School of Architecture Urban Planning and Construction Engineering

Master of Science in Building and Architectural Engineering

Guideline of zero-energy houses for different climate zones of Iran

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Abstract

The more populated the world gets, the more important sustainable design in buildings would be. Iran is a big country located in middle east, having completely different geographics and climate conditions from its north to south, east to west. 700 to 800 years ago, there were smart architects and engineers who designed and built-up buildings which were almost sustainable and adapted for their geographical location. Iran can be categorized to five different climatic locations which have unique condition. Ancient engineers had unique strategies to adapt buildings and use natural conditions to make comfortable houses for the residence.

On the other side, nowadays it can be seen huge number of buildings and houses which are built in ways that are not compatible with climatic conditions. Then, majority of mechanical settings are being used to make the inside environment conditioned. As a result, emission of carbon di oxide has put the natural environment in a hazard and susceptible situation. In the current era, what is considered insignificant is the impact of carbon footprint.

In the current study, it is tried to understand the details and impact of the ancient building strategies on having sustainable buildings. The strategies will be cleared as different passive ways to cool down and warm up buildings in five different representative cities all around the country of Iran.

In the first chapter, Iran five different cities which have representative climate conditions of all the country will be studied. The next chapter consists of literature review on different passive cooling strategies and checking the compatibility of each strategy in each climate. The third chapter focuses on studying vernacular passive architecture of Iran and sees how much useful each strategy can be for a residential building located in different climates. Finally, there will be a chapter suggests the best passive tactics for designers to have sustainable residential buildings in five different cities of Iran.

Key Words:

Weather analysis, Passive strategies, Energy saving, Vernacular architecture of Iran, Iran climatic regions, cooling and heating

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1. Introduction

1.1. How to stop global warming from the scratch

General situation of the earth can be divided into two era, with the turning point of industrial revolution. When the human started to find different ways to benefit from the earth's resources in a huge scale. From then, what is happening is decreasing in the amount of natural resources and increasing in the amount of negative carbon footprint of human on the earth. One of the most hazardous effects is global warming which is a principal issues of the century.

Civilization is basically an essential fact that is needed for growth and better livings. The point which has been neglected in the 20's and 21's century is the impact of development on the natural environment. It must be understood that the earth is not a heritage from ancient people, but the integrity from the future people. Space cooling is the fastest growing energy use within the building sector, a sector that accounted for around 28% of total global energy-related carbon-dioxide (CO2) emissions and for approximately one third of global final energy use in 2018. In emerging economies, such growth is mostly associated with rising incomes , but also due to high temperatures and prolonged heat waves . Thus, the potential increase in demand for space cooling, which has grown by more than three times between 1990 and 2018 , is a critical energy issue. [1]

Fortunately, in the last decades, it can be seen studies and efforts for establishing the importance of sustainable development. In the field of building engineering, the scientists are working on methods and strategies to lessen the effects of construction on the earth. One of the most important issues relates to the ways for keeping the buildings in a conditioned situation and making the inner environment suitable for the residence. There is a clear relationship between cooling down and warming up the buildings and the amount of carbon di oxide which is being made every day by mechanical instruments. Here it can be seen the seriousness of the building and mechanical engineers' job to keep the negative impacts of construction under a logical threshold.

In a nutshell, in the crucial situation of the environment, to decrease the building industry carbon footprint, it is essential for designers and building engineers to consider the whole environment and global warming from the scratch.

The current study tries to find the best strategies exclusive for different climatic situations of the country of Iran. It can be used as a guideline for architects and engineers by giving advices to have sustainable buildings.

Climate change and global warming have been of major concern to the public because of the potential threat to the ecosystem and living environment. The Intergovernmental Panel on Climate Change (IPCC) has projected that the annual temperature increase from the 1960s to the 2100s will be in the range of 1 to 7 K under various CO2 emission scenarios. In addition to temperature change, humidity, wind, and solar radiation are also likely to change over the years because of higher CO2 emissions. Climate change will have a large impact on building energy use for heating and cooling because of the change in outdoor conditions. The impact of climate change will vary greatly according to geographical region and building types. Energy consumption levels for cooling and heating are expected to increase and decrease, respectively, as a result of global warming. However, the impact of climate change on heating and cooling energy use in different locations will vary because of their different climates. A detailed analysis of heating and cooling energy use in the future is needed to better understand the impact of climate change on building energy consumption. [2]

1.2. References

[1] Bezerra, P. et al. (2021) 'Energy & Buildings Impacts of a warmer world on space cooling demand in Brazilian households', Energy & Buildings. Elsevier B.V., 234, p. 110696. doi: 10.1016/j.enbuild.2020.110696.

[2] Wang, H. and Chen, Q. (2014) 'Impact of climate change heating and cooling energy use in buildings in the United States', Energy and Buildings. Elsevier B.V., 82(2014), pp. 428–436. doi:10.1016/j.enbuild.2014.07.034.

2. Weather analysis

2.1. Geographical description

Geographically shown in figure (2-1), *Iran* is located in the northern hemisphere, West Asia and borders the Caspian Sea, Persian Gulf, and Gulf of Oman.

With an area of 1,648,000 square kilometers, *Iran* ranks seventeenth in size among the countries of the world. *Iran* shares its northern borders with *Armenia, Azerbaijan*, and *Turkmenistan*. These borders extend for more than 2,000 kilometers, including nearly 650 kilometers of water along the southern shore of the Caspian Sea. *Iran*'s western borders are with *Turkey* in the north and *Iraq* in the south.

The Persian Gulf and Gulf of Oman littorals form the entire 1,770 kilometers southern border. To the east lie *Afghanistan* on the north and *Pakistan* on the far south. *Iran*'s diagonal distance from *Azerbaijan* in the northwest to *Sistan* and *Baluchestan* Province in the southeast is approximately 2,333 kilometers.

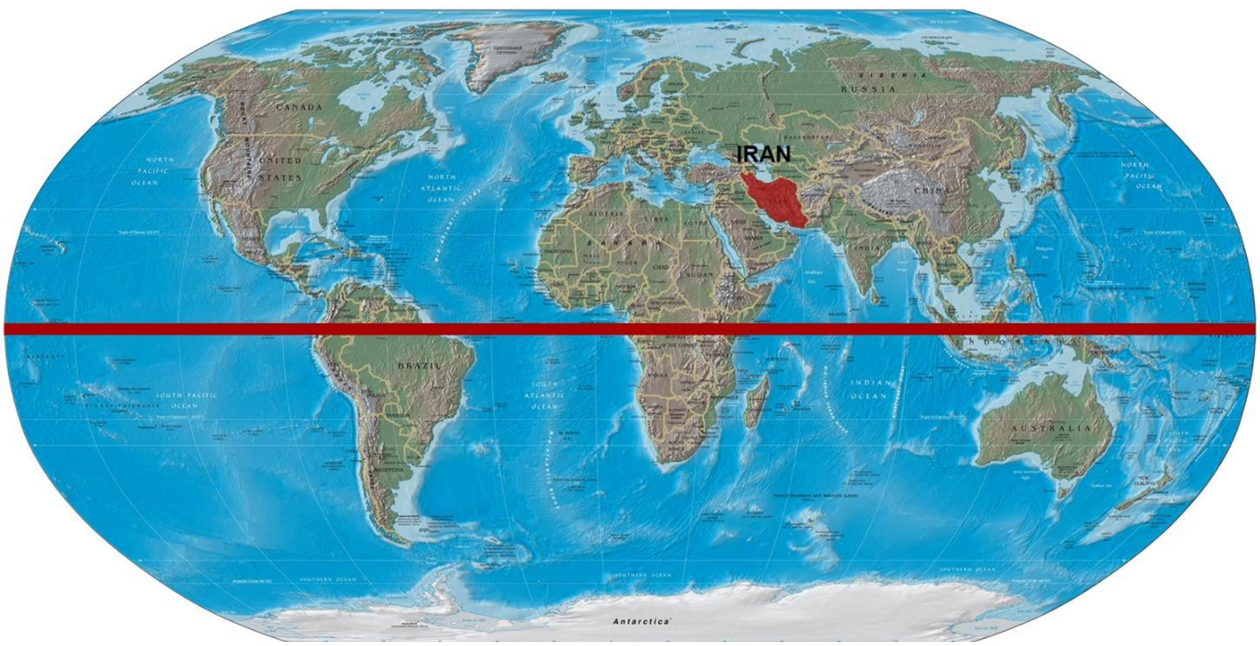

Figure 2-1- location of Iran on the world map, at the northern hemisphere

2.2. Climatic Situation

The most frequently used climate classification map is that of Wladimir Köppen, presented in its latest version 1961 by Rudolf Geiger. A huge number of climate studies and subsequent publications adopted this or a former release of the Köppen-Geiger map. In this classification, the earth is divided into five climatic groups:

- A - tropical
- B - dry
- C - temperate
- D - continental
- E – polar

These groups are subdivided by seasonal precipitation and level of heat.

Based on köppen climatic classification, Iran is divided into four climatic regions, shown in figure (2-2), including A: hot-humid climate, B: hot-arid climate, C: mild-humid climate, and D: cold climate. Five different cities in Iran with specific climate conditions are selected to represent a general situation of climatic and precipitation level of the whole country.

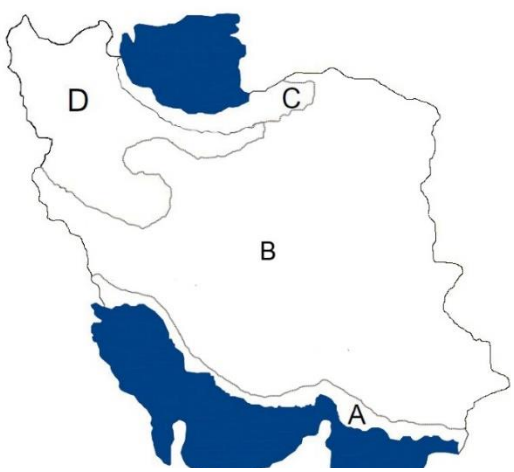

Figure 2-2- four different climatic regions of Iran

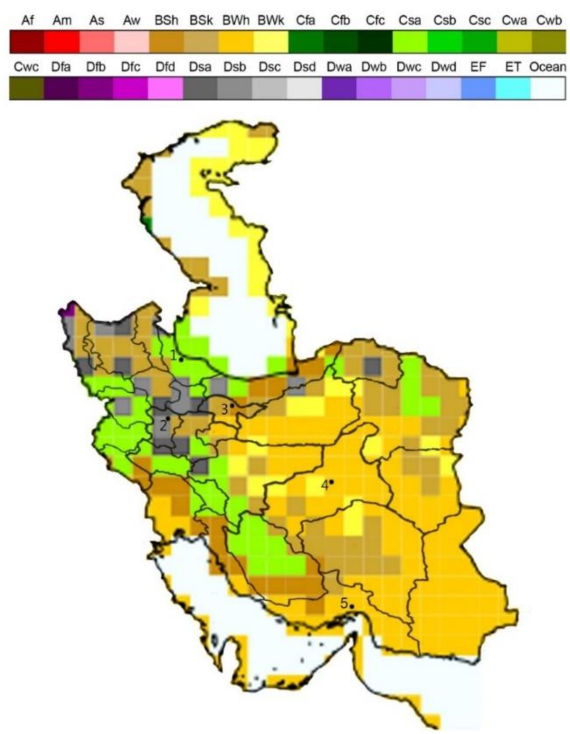

Figure 2-3- Iran five cities in the Koppen climatic map, 1-Rasht, 2-Hamedan, 3-Tehran, 4-Yazd, 5-Bandar Abbas

city	Rasht	Hamedan	Tehran	Yazd	Bandar Abbas
Koppen climate type	Csa	Dsb	Bsh	Bwh	Bwh
Climate description	Humid subtropical- Warm summer- Cool winter	Cold semi arid- Snowy winter- Warm summer	Arid- Hot summer- Cold dry winter	Hot desert- Dry winter	Hot humid

Table 2-1- Koppen Climate type for each city

Figure (2-3) shows country of *Iran* with classification of all regions based on the classification mentioned above, by mentioning five different cities that will be studied in the next chapters. These cities are chosen to be representative of the whole country climatic situations. There is a brief introduction of each city's climate in table (2-1).

2.3. General weather condition

Figure (2-4) is showing Google Earth view of Iran with the appropriate scaling in the bottom of the picture. The location of cities of *Rasht, Hamedan, Tehran, Yazd* and *Bandar Abbas* are shown. In what follows the geographical situation of each city will be discussed.

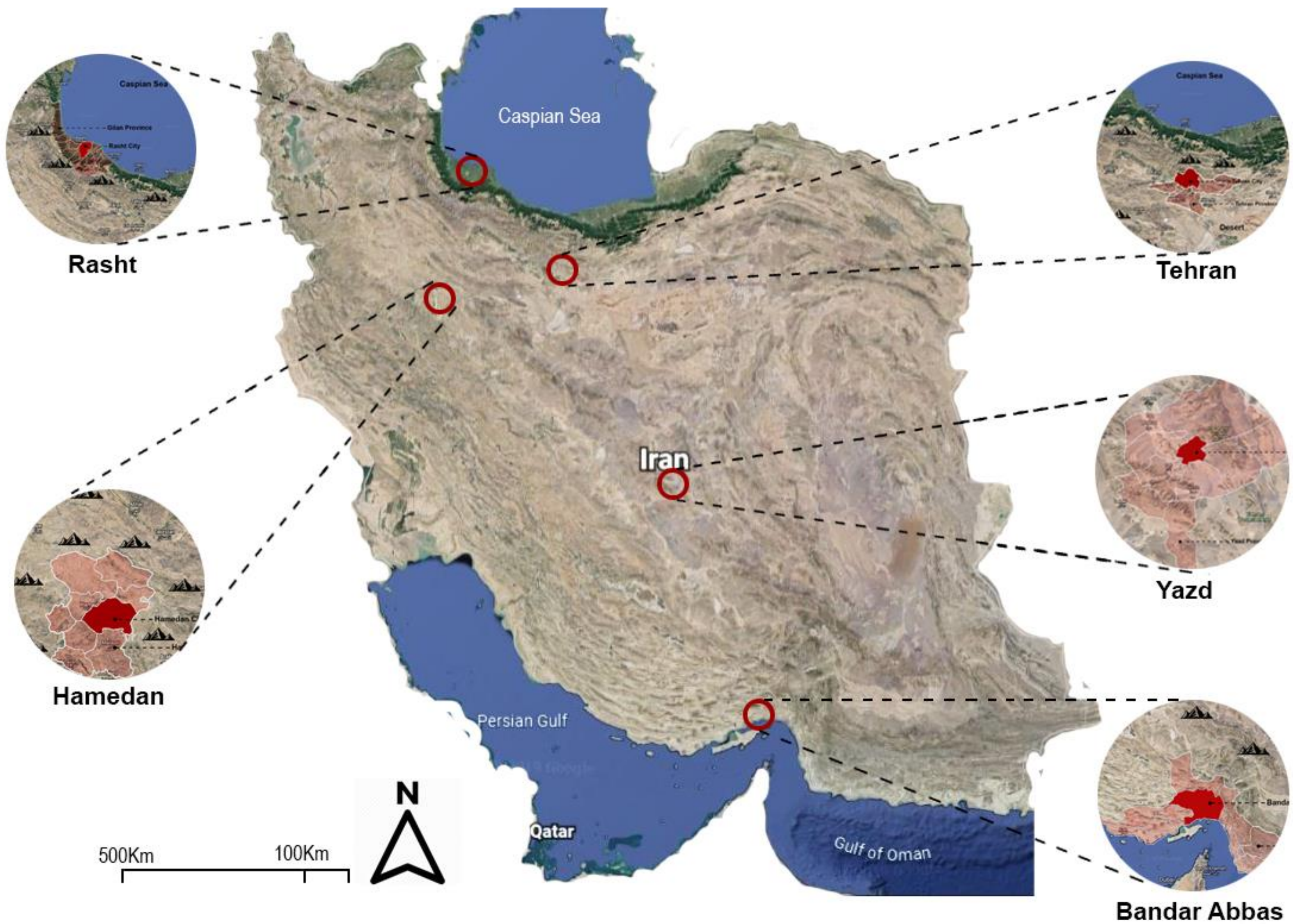

Figure 2-4- Google earth view of Iran with showing cities of Rasht, Hamedan, Tehran,Yazd and Bandar Abbas

- **Rasht**

Rasht is located in the province of *Gilan*, figure (2-5). The climate of *Gilan* is known as the temperate Caspian climate. The Talesh Mountains with north, south and Alborz Mountains along the west-east, act as a barrier to prevent the passage of water from the Caspian Sea and the northwestern wet winds into Iran, and also high altitude, causes heavy rainfall in *Gilan* province. The abundant evaporation of the Caspian Sea increases the humidity (especially in warm months by up to 93%) and modifies the summer air temperature and decreases it in winter, especially in lowland areas near the sea. Therefore, winter glaciation near the seaside has been reported rarely.

Figure 2-5- Rasht city, Gilan province, Iran

- **Hamedan**

Hamadan shown in figure (2-6) located in province of Hamedan lies in a temperate mountainous region to the east of Zagros mountain. The vast plains of the north and northeast of the province are influenced by strong winds, that almost last throughout the year.

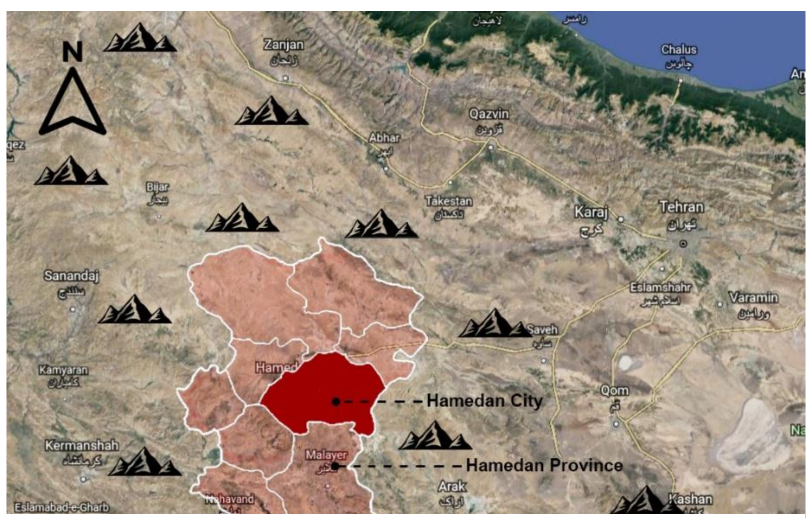

Figure 2-6- Hamedan city, Hamedan province, Iran

- **Tehran**

Tehran, capital city of Iran, is located in the province of *Tehran*, figure (2-7), on the steep southern slopes of the Alborz mountain range, which traces an arc along the coast of the Caspian Sea in northern Iran. Northern part of *Tehran* is limited to mountains while at the south it reaches to desert that causes diversity of geographical situation from north to south. Northern mountains act as a barrier to block entrance of humid air from the Caspian sea to the city causing dry condition.

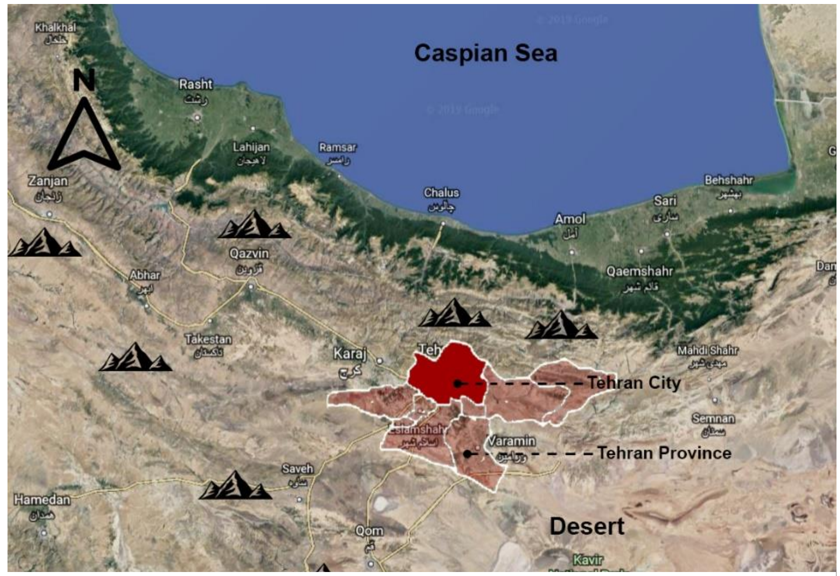

Figure 2-7- Tehran city, Tehran province, Iran

- **Yazd**

Yazd located in Yazd province, figure (2-8) has a hot desert climate. It is the driest major city in Iran, with a yearly precipitation amount of 49 millimeters and only 23 days of precipitation. Since 2017, the historical city of Yazd is recognized as a World Heritage Site by UNESCO. Because of generations of adaptations to its desert surroundings, Yazd has a unique Persian architecture. It is nicknamed the "City of Windcatchers".

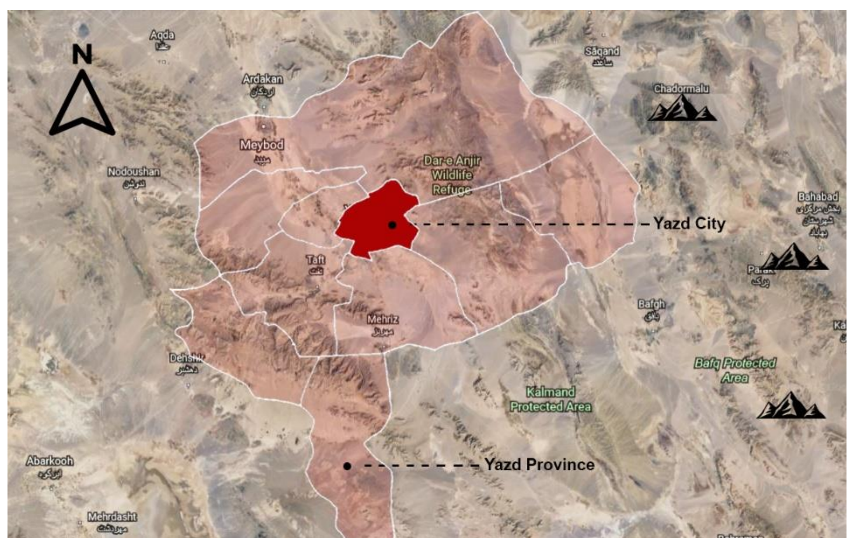

Figure 2-8- Yazd city, Yazd province, Iran

- **Bandar Abbas**

Bandar Abbas is a port city and capital of Hormozgan Province on the southern coast of Iran, on the Persian Gulf, figure(2-9). It is situated on flat ground with an average altitude of 9 meters above sea level.

Figure 2-9- Bandar Abbas city, Hormozgan province, Iran

2.3.1. Dry Bulb Temperature

Outside dry- and wet-bulb temperatures may cause building thermal loads through both heat transfer across building envelope and direct mass exchange by infiltration and ventilation. Coincident weather design conditions are fundamental data, and therefore should be properly selected. This is because the peak thermal loads of buildings are computed with these data, and then used to size HVAC equipment and systems. Oversized HVAC systems result in unnecessary extra capital cost and may lead to low part-load efficiency. Undersized systems, on the other hand, result in a higher risk that the system cannot satisfy actual thermal loads more frequently than the desired. [2]

Detailed data about dry bulb temperature is shown in table (2-2). As it can be seen in the table, coldest and hottest month in *Rasht* are January and August respectively. The situation of the coldest and hottest month is the same in *Hamedan* which are January and August respectively. But for Tehran the coldest month is January while the hottest month is July. *Yazd* has the same situation with *Tehran* by January as the coldest month and July as the hottest one. Finally Bandar Abbas coldest month is January like other cities and the hottest month is June. For all cities being hottest or coldest month is based on the amount of heating/cooling degree hour which is calculated and shown in tables according to a comfort range of 20 to 26°C.

coldest — hottest

RASHT	month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
	min temperature(°C)	-3.6	-1.6	1.9	5.0	9.5	16.2	17.2	18.2	15.6	10.5	4.2	0.0
	max temperature(°C)	19.7	20.3	25.4	27.5	28.5	31.8	34.8	35.3	33.5	28.6	26.3	24.2
	mean temperature(°C)	6.9	7.6	10.5	13.5	19.2	23.4	26.0	26.4	22.5	18.4	12.8	8.8
	mean day temperature(°C)	8.0	8.7	12.0	14.8	20.7	25.0	27.6	28.0	23.9	19.8	14.1	9.8
	mean night temperature(°C)	5.8	6.5	9.1	12.2	17.7	21.8	24.5	24.8	21.1	17.1	11.5	7.8
	heating degree hour(°Ch)	9774	8329	7080	4793	1458	192	34	27	315	1743	5254	8348
	cooling degree hour(°Ch)	0	0	0	5	31	329	1078	1224	289	12	0	0

Table 2-2-a Dry bulb temperatures for each month and heating/cooling degree hours

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coldest → hottest

HAMEDAN

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min temperature(°C)	-20.2	-16.2	-5.2	-0.5	3.7	7.1	12.2	11.8	5.9	1.3	-5.9	-12.4
max temperature(°C)	12.0	15.1	22.0	25.3	28.1	34.5	37.9	38.6	35.1	29.3	18.9	14.2
mean temperature(°C)	-4.0	0.2	7.2	11.5	16.5	21.6	25.6	25.1	19.6	13.9	5.6	0.6
mean day temperature(°C)	-2.3	1.9	9.6	14.0	19.7	25.4	29.1	28.9	23.4	16.9	7.7	2.1
mean night temperature(°C)	-5.7	-1.5	4.9	9.0	13.4	17.8	22.0	21.4	15.8	10.8	3.6	-0.8
heating degree hour(°Ch)	17822	13329	9510	6226	3274	1443	482	596	2254	4945	10340	14407
cooling degree hour(°Ch)	0	0	0	0	21	663	1870	1806	496	17	0	0

Table 1-2-b Dry bulb temperatures for each month and heating/cooling degree hours

coldest → hottest

TEHRAN

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min temperature(°C)	-5.9	-3.1	0.5	6.0	12.3	16.7	20.6	22.0	16.3	9.4	2.9	-1.5
max temperature(°C)	14.0	18.6	25.3	30.3	33.9	38.5	41.6	40.5	36.6	31.0	23.1	16.5
mean temperature(°C)	4.3	7.4	13.0	17.5	23.3	28.3	31.3	30.9	26.2	20.3	11.7	6.2
mean day temperature(°C)	5.4	8.7	14.6	19.4	25.6	30.8	33.7	33.1	28.4	22.3	13.1	7.3
mean night temperature(°C)	3.2	6.2	11.4	15.6	21.0	25.9	28.9	28.7	24.0	18.4	10.4	5.1
heating degree hour(°Ch)	11664	8434	5382	2515	501	32	0	0	74	1299	5994	10286
cooling degree hour(°Ch)	0	0	0	73	624	2414	4152	3764	1341	173	0	0

Table 2-2-c Dry bulb temperatures for each month and heating/cooling degree hours

coldest → hottest

YAZD

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min temperature(°C)	-6.5	-2.9	2.3	8.4	14.8	20.7	22.1	21.0	16.6	10.6	2.4	-2.5
max temperature(°C)	20.3	24.4	30.1	33.0	38.6	42.0	44.6	41.9	38.6	34.6	27.2	21.2
mean temperature(°C)	6.0	10.1	15.7	20.7	26.8	30.9	33.7	31.8	27.2	21.2	13.1	7.9
mean day temperature(°C)	7.9	12.2	18.1	23.4	29.6	33.7	36.4	34.7	30.3	24.2	15.4	10.0
mean night temperature(°C)	4.1	8.0	13.3	17.9	23.9	28.0	30.9	28.8	24.1	18.3	10.7	5.7
heating degree hour(°Ch)	10432	6715	3783	1320	135	0	0	0	44	1202	5177	9037
cooling degree hour(°Ch)	0	0	45	325	1905	3802	5764	4466	2033	446	4	0

Table 2-2-d Dry bulb temperatures for each month and heating/cooling degree hours

coldest → hottest

BANDAR ABBAS

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min temperature(°C)	6.2	9.3	13.2	18.0	23.4	26.3	29.0	28.3	25.6	21.6	13.2	7.5
max temperature(°C)	27.0	29.2	32.9	38.1	42.5	44.5	43.6	42.5	40.5	39.1	34.8	29.6
mean temperature(°C)	16.6	19.5	23.1	27.2	32.0	33.6	34.7	34.1	31.8	29.5	23.9	19.1
mean day temperature(°C)	18.9	21.5	25.2	29.5	34.7	35.9	36.5	35.8	33.8	31.9	26.3	21.6
mean night temperature(°C)	14.3	17.4	20.9	24.8	29.3	31.3	32.9	32.5	29.9	27.1	21.4	16.5
heating degree hour(°Ch)	3003	1388	388	9	0	0	0	0	0	0	346	1939
cooling degree hour(°Ch)	3	47	426	1661	4489	5470	6479	6062	4199	2840	678	97

Table 2-2-e Dry bulb temperatures for each month and heating/cooling degree hours

Graphical dry bulb temperature of cities can be seen in chart (2-1) with clarifying summer and winter time with dashed line. To divide months into summer and winter, criteria of dry bulb temperature=15°C is used. It means that, months with mean temperature more than 15°C are claimed as summer, and months with colder situation are characterized as winter. According to the following charts, Hamedan has the least summer duration, while Bandar Abbas is categorized as summer for the whole year.

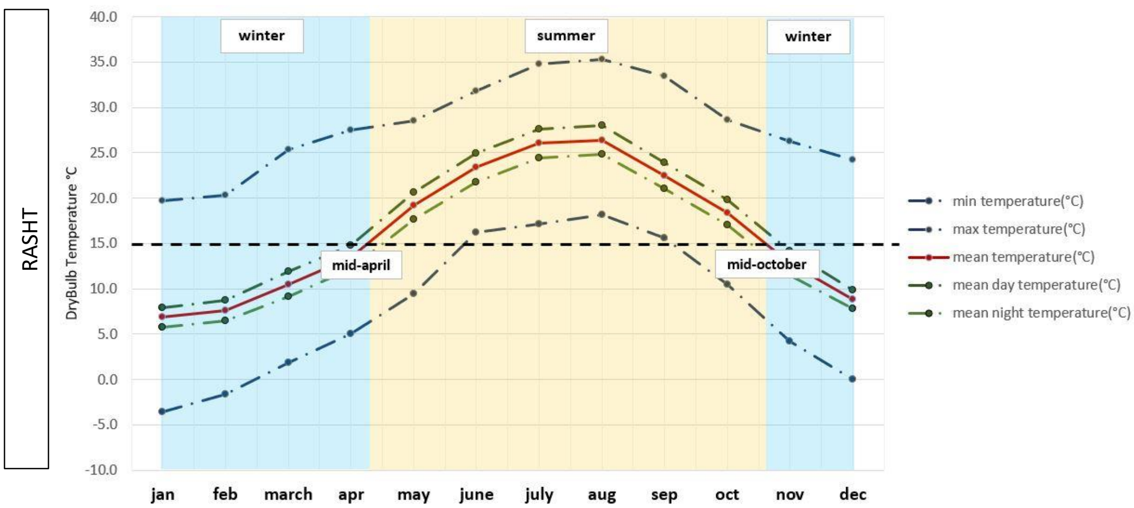


chart 2-1-a dry bulb temperature of each month by specifying summer and winter times, highlighting summer period

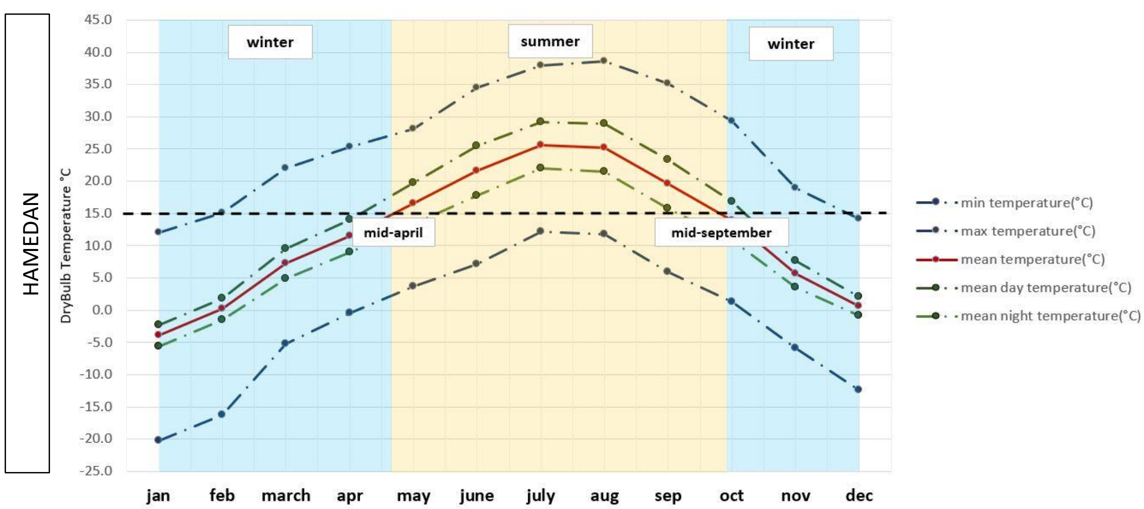
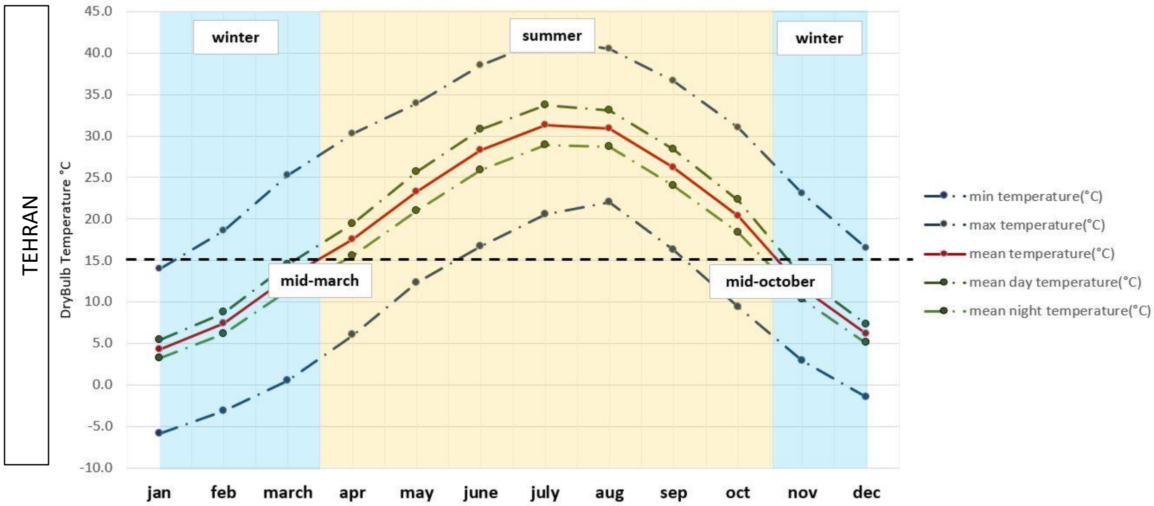


chart 2-1-a dry bulb temperature of each month by specifying summer and winter times, highlighting summer period



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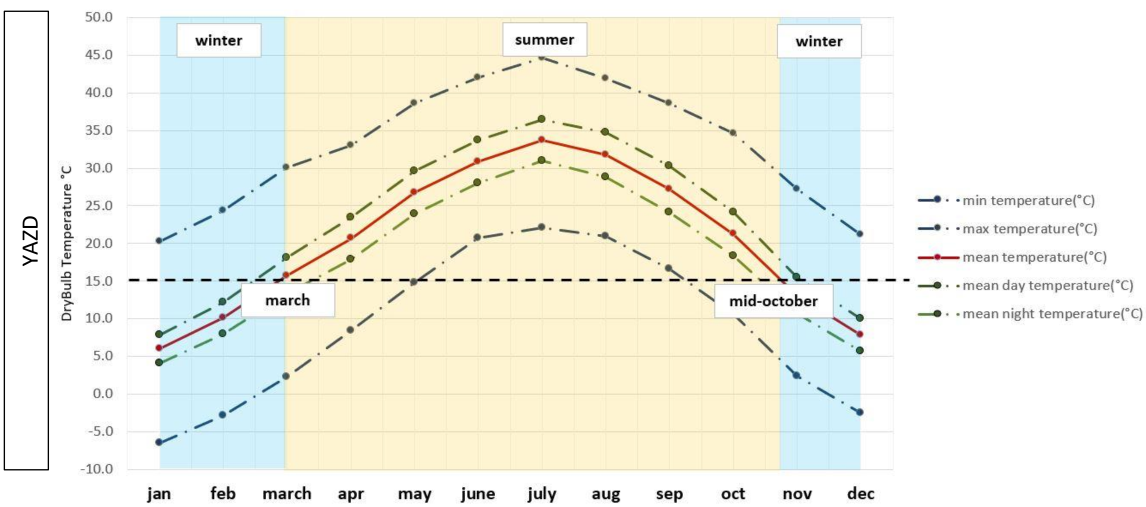


chart 2-1-a dry bulb temperature of each month by specifying summer and winter times, highlighting summer period

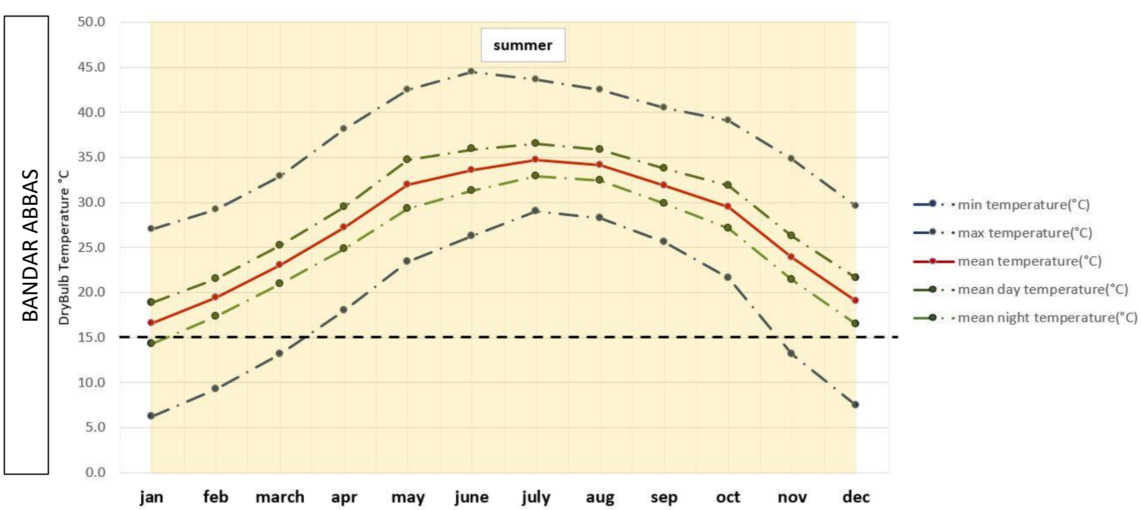


chart 2-1-a dry bulb temperature of each month by specifying summer and winter times, highlighting summer period

2.3.2. Hottest and Coldest Months Diurnal Temperature

For the coldest month with the highest heating degree hour, which is January for all the cities, diurnal dry bulb temperature by clarifying the day with the highest temperature difference and average value of diurnal temperature is shown in chart (2-2). In mid-January, *Hamedan* experiences the highest diurnal temperature of about 22°C with an average value of 10.3°C for the whole month. *Bandar Abbas* as it can be seen has an even situation for the whole January by the average diurnal temperature of 11.5°C which is the highest among other cities. For the hottest month with the highest cooling degree hour, which is August for *Rasht* and *Hamedan*, July for *Tehran* and *Yazd* and June for *Bandar Abbas*, diurnal dry bulb temperature by clarifying the day with the highest temperature difference and average value of diurnal temperature is shown in chart (2-3).As well as the coldest month, *Hamedan* again experiences the highest diurnal temperature of about 23°C with average value of 17.7°C which is the highest among other cities. And *Bandar Abbas* like the previous case has an even situation for the difference of day and night dry bulb temperature by an average value of 10°C.

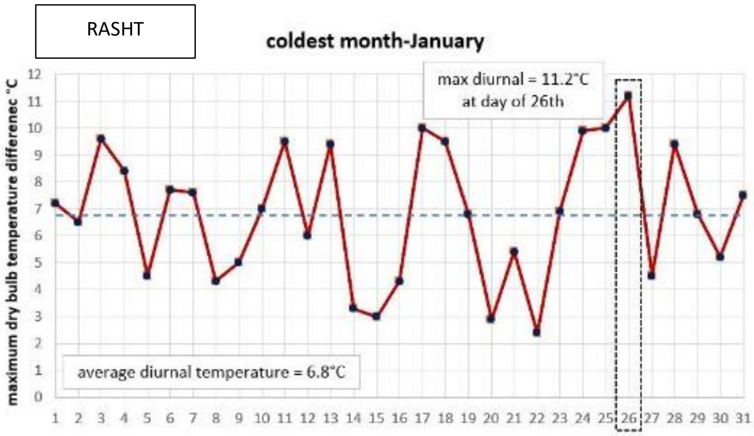


Chart 2-2-a day and night dry bulb temperature difference

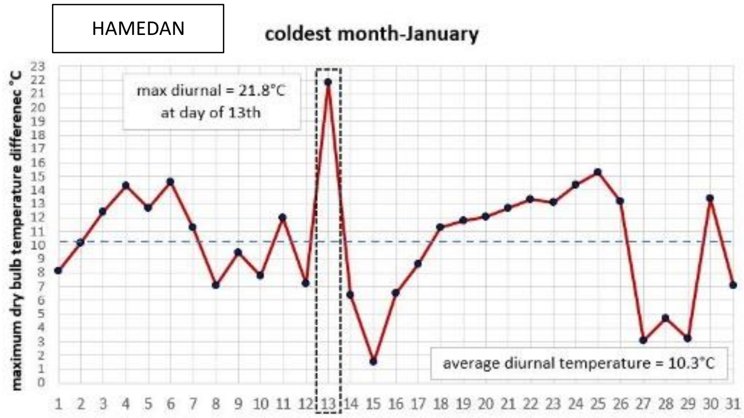


chart 2-2-b day and night dry bulb temperature difference

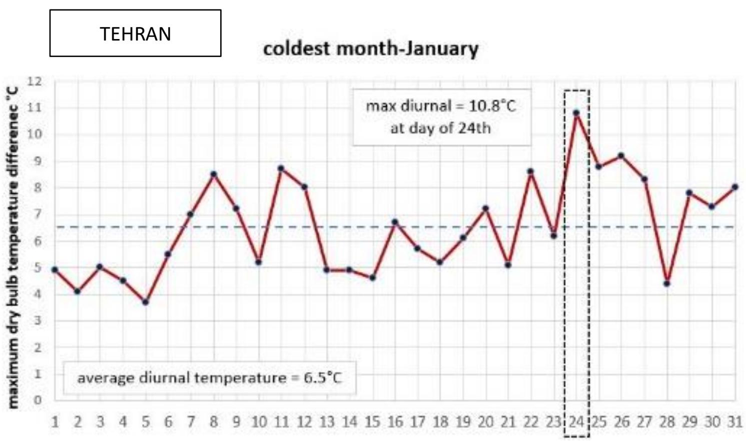


chart 2-2-c day and night dry bulb temperature difference

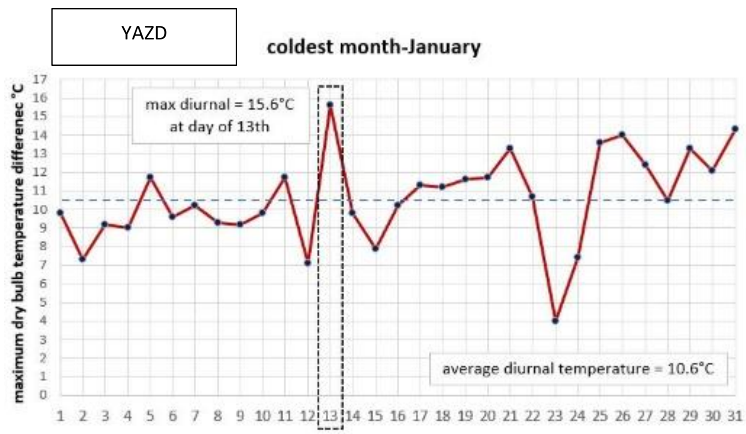


chart 2-2-d day and night dry bulb temperature difference

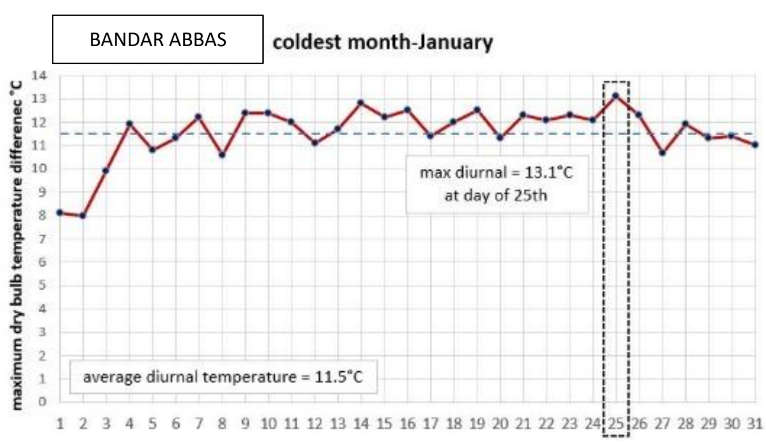


chart 2-2-e day and night dry bulb temperature difference

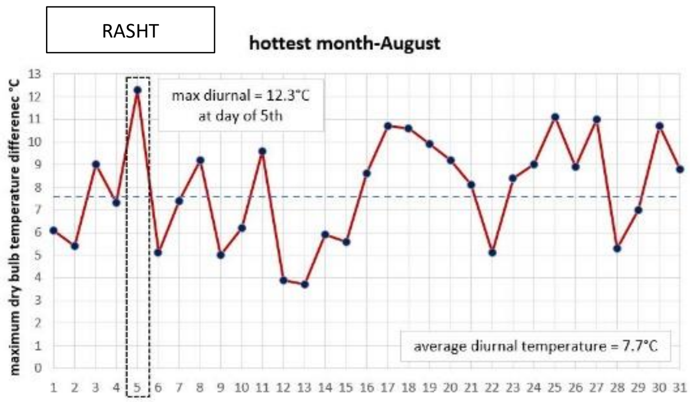


chart 2-3-a day and night dry bulb temperature difference

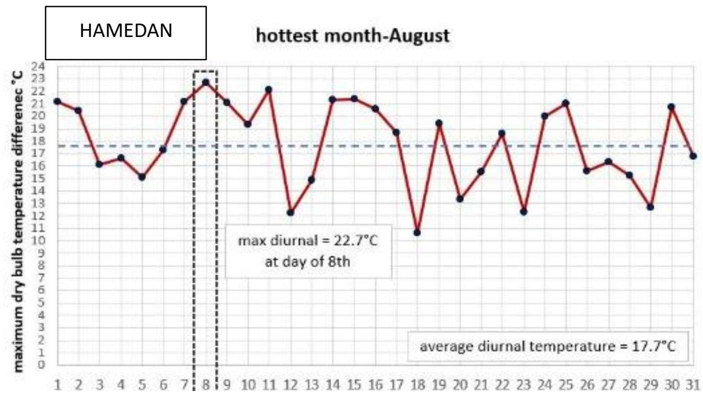


chart 2-3-b day and night dry bulb temperature difference

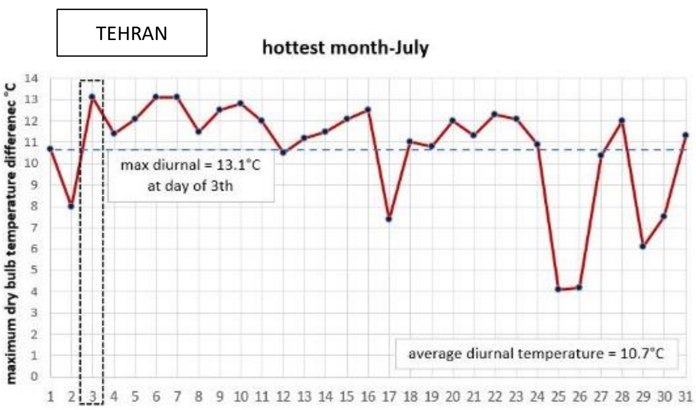


chart 2-3-c day and night dry bulb temperature difference

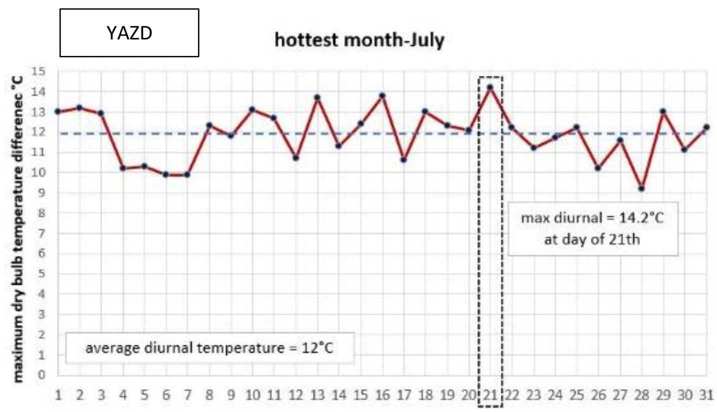


chart 2-3-d day and night dry bulb temperature difference

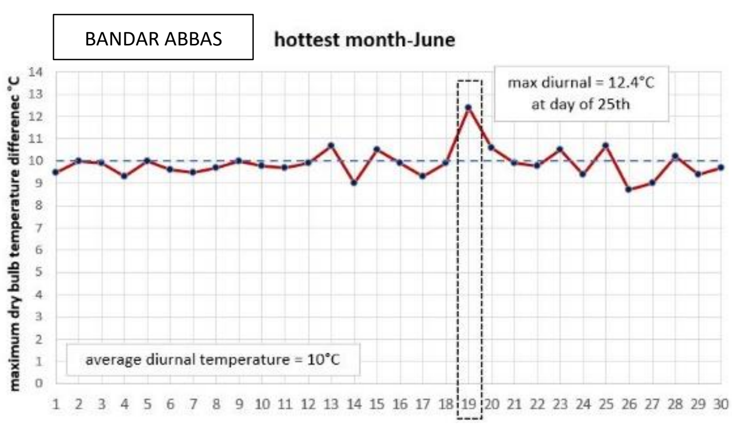


chart 2-3-e day and night dry bulb temperature difference

2.3.3. Heating and Cooling Degree Hour

In early studies, the degree day method was widely used with future weather data to determine the impact of climate change on building energy consumption. Degree day analysis uses the balance point temperature of a building, that at which the building does not require either cooling or heating. The choice of balance point temperature can be different for each region and each type of building. The Heating Degree Days (HDDs) and Cooling Degree Days (CDDs) are calculated hourly over a year as follows:

$$CDD = \sum_{if T_{db}>26}^{365} (T_{db} - 26)$$

$$HDD = \sum_{if T_{db}<20}^{365} |(20 - T_{db})|$$

where T_{db} is the outside dry bulb temperature. This method can provide a quick estimate of the impact of climate change on buildings. However, since solar radiation, humidity, and building characteristics such as thermal mass are not considered in degree day analysis, studies have often found that this method would lead to large deviations as compared to energy simulations. Therefore, hour-by-hour energy simulation is better for studying the impact of climate. [1]

To have a better idea about how much cooling and heating is needed for each city, heating and cooling degree hour based on a comfort range of 20 to 26°C for different months and annually by specifying summer and winter time is shown in chart (2-4). The fact which is clear is that for all the cities except Bandar Abbas, the main demand is heating, that can be solved easily by using thermal insulation. Significantly, Bandar Abbas's main issue is cooling based on the high value of cooling degree hour relative to the heating degree hour.

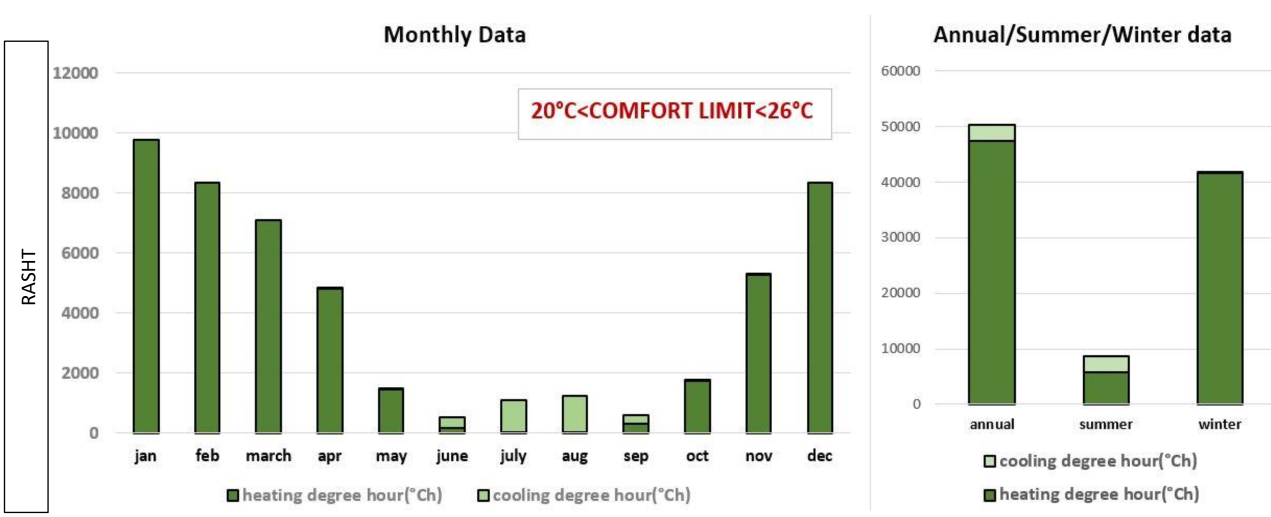


chart 2-4-a cooling and heating degree hour for each month and annual cumulative data with specifying of summer and winter degree hour

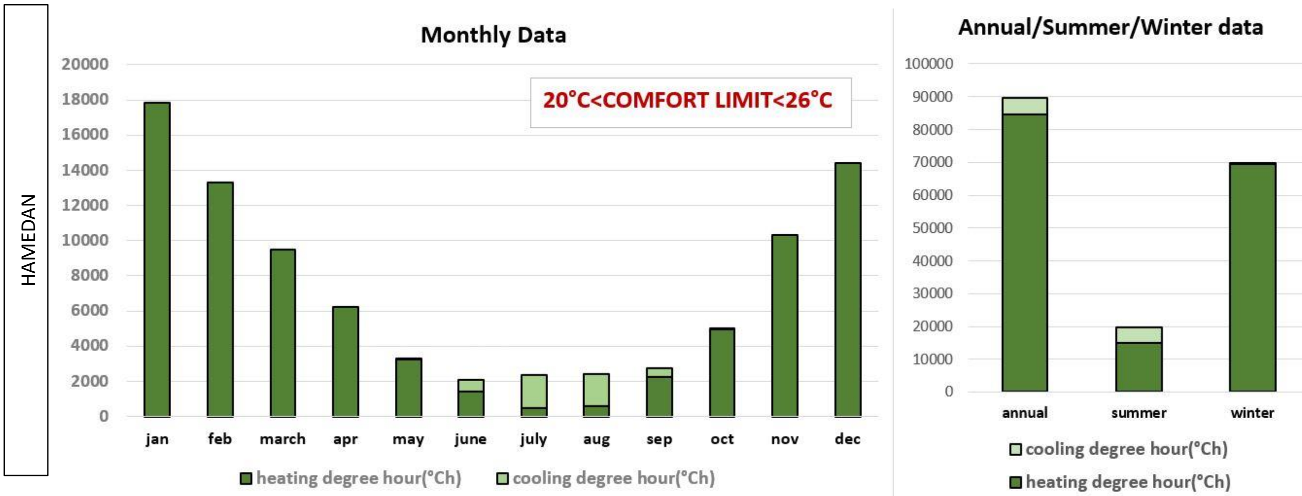


chart 2-4-b cooling and heating degree hour for each month and annual cumulative data with specifying of summer and winter degree hour

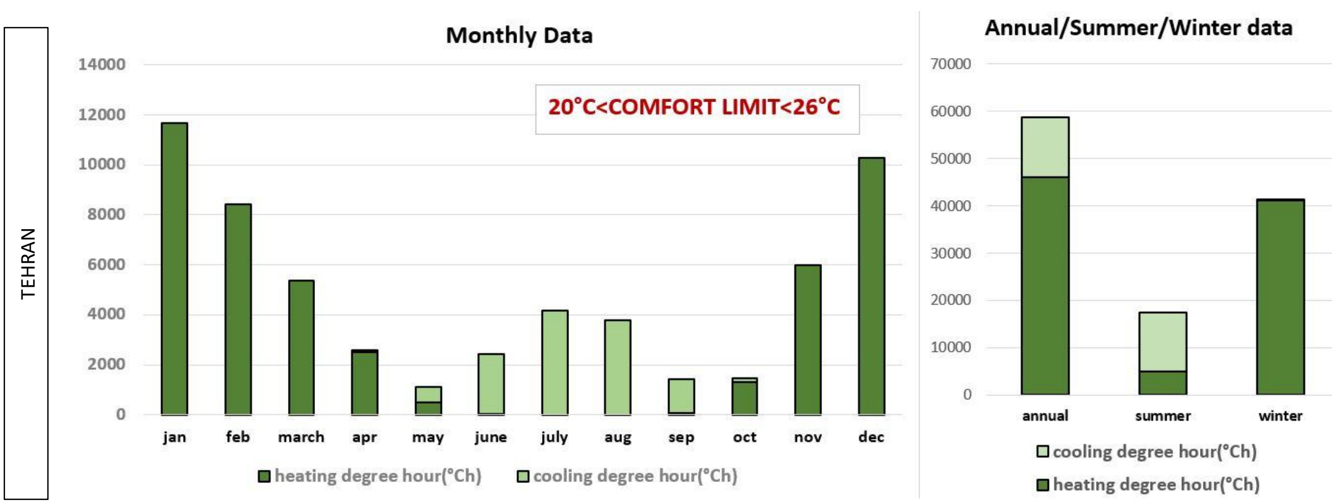


chart 2-4-c cooling and heating degree hour for each month and annual cumulative data with specifying of summer and winter degree hour

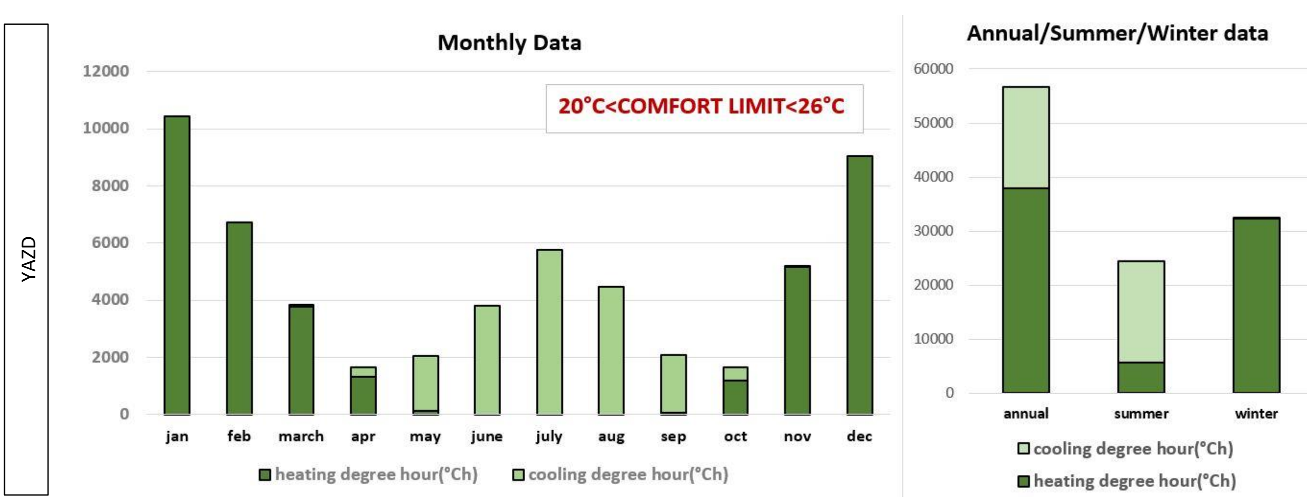


chart 2-4-d cooling and heating degree hour for each month and annual cumulative data with specifying of summer and winter degree hour

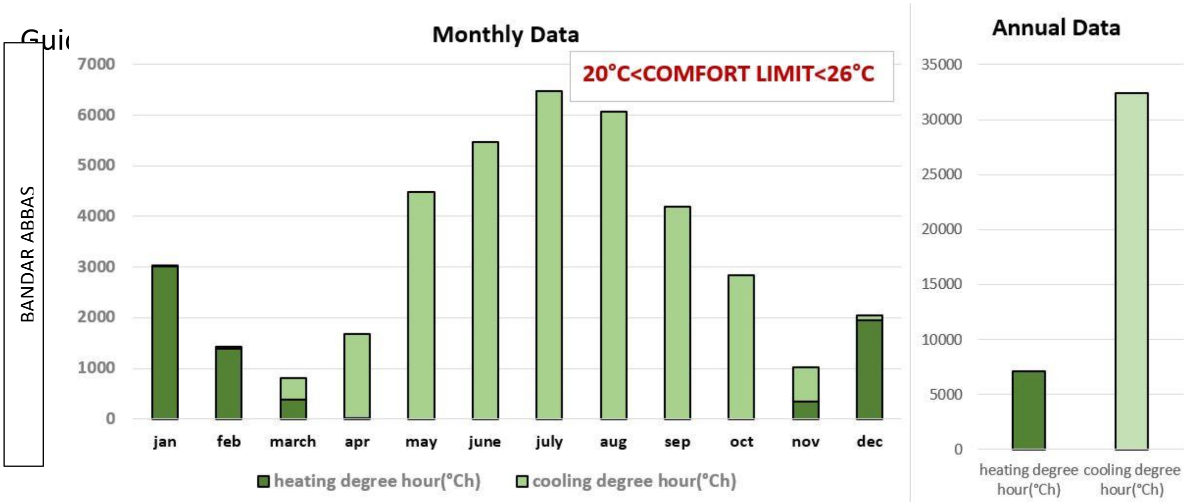


chart 2-4-e cooling and heating degree hour for each month and annual cumulative data with specifying of summer and winter degree hour

2.3.4. Frequency of Dry Bulb Temperature

Table (2-3) is clarifying for each month, frequency of temperatures in different ranges from below 15°C to above 26°C. Considering these tables, *Rasht* has very cold winters and mild summers, as well as *Hamedan*. *Tehran* has very cold winters and very hot summers, as well as *Yazd*. And finally, *Bandar Abbas* is mostly warm and hot during the whole year by having mild winter. Chart (2-5) graphically shows the situation of dry bulb frequency for each month. Green colors show comfort temperatures between 20 to 26°C, while light gray color relates to cold temperature below 15°C and dark gray shows hot temperatures higher than 26°C.

RASHT

	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	97%	3%	0%	0%	0%	0%
feb	97%	3%	0%	0%	0%	0%
mar	85%	12%	2%	0%	0%	0%
apr	67%	26%	4%	1%	1%	1%
may	15%	42%	19%	13%	7%	3%
jun	0%	22%	15%	17%	22%	23%
jul	0%	5%	9%	15%	23%	49%
aug	0%	4%	6%	17%	22%	52%
sep	0%	26%	24%	21%	13%	16%
oct	16%	55%	14%	8%	6%	1%
nov	72%	24%	2%	1%	1%	0%
dec	94%	5%	1%	1%	0%	0%

Table 2-3-a monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

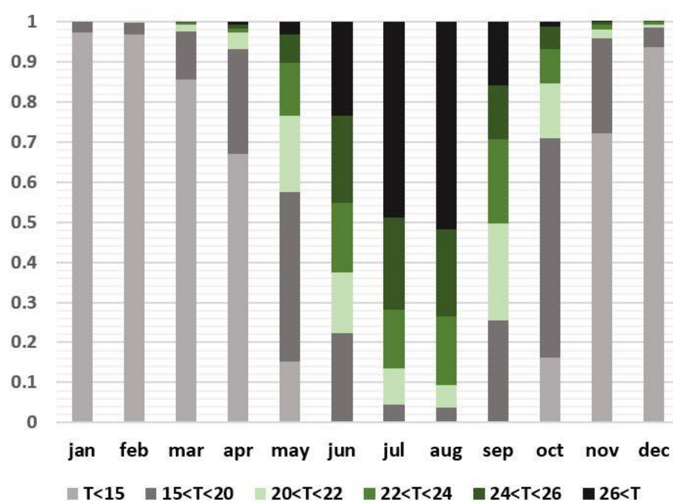


chart 2-5-a monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

HAMEDAN

	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	100%	0%	0%	0%	0%	0%
feb	100%	0%	0%	0%	0%	0%
mar	91%	7%	1%	0%	0%	0%
apr	73%	19%	3%	3%	1%	0%
may	42%	27%	13%	8%	7%	3%
jun	19%	22%	9%	10%	9%	30%
jul	3%	20%	11%	9%	9%	48%
aug	6%	21%	10%	8%	8%	46%
sep	30%	24%	9%	8%	9%	21%
oct	56%	27%	7%	5%	3%	2%
nov	96%	4%	0%	0%	0%	0%
dec	100%	0%	0%	0%	0%	0%

Table 2-3-b monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

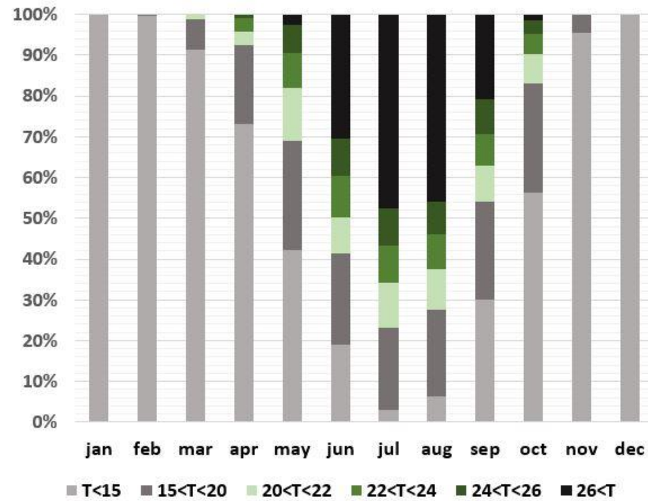


chart 2-5-b monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	40%	34%	12%	9%	5%	1%
feb	17%	39%	15%	14%	10%	6%
mar	1%	25%	15%	17%	15%	26%
apr	0%	1%	9%	17%	16%	58%
may	0%	0%	0%	1%	5%	94%
jun	0%	0%	0%	0%	0%	100%
jul	0%	0%	0%	0%	0%	100%
aug	0%	0%	0%	0%	0%	100%
sep	0%	0%	0%	0%	0%	100%
oct	0%	0%	1%	5%	16%	78%
nov	1%	22%	12%	16%	16%	33%
dec	25%	32%	13%	12%	9%	9%

Table 2-3-e Bandar Abbas monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

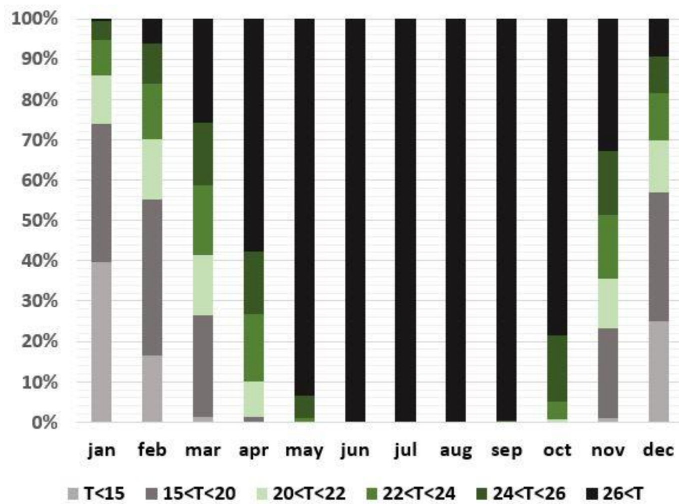


chart 2-5-e monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

TEHRAN	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	100%	0%	0%	0%	0%	0%
feb	96%	4%	0%	0%	0%	0%
mar	66%	25%	5%	3%	2%	0%
apr	34%	37%	11%	8%	5%	5%
may	4%	22%	15%	14%	17%	28%
jun	0%	3%	6%	12%	12%	67%
jul	0%	0%	1%	5%	9%	85%
aug	0%	0%	0%	3%	9%	88%
sep	0%	8%	11%	14%	16%	50%
oct	12%	38%	13%	13%	11%	13%
nov	80%	17%	3%	1%	0%	0%
dec	99%	1%	0%	0%	0%	0%

Table 2-3-c monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

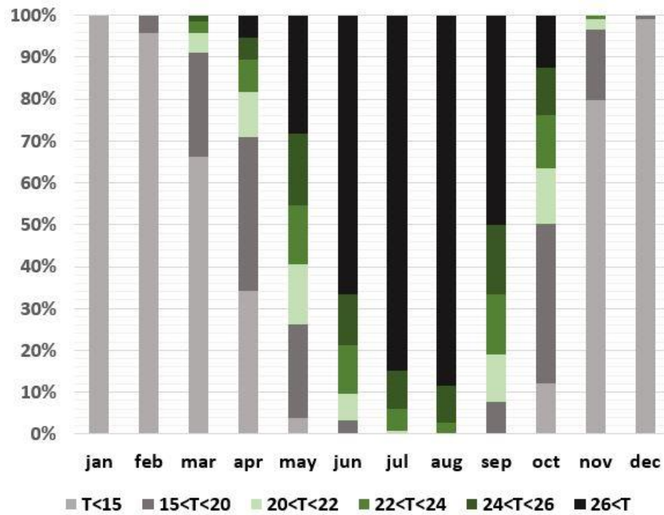


chart 2-5-c monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

YAZD	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	97%	3%	0%	0%	0%	0%
feb	79%	17%	2%	2%	0%	0%
mar	47%	32%	6%	6%	6%	3%
apr	15%	32%	13%	12%	10%	17%
may	0%	9%	11%	13%	13%	53%
jun	0%	0%	2%	7%	12%	79%
jul	0%	0%	0%	1%	4%	95%
aug	0%	0%	1%	4%	8%	87%
sep	0%	7%	13%	13%	13%	55%
oct	12%	33%	12%	11%	10%	20%
nov	67%	23%	5%	3%	1%	1%
dec	91%	8%	1%	0%	0%	0%

Table 2-3-d monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

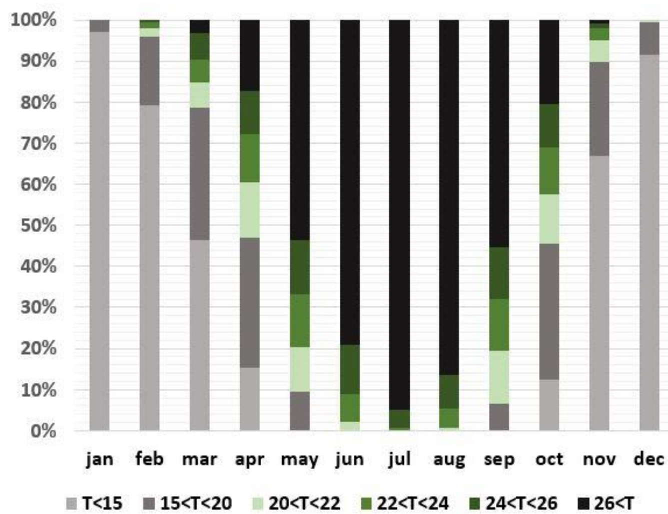


chart 2-5-d monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

BANDAR ABBAS	T<15	15<T<20	20<T<22	22<T<24	24<T<26	26<T
jan	40%	34%	12%	9%	5%	1%
feb	17%	39%	15%	14%	10%	6%
mar	1%	25%	15%	17%	15%	26%
apr	0%	1%	9%	17%	16%	58%
may	0%	0%	0%	1%	5%	94%
jun	0%	0%	0%	0%	0%	100%
jul	0%	0%	0%	0%	0%	100%
aug	0%	0%	0%	0%	0%	100%
sep	0%	0%	0%	0%	0%	100%
oct	0%	0%	1%	5%	16%	78%
nov	1%	22%	12%	16%	16%	33%
dec	25%	32%	13%	12%	9%	9%

Table 2-3-e monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

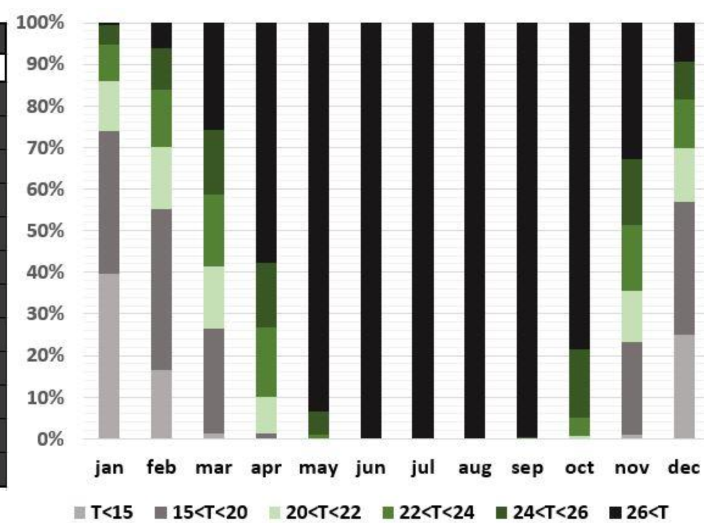


chart 2-5-e monthly frequency of dry bulb temperatures for range of below 15 to above 26°C

2.3.5. Relative Humidity

The object of the study in the air conditioning field is humid air which can be characterized by the two parameters: temperature and humidity. There are both the heat and substances transfer when handling the humid air. In air cooling process, the usual ways are mechanical cooling and evaporative cooling techniques. [3] To find the best passive strategies for each climatical regions it is necessary to study the physical characters of thermal condition for each zone.

Table (2-4) is showing the values of relative humidity during different months by specifying the values for the hottest and coldest month for each city. Also, Chart (2-6) is showing values of relative humidity of each city graphically.

During the whole year, *Rasht* experiences a maximum relative humidity of 100% by having an average value of 80%. Situation for *Hamedan* is completely different. During each month, relative humidity fluctuates a lot, around 90%. There is also around 20% of relative humidity difference between day and night. Average value for wintertime is around 70% while 40% for summertime. During a complete year, *Tehran* has relatively low humidity of about 50% in winter and 30% in summer and difference between day and night relative humidity is not high which is about 10%. Situation for *Yazd* is the same as *Tehran*, with values 10% less. Finally, *Bandar Abbas*, as being near the sea like *Rasht*, has a relatively the same situation with that with an average relative humidity of 62.6% for the whole year.

		coldest						hottest				
RASHT	month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
	min relative humidity(%)	45.0	49.0	44.0	55.0	47.0	44.0	41.0	43.0	53.0	57.0	53.0	51.0
	max relative humidity(%)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	mean relative humidity(%)	81.1	82.5	80.6	83.7	79.1	76.3	74.5	75.5	85.0	86.6	85.9	83.8
	mean day relative humidity(%)	76.4	77.8	75.1	78.5	72.0	70.0	68.4	68.8	80.3	82.1	81.4	80.0
	mean night relative humidity(%)	85.8	87.1	86.1	89.0	86.1	82.6	80.6	82.2	89.6	91.2	90.5	87.6

Table 2-4-a monthly relative humidity

		coldest						hottest				
HAMEDAN	month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
	min relative humidity(%)	33.0	28.0	14.0	19.0	17.0	12.0	10.0	10.0	10.0	10.0	24.0	29.0
	max relative humidity(%)	100.0	100.0	100.0	92.0	91.0	100.0	76.0	73.0	78.0	89.0	100.0	100.0
	mean relative humidity(%)	76.2	69.9	50.1	52.8	45.6	39.5	32.4	30.4	32.1	44.4	66.7	72.1
	mean day relative humidity(%)	69.0	62.3	41.7	43.8	35.6	29.2	24.7	22.6	24.2	35.2	58.8	66.2
	mean night relative humidity(%)	83.3	77.5	58.4	61.7	55.7	49.9	40.2	38.2	40.0	53.6	74.7	78.1

Table 2-4-b monthly relative humidity

coldest (jan) — hottest (july)

TEHRAN

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min relative humidity(%)	28.0	19.0	17.0	18.0	12.0	10.0	11.0	12.0	13.0	17.0	19.0	28.0
max relative humidity(%)	98.0	95.0	85.0	97.0	74.0	78.0	64.0	54.0	74.0	80.0	98.0	99.0
mean relative humidity(%)	60.7	52.6	41.5	42.5	33.1	27.6	27.5	27.9	30.4	38.1	49.7	61.7
mean day relative humidity(%)	55.3	47.1	37.1	35.9	26.3	22.5	22.6	23.3	25.2	32.6	45.2	57.1
mean night relative humidity(%)	66.1	58.1	45.9	49.1	39.8	32.6	32.3	32.4	35.5	43.6	54.3	66.3

Table 2-4-c monthly relative humidity

coldest (jan) — hottest (july)

YAZD

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min relative humidity(%)	20.0	13.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	12.0	19.0
max relative humidity(%)	90.0	81.0	78.0	80.0	46.0	60.0	40.0	40.0	42.0	48.0	85.0	84.0
mean relative humidity(%)	48.8	35.1	24.8	24.2	20.1	16.3	17.2	20.4	19.8	22.5	36.6	50.8
mean day relative humidity(%)	41.8	29.2	19.9	19.2	16.2	12.9	14.0	16.4	15.4	17.4	30.0	43.4
mean night relative humidity(%)	55.8	40.9	29.7	29.1	24.1	19.7	20.5	24.4	24.2	27.6	43.2	58.3

Table 2-4-d monthly relative humidity

coldest (jan) — hottest (june)

BANDAR ABBAS

month	jan	feb	march	apr	may	june	july	aug	sep	oct	nov	dec
min relative humidity(%)	31.0	35.0	34.0	30.0	27.0	31.0	38.0	40.0	40.0	32.0	28.0	26.0
max relative humidity(%)	100.0	100.0	100.0	94.0	94.0	98.0	97.0	96.0	100.0	100.0	96.0	100.0
mean relative humidity(%)	64.2	65.6	62.7	58.3	54.6	59.0	64.2	65.8	67.5	63.5	58.9	62.1
mean day relative humidity(%)	54.7	57.4	54.9	49.3	45.5	51.0	57.5	59.3	60.2	54.0	49.5	52.2
mean night relative humidity(%)	73.7	73.8	70.5	67.2	63.7	67.0	70.9	72.3	74.8	72.9	68.4	72.0

Table 2-4-e monthly relative humidity

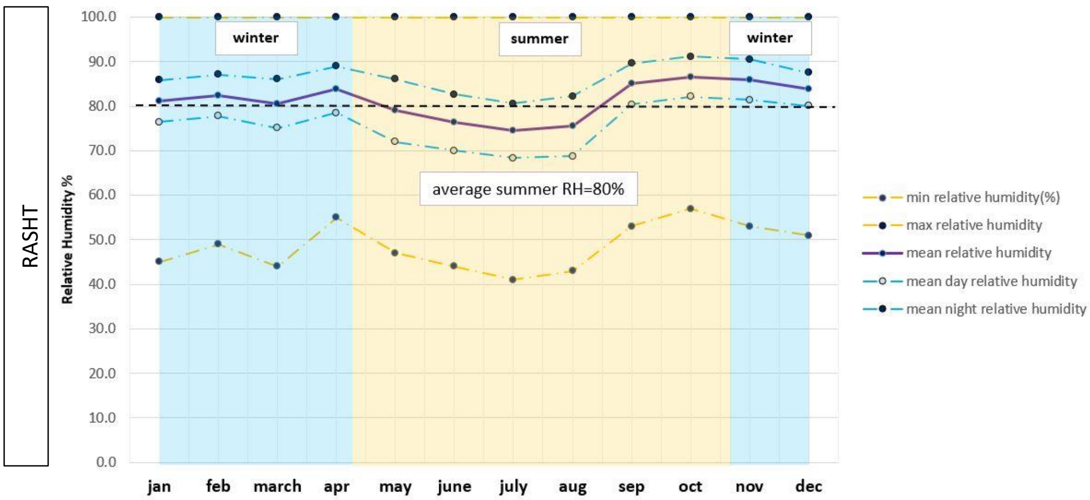


chart 2-6-a graphically relative humidity specifying summertime RH

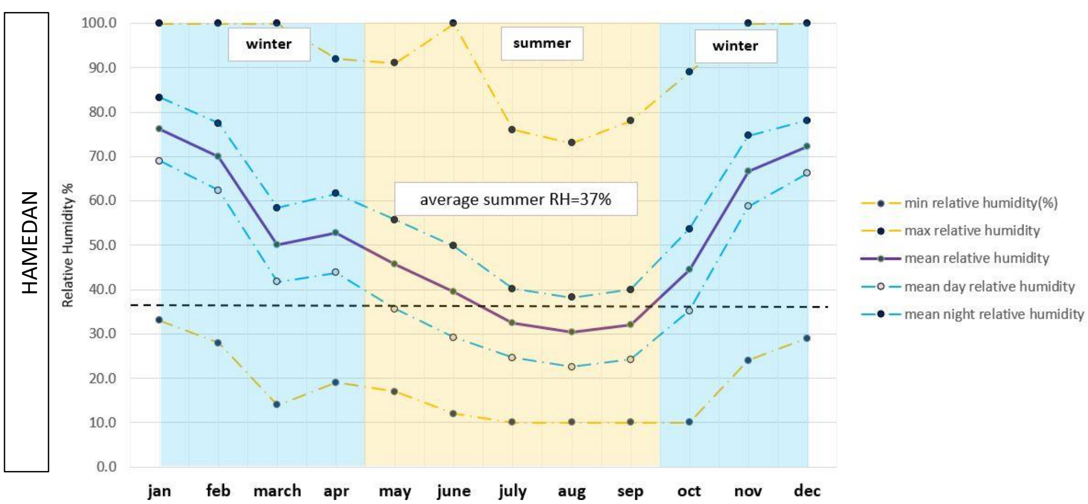


chart 2-6-b graphically relative humidity specifying summertime RH

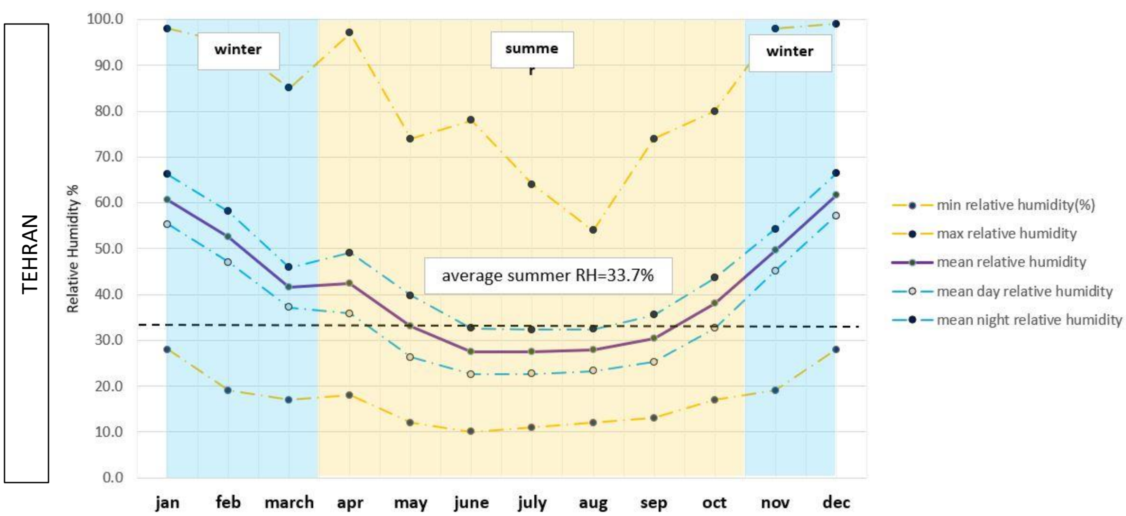


chart 2-6-c graphically relative humidity specifying summertime RH

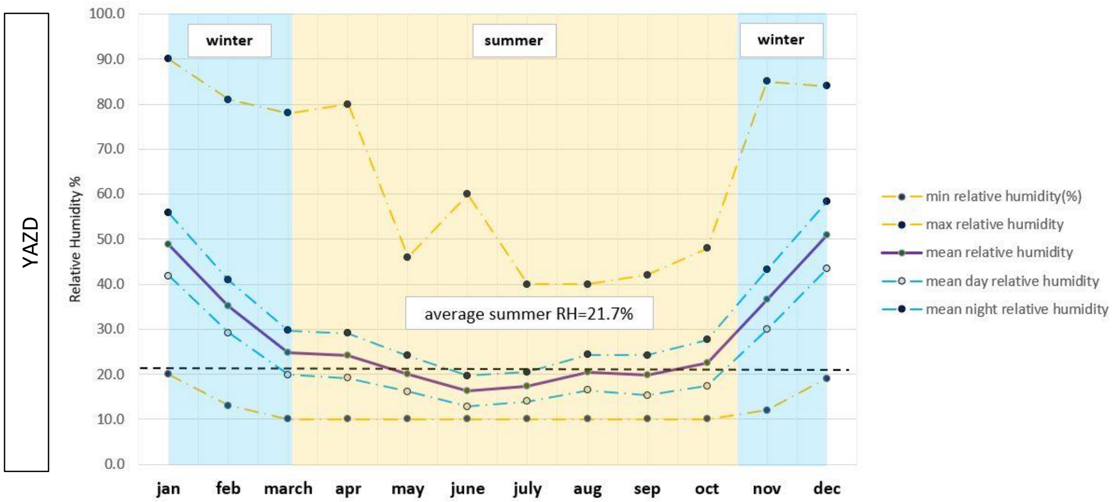


chart 2-6-d graphically relative humidity specifying summertime RH

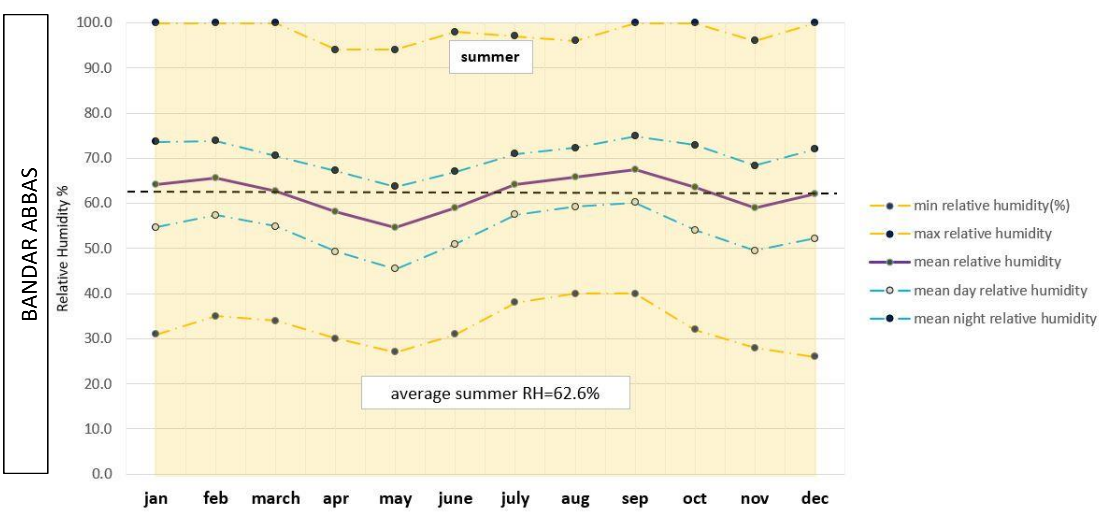


chart 2-6-e graphically relative humidity specifying summertime RH

2.3.6. Sun Radiation

Solar radiation plays a significant role in building energy consumption. The building environment and building thermal energy consumption are responsive to the solar radiation conditions, particularly for buildings with glazed envelopes or large windows. Solar radiation penetrating into rooms through windows can directly impact the indoor thermal environment. It can also increase the outside surface temperature of the envelope, thereby affecting the indoor environment and cooling/heating loads. Solar radiation is regarded as the main contributor to heat gains in buildings, particularly in residential buildings, where the internal gains are extremely low. The US Department of Energy reported that solar heat gain from windows in cooling-dominated climates has a significant energy impact on both residential and commercial buildings.[4]

Table (2-5) is showing the position of the sun at 12 p.m. throughout a year with specifying the zenith angle for each case. And in chart (2-7), cumulative direct normal radiation for each city is shown by specifying the months with the highest and the least radiation gain.

Rasht is located in the northern part of Iran, while Bandar Abbas is at the south and other cities are in between. So, it is clear that the zenith angle of sun in mid-summer is from 16° for Rasht to 5° for Bandar Abbas with 100KWh to 200KWh of direct sun radiation on a unit horizontal surface respectively. Mid-winter for all cities (except Bandar Abbas) creates the same situation by having zenith angle of around 60°.

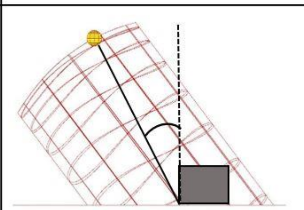
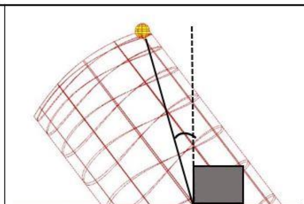
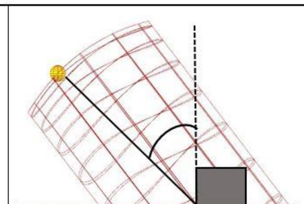
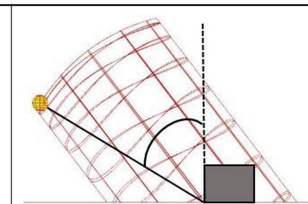
	summer start	mid summer	summer end	mid winter
Rasht				
	15 April	15 July	15 October	15 January
	zenith angle=28°	zenith angle=16°	zenith angle=46°	zenith angle=58°

Table 2-5-a zenith angle of sun in Rasht for different times of the year

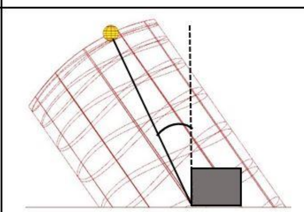
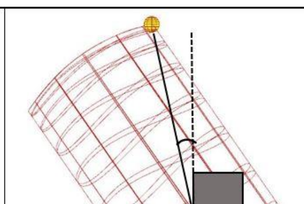
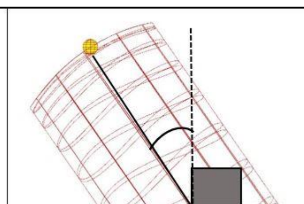
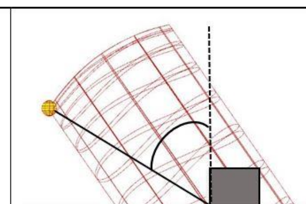
	summer start	mid summer	summer end	mid winter
Hamedan				
	15 April	30 June	15 September	31 December
	zenith angle=25°	zenith angle=12°	zenith angle=32°	zenith angle=58°

Table 2-5-b zenith angle of sun in Hamedan for different times of the year

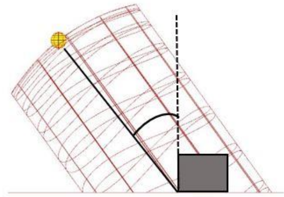
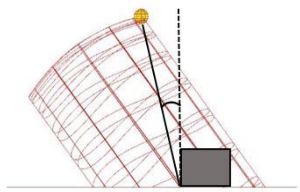
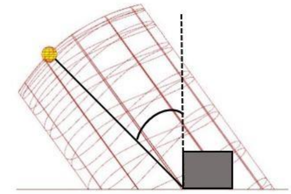
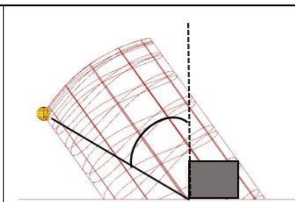
	summer start	mid summer	summer end	mid winter
Tehran				
	15 March	30 June	15 October	31 December
	zenith angle=38°	zenith angle=13°	zenith angle=44°	zenith angle=60°

Table 2-5-c zenith angle of sun in Tehran for different times of the year

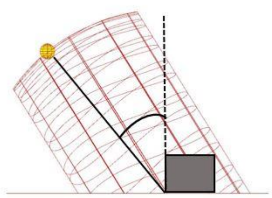
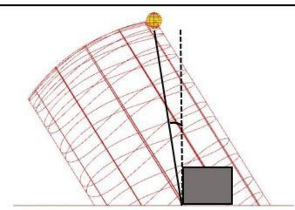
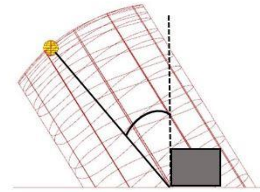
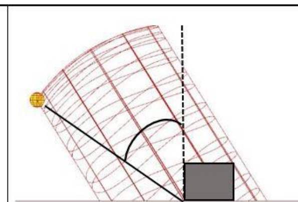
	summer start	mid summer	summer end	mid winter
Yazd				
	1 March	30 June	15 October	31 December
	zenith angle=40°	zenith angle=9°	zenith angle=41°	zenith angle=55°

Table 2-5-d zenith angle of sun in Yazd for different times of the year

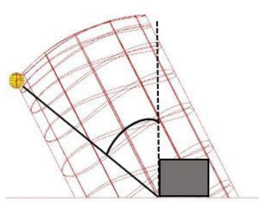
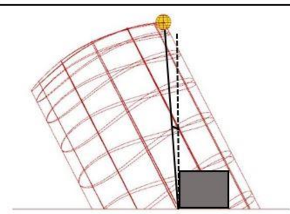
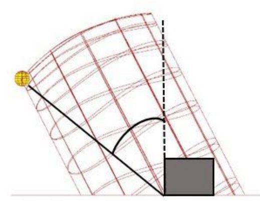
	summer start	mid summer	summer end
Bandar Abbas			
	1 January	30 June	31 December
	zenith angle=51°	zenith angle=5°	zenith angle=51°

Table 2-5-e zenith angle of sun in Bandar Abbas for different times of the year

By considering the zenith angle and total sun radiation on horizontal surface for each city, evaluation for benefiting from the sun to produce energy on one side and locating windows on different walls and surfaces to have the most optimal inner condition on the other side can be done. Considering chart (2-7) and (2-8), for city of Rasht in July there is the most sun radiation gain and in October it is the least for a horizontal surface. Moreover, during the summer, the average daytime direct sun radiation on horizontal surface for a unit area is about 3.5 kwh/m^2 while this value is about 2.7 kwh/m^2 during the winter. During the summer, northern and eastern façade gain the highest radiation while during the winter east and south façade gain the highest radiation.

For city of Hamedan, in July there is the most sun radiation gain and in December it is the least for a horizontal surface. Moreover, during the summer, the average daytime direct sun radiation on horizontal surface for a unit area is about 6.7 kwh/m^2 while this value is about 2.1 kwh/m^2 during the winter. During the summer, northern and eastern façade gain the highest radiation while during the winter east and south façade gain the highest radiation.

For city of Tehran, like Hamedan, in July there is the most sun radiation gain and in December it is the least for a horizontal surface. Moreover, during the summer, the average daytime direct sun radiation on horizontal surface for a unit area is about 5.9 kwh/m^2 while this value is about 1.5 kwh/m^2 during the winter. During the summer, eastern façade gains the highest radiation and the northern and southern façade gain the same radiation and the western façade gains the least, while during the winter east and south façade gain the highest radiation.

For city of Yazd, in September there is the most sun radiation gain and in February it is the least for a horizontal surface. Moreover, during the summer, the average daytime direct sun radiation on horizontal surface for a unit area is about 3.34 kwh/m^2 while this value is about 3.0 kwh/m^2 during the winter. During the summer, northern and eastern façade gain the highest radiation while during the winter east and south façade gain the highest radiation.

For city of Bandar Abbas, in May there is the most sun radiation gain and in August it is the least for a horizontal surface. Moreover, during the summer, the average daytime direct sun radiation on horizontal surface for a unit area is about 5.8 kwh/m^2 while this value is about 5.13 kwh/m^2 during the winter. During the summer, southern and eastern façade gain the highest radiation while during the winter east façade gains the highest radiation.

RASHT

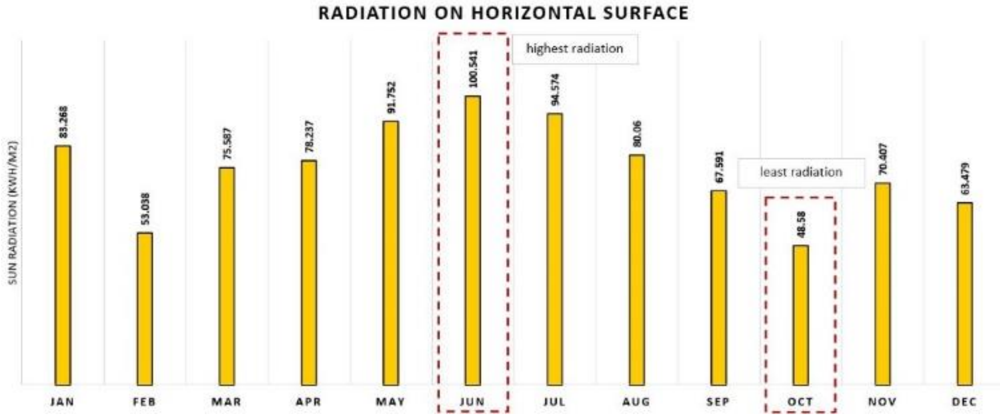


chart 2-7-a direct normal sun radiation for each month

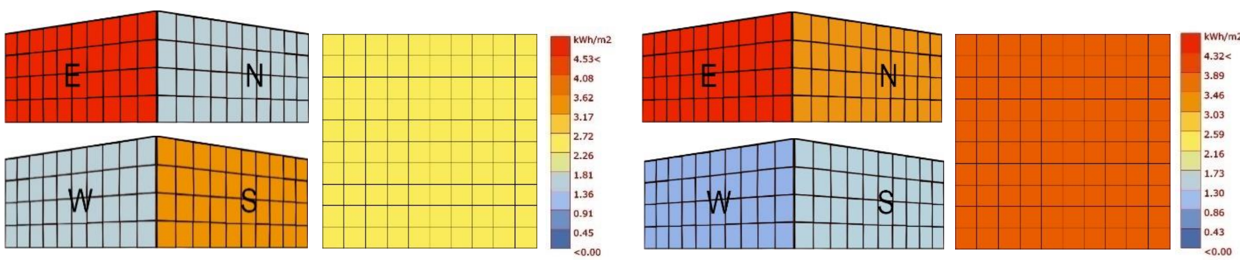


chart 1-8-a average sun radiation gain on vertical and horizontal surfaces during summer(right) and winter(left)

HAMEDAN

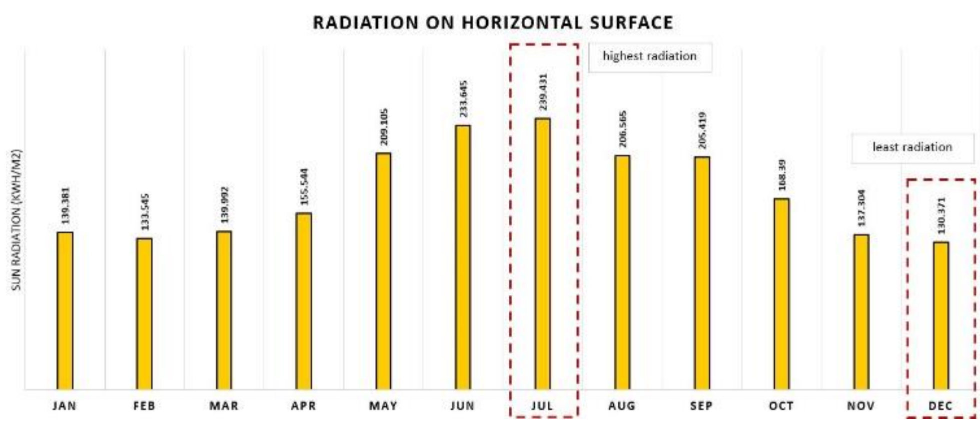


chart 2-7-b direct normal sun radiation for each month

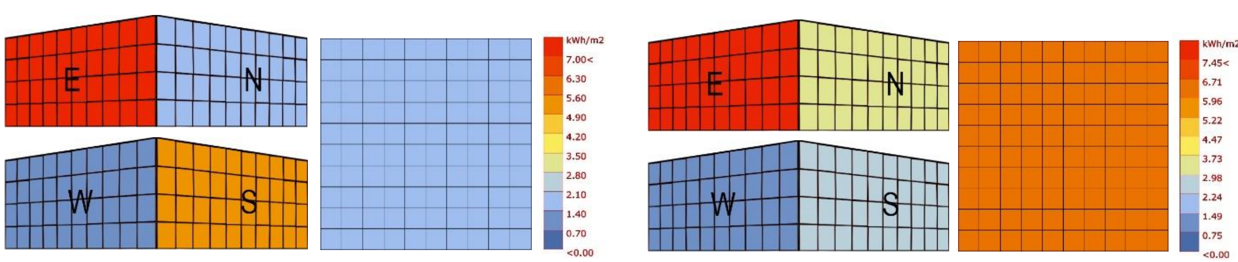


chart 2-8-b average sun radiation gain on vertical and horizontal surfaces during summer(right) and winter(left)

TEHRAN

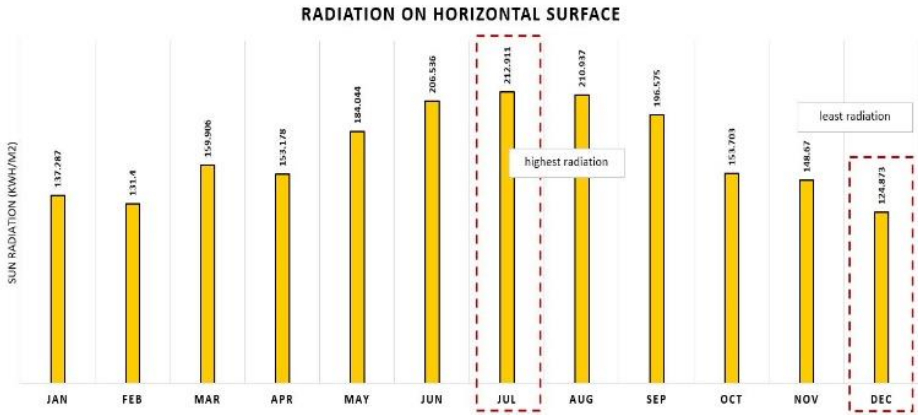


chart 2-7-c direct normal sun radiation for each month

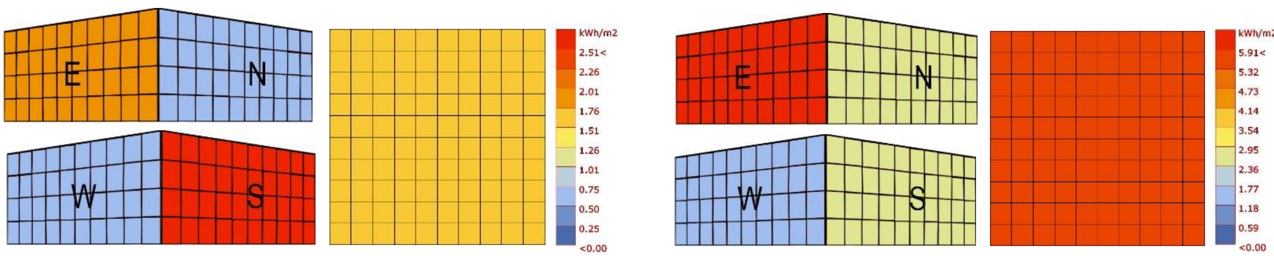


chart 2-8-c average sun radiation gain on vertical and horizontal surfaces during summer(right) and winter(left)

YAZD

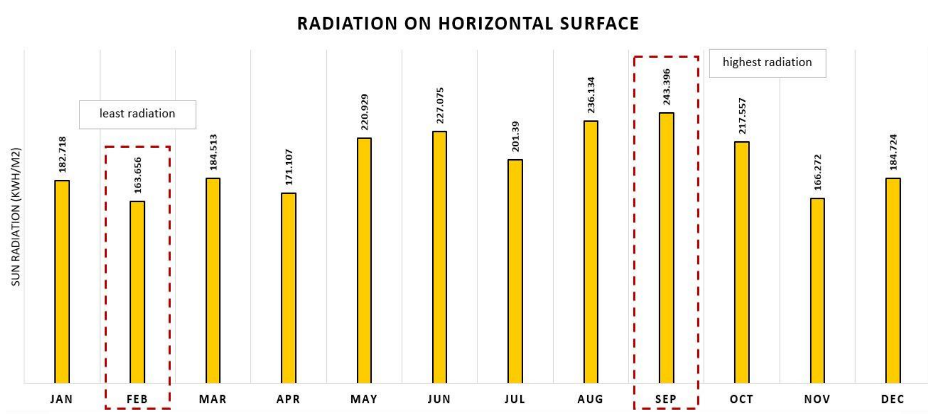


chart 2-7-d direct normal sun radiation for each month

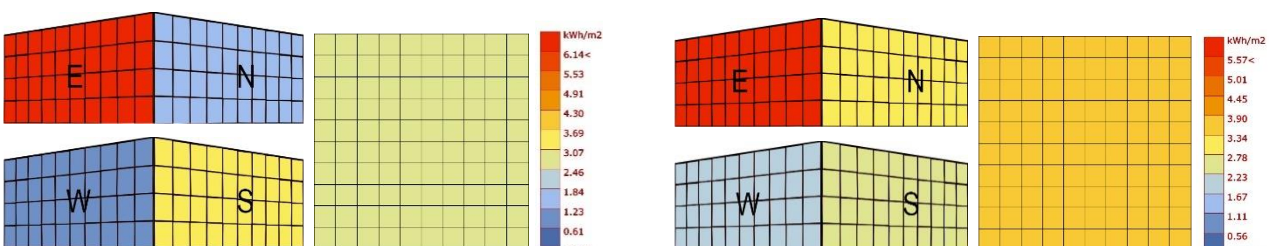


chart 2-8-d average sun radiation gain on vertical and horizontal surfaces during summer(right) and winter(left)

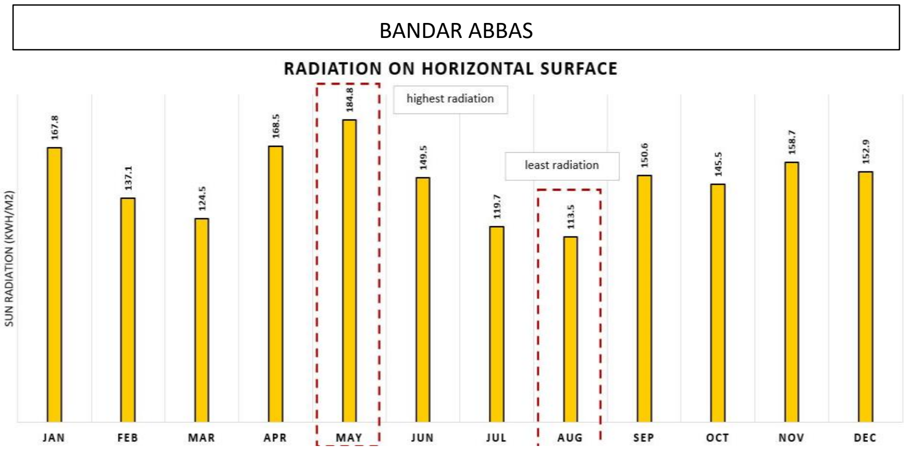


chart 2-7-e direct normal sun radiation for each month

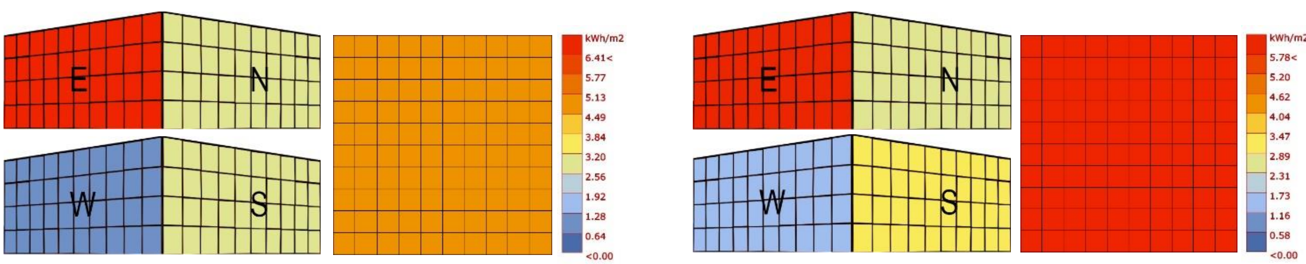


chart 2-8-e average sun radiation gain on vertical and horizontal surfaces during summer(right) and winter(left)

In table (1-6) we can see the total value of direct radiation for summertime and wintertime separately. Also, average values of radiation for the month with the highest and the least sun gain can be seen.

RASHT		month with highest radiation			month with least radiation	
	radiation in summer	total radiation	average day-time radiation	radiation in winter	total radiation	average day-time radiation
	509(KWh/m2)	100 (kWh/m^2) June	0.264 (kWh/m^2)	397.7 (kWh/m^2)	48.6 (kWh/m^2) October	0.094 (kWh/m^2)

Table 2-6-a direct sun radiation for winter and summer time

HAMED		month with highest radiation			month with least radiation	
	radiation in summer	total radiation	average day-time radiation	radiation in winter	total radiation	average day-time radiation
	1090.6(KWh/m2)	239.4(kWh/m^2) July	0.567 (kWh/m^2)	1008.1(kWh/m^2)	130.4 (kWh/m^2) December	0.35(kWh/m^2)

Table 2-6-b direct sun radiation for winter and summer time

TEHRAN		month with highest radiation			month with least radiation	
	radiation in summer	total radiation	average day-time radiation	radiation in winter	total radiation	average day-time radiation
	1320.4(kWh/m^2)	212.9(kWh/m^2) July	0.548(kWh/m^2)	699.6(kWh/m^2)	124.9 (kWh/m^2) december	0.34 (kWh/m^2)

Table 2-6-c direct sun radiation for winter and summer time

YAZD	radiation in summer	month with highest radiation: total radiation	month with highest radiation: average day-time radiation	radiation in winter	month with least radiation: total radiation	month with least radiation: average day-time radiation
	1592.9(kWh/m^2)	243.4(kWh/m^2) september	0.676 (kWh/m^2)	806.5(kWh/m^2)	163.5(kWh/m^2) february	0.487(kWh/m^2)

Table 2-6-d direct sun radiation for winter and summer time

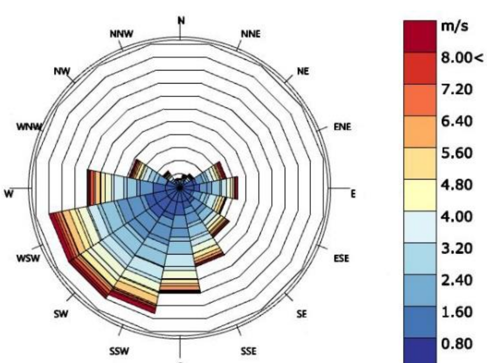
BANDAR ABBAS	radiation in summer	month with highest radiation: total radiation	month with highest radiation: average day-time radiation	radiation in winter	month with least radiation: total radiation	month with least radiation: average day-time radiation
	1773.3(kWh/m^2)	184.8(kWh/m^2) may	0.492(kWh/m^2)	-	113.5(kWh/m^2) august	0.305 (kWh/m^2)

Table 2-6-e direct sun radiation for winter and summer time

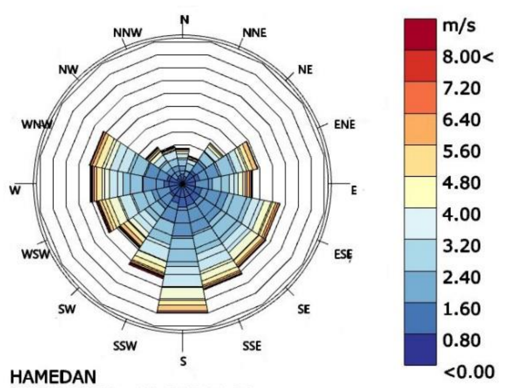
2.3.7. Wind

Natural ventilation, which is to allow the interior of a building to be replenished naturally, not using additional sources of energy by fresh air from the outside, is more economical than mechanical ventilation. In turn, however, natural ventilation is more difficult to quantify and control, as its parameters may be too numerous: the dimensions and configurations of the vents and orifices through which ventilation occurs, other architectural features on the building that may change the course of wind flow, settings of the interior, and the surrounding, and incident wind direction. Many studies have tried to quantify the ways these parameters impact natural ventilation, using analytical models, flow-network models, wind tunnel experiments, and Computational Fluid Dynamics (CFD) simulations. Most of these studies used generically-shaped (i.e., cubic or rectangular) models, with a single orifice on one wall for studying single-sided ventilation, or two openings either on opposite/adjacent walls or on the same wall to investigate cross-ventilation. [5]

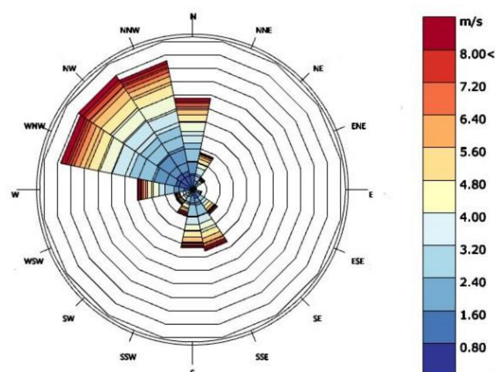
The following graphs are showing the wind speed and direction for each city during its summertime. As it is clear, the main wind direction in Rasht is from west to south, in Hamedan it is mainly from east-south to west, in Tehran is from north to west, in Yazd is from north-east to south-east and in Bandar Abbas is from south to west. These directions can be used for locating the position of windows for having an effective airstream during summertime.



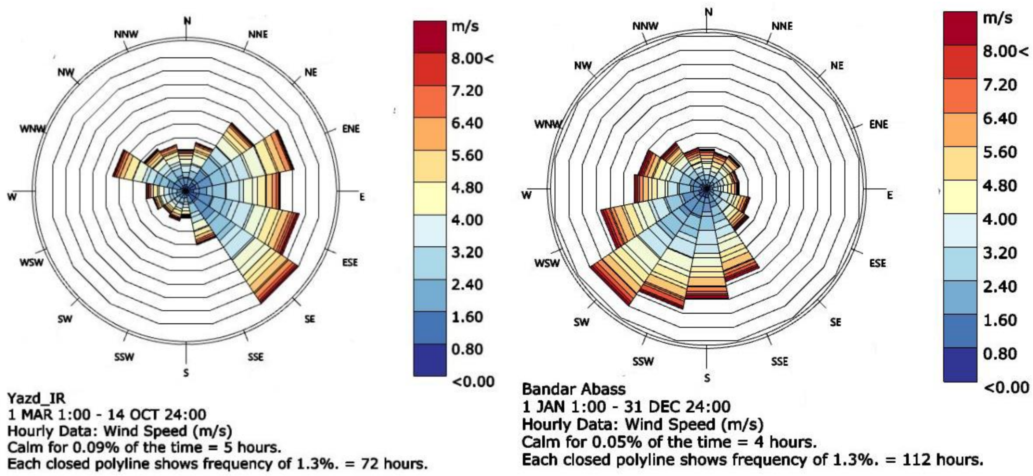
Rasht_IR
15 APR 1:00 - 14 OCT 24:00
Hourly Data: Wind Speed (m/s)
Calm for 1.68% of the time = 74 hours.
Each closed polyline shows frequency of 1.3%. = 57 hours.



HAMEDAN
15 APR 1:00 - 14 SEP 24:00
Hourly Data: Wind Speed (m/s)
Calm for 0.33% of the time = 12 hours.
Each closed polyline shows frequency of 1.1%. = 38 hours.



TEHRAN_IR
15 MAR 1:00 - 14 OCT 24:00
Hourly Data: Wind Speed (m/s)
Calm for 0.47% of the time = 24 hours.
Each closed polyline shows frequency of 1.6%. = 83 hours.



Zhang and Weerasuriya modeled single-sided ventilation (SV) and cross-ventilation (CV) separately. Case SV is the less efficient of the two ventilation modes, but it nevertheless represents a configuration very common in densely populated cities such as Hong Kong, where many rooms (e.g., cellular offices, classrooms, and flats) have windows on only one of their walls. Case CV is the more efficient ventilation mode. It can rapidly remove large amounts of pollutants and heat from an enclosure. The buildings showed in figure (2-10) will be simulated under five incident wind directions from θ = 0° to 180°. Orifice dimensions are 250 mm × 250 mm × 250 mm (height (*H*) × length (*L*) × width (*W*)) with 6 mm-thick walls. Model SV has a 125 mm × 84 mm (height × width) orifice on its windward wall, while model CV has two identical orifices on its windward and leeward walls. [5]

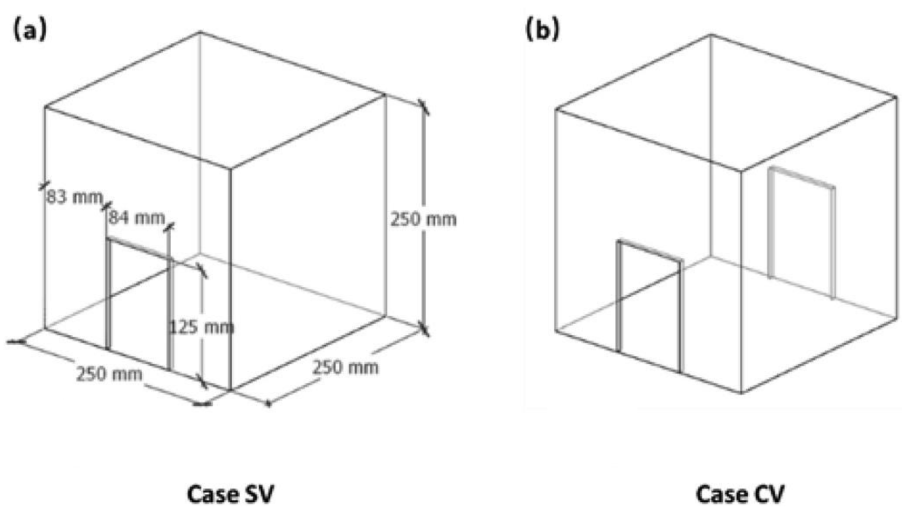


Figure 2-10 buildings with single sided orifice and cross orifices modeled with CFD analysis

In the figure (2-11) it can be seen the distribution of normalized mean wind speed, k which means wind speed (*U*)/reference wind speed (*Uref*) and mean velocity streamlines at *z/H* = 0.1 in case SV and CV for (a) 0°, (b) 45°, (c) 90°, as predicted by CFD analysis. [5]

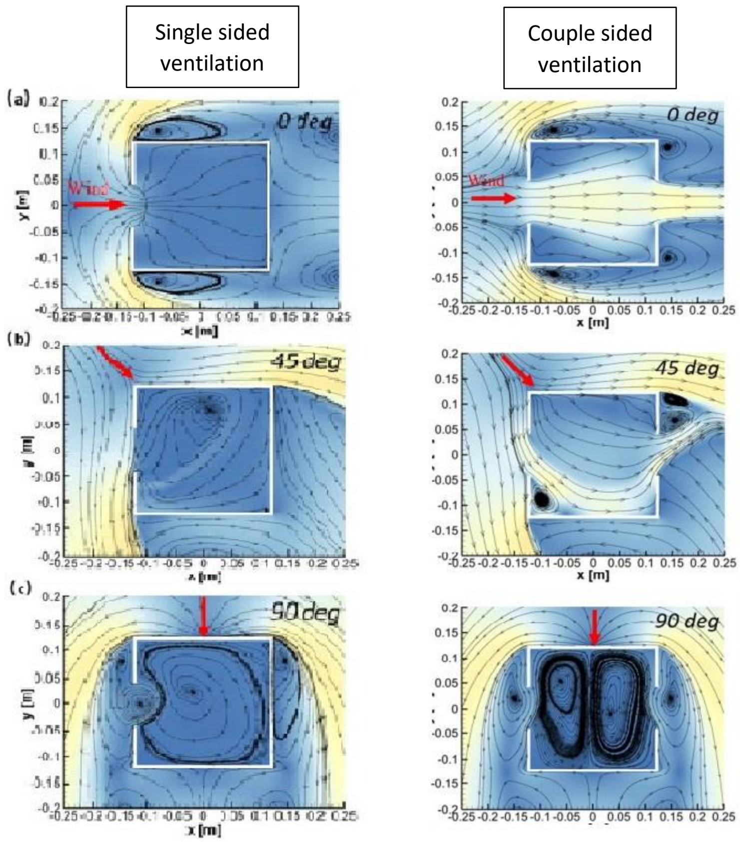


Figure 2-11 distribution of normalized mean wind speed 1 in case SV and CV for (a) 0°, (b) 45°, (c) 90°, as predicted by CFD analysis

By using the wind speed and direction graphs for each city during the summertime and considering the results shown in figure (2-11), there can be an overview of the way of locating the orifices on different walls for having a suitable natural ventilation.

2.3.8. Ground Temperature

Kasuda found that the temperature of the undisturbed ground is a function of the time of year and the depth below the surface and could be described by the following correlation:

$$T = T_{mean} - T_{amp}.\exp\left(-z\sqrt{\frac{\pi}{365\alpha}}\right).\cos\left(\frac{2\pi}{365}\times\left(t_{now} - t_{shift} - \frac{z}{2}.\sqrt{\frac{365}{\pi.\alpha}}\right)\right)$$

Where:

T [°C] Temperature
T_{mean} [°C] Mean surface temperature (average air temperature)
T_{amp} [°C] Amplitude of surface temperature (maximum air temperature minus minimum air temperature)
Z [m] Depth below surface
α $[m^2/day]$ Thermal diffusivity of the ground (dry clay is assumed)
t_{now} [day] Current day of the year
t_{shift} [day] Day of the year corresponding to the minimum surface temperature

The Kasuda equation results in a distribution of temperature with respect to time for different values of soil depth and for a given climate. Respective parameters are shown in table (2-7) for each city. All regions are assumed to have dry clay soil with $\alpha = 0.0268\ {m^2}/{day}$.

	Rasht	Hamedan	Tehran	Yazd	Bandar Abbas
T_{mean}	16.4°C	12°C	18.4°C	20.5°C	27.1°C
T_{amp}	13.4°C	23.8°C	13.4°C	16.5°C	15.1°C
t_{shift}	90 day	254 day	159 day	337 day	341 day

Table 2-7 physical parameters for each city for calculation of ground temperature

Chart (2-9) is showing ground temperature of each city for different depths calculated by the method of Kasuda mentioned above, from the ground surface (equal to air dry bulb temperature) to 5 meters behind. As it can be seen, temperature distribution is sinoside by reaching to a constant temperature for depths more than 5 meter. For each city, the constant temperature is shown separately.

For the coldest and hottest months in each region, charts (2-10) is showing the difference of ground temperature and dry bulb air temperature for different depths. For example considering Yazd by having high value of cooling degree hour in July, only digging 1 meter of soil, we can have 6°C of temperature difference to cool down the house. Or considering Hamedan in January, only 0.5 meter depth can provide about 25°C warmer air to the space.

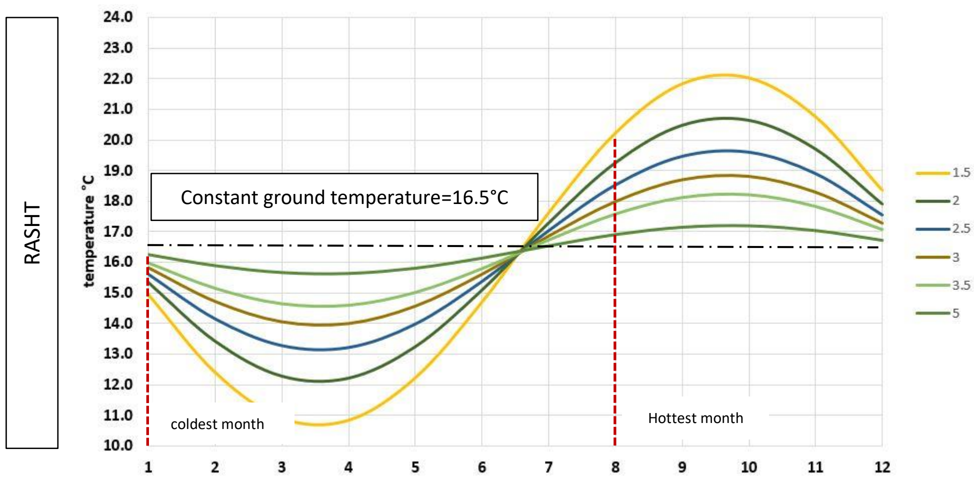


chart 2-9-a ground temperature for different depths and temperature in dashed lines

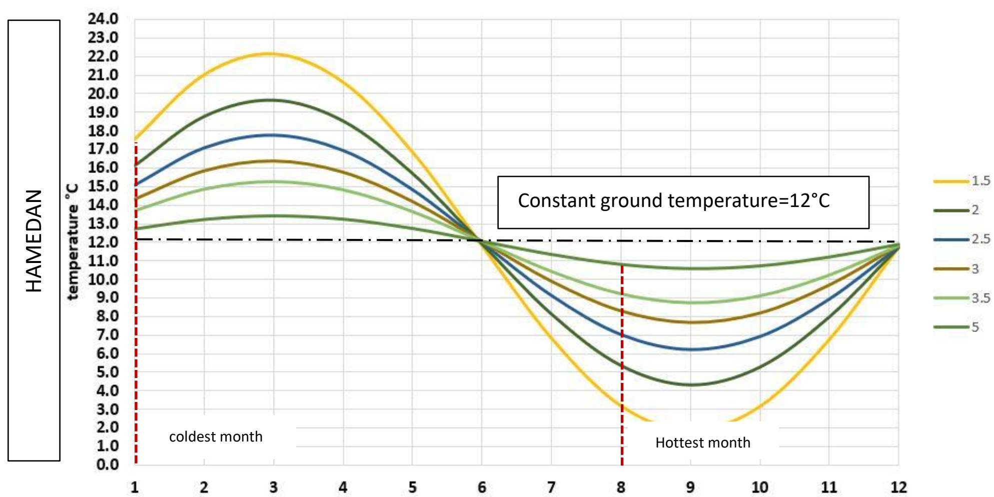


chart 2-9-b ground temperature for different depths and air temperature in dashed lines

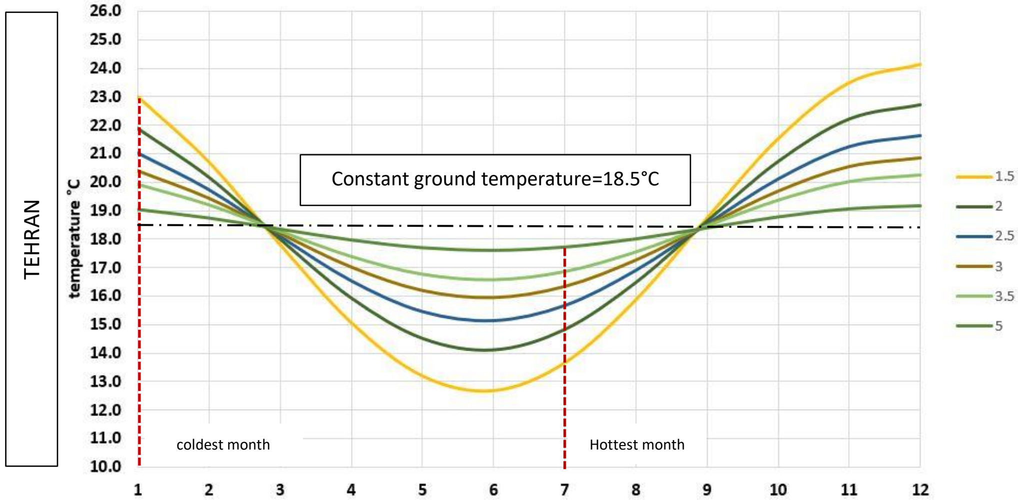


chart 2-9-c ground temperature for different depths and air temperature in dashed lines

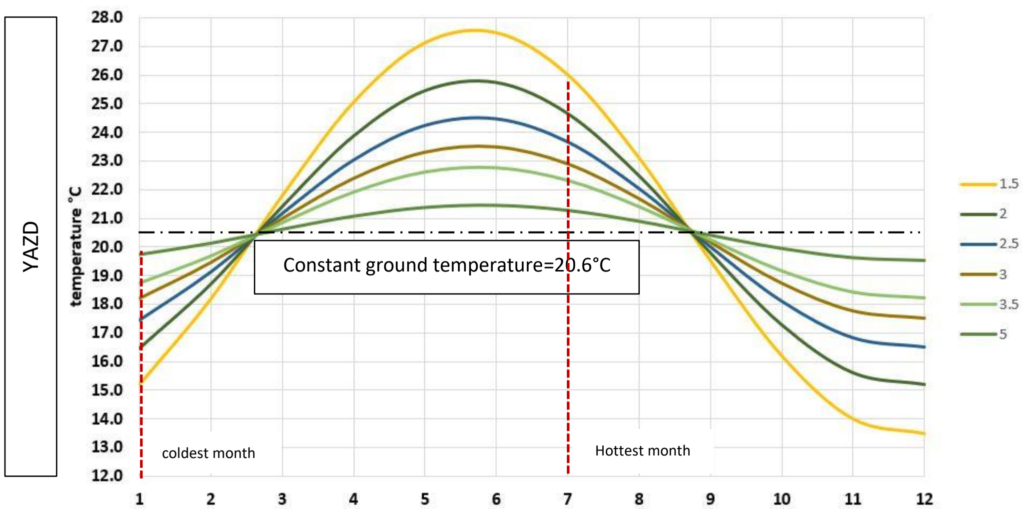


chart 2-9-d ground temperature for different depths and air temperature in dashed lines

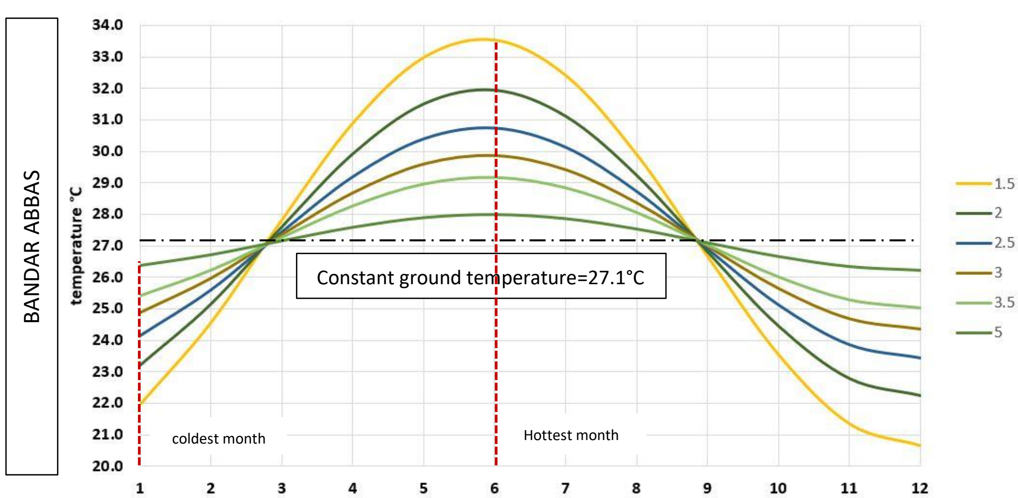


chart 2-9-e Abbas ground temperature for different depths and air temperature in dashed lines

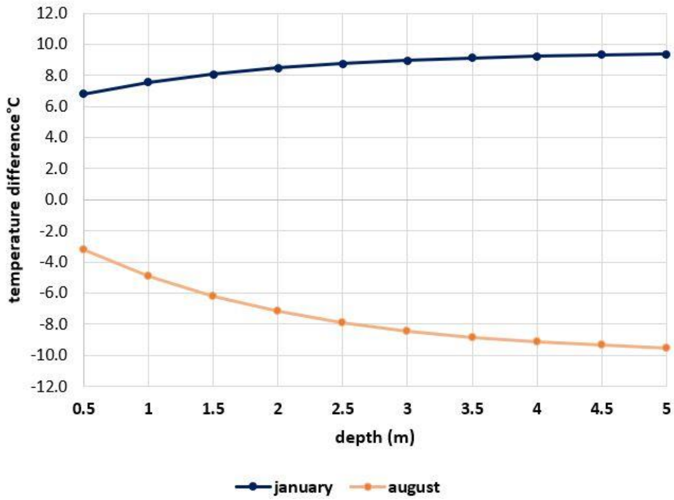


chart 2-10-a Rasht temperature difference between ground and air for coldest and hottest months

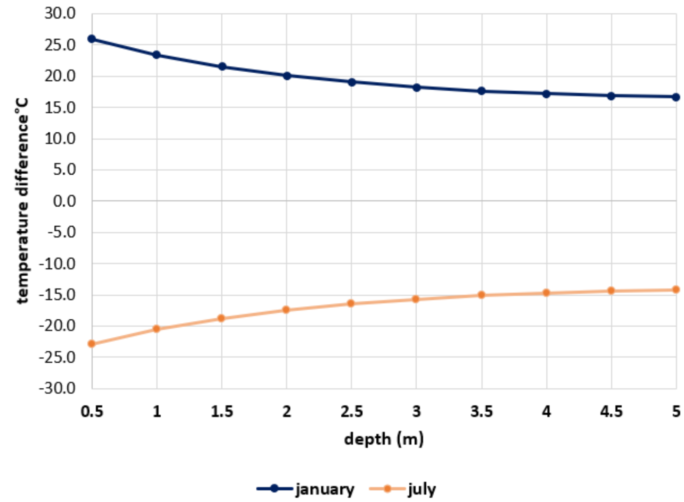


chart 2-10-b Hamedan temperature difference between ground and air for coldest and hottest months

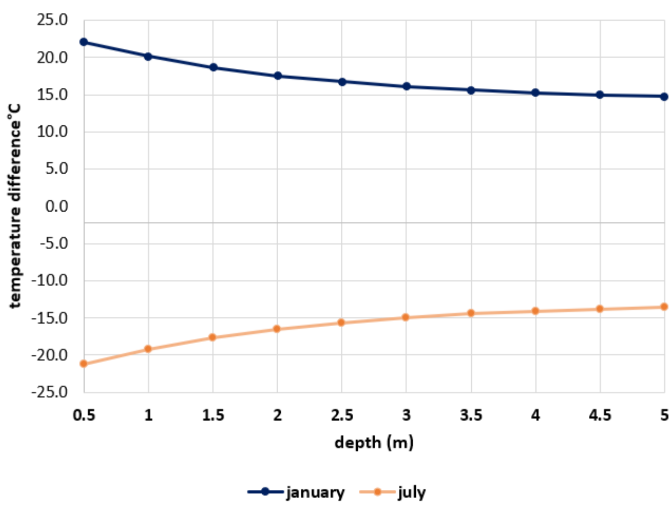


chart 2-10-c Tehran temperature difference between ground and air for coldest and hottest months

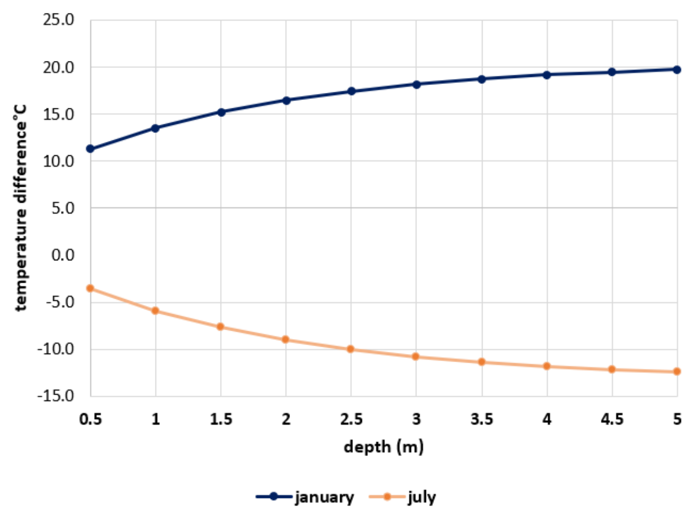


chart 2-10-d Yazd temperature difference between ground and air for coldest and hottest months

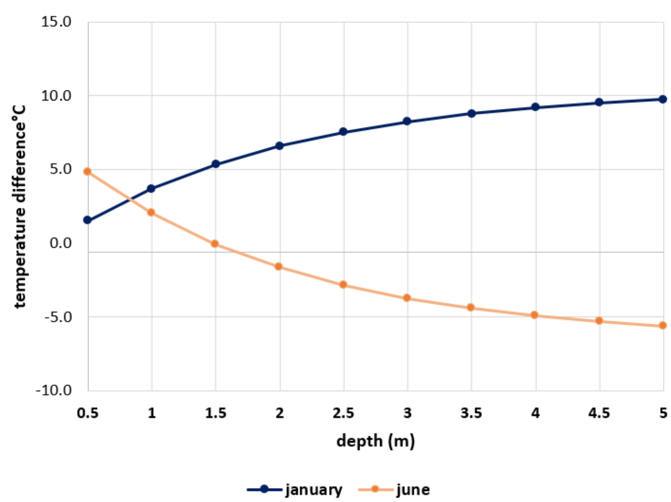


chart 2-10-e Bandar Abbas temperature difference between ground and air for coldest and hottest months

2.3.9. Final comparison

Table (2-8) is a summary of temperature condition for all cities together. As it can be seen, *Hamedan* has shortest summer period, while *Bandar Abbas* has the longest period. *Yazd* and *Bandar Abbas* have maximum dry bulb temperature of about 44.5°C as the hottest cities, on the other hand, *Hamedan* has the harshest condition in wintertime by reaching -20°C. The coldest month is January in all regions and the hottest month varies. Chart (2-11) graphically shows the minimum and maximum dry bulb temperature of all cities.

	summer period days	max dry bulb temperature	min dry bulb temperature	hottest month	clodest month
Rasht	50%	35.3	-3.6	August	January
Hamedan	42%	38.6	-20.2	August	January
Tehran	59%	41.6	-5.9	July	January
Yazd	63%	44.6	-6.5	July	January
Bandar Abbas	100%	44.5	6.2	June	January

Table 2-8- summery of temperature condition for all cities

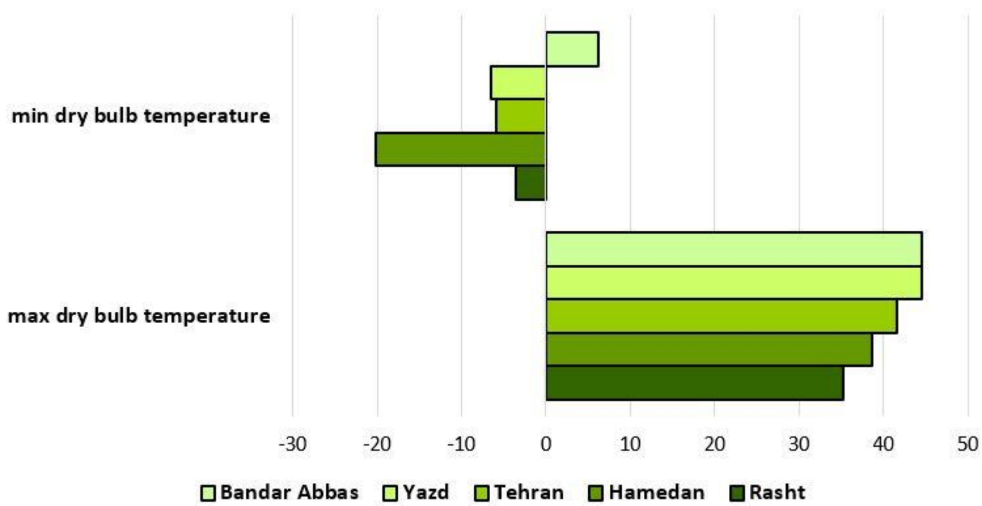


Chart 2-11- minimum and maximum dry bulb temperature

focusing on summertime, table (2-9) is summarizing frequency of temperature of each city by the range of between 20 and 26°C and warmer temperatures more than 26°C, for summer and the hottest month. Situation for *Rasht* is the best among other cities by having 44% of data in the comfort range and *Bandar Abbas* faces harshest condition.

Graphically shown in chart (2-12), we can see the highest frequency for Bandar Abbas, Yazd and Tehran respectively.

	T>26°C in hottest month	20°C<T<26°C in hottest month	T>26°C in summer	20°C<T<26°C in summer
Rasht	52%	44%	24%	44%
Hamedan	46%	26%	28%	0%
Tehran	85%	15%	48%	29%
Yazd	95%	5%	54%	25%
Bandar Abbas	100%	0%	59%	21%

Table 2-9- frequency of temperature in different ranges for summertime

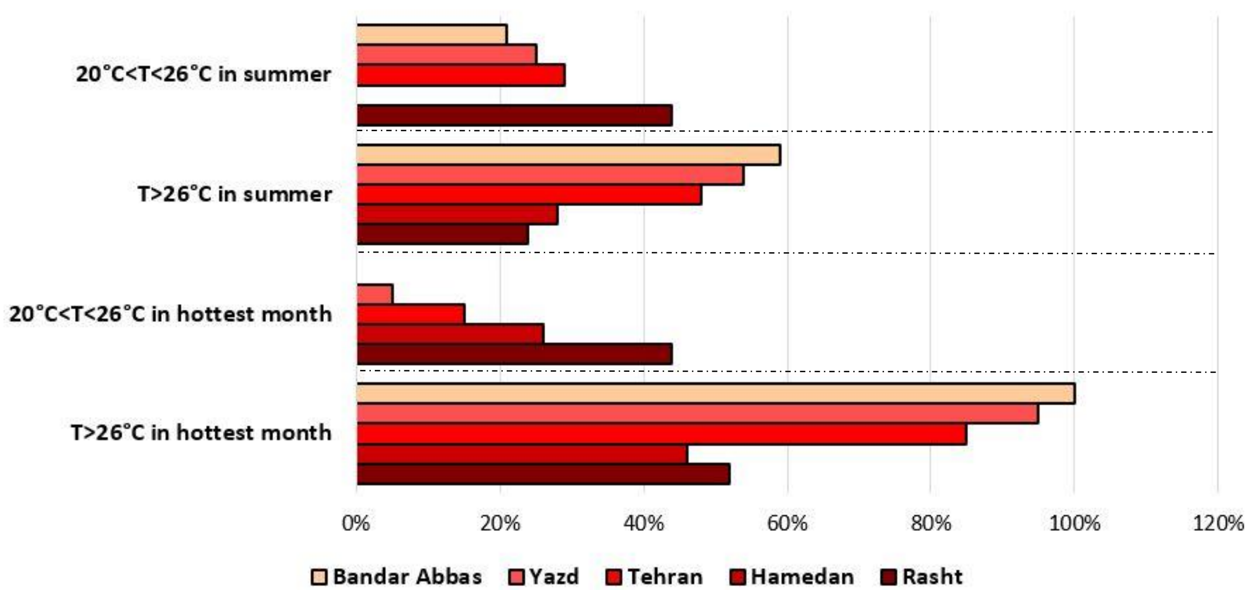


chart 2-12- frequency of temperature in different ranges for summertime looking at wintertime, table (2-10), *Bandar Abbas* has the best condition as being warm all the year. In the coldest month, we can say all the cities left face very harsh situation by having almost 100% of temperatures less than 15°C. looking at them throughout winter, *Tehran* has better situation.

Graphically seen in chart (2-13), situation of *Rasht*, *Hamedan* and *Yazd* to design in winter is the most difficult among others.

	T<15°C in coldest month	15°C<T<20°C in coldest month	20°C<T<26°C in coldest month	T<15°C in winter	15°C<T<20°C in winter	20°C<T<26°C in winter
Rasht	97%	3%	0%	80%	16%	4%
Hamedan	100%	0%	0%	85%	9%	5%
Tehran	100%	0%	0%	49%	13%	19%
Yazd	95%	5%	0%	76%	16%	7%
Bandar Abbas	40%	34%	25%	-	-	-

Table 2-10- frequency of temperature in different ranges for wintertime

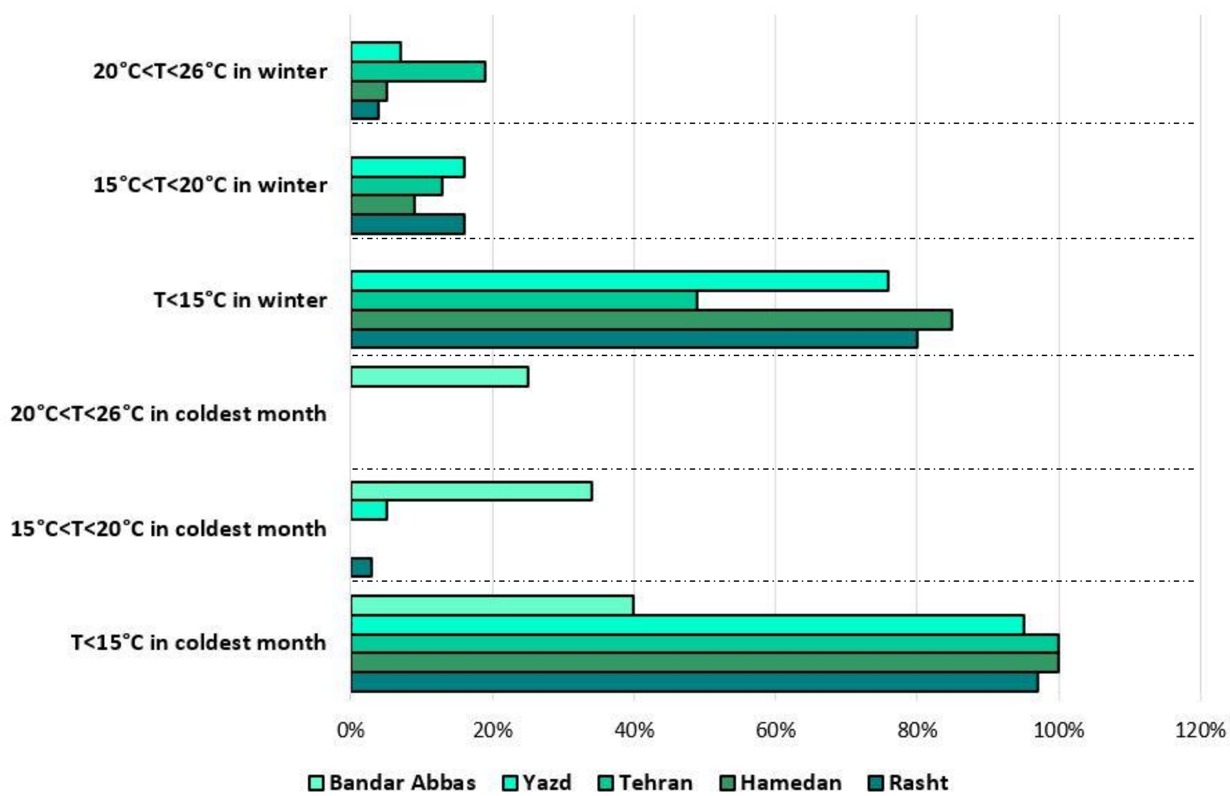


Chart 2-13- frequency of temperature in different ranges for wintertime situation of all cities according to the sun radiation gain is summarized in table (2-11). It is clear that for the month with the highest radiation, the average value of day-time radiation is highest for Yazd in September, while is the least for Rasht in June. In wintertime, the situation is the same. Graphically seen in chart (2-14), Bandar Abbas and Yazd have the highest potential for using sun as a source and Rasht has the lowest.

		month with highest radiation			month with least radiation	
	radiation in summer	total radiation	average day-time radiation	radiation in winter	total radiation	average day-time radiation
Rasht	509 (kWh/m^2)	100 (kWh/m^2) June	0.264 (kWh/m^2)	397.7 (kWh/m^2)	48.6 (kWh/m^2) October	0.094 (kWh/m^2)
Hamedan	1090.6(kWh/m^2)	239.4(kWh/m^2) July	0.567 (kWh/m^2)	1008.1(kWh/m^2)	130.4 (kWh/m^2) December	0.35 (kWh/m^2)
Tehran	1320.4(kWh/m^2)	212.9 (kWh/m^2) July	0.548 (kWh/m^2)	699.6(kWh/m^2)	124.9 (kWh/m^2) december	0.34 (kWh/m^2)
Yazd	1592.9(kWh/m^2)	243.4 (kWh/m^2) september	0.676 (kWh/m^2)	806.5 (kWh/m^2)	163.5 (kWh/m^2) february	0.487 (kWh/m^2)
Bandar Abbas	1773.3(kWh/m^2)	184.8(kWh/m^2) may	0.492 (kWh/m^2)	-	113.5(kWh/m^2) august	0.305 (kWh/m^2)

Table 2-11- sun radiation for the summer and winter for all cities

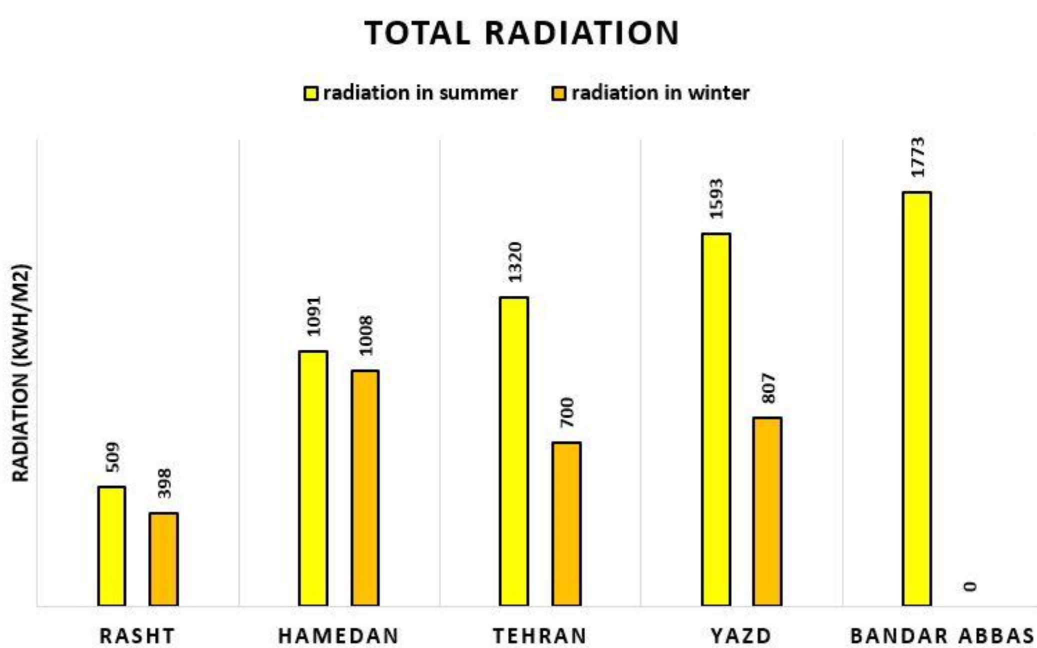


chart 2-14- cumulative sun radiation on horizontal surface for all cities

2.4. References

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[5] Zhang, X., Weerasuriya, A. U. and Tse, K. T. (2020) 'CFD simulation of natural ventilation of a generic building in various incident wind directions: Comparison of turbulence modelling, evaluation methods, and ventilation mechanisms', Energy and Buildings. Elsevier B.V., 229, p. 110516. doi: 10.1016/j.enbuild.2020.110516.

3. Passive Cooling Literature Review

3.1. Passive Strategies

Systematic research on systems of passive cooling is a relatively recent phenomenon. Individual studies on various elements of passive cooling have been carried out in various research institutions during the past 50 years.

When the energy crises of the 1970s aroused interest in the use of natural renewable energies as substitutes for conventional fuels in buildings, this interest was directed to the use of solar energy for heating. This led to the development of active solar heating systems. In time the focus in solar space heating shifted to passive systems, but still the emphasis was on heating. Only in about 1978 did more worldwide interest arise, and systematic research started in passive cooling systems. [1]

Between now and 2050 the global average cooling demand in commercial buildings is expected to increase by up to 275%. Increases in cooling demand are likely to lead to a tripling in the energy demand for air-conditioning by 2050. Cooling systems or techniques that avoid or reduce the need for air-conditioning are therefore important if energy efficiency targets for buildings are to be achieved. Controlled passive cooling systems could play a key role in removing the need for mechanical cooling systems.

A passive cooling system refers to a system that regulates the internal environmental conditions in a building without the need for energy consumption (excluding the energy for actuation or control). Passive cooling control strategies refer to the combination or application of one or more passive control systems to control the internal conditions in a building. Passively controlling internal conditions can involve heat prevention (e.g. solar heat control), dissipation (into sources like the air, ground or water), or can incorporate some storage or modulation of heat (e.g. thermal mass storage). Passive cooling strategies have been used in many buildings and their performance have been presented in many studies. [15]

There seem to be several reasons for the recent emerging interest in passive cooling techniques. The first is obviously the rising cost of electricity, especially during peak demand times. Peak demand is often caused by the increased use of air conditioning in hot summer days. In addition to consumer concern with the rising cost, there is an institutional interest in flattening the demand for energy by cutting down peak demand, which determines the need for generation capacity.

More recently there has been a global interest in reducing the emission of “greenhouse gases” suspected of causing global warming. Reducing power generation by lowering the demand for air conditioning can be helpful also in this respect.

Building can be cooled by passive systems through the utilization of several natural heat sinks such as the ambient air, the upper atmosphere, water and the undersurface soil. Each of these cooling sources can be utilized in various ways, resulting in different systems. The various passive cooling systems are thus classified according to the major, or obvious natural source from which the cooling energy is derived:

- **Building design:** architectural means for minimizing the heat gain of buildings, and consequently their cooling needs, generally would be less expensive than the application of cooling systems, even passive ones. therefore, there is no point in applying passive cooling systems in a hot climate to a building that does not have an appropriate design for that climate.
- **Natural ventilation:** providing direct human comfort, mainly during the daytime. In nocturnal ventilative cooling, the structural mass of the building by ventilation during the night and keeping closed during the daytime, lower the interior daytime temperature.
- **Evaporative cooling:** mechanical or nonmechanical evaporative cooling of air. The humidified and cooled air is then introduced into the building. By using indirect evaporative cooling, for example by roof ponds, the interior space is cooled without elevation of the humidity.
- **Ground cooling:** cooling soil below its natural temperature in each region and utilizing it as a cooling source for a building.[1]

3.2. Building Design

Minimizing the cooling needs of a building by appropriate architectural design mainly means minimizing the solar load and the conductive daytime heat gain through the envelope. In hot regions the summer is the most stressful season and dealing with summer performance issues may govern the climatic design of the building.

The following architectural design features affect the solar load on a building, that is shown in table (3-1) description of each feature on different climates:

- Building layout
- Orientation of main doors and windows
- Window size, location and details
- Shading devices for windows
- Color of the building's envelope
- Vegetation near the building

climate	architectural feature	what to do?
hot dry	building layout	compact building
		minimize external surface area
		deep narrow porches
	building orientation	north-south orientation
		shade southern windows in summer
		irradiation from southern wall in winter
	window	small windows
		large openable windows only with highly insulated shutters
hot humid	building layout	spread-out building
		cross-ventilation
	building orientation	consider wind direction to use it
		provide openings at windward and leeward walls
		as few obstacles as possible in wind's path
		western and eastern windows with operable shutters
	window	each room has at least 2 windows at different walls
		use wing wall where wind is parallel to the wall
	vegetation	provide shading for windows and walls with plants

Table 3-1- architectural features for hot-dry and hot-humid climates

3.3. Natural ventilation

The simplest strategy for improving comfort when the indoor temperature under still air conditions seems to be too warm is by daytime ventilation, providing comfort through higher indoor air speeds.[1]

An understanding of the nature of wind and the pressure that will exert on a building is crucial for architects or designers utilizing available wind energy. A building in the path of an air stream will produce a natural pressure difference. As air molecules are compressed, they increase pressure, and as they are dispersed, they decrease it. The pressure difference between the inlet and outlet locations provides the power to force the air through the building. A complex building in a complex environment will necessitate extreme care in choosing the size and location of the inlets and outlets.

Natural ventilation is achieved by making use of the natural pressure differences surrounding a building, caused by the wind and stack effect. As the temperature increases, the density of air decreases and the air consequently rises. Temperature differences between the inside and outside of the building, and between different areas of the building create pressure differences and subsequently air movement. This is known as “stack effect”. Air movement within the building may also depend on buoyancy, thermal forces. There will always be periods of calm when the wind speed is ineffectual, although these do not generally occur during hot weather. In these situations, buoyancy forces act alone. Natural ventilation is dependent on three climatic phenomena: wind velocity, wind direction and temperature difference.[2]

3.3.1. Daytime natural ventilation

Natural ventilation is particularly the case when the humidity is high and so the higher air speed increases the rate of sweat evaporation from the skin, thus minimizing the discomfort from the sensation of wet skin.

However, when a building is cross ventilated during the daytime the temperature of the indoor air and surfaces closely follow the ambient temperature. Therefore, there is a point in applying daytime ventilation only when indoor comfort can be experienced at the outdoor air temperature, with acceptable indoor air speed.

In buildings that are well protected from solar radiation and that have high insulation of the envelope and high thermal mass, the indoor daytime temperature, in the absence of ventilation, could be well below the outdoor level. In this case daytime ventilation would raise the indoor air and the radiant temperature of surfaces. This occurs most often in residential buildings with low internal heat generation.

When a building is naturally ventilated through open windows and the wind reaches even moderate speeds, the indoor air temperature tends to approach the outdoor temperature level. A high indoor air speed also increases the rate of heat exchange between the indoor air and the interior mass of the building. In most regions the wind speed during the daytime is much higher than at night, when it is almost imperceptible. In the absence of wind, a much greater difference may exist between indoor and outdoor temperatures. Consequently, the indoor air speed, even when the windows are open is significantly lower at night, and the indoor-outdoor temperature difference is greater than during the daytime.

Building materials absorb heat from warm ventilation air during the day. The rate of heat absorption is enhanced by the higher convective heat transfer coefficient, resulting from the high daytime indoor air speed in a cross-ventilated building. Because of the thermal time lag of the building materials, the indoor surfaces are cooler than the indoor air in the morning hours and warmer in the afternoon and evening, when heat flows from the interior mass to the indoor air. Thus, the indoor air temperature in a high mass building reaches its maximum in the evening. Therefore, even if a building is ventilated continuously day and night, for comfort ventilation the indoor temperature is closer to the outdoor level during the daytime but is higher than the outdoor during the night hours. As a result of the combination of low air speed and warm temperature the indoor environment is often most uncomfortable during the evening hours. [1]

Natural ventilation has great effect on human sensation and microclimate of space. [3] Kindah Mousli and Giovanni Semprini in studying the effect of natural ventilation on thermal comfort in Damascus, show that in summer period natural ventilation gives at least 2°C lower temperature respect to the closed window, depending on the kind of ventilation, orientation, structure, height and size of the opening area. And increases 5% to acceptability of comfort period.

In a study by Katarina Kosutova, Twan van Hooff, Christina Vanderwel, Bert Blocken and Jan Hensen[4], on a cross ventilated building with openings equipped with louvers, to reduce solar heat gains while allowing natural ventilation, with wind tunnel experiments and computational fluid dynamics (CFD) simulation, presents the relation between openings and the volume flow rate and air exchange efficiency inside the building.

Four opening positions are studied: (a) openings in the center, (b) lower part of the windward and leeward facades, (c)upper part, (d) one opening in the upper part of the windward facade and one opening in the lower part of the leeward façade, as shown in figure (3-1).

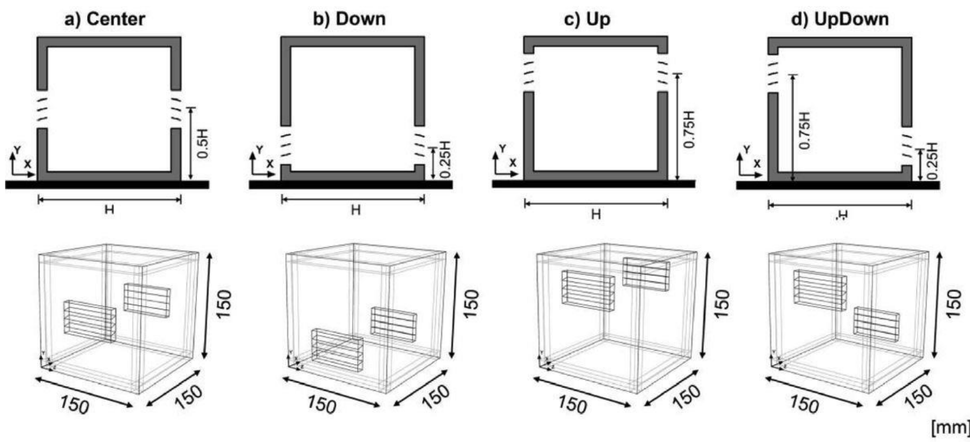

Figure 3-1- geometry of the reduced-scale building models used for the experiments

By experimental tests and simulations with software, the mean velocity vector field for four different opening configurations are studied and showed in figure (3-2)

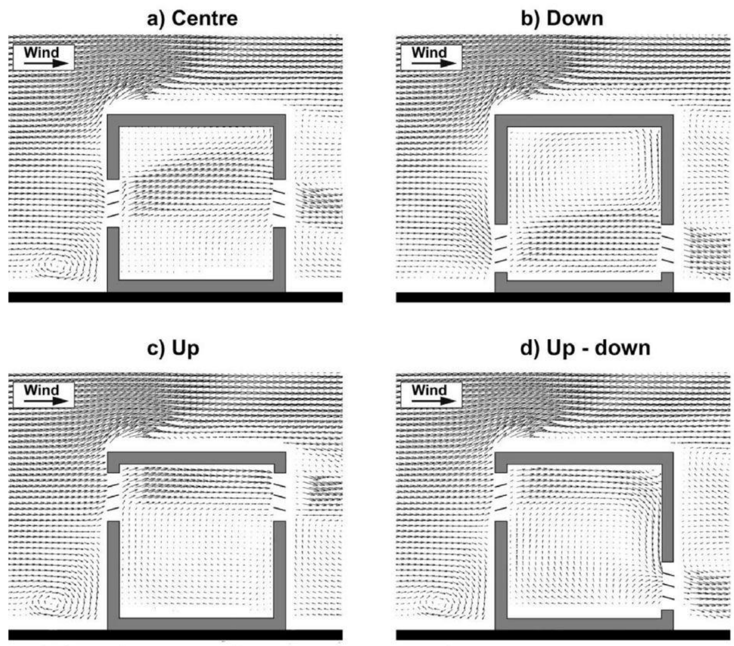

Figure 3-2- mean velocity vector field in the vertical center plane

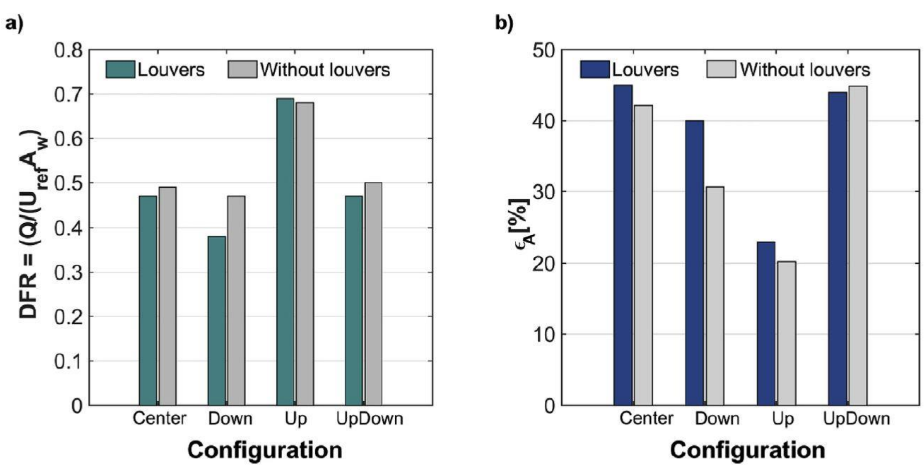

Figure 3-3- (a) Dimensionless volume rate (DFR) and (b) air exchange efficiency for all four configurations. Results for the case with louvers and the case without louvers are included

In the figure (3-3) results of the study for comparing the dimensionless velocity and air exchange efficiency are shown. Based on this table, the building with windows on upper part, has the highest velocity inside the building, while having the least air exchange efficiency according to the unmixed air stream from outside and inside air. The building with up-down window configuration has the second highest air velocity while the highest air exchange efficiency without louvers.

3.3.2. Applicability of daytime natural ventilation

Based on what Givoni presents in his book [1], to clarify climatic applicability, Chart (3-1) shows a suggested boundary on psychrometric chart within which indoor comfort can be provided by natural ventilation during daytime from 7a.m. to 6p.m. in summer for 5 different cities.

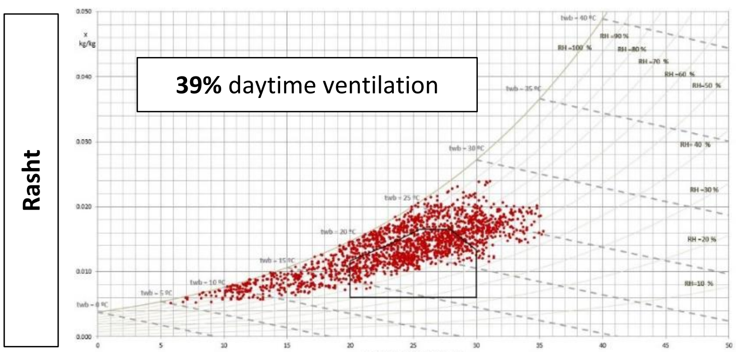

Chart 3-1-a- applicability of daytime ventilation

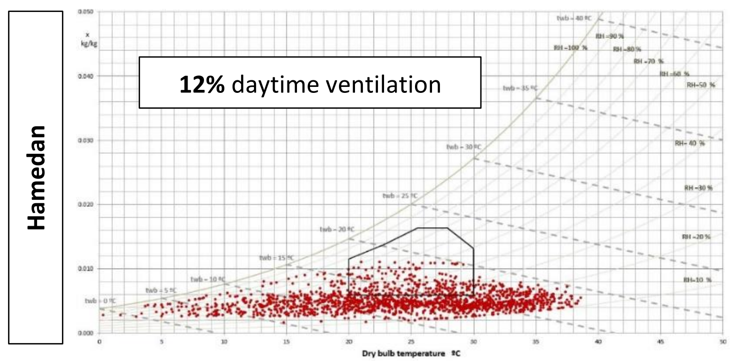

Chart 3-1-b- applicability of daytime ventilation

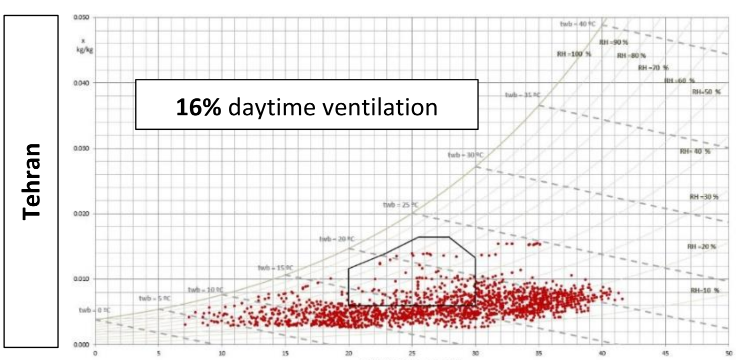

Chart 3-1-c- applicability of daytime ventilation

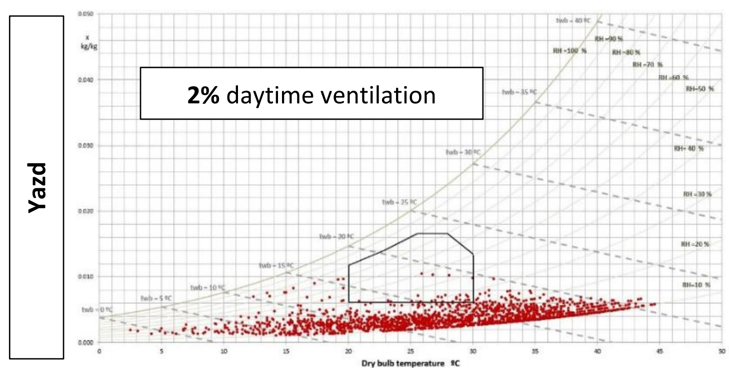

Chart 3-1-d- applicability of daytime ventilation

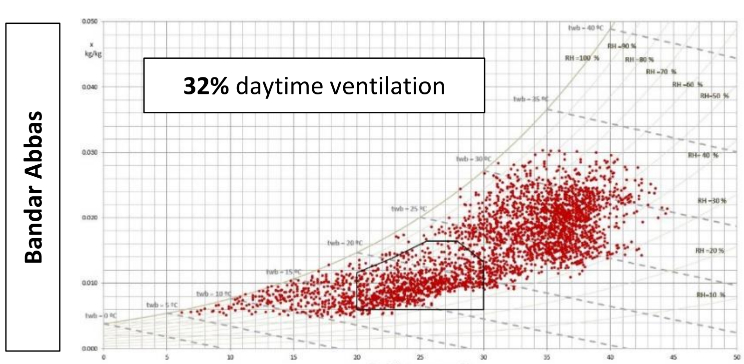

Chart 3-1-e- applicability of daytime ventilation

To have better understanding about impact of natural ventilation, further analysis is done using software of Rhino with plugin of Grasshopper. The results can be seen from table (3-2). Analysis is done on a 10mx10mx4m building with two windows on north and south sides with total dimension of $8m^2$ on each side. For each city, the studies are done during summer. Based on the results, natural ventilation is the most effective way in Rasht with around 80% comfort during summer-time which supports the result of the Givoni chart. Considering cooling demand, for all cities, as the fraction of operable window increases, there is more need of energy to cool down the building.

fraction of operable area of windows	0.5		1	
city	comfort percentage	cooling demand	comfort percentage	cooling demand
	(-)	(kWh/m2)	(%)	(kWh/m2)
Rasht	86%	508.12	81%	837.22
Hamedan	67%	266.93	65%	428.44
Tehran	49%	657.99	53%	1103.95
Yazd	63%	908.88	61%	1572.19
Bandar Abbas	51%	3332.23	49%	6017.09

table 3-2- simulation result of daytime ventilation

3.3.3. Nighttime natural ventilation

When a building is ventilated during the night its structural mass is cooled by convection from the inside, bypassing the thermal resistance of the envelope. During the daytime the cooled mass, when it has sufficient amount and surface area and if it is adequately insulated from the outdoors, can serve as heat sink. By radiation and natural convection, it can absorb the heat penetrating into it, mainly through the windows, along with the heat generated inside. To

This effect, the building should be closed (unventilated) during the daytime to prevent the interior being heated by the hotter outside air.

There is a point in designing a building for ventilative cooling only if comfort conditions can be maintained during the daytime hours in an unventilated building. Attainment of such performance depends both on the climatic conditions and on the design details of the building. From the climatic aspect the main relevant factors affecting the performance of convective cooling are the diurnal temperature range and the typical maximum temperature during the hottest months. A large diurnal range is needed because the achievable drop of the indoor maximum below the outdoor maximum is for a building designed for this purpose, roughly proportional to the outdoor temperature range.

Ventilating the indoor space during the night lowers the indoor temperatures. It is possible to lower the indoor minimum more than the maximum. With nocturnal ventilation rates practical at night in residential buildings, the indoor minimum in a building ventilated at night could be lowered below the level of an unventilated building by about half of the difference between the minimum of a closed building and the outdoor minimum. The drop of the indoor maximum by the nocturnal ventilation is smaller, about one half of the minimum drop.

Ventilative cooling is applicable mainly in arid and desert regions, which have a large diurnal temperature range, about 12 to 15°k or more, and when the night minimum temperature in summer is below about 20°C. In such regions it is possible to store the coolness of the night air in the structural mass of the building. The flow of outdoor air at night through the building can be induced naturally by the wind, where wind speed at night at the building site is sufficient, above 2-3 m/s or mechanically by an exhaust fan. During the following day the cooled mass serves as a heat sink maintaining the indoor temperature well below the outdoor level, if possible, within the comfort range. This temperature reduction can be achieved only if the building is well insulated, with insulation external to the structural mass, and if the building is not ventilated by the hot outdoor air during the daytime hours.[1]

Jared Landsman, Gail Brager and Mona Pingel [5] in a study categorized climatic conditions in which night ventilation can be more successful.

- The buildings in the mild climate are successfully keeping the indoor temperature low, but also tend to be overcooled;
- The night ventilation strategy has very little impact on indoor conditions of the buildings in the mild climate;
- The impact of night ventilation is less significant when there is low internal loads and heavy mass;
- The building in the hot and humid climate is keeping the indoor temperature within the comfort bounds for 88% of the year;
- The night ventilation strategy has advantageous impact on indoor conditions of the building in the hot and humid climate, but not enough to cool the space on its own

Lin Jiang and Mingfang Tang [6] show that combining green roofs and night ventilation can significantly reduce the indoor air temperature and heat gains on sunny day but have no appreciable effect on rainy day.

3.3.4. Applicability of nighttime natural ventilation

Based on limitations stated by Givoni [1], in chart (3-2) it is studied the applicability of night ventilation in summer period for each city. The limitations are:

- diurnal temperature=12~15k
- minimum night temperature<20°C
- wind speed at night=1.5~2 m/s

Rasht

criteria	apr	may	jun	jul	aug	sep	oct
diurnal temperature	6.6	7.1	7.0	7.6	7.7	7.3	6.9
minimum night temperature	5.0	9.5	16.2	17.2	18.2	15.6	10.5
wind speed at night	1.28	2.00	2.20	1.92	2.10	2.32	1.76
night ventilation applicability	×	×	×	×	×	×	×

chart 3-2-a applicability of night ventilation

Hamedan

criteria	apr	may	jun	jul	aug	sep
diurnal temperature	11.8	13.7	16.2	16.6	17.7	18.4
minimum night temperature	-0.5	3.7	7.1	12.2	11.8	5.9
wind speed at night	2.89	2.00	1.55	1.53	1.50	1.42
night ventilation applicability	✓	✓	✓	✓	✓	✓

chart 3-2-b applicability of night ventilation

Tehran

criteria	mar	apr	may	jun	jul	aug	sep	oct
diurnal temperature	8.5	9.0	10.0	11.0	10.7	10.1	10.0	9.3
minimum night temperature	0.5	6.0	12.3	16.7	20.6	22.0	16.3	9.4
wind speed at night	3.22	2.95	3.16	2.93	2.63	2.30	2.31	1.74
night ventilation applicability	×	×	✓	✓	✓	✓	✓	×

chart 3-2-c applicability of night ventilation

Yazd

criteria	mar	apr	may	jun	jul	aug	sep	oct
diurnal temperature	11.7	11.7	12.0	12.3	12.0	12.5	13.3	13.1
minimum night temperature	2.3	8.4	14.8	20.7	22.1	21.0	16.6	10.6
wind speed at night	2.51	2.57	2.64	2.73	2.74	2.69	2.19	2.36
night ventilation applicability	✓	✓	✓	✓	✓	✓	✓	✓

chart 3-2-d applicability of night ventilation

Bandar Abbas

criteria	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
diurnal temperature	11.5	10.4	10.0	10.1	11.2	10.0	7.7	7.2	8.3	10.1	11.1	12.7
minimum night temperature	6.2	9.3	13.2	18.0	23.4	26.3	29.0	28.3	25.6	21.6	13.2	7.5
wind speed at night	2.30	2.29	2.97	2.89	2.94	3.21	3.37	3.49	3.24	2.45	2.61	2.50
night ventilation applicability	✓	✓	✓	✓	×	×	×	×	×	×	✓	✓

chart 3-2-e applicability of night ventilation

Simulation result for the mentioned building with the same windows condition for understanding the effect of night ventilation is seen in table (3-3). Considering comfort percentage results, Rasht has a good condition in case of night natural ventilation which is in contrast with the result from Givoni limitations, as Rasht has diurnal temperature difference around 7 which is lower than 12 to 15K mentioned. We can say that for all cities, day and night natural ventilation are both working to make the inner zones inside the comfort range. And for all cities, increasing the size of operable window, increases the energy for cooling down the building.

fraction of operable area of windows	0.5		1	
city	comfort percentage	cooling demand	comfort percentage	cooling demand
	(-)	(kWh/m2)	(%)	(kWh/m2)
Rasht	80%	274.91	75%	390.00
Hamedan	63%	135.59	61%	164.08
Tehran	47%	388.00	52%	563.81
Yazd	61%	490.24	60%	735.36
Bandar Abbas	49%	2163.50	47%	3699.54

table 3-3- simulation result of nighttime ventilation

3.3.5. Wind driven ventilation

Wind towers or wind catchers have been used in traditional architecture throughout the Middle East and Central Asia for centuries to promote natural ventilation, sometimes incorporating evaporative cooling. They are known as Baadgir in Iran and Malqaf in Egypt. In a traditional wind tower, air entering through the windward opening at the top with positive wind pressure leaves the tower through any of the openings that have a pressure coefficient that is lower. In traditional Baadgirs, the air may be cooled if it flows over moist surfaces or a shallow pond of water at the base of the tower.[13]

Buildings need to be ventilated throughout the year in order to maintain a level of fresh air. In the winter, ventilation should be minimized to reduce heat loss, but it should be maximized in the summer to optimize the human evaporative cooling process. There is often confusion between wind towers and solar chimneys. Wind towers rely on the pressure difference over the building and across the device to drive air through the structure. Solar chimney depends on stack effect for this, but it is a very weak force and cannot move air quickly. The stack effect will only exhaust air if the indoor temperature difference is greater than the outdoor one between the vertical openings, so solar chimneys are often glazed to increase solar gain and air movement. As air is moved from areas of high pressure to areas of low pressure, the air close to the surface is heated and rises, creating low pressure.

Natural ventilation is achieved by making use of the natural pressure difference surrounding a building, caused by the wind and stack effect. Air movement within the building may also depend on buoyancy, thermal forces.

Wind catchers can collect and deliver external air to the building. Chimneys can be used to draw air out of the building, subsequently encouraging a natural air flow, and a combination of wind towers and chimneys can provide a natural form of air delivery and extraction.[2]

Wind catchers and chimneys can have different configurations inside the building. In figure (3-3) different combinations of these elements as inlet and outlet of air can be seen.

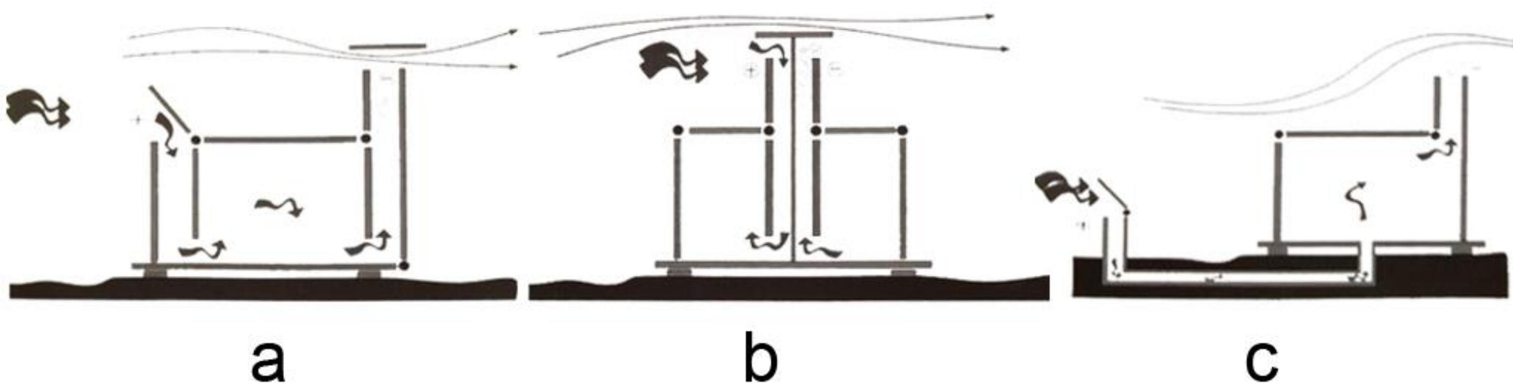

Figure 3-3-a-inlet and outlet of air at different sides of building , b-Badgir combines both inlet and outlet in one device c-wind catcher supplying air through earth-tubes and air is extracted via a chimney

3.3.6. Applicability of wind catchers

Natural ventilation depends on three climatic phenomena: wind velocity, wind direction and temperature difference. Wind ventilation is not effective unless wind speed is in excess of 2.5m/s. Table (3-4) shows potential of each city monthly based on only wind speed.

criteria	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Rasht	-	-	-	1.6	2.5	2.5	2.4	2.3	2.4	2.2	-	-
wind catcher functionality				×	✓	✓	✓	✓	✓	×		
Hamedan	-	-	-	3.3	2.5	1.9	2.0	1.8	1.7	-	-	-
wind catcher functionality					✓	×	×	×	×			
Tehran	-	-	3.3	3.4	3.7	3.3	3.1	2.6	2.5	2.3	-	-
wind catcher functionality			✓	✓	✓	✓	✓	✓	✓	×		
Yazd			3.0	2.9	3.2	3.2	3.2	3.0	2.6	2.3		
wind catcher functionality			✓	✓	✓	✓	✓	✓	✓	✓		
Bandar Abbas	2.60	2.80	3.20	3.40	3.49	3.59	3.90	3.90	3.50	3.00	3.10	2.79
wind catcher functionality	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 3-4- Functionality of wind catcher in different cities based on average wind speed in m/s

Wind catcher applicability needs deeper analysis with CFD software that will be discussed in chapter 4.

3.4. Evaporative cooling

The amount of heat absorbed in the process of water evaporation, it's latent heat, is very high in comparison with the other modes of heat transfer common in buildings. Every gram of water that is evaporated without external heat input extracts from the ambient air, or from a material over which the evaporation takes place, nearly 0.6 Calories. Throughout the ages, this mode of cooling has been used to cool buildings in hot arid regions. Various simple techniques have been used to realize this cooling effect. People have tried such methods as watering the floors or putting wetted matrices made of twigs in windows facing the wind.[1]

One of the main features of the tropical desert climate and temperate continental climate is that sandstorm often appears. At the same time, evaporative cooling can be used as wet filters to filter out the outdoor air, improving indoor air quality. [14]

There are two basically different approaches for cooling down buildings by water evaporation. The first is to cool outdoor air directly through evaporation, and then introduce that air into the building. The air is humidified while its temperature is lowered, and the indoor moisture content is elevated above the outdoor level. This is direct evaporative cooling of the residents and the interior materials in the cooled space. The air flow for direct evaporative cooling can be induced either by mechanical devices, fans, or passively by natural processes, utilizing the wind, temperature difference, or water spray in passive evaporative cooling towers.

The second approach is to cool a given element of the building, such as the roof or a wall, by evaporation. The cooled element in turn, serves as a heat sink and absorbs, through its interior surface, the heat penetrates into the building through its envelope or is generated indoors. This is indirect evaporative cooling. With such systems the indoor radiant and air temperature are lowered without elevating the indoor moisture content of the air.[1]

3.4.1. direct evaporative cooling

Direct evaporative cooling is applicable only in arid regions, and where high-quality water is available in abundance. The maximum WBT is the main climatic criterion for the applicability of this system. The indoor maximum air temperature in reasonably insulated residential buildings, cooled by a direct evaporative cooling system, would be about 3 to 4°k above the maximum ambient WBT.

3.4.1.1. Use of porches for direct passive evaporative cooling

Any system of passive direct evaporative cooling provides significant resistance to air flow and can reduce the wind speed through the opening down to about 10 to 20% of the speed through an unobstructed opening. One way to increase the air flow is to have evaporating pads with an area much greater than the area of the openings through which the air enters the building.

When a porch is available on the windward side of the building like shown in figure (3-7), it is possible to put the evaporative pads in front of it. Windows can be integrated within the pads to allow a view from the porch.

It is important to force the air passing through the wet pads to enter the building through the openings, doors and windows, connecting the porch to the interior, and not to be discharged outward. The cooled air should not be diverted to the sides of the porch and/or above the roof of the building. Therefore, the sides and roof of the porch should be closed, so that after passing the pads the air has no other way but to flow into the building openings. As is the case with window pads, the water wetting the pads can be collected at the bottom and recirculated.[1]

3.4.1.2. Direct evaporative cooling towers with water spraying system

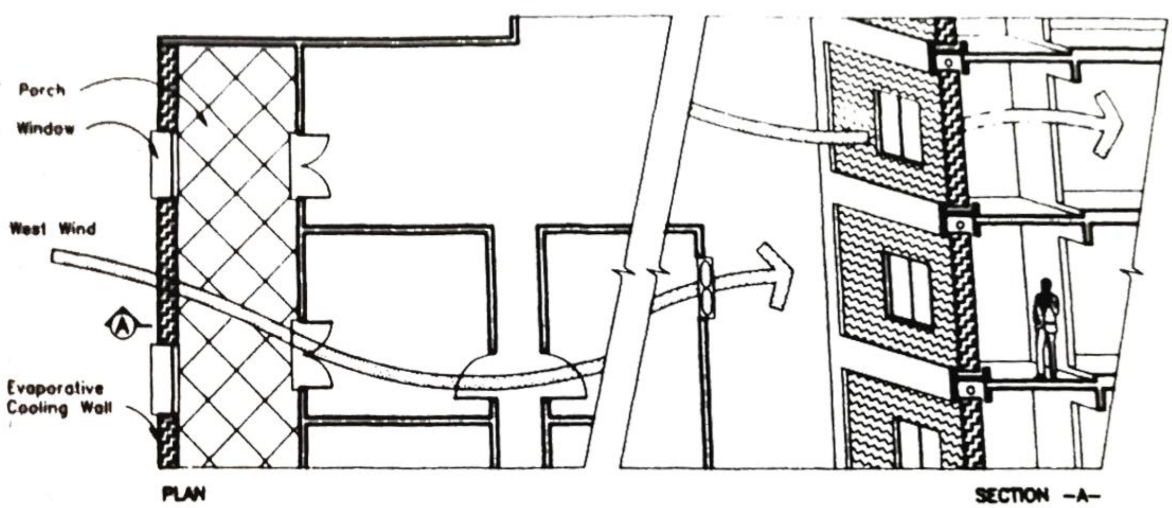

Figure 3-7-Use of porches for direct passive evaporative cooling

Vernacular wind towers that were used for natural ventilation, if combined with a water spraying system, will have function of evaporative cooling. Khani, Bahadori and Dehghani-Sanij[15] developed a wind tower system suitable for hot and dry regions. In order to test and analyze the performance of the proposed wind tower, an actual sized modular wind tower was installed on top of a building in the city of Kerman, Iran. Kerman is located in a hot and dry region, and the temperature variations between day and night are adequate for utilizing a wind tower.

As it can be seen in figure (3-8), this modern wind tower can reduce dry bulb temperature by an average of 10°C and increase relative humidity on average by 37%.

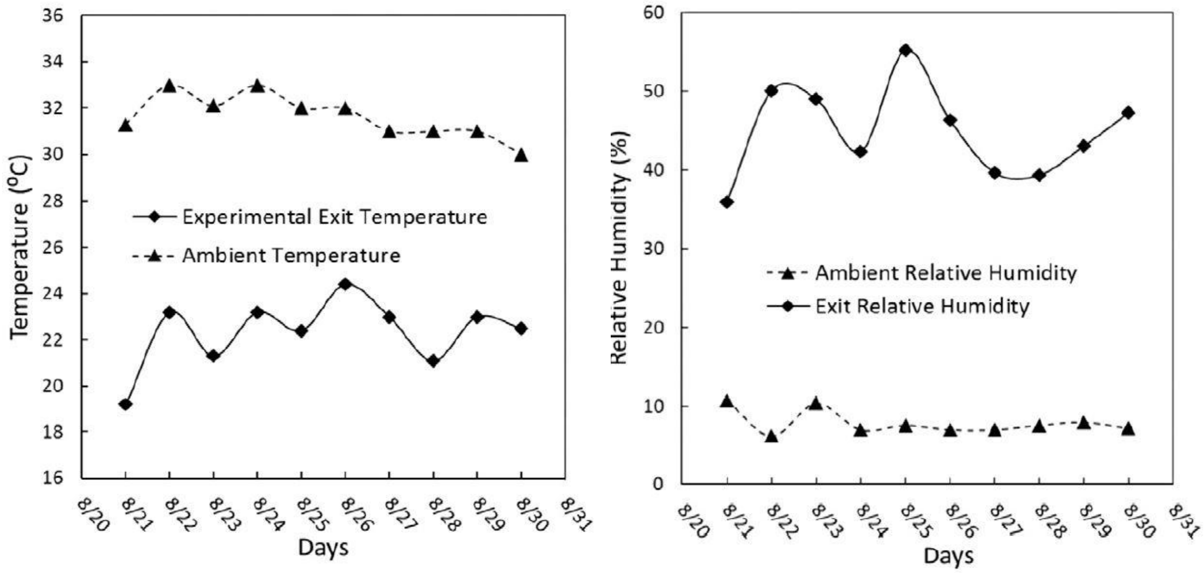

Figure -3-8- Dry bulb temperature and relative humidity of ambient air versus ventilated air

3.4.2. Indirect evaporative cooling

Indirect evaporative cooling reduces the dry bulb temperature of the air without increasing its moisture content. The air supplied to the conditioned space is fed through a heat exchanger that contains air or water that has been cooled separately by a direct evaporative cooler.[14]

3.4.3. Applicability of evaporative cooling

Due to the theory that dry air can hold more water and evaporation needs to absorb heat, the two important indexes to evaluate the applicability of evaporative cooling are the wet bulb temperature and the dry and wet bulb temperature difference. Evaporative cooling is very sensitive to the change of outdoor air condition, so it is necessary to analysis the local climate condition when the applicability of evaporative cooling is studied. [14]

Taking into account the effect on comfort of the higher indoor air speed and the higher humidity associated with direct evaporative cooling, it can be suggested that direct evaporative cooling is advisable only where and when the WBT maximum in summer is not higher than about 22°C and the DBT is not higher than 42°C. [1] The benefits of evaporative cooling are very limited in warm humid conditions, where the potential for evaporation is low.[13]

On the other hand, the main advantage of the indirect evaporative cooling is that air is cooled without modifying its moisture content. As a result, it can be used in humid regions with dry bulb temperature less than 46°C and wet bulb temperature less than 25°C. Using the limitations mentioned, applicability of evaporative cooling for different cities are studied shown in table (3-5). As it can be seen Rasht and Bandar Abbas due to their high relative humidity and max wet bulb temperature are not applicable for evaporative cooling method.

criteria	Rasht	Hamedan	Tehran	Yazd	Bandar Abbas
max Dry Bulb Temperature	35.3	38.6	41.6	44.6	44.5
max Wet Bulb Temperature	27.8	15.7	21	15.5	31.7
applicability of direct evaporative cooling (DBT<42 , WBT<22)		✓	✓		
applicability of indirect evaporative cooling (DBT<46 , WBT<25)		✓	✓	✓	

Table 3-5- Applicability of evaporative cooling in different cities based on max dry bulb and wet bulb

3.5. Ground cooling

Due to the high thermal inertia of the soil, temperature fluctuations at the ground surface are attenuated in the ground and the time lag between the surface and the ground temperature increases with depth. Therefore, at a sufficient depth, ground temperature is lower than the outside temperature in summer and is higher in winter.[13]

In regions with temperate climate the natural temperature of the soil in summer at a depth of two to three meters, may be low enough to serve as a cooling source. In hot regions, on the other hand, the natural temperature of the soil in summer is usually too high to serve as a cooling source. However, it is possible by very simple means to lower the earth temperature well below the natural temperature characteristics of a given location.

When the soil temperature is cool enough, it is possible to use it to cool buildings by several methods. In the case of earth-covered buildings the cool earth mass provides direct conductive passing cooling. This approach would be most suitable in hot, dry regions with mild winters. In regions with hot summers but cold winters the direct-conductive coupling of the indoor space with the surrounding soil may cause a high rate of heat loss in winter. In these regions, indirect active coupling of the building to the cool soil, by circulating air through imbedded in the soil, can provide the required cooling. The air-flow rate appeared to have the highest impact on the performance, with the length of the pipe being the second factor of importance.[1]

3.5.1. Direct coupling of the building with the soil

Direct coupling between a building and the cooled soil can be achievable only when the structural walls and/or the roof of the building are in direct contact with the soil, without any insulation installed in between them. In this situation the cooled soil forms the environment to which the walls and/or the roof are exposed. Direct coupling can be provided with any one of the three first design options outlined above, because the walls and/or the roof are in direct conductive contact with the cooled soil. With such conductive coupling, the indoor surface temperature of the external envelope in contact with the soil will be close to the surrounding earth temperature. figure (3-9) shows a building partially embedded in the soil.

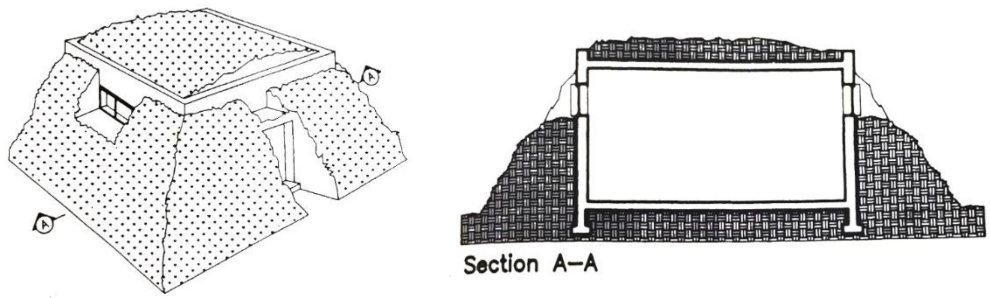

Figure 3-9- a scheme of a building with partially embeded walls

3.5.2. Indirect coupling between the building and the cooled soil

In regions with cold winters a building must be insulated. Direct conductive coupling of the indoor space with the surrounding soil through highly conductive walls, floors, and roof may be undesirable because it would cause a high rate of the heat loss in winter. A system of controlled coupling, which can be activated in summer and stopped in winter, would be the appropriate solution. When the heat transfer between the building and the cooled soil has to be by active means it can be provided either by forced air or by water flow. There are several technical options that can provide this coupling.[1]

A. Air as a circulating medium

Heat exchange with the soil can be done through an array of pipes. These pipes are usually made of plastic such as PVC. The air circulation may be indoor moving through a closed circuit, or it may be outdoor used for ventilation. In arid regions it may be advantageous to locate the intake within the crawl space in order to take advantage of the lower air temperature there. The air will then be supplied at a lower initial temperature, and naturally humidified. [1]

The temperature of earth at a depth of 1.5 to 2 m remains fairly constant throughout the year. This constant temperature is called earth's undisturbed temperature (EUT). The EUT remains higher than ambient air temperature in winter and lower than ambient air temperature in summer. The concept of earth–air heat exchanger (EAHE) is very simple as shown in Figure (3-10). The ambient air is drawn through the pipes of the EAHE buried at a particular depth, moderated to EUT, and gets heated in winter and vice versa in summer. In this way, the heating and cooling load of building can be reduced passively.

The design of earth–air heat exchanger mainly depends on the heating/cooling load requirement of a building to be conditioned. After calculation of heating/cooling load, the design of the earth–air heat exchanger only depends on the geometrical constraints and cost analysis.

The diameter of pipe, pipe length, and number of pipes are the main parameters to be determined. With an increase in length of pipe, both pressure drop and thermal performance increase. A longer pipe of smaller diameter buried at a greater depth and having lower air flow velocity results in an increase in performance of the EAHE system.[11]

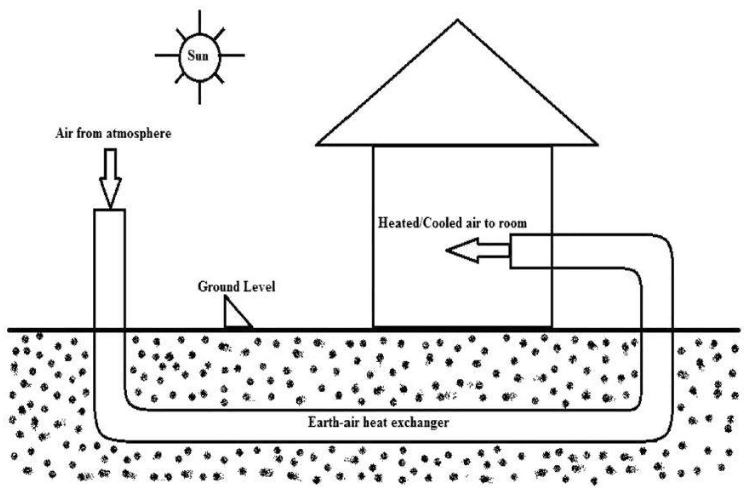

Figure 3-10- one dimensional model of earth-air heat exchanger

In humid regions it would be preferable to take in ambient air from a shaded area away from the crawl space because the air within the crawl usually would be too humid. It is necessary to remove water that may condense in subsoil pipes in humid climates.

This air-cooling system is advantageous for buildings in which higher-than-normal daytime ventilation rates are required-for instance in schools. It is particularly applicable to buildings of lightweight construction because the thermal storage mass of the system is in the soil itself. Also, as the heat sink is separate from, but close to, the served building spaces, almost any low-rise building form maybe considered, especially where the floor would be raised off the ground for any reasons.

In buildings where high ventilation rates are not required a closed circulation system would be more efficient.[1]

B. Water as a circulating fluid

The heat transfer from the building to the cooled soil can be affected by the flow of water rather than air. The water pipes serve as heat exchanger within the building to cool the indoor air. This heat exchanger can either be a conventional fan-coil or a radiant panel. [1] As it can be seen in figure (3-11), building can be attached to the ground by means of pipes filled with water, in summer cooled water and in winter heated water is absorbed from the ground.

C. Heat pump

A heat pump is a machine that transfers heat both to and from a source by employing a refrigeration cycle. Although heat normally flows from higher to lower temperatures, a heat pump reverses that flow and acts as a "pump" to move the heat. Therefore, a heat pump can be used both for space heating in the winter and for cooling (air conditioning) in the summer. In the refrigeration cycle, a refrigerant (known as the "working fluid") is compressed as a liquid then expanded as a vapor to absorb and remove heat. The heat pump transfers heat to a space to be heated during the winter period and by reversing the operation, extracts (absorbs) heat from the same space to be cooled during the summer period.

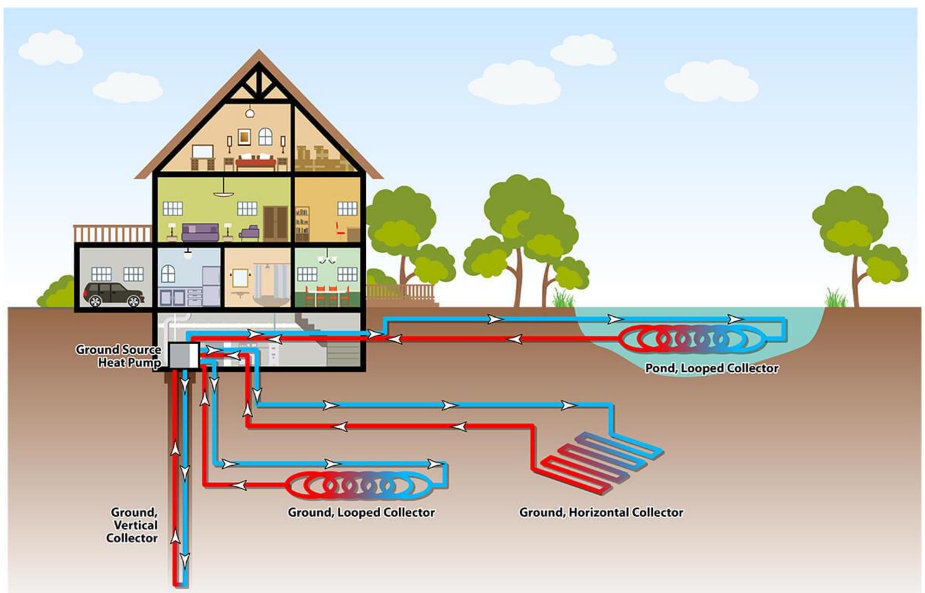

Figure 3-11- schematic model of different kinds of ground source heat exchangers

The most common type of heat pump for domestic use, referred to as a "conventional" heat pump, is the air-to air (air source) system in which heat is taken from air (heat source) at one location and transferred to air (heat sink) at another location. In the winter, a heat pump takes heat from outside air and via a working fluid transports the heat to inside the home. When the outside air temperature drops below -5 to 0°C, the air source heat pump uses electric resistance heat. In the summer, the heat pump reverses the process, removing heat from the home and transporting it to outside air, cooling the home in the process.

A geothermal heat pump is a heat pump that draws heat from or removes heat to the ground or ground water, instead of air. In the winter, a geothermal heat pump transfers heat from the ground or ground water to provide space heating. In the summer, the heat transfer process is reversed; the ground or groundwater absorbs heat from the living or working space and cools the air. A geothermal heat pump benefits from nearly constant ground and ground water temperatures over most of the “temperate” climate zones. These temperatures are higher on average than winter air temperatures and lower on average than summer temperatures. The heat pump does not have to work as hard to extract heat from or move heat to the ground or groundwater at a moderate temperature as from the cold air in winter or to the hot air in summer. The energy efficiency of a geothermal system is thus higher than that of a conventional heat pump. Many geothermal systems are also more efficient than fossil fuel furnaces. As with any heat pump, the actual pump used in a geothermal system is powered by electricity.[12]

3.5.3. Applicability of ground cooling

Geothermal cooling systems, as indirect systems of ground cooling, can be applied in the majority of climates, with the exception of very hot tropical soils, too high ground temperature, and very cold locations with low cooling demand. When the soil surface temperature is too high, it is possible to adopt specific techniques (e.g. water evaporation) to reduce it in order to increase the applicability of such cooling techniques.[10]

To study about how much effective using ground cooling would be in each city, in the warmest month, ground temperature at heights of 0.5m, 1m and 1.5 meters are compared with the highest mean day drybulb temperature and the results are shown in table (3-6). For having an evaluation for applying ground cooling in different cities, the deepest depth for locating pipes is considered 1.5 meters based on cost and constructional matters. As it is clear in the below table, in Rasht and Yazd, locating pipes at depth of 1.5m would make 7.8 and 10.4 degree Celsius drop in temperature and in Hamedan and Tehran, it seems that a depth of 0.5m would be enough as ground temperature reaches much below than air temperature and makes a 26.2 and 23.6 degree Celsius temperature drop. For Bandar Abbas ground cooling does not seem effective as there is little temperature difference between the soil and air dry bulb temperatures.

	mean day temperature(C)	Z=0.5		Z=1		Z=1.5	
		ground T (C)	delta T(C)	ground T (C)	delta T(C)	ground T (C)	delta T(C)
Rasht	28	23.2	4.8	21.5	6.5	20.2	7.8
Hamedan	28.9	2.7	26.2	5.1	23.8	6.8	22.1
Tehran	33.7	10.1	23.6	12.1	21.6	13.7	20
Yazd	36.4	30.1	6.3	27.8	8.6	26	10.4
Bandar Abbas	35.9	38.4	-2.5	35.6	0.3	33.5	2.4

Table 3-6- delta T between warmest day mean temperature and ground temperature at different depths

3.6. References

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4. Cooling potential analysis of different vernacular architecture of Iran

4.1. Ancient architects

Considering that Iran is mainly situated in hot and arid climatic region, in the Iranian vernacular architecture cooling down the buildings had the highest priority [1]. Iran is basically divided into four climatic regions. As mentioned in chapter two of "weather analysis", first region is the dry and hot part, which consists of the most parts of the plateau of Iran. Region two, is cold and snowy part in the north and west of the country. The third one is the hot and humid region which comprises the northern shores of the Persian Gulf and the Sea of Oman and the last region is humid and rainy part which embraces the southern shores of the Caspian Sea.[2]

Ancient Iranian architects have developed different passive strategies to build up buildings in various climatic regions. Around 700 years ago, when there was to electricity or gas driven mechanical instruments available, they designed sustainable systems to adapt the buildings with the nature, which were mostly harsh situations. In what follows, all passive architectural features developed in ancient Iranian architecture in addition to detailed study for each of them using different simulation software as Energy Plus and LadyBug Tools in Grasshopper and CFD analysis by using Design Builder software will be discussed.

4.2. Construction materials

Figure 4-1- Masonry walls with high thermal inertia. Arge-e-Bam, Kerman/Iran

Thermal mass is defined as the thermal materials that can absorb heat, store and release it later. Thermal mass includes building envelope, furniture, internal walls, etc. Thermal storage capacity of building mass is one of the factors describing the building thermal performance. In naturally ventilated buildings, thermal mass is effective for reducing the air temperature fluctuation [5]. Use of high thermal materials for saving the daily heat and dissipate it through night cooling will cause temperature reduction. Cooling down the building with night cooling method needs materials with high thermal inertia. During the day, heat is stored inside the construction materials and during the night, by decreasing the external temperature there will be flow of conditioned air from outside to inside the building and dissipation of the heat stored inside the building materials to the outside. As a result, cooled materials will be capable of capturing the heat of the following day. On the other side, if temperature of the inner space drops below the outside, the heat stored inside the materials enters to the building and this heating/cooling circulation repeats every day. Therefore, using of materials with high thermal inertia like the masonry wall shown in figure (4-1), causes thermal uniformity and decreases diurnal fluctuations inside the building. Moreover, it causes thermal lag of heat transfer from outside to inside.[1]

Based on Givoni's bioclimatic chart, the following charts (4-1) are produced to give a general idea about effectiveness of thermal mass for cooling during summer in different regions for the whole 24 hours of a day. Red dots are representing dry bulb temperatures taken from data in Meteonorm software related to year of 1991 till 2010 of each climate.

Also, applicability of thermal mass and night ventilation are showed in the same charts. Percent values on each graph is showing the success probability of the technique where "mass C+night V" means using of high thermal mass material and ventilation during night from 7 p.m. to 8 a.m.

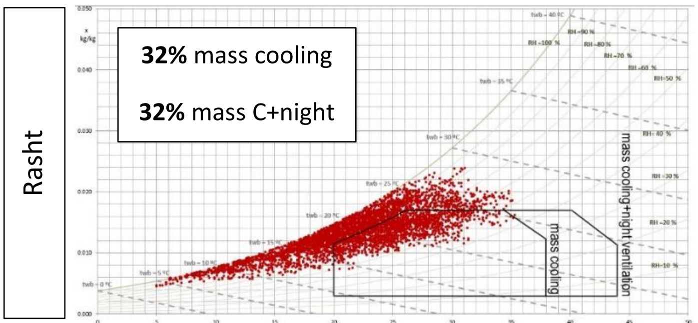


Chart 4-1-a- applicability of mass cooling+night ventilation

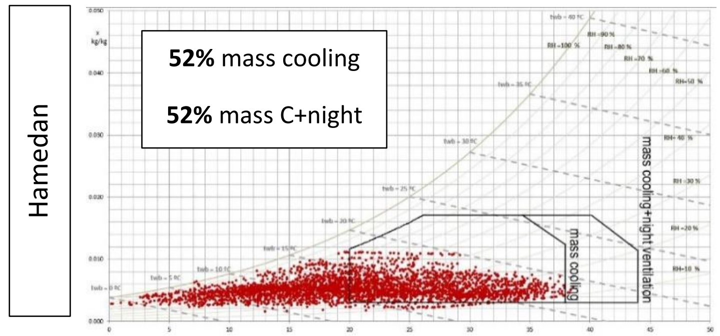


Chart 4-1-b- applicability of mass cooling+night ventilation

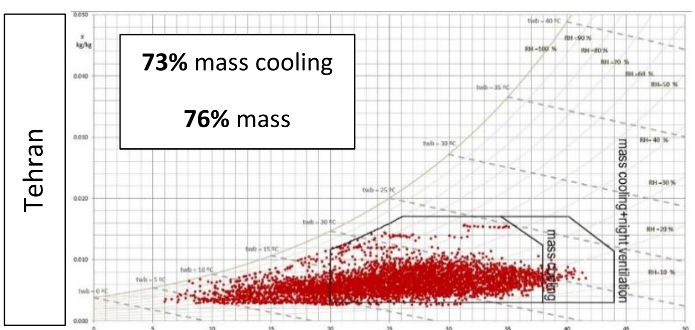


Chart 4-1-c- applicability of mass cooling+night ventilation

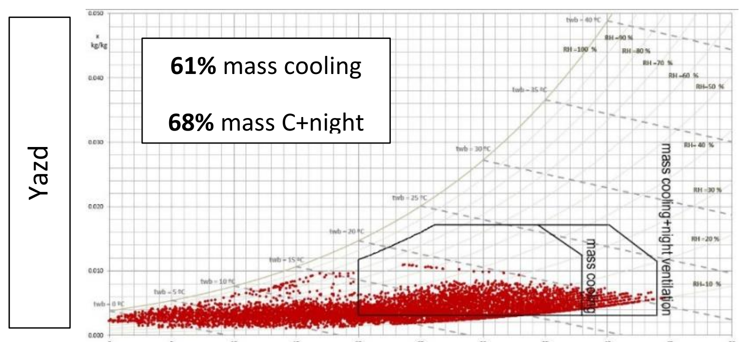


Chart 4-1-d- applicability of mass cooling+night ventilation

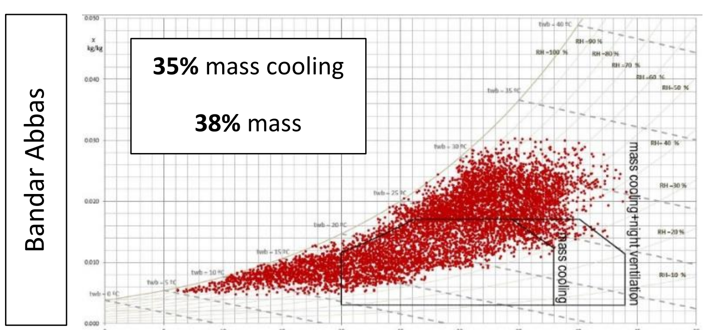


Chart 4-1-e- applicability of mass cooling+night ventilation

Results above based on Givoni's bioclimatic chart declare two main facts:

1. In all climates, the effect of thermal mass and night ventilation on comfort percentage are very close.

2. Strategies above are more effective in cities with lower relative humidity. As it can be seen, Rasht and Bandar Abbas are both located near the sea, so they are more humid than other cities. Tehran, Yazd and Hamedan have higher comfort percentage by using thermal mass as the main material for external walls and roof respectively.
3. Shown in table (4-1), as night ventilation is not a strong passive cooling solution in Rasht and Bandar Abbas, dry bulb temperature and relative humidity during night are shown. As it is clear, during the hottest months, night temperature and relative humidity are relatively high.

Rasht		
month	**night drybulb temperature (°C)**	**relative humidity(%)**
april	10.1	90.6
may	17.6	86.5
june	21.7	83.2
july	24.4	81.1
august	24.7	82.8
september	21.0	90.0
october	17.7	89.7

table 4-1-a- dry bulb temperature and relative humidity during night

Bandar Abbas		
month	**night drybulb temperature(°C)**	**relative humidity(%)**
january	14.1	74.7
february	17.2	74.9
march	20.8	71.3
april	24.8	67.5
may	29.2	64.0
june	31.2	67.3
july	32.9	71.2
august	32.4	72.7
september	29.8	75.1
october	27.0	73.4
november	21.3	69.0
december	16.2	72.9

table 4-1-b- dry bulb temperature and relative humidity during night

To see the effect of mass in thermal behavior of a building in different climates, following analysis are done, showing the time lag that is adjusted to the building. Once simulation is done to see the effect of a 100mm brick wall and in another simulation, properties are changed to brick wall with 400mm thickness which has thermal characteristics very close to what ancient Iranian used in their construction named "*khesht*". It was made of clay soil with physical characteristics shown in table (4-2). As it is clear in the simulation results, *khesht* was able to store heat for at least 10hours that made it a suitable material for very cold and very hot climates.

Charts (4-2) and (4-3) give the sinuside thermal behavior of different materials in the hottest and coldest months respectively. In all climates, 400mm brick converts the outside fluctuating temperature to a steady thermal condition inside the building.

	ƛ (w/m.k)	C (J/kg.k)	ɣ (Kg/m^3)	thickness (mm)	U (Kg/m^2.k)
Khesht	0.711	838.8	1800	400	1.7775
Brick-400	0.89	790	1920	400	2.189
Brick-100	0.89	790	1920	100	8.760

table 4-2- thermal properties of "khesht"

Simulations for the following study are based on a shoe box with geometry shown in figure (4-2).

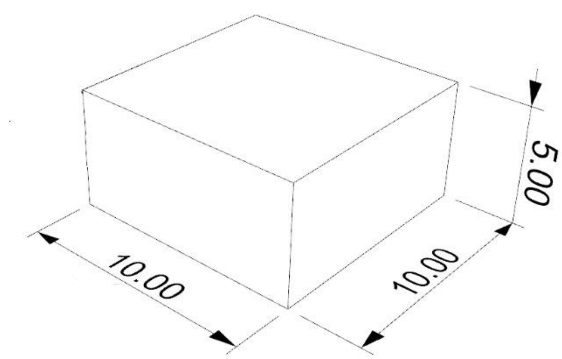


Figure 4-2- shoe box geometry for simulation of building material

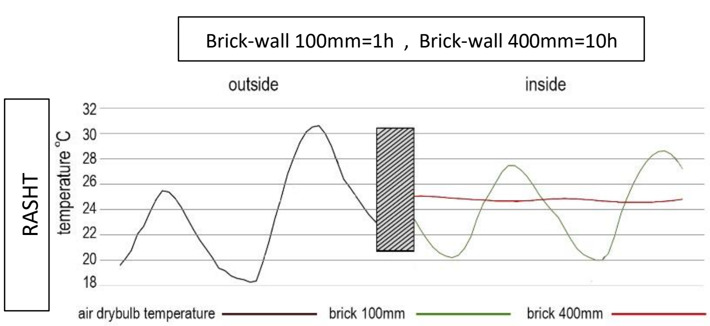


chart 4-2-a time lag simulation result in the hottest day

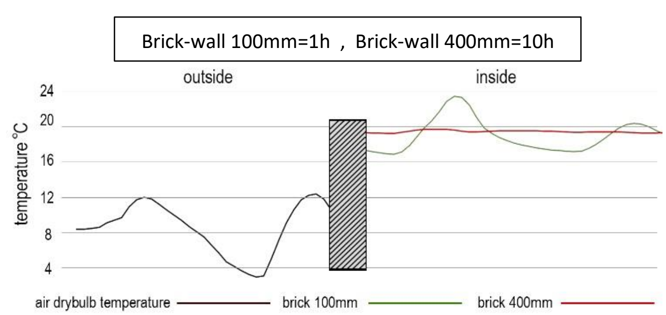


chart 4-3-a time lag simulation result in the coldest day

HAMEDAN

Brick-wall 100mm=1h , Brick-wall 400mm=11h

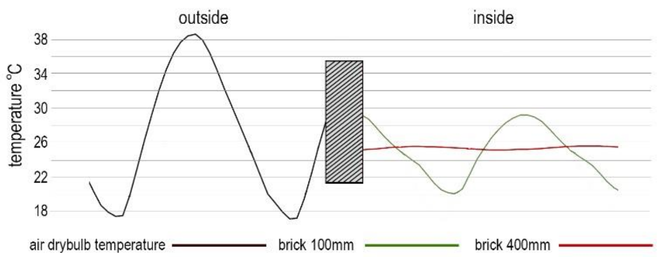


chart 4-2-b time lag simulation result in the hottest day

Brick-wall 100mm=1h , Brick-wall 400mm=13h

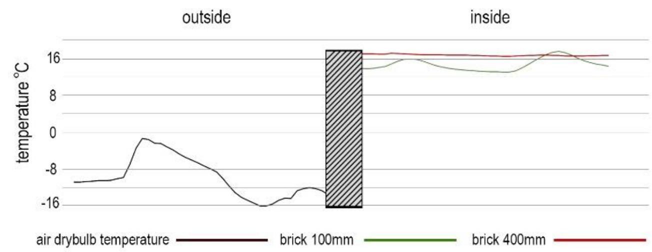


chart 4-3-b time lag simulation result in the coldest day

TEHRAN

Brick-wall 100mm=1h , Brick-wall 400mm=10h

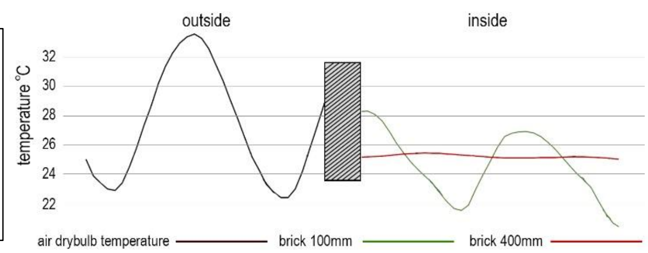


chart 4-2-c time lag simulation result in the hottest day

Brick-wall 100mm=3h , Brick-wall 400mm=11h

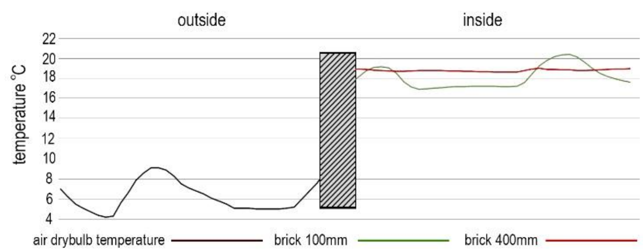


chart 4-3-c time lag simulation result in the coldest day

YAZD

Brick-wall 100mm=1h , Brick-wall 400mm=10h

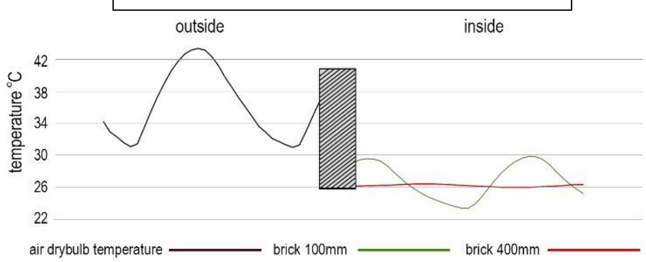


chart 4-2-d time lag simulation result in the hottest day

Brick-wall 100mm=2h , Brick-wall 400mm=14h

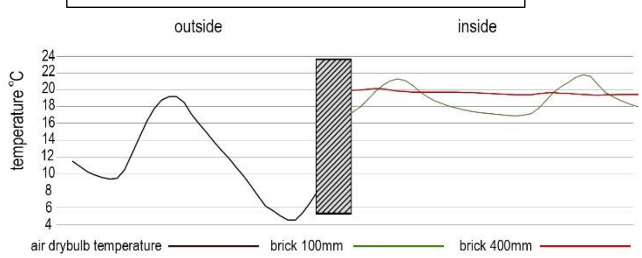


chart 4-3-d time lag simulation result in the coldest day

BANDAR ABBAS

Brick-wall 100mm=1h , Brick-wall 400mm=11h

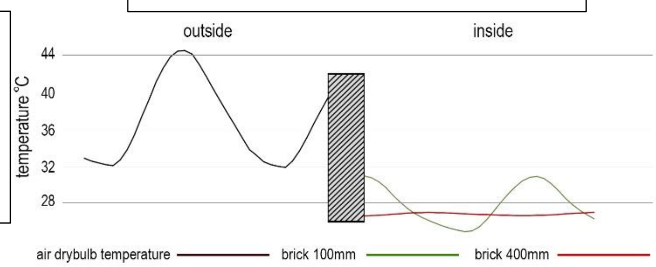


chart 4-2-e time lag simulation result in the hottest day

Brick-wall 100mm=1h , Brick-wall 400mm=5h

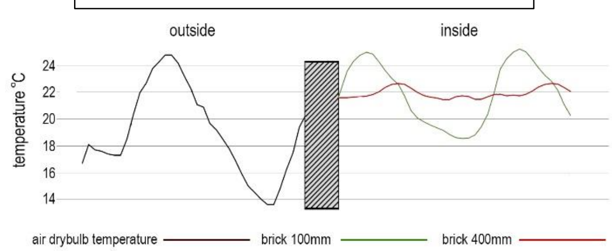


chart 4-3-e time lag simulation result in the coldest day

Based on above charts, the thicker the external wall is, the higher the time lag would be for all climates during summer and winter. As a result, higher thermal inertia helps the building keeps its inner thermal situation. For example, in a cold city like Hamedan during the winter, using a 400mm brick wall, keeps thermal situation of the inner space, 13 hours steady while the outside temperature changes. On the other hand, using a 100mm brick wall can keep the inside zone only 1 hour steady. For a warm city like Yazd during the summer, using brick wall with high thermal inertia causes a time lag of 10 hours which means that the outside thermal fluctuations will affect the inside zone by a delay of 10 hours. This phenomena means that during the day when hot outside thermal condition is not desirable, the 400mm brick wall keeps the inside zone cool for 10 hours as it has been cooled down during the night.

In a nutshell, for all climates, it seems logical to use materials for the external walls with higher thermal inertia. But it must be noticed that having a 400mm wall is not logical and economical in all situations.

4.3. "Baadgir" or wind catcher

As a passive cooling strategy, natural ventilation is an efficient green alternative solution for conventional mechanical ventilation and cooling systems to mitigate energy consumption and CO2 emissions. Natural ventilation's potential to optimize energy-saving with good thermal comfort and an acceptable indoor environment is considerable.

The air velocity is critical in evaluating thermal comfort for naturally ventilated space. The higher the air velocity in the tropical climate, the higher the neutral temperature. This is because the rise in airflow around the occupant's body can enhance sweat evaporation, leading to evaporative cooling in skin level; consequently, individuals have better thermal comfort feeling. Thus, knowing the airflow distribution in naturally ventilated buildings can help determine thermal comfort level achievement.

Windcatcher (also known as Badgir in Persian) is a well-known natural ventilation device that improves indoor quality through reduction of pollution concentrations and air moisture by replacing still air with fresh outdoor air. The Middle East is the birthplace of windcatchers, and an initial type of windcatcher was discovered during archaeological activities in 1970s near Shahrood, Iran (the historical site of Tappeh Chackmaq) where it is estimated that they have been constructed 3000 years ago.

However, the windcatcher application is not limited to the Middle East, and it can be seen all over the world, specifically in densely occupied spaces such as malls, educational buildings, hospitals and offices. For example, more than 7000 windcatchers have been installed in different types of buildings in the UK in the last decade. Windcatchers present some advantages, particularly in dense urban districts and low wind speed areas, primarily when cross-ventilation strategy cannot be implemented due to limitations [6].

In many desert regions of Iran, taking the cool air passing from the roofs was done by wind catchers based on the direction of local winds. This architectural element in Iran and other countries of the Persian Gulf area was used in both catching the wind from outside to inside and passing it from inside of the building to the outside. If warm air according to pressure difference gets through the structure from back, it will work as chimney, especially when the wind speed is low, ventilation of the inner air to the outside happens through this effect. This is the case of having a solar chimney.[1] Two models of *Baadgirs* are shown in figure (4-3).

Figure 4-3- Traditional Baadgir in Yazd/Iran

In this stage for studying the effect of *Baadgir* in different climates, many different approaches are examined to see the best way for understanding natural ventilation through a simple shoe box. After studying some papers with different topics related to wind catchers, it was clear that the best way for this kind of simulation is using a CFD engine software. First of all, in software of Rhino/Grasshopper, a simple shoe box by dimension of 10mx10mx5m with one window as inlet with dimension of 2mx2m was modeled as shown in table (4-3) case one. In further steps, a wind catcher with one inlet of 2mx2m dimension was modeled, once by height of 8m and once by height of 13m shown in table (4-3) case two and three. It is shown in what follows, the result of CFD analysis done with plugin of Butterfly in Ladybug tools/Grasshopper. Direction of wind with speed of 5 m/s applied to the inlet window is also shown. Meshing size to see the wind speed and pressure distribution is fixed to 0.5mx0.5m.

It must be mentioned that CFD analysis are steady state. It means that, the simulation is done for one specific state. For this project case, the study is limited to one specific condition from a complete year.

- step one:

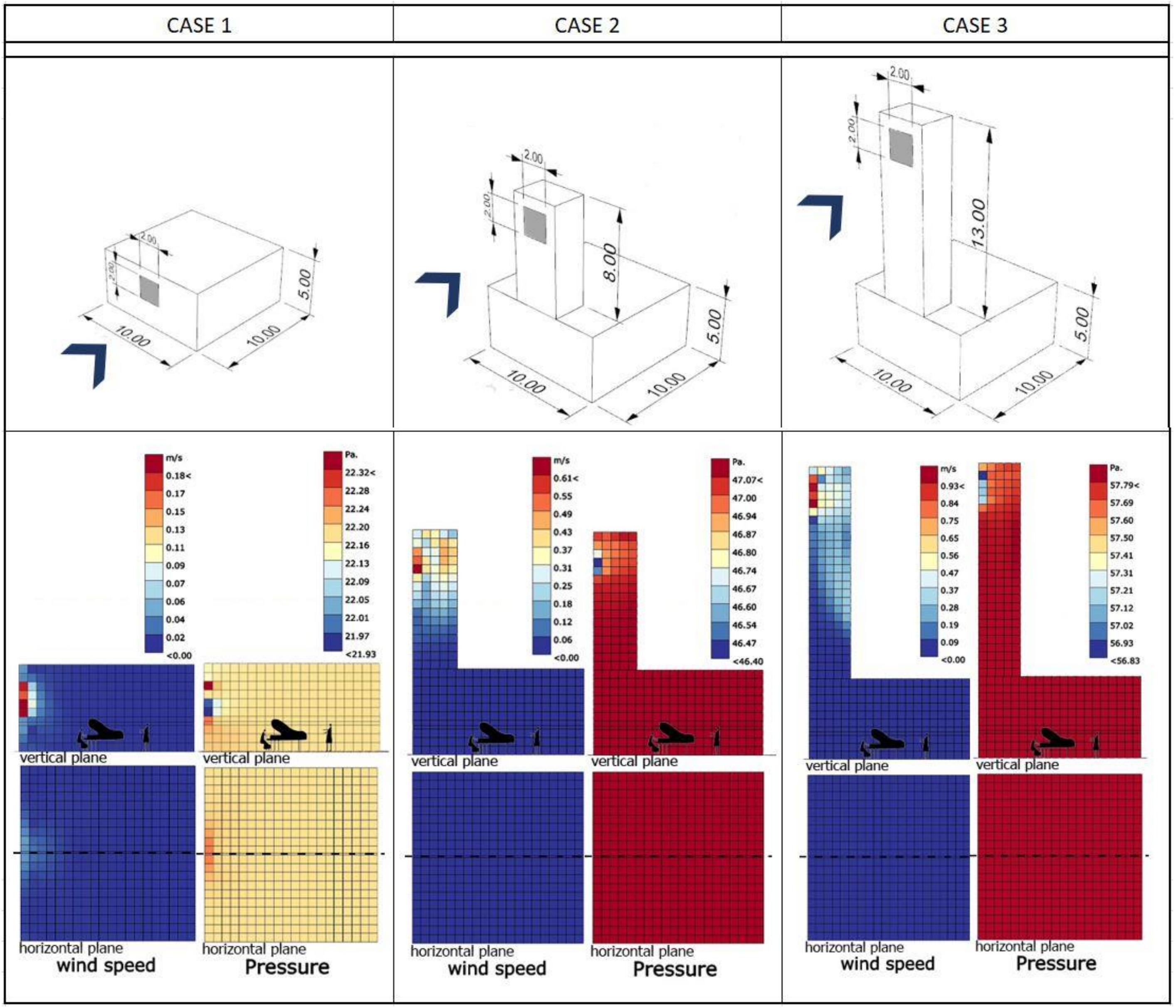


Table 4-3- CFD analysis result done with plugin of Butterfly in Ladybug tools/Grasshopper with inlet airstream of 5m/s

Graphs above are clearly showing the effect of applying a windcatcher on a building. As inlet height of the air increases, with a fixed external wind condition, internal wind speed and air pressure increase. It is approving the positive effect of wind catcher for benefiting from natural ventilation inside a building.

- step two:

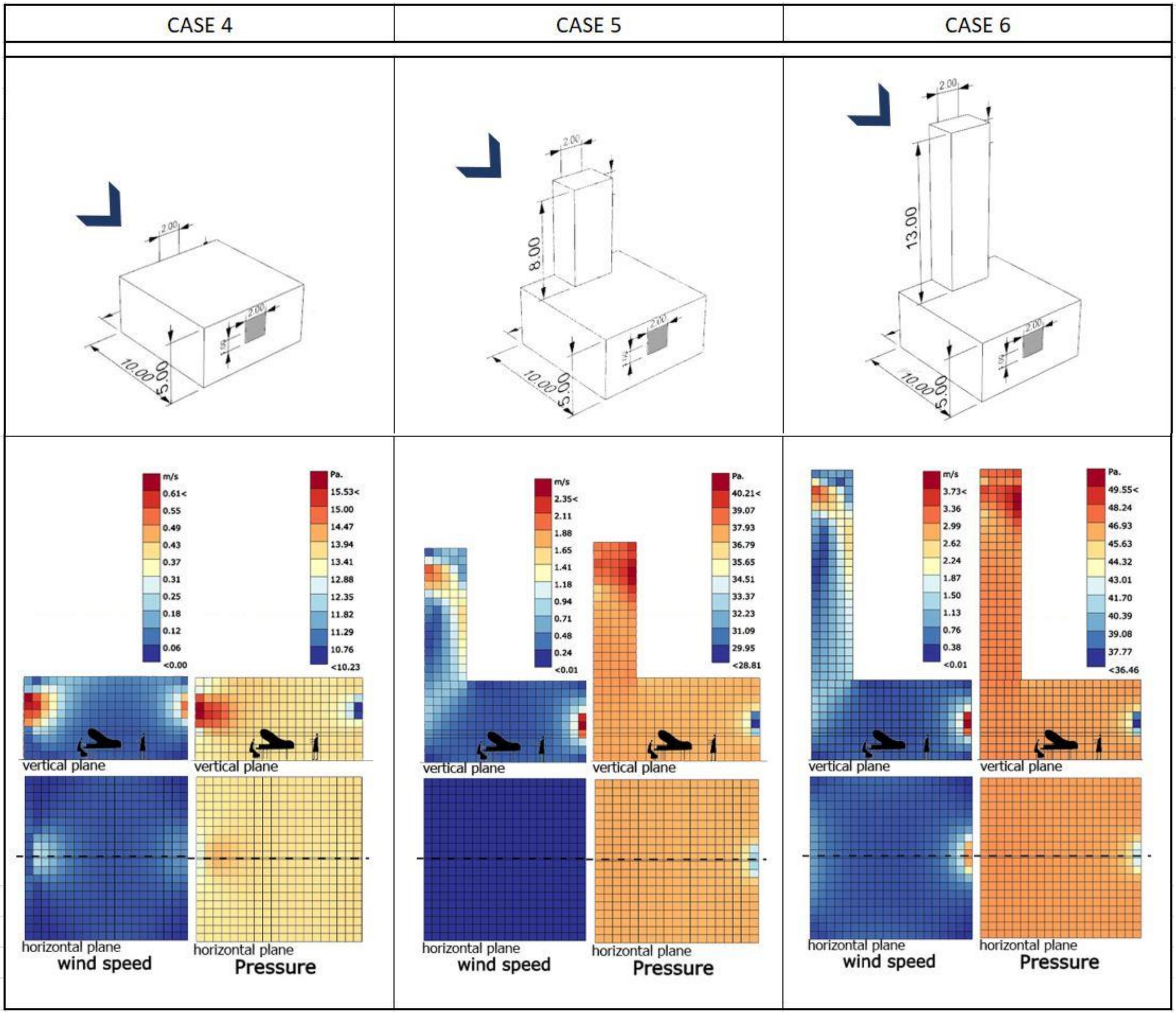


Table 4-4- CFD analysis result done with plugin of Butterfly in Ladybug tools/Grasshopper with inlet airstream of 5m/s with an outlet window on the other side

In the next step, moreover than one window as inlet, there is another window on the opposite side of the building façade as outlet with dimension of 2mx1m. As it can be seen in table (4-4), the clearest difference between this step and the previous one is about movement of air to the horizontal plane of 1.5m which means that a standing occupant would feel the effect of wind coming to the zone, especially near the outlet window and behind the wind catcher place. Like as the result of step one, by increasing the height of inlet, wind speed and air pressure increase at the place of the occupants. Near the windows, these values are at the highest range.

- Step three

After understanding the effect of opening positions on air speed and pressure inside the building, it is needed to study temperature distribution affected by external airflow with specified condition for each climate. The point is that, for each city, the hottest time of year is chosen for this step of analysis. Condition of the hottest hours for each city are shown in table (4-5).

Using software of *DesignBuilder* made it possible to see the temperature distribution in 2D and 3D phases inside the building. It uses *EnergyPlus* engine for energy analysis, then considers the inside surface temperature of all walls and openings moreover to inflow and outflow rate of air related to each opening, it has possibility to run CFD analysis by considering specific condition for each case. In what follows, it can be seen the results of analysis mentioned above for 5 different cities of Iran.

Based on graphs shown in table (4-6), it is clear that adding a chimney with one opening is affecting air velocity inside the building for all cities during the hottest condition of year but it cannot affect the temperature as there is no sensible cooling source present. This fact was known by the ancient architects, so their method for cooling down the hot air coming to the building was benefiting from evaporative cooling which will be discussed later.

City	hottest hour	external condition		
	m/d/h	dry bulb temperature(°C)	wind speed(m/s)	wind direction(°)
Rasht	aug/19/15	35.3	4.6	308
Hamedan	aug/1/16	38.6	3.875	40
Tehran	july/28/15	41.6	4.9	130
Yazd	july/21/15	44.6	3.7	315
Bandar Abbas	june/19/15	44.5	4.9	130

Table 4-5- the hottest thermal condition for all cities

Table of (4-6-a) to (4-6-e) are showing CFD analysis done in *DesignBuilder* for building cases of 4 and 6 which are mentioned in earlier steps. Although there is no suitable effect on temperature distribution inside the buildings with windcatcher, effect of air movement velocity is clearly considerable which makes the condition for the occupants more desirable. In all cities, the temperature inside the building is roughly the same as outside drybulb temperature, this issue will be solved in the next part by the effect of "*hozkhane* or *pool house*" which benefits from evaporative cooling.

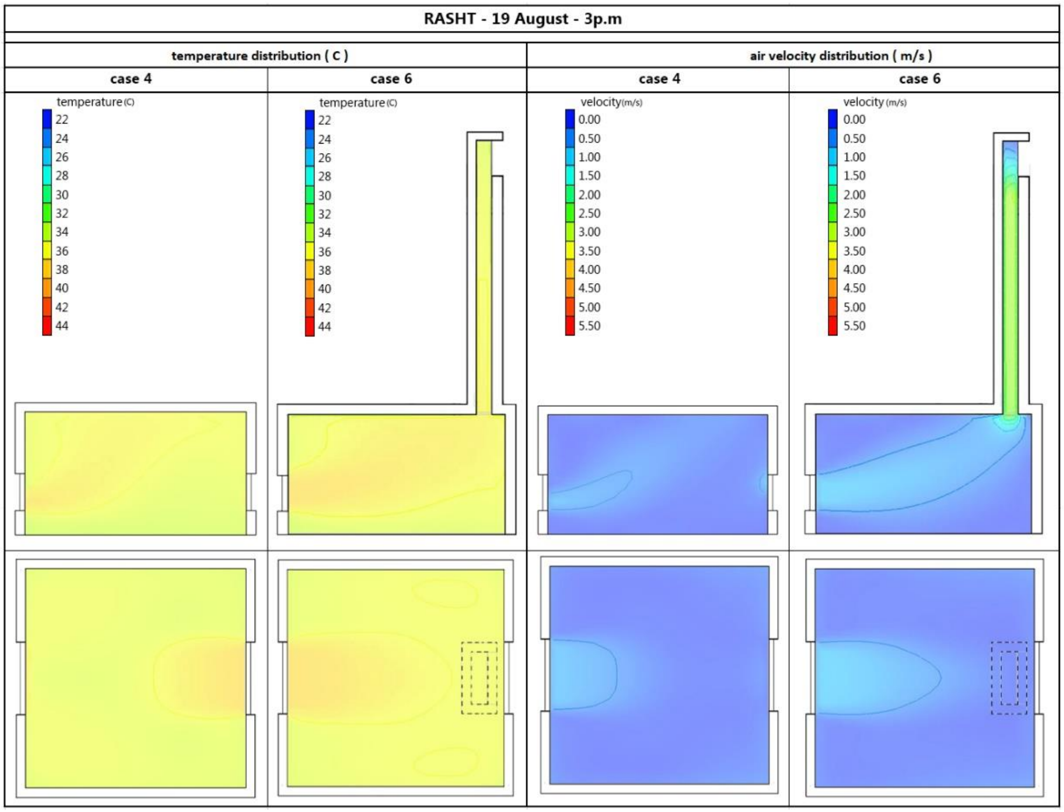


Table 4-6-a air velocity and temperature distribution results using DesignBuilder software, considering the hottest day condition for 2 buildings with/without windcatcher both having inlet and outlet on opposite sides

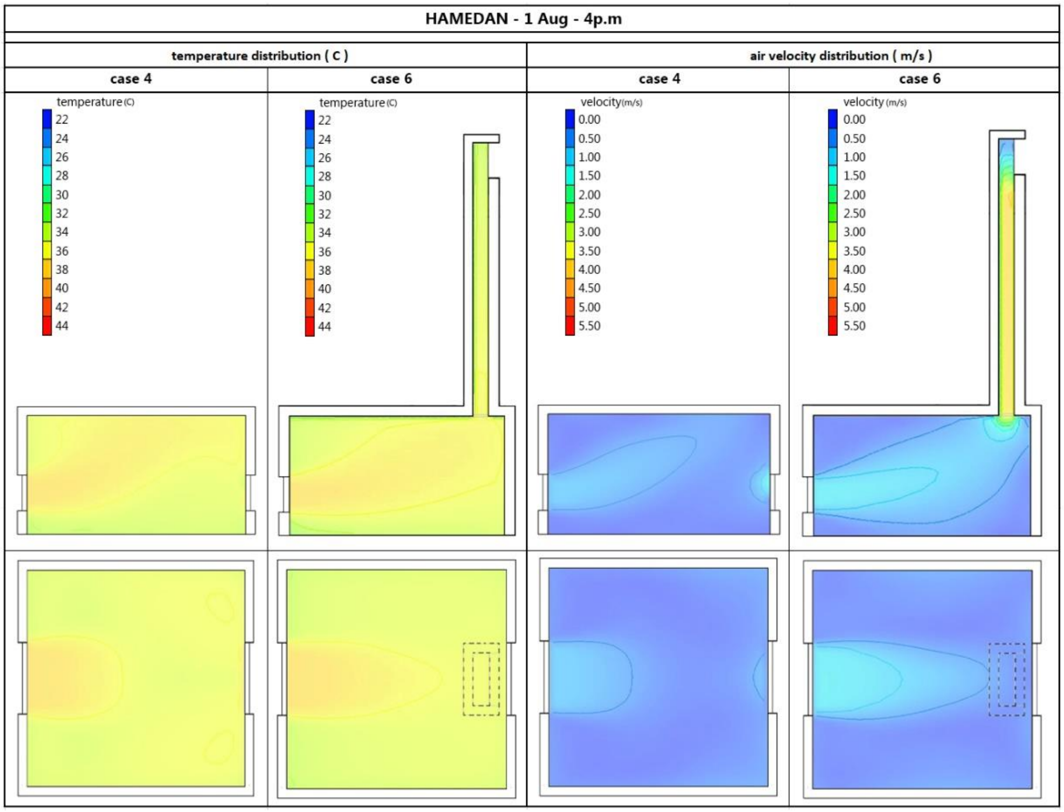


Table 4-6-b air velocity and temperature distribution results using DesignBuilder software, considering the hottest day condition for 2 buildings with/without windcatcher both having inlet and outlet on opposite sides

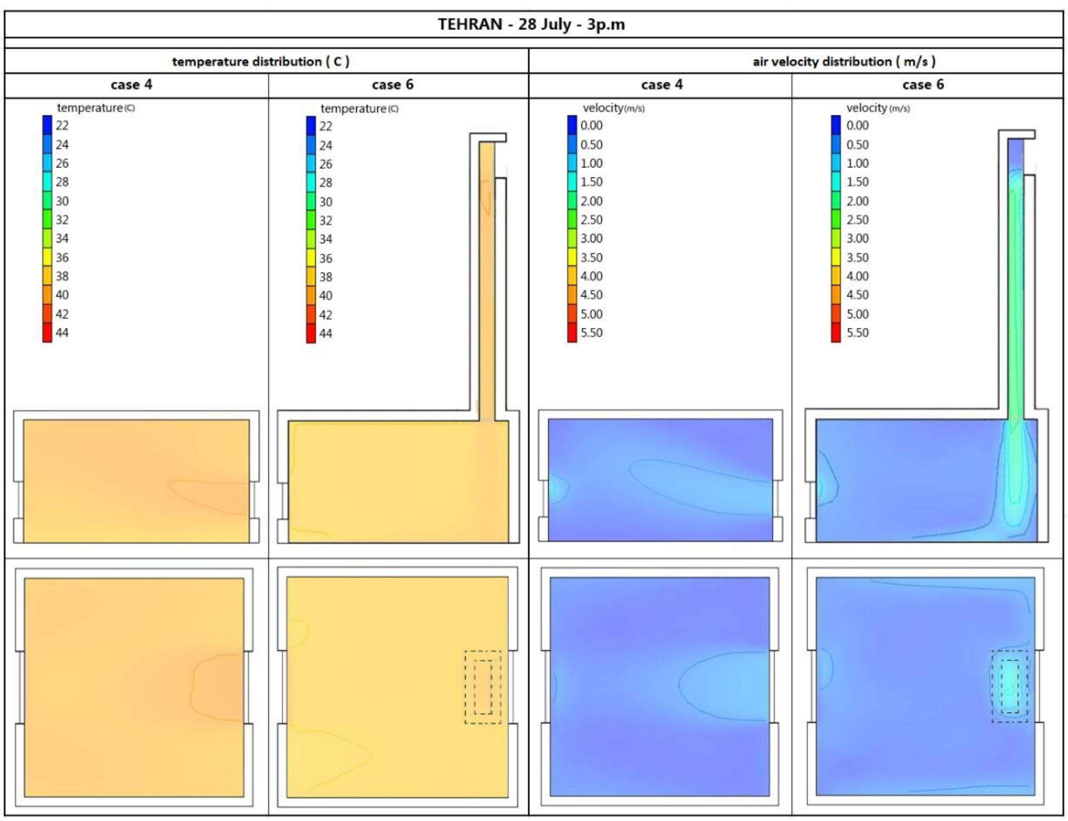


Table 4-6-c air velocity and temperature distribution results using DesignBuilder software, considering the hottest day condition for 2 buildings with/without windcatcher both having inlet and outlet on opposite sides

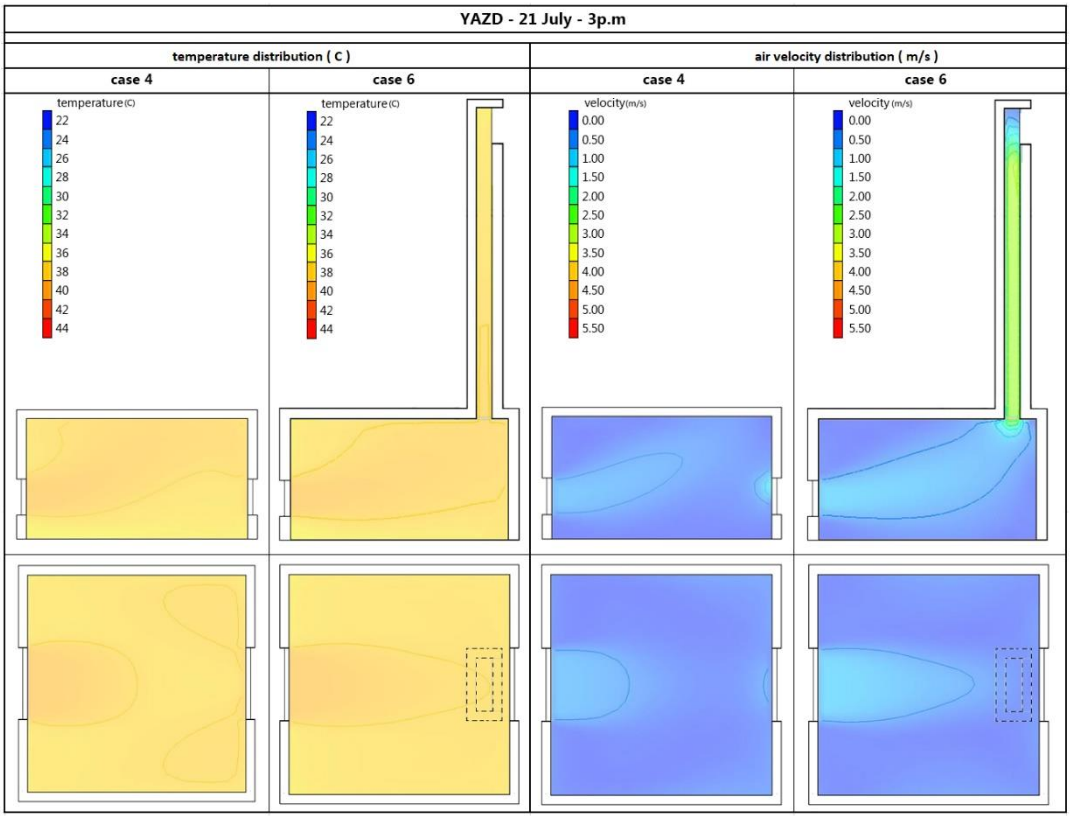


Table 4-6-d air velocity and temperature distribution results using DesignBuilder software, considering the hottest day condition for 2 buildings with/without windcatcher both having inlet and outlet on opposite sides

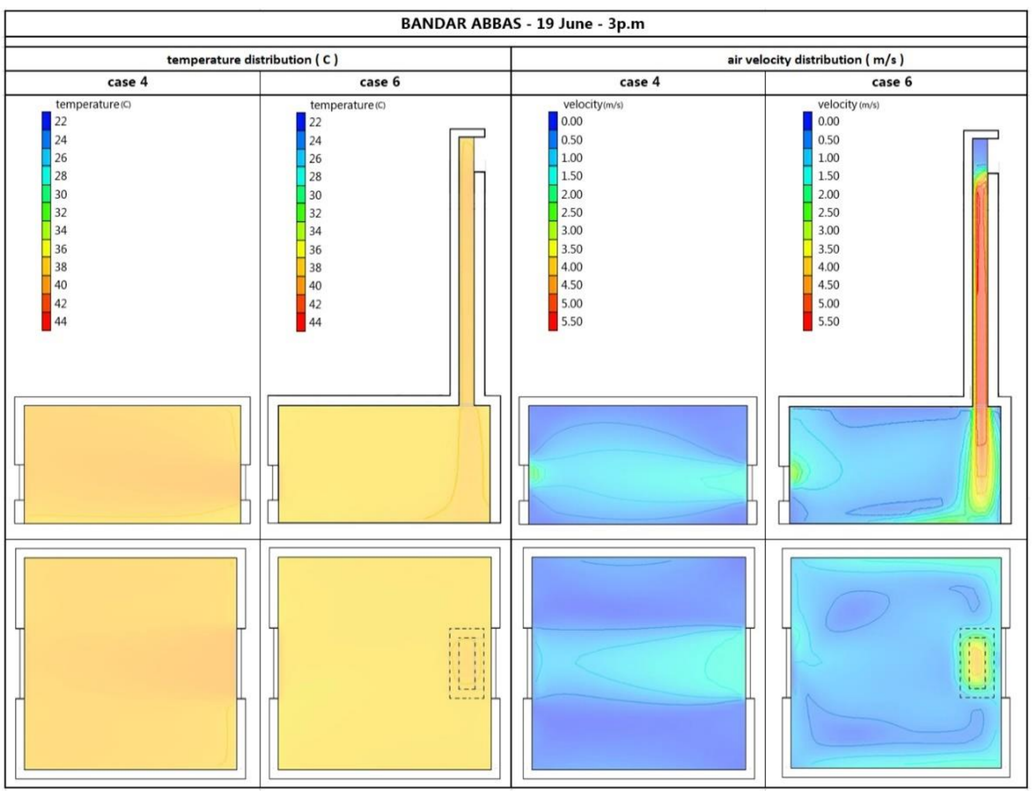


Table 4-6-e air velocity and temperature distribution results using DesignBuilder software, considering the hottest day condition for 2 buildings with/without windcatcher both having inlet and outlet on opposite sides

4.3.1. Functional improvement

Nejat and Ferwati [6] in an experimental and computational study for climate of Malaysia integrated the upper wing wall into the windcatcher to prevent direct solar and rain penetration. The impact of this combination was not considered in previous studies. Moreover, analyzing adaptive thermal comfort is another gap that was not addressed by preceding windcatcher studies, particularly for the tropical climate. Therefore, the research aims to evaluate a two-sided windcatcher incorporated with the upper wing wall from two views: indoor air quality (IAQ) and adaptive thermal comfort. A small-scale model was tested in the wind tunnel. Next, CFD models were validated against experimental data with a good agreement between the two methods. Windcatchers with different upper wing wall lengths ranging between 10 cm and 50 cm were assessed. The results showed that the length increase led to a slight increase in the ventilation rate, and the best performance was seen in the 50 cm configuration. Subsequently, IAQ and adaptive thermal comfort were evaluated at different wind speeds of this climate. The results demonstrated that even in wind speeds below the annual average (2.5 m/s), the windcatcher performance can still satisfy IAQ parameters such as airflow rate and air change rate, recommend by CIBSE Guide A. In addition, based on the simulated conditions the results showed that wind speed from 2.5 m/s to 4 m/s could provide thermal comfort within 50%–80% of the ventilated space. Finally, the estimation of passive cooling power showed that windcatcher could provide a maximum of 9.6 kW cooling power if the wind speed is at 4 m/s and outdoor temperature at 23 °C. [6] In figure (4-4) the graphical result of the study can be seen.

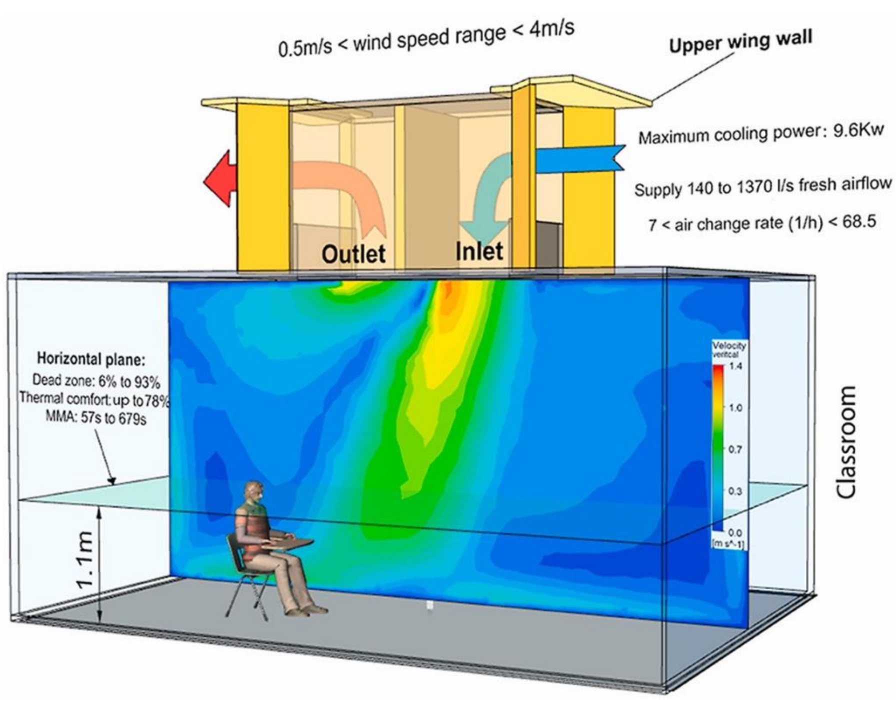


Figure 4-4- graphical result of the best upper wing wall setting configuration

4.4. "Hozkhane" or pool house

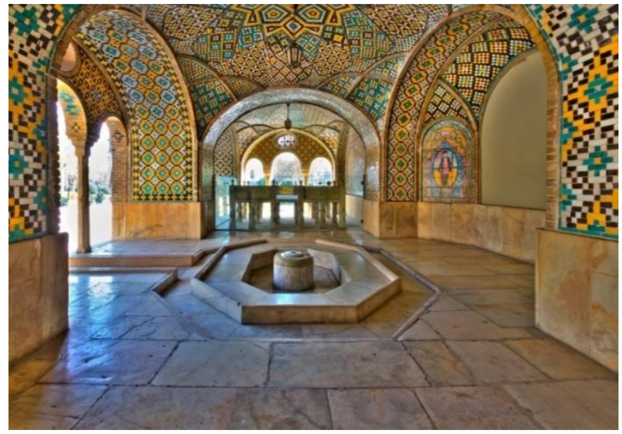


Figure 4-4 Hozkhane or pool house of Golestan Palace, Tehran/Iran

Since the oil crisis in developed countries in the 1970s, the world's energy problem has become more and more prominent. With the rapid development of economy and urbanization, the global warming situation is also developing on an almost day-by-day basis. The world's environmental pollution is facing more and more challenges. Besides, in the context of maintaining urban sustainable development, more attention should be given to the construction industry to research low carbon emission and the energy efficiency for buildings. It is imperative to promote high-efficiency, low-carbon energy-saving air conditioning products. Reducing user costs can also mitigate the impact of climate change, thereby protecting the healthy development of agriculture and natural ecosystems, and further promote the healthy and sustainable development of low-carbon cities. The fundamental driving force in solving this problem lies in the development of an efficient and low-energy refrigeration technology, as well as improving human comfort and solving energy problems. Therefore, the use of dry air energy evaporation cooling technology came into use. Because this technology's cold source is convenient and desirable, and energy consumption is very low, this cooling method has gradually been getting people's attention. Passive evaporative cooling can be divided into direct evaporative cooling and indirect evaporative cooling. Its efficiency is closely related to dry bulb temperature and wet bulb temperature. [7]

Pool house is an area at the same level of the yard, basement or above it which is adjacent to water. Cool water passing through this space humidifies the air and reduces the air temperature. In some cases, cooled air of the pool house is transferred to other building areas with some channels. There is a sample of *Golestan Palace* in Tehran/Iran shown in figure (4-4). Inward air can be captured from the yard or from wind catcher above this area.

Based on Givoni's bioclimatic chart, the following charts (4-3) are produced to give a general idea about effectiveness of evaporative cooling during the summer in different regions for the whole 24 hours of day. Percent on each graph is showing the success probability of the technique.

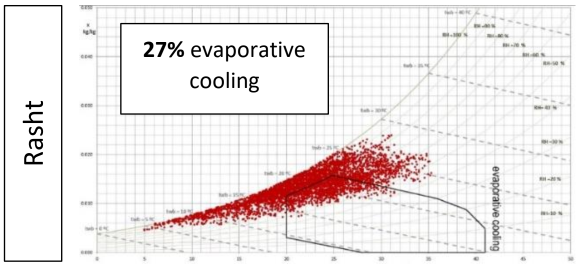


Chart 4-3-a- applicability of evaporative cooling

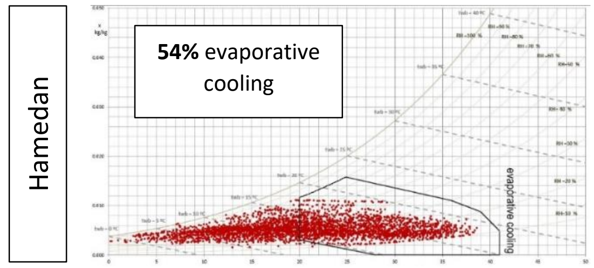


Chart 4-3-b- applicability of evaporative cooling

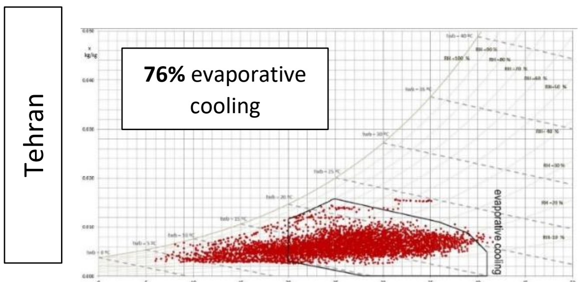


Chart 4-3-c- applicability of evaporative cooling

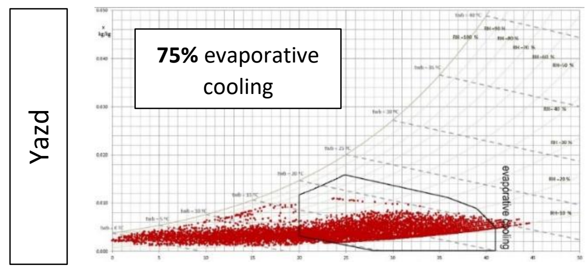


Chart 4-3-d- applicability of evaporative cooling

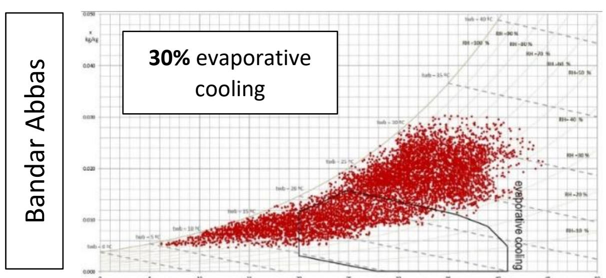


Chart 4-3-e- applicability of evaporative cooling

In the further study, using physics equations helps predicting the cooling effect of water on the hot air coming to the thermal zone in each climatic zone. Evaporative cooling is based on a simple principle. As water evaporates, the latent heat of vaporization is absorbed from the water body and the surrounding air. As a result, both the water and air are cooled during the process. The evaporative cooling process is schematically shown in figure (4-5) and (4-6). Hot, dry air at state 1 enters the evaporative cooler, where it is sprayed with liquid water. Part of the water evaporates during this process by absorbing heat from airstream. As a result, the temperature of the airstream decreases and its humidity increases [5]. Based on physical process happens during evaporative cooling, table (4-7) shows the cooling potential of the phenomena for each city by clarifying condition of outside air related to the warmest hour.

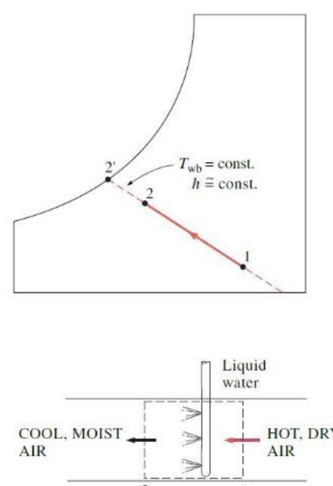


figure 4-5 physical process of evaporative cooling on psychrometric chart

City	hottest hour	condition 1		condition 2	
	m/d/h	Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
Rasht	aug/19/15	35.3	45	31.3	60
Hamedan	aug/1/16	38.6	13	24.6	60
Tehran	july/28/15	41.6	14	26	60
Yazd	july/21/15	44.6	10	27	60
Bandar Abbas	june/19/15	44.5	36	37.5	60

table 4-7 thermal properties of the air at the warmest condition for each city before and after evaporation

Considering a building with a wind catcher and using evaporative cooling by means of a water source like a pool or spray, it would be an effective passive technique for getting warm air inside the building, increasing its velocity and finally cooling down it in *Hamedan*, *Tehran* and *Yazd.* According to table (4-7) and charts (4-3) these cities have low relative humidifies during hot months and have the potential to benefit from evaporative cooling.

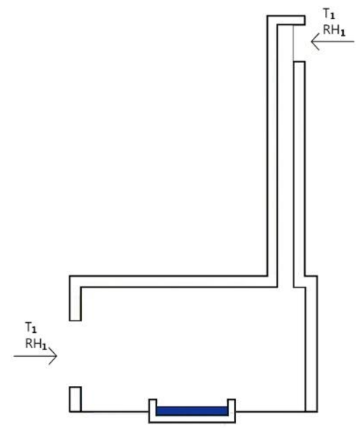


figure 4-6 hot air coming to the building through the openings

4.5. "Hoz" or Courtyard pool

In arid regions, evaporation of water not only decreases the temperature, but also increases the air humidity and quality. Amount of coolness made by water depends on its surface area and temperature, wind velocity and relative humidity of the air. In a moderate condition, one square meter of water can take 200 watts of heat by mean of heat transfer between the air and a very thin layer of water.

To cool down the air and pass it through the building, pool and fountain were used inside the central courtyards to have evaporative cooling. Also penetrating water droplets into the air, wetting the ground surface and using vegetations to widen the water surface were other means for evaporative cooling used in ancient times. A typical traditional house with *Hoz* and vegetation is shown in figure (4-12).

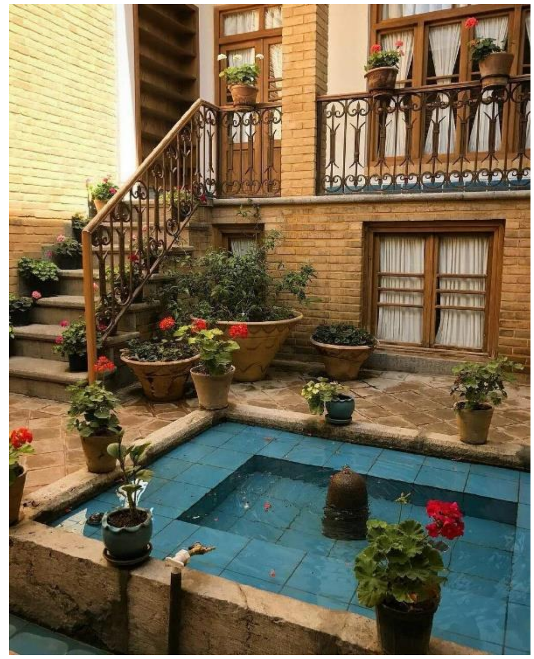


Figure 4-12- Hoz or courtyard pool and vegetation in a typical house, Iran

Like the fact mentioned before in earlier lines, to understand the effect of evaporative cooling in different climates, table (4-9) shows the hottest condition in each city. Using psychrometric chart, to reach a relative humidity of 60%, the final air temperatures are calculated as condition 2. It can be concluded that to benefit from evaporative cooling, general condition of Hamedan, Tehran and Yazd are favorable as these cities have low relative humidity.

City	hottest hour	condition 1		condition 2	
	m/d/h	Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
Rasht	aug/19/15	35.3	45	31.3	60
Hamedan	aug/1/16	38.6	13	24.6	60
Tehran	july/28/15	41.6	14	26	60
Yazd	july/21/15	44.6	10	27	60
Bandar Abbas	june/19/15	44.5	36	37.5	60

table 4-9 hottest temperature with relative humidity for all cities, and the temperatures relates to relative humidity of 60% by means of evaporative cooling

To have a wider perspective related to evaporative cooling effect in different cities, average daytime temperature and relative humidity for summer are studied and the results are shown in table (4-10). It must be mentioned that values of average relative humidity in Rasht for summertime are more than 60% so that there is no way to cool down the air by means of evaporative cooling. According to tables (4-10), evaporative cooling is an effective solution in cities with low relative humidity as in Hamedan, Tehran and Yazd. Like what mentioned in part

3.3, in Givoni's graphs, Rasht and Bandar Abbas do not have appropriate condition to benefit from evaporative cooling. According to table below, during month of November, in Bandar Abbas there is potential of benefit from evaporative cooling as this method can cool down the air temperature about 3 degree Celsius

City	month	condition 1		condition 2	
		Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
HAMEDAN	June	26.3	26.9	19.4	60
	July	30.0	22.8	21.5	60
	August	29.9	20.6	20.7	60
	September	25.7	18.3	17.1	60
City	month	condition 1		condition 2	
		Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
TEHRAN	May	26.1	24.9	19	60
	June	31.4	21.4	22	60
	July	34.3	21.6	24.4	60
	August	33.7	22.2	23.8	60
	September	28.9	23.9	21	60
	October	25.6	31.4	20	60
City	month	condition 1		condition 2	
		Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
YAZD	April	24.0	18.0	15.7	60
	May	30.2	15.3	19.4	60
	June	34.3	12.1	21.1	60
	July	37.1	13.3	23.5	60
	August	35.4	15.5	23.2	60
	September	31.0	14.3	19.6	60
	October	27.1	14.4	17	60
City	month	condition 1		condition 2	
		Temperature(°C)	Relative Humidity(%)	Temperature(°C)	Relative Humidity(%)
BANDAR ABBAS	March	25.8	52.6	24.5	60
	April	30.0	47.3	27.4	60
	May	35.2	43.5	31.3	60
	June	36.4	49.2	33.9	60
	July	36.9	55.9	35.9	60
	August	36.2	57.6	35.8	60
	September	34.2	58.5	33.9	60
	October	32.5	51.7	30.7	60
	November	27.0	47.0	24.5	60

table 4-10 evaporative cooling results for cities with appropriate potential during hot months

4.6. Central courtyard architecture

Making houses with central courtyard surrounded by tall walls around, for capturing cool air is a traditional way to cool down the air throughout the building. The yard heading southward makes two parts of summer rooms and winter rooms. This yard is completely in shadow in the mornings and afternoons and there is always a part of the yard and walls of the rooms inside shadow. Central yards benefiting from radiative cooling during the nights, cool down the spaces of the house. Moreover, making protective shadow during the day and evaporation from the ground, vegetations and water surface, are the most important ways of thermal functions.

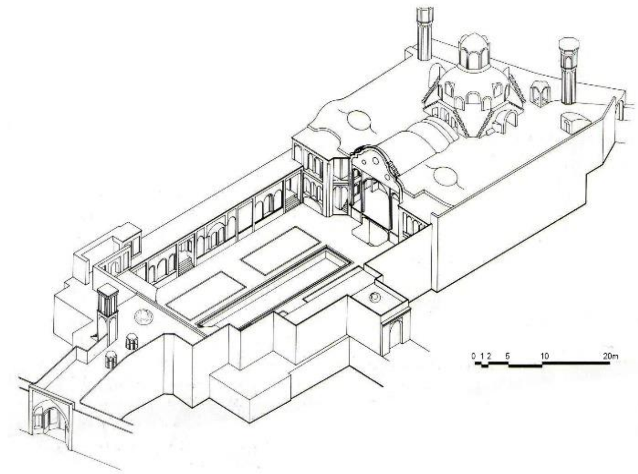


Figure 4-7 3D model on left and section on right of Borujerdiha House, Kashan/Iran

Yards work like trapping the coolness. During the night, yards because of shadows, evaporative cooling and capturing the night cool air, are more conditioned than other outdoor spaces which are completely open. Central yards have an important role in making micro-climates.[1] House of *Borujerdiha* is presented in a 3D model to show the situation of the central yard in figure (4-7). Figure (4-9) shows the situation of building rooms according to the sun position in the sky in summer and winter. As it can be seen, summer room is located at the northern part of the courtyard, while winter room is located at the south.

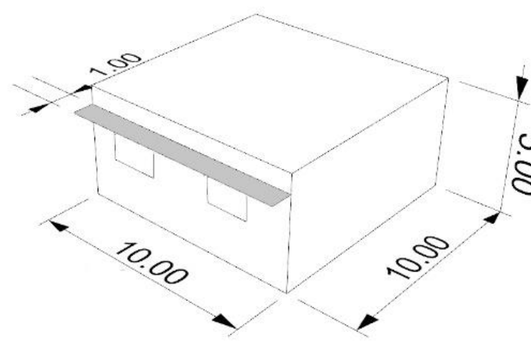


Figure 4-8 shoebox model for studying the effect of shading

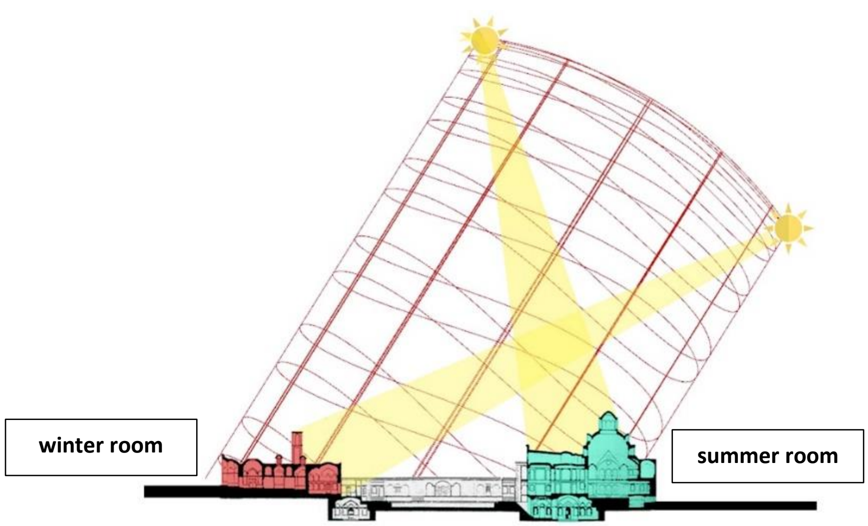


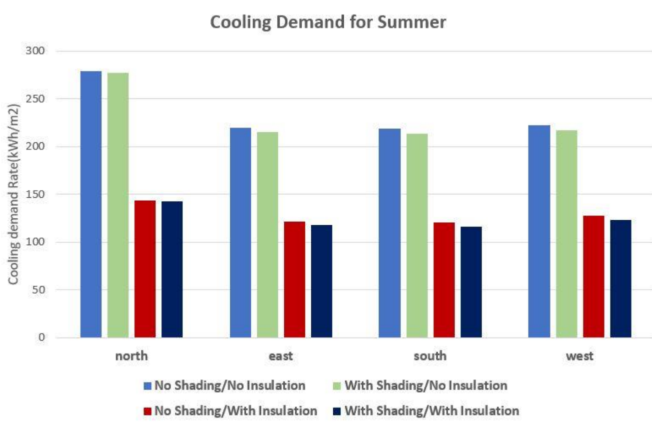
Figure 4-9 3D longitudinal section showing summer and winter rooms with the position of sun in the sky

In what follows, the model shows in figure (4-8) is simulated in Grasshopper plugin of Rhino software to analyze effect of central yard architecture for a building in 5 different cities of Iran.

4.6.1. Summer analysis

RASHT

window location	no insulation				with insulation			
	comfort percentage (%)		cooling demand (kWh/m2)		comfort percentage (%)		cooling demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	76%	76%	278.87	277.71	83%	83%	144.03	142.89
east	77%	77%	219.81	215.15	86%	85%	121.67	118.04
south	76%	76%	219.34	213.53	84%	83%	120.84	116.08
west	76%	76%	222.46	216.90	84%	84%	127.42	123.20



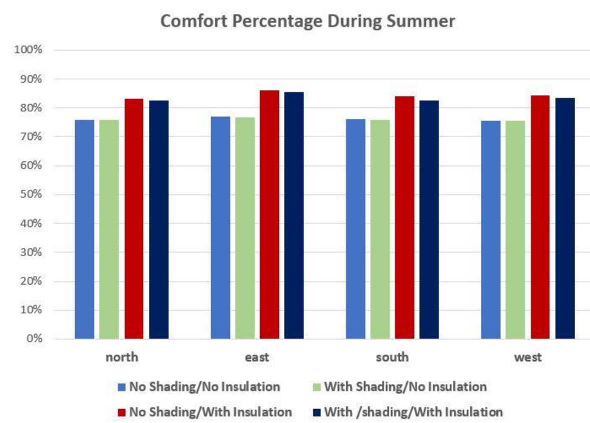
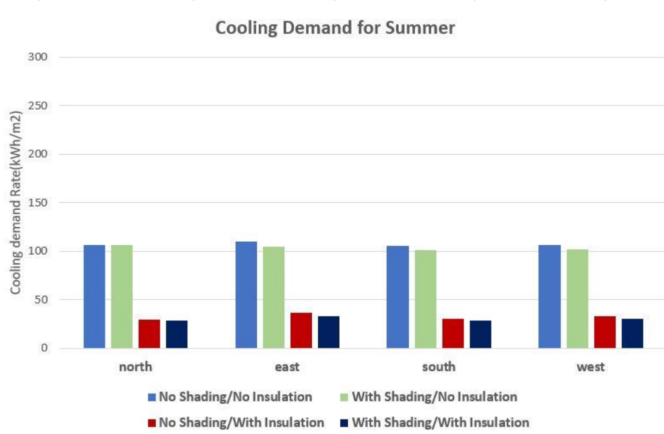


Chart 4-4-a analysis results for summer room during summertime, with/without insulation, and with/without shading

HAMEDAN

window location	no insulation				with insulation			
	comfort percentage (%)		cooling demand (kWh/m2)		comfort percentage (%)		cooling demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	62%	62%	106.69	106.31	73%	73%	29.18	28.91
east	61%	61%	110.12	104.62	75%	74%	36.78	33.01
south	62%	62%	105.96	101.47	74%	73%	30.37	28.54
west	63%	62%	106.56	102.52	82%	80%	32.72	30.11



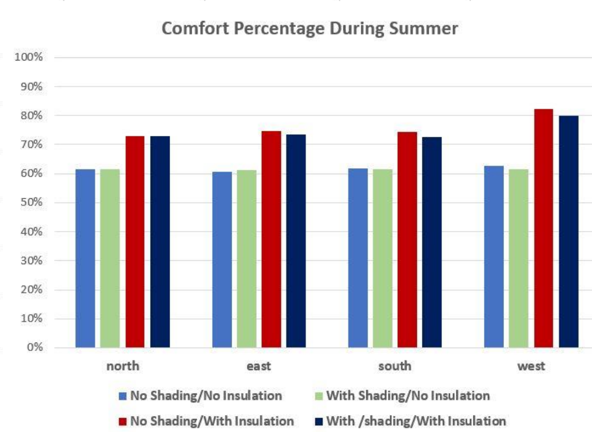
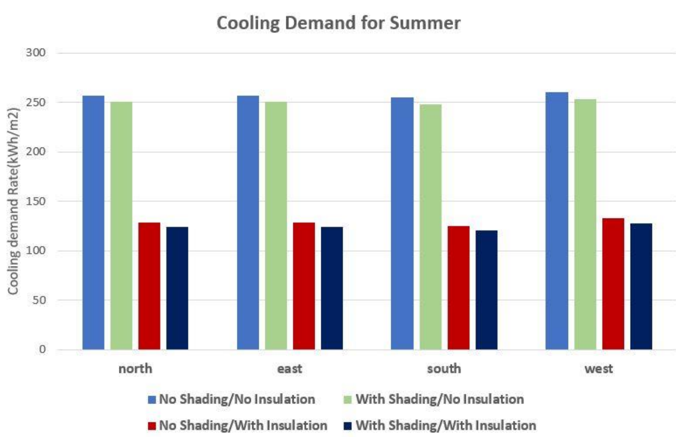


Chart 4-4-b analysis results for summer room during summertime, with/without insulation, and with/without shading

TEHRAN

window location	no insulation				with insulation			
	comfort percentage (%)		cooling demand (kWh/m2)		comfort percentage (%)		cooling demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	47%	46%	256.76	251.02	46%	43%	128.32	123.96
east	47%	46%	256.76	251.02	46%	43%	128.32	123.96
south	46%	46%	255.53	247.78	41%	39%	125.39	121.03
west	46%	46%	260.20	253.03	44%	42%	132.89	127.45



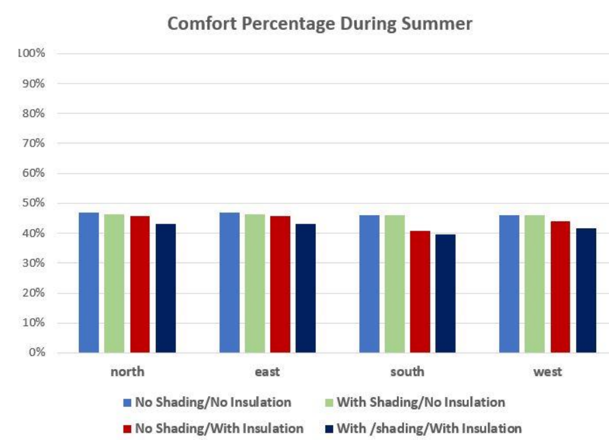
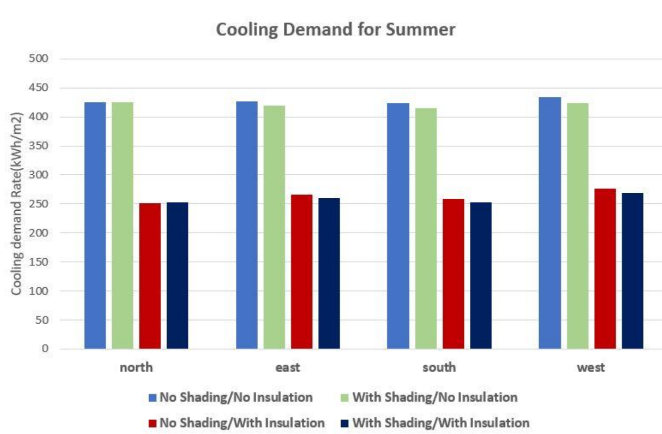


Chart 4-4-c analysis results for summer room during summertime, with/without insulation, and with/without shading

YAZD

window location	no insulation				with insulation			
	comfort percentage (%)		cooling demand (kWh/m2)		comfort percentage (%)		cooling demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	60%	60%	424.58	425.39	43%	43%	252.03	252.23
east	62%	61%	426.42	419.16	57%	54%	265.67	260.45
south	60%	60%	423.57	415.48	48%	44%	258.25	252.87
west	60%	60%	433.47	424.35	52%	50%	275.83	269.66



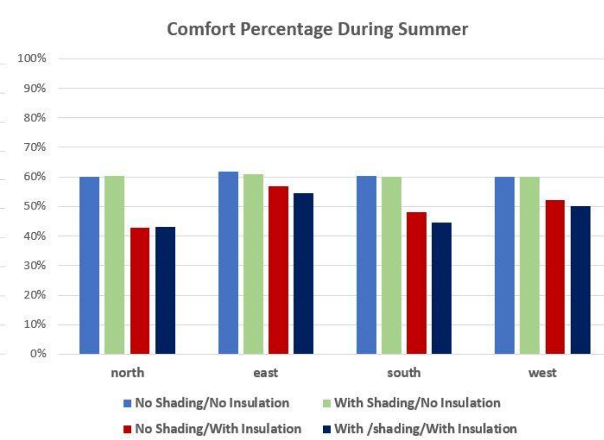
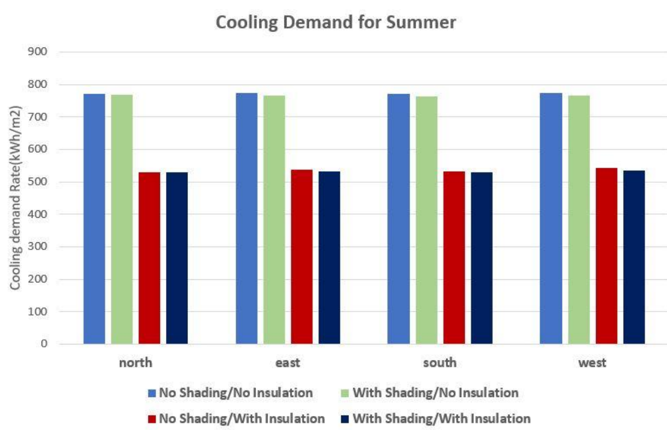


Chart 4-4-d analysis results for summer room during summertime, with/without insulation, and with/without shading

BANDAR ABBAS

window location	no insulation				with insulation			
	comfort percentage (%)		cooling demand (kWh/m2)		comfort percentage (%)		cooling demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	72%	72%	770.59	768.92	44%	43%	530.37	528.67
east	74%	73%	772.21	764.91	49%	46%	537.41	530.83
south	73%	72%	770.68	763.85	49%	45%	533.07	528.38
west	72%	72%	774.59	765.15	50%	47%	543.06	534.82



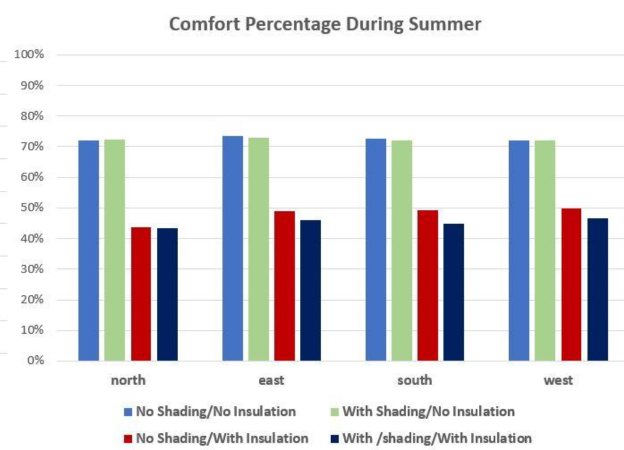


Chart 4-4-e analysis results for summer room during summertime, with/without insulation, and with/without shading

To understand the best situation for windows, a shoebox is studied for the cooling demand energy and comfort percentage during the summertime. According to the results shown in charts (4-4-a), for city of *Rasht* when the window is located at the northern façade, it would cause the maximum energy for cooling down the building. Locating the window at the other sides, causes the same results. The least cooling demand with the highest comfort percentage relates to the southern window with shading for a building with insulation.

According to the results shown in charts (4-4-b), for the city of *Hamedan*, cooling demand for a building with window at the eastern façade causes the maximum energy use during the summertime. The best result for having the least cooling demand energy with the highest comfort percentage relates to a building with window at the western façade, without shading and with insulation.

According to the results shown in charts (4-4-c), for the city of *Tehran*, by considering cooling demand, it is better to have building with insulation, and window must have shading. The location of the window can be at north or eastern façade.

According to the results shown in charts (4-4-d), for the city of *Yazd*, based on cooling demand, the building must have insulation. The window can be located at the eastern or western façade without shading.

According to the results shown in charts (4-4-e), for the city of *Bandar Abbas*, the building must have insulation for causing less cooling demand, and locating the window at the northern façade causes higher comfort percentage, with no difference in having or not having any shading.

4.6.2. Winter analysis

RASHT

window location	no insulation				with insulation			
	comfort percentage (%)		heating demand (kWh/m2)		comfort percentage (%)		heating demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	63%	63%	1219.90	1043.36	95%	95%	1095.95	1096.23
east	64%	64%	1219.11	1043.30	96%	95%	1092.07	1093.40
south	64%	64%	1216.81	1043.69	96%	96%	1082.04	1084.64
west	63%	63%	1219.45	1044.99	95%	95%	1090.07	1091.42

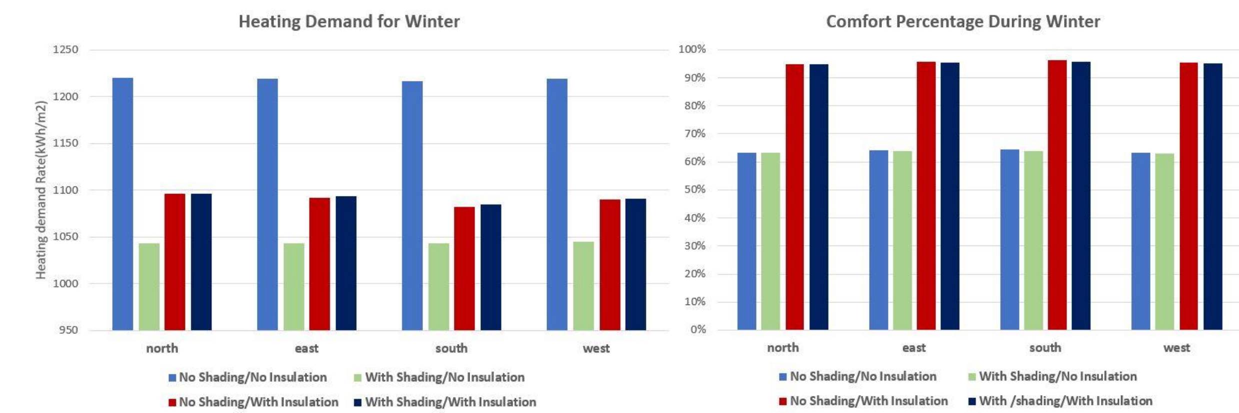


Chart 4-5-a analysis results for winter room during wintertime, with/without insulation, and with/without shading

HAMEDAN

window location	no insulation				with insulation			
	comfort percentage (%)		heating demand (kWh/m2)		comfort percentage (%)		heating demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	25%	25%	1430.21	1429.04	52%	52%	1202.67	1202.20
east	25%	24%	1428.77	1430.70	58%	55%	1196.76	1199.20
south	26%	24%	1426.45	1433.43	67%	61%	1185.67	1193.71
west	25%	25%	1429.45	1431.28	58%	56%	1194.39	1197.06

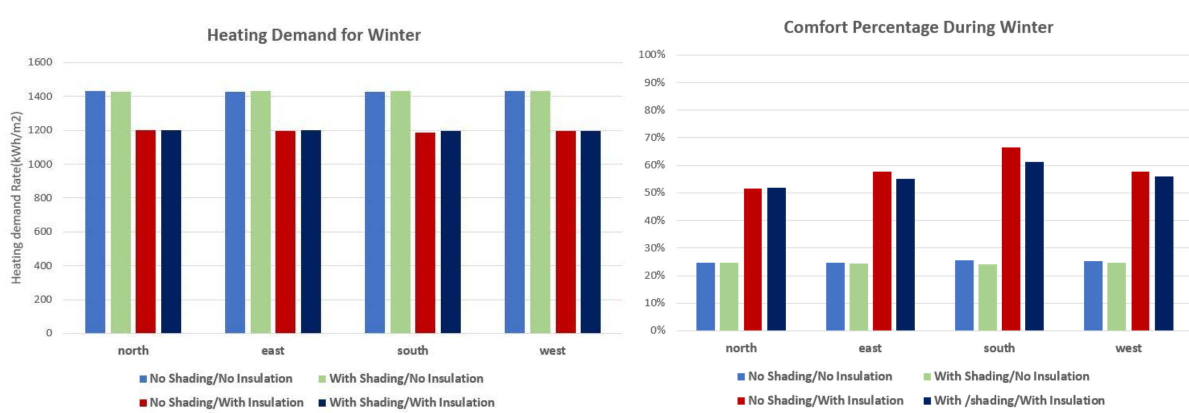
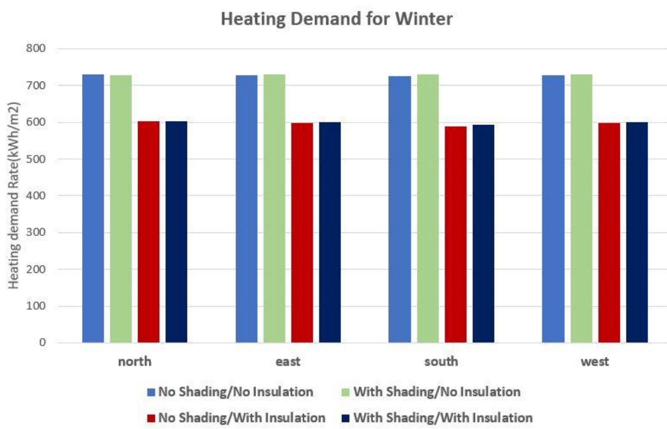


Chart 4-5-b analysis results for winter room during wintertime, with/without insulation, and with/without shading

TEHRAN

window location	no insulation				with insulation			
	comfort percentage (%)		heating demand (kWh/m2)		comfort percentage (%)		heating demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	27%	27%	729.53	728.39	68%	69%	602.41	601.82
east	27%	26%	728.72	729.46	75%	73%	598.63	599.84
south	28%	27%	726.21	730.73	83%	80%	588.34	593.64
west	27%	26%	728.72	729.46	75%	73%	598.63	599.84



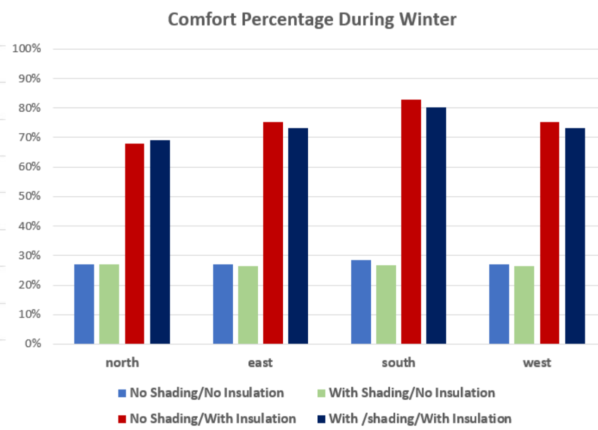
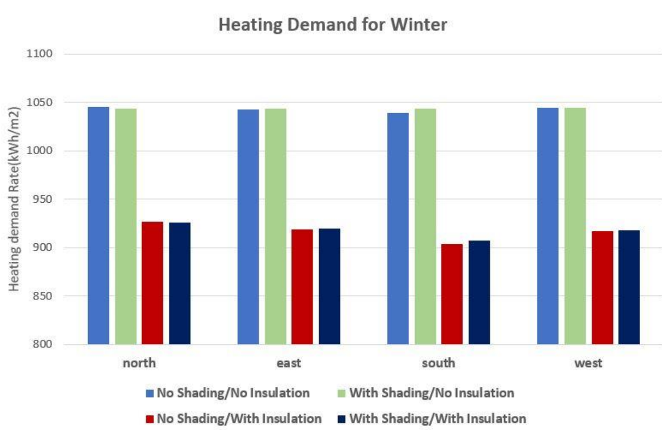


Chart 4-5-c analysis results for winter room during wintertime, with/without insulation, and with/without shading

YAZD

window location	no insulation				with insulation			
	comfort percentage (%)		heating demand (kWh/m2)		comfort percentage (%)		heating demand (kWh/m2)	
	no shading	with shading	no shading	with shading	no shading	with shading	no shading	with shading
north	34%	35%	1045.14	1043.36	64%	65%	927.13	926.18
east	34%	34%	1042.76	1043.30	78%	77%	918.67	919.63
south	37%	35%	1039.54	1043.69	84%	83%	903.58	907.26
west	35%	34%	1044.64	1044.99	71%	70%	917.37	918.26



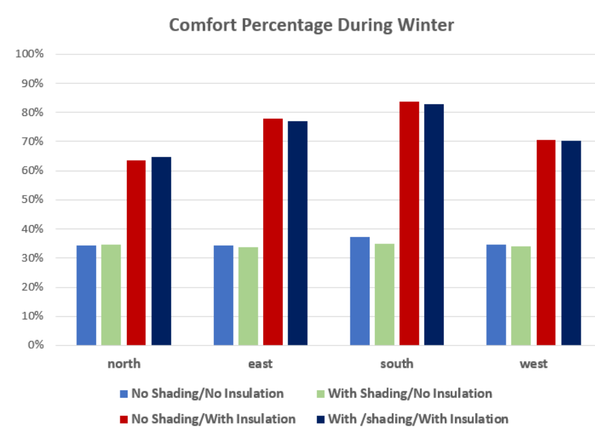


Chart 4-5-d analysis results for winter room during wintertime, with/without insulation, and with/without shading

For studying the shoebox in different situations during wintertime, analysis is done with results shown in charts (4-5). According to the results shown in charts (4-5-a), for city of Rasht the least heating demand energy relates to a building without insulation, but by considering the comfort percentage, the best result relates to a building with insulation and window at south. There is no need for having shading.

According to the results shown in charts (4-5-b), for the city of Hamedan, the results clearly shows that having window at the southern façade, for a building with insulation and without shading causes the least heating demand with the highest comfort percentage.

According to the results shown in charts (4-5-c), in Tehran the situation is the same as Hamedan during wintertime. So the best result by considering heating demand and comfort percentage, relates to an insulated building with no shading and window at the southern façade.

According to the results shown in charts (4-5-d), also in Yazd an insulated building with winow at the southern façade and no shading causes the best results.

4.7. "Godal baghche" or garden pit

In some buildings, like mosque-school of Agha Bozorg in Kashan/Iran showed in figure (4-10), by the central courtyard layout, construction of a garden pit at a level lower than the ground inside the yard makes a cool area. In the summertime, trees shadow prevents sun radiation to the lower spaces, also in the wintertime as leaves of the trees fall, sun radiation can be used. During the summer, there is a significant temperature difference between the garden pit and the upper yard. Garden pit can naturally behave like a cooling source for the upper parts as it has direct contact to soil and benefits from ground cooling and in winter generates heat by ground heating.

Figure 4-10 Godal Baghche or garden pit in mosque-school of Agha Bozorg, Kashan/Iran

To have a better understanding of what a garden pit does, following simulation results in figures (4-11) show wind speed and air pressure inside two different layouts of a building yard, with and without garden pit. Also, a third case shows the effect of a deeper pit. Results are CFD analysis done with Grasshopper/Butterfly plugin in software of Rhino with a base wind speed of 5 m/s and the direction as shows below. Based on simulation results, garden pit affects the wind speed inside the yard, which makes a more suitable situation in a hot day for occupants. As the pit is deeper, the occupant feels higher wind speed also, the air flow pressure would be higher. As a result, garden pit affects positively during hot days.

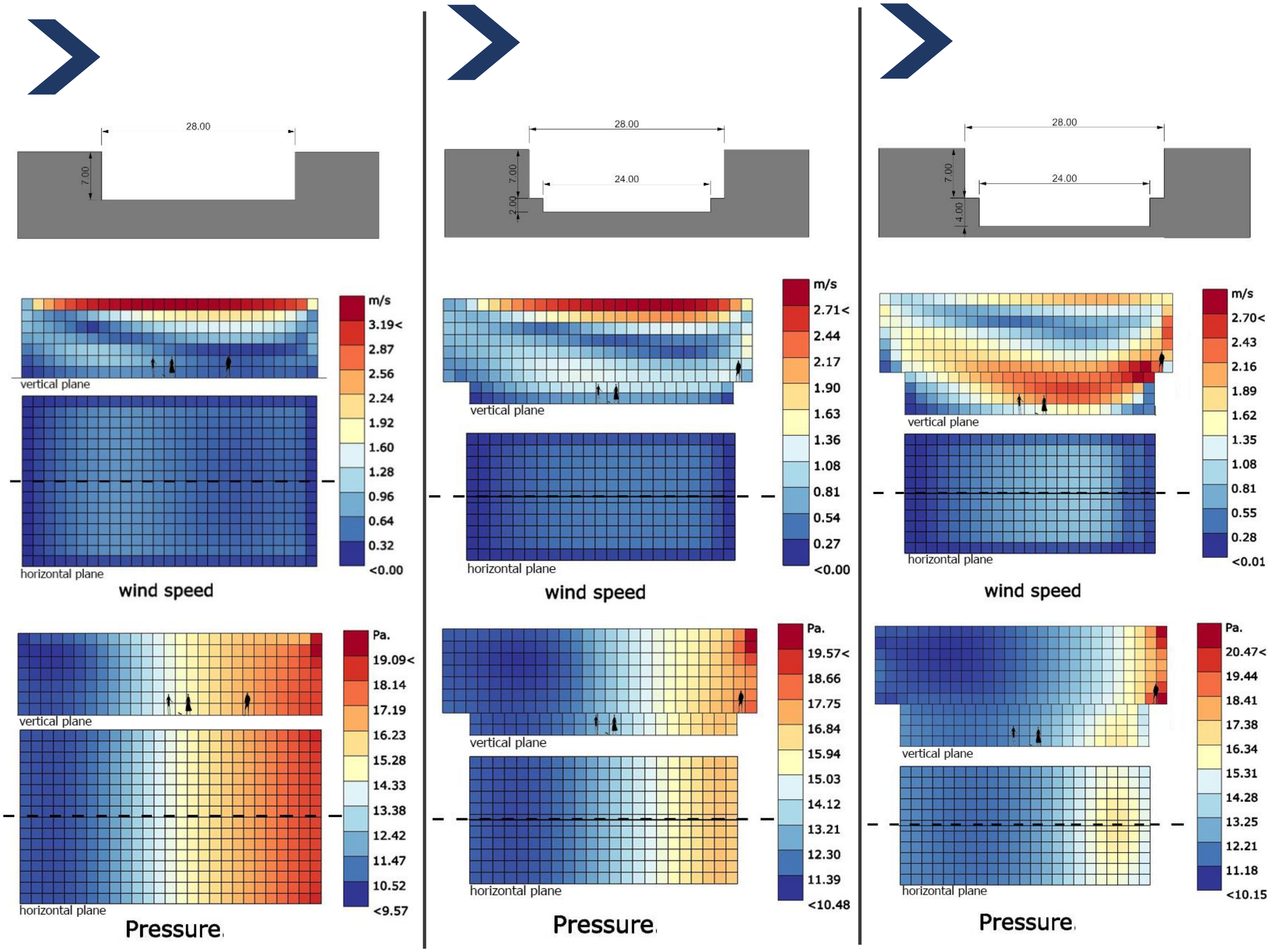


Figure 4-11 wind speed and air pressure for a yard with no garden pit at left, with 2m deep garden pit at middle and with 4m deep garden pit at right

Considering table (4-8) which shows thermal condition of each typical cities in Iran during the hottest hour of a whole year, benefiting from garden pit can affect positively for all climates. The deeper the pit, the higher the air stream would be at the height of a human.

City	hottest hour	external condition		
	m/d/h	dry bulb temperature(°C)	wind speed(m/s)	wind direction(°)
Rasht	aug/19/15	35.3	4.6	308
Hamedan	aug/1/16	38.6	3.875	40
Tehran	july/28/15	41.6	4.9	130
Yazd	july/21/15	44.6	3.7	315
Bandar Abbas	june/19/15	44.5	4.9	130

table 4-8 general thermal condition for five typical cities of Iran

4.8. Reference

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5. Final Guidelines for Architects and Engineers

5.1. Brief guideline

To design a residential house for the climate regions of Iran the following suggestions are claimed:

To completely understand the climatical situations in all region of Iran, the country is divided into 5 different climate zones and for each climate, one city is selected to have the overall relevant features. In chapter 2, different weather features for each city are studied to have an absolute view and introduction of the whole climatic zones.

The climates and cities are divided as follows:

1. *Rasht*, humid subtropical with warm summer and cool winter

2. *Hamedan*, cold semi-arid with snowy winter and warm summer

3. *Tehran*, arid with hot summer and cold dry winter

4. *Yazd*, hot desert with dry winter

5. *Bandar Abbas*, with hot humid climatic condition

In chapter 3, different passive technologies are studied and applicability of each one is measured based on overall properties and texts.

In chapter 4, passive technologies that has been used by ancient Persian architects are studied and the applicability of each technology is evaluated by simulation in different software.

Finally, there is a quite good understanding of suitable passive technologies to adapt residential buildings in 5 different cities of Iran. In the current chapter, there will be a conclusion to help engineers and architects to design zero-energy houses in country of Iran. Table (5-1) shows a brief conclusion of what is studied in the previous chapters.

city	mass cooling	daytime ventilation	mass cooling + night ventilation	windcatcher	windcatcher+hozkhane (evaporative cooling)	window location	shading	insulation	godal baghche
RASHT	not effective	effective	not effective	not effective	not effective	south	yes	yes	effective
HAMEDAN	effective	effective	effective	not effective	effective	west	yes	yes	effective
TEHRAN	effective	effective	effective	not effective	effective	north	yes	yes	effective
YAZD	effective	effective	effective	not effective	effective	east/west	yes	yes	effective
BANDAR ABBAS	not effective	effective	not effective	effective	not effective	north	yes	yes	effective

table 5-1 effectiveness of different passive strategies for all climate zones of Iran

To have a more detailed view about the range of success by applying each technique in process of passive cooling, table (5-2) represents the details.

city	mass cooling	daytime ventilation	mass cooling + night ventilation	windcatcher+hozkhane (evaporative cooling)	window location	shading	insulation
RASHT	32%	86%	32%	27%	south	76%	84%
HAMEDAN	52%	67%	52%	54%	west	62%	82%
TEHRAN	73%	49%	76%	76%	north	47%	43%
YAZD	61%	63%	68%	75%	east/west	61%	57%
BANDAR ABBAS	35%	51%	38%	30%	north	72%	44%

table 5-2 range of effectiveness of different passive strategies for all climate zones of Iran

based on table (5-2) it can be reported that for all cities in country of Iran, using daytime ventilation, applying shadings, and benefiting from thermal insulations are necessary to have a building with low energy demand for cooling and heating during different seasons. According to the wind speed and direction, to have a more efficient natural ventilation, the location of window for each city is reported, also it must be considered that adding windcatchers can enhance the results for cooling down the buildings in all climates, but it must be considered that relative humidity is an important factor which affects the success of windcatcher application. As it is clear in the mentioned table, in cities of Rasht and Bandra Abbas which are located near the sea, by having high relative humidity it is not possible to decrease the internal temperature by using evaporative cooling systems. Also mass cooling integrated with night ventilation is not favorable for above cities.

Finally, further analysis by simulation of a base house with appropriate passive technologies is needed to understand the effectiveness of them in a more detailed way. The results in table (5-1) and (5-2) are suggestions for architects and engineers for design beginning.