Journal of Urban Management and Energy Sustainability (JUMES)

Homepage: http://www.ijumes.com

CASE STUDY RESEARCH PAPER

Thermal Behavior Analysis of Semi-Open Space in Residential Complexes of Mashhad County with the help of Honeybee Energy Plus Software[1]

Danial Goshayeshi[1], Seyed Majid Mofidi Shemirani[2*], Shabnam Teimourtash[3], Mohsen Tabbasi[4]

1 Ph.D. Candidate , Department of Architecture, Mashhad Branch, Islamic Azad University, Mashhad, Iran
2 Assistant Professor, Department of Architecture, Iran University of Science and Technology, Tehran, Iran*
3 Assistant Professor, Department of Architecture, Mashhad Branch, Islamic Azad University, Mashhad, Iran
4 Associate Professor, Department of Architecture, Mashhad Branch, Islamic Azad University, Mashhad, Iran

ARTICLE INFO

Article History:
Received 2024-05-05
Revised 2024-06-05
Accepted 2024-08-31

Keywords:
HoneyBee Software, Mashhad county, Residential Complexes, Semi-Open Space, Thermal Comfort

ABSTRACT

Thermal comfort can affect the performance and efficiency of individuals from physical and mental aspects. it is very important to investigate the impact of shading on thermal comfort in semi-open spaces of Mashhad County with an emphasis on balconies, it seems that no in-depth research focusing has been conducted on this issue so far. Therefore, the present paper, which is based on a simulation approach, investigates and analyzes the thermal comfort in semi-open spaces. The results indicate that what is obtained from investigating the thermal behavior of various models among the various simulation modes in Honeybee Software is that all models are in the thermal comfort range for a very short time (0.05 hours) on the summer solstice day so that it can almost be said that it is not possible to provide thermal comfort at this time; but on the winter solstice day, models number eight and nine have provided the longest duration of thermal comfort with an amount of 2 hours. Of course, it is necessary to point out that after these two models, all the models that are open on one side have created the highest amount of thermal comfort provision on the winter solstice day with 1.75 hours. In addition, from the viewpoint of providing the lowest amount of thermal comfort on winter solstice day, the eastern model with three open sides and the western model with three open sides have gained the weakest position by providing thermal comfort conditions for only 1.25 hours.

DOI: 10.22034/ijumes.2024.2040569.1253

Running Title: Thermal Behavior Analysis of Semi-Open Space in Residential Complexes

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
14	49	16

*Corresponding Author:
Email: *m.mofidi.s1400@gmail.com*
Phone: +985136638920
ORCID: https://orcid.org/0000-0002-2593-1501

1. This paper is taken from Danial Goshayeshi's Ph.D. thesis entitled "Principles of Shading Design on Thermal Behavior of Semi-Open Space of Mashhad County" which is about to be conducted under the guidance of Dr. Seyyed Majid Mofidi Shemirani and advice of Dr. Mohsen Tabbasi at Faculty of Architecture and Urban Planning of Islamic Azad University, Mashhad Branch.

INTRODUCTION

The quality of using different architectural and urban spaces depends on various aspects, among which thermal comfort is known as an important factor. The spaces, which cannot provide comfort conditions, are used less and even avoided (Du et al., 2021). Carmona mentions comfort as a basic need in architectural spaces, and oints out that it is difficult to find out how other space needs can be met without comfort (Endler and Matzarakis, 2007). An investigation into the thermal comfort quality of architectural and urban spaces, on the other hand, is important because various studies have proven the difference in temperature between urban areas and the suburbs. Significant amounts of solar radiation are stored and reflected through large buildings and the impact of roads, which is mainly associated with tall buildings, in urban areas (Erell et al., 2012). The side effects of the human activities and the increase in asphalt surfaces (with low albedo) compared to the green areas cause the emergence of heat island phenomenon and the temperature difference of 2 to 5 degrees between cities and suburban areas is known as this (Farivar and Agharabi, 2020). The Albedo measured in cities shows that paved surfaces store much more heat than the natural ground (Fallah Qalhari et al., 2015). This highlights the necessity of applying solutions to modify the thermal comfort conditions in new developments as well as historical contexts that have undergone changes. The present research was formed aiming at explaining the methods to evaluate thermal comfort indices as well as introducing the software for its calculation. In order to analyze the thermal comfort conditions of the investigated spaces, it is usually done using three thermal indices: standard impactive temperature, physiological equivalent temperature, and forecasting the desired average temperature in two seasons, winter and summer. Therefore, the present research is based on a simulation approach to investigate and analyze thermal comfort in semi-open spaces.

MATERIALS AND METHODS

Thermal Comfort

Thermal comfort in its basic definition is the body reaction to environmental conditions in indoor and outdoor spaces. A more precise definition of these conditions can be summarized in three groups:

The first definition is psychological, which refers to the brain's expression of satisfaction with the environment temperature. The second definition is thermal-physiological, which is related to the biological reaction of the body and the nervous system to external influences on the skin's thermal receptors. The third definition refers to the balance between the flow of heat into and out of the body (Ghoshayeshi et al., 2013). In addition to these three general definitions of comfort conditions, there are also many other definitions that are made especially with regard to cold or hot spaces without comfort (Höppe, 2002).

The second viewpoint raises another issue and considers the human being as an intelligent and active being in regulating his/her thermal comfort. In this viewpoint, the feeling of thermal comfort is influenced by climatic conditions of the environment outside the building, cultural, behavioral, and psychological factors in addition to physiological factors, and can affect these thresholds. Based on these two viewpoints, the two general concepts of thermal comfort and feeling of comfort are the subject of research, and some scales and coefficients have been created to measure these concepts (Hsieh et al., 2016), which are introduced in continuation of widely-used indices of thermal comfort measurement. The evaluation of thermal comfort, especially in urban spaces compared to architectural spaces, is a big challenge, since many environmental and personal (physiological and psychological) factors are involved in it (Jafari, 2008). Therefore, research in the field of thermal comfort of outdoor space is faced with conditions and issues that do not exist in the studies of indoor space (Khrit et al., 2017). In general, the quality of thermal comfort depends on eight factors, which are as follows in order of importance:

1-Air temperature
2-humidity
3-water vapor pressure
4-air flow speed
5-Radiation from the inner walls of space (average radiation temperature)
6-humans (age, gender)
7- Type of human activity
8- Type of human covering.

Thermal Comfort Indices

Many indices have been invented and developed to evaluate the impact of climate on humans and studies of comfort climate in the second half of the 20th century. The models derived from the energy balance equation of the human body are more interesting among them. The first heat balance model was coined and described by Fenger in 1972, which is still used. He developed the thermal indices of the predicted average votes and the prediction of the percentage of dissatisfied people to help ventilation engineers in indoor (closed environment) climate conditions. Two decades later, Jendertzaki et.al (1990) managed to adjust the complex Fenger method by assigning suitable variables for external conditions, which is known nowadays as the MEMI model (Klinsky et al., 2017). The MEMI model stands for the energy balance model for individuals. This model has been used to determine the actual amount of heat fluxes and temperatures of the human body in a certain environment, assuming that the heat loss of the skin is equal to the heat produced by the blood and the heat transferred from the body center to the skin surface (Höppe, 1999) and is considered one of the most widely-used thermal comfort assessment models. The set of thermal indices are divided into two groups of experimental indices including (ET, RT, HOP, OP, WCI) and analytical ones (PT, PET, ITS, HSI, ET*, SET*, OUT-SE, PMV). The basis of analytical indices is based on energy balance (wasteful and productive energy in humans) among them. Most researches have used the indices of "predicted average votes", "standard effective temperature" and "physiological equivalent temperature" in order to predict the comfort temperature in the open space in recent years (Karakounos et al., 1992). Although the PMV index was originally intended to measure indoor thermal comfort conditions, Honjo showed in 2009 that PMV, PET, and SET indices can be currently suitable with regard to the lack of suitable indices for outdoor spaces. The PMV scale is a typical classification of thermal sensation, 7 degrees, the range of which varies from (-3 very cold) to (3+ very hot). Zero on this scale indicates a neutral thermal sensation. These seven degrees are provided by ASHRAE Organization and used by Fenger. Since many comfort criteria such as climate variables, type of clothing, and activity are used together in this method, it is one of the most complete and accurate methods to estimate the comfort range. Numbers slightly higher than (+1) or slightly lower than (-1) cause dissatisfaction in this criterion; Therefore, the comfort range will include -1>PMV>+1 (Kwon and Lee, 2001). This research has been conducted with a simulation approach with the help of HoneyBee Software, in which the studied samples are simulated in Honeybee software after collecting data through library and document reviews (documentation), and the field collection of the studied samples and the output analysis is conducted through the software with the help of logical arguments by determining the determined climatic and physical parameters.

Selection of four-storey apartments as the studied model

As stated in the previous chapters, the purpose of this research was to investigate the thermal behavior in the balcony spaces of Mashhad County apartments. According to the surveys conducted and the statistics obtained from the Center for Studies and Urban Plans of Mashhad Municipality, in the southwest, southeast, northeast, northwest, middle, and central areas of Mashhad, the largest number of building permissions were issued in the past two decades for the construction of four-storey apartments as many as 24,834 pieces. So, it can be found that the most requests of the citizens in recent years are for the construction of four-story apartments. Therefore, for this reason, this research aims to evaluate the thermal behavior of the balconies of this type of apartments.

Sample Collection Method and Size

It is necessary to use Cochran's formula in order to find the number of research samples (Cochran, 2007). Cochran's formula allows selecting the sample size according to the desired accuracy, the desired confidence level, and the ratio or the estimated average of the characteristics of the desired trait in the population. In this research, the goal is to be able to find the appropriate dimensions (length, width, height) of the balconies of four-storey apartments in order to enter them into the simulation software.

Balconies Dimensions

The average dimensions of the height, width, and length of the balconies were found to be 3.78 meters, 1.22 meters and 3.13 meters, respectively after investigating into the dimensions of 378 approved drawings of four-story apartments in Mashhad County. Since the obtained dimensions must have a submultiple of one meter to enter the simulation software used in this research, therefore, the dimensions of the height, width, and length of the balconies in various states are considered to be 4, 1, and 3 meters, respectively.

DISCUSSION AND FINDINGS

Simulation Process with HoneyBee Plugin in EnergyPlus Software Platform

The Honeybee plugin is part of Ladybug Tools plugin collection, the first version of which was released in 2014. Honeybee acts as an application interface (API) for EnergyPlus and transfers information related to building energy consumption simulation from Rhino and Grasshopper environment to EnergyPlus and OpenStudio one, and sends the results back to the Rhino and Grasshopper environments after the simulation. Therefore, architects and designers can perform their energy simulations through modeling in the Rhino environment, away from the usual complications of operating with Energy Plus software.

How to Model in HoneyBee Plugin

It is not possible to directly model open and semi-open spaces in building energy consumption simulation software. Simulation information is only available for spaces with completely-closed geometry in such software; Therefore, it is necessary to first draw a closed geometry and then to complete the closed geometry and activating the air connection between inside and outside (zone mixing object) by placing a window on it to simulate spaces like a balcony. Next, the windows are considered to be always open to simulate the semi-open behavior of the space in the schedule to simulate the thermal behavior of the terrace. If we want to simulate semi-open spaces in the Honeybee (Energy Plus) plugin, we must first draw a closed geometry and then simulate the behavior of a semi-open space by placing windows on the walls and assuming they are always open. The modeling modes considered in this research are according to the following images:

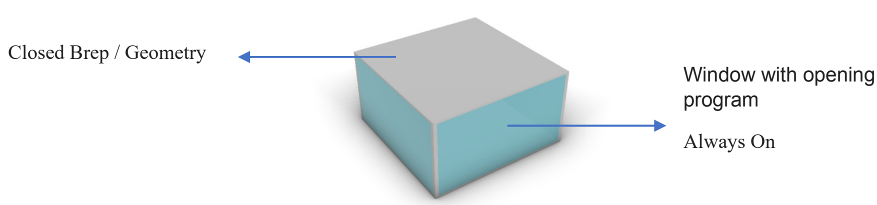

Figure 1: How to Model Semi-Open Space in Honeybee Energy Simulator Software

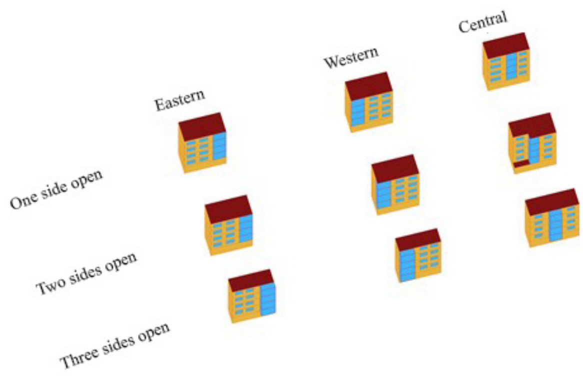

Figure 2: Models considered for balcony study in Honeybee plugin

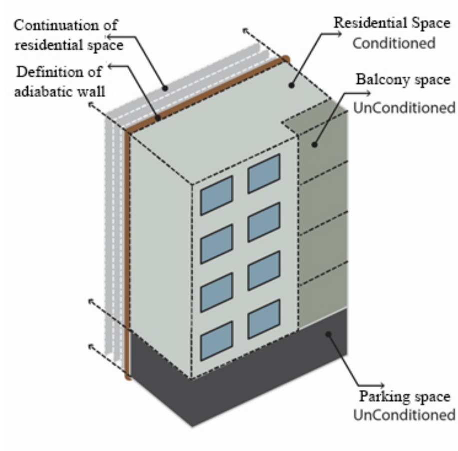

Figure 3: Zoning diagram of spaces in software

Simulation Assumptions

Zoning

Only the section affecting the thermal performance of the balcony was modeled for the zoning of spaces. In this way, the inner section is considered as an adiabatic wall so that the impact of internal heat transfer is not taken into account. On the other hand, the interior section was modeled spatially with possibility of heating and cooling (conditioned space). The terrace and parking space were also modeled spatially without possibility of heating and cooling (unconditioned space) since they are completely effective on the thermal conditions inside and outside as well as the heat transfer with the ground, so that the conditions are closer to reality.

The assumptions of the simulation of spaces in the building simulation software are specified in detail in Table 2.

Table 1: How to allocate cooling and heating load to different building zones

(User) Space Name	Assumption of Simulation
Residential space affecting the terrace performance	With possibility of heating and cooling
Terraces	No possibility of heating and cooling
Parking	No possibility of heating and cooling
The partition between impactive and ineffective residential space	Adiabatic

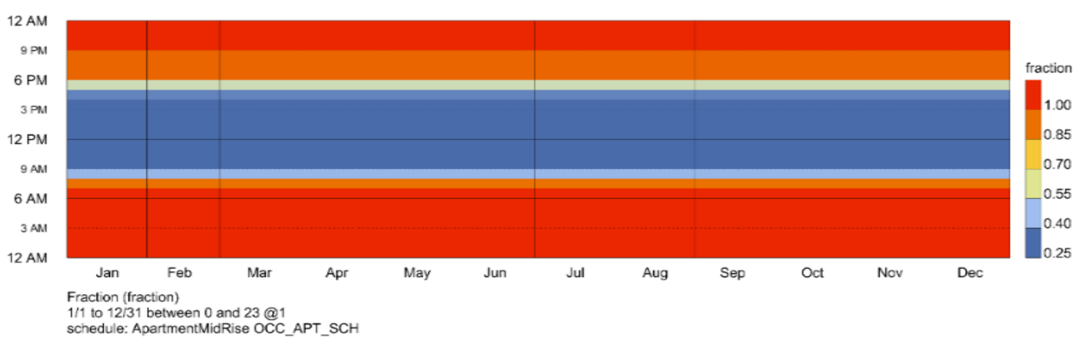

Diagram 1: People's attendance schedule in different months of the year

Program

The space usage program is considered as an intermediate residential building. It should be noted that all the assumptions required by the simulation software are considered to be based on the ASHRAE 90.1 standard of version 2019. The considered schedule is presented in several sections, which will be addresses in detail.

Users (People)

According to the standard, the presence of people per capita is 0.028309 people per square meter. The attendance schedule of people is considered based on the following chart:

Artificial Lighting Loads

The use of artificial lighting per capita is assumed to be 6.45834 watts per square meter.

The schedule for using artificial lighting is according to the following diagram:

In addition, the lighting system characteristics are considered based on the following table:

Table 2: Coefficient and value of the lighting system to calculate cooling and heating load

Coefficient	Value
Radiant fraction	0.6
Visible fraction	0.2
Return fraction	0

Equipment Load

The equipment energy consumption per capita in residential space is assumed to be 6.669994 watts per square meter. The equipment usage schedule is according to the following diagram:

The equipment specifications are also considered based on the following table:

Table 3: Equipment specifications to calculate the cooling and heating load

Fraction	Value
Radiant Fraction	0.5
Latent Fraction	0.2
Lost Fraction	0

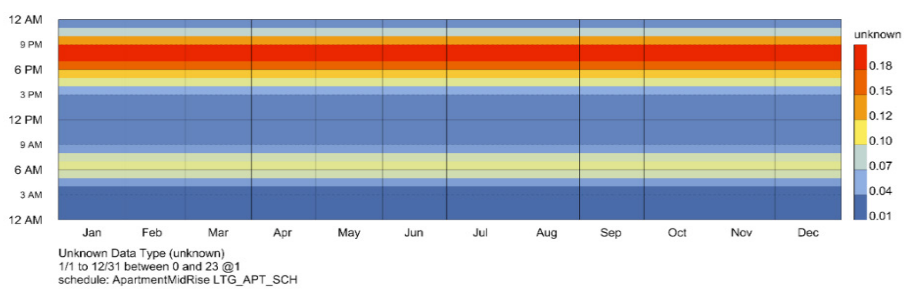

Diagram 2: Schedule of using artificial lighting in different months of the year

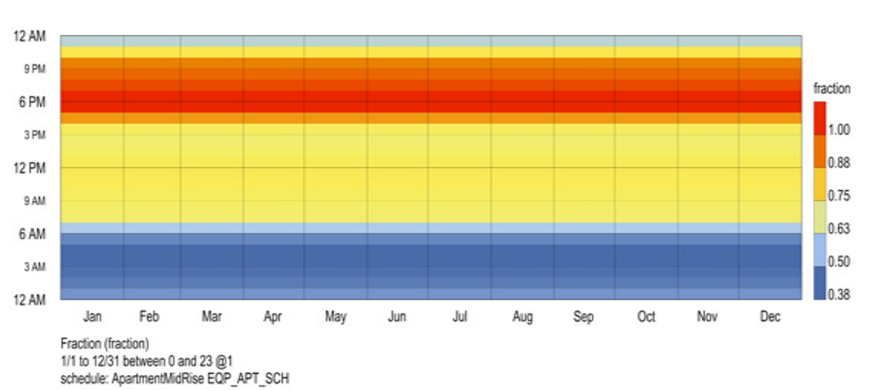

Diagram 3: Schedule of equipment use in different months of the year

(Sanitary) Domestic Hot Water Consumption

The domestic hot water consumption per capita in residential space is 0.149258 liters per hour per square meter. The suitable temperature to consume hot water is considered to be 60 degrees Celsius. The hot water usage schedule is according to the following diagram:

The hot water equipment specifications are considered according to the table below.

Table 4: Specifications of hot water equipment used to calculate the cooling and heating load

Coefficient of Various Fractions	Value
Tangible fraction	0.2
Latent fraction	0.05

Air Infiltration Rate

The amount of unwanted air infiltration for a normal building at an air pressure of 4 pascal is considered to be 0.0003 cubic meters per second and per square meter of the building shell. This value is assumed constant throughout the day and night.

Natural Ventilation

The minimum amount of natural ventilation to provide fresh air is considered to be 0.35 of the air volume of each area per hour.

Installation Systems Settings (Set Points)

The heating system activation temperature is 21.7 degrees Celsius and the cooling system activation temperature is 24.4 degrees Celsius.

Materials and Construction Method

Table 5: Summary of walls' details

Wall Type	U Value	R Value	SHGC
External wall	0.599647	1. 503895	–
External roof	0.208244	4. 638297	–
External floor	0.394078	2.373814	-
Window	2.404504	0. 247408	0. 25
Inner wall	2.116724	0. 308675	–
Interior floor/ceiling	1.155239	0. 701869	–

In the ASHREA standard, the construction method and building materials are suggested based on ASHREA climate zone classification and type of building structure. The climate of Mashhad County is placed in the BSk category based on the Köppen classification and in the 3B category based on ASHREA, so the details in this research are considered for the mentioned climate and concrete structure buildings.

Balconies Modeling and Their Analysis in Honeybee Software

We address the details of balconies in Honeybee Software and their analysis by this software

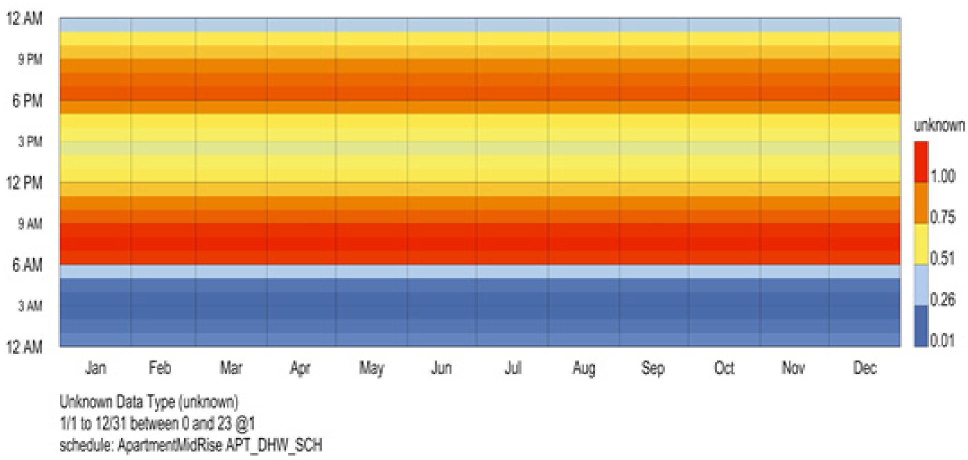

Diagram 4: Schedule of hot water consumption in different months of the year

in this section.

Model Number One: Eastern Balcony (One Side Open)

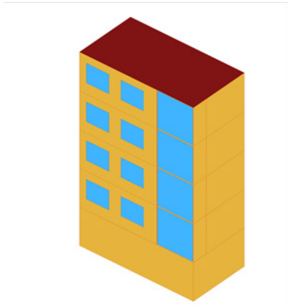

Figure 5: Model Number One Balcony Modeling in Honeybee Software

Figure 6: Average temperature of the surfaces in summer solstice (right) and winter solstice (left) of model number one between 6:00 and 7:00 p.m.

The model number one was simulated throughout the year, especially during the summer and winter solstice days, between 6:00 and 19:00 to evaluate the thermal behavior of the model number one. The model number one experiences PET temperature range from -2.5 °C to 36.7 °C in a year. This model is only 0.05 hours in the range of thermal comfort on summer solstice day (June 22). On the other hand, the number of hours of thermal comfort in this model is more on the winter solstice day (December, 22) and this model creates thermal comfort conditions for 1.75 hours. The average temperature of PET on the summer and winter solstice day is 28.5 and 20.06 degrees Celsius, respectively. The highest PET temperature was 34.02 °C and the lowest temperature was 24.6 °C during the studied hours in the summer solstice. These numbers for the winter solstice are 30.7 and 7.3 degrees Celsius, respectively. The highest PET temperature for the balconies of this model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day.

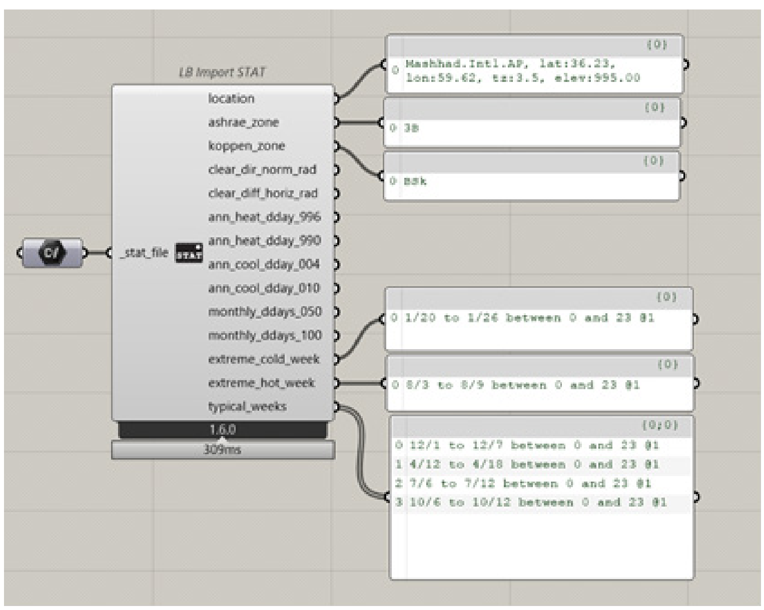

Figure 4: Input of Climatic Classification Information of Mashhad County in Honeybee Software

Model Number Two: Eastern Balcony (both sides open)

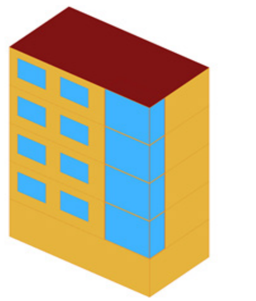

Figure 7: Modeling number two balcony in Honeybee software

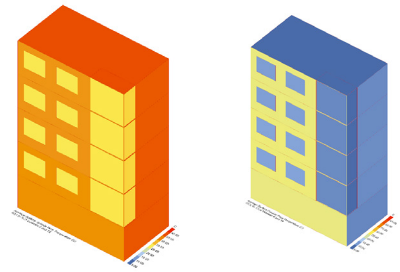

Figure 8: Average surface temperature in summer solstice (right) and winter solstice (left) of model number two between 6:00 a.m. and 7:00 p.m.

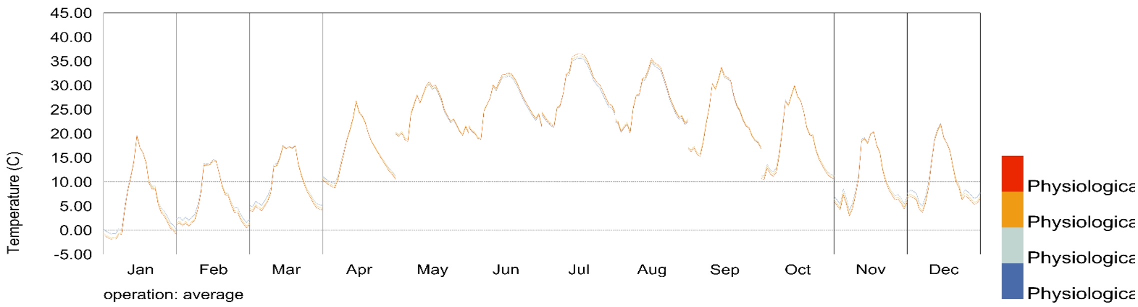

Diagram 5: Annual temperature of balconies (PET) for model number one

Table 6: Quantitative information obtained from the software output for model No. 1

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Eastern, one open side	0.05	1.75	28.50	20.06

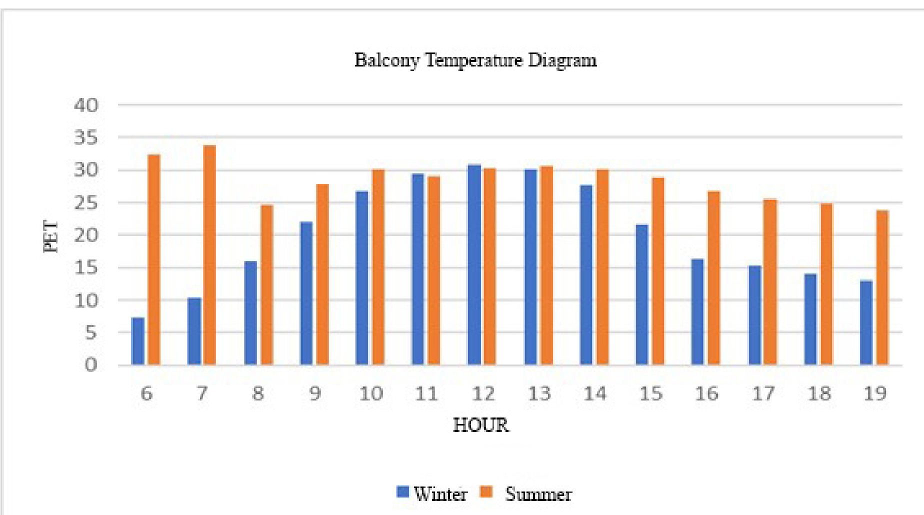

Diagram 6: Balcony temperature in the range of hours studied in summer and winter solstice for sample number one

This model was simulated throughout the year, especially on the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number two. Model number two experiences the temperature range of PET from -2.7 °C to 37.3 °C in a year. This model is in the thermal comfort range for only 0.05 hours on the summer solstice day (June, 22). On the other hand, the number of hours of thermal comfort in this model is more on the winter solstice day (December, 22) and the model creates thermal comfort conditions for 1.5 hours. The average temperature of PET on the summer and winter solstice day is 29.78 and 20.07 degrees Celsius, respectively. The highest PET temperature was 38.2 °C and the lowest temperature was 23.9 °C during the studied hours in the summer solstice. These numbers for the winter solstice are 30.9 and 6.8 degrees Celsius, respectively. The highest PET temperature for the balconies of this model was observed at 7:00 On the summer solstice day and at 12:00 on the winter solstice day.

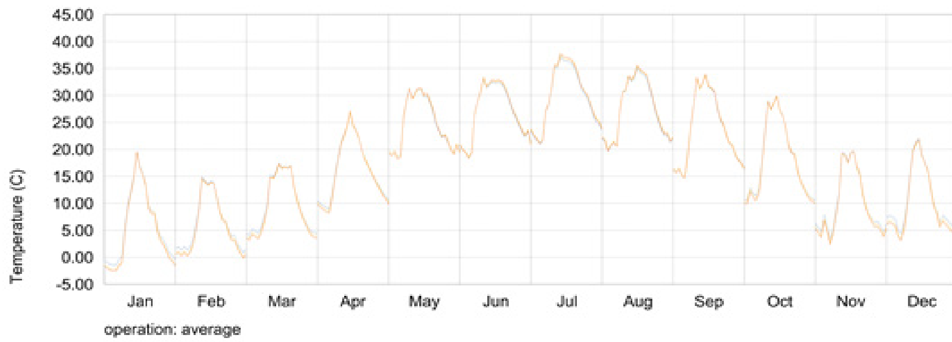

Diagram 7: Annual temperature of balconies (PET) for model number two

Table 7: Quantitative information obtained from software output for model No. 2

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Eastern, one open side	0.05	1.50	29.78	20.07

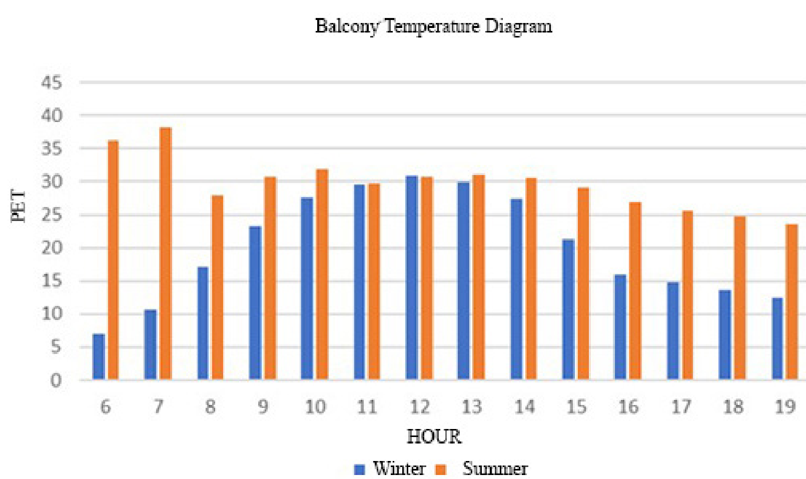

Diagram 8: Balcony temperature in the range of studied hours in summer and winter solstice for sample number two

Model number three: Eastern balcony (three sides open)

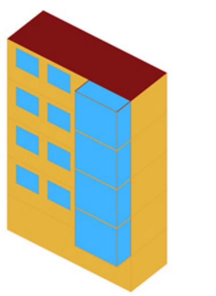

Figure 9: Modeling number three balcony in Honeybee software

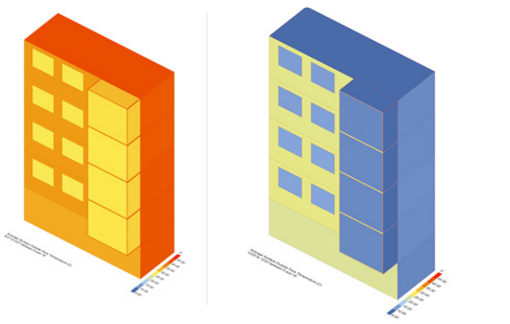

Figure 10: Average temperature of surfaces in summer solstice (right) and winter solstice (left) model number three between 6:00 and 7:00 p.m.

This model was simulated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number three. Model number three experiences a PET temperature range of -4.2 °C to 42.8 °C in a year. This model is only 0.05 hours in the range of thermal comfort on the summer solstice day (June, 22) and 1.25 hours in the range of thermal comfort on the winter solstice (December, 22). The average temperature of PET on the summer and winter solstice day is 31.09 and 19.73 degrees Celsius, respectively. The highest PET temperature was 38.4 °C and the lowest one was 24.4 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 31.6 and 6.5 degrees Celsius, respectively. The highest PET temperature for the balconies of this model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day.

Model number four: West balcony (one side open)

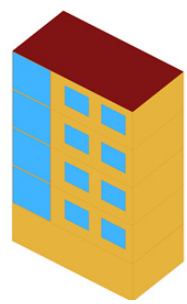

Figure 11: Modeling balcony number four in Honeybee software

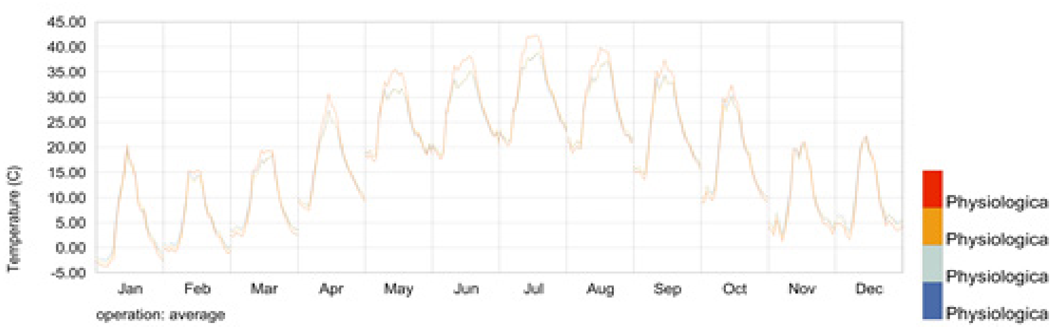

Diagram 9: Annual temperature of balconies (PET) for model number three

Table 8: Quantitative information obtained from software output for model No. 3

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Eastern, three sides open	0.05	1.25	31.09	19.73

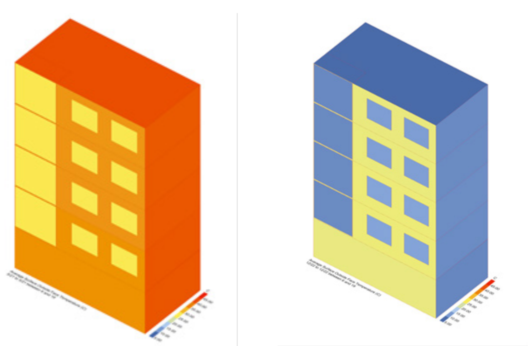

Figure 12: Average temperature of surfaces in summer solstice (right) and winter solstice (left) of model number four between 6:00 a.m. and 7 p.m.

This model was simulated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number four. Model number four experiences the range of PET temperature fluctuation from -2.2 °C to 36.2 °C in a year. On the summer solstice day (June, 22), this model is only 0.05 hours and on the winter solstice day (December, 22), 1.75 hours in the range of thermal comfort. The average temperature of PET on the summer and winter solstice day is 28.38 and 20.07 degrees Celsius,

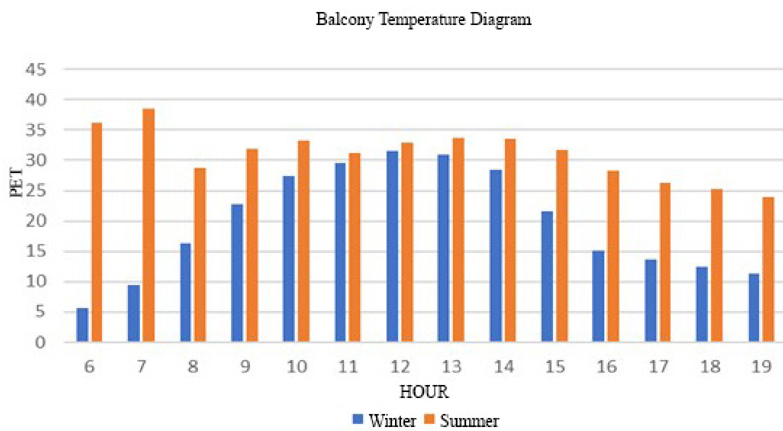

Diagram 10: Balcony temperature in the range of studied hours in the summer and winter solstice for sample number three

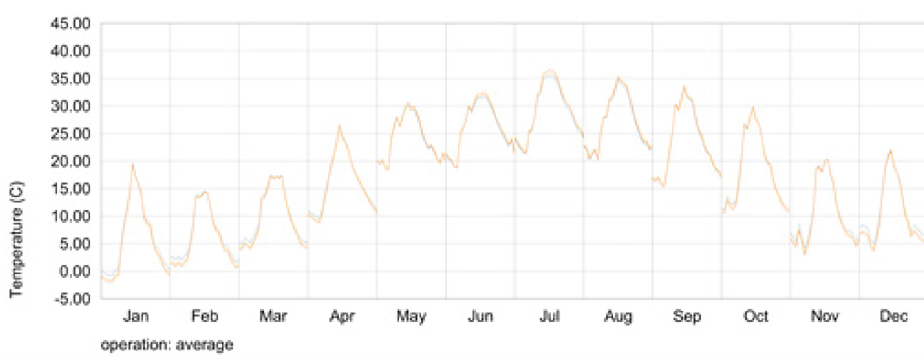

Diagram 11: Annual temperature of balconies (PET) for model number four

Table 9: Quantitative information obtained from software output for model number four

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Western, one side open	0.05	1.75	28.38	20.07

respectively. The highest PET temperature was 34.07 °C and the lowest one was 23.7 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 31.3 and 7.8 degrees Celsius, respectively. The highest PET temperature for the balconies of this model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day.

Model number five: West balcony (both sides open)

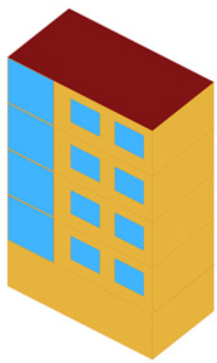

Figure 13: Modeling balcony number five in Honeybee software

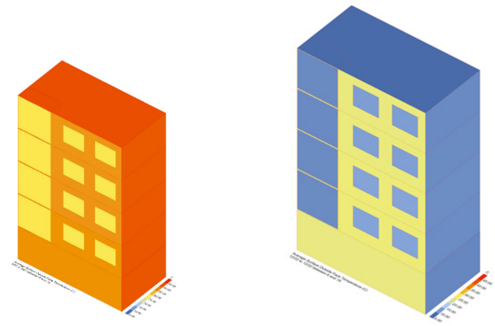

Figure 14: Average surface temperature in summer solstice (right) and winter solstice (left) of model number five between 6 :00 a.m. and 7:00 p.m.

This model was simulated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number five. Model number five experiences the temperature range of PET from -2.6 °C to 37.4 °C in a year. On the summer solstice day (June, 22), this model is only 0.05 hours and on the winter solstice day (December, 22), 1.50 hours is in the range

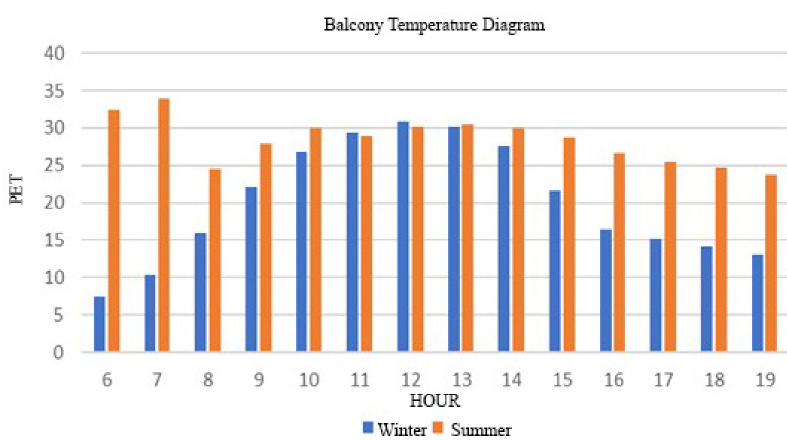

Diagram 12: balcony temperature in the range of hours studied in summer and winter solstice for sample number four

Table 10: Quantitative information obtained from software output for model number five

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Western, both sides open	0.05	1.50	29.07	20.18

of thermal comfort. The average temperature of PET on the summer and winter solstice day is 29.07 and 20.18 degrees Celsius, respectively. The highest PET temperature was 34.3 °C and the lowest one was 23.9 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 31.1 and 7.7 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day. Additionally, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

Model number six: Western balcony (three sides open)

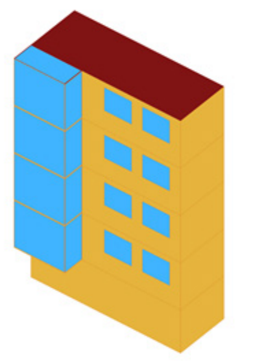

Figure 15: Model number six balcony modeling in Honeybee software

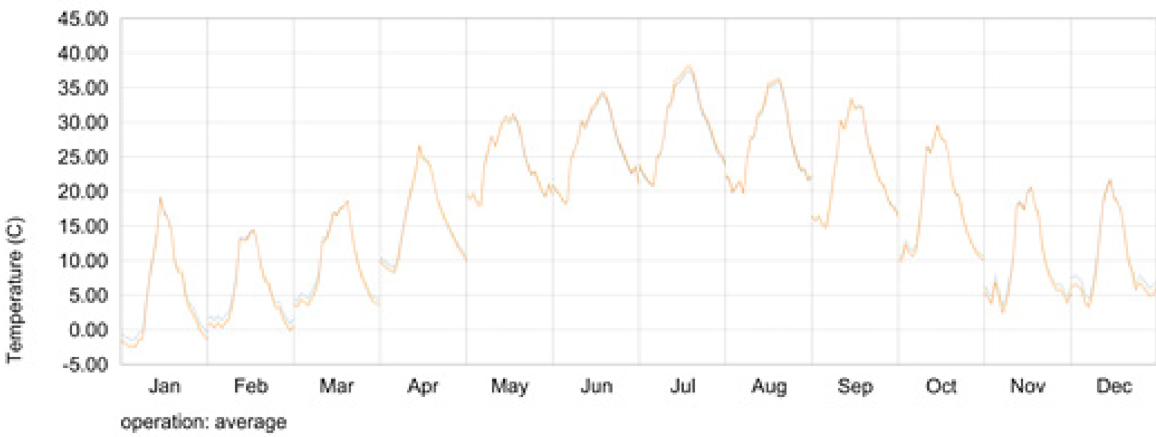

Diagram 13: Annual temperature of balconies (PET) for model number five

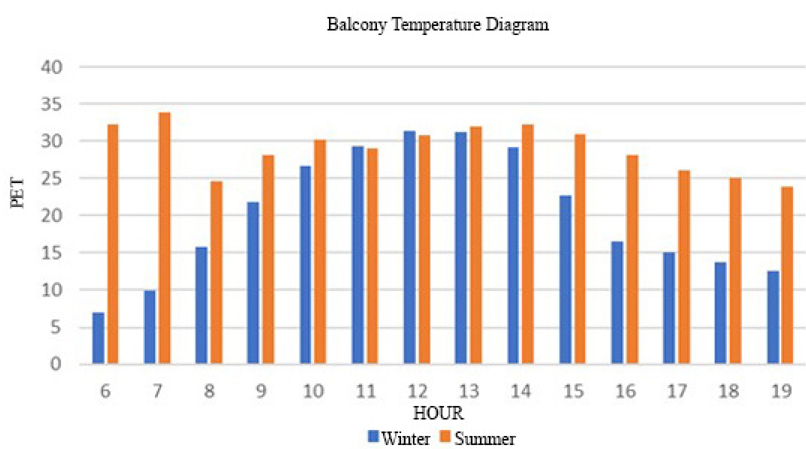

Diagram 14: Balcony temperature in the range of studied hours in summer and winter solstice for sample number five

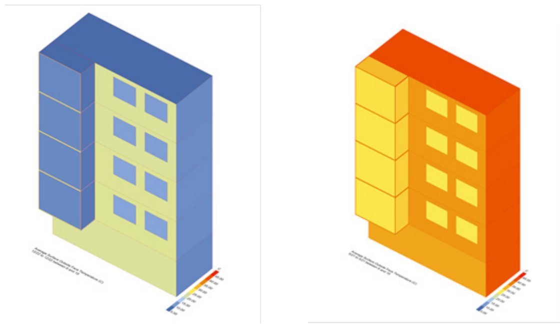

Figure 16: Average temperature of surfaces in summer solstice (right) and winter solstice (left) of model number six between 6:00 a.m. and 7:00 p.m.

This model was simulated and investigated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number six. Model number six experiences the temperature range of PET from -3.8 °C to 42.9 °C in a year. On the summer solstice day (June, 22), this model is only 0.05 hours and on the winter solstice (December, 22), 1.25 hours is in the range of thermal comfort. The average temperature of PET on the summer and winter solstice day is 30.86 and 19.71 degrees Celsius, respectively. The highest PET temperature was 34.1 °C and the lowest one was 23.8 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 31.9 and 7.3 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day. Furthermore, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

Model number seven: Middle balcony (one side open)

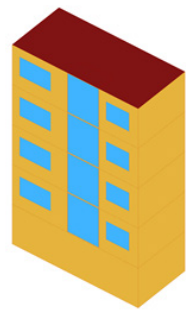

Figure 17: Model number seven balcony modeling in Honeybee software

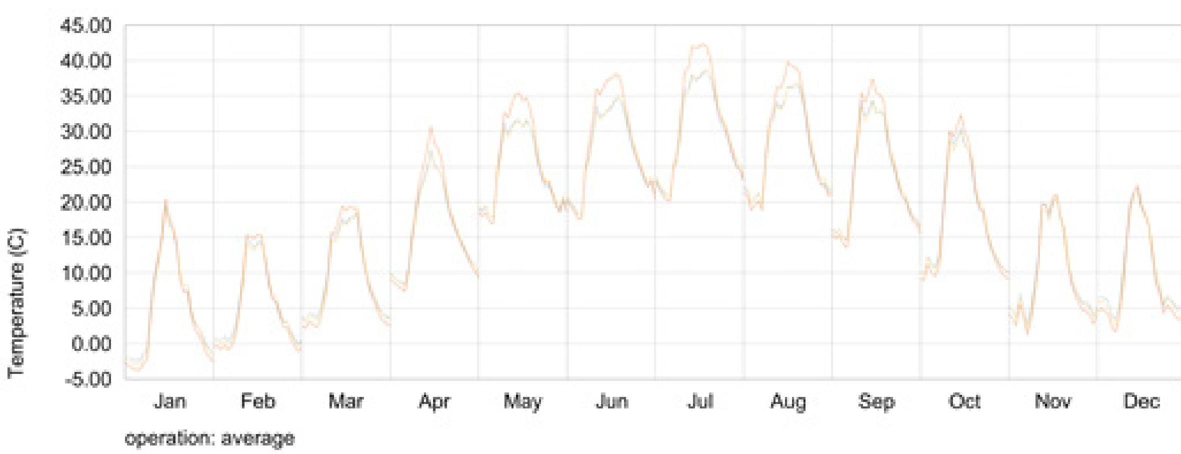

Diagram 15: Annual temperature of balconies (PET) for model number six

Table 11: Quantitative information obtained from software output for model number six

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Western, three sides open	0.05	1.25	30.86	19.71

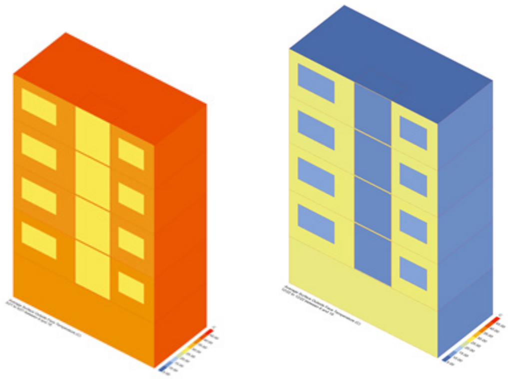

Figure 18: Average surface temperature in summer solstice (right) and winter solstice (left) of model number 7 between 6:00 a.m. and 7:00 p.m.

This model was simulated and investigated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number seven. This model experiences the fluctuation range of PET temperature from -1.1 °C to 35.4 °C in a year. The model is in the range of thermal comfort for 0.05 hours on the summer solstice day (June, 22) and for 1.75 hours on the winter solstice day (December, 22). The average temperature of PET on the summer and winter solstice day is 28.13 and 20.43 degrees Celsius, respectively. The highest PET temperature was 33.8 °C and the lowest one was 23.5 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 30.8 and 7.7 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day. In addition, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

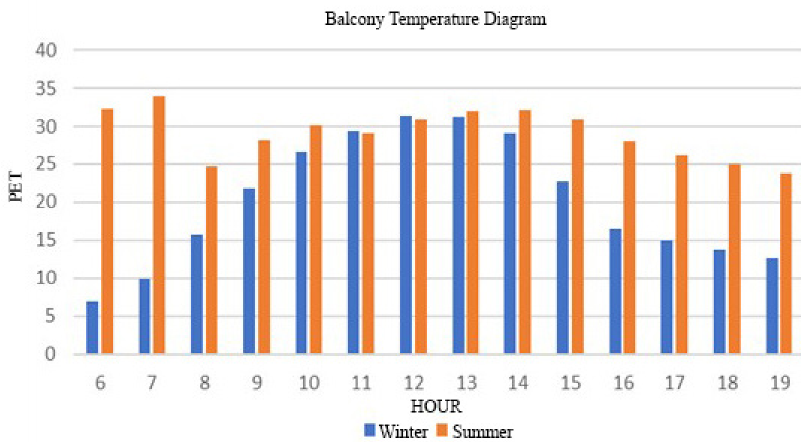

Diagram 16: Balcony temperature in the range of studied hours in summer and winter solstice for sample number six

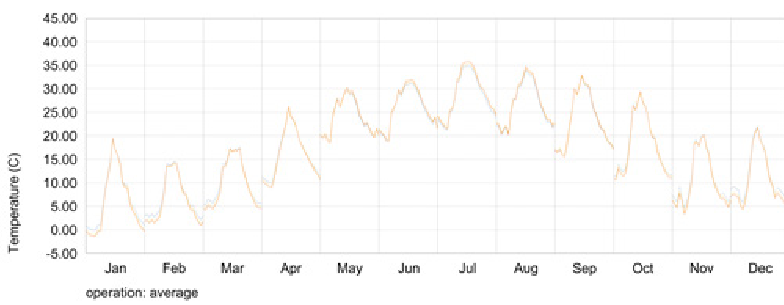

Diagram 17: Annual temperature of balconies (PET) for model number seven

Model number eight: Middle balcony (western, both sides open)

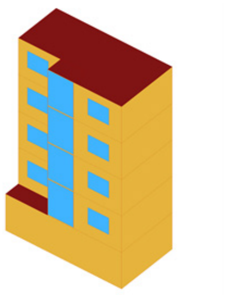

Figure 19: Model number eight balcony modeling in Honeybee software

Figure 20: Average temperature of surfaces in the summer (right) and winter (left) solstice of model number eight between 6:00 a.m. and 7:00 p.m.

This model was simulated and investigated throughout the year, especially on the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number eight. Model number 8 experiences the PET temperature ranging from -2.7 °C to 38.8 °C in a year. This model is in the range of thermal comfort for 0.05 hours on the summer solstice day (June, 22) and for 2.00 hours on the winter solstice (December, 22). The average temperature of PET on the summer and winter solstice day is 29.11 and 20.02 degrees Celsius, respectively. The highest PET temperature was 33.9 °C and the lowest one was 24.1 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 31.2 and 7.2 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 to 13:00 on the winter solstice day. In addition, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

Table 12: Quantitative information obtained from software output for model number seven

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Middle, one side open	0.05	1.75	28.13	20.43

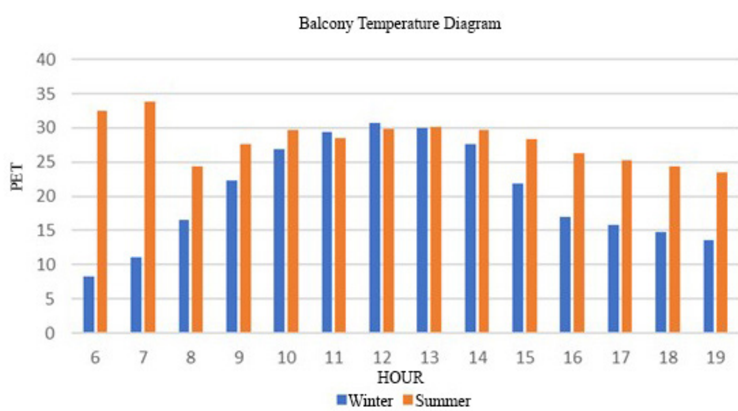

Diagram 18: Balcony temperature in the range of studied hours in the summer and winter solstice for sample number seven

Model number nine: Middle balcony (eastern- both sides open)

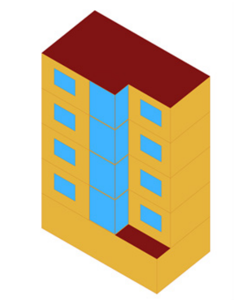

Figure 21: Model number nine balcony modeling in Honeybee software

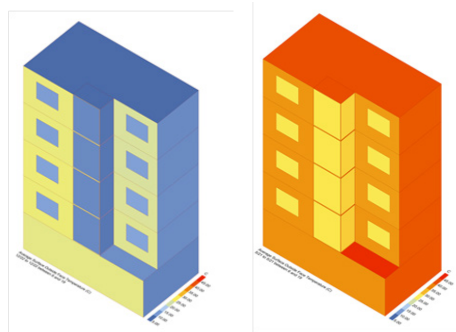

Figure 22: Average temperature of surfaces in summer solstice (right) and winter solstice (left) of model number nine between 6:00 a.m. and 7:00 p.m.

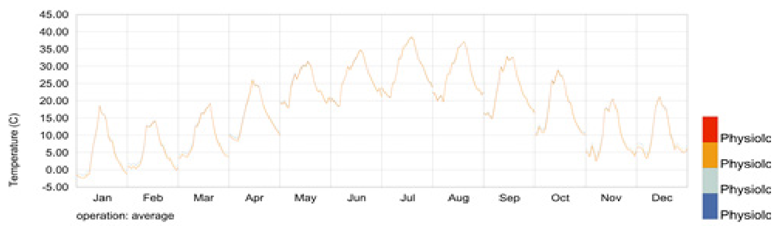

Diagram 19: Annual temperature of balconies (PET) for model number eight

Table 13: Quantitative information obtained from software output for model number eight

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Middle, western, two sides open	0.05	2.00	29.11	20.02

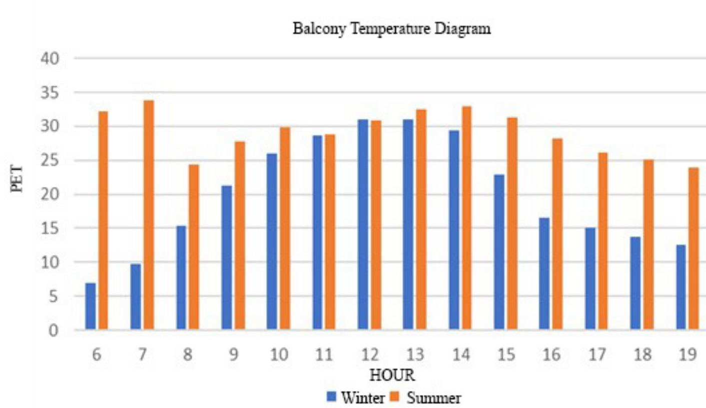

Diagram 20: Balcony temperature in the range of studied hours in summer and winter solstice for sample number eight

Model number nine was simulated and investigated throughout the year, especially on the summer and winter solstice days between 6:00 and 19:00. This model experiences the fluctuation range of PET thermal degree from -1.3 °C to 37.5 °C during the year. On the summer solstice day (June, 22), this model is in the range of thermal comfort for 0.05 hours and on the winter solstice (December, 22) for 2.00 hours. The average temperature of PET on the summer and winter solstice day is 30.91 and 19.85 degrees Celsius, respectively. The highest PET temperature in the summer solstice was 34.3 °C and the lowest one was 23.7 °C. This maximum and minimum temperature for the winter solstice is 0.30 and 7.6 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day. Additionally, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

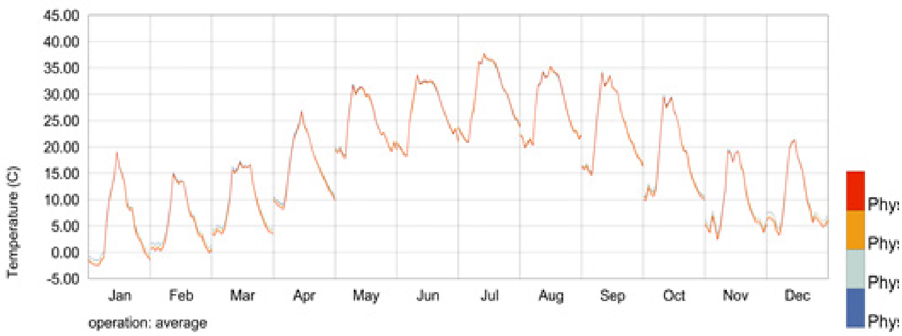

Diagram 21: Annual temperature of balconies (PET) for model number nine

Table 14: Quantitative information obtained from software output for model number nine

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Middle, east, two sides open	0.05	2.00	30.91	19.85

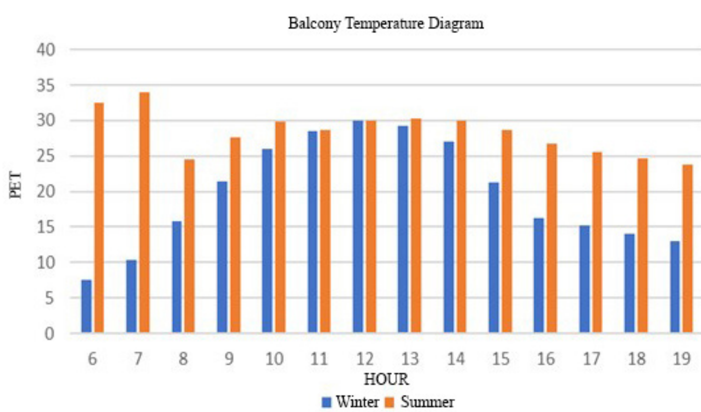

Diagram 22: Balcony temperature in the range of studied hours in summer and winter solstice for sample number nine

Model number ten: Middle balcony (three sides open)

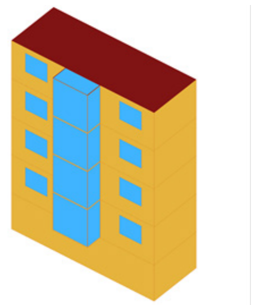

Figure 23: Model number ten balcony modeling in Honey-bee software

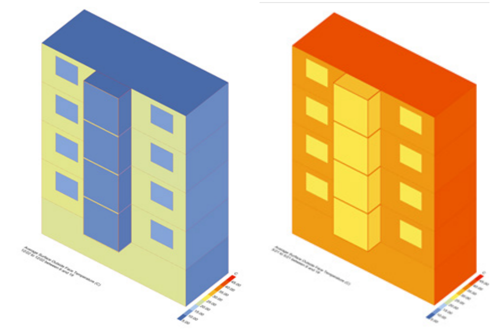

Figure 24: Average surface temperature in summer solstice (right) and winter solstice (left) of model number ten between 6:00 and 19:00

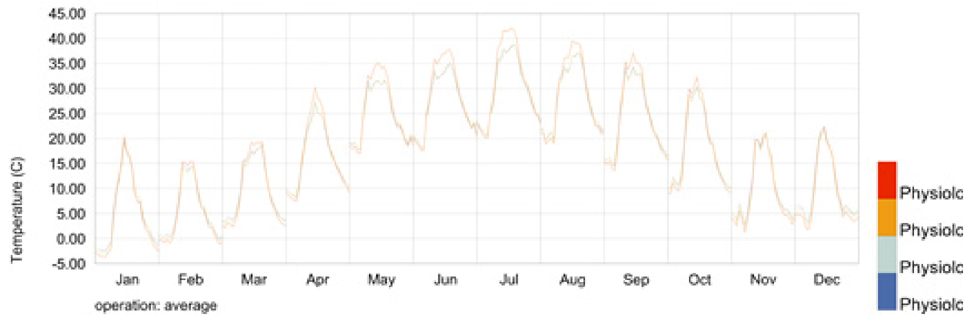

Diagram 23: Annual temperature of balconies (PET) for model number ten

Table 15: Quantitative information obtained from software output for model number ten

Type of Balcony	Number of summer solstice comfort hours	Number of winter solstice comfort hours	Average PET of summer solstice comfort	Average PET of winter solstice comfort
Middle, east, three sides open	0.05	1.50	30.93	19.84

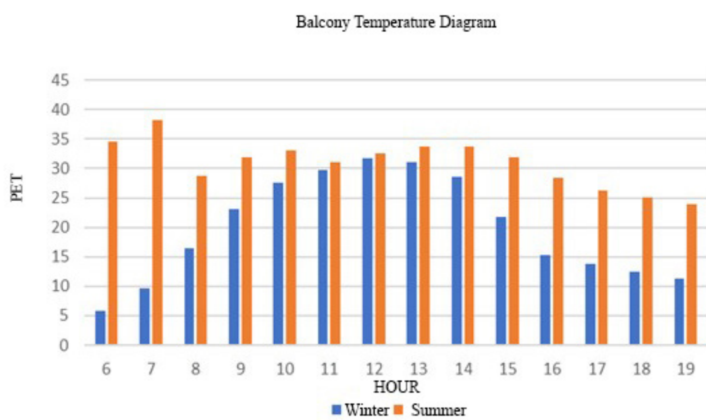

Diagram 24: Balcony temperature in the range of studied hours in summer and winter solstice for sample number ten

This model was simulated and investigated throughout the year, especially during the summer and winter solstice days between 6:00 and 19:00 to evaluate the thermal behavior of model number ten. Model number ten experiences the range of PET temperature fluctuation from -4.2 °C to 42.4 °C in a year. This model is in the range of thermal comfort for 0.05 hours on the summer solstice day (June, 22) and for 1.5 hours on the winter solstice (December, 22). The average temperature of PET on the summer and winter solstice day is 30.93 and 19.84 degrees Celsius, respectively. The highest PET temperature was 37.7 °C and the lowest one was 24.2 °C during the studied hours in the summer solstice. This maximum and minimum temperature in the studied hours for the winter solstice is 32.1 and 5.6 degrees Celsius, respectively. The highest PET temperature for the balconies of the model was observed at 7:00 on the summer solstice day and at 12:00 on the winter solstice day. Additionally, the lowest PET temperature observed on the summer and winter solstice day was at 19:00 and 6:00, respectively.

RESULT AND CONCLUSION

The results obtained from investigating the thermal behavior of various models among the various simulation modes in the Honeybee software indicate that all the models are in the thermal comfort range for a very short time on the summer solstice day (0.05 hours), so that it can be said that it is almost impossible to provide the thermal comfort at this time; But models number eight and nine (central- two sides open from west and east sides) have provided the longest duration of thermal comfort with a duration of 2.00 hours on the winter solstice day. Of course, it is necessary to point out that all the models that are open on one side (including the eastern, western, and central fronts) have created the highest amount of thermal comfort with duration of 1.75 hours on the winter solstice day after these two models. Additionally, the eastern model with three open sides and the western model with three open sides have gained the weakest ranking by providing thermal comfort conditions for only 1.25 hours from the viewpoint of providing the lowest amount of thermal comfort on the winter solstice day.

Table 16: Conclusion of output results of Honeybee Energy Plus software

Balcony Direction	Balcony type	Number of hours of summer solstice comfort	Number of hours of winter solstice comfort	Mean PET of summer solstice comfort	Mean PET of winter solstice comfort	Maximum/minimum PET temperature on summer solstice day
Eastern	One side open	0.05	1.75	28.50	20.06	24/6-34/2
	Both sides open	0.05	1.50	29.78	20.08	23/9-38/2
	Three sides open	0.05	1.25	31.09	19.73	24/4-38/4
western	One side open	0.05	1.75	28.39	20.08	23/7-34/7
	Both sides open	0.05	1.50	29.07	20.19	23/9-34/3
	Three sides open	0.05	1.25	30.86	19.71	23/8-34/1
Central	One side open	0.05	1.75	28.13	20.43	23/5-33/8
	Western, two open sides	0.05	2.00	29.11	20.02	24/1-33/9
	Eastern, two open sides	0.05	2.00	29.15	19.80	23/7-34/3
	Three sides open	0.05	1.50	30.93	19.86	24/2-37/7

REFERENCES

Du, J., Sun, C., Liu, L., Chen, X., Liu, J., (2021), Comparison and modification of measurement and simulation techniques for estimating in summer and winter in a severely cold region, Building and Environment, 107918

Endler, C., Matzarakis, A., (2007). Climate Change and Climate-tourism Relationships in Germany, In: A. Matzarakis, C. R. de Freitas, D. Scott (Eds.), Developments in Tourism Climatology, 260-266.

Erell, E., Pearlmutter, D., & Williamson, T. (2012). Urban microclimate: designing the spaces between buildings. Routledge.

Fallah Qalhari, Gholam Abbas, Meivaneh, Fatemeh and Shakeri, Fahimeh (2015). Evaluation of human thermal comfort using global thermal climate index, case study: Kurdistan Province. Health and Environment, 3, 367-378

Farivar, Sh. and Agharabi, A. (2020). Presentation of climatic solutions in architecture to achieve thermal comfort in Mashhad County, First National Conference on Sustainable Housing, Tehran.

Goshayeshi, D., Shahidan, M.F., Khafi, F., Ehtesham, E. (2013). A review of researches about human thermal comfort in semi-outdoor spaces. European Online Journal of Natural and Social Sciences, 2(4), 516-523.

Höppe, P. (2002). Different aspects of assessing indoor and outdoor thermal comfort. Energy and buildings, 34(6), 661-665.

Höppe, P., (1999). The Physiological Equivalent Temperature-a Universal Index for the Biometeorological Assessment of the Thermal Environment, International Journal of Biometeorology. 43. 71-75.

Hsieh, C. M., Jan, F. C., & Zhang, L. (2016). A simplified assessment of how tree allocation, wind environment, and shading affect human comfort. Urban Forestry & Urban Greening, 18, 126-137.

Jafari, Gh. H.. (2008). Annual survey of the solar elevation angle in sloping surfaces of Iran. Geographical Thought, (2), 3, 30-50..

Karakounos, I., Dimoudi, A., Zoras, S. (2017). The influence of bioclimatic urban redevelopment on outdoor thermal comfort. Energy and Buildings, 158, 1266-1274.

Khrit, N.G., Alghoul, M.A., Sopian, K., Lahimer, A.A., Elayeb, O.K., (2017), Assessing the accuracy of globe thermometer method in predicting outdoor mean radiant temperature under Malaysia tropical microclimate, E3S Web of Conferences 23

Klinsky, S., Roberts, T., Huq, S., Okereke, C., Newell, P., Dauvergne, P., & Keck, M. (2017). Why equity is fundamental in climate change policy research. Global Environmental Change, 44, 170-173.

Kwon, C. W., & Lee, K. J. (2017). Outdoor Thermal Comfort in a Transitional Space of Canopy in Schools in the UK. Sustainability, 9(10), 1753.

HOW TO CITE THIS ARTICLE
Goshayeshi, D., Mofidi Shemirani, S. M., Teimourtash, S., & Tabassi, M. (2024). Thermal Behavior Analysis of Semi-Open Space in Residential Complexes of Mashhad County with the help of Honeybee Energy Plus Software. International Journal of Urban Management and Energy Sustainability, (), -.
DOI: 10.22034/ijumes.2024.2040569.1253