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Analysis of variable-base heating and cooling degree-days for Turkey

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Abstract

The degree-day method is one of the well-known and the simplest methods used in the Heating, Ventilating and Air-Conditioning industry to estimate heating and cooling energy requirements. In this study, the heating and cooling degree-days for Turkey are determined by using long-term recent measured data. Five different base temperatures ranging from 14 to 22°C are chosen in the calculation of heating degree-days. In the case of cooling degree-days, 6 different base temperatures in the range 18 to 28°C are used. Yearly heating and cooling degree-days are given both in tabular form and as counter maps for all the provinces of Turkey (78 weather stations). © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Heating degree-day; Cooling degree-day; Turkey; Energy analysis

1. Introduction

Energy analysis plays an important role in developing an optimum and cost effective design of HVAC system for a building. Although there are different energy analysis methods, which vary in complexity, the degree-day methods are the simplest methods and well-established tools for energy analysis if the buildings use, the efficiency of HVAC equipment, indoor temperature and internal gains are relatively constant. The value of degree-days is a measure used to indicate the demand for energy to heat or cool buildings. The monthly and/or annual cooling and heating requirements of specific buildings in different locations can be estimated by means of the degree-days concept. The method assumes that the energy needs for a building

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are proportional to the difference between the mean daily temperature and a base temperature. The base temperature is the outdoor temperature below or above which heating or cooling is needed [1,2]. In terms of degree-days, the annual energy consumption, Q_{year} [W.day] can be calculated as [1];

$$Q_{\text{year}} = \frac{K_{\text{tot}}}{\eta} DD \tag{1}$$

where K_{tot} is the total heat-transfer coefficient of the building in W/°C, η is the efficiency of the heating or cooling system and DD is the value of degree-days for heating or cooling. For heating, heating degree-days (HDD) can be determined using following expression;

$$\text{HDD} = (1 \text{ day}) \sum_{\text{days}} (T_{\text{b}} - T_{\text{m}})^{+} \tag{2}$$

in which, T_{b} is the base temperature and T_{m} is the daily mean outdoor temperature. Cooling degree-days (CDD) can be calculated in a manner analogous to that for heating degree-days;

$$\text{CDD} = (1 \text{ day}) \sum_{\text{days}} (T_{\text{m}} - T_{\text{b}})^{+} \tag{3}$$

The plus signs above the parentheses of Eqs. (2) and (3) indicate that only positive values are to be counted. Using HDD and CDD, the annual heating consumption, Q_{h}, and the annual cooling requirements, Q_{c}, in terms of kWh can be calculated, respectively as;

$$Q_{\text{h}} = \frac{K_{\text{tot}}}{\eta} \text{HDD} \frac{24}{1000} \tag{4}$$

$$Q_{\text{c}} = \frac{K_{\text{tot}}}{\eta} \text{CDD} \frac{24}{1000} \tag{5}$$

Traditionally, heating degree-days are calculated at a base temperature of 18°C (or 65°F) and cooling degree-days are determined at a base temperature of 22°C (71.6°F) for a typical uninsulated building. However, the average value of T_{b} varies widely from one building to another, because of widely differing personal preferences for the settings of thermostat and of the thermostat setback and because of different building characteristics such as thermal insulation, air leakage and solar gains. Hence degree-days with a base temperature of 18°C in heating or 22°C in cooling must be employed with caution [3].

The traditionally-used base temperatures have been questioned by a number of authors. Said [2] found that a heating base temperature in the range of 18 to 21°C is

suitable in Saudi Arabia depending upon the insulation level. The recommended cooling base temperature is between 23 and 25.5°C for buildings without insulation and between 25.5 and 27.8°C for well-insulated buildings. Kodah and El-Shaawari [4] recommended that a heating base-temperature of 15.5°C (60°F) in Jordan is appropriate. Badescu and Zamfir [5] reported that a 18°C base temperature for heating degree-day calculations is appropriate for living rooms and bedrooms in Romania.

Although analysis of weather data for design of HVAC systems and energy consumption calculations has been completed several years ago for developed countries, this subject has been considered seriously only in recent years in Turkey. The weather data studies in Turkey have been initiated with the construction of modern commercial and domestic buildings, the start of natural gas usage and because of a possible energy crisis. Although some independent studies [6–10] have been performed in recent years to compile weather data, well-established and reliable databases that can be used directly by designers and energy managers still do not exist. Not all of the cities of Turkey were considered in existing studies, and in some studies, the results were based on the data obtained during a short-period of time (only a few years) or the data measured in recent years were not used. In some studies, the results were presented only for one base temperature.

The need to fill the gap in weather data for Turkey provided the stimulus for this project that includes the production of design data, degree-days and bin data for heating and cooling and solar radiation. In this paper, the results of the degree-day studies are reported.

2. Database for temperature

Accurate and reliable weather data are crucial for building energy simulations and analyses. The weather data being used in energy analysis determines the accuracy and characteristics of the results. Therefore, the database used in an energy analysis should cover a long period and depend on recent values [1]. In this study, daily minimum and maximum outdoor dry-bulb temperatures of recent years were used. The data obtained during at least 14 years (except for Eskişehir) were used in the calculations. Daily mean temperatures were obtained by averaging the minimum and the maximum temperatures. The raw data were taken from The State Meteorological Affairs General Directorate (DMİ) on magnetic disks for 78 provinces. Information for the weather stations and periods of the data considered are given in Table 1.

3. Results and discussion

Based on the database for temperature shown in Table 1 and using Eqs. (2) and (3), annual heating and cooling degree-days for various base temperatures were obtained for each province.

Table 1
Information for the provinces considered in the study

Location	Longitude	Latitude	Elevation (m)	Period	Total years
Adana	35.18	36.59	20	1981–1996	16
Adapazarı	30.25	40.47	30	1982–1998	17
Adıyaman	38.17	37.45	678	1981–1998	18
Afyon	30.32	38.45	1034	1981–1998	18
Ağrı	43.08	39.31	1585	1981–1998	18
Aksaray	34.03	38.23	980	1981–1998	18
Amasya	35.51	40.39	412	1981–1998	18
Ankara	32.53	39.57	894	1981–1995	15
Antalya	30.42	36.53	42	1981–1995	15
Ardahan	42.42	41.08	1829	1981–1998	18
Artvin	41.49	41.10	597	1981–1998	18
Aydın	27.50	37.51	57	1983–1998	16
Balıkesir	27.52	39.39	147	1983–1997	15
Bartın	32.21	41.38	30	1981–1998	18
Batman	41.10	37.52	540	1983–1998	16
Bayburt	40.15	40.16	1550	1981–1998	18
Bilecik	29.58	40.09	526	1981–1998	18
Bingöl	40.30	38.52	1177	1981–1998	17
Bitlis	42.06	38.22	1559	1981–1998	18
Bolu	31.36	40.44	742	1981–1998	18
Burdur	30.20	37.40	967	1981–1998	18
Bursa	29.04	40.11	100	1983–1998	16
Çanakkale	26.24	40.08	3	1981–1998	17
Çankırı	33.37	40.36	751	1981–1995	15
Çorum	34.58	40.33	798	1981–1998	18
Denizli	29.05	37.47	428	1983–1998	16
Diyarbakır	40.12	37.55	660	1981–1996	16
Edirne	26.34	41.40	48	1983–1998	16
Elazığ	39.13	38.40	1105	1981–1998	18
Erzincan	39.30	39.44	1215	1981–1998	18
Erzurum	41.16	39.55	1869	1983–1998	16
Eskişehir	30.31	39.46	800	1991–1998	8
Gaziantep	37.22	37.05	855	1981–1996	16
Giresun	38.24	40.55	38	1981–1998	18
Gümüşhane	39.27	40.27	1219	1981–1998	18
Hakkari	43.46	37.34	1720	1981–1998	18
Hatay	36.07	36.15	100	1981–1996	16
Iğdır	44.02	39.56	858	1981–1998	16
İskenderun	36.07	36.37	3	1981–1998	18
Isparta	30.33	37.45	997	1981–1998	18
İstanbul	29.05	40.58	39	1981–1996	16
İzmir	27.10	38.24	25	1981–1996	16
K.Maraş	36.56	37.36	549	1983–1998	16
Karaman	33.14	37.11	1025	1981–1998	18
Kars	43.05	40.36	1775	1983–1998	16
Kastamonu	33.46	41.22	791	1981–1998	18
Kayseri	35.29	38.43	1068	1981–1996	16
Kilis	37.05	36.44	638	1981–1998	18

(*continued on next page*)

Table 1 (*continued*)

Location	Longitude	Latitude	Elevation (m)	Period	Total years
Kırıkkale	33.30	39.50	725	1981–1995	15
Kırklareli	27.13	41.44	232	1981–1998	18
Kırehir	34.10	39.08	985	1981–1995	15
Kocaeli	29.54	40.46	76	1981–1998	18
Konya	32.30	37.52	1028	1981–1996	16
Kütahya	29.58	39.24	969	1981–1998	18
Malatya	38.18	38.21	998	1983–1998	16
Manisa	27.26	38.36	71	1983–1998	16
Mardin	40.44	37.18	1080	1983–1998	16
Mersin	34.36	36.49	5	1983–1998	16
Muğla	28.21	37.12	646	1981–1996	16
Muş	41.31	38.44	1283	1981–1998	18
Nevşehir	34.40	38.25	1260	1981–1998	18
Niğde	34.40	37.59	1208	1981–1998	18
Ordu	37.52	40.59	4	1981–1998	18
Rize	40.30	41.02	4	1981–1996	16
Samsun	36.20	41.17	44	1981–1996	16
Siirt	41.56	37.56	875	1981–1998	18
Sinop	35.10	42.02	32	1981–1998	18
Sivas	37.01	39.49	1285	1983–1998	16
Şanlıurfa	38.46	37.08	547	1980–1993	14
Tekirdağ	27.29	40.59	4	1983–1998	16
Tokat	36.54	40.18	608	1981–1998	18
Trabzon	39.43	41.00	30	1981–1996	16
Tunceli	39.32	39.06	979	1981–1998	18
Uşak	29.29	38.40	919	1981–1998	18
Van	43.41	38.28	1725	1981–1995	15
Yalova	29.16	40.39	2	1981–1998	18
Yozgat	34.49	39.50	1298	1983–1998	16
Zonguldak	31.48	41.27	136	1981–1998	18

3.1. Annual heating degree-days

Table 2 shows the annual heating degree-days with 14, 16, 18, 20, and 22°C base temperatures. As can be seen from Table 2, significant differences between the values of heating degree-days for different locations are evident for the same base temperature. For example, the annual heating degree-days for İskenderun (located in the east Mediterranean) is 690, while it is 5137 for Ardahan (located in the north-east), at a base temperature of 18°C. This shows that a building in Ardahan needs 7.44 times more heating energy than a building located in İskenderun, both having the same characteristics.

Fig. 1 shows variation of the annual heating degree-days with base temperature for the main provinces of Turkey. The heating degree-days increase almost linearly with increasing base temperature. Increasing base temperature from the traditionally accepted value of 18 to 20°C results in approximately 14% higher heating degree-days in Erzurum, whilst the increase is about 40% for Adana. Therefore, thermal

Table 2
The annual heating degree-days for Turkey

Province	Base temperature (°C)				
	14	16	18	20	22
Adana	341	579	874	1220	1610
Adapazarı	1049	1413	1833	2309	2862
Adıyaman	995	1328	1695	2094	2527
Afyon	1878	2325	2828	3395	4025
Ağrı	3353	3867	4423	5031	5692
Aksaray	1743	2157	2626	3153	3738
Amasya	1393	1778	2210	2700	3256
Ankara	1773	2199	2677	3214	3811
Antalya	439	731	1083	1481	1926
Ardahan	3861	4469	5137	5845	6571
Artvin	1535	1951	2429	2983	3619
Aydın	580	867	1213	1603	2037
Balıkesir	1128	1498	1914	2381	2907
Bartın	1330	1747	2226	2777	3403
Batman	1117	1450	1823	2235	2683
Bayburt	3006	3545	4149	4807	5510
Bilecik	1521	1933	2397	2922	3517
Bingöl	1994	2399	2838	3319	3848
Bitlis	2340	2800	3311	3863	4473
Bolu	1832	2291	2821	3423	4091
Burdur	1496	1902	2351	2848	3406
Bursa	1117	1491	1920	2401	2948
Çanakkale	1003	1371	1789	2258	2782
Çankırı	1928	2370	2864	3418	4035
Çorum	1965	2428	2958	3563	4234
Denizli	907	1245	1627	2052	2520
Diyarbakır	1375	1739	2142	2583	3057
Edirne	1403	1791	2224	2708	3250
Elazığ	1805	2211	2653	3135	3662
Erzincan	2129	2564	3047	3577	4164
Erzurum	3637	4205	4827	5499	6207
Eskişehir	2043	2516	3049	3649	4310
Gaziantep	1242	1605	2009	2450	2926
Giresun	957	1328	1765	2263	2830
Gümüşhane	2228	2702	3234	3832	4492
Hakkari	2543	2986	3470	3997	4564
Hatay	528	797	1119	1489	1906
Iğdır	1914	2319	2764	3256	3792
İskenderun	218	420	690	1022	1406
Isparta	1684	2120	2607	3156	3763
İstanbul	1054	1433	1865	2350	2897
İzmir	562	845	1188	1583	2023
K. Maraş	954	1284	1653	2059	2500
Karaman	1809	2229	2698	3222	3809
Kars	3573	4145	4772	5451	6168
Kastamonu	2088	2567	3112	3726	4402

(*continued on next page*)

Table 2 (*continued*)

Province	Base temperature (°C)				
	14	16	18	20	22
Kayseri	2120	2587	3113	3704	4359
Kilis	877	1196	1554	1948	2372
Kırıkkale	1731	2145	2609	3129	3711
Kırklareli	1429	1828	2274	2770	3326
Kırşehir	1923	2365	2857	3404	4018
Kocaeli	1015	1375	1786	2257	2790
Konya	1916	2350	2836	3371	3968
Kütahya	1899	2360	2880	3469	4120
Malatya	1648	2037	2461	2923	3431
Manisa	843	1166	1535	1947	2400
Mardin	1270	1621	2004	2421	2869
Mersin	311	552	852	1211	1622
Muğla	1081	1458	1879	2339	2847
Muş	2656	3088	3563	4082	4647
Nevşehir	2044	2508	3033	3626	4281
Niğde	1922	2362	2856	3414	4038
Ordu	984	1361	1804	2303	2869
Rize	991	1375	1820	2331	2912
Samsun	996	1377	1826	2339	2926
Siirt	1230	1577	1958	2374	2826
Sinop	1038	1430	1879	2390	2969
Sivas	2412	2896	3444	4061	4732
Şanlıurfa	852	1157	1503	1885	2303
Tekirdağ	1193	1586	2032	2531	3098
Tokat	1534	1938	2399	2922	3516
Trabzon	923	1291	1724	2223	2800
Tunceli	1880	2280	2716	3198	3727
Uşak	1525	1945	2414	2939	3526
Van	2454	2938	3476	4069	4721
Yalova	1033	1409	1843	2340	2903
Yozgat	2350	2853	3422	4057	4743
Zonguldak	1162	1557	2020	2557	3181

characteristics of the building and preferences of the occupants should be changed to lower the base temperature if possible. To lower the base temperature, thermostat settings should be reduced to the lower end of the comfort region, thermal insulation should be applied to buildings and air leakages should be minimised. Another factor that affects the value of the base temperature is the solar gain. Buildings should be constructed in such a way that they receive the maximum possible solar radiation during heating season and the minimum during cooling season. A reduction in base temperature from 18 to 16°C lowers the heating-degree days by approximately 13% in Erzurum and 34% in Adana.

A counter map of the annual heating degree-days for an 18°C base temperature is depicted in Fig. 2. The figure shows clearly the non-uniformity of climate of Turkey. For locations near to sea coasts, the heating degree-days have lower values compared with the eastern and the inner regions. The higher degree-days appear in the

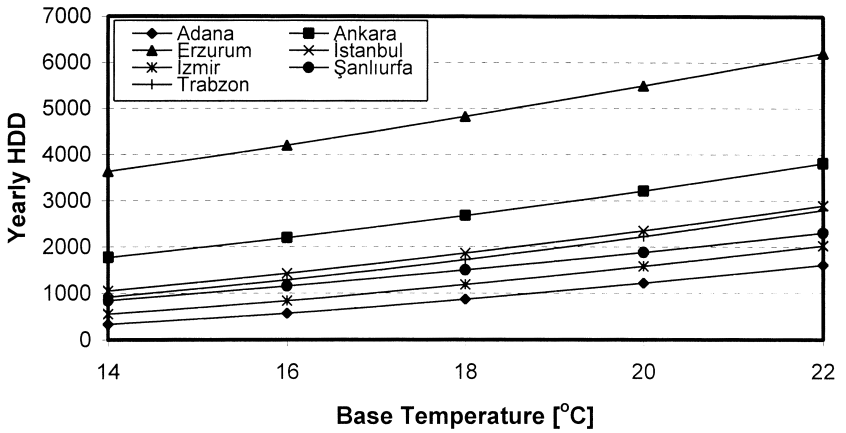

Fig. 1. Variation of yearly heating degree-days with base temperature for the main provinces of Turkey.

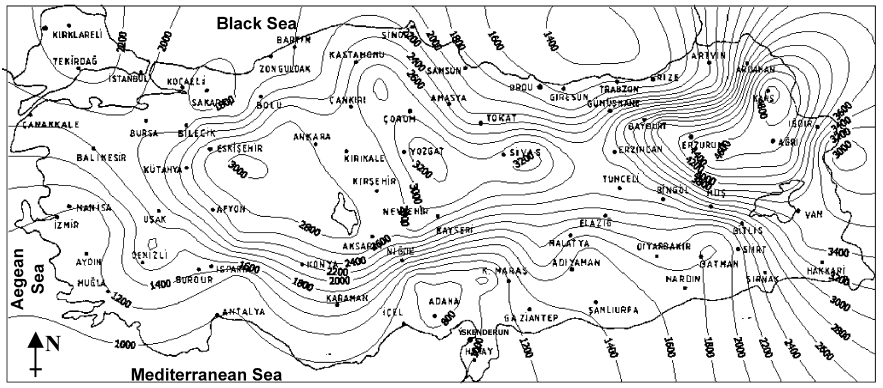

Fig. 2. The counter map of yearly heating degree-days for an 18°C base temperature in Turkey.

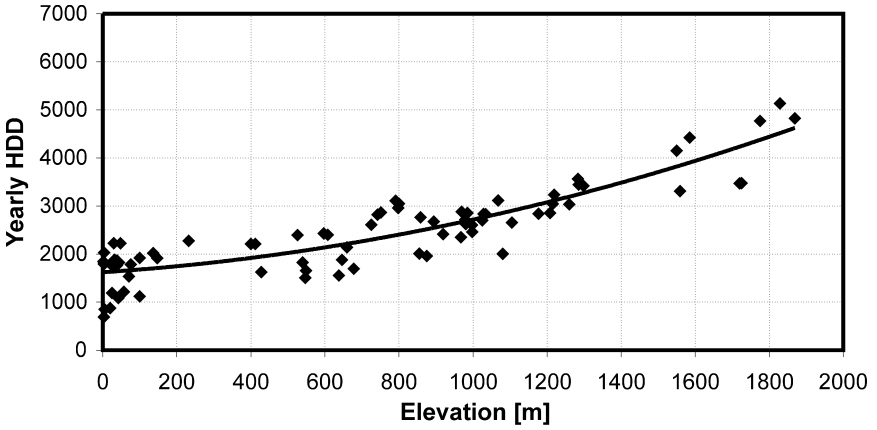

Fig. 3. Variation of yearly heating degree-days with elevation above sea level for Turkey.

eastern and northeastern Turkey. The counters are close to each other in the lower part of the inner region (around Niğde), in the east and in the northeast. This shows a rapid climate change within short distances due to mountainous nature of the landscape in these regions.

The landscape of Turkey, which contains large plains, high plateaus, high mountains and mountain chains, is quite non-uniform. Elevation of the cities varies between zero and 1869 m. A correlation between the heating degree-days and elevation is evident from Fig. 3. The value of the heating degree-days increases with elevation.

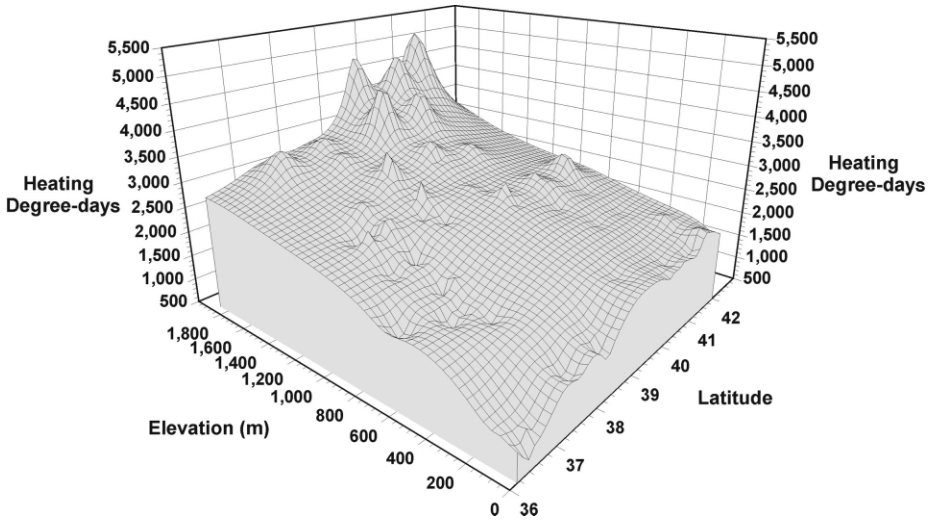

Fig. 4. Variation of yearly heating degree-days with elevation and latitude for Turkey.

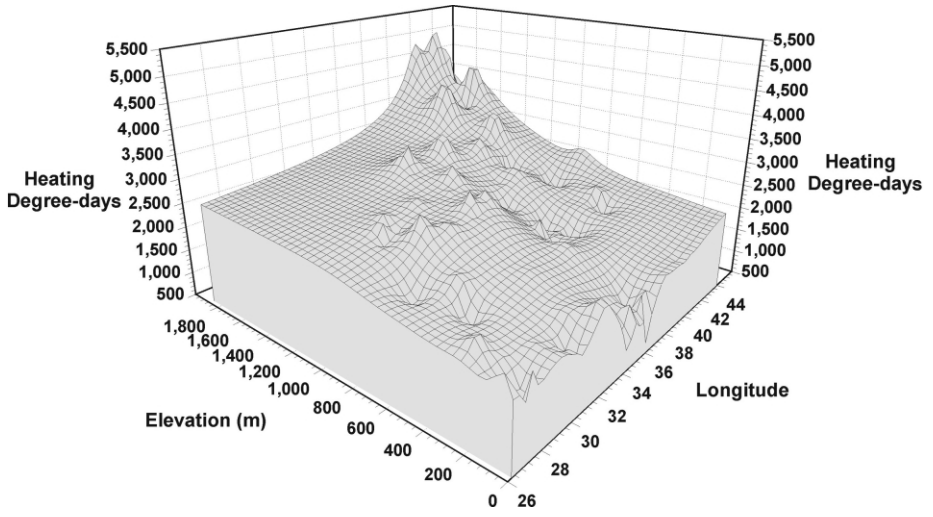

Fig. 5. Variation of early heating degree-days with elevation and longitude for Turkey.

Table 3
The annual cooling degree-days for Turkey

Province	Base temperature (°C)					
	18	20	22	24	26	28
Adana	1520	1136	796	500	255	82
Adapazarı	585	333	155	51	10	1
Adıyaman	1451	1122	824	570	360	198
Afyon	321	156	58	14	2	0
Ağrı	226	104	35	9	1	0
Aksaray	479	273	131	47	11	2
Amasya	574	331	159	57	14	2
Ankara	433	240	109	37	8	1
Antalya	1178	846	562	330	164	68
Ardahan	25	4	0	0	0	0
Artvin	329	154	58	19	5	0
Aydın	1234	895	601	355	170	55
Balıkesir	695	432	226	91	20	4
Bartın	327	149	44	9	1	0
Batman	1364	1044	763	519	318	163
Bayburt	106	36	8	1	0	0
Bilecik	442	238	101	33	7	1
Bingöl	811	562	361	197	83	21
Bitlis	402	224	105	35	6	0
Bolu	213	85	22	4	0	0
Burdur	586	355	183	71	14	1
Bursa	606	359	177	61	12	2
Çanakkale	717	455	249	103	25	4
Çankırı	364	190	76	22	4	0
Çorum	211	84	24	4	0	0
Denizli	1036	730	469	265	120	36
Diyarbakır	1185	896	640	422	242	113
Edirne	629	381	195	72	16	3
Elazığ	790	543	337	179	75	19
Erzincan	470	274	130	44	8	0
Erzurum	88	30	7	1	0	0
Eskişehir	226	93	27	4	0	0
Gaziantep	1061	774	521	312	157	56
Giresun	501	271	108	23	3	0
Gümüşhane	243	111	40	9	2	0
Hakkari	549	345	184	72	18	2
Hatay	1288	929	614	348	139	24
Iğdır	711	471	276	132	43	7
İskenderun	1433	1033	687	398	175	40
Isparta	392	210	88	23	4	0
İstanbul	588	342	159	47	6	0
İzmir	1182	847	559	319	147	44
K. Maraş	1262	937	649	405	210	80
Karaman	468	262	119	39	7	0
Kars	67	17	2	0	0	0
Kastamonu	193	79	23	4	0	0

(*continued on next page*)

Table 3 (*continued*)

Province	Base temperature (°C)					
	18	20	22	24	26	28
Kayseri	251	112	38	8	1	0
Kilis	1329	992	689	429	224	89
Kırıkkale	487	276	128	43	10	1
Kırklareli	592	358	185	72	20	6
Kırşehir	383	202	85	24	4	0
Kocaeli	665	404	204	76	18	2
Konya	424	232	101	31	5	0
Kütahya	251	110	35	7	0	0
Malatya	897	629	407	229	103	33
Manisa	1164	844	570	343	171	62
Mardin	1353	1037	755	515	315	161
Mersin	1279	907	585	317	124	20
Muğla	861	592	369	198	81	22
Muş	584	373	208	92	25	3
Nevşehir	259	121	47	13	2	0
Niğde	342	168	63	14	2	0
Ordu	512	284	119	30	3	0
Rize	452	228	81	13	1	0
Samsun	438	219	76	11	0	0
Siirt	1341	1026	747	509	311	158
Sinop	460	242	92	16	1	0
Sivas	196	82	27	6	1	0
Şanlıurfa	1601	1254	940	665	429	243
Tekirdağ	504	272	112	26	3	0
Tokat	439	234	97	30	5	0
Trabzon	476	245	91	17	1	0
Tunceli	804	555	353	193	85	24
Uşak	475	270	127	43	9	0
Van	248	109	32	6	1	0
Yalova	524	289	123	32	4	0
Yozgat	160	63	20	4	0	0
Zonguldak	350	157	50	14	2	0

The scatter is mainly due to the effects of latitude and longitude. The combined influences on heating degree-days of elevation and latitude and of elevation and longitude are shown in the form of three-dimensional graphs in Figs. 4 and 5, respectively. It is clear from Fig. 4 that, heating degree-days are generally higher when both elevation and latitude are high, although there are some non-uniformities. They are quite small at the opposite corner (where both elevation and latitude are low). Fig. 5 shows the combined influences of elevation and longitude. The value of heating degree-days is generally higher for the regions having a high elevation and a high longitude.

3.2. Annual cooling degree-days

The annual cooling degree-days for base temperatures of 18, 20, 22, 24, 26 and 28°C for 78 provinces of Turkey are given in Table 3. Analysis of Table 3 reveals

that there are significant differences between the values of cooling degree-days for different provinces at the same base temperature. Whilst there is no need for cooling in Ardahan (located in the northeast) for which the value of the cooling degree-day is zero, the cooling requirement is a maximum for Şanlıurfa (located in the southeast) with a cooling degree-day value of 940 at a 22°C base temperature.

The value of cooling degree-days increases significantly with the decrease of base temperature (Fig. 6). Therefore, thermal characteristics of the building and preferences of the occupants should be changed to increase the base temperature if possible. Increasing the base temperature above the traditionally used base temperature of 22°C diminishes the need for cooling completely for some provinces (such as Kars, Çorum, Kütahya, Niğde, and Samsun). However, significant cooling is still required for some cities, especially for those located in the south and the southeast Turkey. Increasing the base temperature from 22 to 24°C results in approximately 29% lower cooling degree-

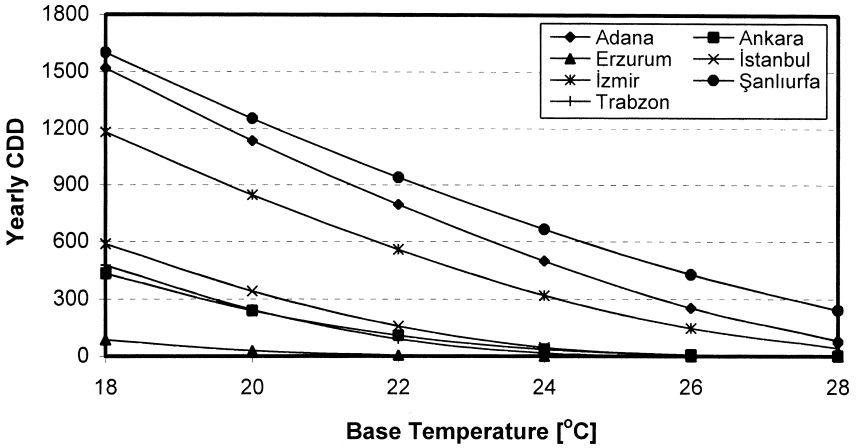

Fig. 6. Variation of yearly cooling degree-days with base temperature for the main provinces of Turkey.

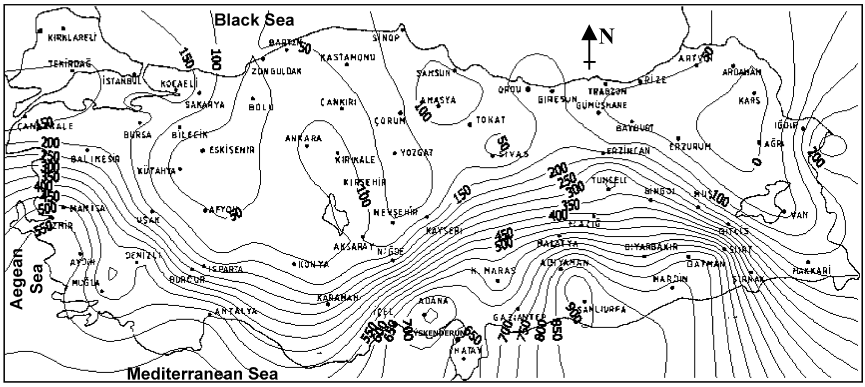

Fig. 7. The counter map of yearly cooling degree-days at a 22°C base temperature for Turkey.

days in Şanlıurfa. The increase in cooling degree days is at the same level (approximately 33%), when the base temperature is changed from 22 down to 20°C.

Fig. 7 shows a counter map of the yearly cooling degree-days at 22°C base temperature for Turkey. As can be seen from the figure, the cooling requirement is essentially zero in the north, northeastern, eastern and the inner regions of Turkey. However, a substantial amount of cooling is needed in the south and southeast Turkey. The counters are close to each other between Adana and Niğde (around Niğde), and in the east.

The correlation observed between elevation and the heating degree-days does not exist in the case of cooling-degree days (Fig. 8). However, combined influence of elevation and latitude on the cooling degree-days is clear from Fig. 9. For the provinces

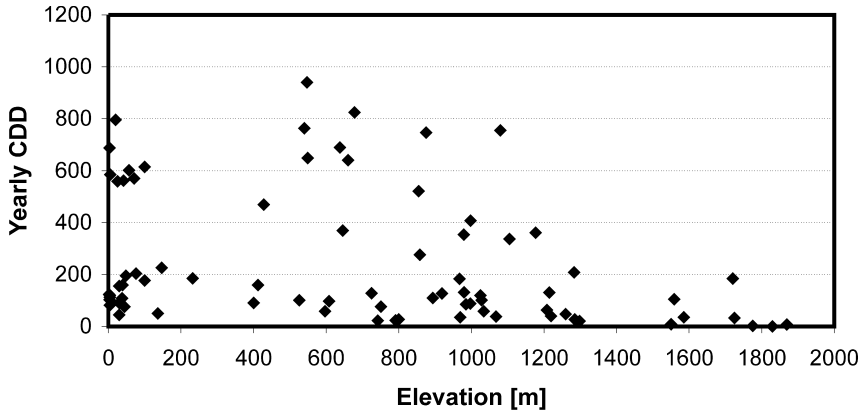

Fig. 8. Variation of yearly cooling degree-days with elevation for Turkey.

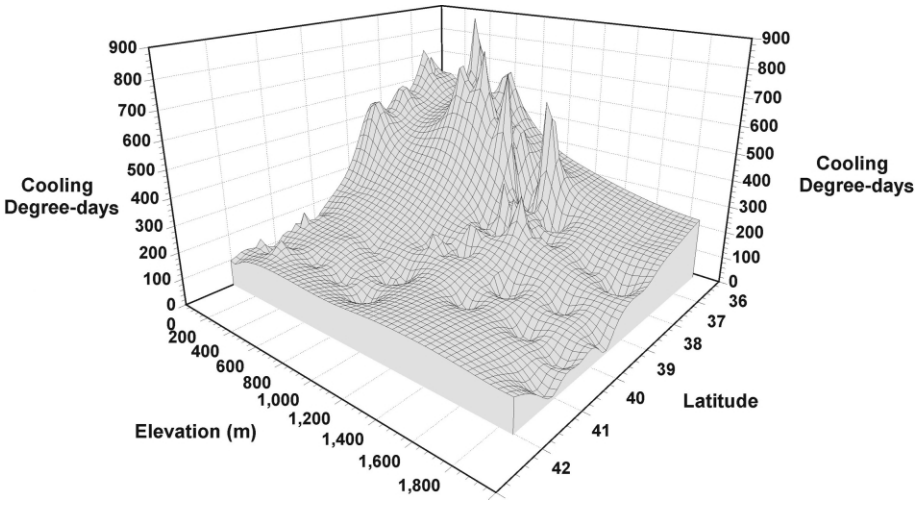

Fig. 9. Variation of yearly cooling degree-days with elevation and latitude for Turkey.

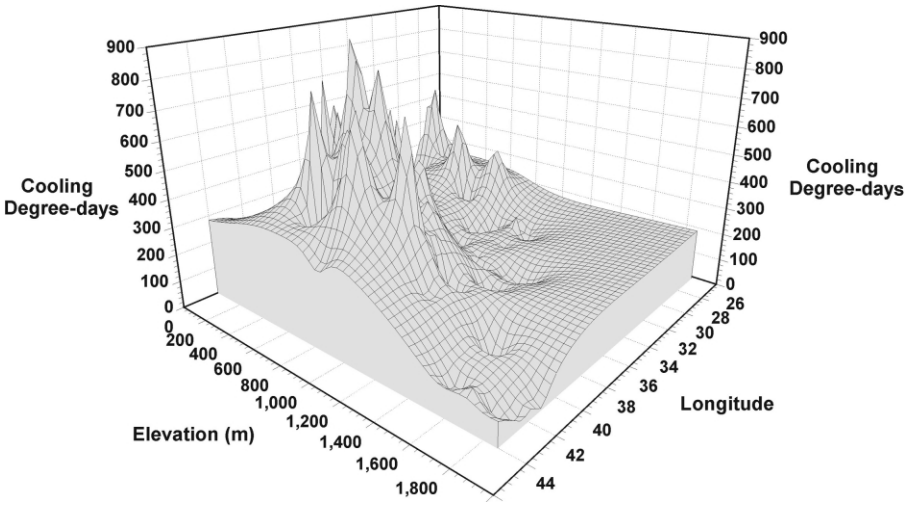

Fig. 10. Variation of yearly cooling degree-days with elevation and longitude for Turkey.

having elevations less than 1100 m and located in the south (where the latitude is less than 39°), cooling is a necessity. The value of the cooling-degree days is generally smaller than 200 at high elevations (>1100 m). This is also the case for the northern part of Turkey (latitude $>40°$).

The combined influence of elevation and longitude on the cooling degree-days (Fig. 10) is not as clear as in the case of elevation and latitude.

4. Conclusions

The heating and cooling degree-days with variable-base temperatures for Turkey are determined using long-term measured data. Base temperatures of 14, 16, 18, 20, and 22°C are chosen in the calculation of heating degree-days. Base temperatures of 18, 20, 22, 24, 26 or 28°C are used in the determination of cooling degree-days. Yearly heating and cooling degree-days are given in tabular forms for all the provinces of Turkey. The cooling and the heating degree-days are also presented on the counter maps. The values of both heating and cooling degree-days exhibit big fluctuations throughout Turkey. While the northeastern and the inner regions of Turkey require comparatively more heating energy, they need less or no cooling.

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