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The Generation of Typical Meteorological Year and Climatic Database of Turkey for the Energy Analysis of Buildings

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Abstract: For sustainable development, a reduction in energy demand is essential. This could be achieved through improving energy efficiency, effective energy conservation and management. The weather conditions of a given region are the most important consideration for the proper design of space AC (Air Conditioning) systems. In this study, the typical meteorological year and climatic database of Turkey for the energy analysis of buildings were generated by SQL (Structured Query Language) database programmimg language. The Finkelstein-Schafer statistical method was applied to analyze the hourly measured weather data of a 23-year period (1989-2012) and select representative TMMs (Typical Meteorological Months). The selection criteria were based on 13 meteorological parameters. These parameters are the daily mean, maximum and minimum values and ranges of temperature, dew-point and wind velocity and the daily values of global solar radiation. According to results of TMY (Typical Meteorological Year), climatic database of Turkey including daily or hourly climate variables was created in SQL data tables.

Key words: HVAC (Heating, Cooling, Ventilating and Air Conditioning), typical meteorological year, heating degree hour, cooling degree hour.

1. Introduction

The design of energy requirements and thermal comfort of buildings requires an updated and very accurate climatological and solar database. A climatological and solar database is very important for calculation of energy efficiency. The hourly amounts of about 10-13 meteorological parameters such as solar radiation, dry bulb temperature, relative humidity, wind speed, atmospheric pressure, etc. are usually needed for energy simulation. A representative database for a year duration is known as a TMY (Typical Meteorological Year), a term mainly used in the USA, or a TRY (Test Reference Year) or a DRY (Design Reference Year), terms mainly used in Europe. TMY, TRY or DRY consists of individual months of meteorological data sets selected from different years over the available data period, which is called a long-term measured data.

The primary objective of these methods is to select single years or single months from a multi-year database, preserving a statistical correspondence. This means that the occurrence and the persistence of the weather should be as similar as possible in the TMY to all available years. These different TMY methodologies have been developed with selection criteria based on solar radiation or on solar radiation together with other meteorological variables [1-5].

The literature review conducted in this work shows that one of the most common methodologies for generating a TMY is the one proposed by Hall, I. J., et al. [4] using the FS (Filkenstein-Schafer) statistical method. The other methodologies for generating TMY use a modified version of it. This method is an empirical approach that selects individual months from different recorded years. The selection criteria

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were based on 13 meteorological parameters. These parameters were the daily mean, maximum and minimum values and ranges of temperature, dew-point and wind velocity and the daily values of global solar radiation. However, four of 13 parameters were considered to be less effective, and therefore, are given zero weight. These variables are the ranges of daily dry-bulb temperature, wet-bulb temperature and wind speed, and daily minimum wind speed. Except for a few changes to the weighting criteria, which account for the relative importance of the solar radiation and meteorological elements, there has been no change in the original methodology which has been adopted by different countries [6-9].

2. Review on Typical Meteorological Year

A TMY consists of the months selected from the individual years and sorted to form a complete year. In the literature, there are many attempts to produce weather databases for different locations. The main objective of these methods is to select representative months from the multi-year database. This methodology has been adopted by different countries: for example, by date of publication, for Holmet Stations [10], Athens [11], Egypt [12], Ibadan, Nigeria [13], Hong Kong [14], Nicosia, Cyprus [15], Saudi Arabia [16], Malaysia [17] and Damascus, Syria [18].

Recently, ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) has started an international project to develop TMY data throughout the world, the IWEC (International Weather Year for Energy Calculations) [5]. Most recently, using the FS method, Kalogirou, S. A. [19] developed TMYs for the city of Nicosia, Cyprus. The study of Kalogirou, S. A. [19] included additional variables such as illuminance, visibility, precipitation and snow fall data. The objective of the present work is to select and implement TMY generating methodologies using long term hourly measured meteorological and global solar radiation data.

For Turkey, only three attempts have been found in the literature for the generation of TMY datasets [20-22]. Pusat, S., et al. [21] generated TMY for 8 cities. Ecevit, A., et al. [20] generated the TMY for Ankara. They stated that solar radiation data were unreliable in Turkey [20, 21]. Therefore, they evaluated the possibility of using the daily sunshine duration or the ratio of the daily sunshine duration to the day-length instead of daily global solar radiation, as the ninth parameter, in obtaining TMY [20, 21]. They used the data of Ankara covering the period 1979-1999 [20]. In the paper of Uner, M. and Ileri, A. [22], TMYs for 23 cities representing demographic and climatic conditions of Turkey were investigated by using actual recordings (1990-1996). They generated the typical meteorological database of 23 locations for building simulations and air-conditioning design [22]. The only deficiency in this study is the number of years used in the generation of TMY. There isn't enough study to generate TMY datasets for Turkish locations in the literature. TMY datasets was generated just for Ankara, and number of years used is not enough for TMY generation.

3. Problem Definition in Measurements and Data

In this study, the meteorological data was obtained from DMI (The State Meteorological Affairs General Directorate) and covered a period of 1989-2012 for 81 cities throughout the Turkey. Meteorological stations are located in city centers and there is generally only one station in each city. There were missing and invalid measurements in the data and they were filled as null. So, the data were checked for wrong entries and missing data. The missing and invalid measurements, accounting for approximately 0.30% of the whole database, were replaced with the values of preceding or subsequent days by interpolation. In the calculations, the year was excluded from the database if more than 15 days measurements were not available in a month.

4. TMY Selection Method

For each station, nine daily meteorological parameters: maximum air temperature (T_{max}), minimum air temperature (T_{min}), mean air temperature (T_{mean}), maximum air relative humidity (RH_{max}), minimum air relative humidity (RH_{min}), mean air relative humidity (RH_{mean}), maximum wind speed (W_{max}), mean wind speed (W_{mean}) and global solar radiation (G) were employed to create an indicator for selecting TMMs (Typical Meteorological Months). The weighting factors used are selected according to existing experience on the influence of the meteorological parameters used on the simulated application. Three sets of weighting factors, all oriented towards energy simulation applications were used, as shown in Table 1.

In the first step, for a given parameter xi, a long-term CDF_m (Cumulative Distribution Function) of xi for each month covering the period of 23-year (1989-2012) was created.

A short-term $CDF_{y,m}$ of xi for year y and month m was also generated. FS statistics are the most common methodology for creating CDF functions while generating typical weather data. This method is an empirical methodology for selecting individual months from different years over the available period. According to FS statistics [23], if a number, n, of observations of a variable X is available and has been sorted into an increasing order X_1, X_2,…, Xn, the CDF of this variable is given by a function Sn(X) which is defined as:

$$S_n(\chi) = \begin{cases} 0 & \text{for } X < X_1 \\ (k - 0.5)/n & \text{for } X_\lambda < \chi < X_{\lambda+1} \\ 1 & \text{for } X > X_n \end{cases} \quad (1)$$

The FS by which comparison between the long-term CDF of each month and the CDF for each individual year of the month was done is given by Eq. (2):

$$FS_{Xi}(y,m) = \frac{1}{N_d}\sum_{j=1}^{N_d}\left| CDF_m(X_{ij}) - CDF_{y,m}(X_{i,j}) \right| \quad (2)$$

where $FS_{Xi}(y,m)$ is the FS statistics of the parameter X_i for year y and month m; j is interval number of data and N_d is the total number of data intervals.

In the second step, the weighted sums of FS_{Xi} were computed by:

$$WS(y,m) = \frac{1}{N_P}\sum_{i=1}^{N_p} WF_{X_i} . FS_{x_i}(y,m) \quad (3)$$

$$\sum_{i=1}^{N_p} WF_{x_i} = 1 \quad (4)$$

where WF_{x_i} is the weighting factors for the FS of the variable X_i and N_p is the total number of the parameters. In this case, the weighting factor for T_{max}, T_{min}, Rh_{max} and RH_{min} is 0.04; for T_{mean}, RH_{mean}, W_{max} and W_{mean} is 0.08 and for global radiation is 0.5. All individual months are ranked in ascending order of WS (Weighted Sums) values [23].

Table 1 Weighting factors for TMY type.

Present (FS)				Weather index
[23]	[24]	[17]	[25, 26]	
1/24	5/100	5/100	1/20	Maximum dry bulb temperature
1/24	5/100	5/100	1/20	Minimum dry bulb temperature
2/24	30/100	30/100	2/20	Mean dry bulb temperature
1/24		2.5/100	1/20	Maximum dew point temperature
1/24		2.5/100	1/20	Minimum dew point temperature
2/24		5/100	1/20	Mean dew point temperature
2/24	5/100	5/100	1/20	Maximum wind speed
2/24	5/100	5/100	1/20	Mean wind speed
12/24	40/100	40/100	5/20	Total horizontal solar radiation
			5/20	Direct solar radiation
	10/100			Relative humidity

Table 2 TMY values for each city of Turkey.

City code	City name	Typical meteorological years											
		Months (1-12)											
		1	2	3	4	5	6	7	8	9	10	11	12
17020	Bartin	2004	2005	2004	2005	2004	2008	2003	1989	2003	2005	2004	2005
17022	Zonguldak	2004	2008	2012	1990	1997	2004	2005	1989	2012	1989	2012	1994
17026	Sinop	2004	1990	2011	1990	2005	2002	1990	1990	2008	1989	2007	1989
17030	Samsun	1995	1998	1994	2001	1995	1998	1995	1999	1989	1997	1995	1997
17033	Ordu	2012	1990	2004	1995	2009	1992	2009	1991	2007	1997	2006	1993
17034	Giresun	2009	1989	2009	1990	2012	1990	2012	1989	2009	1990	2009	1990
17037	Trabzon	2004	1989	2004	1990	2004	1989	2003	1993	2004	1989	2004	1989
17040	Rize	2009	1990	2010	1990	2010	1991	2009	1995	2009	1990	2009	1990
17045	Artvin	2011	1990	2007	1990	2010	1991	2008	1995	1995	1989	2012	1991
17046	Ardahan	1998	2002	1994	1990	2011	2009	2011	1992	2009	1989	2009	2003
17050	Edirne	2011	1994	2011	1992	2011	2002	2010	2010	2010	1994	2009	1993
17052	Kirklareli	2008	1989	2011	1990	2011	1990	2011	1989	2011	1989	2011	1989
17056	Tekirdag	2011	1990	2011	1990	2011	1993	2010	1998	2009	1989	2008	1989
17062	Istanbul	2006	1990	2006	1990	2005	1990	1991	1994	2007	1991	2001	1990
17066	Kocaeli	2009	1990	2011	1990	2009	1990	2010	2007	2007	1990	2012	1990
17069	Sakarya	2011	1990	2012	1990	2008	1992	1998	2012	2006	1990	2012	1990
17070	Bolu	2009	1990	2009	1992	2011	1993	2000	1994	1998	1990	2012	1990
17072	Duzce	2009	1989	2011	1990	2008	1993	2009	1993	2006	1990	2009	1990
17074	Kastamonu	2012	1990	2011	1992	2012	2000	2003	2003	2010	1990	2009	1989
17078	Karabuk	2010	2008	2011	2000	2011	2009	2010	2010	2000	2000	2008	2007
17080	Cankiri	2009	1990	2005	1990	1990	1990	2002	1991	1991	1990	2009	1990
17084	Corum	2009	1990	2006	1990	2010	1990	1999	1989	2003	1989	2008	1989
17085	Amasya	2004	1994	2010	1990	2005	1990	2008	1994	2010	1989	2008	1989
17086	Tokat	2011	1989	2011	2006	2009	1989	2010	1989	2009	1990	2009	1990
17088	Gumushane	2007	2004	1991	1990	2010	1990	2001	1989	2008	1989	2009	1990
17089	Bayburt	2012	1990	2011	1990	2011	1990	2011	1991	2006	1990	2008	1990
17090	Sivas	2011	1989	2007	1992	2010	1993	2008	2008	2006	1990	2011	1995
17094	Erzincan	2011	2003	2010	1995	2010	1989	1998	1989	2009	1992	2009	1997
17096	Erzurum	2006	1995	2007	1990	2005	1990	2006	2005	2006	1990	2007	1997
17097	Kars	2000	1992	2007	1993	2009	1994	2008	1991	2000	1992	2003	1991
17099	Agri	2009	1989	2009	2000	2010	2009	1996	1994	2009	1990	2009	2003
17100	Igdir	2009	1990	2009	1990	2009	1990	2009	2003	2005	1989	2009	1990
17112	Canakkale	2011	1991	2011	1992	2011	2010	1994	2008	2010	1990	2012	1989
17116	Bursa	2011	1991	2011	1990	2005	1990	1999	1989	2009	1990	2009	1990
17119	Yalova	2011	1990	2011	1990	2011	1990	2011	1994	2011	1990	2009	1994
17120	Bilecik	2011	1990	2011	1990	2011	1990	2011	1994	2011	1990	2009	1994
17126	Eskisehir	2012	2012	2011	2010	2009	2007	2011	2007	2011	2007	2008	2012
17130	Ankara	2007	1990	2007	1992	2006	2011	2004	2000	2004	1990	2008	1990
17135	Kirikkale	2009	1989	2007	1990	2010	1989	2008	1989	2006	1990	2012	1990
17140	Yozgat	2012	1990	2010	1991	2009	1990	2011	1989	2008	1990	2012	1989
17152	Balikesir	1993	1990	1995	1990	1990	1991	1994	1996	1995	1990	1995	1989

(Table 2 continued)

City code	City name	Typical meteorological years											
		Months (1-12)											
		1	2	3	4	5	6	7	8	9	10	11	12
17155	Kutahya	2008	1990	2007	1998	2009	1995	1999	1995	2006	1989	2012	1990
17160	Kirsehir	2009	1990	1991	1990	2005	1989	1999	1992	1998	1990	2009	1989
17165	Tunceli	2009	1991	2009	1991	2007	1990	2001	1998	2008	2007	2009	1991
17172	Van	2006	1991	2007	1993	2007	1994	1996	1999	2006	1990	2008	1990
17186	Manisa	2011	1991	2012	1990	2006	1991	2005	1993	1995	1991	2005	1989
17188	Usak	2011	2006	1999	2004	2012	1996	2006	1999	2011	1990	2012	1989
17190	Afyonkarahisar	2004	1990	2011	2005	2009	1993	2010	1989	2000	1990	2011	1989
17192	Aksaray	2011	1993	2008	1990	2010	2007	2007	2007	2009	1990	2009	1989
17193	Nevsehir	1996	1989	2011	1990	2011	1989	2011	1989	1998	1989	2009	1989
17196	Kayseri	2009	1989	2009	1992	2009	1989	2006	1996	2009	1990	2009	1990
17199	Malatya	2012	1994	2011	1993	2012	1995	2006	1995	2009	1992	2008	1993
17201	Elazig	2009	1991	2011	1990	2009	1991	2004	1998	1994	1990	2009	1993
17203	Bingol	2011	1991	2009	1990	2010	1995	2004	2002	2008	1990	2009	1991
17204	Mus	2006	1993	2009	1990	2010	1991	2006	2004	2008	1991	2008	1991
17207	Bitlis	2009	1993	2009	2004	2008	1997	2006	2000	2008	1991	2009	1997
17210	Siirt	2009	1991	2011	1996	2010	1995	2009	2005	2005	1990	2007	2000
17220	Izmir	2011	1990	2012	1990	2009	2012	1996	2011	1990	1990	2010	1989
17234	Aydin	2007	1991	2011	1990	2009	2009	2000	1992	2011	1991	2012	1997
17237	Denizli	2011	1990	2011	1990	2010	1997	1998	1994	2011	1998	2007	1995
17238	Burdur	2011	1990	2011	1990	2009	1993	2006	2006	2006	1990	2012	1990
17240	Isparta	2006	1990	2005	1999	2012	2010	2002	2007	1993	2007	2012	1990
17244	Konya	2004	1990	1994	1991	1991	1995	1991	2002	2002	1997	2001	1997
17246	Karaman	2009	1990	2011	1990	2009	1991	2007	1996	2006	1990	2009	2003
17250	Nigde	1996	1989	2005	1990	2010	1991	1999	1996	2009	1989	2009	1997
17255	Kahramanmaras	2011	1991	2007	1991	2008	2007	1998	2008	2006	1991	2012	1997
17261	Gaziantep	2006	1991	2011	1991	2009	1995	2004	1999	2006	1994	2008	1993
17262	Kilis	2006	1990	1991	1991	2005	2005	1998	1992	2006	1991	2012	1993
17265	Adiyaman	2009	1990	2011	1991	2004	2002	1990	1990	2001	1998	2009	1998
17270	Sanliurfa	2005	1990	2010	1991	2010	1995	2009	1991	2007	1990	2005	2005
17275	Mardin	2006	1990	2011	1991	2011	1994	2011	1989	2011	1990	2009	1989
17280	Diyarbakir	2009	1990	2011	1991	2010	2001	2006	2001	2008	1990	2009	1999
17282	Batman	2009	1990	2011	1990	2011	2010	2007	2007	2011	1990	2009	1990
17285	Hakkari	2011	1990	2012	1993	2010	1989	2011	1989	2010	1989	2009	1990
17287	Sirnak	2011	2000	2011	2003	2011	2002	2007	2001	2011	1991	2009	1999
17292	Mugla	2011	1990	2011	2001	2012	2002	1996	2000	2010	1991	2009	1989
17300	Antalya	1995	2006	1998	2005	1998	2006	1999	2002	1998	2006	1997	2004
17340	Mersin	2009	2004	2009	1991	2009	1993	2007	1999	2009	1990	2009	1990
17351	Adana	2006	1990	2011	1990	2010	1993	2010	1996	2009	1989	2007	1989
17355	Osmaniye	2012	1990	2012	1990	2012	1989	2012	1992	1997	1990	1997	1990
17372	Hatay	2006	1991	2007	2005	2009	2003	2007	2007	2007	1991	2007	1989

5. Results

The calculated TMY values for each city of Turkey are on Table 2.

6. Conclusions

Energy consumption in Turkey is increasing continuously parallel to its development. Because of its limited energy resources, Turkey is heavily dependent on imported oil and gas. Therefore, every means to use energy in a much more rational way should be taken into consideration. HVAC (Heating, Cooling, Ventilating and Air Conditioning) systems are major energy users in residential and commercial buildings.

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 the 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. It is very important to represent the climate of a location. In this study, TMY for 81 cities of Turkey was calculated. It will be very useful source for building simulations to estimate the annual energy consumptions of buildings.

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