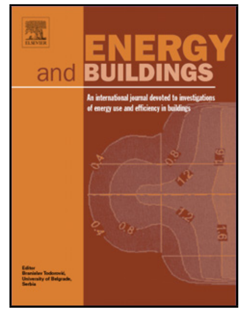
Accepted Manuscript



Title: THE INFLUENCE OF Atrium ON ENERGY PERFORMANCE OF HOTEL BUILDING

Authors: Milica Vujošević, Aleksandra Krstić-furundžić

PII: S0378-7788(17)31613-4
DOI: https://doi.org/10.1016/j.enbuild.2017.09.068
Reference: ENB 7987

To appear in: *ENB*

Received date: 4-5-2017
Revised date: 20-9-2017
Accepted date: 24-9-2017

THE INFLUENCE OF ATRIUM ON ENERGY PERFORMANCE OF HOTEL BUILDING

Milica VUJOŠEVIĆ[a]* and Aleksandra KRSTIĆ-FURUNDŽIĆ[b]

[a] Institute of Architecture and Urban & Spatial Planning of Serbia, Bulevar kralja Aleksandra 73/II, 11000 Belgrade, Serbia, milicavujosevic@yahoo.com

[b] Full Professor, Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, 11000 Belgrade, Serbia, akrstic@arh.bg.ac.rs

[*] Corresponding author; e-mail: milicavujosevic@yahoo.com; address: Institute for Architecture and Urban & Spatial Planning of Serbia, Bulevar kralja Aleksandra 73/II, 11000 Belgrade, Serbia; telephone: +381643532538

This paper analyses annual energy performance of atrium type hotel building in Belgrade. The objective is to examine the impact of the atrium on the hotel building's energy demands for space heating and cooling. Integrated approach through numerical simulations that include Belgrade climate data and thermal comfort parameters, indicates an optimal model of hotel building with atrium for this area. Building energy simulation is carried out using EnergyPlus simulation engine, as a basic tool in the process of building energy optimization. The methodological approach includes the creation of a hypothetical model of an atrium type hotel building, numerical simulation of energy performances of several design alternatives of the hotel building with atrium, and comparative analysis of the obtained results. The main task of analysis is to change certain parameters in the particular model (for example, building structure, orientation, etc.) and to observe how the changes influence energy performance of the building. The goal of this research is to show that the atrium contributes to the heating and cooling energy savings in the rest of the building, but also that the atrium itself demands a lot of energy for its air-conditioning. The most sustainable solution should be to cover energy demands for atrium by using the renewable energy sources. In this case, the atrium can contribute to the energy efficiency of the hotel building in Belgrade climatic conditions, thus reducing its negative impact on the environment.

Key words: *hotel, atrium, energy performance, numerical simulation, heating and cooling demands*.

1. Introduction

Continuous technological development takes large impact on the environment and it needs to be based on the principles of sustainability. In addition to the many important aspects of sustainability in architecture (social, economic, environmental, technical), building energy efficiency is one aspect that touches the three most important issues nowadays - environmental protection, climate change and energy security. One of the causes for climate change is an excessive carbon dioxide emission as a result of the fossil fuels combustion, which is largely influenced by the energy consumption in buildings. Therefore, the fact that energy efficient buildings have less negative impact on the environment makes them inevitable in today's construction industry.

Hotel buildings are chosen for the analysis because tourism is one of the most promising drivers of global economic growth. The size and scope of the sector makes it very important from the perspective of global resources, and even small changes can have large impacts. The contribution of tourism to the total emission of greenhouse gases is estimated to 5.3% (UNEP & WTO, 2005). It is based on carbon dioxide emissions from transport (75%), accommodation facilities (21%) and tourism activities (4%) (Maksin *et al*, 2011). It is estimated that Serbia and Belgrade need more hotels, especially those of high quality, because Serbia was pronounced the fastest growing congress destination in Europe from 2007 to 2010, according to the official list of the International Congress and Convention Association (2012). The Serbian policy and approach to developing sustainable tourism is under unavoidable implications of the broad set of documents, adopted at the national level over the past few years (Orlović-Lovren *et al.*, 2013).

One of the most energy intense sectors in the field of tourism and services is the hotel industry. Energy costs make up the largest part of the general operating costs of the hotel, right after personnel costs. Heated commercial space consumes around 25% of final district heating energy in Belgrade, and hotels make 625,447 m^2 or 2.44% of it (Energoprojekt Entel, 2008).

Numerous researches have investigated the energy performance of hotels. The researches show that hotels consume around 200-400 kWh/m^2 of energy per year (Hotel Energy Solutions, 2011) and almost half of it (48%) is reserved for HVAC (Zanki-Alujević and Galaso, 2005). Meanwhile, commercial buildings in Serbia consume around 376 kWh/m^2 of energy per year, and residential buildings around 200 kWh/m^2 per year (Treći akcioni plan za energetsku efikasnost Republike Srbije za period do 2018. godine, 2017).

The reason for this research lies in large energy consumption for heating, ventilation and air conditioning in buildings, which combined with environment pollution causes climate change. In other words, it concerns the design of energy efficient buildings as a basic starting point in the design process.

The subject of this paper is the creation of an optimal model of hotel building with atrium in Belgrade, in terms of maximizing energy efficiency of the building and reducing its negative impact on the environment. Due to the needs and trends of increased tourism development in Serbia, this study refers to the consideration of atrium type hotel building and its energy efficiency.

The research includes an energy performance analysis of a hypothetical model of the hotel that uses an atrium as a greenhouse for natural passive heating, cooling and ventilation. Several proposals for the atrium design alternatives are taken into consideration in order to examine their impact on the annual heating and cooling energy demands. The subject of this paper is the examination of atrium contribution in terms of passive thermal gains for heating in winter, as well as its contribution to overcoming the problem of overheating during summer. The aim is to show that the atrium can contribute to the energy efficiency of hotels and to indicate the most efficient alternatives regarding the atrium envelope design.

The research method includes the creation of a hypothetical model for the analysis, design of alternatives and application of numerical simulations using computer software, as well as comparative analysis of the selected results. The analyses include the evaluation of alternatives in terms of satisfying thermal comfort with minimum energy consumption for the Belgrade climate conditions. Based on these analyses, the most efficient alternative has been selected.

The description and the comparison of the results lead to the conclusion how alternatives meet the requirements for energy efficient buildings. Today, energy consumption needs to be nearly zero in newly constructed buildings, but in case of hotels this can only be achieved by combining passive and active systems for the use of renewable energy. After the synthesis of the results, the basic principles and conclusions are presented and the recommendations for planning and design of energy efficient hotels with an atrium in the Belgrade climate conditions are defined. The results and recommendations may be useful for architects in designing hotels with an atrium in the climatic regions similar to the Belgrade's. The findings could be extended further to different hotel types with atrium and to different climatic conditions.

2. Creation of a hypothetical model

Architectural features and thermal behaviour of buildings should be taken into account in planning and designing the hotel buildings. The passive building concept is a good way to reduce the needs for heating and cooling, thus reducing the pollution and enhancing the responsible behaviour toward environment. Unlike many other commercial buildings, hotel buildings are unique because of the variety of facilities and functions provided, and operating schedules (Deng and Burnett, 2000). Predicting the rational use of energy in designing the buildings can reduce the use of energy in buildings, as well as the use of polluting energy sources, thereby reducing the CO_2 emissions (Krstic-Furundzic and Kosoric, 2009).

Nowadays, the buildings with atrium present a very attractive building type. According to Aldawoud (2013), atria present some very unique design concerns for architects because there are many key factors that can be associated with the use of this element in buildings and influence its energy performance. All aspects of the atrium in buildings such as atrium proportion, orientation, shape and size, height, shading control of the atrium, atrium's glazing type and ratio, and the thermal mass of the atrium's walls, need careful design consideration (Aldawoud, 2013).

Atrium hotels present a very attractive building type widespread among newly built hotel buildings all over the world. Belgrade, however, does not host any hotel with large glazed atrium, so it is interesting to examine the behaviour of this building type in Belgrade climate conditions. Lack of appropriate comparison models has led to the creation of a hypothetical model instead.

The spatial frame of the research is limited to the Belgrade urban area (Fig. 1). For the purpose of this analysis, a hypothetical model of a new free standing hotel building in Block 26 in New Belgrade has been designed. The location presents an open city block that is still under construction. The southeast corner of the block is selected for a building site.

The created hypothetical model is a “U” shaped building with rooms surrounding a central courtyard from three sides. The fourth side of the courtyard, oriented 33° southwest, is either open to external space or glazed along with its roof, forming a closed greenhouse or an atrium. The ground floor consists of a public area, reception, cafe and a restaurant. Offices and conference spaces are located on the first floor, while guest rooms are located on the second to the sixth floor. The structural system of the building is designed as a reinforced concrete skeleton system. The building envelope is designed as a three-layer structure consisting of an inner wall made of aerated concrete blocks (30 cm), mineral wool thermal insulation (5 cm) and cladding applied on the substructure. The glazing is made of double layered low emission glass framed by aluminium profiles with thermal brake. The flat roof consists of a semi prefabricated concrete structure - prefabricated beams with aerated concrete infill blocks (20 cm), mineral wool roof insulation (20 cm), all necessary membranes and stone finishing. The floor on the ground is made of heavyweight concrete (20 cm), thermal insulation (15 cm) and stone finishing with all necessary layers. All construction elements comply with the current local regulations in terms of thermal conductivity (Pravilnik o energetskoj efikasnosti zgrada, 2011). The achieved thermal conductivity coefficient U [W/(m^{2}K)] is 0.20 (allowed 0.30) for the outer wall, 1.10 (allowed 1.50) for windows and glazing, 0.14 (allowed 0.15) for the flat roof above heated space and 0.23 (allowed 0.30) for the floor above unheated space (basement or ground).

The following alternatives are subject to the numerical simulations, which gives an insight into their energy performances:

- Alternative 1: the building with an open inner courtyard, without the atrium;
- Alternative 2: the building with glazed atrium – the basic atrium type building;
- Alternative 3: the building with glazed atrium and enhanced infiltration in atrium during summer;
- Alternative 4: the building with atrium equipped with shading devices.

Alternative 1 (A1) is the building with an open inner courtyard. The hotel building model without the atrium is created as an ordinary "U" shaped building (Fig. 2), which helps examine the influence of atrium on the building energy performance by comparing this alternative to the alternatives with a glazed atrium. The courtyard, positioned in the central area of the hotel, is open to external factors. No glazing is applied on its top. The building has corridors facing the inner open space. In this case, the building has a large envelope, thereby a large heat transfer surface towards the outside.

Alternative 2 (A2) is the building with glazed atrium – the basic atrium type building. This is the primary model of an atrium type building. The inner courtyard of the building is closed with the glass structure on the south-west side and the glazed skylight on the top (Fig. 3). The corridors on the upper floors are facing the atrium space.

Alternative 3 (A3) is the building with a glazed atrium and enhanced infiltration in the atrium (Fig. 4). The atrium acts as a greenhouse to the rest of the building, especially when positioned on the south side like in this research. The overheating may occur in summer due to the increased amount of solar heat gains achieved through the atrium glazing, requiring more energy for cooling. The basic model (A2) considers the infiltration of 0.5 air changes per hour. One of the solutions to the overheating problem is to enhance infiltration in the atrium to 1.2, which is the highest amount permitted by the Serbian Regulations on Energy Efficiency in Buildings (Pravilnik o energetskoj efikasnosti zgrada, 2011). The cooling by enhanced infiltration for this model is envisaged for the period from 1st May to 30th September during the whole day.

Alternative 4 (A4) is the building with an atrium equipped with shading devices. Another way of reducing the overheating in the atrium in summer is to apply the shading devices in the glass structure of the atrium. As already mentioned, the most window heat gains occur through the atrium glass structure. The atrium of this model is covered by 20 shading surfaces tilted 45 degrees from the glass surface (Fig. 5). The direct solar gains are reduced in the atrium, resulting in the decreased solar heat gains and thus also less energy needed for cooling. Since the movable shading devices use electricity for their operation and require special supporting systems and maintenance, this paper has adopted the fixed shading devices.

These four alternatives are characterized by different envelope surfaces depending on the availability of an atrium and its features. Table 1 shows the envelope and space characteristics of the designed alternatives

The envelope area of the first alternative is 37% larger than the one of other three alternatives because the inner courtyard is open to the external space. The large heat transfer surface also influences the amount of energy required for air conditioning. The atrium of the last three alternatives creates 11% more usable area and 64% more volume than the first alternative has.

3. Numerical simulations

The building energy simulation is carried out using OpenStudio SketchUp PlugIn - the interface that integrates with EnergyPlus simulation engine. The data on loads and schedules are adopted from the U.S. Department of Energy Commercial Reference Building Models of the National Building Stock research. Both programs were developed by National Renewable Energy Laboratory of the United States Department of Energy. This combination of software is chosen because of their availability (freeware), but most of all because of the reliability of EnergyPlus, which is proven to be the most efficient simulation engine used by a variety of other programs, according to Crawley *et al.* (2005). EnergyPlus is an energy analysis and thermal load simulation program. Based on a description of a building from the perspective of the building's physical make-up, associated mechanical systems, etc., EnergyPlus calculates the heating and cooling loads necessary to maintain thermal control set points, conditions throughout a heating, ventilating and air-conditioning system, and the energy consumption of primary plant equipment, as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would (Getting Started with EnergyPlus, 2013). Based on the virtual model of the building and the given climate, the software performs the measurement of certain parameters and predicts the behavior of the building as close to the real situation. Dynamic model demonstrates the process during the whole year. In this way, energy performance of the building is analyzed at the early design stages, providing a possibility to alter the required parameters if needed. The main task of this analysis is to change certain parameters in the particular model (for example building structure, orientation, etc.) and to observe how the changes influence energy performance of the building.

One of the core elements of EnergyPlus are thermal zones. The loads acting upon a thermal zone can be external (energy conducted through the walls, solar radiation through translucent surfaces and infiltration) or internal loads (people heat radiation, lights and equipment heat radiation). Loads and schedules data are adopted from the commercial reference buildings research of the United States Department of Energy (U.S. Department of Energy Commercial Reference Building Models of the National Building Stock). The intent of the reference building models is to characterize the energy performance of typical building types under typical operations. Detailed building energy models require several pieces of information that are not available from standard data sources; therefore, data from several sources were combined in a sensible way to represent "typical" performance (Deru *et al.*, 2011). Some data were determined according to the ASHRAE Standards 90.1-2004, 62.1-2004 and 62-1999; others were adopted from studies titled Prototypical Commercial Buildings (Huang, *et al.,* 1991) and Technical Support Document (Jiang, *et al.,* 2008). All other technical specifications and regulations are taken from the Serbian Regulations on Energy Efficiency in Buildings (Pravilnik o energetskoj efikasnosti zgrada, 2011). The hotel is designed for 100 rooms. The designed indoor air temperature for appropriate thermal comfort is 20°C in winter and 26°C in summer (Pravilnik o energetskoj efikasnosti zgrada, 2011). The default infiltration is 0.5 air changes per hour (ach) and it is present in alternatives 1, 2 and 4, while alternative 3 has infiltration of 1.2 ach in the atrium in summer period. The EnergyPlus uses weather data arranged by World Meteorological Organization, and available free online as IWEC (International Weather for Energy Calculations) file. Specific data file includes, among others, dry bulb/dew point temperatures, pressure, and wind conditions in Belgrade geographic location throughout the year, based on multiannual data collection. The simulation is done in 15 minutes time step.

The considered building consists of the following space types, i.e. thermal zones (Fig. 6): guest rooms (44% of total area, 27% of total volume), corridors (28% of total area, 18% of total volume), offices with conference spaces (9% of total area, 8% of total volume), cafe and restaurant (4.5% of total area, 4% of total volume), retail (4.5% of total area, 4% of total volume) and lobby with atrium (10% of total area, 39% of total volume) in case of A2, A3 and A4, while A1 does not have the atrium.

For each alternative, thermal zones are envisaged as shown in Table 2.

Only energy for heating and cooling of the mentioned areas is taken into account, not including special conditions for the kitchen, service hot water, spa centre etc., as being irrelevant from the viewpoint of this energy analysis. The installation systems are not the subject of the analysis. The heating and cooling demands are calculated as final energy directly consumed in a facility, typically measured with utility meters, without specifying the type of fuel and the energy required for the transmission from the power plant. This gives an insight into the amount of final energy needed for air-conditioning, regardless of the efficiency of the plant or the fuel source. The natural gas district heating and electrical cooling is used in latter stage in calculating the CO_2 emissions because the building will be supplied by district heating network from the New Belgrade heating plant, and it is likely to be cooled by electricity.

Models, i.e. alternatives are designed in OpenStudio SketchUp PlugIn (Figures 2, 3, 4 and 5). The basic orientation of the atrium is 33° southwest, as it fits into the urban setting of New Belgrade open blocks and the orientation towards the main street. Different orientations of the basic atrium type model have been created in the final part of the paper, in order to observe their energy demands.

4. Comparative analysis of the results

The simulations of energy performances of the hotel building alternatives show the amount of energy demands for heating and cooling of the building throughout the year, as well as the amount of solar heat gains achieved through the atrium glazing. When it comes to the total annual amount of final energy for space heating and cooling, Table 2 shows an overall annual consumption, as well as an overview of the building's energy needs for each month in GJ and per square meter in kWh separately for atrium thermal zone and jointly for all other thermal zones in the building. Table 3 indicates how certain variations in alternatives influence the monthly energy needs.

Table 3 shows that the period of demand for heating coincides with district heating season in Belgrade, which lasts from mid-October until mid-April. The summer cooling is inevitable. In transitional period (October and April), the heating and cooling demands make less than 10% of peak demands in January and July respectively, so in this period the building is considered to be air-conditioned naturally to some point.

Figures 7 and 8 show the final energy demands for heating and cooling on monthly basis, Figure 9 shows annual final energy demands, while Figures 10 and 11 present total annual final energy consumption per square and cubic meter.

Figure 7 shows that period of heating demands coincide with district heating season in Belgrade, which lasts from mid-October until mid-April. Figure 8 shows that in the summer cooling is inevitable. In transitional period (October and April), the heating and cooling demands make less than 10% of peak demands in January and July respectively, so in this period the building may be conditioned naturally to some point.

The total annual final energy demand for heating and cooling differs among the alternatives (Fig. 9). The building with open courtyard (A1) consumes the least amount of energy for heating (670 GJ) and cooling (605 GJ), but it also has 11% less building area and 64% less volume than other alternatives. The building with an atrium requires around 40% more energy for air-conditioning (1,078 GJ for heating and 956 GJ for cooling) than the building with a courtyard. The enhanced infiltration in the atrium during summer reduces the total energy consumption by 2% (heating – 1,107 GJ, cooling - 884 GJ). The building with shading devices (A4) has the best performance of all buildings with the atrium as it requires 7% less energy than A2 (heating – 1,213 GJ, cooling - 689 GJ).

Figure 10 shows the total annual final energy consumption per square meter. The alternative 1 needs the least amount of energy per square meter compared to other alternatives (A2, A3 and A4). But, the volume plays an important part in this research. The alternative 1 has almost half less volume than other alternatives. Consequently, A1 needs more energy per volume unit than other alternatives (Tab. 3, Fig. 11). Comparing A1 to A2, the energy demands for heating and cooling are about 3% higher.

The contribution of the atrium to heating is very large during winter. The basic atrium type hotel (A2) is efficient when it comes to heating demands (Fig. 7, 10, 11). It requires the least energy for space heating compared to all other alternatives with an atrium, both totally and per square or cubic meter. The atrium proved to act as a solar heat collector, accumulating the solar radiation in the structure. Unfortunately, Belgrade features pretty high summer temperatures, which creates the problem in large glass spaces. The overheating of the space exposed to the direct sunlight requires a vast amount of energy for cooling. Thus, the two other alternatives have been proposed in order to overcome this problem present in the A2. The alternative 3 presents an attempt to solve the overheating problem by enhancing the infiltration during summer. This solution provides a small improvement, but it still does not provide enough savings in the energy for cooling because of very large solar heat gains through the glazing of the atrium at noon.

The most efficient measure in prevention of the atrium overheating is the placement of shading devices over the glass facade and skylight of the atrium. In case of the alternative 4, the fixed shading devices are placed over the glass facade and skylight of the atrium. In this way, the cooling demands during summer are significantly lower (by 30%) than in the case of A2. But the atrium loses the function of collecting heat during winter, since less solar radiation passes through the fixed shadings. The heating demands increased by 12%. The best solution is to apply the movable shading devices given that an appropriate position of shading plates can be obtained in each period of year.

The solar heat gains through the building's glazing are shown for each thermal zone in Table 4 in order to show the influence of an atrium on heating demands.

These simulations have shown that the atrium largely influences building's energy consumption. (Tab. 4). From the one side, it requires certain amount of energy for its air conditioning, which is not small given its size and volume. From the other and much more important side, the atrium acts as a greenhouse collecting the solar heat in the building structure, not allowing it to be easily cooled. This is why the buildings with an atrium have almost the same needs for heating like those without an atrium in spite of a very large volume of the atrium that needs to be heated.

The first alternative does not have an atrium. It has quite an amount of heat gains through the southwest-facing glazed corridors, and a pretty large amount of heat losses through the same windows due to the fact that there is no tampon zone as in case of the atrium. The main cause for this is 37% larger heat transfer surface compared to other models. But still, the amount of solar heat gains in case of A1 is a little less than the amount of heat added solely through the atrium in other alternatives (Tab.4 and Fig. 12).

The other three alternatives have the same amounts of heat gains and heat losses through windows in each thermal zone, except in the atrium. The alternatives 2 and 3 have almost the same window heat gains and heat losses because the same amount of solar radiation enters through the atrium envelope (Tab. 4, Fig. 12 and 13). The alternative 4 has more than half less window heat gains in the atrium than alternatives without shadings. This is due to the fact that shading prevents the sunlight from coming into the inner space of the atrium, as shading devices are not movable. This can be adjusted with the size, intensity and transparency of the shading structure, but preferably with movable shading devices.

The difference between atrium heat gains and losses in case of the alternative A2 (Fig. 13 and 14) indicates the energy demands for heating and cooling of the atrium all year round.

Environmental pollution depends largely on CO_2 emissions from energy production. In this paper, for the analysis of CO_2 emissions, it is assumed that the heating is provided from the district heating plant with natural gas as heating source, while electricity is used for cooling (Tab. 5). Final to primary energy conversion factor is 1.1 for natural gas and 2.5 for electricity as an energy source according to the Serbian Regulations on Energy Efficiency in Buildings (Pravilnik o energetskoj efikasnosti zgrada, 2011). According to the same Regulations, the CO_2 emission is 0.20 kg/kWh for natural gas and 0.53 kg/kWh for electricity (Tab. 5 and Fig. 15).

4.1 Influence of orientation on the energy consumption

All previously analyzed alternatives have the atrium oriented to the southwest (33° west). If the basic atrium type alternative (A2) was differently oriented, solar heat gains and losses would cause different energy demands for each building (Fig. 14).

In this final step, four different orientations of alternative 2 are considered. The results of simulations are shown in Tables 6 and 7.

Small variations in energy demands are present between differently oriented buildings. Table 6 shows that buildings with south facing atrium require 4% less amount of site energy for space heating than those with atrium facing north. North facing buildings require 4% less energy for cooling than the south facing ones. This means that the summer overheating problem with an atrium can to some measure be reduced by facing the atrium to the north, while retaining its heat collecting contribution during winter via large skylight area.

Buildings with atrium facing north have around 25% less window heat gains through the atrium glazing, and around 15% more heat gains through guestroom windows in comparison to the south facing atrium buildings (Tab. 7). This information can be used when positioning a building on the site, and choosing an orientation of the atrium and the guest rooms.

4. Discussion and conclusions

This paper presents a case study of an atrium type hotel in the Belgrade climate conditions and shows how different concepts of atrium design affect the energy efficiency of building. The research was carried out using the numerical computer simulations of a hypothetical model of a hotel building with atrium and its design alternatives using EnergyPlus simulation engine. The building without atrium was compared to three alternatives of an atrium type building. Several different alternatives were created, analyzed and compared in order to get an insight of their energy performance. A comparison of atrium type buildings was also carried out. The main purpose of this research was to examine the influence of atrium on the building energy performance, more precisely on the energy required for space heating and cooling.

The building without an atrium turned out to consume more energy per volume unit for heating and cooling compared to the building with an atrium. When the inner courtyard of the same building was glazed to form a closed atrium, it turned out to achieve savings in the space heating energy demands. The south-facing atrium behaves as a greenhouse, capturing the solar heat radiation through the exposed surfaces. It is very convenient to have this kind of solar collector as part of the building which contributes to 30% reduction of heating demands in all other areas, excluding the atrium, over a large part of year, from September to May. The only problem was the overheating in the atrium during summer, while the cooling demands for other spaces were similar to those in case of A1 (hotel with an open courtyard). The atrium overheating was tried to be reduced by enhancing the infiltration in the atrium during summer (from May until September), but this produced just slightly better results. Much better results were obtained by applying the shadings on the atrium's facade and roof. The cooling demands were 30% lower than in the standard atrium type model, but unfortunately, the atrium had slightly lost its heat collecting function and the heating demands got 12% higher. The atrium influenced better thermal properties in all other spaces, except in the atrium itself. Compared to the hotel with an open courtyard (A1), the A2 and A3 required 30% less energy for heating of the space excluding the atrium, while 25% less in case of A4. The cooling demands in case of A2 are similar to those of A1, while in case of A3 the demands were 3% less, and 11% less for A4. This research indicates that the atrium could be applicable in Belgrade climatic conditions if energy demands for its heating and cooling are met using the renewable energy sources, such as geothermal energy available in Belgrade or building-integrated solar thermal and PV systems.

Concerning the Serbian Regulations on Energy Efficiency in Buildings, which takes only heating demands into account, alternatives A1, A2 and A3 can be classified as energy class B in relation to the specific annual heating energy consumption (≤ 45 KWh /m^{2}a).

The cooling demands are high due to the atrium, so it can be concluded that the design solutions presented herein (enhanced infiltration and shading devices) should be combined in order to get the best energy efficiency all year round. The best solution would be to apply the adjustable shadings on the atrium's envelope, which can have its full function in summer, but which could be withdrawn during cold period of the year to maximize the heat collecting effect of the atrium.

The other possibility includes the orientation of the atrium to the northeast/northwest side of the building, since the research has shown that north facing atria have 25% less solar heat gains and therefore require 4% less energy for cooling, while partly retaining heat collecting function in winter. That is very convenient to have in mind when designing a new building or closing an existing courtyard with a glazed structure.

This research contributes to the design practice because it shows concrete results of energy simulations of a hotel building with a courtyard and an atrium. Hopefully, it will provide specific information, as well as methodological approach, in designing and optimizing hotel buildings with atrium in the Belgrade climatic conditions from the energy efficiency perspective.

The recommendations for further research include the analyses of different shapes of hotel buildings with atrium and their energy performances in different climatic conditions.

4. Acknowledgement

This research has been carried out as a part of scientific research project "Spatial, Environmental, Energy and Social aspects of the Developing Settlements and Climate Change – Mutual Impacts", financed by Ministry of Education, Science and Technological Development of the Republic of Serbia.

5. References

Aldawoud, A. (2013) The influence of the atrium geometry on the building energy performance, *Energy and Buildings*, No. 57, Elsevier, pp. 1-5.

Crawley, D., *et al.* (2005) *Contrasting the capabilities of building energy performance simulation programs.* Washington: US Department of Energy, University of Strathclyde, University of Wisconsin and National Renewable Energy Laboratory.

Deng, S., Burnett, J. (2000) A study of energy performance of hotel buildings in Hong Kong, *Energy and Buildings,* No. 31, Elsevier, pp. 7-12.

Energoprojekt Entel (2008) *Energy Development Strategy of the City of Belgrade, Part II: The current energy supply in Belgrade*. Belgrade: City of Belgrade, Department of Energy, pp. II-46.

Getting Started with EnergyPlus, Basic Concepts Manual - Essential Information You Need about Running EnergyPlus (2013) The Board of Trustees of the University of Illinois and the Regents of the University of California through the Ernest Orlando Lawrence Berkeley National Laboratory.

Hotel Energy Solutions. (2011) *Analysis on energy use by European hotels: online survey and desk research*. Hotel Energy Solutions project publications.

Huang, J., *et al.*, (1991) *481 Prototypical Commercial Buildings for 20 Urban Market Areas*. Berkeley: Lawrence Berkeley National Laboratory.

Jiang, W., *et al.* (2008) *Technical Support Document: The Development of the Advanced Energy Design Guide for Highway Lodging Buildings.* Richland: Pacific Northwest National Laboratory.

Krstić-Furundžić A., Kosorić V. (2009) Improvement of energy performances of existing buildings by application of solar thermal systems, *SPATIUM International Review,* No. 20, pp. 19-22.

Maksin, M., *et al.* (2011) *Održivi razvoj turizma u Evropskoj Uniji i Srbiji.* Beograd: Institut za arhitekturu i urbanizam Srbije.

Orlović-Lovren V., Crnčević T., Milijić S. (2013) Tourism development in Serbia: On the way to sustainability and European integration, *SPATIUM International Review,* No. 30, pp. 47-53.

Pravilnik o energetskoj efikasnosti zgrada. (2011). Službeni glasnik RS, broj 61/2011.

Treći akcioni plan za energetsku efikasnost Republike Srbije za period do 2018. godine. (2017). Službeni glasnik RS, broj 1/2017.

UNEP, WTO (2005) *Making Tourism More Sustainable - A Guide for Policy Makers*. Paris: United Nations Environment Programme, Madrid: World Tourism Organization.

Zanki-Alujević, V., Galaso, I. (2005) Analysis of sustainable HVAC system in tourism facilities on the Adriatic coast. *Thermal Science*, No. 9(3), pp. 53-67.

Figure 1. Building site location in New Belgrade with a sketch of a hypothetical model of a hotel building with atrium (source: Google Maps, used to present the location of the hotel)

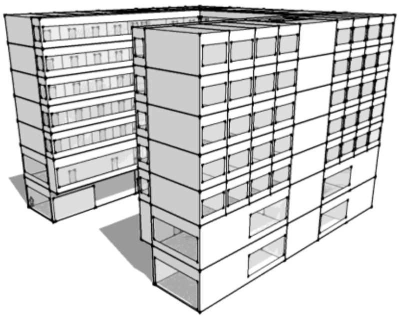


Figure 2. Alternative 1 - model of the building with open inner courtyard

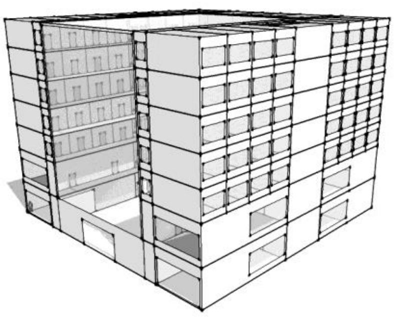


Figure 3. Alternative 2 - model of the building with glazed atrium – the basic atrium type building

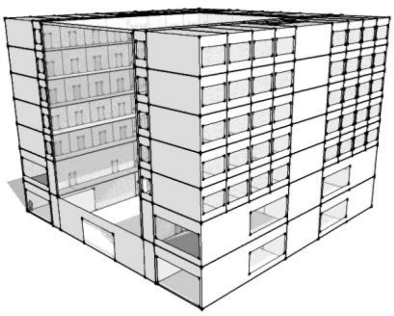


Figure 4. Alternative 3 - model of the building with glazed atrium and enhanced infiltration

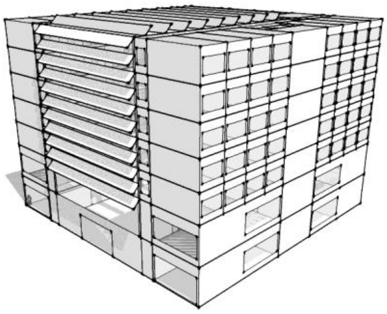


Figure 5. Alternative 4 - model of the building with shading devices applied on glazed envelope of atrium

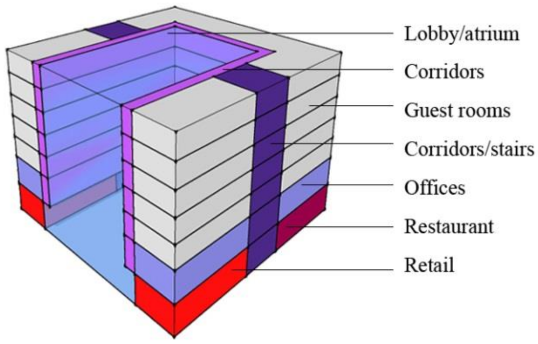


Figure 6. Position of different internal spaces/thermal zones in the model

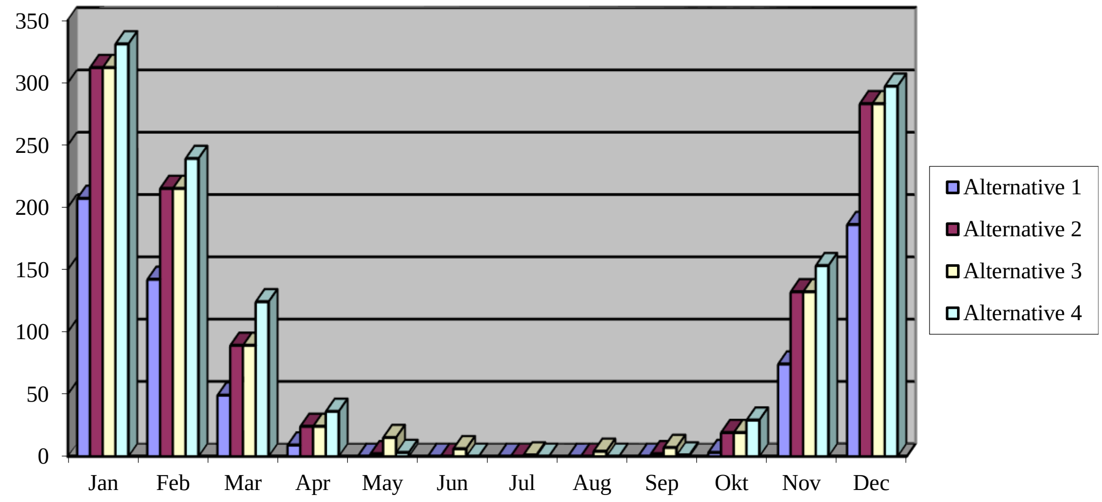


Figure 7. Monthly final energy demands for heating [GJ]

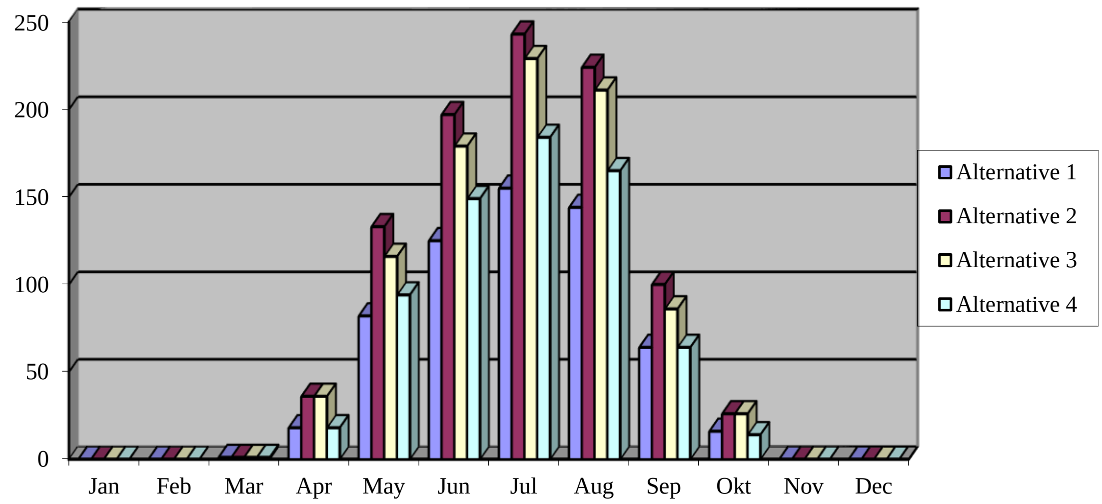


Figure 8. Monthly final energy demands for cooling [GJ]

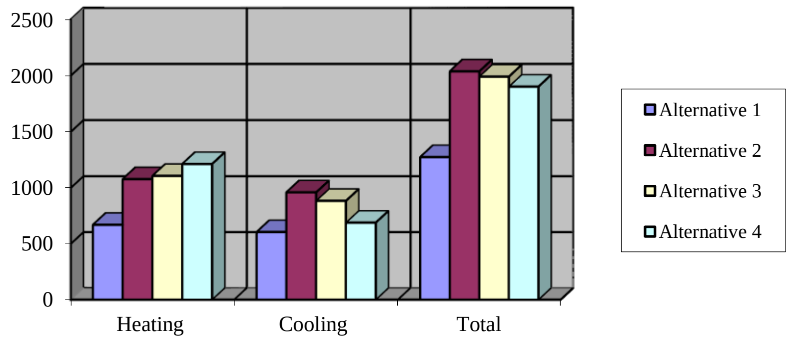


Figure 9. Annual final energy demands (for heating and cooling), [GJ]

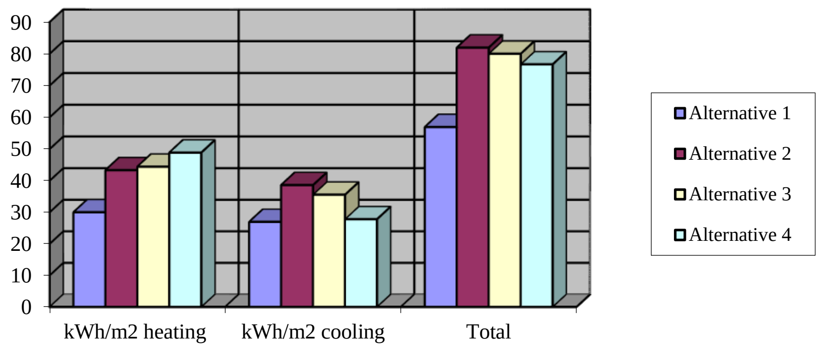


Figure 10. Energy consumption per floor area [kWh/m^2]

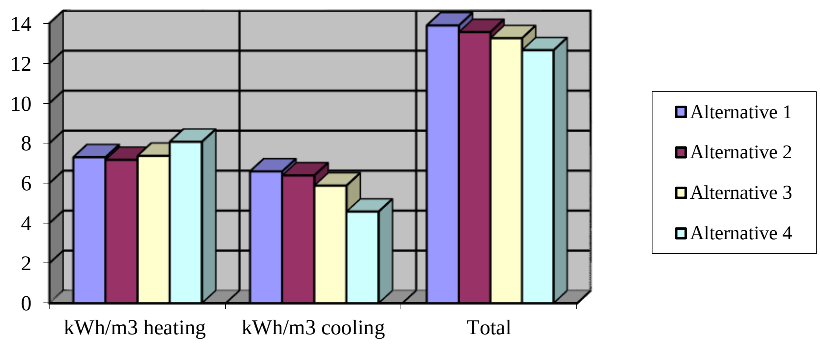


Figure 11. Energy consumption per volume unit [kWh/m^3]

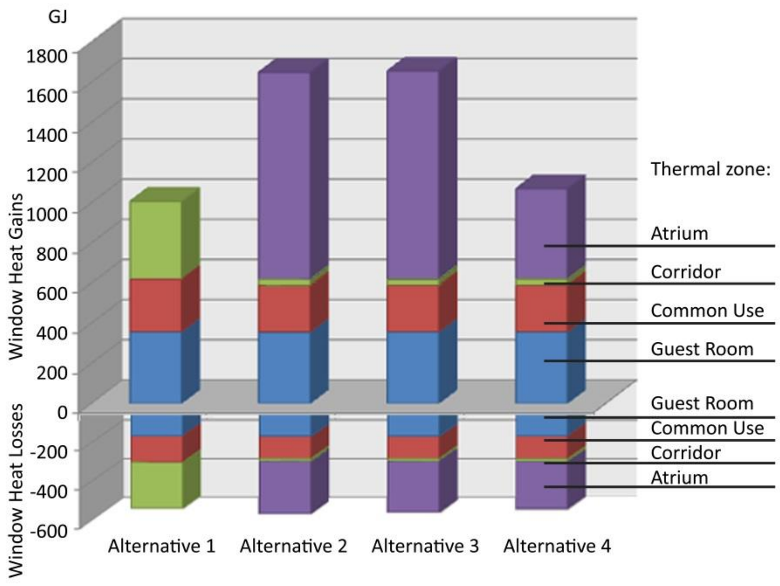


Figure 12. Annual building window heat gains and losses for each thermal zone [GJ]

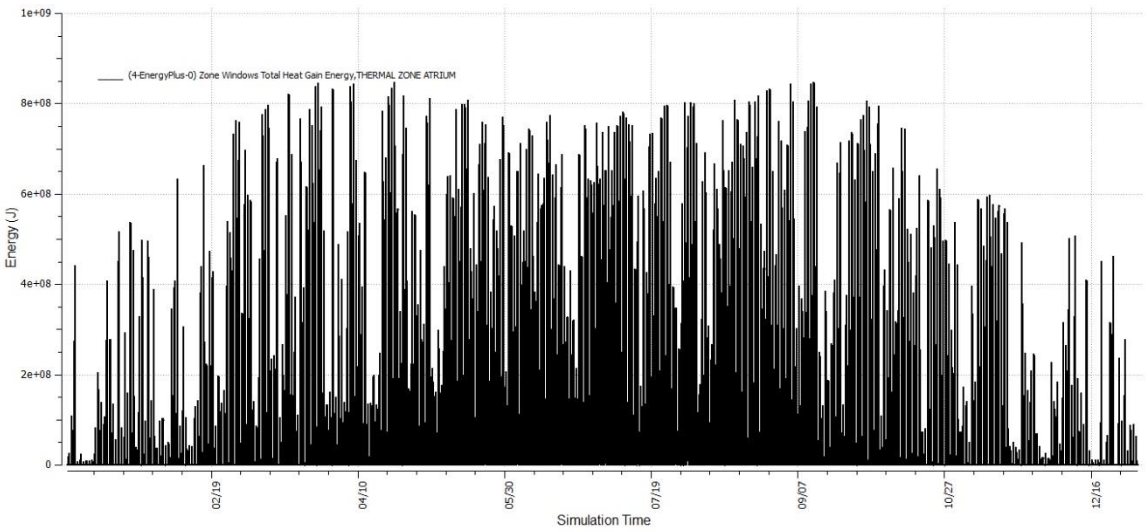


Figure 13. Atrium heat gains of alternative 2 over the year [J]

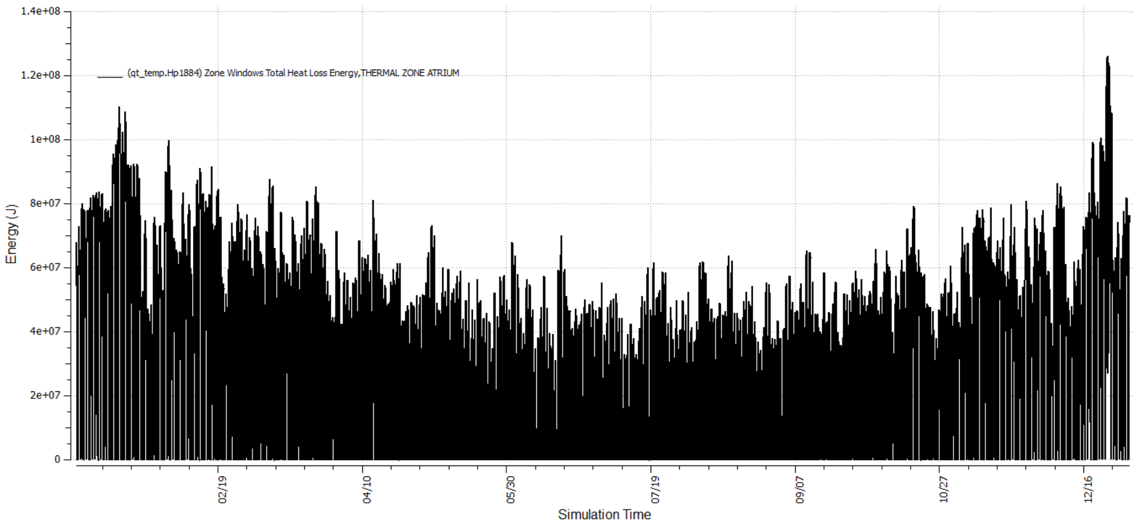


Figure 14. Atrium heat losses of alternative 2 all year round [J]

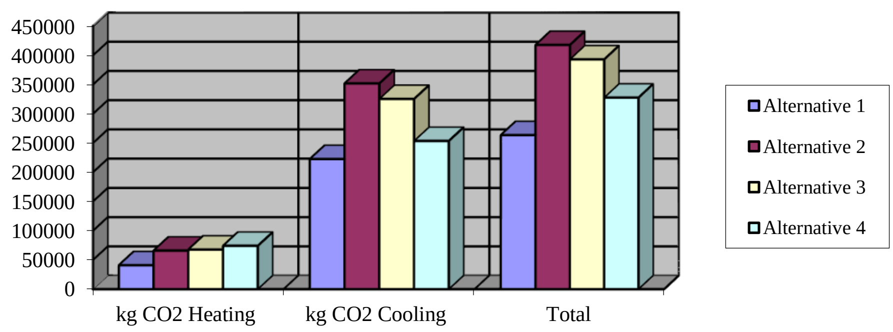


Figure 15. Annual CO_2 emissions from district heating and electrical cooling [kg]

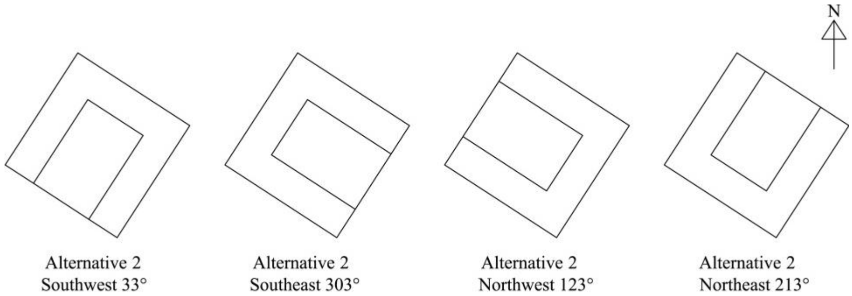


Figure 16. Different orientation of the basic atrium type hotel building - alternative 2

Table 1. Envelope and space characteristics of the designed alternatives

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Gross Wall Area (m^2)	6,054	4,393	4,393	4,393
Window Opening Area (m^2)	2,070	1,545	1,545	1,545
Window-Wall Ratio (%)	34	35	35	35
Gross Roof Area (m^2)	910	1,444	1,444	1,444
Skylight Area (m^2)	0	505	505	505
Skylight-Roof Ratio (%)	0	35	35	35
Total conditioned building area (m^2)	6,211	6,904	6,904	6,904
Atrium area (m^2)	-	693	693	693
Other spaces area (m^2)	6,211	6,211	6,211	6,211
Total conditioned building volume (m^3)	25,489	41,731	41,731	41,731
Atrium volume (m^3)	-	16,242	16,242	16,242
Other spaces volume (m^3)	25,489	25,489	25,489	25,489

Table 2. Envisaged thermal zones in relation to alternatives

	Predicted thermal zones						
	Guestrooms	Corridors	Offices and conf. spaces	Retail space	Lobby with cafe	Cafe	Atrium with lobby
Alternative 1	✓	✓	✓	✓	✓	✓	
Alternatives 2, 3 and 4	✓	✓	✓	✓	-	✓	✓

Table 3. Final heating and cooling energy demands on monthly and annually basis

			Alternative 1		Alternative 2		Alternative 3		Alternative 4	
			Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Monthly (GJ)	January		207	0	312	0	312	0	331	0
	February		142	0	215	0	215	0	239	0
	March		49	1	89	1	89	1	124	1
	April		9	18	24	36	24	36	36	18
	May		0	82	2	133	15	116	3	94
	June		0	125	0	197	6	179	0	149
	July		0	155	0	243	1	229	0	184
	August		0	144	0	224	4	211	0	165
	September		0	64	2	100	7	86	1	64
	October		3	16	19	26	19	26	29	14
	November		74	0	132	0	132	0	153	0
	December		186	0	283	0	283	0	297	0
Annually	Total annual (GJ/a)	Atrium	-	-	602	351	630	297	702	150
		Other spaces	670	605	476	610	477	587	511	539
		Total	670	605	1,078	961	1,107	884	1,213	689
	Per floor area (kWh/m^2)	Atrium	-	-	241	141	252	118	281	59
		Other spaces	30	27	21	27	21	26	23	24
		Total	30	27	43	39	45	36	49	28
	Per volume unit (kWh/m^3)	Atrium	-	-	10.30	6.00	10.78	5.08	12.01	2.56
		Other spaces	7.31	6.60	5.19	6.64	5.19	6.40	5.57	5.88
		Total	7.31	6.60	7.18	6.39	7.37	5.89	8.07	4.58

Table 4. Annual window heat gains and losses for each thermal zone

Thermal zone	Alternative 1		Alternative 2		Alternative 3		Alternative 4	
	Window heat gains (GJ)	Window heat losses (GJ)	Window heat gains (GJ)	Window heat losses (GJ)	Window heat gains (GJ)	Window heat losses (GJ)	Window heat gains (GJ)	Window heat losses (GJ)
Atrium zone	-	-	1,030	-270	1,036	-263	450	-244
Corridor zone	388	-238	31	-13	31	-13	31	-13
Common area	262	-135	232	-116	232	-116	232	-118
Guest room	356	-170	355	-171	356	-171	356	-170
Total facility	1,006	-543	1,648	-570	1,655	-563	1,069	-545

Table 5. Annual final and primary energy consumption and CO_2 emissions

Annual values:	Alternative 1		Alternative 2		Alternative 3		Alternative 4	
	Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Final energy (GJ)	670	605	1,078	956	1,107	884	1,213	689
Primary energy (GJ)	737	1,512	1,186	2,390	1,218	2,210	1,334	1,722
Primary energy (kWh)	204,722	420,000	329,444	663,888	338,333	613,888	370,555	478,333
CO_2 Emission (kg)	40,944	222,600	65,888	351,860	67,666	325,360	74,111	253,516

Table 6. Final heating and cooling energy demands for different orientation of an atrium on monthly and annually basis

			Alternative 2 Southwest 33°		Alternative 2 Southeast 303°		Alternative 2 Northwest 123°		Alternative 2 Northeast 213°	
			Heating	Cooling	Heating	Cooling	Heating	Cooling	Heating	Cooling
Monthly (GJ)	January		312	0	314	0	320	0	320	0
	February		215	0	216	0	223	0	224	0
	March		89	1	91	1	97	1	102	1
	April		24	36	27	35	27	32	27	31
	May		2	133	1	136	1	132	1	129
	June		0	197	0	201	0	197	0	193
	July		0	243	0	247	0	241	0	237
	August		0	224	0	227	0	215	0	212
	September		2	100	0	98	0	93	0	91
	October		19	26	19	24	24	24	24	24
	November		132	0	132	0	142	0	142	0
	December		283	0	287	0	290	0	289	0
Annually	Total annual (GJ/a)	Atrium	602	351	616	366	670	299	675	276
		Other spaces	476	610	472	603	455	636	454	641
		Total	1,078	961	1,087	969	1,124	935	1,130	917
	Per floor area (kWh/m²)	Atrium	241	141	247	147	269	120	271	111
		Other spaces	21	27	21	27	20	28	20	29
		Total	43	39	44	39	45	38	45	37
	Per volume unit (kWh/m³)	Atrium	10.30	6.00	10.53	6.26	11.46	5.11	11.55	4.72
		Other spaces	5.19	6.64	5.14	6.57	4.95	6.93	4.95	6.99
		Total	7.18	6.39	7.24	6.45	7.48	6.22	7.52	6.11

Table 7. Annual building window heat gains and losses for each thermal zone

Thermal zone	**Alternative 2 Southwest 33°**		**Alternative 2 Southeast 303°**		**Alternative 2 Northwest 123°**		**Alternative 2 Northeast 213°**	
	Window heat gains (GJ)	**Window heat losses (GJ)**	**Window heat gains (GJ)**	**Window heat losses (GJ)**	**Window heat gains (GJ)**	**Window heat losses (GJ)**	**Window heat gains (GJ)**	**Window heat losses (GJ)**
Atrium zone	1,030	-270	1,019	-264	830	-264	779	-262
Corridor zone	31	-13	33	-13	33	-13	33	-13
Common area	232	-116	241	-117	295	-117	291	-118
Guest room	355	-171	351	-174	415	-172	440	-172
Total facility	1,648	-570	1,644	-568	1,573	-566	1,543	-565