New outdoor cooling design data for Turkey

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Abstract

Outdoor design conditions are weather data for design purposes showing the characteristic features of the climate at a particular location. In this study, new outdoor design conditions for cooling 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 0.4, 1 and 2% annual cumulative frequency of occurrence and the mean coincident wet-bulb temperature, the mean and standard deviation of the annual maximum dry-bulb temperatures, and the mean daily ranges were obtained. In these calculations, the hourly data measured during at least 13 years were used. The current cooling design conditions used in the calculation of cooling load in Turkey were analysed based on their frequency levels. Comparison of the existing cooling design data with the data obtained in this study revealed that the current cooling design temperatures are generally stringent. © 2002 Elsevier Science Ltd. All rights reserved.

1. Introduction

Energy consumption in Turkey is increasing in steady parallel to its development. Total energy consumption in Turkey was approximately 79 million tons of oil equivalent in 2000 [1]. Since the country’s natural energy resources are insufficient, the amount of energy imported is also increasing and problems related to the energy deficit are on Turkey’s political agenda. This deficit exerts a considerable pressure on the economy. Therefore, every means to use energy in a much more rational way should be taken into consideration.

Heating, cooling, ventilating and air conditioning (HVAC) systems are major energy users in residential and commercial buildings. Energy consumption of buildings in Turkey is calculated
to be 25–30% of the total annual energy consumption according to the data given in Turkey’s Energy Yearbook [1]. Since the standard of living and utilization of HVAC systems are rising dramatically in Turkey, the amount of energy consumed for heating/cooling is also increasing and is estimated to be more than half of the total energy consumption in buildings [2–4].

Due to the intensive use of air-conditioning systems, electricity consumption is high, especially in summer and the shortage of electricity is a big problem for the industry and tourism sectors. Therefore, the government has introduced new ways, such as variable tariffs in electric consumption and more stringent insulation standards in buildings, to encourage the reduction of energy use in recent years.

The first step in the design of air-conditioning systems is 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 indoor conditions specified (comfort conditions) 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 the 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 if cold storage is not an available option [5].

The American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc. (ASHRAE) publishes climatic design conditions corresponding to different levels of probability for several locations in the United States and around the world [6,7]. They are the outdoor conditions that are exceeded during a specified percentage of time. The temperature and humidity conditions were provided at 1, 2.5 and 5 percentile frequency of occurrence during summer months (June through September) in the 1993 edition of the ASHRAE Handbook—Fundamentals [6]. These percentiles were replaced by annual percentile values of 0.4, 1 and 2 in the 1997 edition of ASHRAE Handbook—Fundamentals [7]. The change was made in order to provide design conditions representing the same probability of occurrence anywhere, regardless of the seasonal distribution of extreme temperature and humidity.

Climatic design data may include information on dry-bulb and wet-bulb temperatures, humidity, wind, rainfalls and solar data [8]. For cooling, the 1997 ASHRAE Handbook—Fundamentals [7] provides design values for dry-bulb temperature with mean coincident wet-bulb temperature, wet-bulb and dewpoint temperatures with mean coincident dry-bulb temperature and humidity ratio. The data are obtained from hourly observations and given for 0.4, 1 and 2% annual frequency of occurrence. Design values of dry-bulb and wet-bulb temperatures and dewpoint corresponding to various annual percentiles represent the value that is exceeded on average by the indicated percentage of the total number of hours in a year (8760 h). The 0.4, 1 and 2% values are exceeded on average 35, 88 and 175 h. Mean coincident values are the average of the indicated weather element occurring concurrently with the corresponding design value. In the 1997 ASHRAE Handbook—Fundamentals [7], the data for mean daily range 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 1.0 in cooling. More stringent percentiles are preferred for critical applications such as luxury hotels, hospitals, nurseries or some industrial applications. In this case 0.4 percentile can be used for cooling [5,9].

2. Cooling design data currently used in Turkey

Cooling 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. 115 [10] and by the Turkish Ministry of Reconstruction and Settlement in Technical Publication No. 9 [11]. The cooling design data given in these publications are not detailed for design evaluations and building energy analyses. They include only three weather elements: dry-bulb and wet-bulb temperatures, and mean daily temperature range. It is not clear whether the wet-bulb temperature given is ‘design wet-bulb temperature’ or ‘coincident wet-bulb temperature’.

The existing cooling design data are based on old weather observations 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 method used in determining the cooling design data from the observations is also controversial; the process of the data observed was performed with hand calculations and the criteria followed were not clear. There is no information about whether the design data were based on the average or the maximum of the observations over a certain period of time or some other methods were applied.

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 addition to all these shortcomings, cooling design conditions are not available for some locations. Design data for 55 locations are available in the publication of Ministry of Reconstruction and Settlement [11] and for 69 locations in the publication of Turkish Chamber of Mechanical Engineers [10].

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 complete yet. Some independent studies have been performed to expose climatic design conditions of Turkey in recent years. Turkish Society of HVAC & Sanitary Engineers (TTMD) published results of a project on weather data of Turkey in a report [12]. 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 [7]. The design data were obtained from long-term hourly measurements. Üner [13] presented weather data for 23 cities in Turkey according to the frequency levels used in the 1993
ASHRAE Handbook—Fundamentals [6]. The design conditions were determined using Typical Meteorological Year (TMY) data generated from seven years of hourly observations. The climatic design data given in the 1997 edition of ASHRAE Handbook—Fundamentals [7] are incomplete for Turkey; only eight Turkish localities are considered. A comprehensive analysis of the data for degree-days and temperature bins for 78 weather stations of Turkey was presented previously by the present authors [14,15]. In this paper, the results of the cooling design data studies are reported.

3. Recommended cooling design conditions

The weather design data being used in load calculations and energy analysis determines accuracy and characteristics of the results. 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 [6,8]. 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 [7]. 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 [16].

In this study, cooling 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 provinces 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 (DMI) in diskettes. Table 1 provides information for the weather stations and the periods of the data considered.

Table 2 shows recommended cooling design dry-bulb temperatures for 78 locations within Turkey. Three annual frequency levels (0.4, 1 and 2%) are offered for each location as suggested by the 1997 ASHRAE Handbook—Fundamentals [7]. As can be seen from the table, 0.4, 1 and 2% design dry-bulb temperatures for the locations within Turkey vary between 40.8 and 26.6 °C, 39.7 and 25.1 °C, and 38.5 and 23.5 °C, respectively.

Table 2 also shows mean coincident wet-bulb temperatures. Coincident wet-bulb temperature is the mean of all wet-bulb temperatures occurring at the design dry-bulb temperature. In Turkey, wet-bulb temperature and relative humidity are recorded only at 07:00, 14:00, and 21:00 h. Therefore, it is not possible to obtain coincident wet-bulb temperatures directly. The following approach was used for determining coincident wet-bulb temperature: variation of humidity ratio during a day is insignificant, especially in the summer. Humidity ratio does not fluctuate and it can be assumed to be constant during the day [17–19]. It was calculated at 07:00, 14:00, and 21:00 h using the measured relative humidity and dry-bulb temperatures at these hours. Analysis of the humidity ratio values obtained revealed that the differences between them are insignificant. Since,
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maximum dry-bulb temperatures usually occur between 12:00 and 16:00 h, the humidity ratio calculated at 14:00 h was used with hourly dry-bulb temperature observations to obtain mean coincident wet-bulb temperatures. The psychrometric equations given by the 1993 ASHRAE Handbook—Fundamentals [6] were used in the calculations.

The 1998 ASHRAE Handbook—Refrigeration, Systems and Applications [20] suggests that outdoor design temperatures for 0.4% should be used in refrigeration load calculations (cold storage design). However, in Turkey, monthly average dry-bulb temperature for the hottest month is used commonly in the design of cold stores, following [21]. These temperatures are given by the present authors in [22].

In this study, due to the lack of hourly wet-bulb temperature measurements, design wet-bulb temperatures were not calculated. However, in cooling load calculations, the use of design dry-bulb temperature with the design wet-bulb temperatures produce cooling loads significantly greater than the actual loads. Therefore, design dry-bulb temperatures should be used with the coincident wet-bulb temperatures in computing cooling loads for cooling applications, especially in air-conditioning. The design wet-bulb temperatures are used for evaporative cooling, cooling towers and fresh air ventilation system design [6,7].

The probability of occurrence of very extreme conditions can be required for the operational design of equipment to ensure continuous operation and serviceability [7]. The mean and standard deviation of the annual extreme maximum dry-bulb temperatures are given in Table 2 for 78 locations within Turkey. These data are based on the daily maximum and minimum temperature observations.

Another parameter needed in the calculation of thermal loads is the mean daily range of dry-bulb temperature, which is the mean of the difference between daily maximum and minimum temperatures for the hottest month. The last column of Table 2 presents the mean daily ranges. In Turkey, the maximum daily range of dry-bulb temperature is in Batman (18.2 °C), while Giresun and İskenderun have the minimum daily range (6.1 °C).

The envelopes that cover cooling design conditions calculated at 0.4, 1 and 2% frequency levels for 78 locations within Turkey are shown on a psychrometric chart in Fig. 1. Analysis of the chart reveals that Turkey has a non-uniform climate. The design data are scattered on the chart covering a broad area. Influence of different frequency levels can be seen from the figure. If more stringent design conditions (smaller frequency levels) are selected, the envelope shifts downward, indicating higher design dry-bulb temperatures. However, the picture is not so clear in the case of moisture content.

Counter maps of proposed cooling design dry-bulb temperatures and mean coincident wet-bulb temperatures at 0.4% frequency level is shown in Figs. 2 and 3, respectively. Maximum design dry-bulb temperatures occur in southeastern Turkey, whilst minimum temperatures are in the northeast. The design dry-bulb temperature may exceed 39 °C in the southeast where low humidity in the summer results in considerable solar radiation. The counters are close to each other around a line drawn from Siirt to Trabzon. This shows a rapid climate change in short distances due to mountainous nature of the landscape in these regions. As can be seen from Fig. 3, coincident wet-bulb temperatures do not change much. However, it is slightly higher for locations near the sea costs (around 22–23 °C), compared with the eastern and the inner regions (around 19–20 °C). Similar trends are obtained in the case of other two frequency levels (1 and 2%), although there are changes in the values of the parameters considered.
A comparison of the cooling design data provided in this study with the data available in the literature for Turkey is given in Table 3. TTMD [12] provides cooling design data obtained from hourly observations for four cities and ASHRAE [7] for eight Turkish locations. A good agreement is evident between the values given by ASHRAE [7], TTMD [12] and this study for design dry-bulb and coincident wet-bulb temperatures and maximum dry-bulb temperature. The small
differences between the design values could be due to the use of weather data measurements taken during different years, period of the record, and the methods used in processing the raw data. In the case of mean daily range, there are significant differences between the values given by TTMD [12], ASHRAE [7] and this study. The mean daily range of TTMD [12] is significantly smaller than that of the others.
Table 3
Comparison of the design data obtained in this study with the data available in literature

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4. Analysis of current cooling design conditions for Turkey

In Turkey, the weather data provided by MMO [10] and Ministry of Reconstruction and Settlement [11] are currently effective and used as outdoor design conditions in the calculation of cooling load. Table 4 compares the current cooling design data with the data obtained in this study. The annual frequency levels of the current cooling design dry-bulb temperatures were calculated using the database (Table 1) on which this study is based. For example, the current cooling design dry-bulb temperature is 38 °C for Adana. Analyzing the hourly dry-bulb temperature records between the years 1983 and 1998 (Table 1), the average number of hours (NOH) for which dry-bulb temperature exceeds this value was found to be 17 h. The corresponding annual frequency level was then calculated as 0.2%.

Annual frequency levels of the current cooling design dry-bulb temperatures for the locations within Turkey are between 0.0 and 3.09% (Table 4). The current design conditions usually overestimate cooling design dry-bulb temperature. For 69 of 78 locations, the frequency level of the current cooling design dry-bulb temperature is smaller than the minimum frequency level (0.4%) proposed by the 1997 ASHRAE Handbook—Fundamentals [7]. This means that the specified dry-bulb temperature will be exceeded on average 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 cooling design temperatures are stringent and provide total protection. If the current cooling design data are used, an air-conditioning 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 cooling load based on the current design data. As a result of these, both initial and operational costs of the air-conditioning system will be high. Being a developing country, Turkey should modify the current cooling design data soon.

Only in four locations, the frequency level of the current cooling design dry-bulb temperature is between the levels (between 0.4 and 2%) proposed by the 1997 ASHRAE Handbook—Fundamentals [7]. In five locations (Amasya, Bingöl, Muş, Nevşehir and Tokat) the risk factor of the current cooling design dry-bulb temperature is too high. In these locations, the frequency level is higher than the maximum frequency level (2%) proposed by ASHRAE [7] and, an air-conditioning system designed using the current design data may not be able to provide indoor design conditions for more than 175 h in a year.

The current design wet-bulb temperatures are also generally higher than the coincident wet-bulb temperatures found in this study. Only in Hakkari, Kahramanmaraş, Kars, Muş, Nevşehir, Ordu and Tokat, the current design wet-bulb temperature is lower than the coincident wet-bulb temperature for at least one frequency level. For the remaining 71 locations, the current design wet-bulb temperature is higher than the coincident wet-bulb temperature.

Table 4 also shows the temperature difference between the current design data and the data recommended in this study. Temperature differences, both for dry-bulb and wet-bulb, are generally positive, indicating that the current design temperatures are generally higher than the data obtained in this study.

The current design data and the design data obtained in this study are shown together on a psychrometric chart in Fig. 4 for 0.4% frequency level. A comparison of the envelopes that cover the current design data and the data found in this study reveals that there are significant differences
Table 4
The frequency level of the current design conditions and comparison of them with the data obtained in this study

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</tr>
</tbody>
</table>

* NA: Not available
Fig. 4. Comparison of the current cooling design conditions for Turkey with the conditions obtained in this study at 0.4% frequency level.

between the two. First of all, the current design data covers a broader area on the chart. Secondly, the bottom border of the envelope for the current design data is lower than that of the present data (higher design dry-bulb temperatures). Thirdly, the current design data sit further right on the chart (higher moisture contents). These mean that the current design data will produce larger sensible and latent cooling loads than that of the present design data. When less stringent fre-
quency levels (1 and 2%) are chosen, the envelope for the present design data found in this study shifts upward, indicating smaller design dry-bulb temperatures (Figs. 5 and 6). The differences between the two will be larger.

To be able to evaluate the influence of the data presented in this paper, cooling load calculations of an existing three-storey office building located in Adana (36.59 latitude and 35.18 longitude

Fig. 5. Comparison of the current cooling design conditions for Turkey with the conditions obtained in this study at 1% frequency level.
Fig. 6. Comparison of the current cooling design conditions for Turkey with the conditions obtained in this study at 2% frequency level.

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 conditions selected were 26 °C dry-bulb temperature and 50% relative humidity. Table 5 provides some details of the building and Table 6 summarizes the results. The comparison is given only for the hour at which the maximum load occurs, that is, 16:00 h. The sum of the cooling load components that depend on the outdoor design conditions
Table 5
Some properties of the sample building

<table>
<thead>
<tr>
<th>Element</th>
<th>Area (m²)</th>
<th>U-factor (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer walls</td>
<td>702.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Windows (double glazed)</td>
<td>330.6</td>
<td>3.02</td>
</tr>
<tr>
<td>Total floors</td>
<td>1555.1</td>
<td>0.88</td>
</tr>
<tr>
<td>Roof (insulated)</td>
<td>610</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Table 6
Cooling load of the sample building for 16:00 h

<table>
<thead>
<tr>
<th>Outdoor design data</th>
<th>Cooling load (kW)</th>
<th>Difference (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Q_{out}</td>
<td>Q_{const}</td>
</tr>
<tr>
<td>Currently-used</td>
<td>56.75</td>
<td>81.60</td>
</tr>
<tr>
<td>New (0.4%)</td>
<td>29.06</td>
<td>110.65</td>
</tr>
<tr>
<td>New (1%)</td>
<td>27.76</td>
<td>109.36</td>
</tr>
<tr>
<td>New (2%)</td>
<td>28.65</td>
<td>110.25</td>
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</table>

(Q_{out}) and that do not (Q_{const}) are given separately in Table 6, to be able to see clearly the influence of the outdoor design conditions on the cooling load.

As can be seen from Table 6, if the cooling load of the sample building is calculated using the current design data, the sum of the cooling load components that depend on the outdoor design conditions (Q_{out}) will be larger 95.3, 104.4 and 98.1% than the ones obtained using the data presented in this study for the frequency levels of 0.4, 1 and 2%, respectively. In the case of total cooling load (Q_{tot}), the difference is approximately 25%. This means that the resulting air-conditioning equipment for the sample building will be oversized approximately 25% and this, in turn, will increase the initial equipment cost and operating cost.

5. Conclusion

The existing data of outdoor design conditions for Turkey are old, not detailed and incomplete. In this study, new outdoor design conditions for cooling were determined for 78 locations within Turkey according to the format recommended by the 1997 ASHRAE Handbook—Fundamentals. Dry-bulb temperature corresponding to 0.4, 1 and 2% annual cumulative frequency of occurrence and the mean coincident wet-bulb temperature, the mean and standard deviation of the annual maximum dry-bulb temperatures, and the mean daily ranges were obtained for 78 weather stations. In these calculations, the hourly data measured during at least 13 years were used.

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

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References


