Evaluating the Building Performance of the 'Center for Promotion of Science' in Block 39 in Belgrade, Serbia

Berrak Balci

***Abstract*—**This paper presents the evaluation of the building performance of the previously designed Center for the Promotion of Science in Block 39, in New Belgrade, Serbia. As this complex is going to become technology-oriented building, the intention is to use a scientific way to deal with design more realistic and reliable. The aim of this paper is to build a more sustainable and eco-friendly project through several analyses, such as wind pattern, Psychrometric Chart analysis, shadow analysis, solar analysis, thermal analysis and lighting analysis. While ensuring technological design taking into account building performance analyses, they are also integrated with the architectural design. In conclusion, this project is a combination of architectural design and planning with its scientific approach of performance of buildings.

***Index Terms*—**Building Performance Evaluation, Building Technology, Ecotect Analyses, Multi-Purpose Building, Sustainable Design

I. Introduction

In this project, the Center for Promotion of Science, as indicated in the image below, is seen mainly as an exhibition complex. It will host vast number of visitors and local officers. Its educational purpose should be especially highlighted when considering technological design. Thus, sustainability is one of the main goals in this project to enlighten children or even adults visiting the building having impression of how technology is combined with daily life.

Fig. 1 The Center for Promotion of Science, Belgrade, Serbia

After the process of urban design, creating connected open space system and protecting urban biodiversity, balancing the ground use as well as fostering the local energy production are the three main strategies in intermediate scale. As the target is also to integrate the building with its surrounding, the analysis in urban design can also facilitate considerations in built environment.

There are several strategies applied to the Center for Promotion of Science as follows:

- Using high energy insulation materials for building shell
- Using energy efficient lighting devices, such as LED lighting, lighting controlling and automatic shades system
- Ground-mounded heat pump system as efficient, low-producing pollution in heating/cooling source
- Passive design strategies for optimization of energy consumption
- Selecting local-produced materials for construction use
- Rainwater harvesting system on the of to collect rainwater and to be used in toilet and irrigation
- Local-produced energy source to compensate the energy loads such as solar panel

II. Environment And Physics

A. Temperature and Humidity

Belgrade is in the humid subtropical climate zone, with clear four seasons and uniform precipitation. The monthly temperature ranges from 1.4°C to 23°C respectively in January and July. It receives 690 millimeters precipitation in average annually. Moreover, the figure below indicates that in Belgrade, the temperature difference is huge, almost 50°C in average year.

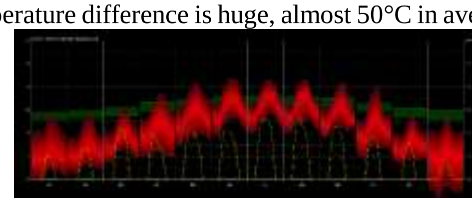


Fig. 2 Temperature Difference in Belgrade

In the winter season from November to January, the humidity reaches its peak (around 80%-90%). From midnight to dawn, Belgrade is very humid, having almost 80% relative humidity. On the other hand, the situation does not have so much difference in summer seasons.

B. Wind Pattern

In this section, it is referred to Autodesk Ecotect Analysis wind rose tool to have an idea about prevailing wind in different aspects including frequency and temperature in New Belgrade. The data are downloaded from EnergyPlus website. From the simulation tools, the frequency of prevailing wind in a year is indicated. As a result, it is depicted that the wind in the Block

Manuscript received July 23, 2017. This work was supported in part by the Department of Architectural Engineering, Politecnico di Milano, Italy.

Berrak Balci is with the Politecnico di Milano, Lecco, LC 23900 Italy (e-mail: berrak.balci@mail.polimi.it).

https://doi.org/10.17758/EAP.EAP917305

39, is dominated by *west and south* side. The speed of wind is mostly within 25 km/h and the average velocity is 10 km/h.

Since Belgrade is cold in winter, the prevailing wind is analyzed in winter. According to the wind rose chart, the prevailing wind in winter comes from south side, bringing cold air with high humidity. This directs the design to take necessary precautions in winter.

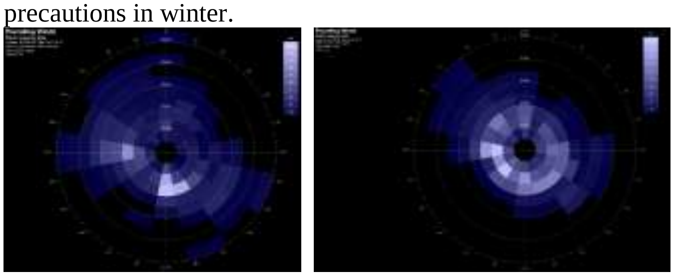


Fig. 3a In Winter (Hrs) Fig. 3b In Summer (Hrs)

Fig. 3 Prevailing Wind

In summer season, the direction of the prevailing wind is from the west and south-west side. Moreover, the average temperature, being above 25°C is higher. Since the microclimate condition is crucial in design phase, in the following steps, more detailed wind analysis are presented.

C. Psychrometric Chart Analysis

Given hourly values for temperature and relative humidity of the site, their distribution is plotted on the psychrometric chart. Following this, the comfort zone in Belgrade, between 17°C to 25°C, is achieved and the relative comfort humidity is between 30% to 90%. From the climate satisfaction chart, it can be seen that the weather in Belgrade is within cold and moderate classification.

As extreme environmental conditions are also considered, active and passive design strategies are applied. As a result, it is realized that ventilation and air-condition must be integrated in summer season. However, some important passive strategies such as natural ventilation, night purge ventilation and passive solar heating are also applied. Once they are applied, it is observed that comfort percentages increased, especially in the summer season from very low to a very high percentage in terms of comfort satisfaction (20% to above 80% in some cases).

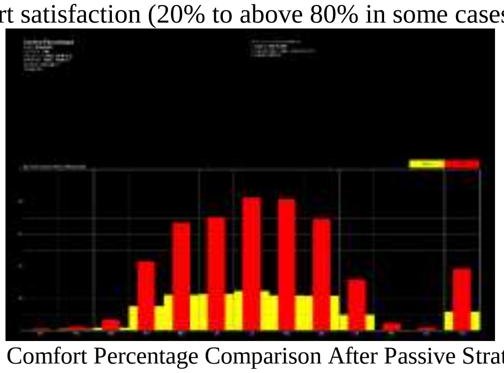


Fig. 4 Comfort Percentage Comparison After Passive Strategies Applied

III. Shadow Analysis

Since this complex, Center for Promotion of Science, is composed of four buildings, it is important to see the effect of shadow, which is shaded by the building itself and the surrounding structures. In the winter season, shadow is casted very long because of the low sun angle. For this reason, only the north side atrium can receive sunlight. Due to this reason, outdoor place is designed for the visitors to rest and relax while they can also enjoy sunlight in winter time. On the other hand, in the summer season, not very long shadow is casted. The advantage of this nature is that there will be abundant natural lighting provided for indoor as well as potential solar energy usage while the drawback is the glare problem.

Fig. 5a Summer 9:00 to 15:00 Fig. 5b Winter 9:00 to 15:00

Fig. 5 Shadow Ranges In Summer and Winter

IV. Solar Analysis

The radiation from the sun received by different façade of buildings is crucial in terms of building performance and lighting. Based on solar analysis on each façade, the angle of the shading device can be determined. Moreover, natural lighting level which is achieved indoor before conducting natural lighting analysis can also be understood.

In the figures below, several yearly solar analyses are depicted. In the figure of year round radiation it is seen that roofs have a potentiality for exploiting solar energy. Thus, a glazing cover would be provided on top of courtyard, which gives potential for using PV panels system to transfer solar energy. From summer season radiation figure, it is inferred that only the upper floor of *east* and *south* side facades need shading devices.

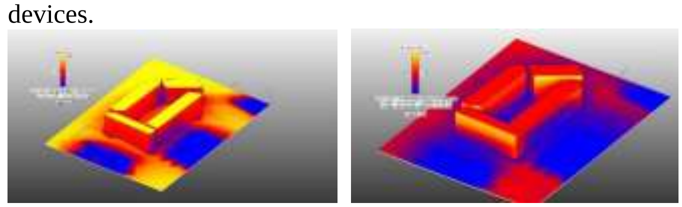


Fig. 6a Summer Season Radiation Fig. 6b Winter Season Radiation

Fig. 6 Radiation in Summer and Winter (Kw/h)

As understood, there are several extreme cases in various seasons, thus, the design of the building should be able to respond such challenges. By minimizing opening size of façade and improving its performance of insulation, it is expected that the solar gain in summer should be minimized and could protect cold wind coming in the winter season. Rainscreen ventilated façade indicates its advantage due to the urban context and high-insulating potentiality.

https://doi.org/10.17758/EAP.EAP917305

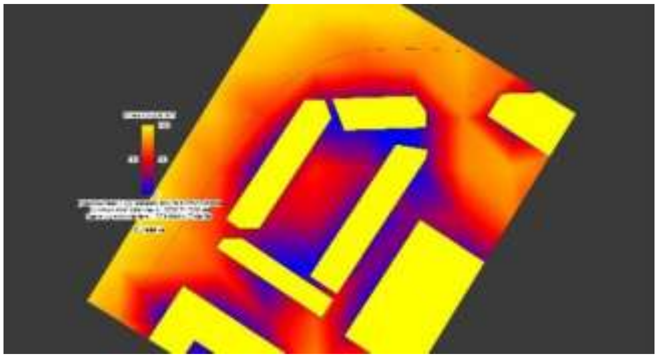


Fig. 7 Year Round Radiation (Kw/h)

Since the atrium is going to be very dark in the winter, it will make people feel colder. For this reason, glazed cover as roof above the courtyard is preferred. It will indeed behave as a greenhouse in the atrium providing extra thermal comfort in the winter. When the summer season is considered, with the system of operable roof which is an integration of PV panels and glazing system, the temperature in the atrium will be controlled.

The image of sustainability of Center for Promotion of Science is considered important in the capital city of Serbia. Solar energy has been harvesting in EU countries for a long period, being 50% of cumulative PV capacity of the world. For this reason, above the atrium, it solar panels are used. In order to design a more reasonable atrium the building integrated PV system has been chosen. The Center for Promotion of Science uses glazing integrated PV panel on roof top which also acts like sunshade preventing direct sunlight penetrating through the atrium.

In the figure below, the consideration of potential solar energy of designed area of installation on top of operable roof is indicated. The area of selected glazing is roughly 2550 square meter covering 80% of the sloped part of glazing roof. The result shows that selected are could potentially generate 543540 KWh in a year. The installed solar panel could potentially cover up to 30% energy loads of heating and cooling.

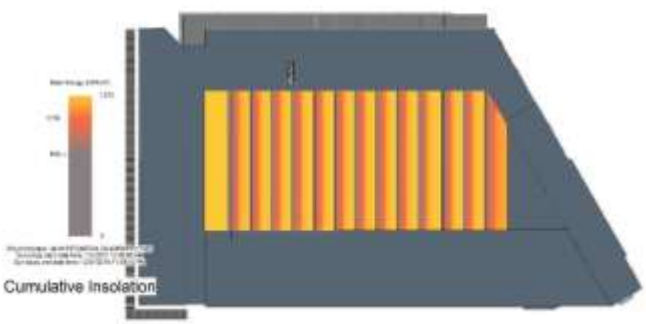


Fig. 8 Cumulative Energy Received in a Year

V. Thermal Analysis

In this section, thermal analysis is carried out in the beginning of design in order to make quick decision of material choice. The aim here is to see the different results when change in material in order to optimize building shape and opening.

There are *five cases* set up and each case represents one building element change in its insulation performance. The schedules of occupation of each thermal zone and other parameters are remained the same. The heating and cooling energy consumption is therefore calculated respectively.

The working hour of buildings is set from 10 am to 10 pm, as it will heavily be used by various people due to its diverse functionalities such as exhibition, library, accommodation and offices. 1 people generates 70 KW per 8 m^2 is set. For the choice of air-conditioning system, mixed-mode system with 95% efficiency and the thermostat ranges from 18-26 Celsius degree is set.

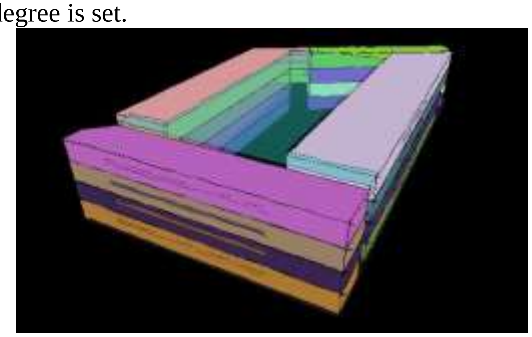


Fig. 9 The Thermal Zone Division

A. Case 1

Case 1 is the baseline model for having a basic design point. It contains very basic building elements, such as roof wall, windows and floor. However, it is with poor insulation. In this case, it can be understood the basic consumption used by buildings in terms of heating and cooling loads in various seasons. In the image and table below, it is depicted the stratification of building element which is applied to the *baseline model*:

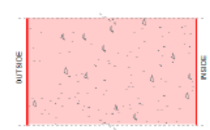
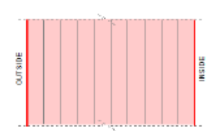
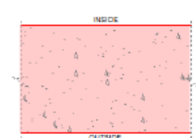
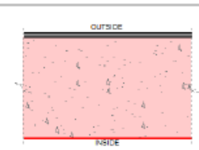
Exterior wall	Concrete reinforcement 250mm	U-value 3.23	
Glazing	Single glazed alumFrame 6cm	U-value 6	
Floor	300mm thick RC concrete	2.98	
Roof	200mm concrete and plaster layer	3.26	

Table I Baseline Model Building Elements

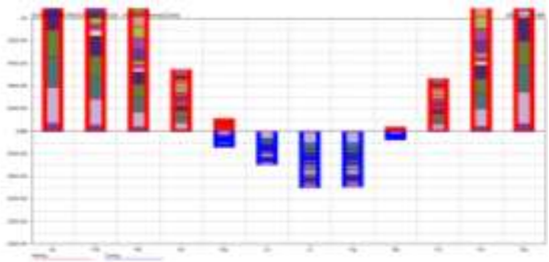


Fig. 10 Monthly Heating/Cooling Loads, Baseline Model

As a result of the study, the average energy consumption per floor area is 154.320 kWh/m^2, annually.

A. Case 2

In the Case 2, only the floor insulation is improved while the rest of the building elements remains the same as the base model. In the image and table below, there is stratification of floor applied to this case:

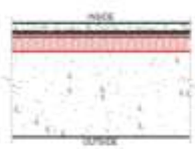
Floor	wood fibers 30mm, airgap 10mm, screed 10mm, insulation rigid 50mm, concrete slab 300mm	U-value 0.14	

Table II Building Elements, Floor Insulation

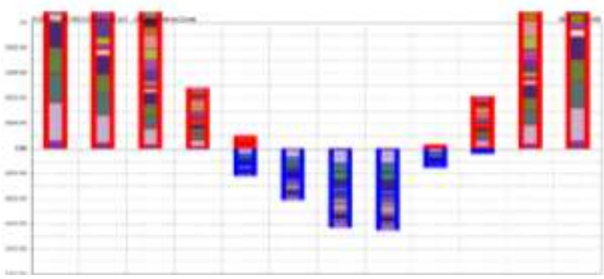


Fig. 11 Monthly Heating/Cooling Loads, Only Floor Improved

The average energy consumption per floor area is 146.972 kWh/m^2.

B. Case 3

In this case, only the exterior wall insulation is improved while the rest of the building elements remain the same as baseline model. In the figure and table below, there is the stratification of floor which is applied to the Case 3 model:

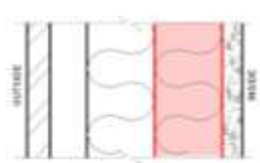
Exterior wall	Cladding 35mm, airgap 55mm, insulation polystyrene rigid 100mm, rock wool acustic 100mm, gypsum board 30mm	U-value 0.28	

Table III Building Elements, Exterior Insulation

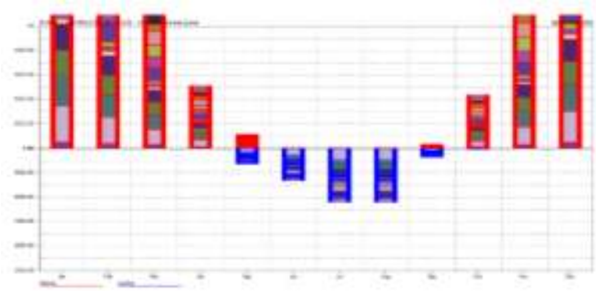


Fig. 12 Monthly Heating/Cooling Loads, Only Exterior Insulation Improved

As a result, the average energy consumption per floor area is 139.322 kWh/m^2, annually.

C. Case 4

In this case, only the performance of glazing is improved while the rest of the building elements remain same as baseline model. In the image and table below, there is stratification of glazing applied to this case:

Glazing Element	Glass 10mm, Air gap 10mm, Glass 10mm	U-value 2.65	

Table IV Building Elements, Double Glazing

Fig. 13 Monthly Heating/Cooling Loads, Only Glazing Improved

D. Case 5

In Case 5, only the roof insulation is improved by applying green roof system while the rest of the building elements remain the same as baseline model.

Green Roof	Soil 200mm, air gap 55mm, insulation 60mm, plaster 10mm, concrete lightweight 250mm	U-value 0.28	

Table V Building Elements, Green Roof

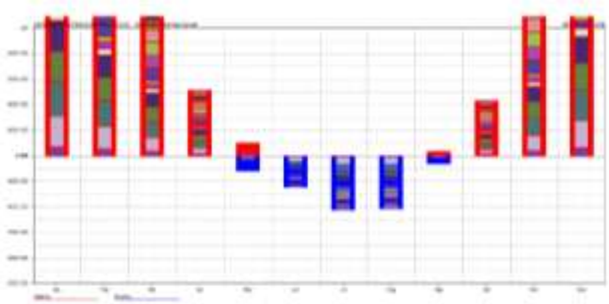


Fig. 14 Monthly Heating/Cooling Loads, Only Improved Roof

E. Case 6

Finally, in Case 6, every designed elements are applied to the building. The average energy consumption per floor area is found 88.669 kWh/m^2 annually.

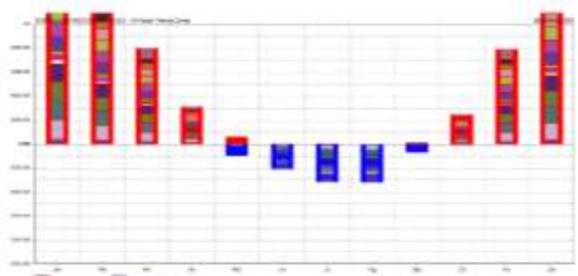


Fig. 15 Heating/Cooling Loads, Whole Building Improved Insulation

F. COMPARISON

In this section, comparisons when changing materials are presented. By changing the roof material, overall energy demands can be reduced by 7%. By changing the glazing material, overall energy demands can be reduced by 18.7%. By changing the wall material, it can be reduced by 9.7%. By changing floor material, it can be reduced by 4.7%. Finally, when all the designed building elements are applied to the project, heating demands will reduce 43%, and cooling will reduce 32%, as shown in diagram below.

Fig. 16a Heating Loads

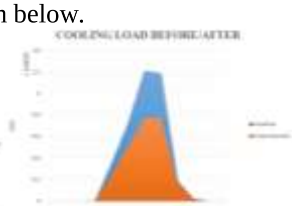


Fig. 16b Cooling Loads

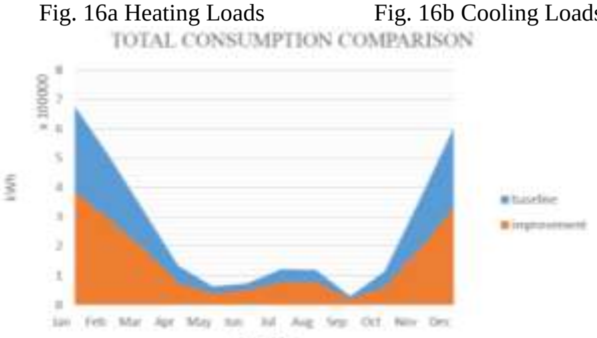


Fig. 16: Before and After Comparison of Heating and Cooling Loads

As a result, it is deduced that glazing is the most important element in this project due to the fact that curtain wall is used in the inside the façade, thus, there is considerable percentage of glass. As the Ecotect tool did not consider the cover of atrium, the result is relatively approximation. Once the atrium is also taken into account, the importance of interior curtain wall would be reduced due to greenhouse effect in winter and ventilation in summer by applying operable roof.

VI. Wind Analysis

Airflow and air quality are crucial for human comfort. Natural ventilation helps designer to achieve passive cooling. A proper design also helps designer to achieve sustainable goal. In this project in Belgrade, wind flow is important to achieve the passive design goal due to the huge temperature differences in winter and summer. The wind flow direction plays an important factor to affect human comfort and energy consumption. Thus, how to provide an occupant-satisfied environment while saving cooling and heating energy become an interesting issue that should be considered during design phase.

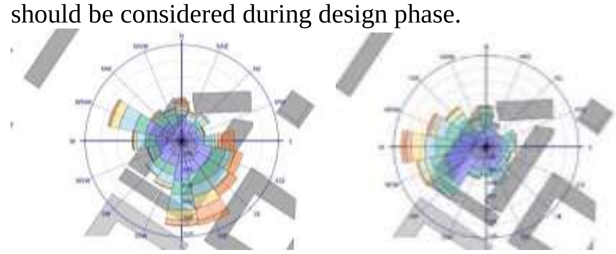


Fig. 17a: in Winter Fig. 17b: in Summer

Fig. 17 Prevalent Wind Directions

From the wind rose diagram it can be seen the prevalent wind mainly comes from *west* and *sout*h side in a year. External wind flow is simulated in the early design phase to understand the impact of wind flow.

In order to achieve quick and easy simulation result, the geometry of model doe CFD simulation is simplified. In this case, three scenarios; building without roof, building with roof opened and building with roof closed are analyzed. The results indicate how the roof affects building atrium airflow. When the roof and entrances are closed, the wind speed within atrium would be minimized. In the winter season, basically, all the openings are closed. In this case, the atrium in winter is not affected by the cold and humid air outside of building.

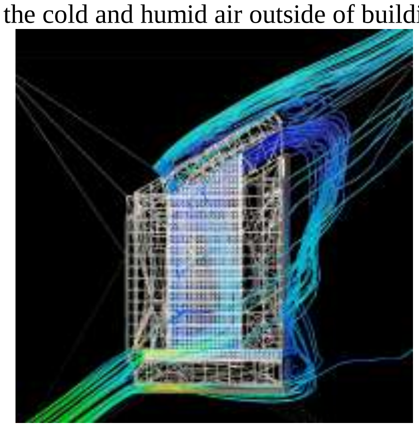


Fig. 18 Top View of Wind Flow, Summer Case, Wind Coming from West

https://doi.org/10.17758/EAP.EAP917305

Moreover, with the help of greenhouse effect, the atrium is expected to maintain higher temperature than outside air, providing comfort for people.

VII. LIGHTING ANALYSIS

Natural lighting in commercial buildings is a crucial strategy for passive design. The electric lighting accounts for 35-50% of total electrical energy use. A smart move of lighting strategy can reduce energy demand dramatically. As the strategy is to avoid direct sunlight due to its brightness, window openings are designed as horizontal, but thin. This with the help of automatic shades, will reduce the possibility of direct sunlight coming.

The lighting level could be determined by illuminance, which is the measure of how much light falls on a surface. A building interior space needs 5 to 100 foot-candles to meet the recommended suggestion. In the ground floor plan, which is the most un-favorite level in terms of natural lighting acquirement the lighting distribution is still acceptable. The exhibition space, due to the inside glazing façade, the light is generally above 80 Foot-candles, which satisfies the requirement.

VIII. BUILDING TECHNOLOGY

This chapter is considered in terms of several aspects as:

- *Natural ventilation:* As the designed height of central atrium in the project is high, natural ventilation becomes a good solution for removing heat in summer season, as there would be lots of heat gains due to the *greenhouse effect*. By opening the roof panels, stack effect could make sure the atrium does not become too hot and it maintains the atrium cool.
- *Floor heating*: Belgrade in winter is cold. Even passive solar gain from covered greenhouse-like atrium and inside glazing façade is applied, the building still needs extra effort heating up the indoor environment. In this case, radiant heating system supplies heat directly to the floor or to panels in the wall or ceiling of a house.
- *Heat recovery system*: A heat recovery system is ideal for building located in colder climates, where there is excess moisture during heating season like Belgrade, because the unit allows to get rid of it. This system supplies continuous fresh air from outside of the building. The heat recovery core of the unit transfers a portion of heat in the stale air being exhausted to the fresh incoming air from outside before being distributed throughout the building.
- *Building envelope*: The façade of building as Center for Promotion of Science is important giving people first impression. It also needs to meet the given requirements in terms of lighting level, aesthetics, energy consideration and maintaining the indoor environment. When considering all the analyses conducted before rainscreen cladding façade comes as the preference.

IX. TECHNOLOGICAL STRATEGIES SCHEME

The images below indicate several technological strategies:

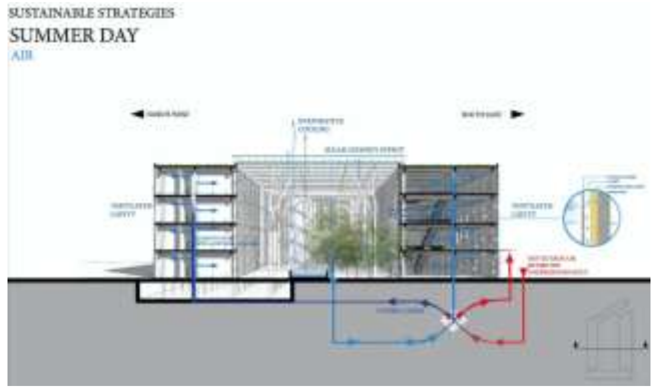


Fig. 19 Air Circulation in Summer Day

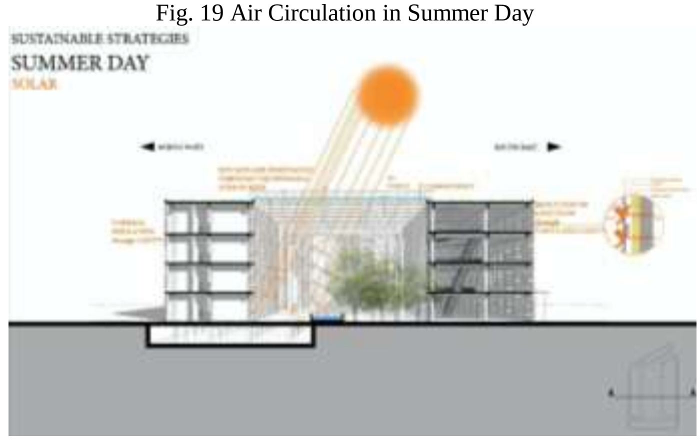


Fig. 20 Solar Strategy in Summer Day

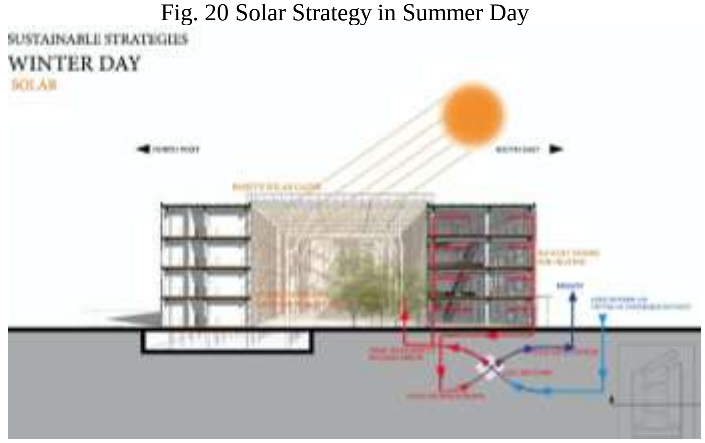


Fig. 21 Solar Strategy in Winter Day

X. CONCLUSION

As the second stage of the work, after the urban and architectural design of the 'Center for Promotion of Science', technological design aims at improving the performance of the complex in Belgrade, Serbia. Considering the extreme climate conditions in Belgrade, the complex is evaluated in lighting, wind, thermal and solar conditions in the area. After several analyses of building performance evaluation, the results in all of them satisfies the standard requirements of a sustainable and energy efficient building design.

REFERENCES

[1] IMM Metholodogy website: www.immdesignlab.com, Accessed on 23rd July

[2] M. Tadi, S.Vahabzadeh Manesh, M. Hadi Mohammad Zadeh, A. Naraghi, 'Environmental and Energy Performances Optimization of Neighborhood in Tehran, via IMM Methodology', January 2014

[3] Climate Consultant 5.5, UCLA Energy Design Tools Group website: Accessed on 23rd July

B. Balci was born in Datca, Turkey in 1989. Being an architect, she obtained her Master of Science degree in Architectural Engineering from Politecnico di Milano in 2016. She was awarded a Gold Scholarship on merit basis in this department and university.

During her Msc studies, she had enhanced her specialty in the area of engineering approach towards architectural design. She worked as a researcher in the IMM Design Lab (International and Multidisciplinary Design Laboratory for Urban Sustainability). The project is mainly based on the sustainability concepts both in urban and architectural aspects. During this time, she collaborated with the University of Belgrade in a workshop in Belgrade, Serbia.

Balci had participated in two competitions for which her team was awarded '*first prizes'.* In addition, she also enrolled in several workshops.