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Investigating thermal comfort in the Kohandej on Mount Khajeh in Sistan, Iran, based on physiological equivalent temperature

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Abstract: *Kohandej building architecture on Mount Khajeh in Sistan dating back to the Parthian and Sasanian periods were affected by climatic factors. This study aimed to investigate the thermal comfort in this building. The novelty of this study lies in examining building thermal comfort in outdoor, semi-open, and indoor spaces in this historically significant site based on the PET index. Four datalogger stations were located outside the castle as a reference, in the courtyard in the castle, in the semi-open space of the northern iwan, and an indoor space. The study findings revealed that the thermal sensations of the reference and outdoor stations were in an extremely hot status, while the stations in semi-open and enclosed spaces ranged from warm to hot status. Meanwhile, the highest average PET value among the stations in various hours of the day pertained to the outdoor station at 45.92°C, while the lowest rate of 38.34°C pertained to the indoor station. To conclude, the indoor station was in a more desirable thermal comfort status than the outdoor station. The results suggest that the architecture of the castle has lowered the temperature in the interior and in the iwan closer to the thermal comfort levels. While the mean radiant temperature fluctuates within 38.69-49.42 °C in the four stations, the mean PET of the indoor space is lower by 7.58 °C than the outdoor space, and the mean PET of the semi-open space is lower by 4.50 °C than the outdoor space.*

Key words: Thermal Comfort, PET index, Mount Khajeh, Kohandej, Sistan, Iran

Introduction

Climatic comfort has been one of the key factors for a human-centered design. In Iranian architecture, functional needs of the buildings were met as well as their

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structural and aesthetic needs.[1] These Iranian traditional buildings can be considered as a functional system in which climatic factors were controlled to improve thermal comfort, especially in hot arid environments.[2] Regionalism and localization of buildings became the main architectural theme in Iran in the 1970s.[3] Regionalism focuses on a localized architectural approach to address the climatic and cultural issues.[4] Since the 1970s decade, some leading Iranian architects have begun to study historical buildings to understand traditional key principles to adapt their designs to climate and culture in Iran. Since then, researchers have honed in on Iranian traditional buildings, which have been formed under the influence of climatic factors.[5] The reformulation of the forgotten living patterns of Iranian people consistent with modern life changes could pave the way for providing comfort for residents.[6] The study of the vernacular architecture of each region shows that due to limited access to fossil energy, in architectural approaches, the focus has mainly been on thermal comfort, which achieved through traditional techniques and methods.[7] In addition, previous researches have shown that vernacular architecture, which is the result of hundreds of years of local habitation, has been compatible with the climate and has reflected many lessons in the field of climate responsive design.[8] This shows that it is critical to focus on and to learn from the solutions of vernacular architecture especially in extreme climates.[9] Although a number of studies consider providing thermal comfort conditions as one of the key features of vernacular architecture in different climates and regions,[10] the review of the literature conducted on vernacular architecture from the aspect of thermal comfort shows that there are reasons such as the lack of quantitative studies conducted in this field which makes it necessary to pay more attention to the climate responsive methods of vernacular architecture and their effects on the environmental parameters of indoor spaces.[11]

Thermal comfort has been a major topic of interest in building design and architecture,[12] which subjectively demonstrates the user's satisfaction with a thermal environment.[13] Studies on this issue began from the early 20th century and brought about

[1] Mehrizi, Masoudi & Hassan Pour, 2023.
[2] Heidari Orojloo, Ghorbani Param & Hassan Pour, 2023.
[3] Hassan Pour, Lewis & Guo, 2015.
[4] Hassan Pour, Lewis & Guo, 2013.
[5] Hamze Nejad, Fadaee & Ildarabadi, 2020.
[6] Hoseinpour, Belali Oskoyi & Keynejad, 2018.
[7] Yang *et al*., 2022; Diz-Mellado *et al*., 2023.
[8] Chandel, Sharma & Marwah, 2016; Rubio-Bellido, Arcas & Lainez, 2016; Philokyprou *et al*., 2017.
[9] Taleghani *et al*., 2014; Chang *et al*., 2021; Tabadkani *et al*., 2022.
[10] Chandel, Sharma & Marwah, 2016; Rubio-Bellido, Arcas & Lainez, 2016; Sargazi, 2016; Victoria *et al*., 2017; Nguyen *et al*., 2019; Davtalab *et al*., 2020.
[11] Bodach, Lang & Hamhaber, 2014; Du, Bokel & van den Dobbelsteen, 2014; Fernandes *et al*., 2015; Xu *et al*., 2016; Huang *et al*., 2017.
[12] Barone *et al*., 2023.
[13] Ashrae, 2017; Tabadkani *et al*., 2022.

considerable results. Research on climate-adapting architecture has been a critical issue and can help discover ways to provide thermal comfort to reduce energy consumption, improve standards and prediction models for controlling the environment, and strength thermal comfort and its acceptance for residents. The above goals can be met by conducting more underlying studies in intended climates and regions. In this regard, it is very important to moderate thermal comfort in all hot and arid regions, in general, and in the Sistan region of Iran, in particular, given its extreme nature and unbearable environmental conditions for residents. For this, it is critical to focus on solutions that moderate thermal comfort in this region due to some outstanding climatic statistics of wind speeds, so-called 120-day winds and the regular wind direction of NW to SE, as well as other climatic considerations such as high temperature, very low humidity, dust and sand storms.[14] The local residents of Sistan, have had knowledge about the climate of the area from the distant past, have provided methods to achieve thermal comfort in the local architecture of this region.[15] Sistani people experience unbearable hot low-humid climate in summer.[16] One of the strategies that was used to adjust the air inside the space is Kharkhaneh. Most of the studies conducted in the field of Kharkhaneh are qualitative and describe its performance in the vernacular housing in the Sistan region.[17] Yet, studies have also been carried out regarding quantitative measurement by examining temperature[18], humidity[19] and wind speed[20] indicators separately. Davtalab and Heidari[21] investigated the effects of Kharkhaneh on the thermal comfort of an outdoor space in the arid and hot climate of Sistan.

As stated above, most of the literature on thermal comfort in Sistan focused on recent local architecture processes, with fewer studies dealing with the thermal comfort of the historical architecture of the region. Considering the significance of the techniques used in the past architecture, which could be inspired and then be integrated with contemporary architecture to create architectural spaces more adaptive to the regional local conditions, to help save energy, and to lay the ground for sustainable architecture in the region, the present study aimed to investigate the levels of thermal comfort in the architecture of the Kohandej building. The word Kohandej means old castle and is also called the Kaferoun castle by locals. The Kohandej is located on Mount Khajeh, which dates back to the Parthian and Sasanian era. The study also aimed to investigate the effects of some of the solutions employed to better understand the climatic situation of the region. Understanding these solutions can also help improve the thermal comfort

[14] Davtalab & Heidari, 2021.
[15] Heidari & Davtalab, 2022.
[16] Heidari, Davtalab & Sargazi, 2024.
[17] Molanaei & Soleimani, 2016.
[18] Heidari & Davtalab, 2020a.
[19] Davtalab & Heidari, 2020.
[20] Heidari & Davtalab, 2020b.
[21] Davtalab & Heidari, 2021.

of the tourists who will visit this region. This study tries to answer the following questions:

- What were the solutions used to improve thermal comfort in the architectural spaces of the Kohandej building?
- What were the most important climatic factors affecting the architecture of the Kohandej building on Mt. Khajeh?
- Which architectural space in the Kohandej building is in a more desirable condition for moderating thermal comfort?

Thermal Comfort

The significance of adjusting thermal comfort conditions to living environments is known to all, as employing solutions to increase the qualitative comfort indicators can make life more desirable and bearable under harsh climatic situations. The main variables of thermal comfort include individual and climatic variables.[22] Effective climatic variables include temperature, air flow, relative humidity and radiant temperature,[23] while individual variables include clothes and activity rates that affect thermal comfort.[24] Thermal comfort conditions refer to a range of temperature and humidity where the body's heat-regulating mechanism operates at its lowest rate.[25] Or it can be regarded as some subjective conditions that express the sense of satisfaction with the thermal conditions of the environment.[26] In this connection, providing comfort in outdoor spaces, as compared to indoor spaces, depends on understanding climactic and environmental conditions, because mechanical cooling and heating equipment in indoor spaces can be used to artificially provide comfort conditions, though at a higher price and energy consumption, while no such mechanisms can be used in outdoor spaces.[27] On the other hand, meeting comfort conditions in outdoor spaces paves the way for meeting comfort conditions in building interior spaces, because outdoor spaces involve and constitute micro climates in the surrounding of buildings. To Richard Hayter, temperature and humidity data, among other factors, are the most important indicators for recognizing thermal comfort.[28]

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[22] Davtalab *et al*., 2020.
[23] Fange, 1972; Givoni, 1992.
[24] Ashrae, 2001.
[25] Givoni, 1992.
[26] Farrokhi & Karaminia, 2023.
[27] Al-yasiri & Szabó, 2021.
[28] Hayter, 2007.

Mount Khajeh

Mount Khajeh or Mount Rostam inside Lake Hamoun is the only rocky mountain in the Sistan plain located in the 30 km southwest of Zabol City. There has been a great interest in studying Iranian historical buildings by westerners in the last two centuries.[29] Ernst Herzfeld resembles it to a large desk stretching in a wide plain, with its set of palaces also known as "Clay-made Persepolis".[30] According to findings, the mountain is identified by two historical eras, namely pre-Islamic and Islamic periods. The pre-Islamic era dates back to the 3rd century A.D. until the end of the Sasanian period, while the second era goes back to the 13th and 15th centuries.[31] Surveys have demonstrated 17 ancient compounds in the mountain, with the latest research by Javad Alaei-Moghadam revealing 36 ancient places pertaining to various historical periods in this mountain.[32] Currently, most of these buildings are lost with nothing left. This mountain had been alternately used by regional residents in various eras due to its appropriate geographical, natural, strategic location and its sanctity. For this, a variety of building and structures of different functions were built there, the most important of which include the Kohandej building, the Kok Kohzad castle, the Chehel Dokhtaran castle, Ziyarat Khajeh Mehdi, Asiaban House, Sheitan House and Pir Gandom Beryan. These buildings were functionally different and included palaces, castles, watchtowers, pilgrimage shrines, graveyards, etc.[33] The most important building of this ancient compound is the Kohandej building,[34] which was selected as the case study of the present study due to the strategic and historical significance of Mt. Khajeh and its still-healthy walls and ceilings. This case study can thus be examined for its thermal comfort conditions.

Methodology

To perform the field survey, measurements were performed on July 1 and 22 and August 8 of 2022 as the representative hot days of summer, due to the steep slope of the location of the Kohandej building and also lack of measurements equipment. Also, due to security and human constraints and the lack of measurement tools at night, meteorological measurement and data recording were carried out at 6 a.m., 9 a.m., 12 p.m., 3 p.m. and 6 p.m. with three-hour intervals, due to much-need moderation of temperature in these hours. The parameters of temperature, relative humidity, wind

[29] Hassan Pour, 2015.
[30] Herzfeld, 1941, 302-303.
[31] Mehrafarin, Mosavi Haji & Bani Jamali, 2011.
[32] Alaei Moghadam, 2015.
[33] Abbasi, 2018; Sarabandi *et al*., 2022.
[34] Vasegh Abbasi, Mehrafarin & Mosavi Haji, 2018.

flow speed and globe temperature were acquired and recorded by each of the designated stations at a height of 1.5 m above the ground level using four meteorological devices of WBGT 8778 and four Anemometer Datalogger devices, which had met necessary ISO 7726[35] and WMO-No. 8[36] standards. The said parameters were directly measured at the designated stations, and the variable of the radiant temperature was computed for all points of measuring based on the variables of temperature, globe temperature and wind speed using Equation 1.

$$T_{mrt} = \left[(T_g + 273.15)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\varepsilon D^{0.4}} \times (T_g - T_a)\right]^{1/4} - 273.15,$$

Computing the mean radiant temperature using temperature, wind speed and globe temperature.[37]

Where Va represents air flow speeds in m/s, Ta temperature in °C, D the diameter of the globe thermometer, Tg globe temperature in °C and ε the coefficient of radiation. This coefficient is 0.95 for the copper-colored black ball.[38]

The Physiological Equivalent Temperature of each of the stations was computed to measure their thermal comfort using RayMan software. Then, data acquired by various meteorological devices and computed by Equation 1 and RayMan software were first entered Excel software by day, hour, station and the climatic variable, as relevant data were analyzed by averaging data on various days and hours and their classification. Because this study fell under applied research and had a descriptive-analytical nature, data were analyzed and processed by using descriptive statistical methods and Excel software.

Study area

The Sistan region covers an area of 8117 square km in southeastern Iran in the north of the province of Sistan and Baluchistan, where its arid and hot climate is the result of the flow of winds blowing over its surrounding deserts.[39] Sistan is located between latitude: 30°15′ to 31°30′ N and longitude: 60°24′to 61°55′ [Fig. 1].[40] This region records a rainfall of around 65 mm and an average annual evapotranspiration of 5000 mm (1986-2016 by Zabol Synoptic Station),[41] with a harsh climate.[42] Climatic

[35] ISO. 7726, 1998.
[36] WMO-No. 8, 2008.
[37] ISO. 7726, 1998.
[38] Ashrae, 2001.
[39] Aibaghi Esfahani, Momeni & Hassan Pour, 2020.
[40] Fathi-Sugoli-Tappeh, Mortazavi & Mousa-Moornegari, 2022.
[41] Shokouhi-Razi, Raimi & Zolfaghari, 2020.
[42] Davtalab *et al*., 2020.

and cultural factors have shaped Sistan vernacular architecture.[43] The Sistan region is one of the windiest regions across the country and for this, it struggles with dust storms, assuming other conditions being met. Erosive and dominant winds are known as 120-day winds, as the region enjoys an arid climate based on Domarten's climate classification and a desertification climate based on Amberger's method.[44] It is note-worthy that the so-called 120-day winds last for around 155 days, starting from May 1 to October 13 each year.

Fig. 1. The location of Sistan and Mount Khajeh (after Davtalab, Heidari & Sarabandi, 2021).

As stated, the case study was the Kohandej building within the historical compound of Mt. Khajeh. This mountain is a trapezoidal basaltic lava and is 120 m above Sistan plain's surface and is lying in the middle of Lake Hamoun, which embraces the moun-tain as an island in rainy seasons when the water levels of the lake rise [Fig. 2].[45]


Fig. 2. The location of the Kohandej building on Mount Khajeh (Photo by F. Sarabandi, 2023).

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[43] Etehadi, Hassan Pour & Mehrpouya, 2021.
[44] Rezaei-Torshizi & Miri, 2020.
[45] Abbasi, 2018.

Results and Discussion
Data collection and Analysis Process

This study investigated the thermal comfort of this building architecture to understand the effects of some of the solutions employed. Data collection should at first be performed by selecting stations for measurement. The parameters of thermal comfort were measured and recorded in the form of a fieldwork based on data acquired by three stations in an open space, a semi-open space and an indoor space at the Kohandej building on Mount Khajeh, as well as a reference station outside of the building [Fig. 3]. These stations were selected because they were accessible, as the points much closer together were selected. Moreover, the outdoor station was selected because the building's central courtyard was the largest section of the building; the indoor station was selected because the building was among the few remaining roofed spaces; the semi-open space station in the northern front was selected because the building's ceiling had survived, and the reference station was selected because it was lying in the northwestern front, in the direction of wind flow and outside the building, which would help identify the general characteristics of the regional climate.

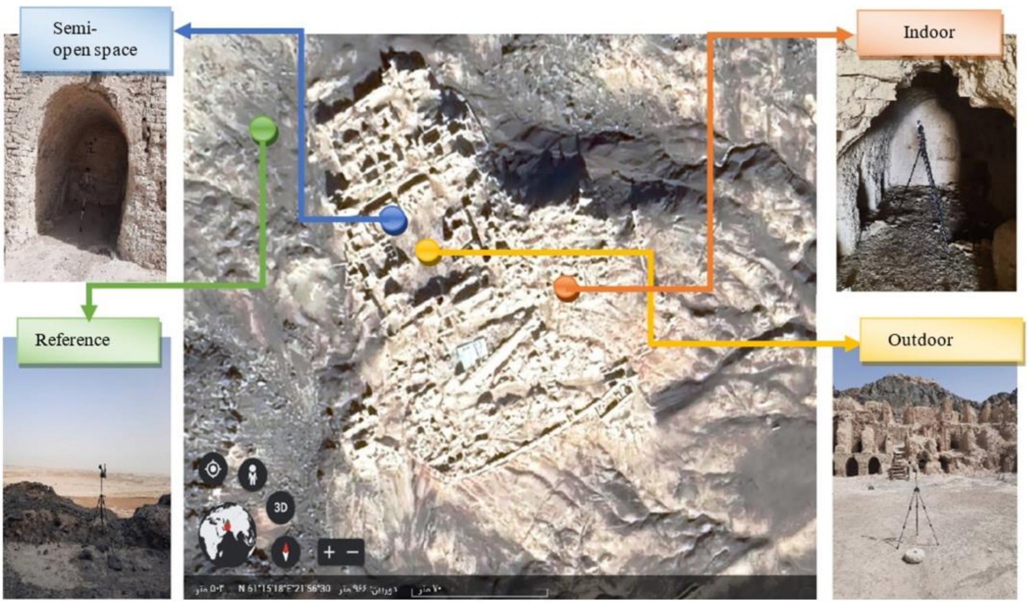

Fig. 3. The designated points for measuring climatic parameters in the historical site of the Kohandej building on Mount Khajeh (Photo by Z. Sarabandi, 2023).

Table 1 shows the value of climatic parameters calculated by formula 1 based on the mean of field measurements after the data were collected by meteorological devices and averaged for the days.

Tab. 1. Parameter values based on the mean of measurement days.

Location	**Hour**	**Ta**	**RH**	**Tg**	**V**	**Tmrt**
Reference	6 AM	32.90	14.93	33.03	1.95	33.60
	9 AM	39.17	9.90	47.27	3.09	49.74
	12 PM	42.47	7.17	51.57	2.19	53.74
	3 PM	45.23	5.30	51.33	4.78	53.65
	6 PM	43.80	6.20	43.70	5.35	43.66
Indoor	6 AM	35.37	13.50	35.70	0.00	33.70
	9 AM	37.33	11.93	37.40	0.00	37.40
	12 PM	39.93	9.27	39.70	0.00	39.70
	3 PM	41.40	7.53	40.60	0.00	40.60
	6 PM	40.10	7.77	40.06	0.00	40.06
Outdoor	6 AM	32.93	14.80	33.10	1.27	33.14
	9 AM	39.37	9.63	49.00	2.25	51.39
	12 PM	44.50	6.57	57.20	1.97	59.89
	3 PM	45.97	5.30	56.10	2.27	58.46
	6 PM	43.60	6.03	44.13	1.16	44.22
Semi-open space	6 AM	34.00	14.17	35.00	0.08	35.04
	9 AM	40.57	9.37	42.60	0.08	42.67
	12 PM	45.87	6.50	48.10	0.09	48.18
	3 PM	45.17	5.80	45.93	0.02	45.94
	6 PM	43.16	6.47	37.93	0.01	37.87

Ta: Air temperature; RH: Relative humidity; Tg: Globe thermometer temperature; V: Wind speed; Tmrt: Mean radiant temperature

Data Analysis

Analysis of Air Temperature

According to Figure 4 and Table 1, the highest temperature in various hours of the day mainly pertained to the semi-open station, which was due to the effects of the radiant temperature of the surrounding materials on the environment and also the reduced wind flow at this station. The key point in the diagram was the higher rate of temperature at the outdoor station at 3 p.m. compared to other stations, which was due to the direct sunlight and lower wind flow at this time at this station compared to others. The lowest temperature in various hours of the day pertained to the closed-space station, except for 6 a.m. when temperature was higher than other stations. This was due to thermal heat being transferred from the walls throughout the day and the lack of air flow at this station, which increased and trapped temperature. Since no sunlight existed at 6 a.m. in other areas, temperature at the indoor station was found to be higher than other stations. Following the semi-open and indoor stations, which recorded the highest and lowest temperature rates, the open space and reference stations held lower temperature rates than the semi-open space station. Also, the reference station held a lower temperature than the outdoor station due to its location in a wide-open area and non-confinement within the building fences, as well as higher wind speed rates. Meanwhile, the open, semi-open and reference stations recorded an almost identical temperature at 6 p.m., which was due to the lack of sunlight at this particular hour.

In general, based on the analysis of average daily temperature rates acquired by the four stations [Fig. 5], the highest mean temperature pertained to the semi-open station, while the lowest difference of temperature pertained to the indoor station, the reasons of which were described in the previous section.

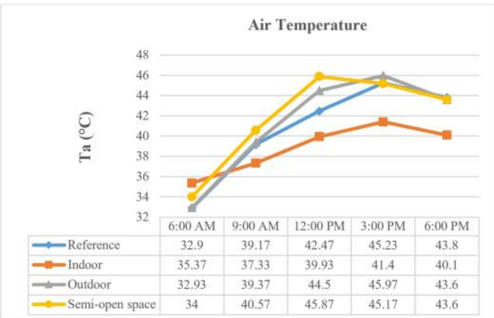

Fig. 4. Air temperature changes in the measurement stations.

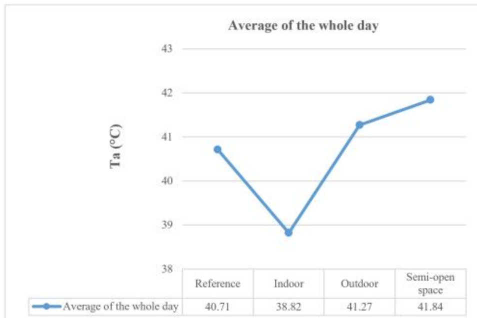

Fig. 5. Mean air temperature in measurement stations during the day.

Analysis of Relative Humidity

According to Figure 6 and Table 1, the highest relative humidity in various hours of the day mainly pertained to the indoor station due to the lack of air flow; meanwhile, the relative humidity of the indoor station was lower than other spaces at 6 a.m., which was due to the effects of thermal heat being transferred from materials to the environment. In this connection, as humidity at the stations increased, temperature decreased, with heat hiding in humidity. The lowest relative humidity in various hours of the day mainly pertained to the semi-open station. The key point in this diagram is the increase of humidity at the semi-open station at 3 and 6 p.m. compared to the reference and outdoor stations, with 6 p.m. recording a very tangible difference. However, the rise in humidity at 3 p.m. may have been due to the rotating angle of the sunlight toward the semi-open station and consequently the effects of the radiant temperature of materials and the environment on this station. Following the indoor and semi-open stations, which held the highest and lowest relative humidity, the reference and courtyard stations respectively held lower humidity compared to the closed station.

Figure 7 shows that based on the analysis of the average relative humidity acquired by the four stations, the highest relative humidity pertained to indoor station and the lowest to the outdoor and semi-open stations, the reasons of which were described in the previous section.

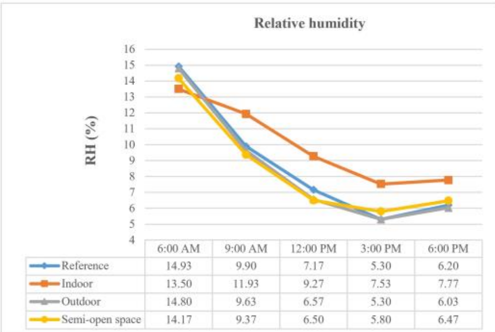

Fig. 6. Relative humidity changes in the measurement stations.

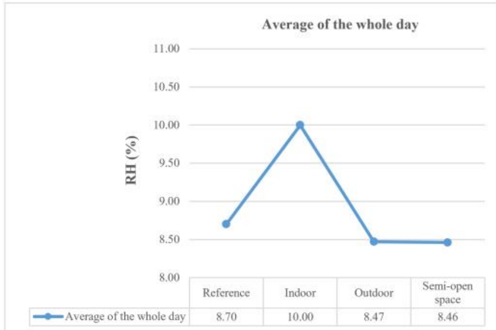

Fig. 7. Mean relative humidity in measurement stations during the day.

Analysis of Wind Speed

Figure 8 illustrates that the highest wind speed in various hours of the day pertained to the reference station, indicating that the station was not confined and that it was located within a fully open area; meanwhile, the lowest wind speed pertained to the indoor station, which was due to its enclosed space and its non-exposure to the direction of the wind flow or the presence of windward hatches. The two outdoor and semi-open stations respectively held lower wind speeds than the reference station due to their exposure to enclosed and wind-shelter spaces. It is noteworthy that the open space had grappled with some severe wind speeds, as noted from the destruction on the building facades; but despite this, it enjoyed less severity than the reference station due to its space located in the wind-shelter space.

Figure 9 indicates that the highest average wind speed pertained to the reference station at 3.47 m/s, while the lowest to the indoor station at 0 m/s. Also, open and semi-open stations held lower differences of wind speeds compared to the reference station at 1.78 and 0.06 m/s, respectively.

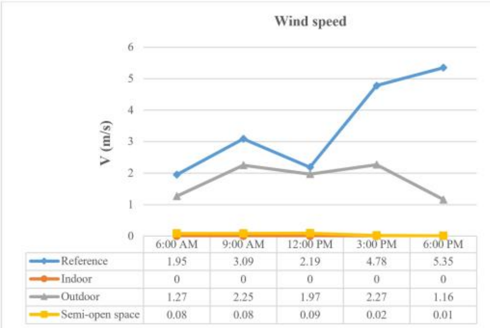

Fig. 8. Wind Speed changes in the measurement stations.

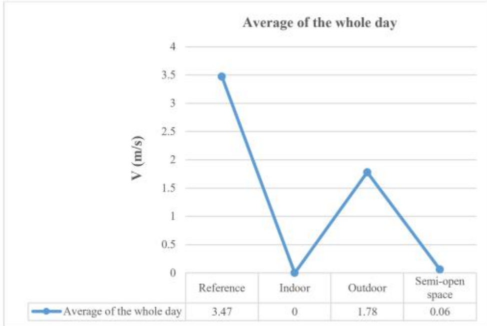

Fig. 9. Mean wind speed in measurement stations during the day.

Analysis of Mean Radiant Temperature

Figure 10 explains that the highest mean radiant temperature mainly pertained to the outdoor station, which was due to the rising temperature as a result of sunlight and the decreased wind speed at this station, except for 6 a.m., when the mean rate was lower than those of other stations and was almost the same as the reference station. This was also due to the effects of sunlight, the radiant temperature of materials on the environment, and wind speeds. Since there was no sunlight at this time at all stations and wind flows were gathering pace at the reference and outdoor stations, the mean radiant temperature in this hour had decreased compared to the other two stations. The lowest mean radiant temperature also pertained to the indoor station due to the lack of direct sunlight, despite the lack of air flow, as the station held a higher mean rate than other stations, except for 6 a.m. Since temperature, sunlight, the heat transfer capacity of materials and air flow affect the mean radiant temperature, the lack of sunlight at all stations and the lack of air flow and walls' heat transfer capacity at the indoor station made the mean radiant temperature at 6 a.m. rise than other stations. Another point was the rising mean radiant temperature at 6 p.m. at the indoor station than the semi-open station, which was due to the presence of air flow at the semi-open station despite sunlight at this hour. Meanwhile, the reference and semi-open stations respectively held lower mean radiant temperature rates than the outdoor station.

Figure 11 depicts that the highest mean radiant temperature pertained to the outdoor station at 49.42°C, while the lowest rate pertained to the indoor station at 38.69°C. Also, the reference and semi-open stations respectively held the mean radiant temperature of 46.77 and 41.94°C than the outdoor station.

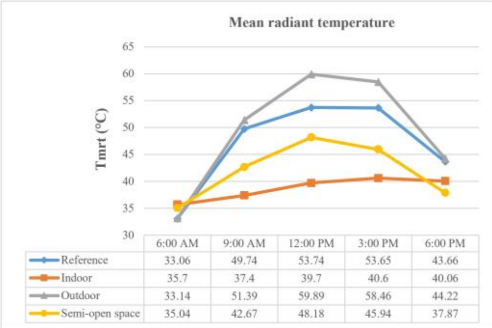

Fig. 10. Mean radiant temperature changes in the measurement stations.

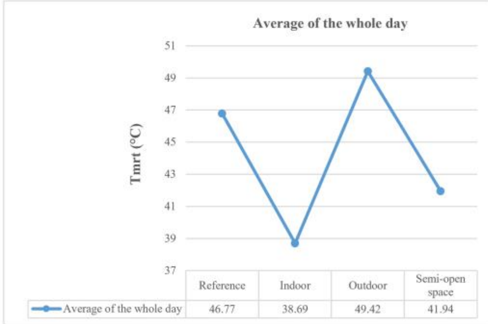

Fig. 11. Mean radiant temperature in measurement stations during the day.

Analysis of PET index

Physiological Equivalent Temperature (PET) is the most appropriate index for evaluating outdoor thermal comfort. PET equals the temperature based on which the human's body heat balance under assumed indoor spaces equates skin temperature under outdoor conditions; in other words, the PET index is used to enable the individual to compare the full effects of a set of outdoor thermal conditions with his personal experience of temperature.[46] Hence, based on field data and using RayMan.v.1.2, this index was computed and analyzed for each of the representative stations, as data inputs for computing PET included temperature, relative humidity, wind speed and the mean radiant temperature. Cloud cover was considered zero okta due to the lack of clouds on measurement days. These values were also considered for an individual 175 cm tall, weighing 75 kg and aged 35 on average. Since PET depends on peoples' coverage and rate of activities, the type of clothes included men's blouses and pants (customary clothing of the region), equivalent to 0.9 col, while the rate of activity for an individual walking slowly was considered 80 w. Below, Table 2 gives the range of thermal sensation based on the PET index.

Figure 12 shows that the highest PET value in various hours of the day mainly pertained to the outdoor station, which was due to its exposure to direct sunlight and fewer winds because of its position in the wind-shelter fence, while the lowest PET value pertained to the indoor station, due to the lack of direct sunlight from 9 a.m. to 3 p.m. The key point in the diagram is the increased PET value at 6 a.m. at the indoor station compared to other points of measurement, with the mean radiant temperature and consequently the PET value increasing at this time due to the lack of sunlight onto all points and the lack of air flow and heat transfer throughout the day at the indoor station. Another key point in the diagram is the lower PET index value at

[46] Davtalab *et al*., 2020.

the reference station at 6 p.m., despite its higher value in various hours of the day as compared to other points. This may be due to a significant rise in wind speed at the said station at 6 p.m., which had created a reverse effect with thermal comfort (wind flow effects depend on temperature and can have a positive role of up to 32.5°C in improving thermal comfort, whereas they will leave reverse effects at higher temperature rates).[47] The PET value at the semi-open station at 6 p.m. also saw a significant decrease, almost equaling the closed-space station. This may be due to the lack of sunlight onto the semi-open station in this hour and little air flows. Following the outdoor and indoor stations, which held the highest and lowest PET values, the reference and semi-open stations respectively held lower PET values compared to the outdoor station, expect for the hours mentioned above. According to the diagrams, it was concluded that the PET index had been affected most by the mean radiant temperature, as factors that contributed to the mean radiant temperature and consequently improved thermal comfort at the measured stations included air flows, the effects of radiant temperature and the heat transfer capacity of materials and walls.

According to Figures 12 and 13, and Table 2, the thermal sensation of the reference and outdoor stations was in an extremely hot status, while the semi-open and closed stations ranged from warm to hot states, though were mainly in the hot status. Meanwhile, the highest average PET value among the stations in various hours of the day pertained to the outdoor station at 45.92°C, while the lowest rate of 38.34°C pertained to the indoor station. As a result, based on the PET index, the indoor station was in a more desirable thermal comfort state and the outdoor station was in an undesirable condition.

Tab. 2. PET values for different levels of thermal sensation on human beings.[48]

PET (°C)	**Thermal sensation**
4	Very cold
8	Cold
13	Cool
18	Slightly cool
23	Comfortable
29	Slightly warm
35	warm
41	hot
41>	Very hot

[47] Heidari, 2012.
[48] Matzarakis, Mayer & Iziomon, 1999; Honjo, 2009; Esch, 2015; Castaldo *et al*., 2018.

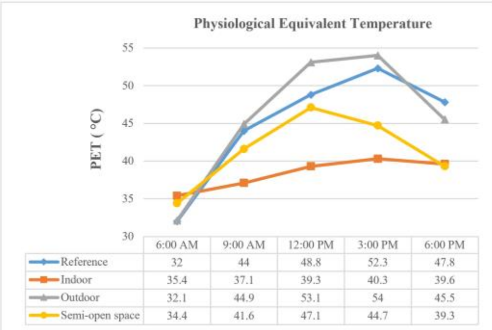

Fig. 12. Physiological equivalent temperature (PET) changes in measurement stations.

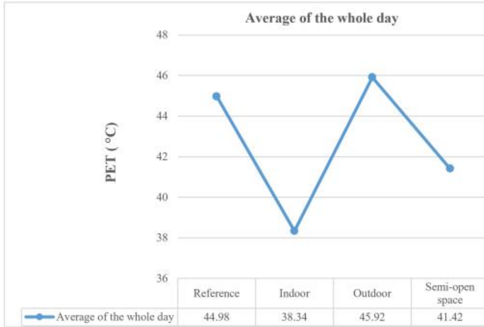

Fig. 13. Mean Physiological equivalent temperature (PET) in measurement stations during the day.

Conclusions

The present study aimed to investigate the levels of thermal comfort in the architecture and the solutions used in the Kohandej building on Mount Khajeh, which dates back to the Parthian and Sasanian eras in the Sistan region. In this study, four different stations of the outdoor space of the building (as a reference), the outdoor space in the interior courtyard of the building, the semi-open space of the northern iwan and an indoor space for measuring the climatic parameters affecting thermal comfort. These spaces were studied in summer in 2022.

According to the measurements and diagrams extracted, the highest amounts of wind pertained to the reference station and the lowest to the closed station. Also, the highest temperature pertained to the semi-open station and the lowest temperature to the closed station. Since humidity and temperature are reversely related, these values are fully reversed in the humidity diagram and the highest humidity pertained to the closed station and the lowest to the semi-open station; meanwhile, the highest mean radiant temperature pertained to the outdoor station and the lowest rate to the indoor station.

Without considering exceptions in each of the diagrams, some of the stations underwent changes due to the lack of sunlight and shading and based on the average measured values in some hours; for instance, while the indoor station held the lowest values in all hours, it held the highest recorded temperature values at 6 a.m., signifying the importance and effects of sunlight and the thermal capacity of materials. Hence, based on studied indicators, the closed and semi-open space stations enjoyed more desirable conditions than the reference and outdoor stations for using local materials and good shading on rooftops (using arched ceilings).

It was concluded that the PET index had been affected most by the mean radiant temperature, as factors that contributed to the mean radiant temperature and consequently improved thermal comfort at the measured stations included air flows, the effects of radiant temperature and the heat transfer capacity of materials and walls**.** According to Discussion, the thermal sensation of the reference and outdoor stations was in an extremely hot status, while the semi-open and closed stations ranged from warm to hot states, though were mainly in the hot status. Meanwhile, the highest average PET value among the stations in various hours of the day pertained to the outdoor station, while the lowest pertained to the indoor station. As a result, based on the PET index, the indoor station was in a more desirable thermal comfort state and the outdoor station was in an undesirable condition**.** In sum, the study found that in the past, appropriate materials and design techniques were employed to get the extremely harsh outdoor climatic situation, where thermal comfort had been defined to be very hot based on PET, closer to desirably warm situations, which could improve thermal comfort for the residents of this building. The results suggest that the architecture of the Kohandej has lowered the temperature in the interior as well as in the semi open spaces closer to the thermal comfort levels. While the mean radiant temperature fluctuates within 38.69-49.42 °C in the four stations, the mean PET of the indoor space is lower by 7.58 °C than the outdoor space, and the mean PET of the semi-open space is lower by 4.50 °C than the outdoor space.

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