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Energy 28 (2003) 1133–1150
ENERGY
www.elsevier.com/locate/energy

New outdoor heating design data for Turkey

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Received 13 September 2002

Abstract

In this study, new outdoor design conditions for space heating were determined for 78 locations within Turkey according to the format recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE). Dry-bulb temperature corresponding to 99%, 99.6% and 97.5% annual cumulative frequency of occurrence, the mean and standard deviation of the annual minimum dry-bulb temperatures were obtained. These calculations used hourly data measured during at least 13 years. The current heating design conditions used in the calculation of space heating load in Turkey were analyzed based on their frequency levels. Comparison of the existing space heating design data with the data obtained in this study revealed that the current space heating design temperatures are generally stringent and provide total protection.

1. Introduction

A significant part of the total energy consumed in the commercial and residential buildings is used for space heating and cooling [1,2]. Therefore, thorough analyses of energy use and conservation in heating, ventilating and air-conditioning (HVAC) systems design and operation become necessary for designers and operators. This necessity comes not only from an economic feasibility viewpoint, but also from the viewpoint of energy standards, which may be obligatory for all future buildings and HVAC systems.

Energy is very important in the Turkish economy. Because of its limited energy resources, Turkey is heavily dependent on imported oil and gas [3]. In 2000, primary energy consumption was equivalent to 79.67 million tons of oil, while production was equivalent to 27.59 million tons

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0360-5442/03/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0360-5442(03)00118-X

of oil, and approximately 35% of demand was met by domestic resources [4]. The country expects a very large growth in energy demand especially for electricity and natural gas as its economy expands [3]. The energy demand will depend more on imported energy in the coming future than at present, for instance, 72% in 2010 and 76% in 2020 [5]. The country spends around 40–50% of its total export income to import fuel, mainly crude oil and natural gas [6]. Therefore, in addition to investigating new domestic energy resources and focusing on increasing domestic production by utilizing public, private and foreign investment, every means to use energy in a much more rational way should be taken into consideration. Energy conservation should be one of the important objectives of energy policy in Turkey. In 1992, Turkey set a National Energy Conservation Center (NECC), which helped create an energy efficiency regulation for industrial establishments. According to the regulation, industrial establishments with energy consumption of more than 2000 tons of oil equivalent should install energy management systems in their plants. In 1998, the Turkish Government introduced a more stringent insulation standard (Turkish Standard No. 825) in buildings to encourage for reducing energy use [7].

Approximately 25–30% of the total annual energy consumed in Turkey is used in buildings [8]. The amount of energy consumed for air-conditioning is increasing steadily and parallel to the increase in living standards and use of air-conditioning equipment. It is estimated that, more than half of the energy consumed in residential and commercial buildings is used for air-conditioning [8–11], although a comprehensive study does not exist.

Design of air-conditioning systems starts with the calculation of heating and cooling loads of the building that depend on its characteristics, the indoor conditions to be maintained, and on outside weather conditions. If the air-conditioning system is expected to provide the comfort conditions required at all times, it should be designed for peak conditions that are determined by the most extreme weather data recorded for the locality in which the building is located. This approach, however, will result in oversized air-conditioning equipment, which in turn, will increase the initial equipment cost and operating cost. The latter is due to the reduced system efficiency of air-conditioning systems at part-load conditions. Therefore, in practice, a risk of slight discomfort under rare extremes of weather is taken and by doing so, both the initial and operating costs of the air-conditioning equipment are reduced considerably [1].

American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc. (ASHRAE) publishes heating design conditions corresponding to different levels of probability for several locations in the United States and around the world [12,13]. They are the outdoor conditions that are exceeded during a specified percentage of time. The heating design data were provided at 99 and 97.5 percentile frequency of occurrence during winter months (December, January and February) in the 1993 edition of the ASHRAE Handbook—Fundamentals [12]. These percentiles were replaced by annual percentile values of 99.6 and 99 in the 1997 edition of ASHRAE Handbook—Fundamentals [13]. The change was made in order to provide design conditions to represent the same probability of occurrence anywhere, regardless of the seasonal distribution of extreme temperature.

For heating, the 1997 ASHRAE Handbook—Fundamentals [13] provides design values for dry-bulb temperature, wind speed and mean coincident dry-bulb temperature. The dry-bulb temperature data are obtained from hourly observations and given for 99.6% and 99% annual frequency of occurrence. Design values of dry-bulb and wind speed corresponding to the various annual percentiles represent the value that is exceeded on average by the indicated percentage of the total number of hours (NOH) in a year (8760 h). For example, outside dry-bulb, temperature falls below the 99.6% design value on average for 35 h in a year. In the case of 99% frequency level, the time period is 88 h. In the 1997 ASHRAE Handbook—Fundamentals [13], the data for annual extreme daily temperatures are also given.

Representing the climatic design data for several frequencies of occurrence will enable engineers to choose different risk levels desired for the project in hand. The choice depends on the comfort level to be maintained indoors, thermal inertia and insulation of the building structure. For ordinary buildings, it is customary to use the design data corresponding to annual percentile of 99 in heating. More stringent percentiles are preferred for critical applications such as luxury hotels, hospitals, nurseries or some industrial applications. In this case, 99.6 percentile can be used for heating [1,14].

2. Heating design data currently used in Turkey

Heating load calculations in Turkey are generally carried out using the climatic design data provided by the Turkish Chamber of Mechanical Engineers (MMO) in Publication No. 84 [15] in which the heating design dry-bulb temperatures are listed for 590 locations within Turkey covering small towns as well. This publication is based on the data given in Turkish Standard No. 2164 [16].

The heating design data given in these publications are not detailed for design evaluations and building energy analysis. They are based on old weather observations [17] that were taken with the limited instrumentation of the past, which raise doubts about the accuracy of the measurements. The design data have not been updated for the last 35 years. Therefore, a possible change in the climatic conditions during the recent decades cannot have been taken into consideration in load calculations.

The existing heating design data were determined by averaging the yearly minimum dry-bulb temperatures observed during 10 successive years for each location [16]. Lack of data for various frequency levels is one of the drawbacks of the existing design data that are based on only one level of probability (frequency of occurrence). Therefore, designers do not have the opportunity to choose different risk levels desired for the project in hand. The same level of risk factor is assumed for all types of buildings because of the lack of design data for different frequencies of occurrence. Therefore, some designers tend to adopt their past experience and modify the existing design data imposed by the official bodies for non-governmental buildings.

In Turkey, the number of studies concerning weather data that are needed for design of air-conditioning systems and energy consumption calculations is very limited. The subject has been considered seriously only in recent years and it is not yet complete. Some independent studies have been performed to expose climatic design conditions of Turkey in recent years. Turkish Society of HVAC and Sanitary Engineers (TTMD) published results of a project on weather data of Turkey in a report [18]. In this report, design data for only six weather stations located in four cities were given according to the frequency levels suggested by the 1997 ASHRAE Handbook—Fundamentals [13]. The design data were obtained from long-term hourly measurements. Üner [19] presented weather data for 23 cities in Turkey according to the frequency levels used in the 1993 ASHRAE Handbook—Fundamentals [12]. The design conditions were determined using

Typical Meteorological Year (TMY) data generated from 7 years of hourly observations. The climatic design data given in the 1997 edition of ASHRAE Handbook—Fundamentals [13] are incomplete for Turkey; only eight Turkish localities are considered.

Design of air-conditioning systems and associated energy consumption calculations are sensitive to weather data used. Incorrect selection of climatic design data may results in an oversized or undersized air-conditioning system design, which would be uneconomic and unsatisfactory for occupant comfort. A proper sizing should result in an equipment large enough to meet thermal loads during peak periods, but small enough to be energy efficient [1]. Proper design and operation of air-conditioning systems are very important for the developing countries like Turkey that are facing with energy deficit and related problems. Therefore, the climatic design conditions used should be detailed, contemporary and reliable.

The need to fill the gap in well-established weather data for Turkey provided the stimulus for this project that includes production of climatic design data, degree–days and bin data for heating and cooling and, solar radiation. Present authors presented [20] new climatic design data for cooling for 78 locations within Turkey using the format suggested by the 1997 ASHRAE Handbook—Fundamentals [13]. A comprehensive analysis of the data for degree–days [21] and temperature bins [22] for 78 weather stations of Turkey was also published previously by the present authors. In this paper, the results of the heating design data studies are reported.

3. Recommended heating design conditions

Weather design data are usually determined by statistical analyses of long-term weather observations. The observations should cover a long period of time and should be taken during recent years [12,14]. The number of years for which the weather data are available determines the breadth of the weather database. In principle, as many years as possible should be considered for a proper analysis. The longer the period of records is, the better and more persuasive the results will be (since shorter periods will exhibit variations from the long-term average). For determining design conditions, weather data for at least 12 years are considered as long-term data by ASHRAE [13]. Ten or more years of weather data are required to increase the statistical reliability of recommended models for weather data and thus the estimated loads [23].

In this study, heating design conditions were obtained for the locations within Turkey for which regular, long-term hourly dry-bulb temperature observations are available. In Turkey, although there are more than 350 weather stations in operation, only 78 of them satisfy these criteria. However, since these weather stations are located in 77 different provinces of Turkey (total number of the provinces in Turkey is 81), they cover almost all parts of the country.

The hourly dry-bulb temperatures measured during at least 13 years between 1981 and 1998 were used in the calculations. The raw data were taken from The State Meteorological Affairs General Directorate (DMİ) in diskettes. Table 1 provides information for the weather stations and the periods of the data considered.

Table 2 shows recommended heating design dry-bulb temperatures for 78 locations within Turkey. Two annual frequency levels (99.6% and 99%) are offered for each location as suggested by the 1997 ASHRAE Handbook—Fundamentals [13]. Apart from these percentiles, design temperatures were also calculated for a less stringent frequency level of 97.5% (Table 2). As can be

Table 1
Weather database and basic information for weather stations

Province	Longitude (°E)	Latitude (°N)	Elevation (m)	Hourly dry-bulb temperatures (°C)		Daily minimum temperatures (°C)	
				Period	Total years	Period	Total years
Adana	35.18	36.59	20	1983–1998	16	1981–1996	16
Adapazarı	30.25	40.47	30	1982–1998	17	1982–1998	17
Adıyaman	38.17	37.45	678	1981–1998	18	1981–1998	18
Afyon	30.32	38.45	1034	1981–1998	18	1981–1998	18
Ağrı	43.08	39.31	1585	1981–1998	18	1981–1998	18
Aksaray	34.03	38.23	980	1981–1998	18	1981–1998	18
Amasya	35.51	40.39	412	1981–1998	18	1981–1998	18
Ankara	32.53	39.57	894	1983–1995	13	1981–1995	15
Antakya	36.07	36.15	100	1983–1998	16	1981–1996	16
Antalya	30.42	36.53	42	1983–1998	16	1981–1995	15
Ardahan	42.42	41.08	1829	1981–1998	17	1981–1998	18
Artvin	41.49	41.10	597	1981–1998	18	1981–1998	18
Aydın	27.50	37.51	57	1983–1998	16	1983–1998	16
Balıkesir	27.52	39.39	147	1983–1997	15	1983–1997	15
Bartın	32.21	41.38	30	1981–1998	18	1981–1998	18
Batman	41.10	37.52	540	1983–1998	15	1983–1998	16
Bayburt	40.15	40.16	1550	1981–1998	18	1981–1998	18
Bilecik	29.58	40.09	526	1981–1998	17	1981–1998	18
Bingöl	40.30	38.52	1177	1981–1998	18	1981–1998	17
Bitlis	42.06	38.22	1559	1981–1998	18	1981–1998	18
Bolu	31.36	40.44	742	1981–1998	18	1981–1998	18
Burdur	30.20	37.40	967	1981–1998	18	1981–1998	18
Bursa	29.04	40.11	100	1983–1998	16	1983–1998	16
Çanakkale	26.24	40.08	3	1981–1998	17	1981–1998	17
Çankırı	33.37	40.36	751	1981–1995	13	1981–1995	15
Çorum	34.58	40.33	798	1981–1998	18	1981–1998	18
Denizli	29.05	37.47	428	1983–1998	16	1983–1998	16
Diyarbakır	40.12	37.55	660	1983–1998	16	1981–1996	16
Edirne	26.34	41.40	48	1983–1998	16	1983–1998	16
Elazığ	39.13	38.40	1105	1981–1998	18	1981–1998	18
Erzincan	39.30	39.44	1215	1981–1998	18	1981–1998	18
Erzurum	41.16	39.55	1869	1983–1998	14	1983–1998	16
Eskişehir	30.31	39.46	800	1983–1998	15	1991–1998	8
Gaziantep	37.22	37.05	855	1983–1998	16	1981–1996	16
Giresun	38.24	40.55	38	1981–1998	18	1981–1998	18
Gümüşhane	39.27	40.27	1219	1981–1998	18	1981–1998	18
Hakkari	43.46	37.34	1720	1981–1998	18	1981–1998	18
Iğdır	44.02	39.56	858	1981–1998	16	1981–1998	16
İskenderun	36.07	36.37	3	1981–1998	18	1981–1998	18
Isparta	30.33	37.45	997	1981–1998	18	1981–1998	18
İstanbul	29.05	40.58	39	1983–1998	16	1981–1996	16
İzmir	27.10	38.24	25	1983–1998	16	1981–1996	16

(*continued on next page*)

Table 1 (*continued*)

Province	Longitude (°E)	Latitude (°N)	Elevation (m)	Hourly dry-bulb temperatures (°C)		Daily minimum temperatures (°C)	
				Period	Total years	Period	Total years
K.Maraş	36.56	37.36	549	1984–1998	15	1983–1998	16
Karaman	33.14	37.11	1025	1981–1998	18	1981–1998	18
Kars	43.05	40.36	1775	1983–1998	15	1983–1998	16
Kastamonu	33.46	41.22	791	1981–1998	18	1981–1998	18
Kayseri	35.29	38.43	1068	1983–1998	16	1981–1996	16
Kırıkkale	33.30	39.50	725	1981–1995	15	1981–1995	15
Kırklareli	27.13	41.44	232	1981–1998	18	1981–1998	18
Kırşehir	34.10	39.08	985	1981–1995	15	1981–1995	15
Kilis	37.05	36.44	638	1981–1998	17	1981–1998	18
Kocaeli	29.54	40.46	76	1981–1998	18	1981–1998	18
Konya	32.30	37.52	1028	1983–1998	16	1981–1996	16
Kütahya	29.58	39.24	969	1981–1998	17	1981–1998	18
Malatya	38.18	38.21	998	1983–1998	16	1983–1998	16
Manisa	27.26	38.36	71	1983–1998	16	1983–1998	16
Mardin	40.44	37.18	1080	1983–1998	16	1983–1998	16
Mersin	34.36	36.49	5	1983–1998	16	1983–1998	16
Muğla	28.21	37.12	646	1983–1998	16	1981–1996	16
Muş	41.31	38.44	1283	1981–1998	18	1981–1998	18
Nevşehir	34.40	38.25	1260	1981–1998	18	1981–1998	18
Niğde	34.40	37.59	1208	1981–1998	18	1981–1998	18
Ordu	37.52	40.59	4	1981–1998	18	1981–1998	18
Rize	40.30	41.02	4	1983–1998	16	1981–1996	16
Samsun	36.20	41.17	44	1983–1998	16	1981–1996	16
Siirt	41.56	37.56	875	1981–1998	18	1981–1998	18
Sinop	35.10	42.02	32	1981–1998	18	1981–1998	18
Sivas	37.01	39.49	1285	1983–1998	16	1983–1998	16
Şanlıurfa	38.46	37.08	547	1983–1998	16	1980–1993	14
Tekirdağ	27.29	40.59	4	1983–1998	16	1983–1998	16
Tokat	36.54	40.18	608	1981–1998	17	1981–1998	18
Trabzon	39.43	41.00	30	1983–1998	16	1981–1996	16
Tunceli	39.32	39.06	979	1981–1998	18	1981–1998	18
Uşak	29.29	38.40	919	1981–1998	18	1981–1998	18
Van	43.41	38.28	1725	1983–1998	16	1981–1995	15
Yalova	29.16	40.39	2	1981–1998	18	1981–1998	18
Yozgat	34.49	39.50	1298	1983–1998	16	1983–1998	16
Zonguldak	31.48	41.27	136	1981–1998	18	1981–1998	18

seen from the table, Turkey has a non-uniform climate. 99.6% and 99% design dry-bulb temperatures for the locations within Turkey vary between −28.0 and 5.2 °C and, −25.4 and 6.4 °C, respectively.

The probability of occurrence of very extreme conditions can be required for the operational design of equipment to ensure continuous operation and serviceability [13]. The mean and stan-

Table 2
Heating design conditions for Turkey

Province	Heating DB (°C)			Min DB (°C)	
	99.6%	99%	97.5%	Mean	StdD
Adana	1.9	3.2	4.9	−1.2	1.6
Adapazarı	−2.1	−1.1	0.3	−5.5	2.1
Adıyaman	−2.6	−1.3	0.3	−5.2	2.5
Afyon	−9.8	−8.0	−5.9	−15.2	2.6
Ağrı	−28.0	−25.4	−21.3	−33.5	3.8
Aksaray	−11.2	−9.1	−6.3	−15.7	5.1
Amasya	−6.4	−4.7	−2.7	−10.7	3.9
Ankara	−9.4	−7.8	−5.7	−12.6	3.2
Antakya	0.3	1.7	3.4	−2.6	1.5
Antalya	1.8	2.8	4.3	−0.8	1.3
Ardahan	−25.7	−23.0	−19.5	−31.0	3.0
Artvin	−5.1	−3.9	−2.4	−8.2	1.9
Aydın	−0.5	0.5	2.1	−3.2	1.4
Balıkesir	−3.8	−2.6	−1.0	−7.7	2.7
Bartın	−4.8	−3.2	−1.4	−9.6	3.3
Batman	−6.5	−4.7	−2.1	−9.8	4.4
Bayburt	−18.9	−16.5	−13.5	−23.9	3.3
Bilecik	−5.4	−4.2	−2.7	−9.2	2.5
Bingöl	−12.7	−10.8	−7.9	−16.7	4.6
Bitlis	−13.0	−10.8	−8.1	−17.2	3.5
Bolu	−9.8	−7.8	−5.3	−15.3	3.3
Burdur	−6.1	−4.9	−3.0	−10.0	1.6
Bursa	−3.4	−2.0	−0.6	−8.0	3.9
Çanakkale	−2.4	−1.3	0.3	−4.9	1.7
Çankırı	−10.8	−8.9	−6.5	−14.7	3.5
Çorum	−10.9	−8.7	−6.2	−16.0	4.3
Denizli	−2.4	−1.4	0.2	−5.8	2.0
Diyarbakır	−8.7	−6.4	−3.9	−12.1	5.2
Edirne	−7.3	−5.5	−3.3	−10.9	3.8
Elazığ	−8.9	−7.4	−5.5	−12.3	3.8
Erzincan	−14.4	−12.1	−9.2	−18.5	4.1
Erzurum	−26.2	−23.1	−19.6	−31.9	4.1
Eskişehir	−9.8	−8.2	−6.0	−15.5	2.2
Gaziantep	−4.5	−3.1	−1.3	−7.9	2.4
Giresun	0.2	1.0	2.3	−1.7	1.5
Gümüşhane	−13.4	−11.1	−8.3	−18.0	3.6
Hakkari	−14.2	−12.4	−10.2	−17.8	2.7
Iğdır	−12.5	−10.7	−8.0	−16.3	3.7
Isparta	−7.9	−6.4	−4.2	−12.4	2.8
İskenderun	5.2	6.4	7.8	2.2	1.9
İstanbul	−1.1	−0.3	1.2	−3.6	2.2
İzmir	1.0	1.9	3.4	−1.4	1.6

(continued on next page)

Table 2 (*continued*)

Province	Heating DB (°C)			Min DB (°C)	
	99.6%	99%	97.5%	Mean	StdD
K. Maraş	−2.4	−1.2	0.5	−5.7	2.3
Karaman	−12.5	−10.1	−7.2	−17.9	5.1
Kars	−23.7	−21.0	−17.8	−28.5	2.2
Kastamonu	−10.4	−8.2	−5.8	−14.7	2.5
Kayseri	−16.2	−13.2	−9.3	−20.5	4.2
Kırıkkale	−8.9	−7.4	−5.1	−12.6	3.6
Kırklareli	−6.6	−5.0	−2.8	−9.6	2.3
Kırşehir	−12.3	−9.9	−7.1	−16.9	4.3
Kilis	−0.8	0.2	1.8	−4.4	2.4
Kocaeli	−1.4	−0.5	0.8	−4.0	2.0
Konya	−11.6	−9.6	−6.9	−15.7	4.8
Kütahya	−9.5	−7.8	−5.9	−14.9	3.1
Malatya	−8.4	−6.7	−4.5	−11.9	2.7
Manisa	−1.9	−0.8	0.8	−4.9	1.6
Mardin	−4.5	−3.2	−1.4	−8.3	2.9
Mersin	3.3	4.4	6.1	0.5	1.9
Muğla	−3.3	−2.1	−0.5	−5.9	1.7
Muş	−21.6	−18.9	−15.3	−26.8	5.0
Nevşehir	−11.6	−9.5	−7.2	−16.2	3.7
Niğde	−12.9	−10.6	−7.5	−17.7	4.2
Ordu	−0.4	0.5	1.8	−3.0	1.8
Rize	−0.2	0.7	1.8	−2.7	1.7
Samsun	−0.8	0.2	1.6	−3.2	1.9
Siirt	−5.7	−3.8	−1.6	−8.6	4.0
Sinop	0.2	1.1	2.2	−2.1	2.1
Sivas	−17.2	−14.4	−10.9	−21.8	3.4
Şanlıurfa	−1.6	−0.3	1.4	−4.6	2.4
Tekirdağ	−3.8	−2.6	−0.5	−7.0	2.3
Tokat	−8.5	−6.4	−4.0	−13.5	4.8
Trabzon	−0.1	0.9	2.2	−2.4	1.7
Tunceli	−12.5	−10.2	−7.3	−16.5	4.5
Uşak	−6.3	−4.9	−3.3	−10.0	1.9
Van	−13.4	−11.6	−9.0	−17.7	3.7
Yalova	−1.0	−0.1	1.2	−4.7	2.2
Yozgat	−13.2	−10.9	−8.4	−17.3	2.8
Zonguldak	−1.3	−0.4	0.7	−4.0	1.7

dard deviation (StdD) of the annual extreme minimum dry-bulb temperatures are given in Table 2 for 78 locations within Turkey. These data are based on the daily minimum temperature observations.

A contour map of the proposed heating design dry-bulb temperatures at 99.6% frequency level is depicted in Fig. 1. The figure clearly shows the non-uniformity of climate of Turkey. For locations near to sea costs, the heating design temperatures have higher values compared with

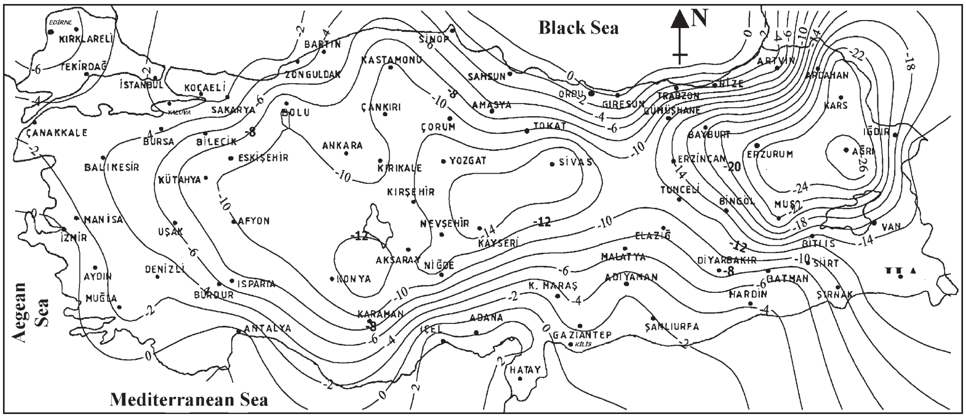

Fig. 1. The contour map of outdoor dry-bulb temperatures as winter design conditions at 99.6% frequency level for Turkey.

the eastern and the inner regions. The lower design temperatures appear in the eastern and north-eastern Turkey. The design dry-bulb temperature may fall below −26 °C in these regions. The contours are close to each other in the east, in the northeast and in the lower part of the inner region. This shows a rapid climate change in short distances due to mountainous nature of the landscape in these regions. Similar trends are obtained in the case of the frequency level of 99% (Fig. 2).

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 0 and 1869 m. A correlation between the heating design temperatures at two different frequency levels and elevation is evident from Fig. 3. The heating design temperature decreases with elevation. The scatter is mainly due to the effects of latitude and longitude. The combined influences on the heating design temperature at 99.6% frequency level 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

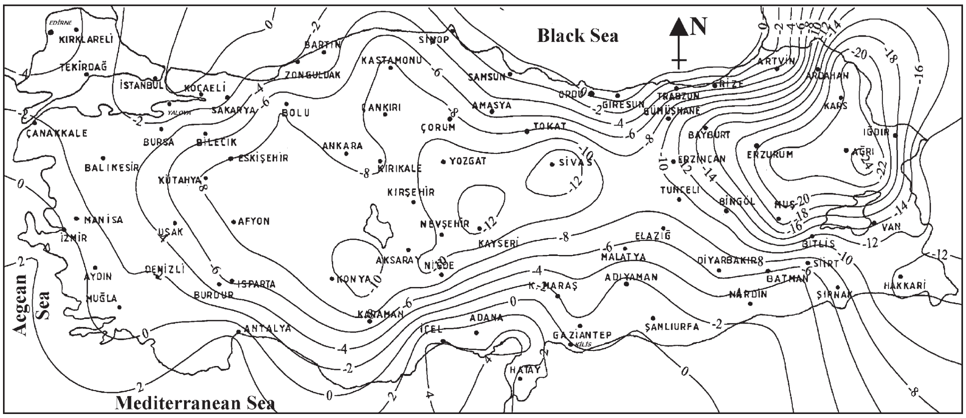

Fig. 2. The contour map of outdoor dry-bulb temperatures as winter design conditions at 99% frequency level for Turkey.

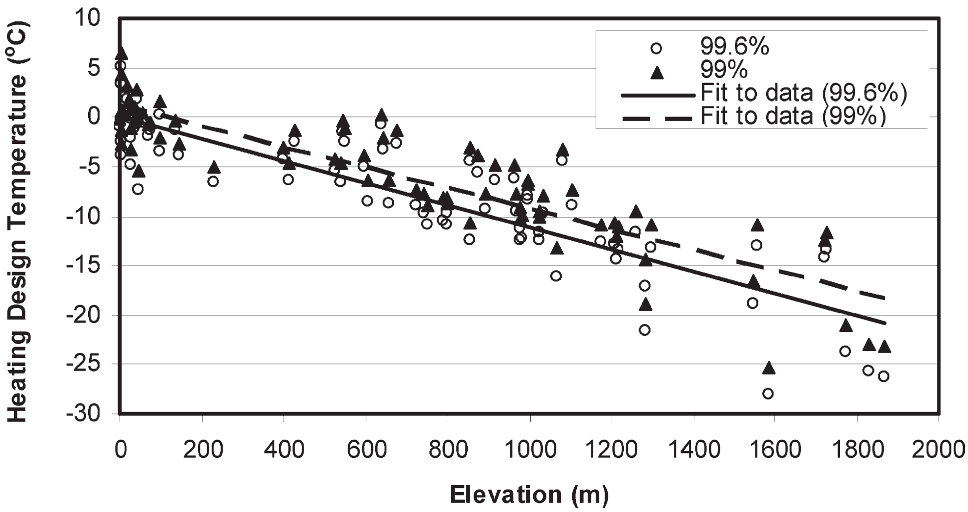

Fig. 3. Variation of heating design temperature with elevation for Turkey.

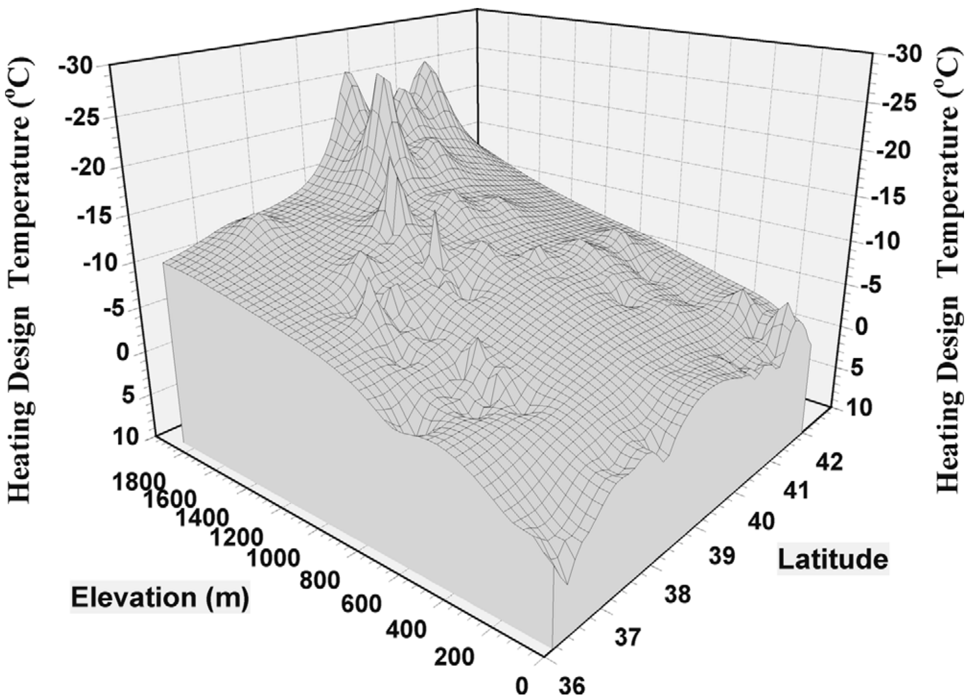

Fig. 4. Variation of heating design data at 99.6% frequency level with elevation and latitude for Turkey.

Fig. 4 that, heating design temperatures are generally lower when both elevation and latitude are high (east and northeast regions), although there are some non-uniformities. They are quite high at the opposite corner where both elevation and latitude are low (Aegean and Mediterranean regions). Fig. 5 shows the combined influences of elevation and longitude. The heating design temperatures are generally lower for the regions having a high elevation and a high longitude.

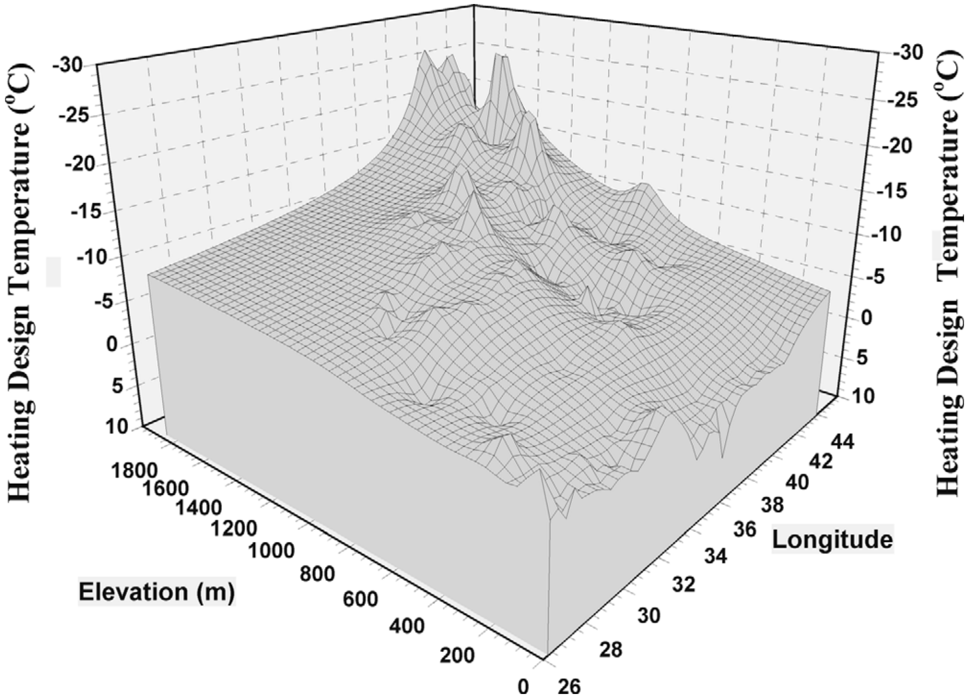

Fig. 5. Variation of heating design data at 99.6% frequency level with elevation and longitude for Turkey.

A comparison of the heating design data provided in this study with the data available in the literature for Turkey is given in Table 3. TTMD [18] provides heating design data obtained from hourly observations for four cities and ASHRAE [13] for eight Turkish locations. A good agreement is evident between the values given by TTMD [18] and this study both for design temperatures at two different frequency levels and the annual extreme minimum dry-bulb temperature.

Table 3
Comparison of design data recommended in this study with the data available in literature

Province	99.6% DB (°C)			99% DB (°C)			Min DB (°C)		
	This study	ASHRAE [13]	TTMD [18]	This study	ASHRAE [13]	TTMD [18]	This study	ASHRAE [13]	TTMD [18]
Adana	1.9	0.0	–	3.2	1.1	–	−1.2	−3.3	–
Ankara	−9.4	−16.7	−10.0	−7.8	−13.3	−7.9	−12.6	−18.9	−13.3
Erzurum	−26.2	−30.6	–	−23.1	−27.2	–	−31.9	−33.3	–
Eskişehir	−9.8	−11.1	–	−8.2	−8.9	–	−15.5	−14.4	–
İstanbul	−1.1	−3.3	−2.0	−0.3	−1.7	−0.5	−3.6	−6.1	−3.6
İzmir	1.0	−2.2	0.3	1.9	−0.6	1.6	−1.4	−4.4	−1.3
Malatya	−8.4	−12.2	–	−6.7	−8.9	–	−11.9	−16.1	–
Van	−13.4	−14.4	–	−11.6	−12.8	–	−17.7	−16.7	–
Antalya	1.8	–	1.4	2.8	–	2.5	−0.8	–	−0.2

The small differences between the values could be due to the use of weather data measurements taken during different years, period of the record, and the methods used in the process of the raw data. The design temperatures at two different frequency levels and the annual extreme minimum dry-bulb temperature given by ASHRAE [13] are significantly smaller than that of the others. For example, the design temperature for Ankara at 99.6% frequency level is −16.7 °C in ASHRAE [13]. The corresponding design temperature is −9.4 °C in this study and −10.0 °C in TTMD [18]. The difference is as big as 8 °C.

4. Analysis of current heating design conditions for Turkey

Heating load calculations in Turkey are generally performed using the weather design data provided by MMO [15]. Table 4 compares the current heating design data with the data obtained in this study. The annual frequency levels of the current heating design dry-bulb temperatures were calculated using the database (Table 1) on which this study is based. For example, the current heating design temperature is 0.0 °C for Adana. Analyzing the hourly dry-bulb temperature records between the years 1983 and 1998 (Table 1), the average NOH for which dry-bulb temperature is less than 0.0 °C was found to be 16 h. The corresponding annual frequency level was then calculated as 99.82%.

Annual frequency levels of the current heating design temperatures for the locations within Turkey are between 100% and 97.61% (Table 4). The current design conditions usually underestimate heating design temperature. For 59 of 78 locations, the frequency level of the current heating temperature is bigger than the maximum frequency level (99.6%) proposed by the 1997 ASHRAE Handbook—Fundamentals [13]. This means that the outside air dry-bulb temperature will be lower than the design temperature less than 35 h in a year. Moreover, those hours do not occur in sequence and thermal inertia of the building attenuates the peak loads if the building is not very light structured. Therefore, it can be concluded that the current space heating design temperatures are stringent and provide total protection. If the current heating design data are used, a space heating system will be oversized and will run at part-load conditions most of the time. Furthermore in practice, an average safety margin of 5–10% is added to the heating load based on the current design data. As a result of these, both initial and operational costs of the space heating system will be high. Being a developing country, Turkey should modify the current heating design data soon.

Only in 11 locations, the frequency level of the current heating design temperature is between the levels (between 99.6% and 99%) proposed by the 1997 ASHRAE Handbook—Fundamentals [13]. In eight locations, the risk factor of the current heating design temperature is too high. In these locations, the frequency level is lower than the minimum frequency level (99%) proposed by ASHRAE [13], and a heating system designed using the current design data may not be able to provide indoor design conditions for more than 88 h in a year.

Table 4 also shows the temperature difference between the current design data and the data recommended in this study. Temperature differences are generally negative, indicating that the current design temperatures are generally smaller than the data obtained in this study.

For critical heating applications, the design data corresponding to 99.6 percentile are used customarily. In this case, the specified indoor air-conditions will be provided by the heating system chosen almost all the hours through the heating season and most of the people living inside the heated space will feel thermally comfortable.

Table 4
The frequency level of current design conditions and comparison of them with the data obtained in this study

Location	Current			This study		Difference with current (°C)	
	DB (°C)	NOH (h)	FL (%)	FL (%) 99.6	99	Δ99.6	Δ99
Adana	0.0	16	99.82	1.9	3.2	−1.9	−3.2
Adapazarı	−3.0	31	99.65	−2.1	−1.1	−0.9	−1.9
Adıyaman	−9.0	0	100.00	−2.6	−1.3	−6.4	−7.7
Afyon	−12.0	22	99.75	−9.8	−8.0	−2.2	−4.0
Ağrı	−24.0	164	98.12	−28.0	−25.4	4.0	1.4
Aksaray	−15.0	15	99.83	−11.2	−9.1	−3.8	−5.9
Amasya	−12.0	6	99.93	−6.4	−4.7	−5.6	−7.3
Ankara	−12.0	19	99.78	−9.4	−7.8	−2.6	−4.2
Antakya	0.0	46	99.47	0.3	1.7	−0.3	−1.7
Antalya	3.0	129	98.52	1.8	2.8	1.2	0.2
Ardahan	−21.0	178	97.97	−25.7	−23.0	4.7	2.0
Artvin	−9.0	3	99.97	−5.1	−3.9	−3.9	−5.1
Aydın	−3.0	5	99.94	−0.5	0.5	−2.5	−3.5
Balıkesir	−3.0	90	98.97	−3.8	−2.6	0.8	−0.4
Bartın	−3.0	114	98.69	−4.8	−3.2	1.8	0.2
Batman	−9.0	29	99.66	−6.5	−4.7	−2.5	−4.3
Bayburt	−15.0	181	97.94	−18.9	−16.5	3.9	1.5
Bilecik	−9.0	5	99.94	−5.4	−4.2	−3.6	−4.8
Bingöl	−18.0	12	99.86	−12.7	−10.8	−5.3	−7.2
Bitlis	−15.0	23	99.74	−13.0	−10.8	−2.0	−4.2
Bolu	−15.0	7	99.92	−9.8	−7.8	−5.2	−7.2
Burdur	−9.0	6	99.93	−6.1	−4.9	−2.9	−4.1
Bursa	−6.0	12	99.87	−3.4	−2.0	−2.6	−4.0
Çanakkale	−3.0	37	99.58	−2.4	−1.3	−0.6	−1.7
Çankırı	−15.0	11	99.88	−10.8	−8.9	−4.2	−6.1
Çorum	−15.0	15	99.83	−10.9	−8.7	−4.1	−6.3
Denizli	−6.0	4	99.96	−2.4	−1.4	−3.6	−4.6
Diyarbakır	−9.0	47	99.46	−8.7	−6.4	−0.3	−2.6
Edirne	−9.0	21	99.76	−7.3	−5.5	−1.7	−3.5
Elazığ	−12.0	22	99.75	−8.9	−7.4	−3.1	−4.6
Erzincan	−18.0	20	99.77	−14.4	−12.1	−3.6	−5.9
Erzurum	−21.0	209	97.61	−26.2	−23.1	5.2	2.1
Eskişehir	−12.0	22	99.75	−9.8	−8.2	−2.2	−3.8
Gaziantep	−9.0	3	99.97	−4.5	−3.1	−4.5	−5.9
Giresun	−3.0	2	99.98	0.2	1.0	−3.2	−4.0
Gümüşhane	−12.0	84	99.04	−13.4	−11.1	1.4	−0.9
Hakkari	−24.0	0	100.00	−14.2	−12.4	−9.8	−11.6
Iğdır	−18.0	7	99.92	−12.5	−10.7	−5.5	−7.3
Isparta	−9.0	29	99.67	−7.9	−6.4	−1.1	−2.6

(*continued on next page*)

Table 4 (*continued*)

Location	Current			This study		Difference with current (°C)	
	DB (°C)	NOH (h)	FL (%)	FL (%) 99.6	99	Δ99.6	Δ99
İskenderun	3.0	11	99.87	5.2	6.4	−2.2	−3.4
İstanbul	−3.0	19	99.78	−1.1	−0.3	−1.9	−2.7
İzmir	0.0	30	99.66	1.0	1.9	−1.0	−1.9
K. Maraş	−9.0	0	100.00	−2.4	−1.2	−6.6	−7.8
Karaman	−12.0	75	99.14	−12.5	−10.1	0.5	−1.9
Kars	−27.0	12	99.87	−23.7	−21.0	−3.3	−6.0
Kastamonu	−12.0	25	99.72	−10.4	−8.2	−1.6	−3.8
Kayseri	−15.0	61	99.30	−16.2	−13.2	1.2	−1.8
Kilis	−6.0	1	99.99	−0.8	0.2	−5.2	−6.2
Kırıkkale	−12.0	19	99.79	−8.9	−7.4	−3.1	−4.6
Kırklareli	−9.0	14	99.84	−6.6	−5.0	−2.4	−4.0
Kırşehir	−12.0	60	99.32	−12.3	−9.9	0.3	−2.1
Kocaeli	−3.0	18	99.80	−1.4	−0.5	−1.6	−2.5
Konya	−12.0	58	99.34	−11.6	−9.6	−0.4	−2.4
Kütahya	−12.0	19	99.78	−9.5	−7.8	−2.5	−4.2
Malatya	−12.0	8	99.91	−8.4	−6.7	−3.6	−5.3
Manisa	−3.0	18	99.80	−1.9	−0.8	−1.1	−2.2
Mardin	−6.0	31	99.65	−4.5	−3.2	−1.5	−2.8
Mersin	3.0	51	99.42	3.3	4.4	−0.3	−1.4
Muğla	−3.0	64	99.27	−3.3	−2.1	0.3	−0.9
Muş	−18.0	178	97.96	−21.6	−18.9	3.6	0.9
Nevşehir	−15.0	15	99.83	−11.6	−9.5	−3.4	−5.5
Niğde	−15.0	31	99.64	−12.9	−10.6	−2.1	−4.4
Ordu	−3.0	6	99.93	−0.4	0.5	−2.6	−3.5
Rize	−3.0	5	99.94	−0.2	0.7	−2.8	−3.7
Samsun	−3.0	13	99.85	−0.8	0.2	−2.2	−3.2
Siirt	−9.0	19	99.78	−5.7	−3.8	−3.3	−5.2
Sinop	−3.0	7	99.92	0.2	1.1	−3.2	−4.1
Sivas	−18.0	38	99.56	−17.2	−14.4	−0.8	−3.6
Şanlıurfa	−6.0	2	99.97	−1.6	−0.3	−4.4	−5.7
Tekirdağ	−6.0	20	99.77	−3.8	−2.6	−2.2	−3.4
Tokat	−15.0	9	99.90	−8.5	−6.4	−6.5	−8.6
Trabzon	−3.0	7	99.93	−0.1	0.9	−2.9	−3.9
Tunceli	−18.0	9	99.89	−12.5	−10.2	−5.5	−7.8
Uşak	−9.0	12	99.87	−6.3	−4.9	−2.7	−4.1
Van	−15.0	32	99.63	−13.4	−11.6	−1.6	−3.4
Yalova	−3.0	12	99.86	−1.0	−0.1	−2.0	−2.9
Yozgat	−15.0	27	99.69	−13.2	−10.9	−1.8	−4.1
Zonguldak	−3.0	19	99.79	−1.3	−0.4	−1.7	−2.6

The difference between the outdoor heating design temperature for 99.6% frequency level ($T_{design,99.6\%}$) and the less stringent ones ($T_{design,99\%}$ and $T_{design,97.5\%}$) were calculated for all the provinces considered in this study using the data given in Table 2. The minimum, maximum and mean values of the differences are given in Table 5 in which $\Delta T_{outdoor} = T_{design,99\%} - T_{design,99.6\%}$ or $\Delta T_{outdoor} = T_{design,97.5\%} - T_{design,99.6\%}$. As can be seen from the table, if a less stringent design condition of 97.5% frequency level is chosen, the outdoor heating design temperature can be higher up to 6.5 °C than the 99.6% design temperature in some provinces.

Analyzing the heating load calculation method described in ASHRAE [13] reveals that heating load is directly proportional with the temperature difference between the indoor and outdoor design temperatures. Therefore, it would be expected that a change in outdoor temperature would affect the indoor temperature at the same magnitude if all other parameters are constant and the building is not very heavily structured, although a phase shift is possible. As a result of this, the indoor temperature would drop from the set value as the same magnitude as the outdoor design temperature ($\Delta T_{outdoor} \approx \Delta T_{indoor}$) during a limited NOH in a heating season, if a less stringent outdoor design temperature is chosen (Table 5).

ASHRAE [12] presents equations for predicted mean vote (PMV) that predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale. If all other weather parameters are constant, the following equation for the relation between PMV and a change in the indoor temperature (ΔT_{indoor}) can be derived from the equations given by ASHRAE:

$$\frac{\Delta(\mathrm{PMV})}{\Delta T_{\mathrm{indoor}}} \cong 0.246 \tag{1}$$

Using the equation proposed by Fanger [24], it is possible to calculate the predicted percent dissatisfied index (PPD), which predicts the number of thermally dissatisfied persons among a large group of people, from PMV. Based on the mean ΔT values, influence of choosing a less stringent outdoor design temperature on PMV and PPD can be seen from Table 5. If a less stringent design condition is chosen, the percent of dissatisfied people (PPD value) increases. It should be noted that, even at the design temperature for 99.6%, about 5% of the people are dissatisfied. The comfort zone specified in ASHRAE [12] is based on 10% dissatisfied. If outdoor design conditions are chosen at 99% frequency level, the percent of the dissatisfied people during the hours in which the outdoor temperature is less than the design temperature for 99% will increase to 8.7% that is still inside the comfort zone. Therefore, for ordinary heating applications, 99% design conditions can be used. However, 97.5% design conditions should be used with

Table 5
Influence of outdoor design temperatures on thermal comfort

Frequency level (%)	$\Delta T_{outdoor}$ ($\approx \Delta T_{indoor}$)			PMV_{mean}	PPD_{mean}
	Minimum	Maximum	Mean		
99.6	–	–	–	0	5
99	0.9	3.1	1.7	0.42	8.7
97.5	1.7	6.5	3.9	0.96	24.5

Table 6
Some properties of the sample buildings

Element	Building A (three floors)		Building B (four floors)	
	Area (m^2)	U-factor (W/m^2 K)	Area (m^2)	U-factor (W/m^2 K)
Outer walls	702.4	0.7	1345.2	0.83
Windows (double glazed)	330.6	3.02	346.5	2.73
Total floors	1555.1	0.88	2167.1	0.88
Roof (insulated)	610	0.38	548	0.38

caution. In this case, 24.5% of the people are expected to be dissatisfied during the hours in which the outdoor temperature is less than the design temperature for 97.5%.

To be able to evaluate the influence of the data presented in this paper, heating load calculations of two existing office buildings located in Adana (36.59 latitude and 35.18 longitude and 20 m altitude) were carried out using both the current outdoor design data and the new data presented in this paper. The indoor design dry-bulb temperature selected was 20 °C. Table 6 provides some details of the sample buildings and Table 7 summarizes the results. As can be seen from Table 7, if the heating loads of the sample buildings are calculated using the current design data, the heating loads will be larger approximately 10%, 19% and 32% than the ones obtained using the data presented in this study for the frequency levels of 99.6%, 99% and 97.5%, respectively. This means that the resulting heating equipment for the sample buildings will be oversized approximately 10–32% and this, in turn, will increase the initial equipment cost and operating cost.

Although calculation of increase in operating cost due to oversized equipment selection is very complex, it was estimated for the sample buildings following [1]. The estimation involves analysis of part-load operating conditions of the heating equipment selected. For this purpose, the annual energy consumptions of the sample buildings under part-load operation were calculated (Table 8) for a typical gas boiler with a rated efficiency of 80% using the bin data for Adana [22]. As can be seen from Table 8, the annual energy consumption will decrease between 4.4% and 12.8% if the less stringent design data (99.6, 99 and 97.5) are used instead of the current design data.

Table 7
Heating loads of the sample buildings

	Heating load (kW)				Difference (%)		
	Currently-used (0 °C)	99.6% (1.9 °C)	99% (3.2 °C)	97.5% (4.9 °C)	99.6%	99%	97.5%
Building A	69.36	62.75	58.35	52.62	10.53	18.87	31.85
Building B	86.05	77.31	71.35	63.52	11.31	20.60	35.48

Table 8
Annual energy consumptions of the sample buildings

	Annual energy consumption (MJ)				Energy saving (%)		
	Currently-used (0 °C)	99.6% (1.9 °C)	99% (3.2 °C)	97.5% (4.9 °C)	99.6%	99%	97.5%
Building A	835 837	799 184	769 875	737 122	4.4	7.9	11.8
Building B	927 279	883 565	856 707	808 601	4.7	7.6	12.8

5. Conclusion

In this study, new outdoor design conditions for heating were determined for 78 locations within Turkey according to the format recommended by the 1997 ASHRAE Handbook—Fundamentals [13]. Dry-bulb temperature corresponding to 99.6%, 99% and 97.5% annual cumulative frequency of occurrence, and the mean and StdD of the annual minimum dry-bulb temperatures were obtained for 78 weather stations. In these calculations, the hourly data measured during at least 13 years were used.

The heating design data obtained in this study were compared with the existing design data. For this purpose, the frequency levels of the existing design temperatures were calculated using the database on which this study was based. It was found that the current heating design temperatures are generally stringent and provide total protection. If the current heating design data are used, a heating system will be oversized and will run at part-load conditions most of the time. This will result in higher initial and operational costs of the heating system. Having limited energy resources, Turkey should use energy very carefully. Therefore, the existing heating design data should be modified by official bodies and designers should be able to choose different risk levels depending upon the project in hand.

6. Acknowledgments

The authors wish to express their gratitude to The State Meteorological Affairs General Directorate (DMİ) for providing meteorological data.

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