THE COMPARISON OF THE ENERGY PERFORMANCE OF HOTEL BUILDINGS USING PROMETHEE DECISION-MAKING METHOD

by

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Annual energy performance of the atrium type hotel buildings in Belgrade, Serbia, climate conditions are analysed in this paper. The objective is to examine the impact of the atrium on the hotel building's energy needs for space heating and cooling, thus establishing the best design among four proposed alternatives of the hotels with atrium. The energy performance results are obtained using EnergyPlus simulation engine software, taking into account Belgrade climate data and thermal comfort parameters. The selected results are compared and the hotels are ranked according to certain criteria. Decision-making process that resulted in the ranking of the proposed alternatives is conducted using Promethee method and Borda model. The methodological approach in this research includes the creation of a hypothetical model of an atrium type hotel building, numerical simulation of energy performances of four design alternatives of the hotel building with an atrium, comparative analysis of the obtained results and ranking of the proposed alternatives from the building's energy performance perspective. The main task of the analysis is to examine the influence of the atrium, with both its shape and position, on the energy performance of the hotel building. Based on the results of the research, the most energy efficient model of the hotel building with atrium can be determined for Belgrade climate area.

Key words: *hotel, atrium, energy performance, simulation, EnergyPlus, multi-criteria decision-making, Promethee, Borda model*

Introduction

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% [1]. It is based on CO_2 emissions from transport (75%), accommodation facilities (21%), and tourism activities (4%) [2]. 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. Numerous researches have investigated the energy performance of hotels. The investigations show that hotels consume around 200-400 kWh/m^2 of energy per year [3] and almost half of it (48%) is reserved for heating, ventilation and air conditioning (HVAC) [4].

The reason for this research lies in large energy consumption for HVAC in buildings, which combined with environment pollution cause climate change on the planet. The

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subject of this paper is the creation of an optimal model of a hotel building with an atrium in Belgrade in terms of maximizing the energy efficiency of the building. Atrium hotels present a very attractive building type widespread among newly built hotel buildings all over the world, so it is interesting to consider the behaviour of this type of buildings in Belgrade climate conditions. The research presents an energy performance analysis of hypothetical models of the hotel building that uses an atrium as a greenhouse for natural passive heating, cooling and ventilation. Four different design alternatives are taken into consideration. The most efficient alternative is chosen among four proposed alternatives regarding heating and cooling energy demands.

The research method includes the creation of a hypothetical model for the analysis, design of alternatives and application of numerical energy simulations using *EnergyPlus* computer software, as well as comparative analysis of the selected results using Promethee (preference ranking organization method for enrichment evaluations), multi-criteria decision-making method. Finally, Borda method is used for selection of the optimal alternative according to all criteria. The result of the analysis is the hierarchy of design alternatives according to selected criteria. The analyses include the evaluation of alternatives in terms of satisfying thermal comfort with minimum energy consumption for the Belgrade climate conditions. Evaluation process of the alternatives could consider various social, economic and psychological criteria, especially those that influence customer satisfaction such as aesthetics and thermal comfort. Therefore, this paper analyses the results related to the energy efficiency of buildings, restricted to the criteria of building energy consumption for space heating and cooling, depending on the thermal heat gains and losses and building floor area and volume.

There are not many published works on the matter of using operational research techniques, such as multi-criteria decision-making methods, in the architectural design analyses, although it is widely used in sustainability assessments and it is quite convenient to compare design alternatives according to multiple criteria. Multi-criteria technique has been selected with regards to its wide use in decision support. It should serve as a useful tool for decision process support [5].

Sustainable development concept includes finding the optimal technical solutions that will enable exploitation of the resources of energy with minimal environmental damage. This type of problem can also be solved by multi-criteria decision making, which is appropriate for making a choice among several known solutions with numerically defined attributes [6]. The research was aimed to develop appropriate multi-criteria decision-making model for selection of the optimal solution of the architectural design proposal.

The most suitable techniques for the design alternative comparison are Promethee and analytical hierarchy process (AHP). The Promethee II has been selected as the preferred method for the appropriate hotel building alternative selection process since its results are consistent, easy to understand, and require less information from decision-makers compared to AHP [7]. Decision-making could be performed using AHP method, which could also find the use in architectural analysis, as it is one of the most widely used multiple criteria decision-making tools [8]. The results may be useful for architects in designing hotels with atrium in the climatic regions similar to the Belgrade's and in understanding the possibilities of multi-criteria decision-making in architectural design process.

Creation of hypothetical model for the analysis

Considering that the current situation in Belgrade hotel industry does not provide a good basis for the analysis of different types of hotels with an atrium, the solution included the analysis on a hypothetical model. The virtual model of the free-standing hotel building with atrium is created for the purpose of this research. The location is the southeast corner of the Belgrade urban Block 26.

The created hypothetical model is an atrium type building with rooms surrounding a glazed central courtyard. The main entrance of the building is oriented 33° southwest. The ground floor consists of a public area, reception, café, 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 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. The glazing is made of double layered low emission glass, framed by aluminum profiles with thermal break. All construction elements comply with the current local regulations in terms of thermal conductivity [9]. The achieved thermal conductivity coefficient U [$Wm^{-2}K^{-1}$] for the outer wall is 0.20 (allowed 0.30), 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). Windows and glazing have achieved U value of 1.10 W/m^2K for glass (allowed 1.50), and 1.4 W/m^2K for aluminum frame (allowed 2.8-3.5).

Four different alternatives (A1, A2, A3, A4) of the model with mentioned characteristics are created regarding the atrium orientation and position within the building (fig. 1): A1 – the building with centrally positioned atrium, surrounded by building from four sides, A2 – the building with centrally positioned atrium, surrounded by building from three sides, A3 – the building with centrally positioned atrium, surrounded by building from two sides, and A4 – the building with atrium positioned on the corner, surrounded by building from two sides.

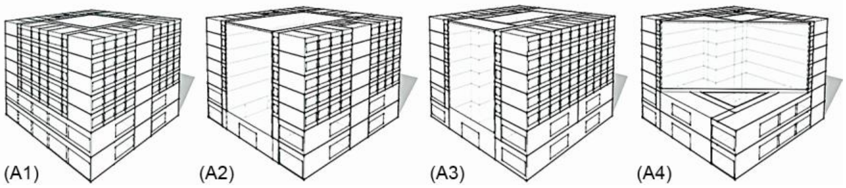

Figure 1. Model of the hotel building

Alternative 1 is the hotel with atrium located in the central part of the building, glazed only on the top and it is surrounded by the rooms from all sides (fig. 1, A1). The atrium receives light only from the top, so its window heat gains depend primarily on the ratio of the atrium area to its height, *i. e.* number of floors of the building. Therefore, the solar heat gains are limited only to the light passed through the roof construction of the atrium.

Alternative 2 has the atrium surrounded by the building from three sides, and it is glazed on one side and on the top (fig. 1, A2). Due to the exposure of an entire side of the atrium to the solar radiation, energy characteristics, primarily solar heat gains, depend on the orientation of the atrium. South oriented atrium achieves greater heat gains comparing to those facing north.

Alternative 3 has the atrium through the entire length of the building in its central part (fig. 1, A3). The atrium is open toward two opposite facades, while the other two opposite sides consist of the guest rooms. The atrium is inserted in the central area of the hotel instead of narrow dark long corridors on the floors. The atrium can additionally be filled with diverse vertical and horizontal communications that make the interior more dynamic.

Alternative 4 has the atrium positioned on the corner of the building, connecting the two neighboring wings of the building together (fig. 1, A4). This kind of space organization provides less guest rooms in relation to the other types, but it is also applicable to the buildings located on the corner of a city block, with an attractive roof terrace and a grand glazed atrium.

Table 1. Envelope and space characteristics of the designed alternatives

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Number of rooms in the hotel	120	100	100	85
Gross wall area, [m^2]	4393	4393	4393	4092
Window opening area, [m^2]	1373	1545	1806	1796
Window-wall ratio, [%]	31	35	41	44
Gross roof area, [m^2]	1444	1444	1444	1444
Skylight area, [m^2]	331	505	499	362
Skylight-roof ratio, [%]	23	35	35	25
Total conditioned building area, [m^2]	7987	6904	6807	6144
Atrium area, [m^2]	520	693	550	416
Other spaces area, [m^2]	7467	6211	6257	5728
Total conditioned building volume, [m^3]	41731	41731	41731	34293
Atrium volume, [m^3]	11063	16242	15902	9818
Other spaces volume, [m^3]	30668	25489	25829	24475

The aim of this research, is to compare energy performance of the different hotel buildings with similar space characteristics (tab. 1). All four hotels have about 100 rooms (85-120). The total building area decreases from A1 to A4 in range of 24%. The alternative 4 has 18% less building volume than other three alternatives. The atrium takes 6-10% of the total building area or 26-39% of the total building volume in all alternatives. Therefore, it participates largely in energy consumption of the building, in spite of its heat collecting properties.

Methodology

The following methodological framework is designed in order to rank four hypothetical models of an atrium type hotel building. The main phases of proposed framework are shown in fig. 2. As a starting point, the research objectives should be defined. Defined models (alternatives) are based on comprehensive research of the hotel buildings with atrium. The creation of hypothetical models as well as simulations of their energy performances should be conducted as the first phase. The definite selection of the criteria for the energy performance comparison is performed after the energy simulations. Seventeen main criteria and 113 sub-criteria are selected for the analysis. In the second phase, Promethee II method was used to rank the alternatives for each criterion, based on the sub-criteria selection. The final ranking of alternatives is obtained using Borda model.

The building energy simulation is carried out using the OpenStudio interface that integrates with EnergyPlus simulation engine. EnergyPlus needs various input parameters that describe the modeled building and the environment surroundings. Local weather data (temperatures, solar radiation, wind speed, evaporation, dehumidification, design conditions, calculated ground temperatures, typical and extreme weather periods) in form of EnergyPlus weather file (.epw), are arranged by World Meteorological Organization. Physical properties and configuration of the building envelope and interior elements (walls, roofs, floors, windows, and doors) are defined by the materialization of the physical structure of the building and the surface distribution (stated in *Creation of hypothetical model for the analysis*). Complete description of building for the analysis using EnergyPlus includes people occupancy, plug and process loads and working schedules based on the activities in each zone, in order to obtain internal heat gains from people activity, lightning and equipment operation that influence energy consumption of the building. 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 [10], prototypical commercial buildings [11], technical support document [12], and ASHRAE standards 90.1-2004, 62.1-2004, and 62-1999. People occupancy is defined by number of person per m^2: lobby 0.32, cafe 0.30, retail 0.16, office 0.05, guestroom 0.03, and corridor 0.10 person per m^2. People activity is 100 Wh per person. Lightning is defined in W/m^2: lobby 10.65, cafe 12.59, retail 14.53, office 9.68, guestroom 10.65, and corridor 4.84 W/m^2. Electrical equipment is defined in W/m^2: lobby 4.09, cafe 2.79, retail 5.49, office 5.81, guestroom 7.31, and corridor 0.00 W/m^2. All other technical specifications, such as design air temperature of 20 °C in winter and 26 °C in summer and the infiltration of 0.5 air changes per hour (ach), are taken from the Serbian Regulations on Energy Efficiency in Buildings [9].

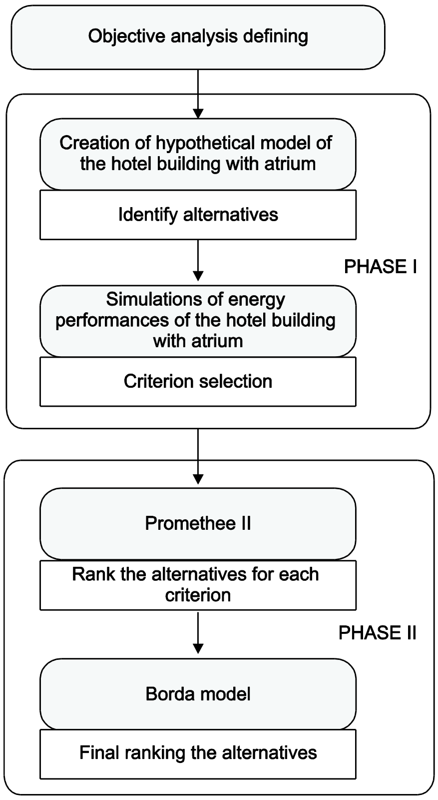

Figure 2. Methodological framework of a hotel building energy performance comparison

The considered buildings consist of the following space types, *i. e.* thermal zones: guest rooms, corridors, offices with conference spaces, cafe and restaurant, retail, and lobby with atrium. 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 of energy analysis. The technical installation systems are not the subject of the analysis. EnergyPlus calculates the heating and cooling loads necessary to maintain thermal control setpoints, 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 ranking of the hotels is performed by Promethee decision-making method. Promethee method is selected as one of the often used multi-criteria methods and its advantage is simplicity of use by the decision-maker, who can easily understand and accept this method, which means that there is no need for external experts in decision-making theory for the implementation of this method. The Promethee method, developed by Brans in 1982, includes Promethee I for partial ranking and Promethee II for complete ranking of alternatives [13]. The Promethee II method was adopted for this paper. The basic principle of Promethee II is based on a pair-wise comparison of alternatives along each recognized criterion. Alternatives are evaluated according to different criteria, which have to be maximized or minimized. The implementation of the Promethee II requires two additional types of information [14].

– Information on the relative importance (*i. e.* the weights) of the criteria considered. Promethee II assumes that the decision-maker is able to weight criteria appropriately, at least when the number of criteria is not too large [15].
– Information on the decision-makers' preference function, which decision maker uses when comparing the contribution of the alternatives in terms of each separate criterion. In order to facilitate the selection of a specific preference function, Vincke and Brans [16] proposed six basic types of criteria: 1 – usual, 2 – U-shape, 3 – V-shape, 4 – level, 5 – V-shape with indifference, and 6 – Gaussian. These six types are particularly easy to define. For each criterion, the value of an indifference threshold, q, the value of a strict preference threshold, p, and the value of an intermediate value between p and q, d, has to be defined [17].

Experts' opinions are set on various parameters such as selection and weight of the criteria. The team of experts who has cooperated in this research includes architects and information managers who are involved in hotel building design and operational research projects. The Promethee method is implemented in five steps [14]:

Step 1. Determination of deviation based on pair-wise comparison:

$$d_j(a, b) = f_j(a) - f_j(b), \qquad j = 1, \ldots, n \tag{1}$$

where $d_j(a,b)$ denotes the difference between the evaluation of a and b on each criterion.

Step 2. Application of the preference function:

$$P_j(a,b) = F_j[d_j(a,b)], \quad j = 1,\ldots,n \tag{2}$$

where $P_j(a, b)$ denotes the preference of alternative a with regard to alternative b on each criterion, as a function of $d_j(a, b)$.

Step 3. Calculation of an overall or global preferences index:

$$\forall a,b \in A, \quad \pi(a,b) = \sum_{j=1}^{n} P_j(a,b) w_j \tag{3}$$

where $\pi(a, b)$ of a over b (from 0 to 1) is defined as the weighted sum $P_j(a, b)$ for each criterion, and w_j is the weight associated with j^{th} criterion.

Step 4. Calculation of outranking flows/Promethee I partial ranking:

$$\phi^+(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a,x) \quad \text{and} \quad \phi^-(a) = \frac{1}{n-1}\sum_{x \in A} \pi(a,x) \tag{4}$$

where $\phi^{+}(a)$ and $\phi^{-}(a)$ denote the positive outranking flow and negative outranking flow for each alternative, respectively.

Step 5. Calculation of net outranking flow/Promethee II complete ranking:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{5}$$

where $\phi(a)$ denotes the net outranking flow for each alternative.

The Borda model, proposed by the French scientist Jean-Charles de Borda in Paris in 1781, represents an important step in the development of modern electoral systems, and indeed in the theory of voting more generally [18]. The Borda rule is an appropriate procedure in multi-person decision making when several alternatives are considered. The discrete Borda count allows showing which alternatives are preferred in pair wise comparisons [19]. Borda matrix is designed according to the ranking matrix: the alternative with first rank (r1) within one criterion would have *m* relative value on the basis of *m* alternatives. The same goes for, alternative with second rank (*m*-1 relative value). Alternatives with *m* rank would receive one relative values. After that, the Borda count matrix multiply with the corresponding weight vector of criteria. The alternative sum with the highest value would be considered as the first rank and the lowest represents the last rank.

Comparative analysis of the results

The numerical 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, tab. 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 2 indicates how certain variations in alternatives influence the monthly energy needs.

The A1 requires the least amount of energy for heating and cooling of the space, followed by A4, A2, and A3 (tab. 2). But, energy demands are not the only thing that needs to be considered in the design process. The annual heat gains and losses achieved through windows of the each thermal zone are also an important aspect of the design, and are shown in tab. 3. The A1 has the least window heat gains and losses compared to other alternatives, which can be positive or negative depending on the summer or winter time of year.

The criteria for the selection of the optimal hotel building alternative are divided into seventeen groups (tab. 4). Every group of criteria consists of several sub-criteria. The selection of the criteria is based on the architectural practice of the energy efficiency evaluation which encompasses annual energy demands for heating and cooling, influenced by thermal heat gains and losses (which depend on the architecture of the building), as well as the shape factor of the building (total floor area and building volume).

The alternatives are compared to each other according to the criteria shown in tab. 4. The Promethee II method was used to rank the alternatives for each criterion, based on the sub-criteria selection. The Borda method is used for final ranking of the alternatives according to the groups of criteria. Before the ranking, a specific preference of criteria weights and preference functions were determined. These values have been defined by the decision makers, taking into consideration the features of alternative structural systems and the design conditions. Decision-making team decided to use V-shape preference function for all criteria.

Table 2. 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		289	0	313	0	325	0	237	0
	February		199	0	216	0	224	0	159	3
	March		81	1	90	1	94	1	61	10
	April		19	29	25	35	27	35	17	47
	May		0	122	1	133	1	134	1	137
	June		0	184	0	196	0	198	0	194
	July		0	227	0	242	0	244	0	234
	August		0	210	0	222	0	221	0	223
	September		0	94	0	100	0	98	0	117
	October		14	26	19	27	22	26	10	45
	November		115	0	132	0	140	0	92	4
	December		259	0	283	0	295	0	215	0
Annually	Total annual [GJa^{-1}]	Atrium	409	164	602	351	672	392	363	379
		Other spaces	562	726	476	610	460	573	430	632
		Total	972	890	1078	961	1132	965	793	1012
	Per floor area [$kWhm^{-2}$]	Atrium	219	87	241	141	339	198	242	253
		Other spaces	21	27	21	27	20	25	21	31
		Total	34	31	43	39	46	39	36	46
	Per vol. unit [$kWhm^{-3}$]	Atrium	10.28	4.11	10.30	6.00	11.73	6.84	10.27	10.74
		Other spaces	5.09	6.58	5.19	6.64	4.95	6.16	4.88	7.17
		Total	6.47	5.93	7.18	6.39	7.54	6.42	6.42	8.17

Table 3. Annual window heat gains and window heat losses for each thermal zone [GJ]

Thermal zone	Alternative 1		Alternative 2		Alternative 3		Alternative 4	
	Gains	Losses	Gains	Losses	Gains	Losses	Gains	Losses
Total	1291	–486	1648	–571	1739	–629	1627	–596
Atrium	421	–107	1030	–270	1134	–371	1074	–288
Corridors	32	–13	31	–14	31	–13	26	–10
Rooms	489	–213	356	–171	383	–163	202	–143
Public	181	–80	116	–59	92	–40	164	–81
Offices	168	–73	116	–57	99	–42	160	–74

Table 4. Groups of criteria and sub-criteria

Group	Prefe-rence	Criterion	Sub-criterion	Criteria weight
1	Max	Building floor area, [m^2]	Total building, atrium, corridors, rooms, public zones, offices	0.02
2	Max	Building volume, [m^3]	Total building, atrium, corridors, rooms, public zones, offices	0.02
3	Max	Building envelope, [m^2]	Gross wall area, window area, window--wall ratio, skylight area, skylight-roof ratio	0.02
4	Min	Monthly building energy demands for heating, [GJ]	Jan., Feb., Mar., Apr., May, June, July, Aug., Sep., Oct., Nov., Dec.	0.05
5	Min	Monthly building energy demands for cooling, [GJ]	Jan., Feb., Mar., Apr., May, June, July, Aug., Sep., Oct., Nov., Dec.	0.05
6	Min	Annual building energy demands for heating, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.09
7	Min	Annual building energy demands for heating per floor area, [MJm^{-2}]	Total building, atrium, corridors, rooms, public zones, offices	0.09
8	Min	Annual building energy demands for heating per volume unit, [MJm^{-3}]	Total building, atrium, corridors, rooms, public zones, offices	0.09
9	Min	Annual building energy demands for cooling, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.09
10	Min	Annual building energy demands for cooling per floor area, [MJm^{-2}]	Total building, atrium, corridors, rooms, public zones, offices	0.09
11	Min	Annual building energy demands for cooling per volume unit, [MJm^{-3}]	Total building, atrium, corridors, rooms, public zones, offices	0.09
12	Max	Window heat gains, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05
13	Max	Infiltration heat gains, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05
14	Max	Opaque surface conduction and other heat gains, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05
15	Min	Window heat losses, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05
16	Min	Infiltration heat losses, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05
17	Min	Opaque surface conduction and other heat losses, [GJ]	Total building, atrium, corridors, rooms, public zones, offices	0.05

After evaluation matrix and preference functions determination, alternatives are evaluated using Decision Lab software. Results of ranking alternatives (A_1, A_2, A_3, A_4) for each criterion (C_1, C_2... C_{17}) are given in tab. 5.

The final ranking of the alternatives is obtained using Borda model. The number of points given to alternative for each ranking is determined by the number of alternatives. There are four different alternatives, therefore, the alternatives receive four points each time they are ranked first, three for being ranked second, two for being ranked third, and one point for being ranked last (tab. 6).

Table 5. The ranking of the alternatives for each criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
A_1	r1	r1	r4	r2	r1	r4	r1	r1	r1	r1	r2	r1	r1	r4	r4	r4	r3
A_2	r2	r3	r2	r3	r3	r2	r3	r3	r3	r3	r3	r3	r2	r2	r3	r3	r1
A_3	r3	r2	r1	r4	r2	r3	r4	r4	r2	r2	r1	r2	r3	r3	r1	r2	r2
A_4	r4	r4	r3	r1	r4	r1	r2	r2	r4	r4	r4	r4	r4	r1	r2	r1	r4

Table 6. The Borda matrix count

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	**Score**	**Rank**
A_1	4	4	1	3	4	1	4	4	4	4	3	4	4	1	1	1	2	2.89	**R1**
A_2	3	2	3	2	2	3	2	2	2	2	2	2	3	3	2	2	4	2.25	**R3**
A_3	2	3	4	1	3	2	1	1	3	3	4	3	2	2	4	3	3	2.4	**R2**
A_4	1	1	2	4	1	4	3	3	1	1	1	1	1	4	3	4	1	2.16	**R4**

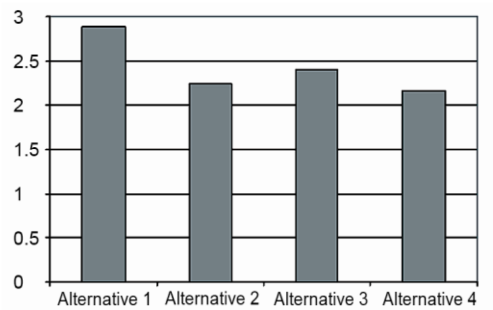

Figure 3. The final ranking of the atrium type hotel building alternatives

Multiplying the Borda matrix count (tab. 6) with the corresponding weight vector of the appropriate criterion (tab. 4), gave the order of four alternatives: $A_1 > A_3 > A_2 > A_4$ (fig. 3). Therefore, A1 is ranked as the optimal model of the proposed atrium type hotel buildings for Belgrade climate conditions.

Discussion and conclusion

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 in buildings. 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 results of the energy performance simulations are compared using multi-criteria decision making methods Promethee and Borda model in the final step. 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, and to select optimal alternative of the hotel building with atrium among proposed four alternatives.

The results of the energy simulation showed the variation between the energy needs of different alternatives. The most energy efficient alternative is A1, the building with centrally positioned atrium, surrounded by building from four sides. This is also the concept of the building that accommodates the most guest rooms and has the best use of space on the location. The other alternatives have their benefits in design concepts, and it is up to investor and an architect to choose the most favourable design, after taking into consideration all necessary factors.

This research could contribute to the architectural design practice because it shows concrete results of energy simulations of the hotel buildings with atrium. Besides that, it shows that operational research techniques can easily be applied in construction management theory. Although multi-criteria decision-making methods are not usually implemented in architecture, it should become practice, since modern problems must be observed by taking into account multiple criteria and aspects. Hopefully, this research will provide the specific information in designing the energy efficient hotel buildings with an atrium in the Belgrade climate conditions, but most preferably it presents a methodological approach of combining different scientific fields in order to achieve the best design solution that can enhance the quality of space around us.

The recommendations for further research include the analyses of different shapes of hotel buildings with an atrium and their energy performances in different climatic conditions. Besides that, input parameters in the simulation could be altered in order to observe the energy performance of the building and to find the best acceptable solution. The Promethee II method is well established multi-criteria decision-making technique but using it in the selection of architectural design proposals is a novel application in building construction industry. The decision-making process can also be conducted using AHP method and the results could be compared to the ones in this research. The selection of the criteria can also be an important issue in such a selection process and this research can provide a recommendation for other researchers.

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