Energy efficiency improvement of the City Hall in Sarajevo

Haris Lulić*
Faculty of Mechanical Engineering
University of Sarajevo
e–mail: lulic@mef.unsa.ba

Jasmina Memić, Emir Sirbubalo
HVAC design d.o.o. Sarajevo
e–mail: jasmina@hvac.ba

ABSTRACT

The present paper describes energy efficiency measures envisioned in the framework of the reconstruction project of the City Hall in Sarajevo. The paper starts with a brief description of the building and the current status of the project of its reconstruction. Following sections give details about thermal characteristics of the building envelope, energy efficiency measures planned for the lighting systems of the building in the light of preservation of its original appearance and under consideration of economic effects of these measures.

Keywords: energy efficiency, historic building, lighting, LED solid state, lighting visualization, cost effectiveness

INTRODUCTION

City Hall is one of the most remarkable architectural examples built at the end of 19th century. It was made in Neo-Moorish style, inspired by Islamic architecture of North Africa and Spain. The building is located at the forefront of the historical part of the city and represents a significant element of its landscape. It has a triangular form with corner towers, its sides having south, north-east and north-west orientation. Hexahedral central hall with a glass dome dominates in the interior space of the building.

Until 1948 the building was utilized for various municipal and administrative purposes, e.g. as a City Court and Parliament House. Since then it housed National and University Library of Bosnia and Herzegovina. On August 1992 it was heavily damaged in a fire caused by direct hits of shells. After the destruction, several interventions were made in order to protect and preserve its construction and other elements from further damage.

In the ongoing reconstruction project a new disposition of useful space is foreseen. The useful space is divided among the following main users

- Headquarters of the City administration
- National library
- Museum of Devastation of the City Hall
- Central public hall of the City

* Corresponding author

- Space for energy facilities

Total useful area of the building of 7716.10m^2 is distributed on five levels. Recapitulation of the useful area is shown in Table 1.

Table 1 Recapitulation of the useful area of the City Hall

Floor	**Area (m^2)**
Basement	1,629.80
Ground floor	1,766.70
Mezzanine	1,315.00
First floor	1,730.90
Second floor	815.50
Attic	
Total net area	7,716.10
Total gross area	10,186.00

The design phase of the reconstruction project was completed in October 2007. In this paper energy efficiency improvement relative to the original design is proposed. The paper firstly analyzes estimated energy use of the building, including the influence of construction details and materials, electrical installations and lighting, and HVAC systems. Based on this analysis of the original design and new or improved technologies available, suggestions are made for improvement of energy efficiency of the building under constraints of preservation of the original elements of interior and exterior architecture. Additionally, an economic analysis of the suggested measures is presented.

BUILDING ENVELOPE

The City Hall was originally built using traditional construction materials (stone, brick, and wood). Emerging tendencies in construction technology of that period can be seen in use of steel, especially for construction of the glass dome above the central hall of the building.

Constraints imposed by requirements of preservation of the original building appearance have eliminated most of the technologically and economically feasible measures for increasing thermal performance of the building envelope from consideration (e.g. exterior or interior insulation). This section is, therefore, only a summary of some of the significant thermal characteristics of the building envelope.

Basement floor is built on stone foundations with overall heat conduction coefficients U of the ground-facing surfaces between 0.713 and 1.050 W/m^{2}K, as calculated in the main design documentation. Underground part of basement walls is made of stone (U = 1.979W/m^{2}K), while the upper part is a combination of brick walls covered by stone on the outside (U = 0.938W/m^{2}K). Basement ceiling is comprised of brick domes. Exterior walls of the ground floor, mezzanine, first and second floor are made of brick, with thicknesses of 75, 60, and 45cm respectively. Heat transfer coefficient for of the attic floor and roof determined to be about 0.563 and 0.476 W/m^{2}K.

Windows are planned to be rebuilt as original, consisting of oak frames with insulated glass of U = 0.8W/m^{2}K. Glazing of exterior doors will be made of laminated glass, with some exceptions where original single-pane glazing will be recreated. A windshield is planned on every entrance, further contributing to thermal insulation.

LIGHTING

In terms of energy efficiency of lighting installations, the City Hall building presents an extraordinary example on several aspects. On one hand, the original appearance of the building should be preserved and its cultural and historical significance should be highlighted, and here illumination of both internal and external side of the building is very significant. On the other hand, new disposition of interior useful space of the building – featuring a range of uses, from classical office and educational spaces to public and museum spaces – requires the lighting system to ensure comfortable working conditions. For a general discussion of the technical and aesthetic issues concerning lighting systems see references [1] and [2].

Description of the energy efficiency measures

The purpose of this section is to detail a number of energy efficiency measures suggested to reduce total installed capacity of the lighting installations relative to the planned installations in the main design documentation of the reconstruction project, while simultaneously taking into account technical parameters of illumination, such as efficacy (lumens per watt), colour temperature, colour rendering index, life and lumen maintenance, availability, switching, dimming capability, aesthetic parameters required in various interior spaces, and economic parameters such as initial investment and maintenance costs.

Interior of the building can be subdivided into five functional groups of spaces with different requirements for luminance level and lighting system. The groups are:

- Offices – functional requirements,
- Representative halls and meeting rooms – decorative and functional requirements (authentic illumination elements, chandeliers reconstructed as original models),
- Central hall and communications – decorative and functional requirements, (authentic illumination elements chandeliers reconstructed as original models),
- Museum space, decorative and functional requirements (with stenographic and accent lighting),
- Services, functional requirements.

An overview of the existing design documentations shows that all the functional and aesthetic requirements for this kind of installations were met. Total installed capacity of the planned lighting installations amounts to 110 kW. A summary of the various types of light sources planned within the installation and their contribution to the total installed capacity is given in Table 2.

Table 2 Summary of light sources currently planned in the main design of the reconstruction of the City Hall, total installed capacity amounts to 110kW.

Type of light source	% of total installed capacity
Fluorescent lamps	65

Type of light source	% of total installed capacity
Halogen or incandescent lamps	25
Metal Halide	5
LED	2
Sodium high pressure	3

Table 2 Continued

Proposal for improvement of the existing design of the lighting system can be summarized in terms of the following two efficiency measures:

- Installation of high-efficiency light sources,
- Installation of lighting control system.

The choice of more efficient light sources was based on products with sufficient lumen output, high efficiency factor, smaller energy consumption, longer lamp lifetime, and smaller adverse environmental impacts.

Fluorescent light sources have been planned for all the spaces within the building where there are no particular functional or aesthetic requirements imposed. Replacing the fluorescent lighting with more efficient light source, such as LED solid-state lamps, can reduce energy consumption up to 40% with same luminous flux required for illumination of the space. Simultaneously, this measure reduces the number of the lighting fixtures proposed by main design. The proposed solution with LED solid-state lamps maintains average luminous flux of $710 lm/m^2$ with potency of $9.2 W/m^2$ ($2.5 W/m^2/100 lx$). Important fact is that these light sources are energy friendly, with no mercury, high lumen maintenance and long lamp life (up to 50000h). This is directly reflected on maintenance costs of the installation.

In main design of the reconstruction project, decorative luminaries – chandeliers, reconstructed as original models – are planned for illumination of parts of the building. They are present in all representative and public spaces with authentic wall decoration and materials used. These lamps are taking part of 25% in interior lighting. If we consider their form, and requirements of the space and its appearance, requirement-conforming light sources should have a warm colour temperature and large colour spectrum. For this purpose halogen high-efficiency lamps should be used. These light sources achieve the quality of light required, with following advantages in terms of overall efficiency: they use up to 40% less energy than standard ones, high lumen maintenance, longer lamp life (up to 3000h), fully dimmable and they provide full intensity instantly.

Lighting control system regulates the light intensity level within spaces according to prescribed parameters, and, at the same time, enables reduction of the total energy consumption. Relative to the current main design, an introduction of the lighting control system would require a complete reworking of the electrical installation design. This would enable proper grouping of light sources, and provide for efficient monitoring of the occupancy of the spaces, and of the intensity of natural lighting, especially in the central hall where significant amount of daylight is present and not distributed uniformly in vertical direction. Control of light intensity on floor levels can contribute to energy savings from 30-50%.

Summary of the light sources proposed for increasing energy efficiency of the lighting installation along with their contribution to the total installed capacity of the lighting system is given in Table 3. Total installed capacity is now estimated to be around 65 kW, including the active lighting control system.

Table 3 Summary of light sources proposed for increasing energy efficiency of the lighting system in the framework of the reconstruction of the City Hall, total installed capacity amounts to 65kW.

Type of light source	% of total installed capacity
LED solid state lighting	65
Fluorescent lamps	5
Halogen ECO	25
Metal halide	5

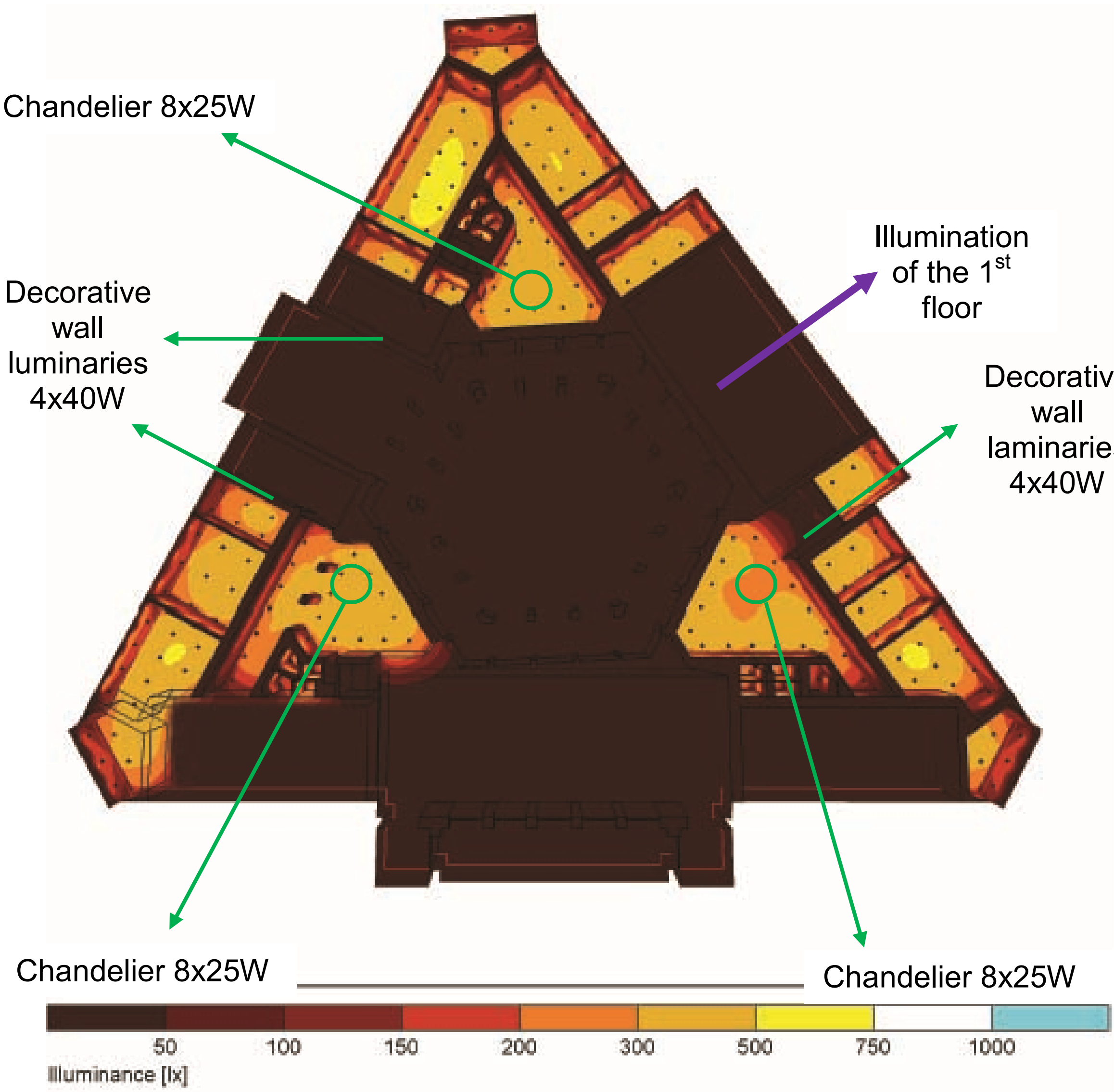

Figure 1 Illuminance of the 2nd floor of the City Hall building using energy efficient light sources

An example of performance of the energy efficient light sources

To illustrate the effect of the energy efficiency measures proposed for the lighting system this section describes in some detail the functional characteristics of the newly proposed system for the second floor of the City Hall.

Figure 1 shows calculation result for the spaces that are planned as offices and 3 lobby halls. For the general lighting, proposed is an installation of high efficiency light sources LED 36W, efficiency 85%, colour temperature 3000K and light output of 2500lm. Considering general needs of the space and requests for light comfort, optical system should avoid glare and should have disperse light distribution. With this solution we maintain average illuminance of 400lx. Every room has manual lighting control system. For an overview of the available commercial products see [3], [4] and [5].

Table 4 Summary of lighting parameters achieved by the energy efficient light sources

FLOOR 2

Room no.	Area (m2)	Average flux required (lm)	Type of light source	Colour temp. (°K)	CRI	Luminous flux (lm)	Power (W)	Luminaire efficency (%)	Luminaire efficacy (lm/W)	Number of lamps	Total luminous flux (lm)	Achieved luminous flux (lm)	Total power (W)
1	32.00	22,720	LED	3,000	90	2,857	36	85.10	67.54	10	28,570	24,313	360
2	35.00	24,850	LED	3,000	90	2,857	36	85.10	67.54	9	25,713	21,882	324
3a	16.26	11,545	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
3b	16.26	11,545	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
4	72.80	51,688	LED	3,000	90	2,857	36	85.10	67.54	19	54,283	46,196	684
5	24.00	17,040	LED	3,000	90	2,857	36	85.10	67.54	4	11,428	9,725	144
6	60.00	42,600	LED	3,000	90	2,857	36	85.10	67.54	14	39,998	34,038	504
7	22.20	15,762	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
8	33.00	23,430	LED	3,000	90	2,857	36	85.10	67.54	8	22,856	19,450	288
9	21.00	14,910	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
10	22.50	15,975	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
11	19.60	13,916	LED	3,000	90	2,857	36	85.10	67.54	6	17,142	14,588	216
12	35.00	24,850	LED	3,000	90	2,857	36	85.10	67.54	9	25,713	21,882	324
13	23.00	16,330	LED	3,000	90	2,857	36	85.10	67.54	4	11,428	9,725	144
14	21.00	14,910	LED	3,000	90	2,857	36	85.10	67.54	4	11,428	9,725	144
15	36.00	25,560	LED	3,000	90	2,857	36	85.10	67.54	7	19,999	17,019	252
16	49.50	35,145	LED	3,000	90	2,857	36	85.10	67.54	12	34,284	29,176	432
17	8.30	5,893	LED	3,000	90	2,857	36	85.10	67.54	4	11,428	9,725	144
18	79.30	56,303	LED	3,000	90	2,857	36	85.10	67.54	15	42,855	36,470	540
19	8.00	5,680	LED	3,000	90	2,857	36	85.10	67.54	17	48,569	41,332	612
20	75.40	53,534	LED	3,000	90	2,857	36	85.10	67.54	14	39,998	34,038	504
21	5.00	3,550	LED	3,000	90	2,857	36	85.10	67.54	2	5,714	4,863	72
22	8.40	5,964	LED	3,000	90	2,857	36	85.10	67.54	4	11,428	9,725	144
23	4.00	2,840	LED	3,000	90	2,857	36	85.10	67.54	1	2,857	2,431	36
	728									**193**	**551,401**	**469,242**	**6,948**
16	chandelier (foyer)		HALOGENA	2800	98	220	25			8	1760		200
18	chandelier (foyer)		HALOGENA	2800	98	220	25			8	1760		200
20	chandelier (foyer)		HALOGENA	2800	98	220	25			8	1760		200
S1	wall luminare (stairs)		HALOGENA	2800	98	630	42			4	2520		168
S2	wall luminare (stairs)		HALOGENA	2800	98	630	42			4	2520		168
S3	wall luminare (stairs)		HALOGENA	2800	98	630	42			4	2520		168
										36	**12,840**		**1,104**
											564,241		**8,052**

Table 4 presents a detailed summary of lighting parameters, such as types of light sources and their physical characteristics and installed capacities, achieved by the newly proposed system for the example second floor of the building for all the useful spaces separately.

Summary of energy and economic parameters of the lighting system

The present section presents results of the suggested energy efficiency measures in comparison to the current main design of the reconstruction project in terms of the installed capacity of the lighting system, estimated total energy consumption and some of the economic indicators of feasibility of the proposed measures. In this section, symbols P1 and P2 denote the available main design proposal and new proposal for improvement of energy efficiency respectively. For information about the software tools and algorithms used for present calculations the reader is referred to [6], [7] and [8].

Table 5 shows some of the common building characteristics relevant for estimation of the performance level of the lighting system and its energy efficiency.

Table 5 Common project parameters

Solution type	Indoor
Lifetime of installation (a)	15
Burning hours per year (h/a)	3380
Environment classification	Clean
Maintained illuminance (lx)	400
Room length, width, height (m)	63, 11.6, 3.9

In Table 6 shows some of the most significant economic indicators of the two lighting solutions. It is evident that at the expense of slightly larger investment costs, a substantial savings can be achieved in terms of energy and maintenance costs over lifetime of the system.

Table 6 Comparative summary of economic parameters

Overall results	**P2**	**P1**
Average total costs per year (EUR/a)	8253.04	10521.92
Total absolute cost of solution over lifetime (EUR)	123795.57	157828.81
Return on investment – ROI	Base	17.12
Amortisation of solution (a)	Base	0.88
Absolute investment costs vs. running costs (EUR)	63306:60490	61194:96634
Ratio of investment costs vs. running costs (%)	51:49	39:61
Numerical ratio of investment vs. running costs	1:1	1:1.6

Simultaneously, as Table 7 indicates annual energy consumption and specific energy consumption of the lighting system per useful area of the building are significantly reduced.

Table 7 Comparative summary of technical parameters

Energy criteria	**P2**	**P1**
Average energy consumption of per year (kWh/a)	29593.47	45854.59
Average energy consumption per area per year (kWh/m^2/a)	40.63	62.75
Total energy consumption over lifetime (kWh)	445402.11	687818.48
Total installed capacity (kW)	8802.80	13383.40

Figure 2 depicts growth of total energy costs of the lighting system over the expected lifetime, along with some of the most important parameters presented in the above tables.

CONCLUSIONS

In conclusion, we can say that with a proper choice of energy efficient light sources and installation of lighting control systems, energy efficiency can be increased around 40%, with total initial investment cost for lighting installation increased not more than 20% in comparison to the current estimated costs. Also, these measures enable use of a smaller number of lighting fixtures, keeping lighting quality within the functional and decorative requirements of the building. Results of the proposed measures will be visible in savings of energy used for illumination, energy used for air-conditioning systems and maintenance costs of the installation.

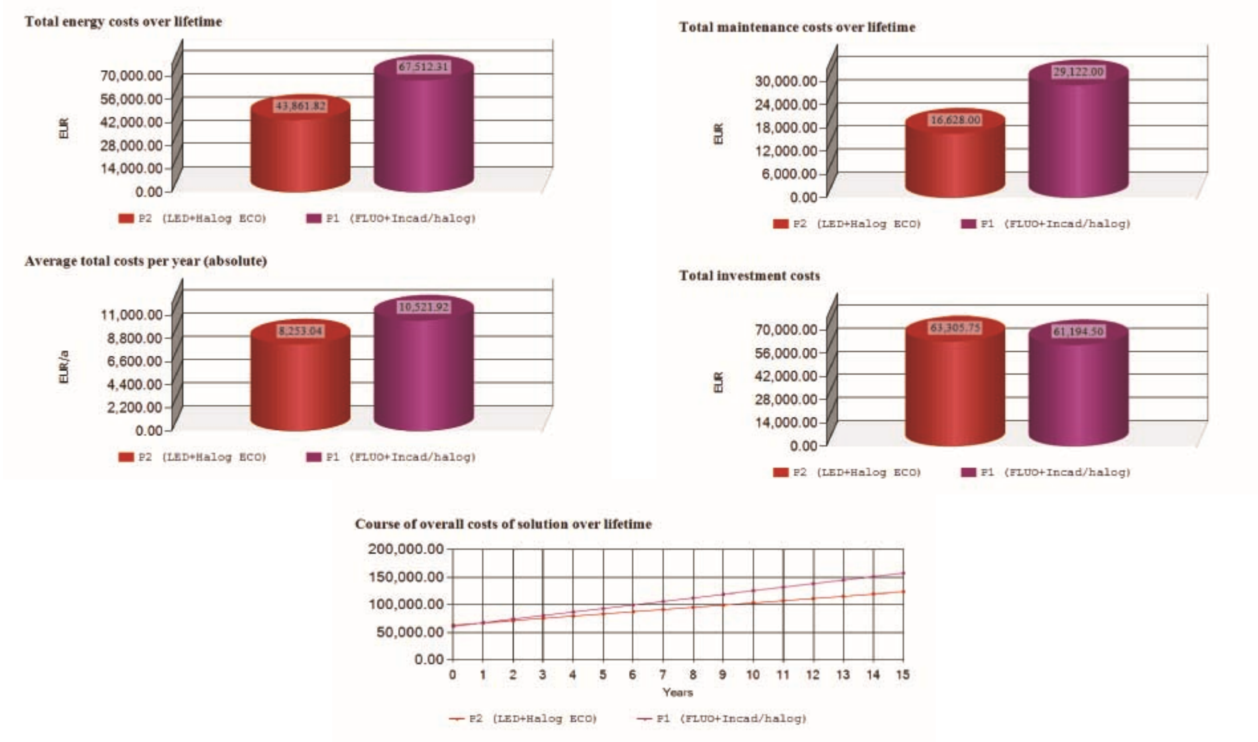

Figure 2 Some of the significant technical and economic parameters of the currently available and newly proposed lighting system

REFERENCES

1. Palladino P., Manuale di illuminazione, Tecniche Nuove, 2005.
2. CIE and CEN normative
3. Royal Phillips Electronics, www.philips.com, last accessed on March 2011
4. Osram GmbH, www.osram.com, last accessed on March 2011
5. Zumtobel Lighting GmbH, www.zumtoebel.com, last accessed on March 2011
6. Relux Informatik AG, Visualization and lighting calculation software
7. Zumtobel Lighting GmbH, ECOCALC, software for calculation and analyses of economic efficiency for lighting solutions (www.zumtoebel.com)
8. Zumtobel Lighting GmbH, ELI-LENI calculator, calculation software for energy consumption and lighting quality (www.zumtobel.com)