,449	3.5
Amasya	4722	4814	2.0
Aydin	12,054	12,330	2.3
Bingol	8132	8109	−0.3
Burdur	4975	5187	4.3
Bolu	1692	1742	2.9
Cankiri	4067	4189	3.0
Elazig	7645	7724	1.0
Gaziantep	10,484	10,723	2.3
Hatay	9427	9868	4.7
Istanbul	2551	2683	5.1
Karaman	4409	4582	3.9
Kayseri	3556	3792	6.7
Konya	3448	3751	8.8
K. Maras	10,983	11,959	8.8
Kilis	12,417	12,439	0.2
Malatya	7337	7748	5.6
Sakarya	3365	3364	−0.1
Siirt	13,319	13,387	0.5
Sivas	2073	2067	−0.3

utilized in the approach. The outdoor temperature density is estimated for each month, and a sample demonstration of outdoor temperature density for Denizli for the month of July is given in Fig. 4. Depending on the outdoor temperature density, the hourly average temperatures are determined for each of the equal length sections. Therefore, the ten equal sections based on the hours of the day are denoted by the variable 't' which varies from 1 to 10 apparently.

Here, the relationship between the mid outdoor temperature line and the hourly outdoor temperature distribution density is investigated. Then, the daily temperature distributions for 58 cities in Turkey are formulated by the following equations:

$$T_{max}(t) = \left(9.73 - 4.912\cdot t + 0.861\cdot t^2 - 0.0523\cdot t^3\right)\cdot(T_{max} - T_{min}) + T_{max} \quad (5)$$

$$T_{min}(t) = \left(4.865 - 2.456\cdot t + 0.4305\cdot t^2 - 0.02615\cdot t^3\right)\cdot(T_{max} - T_{min}) + T_{min} \quad (6)$$

$$T_{nmx}(t) = T_{max}(t) - T_{min}(t) \quad (7)$$

$$T_{nt}(t) = Z\cdot T_{nmx}(t) \quad (8)$$

where $T_{nt}(t)$, $T_{nmx}(t)$, $T_{max}(t)$ and $T_{min}(t)$ indicate the new actual, new maximum, maximum and minimum temperatures for the ten equally-divided sections based on the hours of the day for a specific month. The actual and probable outdoor temperature distributions are then presented in Fig. 5 for Denizli.

After determining the probable outdoor temperature distributions, the monthly cooling degree-hour values can be calculated for part-time and full-time operation in buildings. The monthly total cooling degree-hour can be obtained from

$$r = \sum_{t=1}^{10}(T_{nt}(t) - T_{base}) \quad (9)$$

where the positive values are only considered.

$$MCDH = 0.1\cdot(r\cdot n) \quad (10)$$

where $MCDH$ stands for monthly total of cooling degree-hours, n represents the number of days in a given month, and T_{base} is the indoor reference (base) temperature.

4. Results and discussion

In order to illustrate the use of the present method, a case study is conducted for Denizli in Turkey. The degree-hour values are then calculated for two separate parameters for this case study:

- The total degree-hours for July (with a base temperature of 24 °C) and
- The total degree-hours for a small office building operated part time between 08:00 and 19:00 only during weekdays in July.

The maximum and minimum temperatures for July are taken from the Turkish State Meteorological Service web site for calculations and comparisons. Accordingly, Denizli belongs to the fourth group as given in Table 2, based on the temperature variation coefficient values obtained. Then, T_{nact} and T_{act} values are calculated using Eqs. (2–4). After estimating the probable hourly outdoor temperature distribution, the total cooling degree-hours values were calculated. Ultimately, the total cooling degree-hours for the whole month of July are found to be 3214 °C-hours, whereas the corresponding value for the building part time operation remains between 08:00 and 19:00 for 23 days in July as 2131 °C-hours. The outdoor temperature distribution is assumed to be a unique schedule for every day of the week in the calculation. The application of the present method for the building part-time operation between 08:00 and 19:00 for 23 days in July is presented in Fig. 6.

The monthly maximum, minimum and average cooling degree-hours for a reference temperature value of 24 °C are calculated for Denizli by using the 32-year actual temperature data. The results obtained here are then compared with the model results as given in Table 3 in order to evaluate the differences and superiorities of the present method. It can be observed from here that similar results

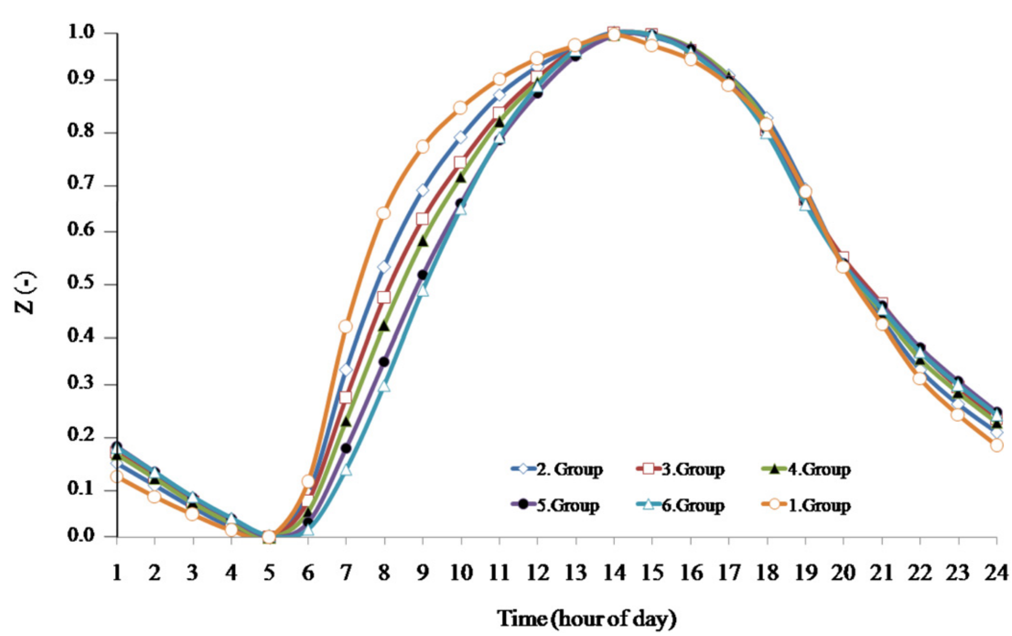
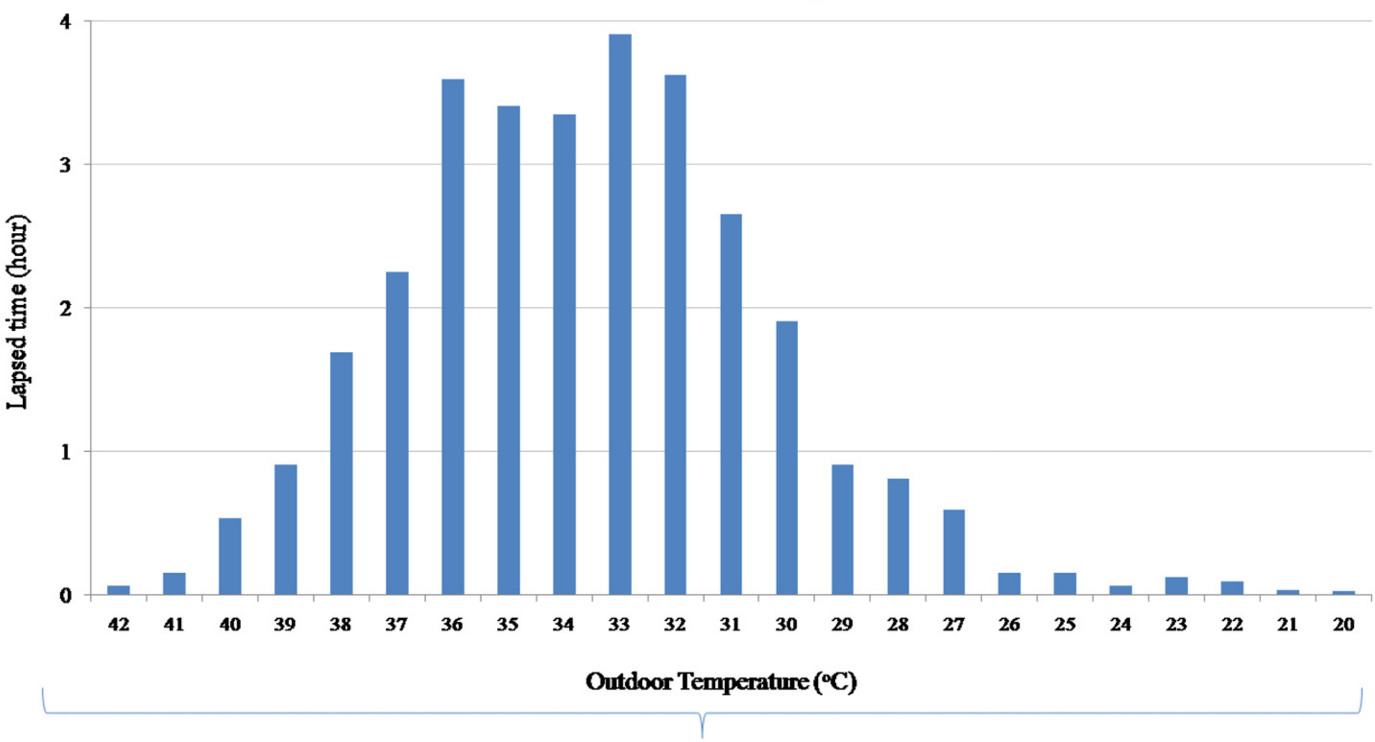


Fig. 3. Variations of temperature difference coefficients for six groups.

Temperature (°C)	00:00 01:00	01:00 02:00	02:00 03:00	03:00 04:00	04:00 05:00	05:00 06:00	06:00 07:00	07:00 08:00	08:00 09:00	09:00 10:00	10:00 11:00	11:00 12:00	12:00 13:00	13:00 14:00	14:00 15:00	15:00 16:00	16:00 17:00	17:00 18:00	18:00 19:00	19:00 20:00	20:00 21:00	21:00 22:00	22:00 23:00	23:00 00:00
42	-	-	-	-	-	-	-	-	-	-	-	-	0,03	0,06	0,09	0,06	-	-	-	-	-	-	-	-
41	-	-	-	-	-	-	-	-	-	-	-	-	0,03	0,16	0,31	0,31	0,25	0,03	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	0,13	0,53	0,94	0,63	0,31	0,16	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	0,09	0,66	0,91	1,09	1,19	0,91	0,25	-	-	-	-	-	-
38	-	-	-	-	-	-	-	-	-	-	0,06	0,34	0,97	1,69	2,28	2,44	1,94	0,88	0,06	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	0,19	0,84	1,72	2,25	3,13	3,13	2,78	1,81	0,28	-	-	-	-	-
36	-	-	-	-	-	-	-	-	-	0,06	0,56	1,34	2,56	3,59	3,25	3,34	3,13	2,31	0,75	0,03	-	-	-	-
35	-	-	-	-	-	-	-	-	0,03	0,19	1,03	2,16	3,19	3,41	3,50	3,56	3,94	3,13	1,63	0,34	-	-	-	-
34	-	-	-	-	-	-	-	-	0,03	0,84	1,78	3,00	3,31	3,34	3,50	3,31	3,34	3,81	2,72	0,69	0,13	-	0,03	-
33	-	-	-	-	-	-	-	-	0,28	1,22	2,94	3,69	3,81	3,91	3,78	4,09	4,03	3,91	3,63	1,59	0,34	0,16	0,00	-
32	-	-	-	-	-	-	-	0,06	1,09	2,13	3,31	4,06	3,41	3,63	3,06	2,63	2,94	3,75	3,91	2,81	1,03	0,28	0,19	-
31	0,03	-	-	-	-	-	-	0,38	1,53	3,19	3,91	3,66	3,91	2,66	2,09	2,03	2,44	3,00	4,53	4,22	2,47	1,16	0,44	0,25
30	0,16	0,06	-	-	-	-	0,09	1,25	2,41	3,59	3,91	3,84	2,75	1,91	1,25	1,28	1,16	2,78	3,69	4,38	3,94	1,72	1,09	0,31
29	0,63	0,25	0,09	0,03	-	-	0,31	1,66	3,66	3,91	3,69	2,97	1,88	0,91	0,84	0,78	0,91	1,22	3,34	4,59	4,50	3,94	2,00	1,53
28	1,28	0,72	0,44	0,09	0,09	0,06	0,97	2,88	3,66	4,00	3,94	2,22	0,97	0,81	0,59	0,66	0,91	1,06	1,81	4,03	5,16	4,66	3,94	2,31
27	2,53	1,66	0,94	0,81	0,31	0,31	2,16	3,66	4,50	4,50	2,44	1,00	0,63	0,59	0,38	0,44	0,69	0,72	1,19	2,50	4,25	4,84	5,00	3,75
26	4,31	2,84	1,84	0,91	0,75	1,06	3,44	4,56	4,09	3,06	1,34	0,69	0,44	0,16	0,34	0,38	0,31	0,75	1,03	2,06	3,25	5,06	5,56	5,50
25	5,44	4,84	3,19	2,31	1,56	1,88	4,56	4,91	3,88	2,06	0,78	0,56	0,28	0,16	0,09	0,28	0,44	0,50	0,88	1,06	2,19	3,13	4,53	5,78
24	5,72	5,25	5,47	4,50	3,28	3,38	5,25	4,06	2,50	0,91	0,53	0,13	0,19	0,06	0,13	0,13	0,16	0,28	0,47	1,03	1,31	2,34	2,84	3,84
23	3,97	5,50	5,72	5,47	4,56	5,31	4,84	3,28	1,53	0,53	0,19	0,22	0,03	0,13	0,16	0,19	0,22	0,25	0,44	0,63	0,84	1,09	2,00	2,81
22	2,69	4,00	4,75	5,31	6,22	6,34	3,94	2,47	1,03	0,41	0,28	0,13	0,06	0,09	0,06	0,06	0,06	0,06	0,19	0,41	0,75	1,28	1,34	1,59
21	1,78	2,34	3,41	4,53	5,13	4,78	2,78	0,75	0,31	0,28	0,09	0,03	0,03	0,03	0,03	0,03	0,06	0,16	0,19	0,25	0,34	0,63	0,97	1,72
20	1,28	1,47	2,31	2,78	3,59	3,50	1,56	0,53	0,34	0,09	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,09	0,13	0,16	0,22	0,34	0,44	0,81
19	0,72	1,38	1,41	1,91	2,41	2,28	0,59	0,34	0,06	0,03	-	-	-	-	0,06	0,03	0,03	0,03	0,09	0,13	0,13	0,16	0,38	0,47
18	0,16	0,31	0,91	1,31	1,53	1,25	0,31	0,13	0,03	-	-	-	-	-	-	-	0,03	0,03	0,03	0,03	0,13	0,13	0,09	0,13
17	0,22	0,22	0,28	0,63	1,03	0,53	0,13	0,06	0,03	-	-	-	-	-	-	-	-	0,03	0,03	0,03	0,03	0,06	0,13	0,13
16	0,06	0,16	0,13	0,31	0,38	0,25	0,06	0,03	-	-	-	-	-	-	-	-	-	-	-	0,03	-	0,03	0,03	0,06
15	0,03	-	0,13	0,03	0,16	0,06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	0,06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-



$T_{nt}(1)$=39.71 °C $T_{nt}(3)$= 36.08 °C $T_{nt}(5)$= 35.04 °C $T_{nt}(7)$= 32.28 °C $T_{nt}(9)$= 31.37 °C

$T_{nt}(2)$= 37.18 °C $T_{nt}(4)$= 35.73 °C $T_{nt}(6)$= 33.68 °C $T_{nt}(8)$= 31.71°C $T_{nt}(10)$= 26.61 °C

Fig. 4. A sample variation of outdoor temperature density for Denizli in July.

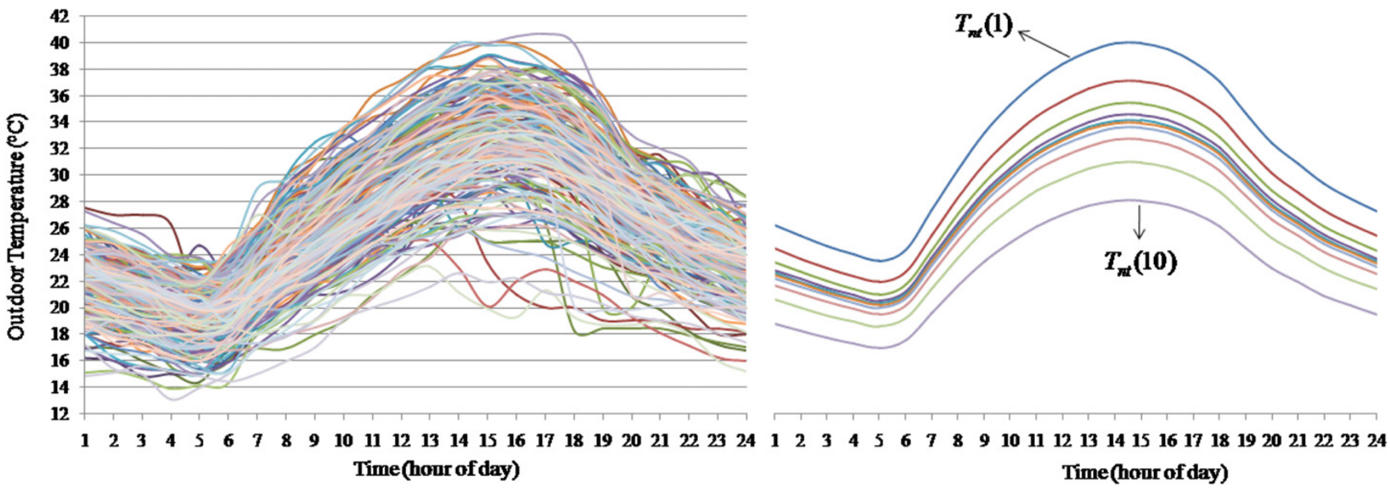


Fig. 5. Actual and predicted outdoor temperature distributions for July.

are obtained with respect to the monthly average cooling degree-hours. One of the most important advantages of the present method is the estimation of monthly total cooling degree-hours. The daily outdoor temperature curve is estimated and plotted for a sample day in Denizli by using the daily weather forecast data along with the maximum and minimum outdoor temperatures. Then, minute based actual data collected are compared with the daily outdoor temperature predictions as shown in Fig. 7. As a result, similar temperature distributions are observed in agreement, where the minute based actual and predicted values deviate by a maximum difference of 2.7 °C.

The cooling load is calculated for a building that is operational part-time between 08:00 and 19:00 for each working day in July. The model building parameters selected are given in Table 4. The total heat transfer coefficient (L) of the model building is calculated from [18]:

$$L = \sum_{i=1}^{m} UA + I(qc_p)_{\text{air}} \frac{V}{3600} \tag{11}$$

Table 2
Temperature variation coefficient for six groups.

Time	Groups					
	1.	2.	3.	4.	5.	6.
01:00	0.121	0.147	0.168	0.164	0.181	0.121
02:00	0.081	0.103	0.120	0.116	0.130	0.081
03:00	0.046	0.060	0.071	0.069	0.080	0.046
04:00	0.014	0.022	0.029	0.029	0.037	0.014
05:00	0.001	0.001	0.001	0.001	0.002	0.001
06:00	0.110	0.088	0.072	0.052	0.030	0.017
07:00	0.414	0.330	0.276	0.230	0.176	0.135
08:00	0.639	0.532	0.473	0.417	0.346	0.300
09:00	0.769	0.684	0.627	0.584	0.517	0.487
10:00	0.845	0.787	0.738	0.710	0.658	0.648
11:00	0.904	0.872	0.835	0.819	0.783	0.789
12:00	0.942	0.927	0.907	0.895	0.875	0.889
13:00	0.968	0.966	0.963	0.955	0.948	0.960
14:00	0.989	0.996	0.994	0.990	0.988	0.993
15:00	0.969	0.987	0.990	0.992	0.990	0.989
16:00	0.940	0.960	0.958	0.965	0.962	0.956
17:00	0.891	0.910	0.896	0.908	0.899	0.894
18:00	0.813	0.827	0.802	0.816	0.802	0.797
19:00	0.680	0.686	0.665	0.670	0.661	0.655
20:00	0.533	0.535	0.550	0.538	0.540	0.533
21:00	0.420	0.429	0.459	0.443	0.456	0.420
22:00	0.314	0.330	0.368	0.352	0.374	0.314
23:00	0.243	0.263	0.297	0.286	0.309	0.243
24:00	0.181	0.207	0.234	0.227	0.248	0.181

here, i represents the physical places where the heat gain occurs such as outside walls, windows, ceiling etc., and I denotes the rates of air exchange per hour. The rates of air exchange per hour arising from the ventilation and infiltration effects are considered for a range of 0.5–2 [6]. In this study, air exchange rates per hour are considered as unity. V is the volume of the office. The quantity $(qc_p)_{\text{air}}$ is the volumetric thermal capacity of air. The average outdoor temperature for cooling hours is calculated as 30.94 °C. The density and specific heat of the air (at 30.94 °C and 101 kPa) are determined as 1.158 kg m^{-3} and 1003 J kg^{-1} K^{-1}, respectively. For these calculations, the EES (Engineering Equation Solver) computer program is utilized as a common software in engineering applications, especially for determination of fluid thermodynamic properties. The quantity $(qc_p)_{\text{air}}$ is determined as 1162 Jm^{-3} K^{-1}.

The average outdoor temperature is 23.87 °C for non-cooling hours during the week, remaining below the reference temperature level of 24 °C. Consequently, any heat gain from non-cooling hours during the week is found to be negligible in this study. The average outdoor temperature for non-cooling hours for the weekend is accepted to be equal to the monthly average outdoor temperature. Hence, the indoor temperature of the office is determined to be 27.11 °C for two days of the weekend. Then the cooling requirement is calculated as

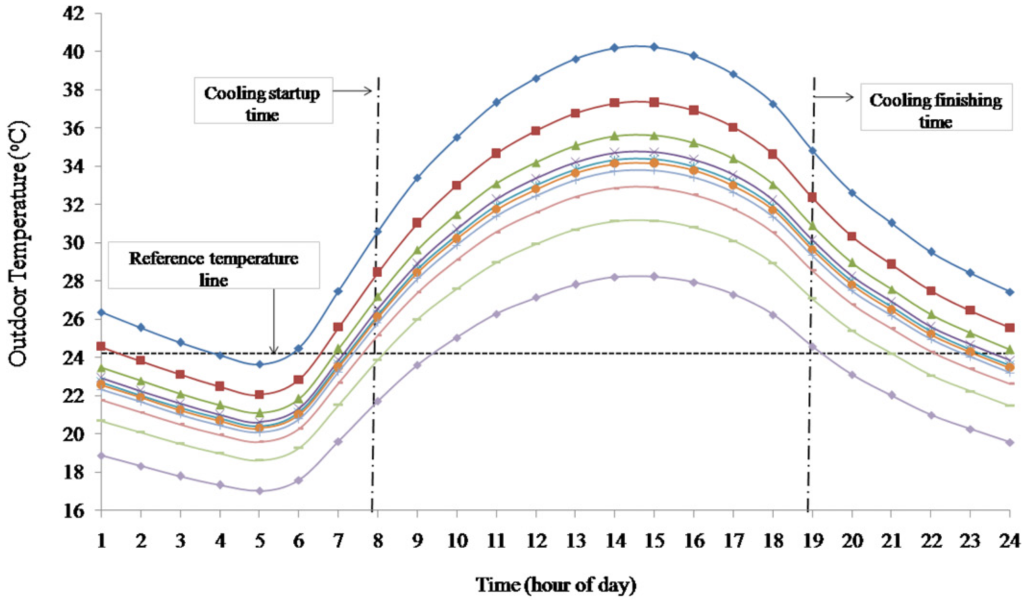
$$HGNC = \left(T_{\text{in}} - T_{\text{ref}}\right) \cdot \left(UA + (qc_p)_{\text{air}} V\right) \tag{12}$$

where $HGNC$ is the non-cooling hours heat gain. The total cooling requirement is calculated as 1033.8 kWh and given in Table 5.

Some advantages of the present approach may be listed as follows:

- The cooling degree-hours can easily be estimated for part-time operation in buildings for each month. There is no need to convert total degree-hours into monthly base values.
- The average cooling load profile can also be estimated for various hours during daytime when cooling is required with respect to different base temperatures. Also, the hours in which cooling is required it varies depending on the base temperature.
- Its simplicity and effectiveness over other complicated simulation tools are preferable

There is a need to work on the incorporation of this approach into the dynamic simulation tools.



Time	New Temperature (°C)									
	$T_{nt}(1)$	$T_{nt}(2)$	$T_{nt}(3)$	$T_{nt}(4)$	$T_{nt}(5)$	$T_{nt}(6)$	$T_{nt}(7)$	$T_{nt}(8)$	$T_{nt}(9)$	$T_{nt}(10)$
08:00	30.61	28.47	27.20	26.55	26.27	26.12	25.83	25.17	23.89	21.73
09:00	33.40	31.04	29.64	28.93	28.62	28.45	28.14	27.41	26.00	23.62
10:00	35.51	32.99	31.49	30.72	30.40	30.21	29.88	29.10	27.59	25.05
11:00	37.33	34.67	33.09	32.28	31.93	31.74	31.39	30.57	28.97	26.28
12:00	38.60	35.84	34.20	33.36	33.00	32.80	32.44	31.59	29.93	27.14
13:00	39.61	36.76	35.08	34.22	33.85	33.64	33.27	32.39	30.69	27.82
14:00	40.19	37.30	35.59	34.71	34.34	34.13	33.75	32.86	31.13	28.21
15:00	40.23	37.34	35.62	34.74	34.37	34.16	33.78	32.89	31.15	28.24
16:00	39.77	36.92	35.22	34.36	33.99	33.78	33.40	32.52	30.81	27.93
17:00	38.82	36.04	34.39	33.55	33.19	32.98	32.62	31.76	30.09	27.29
18:00	37.28	34.62	33.04	32.24	31.89	31.70	31.35	30.53	28.93	26.24
19:00	34.84	32.37	30.90	30.15	29.83	29.65	29.33	28.57	27.09	24.59

$$T_{nt}(t) - T_{base}$$

08:00	6.61	4.47	3.20	2.55	2.27	2.12	1.83	1.17	0.00	0.00
09:00	9.40	7.04	5.64	4.93	4.62	4.45	4.14	3.41	2.00	0.00
10:00	11.51	8.99	7.49	6.72	6.40	6.21	5.88	5.10	3.59	1.05
11:00	13.33	10.67	9.09	8.28	7.93	7.74	7.39	6.57	4.97	2.28
12:00	14.60	11.84	10.20	9.36	9.00	8.80	8.44	7.59	5.93	3.14
13:00	15.61	12.76	11.08	10.22	9.85	9.64	9.27	8.39	6.69	3.82
14:00	16.19	13.30	11.59	10.71	10.34	10.13	9.75	8.86	7.13	4.21
15:00	16.23	13.34	11.62	10.74	10.37	10.16	9.78	8.89	7.15	4.24
16:00	15.77	12.92	11.22	10.36	9.99	9.78	9.40	8.52	6.81	3.93
17:00	14.82	12.04	10.39	9.55	9.19	8.98	8.62	7.76	6.09	3.29
18:00	13.28	10.62	9.04	8.24	7.89	7.70	7.35	6.53	4.93	2.24
19:00	10.84	8.37	6.90	6.15	5.83	5.65	5.33	4.57	3.09	0.59

$$r = 926.4$$

$$MCDH = 0.1 \cdot (r \cdot n) = 0.1 \cdot (926.4 \cdot 31) = 2872\ ^{\circ}C - hour$$

Fig. 6. Application of the present approach for monthly total cooling degree-hours.

Table 3
Comparison of total annual cooling degree-hour values for different base temperature for Denizli.

Base temperature	May	June	July	Aug.	Sept.	Oct.	Total Degree-hour		Difference (%)
							Present study	Ref. [5]	
24 °C	446	1859	3110	2907	1341	134	9797	9676	1.3
26 °C	172	1201	2224	2058	801	45	6500	6186	5.0
27 °C	107	928	1841	1692	583	23	5174	4812	7.5
30 °C	16	321	924	824	164	0	2249	2118	6.1

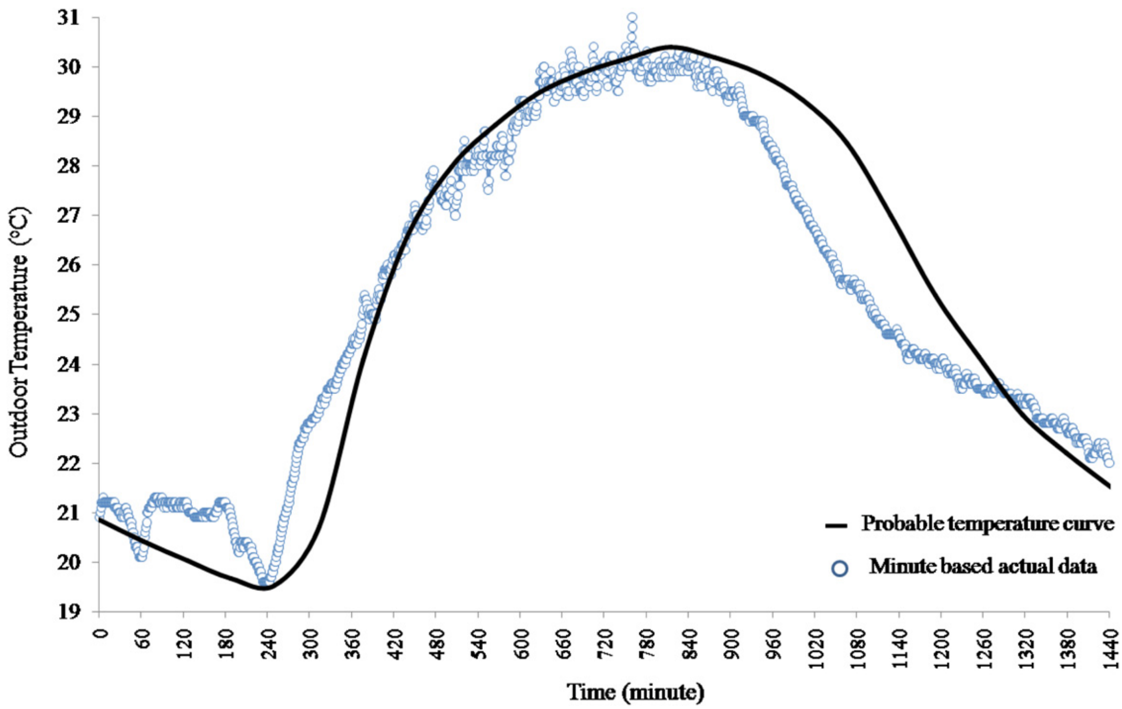


Fig. 7. Variation of actual and predicted temperature distributions for a sample day.

Table 4
Some properties of the small offices model building.

Element Types	Area (m^2)	U (W/m^2 °C)	UA (W/°C)
Outside Wall			
• 2 cm Internal plaster + 20 cm Hallow brick + 3 cm Polystyrene insulation + 3 cm External plaster	96	0.65	62
Double glass Windows	24	3.46	83
Roof			
• 5 cm Fiberglass insulation + 15 cm Concrete with sand and gravel aggregate + 3 cm Cement plaster with sand aggregate	100	0.63	63
Basement (10 cm Insulation – rock wool)	100	0.40	40
		Total UA (W/°C)	248

Table 5
Calculation of cooling requirement.

Heat gains		– (W/°C)	Degree-hours (°C-hours)	Heat gain (kWh)
Conduction	$\sum_{i=1}^{M} UA$	248	2131	528.5
Infiltration	$I(qc_p)_{air}\frac{V}{3600}$	100	2131	213.1
		Heat (W)	Time (h)	Heat gain (kWh)
Persons		536	253	135.6
Lighting		300	253	75.9
Electrical equipment		300	253	75.9
Non-cooling hours				4.8
			Total	1033.8

5. Conclusions

This paper has developed a new method to predict the daily outdoor temperature variations during daytime as a dimensionless temperature variation coefficient (Z) to simplify building energy calculations. The probability distribution of daily outdoor temperature is then formulated by using daily maximum and minimum temperatures. Some findings of this study are:

- Z-curve makes it possible to define the variation in outdoor temperature change without referring to a specified unit like degree Celsius (°C)
- Z-curve for a cooling season exhibits a similar distribution with the actual distribution curve.
- There is no meaningful correlation found between the variations of $Z_{cooling}$ and the climatic zones for Turkey.

This new approach is expected to be beneficial for predicting using degree-hour values for cooling energy requirement for both part- and full-time operations in buildings.

Nomenclature

A	area (m^2)
c_p	specific heat of the air (J kg^{-1} K^{-1})
$HGNC$	non-cooling hours heat gain (kWh)
I	air exchange rates per hour
L	the total heat transfer coefficient (W/°C)
$MCDH$	monthly total cooling degree-hours (°C-hour)
n	number of days in a given month
q	density of air (kg m^{-3})
T	temperature (°C)
V	volume (m^3)
Z	dimensionless temperature variation coefficient (–)

Subscripts

act	actual
max	maximum
min	minimum
nt	new temperature
nmx	new maximum temperature

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