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ENERGY EFFICIENCY IN LIGHTING FOR HISTORICAL BUILDINGS: CASE STUDY OF THE EL AMAN CARAVANSERAI IN PROVINCE OF BITLIS, TURKEY

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ABSTRACT

Historical buildings are bridges between the past and the present. Moreover, it is a mirror of the life of societies, which lived in other ages. Historic buildings need to be illuminated to provide better visual conditions. The demand for electricity is increasing day by day. Energy must be used efficiently to reduce the amount of energy being dissipated. Therefore, energy efficiency in the lighting for historical buildings is a topic of great importance. Various luminaires are used for interior and exterior lighting of historic buildings. However, new lighting technologies, such as light emitting diode (LED) luminaires, are many times more efficient than traditional technologies, such as incandescent luminaires. The use of new technologies can lead to significant reductions in net energy consumption and associated reductions in greenhouse gas emissions. Historic buildings can serve as powerful and highly visible demonstrations of energy-efficient lighting technologies. In this study, the cost and energy efficiency have been analyzed considering the investment costs and the energy consumption of LED luminaires instead of luminaires with incandescent, halogen and metal halide lamps using almost the same luminous flux in the example of the El Aman Caravanserai in Bitlis, Turkey. As a result, of the calculations, the annual energy consumption (9066.6 kW·h) was reduced by 78.21 % compared to the conventional system (41610 kW·h) installed with incandescent, halogen and metal halide lamps. Thus, the cost of using LED lighting system have been amortised in about 135 days. Later, lighting has been made with less energy consumption, and the energy has been used efficiently.

Keywords: energy efficiency, historic buildings, lighting, LED, interior lighting, exterior lighting

1. INTRODUCTION

Historical buildings are bridges between the past and the present, and sources of cultural identity. They are important investments for the future in order to maintain a balance between energy use and cultural values [1]. They are a mirror of the life of societies and communities that lived in other eras. Therefore, historical buildings need to be exhibited correctly and properly. This is achieved by lighting. Because lighting can change the exterior structure and appearance of a building [2].

The lighting needs to enhance the brand image, highlight the beauty of the building and open the surrounding space for confident exploration and enjoyment.

The visual aspect of historical buildings should be brought to the fore, their details should be revealed. In addition, it should attract attention. However, it should not deteriorate the characteristics of the historical building and should not harm the historical building. For this reason, indoor and outdoor lighting of historical buildings is made [3, 4]. Recently, lighting and energy efficiency have become increasingly important [5]. In addition, studies were conducted on lighting of historical buildings and energy efficiency [6–10].

Fig. 1. View of the satellite of the El Aman Caravanserai

Integrated with advanced control systems, LED is one of the solutions for light quality and energy efficiency in the field of sustainable lighting. When designing illumination, one should take into account the historical value of the building, protection of historical buildings, the most appropriate combination between natural and artificial lighting, human visual welfare, perception and vision quality, visual ergonomics and satisfaction [11].

A number of articles have studied and developed LED lighting systems for either interinal or exterior lighting [12–16].

The increase in energy consumption is due to population growth, increased demand for construction services and comfort levels, as well as increased time spent inside buildings, which ensures that the upward trend in energy demand continues in the future [17]. The development of energy efficiency in buildings is necessary to reduce energy dependency and greenhouse gas emissions [18]. Energy efficiency is a reduction for energy consumed without changing the required brightness level of the illuminated environment.

Lighting is widely used because of the basic need. Therefore, the amount of energy used in lighting increases. According to the report by the International Energy Agency, lighting consumption accounts for 19 % of the world's total energy consumption [19]. At the same time, energy consumption in lighting is 20 % of the total energy consumption in Turkey [20]. For this reason, efficient use of energy in lighting is important. Lighting is one of the potential ways to increase energy savings in buildings [21].

Lighting is not about achieving a certain level of brightness, but about providing good visual conditions. Ensuring good visual conditions depends more on the qualitative and quantitative characteristics of lighting [22]. Lighting should affect those who look at facilities and buildings from an artistic point of view [3].

The main goal of lighting is to provide the correct lighting solution for the installation to achieve the highest quality product, or for the image, while releasing the need for energy efficiency.

When installing lighting, you should choose an installation that will not cause any damage to the stone in the historical building. In addition, the installation made during the initial construction process should not be changed as much as possible.

The purpose of the building to be illuminated and the reason for the need for lighting are the determining criteria for the design of the lighting installation. The characteristics of the illuminated building affect the criteria for selecting the lighting element, in terms of image beauty, as well as in terms of comfort i.e. the gloss and glare, colour and temperature of the lighting used. In this study, the energy efficiency of lighting in historical buildings was analyzed using the example of the El Aman Caravanserai in province of Bitlis in Turkey.

2. A BRIEF HISTORY OF THE EL AMAN CARAVANSERAI

The El Aman Caravanserai is located in Bitlis, the esast point of Turkey (latitude 38°29′28″ N, 42°11′36″ E). It is an example of Ottoman architecture of the second half of the 16th century. The El Aman Caravanserai, which is located about 90 m south of the northeast western axis and the longest distance is about 70 m, is one of the largest caravanserais in Anatolia. This building was built to provide shelter for passengers and caravans traveling along the trade routes connecting Asia with Anatolia and Europe [23]. A satellite image of the El Aman Caravanserai is shown in Fig. 1. This study uses an example of a historical building named the El Aman Caravanserai in Bitlis (Turkey), which is currently used as the cultural centre at Bitlis Eren University. The general image of the El Aman Caravanserai is shown in Fig. 2.

Lighting historical buildings that symbolize the city's history is a special issue [10]. When lighting these buildings, lighting should be done that does

Table 1. Characteristics of Interior and Exterior Lighting Installations

Lighting installation		Installed power for each Lamp type P (W)				
Interior lighting		**Power of *I* luminaire (W)**	**Power of *MH* luminaire (W)**	**Power of *H* luminaire (W)**	**Number of luminaire used (pc.)**	**Total power (W)**
Rooms	Staff rooms	100	–	–	15	1500
	Meeting rooms	100	–	–	4	400
	Multi purpose hall	100	–	–	30	3000
	Small cinema	100	–	–	48	4800
	Corridors	100	–	–	10	1000
	Storerooms	100	–	–	4	400
	Toilet	100	–	–	6	600
Total power of interior lighting (W)						11700
Exterior lighting		**Power of *I* luminaire (W)**	**Power of *MH* luminaire (W)**	**Power of *H* luminaire (W)**	**Number of luminaire used**	**Total power (W)**
Facade	Courtyard	–	–	60	9	540
	Northern	–	150	–	2	300
	Western	–	150	–	2	300
	Southern	–	150	–	3	450
	Eastern	–	150	–	3	450
Total power of exterior lighting (W)						2040

****Note to Table 1**: *H* is the halogen lamp, *I* is the incandescent lamp, *MH* is the metal halide lamp.

not physically harm the work and does not describe the person that the work represents. Because while lighting these buildings promotes tourism, lighting architecturally impressive buildings plays an important role in creating the aesthetic identity of the city.

There are no buildings or constructions in the area where the historical structure was built. For this reason, there is no distribution of lighting sources in the interior and on the facade, as well on the front facade territory. Therefore, only luminaires provide night lighting.

At the first stage of construction, the El Aman Caravanserai was illuminated by daylighting. The daylighting of the caravanserai is shown in Fig. 3.

However, after being transformed into a cultural centre, it was illuminated by both daylighting and artificial lighting (Fig. 4).

The light distribution characteristics and physical dimensions of the type of luminaire used in the

Fig. 2. General image of the El Aman Caravanserai

Table 2. Types and Characteristics of Luminaires Used*

Luminaire type	Power (W)	Luminous flux (lm)	Correlated colour temperature (K)	Colour rendering index (CRI)	Lifetime (Hours)
Metal halide	150	12000	4200	85	6000–10000
Halogen	60	630	2800	100	2000–4000
Incandescent	100	1380	2700	100	1000

***Note to Table 2 by the scientific editor:** here and below, the characteristics of luminaires with traditional lamps such as incandescent, halogen, and metal halide lamps is used for the characteristics of the lamps itselves. When is specified power and lifetime of the luminaire, it is necessary to take into account the power and the lifetime also in relation to electronic components, such as ballast, ignitor and driver, as well as taking into account the optical system of the luminaire for determine luminous flux.

Fig. 3. Daylighting of the El Aman Caravanserai

Fig. 4. Daylighting and artificial lighting of the El Aman Caravanserai

lighting of historical buildings are important. The products should be preferred in dimensions that do not affect the aesthetic integrity of the structure and the general appearance during the daylight, or the application points of the luminaires should be positioned so as not to affect the overall appearance [24].

2.1. Lighting of the El Aman Caravanserai

Daylighting and artificial lighting illuminate the El Aman Caravanserai. For artificial lighting are used 117 luminaires with incandescent lamp 100 W as interior lighting, and 9 luminaires with halogen lamp 60 W and 10 luminaires with metal halide lamp 150 W for exterior lighting. Exterior installation project for outdoor lighting is shown in Fig. 5. The design of the interior installation of indoor lighting is shown in Fig. 6. The names of some parts of the historical building are records in the project. Characteristics of interior and exterior lighting system are given in Table 1. In existing electrical installation uses (2×2.5) *NHXMH* cable for interior lighting, and to install exterior lighting (3×2.5) *NHXMH* and (4×4) *N2XH* cables are used.

The power, luminous flux, correlated colour temperature, colour rendering index and lifetime of luminaires with the incandescent, halogen and metal halide lamps used in the historical building of the El Aman Caravanserai are given in Table 2.

3. METHODOLOGY

3.1. Using LED luminaires

LED luminaires consume less energy than conventional luminaires do. Therefore, LED luminaires are widely used in both interior and exterior lighting. In historical buildings, lighting solutions fit the texture of the building can be provided with LED luminaires. For this reason, instead of fitting with metal halide, halogen and incandescent lamps, which are used in the interior and exterior lighting of the El Aman Caravanserai, it is proposed to use LED luminaires, which are suitable for the approximate value of luminous flux of these luminaires to improve the energy efficiency in lighting. The characteristics of the proposed LED luminaires are given in Table 3.

The characteristics of the luminaires used and proposed in the El Aman Caravanserai, such as the

Table 3. Characteristics of the Proposed LED Luminaires

Luminaire type	Power (W)	Luminous flux (lm)	Correlated colour temperature (K)	Colour rendering index (CRI)	Lifetime* (Hours)
LED (instead of metal halide)	90	10000	3000	70	10000–50000
LED (instead of halogen)	20	800	2000	80	10000–50000
LED (instead of incandescent)	15	1521	2700	80	10000–50000

****Note to Table 3 by the scientific editor:*** here and below, the lifetime of luminaires based on LED is used for the characteristics of the LED itselves. However, it is necessary to take into account the lifetime also in relation to electronic components, not only the light source, but the driver too.

Table 4. Characteristics of the Luminaires Used and Proposed

Luminaire type	Power (W)	Luminous flux (lm)	Number of luminaire used (pc.)	Colour rendering index (CRI)	Total power (W)
Incandescent	100	1380	117	100	11700
LED (instead of incandescent)	15	1521	117	80	1755
Halogen	60	630	9	100	540
LED (instead of halogen)	20	800	9	80	180
Metal halide	150	12000	10	85	1500
LED (instead of metal halide)	90	10000	10	70	900

types of luminaires, their power, luminous flux, number of luminaires used, colour rendering index and their total power are given in Table 4.

In the El Aman Caravanserai, used as a cultural centre, it is assumed that the luminaires used for interior lighting work an average of 8 hours a day, and the luminaires used for exterior lighting work an average of 10 hours a day.

The existing electrical installation will use LED lamps, which are used instead of metal halide, halogen and incandescent lamps in interior and exterior lighting systems. Therefore, the extra installation fee, which is cable and workmanship, is not included in the calculations.

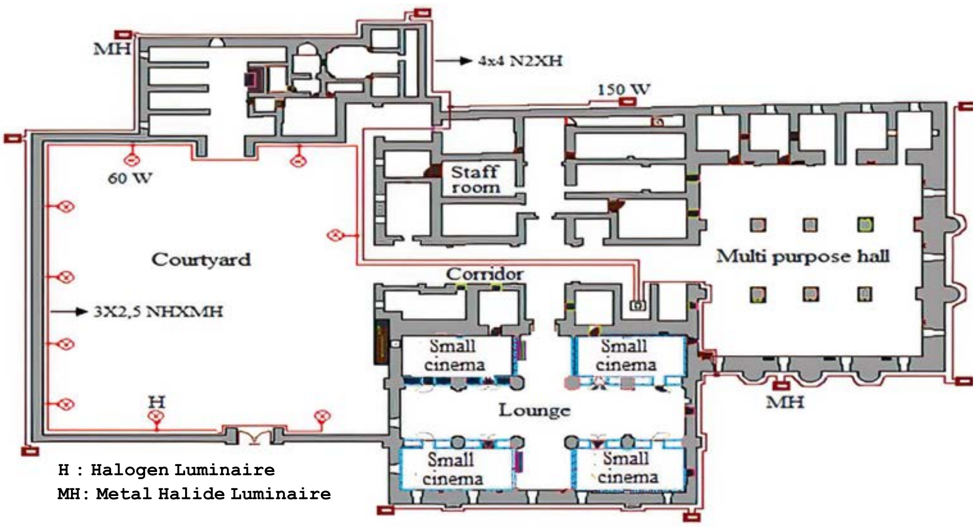

Fig. 5. Exterior installation project for outdoor lighting

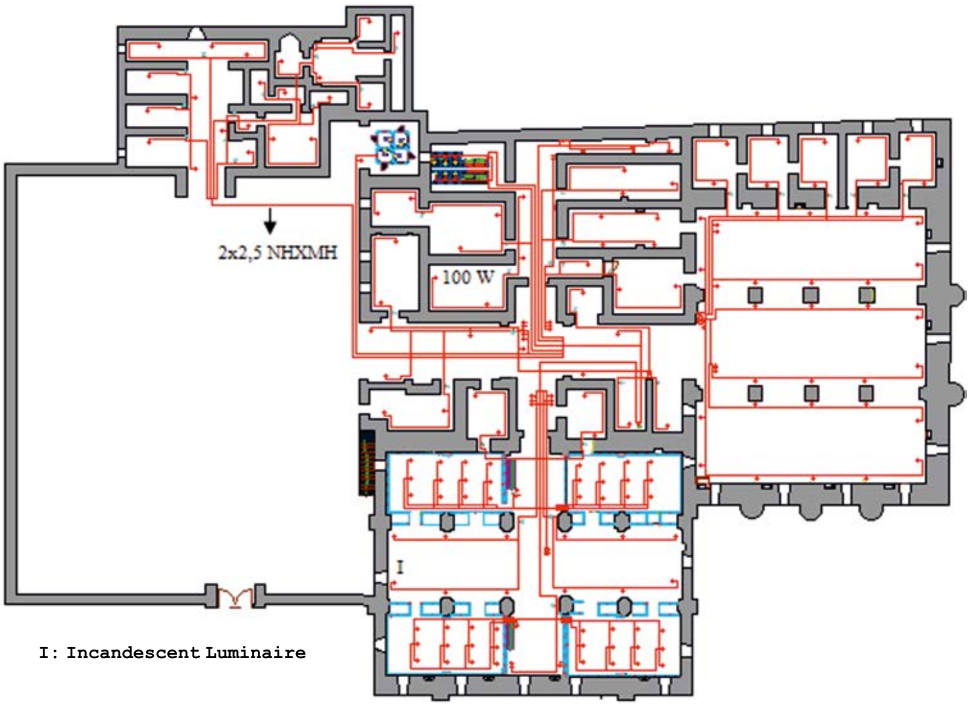

Fig. 6. Interior installation project for indoor lighting

3.2. Calculation of the Cost of the Luminaires that are Used

The costs have been calculated separately for luminaires with incandescent, halogen and metal halide lamps used in the historical building, which is the El Aman Caravanserai, and LED luminaires used instead of these ones.

The calculation of daily energy consumption for lighting installation with traditional lamps is presented below:

– With incandescent lamps

$117 \cdot 100\ W \cdot 8\ h = 93600\ W \cdot h = 93.6\ kW \cdot h;$

– With halogen lamps

$9 \cdot 60\ W \cdot 10\ h = 5400\ W \cdot h = 5.4\ kW \cdot h;$

– With metal halide lamps

$10 \cdot 150\ W \cdot 10\ h = 15000\ W \cdot h = 15.0\ kW \cdot h.$

Total daily energy consumption for lighting installation with incandescent, halogen and metal halide lamps is presented below:

$93.6\ kW \cdot h + 5.4\ kW \cdot h + 15.0\ kW \cdot h = 114\ kW \cdot h.$

Because the historic building is open and used every day of the year, the lighting installation was chosen to operate 365 days a year.

Yearly total energy consumption for lighting installation with incandescent, halogen and metal halide lamps is calculated below:

$114\ kW \cdot h / day \cdot 365\ day = 41610\ kW \cdot h.$

The cost of electricity (from September 2019) is 0.822018 Turkish Liras (TL) per 1 kW·h.

Annual energy consumption fee for lighting installation with incandescent, halogen and metal halide lamps is calculated below:

$41610\ kW \cdot h \cdot 0.822018\ TL / kW \cdot h =$

$= 34204.168\ TL.$

The calculation of daily energy consumption for lighting installation based on LED is presented below:

– Instead of incandescent lamps

$117 \cdot 15\ W \cdot 8\ h = 14040\ W \cdot h = 14.04\ kW \cdot h;$

– Instead of halogen lamps

$9 \cdot 20\ W \cdot 10\ h = 1800\ Wh = 1.80\ kW \cdot h;$

– Instead of metal halide lamps

$10 \cdot 90\ W \cdot 10\ h = 9000\ W \cdot h = 9.00\ kW \cdot h.$

Total daily energy consumption for LED luminaires is presented below:

$14.04\ kW \cdot h + 1.80\ kW \cdot h + 9.00\ kW \cdot h =$

$= 24.84\ kW \cdot h.$

Yearly total energy consumption for LED luminaires is calculated below:

$24.84\ kW \cdot h / day \cdot 365\ day = 9066.6\ kW \cdot h.$

Annual energy consumption fee for LED luminaires is calculated below:

$9066.6\ kW \cdot h \cdot 0.822018\ TL / kW \cdot h =$

$= 7452.908\ TL.$

Lifetime of incandescent lamp is 1000 h.

Annual operation time of the interior lighting system is calculated as

$8\ hour / day \cdot 365\ day = 2920\ h.$

Table 5. Average Prices for Luminaires

Luminaire type	Power (W)	Average cost per luminaire (TL)
Incandescent	100	6
Halogen	60	15
Metal halide	150	90
LED (instead of incandescent)	15	40
LED (instead of halogen)	20	106
LED (instead of metal halide)	90	650

The estimated time period, after which the incandescent lamp in the luminaire should be replaced (replacement time) based on the lifetime of it is calculated as $1000h/(2920\ h/year) = 0.342\ year$.

The lifetime of the LED luminaires varies from 10000 to 50000 hours. In the calculations, 30000 hours were selected, which is the average lifetime of the lamp.

So the LED luminaire (instead of luminaire with the incandescent lamp) replacement time is calculated as $30000h/\ (2920\ h/year) = 10.27\ year$.

Lifetime of halogen lamp is 3000 h.

Annual operation time of the exterior lighting system is calculated as
$10\ hour/day \cdot 365\ day = 3650\ h$.

Replacement time of the fitting with the halogen lamp is calculated as
$3000h/(3650\ h/year) = 0.822\ year$.

So the LED luminaire (instead of luminaire with the halogen lamp) replacement time is calculated as
$30000h/\ (3650\ h/year) = 8.219\ year$.

Lifetime of metal halide lamp is 8000 h.

Replacement time of the luminaire with the metal halide lamp is calculated as
$8000h/(3650\ h/year) = 2.191\ year$.

So the LED luminaire replacement time (instead of luminaire with the metal halide lamp) is calculated as $30000h/\ (3650\ h/year) = 8.219\ year$.

Prices for the luminaires vary from brand to brand or from company to company. Therefore, the average prices for the luminaires according to market research data are shown in Table 5.

This way we can calculate the initial investment cost for lighting installation with traditional lamps:

– With incandescent lamps $6\ TL \cdot 117\ = 702\ TL$;

– With halogen lamps $15\ TL \cdot 9 = 135\ TL 15$;

– With metal halide lamps $90\ TL \cdot 10\ = 900\ TL$.

Then total initial investment cost is
$702\ TL + 135\ TL + 900\ TL\ = 1737\ TL$.

Annual luminaire replacement cost for luminaires with traditional lamps is calculated below:

– With incandescent lamps
$6\ TL \cdot 117/0.342\ = 702\ TL/0.342 = 2052.63\ TL$;

– With halogen lamps
$15\ TL \cdot 9/0.822 = 135\ TL/0.822 = 164.23\ TL$;

– With metal halide lamps
$90\ TL \cdot 10/2.191\ = 900\ TL/2.191\ = 410.77\ TL$.

Annual operating costs for fittings with incandescent, halogen and metal halide lamps are made up of annual charge for energy consumption and the annual cost of replacing the lamps. So, the annual operating cost for lighting system with traditional lamps is
$34204.168\ TL\ + 2627.63\ TL = 36831.798\ TL$.

Total cost of lighting installation with incandescent, halogen and metal halide lamps consists of initial investment costs and annual operating costs, and is equal to $1737\ TL + 36831.798\ TL = 38568.798\ TL$.

Similarly, we can calculate the initial investment cost for LED luminaires that is:

– 15 W LED luminaires (instead of incandescent) $40\ TL \cdot 117\ = 4680\ TL$;

– 20 W LED luminaires (instead of halogen) $106\ TL \cdot 9 = 954\ TL 15$;

– 90 W LED luminaires (instead of metal halide) $650\ TL \cdot 10\ = 6500\ TL$.

Total initial investment costs of LED luminaires is $4680\ TL\ + 954\ TL\ + 6500\ TL\ = 12134\ TL$.

Annual fitting replacement cost for LED luminaires is calculated below:

– Instead of incandescent lamps
$40\ TL \cdot 117/10.27\ = 4680\ TL/10.27 =$
$= 455.696\ TL$;

– Instead of halogen lamps
$106\ TL \cdot 9/8.219 = 954\ TL/8.219 = 116.07\ TL$;

– Instead of metal halide lamps
$650\ TL \cdot 10/8.219\ = 6500 TL/8.219\ = 790.85\ TL$.

Then the total annual fitting peplacement cost for LED luminaires is equal to
$455.696\ TL + 116.07\ TL + 790.85\ TL\ =$
$= 1362.616\ TL$.

The annual operating cost for LED luminaires consists of the annual energy consumption fee and the annual fitting replacement cost, and calculated below as:

$7452.908\ TL + 1362.616\ TL = 8815.524\ TL.$

The total cost for LED luminaires consists of the initial investment cost and the annual operating cost, and calculated below as:

$12134\ TL + 8815.524\ TL = 20949.524\ TL.$

3.3. Calculation of the Amortization Period

According to the cost calculations, in case of using the LED luminaire, the cost is higher than when using fittings with incandescent, halogen and metal halide lamps. However, the amortization period has been calculated to determine the feasibility of using LED luminaires to improve the energy efficiency for the El Aman Caravanserai.

The amortization period when using LED luminaires instead of fittings with incandescent, halogen and metal halide lamps has been calculated, equation (1):

$$C_1 + A_p \cdot C_2 = C_3 + A_p \cdot C_4, \quad (1)$$

where C_1 is the initial investment cost for fittings with traditional lamps (TL), C_2 is the annual operating cost for fittings with traditional lamps (TL), C_3 is the initial investment cost for LED luminaires (TL), C_4 is the annual operating cost for LED luminaires (TL), A_p is the amortization period (year).

The amortization period when using LED luminaires instead of luminaires with traditional lamps in case of the El Aman Caravanserai is calculated in accordance with (1):

$$1737\ TL + A_p \cdot 36831.798\ TL = 12134\ TL + $$
$$+ A_p \cdot 8815.524\ TL,$$
$$A_p \cdot (36831.798\ TL - 8815.524\ TL) =$$
$$= 12134\ TL - 1737\ TL,$$
$$A_p \cdot 28016.274\ TL = 10397\ TL,$$
$$A_p = 0.371\ year = 4.452\ months = 135.415\ days.$$

According to the calculation of amortization period, the cost of lighting in the historical building using LED luminaires have been amortized in about 135 days. This period is available period for improving energy efficiency in the lighting for historical building such as the El Aman Caravanserai.

4. CONCLUSION

The electrical energy used in lighting is 20 % of the total energy. Therefore, it is important to use LED luminaires. To ensure the energy efficiency of lighting, LED luminaires, which are consumed less energy than conventional luminaires should be preferable. As a result, it is predicted that the use of LED luminaires in general lighting will gradually increase.

In the El Aman Caravanserai, the annual energy consumption has been calculated 9066.6 kW·h in interior and exterior lighting using LED luminaires. On the other hand, the annual energy consumption has been calculated 41610 kW·h using luminaires with traditional lamps such as incandescent, halogen and metal halide lamps. Thus, it is expected that switching to LED luminaires will save approximately 78 % of the annual energy consumption compared to existing luminaires with traditional lamps.

The initial investment cost of LED luminaires (12134 TL) has been calculated approximately 86 % higher than the initial investment cost (1737 TL) of luminaires with incandescent, halogen and metal halide lamps. However, the annual operating cost of LED luminaires (8815.524 TL) has been calculated approximately 76 % less than the annual operating cost of luminaires with incandescent, halogen and metal halide lamps (36831.798 TL). According to the calculation, the cost of lighting in the historical building using LED luminaires will be amortized in approximately 135 days. After amortization period, lighting will be made with less energy consumption, and energy will be used efficiently.

Finally, the low energy consumption of LED lighting belongs to the widely discussed topic of how to save energy. Teherefore, the LED luminaire plays an important role in improving the energy efficiency of historical lighting. In other words, the author describe how it is possible to manage energy consumption for a lighting system, and shows how it is possible to obtain significant energy efficiency for historical buildings using lighting system based on LED luminaires.

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