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Comparison of impact of climate change on building energy-saving design for two different climates; Metropolitans of Moscow and Tehran

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Abstract

In the present study, in order to monitor and project climate change impacts on model of the bioclimatic design, a comparative study was conducted between the Middle East and Eurasia as two different climates. This paper used the basic data from 1990 to 2010, and the CMIP5 climate models have been used to project the climate data (radiation, temperature, wind speed, and relative humidity) from the outputs of CanEMS2 model, which its values have been dynamically downscaled using the RegCM4.6 climate model for the period from 2020 to 2049. In this study, the scenario RCP4.5 was used. The results of this study showed that the average annual temperature for the period 2020–2049 as compared with the present decade can be increased 3.27 °C and 4.71 °C for Tehran and Moscow, respectively. On the other hand, relative humidity changes in future compared to base period can be decreased 4% for Tehran and increased 10.5% for Moscow. The total assessment on climate change in the coming decades can lead to a change in bioclimatic design strategies of buildings for both study areas. Generally, with regard to future climate change for both study areas, the percentage of days needed to provide bioclimatic design strategies in the heating sector can be reduced; however, the need for providing cooling strategies for Tehran can significantly be increased. Although these conditions for Moscow can not change significantly, dehumidification strategies in Moscow can be more significant than of those in Tehran for the coming period.

Keywords: Climate scenario, Building modeling, Bioclimatic design strategies, Metropolitan of Tehran and Moscow, Climate adaptation.

1. Introduction

Global warming, as climate change and its implications on life and the development process of human societies, is one of the major challenges of the global community that has attracted a vast amount of attention of scientific and political circles worldwide in the last two decades. Due to unprecedented growth in population and technological advance, and as a result of an increase in society's demand for energy carriers, the earth has begun to warm in recent decades, which has grown more than 4% in the last century (Bauer et al., 2018; Eewell et al., 2018; Lazarus and van Asselt, 2018; Gunningham, 2017; Köhler and Michaelowa, 2014). Most of this energy is currently dependent fossil fuels, and if this trend continues to increase demand and energy consumption, severe climate change will occur as global warming over the next few decades, which can involve many aspects of the life of communities. It is very important to examine and identify the effects of climate change on the industrial, economic and social sectors of the community, and provide strategies and advance warnings to decision-makers and planners to prepare in coping with these impacts. The amount of energy consumption in buildings is one of the cases that has been fluctuating under the influence of climate change (Rogelj et al., 2016; McGlade and Ekins, 2015; Stewart et al., 2013; Schipper, 2000).

Heating and cooling energy in residential buildings is one of the most important and challenging dimensions of modern life, because humans seek the comfort in all circumstances, and one of its aspects is climate and thermal comfort in buildings. It can be stated that in the absence of climatic comfort conditions, almost all human activities in the buildings are challenged. A study on the optimization of heating and cooling energy consumption in buildings and the factors affecting its consumption pattern is one of the most important studies on energy consumption policies. In other words, there are many elements and components that affect the amount of energy consumption, the how and pattern of its consumption. Some of

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these factors are natural and some others are human-made. One of the important natural factors in energy consumption is the human thermal comfort in building, which can be defined and studied as a subset of the biological climate (Aljawabra and Nikolopoulou, 2018; Sharmin and Steemers, 2018; Rubio-Bellido et al., 2016; Zhu et al., 2016).

It is important to note that one of the strategies for saving and proper energy efficiency in buildings is to adopt appropriate strategies for the bioclimatic design. In sum, there are many studies from around the world on the effect of climate change and global warming on energy consumption and demand in buildings. For example, Rubio-Bellido et al. (2016) conducted a study for some cities in Chile on the assessment of the strategies of energy demand reduction in an office building for the 2020s, 2050s and 2080s. Wang and Chen (2014) used the HadCM3 model for some emission scenarios to simulate the demand for energy consumption in hotels, buildings, and hospitals located in cities of the United States for the 2080s. Pierangioli et al. (2017) assessed the effectiveness of passive strategies for the design of building in order to reduce the impact of global warming on the central regions of Italy using simulated data for coming decades. In order to provide passive strategies for the design of buildings and reduce energy demand, Zhou et al. (2013) used global climate models (GCMs) and scenario families A for the simulation of climate change in Adelaide city of Australia in the 2070s. In their study, Zhu et al. (2016) explained a new idea for predicting meteorological data for the simulations of energy demand in buildings of cities in China. However, in this paper, a comparison has been made between the effects of bioclimatic design strategies in Tehran metropolitan area as an example of cities of the Middle East and Moscow as a representative of Eurasian cities. In many studies, the impact of climate change on a given location is made within the framework of the political boundary and a specific country; however, the aim of the present study is to compare the effects of bioclimatic design strategies on two climates and regions where there are very geographical differences. Because sometimes this question arises that how the effectiveness in a particular area of climate change is compared to other regions of the world. Therefore, in this study, Moscow has been assessed and selected as a comparative case with Tehran. Despite the economic crisis since 2008 in Russia, there is still the increasing trend of greenhouse gases (GHG) problem. Interestingly, Russia is not only one of the most intense emitters of GHG, but also one of the most important fossil fuel producers, and on the other hand, it plays a key role in international climate change policies. Russia occupies more than a tenth of the global land area, with nearly two thirds of the country underlain by methane-rich permafrost; consequently, the impacts of temperature increases on its territory are likely to have global repercussions (Sharmina et al., 2013).

Russia is one of the countries that has been severely affected by climate change in the 20^{th} century, and this trend will continue. The high use of fossil fuels to produce electricity is a determinant of the vulnerability of the Russian power system to climate change (Klimenko et al., 2017).

According to a report by the Russian Federal Service for Hydrometorology and Environmental Monitoring (Roshydromet, 2011) for 2011, monitoring data and model calculations show that Russia's climate is more susceptible to global warming than the climate of many other regions of the world. Climate warming in Russia has been registered as taking place at a much faster pace than the warming seen in the rest of the world: anomalies in average annual temperatures in Russia reach 3–4°C [7°C or more, based on 2012 data], while the average global anomalies only slightly exceed 1°C. According to Roshydromet data, over the past 100 years (1907–2006), total warming in Russia stood at 1.29°C, while average global warming, based on the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), was at 0.74°C over a span of 150 years. At the same time, in many regions, such as the Altai region, the temperature increase in the last 100 years has exceeded 3°C. Over the last 25 years, the annual average temperature in Russia rose at a rate of 1.6°C per decade in certain areas. This is an extremely high figure. While changes were distributed unevenly between regions, the major agricultural regions of the country are located in zones experiencing rising annual average temperatures. Thus, they are more sensitive to climate change (Roshydromet, 2011).

In Iran, the total GHG emissions form energy consumption peaked at 528.6 million tons of carbon in 2009 (Iran Energy Balance, 2010). Findings from studies by the Global Environment Organization (GEO) indicate that 90 percent of the pollution source of the carbon dioxide (CO_2) is energy in Iran (UNDP, 2010). According to the World Bank Report 2011, energy consumed by fossil fuels has accounted for 99.52% in Iran compared with other supply resources of energy. According to the report, the high tendency to the supply resources of energy via fossil fuels is generated 480 million tons of CO_2 emissions in 2012, which is expected to double CO_2 emissions if the same trend continues by 2030 (Moshiri et al., 2012). In spite of this issue, in some reports, Iran is the world's ninth emitter of CO_2, which is considered globally with respect to Iran's share of CO_2 emissions (Roshan et al., 2019). In addition to Iran's role in GHG emissions, the effect of climate change on Iran is identified as another challenge in the current and future decades so that various studies have been conducted in Iran on the effect of climate change on variation in the trend of climate factors (e.g., Tabari and Hosseinzadeh Talaee, 2011a, 2011b; Tabari et al. 2011a, 2011b; Shifteh Some'e et al., 2012; Zarenistanak et al., 2014a, 2014b).

It is worth noting that one of the most important sources of producing the GHG emissions is the energy consumption in buildings and its feedback is as CO_2 emissions. Therefore, a proper understanding of future climate change and providing appropriate strategies to these changes in form of the bioclimatic design of building blocks can have an effective role in reducing the demand for heating and cooling energy of buildings, which can contribute to reducing both Co_2 emissions and the impact of climate change trend. Therefore, the aim of the present study is to investigate the effects of climate change on the variation of the bioclimatic design pattern of building for two metropolitan areas of Tehran and Moscow, and compare the results of these two areas.

2. Material and Method

2-1. The case studies

Moscow is the capital city and most populous federal subject of Russia, and the northernmost megacity on the planet. It is also the second most populous city in Europe and the 11th largest city on earth. In 2016, the estimated population was 12.19 million. Moscow, lying between latitudes 55° 56'' N and longitudes 37° 38' E in the Central European Hills between the Oka river and the Volga river, is the most North-West megalopolis in the world. The city of Moscow is 150 meters above the sea level, which is 30-35 meters higher than the level of the Moscow-river. The Moscow River, which is the city main waterway, crosses its territory from the North West to the South East. The length of the river is about 80 km within the city boundaries. Moscow's climate is temperate to continental and has a humid continental climate (Köppen climate classification Dfb) with warm, sometimes hot, somewhat humid summers and long, cold winters (Sedov, 2012). Tehran, is located at 35° 07' N and 51° 24' E. Tehran is one of the 32 provinces of Iran. It covers an area of 18,909 square kilometers (7,301 sq. mi) and is located in the north of the central plateau of Iran. Iran is situated between the Middle East and Asia and has a history of changing its capital city – Tehran being the 32nd one chosen. The population of the city of Tehran has been steadily growing over the last few decades and is now around 8.3 million. There is an estimated population of nearly 8.7 million in the middle of 2016. Tehran features a cold semi-arid climate (Köppen climate classification: BSk) with continental climate characteristics and a Mediterranean climate precipitation pattern. Tehran's climate is largely defined by its geographic location, with the towering Alborz mountains to its north and the country's central desert to the south. It can be generally described as mild in spring and autumn, hot and dry in summer, and cold and wet in winter (Roshan et al., 2010; Ghanghermeh et al., 2013).

Figure 1. The geographic location of the metropolitan areas of Moscow and Tehran.

2-2. Climate Data

In this study, four main meteorological parameters such as temperature, relative humidity, wind speed and radiation were used for building energy simulation need. According to the specific format of input data of simulation building software, these data should be displayed hourly or over a 24-hour period. Therefore, for building energy simulation need, the study period is divided into the present period that includes data from 1990 to 2010 and for the next decades, covering 2020-2049. However, we used Meteonorm software for both stations in our base period. Meteonorm, as a powerful software for producing climatic data, has a strong climatic database, which serves as a source for the input of radiation data and other climatic data in building simulation. This software is able to extract climatic data for each site using interpolation method. One of the features of this software is the production of hourly and even minute data. Meteonorm inputs for global radiation come from the Global Energy Balance Archive (GEBA, http: // protogeba. ethz.ch). All weather data of this software is provided by the World Meteorological Organization (WMO) and the NCDC. In this software, the Stochastic Generation, to generate global radiation daily data, Markov chain model has been used. Generating temperature data is based on global radiation and measured values of approximately 5,000 sites worldwide. Meteonorm has also been able to produce other meteorological data, such as precipitation, wind speed, relative humidity and radiation. (Roshan et al., 2019, Belcher et al., 2005). Therefore, in this paper, version 7.2 of Meteonorm software has been used to produce climatic data.

While global climate models are used to simulate large-scale patterns suitable for weather projecting and large-area climate trends, they lack the level of detail needed to model conditions at local and regional scales. With a method called dynamical downscaling, researchers can use outputs from coarse-resolution global models to derive higher-resolution regional climate data. The enhanced resolution allows regional models to better account for topographic details, while also improving the ability to simulate surface variables such as air temperature, precipitation, and wind. This study used RegcM4.6 versions for dynamical downscaling.

The main structure of the RegCM climate model is based on three steps: the preprocessing (territory designation, preparation of boundary layer conditions data, etc.), the main model (the introduction of the conditions defined in the model and its implementation) and the post-processing (preparation of model outputs for analysis). It should be noted that for the implementation of the RegCM climate model in this study, three series of data are needed, including:

- Boundary conditions containing the meteorological data that are the same as data from the global CanEMS2 model in this study.
- Surface cover data including topographic data, vegetation cover, land use, soil texture, depth of seawater and lakes with a horizontal resolution of 30 seconds, prepared by the U.S. Geological Survey (USGS), and all data made available by a website: http://www.ictp.ictp.triste.it/~pubrgcm/regcm
- Sea surface temperature data, which is used datasets of the global CanEMS2 model.

However, in order to project the future data, two climate models, including general circulation model (also known as a global climate model, both labels are abbreviated as GCM) and the downscaling regional climate model have been used. The first category of these models is the CanEMS2 from collection of the CMIP5 climate models with pixel dimensions of 2.8 × 2.8 degrees related to Canadian Centre for Climate Modeling and Analysis (CCCma), which will be used as the GCM. Estimated data for the 21st century is under the RCP4.5 scenario and for future time period (2020-2049) at an hourly time resolution.

2-3. Details of the modeling of building heating and cooling strategies

Climate Consultant software is sponsored by the California Energy Commission and developed by the University of California at Los Angeles (UCLA) (Iyengar, 2015). Climate Consultant ver. 6 was developed by the UCLA Energy Design Tools Group. This version of Climate Consultant was developed with support from the California Energy Commission PIER Program (Public Interest Energy Research). This software is for designing and remodeling the buildings that are truly climate responsive that depends firstly on gaining a detailed accurate understanding of the local climate. Climate Consultant reads the local climate data in EPW (Energy Plus Weather file) format and displays dozens of different graphic charts of various weather attributes. The purpose of Climate Consultant is not simply to plot climate data, but rather to organize and represent this information in easy-to-understand new ways that reveal the subtle attributes of climate and its impact on built form. One of the best charts that the software produces is psychrometric chart of comfort strategies. This chart is one of the most powerful design tools in Climate Consultant. It shows dry bulb temperature across the bottom and moisture content of the air up the side. Every hour in the EPW climate data file is shown as a dot on this chart. The Design Guidelines screen shows a list of suggestions, specific to this particular climate and selected set of Design Strategies, to guide the design of buildings such as homes, shops, classrooms, and small offices. Architects call these envelope dominated because they do not have large internal thermal loads, and thus the design of the building's envelope will have a great deal of impact on the thermal comfort of the occupants (Liggett and Milne, 2017). In this architecture software, two types of building are proposed for modeling. One is residential and another is small-non residential building types. Therefore, in the present research, the type of building of residential is used.

3. Results

3-1. The patterns of climate change in relative humidity and temperature

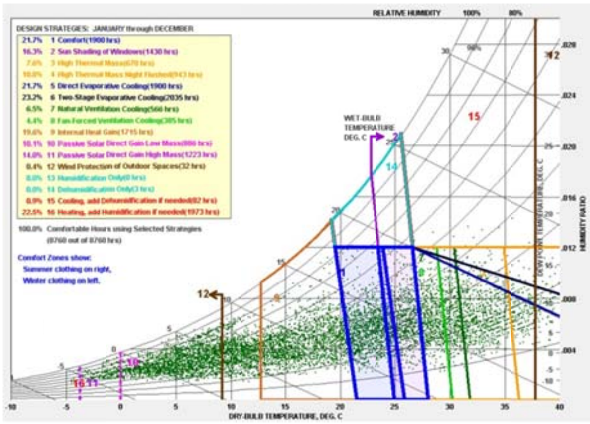
Table 1 displays patterns of climate change in relative humidity and temperature with the monthly time scale for both present and future time periods. As seen in Table 1, relative humidity changes for Tehran had a declining trend in all months of the future years. As expected, the future mean relative humidity will be decreased by 4%. Meanwhile, the highest decline in relative humidity for Tehran could be attributed to summer, which is 6.7% for July and 7.6% for August. Contrary to the results obtained for Tehran, there was an increasing trend in relative humidity in Moscow for the 12 months of the year. In the coming decades, the average relative humidity is expected to increase by 10.5%. However, the greatest increase in relative humidity for Moscow was simulated with 14.9% and 14.3% for May and June in spring, respectively (Table 1). Temperature is another factor that has an influence on thermal comfort conditions in occupants of buildings. The combination of different thresholds of temperature and different thresholds of relative humidity can obtain different conditions in terms of indoor thermal comfort and energy demand. On the other hand, the overall output of this part shows that for both stations, the mean temperature will be increased for all 12 months of the year compared with the base period. Then the lowest increase in temperature changes for Tehran could be attributed to cold-related seasons, and its highest increase has been simulated from the middle of spring to summer. Overall, June and July (with an increase of 8 °C and 7.33 °C, respectively) in the coming decades, will reflect the largest increase in temperature as compared to other months. At the Moscow's station, the highest temperature increase was 8.37 °C for June in the late spring and the next increases in temperature were 7.82°C and 7.32 °C for July and August, respectively. It is generally expected that over the project period (2020-2049), the mean annual temperature of Tehran will increase by 3.27 °C and reached up to 21.66 °C, and for Moscow, this rate will be increased by 4.71 °C, which the mean annual temperature is expected to increase to 10.30°C (Table 1).

3-2. Analysis for the bioclimatic design

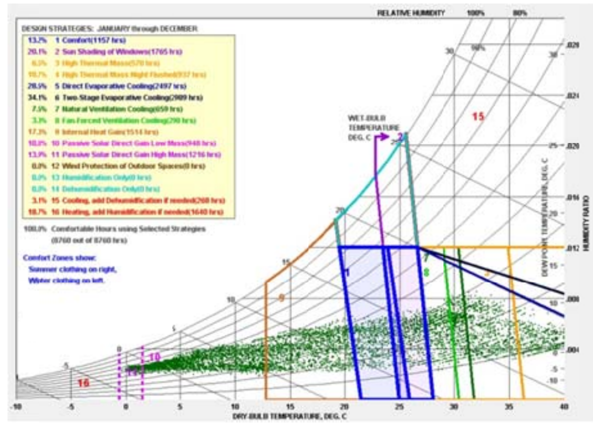
The results of modeling the new climate conditions over the coming decades for Tehran indicate an increase in temperature and a decrease in relative humidity compared to the base period; therefore, based on the distribution of temperature and relative humidity data in Figure (2a), it can be seen that the type of its climate can be changed to warm and dry conditions. However, for Moscow, the overall climate conditions show that due to an increase in relative humidity and temperature, the type of its climate can be changed to slightly warmer and more humid conditions than the current climate condition. By implementing these changes on a psychrometric chart, bioclimatic design strategies were specified based on the ASHRAE 55 standard.

Table 1. Comparison of mean monthly temperature and relative humidity in Tehran and Moscow for the two study periods in the current and future.

Month	Tehran				Moscow			
	Tem-Present	Tem-Future	Hum-Present	Hum-Future	Tem-Present	Tem-Future	Hum-Present	Hum-Future
Jan	4.3	4.9	20.1	16.5	-6.5	-2.0	14.8	21.6
Feb	7.3	8.3	20.1	18.3	-7.5	-1.7	13.2	21.3
Mar	13.0	14.1	21.6	18.9	-1.6	1.5	16.8	25.4
Apr	17.7	21.5	24.5	17.6	6.6	8.5	23.8	36.7
May	23.4	29.3	25.7	21.9	12.6	16.7	31.2	46.1
Jun	28.4	36.4	28.1	25.5	15.4	23.8	41.0	55.3
Jul	31.3	38.6	35.0	28.3	19.4	27.2	48.8	57.2
Aug	30.8	36.7	34.1	26.5	17.1	24.4	47.1	58.1
Sep	26.2	30.6	31.5	26.0	11.6	14.5	38.3	50.0
Oct	20.5	21.5	26.4	24.2	5.6	7.0	30.9	39.5
Nov	11.7	11.9	22.5	21.8	-0.3	3.1	21.8	31.5
Dec	6.1	6.1	23.5	19.6	-5.3	0.5	16.0	26.3
Mean Annual	**18.4**	**21.66**	**26.1**	**22.1**	**5.6**	**10.30**	**28.6**	**39.1**



(a)



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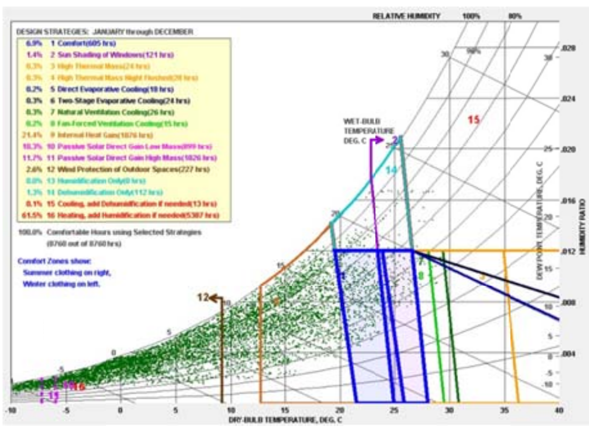
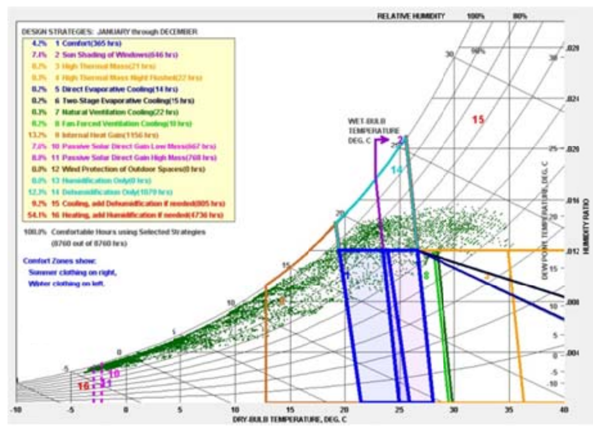


(c)



(a)

Figure 2. The psychrometric chart for showing bioclimatic design strategies based on simulated and observed climate data. a) Tehran present period; b: Tehran future period; c: Moscow present period; d: Moscow future period.

By extracting the hours required for each of the bioclimatic design strategies of the above charts, the difference between simulated and observed climate conditions is clearly visible in Figure 3. The left x axis in this figure from sun shading of windows to fan-forced ventilation cooling shows cooling strategies in hot conditions of the year. Based on these strategies, the only significant change for Russia is related to sun shading of windows with a frequency of 1.4 % for the observation period and will be increased 7.4% in the coming decades. In other words, the need to avoid sun exposure also the average temperature increase in new climate conditions should be considered. However, for other cooling strategies such as high thermal mass, high thermal mass night flushed, natural ventilation cooling, and fan-forced ventilation cooling, there were significant changes or slight changes observed that can be overlooked. Because even though with respect to global warming, temperature increase in cold-related seasons of the year and spring may not be sufficient to increase cooling demands, and the extreme cold climate conditions are always dominated during this time period. On the other hand, based on the surplus heat in summer, the only proposed strategy is to pay more attention to sun shading of windows, which can be effective in providing indoor thermal comfort. Changes in the bioclimatic cooling strategies for Tehran were more evident than of those in Moscow because the overall mean annual temperature in Tehran can to two times more than Moscow and any increase change in temperature for Tehran can be resulted in a larger variations in providing the bioclimatic cooling strategies. For bioclimatic zones, sun shading of windows, direct evaporation cooling, two-stage evaporative cooling, and natural ventilation cooling were 3.8%, 6.8%, 10.5% and 1% respectively; therefore, the need to use these bioclimatic strategies is expected to increase in the future. However, on the left side of x axis, bioclimatic zones 9-12, which include internal heat gain to wind protection of outdoor spaces, show the heating strategies in cold climate conditions. For Moscow, according to the climate conditions in the next decades, 8.2%, 2.7%, 0.9% and 2.6%, will be reduced from the frequency of the need for heating strategies of internal heating gain, passive solar direct gain low mass, passive solar direct gain high mass, and wind protection of outdoor spaces, respectively (Fig. 2).

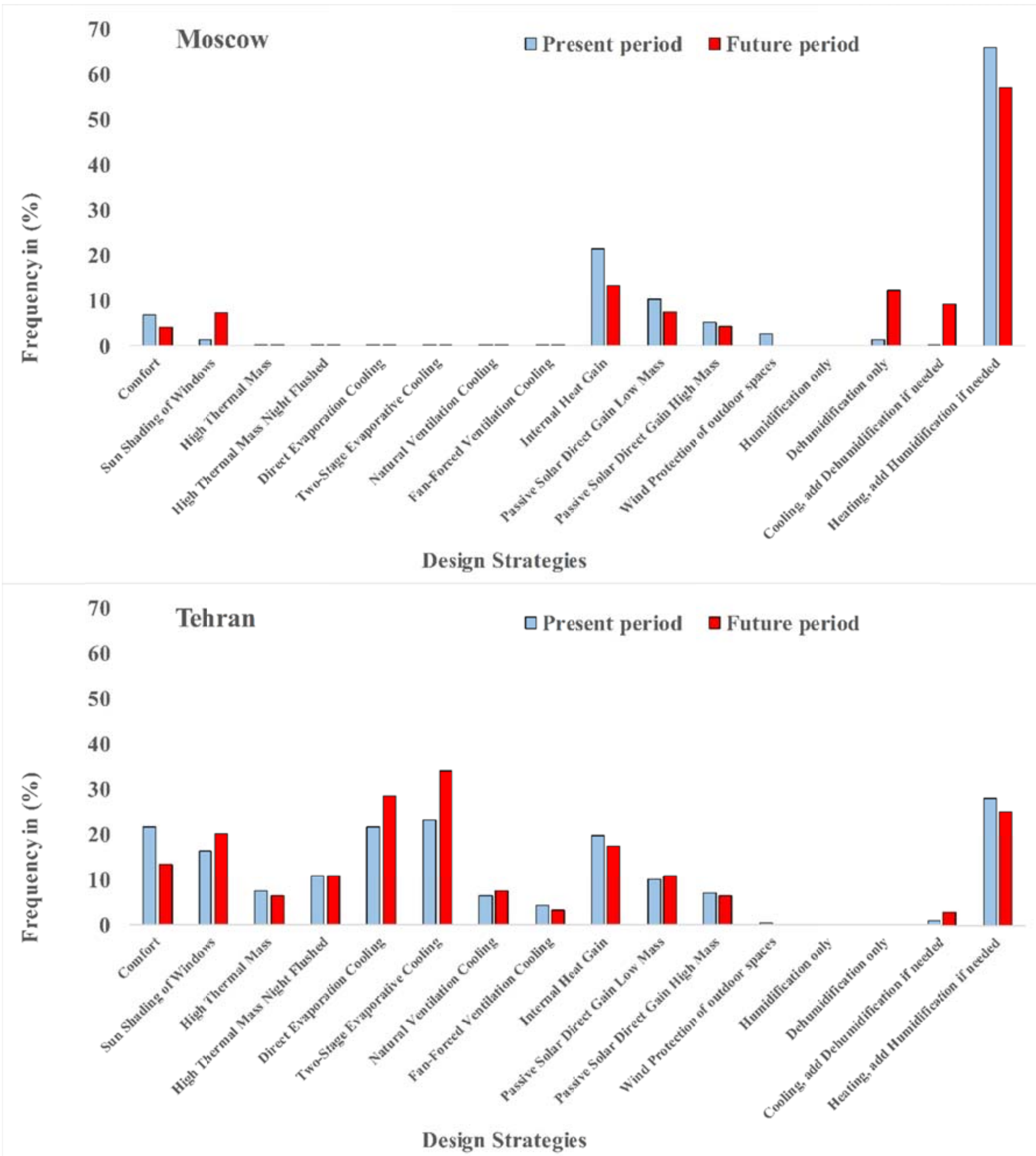


Figure 3. Comparison of bioclimatic design strategies based on observed data and time series of simulated data based on the RCP 4.5 Scenario for both metropolises, Moscow and Tehran.

It is natural that with increasing air temperature, the need for solar direct gain is reduced during the winter season. Moreover, the average temperature increase in fall from 0 to 3.5 °C and in winter from -5.2 °C to -0.7 °C can be an effective factor in reducing the need for internal heat gain. However, for Tehran, the only significant change in the heating was a decrease of 2.3% in the need for bioclimatic design strategy of the internal heat gain. In the following, based on the x-axis in Figure 3, the left-hand side of the bioclimatic zones 13 to 16, which contains humidification only to heating, adding humidification if needed, determines the humidity strategies. In Moscow, as mentioned earlier, based on future climate changes, a rise in relative humidity was observed in all months of the year, but the combination of the increased humidity and increased summer temperature results in uncomfortable conditions for the building occupants in the season. Therefore, based on the humidity strategies, the need for dehumidification in warm-related seasons of the year is proposed to provide indoor thermal comfort as one of the main bioclimatic strategies in the time period. Because the outputs show that for both dehumidification only and cooling, add dehumidification if needed, 11% and 9.1% of frequency of the need for these strategies will decrease in the future, respectively. In addition, the outputs show that in the cold season for providing indoor thermal comfort, the use of the heating, add humidification if needed is reduced by 8.8%. On the other hand, the use of humidification only at any time of the year cannot provide indoor comfort conditions alone, neither for the observation period nor for the future. Changes in humidity strategies for Tehran were less than of those in Moscow. First, there is no change in the future for any of the two strategies, humidification only and dehumidification only, and for both study periods, the need for these two strategies is considered to be zero (Figure 3). However, in general, with increasing temperature during the cold-related season, the severity of cold weather is decreased, which resulted in a 3% reduction in the need for heating, add humidification if needed. On the other hand, not only the increase in summer temperature, but also the increase in warm period, and sometimes combined with high humidity, which these conditions may occur during a limited period of the year, can be decreased by 2.2% the demand for using cooling, add dehumidification if needed.

One of the most important outputs of Figures 2 and 3 is the assessment of thermal comfort changes in the time periods for both Tehran and Moscow. In general, the number of days with normal thermal comfort conditions is very short in Moscow. In other words, no bioclimatic strategy is needed to provide indoor thermal comfort during these days. However, the effect of global warming will also reduce the thermal and bioclimatic comfort conditions. Its main factor can be increased temperature and humidity for the warm period of the year. Because the increase of winter temperature cannot be the same, this can lead to a decrease in the number of very cold days and more occurrence of days in the thermal comfort zone. In Moscow, during observation period (6.9% of days), thermal comfort event can be reduced by 2.7% in the period 2020-2049 so that the frequency of thermal comfort event for the next decades in Moscow will be 4.2%. The length of the climate comfort period for Tehran can be more than of that in Moscow. Its evidence was a frequency of 21.7% in the observation period. However, temperature rise has led to an 8.5% reduction in the frequency of days of thermal comfort in the future. In other words, in Tehran, 13.2% of days will naturally have indoor thermal comfort in the next decades. The cause of this decline is related to rising temperature, especially in late summer and early fall. As expected in late summer and early fall, the nature of climate can change to cool air and reduce the summer temperature. However, with increasing global warming, the decline in temperature in late summer and early fall can be transmitted into the middle of fall with the time delay, which can lead to a further reduction in the frequency of thermal comfort event in the future.

The appendix of the paper (Tables 2 and 3) presents bioclimatic design strategies for storing energy and providing indoor thermal comfort based on the observation and future periods in both studied cities.

4. Discussion and Conclusion

The findings of this study revealed that the results of the CanEMS2 climate model and the RCP 4.5 scenario indicated a higher rate of temperature increase for the next decades in Moscow compared to Tehran. Because temperature increase rate in Moscow (1.44°C) can be higher than Tehran, so the mean annual temperature increase in Tehran is 3.27°C and in Moscow is 4.71 °C. Similar results for both study areas were the highest temperature increase rates for June and July in the summer and the lowest temperature increase rates for the months in the fall. Many studies have been determined that the effect of global warming leads to a further increase in temperature in hot months of the year and lower temperature rise is in cold-related seasons. For example, Saboohi et al. (2012) in a study on 35 stations in Iran demonstrated that the global warming trend for the summer is more than other seasons of the year (Saboohi et al., 2012). In a study, Soltani et al. (2011) showed that stations in Zagros had an increasing trend in months related to the summer. Furthermore, Roshan et al. (2012) in a study found that 52% of their study stations are located in dry, Mediterranean, semi-humid, and humid regions. Based on this study, diagnostic of the mean temperature rise in Iran in 2100 compared to the base period (1960-1990) is 4.25 °C. The highest increasing trend in temperature has occurred during recent years in summer. In another study, Varentsov et al. (2017) demonstrated that due to the expansion of Moscow, temperature increase changes are observed, especially in summer, which have led to more hot days in Moscow. Additionally, their results for the summer revealed that the increase in both the night-time and day-time temperatures was 0.3°C and 0.60°C over the last 40 years, respectively.

The observed differences for Tehran and Moscow show a decreasing trend in relative humidity in Tehran and an increase rate in Moscow. As the results showed, relative humidity rates for Tehran can be decreased for all months of the year and increased for Moscow. The mean annual relative humidity showed that the reduction rate of it in the future for Tehran can be 4% and increase rate of it for Moscow can be 10.5%. Increasing temperature and decreasing relative humidity in Tehran could lead to a change in bioclimatic design strategies of buildings, as a combination of these conditions can estimate the warm and dry conditions for Tehran in the future. However, increasing both relative humidity and temperature in Moscow can result in a wetter and warmer climate than the current climate in Moscow. Therefore, the effect of this climate change should also be considered in bioclimatic design of buildings for the next decades. For Moscow, the findings showed that considering climate change in the future, the total frequency of different cooling strategies can increase by 5.8% compared to the observation period, which is much higher for Tehran (20.2%). On the other hand, the decrease rate in relation to the need for bioclimatic design strategies of heating is estimated to be 2.6% for Tehran and cooling system design, which is significantly higher for Moscow (14.4%). Moreover, in Moscow, the use of bioclimatic design strategies has decreased by 11.3%, and only 1% for Tehran. The use of humidity strategies and increasing dehumidification for these cities is based on climate changes in the future. Another important thing is to reduce the rate of days of indoor bioclimatic comfort for both metropolises based on heating in the next decades. Such a downward trend for Tehran indicates values greater than Moscow. Some studies have also showed the effect of climate change and variation of the need for cooling and heating energy for Tehran and Moscow. Roshan et al. (2012) have discussed the effects of climate change and variation of the need for cooling and heating energy for Iran by the year 2100. One of their results was decreasing the need for heating energy and increasing the need for cooling energy for the central regions of Iran, including Tehran. Based on climate change models for Moscow, Klimenko et al. (2016) demonstrated that due to the global warming in the coming decades, energy demand for heating in clod-related seasons is decreasing, and on the other hand, the energy demand for cooling is increasing. Finally, according to the results, it can be concluded that the impact of global warming on both Moscow and Tehran cannot be a very improbable event so that with changing climate in the future, a new management in bioclimatic design of buildings and storage of energy should be taken. However, as the results showed, there are different priorities for the two cities in terms of bioclimatic design, which are due to the different climate conditions and different effects of climate changes on them for the next decades.

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Appendix

Table 2. Bioclimatic design strategies for the two present and future periods of Moscow. P represents Present and F denotes Future periods. Some strategies are applied for both periods, and some are proposed for a specific period that includes present or future periods.

P and F	For passive solar heating face most of the glass area south to maximize winter sun exposure, but design overhangs to fully shade in summer
P and F	Provide double pane high performance glazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain
P and F	Lower the indoor comfort temperature at night to reduce heating energy consumption (lower thermostat heating setback) (see comfort low criteria)
P and F	Tiles or slate (even on wood floors) or a stone-faced fireplace provides enough surface mass to store winter daytime solar gain and summer nighttime 'coolth'
P and F	Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy
P and F	High Efficiency furnace (at least Energy Star) should prove cost effective
P and F	Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well insulated (to lower Balance Point temperature)
P and F	Extra insulation (super insulation) might prove cost effective, and will increase occupant comfort by keeping indoor temperatures more uniform
P and F	Steep pitched roof, with a vented attic over a well-insulated ceiling, works well in cold climates (sheds rain and snow, and helps prevent ice dams)
P and F	Sunny wind-protected outdoor spaces can extend living areas in cool weather (seasonal sun rooms, enclosed patios, courtyards, or verandahs)
P and F	If a basement is used it must be at least 18 inches below frost line and insulated on the exterior (foam) or on the interior (fiberglass in furred wall)
P and F	Traditional passive homes in cold clear climates had snug floorplan with central heat source, south facing windows, and roof pitched for wind protection
P and F	Traditional passive homes in cool overcast climates used low mass tightly sealed, well insulated construction to provide rapid heat buildup in morning
P and F	Traditional passive homes in cool overcast climates used low mass tightly sealed, well insulated construction to provide rapid heat buildup in morning
P and F	Trees (neither conifer or deciduous) should not be planted in front of passive solar windows, but are OK beyond 45 degrees from each corner
P and F	Locate garages or storage areas on the side of the building facing the coldest wind to help insulate
P and F	Use vestibule entries (air locks) to minimize infiltration and eliminate drafts, in cold windy sites
P and F	Insulating blinds, heavy draperies, or operable window shutters will help reduce winter night time heat losses
P and F	Windows can be unshaded and face in any direction because any passive solar gain is a benefit, and there is little danger of overheating
F	Carefully seal building to minimize infiltration and eliminate drafts, especially in windy sites (house wrap, weather stripping, tight windows)
F	In this climate air conditioning will always be needed, but can be greatly reduced if building design minimizes overheating
F	Super tight buildings need a fan powered HRV or ERV (Heat or Energy Recovery Ventilator) to ensure indoor air quality while conserving energy

Appendix

Table 3. Bioclimatic design strategies for the two present and future periods of Tehran. P represents Present and F denotes Future periods. Some strategies are applied for both periods, and some are proposed for a specific period that includes present or future periods.

P and F	On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed
P and F	Earth sheltering, occupied basements, or earth tubes reduce heat loads in very hot dry climates because the earth stays near average annual temperature
P and F	An Evaporative Cooler can provide enough cooling capacity (if water is available and humidity is low) thus reducing or even eliminating air conditioning)
P and F	Flat roofs work well in hot dry climates (especially if light colored)
P and F	For passive solar heating face most of the glass area south to maximize winter sun exposure, but design overhangs to fully shade in summer
P and F	Provide double pane high performance glazing (Low-E) on west, north, and east, but clear on south for maximum passive solar gain
P and F	Traditional passive homes in hot dry climates used high mass construction with small recessed shaded openings, operable for night ventilation to cool the mass
P and F	Traditional passive homes in hot windy dry climates used enclosed well shaded courtyards, with a small fountain to provide wind-protected microclimates
P and F	Humidify hot dry air before it enters the building from enclosed outdoor spaces with spray-like fountains, misters, wet pavement, or cooling towers
P and F	Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning
P and F	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required
P and F	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
P and F	Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain
P and F	Lower the indoor comfort temperature at night to reduce heating energy consumption (lower thermostat heating setback) (see comfort low criteria)
P and F	Provide enough north glazing to balance daylighting and allow cross ventilation (about 5% of floor area)
P and F	To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and outlet (open stairwells, two story spaces, roof monitors)
P and F	Heat gain from lights, people, and equipment greatly reduces heating needs so keep home tight, well insulated (to lower Balance Point temperature)
P and F	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
P	Organize floorplan so winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation
P	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
F	A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates
F	Raise the indoor comfort thermostat set point to reduce air conditioning energy consumption (especially if occupants wear seasonally appropriate clothing)