Spatial distributions of heating, cooling, and industrial degree-days in Turkey

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Summary

The degree-day method is commonly used to estimate energy consumption for heating and cooling in residential, commercial and industrial buildings, as well as in greenhouses, livestock facilities, storage facilities and warehouses. This article presents monthly and yearly averages and spatial distributions of heating, cooling, and industrial degree-days at the base temperatures of 18 °C and 20 °C, 18 °C and 24 °C, and 7 °C and 13 °C, respectively; as well as the corresponding number of days in Turkey. The findings presented here will facilitate the estimation of heating and cooling energy consumption for any residential, commercial and industrial buildings in Turkey, for any period of time (monthly, seasonal, etc.). From this analysis it will also be possible to compare and design alternative building systems in terms of energy efficiencies. If one prefers to use set point temperatures to indicate the resumption of the heating season would also be possible using the provided information in this article. In addition, utility companies and manufacturing/marketing companies of HVAC systems would be able to easily determine the demand, marketing strategies and policies based on the findings in this study.

1. Introduction

The degree-day method is commonly used to estimate energy consumption for heating and cooling in residential, commercial and industrial buildings, as well as in greenhouses, livestock facilities, storage facilities and warehouses (Environment Canada, 1978, 1987; ASHRAE, 1989; Yesilirmak and Yildiz, 2001; Yildiz and Yesilirmak, 2001). This approach is also used for estimating plant and insect growth, and freezing and thawing of soil and water surfaces (Thomas, 1953; Ramirez, 1964; McKay et al., 1967; Neild and Seeley, 1976; Environment Canada, 1978, 1987, 1990; Edey, 1980; Agriculture Canada, 1993; Bootsma, 1994; Lenihan and Neilson, 1995; Sykes and Prentice, 1996; Singh et al., 1998; Yildiz, 1998; Yildiz et al., 1998).

Estimating energy requirements and fuel consumption for heating, ventilating and air conditioning (HVAC) systems at any temporal scale can be difficult due to the many dynamic factors which influence energy requirements. Therefore, the most reliable method for estimating future energy requirements of a building is the past operating experience. If such records do not exist, then calculations for estimating energy requirements for HVAC systems are often necessary, especially for new buildings.

Turkey is one of the pilot regions chosen by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 1991). Several general circulation models (GCMs) have been run over the country, and projections have been generated. Based on these projections, a temperature increase of approximately 2 °C (winter) to 3 °C (summer) is expected in the future. However, the findings of Kadioglu (1997) based on a trend analysis of climate series in Turkey, are not in agreement with the GCM projections. Due to the fact that climate is changing, updating climatic design parameters becomes vital. In an earlier study, engineering weather data for designing HVAC systems for buildings were developed for Turkey (Yildiz and Yesilirmak, 1998). To complement Yildiz and Yesilirmak (1998), the study presented in this article was performed in order to develop heating, cooling, and industrial degree-days as an integral part of an extensive study, aimed at determining heating, cooling, industrial, freezing and thawing degree-days, as well as growing degree-days at different base temperatures across Turkey. The findings provided in this article will facilitate designers in estimating monthly, seasonal, and annual heating and cooling energy consumptions for residential, commercial and industrial buildings. It will also enable the comparison and design of alternative building systems in terms of energy efficiencies.

2. Materials and methods

2.1 Materials

In this study, the number of heating, cooling and industrial degree-days and corresponding number of days were determined for 100 different locations across Turkey (Fig. 1). All cities were included in this study, as well as some towns, which exhibited some kind of importance and differences in microclimate (e.g. the tourist-oriented towns of Kuşadası and Bodrum, as well as the Dalaman Airport, were included in this study along with the nearby cities of Aydın and Muğla). Meteorological data for each location were provided by the State Meteorological Service of Turkey (DMI). The daily dry-bulb temperature values for a 30-year period (1975–2004) were used. If the data for any location were not sufficient, reliable or available electronically, then the location was not included in the study.

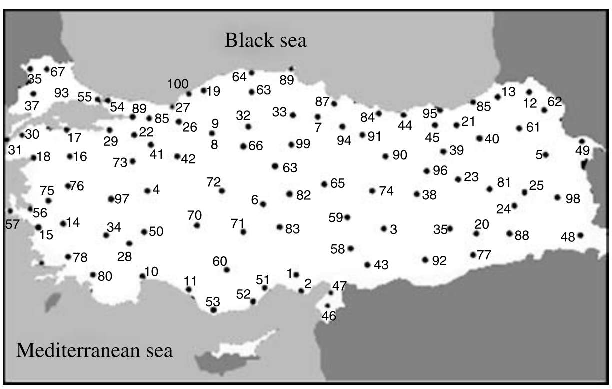

Fig. 1. Station locations used in the study

2.2 Degree-day method

Since many factors which influence the energy requirements of buildings are dynamic and vary in time, the calculations that take all variations into account are quite complex. Therefore, estimating energy requirements and fuel consumption of HVAC systems for either short or long-term operation can be difficult. As a result, the records of past energy requirements and/or fuel consumption for a particular residence are the best basis for estimating future energy use. However, when past records are not available, data from similar local dwellings can be used with caution. Since people have different living habits, even identical residences can have very different energy use patterns. Therefore, energy consumption must often be estimated from computed heating or cooling loads.

Any estimating method produces a much more reliable result over a long period of operation than over a short period. Almost all methods provide a reasonable result over a full annual heating and/or cooling season, but estimates for shorter periods, for example, a month, can be inaccurate.

The degree-day method for estimating heating energy requirements is based on the assumption that, on a long-term average, energy consumption will be proportional to the difference between the mean daily temperature and a heating base temperature of 18 °C or 20 °C. For estimating cooling energy requirements, this is based on the assumption that energy consumption will be proportional to the difference between the mean daily temperature and a cooling base temperature of 18 °C or 24 °C (Environment Canada, 1982, 1988). The difference between the mean daily temperature and the base temperature is called a “degree-day” (ASHRAE, 1989). In determining the heating and cooling base temperatures for buildings, solar and internal heat gains for buildings are taken into account. For example, if the internal temperature of a residential building is to be maintained at 21 °C, it is assumed that the solar and internal gains maintain this temperature until the external temperature drops below 18 °C (ASHRAE, 1989). Therefore, the most commonly used base temperature for residential heating is 18 °C (ASHRAE, 1989; Williams and MacKay, 1970; Wilson, 1973). In other words, on a day when the mean external temperature is 10 °C below 18 °C, twice as much energy is consumed as on days when the mean temperature is 5 °C below 18 °C. An equation has been developed for this concept stating that energy consumption is directly proportional to the number of degree-days in the estimation period.

For industrial degree-days base temperatures of 7 °C or 13 °C are used (ASHRAE, 1989; Environment Canada, 1982, 1988; Williams and MacKay, 1970; Wilson, 1973). For example, if the internal temperature is to be maintained at 15–16 °C in an industrial building, it is assumed that the solar and internal gains maintain temperature at this threshold until the external temperature drops below 13 °C. Similarly, if the internal temperature is to be maintained at 10 °C in an industrial building, it is again, assumed that solar and internal gains maintain this temperature until the external temperature drops below 7 °C. The base temperature of 7 °C is also used for determining heating energy consumption in greenhouses (Wilson, 1973).

2.3 Determination of heating degree-days and corresponding number of days

This article presents the heating, cooling and industrial degree-day components of a much more extensive study. Daily heating degree-day accumulation (t_h) is defined as the deviation of the mean temperature from a heating base temperature of 18 °C or 20 °C (Eq. (1)), and has the same unit as temperature. When the mean temperature is greater than the base temperature, the degree-day for that day is zero.

$$t_h = t_b - t_d \tag{1}$$

where t_b is the base temperature (18 °C or 20 °C), and t_d is the mean daily air temperature. The mean daily air temperature, t_d, is defined as:

$$t_d = (t_{max} - t_{min})/2 \tag{2}$$

where t_{max} is the daily maximum temperature, and t_{min} is the daily minimum temperature.

For a certain period of time (weekly, monthly, seasonal, annual, etc.), accumulated heating degree-day (D_h) is defined as:

$$D_h = \sum_{j=1}^{N} (t_h)_j \quad \left\{ \begin{array}{l} \text{If } t_d < t_b \text{ then } t_h = t_b - t_d \\ \text{else } t_h = 0 \end{array} \right\} \tag{3}$$

where N is defined as the period of time (number of days).

The corresponding number of days for heating degree-days were also determined and are presented in this article. Using the corresponding number of days, one can estimate the length of the heating season for a residential and commercial building at any particular location. The corresponding number of days for the accumulated heating degree-days for any period of time is determined by summing the days with t_d less than t_b.

The D_h findings presented in Table 1 do not have any set point temperature to define the resumption of the heating season. However, the D_h findings for the base temperatures of 18 °C and 20 °C, presented in Table 2, have set point temperatures of 12 °C and 15 °C, respectively. When the mean daily temperature drops below these set point temperatures the heating season is considered to have resumed, heating degree days accumulate, and the corresponding number of days is used to estimate the length of the heating season. Using the D_h values for the base temperature of 20 °C and the set point temperature of 12 °C, the heating regions were established (Table 3); the distributions are presented in Fig. 2. In several earlier studies, heating degree-days for Turkey were determined at different base temperatures for different locations (Yener and Gurdil, 1987; Dagsoz, 1995). However, in these studies, either only a couple of years' weather data were used, or no information was available. Even though these studies provided quite valuable information, they were limited in terms of the base temperatures and the set point temperatures investigated. In another study, even though it did not have any design purposes, seasonal heating and cooling

Table 1. Monthly averages of the heating degree-days (D_h) and corresponding number of days (N) at the base temperature of 18 °C

Station	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		March		April		May		June		July	
	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N	D_h	N
1 Adana					4	3	100	25	214	31	254	31	217	28	144	29	39	17	7	4				
2 Karataş					3	2	92	23	204	31	245	31	210	28	148	30	42	20	4	4				
3 Adiyaman					32	12	220	29	368	31	422	31	359	28	264	31	98	23	24	10				
4 Afyon	4	4	39	14	184	29	371	30	499	31	555	31	484	28	401	31	226	29	119	24	27	11	6	4
5 Ağri	6	3	65	19	277	31	515	30	755	31	896	31	791	28	684	31	351	30	195	31	60	20	6	3
6 Aksaray	1	1	31	12	167	29	360	30	500	31	551	31	483	28	380	31	191	28	93	22	14	8	2	1
7 Amasya			17	8	122	26	306	30	427	31	476	31	410	28	310	30	141	25	62	17	6	4	1	1
8 Ankara	2	2	30	12	163	28	361	30	492	31	554	31	473	28	380	31	204	28	99	22	20	10	3	2
9 Esenboğa	7	5	63	20	232	30	423	30	547	31	622	31	532	28	444	31	258	30	141	27	45	17	8	5
10 Antalya					16	10	138	28	237	31	274	31	246	28	197	31	79	26	14	9				
11 Alanya					4	3	79	25	163	31	204	31	191	28	150	31	52	22	7	5				
12 Ardahan	74	25	174	29	363	31	560	30	821	31	918	31	822	28	698	31	407	30	282	31	159	29	67	24
13 Artvin	8	6	45	16	140	27	297	30	445	31	498	31	434	28	355	31	192	27	110	23	32	14	7	5
14 Aydin					33	13	171	28	270	31	310	31	267	28	200	31	78	22	15	7				
15 Kuşadası			1	1	39	16	159	27	235	31	280	31	261	28	212	31	95	26	23	13				
16 Balikesir			6	4	84	23	249	30	355	31	403	31	361	28	304	31	144	27	53	17	4	2		
17 Bandırma			7	5	86	25	240	30	338	31	392	31	366	28	330	31	180	28	75	22	5	3		
18 Edremit			1	2	52	18	201	29	289	31	336	31	307	28	257	31	112	26	27	12	2	1		
19 Bartin	3	2	41	18	142	29	289	30	383	31	438	31	399	28	351	31	212	29	98	25	12	9	2	2
20 Batman			1	1	43	16	244	30	416	31	466	31	373	28	269	31	97	24	24	10				
21 Bayburt	30	13	107	24	279	31	486	30	676	31	769	31	690	28	575	31	326	30	207	30	95	25	24	13
22 Bilecik	3	2	32	13	142	26	307	30	425	31	482	31	430	28	361	31	194	27	96	22	17	9	4	3
23 Bingöl			8	4	135	28	365	30	552	31	642	31	563	28	457	31	214	29	87	21	6	4		
24 Bitlis	1	1	34	15	211	31	419	30	588	31	652	31	583	28	522	31	307	30	162	29	31	14	1	1
25 Tatvan	3	2	57	21	251	31	431	30	585	31	646	31	576	28	534	31	332	30	190	30	41	17	2	2
26 Bolu	14	8	69	21	195	30	365	30	476	31	534	31	474	28	409	31	244	29	143	28	50	18	16	9
27 Akçakoca	2	2	38	17	129	29	258	30	337	31	397	31	383	28	361	31	238	29	120	28	15	11	2	2
28 Burdur			11	6	123	26	316	30	441	31	483	31	426	28	354	31	192	29	84	21	10	5	1	1
29 Bursa			10	6	94	25	244	29	333	30	389	31	357	28	305	30	156	27	58	18	3	2		
30 Çanakkale			4	3	76	22	216	29	305	31	361	31	340	28	308	31	163	30	52	20	2	1		
31 Bozcaada			2	2	62	21	186	29	264	31	309	31	295	28	264	31	135	28	49	20	2	2		
32 Çankiri	3	2	41	15	192	30	396	30	523	31	585	31	490	28	394	31	206	29	102	23	20	11	3	2
33 Çorum	8	6	55	19	205	30	388	30	511	31	574	31	502	28	413	31	226	29	127	25	33	16	7	5
34 Denizli			1	1	64	20	228	29	336	31	379	31	333	28	256	31	108	23	32	12	2	1		
35 Diyarbakir			1	1	64	20	287	30	457	31	515	31	424	28	313	31	129	26	38	14				

Table 2. Annual average heating degree-days (D_h) and corresponding number of days (N) for different base temperature and set point temperature combinations

Station	Degree-days and number of days					
	$t_b = 18\,°C/12\,°C$		$t_b = 20\,°C/12\,°C$		$t_b = 20\,°C/15\,°C$	
	D_h	N	D_h	N	D_h	N
1 Adana	697	81	858	81	1178	129
2 Karataş	658	75	808	75	1128	124
3 Adiyaman	1603	137	1877	137	2086	169
4 Afyon	2706	192	3090	192	3315	227
5 Ağri	4420	227	4874	227	5068	257
6 Aksaray	2565	181	2927	181	3147	215
7 Amasya	2061	159	2379	159	2613	195
8 Ankara	2573	184	2941	184	3157	217
9 Esenboğa	3093	207	3506	207	3752	245
10 Antalya	901	102	1104	102	1449	154
11 Alanya	454	57	568	57	1022	127
12 Ardahan	5094	267	5628	267	5895	308
13 Artvin	2305	176	2658	176	2920	217
14 Aydin	1077	108	1294	108	1582	152
15 Kuşadası	974	98	1170	98	1530	154
16 Balikesir	1724	146	2016	146	2285	188
17 Bandırma	1769	153	2075	153	2355	196
18 Edremit	1322	125	1571	125	1864	170
19 Bartin	2109	175	2458	175	2735	217
20 Batman	1748	141	2030	141	2231	172
21 Bayburt	4025	234	4492	234	4742	273
22 Bilecik	2256	172	2600	172	2854	211
23 Bingöl	2865	183	3231	183	3414	211
24 Bitlis	3333	210	3753	210	3942	239
25 Tatvan	3344	217	3777	217	3957	245
26 Bolu	2717	199	3115	199	3395	243
27 Akçakoca	2004	172	2348	172	2641	217
28 Burdur	2251	175	2601	175	2811	208
29 Bursa	1699	145	1989	145	2266	188
30 Çanakkale	1548	139	1826	139	2140	187
31 Bozcaada	1242	120	1482	120	1842	176
32 Çankiri	2745	191	3127	191	3350	225
33 Çorum	2819	198	3214	198	3452	235
34 Denizli	1520	135	1791	135	2035	173
35 Diyarbakir	2054	155	2364	155	2553	184

Table 3. Heating regions in Turkey ($t_b = 20\,°C/12\,°C$)

Region	Degree-day main-group	Degree-day sub-group	Altitude	General distribution
I	<1500	<1500	<100 m	Aegean and Coastal Mediterranean
II	1500–2500	1500–2000	<100 m	Coastal Black Sea
		2000–2500	<100 m	Black Sea and Marmara
		2000–2500	500–1000 m	Southeastern Anatolia
III	2500–3500	2500–3000	500–1000 m	Multiple Regions
		3000–3500	500–1000 m	Transitional Regions
		3000–3500	1000–1500 m	Central Anatolia
IV	>3500	3500–4000	1000–1500 m	Central Anatolia (high altitudes)
		3500–4000	>1500	Eastern Anatolia
		>4000	>1500	Eastern Anatolia (north)

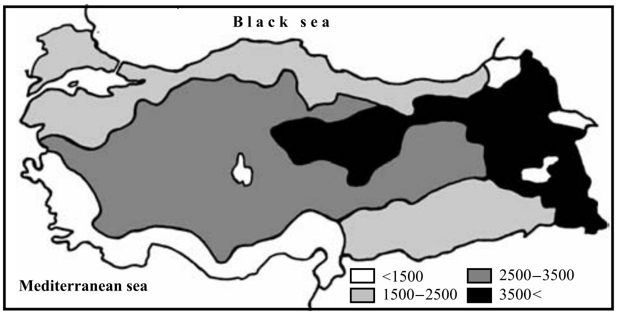

Fig. 2. Distribution of the heating regions in Turkey ($t_b = 20\,°C/12\,°C$)

degree-days in Turkey were determined in the context of climate change (Kadioglu et al., 2001). Therefore, it was one of the objectives of this study to develop up-to-date heating degree-day information for different base temperature and set point temperature combinations across Turkey using reliable long-term weather data.

2.4 Determination of cooling degree-days and corresponding number of days

Daily cooling degree-days (t_c) are defined as the deviation of the mean temperature from a cooling base temperature of 18 °C or 24 °C (Eq. (4)), and has the same unit as temperature. When the mean temperature is below the base temperature, then the cooling degree-day for that day is zero.

$$t_c = t_d - t_b \qquad (4)$$

Table 4. Annual averages of the cooling degree-days at the base temperatures of 18 °C and 24 °C

Station	Lat.		Longit.		Altitude meter	Number of degree-days	
	°	′	°	′		$t_b = 18\,°C$	$t_b = 24\,°C$
1 Adana	36	59	35	21	27	1376	404
2 Karataş	36	34	35	23	22	1235	302
3 Adiyaman	37	45	38	17	672	1441	582
4 Afyon	38	45	30	32	1034	359	21
5 Ağri	39	44	43	03	1632	240	10
6 Aksaray	38	23	34	03	965	465	42
7 Amasya	40	39	35	51	412	589	66
8 Ankara	39	57	32	53	890	449	44
9 Esenboğa	40	07	33	00	949	259	11
10 Antalya	36	53	30	42	42	1129	310
11 Alanya	36	33	32	00	7	1178	282
12 Ardahan	41	07	42	43	1829	21	0
13 Artvin	41	11	41	49	628	252	10
14 Aydin	37	51	27	51	56	1151	320
15 Kuşadası	37	52	27	15	22	841	133
16 Balikesir	39	39	27	52	146	687	86
17 Bandırma	40	21	27	58	58	540	30
18 Edremit	39	35	27	01	21	916	199
19 Bartin	41	38	32	20	30	303	5
20 Batman	37	53	41	07	540	1347	567
21 Bayburt	40	15	40	14	1584	112	3
22 Bilecik	40	09	29	58	539	385	23
23 Bingöl	38	52	40	30	1177	765	176
24 Bitlis	38	22	42	06	1573	343	18
25 Tatvan	38	29	42	18	1664	240	5
26 Bolu	40	44	31	36	743	160	1
27 Akçakoca	41	05	31	10	10	265	2
28 Burdur	37	40	30	20	967	595	76
29 Bursa	40	11	29	04	100	643	74
30 Çanakkale	40	08	26	24	6	668	76
31 Bozcaada	39	50	26	04	28	538	26
32 Çankiri	40	36	33	37	751	392	31
33 Çorum	40	33	34	57	776	231	7
34 Denizli	37	47	29	05	425	991	250
35 Diyarbakir	37	54	40	14	677	1286	514

Table 5. Monthly averages of the cooling degree-days and corresponding number of days at the base temperature of 18 °C

Station	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		March		April		May		June		July	
	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N
1 Adana	320	31	249	30	119	28	9	5							2	2	32	13	114	27	219	30	309	31
2 Karataş	302	31	240	30	115	29	11	7							1	1	17	10	86	27	187	30	276	31
3 Adiyaman	383	31	238	30	56	18	1	1									15	7	94	21	255	30	396	31
4 Afyon	119	28	41	16	3	2											1	1	15	7	60	19	121	27
5 Ağri	95	28	17	11																	16	9	111	28
6 Aksaray	151	30	47	18	3	2									1	1	2	2	24	9	78	22	161	30
7 Amasya	168	31	78	22	11	5											10	5	44	14	110	26	168	30
8 Ankara	149	29	52	18	4	3											2	2	22	9	69	20	151	29
9 Esenboğa	100	27	19	11	1	1													7	4	29	12	104	26
10 Antalya	299	31	185	30	55	21	2	2									7	4	68	22	203	30	304	31
11 Alanya	293	31	213	30	94	28	7	5									11	8	77	26	193	30	284	31
12 Ardahan	8	6	1	1																	1	1	12	7
13 Artvin	72	25	34	14	7	4											5	3	22	8	43	16	69	26
14 Aydin	282	31	166	30	49	18	3	2							1	1	14	8	90	24	230	30	314	31
15 Kuşadasi	219	31	122	29	35	15	5	3									7	4	45	18	163	30	243	31
16 Balikesir	194	31	94	26	20	8											8	3	39	13	140	28	192	31
17 Bandırma	165	31	75	25	15	7	1	1									3	2	20	9	103	27	158	31
18 Edremit	254	31	135	28	27	13	1	1									5	4	59	19	176	29	261	31
19 Bartin	102	29	22	12	3	3											1	1	13	6	55	21	107	29
20 Batman	377	31	217	29	36	15											12	6	79	21	257	30	411	31
21 Bayburt	41	17	9	6															1	1	9	5	51	18
22 Bilecik	116	29	46	17	11	5											6	2	22	9	70	21	113	28
23 Bingöl	249	31	104	26	4	3											1	1	22	10	117	26	267	31
24 Bitlis	127	30	26	15															2	2	38	16	150	30
25 Tatvan	89	29	15	9															1	1	23	13	113	29
26 Bolu	58	23	14	9	1	1											1	1	6	3	26	12	54	22
27 Akçakoca	95	29	23	13	4	2											2	1	6	3	40	19	94	29
28 Burdur	189	31	75	23	6	5											2	1	25	10	104	25	194	30
29 Bursa	187	31	80	24	15	6	2	1							1	1	9	4	34	13	126	28	187	30
30 Çanakkale	204	31	94	27	18	9	1	1											22	11	124	29	205	31
31 Bozcaada	146	31	87	28	25	10	1	1									3	2	20	11	105	28	151	31
32 Çankiri	131	29	37	15	2	2											1	1	17	8	62	19	143	29
33 Çorum	80	25	24	11	2	1											1	1	11	6	35	14	79	26
34 Denizli	265	31	139	29	30	11	1	1									13	7	73	19	196	29	276	31
35 Diyarbakir	365	31	196	29	24	11											5	4	61	17	235	30	400	31

Column group header: Number of degree-days and number of days where t_b is the base temperature (18 °C or 24 °C), and t_d is the mean daily air temperature. The mean temperature, t_d, was defined earlier in Eq. (2).

For a certain period of time (weekly, monthly, seasonal, annual, etc.), accumulated cooling degree-day (D_c) is defined as:

$$D_c = \sum_{j=1}^{N} (t_c)_j \quad \left\{ \begin{array}{l} \text{If } t_d > t_b \text{ then } t_c = t_b - t_d \\ \text{else } t_c = 0 \end{array} \right\} \tag{5}$$

where N is the period of time (number of days). The corresponding number of days for the accumulated cooling degree-days for any period of time is determined by summing the days with t_d greater than t_b. Also in this study, the corresponding number of cooling degree-days were determined and are presented in this article. Using the corresponding number of days, one can estimate the length of the cooling season for any particular location.

2.5 Determination of industrial degree-days and corresponding number of days

The daily industrial degree-day (D_i) is defined as the deviation of the mean temperature from a heating base temperature of 7 °C or 13 °C (Eq. (1)).

Table 6. Monthly averages of the cooling degree-days and corresponding number of days at the base temperature of 24 °C

Station	Number of degree-days and number of days																							
	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		March		April		May		June		July	
	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N	D_c	N
1 Adana	134	31	73	27	9	7											1	1	14	6	49	24	123	31
2 Karataş	116	31	63	27	7	5													5	3	22	18	90	31
3 Adiyaman	197	31	71	23	3	2													13	6	89	23	210	31
4 Afyon	7	6	1	1																	3	2	11	8
5 Ağri	3	3																					8	5
6 Aksaray	15	10	1	1															1	1	5	3	21	13
7 Amasya	22	12	5	3															3	2	12	7	23	12
8 Ankara	18	10	2	2																	4	3	21	12
9 Esenboğa	5	4																					6	5
10 Antalya	113	31	26	16	2	1													4	3	44	18	119	30
11 Alanya	107	31	40	22	3	2													3	2	29	18	99	31
12 Ardahan																								
13 Artvin	3	2	2	1															1	1	1	1	4	2
14 Aydin	97	29	20	12	1	1													8	5	64	23	129	30
15 Kuşadası	42	22	7	5	1	1													2	1	19	11	62	26
16 Balikesir	30	18	6	5															2	1	18	10	30	17
17 Bandırma	10	11	1	1															1	1	7	5	11	9
18 Edremit	73	26	13	8															2	2	30	15	81	27
19 Bartin	1	2																			1	1	2	2
20 Batman	191	31	55	21	1	1													7	4	88	24	225	31
21 Bayburt	1	1																					2	2
22 Bilecik	6	5	2	1															1	1	4	3	9	5
23 Bingöl	70	27	6	5																	13	8	88	27
24 Bitlis	4	5																					13	10
25 Tatvan	1	1																					4	4
26 Bolu	1	1																					1	1
27 Akçakoca	1	1																					1	2
28 Burdur	29	18	2	2																	8	6	37	17
29 Bursa	27	17	3	3															2	1	13	8	28	17
30 Çanakkale	33	21	2	3																	7	6	34	21
31 Bozcaada	6	6	1	1	1	1															5	4	13	6
32 Çankiri	12	8	1	1																	3	2	16	11
33 Çorum	3	3	1																		1	1	3	2
34 Denizli	84	27	14	8	1	1													7	4	47	18	97	27
35 Diyarbakir	179	31	43	18															4	3	73	21	214	31

When the mean temperature is above the base temperature, then the degree-day for that day is zero.

$$t_i = t_b - t_d \quad (6)$$

where t_b is the base temperature (7 °C or 13 °C), and t_d is the mean daily air temperature. The mean temperature, t_d, was defined in Eq. (2).

For a certain period of time (daily, weekly, monthly, seasonal, annual, etc.) the accumulated industrial degree-day is defined as:

$$D_i = \sum_{j=1}^{N} (t_i)_j \quad \left\{ \begin{array}{l} \text{If } t_d > t_b \text{ then } t_i = t_b - t_d \\ \text{else } t_i = 0 \end{array} \right\} \quad (7)$$

where N is defined as the period of time (number of days).

The corresponding number of industrial degree-days were also determined and are presented in this article. Using the corresponding number of days, one can estimate the length of the heating season for industrial buildings at any location. The corresponding number of days for the accumulated industrial degree-days for any period of time is determined by summing the days with t_d less than t_b.

3. Results and discussion

Due to the space limitation, tabulated degree-day values for only 35 stations are presented in alphabetical order in this article (Tables 1, 2, 4, 5, 6, 8, and 9). Readers are referred to Yildiz and Sosaoglu (2006) for the other stations which are not presented here.

3.1 Heating degree-days

Table 1 shows the monthly averages of heating degree-days (D_h) and their corresponding number of days which were determined for 100 different locations at the base temperature of 18 °C. The findings show that at the base temperature of 18 °C, relatively high D_h values were observed at Ardahan, Sarikamis, Kars, Agri and Erzurum (northeast region of Turkey) (Table 1). It was also observed that intensive monthly D_h accumulations were generally realized in the months of December, January, and February. Conversely, very low monthly D_h accumulations were observed at Alanya, Iskenderun, Mersin, Anamur, and Silifke (Mediterranean coastal cities).

The D_h findings which were presented in Table 2 for the base temperatures of 18 °C and 20 °C had a temperature set point of 12 °C or 15 °C; that is, heating would not start in the fall until the mean daily temperature dropped below the set point temperature. Therefore, these findings were naturally lower than the D_h values determined for the case when no set points temperatures were used. In this study, an attempt was made to develop heating regions for the base temperature of 20 °C and the set point temperature of 12 °C. These regions and their corresponding numerical D_h ranges are presented in Table 3 along with the general spatial distributions in Fig. 2. Based on these findings, the lowest energy consumption for heating occurs in the coastal Aegean and Mediterranean regions, while the highest energy consumption is observed in the regions which experience severe winter

Table 7. Cooling regions in Turkey ($t_b = 18$ °C)

Region	Degree-day main-group	Degree-day sub-group	General distribution
I	<250	<250	Northern parts of the eastern Anatolia, Central Anatolia – high altitudes
II	250–500	250–500	Central Anatolia and Black Sea coast
III	500–750	500–750	Marmara and Trace
IV	>750	750–1000	Western parts of eastern Anatolia
		1000–1250	Mediterranean and Aegean coasts
		>1250	Southeastern Anatolia

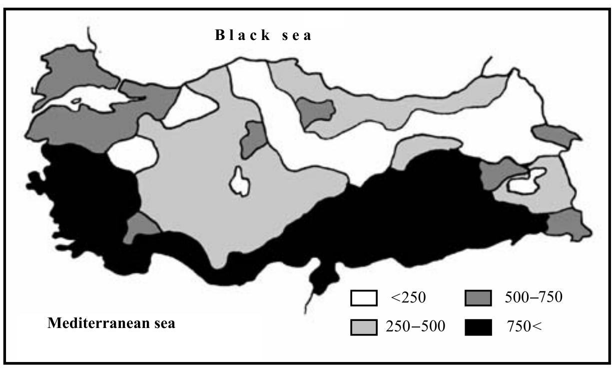

Fig. 3. Distribution of the cooling regions in Turkey ($t_b = 18$ °C)

Table 8. Monthly averages of the industrial degree-days (D_i) and corresponding number of days (N) at the base temperature of 7 °C

Station	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		March		April		May		June		July	
	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N
1 Adana									2	2	5	4	7	4	1	1								
2 Karataş									3	2	6	4	9	4	1	1								
3 Adiyaman							10	5	53	18	87	26	65	19	21	8								
4 Afyon					5	3	77	17	165	27	217	29	177	26	92	20	14	7	2	1				
5 Ağri					14	7	187	27	414	31	555	31	480	28	343	31	61	16	3	2				
6 Aksaray					3	2	74	16	168	26	213	28	177	25	82	16	8	4	1	1				
7 Amasya							39	13	107	23	145	26	117	22	48	13	3	2						
8 Ankara					3	2	69	16	158	27	215	30	167	26	81	18	8	5						
9 Esenboğa					8	5	108	23	208	29	282	31	222	28	120	24	16	8	2	1				
10 Antalya							1	1	4	4	9	6	12	6	2	1								
11 Alanya											1	1	3	2										
12 Ardahan			4	2	48	17	230	29	480	31	577	31	512	28	357	31	93	22	20	9	1	1		
13 Artvin					1	1	36	12	117	25	162	28	133	24	72	17	12	5	1	1				
14 Aydin							4	3	18	8	26	12	24	9	6	3								
15 Kuşadası							3	2	16	7	23	10	25	9	7	3								
16 Balikesir							20	8	59	17	86	21	79	18	37	13	1	1						
17 Bandırma							15	7	44	15	75	22	79	20	43	16	2	2						
18 Edremit							7	4	25	10	42	16	44	13	16	7								
19 Bartin					1	1	32	11	71	20	111	25	104	22	55	18	3	3						
20 Batman							15	7	92	22	130	27	77	20	23	6								
21 Bayburt			1	1	20	9	162	25	335	31	428	31	380	28	236	29	44	14	6	4				
22 Bilecik					2	1	47	13	106	23	152	26	134	23	75	17	10	5						
23 Bingöl					1	1	66	17	213	30	301	31	253	28	129	25	9	4						
24 Bitlis					4	2	101	22	247	31	311	31	273	28	182	30	34	13	2	2				
25 Tatvan					8	4	110	25	244	31	288	31	265	28	196	31	42	15	4	3				
26 Bolu					4	3	75	17	146	26	197	28	169	25	99	21	18	8	2	1				
27 Akçakoca							19	9	48	16	81	22	92	22	58	19	6	5						
28 Burdur					1	1	42	13	110	25	145	29	120	24	55	15	5	3						
29 Bursa							19	9	50	16	82	21	81	19	36	13	1	1						
30 Çanakkale							12	6	36	12	61	19	63	17	28	11	1	1						
31 Bozcaada							4	3	19	8	33	13	40	13	18	8								
32 Çankiri					4	3	88	21	185	29	244	31	181	27	86	19	7	4						
33 Çorum					5	3	84	20	175	28	234	30	193	27	101	21	11	5	2	1				
34 Denizli							14	6	47	14	69	19	59	15	20	8								
35 Diyarbakir							27	10	122	26	175	30	119	25	36	11	1	1						

Table 9. Monthly averages of the industrial degree-days (D_i) and corresponding number of days (N) at the base temperature of 13 °C

Station	Aug.		Sept.		Oct.		Nov.		Dec.		Jan.		Feb.		March		April		May		June		July	
	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N	D_i	N
1 Adana							18	8	70	23	101	29	81	24	31	13	1	2						
2 Karataş							19	8	66	21	95	27	78	22	33	13	1	1						
3 Adiyaman					2	1	86	22	213	31	267	31	218	28	119	25	17	9	1	1				
4 Afyon			4	2	63	18	222	29	344	31	400	31	343	28	247	30	97	21	30	11	1	1		
5 Ağri			9	4	126	28	365	30	600	31	741	31	649	28	529	31	202	29	64	20	4	3		
6 Aksaray			2	1	52	16	212	28	345	31	396	31	341	28	227	29	70	18	20	8				
7 Amasya			1	1	26	12	162	27	273	30	321	31	270	28	167	26	41	14	10	4				
8 Ankara			2	2	50	16	212	29	337	31	399	31	332	28	227	29	78	20	22	9	1	1		
9 Esenboğa			7	4	91	23	273	30	392	31	467	31	391	28	289	31	117	25	37	14	2	2		
10 Antalya							28	13	89	27	121	29	106	26	55	21	3	3						
11 Alanya							7	5	32	16	57	23	57	21	26	13	1	1						
12 Ardahan	6	4	55	17	208	31	410	30	666	31	763	31	681	28	543	31	257	30	133	27	38	16	6	4
13 Artvin			4	2	37	14	153	26	291	31	343	31	292	28	206	27	78	18	27	10	1	1		
14 Aydin					2	2	57	16	122	27	157	29	130	26	67	19	9	6						
15 Kuşadası					2	2	52	15	99	21	133	25	127	24	74	21	10	7						
16 Balikesir					12	6	113	23	202	29	249	30	221	27	158	26	41	14	5	3				
17 Bandırma					11	5	103	22	185	29	238	30	226	27	181	28	59	19	8	6				
18 Edremit					6	3	75	20	140	27	184	29	168	27	112	2	19	10	1	1				
19 Bartin			1	1	32	14	144	27	229	30	283	31	259	27	200	29	81	22	15	7				
20 Batman					4	2	104	24	261	31	311	31	232	28	122	26	16	7	1	1				
21 Bayburt	1	1	22	9	129	28	336	30	521	31	614	31	549	28	420	31	179	28	77	21	13	7	1	1
22 Bilecik			1	1	39	14	163	26	271	30	328	31	290	28	212	28	77	19	20	8				
23 Bingöl			1	1	29	13	215	29	397	31	487	31	422	28	302	31	85	21	15	7				
24 Bitlis			2	1	69	23	269	30	433	31	497	31	442	28	367	31	160	28	47	16	1	1		
25 Tatvan			5	3	101	27	281	30	430	31	491	31	435	28	379	31	184	29	62	19	2	2		
26 Bolu			7	5	66	20	216	29	321	31	379	31	333	28	255	30	110	23	38	13	3	2		
27 Akçakoca			1	1	24	11	118	25	189	28	244	30	245	27	210	30	101	25	20	11				
28 Burdur					27	11	168	28	286	31	328	31	285	28	200	30	69	19	16	7				
29 Bursa					14	8	111	23	187	28	238	29	220	26	159	27	45	16	6	4				
30 Çanakkale					11	5	90	20	157	26	209	29	201	27	155	29	38	17	2	2				
31 Bozcaada					8	4	65	18	119	24	160	27	158	25	118	25	24	12	2	2				
32 Çankiri			3	2	64	20	247	30	368	31	430	31	349	28	240	30	76	21	20	9				
33 Çorum			5	3	72	20	238	30	356	31	420	31	361	28	259	30	93	23	32	12	1	1		
34 Denizli					8	4	96	22	184	29	226	30	193	27	114	24	26	10	3	2				
35 Diyarbakir					7	4	141	27	302	31	360	31	283	28	161	29	29	12	2	2				

conditions, such as the eastern regions and high altitude areas of the central region of Turkey. For example, if Sarikamis ($D_h = 5566$) and Iskenderun ($D_h = 516$) are compared, assuming that the building orientations are the same, it is obvious that a residential dwelling at Sarikamis would have 11 times higher heating energy consumption than the very same building in Iskenderun.

3.2 Cooling degree-days

Table 4 shows the annual averages, and Tables 5 and 6 the monthly averages, of cooling degree-days (D_c) and the corresponding number of days which were determined for 100 different locations at the base temperatures of 18 °C and 24 °C. As Table 4 shows, the maximum D_c had an accumulation of 1638 at the location of Sanliurfa, followed by other locations located in the same region; e.g. Adiyaman, Adana, Iskenderun, Batman, Siirt, and Mardin. In contrast, Ardahan, Kars, and Sarikamis had zero accumulations of cooling degree-days. Table 4 also shows that, even though the magnitudes varied, the degree-day accumulations at 24 °C followed similar trends across the country. Tables 5 and 6 show that the maximum accumulation of cooling degree-days generally occurred in July. Exceptions are found in the Black Sea and Marmara regions where maximum accumulations are found in August. This variation can probably be explained by the effects of proximity to the sea and by latitude. Generally speaking, the cooling season extends from June to September; however, in some regions, the season also includes the months of May and October, and even April in some cases. As a result, across Turkey, no cooling is necessary for the five-month period from November through March, and at some locations no cooling is required throughout the entire year.

Based on the findings at the cooling base temperature of 18 °C, a total of four cooling regions have been identified for Turkey. These regions, and their corresponding numerical cooling degree-day ranges, are presented in Table 7 and the general spatial distributions are presented in Fig. 3. It should be noted however, that, if an exact figure is needed for a particular location, one should refer to the findings presented in Tables 4, 5 and 6 and not to the general distributions presented in Fig. 3.

3.3 Industrial degree-days

Table 8 shows the monthly averages of industrial degree-days (D_i) and their corresponding number of days which were determined for 100 different locations at the base temperatures of 7 °C and 13 °C. Table 8 indicates that relatively high D_i values were observed at Ardahan, Sarikamis, Kars, Agri, and Erzurum, with values of 2322, 2141, 2088, 2057, and 2053, respectively. If very low monthly D_i accumulations are excluded, then almost all accumulations are found in an eight month period, with the most intense accumulations, occurring from December to February. In contrast, several locations revealed very small monthly D_i accumulations i.e., at Alanya, Iskenderun and Anamur, Mersin, Adana, Dalaman, Bodrum, and Silifke, with the latter five locations also having very low accumulated D_i values during very short periods. Table 9, shows similar trends for the monthly D_i accumulations at the base temperature of 13 °C but with different magnitudes than those observed at 7 °C.

4. Conclusions

As a result of this study, using the monthly distributions of heating, cooling, and industrial degree-days determined for corresponding base temperatures, one can easily estimate the heating and cooling energy consumption for any residential, commercial and industrial building, such as factories, greenhouses, and warehouses at any temporal scale (i.e. monthly, seasonal, etc.). This would also make it possible to compare and to suggest designs for alternative building systems in terms of energy efficiencies. If one prefers to use set point temperatures (sometimes there is no other choice) to indicate the resumption of the heating season, this would also be possible using the information provided in this article. Besides, manufacturing/marketing companies of HVAC systems, as well as utility companies, would be able to easily determine the demand, marketing strategies and policies based on the findings of this study.

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References

Agriculture Canada (1993) Risk analyses of growing degree-days in Atlantic Canada. Research Branch Technical Bulletin 1993-5E, Ottawa, Canada

ASHRAE (1989) Handbook of Fundamentals, ASHRAE, Inc. Atlanta, GA 30329, U.S.A. pp 28.1–28.9

Bootsma A (1994) Long term (100 Yr) climatic trends for agriculture at selected locations in Canada. Climatic Change 26: 65–88

Dagsoz KA (1995) Türkiye'de Derece-Gün Sayıları, Ulusal Enerji Tasarruf Politikası, Yapılarda Isı Yalıtımı. İzocam A.Ş., Istanbul, Turkey

Edey SN (1980) Degres-jours de Croissance et Production des Cultures au Canada. Agriculture Canada Publication No. 1635, Ottawa, Canada

Environment Canada (1978) The climates of Canada for agriculture. The Canada Land Inventory Report No. 3, Ottawa, Canada

Environment Canada (1982) Canadian Climate Normals, 1951–1980. Volume 4 – Degree Days, Atmospheric Environment Service, Ottawa, Canada

Environment Canada (1987) The climate of Montreal. Ottawa, Canada, pp 36–39

Environment Canada (1988) Handbook on climate data sources of the atmospheric environment service, Ottawa, Canada, pp 3–5 and 3–6

Environment Canada (1990) Eastern Canadian Boreal and sub-Arctic Wetlands. In: A resource document. Ottawa, Canada

IPCC Working Group I (1991) Policy makers summary. In: Houghton JT, Jenkins GJ, Ephraums JJ (eds) Climate change: The IPCC Scientific Assessment. Cambridge, U.K.: Cambridge University Press

Kadioglu M (1997) Trends in surface air temperature data over Turkey. Int J Climatol 17: 511–520

Kadioglu M, Sen Z, Gultekin L (2001) Variations and trends in Turkish seasonal heating and cooling degree-days. Climate Change 49: 209–223

Lenihan JM, Neilson RP (1995) Canadian vegetation sensitivity to projected climatic change at three organizational levels. Climatic Change 38: 51–86

McKay GA, Mooney OR, Maybank J, Pelton WL (1967) The agricultural climate of Saskatchewan. Canada Department of Transport, Climatological Studies No. 10. Toronto, Canada

Neild RE, Seeley MW (1976) Applications of growing degree days in field corn production. In: Agrometeorology of the Maize (Corn) Crop. WMO – No. 481, Geneva, Switzerland, pp 426–436

Ramirez JM (1964) The agro-climatology of North Dakota. Part 1-Air temperature and growing degree days. North Dakota State University, Extension Bulletin No. 15. Fargo, North Dakota, U.S.A.

Singh B, Maayar ME, Andre P, Bryant CR, Thouez JP (1988) Impacts of a Ghg-induced climate change on crop yields: effects of acceleration in maturation, moisture stress and optimal temperature. Climatic Change 38: 51–86

Sykes MT, Prentice IC (1996) Climate change, Tree species distributions and forest dynamics: a case study in the mixed Conifer/Northern Hardwoods Zone of Northern Europe. Climatic Change 34: 161–177

Thomas MK (1953) Climatological Atlas of Canada. National Research Council Canada, Ottawa, Canada

Williams GDV, MacKay KH (1970) Tables of daily degree-days above or below any base temperature. Canadian Department of Agriculture, Publication No: 1409, Ottawa, Canada, 1970

Wilson CW (1973) The Climate of Quebec – The Application of Climatic Information – Part two. Environment Canada, Atmospheric Environment, Ottawa, Canada

Yener C, Gurdil F (1987) Türkiye Derece-Gün Değerlerinin Belirlenmesi ve Derece-Gün Yöntemi, TÜBİTAK Yapı Araştırma Enstitüsü. Rapor No: H139, Ankara, Turkey

Yesilirmak E, Yildiz I (2001) Monthly and annual averages of growing degree-days at different base temperatures for Turkiye. GAP 2nd Agricultural Congress: October 24–26, Harran University, Sanliurfa, Turkey

Yildiz I (1998) HVAC Design in Turkish Greenhouses. Adnan Menderes University Publ. No: 6. Adnan Menderes University, Aydin, Turkey

Yildiz I, Yesilirmak E (1998) Turklim: Türkiye İklimsel Tasarım Kriterleri, I. Ege Bölgesi Tarım Kongresi, 7–11 Eylül, Aydin. T.C. Ziraat Bankası Genel Müdürlügü Basimevi, Ankara, Turkey, Cilt 2, pp 148–155

Yildiz I, Gürbüz T, Bozer S (1998) HVAC Designs for Livestock Buildings in Turkiye: Degree-Day Approach. Ege Bölgesi I. Tarım Kongresi, 7–11 Eylül 1998, Aydin. T.C. Ziraat Bankası Genel Müdürlügü Basimevi, Ankara, Turkey, Cilt 2: pp 164–172

Yildiz I, Yesilirmak E (2001) Monthly and annual averages of freezing and thawing degree-days and number of days for Turkiye. 20th National Congress on Agricultural Mechanization and Energy: September 13–15, Harran University, Sanliurfa, Turkey

Yildiz I, Sosaoglu B (2006) Tabulated distributions of heating, cooling, and industrial degree-days in Turkey. http://cronus.uwindsor.ca/users/i/iyildiz/index.nsf/inToc/DE7232EF7BA6FCC5852570A00060756D

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