Journal of Civil Engineering and Architecture 9 (2015) 1252-1260
doi: 10.17265/1934-7359/2015.10.013

Degree-Day Analysis for Different Locations in Turkey and Effect on Architecture Conceptualism

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Abstract: Energy analysis plays an important role in developing an optimum and cost effective design of HVAC (heating, ventilating and air conditioning) system for an architecture. Although there are different energy analysis methods, which vary in complexity, the degree-day methods are the simplest methods and well-established tools. Energy consumption increases as the number of heating and cooling degree days increases and falls as the number of heating and cooling degree days falls. The value of degree days is a measure which can be used to indicate the demand for energy to heat or cool buildings and spaces. The monthly or annual cooling and heating requirements of specific buildings in different locations can be estimated by means of the degree-day concept. The base temperature is the outdoor temperature below or above which heating or cooling is needed. In this study, the degree days for the period of 2008~2012 were calculated for Turkey (10 cities) and also to develop new software for easy analysis about cooling degree days. This paper can be helpful for designing facade and also contribute to degree-day analyses.

Key words: Cooling degree days, Turkish architecture, building energy conservation.

1. Introduction

Degree days are well known as an important climatic indicator which can be used in the HVAC (heating, ventilating and air conditioning) industry to estimate the demand for heating and cooling services. The degree days are the summation of temperature differences between average outdoor air temperature and base temperature, which is referred as the outdoor temperature at which heating or cooling systems do not need to be run. When outdoor temperature is below the base temperature, the heating system needs to provide heat. On the other architectural design, principles affect to design materials, building set and so on. The literature survey confirms that degree days affected to design principles, which are still a great subject of study. By using degree-day method, climate in the cities of Turkey was compared and analyzed during the period of 2008~2014. Ten different locations were taken under consideration.

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Mourshed [1] developed an equation for calculating degree days from low-resolution temperature days by exploring the relationship between degree days and annual mean temperature of 5,511 locations around the world. Using the multiple non-linear regression, Papakostas et al. [2] calculated cooling degree days in two main cities of Greece (Athens and Thessaloniki) from 1983 to 2002. Christenson et al. [3] estimated heating degree days and cooling degree days for four representative Swiss locations during the period of 1901~2003. Baumert and Selman [4] summarized the methodologies used by the World Resources Institute for calculating annual HDD (heating degree days) and CDD (cooling degree days) for 171 countries. Buyukalaca et al. [5] calculated HDD and CDD for different base temperatures in Turkey.

Jiang et al. [6] used to detect annual and seasonal variations of heating and cooling degree days in Xinjiang, China, by using the Mann-Kendall trend test and linear regression techniques during the period of 1959~2004. Roltsch et al. [7] used seven methods of estimating degree days at each of nine locations

during two years in California and compared to degree-day values calculated by hourly summation.

2. Study Area

Ten cities are selected, which are Isparta, Burdur, Antalya, Trabzon, Giresun, Erzurum, Diyarbakır, İzmir, Ankara, İstanbu. These cities are very important and they have high social impact for Turkey.

Turkey climate can be described as a temperate climate with relatively cold winters and warm summers in Mediterranean hot summers, which is greatly influenced by sea-air currents from the west, cold polar air from Balkans, as well as warmer, sub-tropical air from the southeast. Fig. 1 shows annual temperature analysis in Turkey.

In winter, polar-continental fronts often dominate, bringing cold and frosty weather with temperatures far below zero and sometimes heavy snowfall. The late summer and autumn months are often influenced by dry and continental air mass that brings plenty of warm days. The average air temperatures amount to 6 °C~8.5 °C for a year and the annual rainfall is 500 mm~700 mm, of which snow constitutes only 5%~20%. Heating season somewhere lasts from six to eight months. The heating season starts when indoor temperature is 16 °C at least 10 days. Moreover, during hot summers, there is a need to provide cooling.

3. Methodology

To estimate cooling degree days, it is required to measure maximum and minimum outside air temperature (T_{max} and T_{min}). Base temperature (T_b) is set by user and T_{base} is outdoor temperature at which heating or cooling systems do not need to be run. There are four possible relationships between the base temperature and diurnal temperature variation, resulting in four different scenarios. Depending on these four scenarios, daily CDD is calculated from the base temperature T_b, daily minimum and maximum temperatures, respectively, using the Eq. (1) below:

$$CDD_d = \begin{cases} 0.5(T_{max}+T_{min})-T_b & T_{min} \geq T_b \\ 0.5(T_{max}-T_b)-0.25(T_b-T_{min}) & T_{min} > T_b \text{ and } (T_{max}-T_b) > (T_b-T_{min}) \\ 0.25(T_{max}-T_b) & T_{min} < T_b \text{ and } (T_{max}-T_b) < (T_b-T_{min}) \\ 0 & T_{max} \leq T_b \end{cases} \quad (1)$$

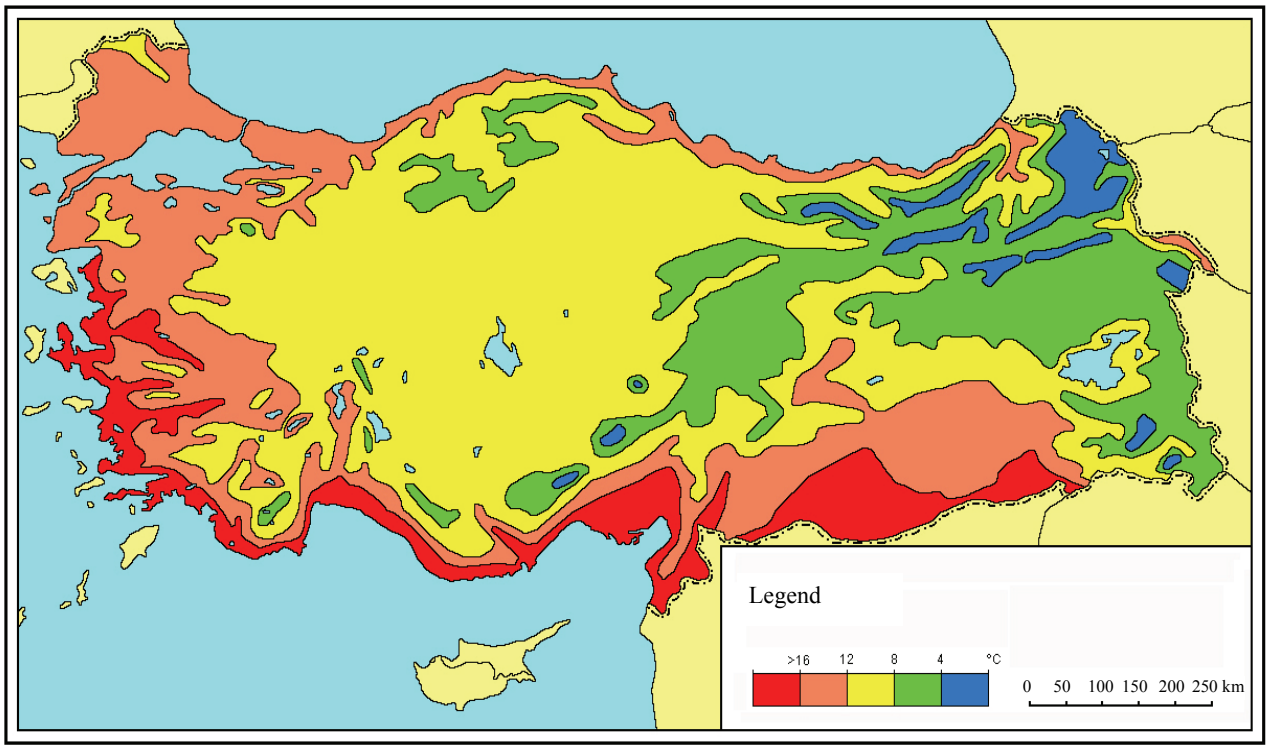

Fig. 1 Annual temperature in Turkey.

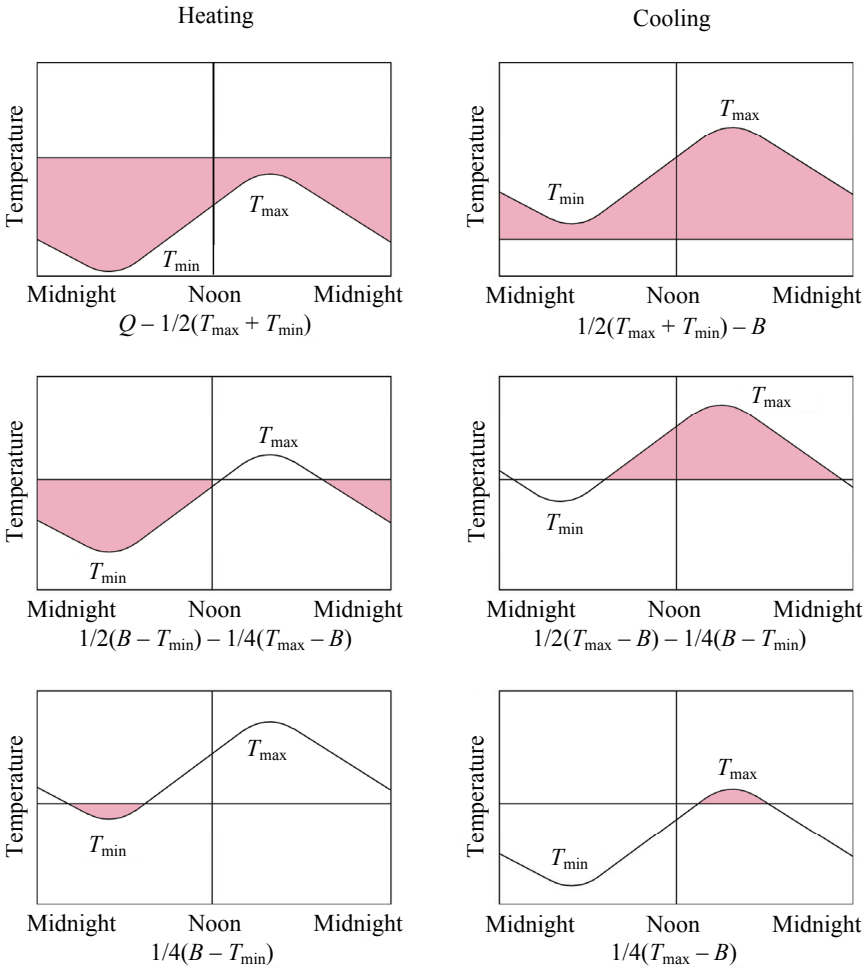

Fig. 2 Degree days formula [8].

Daily CDD can be calculated using the same parameters. Fig. 2 shows the graphical representation of formula used to calculate heating and cooling degree days.

3. Obtained Results

3.1 Comparison of Cooling Degree Days in Turkish Cities

Cooling degree days for different locations in Turkey are set for different base temperatures from 18°C to 26°C.

3.2 Calculation

3.2.1 Fabric Loss

The *U*-factor/*U*-value is the overall heat transfer coefficient that describes how well a building element conducts heat or the rate of transfer of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure. The elements are commonly assemblies of many layers of components such as those that make up walls, floors, roofs, etc. It measures the rate of heat transfer through a building element over a given area under standardized conditions. The *U*-value of a material in a structure is the rate at which heat will pass through a given area for a given temperature difference. It is a property of the material in a structure and is usually measured in the unit of $W/m^2/°C$.

Cooling energy loss = 1,000 × 24 × CDD Annual × *U* (units in $kWh/year/m^2$)

CDD can be calculated in a manner analogous to that for heating degree days:

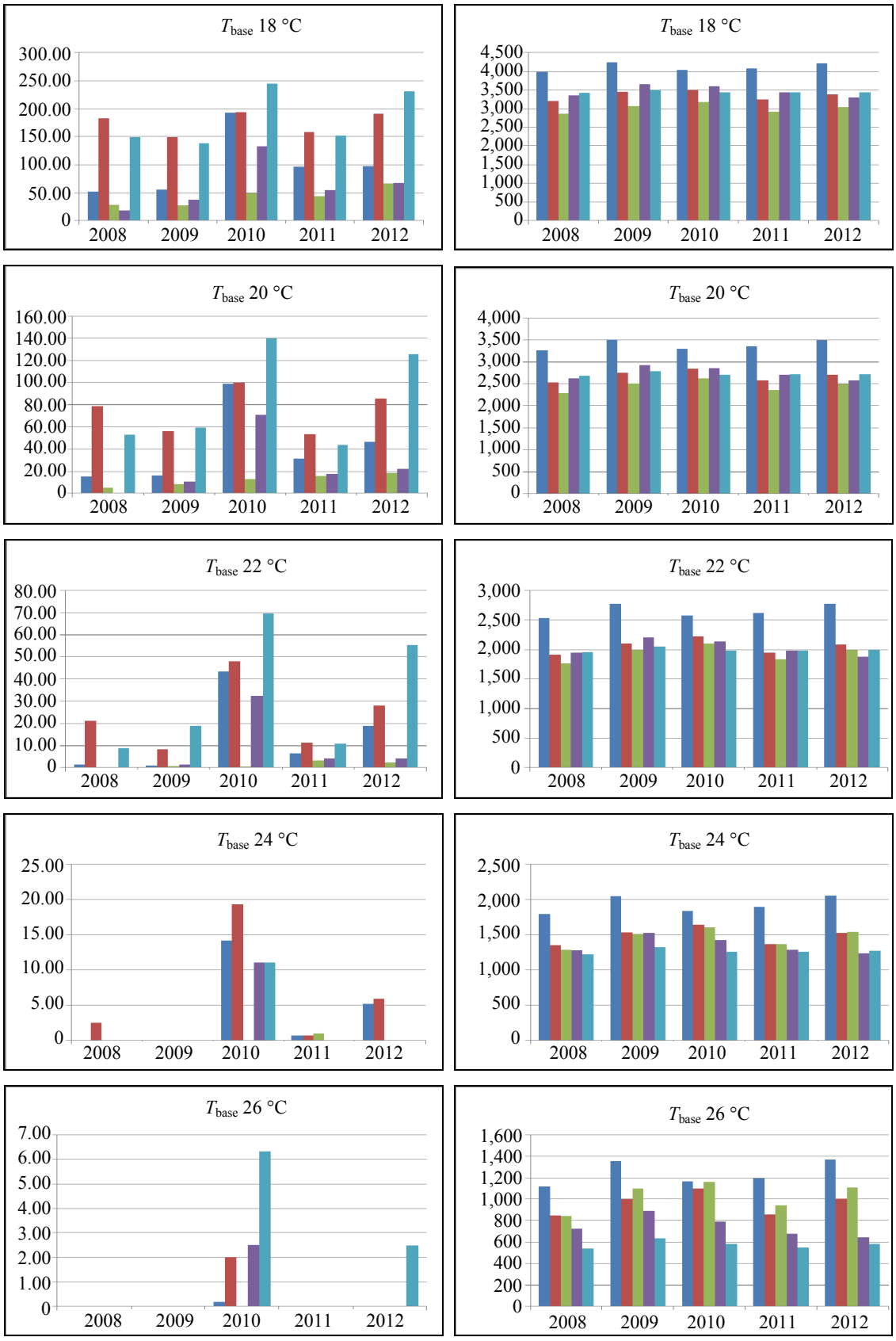

Fig. 3 Different cities' temperatures in different years.

$$\text{CDD} = (1 \text{ day}) \Sigma_{\text{Days}} (T_m - T_b)$$

The plus signs above the parentheses of and indicates that only positive values can be counted.

The specification of walls and roofs in India and their *U*-values should be taken into consideration.

Base temperature = 18 °C, then annual cooling degree days = 4,078.36 kWh/year/m^2.

If minimum U-value of 0.8W/m^2/°C is considered for walls, cooling energy loss is 78.3 kWh/year/m^2.

If maximum of *U*-value of 4.12 W/°C for walls is considered, cooling energy loss is 403.3 kWh/year/m^2.

Number of units saved per year per square meter is 325. Percentage saving in energy is 80.6%.

The energy loss calculation and some in-depth CDD analysis for Turkey are shown in Table 1.

Table 1 Energy loss calculations for the ten cities in Turkey (CDD).

Year	T_{base} (°C)	Antalya				Isparta			
		CDD	Energy loss with U = 0.8	Energy loss with U = 4.12	Energy saved (kWh/year/m^2)	CDD	Energy loss with U = 0.8	Energy loss with U = 4.12	Energy saved (kWh/year/m^2)
2008	18	2,864.17	54.99	82.48	27.50	18.00	0.35	0.51	0.17
	20	2,296.56	44.09	66.14	22.05	0.00	0.00	0.00	0.00
	22	1,770.78	34.00	50.99	17.00	0.00	0.00	0.00	0.00
	24	1,284.89	24.67	37.00	12.33	0.00	0.00	0.00	0.00
	26	846.92	16.26	24.39	8.13	0.00	0.00	0.00	0.00
2009	18	3,072.78	59.00	88.49	29.50	37.50	0.72	1.08	0.36
	20	2,514.11	48.27	72.40	24.14	10.50	0.20	0.30	0.10
	22	1,988.72	38.18	57.27	19.09	0.00	0.00	0.00	0.00
	24	1,513.67	29.06	43.59	14.53	0.00	0.00	0.00	0.00
	26	1,099.25	21.11	31.65	10.55	0.00	0.00	0.00	0.00
2010	18	3,180.53	61.07	91.59	30.53	132.50	2.54	3.81	1.27
	20	2,624.64	50.39	75.58	25.20	0.00	0.00	0.00	0.00
	22	2,093.03	40.19	60.27	20.09	0.00	0.00	0.00	0.00
	24	1,603.53	30.79	46.18	13.39	0.00	0.00	0.00	0.00
	26	1,159.81	22.27	33.40	11.13	0.00	0.00	0.00	0.00
2011	18	2,912.03	55.91	83.86	27.96	54.50	1.05	1.56	0.52
	20	2,354.67	45.21	67.81	22.60	0.00	0.00	0.00	0.00
	22	1,839.78	35.32	52.98	17.66	0.00	0.00	0.00	0.00
	24	1,370.36	26.31	39.46	13.16	0.00	0.00	0.00	0.00
	26	940.83	18.06	27.09	9.03	0.00	0.00	0.00	0.00
2012	18	3,045.86	58.48	87.72	29.24	67.50	1.30	1.94	0.65
	20	2,496.28	47.93	71.89	23.96	22.00	0.42	0.63	0.21
	22	1,995.08	38.31	57.45	19.15	0.00	0.00	0.00	0.00
	24	1,541.67	29.60	44.40	14.80	0.00	0.00	0.00	0.00
	26	1,110.06	21.31	31.96	10.66	0.00	0.00	0.00	0.00
Year	T_{base} (°C)	Burdur				Trabzon			
		CDD	Energy loss with U = 0.8	Energy loss with U = 4.12	Energy saved (kWh/year/m^2)	CDD	Energy loss with U = 0.8	Energy loss with U = 4.12	Energy saved (kWh/year/m^2)
2008	18	52.44	1.01	1.51	0.50	183.11	3.52	5.27	1.76
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Table 1 continued)

Year	T_{base} (°C)	Burdur				Trabzon			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2009	18	56.25	1.08	1.62	0.54	149.00	2.86	4.29	1.43
	20	16.42	0.32	0.47	0.16	56.03	1.08	1.61	0.54
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2010	18	192.28	3.69	5.53	1.85	193.53	3.72	5.57	1.86
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2011	18	96.61	1.85	2.78	0.93	158.89	3.05	4.57	1.53
	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2012	18	97.50	1.87	2.08	0.94	191.58	3.68	5.51	1.84
	20	46.47	0.89	1.33	0.45	85.78	1.65	2.47	0.82
	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Year	T_{base} (°C)	Giresun				Erzurum			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2008	18	3,992.78	76.66	114.99	38.33	3,202.53	61.49	92.23	30.74
	20	3,260.78	62.61	93.91	31.30	2,533.61	48.65	72.96	24.32
	22	2,528.78	48.55	72.82	24.28	1,917.64	36.82	55.22	18.41
	24	1,796.83	34.50	51.74	17.25	1,353.75	25.99	38.98	13.00
	26	1,116.50	21.44	32.15	10.72	848.14	16.28	24.42	8.14
2009	18	4,232.17	81.26	121.88	40.63	3,453.19	66.30	99.45	33.15
	20	3,502.17	67.24	100.86	33.62	2,752.42	52.85	79.26	26.42
	22	2,772.17	53.23	79.83	26.61	2,100.50	40.33	60.49	20.16
	24	2,043.81	39.24	58.86	19.62	1,531.00	29.40	44.09	14.70
	26	1,356.50	26.04	39.06	13.02	1,000.03	19.20	28.80	9.60
2010	18	4,026.89	77.32	115.97	38.66	3,514.36	67.48	101.21	33.74
	20	3,296.89	63.30	94.95	31.65	2,841.86	54.56	81.84	27.28
	22	2,566.89	49.28	73.92	24.64	2,224.53	42.71	64.06	21.36
	24	1,839.06	35.31	52.96	17.65	1,644.72	31.58	47.36	15.79
	26	1,167.28	22.41	33.61	11.21	1,098.61	21.09	31.64	10.55
2011	18	4,077.33	78.28	117.42	39.14	3,247.36	62.35	93.52	31.17
	20	3,347.33	64.27	96.40	32.13	2,580.64	49.55	74.32	24.77
	22	2,617.33	50.25	75.37	25.13	1,944.58	37.34	56.00	18.67
	24	1,889.06	36.27	54.40	18.13	1,367.72	26.26	39.39	13.13
	26	1,195.50	22.95	34.43	11.48	856.75	16.45	24.67	8.22

(Table 1 continued)

Year	T_{base} (°C)	Giresun				Erzurum			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2012	18	4,213.08	80.89	121.33	40.45	3,384.69	64.99	97.47	32.49
	20	3,493.08	67.07	100.60	33.53	2,709.11	52.01	78.02	26.01
	22	2,773.08	53.24	79.86	26.62	2,086.61	40.06	60.09	20.03
	24	2,055.39	39.46	51.19	19.73	1,521.89	29.22	43.83	14.61
	26	1,372.50	26.35	39.52	13.18	1,004.33	19.28	28.92	9.64
Year	T_{base} (°C)	Diyarbakır				İzmir			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2008	18	3,353.61	64.39	95.58	32.19	78.14	1.50	2.25	0.75
	20	2,624.92	50.40	75.59	25.20	0.00	0.00	0.00	0.00
	22	1,946.53	37.37	56.06	18.69	0.00	0.00	0.00	0.00
	24	1,281.53	26.41	36.90	12.30	0.00	0.00	0.00	0.00
	26	726.06	13.94	20.91	6.97	0.00	0.00	0.00	0.00
2009	18	3,659.94	70.27	105.40	35.14	73.11	1.40	2.10	0.70
	20	2,929.94	56.25	84.38	28.13	1.42	0.03	0.04	0.01
	22	2,199.94	42.24	63.35	21.12	0.00	0.00	0.00	0.00
	24	1,518.11	29.15	73.72	14.57	0.00	0.00	0.00	0.00
	26	892.61	17.14	25.70	8.57	0.00	0.00	0.00	0.00
2010	18	3,593.42	68.99	103.49	34.50	178.14	3.42	5.13	1.71
	20	2,863.42	54.98	82.46	27.49	0.00	0.00	0.00	0.00
	22	2,136.61	41.02	61.53	20.51	0.00	0.00	0.00	0.00
	24	1,426.22	27.38	41.07	13.69	0.00	0.00	0.00	0.00
	26	792.00	15.21	22.80	7.60	0.00	0.00	0.00	0.00
2011	18	3,438.61	66.02	99.03	33.01	63.92	1.23	1.84	0.61
	20	2,708.61	52.01	78.00	26.00	0.00	0.00	0.00	0.00
	22	1,981.06	38.04	57.05	19.02	0.00	0.00	0.00	0.00
	24	1,288.86	24.75	37.11	12.37	0.00	0.00	0.00	0.00
	26	674.42	12.95	19.42	6.47	0.00	0.00	0.00	0.00
2012	18	3,299.25	63.35	95.01	31.67	126.17	2.42	3.63	1.21
	20	2,582.61	49.59	74.37	24.79	32.33	0.62	0.93	0.31
	22	1,874.53	35.99	53.98	18.00	0.00	0.00	0.00	0.00
	24	1,234.94	23.71	35.56	11.86	0.00	0.00	0.00	0.00
	26	646.31	12.41	18.61	6.20	0.00	0.00	0.00	0.00
Year	T_{base} (°C)	Ankara				İstanbul			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2008	18	28.03	0.54	0.80	0.27	3,416.94	65.61	98.40	32.80
	20	0.00	0.00	0.00	0.00	2,684.94	51.55	77.32	25.78
	22	0.00	0.00	0.00	0.00	1,952.94	37.50	56.24	18.75
	24	0.00	0.00	0.00	0.00	1,223.19	23.49	35.22	11.74
	26	0.00	0.00	0.00	0.00	541.92	10.40	15.60	5.20

(Table 1 continued)

Year	T_{base} (°C)	Ankara				İstanbul			
		CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)	CDD	Energy loss with $U = 0.8$	Energy loss with $U = 4.12$	Energy saved (kWh/year/m^2)
2009	18	27.33	0.52	0.78	0.26	3,510.61	67.40	101.10	33.70
	20	8.14	0.16	0.23	0.08	2,780.61	53.39	80.08	26.69
	22	0.00	0.00	0.00	0.00	2,050.61	39.37	59.05	19.69
	24	0.00	0.00	0.00	0.00	1,321.42	25.37	38.05	12.69
	26	0.00	0.00	0.00	0.00	635.61	12.20	18.30	6.10
2010	18	48.78	0.94	1.40	0.47	3,440.69	66.06	99.09	33.03
	20	0.00	0.00	0.00	0.00	2,710.69	52.05	78.06	26.02
	22	0.00	0.00	0.00	0.00	1,980.69	38.03	57.04	19.01
	24	0.00	0.00	0.00	0.00	1,254.00	24.08	36.11	12.04
	26	0.00	0.00	0.00	0.00	584.42	11.22	16.83	5.61
2011	18	43.50	0.84	1.25	0.42	3,442.81	66.10	99.15	33.05
	20	0.00	0.00	0.00	0.00	2,712.81	52.09	78.12	26.04
	22	0.00	0.00	0.00	0.00	1,982.81	38.07	57.10	19.03
	24	0.00	0.00	0.00	0.00	1,252.81	24.05	36.08	12.03
	26	0.00	0.00	0.00	0.00	551.75	10.59	15.89	5.30
2012	18	66.69	1.28	1.92	0.64	3,433.69	65.93	98.89	32.96
	20	18.33	0.35	0.52	0.18	2,713.69	52.10	78.15	26.05
	22	0.00	0.00	0.00	0.00	1,993.69	38.28	57.41	19.14
	24	0.00	0.00	0.00	0.00	1,273.69	24.45	36.68	12.23
	26	0.00	0.00	0.00	0.00	582.94	11.19	16.78	5.60

4. Conclusions

Turkey has a Mediterranean climate with plenty of sunshine, mild temperatures and a limited amount of rainfall. The heating and cooling degree days with variable-base temperatures (18 °C, 20 °C, 22 °C, 24 °C, 26 °C or 28 °C) are used in the determination of cooling degree days for Turkey. The hottest place in Turkey is Antalya where annual CDD is about 4,300 W/m^{2}K. The coldest city is Erzurum, where seasonally heating should be provided.

Degree-day method is very useful to estimate the demand for heating and cooling services that is why it is used as important climatic indicator in the HVAC industry. In this study, the variable base CDD for Turkey and CDD for Poland were checked by using long-term (2008~2012) data. The base temperatures (18 °C, 20 °C, 22 °C, 24 °C and 26 °C) are chosen to calculate degree days. All results are given in tables. Finally, the boundaries of applicability of various building design strategies and heating/cooling systems in different climates are affected. These strategies are based on the expected indoor-outdoor temperatures achievable with the different strategies and design decisions.

Heating represents an important share of the building energy consumption in cities, sometimes countries. With temperate climates, the energy consumption for cooling and the summer comfort problems are treated superficially. Based on the selected cities' temperatures, annual heating and cooling degree days with various base temperatures were obtained for each province. The northeastern and the inner regions of Turkey comparatively require more heating energy, the situation of which will affect facade design and standardization.

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