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NEW MODELS FOR SIMULATING DAILY MINIMUM, DAILY MAXIMUM AND HOURLY OUTDOOR TEMPERATURES

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ABSTRACT
In this study, simple mathematical models based on trigonometric functions were derived for the daily maximum and minimum dry-bulb temperatures and hourly dry-bulb temperature to simulate the long-term measured data. The coefficients of the recommended models for 78 provinces of Turkey were determined using the hourly data measured during at least 15 years. It was seen that the statistical indicators for the models such as mean absolute error, root mean square error and correlation coefficient are at acceptable levels. The models can also be used to describe temperatures for other locations.

INTRODUCTION
The weather data such as outdoor temperature, relative humidity, wind velocity, and solar radiation are main inputs in the energy analysis, simulation and design of many engineering systems. The type and format of the weather data required depends on the objective of the study and the type of analysis and simulation tool. Two approaches are generally used in the development of representative weather data; selection from real recorded data and synthetic generation [1]. The main advantage of the synthetic generation of weather variable is the readily usage of mathematical expressions in the computer programs and thus, not requiring tedious inputting work for the variables and database files for simulation.

There are many studies dealing with modeling of weather data. Erbs et al. [2] suggested an equation to calculate hourly ambient temperature from monthly average values. Knight et al. [3] presented models for generating hourly series of solar radiation and ambient temperature values. A method was proposed to present the daily and yearly variations of temperature for Northern Cyprus by Sezai and Taşdemiroğlu [4]. Hokoi et al. [5] proposed a statistical method to generate synthetic weather data as an alternative to the use of hourly historical data. Yoshida and Terai [6] developed a method for modeling weather data (temperature, global solar radiation, and absolute humidity) by time and Fourier series for air-conditioning load calculations. Alaruri and Amer [7] studied empirical regression models for the weather data measured in Kuwait during the years 1985, 1986 and 1987. They developed empirical equations for expressing the monthly average of daily measurements as a function of month of the year by employing least-squares linear regression analysis. Canada et al. [8] presented monthly average of daily data over the period 1989-1992 for eight meteorological parameters and obtained equations for six of them (global and diffuse solar radiation, sunshine duration, minimum and maximum ambient temperature, atmospheric pressure, specific humidity and wind speed) for Valencia, Spain as a function of the month of the year using a multiple regression method. Regression models were presented for the weather data of Oman by Dorvlo and Ampratwum [9]. Al- Garni et al. [10] used a linear regression model to present weather data collected in Dhahran, Saudia Arabia. Dorvlo [11] derived typical annual functions for global irradiation and mean, minimum, and maximum temperatures for Seeb, Sultanate of Oman, using Fourier analysis. Ünal et al. [12] produced equations for daily average temperature and daily total solar radiation throughout the year for some cities of Turkey. The monthly average data obtained from 1984 bulletin of DMİ were used in the study. Oğulata and Yılmaz [13] developed equations analytically for determining the variation of ambient temperature during daytime. They verified the equations using the measured data for some locations selected from different countries. Arınç et al. [14] reported a mathematical formulation for the hourly variation of ambient temperatures for solar system design in Turkey. They expressed the hourly variation of ambient temperatures with polynomials using average temperatures at 7, 14, and 21 h. They presented results for only two locations and two different months. Yılmaz and Bulut [15] modeled the meteorological data of Şanlıurfa with mathematical equations using the data measured during 14 years.

The main objective of the present study is to obtain simple models for daily extreme and hourly dry-bulb temperatures. Validation of the models was performed for 78 provinces of Turkey for which hourly temperature records are available. The coefficients of the recommended models were determined using the hourly data measured during at least 15 years between 1981 and 1998. Although the weather variables are stochastic and random, the representative equations derived for the weather variables in this study have only one parameter, namely the day of year. The coefficients of the equations were determined in such a way that the minimum errors were obtained.

VARIATION OF DAILY MAXIMUM AND MINIMUM OUTDOOR DRY-BULB TEMPERATURE

The following equations were determined for daily maximum and minimum temperature in ^{o}C, respectively;

$$T_{\max} = T_1 - (T_1 - T_2) Cos\left[\frac{2\pi}{365}(n-25)\right] \quad (1)$$

$$T_{\min} = T_3 - (T_3 - T_4) Cos\left[\frac{2\pi}{365}(n-25)\right] \quad (2)$$

where n is the number of days starting from 1 January. For 1 January *n*=1, and for 31 December *n*=365. T_1, T_2, T_3 and T_4 are coefficients and they should be determined by means of statistical error tests for each location separately. The values for mean absolute error (MAE), root-mean-square error (RMSE), and correlation coefficient (r) of the equations obtained were calculated for each location considered in this study. Tables 1 and 2 show the coefficients obtained and the statistical errors for Equations 1 and 2, respectively.

It can be seen from Tables 1 and 2 that correlation coefficients are in the range of 0.81 and 0.95. This means that the equations obtained represent generally the measured data satisfactorily. For some locations, the correlation is very good such as for Adıyaman, Batman, Diyarbakır, Hakkari, Kahramanmaraş Siirt and Şanlıurfa. The MAEs are between 1.96 and 4.51, whilst RMSEs are in the range of 2.51 and 5.12 throughout Turkey.

Figure 1 shows variation of the measured daily maximum temperature and the data obtained from Equation (1) for three biggest provinces (İstanbul, Ankara, İzmir) in Turkey. Although the measured data fluctuate and vary in a band, the values obtained from the equation follow the variation of the daily maximum temperature throughout the year.

The monthly mean of the daily maximum temperature obtained from Equation (1) and from the measurements is compared in Figure 2 for the same locations. It can be seen that the accuracy of the equation is very high on monthly bases.

Variation of the measured daily minimum temperature and the data obtained from Equation 2 for the same provinces are also depicted in Figure 3. The trend here is very similar to that for the daily maximum temperature. As can be seen from Figure 4, which compares the measured and the calculated (Equation 2) values of the monthly mean of the daily minimum temperature, Equation (2) produces values very close to the measured ones. This means that Equation (2) is quite good in predicting the long-term data on monthly bases.

Table 1. Coefficients and statistical errors for the equation for daily maximum temperature (Eq. 1).

Province	T_1	T_2	$\pm$ MAE [^{o}C]	RMSE [^{o}C]	r
Adana	25.27	15.28	2.66	3.42	0.90
Adapazarı	19.25	9.08	3.81	4.80	0.85
Adıyaman	22.76	7.94	2.97	3.71	0.94
Afyon	17.00	4.65	3.82	4.74	0.88
Ağrı	13.07	-4.49	3.69	4.75	0.93
Aksaray	18.32	5.56	3.89	4.87	0.88
Amasya	19.70	7.63	4.10	5.09	0.86
Ankara	17.57	4.72	3.75	4.65	0.89
Antakya	23.25	13.47	2.86	3.71	0.88
Antalya	24.01	13.88	2.72	3.38	0.90
Ardahan	10.63	-4.20	3.70	4.64	0.91
Artvin	16.71	6.70	3.98	4.89	0.82
Aydın	24.63	12.86	2.78	3.53	0.92
Balıkesir	20.10	8.66	3.70	4.62	0.87
Bartın	18.31	8.63	3.59	4.58	0.83
Batman	23.54	7.49	2.99	3.84	0.95
Bayburt	13.12	-1.15	3.63	4.50	0.91
Bilecik	17.45	6.03	3.97	4.92	0.85
Bingöl	18.23	1.53	3.13	4.00	0.95
Bitlis	15.55	0.36	2.84	3.62	0.95
Bolu	16.77	5.74	4.13	5.11	0.84
Burdur	19.13	6.45	3.12	3.96	0.92
Bursa	19.93	9.00	3.64	4.59	0.86
Canakkale	19.29	8.42	2.72	3.47	0.91
Cankırı	17.80	4.18	3.76	4.69	0.90
Corum	17.15	4.93	3.88	4.81	0.87
Denizli	22.01	9.88	3.27	4.10	0.90
Diyarbakır	22.16	6.25	2.97	3.79	0.95
Edirne	19.30	6.72	3.64	4.58	0.89
Elazığ	18.68	3.05	3.14	3.98	0.94
Erzincan	16.70	2.17	3.61	4.52	0.92
Erzurum	11.94	-4.19	3.60	4.58	0.93
Eskisehir	16.92	4.35	4.03	4.96	0.87
Gaziantep	21.61	7.51	2.97	3.72	0.94
Giresun	17.46	9.18	3.00	3.89	0.83
Gümüshane	15.62	2.75	3.96	4.88	0.88
Hakkari	14.80	-1.16	3.06	3.88	0.95
Iğdır	19.07	3.75	3.32	4.29	0.93
Isparta	18.22	5.93	3.18	4.00	0.91
İskenderun	23.47	15.44	2.17	2.81	0.90
İstanbul	18.29	8.08	3.01	3.79	0.89
İzmir	22.56	11.84	2.73	3.43	0.91
K. Maras	22.38	8.95	3.13	3.88	0.93
Karaman	18.46	5.26	3.94	4.95	0.88
Kars	11.69	-3.62	3.55	4.43	0.93
Kastamonu	15.81	3.72	3.94	4.89	0.87
Kayseri	17.54	4.24	4.05	5.05	0.88
Kırıkkale	17.85	4.65	3.75	4.67	0.89
Kırklareli	18.45	6.13	3.43	4.30	0.90
Kırsehir	17.11	4.26	3.85	4.79	0.88
Kilis	23.07	9.36	2.92	3.69	0.93
Kocaeli	19.15	8.90	3.62	4.54	0.85
Konya	17.54	4.54	3.87	4.82	0.89
Kütahya	16.75	4.81	3.99	4.92	0.86
Malatya	19.10	3.75	3.33	4.20	0.93

Table1. (Continued)

Province	T_1	T_2	± MAE [°C]	RMSE [°C]	r
Manisa	22.74	10.11	3.24	4.06	0.91
Mardin	20.23	5.18	2.96	3.73	0.94
Mersin	22.98	14.79	2.03	2.64	0.91
Muğla	21.06	8.89	2.91	3.68	0.92
Mus	15.68	-2.52	3.56	4.64	0.94
Nevsehir	15.90	3.47	3.89	4.86	0.88
Niğde	17.14	4.64	3.77	4.76	0.88
Ordu	18.19	9.53	2.99	3.88	0.85
Rize	17.67	9.38	2.68	3.45	0.86
Samsun	17.72	9.55	3.07	4.04	0.82
Siirt	21.46	6.10	2.92	3.72	0.95
Sinop	17.03	8.43	2.89	3.73	0.85
Sivas	15.02	1.11	4.06	5.06	0.89
Sanlıurfa	23.95	9.37	2.83	3.58	0.95
Tekirdağ	17.67	7.52	2.62	3.48	0.90
Tokat	18.34	6.64	4.13	5.12	0.85
Trabzon	17.70	9.65	2.95	3.86	0.83
Tunceli	18.64	2.58	3.17	4.04	0.94
Usak	18.52	6.59	3.39	4.25	0.89
Van	14.58	1.08	2.49	3.19	0.95
Yalova	19.11	9.49	3.08	4.00	0.86
Yozgat	14.31	2.07	3.89	4.82	0.87
Zonguldak	16.60	8.34	3.30	4.29	0.81

Table 2. Coefficients and statistical errors for the equation for daily minimum temperature (Eq. 2).

Province	T_3	T_4	± MAE [°C]	RMSE [°C]	r
Adana	14.27	5.04	2.08	2.65	0.93
Adapazarı	9.78	1.99	2.62	3.35	0.86
Adıyaman	11.81	0.65	2.41	3.03	0.93
Afyon	5.21	-3.62	2.83	3.65	0.86
Ağrı	-0.43	-13.99	4.30	5.93	0.85
Aksaray	5.81	-3.88	3.07	4.01	0.86
Amasya	7.35	-1.24	2.78	3.58	0.86
Ankara	6.14	-3.28	2.81	3.62	0.88
Antakya	13.68	3.73	2.30	2.96	0.92
Antalya	12.51	3.95	2.05	2.60	0.92
Ardahan	-2.82	-15.39	3.81	5.05	0.87
Artvin	7.73	-1.19	2.45	3.10	0.90
Aydın	11.50	3.24	2.46	3.15	0.88
Balıkesir	9.17	0.50	2.83	3.60	0.86
Bartın	7.27	-0.52	2.66	3.36	0.85
Batman	9.94	-0.85	2.62	3.37	0.91
Bayburt	0.82	-9.90	3.39	4.47	0.86
Bilecik	7.81	-0.59	2.70	3.45	0.86
Bingöl	6.55	-5.48	2.66	3.52	0.92
Bitlis	4.36	-6.42	2.74	3.50	0.91
Bolu	4.89	-3.25	2.90	3.78	0.84
Burdur	7.20	-2.00	2.54	3.25	0.89
Bursa	8.88	0.80	2.74	3.53	0.85
Canakkale	10.79	2.31	2.64	3.41	0.87
Cankırı	4.51	-4.56	3.01	3.82	0.86
Corum	3.76	-4.36	3.07	3.91	0.83
Denizli	10.76	1.48	2.53	3.23	0.90
Diyarbakır	8.60	-3.00	2.72	3.51	0.92
Edirne	7.98	-1.10	2.83	3.65	0.87

Table 2. (Continued)

Province	T_3	T_4	± MAE [°C]	RMSE [°C]	r
Elazığ	7.23	-4.00	2.72	3.46	0.92
Erzincan	4.76	-6.04	3.00	3.95	0.89
Erzurum	-1.91	-14.39	4.51	5.87	0.83
Eskisehir	3.61	-4.94	3.05	3.85	0.84
Gaziantep	9.21	-1.60	2.41	3.02	0.93
Giresun	11.67	3.57	2.25	2.84	0.90
Gümüshane	4.03	-5.75	2.87	3.77	0.88
Hakkari	5.09	-8.22	2.59	3.41	0.94
Iğdır	5.67	-6.45	2.91	3.79	0.91
Isparta	5.46	-3.06	2.79	3.56	0.86
İskenderun	16.46	7.93	1.96	2.51	0.92
İstanbul	10.71	2.46	2.34	2.95	0.89
İzmir	13.40	4.74	2.43	3.09	0.89
K. Maras	11.31	0.72	2.21	2.84	0.94
Karaman	5.20	-4.32	3.29	4.35	0.84
Kars	-1.47	-13.89	3.63	4.83	0.88
Kastamonu	4.20	-4.27	2.72	3.44	0.87
Kayseri	2.78	-6.23	3.49	4.56	0.81
Kilis	11.67	1.98	2.34	2.98	0.92
Kırıkkale	6.50	-3.04	2.81	3.63	0.88
Kırklareli	8.40	-0.53	2.77	3.56	0.87
Kırsehir	5.34	-4.61	2.94	3.87	0.88
Kocaeli	10.74	2.54	2.45	3.11	0.88
Konya	5.26	-4.96	2.86	3.72	0.89
Kütahya	4.85	-3.46	2.93	3.75	0.84
Malatya	8.33	-2.95	2.65	3.35	0.92
Manisa	11.23	1.91	2.66	3.39	0.89
Mardin	12.19	-0.21	2.92	3.67	0.92
Mersin	15.34	6.21	1.98	2.54	0.93
Muğla	9.37	0.05	2.66	3.30	0.89
Mus	3.50	-9.95	3.64	5.08	0.88
Nevsehir	4.81	-3.77	3.42	4.35	0.81
Niğde	4.95	-4.74	2.90	3.91	0.87
Ordu	10.67	2.51	2.23	2.82	0.90
Rize	10.82	2.45	2.11	2.66	0.91
Samsun	10.67	2.77	2.30	2.97	0.88
Siirt	10.99	-0.96	2.36	3.05	0.94
Sinop	11.20	3.17	2.19	2.73	0.90
Sivas	3.19	-6.50	3.33	4.39	0.84
Sanlıurfa	12.59	1.22	2.32	2.88	0.94
Tekirdağ	9.97	1.29	2.46	3.17	0.89
Tokat	6.86	-1.69	2.94	3.84	0.84
Trabzon	11.47	3.49	2.21	2.84	0.89
Tunceli	6.84	-4.86	2.89	3.77	0.91
Usak	6.83	-1.81	2.58	3.26	0.88
Van	3.73	-7.53	2.57	3.41	0.92
Yalova	9.63	1.95	2.52	3.19	0.86
Yozgat	3.82	-5.48	3.12	4.02	0.85
Zonguldak	10.22	2.58	2.53	3.25	0.86

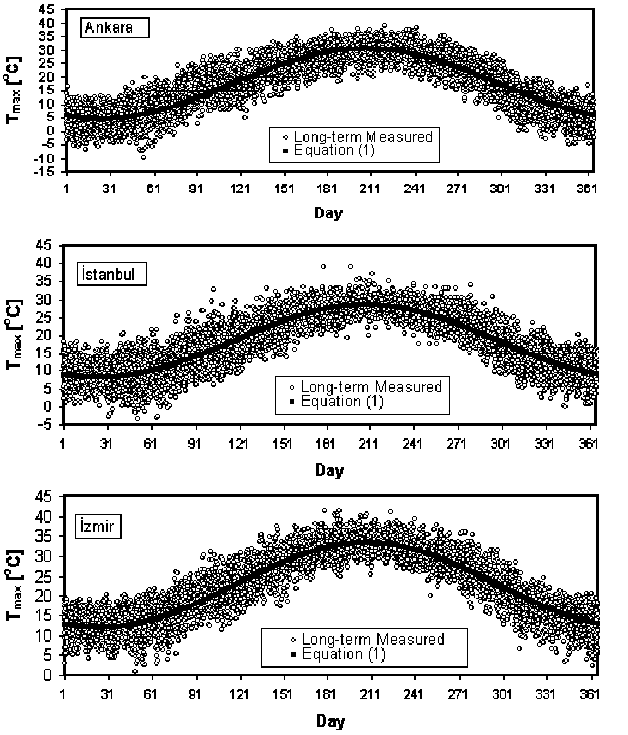

Fig.1. Variation of daily maximum dry-bulb temperature for the biggest provinces of Turkey.

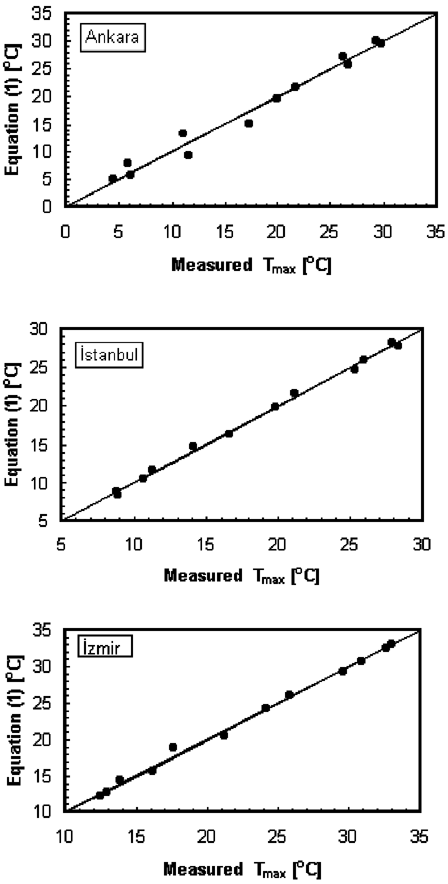

Fig.2. Comparison of the monthly mean of the daily maximum temperature obtained from Equation (1) and from the measurements.

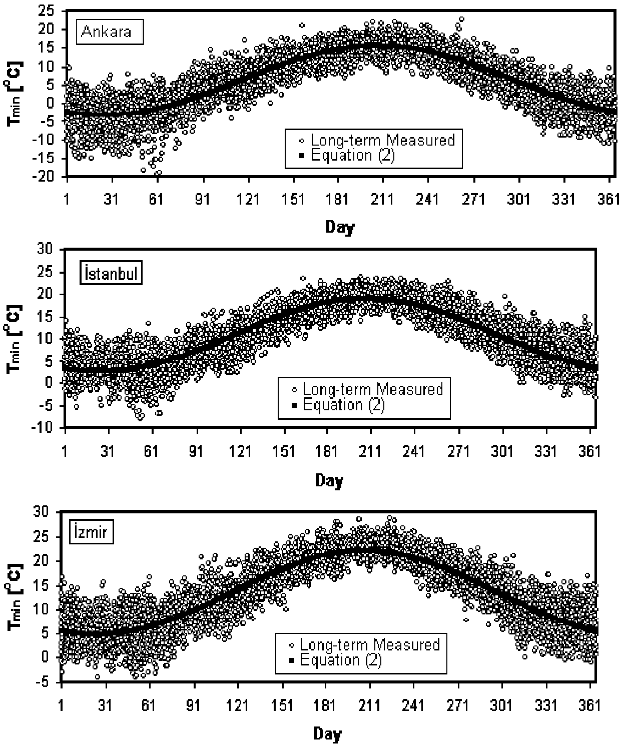

Fig.3. Variation of daily minimum dry-bulb temperature for the biggest provinces of Turkey.

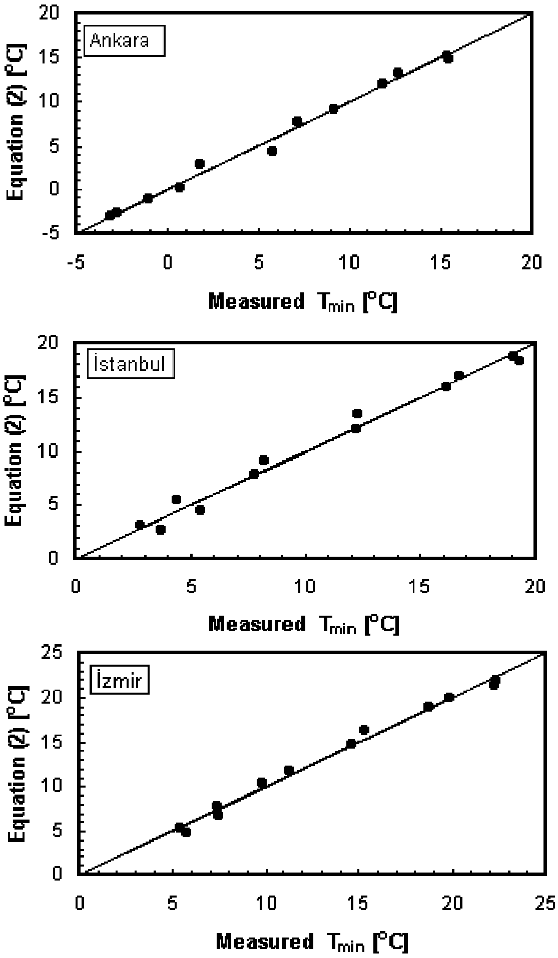

Fig.4. Comparison of the monthly mean of the daily minimum temperature obtained from Equation (2) and from the measurements.

MATHEMATICAL MODEL FOR VARIATION OF HOURLY OUTDOOR DRY-BULB TEMPERATURE

The outdoor dry-bulb temperature varies in 24 h period for a day. In the design and simulation of energy related systems, it is necessary to know the diurnal variation of hourly temperature. In this study, the hourly variation of outdoor dry-bulb temperature was expressed with mathematical formulations using the daily minimum and the maximum temperatures. The day was divided into two periods for modeling. These periods were determined according to the time at which the daily minimum or maximum temperature occurs. The first period covers the time period between the occurrence of the daily minimum (t_{min}) and maximum temperatures (t_{max}). The second period covers the remaining time. The equations for hourly outdoor dry-bulb temperature (T) were determined for two periods of the day separately.

For the 1st period ($t_{max} \geq t \geq t_{min}$) :

$$T = T_{\min} + (T_{\max} - T_{\min})\left\{ Sin\left[\frac{\pi}{2}\left(\frac{t - t_{\min}}{t_{\max} - t_{\min}}\right)\right]\right\}^{1.4} \quad (3)$$

For the 2nd period ($t_{min} \geq t \geq t_{max}$);

$$T = T_{\max} - (T_{\max} - T_{\min})\left\{ Sin\left[\frac{\pi}{2}\left(\frac{t - t_{\max}}{24 + t_{\min} - t_{\max}}\right)\right]\right\}^{1.2} \quad (4)$$

in which T_{max} and T_{min} can be calculated from equations (1) and (2) respectively or can be directly taken from the measured data if available. Note that in the second period, *$t=t+24$ if $t \leq tmin$*. t_{min} and t_{max} are the times for the occurrence of the daily minimum and maximum temperatures respectively [13,15]:

$$t_{\min} = 12 - (t_d / 2) \quad (5)$$

$$t_{\max} = 12 + \left[t_{\min}(12 - t_{\min})\right]/13.5 \quad (6)$$

where t_d is the day length and can be calculated as follows:

$$t_d = (2/15) ArcCos[-\tan\phi \tan\delta] \quad (7)$$

where ϕ is the local latitude and δ is the solar declination angle:

$$\delta = 23.45 Sin\left[\frac{2\pi}{365}(n + 284)\right] \quad (8)$$

in which n is the number of days starting from 1 January.

The root mean square error of the mathematical model for hourly outdoor dry-bulb temperature is in the range from 2.40 to 4.42. The hourly variation of outdoor dry-bulb temperature on 23rd July for İstanbul, Ankara and İzmir is shown in Figure 5. Although outdoor dry-bulb temperatures vary from year to year, the mathematical model follows the variation. The outdoor dry-bulb temperatures vary approximately in a band of ±10 °C during a day for all the provinces considered. The mathematical model produces values within the band.

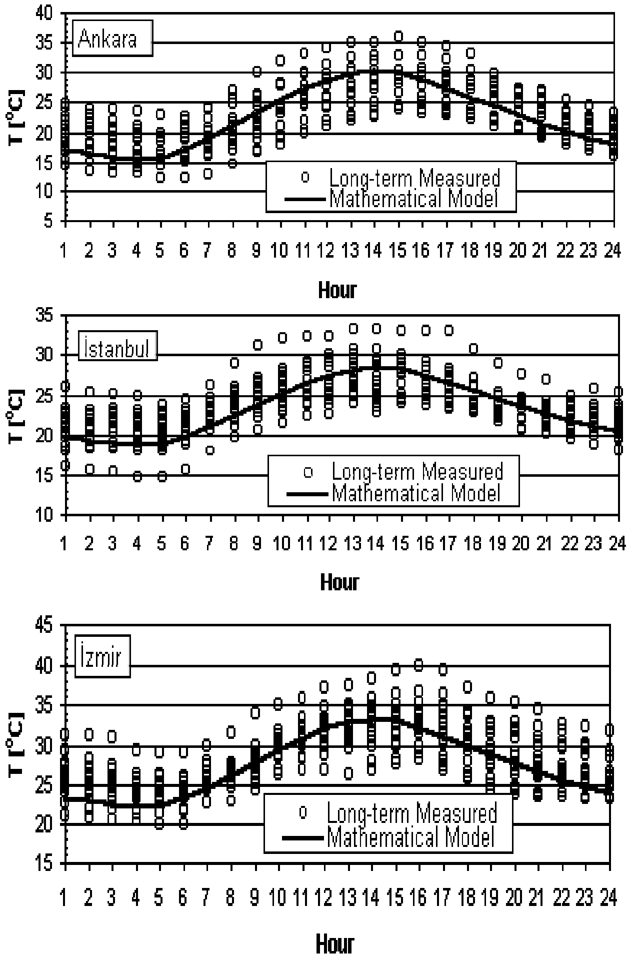

Fig.5. Hourly variation of outdoor dry-bulb temperature for the biggest provinces of Turkey on 23rd July (n=204).

Figure 6 shows hourly variation of dry-bulb temperature in July for İzmir. 17 July (n=198) is chosen as the monthly average day of July in this study. It is seen that the mathematical model has good agreement with both the measured data and the model proposed by Erbs et al. [2].

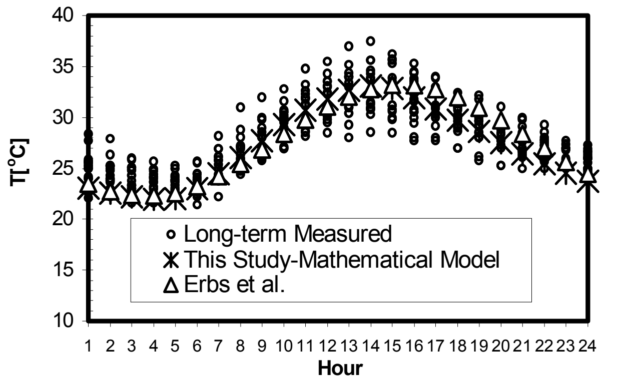

Fig.6. Variation of hourly dry bulb temperature in monthly average day of July for İzmir.

Comparison of the monthly mean temperatures available in literature [1,12] and the data obtained both from the models and long-term measurements for İzmir is shown in Figure 7. There are no significant differences between the data obtained in this study and the data available in the literature.

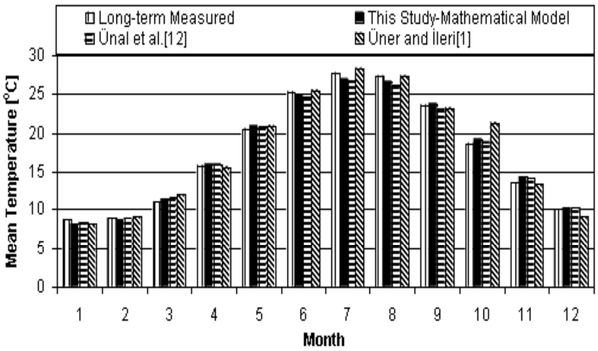

Fig.7. Comparison of monthly mean temperatures in İzmir.

CONCLUSION

Simple mathematical models based on trigonometric functions were developed for daily maximum and minimum dry-bulb temperatures and hourly dry-bulb temperature to simulate the long-term measured data. The models for daily maximum and minimum temperatures have only one parameter, namely the day of the year. Although the measured data fluctuate, the values obtained from the equations follow the variation of the daily maximum and minimum temperatures and the models are quite good in predicting the long-term data on monthly bases.

The model for diurnal variation of hourly outdoor temperature utilizes the daily maximum and minimum temperatures. New models for outdoor temperature were implemented for 78 provinces of Turkey for which hourly temperature records are available. The parameters of the recommended models were determined using at least 15 years long-term measured data. It was found that the statistical indicators such as the mean absolute error, the root mean square error and the correlation coefficient for the models are at acceptable levels. Comparison of the models with the measured data and the models available in the literature revealed that the mathematical models developed are in good agreement with both the measured data and the models proposed in literature. It is expected that the models developed for outdoor temperatures will be useful to the designers of energy related systems as well as those who need to have fairly good estimates of daily or hourly variation of outdoor temperature for any specific location.

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