Int. J. Urban Manage Energy Sustainability, 3(3): 71-83, 2022

Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com

ORIGINAL RESEARCH PAPER

Climatic compatible future cities locating approach to less non-renewable energy consumption

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ARTICLE INFO

Article History:
Received 2022-08-21
Revised 2022-11-15
Accepted 2022-12-18

Keywords:
Future Cities
Locating
Climate Factors
Energy
Design Strategies

DOI: 10.22034/jumes.2022.1982956.1101

ABSTRACT

More than half of the world's population lives in cities. Cities and climate have tremendous interactions. Slight changes in one of the climatic factors disrupt the balance of civilizations. Hence, neglecting these factors makes cities face hazards. Due to explosive population growth and urbanization, locating climatic compatible future cities is a worldwide concern. The main goal of the present study is to identify effective climate factors on future cities locating approach to less non-renewable energy consumption and compatible with climate. For this purpose, using a questionnaire from experts, providing pairwise comparison in Expert Choice software, and structural analyzing with Micmac software, data were divided into four factors and 23 sub-factors. Results show that the temperature and solar radiation factors have the highest effects. The lowest score is dedicated to the wind factor. Micmac structural analysis shows that altitude, latitude, radiation direction, and distance from the sea factors are key and sensitive (driver) factors; radiation duration, time-dependent fluctuations, sky cover and sunshine hours, and precipitation factors are high-risk (linkage) factors; atmospheric specifications, relative humidity fluctuations, heat gain, glacial days, horizontal pressure gradient factors are dependent factors, and solar radiation fluctuations factor is an independent (autonomous) factor.

Running Title: Climatic compatible future citie

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
57	05	0

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1. Introduction

Throughout history, human beings and nature have interactions, and the climate and how to master it, has been the most crucial concern in the way of creating biological colonies (e. g. cities, rural, etc.). Therefore, in the life-cycle of cities and regions, there has been a mutual relationship between humans and the environment from the beginning, and the environment has acted as a determinative phenomenon, and creating and vanishing of many cities have a direct relation with the presence or absence of favorable climatic conditions (Purdeihimi, 2010).

Climate is referred to the weather conditions of a geographical zone including temperature, humidity, atmospheric pressure, wind, precipitation, solar radiation, glacial days, and other meteorological characteristics over a relatively long period (which are measured in atmospheric stations). Climatic elements are intensified, reduced, or moderated by climatic factors. Climatic factors include altitude, geographical longitude and latitude, distance and proximity to the sea, land surface cover, etc. (Asakere, 2007). Undoubtedly, the climate of each region is an influential factor in determining the architectural form of that region.

Future cities, as pre-provided residences with previous models and plans (urbanization before urbanity), are considered as a new phenomenon (Shahryar et al., 2016, 2017). Future cities conduct human mind toward utopia and ideal accumulation in these cities, and creative ideas associated with creative thoughts of urbanization are introduced as a pattern with construction and implantation model for citizens living in an appropriate region without concern (Esmaeilpour and Keykha, 2020). Therefore, the most important issue facing the development and creation of future cities is the location of their future development. Since the beginning of human settlement on the earth, locating was performed in order to better access to food resources and find a place for hunting, shelter, and a workplace (Livani, 2008). Optimal locating tries to help decision-makers and planners in choose the right places to carry out activities by legalizing indicators and factors affecting decision-making and providing logical solutions. This operation, without considering the spatial relations and geometry of the space, can lead to inappropriate results (Salimi et al., 2012). Locating is the process of searching and selecting an appropriate location for the establishment of a building or usage according to the intended goals; so that the best performance is achieved according to the intended purposes of the action (Abbasi, 2014). From another point of view, locating is the act of making a decision and determining the coordinates for the establishment of a new complex or equipment among a set of assumed positions, observing the limitations, and considering the desired criteria (Yekani, 2019). Theory of locating aims to choose the most appropriate location for activities based on the existing realities and the factors affecting them (Rezaeizade Mahabadi and Babaei, 2017). Optimal locating of future cities based on effective climate parameters to prevent environmental crises, as well as proper and sustainable use of the facilities of a region, is one of the critical issues facing today's world (Moein Far and Beyg Babaee, 2020). Due to global warming and predicted short- and long-term heat waves (especially in Iran) (Freidooni et al., 2015), the climate is one of the essential factors for deciding about the locating future cities; cities that humans are forced to plan them today, due to the indiscriminate development of urbanization and massive migrations (He et al., 2020). According to Oke (2006), if the weather factors are ignored, especially in tropical areas, we may face issues such as deaths due to high temperatures, reduction of comfort, expensive ventilation systems, and destructive floods in the future. (Oke, 2006). Also, paying attention to climatic potentials and their optimal use will lead to reduce energy consumption, and this will be a step towards sustainable urban development. Therefore, climate analysis is essential in the studies of future city locating in regards to a few aspects, including the impact on the physical development of urban residences and their development directions, affecting the emergence and exact locating of cities, influenced on urban construction and texture (density, direction and roads width, height, etc.), creation of green spaces and parks, Identifying the location of industrial activities and constructing the transportation networks, reducing pollution and saving in energy consumption (Pourjafar et al., 2012).

2. Literature review

Many attempts have been done to reduce energy consumption in built areas (Nicol and Humphreys, 2002; Nguyen et al., 2012; Attia and Carlucci, 2015; Takasu et al., 2017; Singh et al., 2018) which their results can be extendable to the future cities. Martilli (2014) studied thermal comfort in cities in terms of the shape and form of buildings and urban density approach to reducing energy consumption and greenhouse gases. Alghoul et al. (2017) studied the energy consumption in buildings in Libya. They concluded that, for case studies, adding windows to the facade leads to an increase in annual energy consumption by 6 to 181%.

Temperature has been identified as the most vital factor in urban region (outdoor) comfort in several studies compared to radiation, wind, and precipitation (or humidity) (Chen et al., 2018; Lai et al., 2014; Liu et al., 2016; Tsitoura et al., 2014). Regarding the comparison of the two factors of radiation and wind, researchers' experiences are divided into four categories: first group suggested that radiation had more significant influence or higher association than wind (Hwang and Lin, 2007; Lin et al., 2011; Liu et al., 2016; Shih et al., 2017; Tseliou et al., 2015; Xu et al., 2018; Yang et al., 2013; Yin et al., 2012). The second group believed that wind had a greater impressment than radiation (Krüger and Rossi, 2011; Metje et al., 2008; Walton et al., 2007). The third group recommended that wind and radiation change dynamically in outdoor space (Lai et al., 2017; Lau et al., 2019; Nakayoshi et al., 2015; Vasilikou and Nikolopoulou, 2019). The last group stated that the impact of wind and radiation on human have directions (Hadianpour et al., 2019; Kubaha et al., 2004). Also, about precipitation (or humidity) there are two different opinions: first, the humidity had a negligible influence (Chen et al., 2018; Cheng et al., 2012; Kantor et al., 2012; Lai et al., 2014), and second, humidity was perceived as the most unpleasant parameter under high air temperature (Chow et al., 2016).

Shahryar et al. (2016) studied the feasibility of new cities' locating and developments in Qazvin province using the fuzzy analytical hierarchy process (FAHP). Data was obtained using Delphi and pairwise questionnaires.

Shahryar et al. (2017) studied locating suitable areas according to climatic parameters for constructing new cities in Qazvin province. The method of this study is to determine the importance and weight of climatic parameters using fuzzy-AHP and data from two questionnaires, Delphi and pairwise comparison method. The susceptible areas in terms of climate conditions were identified in a case study in Qazvin province. The results show that, according to climate conditions for creating new cities, 9.6% area of the province was located in the highly desirable region, 31.3% in the favorable region, 40.7% in the moderate region, 12.3% in the undesirable region, and 9.1% in the complete undesirable region, respectively.

Javed et al. (2022) surveyed analyzing future technologies and requirements for future smart cities. Various technological challenges of future smart cities have been discussed. Finally, the future dimensions of smart cities to develop smart cities with the precedence of smart living were identified.

Javaheri taghaddos et al. (2020) studied the role and impact of future cities in creating the physical-spatial structure balancing through the rank-size method to identify the impact of used factors, and scenarios for the development of a spatial organization and determining the location of new cities were performed by MicMac software. The results indicate that except for the new city of Andisheh in the Tehran metropolis, other new cities around the Tehran have faced many problems in attracting the population.

Ramezani and Karimi Rad (2021) have conducted research to identify and comply the city of Hashtgerd, as a case study, with the criteria of McHarg's method based on the ecological model of urban, rural, and industrial development. The comparison of parameters with the ecological model of urban, rural, and industrial development and the proposed criteria indicates that factors such as inclination, geographical direction, parent rock, depth, structure of soil, and vegetation are placed in McHarg's 1st class (suitable class). Other factors are in McHarg's 2nd class (almost appropriate class) and none of the parameters are in the inappropriate class.

Ballarini et al. (2021) studied the impact of climate changes on heating and cooling energy demand, overall energy performance, and risk of overheating typical residential buildings (existing and renovated) in the largest populous city of Italy, Milan. The modeling method has been widely adapted to generate future climate data related to various scenarios. The results show that climate changes cause a paradigm shift in building energy performance.

Cuchiella and Rotilio (2021) discuss planning and retrofitting of energy for future cities and point to the vital role of government departments in future cities. They suggested three principles, i.e., knowledge, planning and sharing of the city, which can bring economic, social, and environmental sustainability.

Amiri Ade et al. (2022) employed Design Builder software to study the impact of microclimatic factors on optimizing energy consumption in urbanization in Tehran. Results show that green roofs could be significantly effective in reducing heating and cooling loads. Also, the eastern and western facades should be considered without openings. They found that, in every survey of future cities, the locating is based on economic, social, and environmental resources. Analysis of influential climatic factors and elements is necessary to achieve the optimal locating of the future cities for reducing energy consumption.

2.1. Worldwide Experiences of the Future Cities

Future cities in today's world, are planned residences that are consciously created in response to predetermined goals and to solve population problems and pressures to achieve a kind of spatial balance between large urban and rural regions (Azizi and Shojaei, 2009). Forecasting the future is a systematic effort to look scientifically at the long-term future, which must be conducted by using the analysis of sources, patterns and factors of change or stability to visualize a potential future and plan for them.

The main characteristics of future cities based on four case studies worldwide i. e. the future city of Masdar (United Arab Emirates), The future city of NEOM (Saudi Arabia, the Line and Sindalah), Dragonfly Skyscraper (Roosevelt Island in New York State), and Chongming Dongtan Eco-city in Shanghai are Carbon free, using renewable energy, less energy consumption, conservation of energy, water recycling, climatic compatible urban and buildings design and planning, etc.

Based on the literature review, it can be resulted that, although different aspects of future cities have been examined separately; however, a coherent approach resulting from the integration of climatology (studying the effect of climatic factors on locating of future cities), urban studies (design and planning), studies from the perspective of reducing energy consumption and finally providing strategies for buildings design and construction has not been seen so far. Although previous studies answered many questions about practical significances about future cities and urbanization, but some scientific gaps still remained that should be filled.

How can climatological factors affect the climatic compatible future cities locating? What changes in climatological factors impressments prioritizing in locating future cities are happened when low non-renewable energy consumption approach is considered? And the core question of, "How can locating the future cities compatible with climatic factors approach to less non-renewable energy consumption?"

To fill the above gaps of science, using a questionnaire from experts, pairwise comparison in Expert Choice software, and Micmac structural analysis, data were studied.

3. Methodology

The present study is applied-research in terms of purpose, because its results can be used in all issues related to urbanization, modeling, urban-regional planning, etc. In terms of nature, it is an exploratory-analytical study; the exploratory method can be followed by reviewing the literature, negotiating with experts in the relevant area and conducting focused interviews with individuals or groups, reading various texts and writings. To that end, the effective climate factors were first identified through library and documentary studies, then using the Analytical hierarchy process (AHP) through a field questionnaire, a pairwise comparison was conducted between the factors by a group of experts through the

Expert Choice software, and the factors and sub-factors were scored. Using this manner, the ranking of the factors and sub-factors was evaluated as effective factors in locating climatic compatible future cities approached to reducing energy consumption. Then, Micmac software (structural analysis, which is a tool adapted for global thinking over a given sector) was used to study the relationships between the variables, the extent of impressment and impressionability of the parameters, to extract the key and important climate factors that are effective on the locating of future cities with the approach of reducing energy consumption. The statistical population in this study is a group of experts and specialists in the field of urban planning, mechanical engineers, climatologists, and relevant organizations. In this research, the statistical population studied, based on the theoretical saturation, includes 30 experts. The mentioned experts have at least six years of experience in urban designing, regional planning, urban geography, climatology, mechanical engineering, or university lecturers. This group was selected by the snowball sampling method which was used as a targeted method to collect data. The advantages of the Micmac method are as follows: The first goal of such an analysis is to stimulate the thinking within the group and to initiate a reflection on 'counter-intuitive' aspects of the system's behaviour. In addition, the method presents the advantage of allowing a qualitative study of significantly different systems e. g., aeronautical engineering, dairy, urban planning, etc.

According to the literature review, the climatic factors and sub-factors which affect the locating of future cities (approach to reducing energy consumption) are temperature and its sub-factors (Asakere, 2007; Mohammadi, 2010 and 2011; Alizadeh et al., 2011; Kaviyani and Alijani, 2016; Chen et al., 2018), solar radiation and its sub-factors (Asakere, 2007; Liu et al., 2016; Shih et al., 2017; Xu et al., 2018), precipitation and its sub-factors (Asakere, 2007; Mohammadi, 2010 and 2011; Alizadeh et al., 2011; Kaviyani and Alijani, 2016), and wind and its sub-factors (Omidvar, 2010; Shahryar et al. 2016 and 2017, Lau et al., 2019; Vasilikou and Nikolopoulou, 2019; Hadianpour et al., 2019).

4. Results and Discussion

4.1. Hierarchical Analysis and Scoring of climatic factors and sub-factors

Fig. 1 depicts the radar-pie diagram weights of climatic factors and sub factors shows, based on the literature review, the climatic factors and sub-factors affecting the locating of future cities approach to reducing energy consumption. The factors are divided into four main categories i. e. temperature, wind, solar radiation, and precipitation which have some sub-factors affecting them. These include total of 23 sub-factors which are temperature, wind, solar radiation, and precipitation that including six, five, three, and nine sub-factors, respectively. These parameters have been selected by Expert Choice software (using the AHP method) through interviews based on the experts' comments.

The temperature and solar radiation factors with the score of 0.425 and 0.417, respectively, have the highest effects on future cities locating approach to reducing energy consumption (see Fig. 1 (a-c)). The lowest score was dedicated to the wind factor by 0.040 score.

The sub-factors affecting on the scoring of future cities locating approach to lessen energy consumption respectively from highest to lowest are solar-radiation duration (with the weight of 0.261), thermal energy (heat gain) (0.161), solar direction (0.126), solar radiation fluctuations (0.119), altitude (0.062), latitude (0.037), sky cover or sunshine hours (0.036), atmospheric specification (0.03), relative humidity fluctuations (0.023), etc. Also, the parameters of dominant wind direction with a score of 0.004, ocean circulation and earth rotation with a score of 0.001, have the lowest value and significance among other factors.

4.2. Structural Mic Mac Analysis of Climate factors

The structural Micmac analysis is a method to identify the relationships between the factors. The effect of each factor is evaluated in relation to other factors, so that if there is no, weak, average, or strong relationship, it would be 0, 1, 2, and 3, respectively. In this system, factors that play a key and sensitive role, as well as dependent factors, independent and high-risk factors are identified. The characteristics of the matrix of direct

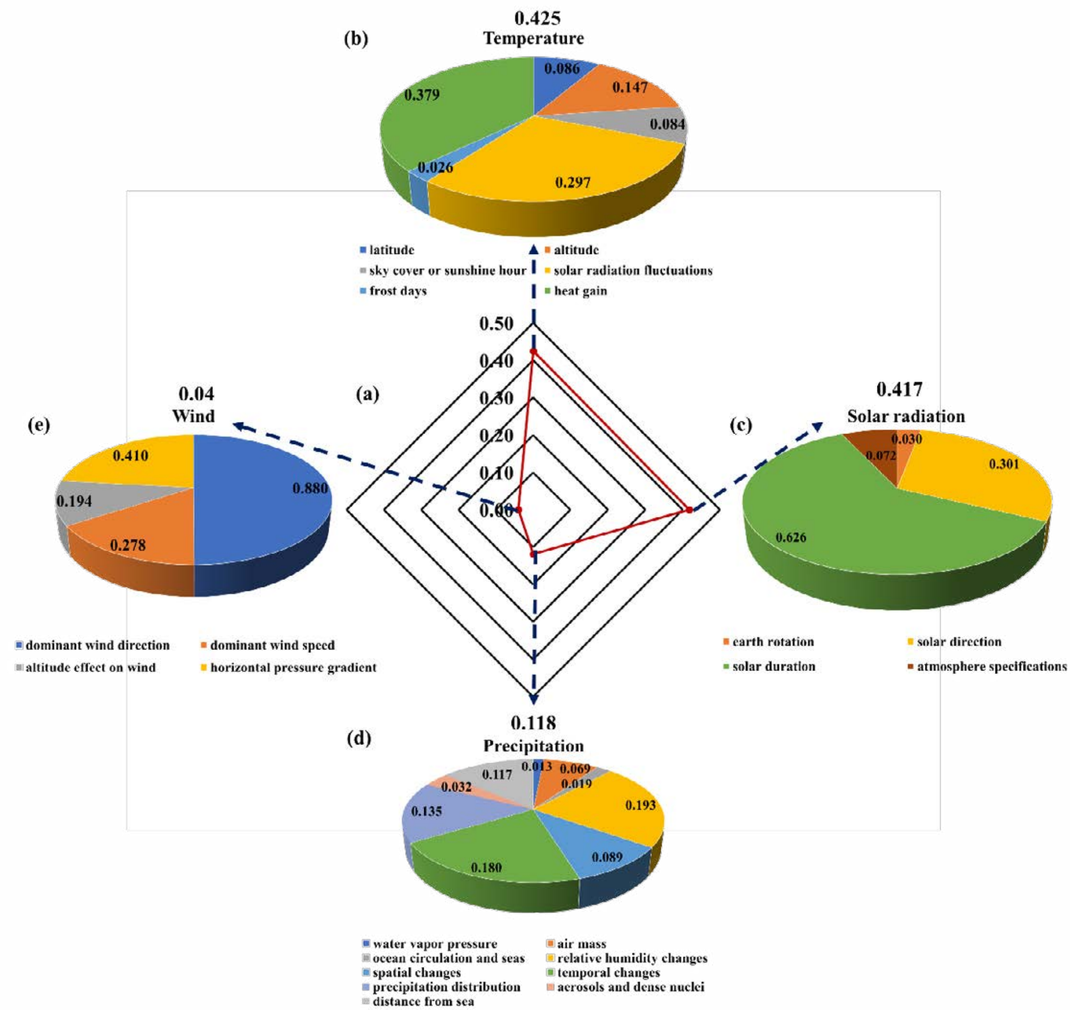


Fig. 1. Radar-Pie diagram of weights of climatic factors and sub-factors (a) factors radar diagram; (b) temperature sub-factors pie diagram; (c) solar radiation sub-factors pie diagram; (d) precipitation sub-factors pie diagram; (e) wind sub-factors pie diagram.

influence (MDI) are as follows: numbers of 0, 1, 2, 3, and P are 71, 20, 49, 56, 0, respectively. The matrix size is 14 × 14. From Fig. 2, the partitioning of each of the factors is presented based on their impressment and impressionability.

From Fig. 2 (direct map of Micmac analysis) and results of AHP method partitioning of climatic factors affecting the location of future cities approach to reducing energy consumption are as follows:

1- Partition I includes altitude, latitude, radiation direction, and distance from the sea factors are key and sensitive (driver) factors.

2- Partition II contains radiation duration, time-dependent fluctuations, sky cover and sunshine hours, and precipitation factors are high-risk (linkage) factors.

3- Partition III consists of atmospheric specifications, relative humidity fluctuations, heat gain, glacial days, and horizontal pressure gradient factors are dependent factors.

4- Partition VI encompasses solar radiation fluctuations factor is an independent (autonomous) factor.

From Fig. 3 which shows direct and indirect graphs of climatic factors effects, it can be observed that the outgoing red arrows from latitude, altitude, radiation direction, and distance from the sea are more than the incoming arrows. This means that, these factors have high impressment and low impressionability and are considered as key and sensitive (driver) factors. But the factors located at partition II have more outgoing and incoming arrows, which are called high-risk (linkage) factors that can be considered as key factors with little changes in the factors above the diameter of partition II. In partition III, most of the arrows are incoming because they have high impressment and low impressionability. In partition VI, some factors have low impressment and impressionability, which are called independent (autonomous) factors. For partition V, the factors tend to be in one of the areas, but the system is not able to identify them that the factor of solar radiation has been identified as an uncertain parameter in this study. It is noteworthy to mention that the solution stability after 2 iterations became 100% and three more iterations have been done to confirm it.

4.3. Envisage vision of future climatic compatible low energy consume cities and buildings

Every future climatic compatible low energy consume city needs suitable buildings for that city, because cities are interconnected colonies of buildings. Although several strategies from the perspective of urban planning exist to development of the future cities; many applicable strategies are underway to help from the building and architectural point of view. In the following, first, strategies from the perspective of urban planning to locating future cities based on climatic parameters are presented, then the optimal design strategies for the future buildings (low energy consumption) are introduced.

From an urban planning perspective:

1- Based on obtained scores of solar radiation (0.417), solar direction (0.126), and solar radiation fluctuations (0.119), using renewable and sustainable solar energies e. g. solar cells and solar collectors reduce energy demands.

2- According to wind factor and its sub-factors (i. e. dominant wind speed and wind direction) using on- and off-shore horizontal- and vertical-axis wind turbines enhance energy production. Also, according to the distance from the sea factor hydropower, ocean energy, and water turbines can be used.

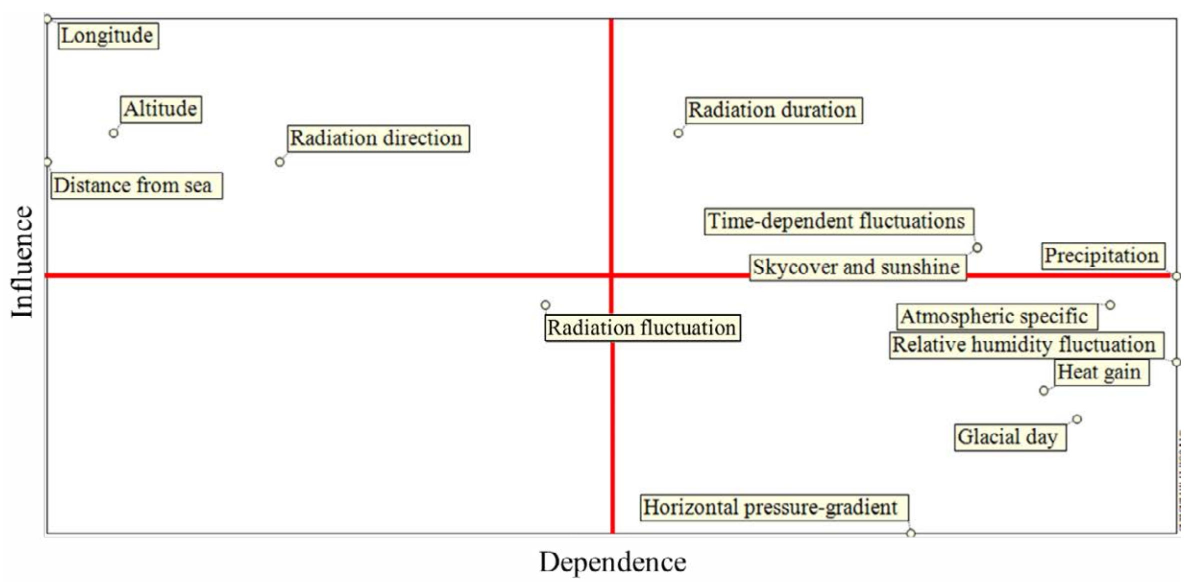
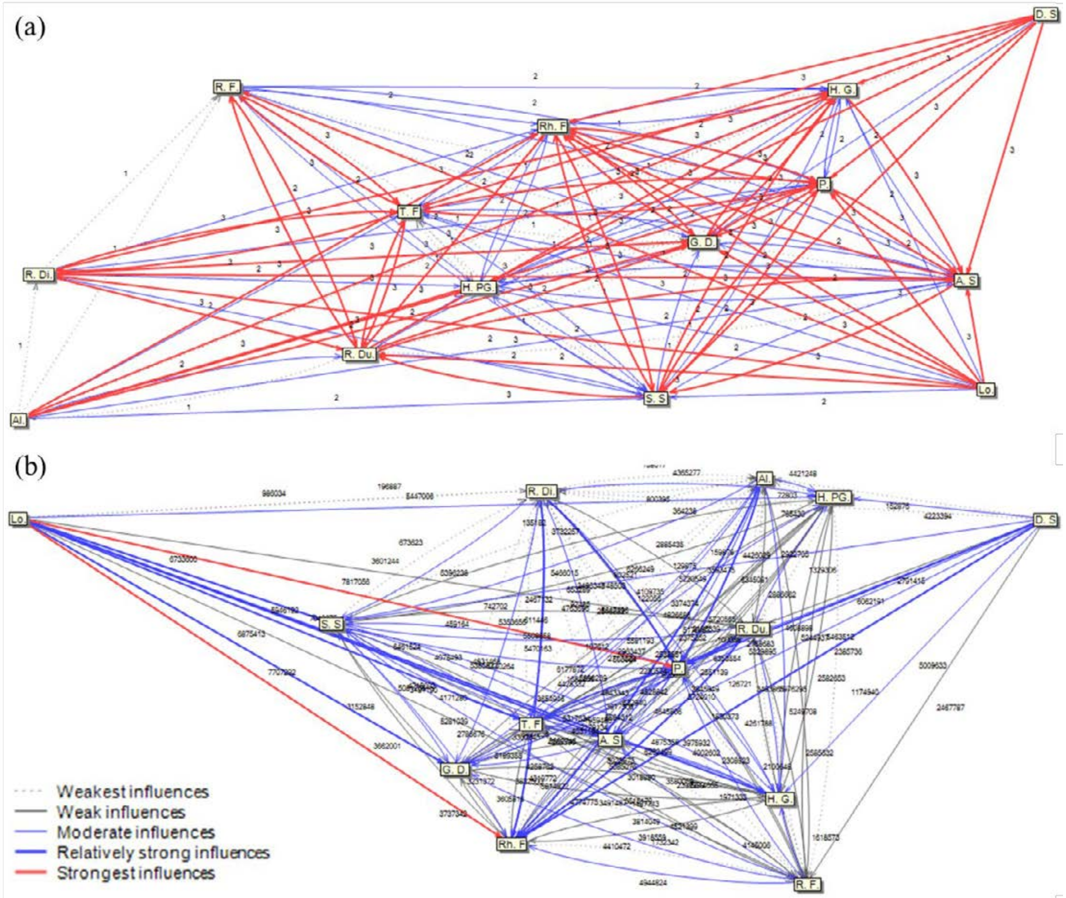


Fig. 2. Direct map: climatic factors partitioning



Long label	Altitude	Atmospheric specific	Distance from sea	Glacial day	Heat gain	Horizontal pressure-gradient	Longitude
Short label	Al.	A. S	D. S	G. D.	H. G.	H. PG.	Lo.

Long label	Precipitation	Radiation direction	Radiation duration	Radiation fluctuation	Relative humidity fluctuation	Skycover and sunshine	Time-dependent fluctuations
Short label	P.	R. Di.	R. Du.	R. F.	Rh. F	S. S	T. F

Fig. 3. Graphs (a) direct effects; (b) indirect effects.

3- Due the importance of the wind factor in minimizing energy consumption, locating and designing cities based on the wind in such a way that the direction of the city, streets, passages, and alleys are made in the direction of the favorable wind. The location of the buildings, elements and the wind turbines farm should be in such a way that, proper ventilation can be provided. Also, similar to wind direction, the solar direction should be considered.

4- Same as the global experience, the development of green infrastructures and spaces can enhance air quality and balance real feel temperature.

5- Become a "sponge city" by restoring surrounding green spaces (if exist) to restrict landslides and floods, and boost drainage in ways that mimic natural streams and rivers.

5- Low values of precipitation (according to precipitation factor with a score of 0.118) and hotter summers have required constructing more efficient and bigger rain harvesting systems and desalination facilities to process seawater, while setting up systems to carefully track water use and trigger early warnings of dry periods. Also, dew collection technology can be helpful.

6- Based on altitude and buildings height, high-raised cities consume higher energy values. So, it is reasonable to construct low-raised cities in higher altitude locations.

7- Keeping a reasonable distance from both very low- and high-latitude locations cause optimal energy consumption for cooling (or dehumidification) and heating (humidification).

From a building design and architectural perspective (see Fig. 4-5).

It is noteworthy to mention that, after the first step of locating a future city based on climatic parameters (in the way that presented with Micmac analysis and AHP method), the following strategies can be helpful to attenuate energy consumption.

1- Construction green roofs buildings help to improve outdoor air quality and humidity moderation; also, green color moderates the solar radiation reflection. Besides, humidity and shade (prevent overheating) attenuate energy consumption for cooling purposes. On the other hand, using light-colored building materials and cool roofs (with high emissivity) minimize conducted heat gain (Fig. 4(b)).

2- Minimize or eliminate west-facing glazing and vegetation reduces summer and fall afternoon heat gain. Trees should not be planted in front of passive solar windows but are OK beyond 45 degrees from each corner (Fig. 4(e)).

3- Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes

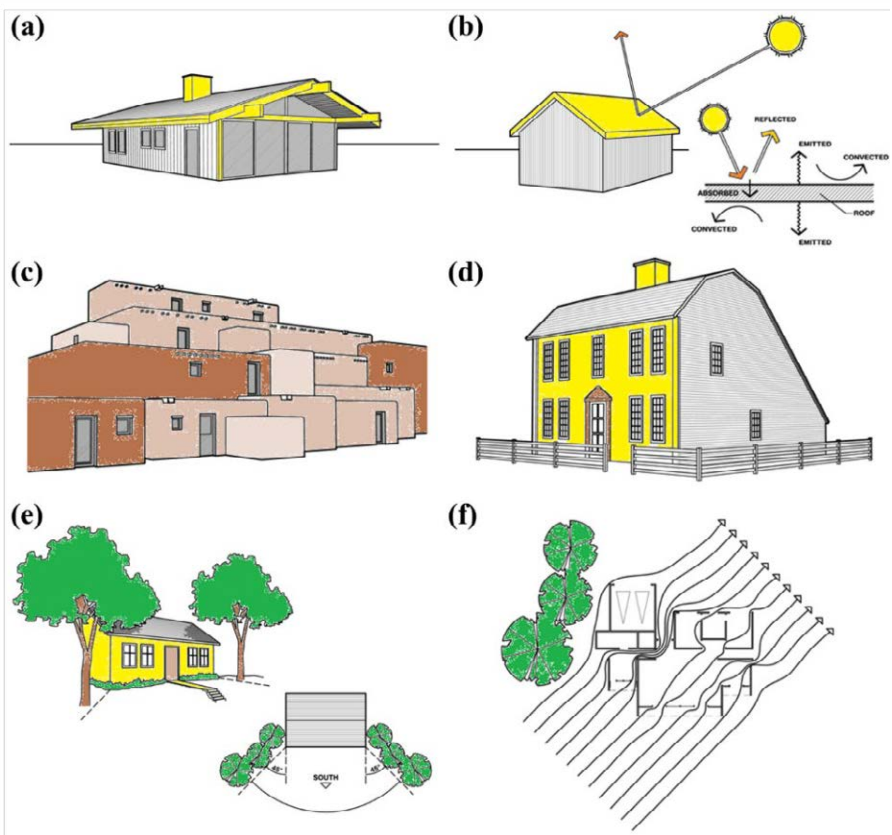


Fig. 4. envisages future cities buildings approach to low energy consumption.

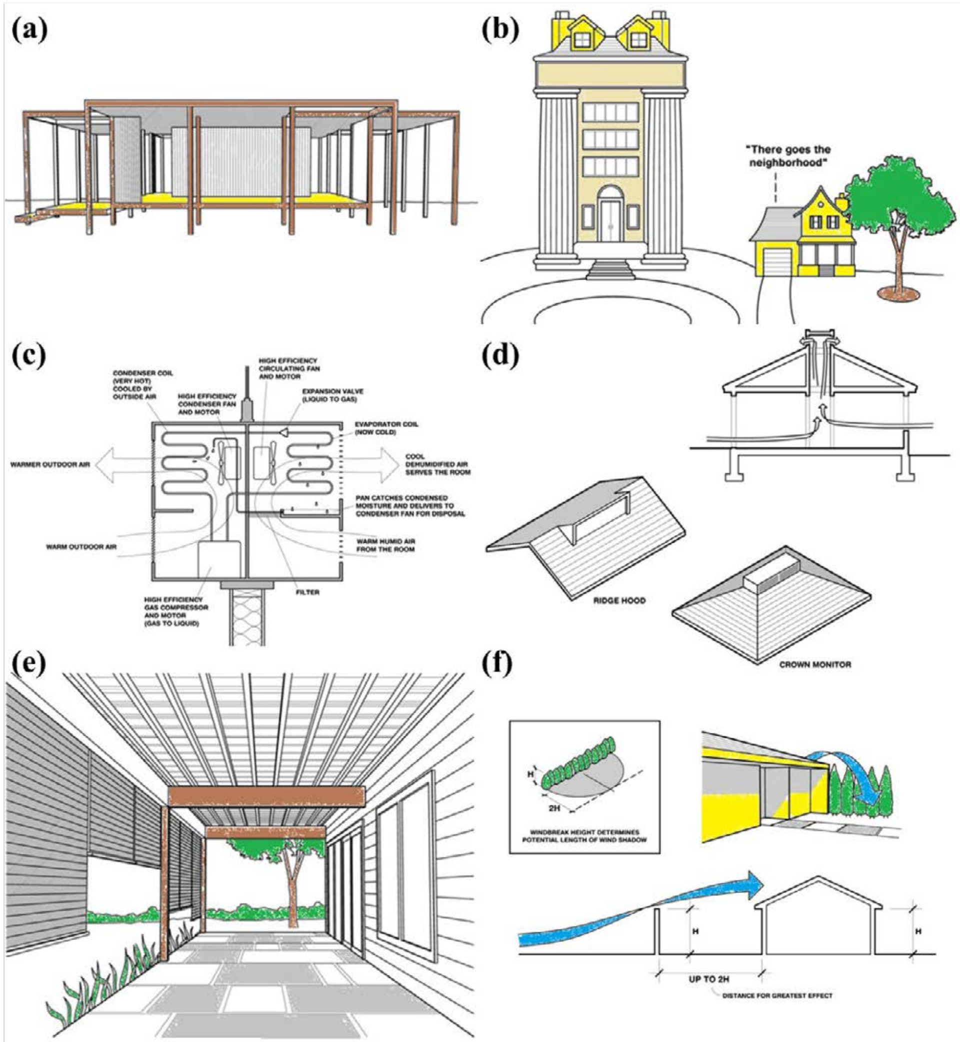


Fig. 5. envisages future cities buildings approach to low energy consumption.

can extend living and working areas in warm or humid weather. Also, open outdoor space can be used as passive solar gain in winter (Fig. 5(a, e, f)).

4- low pitched roofs with wide overhangs work well in temperate climates (Fig. 4(a)).

5- Exterior wind shields or dense planting can protect entries from cold winter winds (wing walls, wind breaks, fences, exterior structures, or land forms) (Fig. 4(e, f), 5(e, f)). Keeping the building size optimum, preventing waste of heating and cooling energies (Fig. 5(b)). In addition, using high efficiency air conditioner, heat pump, unit package, radiators, etc. reduces energy consumption (Fig. 5(c)).

6- Locating door and window openings on opposite sides of the building facilitates cross ventilation in late spring, summer, and early fall which leads to tremendous cooling energy reduction (Fig. 4(f), 5(d)). To produce stack ventilation (Fig. 5(d)), even when wind speeds are low, the vertical height between the air inlet and outlet should be maximized (open stairwells, two-story spaces, roof monitors).

7- Traditional passive homes in hot dry climates used high mass construction with small recessed shaded openings, operable for night ventilation to cool the mass. Traditional passive home in cold clear climate had snug floorplan with a central heat source, south-facing windows, and roof pitched for wind protection (Fig. 4(c, d), 5(a)).

5. Conclusion

Climate is an unstable and unsteady phenomenon which all its factors affect each other. In the present study, using experts' questionnaire, providing pairwise comparison in Expert Choice software, and structural analyzing with Micmac software, the effect of climatic parameters on the locating of future cities were studied approach to energy consumption reduction. Results show that the temperature and solar radiation factors with the score of 0.425 and 0.417, respectively, have the highest effects and the lowest score is dedicated to the wind factor by 0.040 score. The sub-factors affecting on the scoring of future cities locating respectively from highest are solar-radiation duration (with the weight of 0.261), thermal energy (heat gain) (0.161), solar direction (0.126), solar radiation fluctuations (0.119), altitude (0.062), latitude (0.037), sky cover or sunshine hours (0.036), atmospheric specification (0.03), relative humidity fluctuations (0.023), etc. Also, the parameters of dominant wind direction with a score of 0.004, ocean circulation and earth rotation with a score of 0.001 have the lowest value and significance among other factors. Micmac structural analysis shows that altitude, latitude, radiation direction, and distance from the sea factors are key and sensitive (driver) factors; radiation duration, time-dependent fluctuations, sky cover and sunshine hours, and precipitation factors are high risk (linkage) factors; atmospheric specifications, relative humidity fluctuations, heat gain, glacial days, horizontal pressure gradient factors are dependent factors and solar radiation fluctuations factor is an independent (autonomous) factor. The factors of precipitation, atmospheric specifications, and relative humidity affect on the formation of human communities, providing their livelihood; the factor of wind speed and its direction is influential in the construction of urban facilities, the direction of the city, streets, passages, and alleys.

These changes in climatic parameters cause changes in energy consumption reduction; if future cities are located correctly, it will reduce energy consumption and increase their performance. Hence, paying attention to climatic parameters and their role in the cities locating, to reduce energy consumption is an inescapable necessity. In order to conduct future researches, it is suggested to identify the effects of climatic nesting on the influential climatic factors in locating future cities approach to reduction energy consumption. Also, it is interesting to study the roles of artificial intelligence and information technology and their applications in future cities locating and energy consumption reducing.

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HOW TO CITE THIS ARTICLE

Freidooni, F.; Freidooni, S.; Gandomkar, A. (2022). Climatic compatible future cities locating approach to less non-renewable energy consumption. J Urban Manage Energy Sustainability, 3(3): 71-83..

DOI: 10.22034/jumes.2022.1982956.1101