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ORIGINAL RESEARCH PAPER

Investigating the role and importance of sustainable architecture in optimal fuel consumption and pollution reduction (Case study: Semnan wind-Catchers)

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Abstract: Wind-catcher is known as an important element in traditional Iranian architecture, especially in hot and dry areas. The purpose of this study is to investigate the role and importance of traditional Iranian architecture with emphasis on wind-catcher in reducing energy consumption in residential homes. For this purpose, Semnan province was selected as a study area and in the first step, based on theoretical foundations and field visits, suitable areas were identified for the establishment of wind-catcher in the province. The prepared information layers were combined using the overlay technique and GIS tools and the final map showing the distribution of wind-catchers was prepared. In the second step, using two indices of Olgyay and effective temperature index (ET), the temperature of thermal comfort in the province was determined. Finally, the temperature difference was calculated by comparing the temperature in the residential houses adjacent to the wind-catcher and the internal temperature of the traditional buildings that had win-catchers. In the final step, the amount of energy consumption for heating or cooling in residential houses in Semnan province was estimated to determine the role and importance of wind-catchers. The results showed that April, May, June and October are in the zone of thermal comfort and there are times when wind-catchers will not be very useful in the province. On the other hand, July, August and September due to high temperatures and December, January, February and March due to high cold are good times to use wind-catchers. Also, the highest degree of conformity of the measured temperatures is observed in the cities of Semnan, Garmsar, Damghan and Shahrood, respectively. The amount of energy required to produce cooling is equal to 1700 kWh. However, if a wind-catcher is used, due to the reduction of coefficients and refrigeration losses, this amount will be equal to 1200 kWh. Also, the amount of energy required per month for heating in a residential unit is equal to 110 kWh, which is reduced to 90 kWh in the case of windshield application.
Keywords: Wind-catcher, Energy consumption, Olgyay index, Thermal comfort, Semnan

1. Introduction

Today, the negative consequences and limitations of using fossil fuels and increasing energy consumption have increased the tendency to use renewable energy. Considering that the construction industry plays a major role in creating environmental challenges, especially global warming, by consuming 40% of global energy (Morahemi *et al*., 2017), Humans are looking for ways to reduce the consumption of non-renewable resources, develop the use of clean energy, eliminate or reduce the consumption of pollutants or substances that are harmful to nature in the construction industry. In general, environmental issues, climate change due to the consumption of fossil fuels and the increase of greenhouse gases on the one hand and the high cost of these fuels on the other hand, have provided the grounds for change in the widespread use of renewable energy (Fatemi & Taki, 2015). This is why many years ago, the inhabitants of Iran with special skills have used the potentials on earth and by implementing special techniques and rules in the field of optimal use of energy and natural resources, especially the sun and wind, and climate harmony, have used it (Zandieh & Parvardinejad, 2010). Indigenous Iranian architecture has unique features that in addition to aesthetic and cultural issues, in the direction of environmental approaches to sustainable architecture have also taken effective steps, so the use of valuable models of

Iranian architecture is very important and instructive. The study of the elements and features of Iranian indigenous architecture shows that this architecture has best responded to climate challenges and has met the needs of residents using natural and inexpensive methods. In general, various factors such as topography, climatic characteristics, economic capabilities, and livelihood and water resources in Iran have caused the emergence of different physical tissues. This special geographical and climatic location along with the intelligence of the past of this land in using natural energies such as wind and sun, both in hot and dry regions and in humid regions of the country, caused this unique architecture to appear (Ziabakhsh *et al*., 2011). In fact, traditional Iranian architecture has a strong and rich support for various aspects of sustainability, Iranian art and culture and shows a special share and value of this art and culture (Mahdavinejad & Javanroodi, 2011). About 30% of the world's energy is consumed in the domestic and commercial sectors, of which a significant portion is spent on cooling and heating buildings (Lu & Wang, 2014). Since cooling and heating systems consume about 60 percent of a building's energy, the use of passive systems such as wind-catchers can be a traditional but useful alternative to reducing energy consumption. Wind-catchers is a part of the body of buildings in hot and dry areas, which has played an effective role in adjusting the temperature and bringing the temperature of the living space to a temperature within human comfort by directing wind flow and using clean energy in nature. In fact, the use of wind-catchers in hot and dry climates is one of the masterpieces of Iranian engineering, but over time, the capabilities of this element are gradually forgotten and is considered only as a decorative element (Poorahmadi & Ayatalahi, 2011). There are also wind-catchers in Yazd, Kerman and Isfahan provinces. Wind-catchers may be mentioned as the most famous feature of hot and dry climate buildings. Wind-catchers mean a valve that is installed for the passage of wind in the house (Morahemi *et al*., 2017).

The wind-catcher is considered as a part of the body of buildings in hot and dry areas, which has played an effective role in regulating the temperature and bringing the temperature of the living space to the temperature of human comfort by directing the wind flow and using clean energy (Fig. 1).

Fig 1. View of the wind-catchers in native architecture

Wind-catchers have been built in different places since ancient times, and their structure and design have varied from place to place and have been innumerable. The important point is that despite the different structures, they all have the same function; this means that they all carry the dominant and desirable winds into residential spaces (Mahmoodi Zarandi, 2016). The wind-catcher is essentially an example of clean energy. Since seasonal and daily winds are one of the main climatic features of the hot and dry regions of Iran, wind-catchers in these areas were also built in the direction of pleasant and fast winds. The function of the wind-catchers is to capture the desired wind and direct it into the main rooms of the building or the cool wind draws the outside space into the main spaces (Poorahmadi & Ayatalahi, 2011). The basic function of a wind-catcher can be summarized in two parts: first, it directs pleasant air in, and second, it expels hot and polluted air. The presence of wind-catchers has a direct relationship with the climate of each region; in areas where the intensity of hot weather is higher, the number of wind-catchers will be higher (Mahdavinejad & Javanroodi, 2011). In traditional Iranian architecture, the most obvious method of managing the flow and air temperature in buildings is wind-catcher. The most important thing about wind-catcher is that they do not need energy)Roohi, 2014). This means that the operation of the wind-catcher is based on the laws of natural ventilation and using wind power)Mohammadi Sangli & Gharashi, 2016).

The purpose of this study is to investigate the importance and role of traditional Iranian architecture (especially wind-catchers) in saving fuel consumption.

In general, the architecture of housing in Semnan is such that renewable energy, such as air flow and sunlight, is used in a completely appropriate and optimal way to reduce the use of fossil fuels. In addition, it is possible to guarantee environmental sustainability. In Semnan province, like other hot and dry regions of Iran, wind-catcher has been used as a climatic element of architecture in building (Hekmatnia & Ansari, 2012).

2. Materials and Methods

2.1. Study area

The study area in this study is Semnan province, which has an area of 97491 square kilometers and between 51° and $51'$ to 57° and $3'$ east longitude of the meridian and 34° and $13'$ to 37° and $20'$ north latitude of the equator is located)SCI, 2019). Figure 2 shows the location of the study area on a map of Iran. There are about 85 healthy wind-catchers in Semnan province.

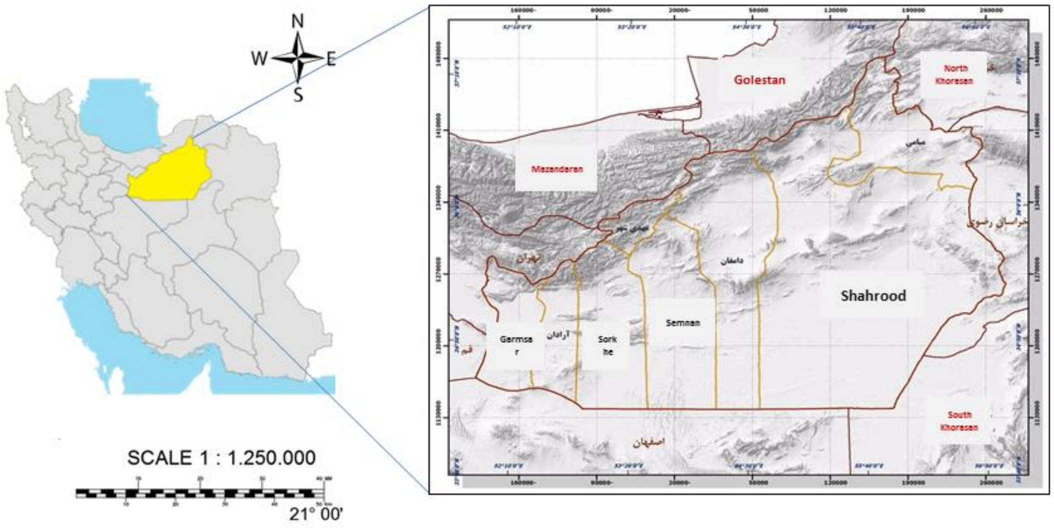

Fig. 2- Location of Semnan province on the map of Iran

The climate of Semnan province is affected by hot and dry air currents of Kavir plain, but factors such as distance from the sea, direction and length of mountains, altitude and winds are also effective in the climate of this province. In this province, three types of climates can be identified: relatively cold and dry climate in winter and temperate in summer (northern part of the province), desert climate and relatively hot and dry in summer and cold and dry in winter (Southern part of the province) and relatively cold and humid climate in winter and temperate and humid in summer (northeast of the province))Shafei Sabet *et al*., 2019).

The average maximum temperature in the hottest months is 25 °C and the average minimum temperature in the coldest months is -11 °C. In Semnan province, rainfall is very low and often in the form of rain and in the cold seasons of the year, the amount of which reaches an average of 145 mm per year. Due to the fact that the amount of relative humidity is directly related to rainfall, so the amount of humidity increases from west to east of the province and from south to north. So that the percentage of relative humidity in Shahrood is 49% and in Garmsar is 40%. Shahrood has the highest annual rainfall among the cities of the province with 161.1 mm and Damghan has the lowest annual rainfall with 120.2mm)IMO, 2011).. Also, the average number of frosty days during the year is about 48 days)Khajoo *et al*., 2020).

In Semnan province, due to having a hot and dry climate, architecture in harmony with the climate has been created. In such spaces, the use of local materials that have the least adverse effect on the environment, as well as reducing the amount of energy consumed using local materials, has led to environmental sustainability and increased durability of the building)Ziari & Khodadadi, 2013).

2.2- Methodology

This research is of applied type which has been done by mixed method (quantitative and qualitative). At first, based on theoretical foundations and field studies, the distribution of wind-catchers in Semnan province was determined and using GIS tools and ArcGIS software, version 9.3, the wind-catcher zoning map was drawn in the province.

Then, the comfort climate of the study area was determined. In order to determine the thermal comfort in the study area, two Olgyay indices and effective temperature index (ET) were used. For this purpose, long-term statistics of 3 synoptic stations around the study area and in the statistical period of 25 years (1994-2019) have been used. Olgyay index consists of four elements: maximum temperature, maximum relative humidity, minimum temperature and minimum relative humidity, and is calculated for the two parts of night conditions and daily conditions)Sener *et al*., 2011).

The two dots connect the day and night conditions and draw a line segment, the location of which determines the comfort conditions for that month. The center of the chart is the comfort zone. This is a place where the temperature is not high and the humidity is moderate. By moving to the sides, the degree of desirability decreases)Blen & Martin, 2008).

The temperature rises upwards and naturally the conditions become unfavorable. To the right, the relative humidity rises and the air becomes sultry and unfavorable. The two elements of maximum temperature and minimum relative humidity are used to calculate daily conditions. The effective temperature index is also measured by the following formula)Chou *et al*., 2019):

Equation (1):

$$Et = t -)0.4\ (t-10) \times (1-Rh\ /100))$$

In this formula, T is the average temperature (in Celsius) and RH is the average relative humidity (in percent). A guide to this indicator is provided in Table 1.

Table 1- Effective temperature index value and thermal coefficient

ET value	Thermal coefficient
More than 30	Very hot
27.5 - 30	Humidity
25.6 – 27.5	Very hot
22.2 – 25.6	Hot
17.8 – 22.2	Comfort
15.5 – 17.8	Cool
1.6 – 15.5	Very cool
-10 – 1.6	Cold
-20 – (-10)	Very cold
Less than 20	Very cold

Source: De Freitas et al., 2008

Then, through field harvesting, the internal temperature of wind-catchers in Semnan province was measured and compared simultaneously with the ambient temperature. For this purpose, the study team used standard and identical thermometers and hygrometers. A total of 84 points (wind-catchers) were measured and entered in the results in an Excel file.

Finally, the temperature difference was calculated by comparing the temperature in the residential houses adjacent to the wind-catchers and the internal temperature of the traditional buildings that had wind-catchers. In the final step, the amount of energy consumption for heating or cooling in residential houses in Semnan province was estimated to determine the role and importance of wind-catchers.

For this purpose, Equation 2 is used to calculate the energy required to provide heating in residential homes)Shi & Liu, 2019):

Equation (2):

$$Q_{H,nd} = Q_{H,nd,cont} = Q_{H,ht} - \eta_{H,gn} Q_{H,gn} \qquad (MJ)$$

Where in:

$Q_{H,nd,cont}$: Energy required to supply heating in continuous operation (MJ)

$Q_{H,ht}$: Total heat loss from the area during the heating period (MJ)

$Q_{H,gn}$: Total heat acquired from the area during the heating period (MJ)

$\eta_{H,gn}$: Dimensional coefficient of thermal acquisition

Heat loss from the building is calculated as the sum of heat loss due to heat transfer from the walls plus heat loss due to ventilation and from the following equation:

Equation (3):

$$Q_{Ht} = Q_{tr} + Q_{ve} \qquad (MJ)$$

Where in:

Q_{tr}: Heat loss from building walls (MJ)

Q_{ve}: Heat loss due to ventilation (MJ)

Heat loss due to the walls of the building occurs due to temperature differences inside and outside and in the form of conduction from the walls. It is calculated by the following equation.

Equation (4):

$$Q_{tr} = H_{tr,adj}\left(\theta_{int,set,H} - \theta_e\right)t \qquad (MJ)$$

Where in:

$H_{tr,adj}$: Overall area heat transfer coefficient (W/K)

$\theta_{int,set,H}$: Setting point temperature in heating mode (C˚)

θ_e Average outdoor temperature per month (C˚)

t: The desired duration, which is equal to the number of days in the month × 0.0644 (Msec)

Also, the cooling load is obtained from the following equation)Shi & Liu, 2019):

Equation (5)

$$Q_{c,nd} = Q_{c,nd,cont} = Q_{c,gn} - \eta_{C,ls} Q_{c,ht} \qquad (MJ)$$

Where in:
$Q_{c,nd,cont}$: Perceived energy required to provide cooling in continuous operation (MJ)
$Q_{c,ht}$: Total heat loss from the area during the cooling period (MJ)
$Q_{c,gn}$: Total heat acquired from the area during the cooling period (MJ)
$\eta_{C,gn}$: Dimensional coefficient of thermal acquisition

3. Results

In the first step of the research, based on field studies and review of documents and reports, the distribution of wind-catchers in Semnan province was investigated and a zoning map was drawn (Fig. 3).

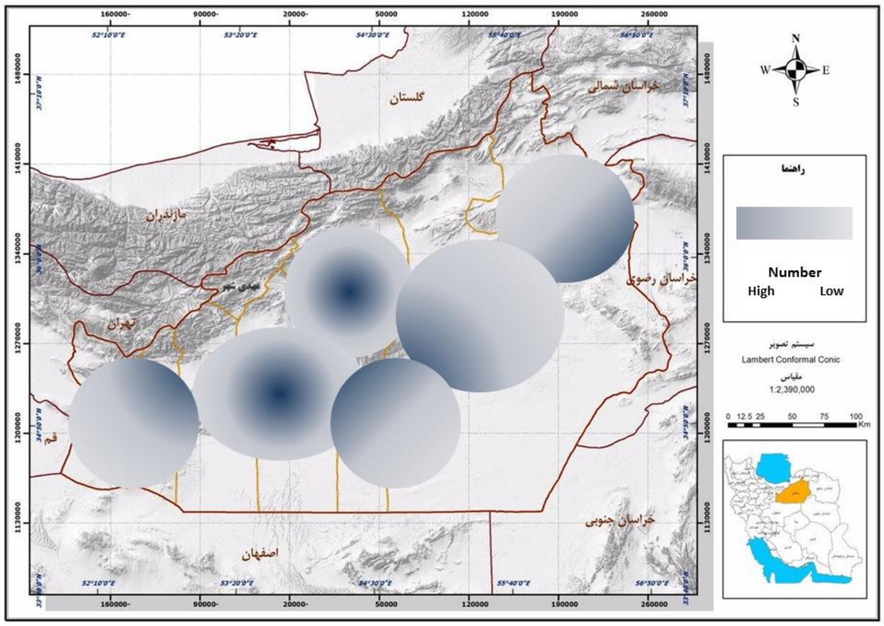

Fig. 3- Distribution map of wind-catchers in Semnan province

According to the synthesis of synoptic station data in the study area in the desired time period, human thermal and climatic comfort has been determined and presented based on the effective temperature (Olgyay method) (Table 2).

Table 2- Human thermal comfort in Semnan based on effective temperature (Olgyay method)

Month	Daily conditions (Maximum temperature / minimum humidity)	Night conditions Minimum temperature / maximum humidity)	Comfort coefficient
Oct	30% / 22.4 C°	67% / 8.80 C°	Comfort
Nov	37% / 14.8 C°	73% / 3.20 C°	Cool
Dec	48% / 8.20 C°	80% / -1.00 C°	Very Cool
Jan	49% / 6.10 C°	80% / -2.70 C°	Very Cool
Feb	41% / 8.80 C°	76% / -1.3 C°	Very Cool
Mar	35% / 14.1 C°	71% / 2.80 C°	Very Cool
Apr	30% / 21.1 C°	64% / 8.50 C°	Comfort
May	28% / 26.3 C°	60% / 13 C°	Comfort
Jun	25% / 31 C°	52% / 17.5 C°	Comfort
Jul	25% / 33.1 C°	51% / 20.3 C°	Hot
Aug	24% / 33.4 C°	52% / 19.1 C°	Hot
Sep	25% / 29 C°	58% / 14.8 C°	Hot

Source: Authors based on research findings

According to the temperature and humidity indices in Semnan province, it can be concluded that four months (April, May, June and October) are in the range of thermal comfort and four months (December, January, February and March) in conditions far from thermal comfort. And they are very cool. November is in cool conditions and is moderate. July, August and September are also in warm climates. None of the months of the year in this study area are in the humid and sultry zone. Based on the quantitative effective temperature index (ET), the comfort climate of Semnan can be determined.

The comfort climate classification of Semnan province based on Olgyay index is shown in Table 3. Green colors indicate the months in the thermal comfort zone. According to Olgyay index, April, May, June and October are in the zone of thermal comfort and there are times when wind-catchers will not be very useful in the province. On the other hand, July, August and September due to high temperatures and December, January, February and March due to high cold are good times to use wind-catchers.

Table 3- Monthly values of Olgyay index in Semnan province (Source: Authors)

Mar	**Feb**	**Jan**	**Dec**	**Nov**	**Oct**	**Sep**	**Aug**	**Jul**	**Jun**	**May**	**Apr**
Very cool	Very cool	Very cool	Very cool	Cool	Comfort	Hot	Hot	Hot	Comfort	Comfort	Comfort

Hot	**Comfort**	**Cool**	**Very cool**

The results for measuring the ambient temperature inside and outside the wind-catchers are presented in Table 4.

Table 4- Measuring the temperature and humidity of the outside and inside wind-catchers in different parts of Semnan province

Row	Wind-catcher position	Date	Average internal temperature	Average outdoor temperature	Average internal humidity	Average outdoor humidity
1	Semnan	Oct	23 C°	25 C°	31%	27%
2	Garmsar	Nov	18 C°	11 C°	37%	30%
3	Damghan	Jul	35 C°	39 C°	26%	23%
4	Shahrood	Aug	30 C°	36 C°	22%	21%

As it is clear from the results, the difference between the measured temperature inside the wind-catchers and the comfort temperature of the province is very small, so that they can be considered compatible in many months of the year. On the other hand, the internal temperature of the wind-catchers and the temperature of the external environment are significantly different from each other, which indicate the role of wind deflectors in modulating the internal ambient temperature of structures. The same is true of relative humidity; so that the relative humidity inside the wind-catchers is almost the same as the recorded relative humidity for the comfort temperature (Fig. 4).

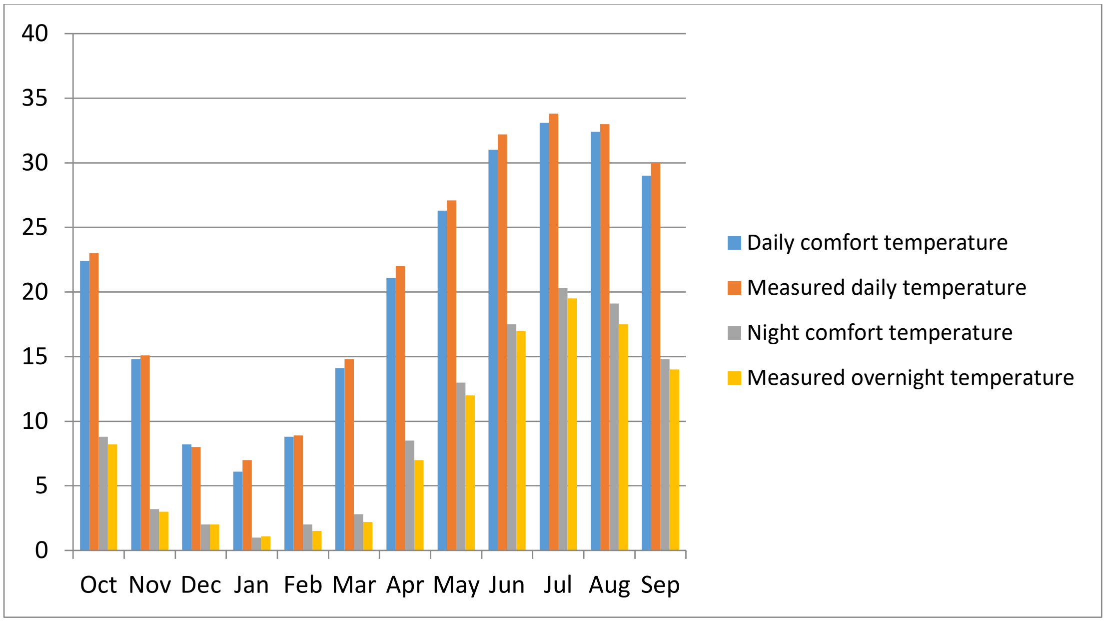

Fig. 4- Comparative diagram of day and night comfort temperature in Semnan province and the average temperature measured in the province's wind-catchers in the months of the year

From the comparison of the obtained results, it can be seen that the highest rate of compliance is observed in the cities of Semnan, Garmsar, Damghan and Shahrood, respectively. In other words, wind-catchers in Semnan city have a greater role in temperature regulation than other cities and in Shahrood city this role is less (compared to other cities in the province). In the final step, the amount of energy consumption in residential houses in Semnan province in 2 different cases was investigated:

A) Current residential houses without the use of wind-catchers;

B) The mode of using the win-catchers. To assume the same conditions, the building was simulated. The building has 1 floor and has the following specifications:

Table 5- Specifications of the outer layers of the default building

Name each layer	Thickness (mm)	Heat resistance (K.m^2/W)
Gypsum board	25	0.155
LW concrete block	203	0.58
face brick	100	0.076
iso	20	0.482
LW concrete block	203.2	0.355

Table 6- Floor 1 specifications of the default building

Floor area (m^2)	148
Area of windows (m^2)	52
Floor to ceiling height (m)	3
Roof heat transfer coefficient	0.424 W/K.m
Floor heat transfer coefficient	0.568 W/k.m
Air purity coefficient	1

Based on the assumptions given in the previous tables and also the following equation, the energy required to cool a residential unit in Semnan province (in one month) can be estimated:

$$Q_{C,nd} = Q_{C,nd,cont} = Q_{C,gn} - \eta_{C,ls} Q_{C,ht} \qquad (MJ)$$

The amount of energy required to produce cooling is equal to 1700 kWh. However, if a wind-catcher is used, due to the reduction of coefficients and refrigeration losses, this amount will be equal to 1200 kWh. Also, the amount of energy required per month for heating in a residential unit is equal to 110 kWh, which is reduced to 90 kWh in the case of wind-catcher application. Since the basic price of monthly energy consumption per 1000 to 2000 kWh in hot months and in hot areas is equal to 110 Rials, so the monthly cost of a residential unit with default conditions is equal to 187000 Rials per month in six months the year is equivalent to 1122,000 Rials. Also, the basic price of monthly energy consumption per 0 to 100 kWh in non-hot months and in hot and dry areas is equal to 350 Rials, which is equivalent to

231,000 Rials in six months of the year. Table 7 is a scale of two scenarios.

Table 7- Comparison of energy consumption and related costs in terms of use and non-use of wind deflectors

Scenario	Energy consumption to produce heating	Cost 6 months (Rials) To create heating	Energy consumption for cooling production	Cost 6 months (Rials) To create cooling
No use of wind-catcher and default mode (1-storey building)	660	231000	10200	1122000
Use a wind-catcher	540	189000	7200	712000

4. Discussion

In Semnan province, as in other hot and dry regions of Iran, wind-catcher has been used as a climatic element of architecture in buildings)Hekmatnia & Ansari, 2012).

As (Mohammadi Sangli & Gharashi, 2016) pointed out, natural ventilation is one of the most effective methods of providing passive comfort, because it can be used in large and complex buildings and can be used in all climates for a reason. In this research, an attempt was made to calculate and compare the amount of energy consumption for the production of cooling and heating in the buildings of the study area in two modes of using the wind-catcher and the current conditions (without using the wind-catcher).

The results indicate that in general, the northeastern part as well as the west and southwest have a higher potential for wind-catcher. This is consistent with the results of research)Valian et al., 2020). Meanwhile, the northern parts of the city, and especially the Mahdishahr area, have the lowest score in this regard, which of course can be considered reasons. Among other things, the location of this city is such that it is at a higher altitude level than other areas, which leads to a decrease in the average annual temperature. Also, high rainfall indicates more cloudiness and reduced sunshine in this area, which ultimately reduces the potential of the area for wind-catcher. The results of this section confirms those of previous ones)Ziari & Khodadadi, 2013; Hekmatnia & Ansari, 2012).

It should be noted that the southern parts of the province, which include desert areas, have little potential for the establishment of wind-catchers. In this regard, there are reasons such as the presence of dust phenomenon, decrease in relative humidity, excessive high temperature and also decrease in altitude. In addition to the above, we can also point to the depopulation of large parts of the south of the province, which in practice, according to research)Mahdavinejad & Javanroodi, 2011) makes the construction of wind-catchers in such environments unnecessary and unjustified.

5. Conclusion

As it is clear from the results, the amount of energy consumption in the cooling and heating sector has a significant reduction in the installation of the wind-catcher, but this difference in the field of cooling is greater than heating.

As a result, it can be stated with certainty that wind-catcher has a great role and importance in reducing energy consumption in residential areas in hot and dry areas. Especially in the field of cooling and heating production and it is better to use this feature in the architecture of residential and even office houses.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Blen, M., Martin, G., 2008. Weather Climate and Tourism a Geography Perspective, Annals of Tourism Research, vol 23, No3, pp 571-591.)https://doi.org/10.1016/j.annals.2004.08.004).

Chou, Y.C., Yen, H.Y., Dang, V.T., Sun, C.C. 2019. Assessing the Human Resource in Science and Technology for Asian Countries: Application of Fuzzy AHP and Fuzzy TOPSIS, *Symmetry* , 11(2), 251. https://doi.org/10.3390/sym11020251

De Freitas, C.R., Scott, D., McBoyle, G., 2008. "A second generation climate index for tourism: specification and Verification " International of Biometeorotogy.52:399-407.)DOI: 10.1007/s00484-007-0134-3).

Fatemi, S., Taki, D. 2015. The role of architecture in optimizing energy consumption in buildings, the 3rd National Conference on Climate, Building and Optimizing Energy Consumption with a Sustainable Development Approach, Isfahan - Isfahan Province Building Engineering System Organization. https://www.civilica.com/Paper-CBOEC03-CBOEC03_056.html

Hekmatnia, H., Ansari, J. 2012. Meybod Housing Planning with a Sustainable Development Approach, Human Geography Research, Vol 44 (79), 191-207 pp. https://jhgr.ut.ac.ir/article_24532.html

IMO, 2011. I. R. of Iran Meteorological Organization. {www.irimo.ir}.

Khajoo, M., Tayebi Sani, S.M., Fahiminejad, A., Morsal, B. 2020. Evaluating and Analyzing the Spatial Justice in the Distribution of Sports Applications and Services in Garmsar County, Geographical Researches. 2019; 34(4): 551-558 pp. DOI: 10.29252/geores.34.4.551.

Lu, Z.S., Wang, R.Z., 2014. Experimental performance investigation of small solar air-conditioning systems with different kinds of collectors and chillers.Solar Energy, Vol. 11, pp 07–14, 2014.

Mahdavinejad, M.J., Javanroodi, K. 2011. Comparative comparison of the effect of air flow on two types of Yazdi and Kermani wind-catcherss, Journal of Fine Arts, Vol. 48; 3, No. 4, 69-79 pp. https://jfaup.ut.ac.ir/article_29678.html

Mahmoodi Zarandi, M. 2016. An analysis of the orientation, location and service spaces of wind-catcherss in the native houses of Yazd, Maskan and Rural Environment Magazine, Vol. 35, No. 153: 35-46 pp. URL: http://jhre.ir/article-1-718-fa.html

Mohammadi Sangli, K., Gharashi, S. 2016. Sustainable urban development; global approach with local solutions (case study: review of sustainability criteria in traditional architecture of Yazd city), art and architecture studies, Vol. 11 & 12, No. 4-5, 87-99 pp. https://www.sid.ir/fa/journal/ViewPaper.aspx?id=273779

Morahemi, S., Yari Broojeni, N., Saadvandi, M. 2017. The typology of Laft port wind-catcherss based on facade decorations, housing and rural environment, Vol. 159, 19-34 pp. http://jhre.ir/article-1-1217-fa.pdf

Poorahmadi, M., Ayatalahi, S.M.H. 2011. Reconstruction strategies of Yazd windbreaks based on spatial relationship with summer residence, city and local architecture, No. 1, 7-18 pp. https://www.magiran.com/paper/966952

Roohi, S. 2014. The use of wind energy in wind-catcherss in order to reduce the cooling load of the building, the Second International Congress of Structural, Architectural and Urban Development, Tabriz - The Permanent Secretariat of the International Congress of Structural, Architectural and Urban Development, https://www.civilica.com/Paper-ICSAU02-ICSAU02_1193.html

Şener, Ş., Sener, E., Karaguzel, R. 2011. Solid waste disposal site selection with GIS and AHP methodology: a case study in Senirkent–Uluborlu (Isparta) Basin, Turkey. Environmental Monitoring and Assessment, 173(1-4), 533–554. https://link.springer.com/article/10.1007%2Fs10661-010-1403-x

Shafei Sabet, N., Hosseini Hasel, S., Naseri, M. 2019. Assessment of Rural Management, Empowerment of Local Stakeholders and Physical Developments of Rural Settlements (Case Study: Semnan Province), Housing and rural environment, Vol. 38, No. 165, 113-128 pp. (persian). https://www.sid.ir/fa/journal/ViewPaper.aspx?ID=476470

Shi, Y., Liu, X. 2019. Research on the Literature of Green Building Based on the Web of Science: A Scientometric Analysis in CiteSpace (2002–2018), Sustainability 2019, 11(13), 3716; https://doi.org/10.3390/su11133716

SYSP, 2015. Statistical Yearbook of Semnan Province, Iranian Statistical Center Publications, 77 p.

Valian, T., Mofidi Shemirani, S.M., Mahmoodi, M. 2020. Investigating and Identifying Sustainable Development Patterns in Indigenous Iranian Architecture (Case study: Semnan wind-catchers), geores. 2020; 35 (2). (In press).
URL: http://georesearch.ir/article-1-877-fa.html

Zandieh, M., Parvardinejad, S. 2010. Sustainable development and its concepts in Iranian residential architecture, housing and rural environment, No. 29, 2-21 pp. http://jhre.ir/article-1-36-fa.html

Ziabakhsh, N., Zad, G., Davoodi, A. 2011. Comparative study of sustainability in residential and indigenous architecture of hot and dry climate based on wind-catcherss and materials (Case study: Nain and Taft houses), National Conference on Civil Engineering, Architecture, Urban Planning and Energy Management, Islamic Azad University, Ardestan Branch, https://www.civilica.com/Paper-NCCEAUPEM01-NCCEAUPEM01_057.html

Ziari, Y., Khodadadi, R. 2013. Investigating and locating postal service centers using AHP method in GIS environment (Case study: Semnan city), Environmental Management, No. 10, 73-89 pp. https://www.sid.ir/Fa/Journal/ViewPaper.aspx?ID=202886