Renewable Energy 101 (2017) 156–167

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Determining new threshold temperatures for cooling and heating degree day index of different climatic zones of Iran

Gh.R. Roshan [a,*], A.A. Ghanghermeh [a], S. Attia [b]

[a] Department of Geography, Golestan University, Gorgan, Iran
[b] Sustainable Buildings Design Lab, Department ArGEnCo, Applied Sciences, Univeristé de Liège, Belgium

ARTICLE INFO

Article history:
Received 18 April 2016
Received in revised form
21 August 2016
Accepted 25 August 2016

Keywords:
Meteorology data
Base temperature
Thermal comfort
Olgyay diagram
Percentile method
Building regulations

ABSTRACT

Iran is a country with a variety of different climates. Determining the threshold temperatures suitable for providing thermal and climatic comfort is necessary and vital to its population well-being. This research presents new threshold temperatures in order to calculate the degree day index required for heating and cooling by taking advantage of the 12 stations that are representative of the diversity of Iran's climate. Using Olgyay diagram, different bioclimatic ranges of 12 weather stations and their frequencies were compiled, processes and analysed. Mean daily data of temperature and relative humidity were used for the period of 1950–2010. Based on the frequencies of temperature readings falling in Olgyay's diagram comfort zone, representive temperature thresholds were selected based on 40 to 60 percentiles or (P20), 25–75% percentile (P50) and the threshold of 10–90% percentile. The findings of this study shows that Mashhad with 29.6% and Anzali with 2.33% of frequencies, have experienced the maximum and minimum days of comfort. After analyzing various percentiles to determine the threshold temperatures, it was observed that there is a little difference among the stations for determining the minimum threshold for the comfort. Differences are more obvious in the maximum thresholds. In total, minimum base temperatures (HDD) belonged to Ardabil stations that were 20.50, 20.90 and 20 deg C for P20, P50 and P80 respectively. The maximum temperature for calculating CDD with values of (P20 = 25 °C; P50 = 26.25 °C; P80 = 27.50 °C) is dedicated to Zabol station. The findings present more reasonable thermal comfort thresholds that can be used by architects, engineers and policy makers to achieve, in turn, more energy efficient homes and high quality indoor and outdoor living environments.

1. Introduction

Climate change is one of the major challenges of the 21st century requiring global strategies for efficient energy supply, sustainable use of resources and the reduction of greenhouse gas (GHG) emissions [1]. The massive population growth in the urban centers of Iran faces the affected regions with major challenges regarding energy supply and energy use as well as in the adaptation to climate change. These regions also offer enormous potentials in heading towards sustainable, climatically adapted urban development. There is a demand to the construction 1.5 million new housing units per year in Iran. With the construction of new settlements, consumption of energy, commodities and resources there is a serious need to develop solutions and strategies for energy efficient, comfortable and resilient urban development. There is therefore a need for specifying criteria for the indoor and outdoor environment for design, energy calculations, performance and operation of buildings.

The degree day index as could be seen as one of the most practical and simple indices in determining required energy for providing comfort climate is. The total mean deviation of daily temperature of human comfort temperature is called threshold degree day temperature. In temperatures higher than threshold temperature, there is a need to cool the environment and in temperatures lower than it, there is a need to heat the environment which are called cooling and heating requirements respectively [2]. Heating degree days (HDD) and cooling degree days (CDD) in different aspects, are considered an important and effective indicators. The measure of heating and cooling degree-days can provide a clear and accurate picture of the thermal needs of the building, the city and the region, it also play a positive role in

* Corresponding author. Department of Geography, Golestan University, Shahid Beheshti, 49138-15759 Gorgan, Iran.
E-mail addresses: r.rowshan@yahoo.com; ghr.roshan@gu.ac.ir (Gh.R. Roshan).

http://dx.doi.org/10.1016/j.renene.2016.08.053
0960-1481/

providing thermal comfort and improving energy consumption patterns [3]. Estimating and calculating average value of degree-day requirement for heating and cooling as basic information to estimate the amount of energy needed for heating the building in winter and cooling it in the hot season is a result of energy consumption planning.

To date, a variety of HDD and CDD data are available in the literature and standardization for varies cities worldwide. However, in the case of Iran most HDD and CDD thresholds classifications are generic and there is no specific data for specific locations. Especially that Iran is a country with extreme climate and topographic variability. For instance during extreme winter in the North, many parts of the South experience very thermally comfort climate conditions, including cities such as Chabahar, southern coast islands and some coastal cities in the Persian Gulf and the Oman Sea. On the other hand, in hot summers, cities such as Ardabil, Khalkhal and some highlands experience cool weather accompanied with pleasant thermal comfort. The presence of Iranian cities in different geographical areas such as forests, deserts, beaches and mountain regions influence the climate variability strongly. The combination of different weather systems and atmospheric mass over the years with local topography agents causes great disparities between cities. Even cities, which are relatively close to each other, experience differences in climatic conditions. Therefore, the is a serious necessity to conduct a fundamental review of climate in different Iranian cities and more important set up new thresholds temperature to support designers and city planners with validated information that can help them to implement energy efficient strategies in each location independently in order to achieve maximum thermal comfort inside and outside buildings.

The percentile method is applied frequently in the environmental sciences, such as climatology and biometeorology; and according to the data frequencies, it aims to identify upper and lower thresholds. The idea of using the percentile method in this study was based on this fact that in some valid studies, the 90th and 10th percentile of the maximum and minimum temperature of the stations were used to identify the bioclimatic indexes such as heat and cold waves, respectively [4,5]. Hence, based on this method, thermal thresholds identifying the heat and cold waves are different for different stations. According to what is mentioned above, it can be concluded that thermal comfort zones of each area needs to be identified according to the climate pattern of that area. We believe that the local people of each area can adapt themselves to their surrounding climate; therefore their tolerance and bio-comfort is different in different climates. On the other hand, considering the huge climate variability in Iran, identifying a fixed base temperature of 18–24 °C for monitoring the demand in cooling and heating energy, cannot justify an appropriate threshold for this climate variability. Therefore, in this study we aimed to identify the dominant possibilities in comfort of each station according to its behavior and thermal pattern, based on the identifying the thermal thresholds of P20 as representative for the ideal comfort zone, P50 as favorable comfort zone and P80 as appropriate comfort zone. According to their applications and aspects, these three different thermal bases can be used in different ways. For example, considering the global warming and increase in the maximum temperature records, making use of P80 thermal threshold for CDD can be an appropriate thermal base for stations having experienced temperature increase in the recent years. Eventually, it must be mentioned that in this study some new based temperature thresholds have been introduced, but it must be considered that these new based temperatures have been chosen in the comfort zone which was proposed by Olgyay before. In the present study, we just suggest some new threshold temperatures based on the data frequencies in the comfort zone.

In this context, this study focuses on the determination of new threshold temperatures for cooling and heating degree day index of different climatic zones of Iran. The new threshold temperatures for cooling and heating degree day index has been proposed as providing designers and facilities managers with the opportunity of reducing energy consumption yet ensure that thermal comfort is maintained by allowing buildings to operate in free-running mode rather than use mechanical systems for cooling and/or heating. This arises as a consequence of the fact whilst mechanical systems require energy for their operation, buildings in free-running mode, where occupants can freely adapt their local/personal environment by opening/closing windows, altering dress etc, largely do not. Whilst buildings which use mechanical cooling or heating systems customarily use broadly fixed temperature limits which are independent of outdoor air temperature to define the upper and lower boundaries of the zone of thermal comfort1, the fluid temperature limits of the new threshold temperatures for cooling and heating degree day index are set in relation to the variant outside air temperature [6,7]. Also from the viewpoint of the land use planning and long-term and mid-term planning of Iran, the results of this study can have a determinant role on climate change, energy consumption, housing, urban development, economic development and some other social and economic arenas. The importance of the present study lays its ability to provide a finer classification that would facilitate the implementation of environmental strategies that are tailored to the local context. Therefore, the results of this study are considered as guidelines for architects and civil engineers in Iran. The accurate and specific determination of bioclimatic characteristics of a location or city, can help designer to select environmental urban patterns and construction techniques that achieve thermal comfort, occupants well beings and reduce the depends on fossil fuels. On the long term this will lead to decreasing cooling and heating loads and consequently the cost pressure on inhabitant's budget and government's energy supply.

This paper is organized into six sections. The first section identifies the context of the research and its importance. The second section reviews different thermal comfort models and establishes an understanding of Iran's climatic situation. The third and fourth section identifies the research methods, used materials and studied weather stations. The demonstration and processing of the results are presented in section five. The final section discusses the research findings and limitations along with the implications for the design practice community and future research.

2. Climate and human comfort

One of the most important issues in applied climatology is the branch of bioclimatology, which is presented as an independent branch in climatology. Various scholars have written numerous books and articles on the subject and they have also devised methods [8–13]. In fact, bioclimate, investigates the weather conditions in relation to organism and in particular to human [14]. Considering climatic parameters of human comfort, outdoors and indoors, is an important field in climatology studies. These are part of a larger topic in applied climatology entitled climates and built environments or bioclimatic architecture and climate adapted built environment.

Generally there are two general methods for monitoring and analyzing bioclimatic conditions. The first method can be called the indices method that is based on empirical measurement and computational calculation covering a range of simple to complex indices. For example, humidex is an example for simple indices that although various methods have been proposed to calculate this index but in most of them, two parameters of temperature and relative humidity are used [15–17]. Wind chill index is another simple bioclimatic computational index which only uses two components of temperature and wind speed and a lot of work has been done on the basis of this index all over the world [17–20]. However, other simple to relatively simple indices include apparent temperature which was first presented by Steadman (1984) [21] or effective temperature which was founded by Houghton and Yaglou (1923) [22] and also the wet-bulb globe temperature (WBGT) which was first presented by Yaglou and Minard (1957) [23,24]. Physiologically equivalent temperature (PET) is one of the most widely used bioclimatic indicators that for its calculation a long and complex computational process is required [25]. Since the computational process of this index is so long, RayMan software is designed in order to easily receive output from this index [26,27].

The second method for monitoring and analyzing bioclimatic conditions is based on using bioclimatic diagrams. Perhaps Victor Olgyay is one of the pioneers in designing comfort climate diagrams. In order to determine comfort outside of the building, Olgyay presented a diagram designed to potentially determine the conditions of outdoor comfort by considering parameters such as wind speed, radiation and humidity requirements [28]. Givoni's bioclimatic diagram of buildings is another bioclimatic diagram, which was designed in order to improve the interior condition of a building based on the climatic condition of the site and with regard to changes in average temperature and monthly humidity, natural heating and cooling solutions for buildings [29]. Later limitations of Givoni's diagram were investigated by Watson and Labs [30]. Until the psychrometric chart emerged as another widely used bioclimatic diagram based on which several studies have been done [31,32].

With regard to the above-mentioned methods, it can be seen that many bioclimatic indices have been developed in the last 50 years. The most used method according to literature is the degree day index. Various studies around the world have used different temperatures to calculate HDD and CDD considering their climate and geographical location. For example Petralli et al. (2011) [33], have chosen the range of 17–22 °C as their comfort range in the analysis of some climate indices including HDD and CDD for the city of Florence, Italy. In another study in Saudi Arabia, three thermal comfort thresholds were selected to calculate the heating and cooling requirement. The first threshold includes 18 to 24, the second one includes 18 to 20 and the third threshold includes 7–13 °C (Rehman et al., 2011) [34]. Contraversly, in another study in Saudi Arabia, Al-Hadhrami (2013) [35] chose 18.3 °C as a base temperature of HDD and CDD. In a study in Hong Kong, Lam et al. (2005) [36] have chosen the base temperature of 16 and 24 as a basis for calculating of HDD and CDD respectively. On the other side, (Jiang et al., 2009) [37] have chosen the temperature range of 18–24 as the comfort criterion in order to monitor changes cooling and heating energy requirements in 51 cities of China. Cvitan and Sokol Jurković (2015) [38] selected three temperature bases for their calculations to determine the monthly trend for energy demand in heating and cooling in Croatia. Thus there are different temperature threshold determinations to calculate HDD and CDD in the above listed example. For this study they selected degree days index and they opted to three temperature basis of 10, 12 and 15 °C were selected for HDD and also to calculate CDD, 18, 21 and 23 °C were chosen as the basis for calculation. Sivak (2009) [39] chose 18 °C as the base temperature for CDD calculation in study for presenting an overall view of cooling energy required for 50 metropolitan of the world. Another study that aimed to evaluate the impact of climate change on electricity need in Cyprus, base temperature to calculate CDD and HDD were selected as 18 and 22 °C respectively (Zachariadis 2010) [40]. It should be noted that most studies in the field of monitoring HDD and CDD were carried out by researchers from Greece and Turkey. Dombayc (2009) [41] is a Turkish researcher, who chose 17.5–22 °C in his study of range of thermal comfort for cities in Turkey, but Yildiz and Sosaoglu (2007) [42] have applied three thermal comfort thresholds of 18–20 °C, 18–24 °C and 7–13 °C in their research. Also Zekai et al. (1998) [43], have chosen the temperature threshold of 15–24 °C. The study of Greece confirmed the fact that temperature base of 14, 15 and 18 were the criterion for determining the HDD and temperature base of 24 and 26 were determined as a measure of CDD (Matzarakis and Balafoutis 2004; Papakostas et al., 2010; Moustris et al., 2014) [44–46].

In Iran, early pioneers research on climate and human comfort in residential areas was mostly related to the works of Riazi (1977) [47], Razjooyan (1988) [48] and Kasmaii (1993) [49]. Kasmaii (1993) calculated and plotted climatic zoning map of Iran with regard to housing and residential areas around the country. Also Khalili (1999) [50], investigated heating and cooling degree-days in Iran based on three-dimensional analysis and plotted maps of the annual need of heating and cooling. Most works in the field of HDD and CDD for Iran have been conducted in Persian and they have been published in the magazine inside Iran and rare studies such as Roshan and colleagues (2012) [51] are available in international journals. However, no study conducted a fundamental review for choosing the range of thermal comfort in different cities of Iran. Although many researchers inside the country have chosen 18 to 24 and 18–21 °C as the threshold of thermal comfort [49–53], but according to the above-mentioned considerations it important that a new range of thermal comfort should be defined for different regions of Iran. Despite the previous studies that focused on base temperature of thermal comfort in Iran, diversity of climate and topography have not been considered in these previous works. As the research literature shows, all of them used same and similar thresholds for all cities.

Therefore, the present study is intended to determine the criterion of choosing of thermal comfort threshold of each city based on the frequency of temperature events of days with thermal comfort. Determining the thresholds of thermal comfort considering the climatic conditions of each station, which are resulted from various factors such as the air mass transition, topography, latitude and longitude, distance and proximity to land, sea, forest etc., is in itself a novel methodology to generate and in the same time validate the results that was not achieved by previous studies for the case of Iran. It is expected that by considering the specific characteristics of the climate in each city, building and city experts will be able to better present a thermal comfort range or in other words an appropriate temperature base in order to estimate HDD and CDD. In order to determine the new threshold temperature for the cooling and heating degree day index we took three measures. First analyse the bioclimatic conditions of weather stations located in 12 cities. Second determine the base threshold temperature for HDD and CDD calculation. Third calculate the new values of HDD and CDD.

3. Place, instrumentation and data

3.1. Selected weather stations

Iran is a country with climatic diversity and remarkable topography which led to the selection of 12 weather stations, as the representative of this geographic and climatic diversity (Fig. 1). One of these climatic zones includes provinces and cities which are located in the South of Iran and in the Northern Coast of Persian Gulf and Oman Sea. It is worth noting, the climatic regime of these station change from the West Coast to the East Coast. Abadan was selected near the West Coast, Bandar e Abbas was selected for central half of Persian Gulf's Coast and Chabahar was selected for

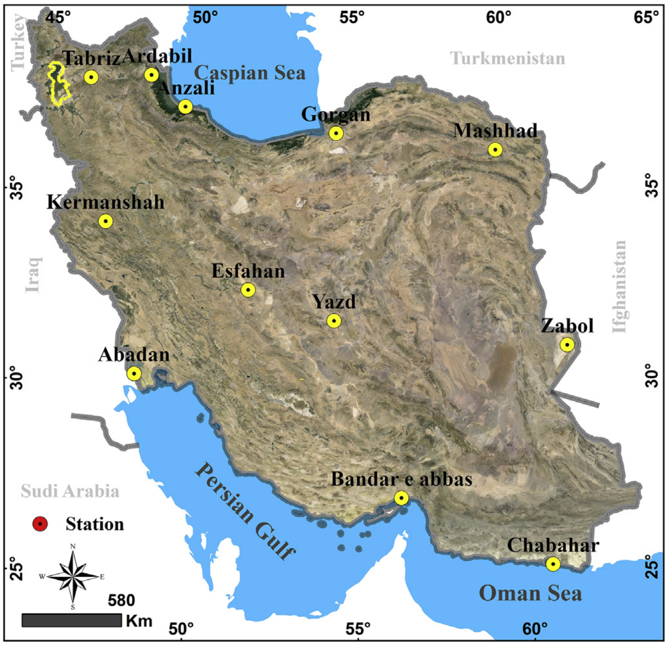

Fig. 1. Distribution of selected stations in the geographic zone of Iran.

the East Coast and these stations had dry and warm to warm and humid weather. Reports indicate that the annual mean temperature and relative humidity of Abadan is 25.5 °C and 44.6%, of Bandar e Abbas is 27 °C and 65.20% and of Chabahar is 26.3 °C and 72.7% respectively. The prevailing weather systems affecting these regions include subtropical systems and Sudanese sand storms which are crossing the Arabian Peninsula. Yazd and Esfahan are among central stations of Iran having cold and dry weather in winter and hot and dry weather in summer. Long-term average temperature and relative humidity for Yazd is 19.2 °C and 30.10% and for Esfahan they are 16.42 °C and 36.3% respectively. The main weather systems affecting these stations include Subtropical high pressure system in the warm period of the year and western weather systems in the cold period of the year. Northern cities can be divided into two groups including cities adjacent to the Caspian Sea and cities outside of the Caspian Sea limits. Anzali is a Northern City located in the Southwestern Coasts and Gorgan is located in Southeastern Part of the Caspian Sea. Based on long-term annual average, the relative humidity of Anzali station as the representative of Southwestern Cities of the Caspian Sea is 84.40% that this humidity is reduced by moving to the East, and it reaches 69.73% for the city of Gorgan. Also the annual long-term temperature of Anzali is 16.27 and of Gorgan is 17.80 °C. The prevailing weather systems affecting these regions include local system of land-sea breeze and the western winds. But the city of Ardebil is one of the very cold cities of northern half of the country that experience very cold winters and cool summers. The average annual temperature of this station is 14.9 °C and its relative humidity is 71.55%. In North East of Iran, Mashhad station is selected which is severely affected by Siberian high pressure in the cold period of the year and experiences cold and dry conditions. Being affected by monsoon rains in the warm period of the year and 120-day winds of Sistan in the late spring to midsummer is of main features of this station and most of the climatic conditions of this station given the long-term average annual relative humidity of 37.06% and 22.07 °C evokes the warm and dry weather pattern for this station. Finally, Tabriz and Kermanshah are representatives of West and Northwest stations of Iran that are affected by the system that arise from the Mediterranean and the Red Sea and their rain period is related to cold seasons of autumn and winter. While in the warm period of the year with withdrawal of precipitation causing systems and replacement of the Azores high pressure, it experiences warm and dry weather. The average temperature and relative humidity for Tabriz is 12.6 °C and 52.50% and for Kermanshah, they are 14.49 °C and 46.32% respectively (Fig. 1). Table 1 shows details of meteorology for our case study.

3.2. Instrumentation and data

In this study, the average daily temperature and relative humidity data is used to plot bioclimatic conditions. Since Iran has different climatic diversity, 12 stations that represent different climatic conditions of Iran were selected and analyzed. It should be noted that the duration of used time series was from 1950 to 2010 and the data was collected from Iran's Meteorological Organization. It is worth noting that data were complete in almost all stations and less than 2% of daily data was missing in six stations only, where reconstruction was performed by linear regression. Thus the results were approved after validation of reconstructed data with a run-test conducted to ensure data heterogeneity.

Since hand drawing of each of the events on Olgyay diagram was time consuming and difficult due to the wide range of the data, Olgyay diagram was digitalized to quickly and easily receive output for each station.

4. Methodology

It is notable that in this study, Olgyay diagram was divided into 12 bioclimatic classes and frequency of occurrence of each of the bioclimatic classes is reported for each station in Table 2. But the most important part of this study is to determine new threshold temperatures to calculate HDD and CDD indices of the observational Stations.

The climatic comfort is usually determined by setting the top and bottom of the comfort boarders as non-comfort zones. However, without defining those limits, usually the zoning of climate comfort will be geographically uneven. This condition would not provide the possibility of distinguishing ideal, favorable and appropriate comfort zones. On the other hand, the boarder of these thresholds cannot be defined as an absolute value because in each geographic region, with respect to the frequency of climatic conditions and characteristics of physiological, adaptation will vary. So it is necessary that new thresholds with dominant climatic frequency be defined in each geographic region. In this study, some thresholds are proposed based on the frequency thresholds of 10, 25 and 40% in proportion to the statistical distribution center or P20, P50 and P80 based on the total distribution which their criteria are as follow (Fig. 2):

a. 20% of comfort zones statistically mean that 80% in two ranges of the normal distribution is located outside the ideal comfort zone.
b. 50% of comfort zones statistically mean that 50% in two ranges of the normal distribution is located outside the favorable comfort zone.
c. 80% of comfort zones statistically mean that 80% in two ranges of the normal distribution is located outside the appropriate comfort zone.

Comfort zone statistically means total of comfort frequency in the standard boarder which is beyond the threshold model.

It should be mentioned that frequency distributions may be different due to the experiences but we believe that the best threshold borders are the abovementioned suggestions. So, based

Table 1
Long-term mean of monthly and annual of temperature (°C) and relative humidity (%) for the twelve stations used.

Stations	Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abadan	Hum	69.8	59.8	50.7	42.8	31.8	24.9	25.6	28.8	32.7	44.0	56.4	68.2	44.6
	Tmp	12.7	14.8	19.3	25.0	31.1	35.0	36.7	36.2	32.9	27.4	20.1	14.4	25.5
Anzali	Hum	86.3	86.3	87.9	86.1	83.9	79.5	77.0	79.7	84.9	87.3	87.7	86.4	84.4
	Tmp	7.2	6.9	8.9	13.6	18.9	23.4	25.9	25.7	22.6	18.1	13.7	9.8	16.3
Ardabil	Hum	75.6	74.1	72.7	65.8	69.9	69.3	67.2	69.4	72.7	73.8	73.6	74.6	71.6
	Tmp	−2.4	−0.9	3.5	9.8	12.9	16.1	18.3	18.2	15.7	11.1	5.8	0.6	9.1
Bandar e Abbas	Hum	65.0	68.4	67.4	63.7	60.6	63.1	67.8	69.5	67.8	64.6	61.1	63.6	65.2
	Tmp	17.8	19.3	22.5	26.4	30.6	33.3	34.3	33.9	32.2	29.2	24.2	19.6	27.0
Chabahar	Hum	63.0	68.1	70.9	72.2	74.8	78.1	79.3	79.5	78.4	74.8	68.2	63.9	72.7
	Tmp	19.9	20.8	23.5	26.7	29.6	31.4	30.7	29.5	28.7	27.6	24.4	21.5	26.3
Esfahan	Hum	58.5	47.7	40.3	35.8	29.9	20.5	21.0	21.6	23.4	33.7	46.4	57.2	36.3
	Tmp	3.3	6.0	10.6	16.0	21.2	26.6	29.1	27.6	23.4	17.0	10.3	5.1	16.4
Gorgan	Hum	73.4	72.6	74.3	71.4	66.7	63.0	64.6	67.0	68.3	69.5	72.2	74.0	69.7
	Tmp	7.7	8.3	10.8	16.1	21.2	25.4	27.8	27.8	24.7	19.3	14.1	9.8	17.8
Kermanshah	Hum	73.4	67.6	59.4	54.5	46.2	26.6	21.6	21.2	23.4	37.6	57.1	70.3	46.3
	Tmp	1.7	3.4	7.9	12.8	17.4	22.9	27.3	26.7	21.9	16.2	9.5	4.5	14.5
Mashhad	Hum	75.6	73.5	68.9	61.0	49.3	36.6	33.8	33.4	37.9	50.5	63.9	72.8	54.7
	Tmp	1.6	3.5	8.5	14.7	19.5	24.4	26.6	24.7	20.3	14.4	9.0	4.1	14.3
Tabriz	Hum	72.3	68.6	60.3	54.7	49.2	38.6	33.6	34.1	36.2	48.6	63.6	71.2	52.5
	Tmp	−1.9	0.1	5.5	11.5	16.7	22.2	26.3	26.0	21.4	14.4	7.2	1.3	12.6
Yazd	Hum	53.4	43.8	36.1	30.7	23.5	16.4	16.1	15.8	17.2	25.3	36.4	47.3	30.1
	Tmp	5.8	8.6	13.5	19.4	24.8	30.0	31.9	30.0	25.9	19.5	12.6	7.6	19.2
Zabol	Hum	57.0	52.6	46.7	38.6	29.6	24.7	22.7	21.6	23.4	32.2	42.7	53.4	37.1
	Tmp	8.6	11.3	16.8	23.5	28.6	32.8	34.6	32.9	28.3	22.0	15.2	10.0	22.1

Table 2
Frequency percentage of bioclimatic zones of index stations based on Olgyay diagram.

Stations / Bioclimatic zones	Abadan	Anzali	Ardabil	Bandar e Abbas	Chabahar	Esfahan	Mashhad	Tabriz	Yazd	Zabol	Gorgan	Kermanshah
Comfort	18.3	2.33	5.47	16.41	16.96	21.5	29.64	24.77	14.63	19.59	15.14	21.6
Radiation requirement	32.06	28.59	48.77	17.19	8.87	33.95	35.2	32.69	34.36	34.17	40.1	37.21
Windy requirement	6.56	24.55	0.56	26.83	32.52	0.24	0.65	0.33	0.14	1.14	26.61	0.23
Windy-humidity requirement	9.75	1.36	0.41	1.08	0.89	12.3	3.46	4.08	19.1	15.93	1.18	5.89
Excessive humidity	0.8	28.62	3.76	1.71	6.52	0.13	0.82	0.05	0.21	0.33	3.4	0.35
Relative humidity deficit	0.19	0.69	0.48	0.02	0.33	0.48	0.42	0.35	0.55	0.34	0.52	0.41
Frost	1.18	12.93	24.42	0.45	0.83	23.81	23.08	24.84	17.01	8.84	12.1	25.78
Freezing	0.07	0.27	16.14	0.08	0.21	2.31	6.41	12.53	0.99	0.25	0.25	4.49
Severe dry	15.76	0.01	0	1.94	0.37	0.09	0.02	0.01	0.26	5.09	0.04	0.11
Heat stroke risk	2.72	0.66	0	34.18	32.48	0.11	0.01	0.01	0.13	0.37	0.63	0.12
Severe heat exhaustion	0.53	0	0	0	0	0.07	0	0	0.03	0.28	0	0.04
Humidity requirement	12.07	0	0	0.1	0.03	5.01	0.3	0.35	12.58	13.66	0.03	3.77
Total	100	100	100	100	100	100	100	100	100	100	100	100

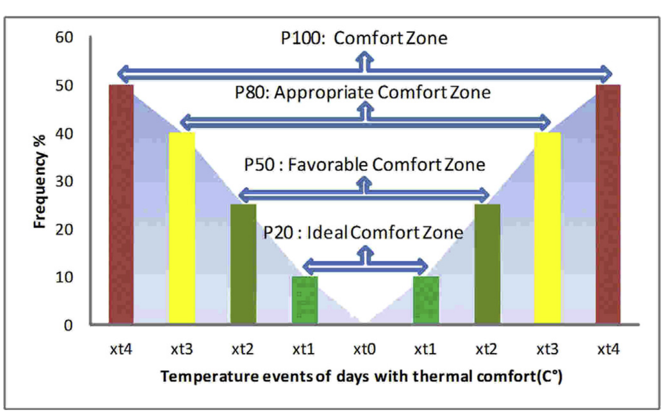

Fig. 2. Suggestion different thresholds of comfort zone.

on these thresholds of frequency different thermal comfort thresholds are defined for each geographical area.

These domains were introduced as new thermal comfort for determining base temperatures for HDD and CDD calculation (Equation (1)):

$$L_p = (n+1)\frac{s}{100} \tag{1}$$

In Equation (1), L_P is an equivalent for the threshold rank of the percentiles of 10, 25, 40, 60, 75 and 90%, n is an equivalent for number of samples and s is an equivalent for percentiles. In the final step after determining the base temperature, required cooling day-degree values (Equation (2)) and heating (Equation (3)) are calculated as follows:

$$\mathrm{CDD} = \sum_{1}^{N} (\mathrm{T} - \theta), \quad \theta < \mathrm{T} \tag{2}$$

$$\mathrm{HDD} = \sum_{1}^{N} (\theta - \mathrm{T}), \quad \theta > \mathrm{T} \tag{3}$$

In Formula (2) and (3), cooling requirement is calculated by CDD and heating requirement is calculated by HDD for a given period of N days. In these formulae, T is the average daily temperature and θ is the base temperature that with regard to the threshold of different percentiles, different numbers are proposed for each station.

5. Results

5.1. Analysis of bioclimatic conditions of twelve stations

This section presents the results of weather station plots and frequency values of the twelve studied weather data files. As shown in Fig. 3, Olgyay diagram is divided into 12 bioclimatic zones. The frequency of occurrence of each of the bioclimatic conditions of the various twelve stations is plotted and presented Fig. 4a,b and Table 1.

The findings show that on the basis of Comfort Zone, the frequency of days with comfort fluctuates from at least 2.33% of the whole statistical period for Anzali to its maximum of 29.64% for Mashhad. If one pays attention to the outputs of coastal cities of Persian Gulf, it can be seen that for Abadan station about 18.30% of time series, comfort conditions have been fulfilled and if in 32% of days of observational period be provided, frequency of comfort days increases. Also in 28.38% of study period, some ranges of thresholds of humidity requirement, windy requirement and humid-wind should be provided for climate comfort to be provided. But in this station, there is no report of freezing and frost with the lowest event rate of 1.18% has been reported in its lowest level. On the other hand the risks of heat stroke and heat exhaustion with values of 2.75 and 0.53% have the lowest level. For Abadan, although dry weather conditions, is the most important inhibiting factor of the fulfillment of climatic comfort condition, but it covers around 20.26% of data frequency along with other inhibiting factors such as humidity deficit, the risk of heat exhaustion and severe frost. However, the effect of inhibiting factors mentioned above is so that eliminating their effectiveness in order to provide bioclimatic comfort conditions is not compensable by other climatic parameters. In Bandar e Abbas station, 16.41% of days are located in comfort zone and the risk of heat exhaustion is the most important inhibiting factor for this station and these conditions have assigned 34.18% of data frequencies to themselves. On the other hand, freezing and frosting include 1% of the frequencies. In general, in case of providing of radiation conditions, humidity requirement, wind requirement and humid-wind requirement, this potential of providing climate comfort will exist for 45.2% of the days. But the total of inhibiting factors of climate comfort for Bandar e Abbas station include phenomena such as frost, heat exhaustion, excess humidity and relative humidity deficit which include 38.38% of frequencies in total but 16.96% of study days of Chabahar station, with minor differences with Bandar e Abbas, are located in comfort zone.

Similar to Bandar e abbas, in this station the most important inhibiting factor is the risk of heat exhaustion, and from the total of inhibiting factors (40.47% of days), about 32.48% of days' frequencies belong to this inhibiting factor. But in case of the fulfillment of radiation requirement, windy requirement and windy-humidity requirement, about 42.31% of events have the potential for entering the comfort zone. The important point about the difference between Abadan and two stations of Bandar e Abbas and Chabahar is its geographical location. Abadan has been both affected by Persian Gulf's body of water and by systems that directly pass Saudi land. This condition can be recognized from Olgyay diagram of Abadan city, because data distribution shows that this station, apart from the experience of humidity higher than 50%, has remarkable records of relative humidity lower than 50%. For Bandar e abbas, the concentration of events has been on the thresholds higher than 50% of relative humidity that this condition has been intensified for higher humidity thresholds in Chabahar. According to the Olgyay diagram and comfort zone it can be seen that although one can rarely find days with comfort in which humidity is lower than 30% for Abadan, the distribution of days with comfort

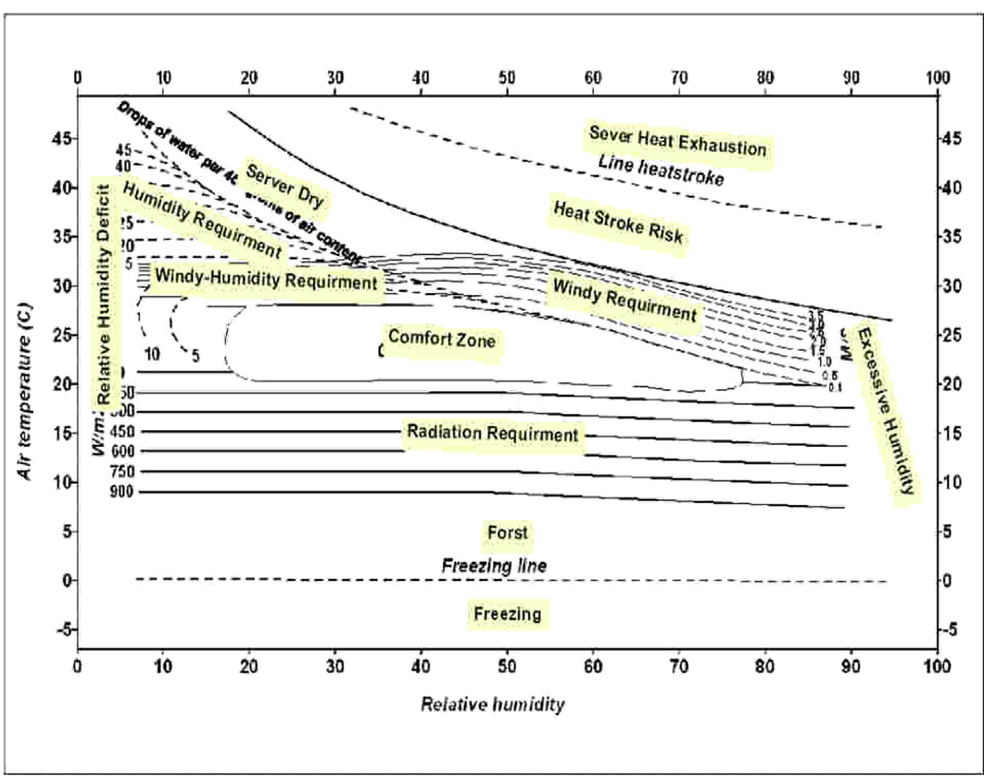

Fig. 3. 12 bioclimatic zones for Olgyay diagram.

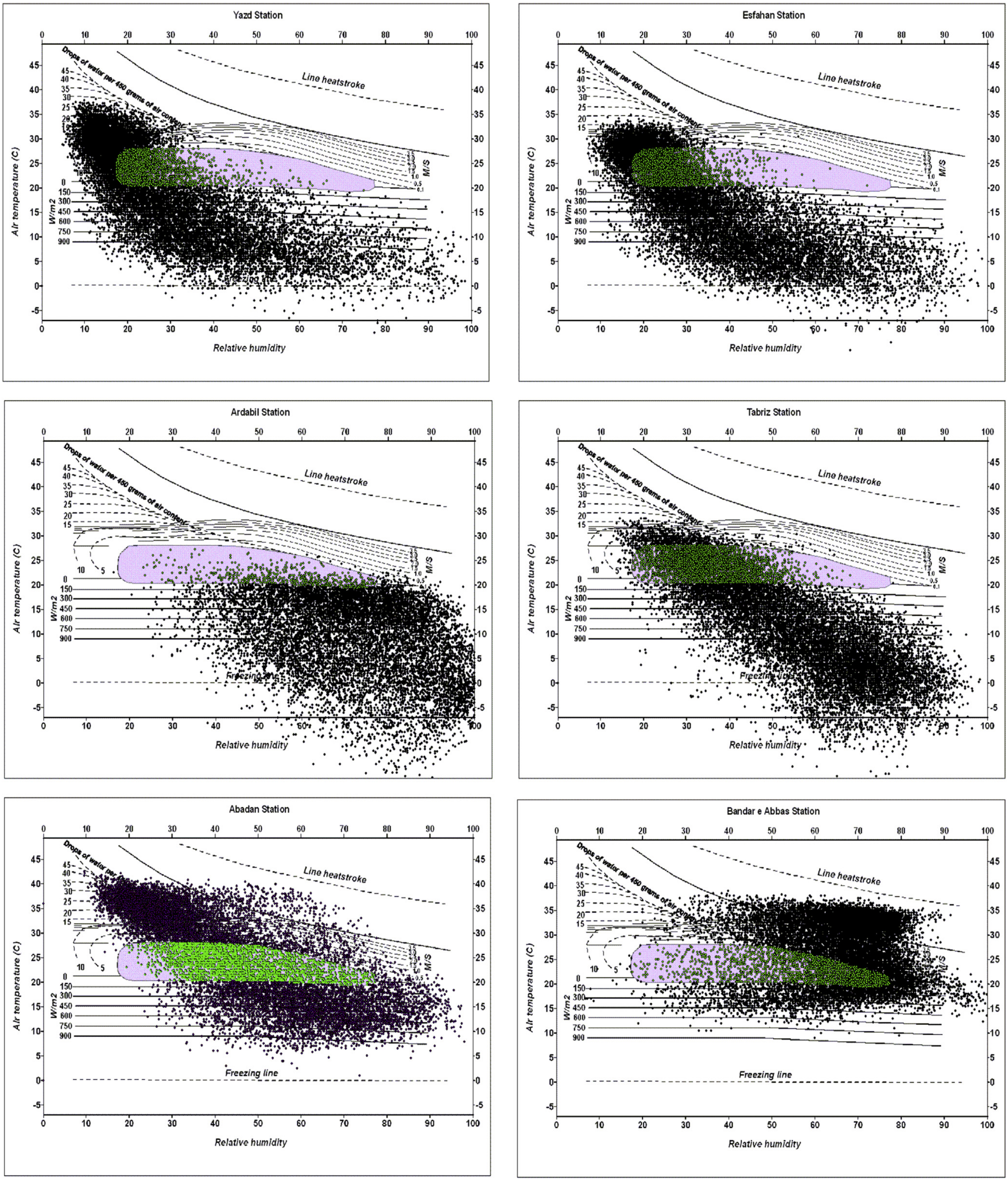

Fig. 4. a: Distribution of daily bioclimatic conditions of selected stations for 1950 and 2010 for 6 cities in Iran country. b: Distribution of daily bioclimatic conditions of selected stations for 1950 and 2010 for 6 cities in Iran country.

of this city in the comfort zone is more uniform compared with Bandar e Abbas and Chabahar. For the two stations of Bandar e Abbas and Chabahar, the concentration of days with comfort are located in the eastern end of the comfort zone (Fig. 4a,b).

In the stations of the Caspian Sea coasts, the most important inhibiting factor of climate comfort is the excess of relative humidity with 28.62% and frosting with 12.93% of frequencies. But the most important inhibiting factor for Gorgan is frosting which is

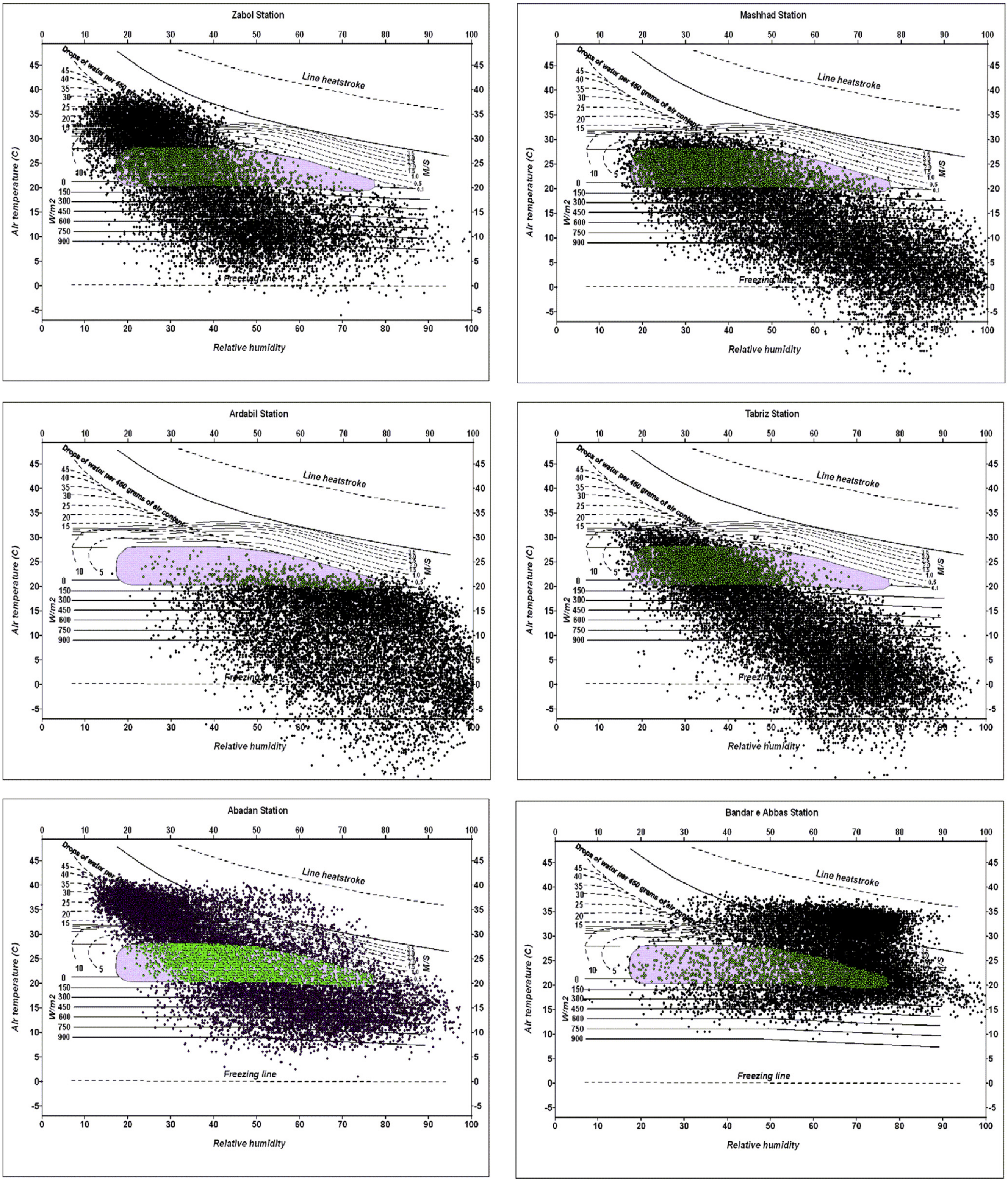

Fig. 4. (*continued*).

nearly close to Anzali with 12.10%. But the second factor is the excess of humidity which its frequency compared to Anzali, is considerably low with 3.4% of data frequencies. On the other hand, Gorgan has had the experience of climate comfort in 15.14% of the days which this percent is much lower for Anzali. For Anzali in case of the fulfillment of radiation requirement, windy requirement and windy-humidity requirement, about 54.5% of days have the potential for entering the comfort zone and this number for Gorgan is 67.92% of the days. Another important point for differences between Anzali and Gorgan is in the concentration of comfort days in the comfort zone. In Anzali, these days have tended towards to the very end of eastern part of the zone so that most comfort days have had more than 70% of humidity. But this condition in Gorgan is so that most of comfort days are scattered in the whole eastern half (Fig. 4b). At the same time Ardabil stations as other representative of northern stations of the country with 5.47% of days located in the comfort zone has experienced a different pattern compared to two stations of Anzali and Gorgan. In Ardebil, freezing and frosting have included 40.56% of the inhibiting factors that in case of the fulfillment of radiation requirement, about 47.88% of study days have the potential for entering the comfort zone. For central stations of Iran, Yazd with 14.63% and Esfahan with 21.5% of days are located in the comfort zone. Interestingly, for both of these stations, the most important inhibiting factor is to provide comfort conditions for frosting which includes 17% of studied days' frequency for Yazd and 23.81% studied days' frequency for Esfahan. Also radiation is considered as the most important factor for providing climate comfort conditions for days outside comfort zone. Nevertheless, according to Olgyay diagram, the distribution of most comfort days is located in the western half of the zone so that most of these days have a relative humidity lower than 40% (Fig. 4a). In the following, one can refer to the bioclimatic conditions of stations located in west and Northwest of the country.

For Tabriz, 24.77% of study days and for Kermanshah, 21.60% of them are located in the comfort zone. In these two stations, except for frosting factor, freezing factor is one of the most important inhibiting factors that the impact of these two factors is 37.37% of frequencies for Tabriz and 30.27% of frequencies for Kermanshah. But in case of the fulfillment of radiation requirement, 32.21 &% and 37.21% of the study days for Tabriz and Kermanshah, have the potential to enter the comfort zone. The important point is that except from the radiation factor, fulfilling windy-humidity requirement can be the second effective factor in providing bioclimatic comfort of these two stations. Also the distribution of the comfort days of these two stations in Olgyay diagram is so that in Tabriz, the distribution of these days in the whole western half of comfort zone is with relative humidity threshold of lower than 50% but the situation is similar to Esfahan and Yazd for Kermanshah.

Finally the results of stations of North East and East of Iran can be presented. As previously mentioned, among all study stations, maximum days with climatic comfort conditions is in Mashhad but from the total time series of Zabol station, 19.59% of days are located in the comfort zone. For Mashhad stations due to its specific geographical position which is affected by Siberian high pressure in the cold season, the most important inhibiting factors include frosting and freezing which covers 29.49% of days in total but for Zabol, the most important factors are frosting with 8.84% and severe dryness with 5.09%. On the other hand, in case of the fulfillment of the radiation requirement for Mashhad, 35.2% of days have the potential for providing comfort conditions and low percentage of days with 3.46% can be located in the comfort zone with regard to the provision of wind-humidity conditions. Although providing of radiation requirement for 34.17% of days can provide the potential for the occurrence of comfort in Zabol but in case of the fulfillment of both factors of humidity requirement and windy-humidity requirement, this potential exists for the occurrence of bioclimatic comfort for 29.59% of days. It is worth noting that the distribution of Zabol's comfort days in Olgyay diagram is similar to Tabriz but in Mashhad, the concentration of data, except for western half, tends towards the east of elliptic zone (Fig. 4a,b).

5.2. Determination of new threshold temperatures for HDD and CDD calculation

As stated earlier, the main purpose of this study was to modification the threshold temperatures in order to calculate HDD and CDD for different climatic zones of Iran. Thus, according to Formula (1), (3) thermal thresholds were presented based on days located in the comfort zone. In Table 3, thermal range of the comfort zone based on 20% of central data or the percentile of 40–60% along with threshold percentile of 25–75% which is the representative of prevailing frequency of 50% of central data are presented and also the range of percentile of 10–90% is shown. It should be noted that in order to summarize, the terms of P20, P50 and P80% which are representative of the abovementioned thresholds are used. So at first glance it can be seen that if the range of percentiles are limited, the extent of temperature threshold becomes lower.

Based on 20% frequency of central data, it can be seen that lowest temperature threshold with the amount of 20.90–21.50 °C belong to Ardebil station but Esfahan station with the minimum difference with Zabol, shows the highest temperature threshold with the amount of 23.50–25.10 °C compared with other study stations. Then, Ardebil has the lowest temperature base of thermal comfort but based on these two bases, Zabol has the highest thermal comfort threshold. In comparison of different stations, interesting differences can be extracted. For stations in the margin of Persian Gulf and Oman Sea, by moving from the West coast to the East, the extent and value of temperature threshold decreases. It means that the maximum extent and the amount of temperature threshold belong to Abadan and its minimum is for Chabahar. As already stated this is due to Abadan's being influenced by two kinds of weather systems affected by both land and sea while in two other stations, The prevailing climatic influence is by Persian Gulf and Oman Sea. For example, on the basis of 50% of the central data's frequency, base temperature for thermal comfort in Abadan has been 22–25.80 °C while this threshold for Chabahar has been 21–23.5 °C. In the northern coast of Iran, on average, based on three studied thresholds, the extent of thermal comfort threshold calculated for Anzali is one degree lower than Gorgan; also the base threshold temperature for thermal comfort for Anzali occurs in lower temperature values compared to Gorgan. In a comparison between Kermanshah and Tabriz, the scope of thermal comfort for Kermanshah is 0.20 °C higher than Tabriz and also base temperature of thermal threshold in Kermanshah is a little lower than Tabriz. For two stations of central Iran which include Esfahan and Yazd, The findings show that base temperature of thermal thresholds for Esfahan is a little higher but no significant difference can be seen in band and comfort zone of these two stations. Finally, for Mashhad in comparison with Zabol, thermal threshold values of base temperature are a little lower but no significant differences in the threshold zone can be seen. Therefore, it is remarkable that for stations located in a specific geographical area, some differences in their extent and thermal comfort range can be seen (see Table 3).

5.3. Calculation of new HDD and CDD values

In this section, after determining base temperature or in other words temperature thresholds of thermal comfort, using daily data from 1950 to 2010, the annual average of heating and cooling degree day of selected stations is calculated and results are presented in the form of Fig. 5.

As it can be seen from Fig. 4, HDD and CDD values are presented for all three proposed thresholds.

At first, by comparing required values of HDD and CDD of different stations it can be seen that in most of these stations, HDD demand is greater than the CDD demand. Based on Fig. 2 it can be seen that according to three studied temperature thresholds, the minimum required annual HDD for the Persian Gulf and Oman Sea coastal towns has been calculated that based on the fiftieth percentile (P50), Chabahar, Bandar e Abbas and Abadan stations

Table 3
Base temperature (°C). of thermal comfort range for middle 20, 50 and 80% of comfort zone.

Station	P20		P50		P80	
	Base temperature for HDD	Base temperature for CDD	Base temperature for HDD	Base temperature for CDD	Base temperature for HDD	Base temperature for CDD
Abadan	23.00	24.50	22.00	25.80	20.80	27.10
Gorgan	22.20	23.50	21.40	24.50	20.50	26.00
Tabriz	23.50	24.80	22.50	25.90	21.10	27.00
Yazd	23.10	24.70	22.00	25.90	21.00	27.00
Anzali	21.30	22.00	21.00	22.70	20.00	24.00
Ardabil	20.90	21.50	20.50	22.20	20.00	23.50
Bandar e Abbas	21.50	22.70	21.00	24.00	20.20	25.50
Chabahar	21.60	22.50	21.00	23.50	20.50	25.00
Esfahan	23.50	25.10	22.50	26.20	21.20	27.20
Kermanshah	23.10	24.60	22.00	25.80	21.00	27.00
Mashhad	23.40	25.00	22.25	26.00	21.00	27.00
Zabol	23.50	25.00	22.50	26.25	21.00	27.50

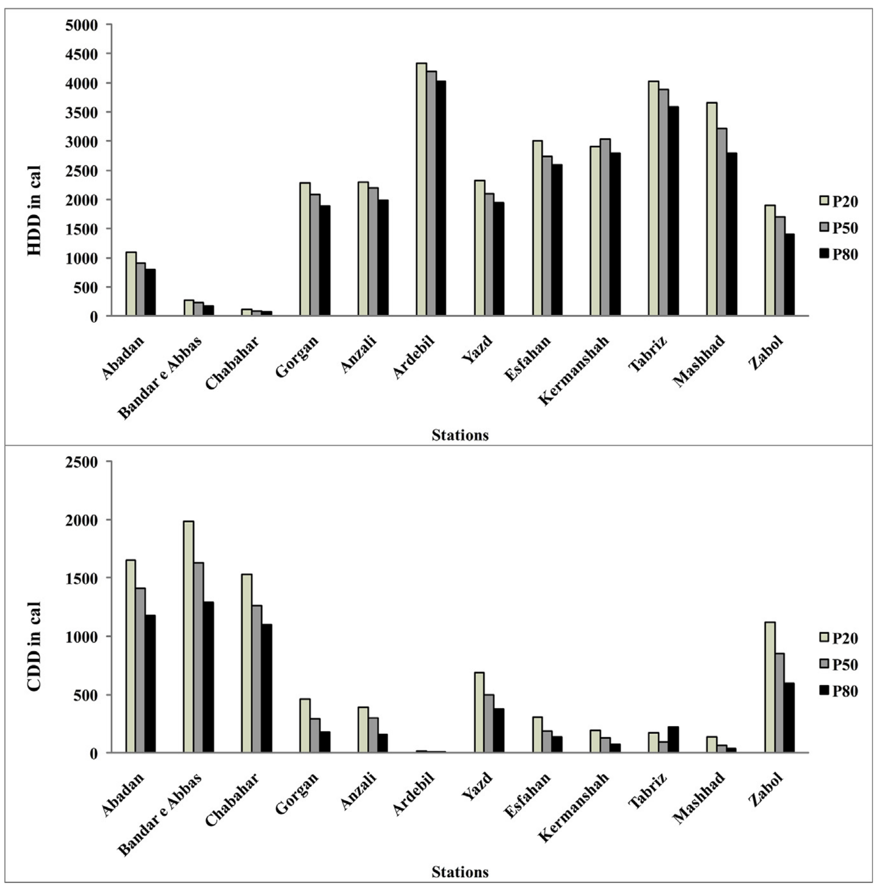

Fig. 5. The average annual heating and cooling energy requirements based on the three proposed thermal comfort scopes.

with values of 88.9, 227.6 and 905.3° day have obtained the minimum heating requirement respectively. However, based on three proposed thresholds, cities of Ardabil, Tabriz and Mashhad have the highest requirement for the heating energy that according to the Fiftieth percentile, Ardebil with 4193° day, Tabriz with 3883.4° day and Mashhad with 3221° day is in first to third places.

On the other hand, the maximum CDD requirement was calculated for Abadan (P50 = 1408CDD), Bandar e Abbas (P50 = 1632CDD) and Chabahar (P50 = 1262CDD) that after these three coastal cities of Persian Gulf and Oman Sea, two cities of (Zabol P50 = 850.6CDD) and Yazd (P50 = 497.8CDD) are ranked in the next places for cooling energy requirements. Furthermore, the findings show that the minimum cooling energy requirement for Ardebil (P50 = 7.6CDD) and Mashhad (P50 = 66.8CDD) are placed in the lowest levels compared to other stations (Fig. 5).

6. Discussion and conclusion

Iran is a country with diverse geographic and climatic conditions. Determining the thermal comfort thresholds in a hot climate is crucial for building energy efficiency and occupant productivity and well-being [53]. Therefore, this fact makes the thermal comfort ranges be different for different regions of the country. In the present study, 12 stations which are the representative of diverse climatic and topographic conditions of Iran were used. In the following, to review the thermal comfort thresholds of different regions of Iran, Olgyay diagram was used. For determining base temperatures of thermal comfort, the procedure was based on this principle that based on the percentile method, three suggested thresholds were selected and based on them, comfort zones of each station was determined. But before that considering that 12 bioclimatic classes were recognizable based on the Olgyay diagram, so the frequency of different bioclimatic classes were calculated for each observational station.

Findings of this section showed that Mashhad with 29.64% of the frequency of days in the comfort zone had the most ideal conditions of comfort compared with other stations and Anzali with 2.33% of the frequency of days had the least experience of days with thermal comfort. Among the observational stations, the most experience of freezing and frost event belonged to Ardebil and for stations of Tabriz, Kermanshah, Mashhad, Esfahan, Yazd and even Zabol; the most important inhibiting factor was the event of frost conditions. But Bandar e Abbas and Chabahar had the most experience of days with the risk of heat exhaustion and this factor is the most important inhibiting factor of comfort in these two stations. Although the most important inhibiting factor for Abadan is affected by severe dry but in Anzali, the excess of humidity is the most important inhibiting factor for not having the event of comfort. The results showed that Olgyay diagram could show climate and bioclimatic differences of different regions. For example, for the Persian Gulf and Oman Sea coastal cities, the type of data distribution showed that climatic and bioclimatic characteristics of Bandar e Abbas and Chabahar are different from Abadan. So that Bandar e Abbas and Chabahar, due to the experience of high humidity, their dominant climatic regime was affected by Persian Gulf and Oman Sea, but Abadan has also been affected by Persian Gulf and also by hot and dry systems which directly pass the Arabia land. In the following, based on the main objective of this study, new thermal comfort thresholds were proposed for all the observational stations that the findings show that according to the different percentiles, the minimum lower threshold temperature (base temperature) for providing comfort belonged to Ardebil station and the maximum higher threshold of temperature belonged to Zabol station. It is also worth noting that the sensitivity of the proposed method is so that minimum differences in the domain and base temperature of thermal comfort are visible even for stations located in a geographically similar area and it this could indicate the validity of the proposed method.

Obviously, having different based temperatures, the results of this paper is different from the previous studies in Iran. For instance, according to Mehrabi et al. (2011) [54] in providing the heating atlas of Iran, by considering 24 as the fixed temperature in calculating heating energy, the maximum difference in results is related to the P80, P50 and at last to P20. A comparison between these two studies shows that the demand for heating energy in these three thresholds in the present study is more than that of Mehrabi et al. (2011) [54] Similar results can be observed in Faraji et al. (2008) [55] and Roshan et al. (2012) [51]. In Masoudian et al. [56,57] study, to calculate the HDD index, the chosen fixed temperature is 25 °C, in comparison to the P80 based temperature of the research stations shows a great difference. While Khalili (1999) [50] and Zolfaghari et al. (2009) [58], by choosing 18 °C for calculating the heating need, the outcome of their study shows the most amount of overlap with P80. On the other hand, in some studies like Khalili (1997) [59] and Zolfaghari et al. (2009) [58], the temperature of 21 °C was chosen to evaluate the CDD. So, considering this thermal threshold, in comparison to the three suggested thresholds, more demand in cooling energy has been observed in which the least difference was related to the P20 threshold.

In total, findings of this study revealed that the maximum average annual HDD and CDD requirement belong to Ardebil and Abadan respectively. Findings of this study confirm the fact that heating energy requirement for all observational cities was higher than the need for cooling energy. Finally, as some studies suggest [60] that, in order to determine the temperature threshold, the application of thermophysiological indices should be evaluated.

References

[1] J. Bilbao, R. Román, C. Yousif, D. Mateos, A. De Miguel, Total Ozone column, water vapour and aerosol effects on erythemal and global solar irradiance in Marsaxlokk, Malta, Atmos. Environ. 99 (2014) 508–518.

[2] W.M.O, International Meteorological Vocabulary, W.M.O, No. 182, TP 91, 1991, p. 116.

[3] A. Rahimikhoob, M.R. Behbahani, M.H. Nazaifar, Estimation of cooling degree days from AVHRR data and an MIF neural network, case study: Khoozestan province of Iran, Can. J. Remote Sens. 34 (2008) 596–600.

[4] X. Zhang, E. Aguilar, S. Sensoy, H. Melkonyan, U. Tagiyeva, N. Ahmed, N. Kutaladze, F. Rahimzadeh, A. Taghipour, T.H. Hantosh, P. Albert, M. Semawi, M. Karam Ali, M. Halal Said Al-Shabibi, Z. Al-Oulan, T. Zatari, I. Al Dean Khelet, S. Hammoud, M. Demircan, M. Eken, M. Adiguzel, L. Alexander, T. Peterson, T. Wallis, Trends in middle east climate extremes indices during, J. Geophys. Res. 104 (2005) 1930–2003.

[5] F. Rahimzadeh, A. Asgari, E. Fattahi, Variability of extreme temperature and precipitation in Iran during recent decades, Int. J. Climatol. 29 (2009) 329–343.

[6] ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers), ANSI/ASHRAE Standard 55–2004. Thermal Environmental Conditions for Human Occupancy, ASHRAE, Atlanta, 2004.

[7] CEN (Comité Européen de Normalisation), 2007/BSI (British standards Institution), 2008. BSEN 15251:2007. Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. Brussels: CEN, London: BSI.

[8] A.J. McArthur, Thermal interaction between animal and microclimate: a comprehensive model, J. Theor. Biol. 126 (1987) 203–238.

[9] B.K. Armstrong, Stratospheric ozone and health, Int. J. Epidemiol. 23 (1994) 873–885.

[10] G.S. McMaster, W.W. Wilhelm, Growing degree-days: one equation, two interpretations, Agric. For. Meteorol. 87 (1997) 291–300.

[11] M. Morabito, A. Crisci, L. Cecchi, P. Modesti, G. Maracchi, G. Gensini, S. Orlandini, A biometeorological procedure for weather forecast to assess the optimal outdoor clothing insulation, Eur. J. Appl. Physiol. 104 (2008) 221–228.

[12] E. Simelton, E.D.G. Fraser, M. Termansen, T.G. Benton, S.N. Gosling, A. South, N.W. Arnell, A.J. Challinor, A.J. Dougill, P.M. Forster the socioeconomics of food crop production and climate change vulnerability: a global scale quantitative analysis of how grain crops are sensitive to dry, Food. Secur. 4 (2012) 163–179.

[13] A.B. Singh, C. Mathur, An aerobiological perspective in allergy and asthma, Asia. Pac. Allergy 2 (2012) 210–222.

[14] S.N. Gosling, E.K. Bryce, P. Grady Dixon, K.M.A. Gabriel, E.Y. Gosling, J.M. Hanes, D.M. Hondula, L. Liang, P.A. Lean, S. Muthers, S.T. Nascimento, M. Petralli, J.K. Vanos, E.R. Wanka, V. Mahillon, Glossary for biometeorology, Int. J. Biometeorol. 58 (2014) 277–308.

[15] S. Carlucci, L. Pagliano, A review of indices for the long-term evaluation of the general thermal comfort conditions in buildings, Energy Build. 53 (2012) 194–205.

[16] A.A. Ghanghermeh, Gh.R. Roshan, A.J. Orosa, J.L. Calvo-Rolle, A.M. Costa, New climatic indicators for improving urban sprawl: a case study of Tehran city, Entropy 15 (2013) 999–1013.

[17] A.J. Orosa, A.M. Costa, A.R. Fernández, Gh.R. Roshan, Effect of climate change on outdoor thermal comfort in humid climates, J. Environ. Health Sci. Eng. 12 (2014) 1–9.

[18] U. Danielsson, Wind chill and the risk of tissue freezing, J. Appl. Phys. 81 (1996) 2666–2673.

[19] Gh.R. Roshan, G. Mirkatouli, A. Shakoor, V. Mohammad-Nejad, Studying wind chill index as a climatic index effective on the health of athletes and tourists interested in winter sports, Asian. J. Sports Med. 1 (2010) 108–116.

[20] J.H. Jeong, D.H. Kim, An outdoor comfort index framework based on GIS for supporting optimal environment, Int. J. Softw. Eng. Appl. 7 (2013) 211–220.

[21] R.G. Steadman, A universal expression of apparent temperature, J. Appl. Meteorol. 23 (1984) 1674–1687.

[22] F.C. Houghton, C.P. Yaglou, Determining equal comfort lines, J. Am. Soc. Heat. Vent. Eng. 29 (1923) 165–176.

[23] C.P. Yaglou, D. Minard, Control of heat casualties at military training centers, Am. Med. Assoc. Arch. Ind. Health 16 (1957) 302–316.

[24] K. Blazejczyk, Y. Epstein, G. Jendritzky, H. Staiger, B. Tinz, Comparison of UTCI to selected thermal indices, Int. J. Biometeorol. 56 (2012) 515–535.

[25] T.M. Giannaros, D. Melas, A. Matzarakis, Evaluation of thermal bioclimate based on observational data and numerical simulations: an application to Greece, Int. J. Biometeorol. 59 (2015) 151–164.

[26] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments – application of the RayMan model, Int. J. Biometeorol. 51 (2007) 323–334.
[27] A. Matzarakis, F. Rutz, H. Mayer, Modelling radiation fluxes in simple and complex environments: basics of the RayMan model, Int. J. Biometeorol. 54 (2010) 131–139.
[28] V. Olgyay, Bioclimatic orientation method for buildings, Int. J. Biometeorol. 11 (1967) 163–174.
[29] B. Givoni, Man, Climate and Architecture, second ed., Applied science publishers, London, 1976.
[30] K. Watson, K. Labs Climate Design: Energy Efficient Building Principles and Practices, MC Grow-Hill, 1983.
[31] M. Tahbaz, Psychrometric chart as a basis for outdoor thermal analysis, Int. J. Archit. Eng. Urban. Plan. 21 (2011) 12–20.
[32] N.A. Al- Azri, H.Y. Zurigatb, N. Al-Rawahia, Selection and assessment of passive cooling techniques for residential buildings in Oman using a bioclimatic approach, J. Eng. Res. 10 (2013) 53–65.
[33] M. Petralli, L. Massetti, S. Orlandini, Five years of thermal intra-urban monitoring in Florence (Italy) and application of climatological indices, Theor. Appl. Climatol. 104 (2011) 349–356.
[34] S. Rehman, L.M. Al-Hadhrami, S. Khan, Annual, and seasonal trends of cooling, heating,and industrial degree-days in coastal regions of Saudi Arabia, Theor. Appl. Climatol. 104 (2011) 479–488.
[35] L.M. Al-Hadhrami, Comprehensive review of cooling and heating degree days characteristics over Kingdom of saudi arabia, Renew. Sustain. Energy Rev. 27 (2013) 305–314.
[36] J.C. Lam, C.L. Tsang, L. Yang, D.H.W. Li, Weather data analysis and design implications for different climatic zones in China, Build. Environ. 40 (2005) 277–296.
[37] F. Jiang, X. Li, B. Wei, R. Hu, Z. Li, Observed trends of heating and cooling degree-days in Xinjiang Province, China, Theor. Appl. Climatol. 97 (2009) 349–360.
[38] L. Cvitan, R.S. Jurković, Secular trends in monthly heating and cooling demands in Croatia, Theor. Appl. Climatol. (2015), http://dx.doi.org/10.1007/s00704-015-1534-7.
[39] M. Sivak, Potential energy demand for cooling in the 50 largest metropolitan areas of the world: implications for developing countries, Energy Policy 37 (2009) 1382–1384.
[40] T. Zachariadis, Forecast of electricity consumption in Cyprus up to the year 2030:The potential impact of climate change, Energy Policy 38 (2010) 744–750.
[41] Ö. Dombayc, Degree-days maps of Turkey for various base temperatures, Energy 34 (2009) 1807–1812.
[42] Z. Yildiz, B. Sosaoglu, Spatial distributions of heating, cooling, and industrial degree-days in Turkey, Theor. Appl. Climatol. 90 (2007) 249–261.
[43] S.E.N. Zekai, Kadiog Lu, M.I. Lu, Heating degree-days for arid regions, Energy 23 (1998) 1089–1094.
[44] A. Matzarakis, K. Balafoutis, Heating degree-days over Greece as an index of energy consumption, Int. J. Climatol. 24 (2004) 1817–1828.
[45] K. Papakostas, T. Mavromatis, N. Kyriakis, Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece, Renew. Energy 35 (2010) 1376–1379.
[46] K.P. Moustris, P.T. Nastos, A. Bartzokas, I.K. Larissi, P.T. Zacharia, A.G. Paliatsos, Energy consumption based on heating/cooling degree days within the urban environment of Athens, Greece, Theor. Appl. Climatol. 122 (2015) 517–529.
[47] J. Riazi, Climate and Comfort in Building, Center of Houses and Building Researches, Iran, Tehran, 1977.
[48] M. Razjooyan, Comfort with Using Climate Adaptable Architecture, Tehran University, 1988, p. 285.
[49] M. Kasmaii, Climate and Architecture, Tehran Baztab Press, 1993, p. 230.
[50] A. Khalili, Three dimensional analysis of heating and cooling degree days in Iran, Geogr. Res. 54–55 (1999) 7–18 (in Persian).
[51] Gh.R. Roshan, J.A. Orosa, T. Nasrabadi, Simulation of climate change impact on energy consumption in buildings, case study of Iran, Energy Policy 49 (2012) 731–739.
[52] F. Taqavi, Linkage between climate change and extreme events in Iran, J. Earth. Sp. Phys. 36 (2010) 33–43.
[53] S. Attia, S. Carlucci, Impact of different thermal comfort models on zero energy residential buildings in hot climate, Energy Build. 102 (2015) 117–128.
[54] M. Mehrabi, A. Kaabi-Nejadian, M. Khalaji Asadi, Providing a heating degree days (HDDs) atlas across Iran entire zones, World Renewable Energy Congress 2011-Sweden, 8–13 May 2011, Linkoping
[55] A. Faraji, M. Zahedi, A.A. Rasulei, Degree-day zoning, the need for cooling and heating energy in Azarbayjan region, in the geographic information system, Res. Phys. Geogr. 66 (2008) 8–22 (In Persian).
[56] S.A. Masoudian, R. Ebrahimi, M. Mohammadei, Spatiotemporal zoning, the annual and seasonal cooling and heating need in Iran, Sci. Res. Quart. Geogr. Data (SEPEHR) 23 (2014a) 33–46 (In Persian).
[57] S.A. Masoudian, R. Ebrahimi, E. Yarahmadei, Spatiotemporal analysis of the monthly procedure of degree-day heating in Iran territory, J. Geogr. Reg. Dev. Res. 23 (2014b) 18–27 (In Persian).
[58] H. Zolfaghari, R. Hashemei, P. Radmehr, Analysis of the heating and cooling needs in the North West of Iran, Phys. Geog. Res. 70 (2009) 21–34 (In Persian).
[59] A. Khalili, Three dimensional variation of annual long term temperature averages in Iran, J. Nivar 29 (1997) 1–13 (In Persian).
[60] D. Constantinescu, S. Cheval, G. Caracaş, A. Dumitrescu, Effective monitoring and warning of urban heat island effect on the indoor thermal risk in Bucharest (Romania), Energy Build. 127 (2016) 452–468.