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# Assessing Permeability of Design in the Modulation of Thermal Comfort Using Bioclimatic Digital Indicators (Field Study of Larry'sHouse in Yazd City)

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***Abstract:*** *Many specific environmental factors play important role in clarifying field of thermal comfort and thus environmental comfort. Among these factors, Designers pay attention to components that can becontrolled in field of design to improve comfort quality. Air temperature, humidity, radiation and wind speed are among indicators and environmental factors defining the boundaries of their comfort; the temperature and humidity factors cannot be raised except in special cases in design, but the radiation from the Sun and surface of Earth under name of "mean radiant temperature" (MRT) can be greatly influenced by design.Main goal of this study is to show effect of design solution on the control and modulation of comfort components. According to this research, field study is appropriate way to collect basic data and to test hypothesis. We conduct a research about Yazd in which habitation is not possible except in the light of intelligent design and utilization of natural resources and mitigation of region's harsh climate. Due to the diversity of urban spaces in the process, we restrict our study to residential house. We select Larry'shistorical house situated in old texture of Yazd City. Result analysis is performed by simulation and data calculation through valid climate index based on energy balance of human body in the form of predicted mean vote (PMV), physiological equivalent temperature (PET) and standard effective temperature. Comparing the data with data of Yazd synoptic station shows how effective is spatial structure in the microclimate conditions. Results of this study are representative of successful design solution in modulation of climatic conditions in people's accommodation during the hottest days of summer and the coldest days of winter in this region.*

***Key Words:*** *climatic design, physiological temperature index, microclimate, human energy balance model, environmental comfort.*

## INTRODUCTION

Natural forces and their applicationsattract attentions of planners and architecture in improving environmental space under title ofclimatic design, heat welfare, climatic design and comfort. In the field of thermal comfort, combination of environmental variables provide specialinsightregarding physiology. Many studies are conducted in field of heat welfare and urban fabric. These studies assess how effective is spatial structure on the urban aerodynamics. Urban levels creates a complex micro-scale structure: this patterns consist of variablesincluding radiative and thermal properties of surfaces, the amount of radiation received from adjacent surfaces and shadows caused by surrounding objects (Robayasni, 2004). In the current studyin

addition to environmental factors effective in the thermal comfort, we assess factors that are changed by controllable design and effectiveness of design. So this study is considered as case study assessing structure of the physical design. It is conducted to present designers' intervention in controlling wind, amount of received radiation as two critical variables of the climate that modulates temperaturein residential houses of Yazd City(in microclimate). Acase study is historical house of Larry situated in old texture of Fahadan. Data collection is performed in the coldest days of the year, from December 22, 2014 to January 20, 2015 in the time span ranged from 9 am to 15 pm. Data analysis with valid climatic indexes based on the energy balance of human body is adoptedin the form of predicted mean vote, physiological equivalent temperature, and standard effective temperature. RayMan software is used in this study to accurately simulate and calculate data. At last, extracted data is depicted by Excel software for clear presentation.

## 2. Background

Traditionally studies of thermal comfort are conducted in two ways, i.e. laboratory studies and field study. One of the most leading research in this respect is a study conducted in 1833 in England that is in field of interactive effects between climate and architecture (Luke Howard, 1833). Koenigsbergeret al. (1972) in "Manual of Tropical Housing and Building" present criteria to design building and settlement. This book discusses different classifications, recognition of local climate, way of identifying it with the climate area, conditions of human thermal comfort and,design criteria of discussion (Koenigsberger, 1972). Razjoyan in a book titled "Comfort by Architecture in Harmony with Climate", assesses measures of comfort and analyzes components of sun, wind and their control method to reach modulation of comfort in Iran (Razjoyan, 1367, 1379). Kasmaee (1378) in "Climate and Architecture" deals with climatic factors, climate and building, climate and human. Bentley et al. in a book titled "Responsive Environments" presents a method for interaction of city and climate. Also, they put emphasis on the radiation and wind among environmental factors (Bentley, 2000). In "Microclimatology" (written by Kaviani, 1380), adaptation and modulation ofconstruction is assessedin climate; furthermore, changes resulted from building constructionareanalyzed in the state of radiation, heat, humidity, aerodynamic properties of surrounding. In addition, this matter are discussed in many countries. In a research called "Comfort Improvement by Use of Environmental Design", climactic factors are analyzed in association with urban environments, buildings, and condition of human life (De la Espriella, 2002). In Bangladesh, one research deals with changes of weather and effect of climatic condition on the tuition fee planning (Hass & Nahiduzzaman: 2008).

### 2.1. Heat Comfort

Physiologically, thermal comfort conditions are scope composed of temperature and humidity in which mechanism of regulation of body temperature has minimum activity (Givonis, 1976). There are many explanationsabout definition of thermal comfort. Ashrae considers thermal comfort as mental condition representing people's satisfaction about ambient temperature. Mental conditions in the writing of Ashrae indicate combination of mental and physical conditions into feeling called thermal comfort. Many variables are effective in determining comfort limits. Examples are environmental factors and individual variables including physical factors (wear rate and activity rate), and psychological factors (thermal expectation, attendance duration, presence's experience, etc.).Olgyay considers a limit for thermal comfort on which the definition is based. Forhim, thermal comfort is a condition in which minimum energy consumption is used to create desirable environment. In addition to study conducted in the field of definition and principle of comfort, many studies are conducted to determine comfort limit by means of digital indexes. Now, well- known indexes are suggested. The indexes are associated with human physiology that are derived from energy balance equation of human body. Today in many studies, bioclimate has special status. Indexes of physiological equivalent temperature and predicted mean vote are known as PET and PMV respectively (Matzarakis, 2001,

45). One of most comprehensive thermal indexes in the field of standard effective temperature is known as SET;furthermore, Ashrae Institute succeeds in achieving complete model for this index in 1972.

### 2.2. Relationship of design and climatic variables

Many researches are conducted in field of urban structure and its effect on the urban climate. Studies based on theurban density and width- to- length ratio have relationship with climatic variables. It seems they play important role in the structural patterns in urban climate (Oke, 1987). Mere existence of a city effects on the local climate, it changes not only the city but also urban climate. Urban levels of construction creates complex micro-scale structure. These patterns consist of variables including radiative and thermal properties of surfaces, the amount of radiation received from adjacent surfaces, sky view factors, and shadows caused by surrounding objects (Robayasni, 2004). Air temperature, humidity, radiation and wind speed are environmental factors and indexes for the definition of comfort limits. The studies show that temperature and humidity factors cannot be raised except in special cases of design. But wind variable as well as radiation received from sun and surface of ground can be influenced by the design (Bentley, 2001). Intervention of designer in the form, orientation, materials, sky view factor, and shadowiness results in the changes of radiation and wind properties. Applying design solutions to control air temperature and humidity are very limited and impalpable.

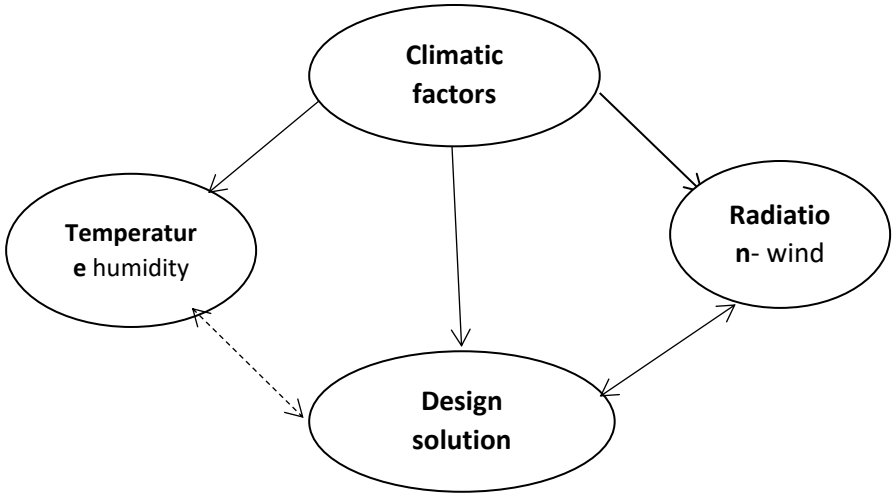



**Figure 1.** Relationship between design and climatic variable (source: Authors)

## 3. Research Methodology

Research method in this study is to assess case study that is conducted based on the observation and quantitatively environmental variables in the coldest day of the year from December 22, 2014 to January 20, 2015 in historical house of Larry in Yazd City. Time interval of the research is ranged from 9 a.m. to 15 p.m. and it is extracted (recorded) once every 10 minutes. Selecting above- mentioned time interval is due to the presence of visible radiation as an important factor for weather conditions of this climate during these hours. Data are extracted in both microclimatic levels (case study) and urban climate (ten- minute data recorded in the synoptic station). Then climatic digital indexes are used to compare data and to assess the effect of architecture in creating positive or negative changes.

### 3.1. Space of Study

Architectural texture and structure of Yazd region is one of prominent examples of hot and dry climates. Location that is studied in this research is house of Larry. It is set of buildings built in thirteen century that have special architectural spaces of desert house in which characteristics of desert architecture is visible. It is composed of two parts i.e. inner and outer parts. Most parts of building are inner part. Then, the yard is located in the center; aristocratic part of building is formed around the yard for four seasons of the year. Selected point to extract data in inner yard (large yard) is selected in center of yard with the same distance from fronts.

**Table 1.** Climatic data of Yazd City (source: Authors)

| Case study | Longitude | Latitude | Height | Type of climate (based on Domarten) |
|---|---|---|---|---|
| Yazd City | 54, 17 | 31, 53 | 1230 | Dry desert |

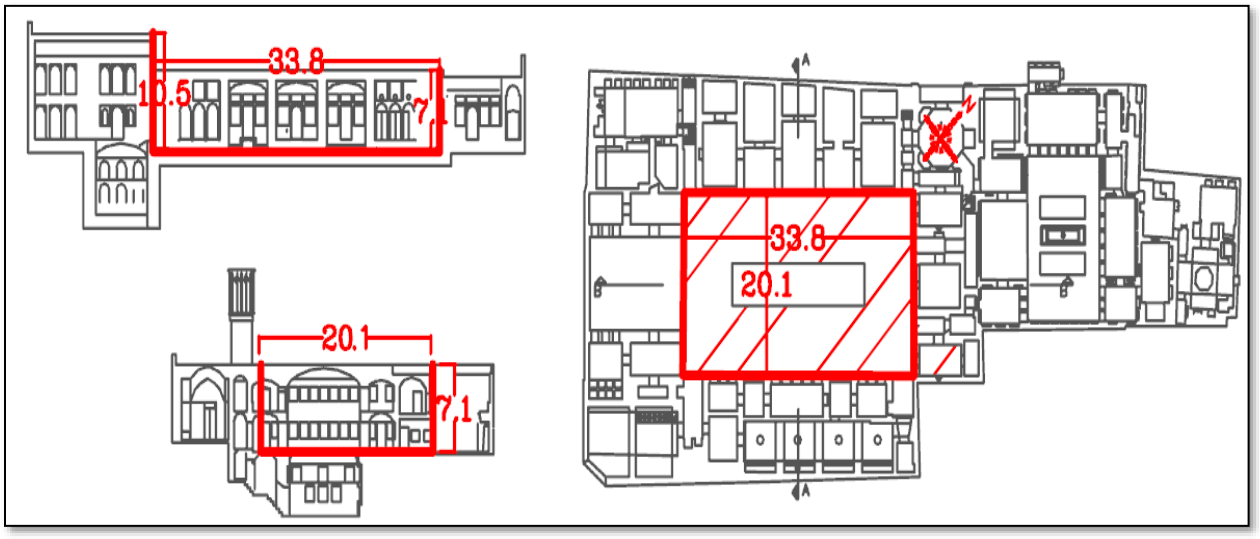
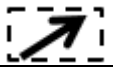



**Figure 2**. space studied in the house of Larry; (source: Authors)

**Table 2.** Physical data that are in the building (source: Authors)

| Case study | Area of construction | Area of yard | W/L ratio | View | Height of view | Sky view factor | Construction orientation |
|---|---|---|---|---|---|---|---|
| House of Larry | 1700 | 679 | 2.6 | South view | 10.5 | 0.698 | Northeast-southwest direction |
| | | | | Other views | 7.15 | 0.756 |  |

### 3.2. Data - Collection Tools

We use data logger to measure “temperature variable and air humidity” and we use thermal anemometry to measure velocity. All instruments are installed on the tripod with height of 1.1 m. but receiver of wind speed is installed in the height of 2 m. Air temperature and relative humidity are recorded in the interval of 10

seconds. Furthermore, wind speed is recoded with same time interval. During measurement, thermal anemometer valve was set to increase the accuracy based on wind direction. Table 3 shows specifications of measurement instrument for environmentally climatic variables used in this study.

**Table 3.** Specifications of measurement instrument for climatic variables(source: Authors)

| Variable | Unit | Instrument | Amount of error | Storage method | Time interval | Calibrating company |
|---|---|---|---|---|---|---|
| Air temperature | C° | Skey:DataHog2rht+ Sensor,SDL5060 | ± 0.2C⁰ | manual | 10 min | Sky Instruments Ltd. |
| Relative humidity | % | Skey:DataHog2rht+ Sensor,SDL5060 | ± 1% | manual | 10 min | Sky Instruments Ltd. |
| Wind speed | m/s | Tes:1341(Hot Wire Anemometer) | ± 3%ofreading ± 1%FS | manual | 10 min | TES Electrical Electronic Corp.No:100805458 |

### 3.3. Method of Data Analysis Results

In order to calculate indexes of "physiological equivalent temperature, predicted mean vote, and standard effective temperature, we can use different methods and equations. In terms of complexity and expansion of related equations, experts with different expertise design and present suitable models and software to calculate these applied indexes. In this study, we analyze data results taken from RayMan software. RayMan model that is designed by Andreas Matzarakis to calculate radiative fluxes especially among urban buildings. One of the suitable methods is used to calculate mean radiant temperature and thus physiological equivalent temperature, predicted mean vote, effective standard temperature (Matzarakis&Rutz, 2007 .323). Required variables in this model is categorized in 5 groups that include (1) time variable based on the year, month, day and time variable according to hour and minute to evaluate comfort condition in specified time; (2) position information such as longitude, latitude, and altitude that can give simulation of environmental condition that is excluded from this study, (3) meteorological variables, to calculate thermal indexes including air temperature, relative humidity, air flow and the mean radiant temperature; (4) personal information as physiological properties in the model that should be personal characteristics such as height, weight, age and gender and (5) kind of coverage and activity. Given that physiologic data is about different coverage and activity, so according to models and views of researcher, we can consider some cases as medium state or standard state. For example, these variables can be included about average height, weight and age in the society. About 0.9 coverage of Chloe and average activity such as driving with 80 watt can be intended for man or women. It can be said that there is a few differences in this respect between man and woman and it can be ignored in many cases. After defining variables and entering data, calculated values for every physiologic- temperature index can be obtained.

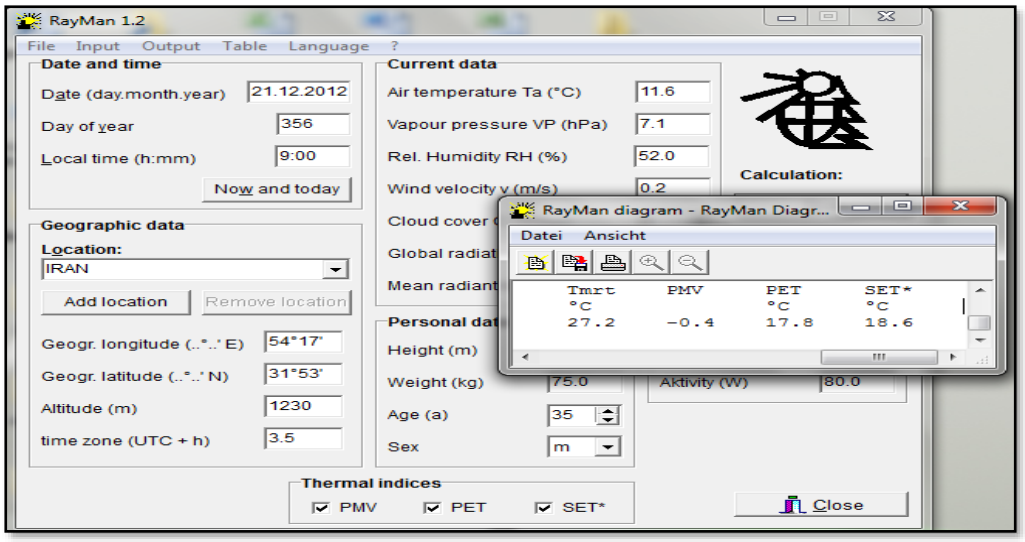



**Figure 2.** Extracted data from RayMan software (source: Authors)

## 4. Research Findings

While using Ray Man software, characteristics such as physiological equivalent temperature, predicted mean vote, standard effective temperature in above time interval in place of study as well as data of synoptic station are extracted. Obtained data can be depicted for clear presentation and comparison.

### 4.1. Comparison between PET in Microclimate and PET in Urban Climate

Emotional classification is done in definition of this characteristics whose range changes from -3.5 (cold) to +3.5 (warm). Table 4 indicates physiological equivalent temperature based on the physiologic stress of 9 degree for people of Europe and Southeast Asia. Due to similarity of Asian region in terms of radiation, research measures of digital division are as follows.

**Table 4.** Physiological equivalent temperature (source: Lin & Matzarakis, 2010 ,21)

| Impression | West and central Europe | Southeast Asia |
|---|---|---|
| Freeze | Less than 4 | Less than 14 |
| Very cold | 4-8 | 14-18 |
| Cold | 8-13 | 18-22 |
| A little cold | 13-18 | 22-26 |
| Comfort | 18-23 | 26-30 |
| A little warm | 23-29 | 30-34 |
| Warm | 29-35 | 34-38 |
| hot | 35-41 | 38-42 |
| Very hot | More than 14 | More than 42 |

As observed in above table, comfort range of Southeast Asia is less than Europe's. In the current study with regard to more comfort of PET than Europe as well as people conformity with warm weather of studied place, we determine "a little warm" for range of comfort. Personal information is assumed by 35 years old, metabolic rateof 80 watt, and 9% conductivity coefficient of clothing. Figure 3 shows physiological equivalent temperature in time interval of 9 am and 15 pm in both microclimate and urban climate. As observed in

diagram of figure 3, there are many differences between characteristic of PET in microclimate and urbanclimate. Diagram of microclimate is in time interval of comfort (light blue) for most hours. Temperature condition between 9 and 10 is in the state of a little (medium) cold stress; temperature between 11:40 and 12 and between 12:20 and 13 is the state of medium warm stress. This thermal rise with regard to being in winter is in favor of comfort state. In diagram of urban climate, we witness cold stress in most of time. Except time between 11:30 and 12:10, most of times was in the condition of a little (or medium) cold stress.

**Figure 3.** House of Larry in Yazd City (source: Authors)

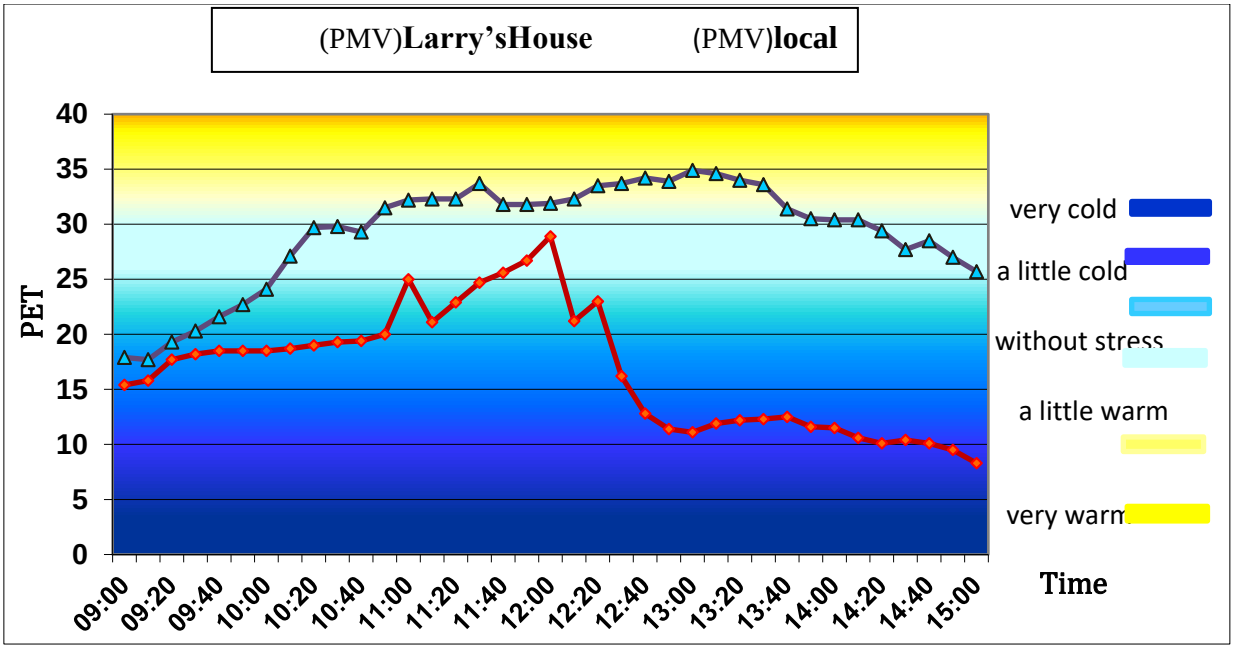



**Figure 3**. PET in yard of Larry's house in day of data collection (source: Authors).

### 4.2. Comparison between PMV in Microclimate with PMV in Urban Climate

As other characteristics to evaluate "predicted mean votes", figure division is done based on the physiologic stress. Domain from -3.5 - +3.5 including 9 physiological states presented in the following table are according to defined thresholds. If this index is between 0.5 and 0.5, comfort condition is predominant; with regard to climate of this region and field studies conducted in this respect, this value is acceptable for value higher than

+0.5. To enter personal information to calculate the predicted mean vote is similar to other entered information for other characteristics.

**Table 5.** Predicted mean vote (PMV) (source: Lin & Matzarakis, 2010, 2014)

| physiological stress | Thermal sensitivity | PMV |
|---|---|---|
| Extreme cold stress | Very cold | - |
| Very cold stress | Cold | -3.5 |
| Medium cold stress | Cool | -2.5 |
| With no cold stress | Comfort | -0.5 |
| A little warm stress | A little warm | 0.5 |
| Medium warm stress | Warm | 1.5 |
| Sever warm stress | Very warm | 2.5 |
| Extreme warm stress | hot | 3.5 |

Figure 4 depicts diagram of predicted mean vote in microclimate (place of study) and urban climate (information of synoptic station). In diagram of microclimate, diagram is in comfort domain with little warm stress for most of hours. On the contrary, diagram goes in the cold stress path in diagram of urban climate; it is defined in time interval between 10 and 12 am in thermal comfort.

**Figure 4**. House of Larry in Yazd (source: Authors)

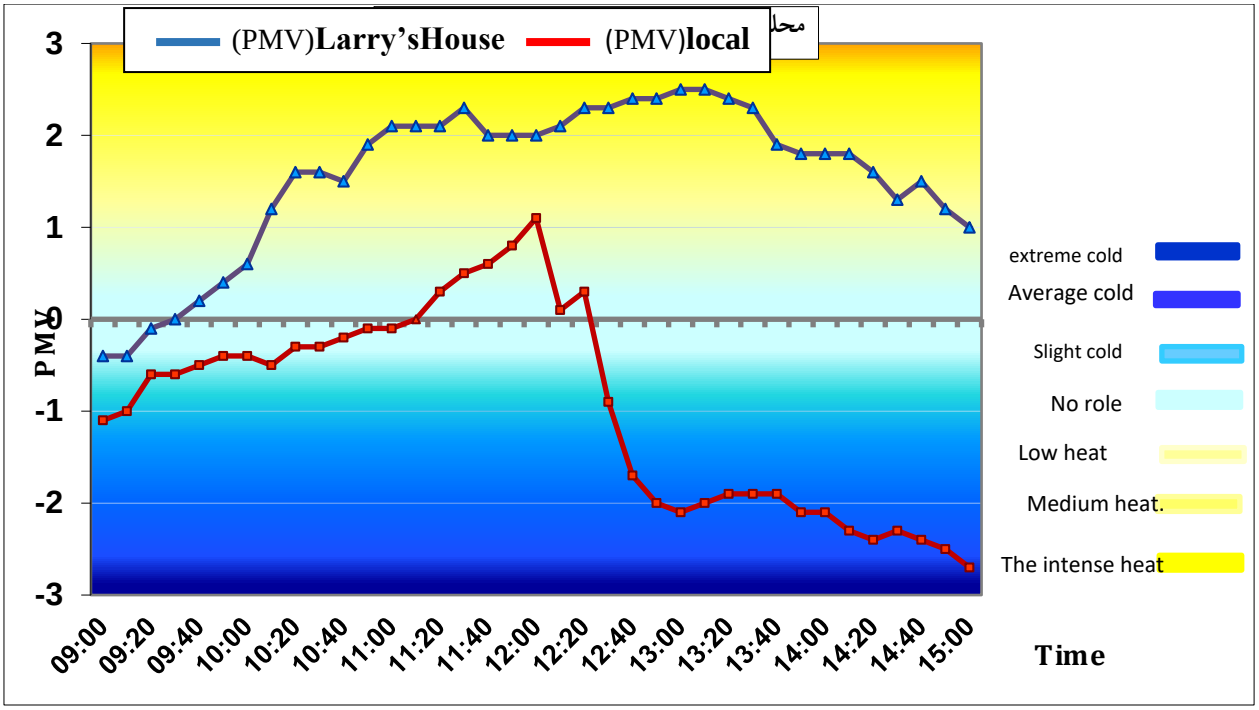



**Figure 4**. PMV in Larry's house in day of extraction (source: Authors)

### 4.3. Comparison between SET in Microclimate and SET in Urban Climate

Threshold defined in SET is presented as in Table 6. Thresholds are stated infreeze interval less than 14 and very hot threshold of PET more than 42 and comfort threshold between 26 and 30.

**Table 6**. Effective standard temperature (EST); (source: Lin & Matzarakis, 2012, 2014)

| Impression(feeling) | Southeast Asia |
|---|---|
| Freeze | Less than 14 |
| Very cold | 14-18 |
| Cold | 18-22 |
| A Little cold | 22-26 |
| Comfort | 26-30 |
| A little warm | 30-34 |
| Warm | 34- 38 |
| Hot | 38-42 |
| Very hot | More than 42 |

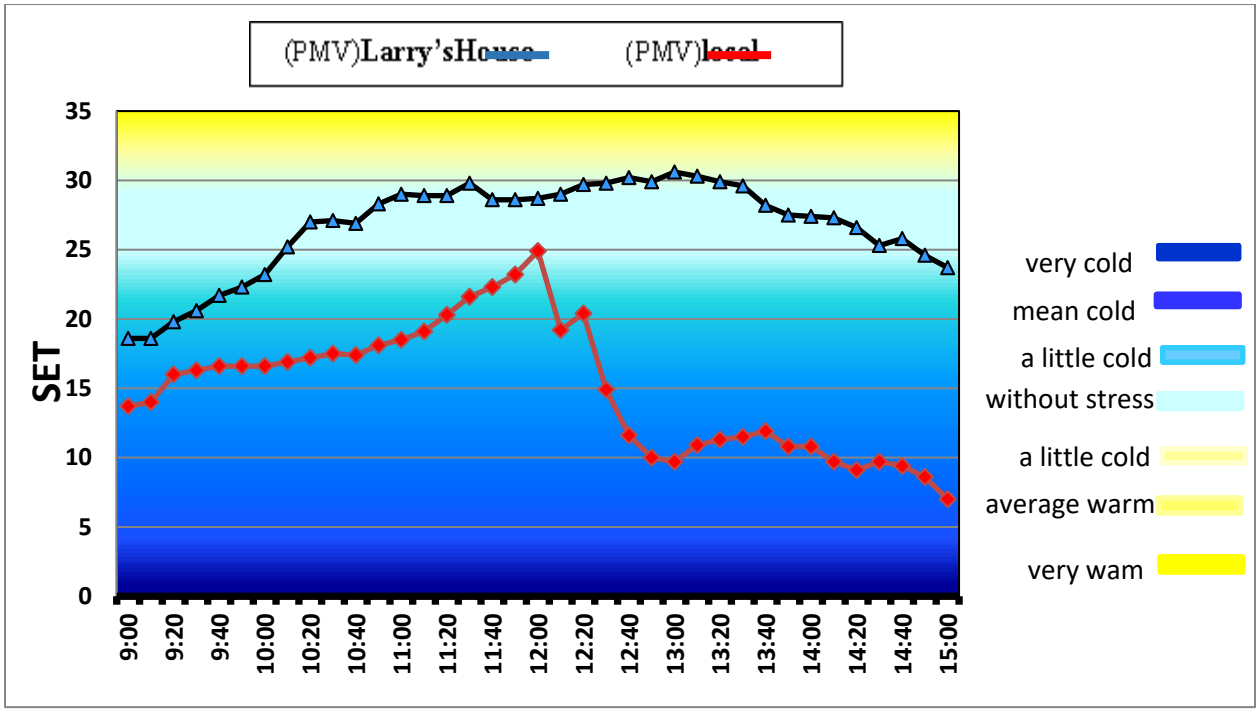



**Figure 5.** SET in yard of Larry's house in data collection day (source: Authors)

In figure 5, diagram of standard effective temperature (SET) is shown. When we compare both diagrams as ones assessed in other characteristics, we witness spatial difference between data in defined thresholds. As observed in figure 5, diagram of microclimate in most of hours is in comfort interval and has less cold stress between 9 am and 10 am;diagram goes stress path or close to threshold with less warm stress in rest of hours.

### 5- Effect of Construction'sGeometry and Design on the Thermal Adjustment

Studies about city structure and its effect on urban climate is one based on the urban density, W/L ratio, sky view factor, in comparison to climatic variables. In the current study while we assess wind variable and radiation in form of digital bioclimatic indexes we observe remarkable difference in the weather conditions in both natural and designed systems. Therefore, in designed space, environmental condition tends to reduce weather stress. Yard ofLarry's Houseis designed in the light of spatial conformity with length to width ratio of 1.6, width to height ratio of 3.2 in southern view and 4.7 in northern view as well as length to width ratio of 2.8 (figure 6).

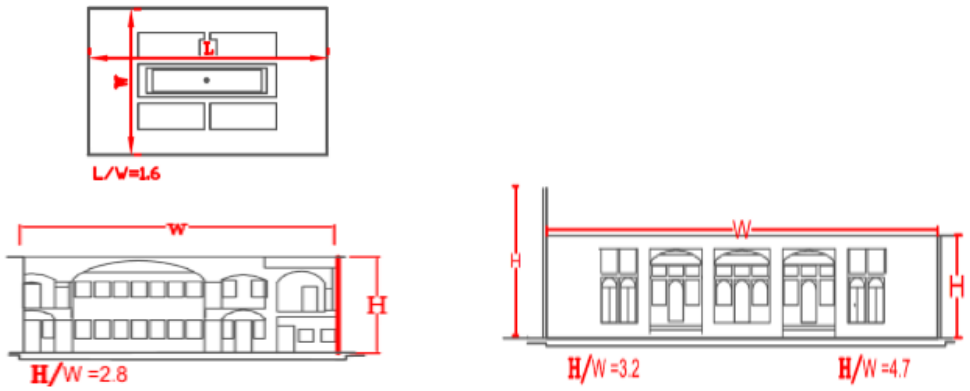



**Figure 6**. Dimensions and proportions of the yard of Larry's house (source: Authors)

Sky view factor is other design variable equal to 0.698 in southern view and 0.756 in other views that succeed in controlling mean radiant temperature of construction. Sky view factor in southern view (alcove) reduces due to moreshadowiness, less sun reception and increase of height: in other fronts, sky view factors is increased, so there are more radiation and less shadowiness in northern view due to orientation and view factor (figure 7).

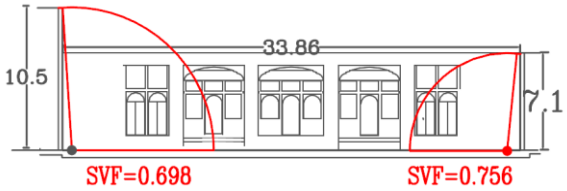



**Figure 7.** Sky view factor, southern view and other view in yard of Larry's house (source: Authors)

While assessing recorded data of environmental factors, we witness tangible control of components of wind and radiation in designed systems in comparison to local climate that is effective in the weather condition. In the current study we observe climatic characteristic involving environmental factors. Studies statistics of environmental space is shown for the local space (synoptic station) with minimum and maximum values in table 7.

**Table 7**. Recorded data of wind and radiation variables in two climate under study(source: Authors)

| | **Minimum** | | **Maximum** | | **Mean** | |
|---|---|---|---|---|---|---|
| Variables | urban | local | urban | local | urban | local |
| wind | 0.1 | 0.4 | 0.5 | 3 | 0.2 | 1.9 |
| MRT | 27.2 | 25.8 | 46.4 | 38.1 | 37.1 | 31.5 |

## 6. Conclusion

The results achieved from two climatic analyses i.e. microclimate (spatial case study) and local climate (Yazd synoptic station) by means of digital temperature-physiological characteristics show many differences between two climates in terms of thermal threshold. As observed in above figures, in spite of little difference between outputs of PMV, SET, and PET indexes, thermal threshold can be assumed the same for all indexes. Given that comparison performed in output of two climates all indexes are formed from general trend: in all indexes in microclimatic region, data are in low comfort threshold and thermal stress in most of intervals. This thermal rise with regard to being in the winter is in favor of comfort in the environment. In region of local climate, indexes are opposite of output in microclimate. And most of intervals are in the cold threshold.

The results showing optimized method of climatic design lead to minimum energy demand in the coldest times of year. In this construction, we witness thermal control of environment whilefollowing design principle passively. Design for appropriate orientation of construction, sky view factor, geometry of construction (width, length, height) and building material are among solutions applied in the microclimate leading to comfort adjustment.

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