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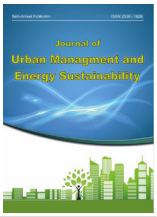

CASE STUDY RESEARCH PAPER

Thermal Behavior Analysis of Semi-Open Space in Residential Complexes of Mashhad City with the Help of ENVI-met Software[1]

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ARTICLE INFO

Article History:
Received 2024-05-15
Revised 2024-07-14
Accepted 2024-08-17

Keywords:
ENVI-met Software, Mashhad city, residential complexes, semi-Open space, thermal comfort

ABSTRACT

Building form has a great influence on energy conservation and a correct architectural design can play a significant role in this field. Shading and its impact on thermal comfort of the residents are among the concepts which are of great importance in the subject of buildings' architectural design with regard to the regional climate. In this paper, an attempt was made to analyze the thermal behavior extent of these semi-open spaces in residential complexes of Mashhad City with the help of ENVI-met software. Therefore, the present paper, which is based on a simulation approach, investigates and analyzes the thermal comfort in semi-open spaces. By comparing different models simulated with Envi-met software, it can be found out that none of the investigated models achieve the thermal comfort conditions on the day of the summer solstice, but the double-closed model, located on the central side of the building, provides the maximum amount of thermal comfort conditions at a rate of 6 hours on the day of the winter solstice. After this model, the one side closed ones, located in the central side of the building, and three sides closed ones, located in the western side of the building, provide the most thermal comfort time. The weakest models in terms of the duration of providing thermal comfort conditions are the one sided closed and double-closed models located on the west side of the building, which never provide thermal comfort conditions during the summer and winter solstice days.

DOI: 110.22034/IJUMES.2024.711844

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

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
85	36	04

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

INTRODUCTION

In general, thermal comfort is a mental condition in which a person is not dissatisfied with environment's thermal condition and is not going to change the condition into a warmer or colder condition. The thermal comfort can affect the performance and efficiency of individuals from physical and mental aspects. A suitable architectural design, which is based on various aspects of providing people's comfort, can significantly contribute to reduce energy consumption, increase the time people spend in different spaces and their willingness to use them, increase attendance visitors and many other benefits in addition to strengthening the physical and mental conditions of people. Although it is very important to investigate the impact of shading on thermal comfort in the semi-open spaces of Mashhad City emphasizing on balconies, it seems that no in-depth research has been conducted focusing on this issue so far. Therefore, in this paper, an attempt is made to investigate the comfort climate conditions of Mashhad City based on the principles of shading design in semi-open spaces by ENVI-met software using PET (Physiological Equivalent Temperature) index.

Problem Statement

Different parts are influential in the climatic design of a building, but the role of form and architectural design is much more prominent among them due to the constant connection of this part with surrounding climate and its important impact on thermal performance of the building. In general, various parts of the building can be classified into open or external, closed or internal, and semi-open parts. However, some researchers believe that the current standards for investigating the thermal comfort cannot define the characteristics of thermal comfort in semi-open spaces well (Cao, et al. 2018; Cardoso, et al. 2018; Dahlan & Gital, 2016). According to Shooshtarian's definition, thermal comfort is generally defined as a typical mental and physical condition that expresses human satisfaction in relation to the surrounding thermal environment (Shooshtarian, et al., 2020). In addition, the authenticate ASHRAE1 standard 2017-55, defines the thermal comfort as "mental conditions that express the individuals' satisfaction with environment's thermal conditions and are expressed in the form of psychological evaluations." The same standard describes an acceptable thermal environment as "an environment in which a significant majority of residents (more than 80%) consider the thermal condition to be acceptable" (ANSI/ASHRAE Standard 55, 2017). Some research institutes consider the thermal comfort to be achieved where "There is a wide range of satisfaction with the thermal environment, meaning most individuals feel neither too cold nor too hot" (CIBSE, 2006). It can be mentioned that the thermal comfort is a thermal condition depending on the physical and mental condition in which most individuals do not have a reason to change their conditions into warmer or colder ones. Since the perception of thermal comfort depends on people's mind, it can be different among different people relative to a single thermal condition.

Research Importance and Necessity

One of the major weaknesses of the studies that have been in pursuit of redesigning or designing residential complexes in order to achieve thermal comfort is not to pay attention to the buildings' energy efficiency. The review of the conducted research indicates the existence of a kind of split between studies of thermal comfort in open and semi-open spaces and sustainable architecture. Those researchers in the field of thermal comfort, who have intended to provide solutions and optimal design scenarios in scale of residential spaces, have simulated living spaces in the four main directions and different height to width ratios and have prescribed one of the states as the optimal option for design ignoring the recommendations and concerns of energy architects so far. However, it is possible that the

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building's optimal direction in such a way that the thermal comfort is met for its residents may be in conflict with the goals of sustainable architecture, i.e. the optimal energy consumption of the building (Achour-Younsi & Kharrat, 2015; Ali-Toudert & Mayer, 2007; Andreou, 2013; (Taleghani et al. 2016).

Research Background

Studies are introduced in two parts of concepts and theories related to semi-open space and its types in this section, and then the ENVI-met software used in this paper to investigate the thermal comfort in semi-open spaces of residential apartments.

MATERIALS AND METHODS

Concepts and Theories Related to Semi-Open Space

In terms of form, space is classified into three categories: open, semi-open, and closed. The term open space was probably coined for the first time in 1833 AD in Great Britain. The first definitions of open space in the 20th century are the result of a typical "empty" perception of space or anything that can be imagined from the remaining full volumes (Simeoforidis, 1993).

Concepts and Theories Related to Environmental and Thermal Comfort

According to Cremona (2007) "unless the space is comfortable, it is unlikely to be used", and if it is used, it is only for passing through, not long-term presence. Environmental comfort is the feeling of satisfaction and comfort resulting from the coordination of physiological, psychological, and physical aspects of human beings and his/her surrounding environment, which includes a wide range of thermal, acoustic, visual, olfactory, and air quality comfort conditions to beauty. Creating comfort in living spaces has a direct role in the amount of their use, the behavior, and type of people's presence. Each of these environmental factors affect the human senses through the variables such as cold, heat, sound, and light, and this response to environmental stimuli determines the level of comfort. Although the factors affecting the comfort do not have equal weight, most studies emphasize the thermal conditions as the most influential issue on satisfaction with space and the most important measure of general comfort (Frontczak, 2003; Wargocki, 2011; Lo et al,) and have assumed the calculation of thermal comfort to have priority over audio and visual comfort (Oral et al, 2004).

There are different interpretations of the term "thermal comfort". Nielsen says that the thermal comfort is a person's feeling of satisfaction with a certain environment. The thermal comfort is different from one person to another, and includes psychological aspects as well besides physiological aspects (Nielsen, 2015). The opinion of many science researchers is that thermal neutrality is a more accurate interpretation of thermal comfort, because the human body feels neither coldness nor heat in such an environment (Watson, 1983). The human's thermal comfort depends on several factors including four climatic elements, i.e. air temperature, air humidity, sunlight, and airflow. Of course, the human's final sense against the environmental conditions depends on non-climatic factors such as type of clothing, ability to adapt and getting used to the climatic conditions, age, gender, appearance, the amount of subcutaneous fat, the body state in terms of health, type of food and beverages consumed, and the skin tone (Kasmaei, 1993).

ENVI-met Software

Envi-Met is one of the software that has very good and extensive capabilities in simulating the conditions of the studied environment. This software is a computational fluid dynamic (CFD) software that has a cell grid from 0.5 to 10 meters. The software includes relative humidity and air temperature (with displacement diffusion equation) as well as wind flow. One of the most important features of the software compared to similar software is the capability to calculate the evaporation-transpiration conditions of plants in its ego. In general, two categories of data called "input file" and "configuration file" are needed to operate in the software setting

(Bruse, 2015). The first category is the input file that is actually a model that determines the physical specifications of the simulated area such as buildings, vegetation, and land surface. The second category is the configuration file in which the initial weather information, duration, time, and date of the simulation and the thermal specifications of the walls and roofs of the buildings are shown.

Methodology

This research has been conducted with a simulation approach by Honey Bee software, the field collection of the studied samples is used where after collecting data through documentary and library reviews (documentation) to simulate the samples in ENVI-met Software and the output analysis is conducted through the software with the help of logical arguments by determining the determined climatic and physical parameters.

Table 1: Introduction, Definition, and Function of Types of Semi-Open Spaces

Types of Semi-Open Space	Definition and Function
Portico	The house front, a porch to be built in the second order. Canopy, a curtain that hangs in front of the house (Moen, 2004). The portico is defined as a covered corridor with pillars in front of the building, or the covered front of the house (Rafei et al., 2004). From these definitions, it follows that the portico was the introduction to entering the interior space.
Clerestory	Sitting from the horse's saddle, roofed porch, pavilion-like inside the big room with a slightly higher floor, and roofed summer house (Moen, 2004). In the Amid Dictionary, Soffeh (Clerestory) is defined as a porch, throne, a pavilion-like inside a room or a mosque, a summer house with a roof and a shady place (Amid, 1998). In Mehrazi Dictionary, Soffeh is defined as a roofed platform and a porch whose floor is higher than the ground, and one side of which is open (Rafei et al., 2004). In traditional Iranian architecture culture, the first meaning considered for the word Soffeh is platform (Falahfar, 2001). This shows the emphasis of this roofed space on the floor.
Moonlight	Moonlight is a roofless space that existed in most houses in tropical regions and was used as a living and sleeping space in hot seasons' nights (Falahfar, 2001). The goal is to pay attention to the sky in building the moonlight. As in most references, terrace is the French equivalent of moonlight, and the word terrace is defined as roof in Amid Dictionary (Amid, 1998).
Porch	In Amid Dictionary, a porch is defined as a clerestory, the front of a room, and a part of a building that is open in front without doors and windows. Its different types are moonlight, sleep-in-spring location, balcony, and terrace (Amid, 1998). It is introduced as a porch or front room, a roofed space, which is open from one to three directions in Mehrazi Dictionary (Rafei et al., 2004). The porch is a mediator, and this mediation is fully manifested in its dual form, which is closed in some directions and open in some other ways (Mahmoudi, 2006). In the fourth topic of the National Building Regulations, the meaning of the porch is the roofed spaces and three-side enclosure, which can be seen as an protrusion in the main building (National Building Regulations, 2009).
Terrace	In Moein Dictionary, three definitions are given for the terrace. First, s sleep-in-spring location; Second, porch, and third, moonlight (Moen, 2004). It is also introduced in Mehrazi Dictionary as the French equivalent of moonlight (Rafei et al., 2004). There are four definitions for terrace in Amid Dictionary; Roof, roof top, moonlight, and wide porch in front of the upper floors of the building (Amid, 1998). Dehkhoda Dictionary defines moonlight as a synonym of porch in front room or rooms and balcony (Dehkhoda, 1998). In the fourth topic of the National Building Regulations, the meaning of the terrace is the non-roofed spaces that result from the recession of upper floors of the building (National Building Regulations, 2009).
Balcony	The balcony is defined as protrusion in front of rooms on the second floor. This space has a small width and is considered as a canopy for the lower floor. The balcony is usually roofless and has a picnic site and footrest (Dehkhoda, 1995). According to the definition presented in Amid's Dictionary, the distinction between a balcony and a terrace is that it is smaller than a terrace and this, of course, makes its use different as well (Amid, 1998). As in the French dictionaries, balcony is defined equivalent to banister (handrail) and fence (Parsa, 2004). Balcony is defined as the equivalent of a small porch in Mehrazi Dictionary. This space has a body similar to the porch and only its width is less (Rafei et al., 2004). In traditional Iranian architectural dictionary, the balcony definition has become more complete and is considered equivalent to a small porch located on the upper floors of a building (Falahfar, 2001). In the fourth topic of the National Building Regulations, the balcony is created from the protrusion of the floors in the main volume of the building, which is often a roofed space (National Building Regulations, 2009).

Selection of Four-Storey Apartments as the Studied Model

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

Sample Collection Method and Size

It is necessary to use Cochran's formula in order to find the number of research samples (Cochran, 2017). 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 characteristic of the desired trait in the population. The goal is to be able to find the appropriate dimensions (length, width, height) of the four-storey apartments' balconies in this research in order to enter them into the simulation software.

Table 3: How to allocate sampling

142	37.56	9329
23	6.24	1550
16	4.21	1046
38	10.21	2536
68	17.66	4387
91	24.11	5988
378	100.00	24863

Urban Areas	Number of Permissions Issued	Percent of Total	Number of Samples
South West	9329	37.56	142
Central	1550	6.24	23
South East	1046	4.21	16
North East	2536	10.21	38
North West	4387	17.66	68
Middle	5988	24.11	91
Total	24863	100.00	378

Balconies' Dimensions

After making an investigation into the dimensions of 378 approved drawings of four-storey apartments in Mashhad City, the average dimensions of the height, width, and length of the balconies were found to be 3.78, 1.22, and 3.13 meters, respectively. 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 Trend in ENVI-met Software

Three series of balconies on the south front of a four-story apartment, where the location of the balconies on the floors are the same in terms of height but different in terms of enclosure and indentation or protrusion, were modeled in Mashhad City in ENVI-met software and were checked from 6:00 to 19:00 in temperature and thermal comfort conditions according to the regular meteorological table in the software on two days of the summer and winter solstice (first day of summer and first day of winter), which have the highest and lowest amount of sunlight throughout the year at these times, re-

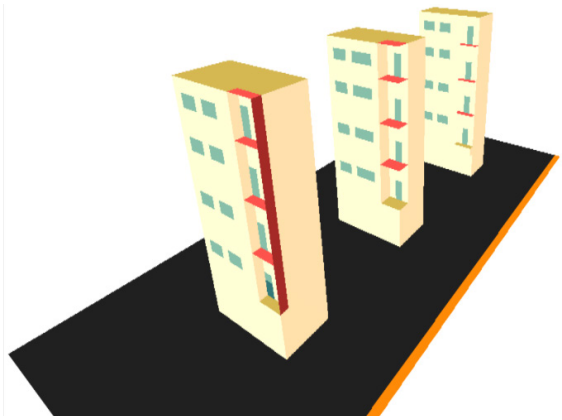


Figure 1: Modeling of number one series balconies on the east and south side

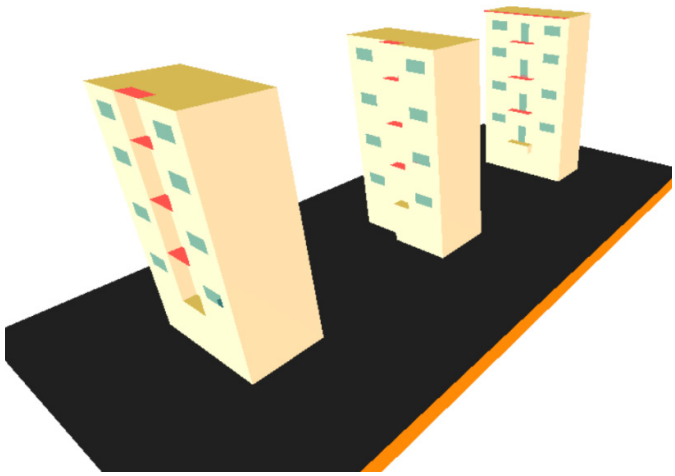


Figure 2: Modeling of number two series balconies in the middle and facing south

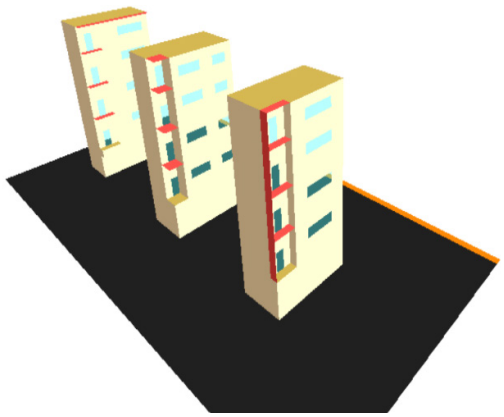


Figure 3: Modeling of number three series balconies on the west side and facing south

spectively. The building materials are insulated and the floor is considered to be asphalt, and the dimensions of height, width, and length of the balcony are assumed to be 4, 1, and 3 meters, respectively. Additional climatic information (wind speed, air temperature, humidity) were entered based on the average data of the last few decades obtained from the Mashhad Synoptic Station.

Analysis of Graphs for Number One Series Balconies

The modeled balconies in series one are all located on the east-south side, on the first floor, and at a height of four and a half meters from the ground, and have three different modes including model number one: double-closed in the building depth; Model number two: one side is closed as a protrusion and model number three: both sides are open. As can be seen in pictures 4 and 5, the meteorological data entered into the software is based on the data recorded at Mashhad Synoptic Station (located at Hasheminejad Airport) on the first day of winter and summer. In addition, the time period from 6:00 to 19:00 was selected for investigation since it is the time period compatible with the sunrise and sunset times in Mashhad City on the mentioned dates.

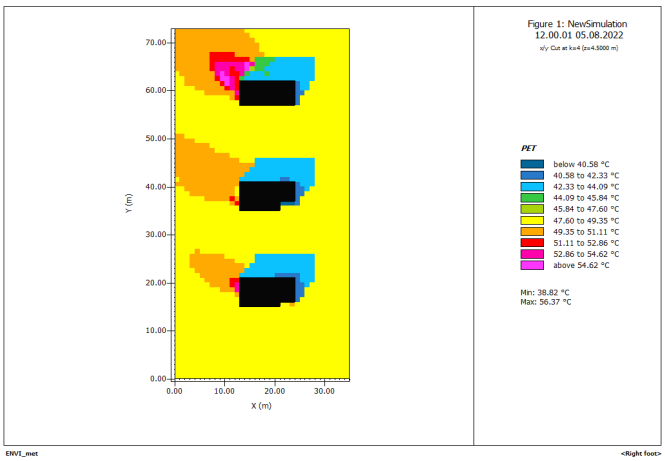


Figure 4: Buildings' thermal behavior at 12:00 noon in the summer solstice position

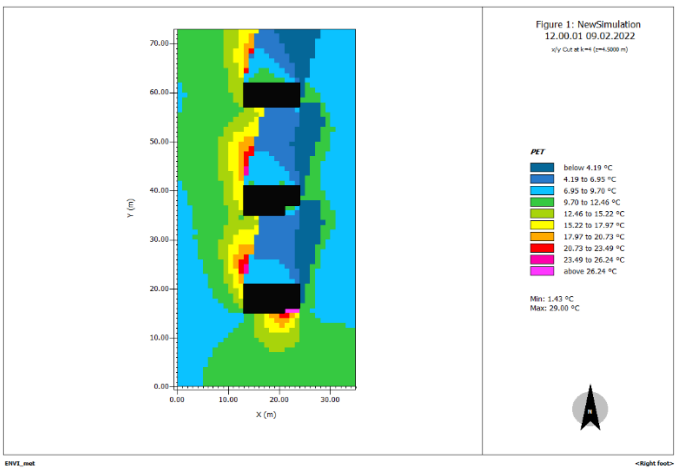


Figure 5: Buildings' thermal behavior at 12:00 noon at the winter solstice

The output graphs of the ENVI-met software for their thermal behavior at 12:00 noon in the summer solstice position, their thermal behavior at 12:00 noon in the winter solstice position, as well as the external surface temperatures of the buildings in these two positions can be observed in figures 6 to 7.

As can be seen in figures 6 and 7, the maximum range of the temperature of the building's outer surface at 12:00 noon of the summer solstice respectively belongs to the state of double-side closed, one side closed, and three sides closed in the models created at the first series (building's eastern front). Although the temperature amount of the building's external surface in the conditions close to the building in the three sides closed state located on the east front is higher than the one side closed state located in the eastern front, the range of heat diffusion in the one side closed state is greater than the range of heat diffusion surrounding the building in the three sides mode (state). So, it can be concluded that the three sides closed model located on the eastern front on the summer solstice day creates more temperature alongside the building's outer surface, but the range of this heat release is not

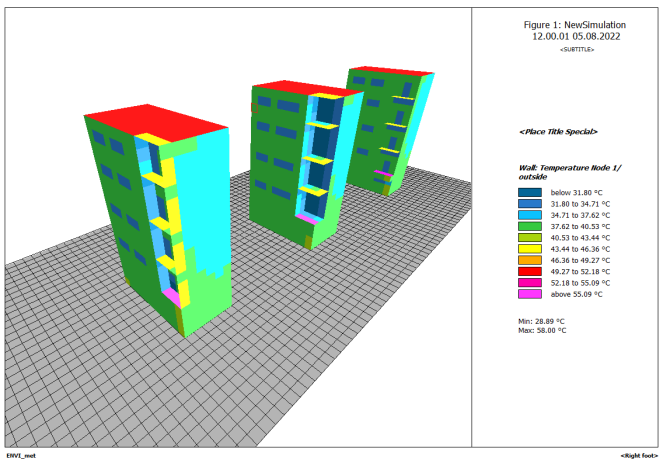


Figure 6: Building's outer surface temperature at 12:00 noon in the summer solstice position

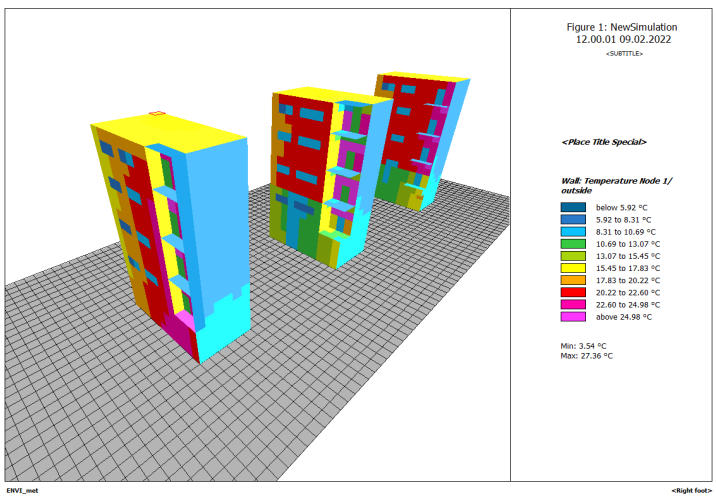
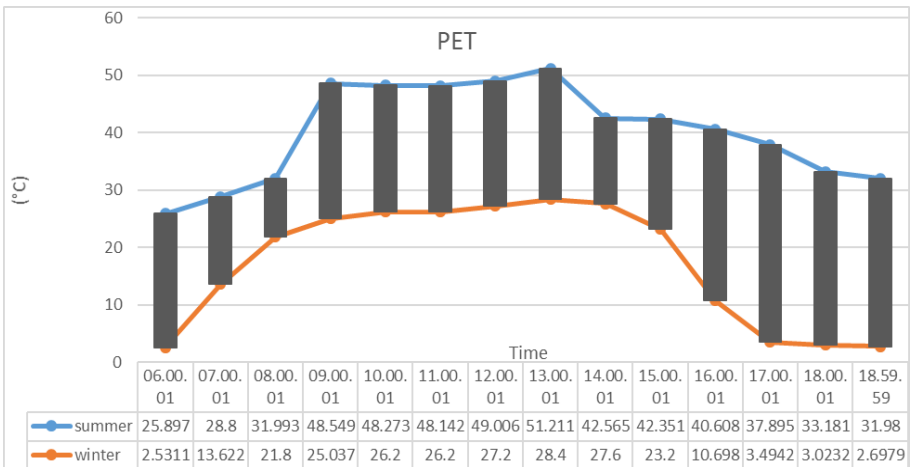


Figure 7: Building's outer surface temperature at 12:00 noon in the winter solstice position

wide. Furthermore, at 12:00 noon on the day of the winter solstice, in the model of the balconies located on the east side, three sides closed, one side closed and two sides closed models emit the most heat on the building's outer surface and its surroundings, respectively.

Analysis of the first series' balconies: Model number one (both sides closed) (double-side closed)

In model number one of the first series, where the balconies are open and closed on both sides, and the balconies are built deep into the building, the lowest PET temperature of 25.89 degrees Celsius was obtained at 6:00 am during the summer solstice, while the highest temperature of this index was recorded at 51.21 degrees Celsius at 1:00 pm on the same date. On the other hand, the lowest PET temperature was 2.53 degrees Celsius at 6:00 am during the winter solstice. Meanwhile, the highest temperature of this index on this date is 28.4 degrees Celsius at 1:00 pm. Compared to the other two types of balconies located on the eastern front, this balcony produces the highest amount of heat on the summer solstice and the lowest one on the winter solstice in surrounding environment on the external side of the building. You can see the



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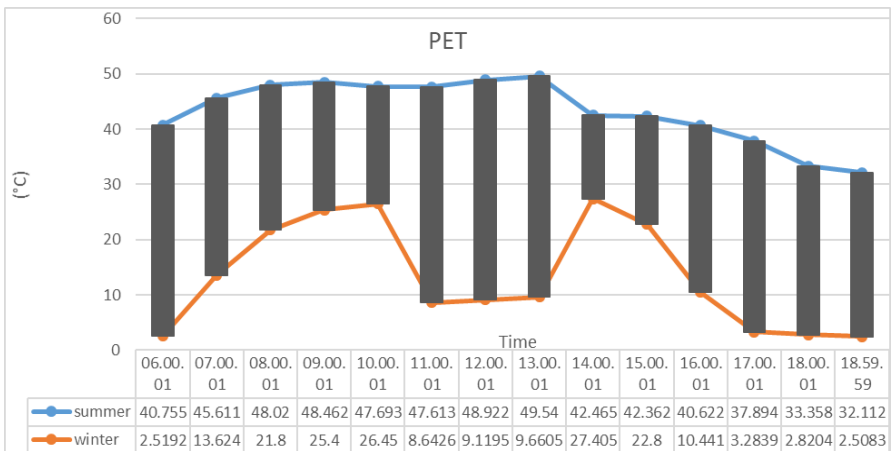
summer	25.897	28.8	31.993	48.549	48.273	48.142	49.006	51.211	42.565	42.351	40.608	37.895	33.181	31.98
winter	2.5311	13.622	21.8	25.037	26.2	26.2	27.2	28.4	27.6	23.2	10.698	3.4942	3.0232	2.6979

Chart 1: Comparison of PET temperature of first series balconies: Model one (double-side closed) in summer and winter solstice



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	40.755	45.611	48.02	48.462	47.693	47.613	48.922	49.54	42.465	42.362	40.622	37.894	33.358	32.112
winter	2.5192	13.624	21.8	25.4	26.45	8.6426	9.1195	9.6605	27.405	22.8	10.441	3.2839	2.8204	2.5083

Chart 2: Comparison of PET Temperature of First Series Balconies: Model Two (One side Closed) in Summer and Winter Solstice

physiological equivalent temperature changes trend separately and in more details during the hours of 6:00 am to 7:00 pm on winter and summer solstice days in model number one of the first series in chart 1.

Analysis of Balconies of the First Series: Model Two (One side Closed)

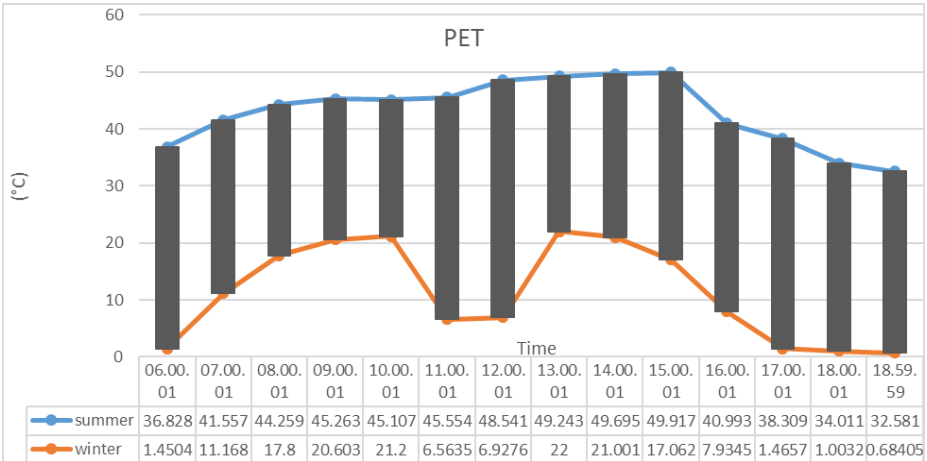
In model number two of the first series, where the balconies are open on three sides and closed on one side, and the balconies are protruding and built on the façade of the building, the lowest PET temperature is 32.11 degrees Celsius at 7:00 pm in the summer solstice, while the highest temperature in this day was recorded to be 49.54 degrees Celsius at 1:00 p.m. The lowest PET temperature is 2.5 °C at 7:00 pm and the highest temperature is 27.4 °C at 2:00 pm in winter.

Analysis of Balconies of the First Series: Model Three (Three sides Closed)

In model number three of the first series, where the balconies are open on one side and closed on three sides, and the balconies are built in the building depth (with the difference that the building is not built with building materials on the east side and only operates only as a barrier against the sunlight and wind), the lowest PET temperature is 32.5 °C at 7:00 pm on the summer solstice and the highest temperature on the same date is 49.91 °C at 3:00 pm. The lowest PET temperature is 0.68 °C at 7:00 pm in winter and the highest temperature is 22 °C at 1:00 pm. Compared to the other two models of the balcony located on the east side, this model creates the lowest amount of heat emission in the surrounding space outside the building on the day of the summer solstice and the most on the day of the winter solstice.

Comparative Analysis of Different Models of the First Series Balconies

These three modes are compared with each other during the summer and winter solstices, so that a more accurate analysis can be provided for these three models under equal climatic conditions in order to achieve a correct analysis of the comparison made in the balconies of the first series. Therefore, we can consider charts for the balconies of the first series in summer and winter solstice separately. You can see the comparison made between the three balcony models of the first series in the summer and winter solstice modes in charts 4 and 5.



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	36.828	41.557	44.259	45.263	45.107	45.554	48.541	49.243	49.695	49.917	40.993	38.309	34.011	32.581
winter	1.4504	11.168	17.8	20.603	21.2	6.5635	6.9276	22	21.001	17.062	7.9345	1.4657	1.0032	0.68405

Chart 3: Comparison of PET temperature of first series balconies: Model number three (three- side closed) in summer and winter solstice

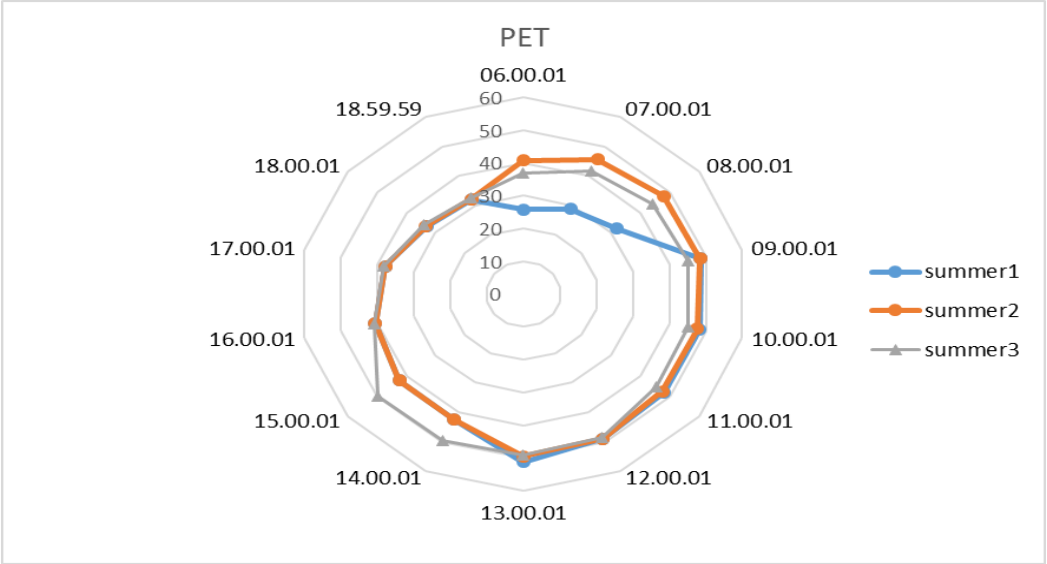


Diagram 4: Comparison of Three Balcony Models of the First Series in the Summer Solstice

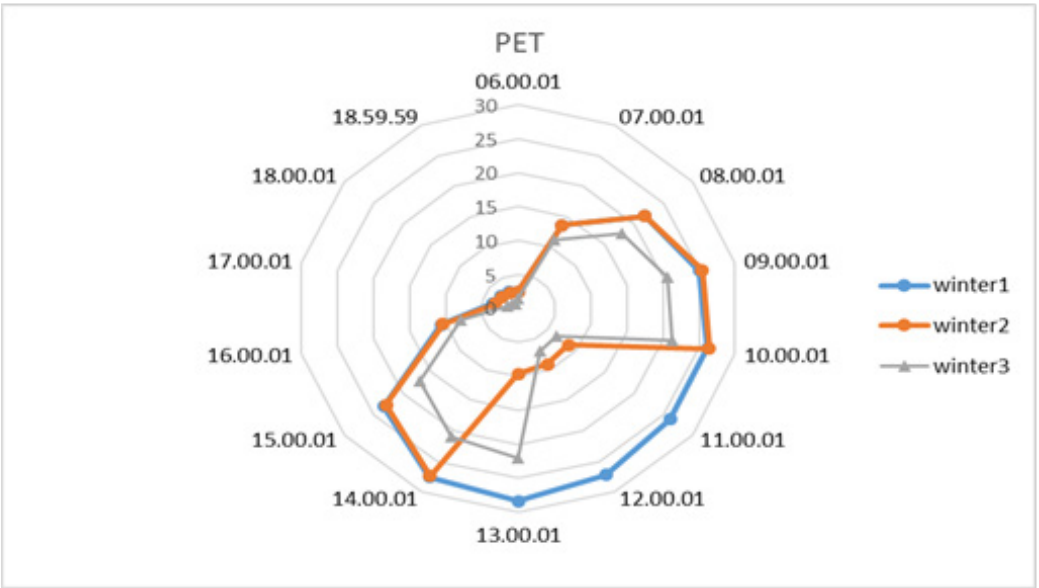


Chart 5: Comparison of three balcony models of the first series in the winter solstice

Conclusions from the Comparison of the Three Models of the First Series (Eastern Front)

According to the comparative studies conducted among the three balcony models in the first series, none of the three balcony models located on the eastern front achieve the thermal comfort conditions on the day of the summer solstice. The two sides closed model is within the comfort range at 8:00, the one side closed model at 8:00 and 15:00 (two hours), and the three sides closed model is within the comfort range between 8:30 and 10:00 and 13:00: 00 to 14:00 on the winter solstice, but since the thermal behavior chart trend of two sides closed and

one side closed models is fluctuating on the day of the winter solstice, the general conditions in this series (balconies located in the east of the building) for the two sides closed model is evaluated to be more stable and better than other models of this series on the day of the summer and winter solstice.

Analysis of Graphs for Balconies Series Number Two

The balconies of the second series, which are all located on the south side and at a height of four and a half meters from the floor, are investigated in three different modes, i.e. model number one: three sides closed in the depth of the building, model number two: one side closed as a protrusion and model number three: double-side open by recession of a part of the building so that it receives light from the west side. The ENVI-met software output graphs for the thermal behavior at 12:00 at the summer and winter solstice positions are shown in the figures below.

As can be seen in Figures 8 and 9, the maximum temperature of the outer surface of the building at 12:00 noon of the summer solstice belongs to two sides closed, one side closed, and three sides closed, respectively in the created models of the second series (the middle front of the building). In addition, the range of heat emission in the state of two sides closed is slightly more than the range of heat emission surrounding the building in other conditions of the same front, but the amount of this difference is insignificant. Hence, it can be concluded that the conditions of thermal behavior of these three models at 12:00 noon in summer solstice do not make much difference in terms of heat emission range in the surrounding area of their building. Furthermore, the two sides closed, one side closed, and three sides closed models emit the most heat on the outer surface of the building and its surroundings, respectively at 12:00 noon on the day of the winter solstice in the model of the balconies located in the middle of the building. Unlike the summer solstice state of these models, this difference in thermal behavior is very evident and prominent among these three models.

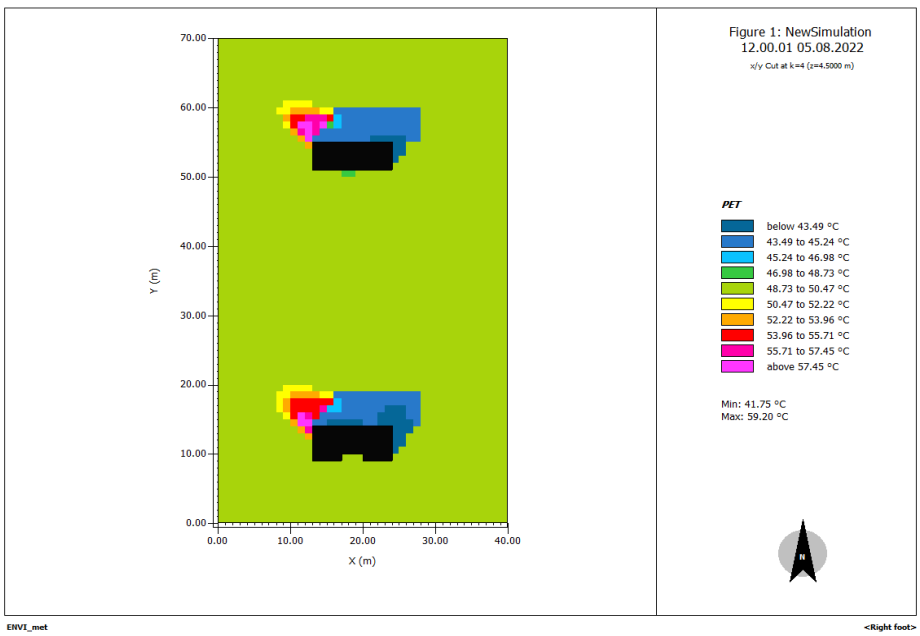


Figure 8: Thermal behavior of the first two models of building of the second series at 12:00 noon in the summer solstice position

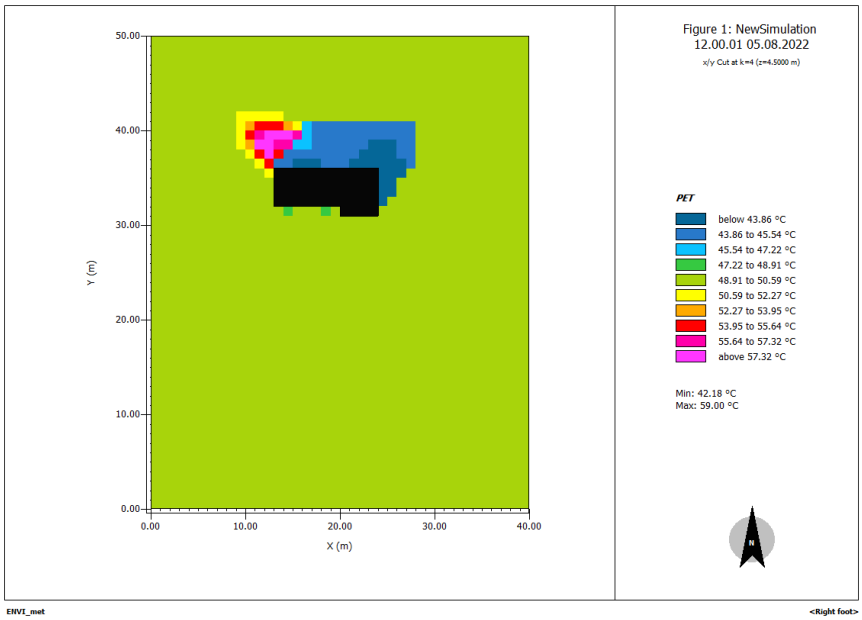


Figure 9: Thermal behavior of the third model of the building from the second series at 12:00 noon in the summer solstice position

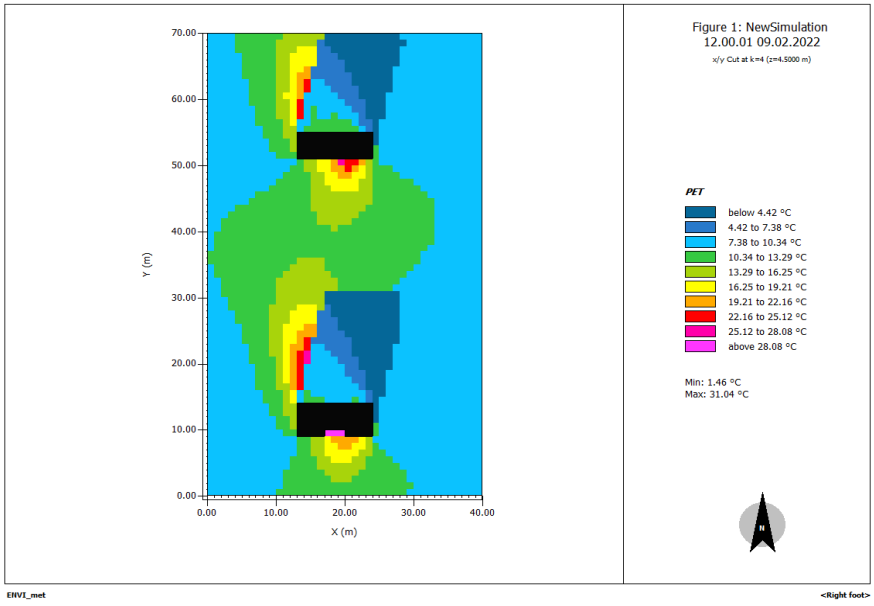


Figure 10: The thermal behavior of the first two models of building of the second series at 12:00 noon in the winter solstice position

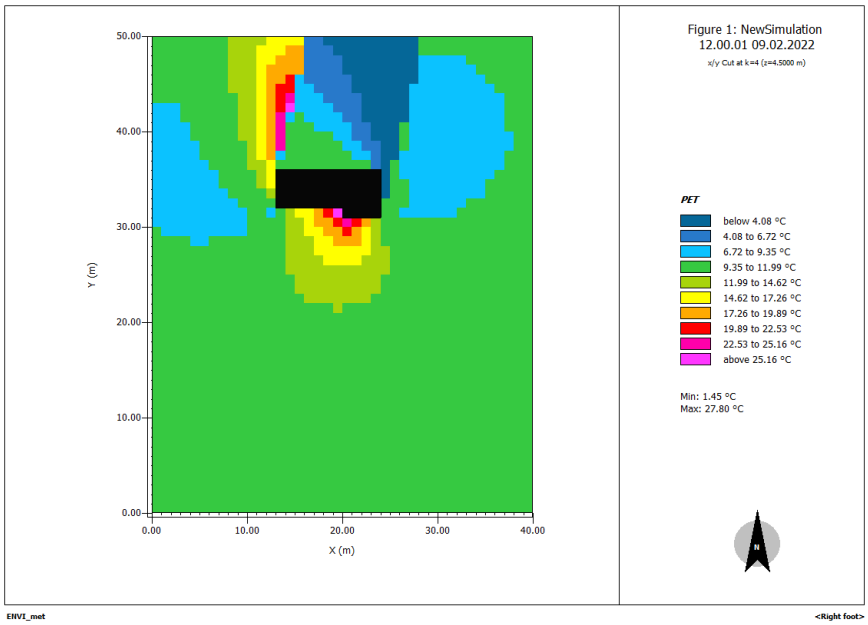


Figure 11: Thermal behavior of the third model of the building of the second series at 12:00 noon in the winter solstice position

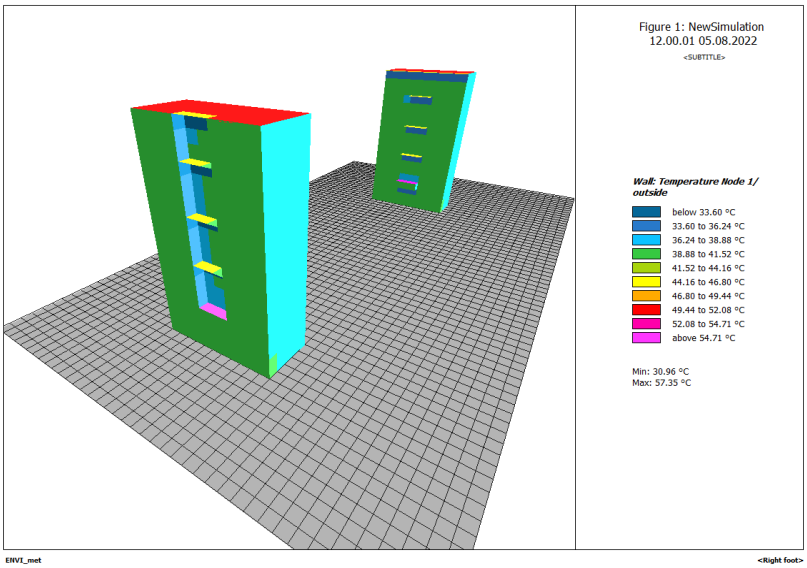


Figure 12: The temperature of the outer surface of the first two models of building of the second series at 12 o'clock on the summer solstice

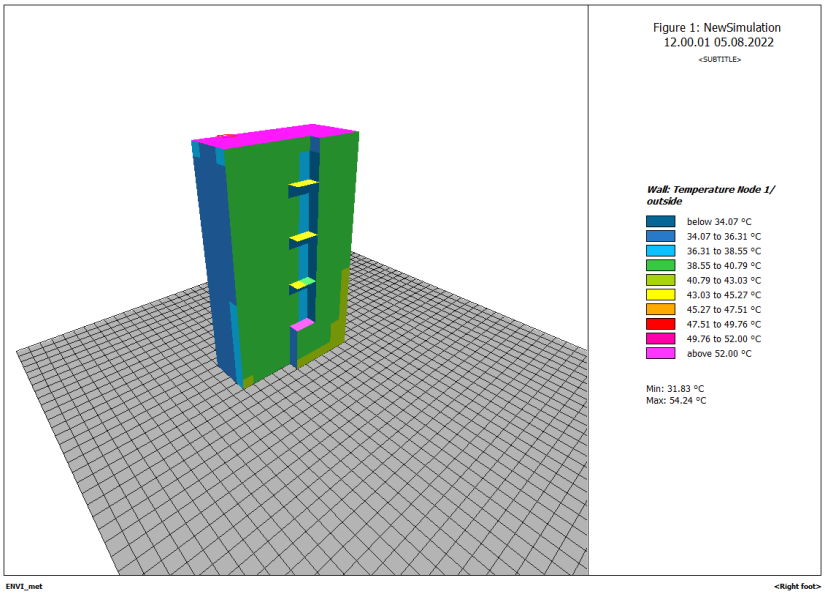


Figure 13: The temperature of the outer surface of the third model of the building of the second series at 12 o'clock on the summer solstice

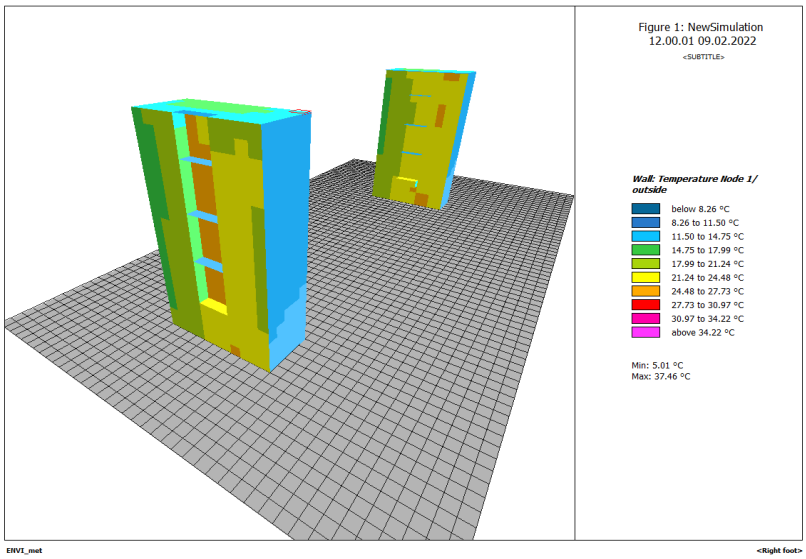


Figure 14: The temperature of the outer surface of the first two models of building of the second series at 12 o'clock on the winter solstice

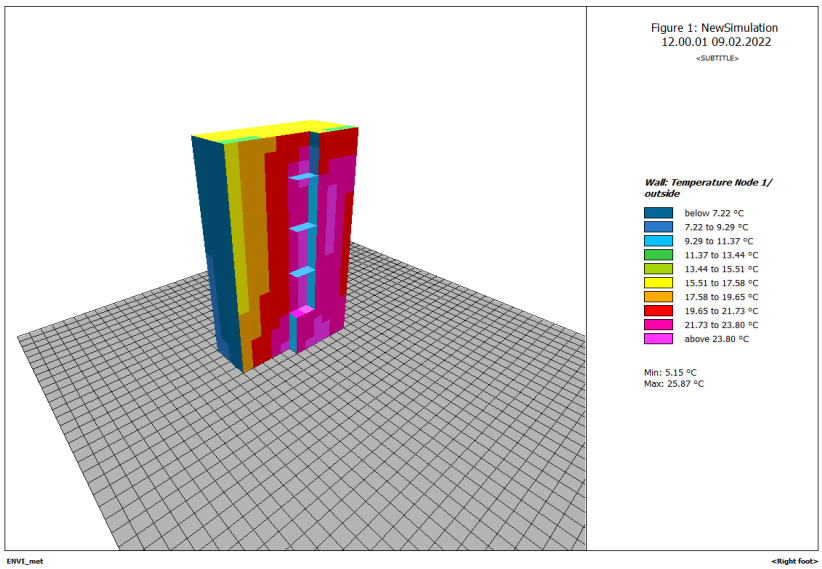
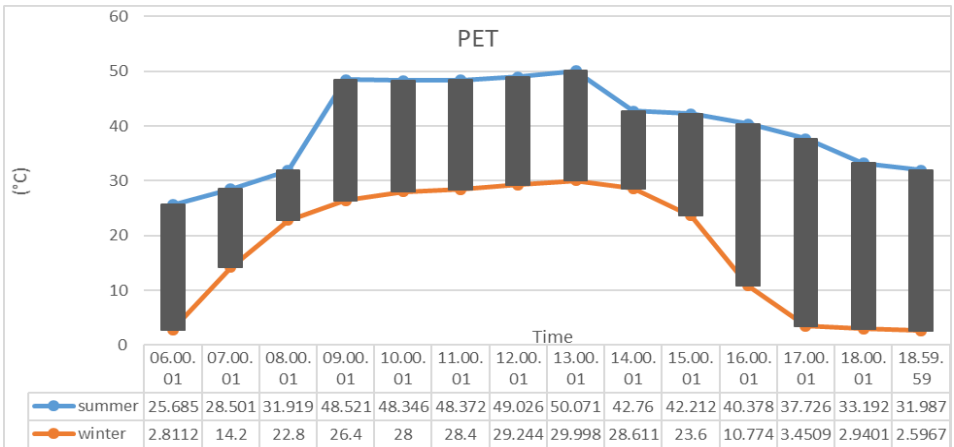


Figure 15: The temperature of the outer surface of the third model of the building of the second series at 12 o'clock on the winter solstice

Analysis of Second Series Balconies: Model One (Three sides Closed)

The lowest PET temperature is 25.68 degrees Celsius at 6:00 am in the summer solstice in model number one of the second series, where the balconies are open on one side and closed on three sides, and the balconies are built deep in the central part of the building, while the highest temperature on this date was 50 degrees Celsius and was recorded at 1:00 p.m. the lowest PET temperature is 2.59 °C at 7:00 pm in winter and the highest temperature is 29.9 °C at 1:00 pm. Chart 5 provides more information in this regard. The trend of hourly changes during the summer solstice and winter solstice can be observed based on this diagram.



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	25.685	28.501	31.919	48.521	48.346	48.372	49.026	50.071	42.76	42.212	40.378	37.726	33.192	31.987
winter	2.8112	14.2	22.8	26.4	28	28.4	29.244	29.998	28.611	23.6	10.774	3.4509	2.9401	2.5967

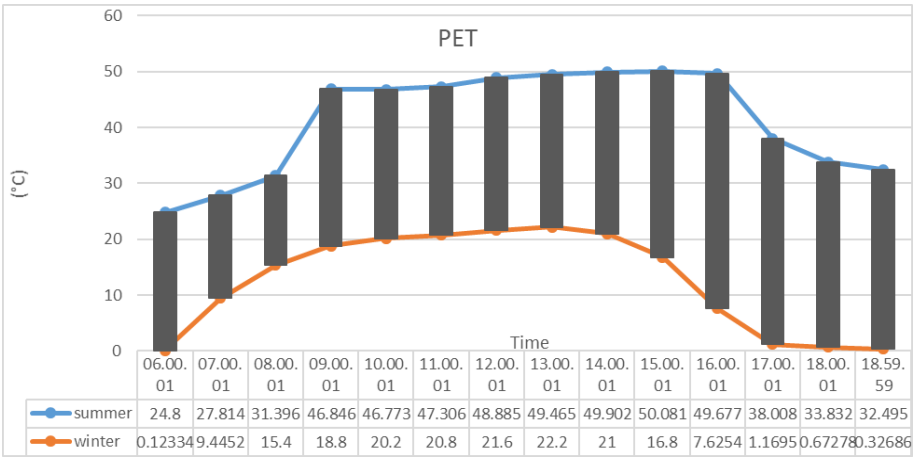
Chart 5: Comparison of PET temperature of balconies of the second series: model one (closed on three sides) in summer and winter solstice

Analysis of Second Series Balconies: Model Number Two (One side Closed)

The lowest PET temperature is 24.8 degrees Celsius at 6:00 am on the summer solstice in model number two of the second series, where the balconies are open on three sides and closed on one side, and the balconies are protruding from the building in the central part while the highest temperature on this date was recorded at 50 degrees at 3:00 pm. The lowest PET temperature is 0.12 °C at 6:00 am and the highest temperature is 22.2° C at 1:00 pm in winter.

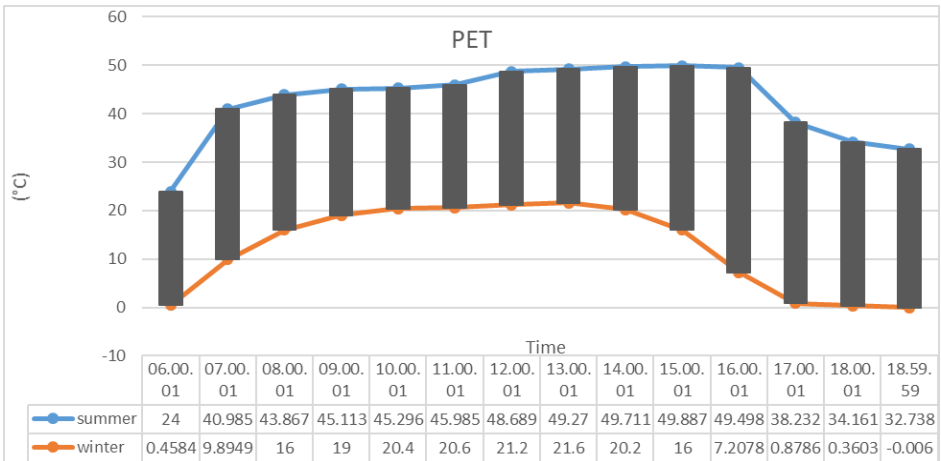
Analysis of Second Series Balconies: Model Number Three (Double-Side Closed)

The lowest temperature of PET is 24 °C at 7:00 pm in the summer solstice in model number three of the second series, where the balconies are open and closed on both sides, in such a way that some part of the building is recessed, and the balcony is located in the central part of the building and receives light from the west side due to the recession of the building and the highest temperature is 49.88 °C at 3:00 pm on the same day on this date. The lowest PET temperature is 0 °C at 7:00 pm and the highest temperature is 21.6 °C at 1:00 pm in winter.



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	24.8	27.814	31.396	46.846	46.773	47.306	48.885	49.465	49.902	50.081	49.677	38.008	33.832	32.495
winter	0.12334	9.4452	15.4	18.8	20.2	20.8	21.6	22.2	21	16.8	7.6254	1.1695	0.67278	0.32686

Chart 6: Comparison of PET temperature of second series balconies: model number two (one side closed) in summer and winter solstice



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	24	40.985	43.867	45.113	45.296	45.985	48.689	49.27	49.711	49.887	49.498	38.232	34.161	32.738
winter	0.4584	9.8949	16	19	20.4	20.6	21.2	21.6	20.2	16	7.2078	0.8786	0.3603	-0.006

Chart 7: Comparison of PET temperature of the second series balconies: model number three (double-side closed) in summer and winter solstice

Comparative Analysis of Different Models of Second Series Balconies

These three modes should be compared with each other in summer and winter and an analysis of these three models should be presented in equal climatic conditions in order to receive a correct analysis of the comparison made for the second series balconies. Therefore, the following charts can be considered separately for the second series balconies in summer and winter solstice:

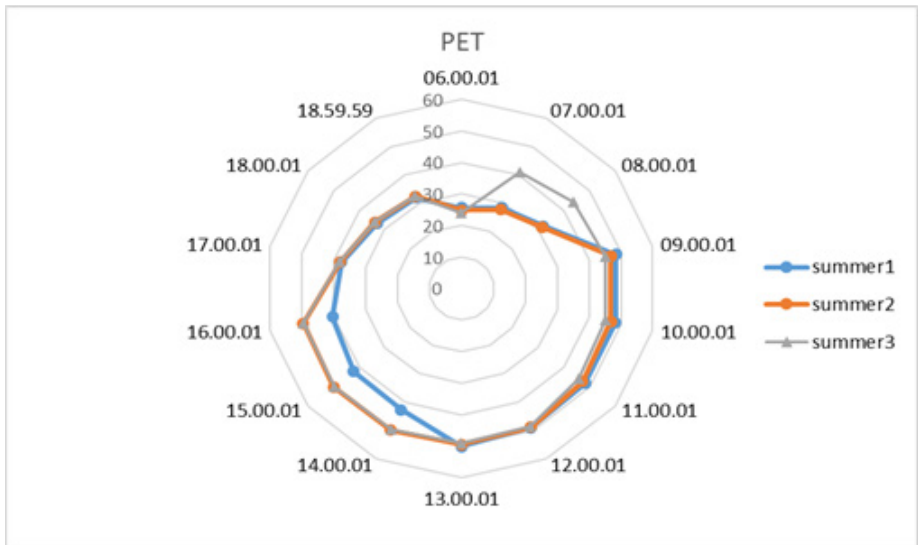


Chart 8: Comparison of three balcony models of the second series in the summer solstice

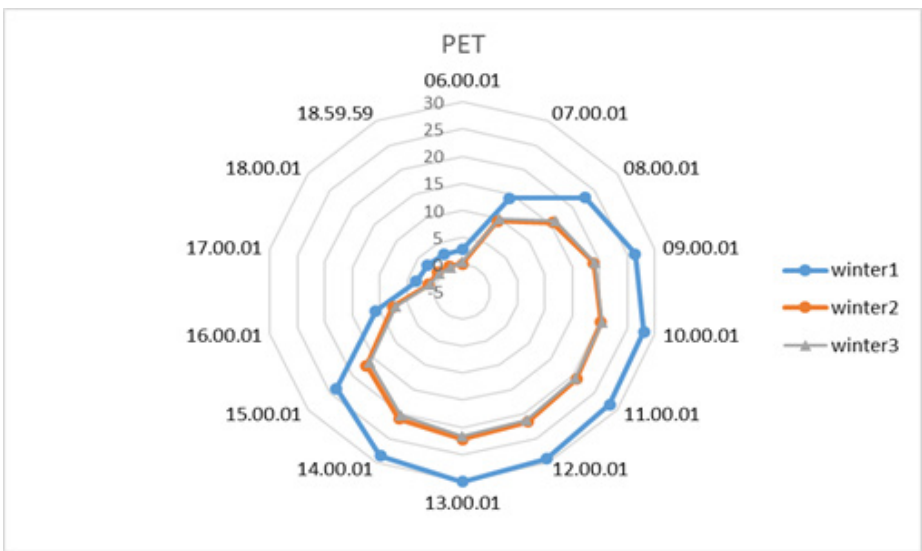


Chart 9: Comparison of three balcony models of the second series in winter solstice

Evaluation of the Comparison of Three Models of the Second Series (Central Front)

The double-side closed balconies of the model number two have better conditions than the other two modes of this model in summer and winter and its temperature range on the first floor of the building is closer to the thermal comfort range. None of the three models of the central front balcony meet the thermal comfort conditions on the day of the summer solstice, but the two sides closed model is in the thermal comfort range from 8:30 to 14:30, the one side closed model from 9:00 to 14:00, and the three sides closed one is in the thermal comfort range only at 8:00 on the day of the winter solstice.

Analysis of Graphs for Series Number Three Balconies

Series three balconies, all of which are located on the west-south side, on the first floor and at a height of four and a half meters from the floor, are considered in three different modes, i.e. model number one: two sides closed in the depth of the building, where a barrier on the west side prevents the sun from penetrating , model number two: one side closed as a protrusion and model number three: two sides open, and the output graphs of the ENVI-met software for their thermal behavior at 12:00 noon in the summer solstice position and at 12:00 noon in the winter solstice position as well as the temperatures of the outer surface of the buildings in these two positions can be seen in the following figures.

As can be seen in Figures 16 and 17, the maximum temperature of the outer surface of the building at 12:00 noon on the summer solstice belongs to the state of one side closed, two sides closed, and three sides closed, respectively in the created models of the third series (the western front of the building) but no significant difference was seen between the three models of the western front regarding the lowest ambient temperature around the building at this time. Furthermore, the range of heat emission in the surrounding environment of the building in the state of the two sides closed of the western front is less than the other two states of this model. By investigating Figure 20-4, it can be seen that the maximum temperature of the environment surrounding the building belongs to three sides closed, one side closed, and two sides closed models, respectively at 12:00 noon on the day of the winter solstice. At this time, the maximum range of heat emission in the environment surrounding the building is assigned to three sides closed, two sides closed, and one side closed models, respectively. Therefore, it can be concluded that the three sides closed model located on the west side is ranked first on the middle day of the winter solstice in the western front both in terms of the amount of temperature created surrounding the building and of the emission range of this heat in the surrounding environment of the building.

The lowest PET temperature is 25.22 degrees Celsius and at 6:00 am and the highest temperature is equal to 47.49 degrees Celsius and recorded at 1:00 pm on the summer solstice in model number one of the third series, where the three-side closed balcony is built in the depth of the building and a barrier on the west side prevents the sun penetration. The lowest PET temperature is 0.98 °C at 6:00 am and the highest temperature is 22.8 °C at 1:00 pm in winter.

Analysis of Third Series Balconies: Model Number Two (One Side Closed)

The lowest PET temperature is 24.2 degrees Celsius and at 6:00 o'clock in the morning in the summer solstice in model number two of the third series, where the balcony is open on three sides and closed on one side, and the balcony is designed as a protrusion from the building in the western-southern part and at the same time, the highest temperature was recorded at 50 degrees Celsius at 3:00 p.m. The lowest PET temperature is -1.18 degrees Celsius at 6:00 am and the highest temperature is 17.8 degrees Celsius at 1:00 pm on the same day in winter.

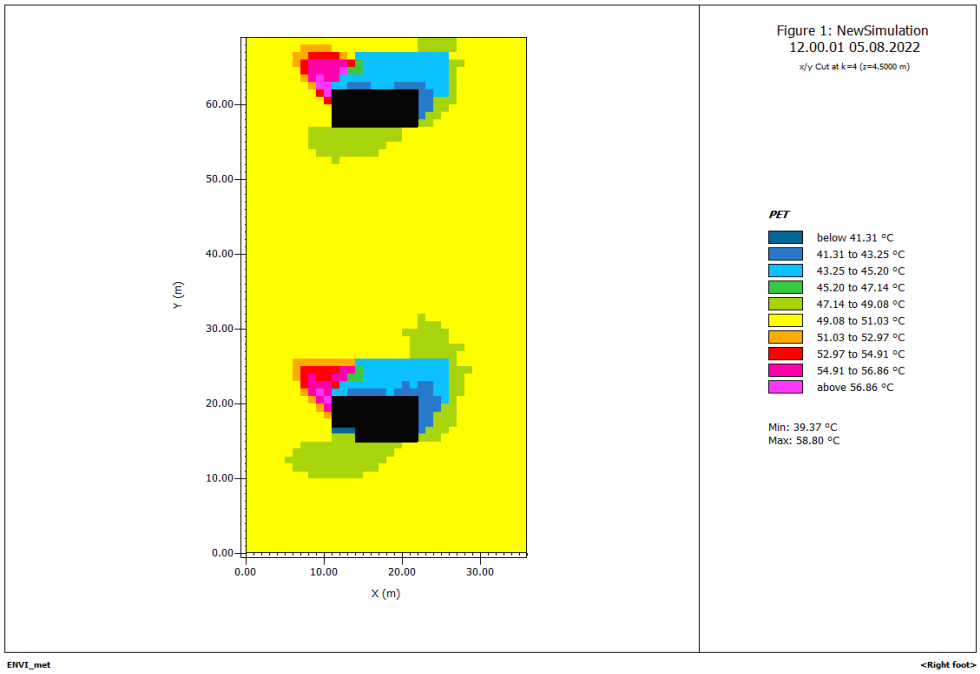


Figure 16: Thermal behavior of the first two models of the building from the third series at 12:00 noon in the summer solstice position

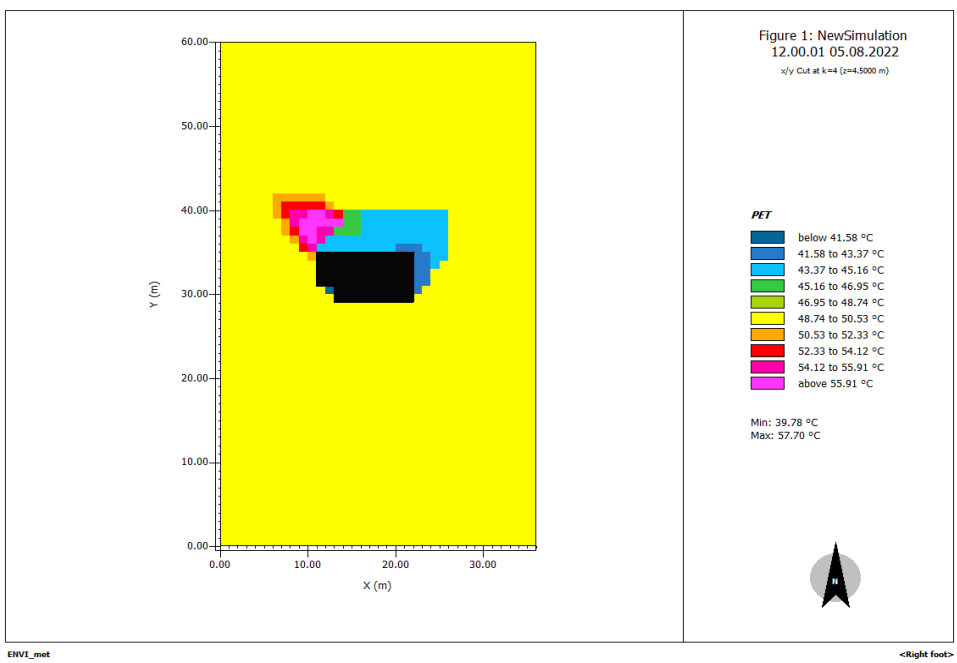


Figure 17: Thermal behavior of the third model of the building from the third series at 12:00 noon in the summer solstice

position

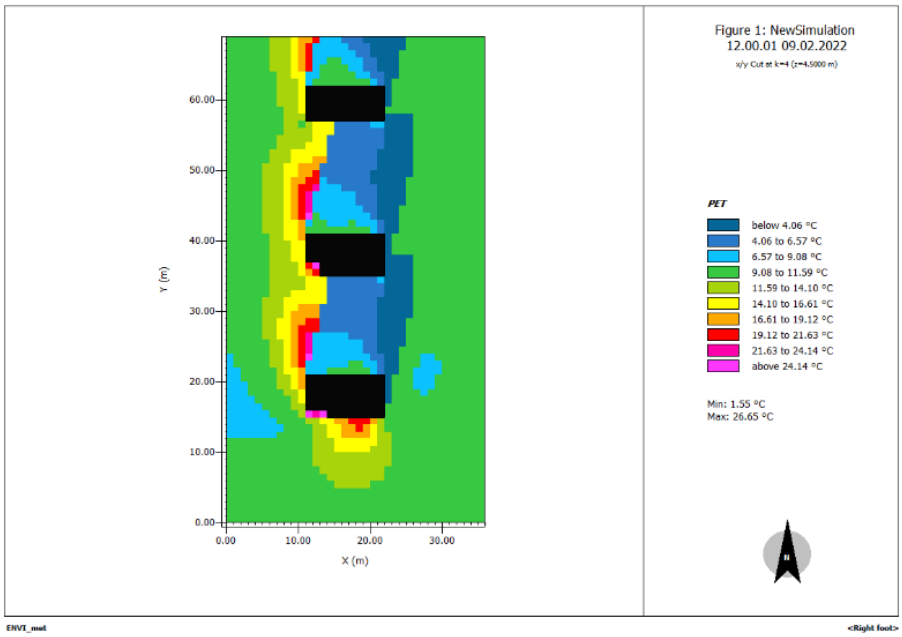


Figure 18: Thermal behavior of building models from the third series at 12:00 noon in the winter solstice position

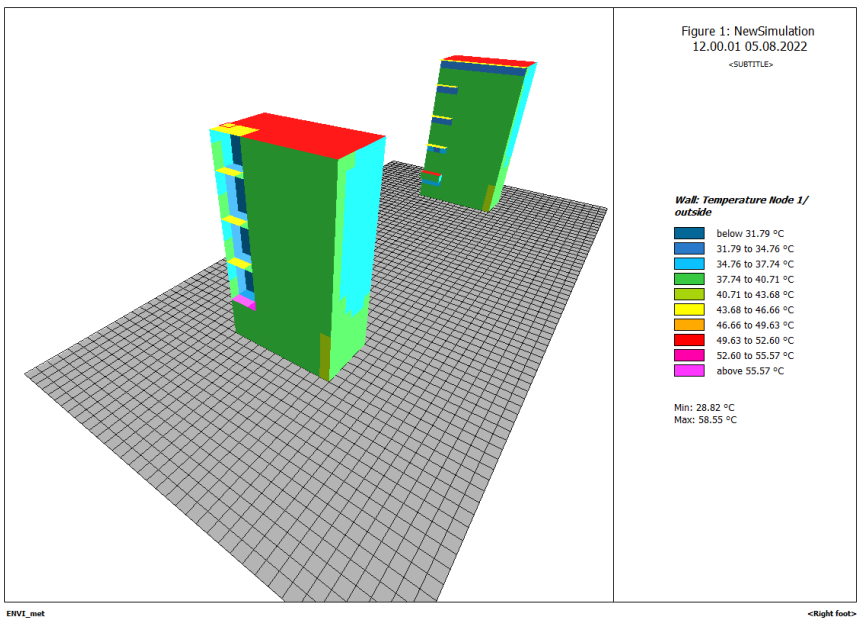


Figure 19: Temperature of the outer surface of two building models from the third series at 12:00 noon in the summer solstice position

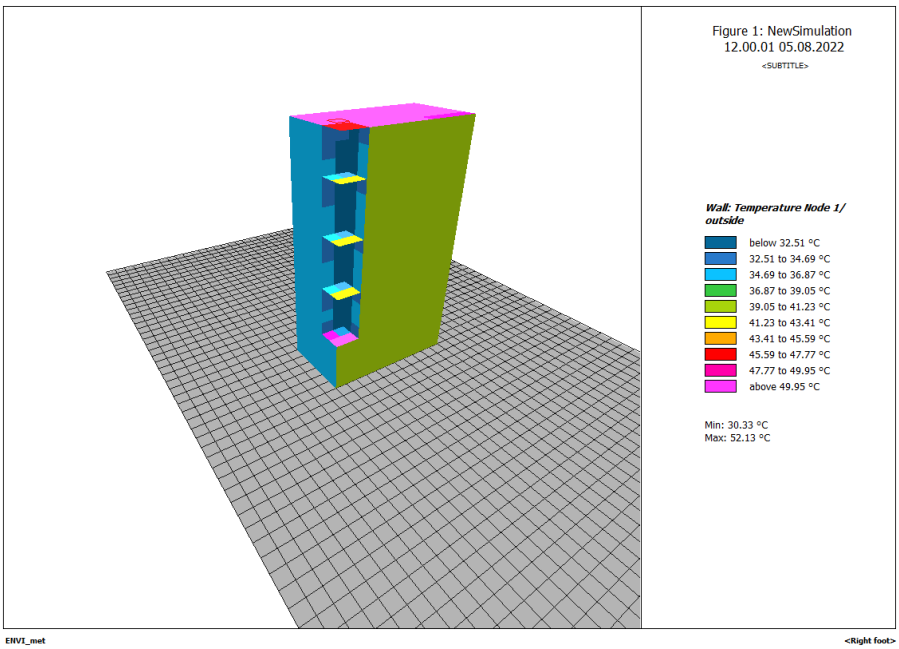


Figure 20. Temperature of the outer surface of the third model of building from the third series at 12:00 noon in the summer solstice position

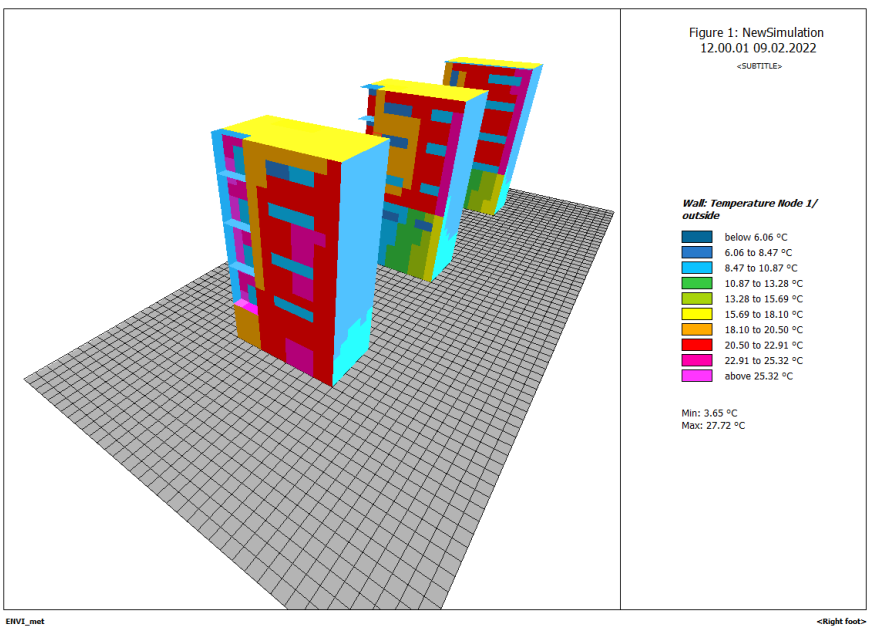
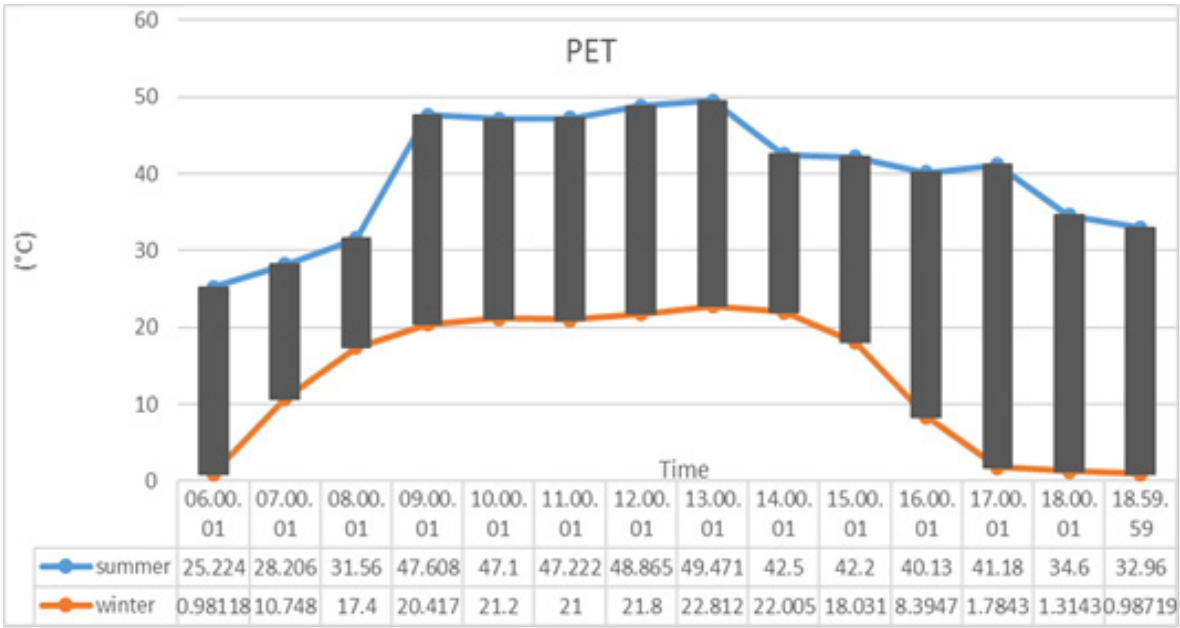


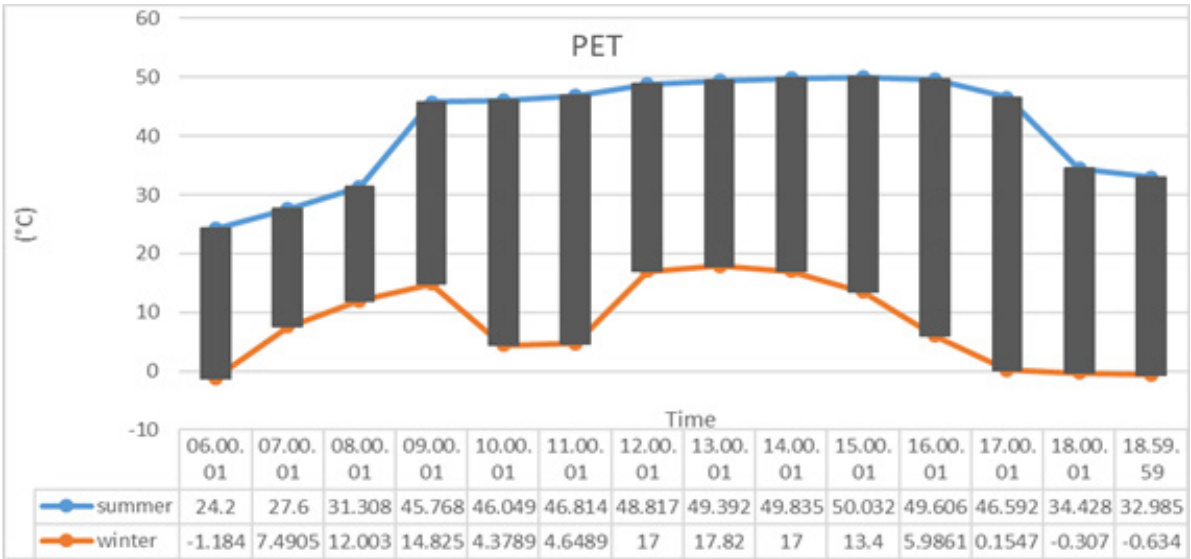
Figure 21: Temperature of the outer surface of three building models from the third series at 12:00 noon in the winter solstice position

7-4-1 Analysis of Third Series Balconies: Model One (three sides closed)



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	25.224	28.206	31.56	47.608	47.1	47.222	48.865	49.471	42.5	42.2	40.13	41.18	34.6	32.96
winter	0.98118	10.748	17.4	20.417	21.2	21	21.8	22.812	22.005	18.031	8.3947	1.7843	1.3143	0.98719

Chart 10: Comparison of PET temperature of third series balconies: model number one (three sides closed) in summer and winter solstice



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	24.2	27.6	31.308	45.768	46.049	46.814	48.817	49.392	49.835	50.032	49.606	46.592	34.428	32.985
winter	-1.184	7.4905	12.003	14.825	4.3789	4.6489	17	17.82	17	13.4	5.9861	0.1547	-0.307	-0.634

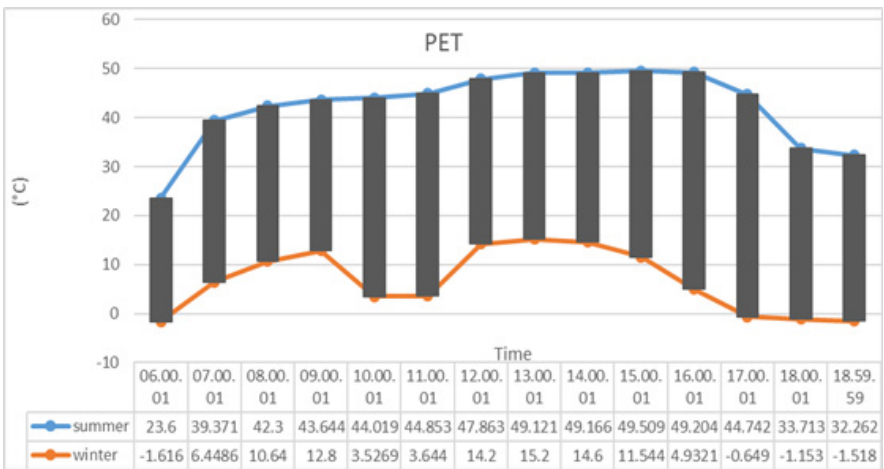
Chart 11: Comparison of PET temperature of third series balconies: Model number two (one side closed) in summer and winter solstice

Analysis of Third Series Balconies: Model Number Three (Both Sides Closed)

The lowest PET temperature is 23.6 degrees Celsius at 6:00 am in the summer solstice in model number three of the third series, where the balcony is open on both sides and closed on both sides, and the balcony is located in the west-south section, and the highest temperature is 49.5 degrees Celsius and is recorded at 3:00 pm. The lowest PET temperature is -1.6 °C at 6:00 am and the highest one is 15.2 °C at 1 pm in winter.

Comparative Analysis of Different Models of Third Series Balconies

The three conditions should be compared in summer and winter and an analysis should be presented in equal climatic conditions in order to better understand the conditions and to be able to get a correct analysis from the comparison of the third series balconies. Therefore, the following cumulative charts can be created separately for the balconies of the third series in summer and winter solstice. Charts 10 to 12 show the comparison of the three balcony models of the third series with each other on the summer and winter solstice days.



	06.00.01	07.00.01	08.00.01	09.00.01	10.00.01	11.00.01	12.00.01	13.00.01	14.00.01	15.00.01	16.00.01	17.00.01	18.00.01	18.59.59
summer	23.6	39.371	42.3	43.644	44.019	44.853	47.863	49.121	49.166	49.509	49.204	44.742	33.713	32.262
winter	-1.616	6.4486	10.64	12.8	3.5269	3.644	14.2	15.2	14.6	11.544	4.9321	-0.649	-1.153	-1.518

Diagram 12: Comparison of PET temperature of third series balconies: Model number three (both sides closed) in summer and winter solstice

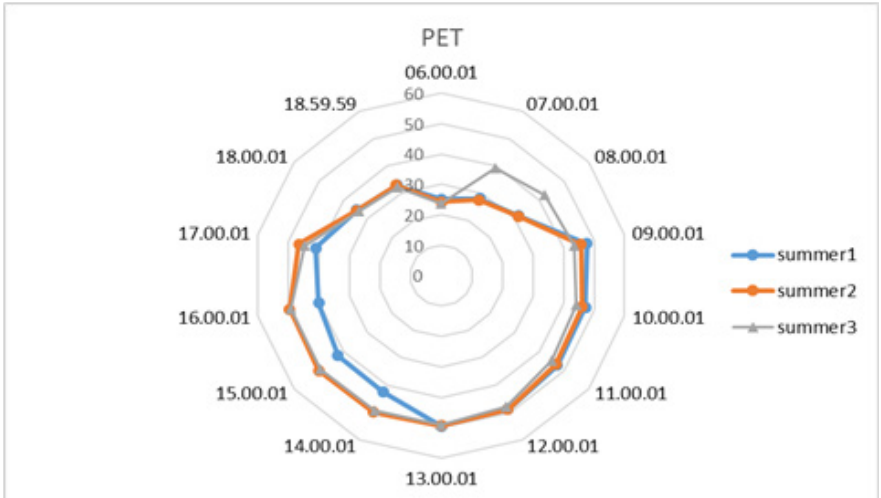


Diagram 13: Comparison of three balcony models of the third series in summer solstice

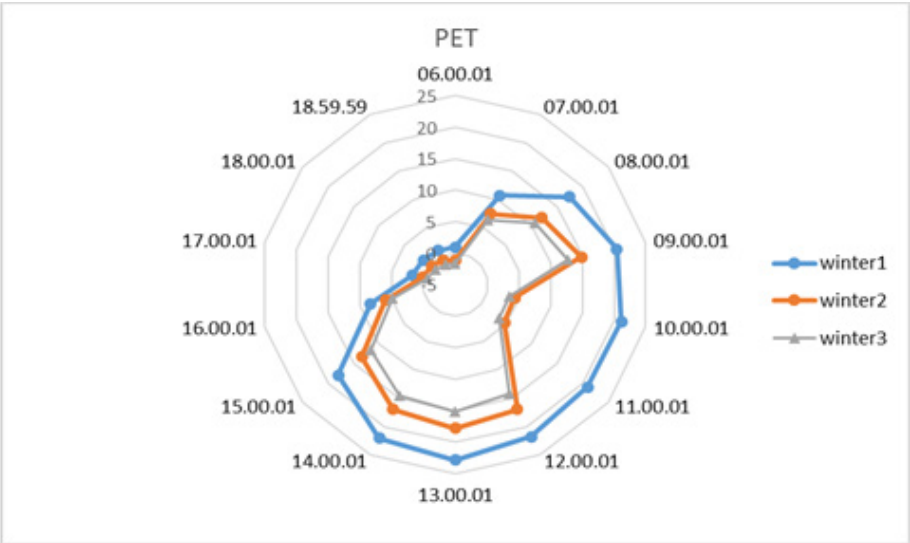


Diagram 14: Comparison of three balcony models of the third series in winter solstice

Conclusions from the Comparison of Three Models of the Third Series (Western Front)

According to the surveys conducted on the days of summer and winter solstice, the three-side closed balconies of model number three have better conditions than the other two models of this series. To be more precise, none of the three models located on the western front achieve thermal comfort conditions on the day of the summer solstice, but the three-side closed model on the western side is within the range of thermal comfort from 9:00 to 14:00 on the day of the winter solstice while the other two models of the third series do not meet these conditions.

RESULT AND CONCLUSION

By comparing different models simulated by ENVI-met Software, it can be concluded that none of the investigated models achieve thermal comfort conditions on the summer solstice day, but the two sides closed model located on the central side of the building provides the maximum amount of thermal comfort with an amount of 6 hours on the winter solstice day. After this model, the one-side closed models located in the central side of the building and three sides closed ones located in the western side of the building provide the most thermal comfort time. The weakest models in terms of the duration of providing thermal comfort conditions are the one side closed and double-side closed models located on the west side of the building, which never provide thermal comfort conditions during the summer and winter solstice days.

Table 4: Conclusion of output results from ENVI-Met software

Balcony series	Balcony model	Hours of comfort on summer solstice day	Hours of comfort on winter solstice day	Average PET temperature on summer solstice day	Average PET temperature on winter solstice day	Maximum/ minimum PET temperature on summer solstice day	Maximum/minimum temperature of PET on winter solstice day
Balconies of the first series (east)	Model 1: two sides closed	0	1	40.02	17.26	25.89-51.21	2.53-28.4
	Model 2: one side closed	0	2	43.24	13.32	32.11-49.54	2.5-27.4
	Model 3: three sides closed	0	2.5	42.98	11.21	32.5-49391	0.68-22
Balconies of (central) second series	Model 1: three sides closed	0	1	39.90	18.13	25.68-50.0	2.59-29.9
	Model 2: one side closed	0	5	41.23	17.32	24.8-50.0	0.12-22.2
	Model 3: two sides closed	0	6	42.67	12.41	24.0-49.88	0-21.6
Balconies of the third series (west)	Model 1: three sides closed	0	5	39.91	13.50	25.22-49.47	0.98-22.8
	Model 2: one side closed	0	0	44.96	8.04	24.2-5.0	-1.18-17.8
	Model 3: two sides closed	0	0	42.38	6.61	23.6-49.5	-1.6-15.2

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