Analysing The Climatic Impact Of Central Courtyards In Traditional Houses Of Tabriz

Sasan Moradi [a], Mehrdad Matin [b,*], Rima fayaz [c]

[a] Ph.D. Candidate, Faculty of Architecture and Urbanism, IAU, Centeral Tehran Branch, Tehran, Iran

[b] Assistant Professor, Faculty of Architecture and Urbanism, IAU, Centeral Tehran Branch, Tehran, Iran

[c] Associate Professor, Faculty of Architecture and Urbanism, University of Art, Tehran, Iran

Received: 14 March 2018 - Accepted: 10 May 2018

Abstract

As an inseparable organ, courtyards have influenced the history of architecture with their presence in the context of constructed sites and in a wider sense (architecture), it has provided permissive answers to numerous aspects of climatic, cultural and security demands of the residents. Discovering different aspects of environmental and climatic function in the central courtyard of the traditional residential structures in the cold regions of the country is the main goal of this research. The main fundamental subject that this research is based on, is “to what extent a closed yard in a region with cold climate can be responsive to the unfavorable climate conditions?” and “to what extent it can protect the residents against the unfavorable climate conditions?” In order to answer the main questions of the research, the traditional courtyard houses in the city of Tabriz are selected as the case studies.

The methodology of this study is quantitative. Through comparative analysis, the samples were used based on the outdoor thermal comfort criteria using simulation software. ENVI-met numerical modeling method and the Rayman software model were employed. For this purpose, the PMV and PET indices are calculated and analyzed as the measure for estimating thermal comfort indices in the open spaces and also other indices including air temperature, mean radiant temperature, relative humidity, and wind speed that influences the thermal comfort. The results indicate that according to the PMV and PET indices, courtyards and their adjacent open spaces will be set outside of the comfort zone, especially during the winter, and closed yards does not possess the capability of thermal improvement in comparison to the exterior open spaces. Also, results of the study indicates that, by decreasing the area of the courtyards and the surrounding walls along with the increase of the shaded areas, we are not only limiting the possibility of ventilation in the summer but, this will also decrease the amount of passive heat storage in the surfaces of courtyards in the cold seasons. As the most important accomplishment of this research we can focus on the fact that physical specifications of traditional houses with courtyards in Tabriz do not possess a climatic approach, and the central courtyards in this region are elements which are subordinate to the historical, social and cultural or safety roles of them

Keywords: Cold climate, Central courtyard, Traditional houses, Computer simulations, Thermal comfort, ENVI-met software

1. Introduction

Courtyards have influenced the history of architecture as an inseparable organ, along with the housing and shelters throughout the course of human civilization and with a presence in the heart of structures and in a wider sense of architecture, have provided answers to numerous aspects of climatic, cultural and security demands. The environmental and climatic aspect of the central courtyard is a factor that all of the experts have a mutual accordance regarding its existence and discovery of the hidden aspects of its climatic and environmental roles of it are one of the discussions that have started a new set of studies in this field. From the environmental point of view, experiences from its prolonged history indicate that the central courtyard has served as an efficient and responsive apparatus in the terms of protection from the inconvenient weather and environmental conditions and the use of passive energies. These experiments were mainly tested in the hot and dry deserts areas and they are surveyed in a long list of studies. In the cold western highlands of the country, we observe the creation of housing units that include central yards that have answered a large portion of living, cultural, social demands of the residents in the mentioned areas. Analysing the quality of environmental function of the central courtyard against the unfavorable climatic conditions and the use of natural forces on providing the thermal comfort for the residents in the traditional areas of cold places in the country is one of the subjects that are less noticed by the researchers. The answer to the question of ‘central courtyards in the cold areas have a climatic approach or it is rather than to include a cultural footprint that is borrowed from the warm and dry areas?’ inaugurates a new set of studies in this field. This study does not intend to support or refute the cultural aspect of the central courtyard, but it is rather based on the question that whether the closed courtyards in cold climates can respond to the unfavorable climatic conditions, or if it can protect its residents from unfavorable climate conditions. This research also tries to answer the following question: “how much the thermal comfort in central courtyards of the traditional houses in Tabriz is different from the outside open spaces?” In order to answer this question, the traditional houses in Tabriz with central courtyards were selected as the case studies, and two approaches were considered for the conduct of the research. The first approach is to classify the typology of the mentioned houses from the viewpoint of climatic and physical specifications and the second approach is evaluating the

***Corresponding author Email address:mehrdad.matin@ymail.com

efficiency of the mentioned courtyards in providing thermal comfort in the critical seasons. By analyzing and calculating the thermal comfort and other interfering factors on the thermal comfort we can analyze and evaluate the extent of climatic efficiency of the mentioned courtyards.

2. Research Background

The climatic and environmental role of the courtyards is studied and analyzed in numerous studies. In a part of his Ph.D. thesis, Mohammad Taleghani (2014), shows a higher thermal comfort in the closed yards, as they generate better and longer thermal comfort compared to the linear and singular forms which was based on the computer simulation and field measurements on three different types of building forms, including: single (in which the yard is surrounds the building) - linear (yard is located on one side of the building) and the central yard (the yard is located within the building) (Taleghani, 2014). In a research related to the scale of productivity and energy efficiency, Yasa and Ines (2013), have analysed the houses with central courtyards in different climatic conditions including the hot and dry, cold, warm and humid conditions using computer simulations and have analyzed seven different types of houses with central courtyards in relation to the rate of solar radiation by different building surfaces and the movement of the sun on the thermal function of the building using computer simulations in order to find the thermal comfort conditions and the role of energy consumption. According to their result , the effects of shadow and its cooling load will be reduced as the proportions of the courtyard's length and width becomes closer to the shape of a square (Yasa, 2013). Mohsen Taban (2013), presents an efficient pattern for the courtyards in the city of Dezful in order to mark a correct employment of this element in the architectural design of the contemporary housings by analyzing the dimensions of the central courtyard in the existing traditional residential buildings of Dezful (with a focus on the evaluation of shadow on the surfaces of the courtyard). The recommended dimensions include a 1 to 1.4 ratio between the courtyard's length and width along with a 1.1 to 1.2 ratio between the length and the height of the courtyard's enclosing walls which is offered as the efficient pattern for the dimensions of central courtyards in the city of Dezful (Taban et al, 2013). In Soflaei's Ph.D thesis (2016), which is aimed to analyze and compare different type of courtyards in various hot and dry climate conditions of Iran, she offers an environmental-physical analysis of the selected cases that include physical proportions for the design of the courtyard as a private open space (Miansara) in the residential complexes (Soflaei, 2006).

3. Research Methodology

The focus of this research is on the study and analysis of the climatic role of the central courtyards and the effective factors on thermal comfort conditions in the courtyards of traditional houses in the city of Tabriz.

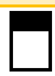
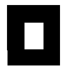
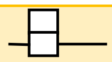
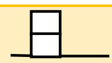
The methodology of this study is quantitative. Through comparative analysis, the samples were used based on the outdoor thermal comfort criteria using simulation software. The computer simulation method is considered as a tool for data retrieval and analysis of data and defining the relationships between variables. So that, for analyzing the findings, the virtual simulation tools and numerical modeling of the micro-climate called "ENVI-met" have been used. Envi-met software is used as the most commonly used software to model thermal comfort in outdoor spaces. Version (4.3.1) of the software is downloadable and installed from the official site of Envi-met. The latest version has three-dimensional editing, as well as more accurate calculating capabilities for building envelope and wall temperatures. The Simulation is performed using version (4.3.1) of the software.
The output of the model is available in two modes: graphical mapping and numerical values with graphing capability.The numerical modeling was done with the aim of analyzing the response of the courtyards in traditional buildings to the climatic conditions in the city of Tabriz.
The computer simulation is performed using climatic software, including version 4.3.1 of the ENVI-met software in order to identify and analyze the thermal comfort quality and its impact factors on the area under study.The other software model that is employed in this research is entitled as the 'Rayman' model. This model software is designed by Dr. Matzarakis in the Institute of climatology at the University of Freiburg. It has the capability of calculating the Tmrt and PET parameters, using the geographical latitude and the total radiation (Mazarakis, Rutz, 2007: 323).

4. Phases of research

This research is conducted in three different stages;the first step is exploring the typology of the traditional houses with courtyards in the city of Tabriz based on the physical indices and specifications which can influence the microclimate and thermal condition of the courtyards and their adjacent spaces. In this regard, a number of 120 cases were selected among the traditional houses in the historical area of Tabriz, belonging to the different periods of time that ranging from Qajar to the first Pahlavi era using library and documentary resources (Organisation of cultural heritage of East Azerbaijan province). Among these buildings, those which lack the precise and authentic information or documents in relation to the indices of the typology, or those which lack a courtyard or were constructed as palaces or urban fabric were omitted; and a final number of 64 houses were selected for the process of typology. The typology of samples determines the path to the selection of a limited number of specimens (as sample head) to measure and test them. The following criteria were selected as the indices for the typology of the existing houses: The orientation in respect to the south , shape of the courtyard (massing of the plan in different sides of the plan), massing of floor, length and width of the courtyard (L) and (W), height of the courtyard's sidewalls (H), area of the courtyard (S), proportions of the courtyard that

includes the width and length proportions in respect to the height of the surrounding sidewalls, as (L/H) and (W/H) respectively.
In the second step of the research in order to achieve a criterion that can be used to select the head of the samples, Table (1) is developed, and the maximum and minimum frequency resulting from the categorization are based on the criteria of the physical proportions of the research in this study. By comparing and searching in the classification, we can extract the closest sample to the maximum frequency, and also the closest sample to the minimum frequency, based on table (1).

Table 1
Selection criteria for sample heads

Criteria	Maximum frequent	Minimum frequent
Orientation (rotation from the south)	(1 -5) SE	(21 – 50) SW
Form of the courtyard (Plan massing)		
Massing of the floors		
Length of the courtyard (L)	(15.1-20) m	(30.1-35) m
Width of the courtyard (W)	(10.1-15) m	(20.1-25) m
Area of the courtyard (S)	(200-300) m^2	(600-700) m^2
Height of the building (H)	(8.1-9) m	(5.1-6) m
width and length proportions (W/L)	0.9	0.6
Width and height proportions (W/H)	2	3

After the implementation of classification and comparison, the Nematzadeh house (As the first sample head) is selected as the representative of the house types with the most frequency and the house of Sattarkhan (As the second instance head) is also selected as the representative of the types with the least frequency in the selected city texture. Indeed, the Nematzadeh house possesses the physical specifications that have the most affinity and coordination with the existing types in the city texture and the Sattarkhan house has the least affinity and similarity in the terms of aforementioned typological factors.
The simulation results of these two houses, will show that to what extent the Nematzadeh house - which has the most affinity with the common types of houses in the studied area - has conformity with the climatic requirements and provides thermal comfort for the residents of this courtyard house in comparison to the Sattarkhan house - which has the least affinity to the existing cases.
In the third step, in order to provide the raw climatic data for the simulation process, the information from the synoptic station related to the 2016 statistical period in Tabriz was employed. According to the 2016 weather data, January and July were marked as the coldest and warmest months of the year respectively. Therefore, the statistical data for January is considered as the critical cold month in winter and the June as the critical warmest month in summer. In order to start the simulation of the two mentioned houses, the surrounding open spaces were also modeled considering the surrounding texture, pathways, and open spaces. Then, to register and perceive the climatic data throughout the simulation process and in order to have a statistical and numerical analysis, 2 virtual sensors were defined and located in the center of each of the yards along with 2 virtual sensors in the outer area of the yard (in the southern part of the texture) as the reference nodes. In figures 3 and 4, we can analyze the functions and impacts of each of the yards in terms of providing thermal comfort and prevention of the thermal loss in the considered cases. The focus of this research includes analyzing the calculation of the thermal comfort conditions within the courtyards. In order to achieve this goal, PMV and PET indices are evaluated as the measures for estimation of thermal comfort in the open spaces. Calculation and analysis of other indices, including: air temperature, mean radiant temperature, relative humidity and wind speed that influence the thermal comfort will also be studied and analysed.

5. Capabilities of the Envi-met Software

Softwares for the energy simulation are gaining an accumulating course of development in the context of buildings [and constructions]. These types of software are employed in the different construction scales that range from the scale of the city to a local neighborhood, neighboring units, buildings, and building elements. Software types vary a lot depending on their scales and their application domains. One of the most reputable and reliable software that is capable of simulating microclimatic conditions in open spaces including courtyards, is ENVI-met software. It was first developed and published in 1998 by professor Michael Bruse, and is employed in different contexts including urban design, architecture and climatological studies for the purpose of calculation and simulation of subcontinents. This software is capable of simulating the s microclimate conditions on different scales, ranging from a courtyard to an urban locality in an inclusive format. The ENVI-met software is a three-dimensional (3D) model that is able to simulate the mutual interactions of the surface, plants and the air in the urban areas with the horizontal resolution capacity of 0.5 to 10 meters in the time span of 24 to 48 hours, in the 10 second time intervals. This software can calculate the air temperature (in centigrade), water vapor Pressure (in hPa), relative humidity (in percentage), the speed of the wind flow (m/s), mean radiant temperature (in centigrade) and presents the results for the analysis (Bruse. M, 2017).
Numerous studies are done using ENVI-met software and its performance have been subjected to analysis and validation. In a research using the ENVI-met software, Thapar (2007) analyzed and measured the thermal comfort in the open spaces and also the urban air quality during the warmest season of the year in two different city textures in Dubai, including an old neighborhood (Deira region) and a relatively newer one (Dubai Marina). Results indicated that formation of shadows, ventilation, and the vegetative field has a considerable role on the improvement of microclimatic conditions in the considered areas (Thapar; Yannas, 2008). In another study by Taleghani, et al (2014), the north-south and east-west pathways in Netherlands are modeled by the ENVI-met software aiming to find the warmest days of the year, and a number of factors including the mean radiant temperature, air temperature, relative humidity and the wind flow speed were calculated and analyzed. Results indicated that the mean radiant temperature has the most effective role on thermal comfort index in the pathways (Taleghani et al, 2014).

6. Thermal Comfort

As a part of the living spaces, courtyards allocate a range of different activities and usages , and as long as the residents demand thermal comfort in their living spaces in order to raise their capabilities, analysing the thermal comfort and the impact of climatic factors on thermal comfort in the courtyards from the viewpoint of different climatic indices are indispensable. Different definitions are presented for the thermal comfort index. According to the ASHRAE standard, thermal comfort indicates a subjective quality that describes the satisfaction level of the residents from the temperature in the environment (ASHRAE,55 : 2001). In such a condition, the human body would neither sense cold nor hot. Maintaining the thermal comfort is done by balancing of temperature between the body and the surrounding environment.
The majority of the studies in the context of thermal comfort are dedicated to the analysis of thermal comfort in the interior spaces and the thermal comfort in the open spaces, including yards are less studied. While facing climatic variables, exterior spaces are uncontrollable, such variables make it difficult to reach the comfort level. The interactions between these climatic variables are much complex, therefore research in the open spaces has more obstacles to pass through in their course compared with the similar studies in the interior spaces of buildings which include a more controllable set of conditions. In a large number of performed studies during the past years, indices of SET, PMV and PET are employed in order to forecast the thermal comfort conditions in the spaces. The result of the investigations for the validation of these indices indicate that the SET and PET indices have a relatively high correlation coefficient (higher than 89%), with the thermal sensation comfort in the open spaces (Monteiro & Alucci, 2009).
In order to evaluate the climatic impact and the thermal comfort quality in the courtyard of the mentioned houses in this research, all of the three main indices were extracted and they will be compared and analyzed during the evaluation of the thermal comfort of the open spaces; along with the mentioned indices, other factors including the air temperature, mean radiant temperature, relative temperature, wind flow speed that affects the thermal comfort will also be analysed and evaluated in the analysis of the findings.

7. Geographic Location and Introducing the Studied Cases

7.1. Tabriz Geographic Location

The city of Tabriz, with an expanse of 25056 hectares is located between 38°1'15" N - 38°8" N and 46°5' E - 46°22' E. The average elevation of the city from the sea level is 1460 meters (Development and reconstruction plan of Tabriz city, 2013). Some of the climatic conditions of Tabriz are cold, severe and long-lasting winters as the ground stays covered with the snow for several months. The precipitation during the winter usually includes snow and a small spring separates winter from summer in this region. By analysing the meteorological data in the city of Tabriz, we can figure out that in 62% of the time in a year, weather is either cold or severely cold while in the 17% of the time the weather is perceived as warm - it never becomes really hot in Tabriz - and in the 21% of the year it has a moderate climate (Shaqaqi, 2016, 2).

7.2. Historical Houses of Tabriz

As one of the main urban centers during the Qajar era, Tabriz is noticeable due to its traditional houses. An approximate number of 300 valuable old houses exist within the city of Tabriz, in which 80 are dedicated to cultural, artistic and academic uses by the Tabriz organization of cultural heritage and tourism. Most of these buildings are located in the historical section of the city (Figure. 1).

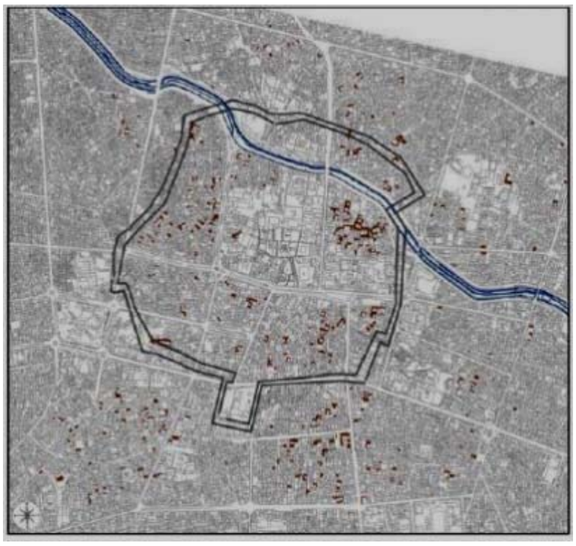


Fig. 1.The historical area of the urban fabric in Tabriz and location of the historical houses (Source:Organization of national heritage and tourism in East-Azerbaijan province)

Traditional houses in Tabriz have an introverted form, and the majority of essential spaces in the building have an overlook to the courtyard, as the lighting and and ventilation of the building was supplied by the courtyard. In the majority of instances, the main part of the building is situated in the northern side of the courtyard; in this way, the sunlight will be usefully employed during the winter. Most of these houses are designed as a two-story block with a basement. Some of the buildings are single story and some other are two stories. Many of the single-storey or two-storey buildings have a basement with a ceiling that stands one meter higher than the surface level of the courtyard for the ease of lighting and ventilation in the space. In some of the medium or large buildings, a pool-house is designed and constructed in the basement which was considered as a suitable place for rest, living and leisure, in combination with the adjacent spaces, especially in the past (Soltanzadeh, 2010). Courtyard of these houses are usually large and full of trees, flooring of the courtyards are usually brickwork. Big stone pools in different shapes are located in the courtyards (Kasmaei, 2015 ,89).

8. Selection of the case studies

Based on the research in the available books, resources and the online website of national heritages organization of East-Azerbaijan province, names, and specifications of an estimated number of 120 historical houses that date back to the late Zand and the Qajar or Pahlavi era were chosen for the study. Of. Those houses (120 houses) that lack complete information or documents according to the typological indices or lack courtyards within (in the form of palaces or urban fabrics) were eliminated from the list of houses, as a number of 64 houses were selected for the typology. And as it was mentioned in research method section of this article, two cases one Nematzadeh and the other one Sattarkhan houses were selected for the purpose of simulation and analysis.

8.1. House of Nematzadeh

Nematzadeh house is one of the beautiful traditional houses in Tabriz which dates back to the Qajar era. This building is constructed in two stories, including the ground floor and the first floor. The building has an entrance porch which provides the access to the courtyard. The building is constructed on the northern and eastern sides of the courtyard. The ground floor incorporates the main entrance in its eastern side, the porch to the building entrance, provides access to the stairs of the first floor and two rooms, and in the northern side the windcatcher and hall of the building and two squinches exist either sides of the windcatcher. Also the ground floor has a windcatcher, hall and two squinches in the corners of the northern side of the building and four rooms in the eastern side of it. Facade of the building includes a balcony with two pairs of columns and sash windows, brickwork and stucco (Tabriz organization of cultural heritage and tourism).

8.2. House of Sattarkhan

Sattarkhan house belongs to the second Pahlavi era although its primary building originally belongs to the Qajar period. Since it belongs to Sattarkhan “Sardar-e melli” [National supreme commander], it is well known under this title, some of the specifications of this building includes: internal courtyards (in the southern part of the building), and the outdoor courtyard (In the northern part) which also includes all of the internal spaces of a traditional house. The roof covering is lumber and timber sheathes type. The executed break work in the northern facade is one of the specific architectural qualities of this building (Esmail Sangari, 2014: 212)

Table 2
Physical specifications of the case studies(Source: Authors)

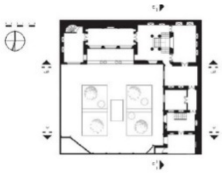
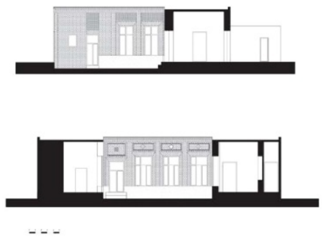
	Nematzadeh's House	**Sattar Khan 's House**
Position and orientation In texture		
Ground Floor plan		
First floor plan		
Sections And views		

Table 3
Physical specifications of the case studies(Source: Authors)

row	**Name of the work**	**orientation**	**Form of the courtyard (Plan massing)**	**Extent of the courtyard**	**Width of the courtyard (W)**	**Length of the courtyard (L)**	**Area of the courtyard (S)**	**Width and length proportions (W/H)**	**Massing of the stories**	**Altitude of the building**	**Width and height proportions (W/H)**	**width and length proportions (W/L)**
1	**Nematzadeh's House**	5 SE		E-W	15.5	16.2	251	0.95		6.9	2.2	.3
2	**Sattar Khan's House**	26 NE		N-S	18	35	630	0.51		5.2	3.5	6.7

9. The Simulation Process

As it was previously mentioned, the scope of this research includes the research and analysis of the climatic performance of the central courtyards and to analyzing the impact of effective factors on the thermal comfort in the traditional houses in the city of Tabriz. In order to start the simulation process, the following steps were taken: At first, the case studies were modeled along with their textures, pathways and surrounding open spaces, according to the (Figures 2 and 3) in the ENVI-met software

Subsequently, for recording the climatic information during the simulation process, and in order to have a statistical and numerical analysis of the simulation process, two virtual sensors were set and located in the open spaces of the courtyards (R2 and R4) as the reference nodes (Figures 2 and 3).

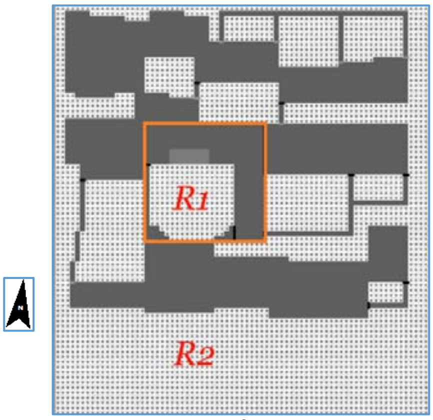


Fig. 2. Modeling of Nmatzadeh house
(Source: Authors)

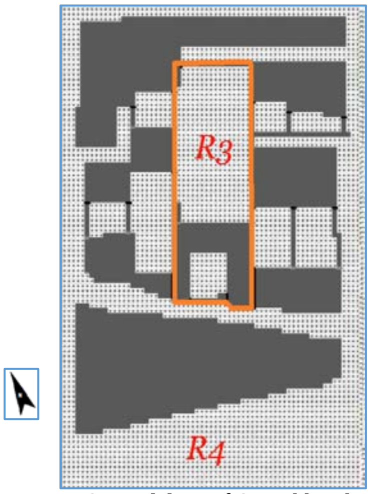


Fig. 3. Modeling of Sattarkhan house
(Source: Authors)

Table 4
Preliminary data utilized in the software(extracted from the Tabriz synoptic aerology station in the 2016 statistical year)

Meteorological parameters	January 4th,	August 6th,]	Meteorological parameters	January 4th,	August 6th,
Maximum daily temperature	-0.4 (°C)	35.50 (°C)	**Cloudiness**	3 octas	2 octas
Minimum daily temperature	-10.6 (°C)	21.70 (°C)	**Global Horizontal [i]*Radiation**	401 W/m2	717 W/m2
Mean daily temperature	-5.5(°C)	28.6(°C)	**Reflected radiant coefficient of the wall**	0.4	0.4
Maximum daily relative humidity (in 2m height)	88(%)	48.0(%)	**Reflected radiant coefficient of the floor**	0.3	0.3
Minimum daily relative humidity (in 2m height)	64(%)	16.0 (%)	**Reflected radiant coefficient of the ceiling**	0.3	0.3
Direction of the dominant wind (North orientation is considered as 0)	30 (deg)	60 (deg)	**humidity and base soil temperature (in the 0-20 cm) [ii]****	50 (%) 0.0 (°C),	50 (%) 26.0 (°C),
Mean wind flow speed in the 10m height (In the meteorological station)	3.0 m/s	6.68 m/s	**humidity and base soil temperature **(in the 20-50 cm)**	,50 (%) 3.0 (°C)	,50 (%) 24.0 (°C)
Average wind speed proportioned based on the Power Law in the 10 m height (in the opening of the model in the urban texture) [iii]***	2.16 m/s	4.0 m/s	**humidity and base soil temperature **(in the 50-200 cm)**	60 (%) 7.0 (°C)	60 (%) 22.0 (°C)

Preliminary data which are considered for the simulation are according to the Table.4 , which include the geographical location (Geographical latitude and longitude), elevation from the sea level, primary temperature, wind speed and orientation (in the 10m height), relative humidity (in the 2m height), absolute humidity in the 2500m altitude (above the model area), temperature, humidity of the soil, type of trees, vegetation coverage, the extent of cloudiness based on the data and time. These data were gathered for 2016 statistical year from Tabriz synoptic station. Based on the weather data of the year 2016, the month of February is considered as the coldest month of the year. Therefore, the statistical data from the month of February is considered as the critically cold month of the year, and the month of June as the critically warmest month of the year (Table. 4).

The focus of this study is on the evaluation of thermal comfort in the courtyards. To reach this goal, PMV and PET indices will be analyzed as the most prevalent methods for predicting the thermal comfort in the open spaces. Other indices including air temperature, average radiant temperature, relative humidity, wind speed which influences the thermal comfort were analyzed and studied along with the mentioned indices. We can analyze the function and effect of each of the courtyards in providing thermal comfort and preventing thermal loss in the cases under study.

The model outputs in the both of graphical zoning maps in the winter (January 4th) between 6:00 in the morning until 12 at noon and 14 in the afternoon, and in the summer (August 6th) for the hours between 5:00 in the morning until 13 in and 14:00 in the afternoon), and the numerical values are provided and presented in the form of an Excel chart for a 24 hour cycle in order to have a more accurate analysis of the research indices.

10. Analysis of the Findings

10.1 Analysing the PMV Index

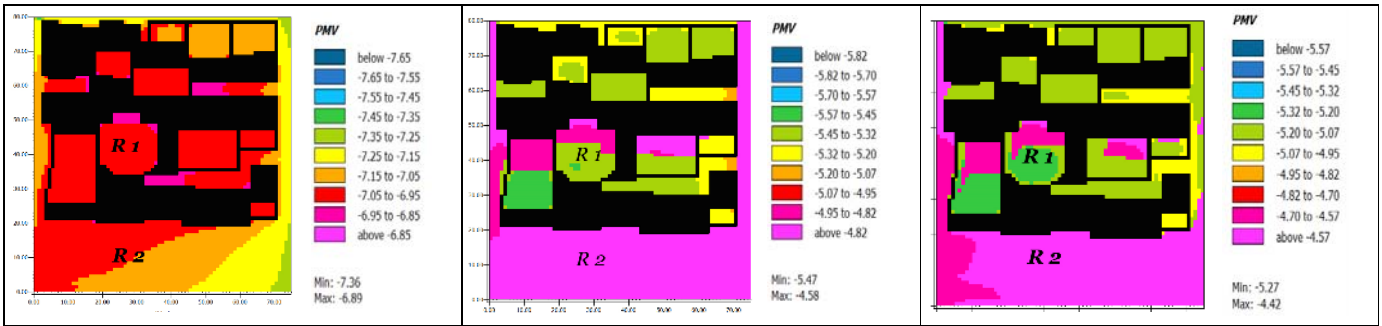
The PMV index is one of the most prevalent known methods for predicting thermal comfort limit, since in this method, many different indices of thermal comfort, including climatic variables, type of clothing and activities are employed together. This index is presented as a seven-point scale by the ASHRAE society according to Table. 5. In the following table (Table. 5), the 0 symbol describes the neutral thermal sensation (comfort) and the number which slightly exceeds +1 or subsides -1 would lead to dissatisfaction; therefore, the comfort limit would include the following range of -1 < PMV > +1 (Iran's National organization of Standard, 2011)

Table. 5
ASHRAE's Seven-layered thermal comfort zone.(ISO 730:2005)

Very cold	Cold	Slightly Cold	Neutral	Slightly warm	Warm	Hot
-1	-2	-3	0	+1	+2	+3

10.2. Analysing the PMV Index in the Winter

Analysing and comparing the PMV index values for the mentioned date in the month of February indicates that none of the defined nodes in the center of the yards (R1 and R3), and the open spaces in their southern areas (R2 and R4) are not located in the thermal comfort limit over the whole day and night, the thermal comfort limit is defined in a range between minimum -1 to maximum +1. Numerical findings which are the result of simulation in (Figure. 6). indicate that the range of fluctuations of the PMV index for both courtyards and their adjacent open space is equal between the 5 PM in the dusk and 7 in the morning, and there is no evident difference between the PMV index in the mentioned points. But the PMV index value in the time span between 7 in the morning until 17:00 does change for the mentioned points. On comparing the PMV value in the courtyards of both houses in the research, courtyard in the Sattarkhan house has a better thermal condition as the PMV index value in 14:00 (the warmest hour of the day) reaches for the amount of -7.4, but this would yet be 7.3 points (in the terms of PMV index) lower than the minimum range of thermal comfort (Figure. 6). The PMV value in the coldest hours in a whole day (before the sunrise) is inscribed as 7 in the PMV scale which is 6 points lower than the minimum range of the thermal comfort span, it shows the long distance of the governing conditions on these courtyards from the thermal comfort limit (Figure. 6).



6 o'clock	12 o'clock	14 o'clock

Fig. 4. Graphical zoning, results of the simulation of the PMV index (Nematzadeh house) in the winter, January 4th

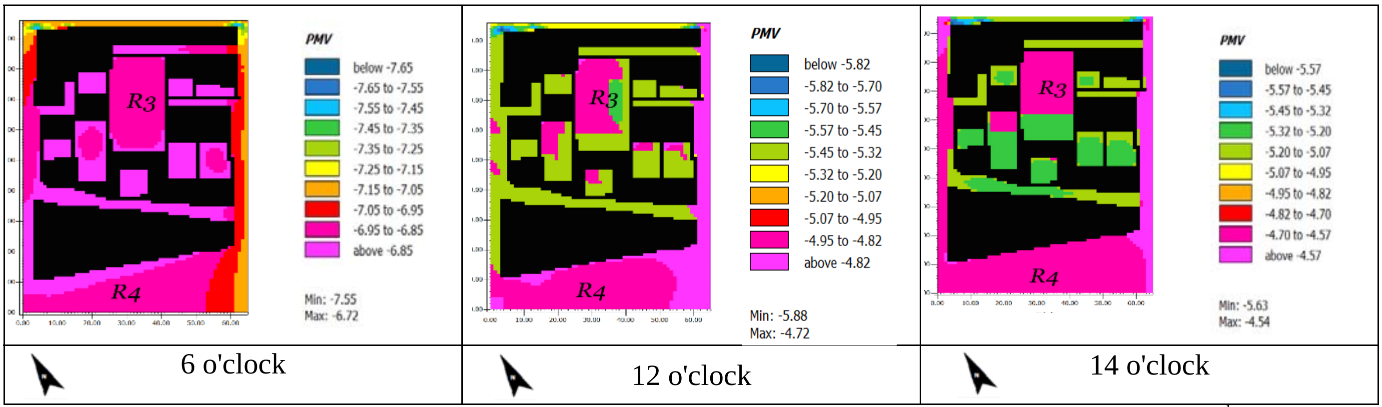
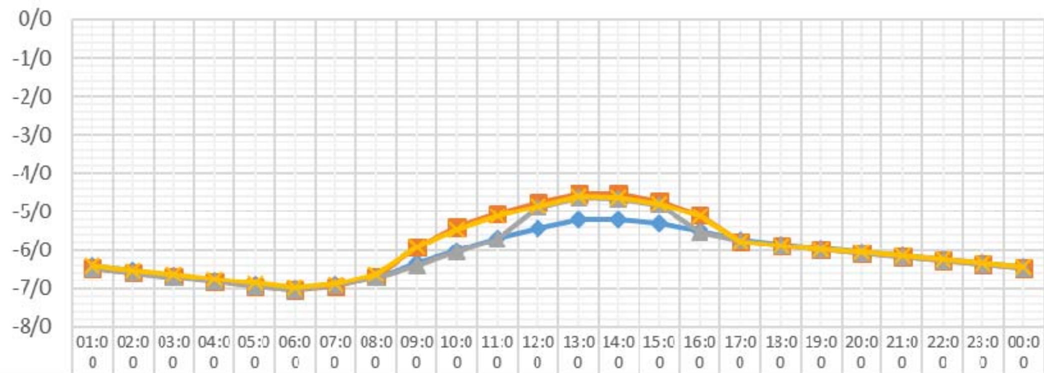


Fig. 5. Graphical zoning, results of the simulation of the PMV index (Sattarkhan house) in the winter, January 4th



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
PMV-R1-Nemat zadeh	-6/4	-6/5	-6/7	-6/8	-6/9	-7/0	-6/9	-6/7	-6/3	-6/0	-5/7	-5/4	-5/2	-5/2	-5/3	-5/5	-5/7	-5/9	-5/9	-6/0	-6/1	-6/2	-6/3	-5/4
PMV-R2-Open space	-6/5	-6/6	-6/7	-6/8	-6/9	-7/0	-6/9	-6/7	-5/9	-5/4	-5/0	-4/7	-4/5	-4/5	-4/7	-5/1	-5/8	-5/9	-6/0	-6/1	-6/2	-6/3	-6/4	-5/5
PMV-R3-Satar khan	-6/5	-6/6	-6/7	-6/8	-6/9	-7/1	-6/9	-6/7	-6/4	-6/0	-5/7	-4/9	-4/6	-4/7	-4/8	-5/5	-5/8	-5/9	-6/0	-6/1	-6/2	-6/3	-6/4	-5/5
PMV-R4-Open space	-6/4	-6/5	-6/6	-6/7	-6/9	-7/0	-6/9	-6/6	-5/9	-5/5	-5/1	-4/8	-4/6	-4/6	-4/8	-5/1	-5/8	-5/9	-6/0	-6/1	-6/1	-6/2	-6/3	-5/4

Fig. 6. The 24-hour changes of PMV index in the winter (R1-R2-R3-R4)

10.3 Analysing the PMV Index in the Summer

Findings of the numerical modeling based on the PMV index in summer indicate that during the whole hours of the day (including 8:00 till 20:00), the courtyards (R1 and R3 nodes) and the exterior open spaces (R2 and R4 nodes) are outside the comfort zone. The maximum absence of thermal comfort in the mentioned spots is registered in the 16:00 afternoon which can be the result of sol-air temperature and growth of the radiant reflection of surfaces and envelopes. In 16:00, PMV for the regarded nodes reaches the amount of 5.4 which is considered as a very hot condition based on (Table. 5). Although thermal comfort is provided in the courtyards overnight (from 20:00 to 8:30 in the morning) there is any meaningful relationship between the governing conditions in the courtyards and the open spaces on the surrounding environment of the peripheries, and an equal condition is registered for all nodes in the terms of thermal comfort.

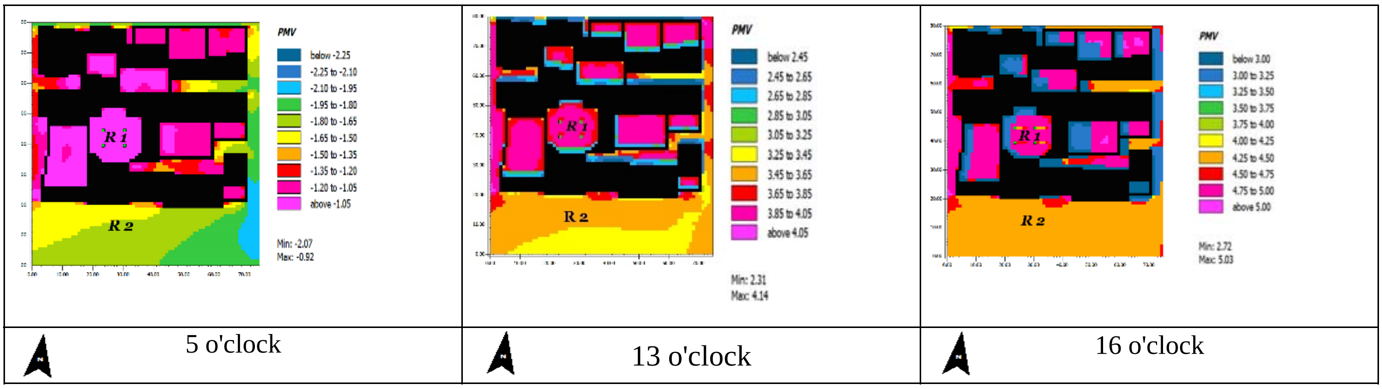


Fig. 7. Graphical zoning, results of the simulation of the PMV index (Nematzadeh house) in the summer, August 6th

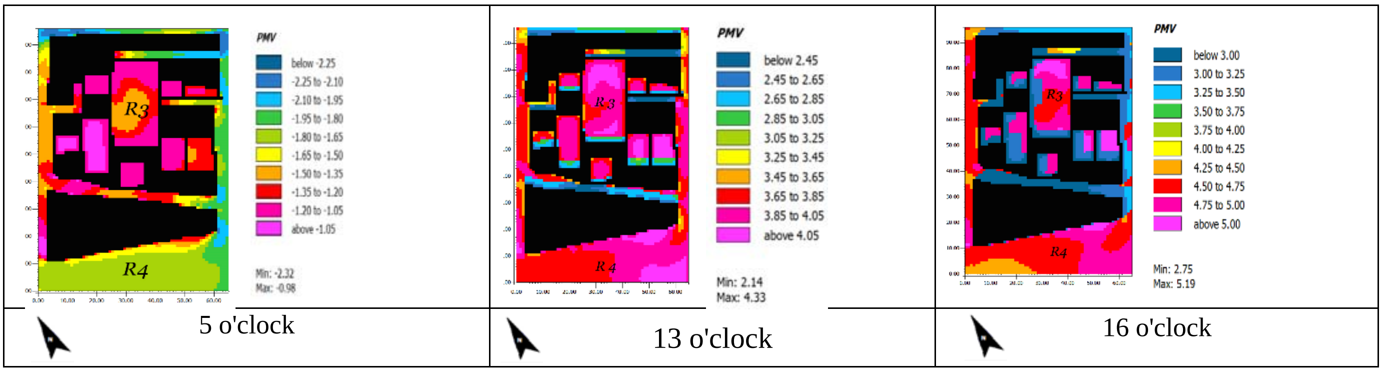


Fig. 8. Graphical zoning, results of the simulation of the PMV index (Sattarkhan house) in the summer, August 6th

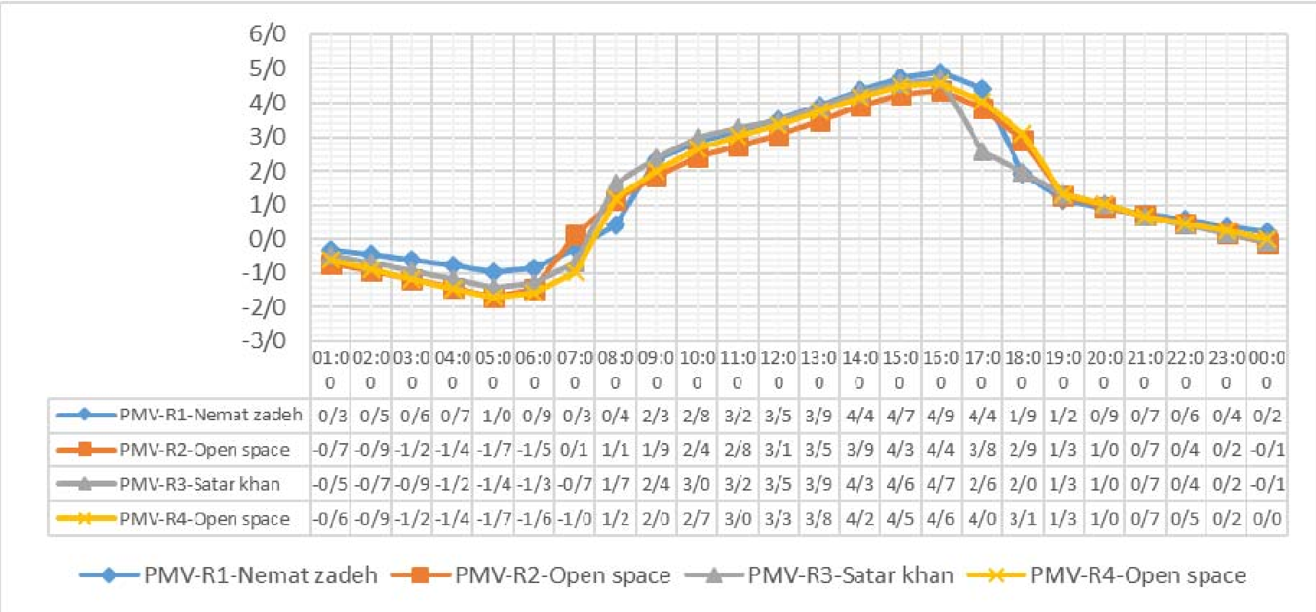


Fig. 9. The 24-hour changes of PMV index in the summer (R1-R2-R3-R4)

10.4 Analysing the PET Index

As it was elaborated in a comparison between the prevalent thermal indices, the PET index has a relatively more reputability and universality for estimation of thermal comfort in open spaces in comparison to PMV index. The acceptable span for PET index according to the common standard is defined in Table. 6:

Table. 6
Zone of the thermal comfort index (PET), Source: Matzarakis, 2007.

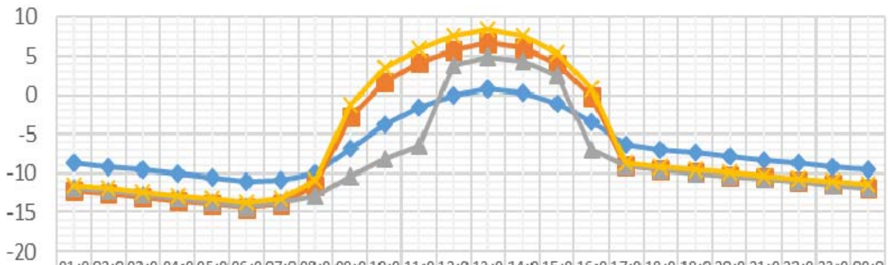
Freezing	dVery Col	Cold	Slightly cold	(Neutral (Comfort	Slightly wam	Warm	Hot	Very hot
Less than 4	4-8	8-13	13-18	18-23	23-29	29-35	35-41	more than 41

Since the maps of zoning and numerical values of the PET index levels are not extractable in the research version of ENVI-met software, the registered findings in the reference nodes (R1, R2, R3, R4), they are converted into analysable numerical outputs and were extracted according to Figure. 10 and Figure. 11.

10.5. Analysing the PET Index in the Winter

Comparing the reference table (Table. 6), and (Figure. 10) which includes the changes in the PET index during winter (January 4th) shows that all of the reference nodes of the test (R1, R2, R3, R4) are set outside of the thermal comfort limit. Also, according to Figure. 10, between 17:00 (from the sunset) to 6:00 in the morning, the fluctuations in the PET index have a relatively steady rate, but after the dawn and with the rise in the thermal reflection from the radiation of sun, the PET index for each of the reference nodes have a sum of 7.3°C difference.

In the warmest time of the following day (14:00), the PET index for the courtyard in the Nematzadeh house (R1), reaches to 0.3° C which is 17.7° C cooler than the minimum thermal comfort temperature, that is 18° C, and shows the freezing conditions for the mentioned courtyard. The registered value for the courtyard in Sattarkhan house indicates 7.13 which is classified in the very cold limit, according to the Table. 6. Therefore, based on the PET index in both courtyards, when the sol-air temperature reaches its lowest amount, it is 16° C colder than the minimum temperature of thermal comfort limit.



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
PET-R1-Nemat zadeh	-8/7	-9/1	-9/6	-10	-11	-11	-11	-10	-6/8	-3/8	-1/6	-0/1	0/8	0/3	-1/1	-3/4	-6/3	-7	-7/4	-7/9	-8/3	-8/7	-9/1	-9/5
PET-R2-Open space	-12	-13	-13	-14	-14	-14	-14	-12	-2/8	1/6	4/1	5/7	6/6	6	4	-0/2	-9	-9/5	-9/9	-10	-11	-11	-11	-12
PET-R3-Satar khan	-12	-12	-13	-13	-14	-14	-14	-13	-10	-8/1	-6/4	3/8	4/8	4/3	2/5	-7	-9	-9/6	-10	-10	-11	-11	-12	-12
PET-R4-Open space	-12	-12	-12	-13	-13	-14	-13	-11	-1/3	3/4	5/9	7/5	8/3	7/6	5/4	0/8	-8/6	-9/1	-9/5	-9/9	-10	-11	-11	-11

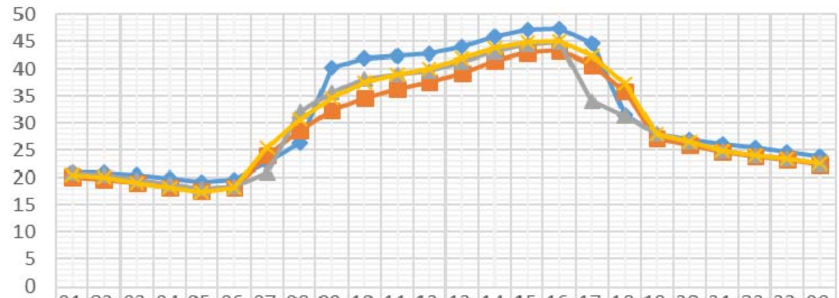
Fig. 10. The 24-hour changes of PET index in the winter (R1-R2-R3-R4)

10-5. Analysing the PET Index in the Summer

Analysing the fluctuations of the PET index for the day of 15 Mordad (Figure. 11) indicates that all of the reference sample nodes are set outside the comfort limit between 6:00 in the morning and 12:00 midnight. In 16:00, the registered PET value for the courtyard in Nematzadeh reaches for its maximum amount of 3.47°C, while the same index is registered as 8.44° C for the courtyard of Sattarkhan house; it implies that during the warm hour of the day, courtyard of Sattarkhan house is 5.2° C colder in the scales of PET index from Nematzadeh courtyard. It may be because of the higher air flow in Sattarkhan courtyard with respect to its vaster area compared to the courtyard in Nematzadeh house.

Also the course of variations (Figure. 11), explains that the space of courtyards are in the comfort limit only during the nights, from the midnight to 6:00 in the morning, in which no significant differences are perceived between the courtyards and the exterior open spaces in the terms of PET index and the mentioned courtyards cannot respond to the thermal comfort demands of the residents during the day when the critical thermal conditions are dominant.

Comparison between (Figure. 10), and (Figure. 11), indicates that the value of EPT index for the sample reference nodes during winter include more fluctuations in respect to the summer. Indeed, the existing differences between the values of PET index that are results of the registered data in the reference nodes (R1, R2, R3, R4) during summer, have a more evident difference in respect to the days in the summer which can be due to the difference on the formed shadow on the horizontal areas of the courtyard and the open spaces during the winter and summer.



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
PET-R1-Nemat zadeh	21	21	21	20	19	20	23	26	40	42	42	43	44	46	47	47	45	32	28	27	26	25	25	24
PET-R2-Open space	20	20	19	18	18	18	24	29	32	35	36	38	39	41	43	43	41	36	27	26	25	24	23	22
PET-R3-Satar khan	21	20	20	19	18	19	21	32	36	38	39	40	41	43	45	45	34	31	28	27	25	24	23	23
PET-R4-Open space	20	20	19	18	17	18	25	31	35	38	39	40	42	44	45	45	42	37	28	27	25	24	23	23

Fig. 11 The 24-hour changes of PET index in the summer (R1-R2-R3-R4)

10.7. Analysing the Tmrt Index

According to the performed studies the "mean radiant temperature" has the main role in the thermal sense of the people and has the most impact on the "Physiological equivalent temperature". It is obvious that the high levels of radiant temperature has a significant role in cold regions, and open spaces with a higher mean average, are in priority for elevating a positive sense of thermal sense for the occupants.

10.8. Analysing the Tmrt index in the Winter

Analysing (Figure. 14), during winter shows that the mean radiative temperature during the day has a number of different variations equivalent to 25°C after the sunrise for the (R1, R2, R3, R4) nodes, but after the sunset in 17:00, the mean radiative temperature has a more steady trend during the night with a maximum of 3° C for the mentioned nodes.

The numerical findings indicate that the minimum amount of mean radiation is at 6:00 in the morning while its maximum is reached at 13:00 noon in the mentioned nodes. Also, findings show that the registered radiant temperature during the day in the courtyard of Sattarkhan house is significantly higher in respect to the courtyard in Nematzadeh house. Although from the 17:00 o'clock until 11:00 on the next day, the radiant temperature of these two yards are not considerable, but after 11:00 o'clock the radiant temperature in the courtyard of Sattarkhan house grows in an increasing manner compared with the Nematzadeh house and reaches its maximum with a value of 1.25°C on 12:00. This difference reaches 3.23°C at 15:00 o'clock as the courtyard of Sattarkhan house was 25° C warmer for a duration of 4 hours in the terms of mean radiant temperature. The high 25° C difference of radiant temperature between the northern and southern courtyards of Sattarkhan house (Figure. 13) also has a focus on this fact that smaller and more surrounded courtyards reduce the mean radiant temperature to a high degree. In general, we can perceive from the findings of the zoning and numerical maps that the diminution and increase in the extent of enclosure of courtyards are not only useless in the cold areas but will lead to the increase in the areas of the shadow and by preventing the radiation during the day, reduces the warming effect of the sunlight and also the passive warming of the surrounding spaces of the courtyards in the cold seasons of the year.

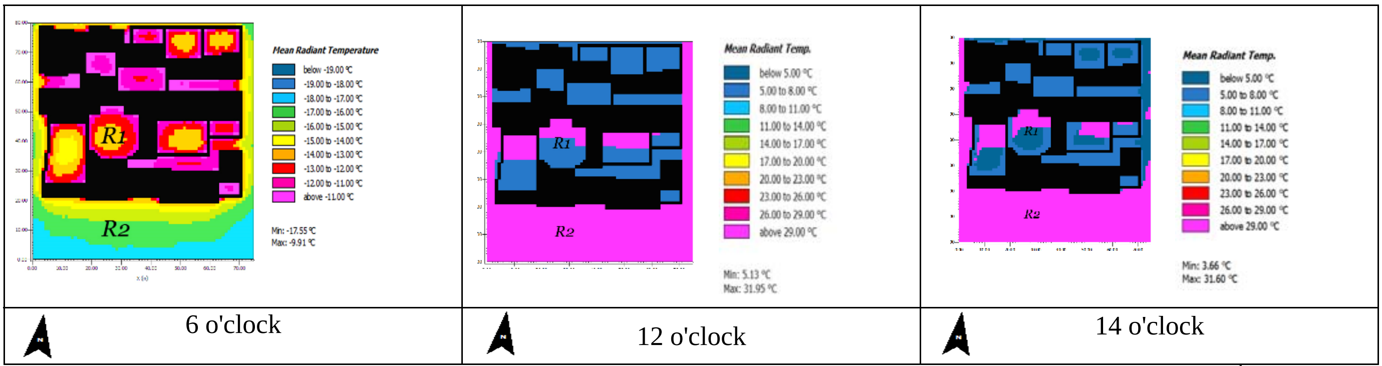


Fig. 12. Graphical zoning, results of the simulation of the Tmrt index (Nematzadeh house) in the winter, January 4th

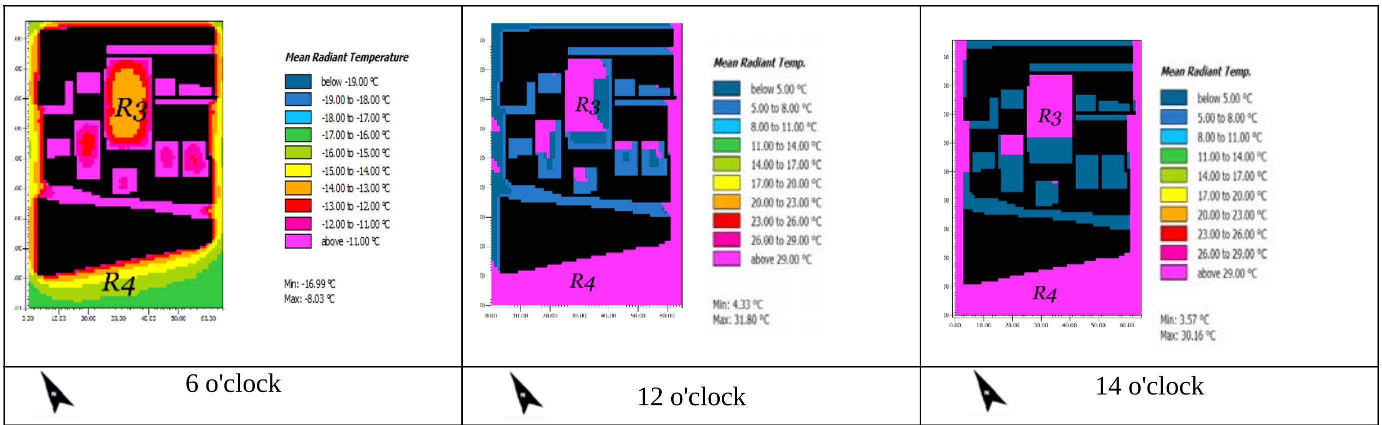


Fig. 13. Graphical zoning, results of the simulation of the Tmrt index (Sattarkhan house) in the winter, January 4th

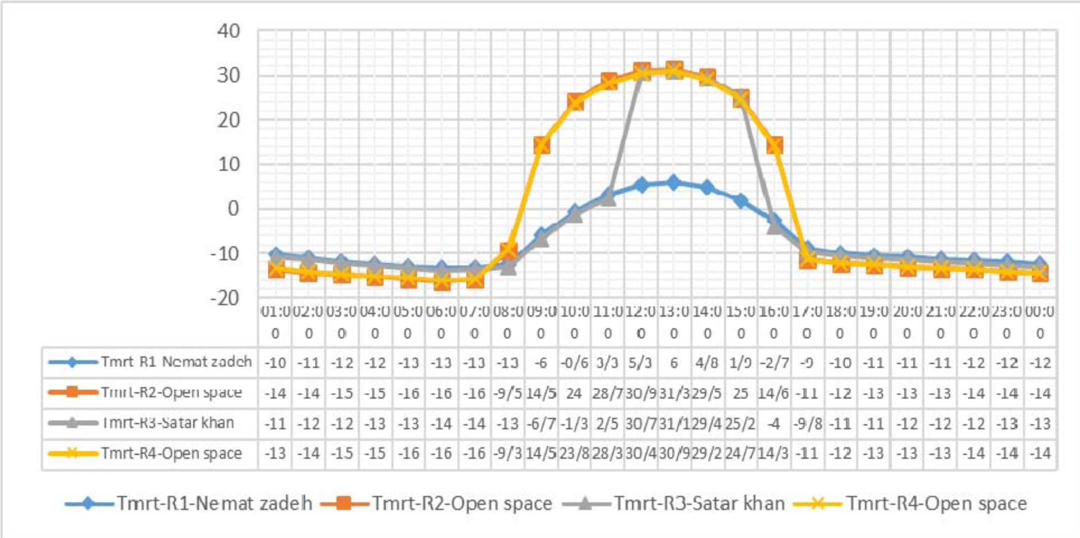


Fig. 14. The-24 hour changes of Tmrt index in the winter (R1-R2-R3-R4)

10.9. Analysing the Tmrt index in the Summer

Findings that are presented in (Figure. 17), indicate that even in the winter, the average radiation temperature in open spaces (R2 and R4) have a relatively equal value. Also, the numerical findings indicate that the amount of radiative temperature between the (R1, R2, R3, R4,) reference nodes does not have a considerable difference from 17:00 in the afternoon, with the dusk until five o'clock in the morning. In the summer, gradually after the sunrise in 6:00, significant variations are observable in the mean radiation, unlike the winter in which the difference between the radiant temperature for the both the courtyards last until 15:00, in the summer, this difference stays until 9:00 in the morning and subsequently the radiant temperature values for the both yards become closer to each other and gradually overlap and this process goes on until 16:00. After 16:00 afternoon, the values of radiant temperature have their own different courses until 19:00 when the radiant temperatures values become closer to each other. Generally, in the time of summer, we can consider the amount of radiant temperature in the both yards in an equal level. Slight variations of the radiant temperature between two courtyards during the times of the day can be a result of vertical radiation of the sun on the surface of the courtyards during the summer, as the extent of the vertical radiation of the sun will contribute to the coordination and convergence of the radiation in the reference node and its inclined radiation in the summer develops the difference in the mean radiation during the day. In other words, the role of direct radiation and radiation from the vertical surfaces of the courtyards and pathways in the thermal fluctuations in the hot seasons of the year is much more important than vertical side walls. Due to the inclined radiation of the sun during the winter and shading of vertical surfaces, or horizontal flooring material receive different radiations and this leads to changes in the mean thermal temperature for different proportions of the spaces, courtyards and open spaces. The effective factor during the winter in the extent of mean radiant temperature, are the vertical areas, while in the summer the extent of the radiative temperature of the environment can be taken from the horizontal surfaces. Generally, in order to increase the radiant temperature in the summer, planting deciduous trees can develop a type of shade on the surface of the courtyards and the enclosure will be exposed to the radiation of the sun which will cause the warming and elevation of thermal comfort via increasing the mean radiant temperature.

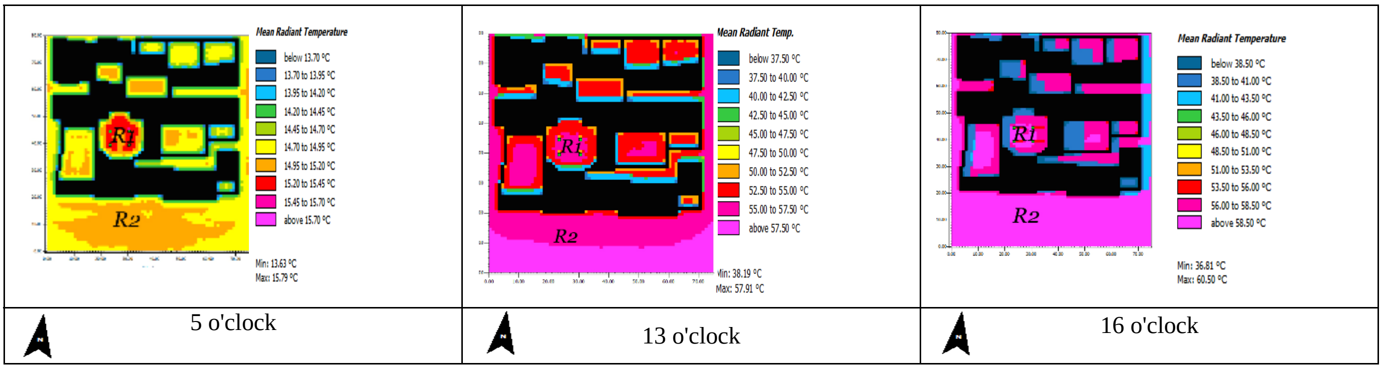


Fig. 15. Graphical zoning, results of the simulation of the Tmrt index (Nematzadeh house) in the summer, August 6th

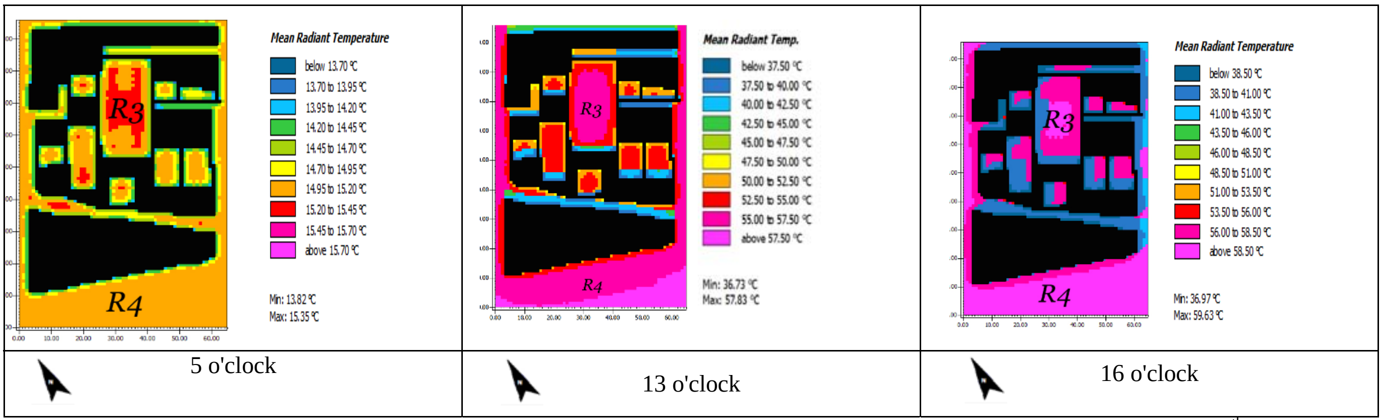


Fig. 16. Graphical zoning, results of the simulation of the Tmrt index (Sattarkhan house) in the summer, August 6th

Fig. 17. The 24-hour changes of Tmrt index in the summer (R1-R2-R3-R4)

10.10 Analysing the Wind Flow Index

Studies on the wind flow speed in the city of Tabriz indicate that the average yearly wind speed in this city is registered on 3 to 5 m/s value in different directions. The east-west direction has the first place in the terms of wind flow speed, and the north-east/ south-west directions have the dominant wind flow. Analysing the role of central courtyards in the control of wind flow, especially during the cold seasons of the year and its impact on the providing thermal comfort in the courtyards of traditional houses in the city of Tabriz can answer one of the questions of this research.

10.11. Analysing the Wind flow Index in the Winter

Performed studies show that the wind flow during the winter is slower than the summer. In general, the flow of the dominant wind in this month is in the 30°NE and the mean wind flow speed in the 10m height (in the synoptic station of Tabriz) for the year 2016 is recorded as 3.3 m/s. Analysing the extracted Charts from the numerical modeling shows that the reference nodes of the courtyard in the Nematzadeh house (R1) with the mean value of 0.1 m/s has the lowest speed, and courtyard of the Sattarkhan house (R3) has the most wind speed with a value of 1 m/s. Courtyard of Nematzadeh house and courtyard of Sattarkhan house are able to reduce the wind speed to the extent of 1.5 m/s and 0.5 m/s respectively; this explains that the wind speed in the smaller courtyards with the dimensional proportions close to the shape of a square has a more reduction rate compared with the wide courtyards in a north-south orientation. Although Nematzadeh house decreased the wind flow speed by 1.5 m/s, according to the Charts and graphical maps, its temperature does not have a significant difference with the open spaces, which explains the partial role of the wind flow in defying the thermal condition of the courtyards. According to the analyses presented in the mean radiant temperature section in this paper, the radiation factor during the day, clearly impacts the cooling effects of the wind flow; slight differences of maximum 1°C, between different nodes (R1, R2, R3, R4) during different hours of the day and night during the summer supports this fact.

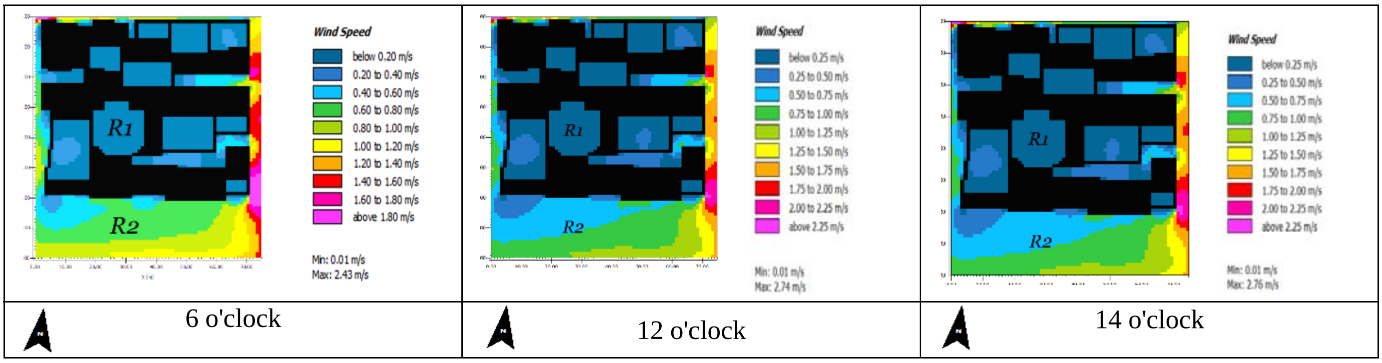


Fig.18. Graphical zoning, results of the simulation of the wind speed index (Nematzadeh house) in the Winter, January 4th

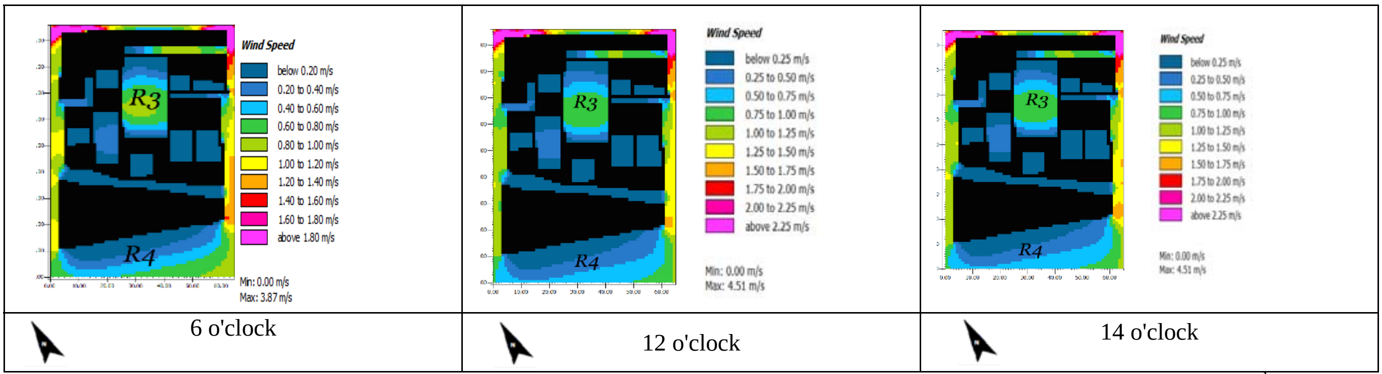
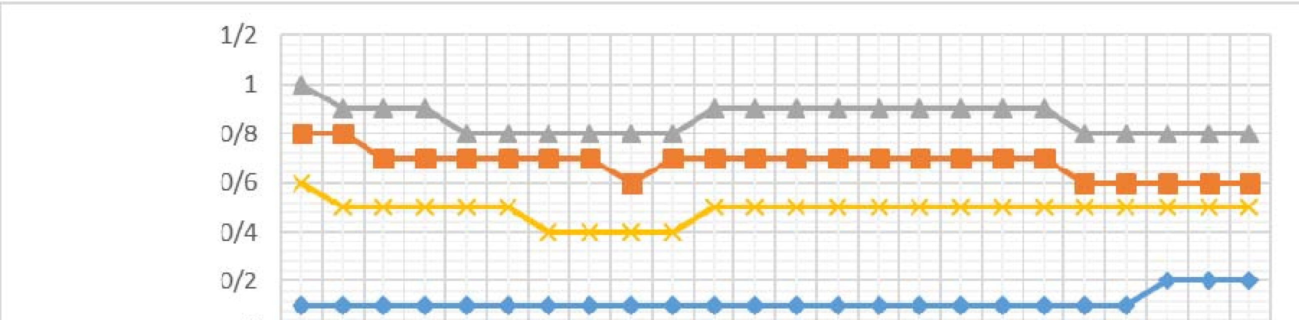


Fig. 19. Graphical zoning, results of the simulation of the wind speed index (Sattarkhan house) in the Winter, January 4th



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
V-R1-Nemat zadeh	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/1	0/2	0/2	0/2
V-R2-Open space	0/8	0/8	0/7	0/7	0/7	0/7	0/7	0/7	0/6	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/6	0/6	0/6	0/6	0/6
V-R3-Satar khan	1	0/9	0/9	0/9	0/8	0/8	0/8	0/8	0/8	0/8	0/9	0/9	0/9	0/9	0/9	0/9	0/9	0/9	0/9	0/8	0/8	0/8	0/8	0/8
V-R4-Open space	0/6	0/5	0/5	0/5	0/5	0/5	0/4	0/4	0/4	0/4	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5	0/5

Fig. 20. The 24-hour changes of wind speed index in the Winter (R1-R2-R3-R4)

10.12 Analysing the Wind flow Index in the Summer

Wind flow in Tabriz during summer is recorded as more severe than in the winter. The wind flow direction in this month (summer) is 60° North and the mean wind speed of 6.68 m/s in10m elevation (in the meteorological station of Tabriz) for the year 2016. Although in the winter, due to the severe cold in the region, the acceleration of the wind and penetration of the wind flow inside the courtyards are not desirable but in the summer acceleration in the speed of the wind can be employed as a positive factor which can be considered for the purposes of natural ventilation. Surveying Charts of the wind speed in the month of July represents that the wind speed during a day and night will reach a value of 0.2 m/s in the Nematzadeh house which is considered as still air but the Sattarkhan courtyard has a more desirable conditions in the terms of wind flow during the summer, as the mean air flow speed in this courtyard reaches an estimated value of 1.3 m/s which is 0.9 m/s faster than the wind speed in the Nematzadeh courtyard. The wind speed in Sattarkhan courtyard increases to 1.7 m/s during the night which can be used by employing openings in order to have a natural ventilation of interior spaces, but in the Nematzadeh house this capability is not possible to achieve because of the relative immovability of the air. Not only the ventilation possibilities, but even in the cold seasons of the year the use of passive heating on the surface of the courtyards will also be increased with the reduction in the size of the yards and increasing their surrounding walls.

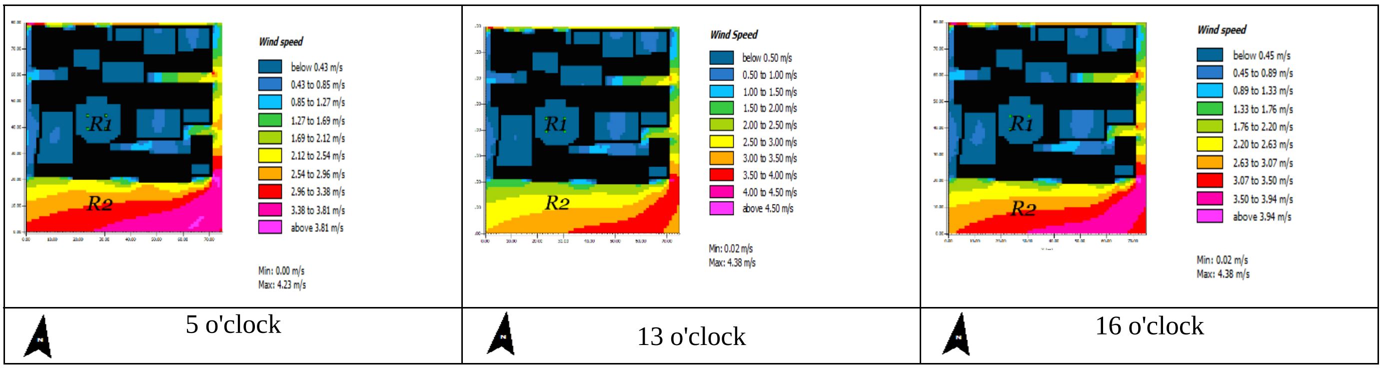


Fig. 21. Graphical zoning, results of the simulation of the wind speed index (Nematzadeh house) in the summer, August 6th

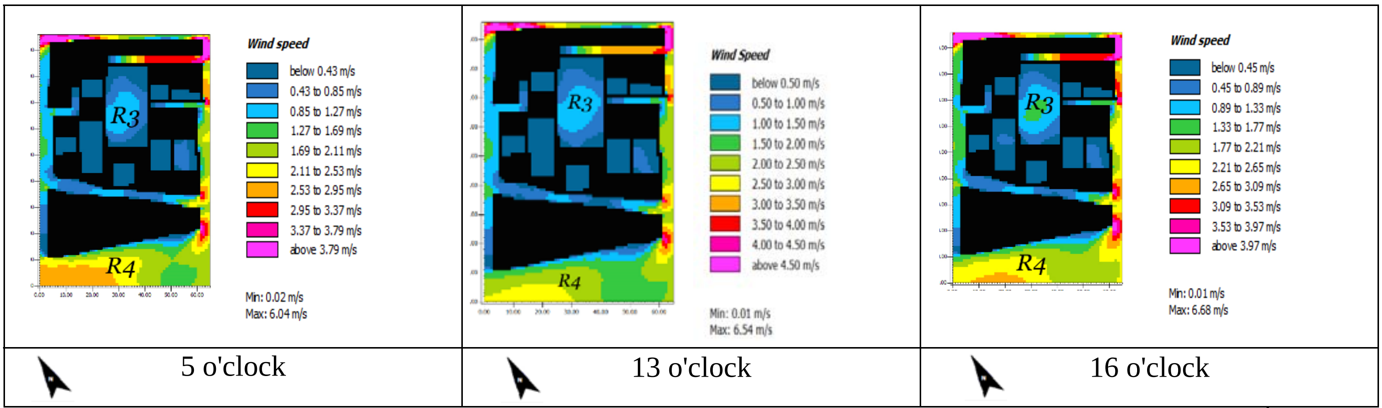


Fig. 22. Graphical zoning, results of the simulation of the wind speed index (Sattarkhan house) in the summer, August 6th

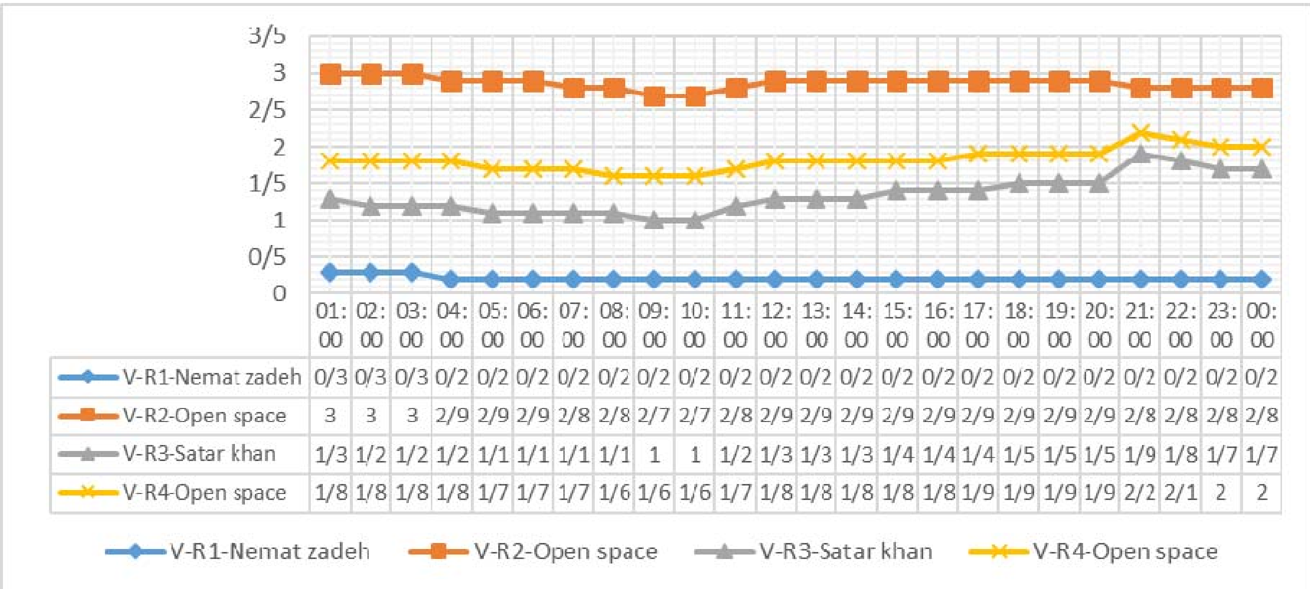


Fig. 23. The 24-hour changes of wind speed index in the summer (R1-R2-R3-R4)

10.13 Analysing the air Temperature Index in the Winter

Among the impactful factors on the conditions of thermal comfort, air temperature is identified as the most important one. While analyzing the variations based on Figure. 26, and graphical zoning maps (Figure. 24) and

(Figure. 25) the maximum temperature difference between the four sample nodes is calculated with a maximum of 0.6°C in 14:00 which is not considered as a meaningful difference. According to Figure. 26, Nematzadeh courtyard (R1) and the open space (R2) have an equal temperature from 18:00 until 09:00, but after 09:00 in the morning and after the radiation on the fabric of the building and the mean radiant temperature increases and thermal reflection from the surfaces starts, temperature of the open space (R2) increases and in 14:00, the open space (R2) is registered as 0.6° C warmer. The relative increase of the open space temperature (R2), in respect to the surrounded courtyard (R1) is due to the fact that open spaces are generally to solar radiation while the low angel radiations of sun during the winter, some parts of the flooring of the garden and the vertical massings facing North, East and West and the surrounded courtyards remain in the shade. Although the open spaces are facing the wind flow they are rather warmer than the surrounded spaces like in a courtyard which confirms the effective nature of the radiation factor and thermal reflection from the surfaces and massings in respect to the wind flow. Therefore, avoiding shades on the surfaces is more effective than only the protection against the wind in decision making during design.

By comparing the small southern courtyard of the Sattarkhan house (Andaruni courtyard) and northern courtyard which has an area equal to eight-times greater than the southern courtyard, no significant changes in the thermal conditions of the courtyards are visible and this rule is true for the Nematzadeh house that has a smaller area compared to Sattarkhan courtyard (Figure. 25). Therefore, by the diminution in the area of the courtyards, better thermal conditions are not achieved in the courtyards. Generally, analyzing the fluctuations in temperature it is obvious that all of the sample reference nodes (R1, R2, R3, R4) are set outside the comfort temperature and in a sub-zero centigrade degree and the freezing condition, and the surrounding courtyards (R2, R3) does not have the capability of providing thermal comfort or sudden changes compared with the exterior temperature. Also the important point which is resulted from the study of findings in regard to the rotation angel of the courtyard, is that no considerable difference between the rotation degree of the Sattarkhan courtyard which has an equivalent of 26 degrees in respect to the north or Nematzadeh house which is located in an opposite direction with an East orientation, is observed. It is obvious that various orientation angles has no effect on the courtyards in terms of thermal comfort, but there will be considerable impacts through the openings from an external radiation to the interior.

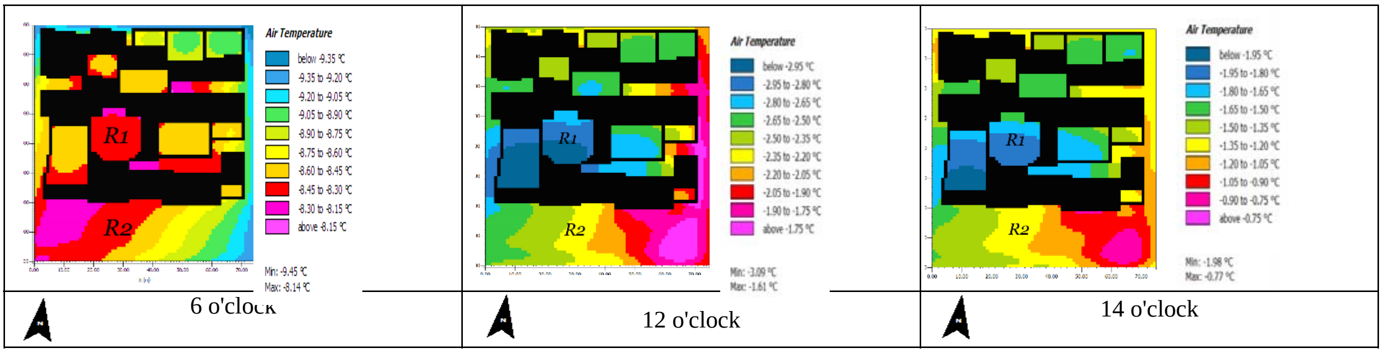


Fig.24.Graphical zoning, results of the simulation of the air temperature index (Nematzadeh house) in the Winter January 4th

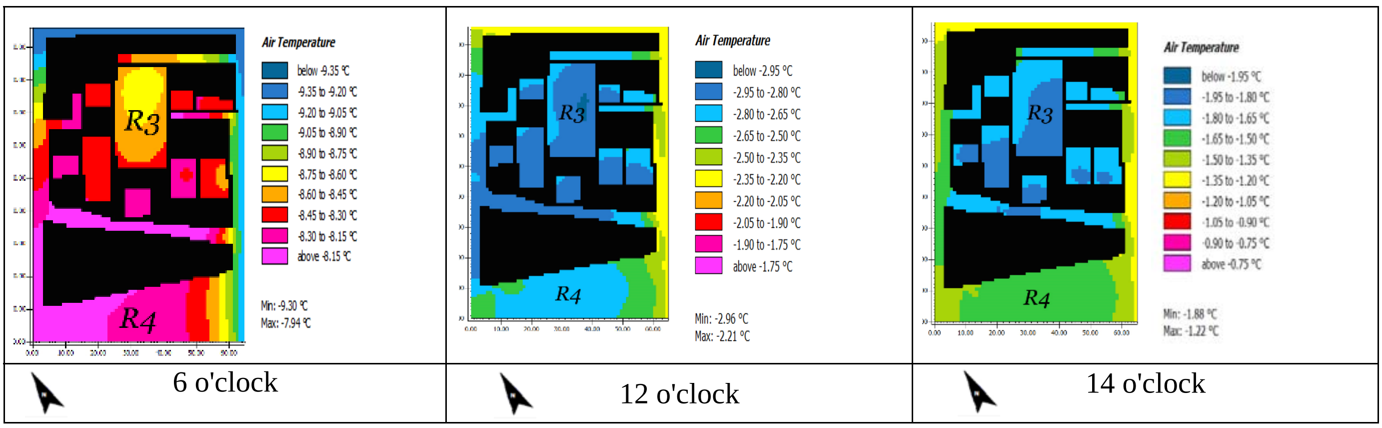


Fig. 25. Graphical zoning, results of the simulation of the air temperature index (Sattarkhan house) in the Winter January 4th

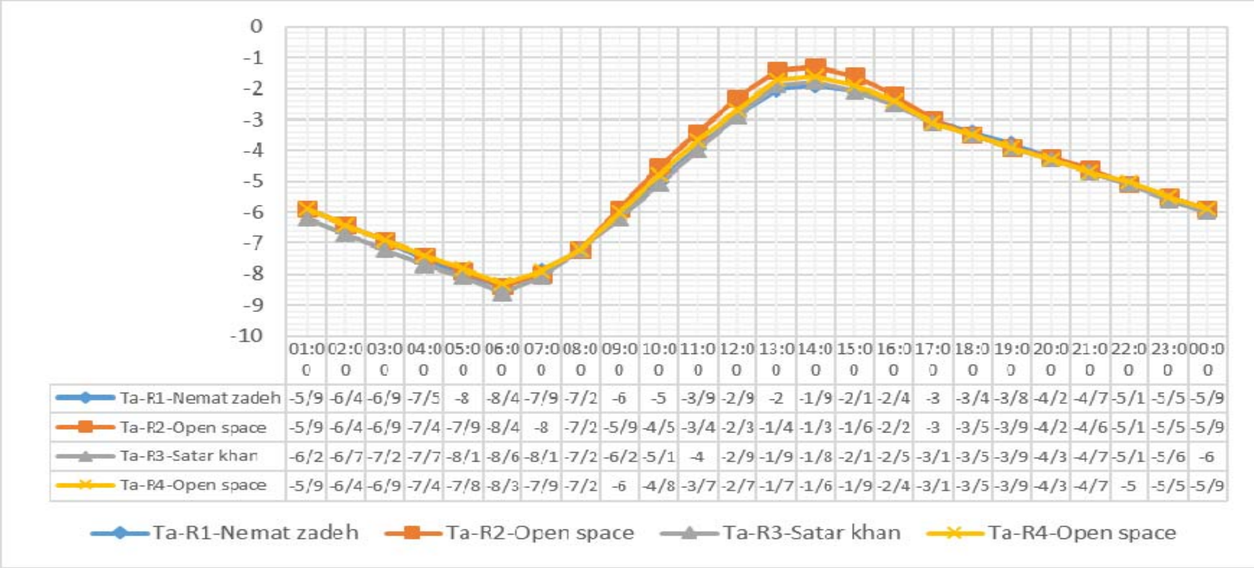


Fig. 26. The 24-hour changes of air temperature index in the Winter (R1-R2-R3-R4)

10.9. Analysing the air Temperature Index in the Summer

Analysing the charts of the variations in the temperature during summer Figure. 29. indicates that there exists no significant difference between the two courtyards and their surrounding open spaces. The maximum variations between the data record nodes are registered as 0.5 degrees between 20:00 until 08:00 in the morning. Also, the variations in the mentioned charts indicate that, from 9:00 when the effect of sunlight on the areas and sidewalls will begin, gradually the lack of thermal comfort becomes dominant in all of the reference nodes and this process continues until midnight.

With a negative radiation overnight, an overall favorable condition is observable in the courtyards between 1:00 and 21:00, but gradually after 21:00 the courtyards will become warm in a way that they reach their maximum temperature in 16:00. In 16:00 Nematzadeh house is 0.3°C and 0.6° C colder than their adjacent open spaces. In a comparison between the registered temperatures between the two courtyards in 16:00, Nematzadeh house was registered as 0.5° C colder than the Sattarkhan house. Also, maximum thermal variation between the nodes and different surfaces for each of the courtyards reaches a maximum of 0.3° C which is not a considerable value.

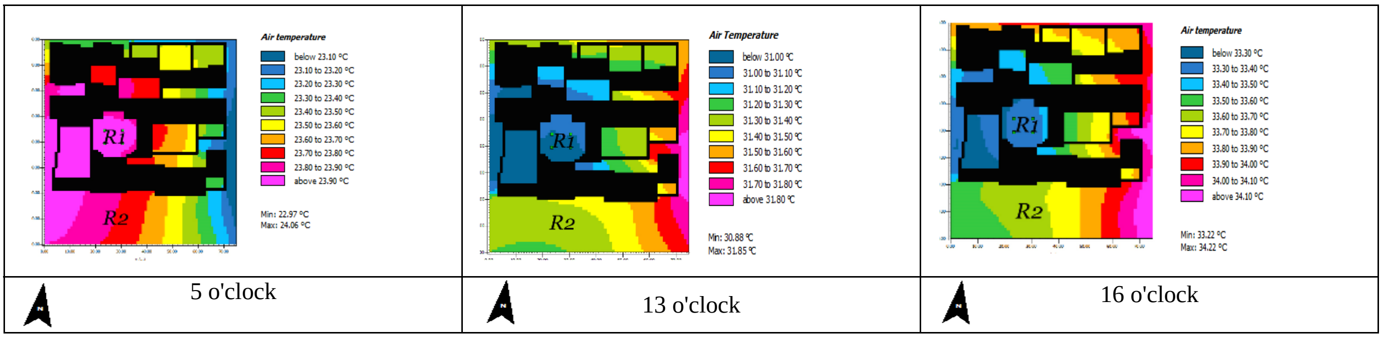


Fig.27. Graphical zoning, results of the simulation of the air temperature index (Nematzadeh house) in the summer, August 6th

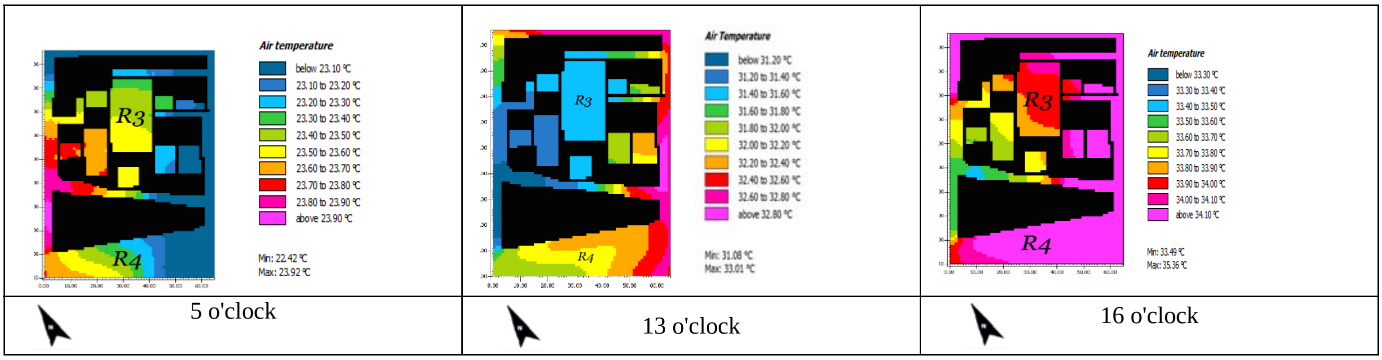
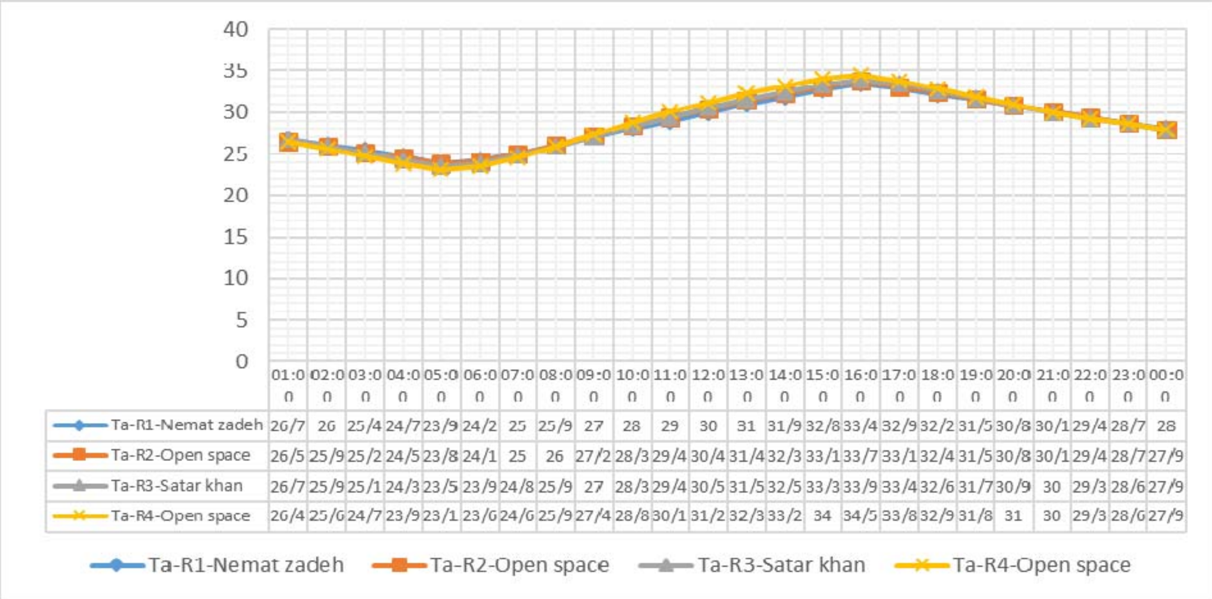


Fig. 28. Graphical zoning, results of the simulation of the air temperature index (Sattarkhan house) in the summer, August 6th



	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
Ta-R1-Nemat zadeh	26/7	26	25/4	24/7	23/9	24/2	25	25/9	27	28	29	30	31	31/9	32/8	33/4	32/9	32/2	31/5	30/8	30/1	29/4	28/7	28
Ta-R2-Open space	26/5	25/9	25/2	24/5	23/8	24/1	25	26	27/2	28/3	29/4	30/4	31/4	32/3	33/1	33/7	33/1	32/4	31/5	30/8	30/1	29/4	28/7	27/9
Ta-R3-Satar khan	26/7	25/9	25/1	24/3	23/5	23/9	24/8	25/9	27	28/3	29/4	30/5	31/5	32/5	33/3	33/9	33/4	32/6	31/7	30/9	30	29/3	28/6	27/9
Ta-R4-Open space	26/4	25/6	24/7	23/9	23/1	23/6	24/6	25/9	27/4	28/8	30/1	31/2	32/3	33/2	34	34/5	33/8	32/9	31/8	31	30	29/3	28/6	27/9

Fig. 29 The 24-hour changes of air temperature index in the summer (R1-R2-R3-R4)

11. Conclusion

The main objective in this research is that to what extent a surrounded courtyard in a region with a cold climate can control the unfavorable weather conditions in the environmental terms and protect its residents from the bad climatic conditions. In order to answer to the question of the research, a number of 120 cases of traditional houses of Tabriz, in the historical boundary of the city were identified, in which a number of 64 houses with courtyards and a 64 count of them which include authentic data and documents for the typology. Two traditional houses of Nematzadeh and Sattarkhan were selected for the process of modeling and analysis. The research method is a descriptive-analytical type, and the collection of data were done through the library, documentative study, and field research on the selected cases; in order to analyze data, “ENVI-met” and the Rayman software model were employed. Computer simulation is performed in the ENVI-met software in order to identify and analyze the quality of thermal comfort and impactful factors on the thermal comfort in the area of the research.

•-Results of the research indicate that courtyards and their adjacent open spaces, especially during the winter are set outside of the comfort limit based on the two indices of PMV and PET. According to the PET index, both of the courtyards in the summer, even in the warmest hours of the day in which the sol-air temperature reaches its maximum value, are 16°C colder than the minimum thermal comfort limits.

•The resulting analysis from the table of temperature changes in the winter shows that all of the reference nodes (R1, R2, R3, R4) does not have the capability of thermal enhancement compared with the exterior open spaces.

•Results of the analysis on the mean radiant temperature index indicate that the radiation factor during the daylight impacts the cooling effects of the wind flow. Minute differences of maximum 1°C between different nodes (R1, R2, R3, R4) in different hours of the day in the winter supports the significance of this difference.

•Results of the study on the mean radiant temperature that were registered in a day during summer in the courtyard of the Sattarkhan house is higher in a meaningful sense. This means the diminution and increasing sidewalls is not only useless in the cold climatic conditions, but it will contribute to the creation of shadows under the shades; it means that increasing the size and increasing the covered areas under the shades that disrupts the heating effect of the sun and its radiations in the courtyard, also has a negative impact on the passive heating of the adjacent spaces of the courtyard in the cold seasons.

•Although the courtyard of Nematzadeh house has a 1.5 m/s impact on the flow of the wind, but its temperature does not have a significant difference with the exterior open spaces, this indicates the slight role and insignificant value of the wind flow on deciding the thermal conditions of the courtyards.

•Studies related to the wind flow index in the winter show that, although wind speed in the open spaces are closer to the flow of the wind but they do not possess less temperature compared with the courtyards. This point is due to the importance of the radiation factor and thermal reflection from the surfaces and building massing. Thereupon, avoiding the development of shadows on the horizontal surfaces had a more urgency than to protect the building from the wind is a subject to be considered in the decision makings for the design in the region.

•Although small and surrounded walls prevent the direct flow of wind through the courtyard and develop shades, but they limit the sunlight at the same time which increases the backup of heat in fabrics and surfaces in the courtyard.

•Results of the findings indicate that the less the area of the courtyards, and their surroundedness, will not help the ventilation during the summer; by reducing the shaded surfaces, some of the passive heat absorbed on the surface of the courtyards in the cold seasons will be decreased, too.

As one of the most important achievements of this research we can focus on one of the findings that explains the physical specifications in the traditional houses with courtyards in Tabriz are not climatic and the central courtyard in these regions is a factor which is mostly subordinate to historical, social, cultural factors or those which are related to the security. At the end of this research, a climatic study on the central courtyards in different cities which are located in the cold climate condition, and analysis on the climatic role of the central courtyards in the hot and dry areas in the cold seasons of the year is proposed as the further research.

---

[i] Due to the absence of the data related to the global horizontal radiation, the following amounts are extracted from the Meteonorm software.

[ii] [ii] The values related to the temperature or the relative himidity of the ground, were simulated values at first but these values are calculated during the simulation process gy. These values according to the recieved or wasted ener are extracted from the Continental file of Tabriz (Downladable from the Energy plus web domain)

[ii] The values related to the temperature or the relative himidity of the ground, were simulated values at first but during the simulation process these values are calculated according to the recieved or wasted energy. These values are extracted from the Continental file of Tabriz (Downladable from the Energy plus web domain)

[iii] Windflow speed in the meteorological station outside of the city is conditioned for the urban texture of Tabriz using the power law.

References

1) 14384 Standard “Determining the PPD, PMV thermal comfort indice and the indice for the local thermal comfort” Iran’s National organization of Standard, 2011.
2) Bruse, M. & Fleer, H. (1998) "Simulating surface-plant-air interactions inside urban environments with a three- simentional numerical model," Environmental Modelling and software, 13, 373-384.
3) Bruse, M. (2017) ENVI-met 4.1: model overview, Available online at: http://www.envi-met.com/introduction.
4) Development and reconstruction plan of Tabriz city (2013), General regional analysis, Vol. 4 (identifying the city), Ministry of Roads and Urbanization, Central organization of roads and urbanization of East-Azerbaijan province, Naghsh-e Mohit consultant engineers group
5) Esmaeili Sangari, H., Omrani, B. (2014). “Old houses in Tabriz”, Forouzesh, Tabriz.
6) General development and urbanization plan of Tabriz, (2013), General analysis f the region, Vol. 4., (identifying the city), Ministry of roads and urbanization, central office of road and urbanization ministry, East Azerbaijan province, Naghsh-e Mohit consultant engineers.
7) Ghiaei, M., Mahdavinia, M., Tahbaz, M., Mofidi Shemirani, S. M. (2011), Methodology of selecting energy simulation software the the field of the architecture, Hoviat-e Shahr quarterly, Spring, 2013, Vol. 7., Issue 13, pp. 45-54.
8) Honjo , T.(2009). Thermal Comfort in Outdoor Environment; Global Environmental Research ,13.pp 43-47.
9) ISO 7730:2005, Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Japan.
10) Kasmaei, M. (2015), Zonation and handbook for the continental design of East Azerbaijan province, Center research for construction, Tehran.
11) Matzarakis, A., Rutz, Frank & Mayer, Helmut (2007), Modelling radiation fluxes in simple and complex environments-application of the RayMan model. International Journal of Biometeorology, 51, 323-334.
12) Monteiro, L. & Alucci, M. P. (2009). Thermal comfort index for the assessment of outdoor urban spaces in subtropical climates; The seventh International Conference on Urban Climate,Yokohama,
13) Shaqaqi, S., Mofidi, M. (2016), Link between the sustainable development and continental design in the design of buildings on the cold and dry areas: (Case study, Tabriz city), Natural environment sciences and technology quarterly, Vol. 10., Issue 3, Spring 2008.
14) Soflaei, F. (2016). Environmental impact of central courtyards in the architecture of the residential units in the hot and dry areas of Iran, Ph.d thesis, Islamic Azad University, Research and science branch, Tehran.
15) Soltanzadeh, H. (2010) “Tabriz, a secure brick in the architecture of Iran”, Center of cultural studies. Tehran.
16) Taban, M., Pourjafar, M., Bemanian, M. R., Heydari, S. (2013). Defying the efficient pattern for the central courtyards for the residential houses in Dezful (based on analysis of the received shadows on the different threes in the courtyard), Tehran, Baagh quarterly, Nazar publications, issue, 27.
17) Taleb, H. & Taleb D. (2014) "Enhancing the thermal comfort on urban level in a desert area: Case study of Dubai, United Arab Emirates," Urban Foresty & Urban Greening, 13, 253-260.
18) Taleghani, M.(2014), (Dwelling on Courtyards), Exploring the energy efficiency and comfort potential of courtyards for dwellings in the Netherlands, Delft University of -Technology, Faculty of Architecture and the Built Environment, Department of Architectural Engineering + Technology
19) Taleghani, M., Kleerekoper, L., Tenpierik, V. & Dobbelsteen A. (2014) "Outdoor thermal comfort within five different urban forms in the Netherlands," Building and Environment, 1-14.

20) Thapar, H.,Yannas, S. (2008), Microclimate and Urban Form in Dubai, Environment & Energy Studies Programme, Architectural Association School of Architecture, London, UK, PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October 2008
21) Watson, D., Labs, K. (2006). Bioclimatic Design at the Planning Scale, In D. Watson, & A. Plattus,Time saver for urban design, New York.
22) Yasa, E. (2013), Evaluation, In terms of Solar Heat Gains, of the Effects of Courtyard Building Shapes on Microclimate according to Different Climatic Regions,Climamed 13 proccedings Book VII, Mediterranean Congress of Climatization, Istanbul, P 82-91.