Shahid Beheshti University

Sustainable Earth Review

Journal homepage: http://sustainearth.sbu.ac.ir

Assessing residences' climatic compatible comfort approach to low-cost low energy consume strategies (Case study: Qazvin city, Iran)

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ABSTRACT

Climatic conditions inside and outside of the buildings are one of the most influential factors affecting human comfort. Considering the increase in population, pollution, and energy crises, providing climatic comfort conditions inside the building is a significant issue. compatibility with the climate and consuming less energy is the right approach to overcome this crisis. The purpose of the present study is to investigate the climatic comfort conditions and optimize energy consumption (approached to zero-energy strategies) in buildings of Qazvin city, Iran. The data of 29 climatic parameters of the Qazvin synoptic station were used during the statistical period of 2000-2020. The climatic comfort range of Qazvin city was checked. Then, climatic-compatible comfort conditions and optimization of energy consumption in the buildings were analyzed with four different comfort models. The results showed which months have comfortable or uncomfortable conditions in each of the studied parameters. The examination indicates that approach to ASHRAE 55 comfort, Comfort 2013, Adaptive comfort, and ASHRAE 2005 model, respectively, 12.4%, 9%, 9.2%, and 7.2% of the year (1085, 785, 810, and 632 hours), the buildings of are within the natural comfort range. The zero-energy design strategies i. e. Small well-insulated skylight windows, minimize or eliminate west-facing glazing, efficient natural ventilation, low-pitched roofs with wide overhangs, etc. enhance residences' climatic compatible comfort. The results of the comparison of climate-compatible comfort strategies with existing situations suggested that the high energy consumer, costly ineffectiveness utilities, and building design are used to supply the residents' comfort.

ARTICLE INFO

Keywords:
Climatic comfort
Comfort models
Design strategies
Qazvin
Zero-energy

Article history:
Received: 10 Mar 2023
Accepted: 24 May 2023

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Citation:
Freidooni, F. et al., (2023). Assessing residences' climatic compatible comfort approach, *Sustainable Earth Review:* 3(3), (45-64).

DOI: 10.48308/SER.2023.234143.1032

1. Introduction

Throughout history, human beings and nature have interactions, and the climate and how to master it, have been the most crucial concern in the way of creating biological colonies (e. g. cities, rural, etc.) (Freidooni et al., 2022). In several last decays, along with global warming and the worldwide beginning of the energy crisis, strives for reducing energy consumption to provide residences comfort have been paid attention significantly, especially in the field of construction and buildings' energy functionality improvement0 (Barger et al., 1998; Maier et al., 2009; Nasrollahi et al., 2017; Luo et al., 2018; Hashemi Rafsanjani and Heidari, 2018; Abdollahzadeh et al., 2021; Freidooni et al., 2021; Mokhtari et al., 2022; Zheng et al., 2022; Raimundo et al., 2022; Wang et al., 2023; López-Pérez and Flores-Prieto, 2023). It is clear that relevant designing and construction of elements and components of a building may lead to the reduction of energy consumption and, reduction of negative consequences for environmental and economic saving during the life-cycle of the building (Yang et al., 2017).

Due to predicted short and long-term heat waves (Freidooni et al., 2015)0, thermal comfort is one of the most important types of comfort for users of a building. In fact, it can be said that this is the main prerequisite for creating other comforts (e. g. relationships, life standards, mental comfort, etc.) in a building. This is intensified in very cold, hot, dry, or humid climates having irritative climatic factors, and the designers should look for approaches to reduce the intensity of these factors, to reach an acceptable level of comfort. Several studies (Nicol et al., 2002; Nguyen et al., 2012; Martilli, 2014; Attia and Calucci, 2015; Goia, 2016; Takasu et al., 2017; Yang et al., 2017; Singh et al., 2018) have been conducted for this purpose which some of them will be discussed following. Alghoul et al. (2017) and Misiopecki et al. (2018) studied the effects of windows' position on energy consumption. The results showd that energy consumption increased by 6 to 181% and decreased up to 50% according to windows position, respectively. Shaeri et al. (2018) and Eskandari et al. (2018) studied the effect of terraces on the thermal comfort of rooms in traditional houses. The results indicate that the south side is the best position to use the terrace. Using terraces in mild and humid, hot and humid, cold and mountainous, and hot and dry climates can reduce energy consumption in buildings by 32%, 26%, 14%, and 29%, respectively. Shaeri et al. (2019) studied the window-to-wall area optimal ratio in buildings in hot, humid, hot and dry, and cold climates of Iran, and found that the optimal ratio is 20 to 30 percent in the north facade of buildings for all climates. Ziarani and Haghighi (2019) investigated the performance of a radiant cooling ceiling system in a room under direct solar radiation by a combination of numerical and analytical solutions. Assessments are implemented in four distinct climates in Iran which include Tabriz (dry and cold), Tehran (mild and dry), Rasht (mild and humid), and Yazd (dry and hot) in the hottest hour of the hottest day of the year 2017. Results demonstrate that by using coated glass, energy usage can be reduced by 49–58%. Furthermore, changing the room's orientation from west to south can boost the energy saving. Ziaei and Valinejad (2022) 0analyzed the optimization of daylight performance and thermal comfort in classrooms in Tehran and Sari (Iran). The results show that the use of a louver curtain in Tehran with a lower sky cover than Sari is more effective in terms of providing daylight and thermal comfort, especially where the window-to-wall ratio is higher. Yan et al. (2022) evaluated the thermal response and thermal comfort of the split air conditioned in residential buildings. The results showed that the operating mode of split air-conditioned buildings does not affect occupants' thermal adaptive ability. Adaptive models can be used for evaluation when outdoor temperature is below 30°C. De Masi et al. (2023) studied the incidence of windows design on energy and visual comfort under climate change. The case study is an office building located in a representative European climate. The results show that the cooling load will increase by 40%–79% and the heating load will decrease by 15%–71% by 2090. Murathan and Manioğlu (2024) evaluated annual heating, cooling, and total energy consumption and indoor environment comfort conditions in the zones applying Phase Change Material (PCM) on the building envelope and inner walls and inner floors using the Energy Plus simulation tool. The study was done for Istanbul representing a temperate humid climatic zone and for Diyarbakir representing a hot-dry climatic zone in the same degree-day region. The total energy load of the building was reduced by 11.96% and 9.69% in Istanbul and Diyarbakır respectively. Operative temperature values in the zones changed by 1.04 °C – 3.32 °C in Istanbul and by 0.87 °C – 1.16 °C in Diyarbakır with the PCM application contributing to the improvement of indoor comfort conditions. Based on the literature review it can be resulted that the main objective of previous studies has been concentrated on optimizing the design (to provide climate comfort) of some parts of a building (e. g. windows, balconies, etc.) using a few climatological parameters. Even though these valuable studies assessed a few senses of interior comfort, many aspects of lessening energy consumption, ignoring costly utilization, and providing natural climatic compatible residents' comfort are neglected. On the other hand, some practical energy models are presented which is useful for understanding their efficiency. Although previous studies answered to many questions about the fundamental and practical significances of energy consumption and residences' comfort, but some scientific gaps still remained that should be filled. How climatological parameters can affect climate-compatible buildings' design? What changes in design strategies are happened when different energy comfort models are applied? How residences' natural comfort is affected by climatological parameters? And the main question of "How can enhance the residences' comfort using zero-energy approaches?" To fill the above gaps of science, four different energy comfort models i. e. ASHRAE 55, Comfort model 2013, Adaptive model, and ASHRAE 2005 dealing with Qazvin synoptic station, Iran data are conducted (ASHRAE Standard 55, ASHRAE Standard, 2004; ASHRAE handbook of fundamentals, 2005; ASHRAE handbook of fundamentals, 2017; California Energy Code, 2008; de Dear et al., 2001, 2002; Nicol, 1993; Nicol et al., 2017).

2. Material and Methods

2.1. Climate data and case study

According to Fig. 1 Qazvin city (Fig. 1(c)) is one of the cities of Qazvin province (Fig. 1(c)) in Iran (Fig. 1(a, b)). Qazvin is located at a distance of 150 km from the capital of the country in the northwest region of Iran. According to the national division map, there are five central districts of Roodbar Alamoot, Roodbar County, Tarom Sofla, and Koohin. Also, seven cities of this County are Qazvin, Eqbaliyeh, Mahmudabad-e Nemooneh, Moallem Kelayeh, Razmian, Sirdan, and Koohin. Qazvin County occupies more than a third of 15,805 km^2 area of the province, i.e., 5,693 km^2. This County is in 49 to 51 longitudinal east degree and 36 to 37, latitudinal north degree in 1278 altitude from the sea level. It is a cold and mountainous city. Its annual precipitation is 318mm and average temperature is 26C°. In the northern area of Qazvin, there are the Alborz mountains. Its southern and eastern regions are surrounded by a relatively flat plain. In the present study, the following parameters of Qazvin station during the statistical period of 2000-2020 have been considered: rainy, snowy, glacial, and dusty days, total sunny hours and sunny days, days with eyesight less than 2km, average minimum and maximum temperature, the lowest and highest temperature, average temperature, dry-bulb temperature, dew point temperature, average relative humidity of 03, 09, and 15, relative humidity, 0 to 2, 3 to 6 and 7 to 8 cloudy days, wind speed, mild wind, precipitation more than 1 and 10 mm, average precipitation, maximum precipitation in 24 hours, vapor pressure of saturated water, station pressure.

2.2. Comfort models

California Energy Code Comfort Model, 2013 is introduced by the Psychrometric chart with parallel sides defined by the comfort low and comfort high dry bulb temperatures. The Comfort 2013 model says that to size space conditioning equipment the indoor design temperatures shall be 20°C (68°F) for heating to 23.9°C (75°F) for cooling. The Code gives no guidance for comfortable levels of humidity (California energy code, 2008). The ASHRAE 55 is also known as the PMV (Predicted Mean Vote) model. It is an experimentally derived algorithm that considers dry bulb temperature, humidity, air velocity, and metabolic activity. It has two comfort zones for summer and winter clothing and the slightly sloped temperature limits account for the fact that in dryer air people are more comfortable at slightly higher temperatures (ASHRAE Standard 55, 2004). The Adaptive Comfort model applies in naturally ventilated spaces where people can open and close windows. Indoor conditions are acceptable when average outdoor air temperatures are between 50° F and 92° F, and when indoor temperatures can be held within a specified 10-degree indoor operative temperature range (de Dear and Brager, 2001, 2002; Nicol, 1993; Nicol et al., 2017). This model does not apply when a building's heating system is in operation. It does not apply if there is an air conditioning system. It assumes that people will adapt their clothing to the climate (1.0 to .5 Clo) and that they are engaged in sedentary activities such as reading (1.0 to 1.1 Met). The Adaptive comfort model considers natural ventilation. The temperatures are defined by slightly sloped lines that account for the effect of humidity on comfort.

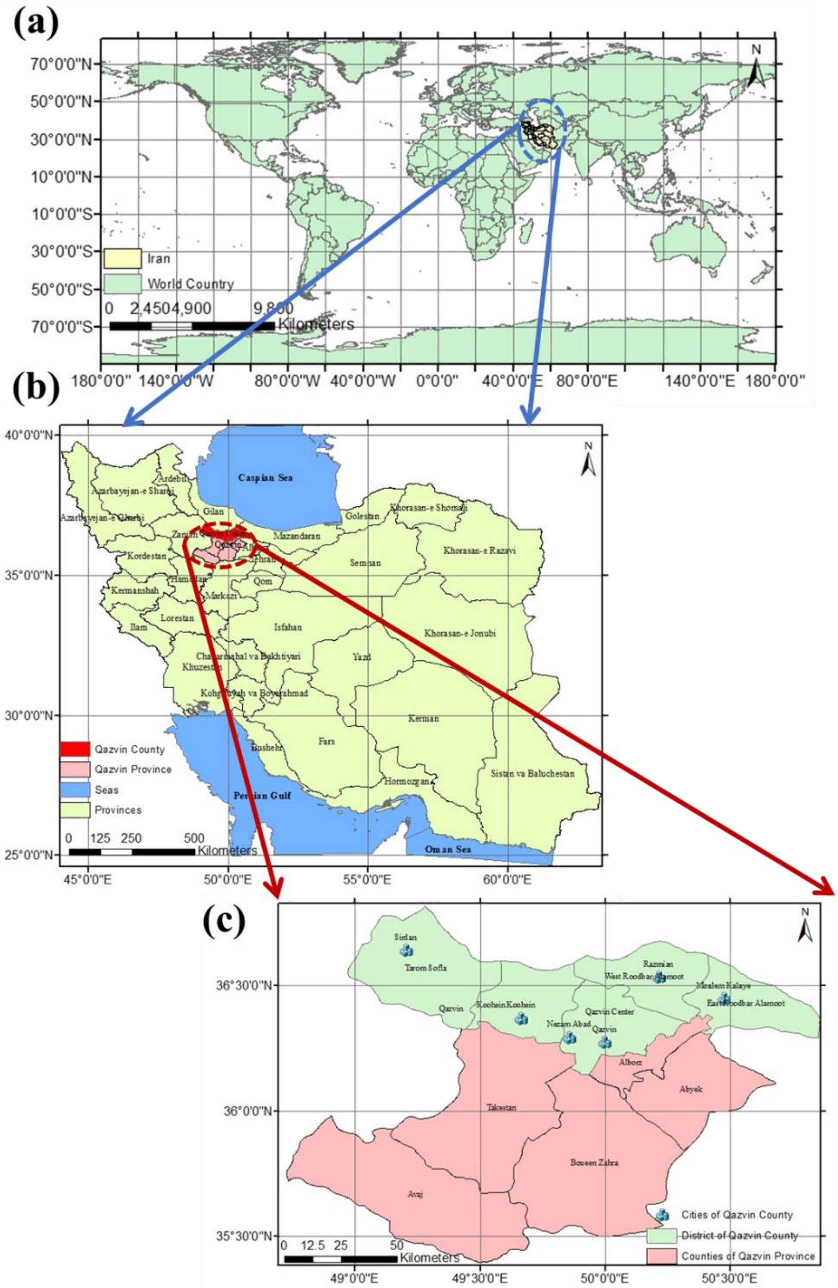

Fig. 1. (a) Iran location on the world map; (b) Qazvin province location on Iran map; (c) Qazvin province map.

3. Results and discussion

3.1. Climate data analysis

In the following, the climatic comfort zone of Qazvin city was analyzed by Climate Consultant software, First. Then, to determine the comfort conditions criteria, four climatic comfort models have been applied which were mentioned previously. In order to analyze the climatic comfort zone of Qazvin city, the hourly climatic data of Qazvin meteorological station during the statistical period (2000-2020) were introduced into the Climate Consultant software, and the graphs of wind speed, wet-bulb temperature, dry-bulb temperature, temperature changes, sky cover and the daily path of the sun were extracted. Plotted charts are presented in Figs. 2-6. Fig. 2 shows annual- and monthly-averaged temperature range (˚C) (Fig. 2 (a)), monthly-averaged (per hour) dry bulb temperature (˚C) (Fig. 2 (b)), and monthly-averaged (per hour) wet bulb temperature (˚C) (Fig. 2 (c)). the range of temperature changes according to November, December, January, February, and March are not within the comfort zone. The hourly-averaged (per month) temperature of June and September is within the comfort zone. Sometimes, the hourly temperature of April, May, July, August, and October is within the comfort zone. Fig. 2 (b) shows 16% of monthly-averaged (per hour) dry-bulb temperature stay between 24 and 38 ˚C in June, July, August, and September. 14% of monthly-averaged (per hour) dry-bulb temperature stay between 18 and 24 C° are observed in May, June, July, August, September, and October. The highest frequency of dry-bulb temperature less than 0° occurs between 8 Pm and 8 Am in December and January. The dominant dry-bulb temperature has a frequency of 57% and its temperature is between 0 and 18 C°. Fig. 2 (c) shows that 23% wet-bulb temperature of hours of the year (per month) is below 0 C°, mainly in November, December, January, and February. At midnight, 75% of wet-bulb temperature data is between 0 and 18 C° and 2% is between 18 and 24 C° in July.

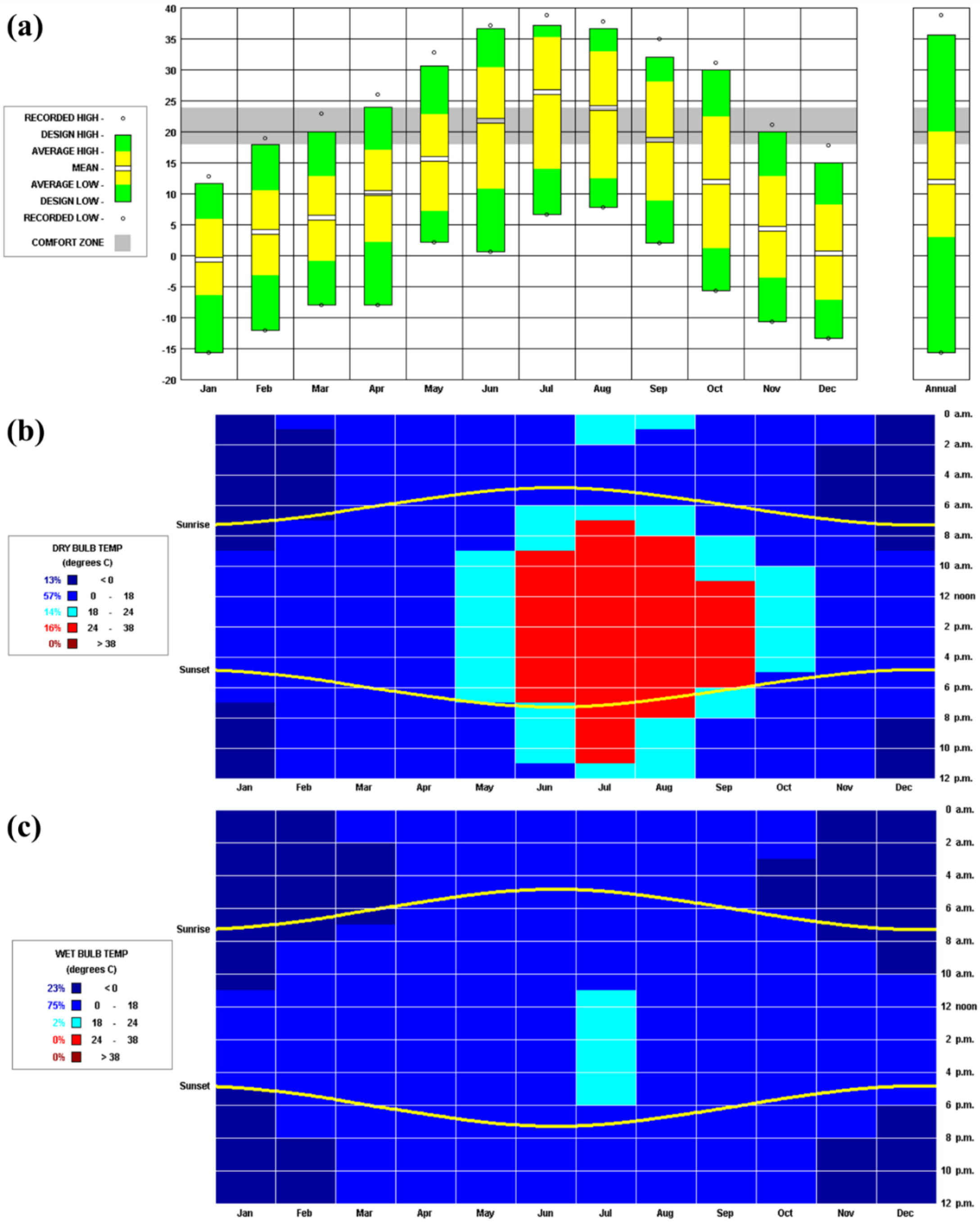

Fig. 2. Qazvin, Iran synoptic station: (a) annual- and monthly- averaged temperature range (˚C); (b) monthly-averaged per hour dry bulb temperature (˚C); (c) monthly-averaged per hour wet bulb temperature (˚C).

Fig. 3 indicates hourly changes per month of dry-bulb temperature (yellow dot) versus relative humidity (green dot) and comfort zone (gray-shaded region). In May, September, and October, both parameters of dry-bulb temperature and relative humidity are in the comfort zone during some hours of the day. According to these parameters, there are no comfort conditions in November, December, January, February, and March. The maximum comfort time is observed between 9 Am to 8 Pm (Fig. 3).

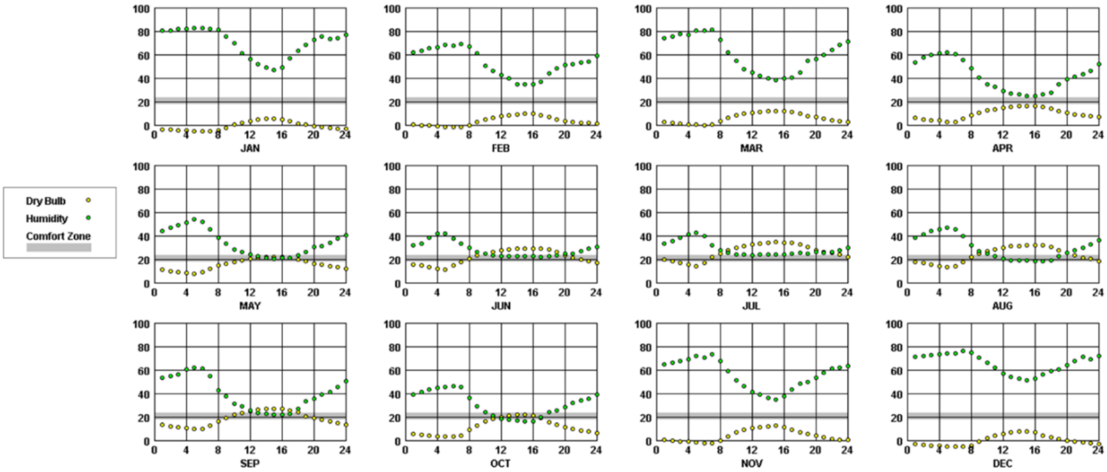

Fig. 3. Qazvin, Iran synoptic station: hourly change per month of dry bulb temperature (yellow dot) versus relative humidity (green dot) and comfort zone (gray shaded region).

Fig. 4 depicts monthly-averaged radiation (Wh/m^2) (Fig. 4(a)), annual- and monthly-averaged total cloud cover (%) (Fig. 4(b)), and monthly-averaged per hour sky cover (%) (Fig. 4(c)). From Fig. 4(a) the radiation comfort zone varies between 760 and 890 Wh/m^2. The maximum of global horizontal radiation in May, June, August, and September is in the comfort zone; but in July, the maximum of the mentioned phenomenon is more than the maximum radiation comfort limit. Diffuse and direct vertical radiations are below the comfort zone most of the year. According to Fig. 4(b), the average cloud cover in March and July compared to the other months has the highest and the lowest values, respectively. In spring, compared to autumn, more cloud cover is observed in Qazvin station. Pursuant to Fig. 4(c), the highest frequency of sky covers equal to 38% of total hours (annual-averaged) can be found in all months with 30-60% sky coverage except in the summer. The lowest sky cover with 2% frequency is observed between 08:00 to 12:00 in July with the coverage less than 10% of the sky. The sky cover is between 60-80% in December, February, March, April, and May. Fig. 5 demonstrates annual- and monthly-averaged wind speed range (m/s) (Fig. 5(a)) and monthly-averaged per-hour wind speed (m/s) (Fig. 5(b)). The annual-averaged wind speed is between 3 and 5 m/s (see Fig. 5(a)). The highest average wind speed is observed in May and June (between 5 and 9 m/s) and the lowest one is in January (below 2 m/s). The highest frequency of wind with a velocity of 3 to 5 m/s is calculated in the first six months of the year between 19:00 and 09:00, and in the second six months, between 11:00 and 24:00 o'clock (Fig. 5(a-b)). Sun shading chart at summer-fall seasons (Fig. 6(a)) and winter-spring seasons (Fig. 6(b)) are represented in Fig. 6. At summer and fall (Fig. 6(a)) seasons totally 1216 hours represented warm or hot radiation, 470 hours of radiation is in the comfort zone and 912 hours of radiation is below the comfort condition. In June and July, the radiation is in the warm or hot region from 07:00 to sunset, but from August, the radiation has gradually decreased from above the comfort level to the below comfort level in November and December. In October, the most radiation comfort conditions are found. Fig. 6(b) represents 348 hours of warm or hot radiation, 389 hours of radiation within the comfort zone, and 1775 hours of radiation below the comfort limit. The radiation conditions are below the comfort limit in December, January, February, and most of March. April and May have the most hours of comfort. Most of the times, comfort is observed between 09:00 and sunset.

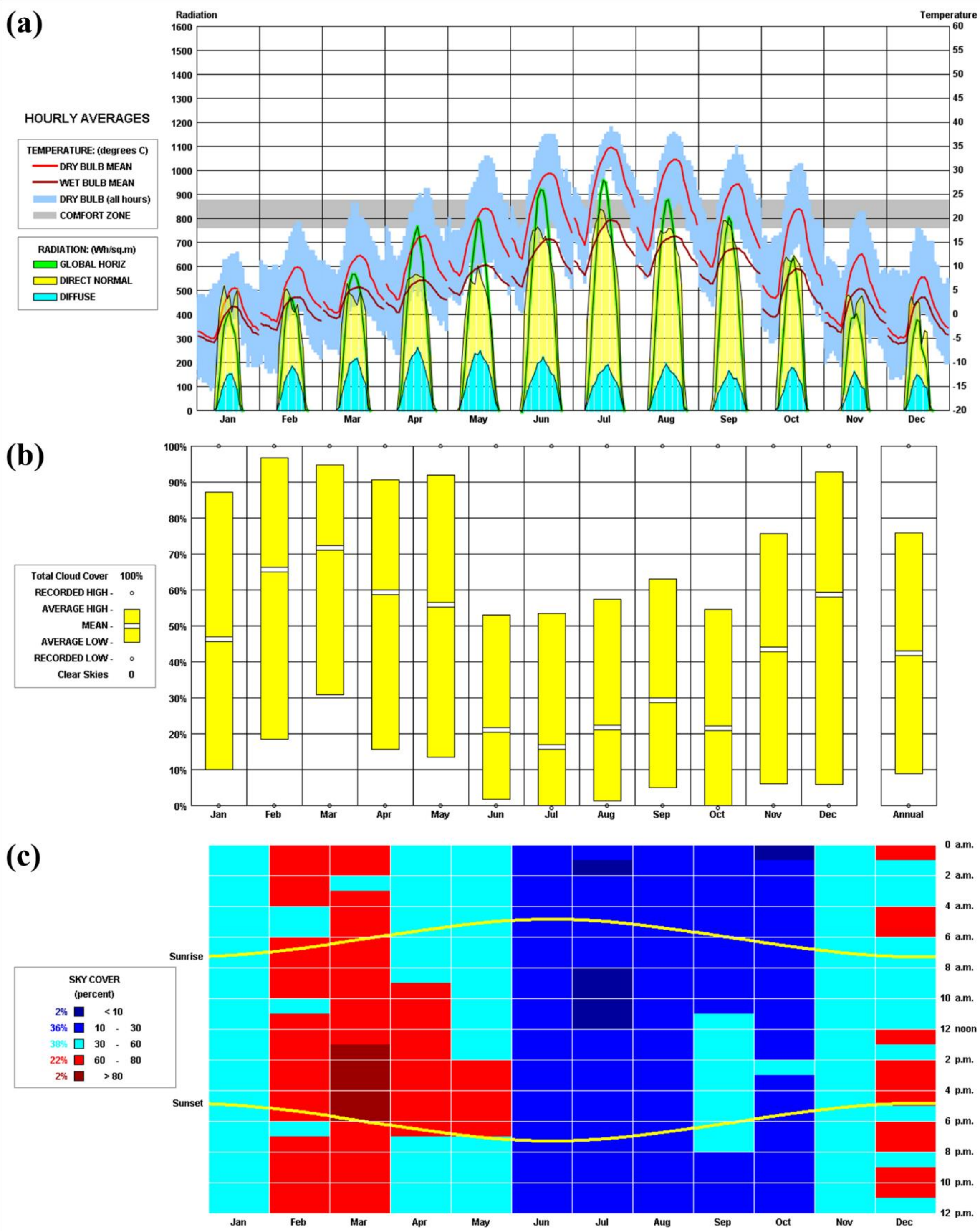

Fig. 4. Qazvin, Iran synoptic station: (a) monthly-averaged radiation (Wh/m^2); (b) annual- and monthly-averaged total cloud cover (%); (c) monthly-averaged per hour sky cover (%).

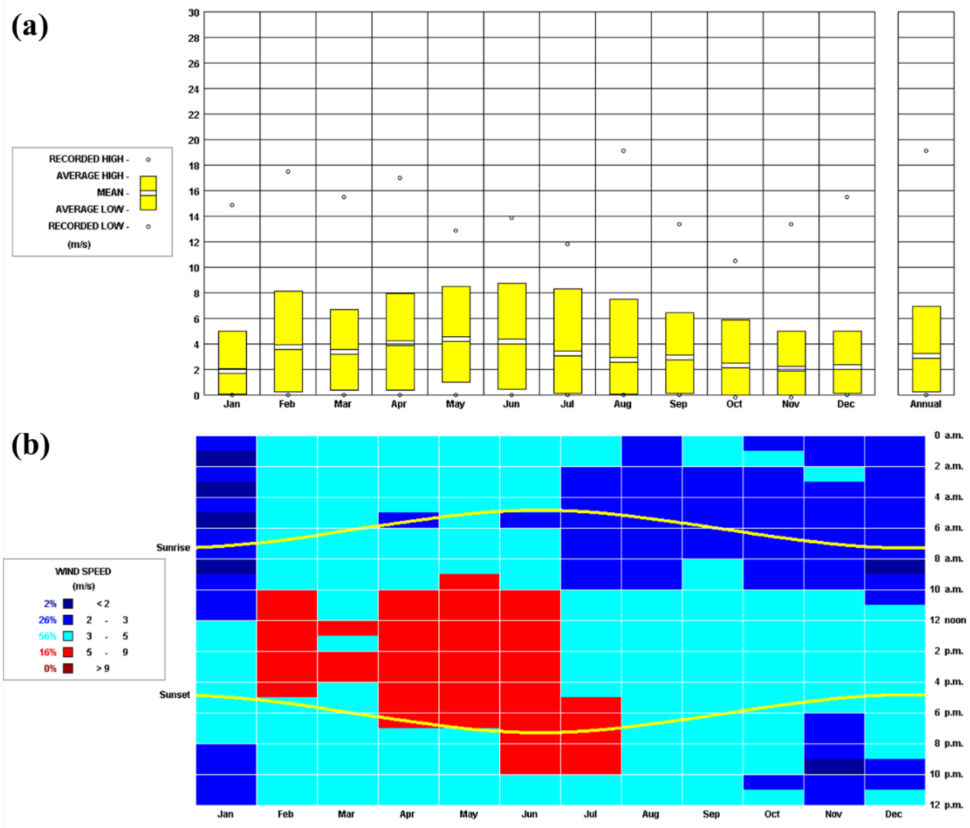

Fig. 5. Qazvin, Iran synoptic station: (a) annual- and monthly-averaged wind speed range (m/s); (b) monthly-averaged per hour wind speed (m/s).

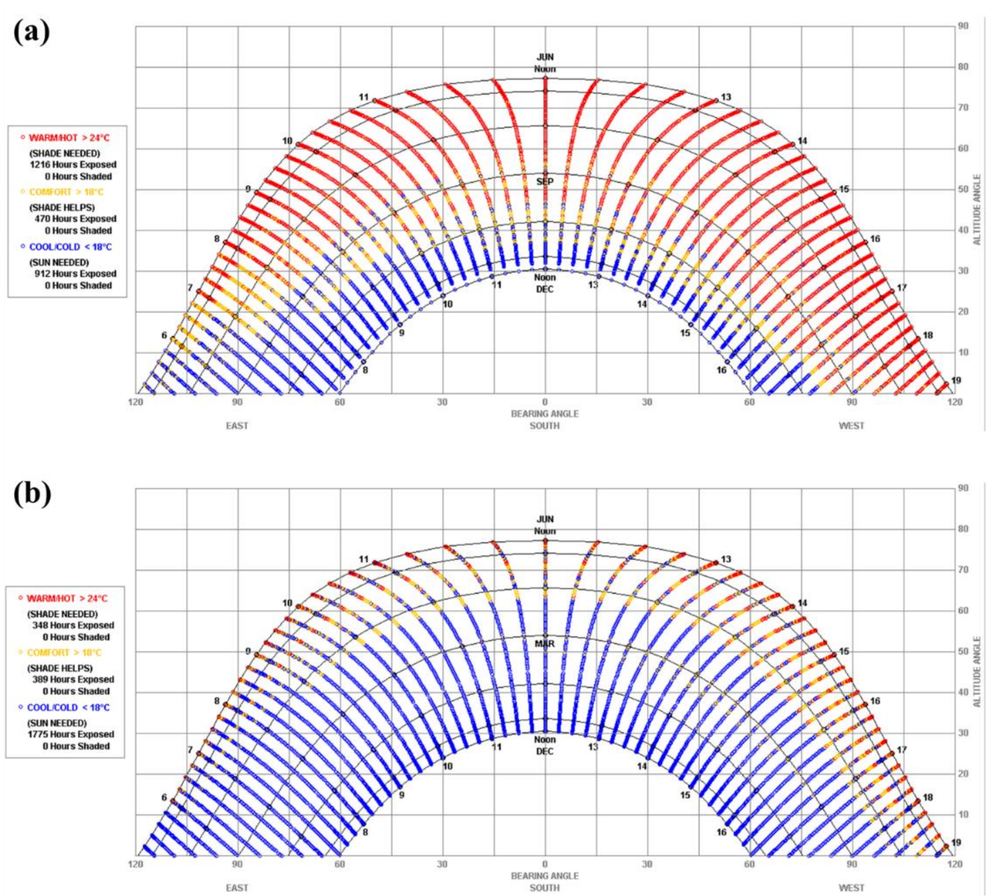

Fig. 6. Qazvin, Iran synoptic station: sun shading chart (a) summer-fall; (b) winter-spring.

3.2. Climate comfort condition analysis based on four different comfort models

To analyze the climate comfort conditions of Qazvin city and design the buildings compatible with the regional climate and optimal energy consumption, using climate consultant software and four different climate comfort models, California comfort Energy Code Model 2013, ASHRAE Standard Comfort Model 55, ASHRAE 2005, and the Adaptive Climate Comfort Model 2010 the climatic comfort zone of Qazvin station are drawn on the psychrometric chart only by considering the climatic parameters in Fig. 7. Approach to ASHRAE 55 (Fig. 7(a)), Comfort 2013 (Fig. 7(b)), adaptive model (Fig. 7(c)), and ASHRAE 2005 (Fig. 7(d)), 12.4, 9, 9.2, and 7.2% of annual hours (1085, 785, 810, 632 hours), respectively, the environmental climate conditions are normally within the comfort zone. The difference between the two ASHRAE 55 and ASHRAE 2005 models with the other two models is in the division of the comfort zone into summer and winter modes. Accordingly, in the two mentioned models, comfort zone changes as a function of clothing, metabolic temperature, and type of activity.

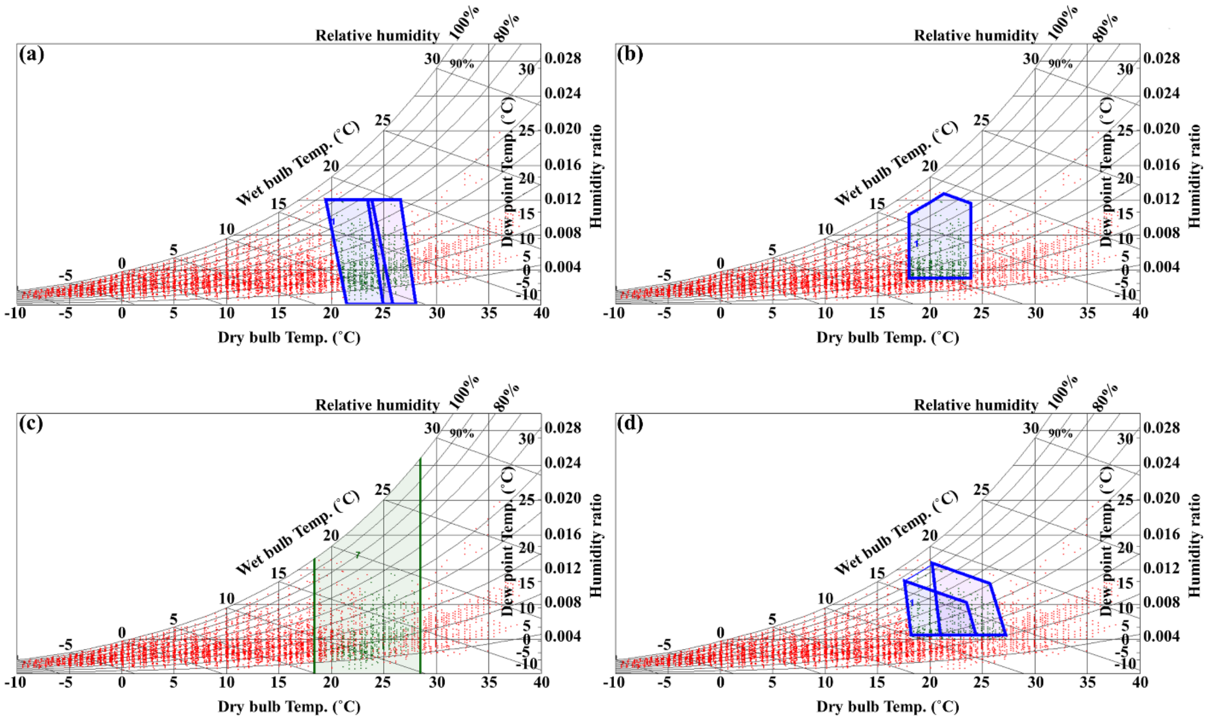

Fig. 7. Natural comfort zone (percentage per year or number of hours per 8760 hours (one year)), Qazvin province based on (a) ASHRAE 55 model (12.4% or 1085 h); (b) Comfort 2013 model (9% or 785 h); (c) Adaptive model (9.2% or 810 h); (d) ASHRAE 2005 model (7.2% or 632 h);

3.3. Analysis of climate comfort condition enhancement by zero-energy methods (natural air conditioning)

Five methods of using sun shading of windows, materials with high thermal mass, materials with high thermal mass night flushed, natural ventilation cooling, and wind protection of outdoor spaces have been analyzed to achieve zero-energy methods (natural air conditioning). Fig. 8 demonstrates the enhancement of climatic comfort conditions with zero-energy methods considering above mentioned comfort models.

Table 1 shows the contribution of each method in providing comfort conditions in terms of percentage and number of hours, to review and analyze five zero-energy methods in four mentioned models. In some methods, overlapping the zero-energy methods is obvious in the psychrometric chart; so, considering the mentioned overlaps, the calculation of the final percentage of comfort has been performed.

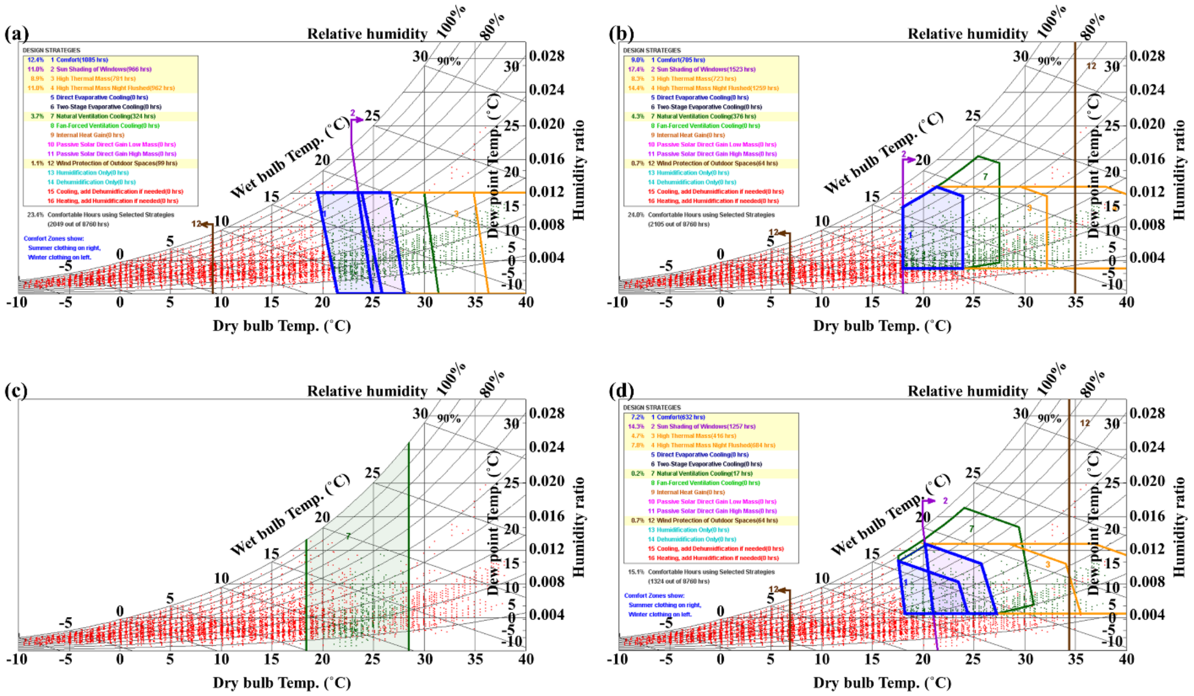

Fig. 8. improvement of climate comfort approach to zero-energy methods, Qazvin province based on (a) ASHRAE 55 model; (b) Comfort 2013 model (9% or 785 h); (c) Adaptive model (9.2% or 810 h); (d) ASHRAE 2005 model (7.2% or 632 h).

Table 1. The contribution of zero-energy methods in providing comfort conditions

Model	ASHRAE 55		Comfort 2013		Adaptive		ASHRAE 2005	
Method	%	h*	%	h	%	h	%	h
Provided comfort	23.4	2049	24.0	2105	9.2	810	15.1	1324
Sun shading of windows	11.0	966	17.4	1523	0	0	14.3	1257
High thermal mass	8.9	781	8.3	723	0	0	4.7	416
High thermal mass night-flushed	10.99	962	14.4	1259	0	0	7.8	684
Natural ventilation cooling	3.7	324	4.3	376	0	0	0.2	17
Wind protection of outdoor spaces	1.1	99	0.7	64	0	0	0.7	64

* Hours denoted with "h".

The results of Table 1 show that, sun shading of windows plays a crucial role in comfort conditions due to covering the maximum values of total hours among other methods. After that, using high thermal mass night-flushed has significant effects on comfort conditions.

3.4. Climate comfort conditions and optimal design strategies based on ASHRAE 55 model

Fig. 9 represents the psychrometric diagram of optimal design strategies for air conditioning and building construction based on the lowest energy consumption to ensure residents' thermal comfort considering the criteria of the ASHRAE 55 model.

Considering the minimum use of high energy consumption and costly (i. e. Dehumidification devices) systems, the best design strategies for building plans and air conditioning in the climate of Qazvin city based on the ASHRAE 55 model, include sun-shaded windows, materials with high thermal mass night flushed, evaporative cooler, considering indoor thermal loads, Passive solar direct gain high mass (materials), wind protection of outdoor spaces, cooling and heating along with dehumidification and humidification (if needed). But it is quite clear that, the use of cooling and dehumidification systems such as gas coolers and other refrigeration systems (e.g. chillers) except evaporative coolers is not necessary, because it contributes only 16 hours a year in providing comfort. The highest rate of energy consumption in this climate is related to heating and humidification (if needed). Also, the great influence of passive heating and considering indoor loads is evident in providing comfort conditions.

In the following, building design strategies are proposed based on climatic conditions according to the criteria of the ASHRAE 55 model to achieve the mentioned conditions.

According to the Figs. 10-11 and the criteria of the ASHRAE 55 model in Qazvin city, strategies can be presented for the construction of climate-compatible buildings. These strategies for optimizing energy consumption are as follows Figs. 10.

If the ground floor is used for living, its foundation should be constructed at least half a meter below the glacial level and insulation should be used inside and outside of the building (Fig. 10(a)). Extra insulation may be cost-effective and increases the residents' comfort by prevailing a more uniform indoor The building plan design should be in such a way that the sunlight (solar radiation) permeates inside during the day in winter (Fig. 10(d)). Therefore, spaces must be aligned with the solar radiation direction. Reducing and removing the radiations of the western façade (Fig. 10(e)) reduces heat gain in the evenings of summer and early autumn. This is possible by creating green areas (i. e. green walls, vegetation, etc.). Screened porches and patios may provide passive cooling comfort using ventilation, which is very useful in hot climates also prevents the entry of annoying insects. Shading prevents heat and temperature from being increased. The open area in the summer is considered as recessing factor, and in the winter, passive solar heating can be used. Using vegetation (Fig. 10(d)), especially on the west temperature (Fig. 10(b)). Using well-insulated small roof windows (Fig. 10(c)) increases the rate of light energy and decreases cool loads during the day (the area of these roof windows is less than 3% of the floor area in dry climates and 5% in rainy and cloudy climates). The heat transfer can be reduced from 10% to 6% by 20 cm of insulation between the columns in the central walls. Using building materials with light colors and cool roofs minimizes the conduction heat transfer. Using high reflective materials minimizes the amount of heat received by the roof in the summer. The use of low-pitched gabled roofs and wide canopies is also proposed for this region.

side of the building, reduces heat gain from the western sun radiation.

In high-mass well-made walls, insulation should be placed on the exterior, heavy materials should be placed interior, and finishing should be performed on it (Fig. 11(c)). Interior surfaces with higher thermal mass are considered colder than other surfaces on hot days; so, they reduce the variations of day and night temperature (Fig. 11(d)). The placement of doors and windows on two opposite sides with large openings facing the wind enables natural ventilation. If the windows are well-shaded and their direction is in line with the desired winds; appropriate and effective natural ventilation can reduce or eliminate the use of air conditioning systems (Fig. 11(e-f)).

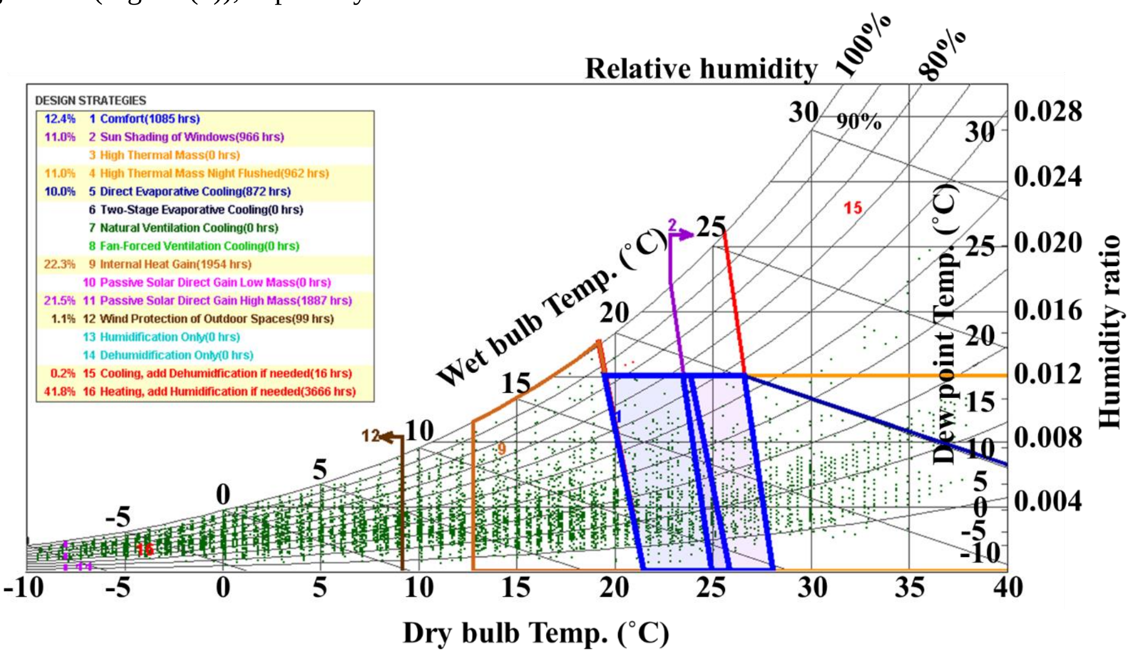

Fig. 9. Psychrometric diagrams of optimal design strategies for prevailing comfort based on the ASHRAE55 model.

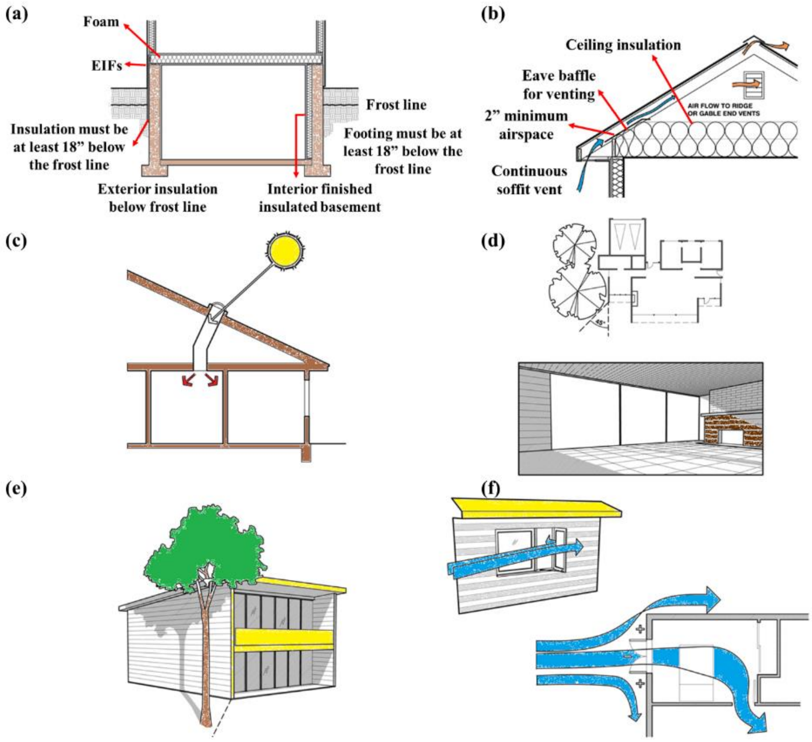

Fig. 10. Climate-compatible design solutions based on ASHRAE 55 (a) is used it must be at least 18” below frost line and insulated on the exterior (foam) or the interior (fiberglass in furred wall); (b) Extra insulation might prove cost-effective, and will increase occupant comfort by keeping indoor temperature more uniform; (c) Small well-insulated skylights windows (less than 3% of floor area in clear climate, 5% in overcast) reduce daytime lighting energy and cooling loads; (d) Organize floorplan so winter sun penetrates daytime use spaces with specific functions that coincide with solar orientation; (e) Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain; (f) Efficient natural ventilation.

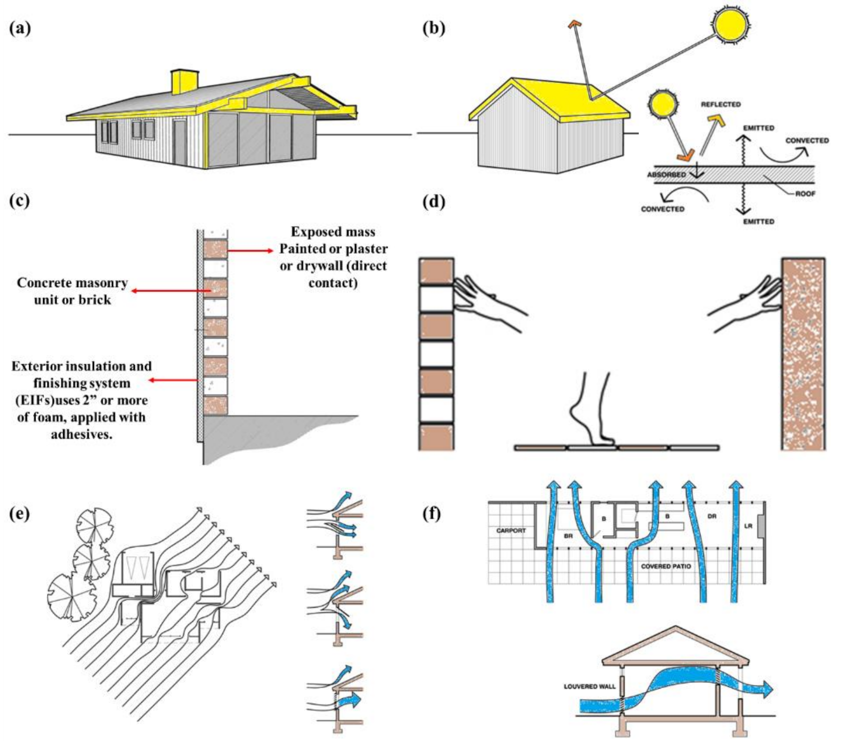

Fig. 11. Climate-compatible design solutions based on ASHRAE 55 (a) low-pitched roofs with wide overhangs work well in temperate climates; (b) use light-colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain; (c) the best high mass walls use exterior insulation (like EIFS foam) and expose the mass on the interior or add plaster or direct contact drywall; (d) high mass interior surfaces (tile, slate, stone, brick or adobe) feel naturally cool on hot days; (e) to facilitate cross ventilation, locate door and window openings on opposite sides of building with larger opening facing up-wind; (f) use open plan interiors to promote natural cross ventilation or use louvered doors.

3.5. Climate comfort conditions and optimal design strategies based on Adaptive model

Fig. 12 illustrates the psychrometric diagram of optimal design strategies for air conditioning and building construction based on the lowest energy consumption to ensure residents' thermal comfort considering the criteria of the Adaptive model.

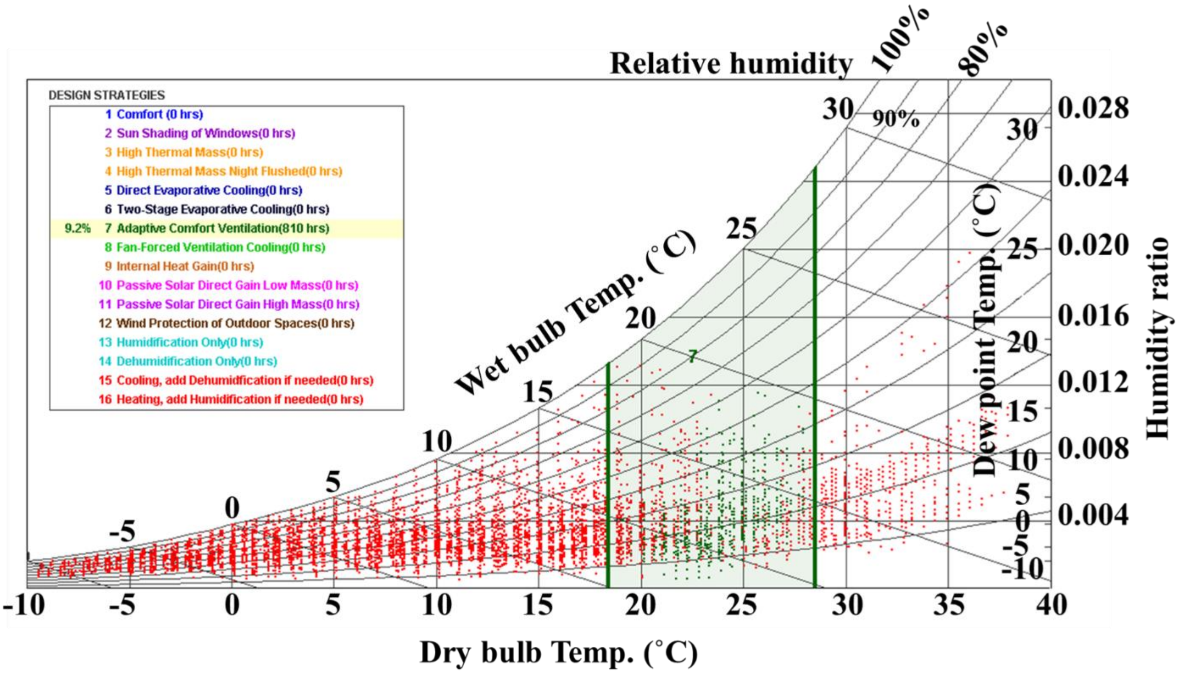

Fig. 12. Psychrometric diagrams of optimal design strategies for prevailing comfort based on adaptive model.

In this model, any non-renewable energy is not used and only the designing of buildings and adaptation of residents to the climatic conditions of Qazvin city are considered. The strategies used in this model are based on Figs. 12-13 are as follows:

If the soil is wet, the building should be constructed over the ground floor to minimize dampness and maximize natural ventilation underneath (Fig. 13(c)). Canopy windows and operable sunshades reduce energy consumption for cooling. On hot days, the movement of indoor air by ceiling fans causes the real feel temperature to be 2.8 C° lower than the ambient temperature; so, less energy is consumed for cooling (Fig. 13(c, f)). Buildings in which air circulation and natural or cross ventilation are well designed may provide the coolness of the night to deal with the thermal mass (heat gain from) of heavy materials ((Fig. 13(b, e))). To create chimney ventilation, even when the wind speed is very low, the height of the chimney should be as high as possible.

Shaded outdoor spaces (balcony, patio, and porch) allied with the direction of prevailing and favorable winds, increase residing area with natural ventilation and comfort conditions (Fig. 13(a-b)). The placement of doors and windows on two opposite sides with large openings facing the wind facilitates natural ventilation (Fig. 13(e)). It is recommended to use an indoor open plan model or shutters and open doors to increase wind streams and natural and cross ventilation (Fig. 13(b)). If the windows are well-shaded and their direction is in line with the favorable winds, appropriate and effective natural ventilation can reduce or eliminate the use of air conditioning systems. Traditional passive houses are made of high and operable roofs and windows, also, their deep shading by the canopy is very important. Using vegetation, especially on the west side of the building reduces heat gain from western radiation (Fig. 13(a, d)).

3.6. Climate comfort conditions and optimal design strategies based on ASHRAE 2005 model

The best solution for designing building plans and ventilation systems in the climate of Qazvin city based on the ASHRAE 2005 model (see Fig. 14 which demonstrates design solutions based on the ASHRAE 2005 model), considering their lowest use of high energy consumption and costly systems, is applying sun shaded windows (14.3% of the year), high mass night flushed materials (7% of the year), evaporative cooler (14.7% of the year), cooling with natural ventilation (0.2% of the hours of the year), using indoor thermal load (16.6% the year), receiving passive solar energy by heavy materials (high mass) (20.8% the year), cooling and heating (40.9% of the hours of the year) and humidification (10.3% of the year). But the use of cooling and dehumidifying systems such as gas coolers and chillers except for evaporative coolers (one or two-stage evaporative coolers and air-washers) is not required, because it contributes only 48 hours of the year in providing comfort. The highest rate of energy consumption in this climate (Qazvin city) is for heating and humidification. Also, the great influence of passive heating and interior loads in providing comfort conditions is evident.

Heat gain from lamps, people, and household appliances significantly reduces the need for heating; if the house is sealed and well insulated, using unit packages (instead of furnace room) with a high energy grade helps in optimal energy consumption (Fig. 14(a)). In sunny wind-protected outdoor spaces' (Fig. 14(b)), the sun can expand the residing space in cold weather; these places include sunshiny rooms in different seasons, enclosed patios, courtyards, and balconies. Trees should not be planted in front of passive solar energy absorption windows; it is correct to plant them behind the angle of 45 degrees in proportion to each corner (Fig. 14(c)). Buildings and units should be modeled as small as possible to prevent heat and cold energy loss.

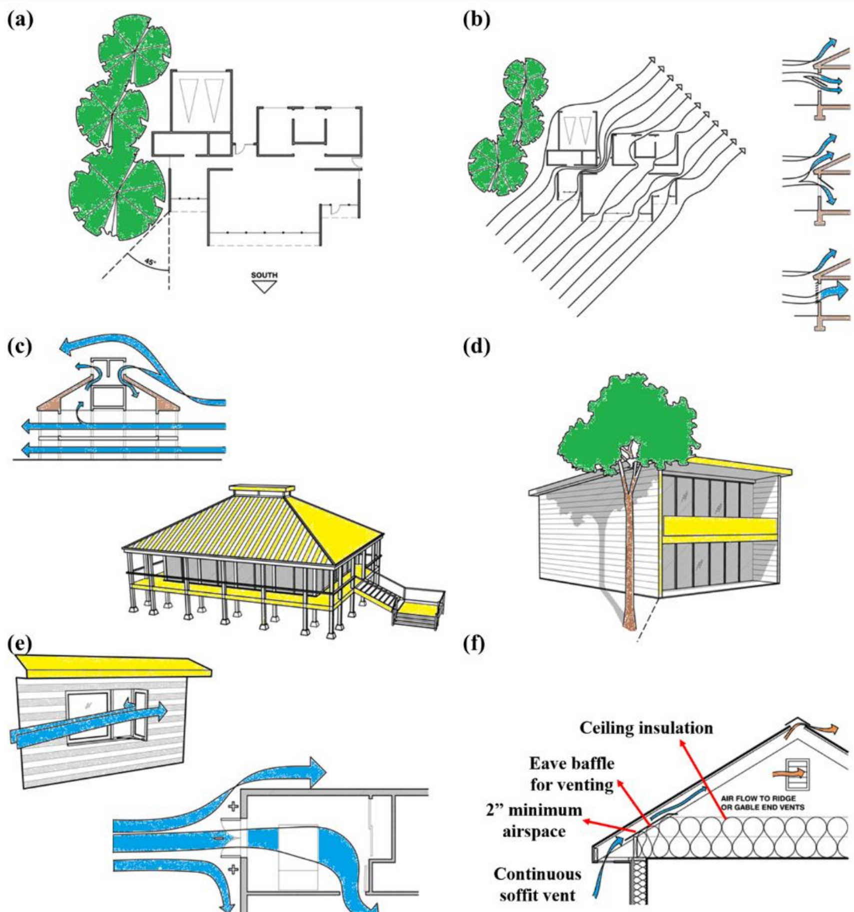

Fig. 13. Climate-compatible design solutions based on adaptive model (a) Use plant materials especially on the west to minimize heat gain; (b) to facilitate cross ventilation, locate door and window openings on opposite sides of the building with larger opening facing up-wind; (c) If soil is moist, rise the building high above the ground to minimize dampness and maximize natural ventilation underneath the building; (d) Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain; (e) Efficient natural ventilation; (f) steep pitched roof, with a vented attic over a well-insulated ceiling, works well in cold climate (sheds rain and snow, and helps prevent ice dams).

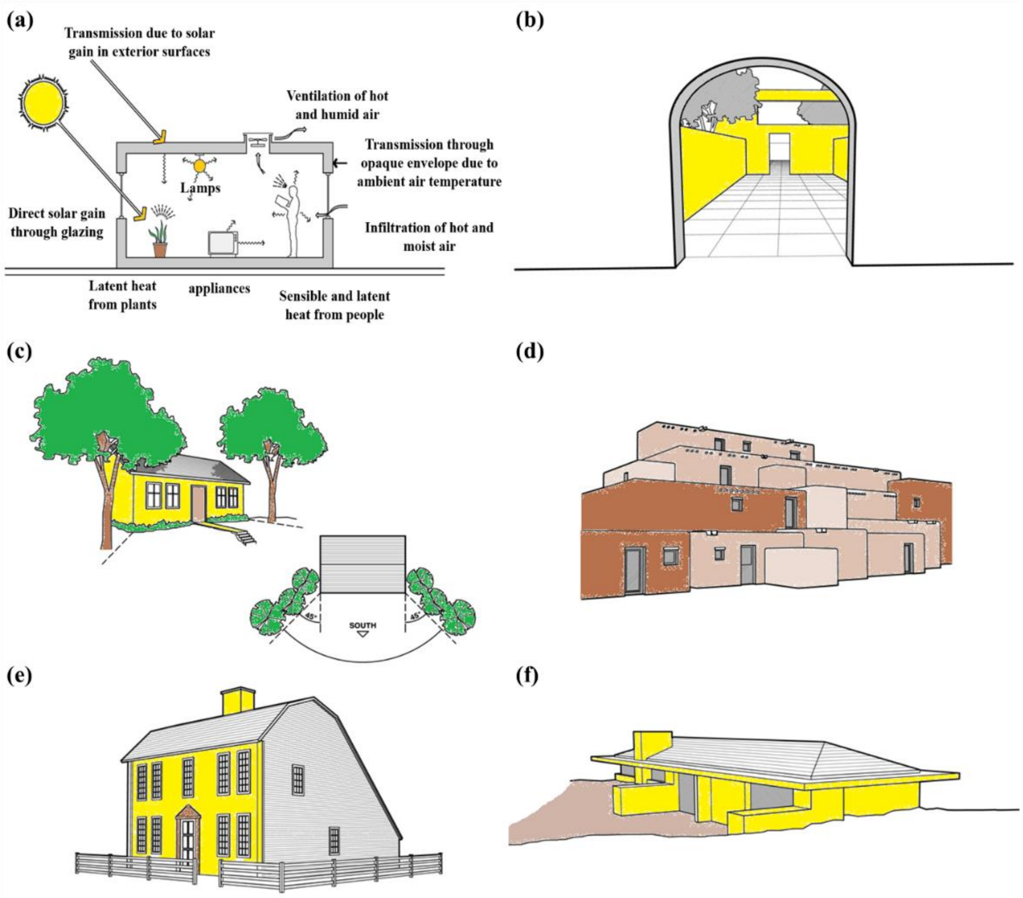

Fig. 14. Climate-compatible design solutions based on ASHRAE 2005 model (a) Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, and well insulated; (b) Sunny wind-protected outdoor spaces can extend living areas in cool weather; (c) Trees should not be planted in front of passive solar windows, but are OK beyond 45 degrees from each corner; (d) Traditional passive homes in hot dry climates used high mass construction with small recessed shaded openings, operable for night ventilation to cool the mass; (e) Traditional passive homes in cold clear climates had snug floorplan with a central heat source, south facing windows, and roof pitched for wind protection; (f) Earth sheltering, occupied basements, or earth tubes reduce heat loads in very hot dry climates because the earth stays near average annual temperature.

For passive solar heating surfaces, most of the south facade should be in glass to benefit from the maximum amount of radiation in the winter, but in the summer, operable canopies should be applied for complete shading. The western sun should be prevented from the facade of the building because northern and southern radiations can be easily shaded (Fig. 14(c)). It is recommended to use double-glazed windows with high radiation performance (less light transmission) on the west, north, and east sides. It is also recommended to use transparent glass in the south to get the most passive solar gain. Using indoor surfaces with high mass, such as concrete floors, thick walls, and fireplaces, improves passive heating in the winter and pleasant night cooling in the summer. On hot days, the circulation of indoor air by ceiling fans causes the real feel temperature less than the ambient temperature. The canopy of the windows and operable canopies significantly reduce energy consumption for cooling. In hot and dry weather conditions, ground-sheltered and residential basements reduce the amount of heat gain, because the Earth's temperature is often close to the average annual temperature (Fig. 14(f)). In hot and dry climates heavy materials can be used with canopied openings as in traditional passive houses (Fig. 14(d, e)) because it provides the ventilation required at night to stay cool. Placing parking lots and warehouses on the windward side helps to better insulate the indoor space and reduces heat loss through the walls.

3.7. Optimal solutions based on climate Comfort 2013 model

This model is the last proposed energy model. The number of definable comfort criteria parameters for this model is more than other models. So, it is more applicable to find solutions for climate-compatible design strategies with the minimum energy consumption. Fig. 15 presents the psychrometric diagram of the best-mentioned solutions approach to the Comfort 2013 model. By providing the conditions presented in Fig. 15(a), it is possible to provide residents comfort 100% of the time. The highest rate of energy consumption is used in evaporative cooling and heating in this strategy. By enabling the conditions presented in Fig. 15(b), providing residents comfort for 8723 hours, equivalent to 99.6% will be possible. In this strategy, energy consumption for dehumidification and cooling has been eliminated compared to the previous strategy, and the passive gain of solar heat by light materials (low mass) has been added to it. By enabling the conditions presented in Fig. 15(c), it is possible to provide residents comfort for 8723 hours equivalent to 99.6%. The essence of this strategy is spending a lower initial cost to purchase and design the air conditioning systems to provide comfort conditions. However, the rate of energy consumption for heating purposes has increased significantly by 54.1% (4735 hours per year).

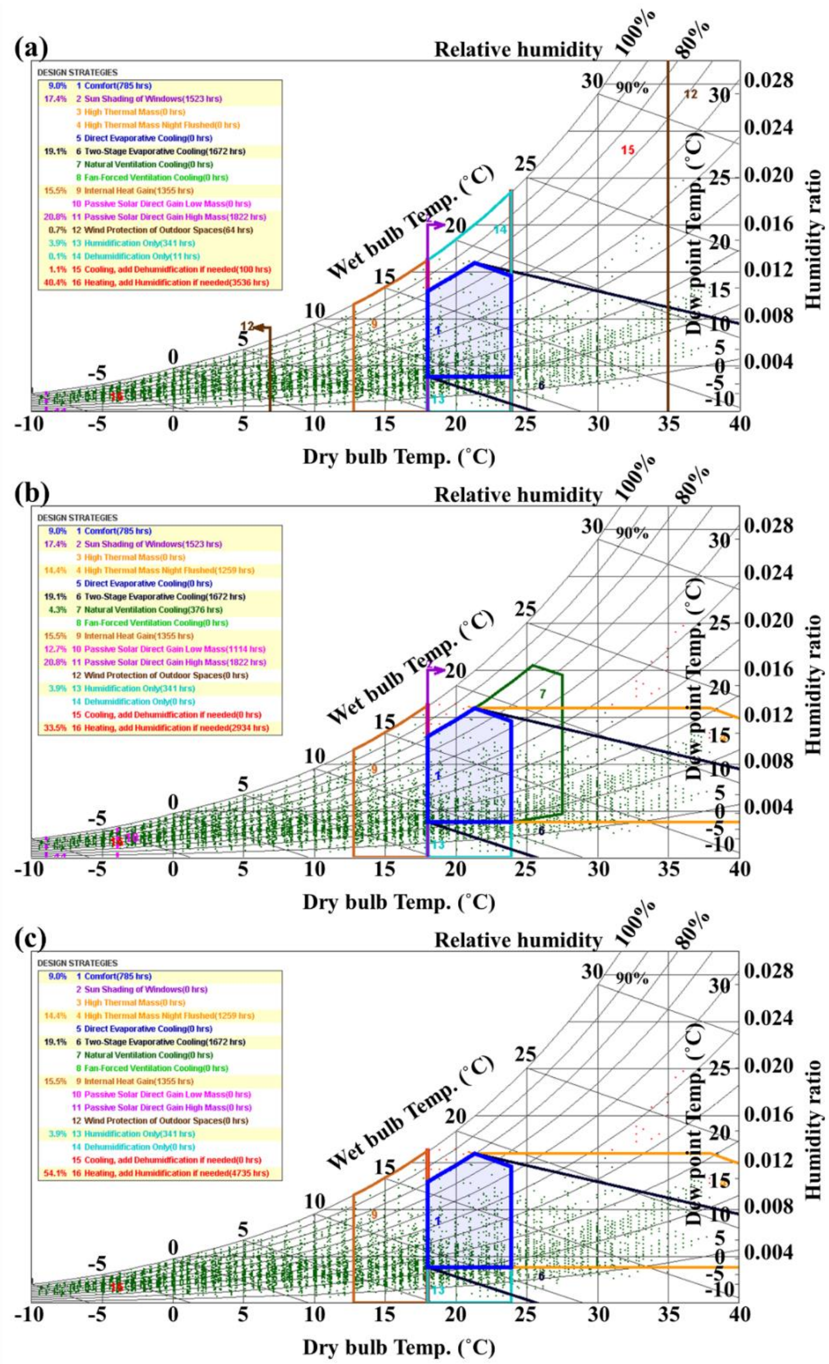

Fig. 15. Psychrometric diagrams of optimal design strategies for prevailing comfort based on the Comfort 2013 model.

3.8. Analysis and comparing different climate comfort strategies

By using indoor humidity regulator systems i.e., humidification and dehumidification methods, comfort conditions are provided for 3.9% and 0.1% of the year, respectively. By including natural comfort conditions, 13% of the year (1137 hours), the residents' comfort is ensured (Fig. 16(a)). By utilizing cooling and heating systems 17.5% and 69.5% of the year, respectively, comfort criteria are passed. By heating, ventilation, and cooling systems plus natural comfort conditions, 96% of the year the comfort condition is met (Fig. 16(b)). In this strategy (Fig. 16(b)), the rate of energy consumption for heating and cooling is significantly higher than other strategies (Fig. 16(a)), so it is necessary to use natural ventilation methods, air circulation, passive methods, etc. By using forced fan ventilation for cooling, comfort conditions are provided for 4.2% of the year, and considering the natural comfort conditions, 13.2% of the year (1154 hours), the residents' comfort is provided (Fig. 16(c)).

By using direct and two-stage evaporative coolers, comfort conditions are provided for 17.9% and 19.1% of the year, respectively, and by including natural comfort conditions, 28% of the year (2457 hours), the residents' comfort is provided (Fig. 16(d)).

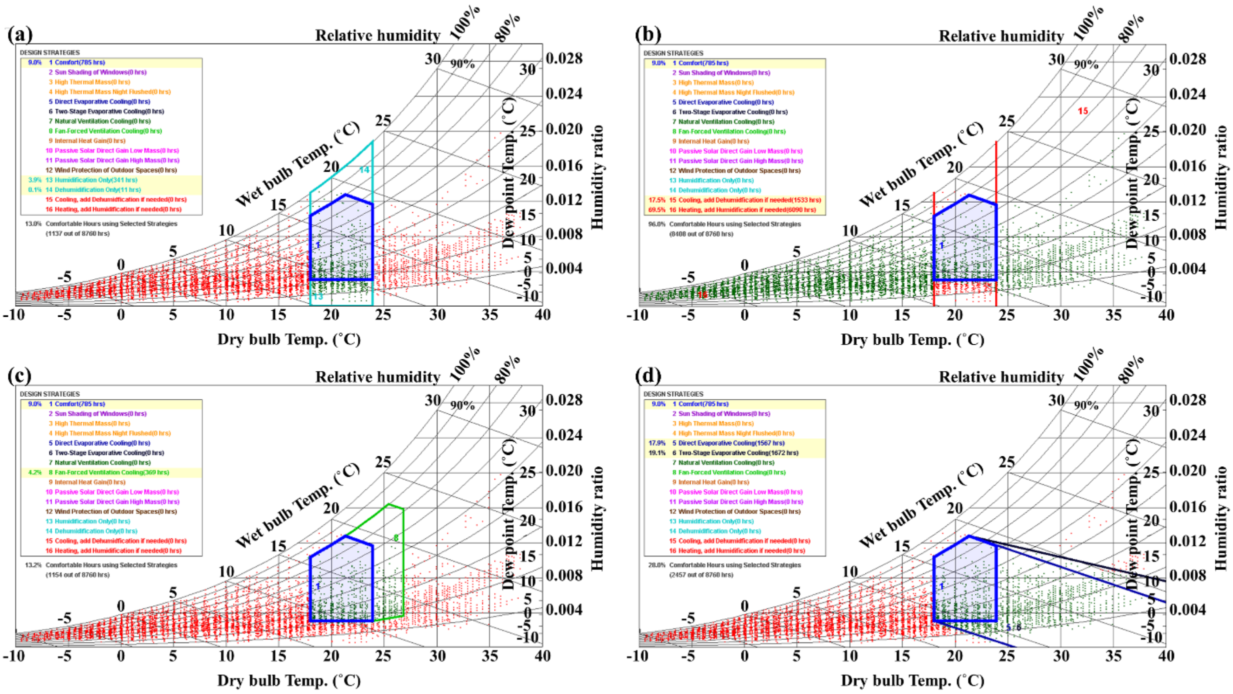

Fig. 16. Climatic comfort provision strategies (a) humidify; (b) cooling and heating with energy consumption; (c) fan forced ventilation cooling; (d) evaporative cooling.

Employing windows shading, using materials with high thermal mass night flushed, cooling with natural ventilation, and optimal use of wind flow, respectively, 17.4, 8.3, 14.4, 4.3, and 0.7% of the year, comfort conditions are provided, and by including the natural comfort conditions, 24% of the hours of the year (2105 hours) the residents' comfort is met (Fig. 17(a)). By involving the interior loads, 15.5% of the year comfort conditions are supplied, plus natural comfort conditions, in 24.4% of the year (2140 hours), the residents' comfort is secured (Fig. 17(b)).

By windows and doors shading, comfort conditions are provided in 17.4% of the year, and adding the natural comfort conditions, in 9% of the year (785 hours), the residents' comfort is yielded (Fig. 17(c)). The difference between these two methods (Fig. 17(b, c)) is in providing comfort conditions in terms of solar radiation.

By using two passive methods of solar energy absorption by light and heavy materials (low and high thermal mass, respectively) in the building, comfort conditions can prevail for 12.7 and 20.8 % of the year, respectively, plus natural comfort conditions, in 40.9% of the year (3581 hours), the residents' comfort of the is secured (Fig. 17(d)).

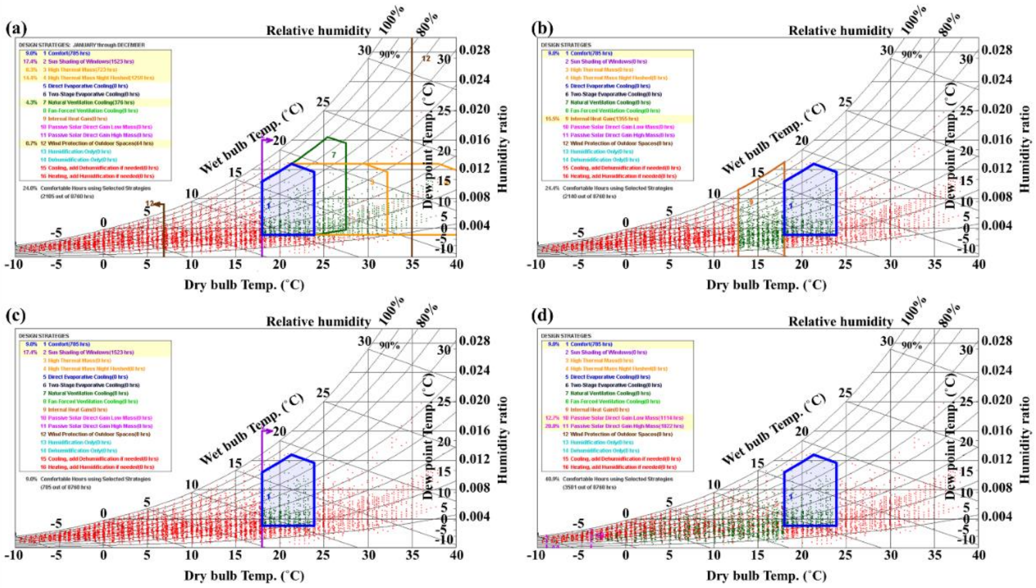

Fig. 17. Climatic comfort provision strategies (a) natural ventilation cooling; (b) internal heat gain; (c) sun shading of windows; (d) passive solar heat gain.

3.9. Suitable climatic comfort provision strategies for Qazvin city

Nowadays in Qazvin city, prevailing and suitable climatic comfort provision strategies (which is discernible in Fig. 18) include applying a direct evaporator cooler (17.9%), internal heat loads (15.5%), heating with a unit package or furnace rooms (to utilize radiators) or gas heater (54.1%). From Fig. 18 it is obvious that humankind provides its comfort conditions with any cost for survival, but in the present study, the fundamental question has been answered that it is possible to continue living (in comfort conditions) by spending less money, less energy, creating less pollution and preventing global environmental destruction using nature for nature.

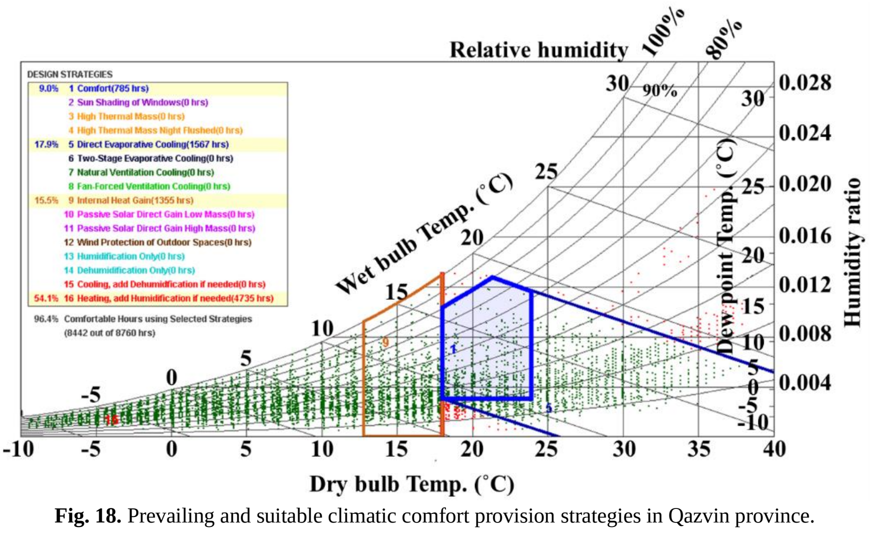

Fig. 18. Prevailing and suitable climatic comfort provision strategies in Qazvin province.

4. Conclusion

By using Climate Consultant software and four different comfort models, residences' climatic compatible comfort approach to low-cost low energy consume strategies in Qazvin City, Iran is studied. The major findings are as follows:

1. May, September, and October have comfortable dry-bulb temperatures and relative humidity in Qazvin. The uncomfortable conditions of them are from November to

March. June and September have comfortable hourly temperatures.

2. May to September have comfortable global horizontal radiation, with July having more than the maximum comfort level. Cloud cover is highest in March and lowest in July.

3. Wind speed is highest in May and June, and lowest in January.

4. The sun shading chart shows radiation is in the hot zone from 07:00 to sunset in June and July but decreases beyond the comfort zone from August to December. October has the most radiation comfort conditions.

5. The results suggest that, in the comfort model of ASHRAE 55, Comfort model 2013, adaptive model, and ASHRAE 2005 12.4%, 9%, 9.2%, and 7.2% of the year (1085, 785, 810, and 632 hours), respectively, the environmental conditions are naturally within the comfort zone.

6. The zero-energy design strategies i. e. Small well-insulated skylight windows, minimize or eliminate west-facing glazing to reduce summer and fall afternoon heat gain, Efficient natural ventilation, low-pitched roofs with wide overhangs work well in temperate climates, cool roofs, high mass interior surfaces, facilitate cross ventilation, locate door and window openings on opposite sides of building with larger opening facing up-wind, use open plan interiors to promote natural cross ventilation or use louvered doors, etc. enhance residences' climatic compatible comfort.

7. The results of the comparison of climate-compatible comfort strategies with the existing situation in Qazvin suggested that the high energy consumer, costly ineffective utilities, and building design are used to supply the residents' comfort.

Therefore, it is necessary to review the locating of future cities with the cornerstones of climatic-compatible buildings and optimal energy consumption. The above analysis provides the necessary solutions to optimize and reduce the consumption of non-renewable energy which leads to climatic and environmental conditions adaption. Hence, sustainable cities and ultimately sustainable urban development can be reached.

Acknowledgment

The authors sincerely express their gratitude to the anonymous reviewers for their constructive criticism and thoughtful comments that were beneficial to the improvement of the revised manuscript. This article was not under any financial support.

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