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DAYLIGHTING APPLICATION SUITABLE FOR ARCHITECTURAL DESIGN WITH LIGHT TUBE IN WAREHOUSES

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ABSTRACT

With the increase in the use of daylight in architecture, providing visual comfort values as well as physical and psychological effects on people and minimizing the lighting energy need of the building have become important in terms of design. Today, with the development of daylight technologies, economic light tubes have become popular in Architecture. Light tubes have become an effective method in Architecture in terms of energy efficiency to illuminate areas of a building that are exposed to limited sunlight. In addition, people prefer to use daylight by nature. Therefore, the use of light tubes continues to increase in buildings with modern architecture. However, due to architectural design and necessities, daylight is used in a limited way in interior areas. While architects determine the position of the light tubes in the building in order for daylight to reach the dark and dim spots of the buildings, knowing the Illuminance level performance of the positioned light tubes has become a necessity for efficient use. In the study conducted to solve this problem, the Daylight Factor Method specified in the European Union EN 17037:2018 Standard was used in the use of light tubes. As stated in the relevant standard, the methods in the daylight factor value ISO 15469:2004 were used. The evaluation of the buildings in terms of daylight performance was calculated in the simulation environment according to the horizontal luminance of the daylight openings. With the designed simulation, the values in the conditions specified in the criteria related to the light tubes are provided. In this way, a light tube that provides energy efficiency is compatible with the circadian rhythm and is compatible with the architecture of this building, and optimum illuminance level values have been determined for the warehouse, which is the subject of the study in the simulation environment.

Keywords: Daylighting, architectural lighting, light tube, lighting design, physical environment control.

1. INTRODUCTION

The use of daylight as a design principle in architecture begins in the ancient Roman period. It is known that in the buildings of the period, the principle of absorbing the light coming from the wall openings into the interior volume was based and the building positions were determined according to the daylight evaluation. Before the spaces were electrically illuminated, the relationship between space and daylight was of great importance to architects. With the invention of electricity in the historical process, the period of artificial lighting has begun in architecture. However, the lighting effect of daylight continued to attract more people's attention than artificial lighting. Mankind has tried to use natural lighting as much as possible. Therefore, the use of daylight has been important in architecture throughout history (Ünver, et al, 2003, Plympton et al. 2000, Cengiz, 2019, Whitehead, 1998, Cengiz, 2020, Yıldırım et al.2017, Cengiz, 2021).

The main purposes of illumination with daylight are; To provide ambient lighting requirements during daylight hours, to prevent disturbing brightness rates by creating a homogeneous distribution of daylight, to ensure full integration with other building systems, to have a design where users can perceive the dynamic natural events outside during the day, to design an architectural structure with a high energy saving rate. For this purpose, attention should be paid to the architectural process stages in terms of lighting according to the features listed below in the design process (Cengiz, 2021, Özkiper, 2021).

- The climate zone where the building is located
- Layout plan and location of the building
- Size, shape, and location of openings such as windows and skylights
- The function and usage hours of the building
- Shading for cooling and visual comfort
- Creating an interior design concept with light colors and highly reflective surfaces
- An element layout application that does not block the sunlight
- Installation of lighting automation systems with daylight sensors and dimmable units
- Properties of glass and similar transparent materials used
- Optimal combination of daylight and artificial light

Light tubes can reach the depths of the space where the windows, which is the most known method of getting daylight into the space, are limited to receive daylight (Cengiz, 2021, Özkiper, 2021). While the windows can carry the daylight to a maximum depth of 6 meters depending on the floor height, the light tubes can reach deeper depending on the daylight efficiency and the light reflection of the light pipe. With the collectors placed on the roof and the vertical shafts to be created afterward, it can be effective not only on the upper floors of the buildings but also on the lower floors. Especially for climatic regions where daylight is effective, that is, it can be effective in the southern regions, while its effectiveness decreases in the northern hemisphere. For these regions where daylight is less effective, it can be used by integrating with systems that capture and collect light, called heliostat, to be placed on the roof. It does not cause glare as they provide a homogeneous distribution at the same time while taking the daylight into the space (Onaygil and Güler, 2007, Onaygil, 2005, Onaygil and Güler 2003). In addition, since they do not carry the thermal effect of daylight to the space, it helps to reduce cooling loads (Ozgun, 2007, Öztürk, 2003, Doğan, 2017, Demirci, 2008). Example light tube illumination is shown in Figure 1.

Fig. 1. Example light tube illumination

2. USE OF LIGHT TUBES IN ARCHITECTURE

In architecture, the light tube is used as a source to direct light to dark, dim areas where daylight cannot reach during the day. Combining windows and light tubes can improve daylight in a room. With its multiple reflection mechanism, the light tubes transmit the sunlight more homogeneously. Daylight has several advantages in terms of human health and comfort (Hopkinson and Petherbridge, 1966, Plympton, et al. 2000, Kim and Kim, 2010, Mohapatra et al. 2020). Daylight systems can reduce heating and cooling costs in buildings (Lapsa et al. 2007, Darula et al. 2013, Kocifaj et al. 2008, Mohapatra et al. 2020). With the use of light tubes, daylight creates a positive effect in areas that receive much less light than windows (Whitehead, 1998, Swift and Smith, 1995, Kocifaj et al, 2008, Carter, 2002). Using daylight or natural light can reduce energy consumption by up to 30%. The light tube saves energy (Dutton and Shao, 2007, Shao et al. 1998, Oakley et al. 2000, Mohapatra et al. 2020). In addition, the use of light tubes provides benefits to human health in terms of circadian rhythm and physiological effects (Kennedy and ORourke, 2015, Hanneborg, 1901, Mohapatra et al. 2020). It was first discovered by Hanneborg of Norway in 1900 that a light tube brings light to the central area inside large structures (Hanneborg, 1901, Smart, 1983). Fiber optic lighting as a new technology that will create a light tube effect today also has very good transmission properties, but Fiber optic lighting is very expensive compared to light tubes (Smart, 1983, Mohapatra et al. 2020). Nowadays, the light tube has become popular in the development of daylight technology. It is an efficient method to bring light to areas of a building that are exposed to limited sunlight (Baroncini et al. 2010, Mohapatra et al. 2020). In some studies on light tubes, successful results have been found that diffusers are effective in the performance of daylight systems. Found (Edmonds et al. 1995). Today, applications of tubular daylighting devices such as windowless rooms, tunnels, underground passages, and corridors are becoming quite common (Mohapatra et al. 2020, Darula et al. 2013).

Since light tubes are not expensive, their use is increasing. Room windows or skylights are generally not capable of illuminating the center of a building. Light tubes are the best method for daylighting and provide adequate lighting levels. Since the light from the sun is available during the daytime, light tubes should be used to provide energy-efficient lighting to make the most of daylight possible (Sabiha et al. 2015, Mohapatra et al. 2020). The active use of daylight depends on the external conditions as well as on the technologies applied in the design of the light tubes (Al-Marwaee and Carter, 2006). Light tubes can carry and disperse natural light without heat transfer in dark areas (Malet-Damour et al. 2014). Commercially available light tube systems consist of three main components: the daylight collector, the light tube, and the diffuser. The collector is mounted on a roof that normally looks like a transparent dome structure, eliminating unwanted ultraviolet light and insulating the light tube against rain and dust particles. It is possible to transmit daylight by using a hollow tube (Solatube), polymer fiber, and special quartz fiber Himawari (Kumar, 2013, Mohapatra et al. 2020). There are also other methods of daylight illumination such as a solar tube, SunScope, light tube, light tube, and tubular skylight. In Figure 2, the side view of the light tube illumination is given.

Fig. 2. Side view of light tube illumination

2.1. Light Tubes

Light transmission efficiency is an important indicator of light tube performance and depends on the geometry of the light tube, optical parameters of the light tube, and sky conditions (Komar and Darula, 2012). The principle of directing light in a tube is based on multiple reflections. These tubes are normally made of aluminum alloys. Light intensity is lost in angled, long, or flexible tubes.

This research focused on the simulation study in terms of the Illuminance level of flat light tubes on a rectangular surface. Light tubes are used to transport light to unlit parts of a building with even illumination level distribution. Light tube application can be considered in factories, schools, warehouses, institutions, corridors, and offices for commercial purposes, and in kitchens, living rooms, stairs, toilets, and bathrooms for residential purposes. Figure 3 shows a bath before and after the application of the light tube.

Fig. 3. A bath before and after the application of the light tube.

2.2. Daylight Diffusers

A diffuser diffuses or diffuses light evenly, like a lighting source. Diffusers are one of the main design tools for changing the (acoustic) conditions of rooms, semi-enclosed spaces, and the outdoor environment (Cox and D'antonio, 2009). Transparency will vary according to material properties. Different diffusers are selected depending on the required use. For example, a transparent diffuser (made of polycarbonate) is preferred in corridors where the amount of light is more important. However, opal diffusers are used for uniform daylight (Efe and Varhan, 2020, Efe, 2018). Various types of optical diffusers are available using opal glass, frosted glass, holographic and gray glass. Figure 4 shows the reflection of daylight by the diffuser before and after the light tube application.

Fig. 4. Reflection of daylight by the diffuser before and after light tube application

2.3. Structure of Light Tubes

Light tubes are divided into three according to their manufacturing types;

- Light tubes with mirror surface: Depending on the reflective surface inside the tube and the length of the path it takes, the daylight performance it takes into the space is affected. Daylight can be efficient up to 12 m in a tube with a diameter of approximately 300mm.

- Prismatic surface light tubes: This type of light tubes consists of prismatic surfaces that can redirect the light. Prismatic surfaces in the pipe act as mirrors by increasing the reflection.

- Lens system light tubes: After the light is collected in lens system light tubes, it is transmitted to the mirror with the lens. These systems have two disadvantages. Lenses added to the system increase the cost, and at the same time, their efficiency may decrease as a result of long-term contamination of the lenses. (Ozturk, 2006). Thanks to the lenses placed in the pipe, the length of the light transport path are increased. With the help of mirrors, light propagation in the pipe is provided. It is aimed to increase the efficiency in carrying daylight by means of these additions in the internal structure of light tubes. There are tube structures with a simpler structure, the interior of which is covered only with a reflective film.

The use of light tubes continues to become widespread in the world. There are often types of light tubes that have a simple structure and do not need any additional collector system. In these systems, pipes manufactured as straight or elbowed by means of the outer dome placed on the roof are covered with a 95% reflective film on the inner surface. In this way, daylight is delivered to the dark spots of the relevant area.

2.4. Light Tube Standards

With the increase in the use of daylight in architecture, providing visual comfort values along with the physical and psychological effects on people and minimizing the building's lighting energy requirements have become important in terms of design (Köknel Yener, 2002, Kurtay, 2002, Köknel Yener, 2003). With this aim, the European Union Standard EN 17037:2018 "Daylight in Buildings" was put into effect in June 2019 by the European Standardization Committee to cover residential and non-residential buildings for daylight use in buildings. EN 17037:2018 was accepted as a Turkish Standard by the TSE Technical Committee on 28.01.2019.

In the EN 17037:2018 standard, it is recommended to use two different evaluation methods based on Daylight Factor and Detailed Daylight Modeling in order to provide sufficient daylight illumination in the relevant areas. Daylight Factor Method: According to TS EN 17037:2019, in the Daylight Standard in Buildings, the first method recommended to provide sufficient daylight illumination in buildings is the Daylight Factor method. It is calculated by taking the ratio of the daylight illuminance occurring on the working plane indoors to the illuminance occurring on the outer horizontal plane. In this study, the Daylight Factor Method was used.

In the relevant standard, it is recommended to calculate the daylight factor value for the volumes using the ISO 15469:2004 method (ISO. 15469:2004). In the standard, the evaluation of buildings in terms of daylight performance varies according to whether the daylight openings are vertical (windows) or horizontal (roof skylights). In the evaluation of spaces with horizontal daylight deficits in terms of daylight performance, only the condition that the targeted illuminance level is provided in 95% of the space is taken as a basis. In this study, since the entrance of the light tubes is horizontal to the roof, they are in the status of spaces with horizontal openings. For this reason, calculations were made according to the spaces with horizontal openings from the Daylight Factor Methods.

According to this criterion, the 50 lux value, which must be provided in the warehouse in the lighting made with the light tube, must be provided in 95% of all measured points.

3. LIGHT TUBE SIMULATION

The aim of a lighting designer is to always create comfortable, healthy, and beautiful spaces for its users. In the design process, the designer makes use of direct and indirect lighting types, taking into account functional and psychological needs. The comfort of a space can be increased or decreased with the chosen lighting. The designer chooses the lighting system according to the environment he wants to create. Relevant lighting standards, energy savings, and user comfort are taken into account in the decision-making process. The main elements to be considered in lighting design are the architectural features of the space and the purpose of use of the space. Physical properties such as the types of materials used, colors, textures, reflection coefficients, and height of the space play a decisive role in the designer's decisions (Apaydın, 2012, Cengiz and Cengiz, 2018, Aykal et al. 2011, Cengiz and Cengiz, 2021). Direct lighting transmits 90-100% of the light from luminaires directly to the work area. It is important to avoid glare in direct lighting. With direct lighting, the ceiling appears darker than the working area. Direct lighting is a type of lighting that provides energy efficiency.

In this study, it was tried to improve the visual comfort of the environment by using a light tube (circadian rhythm, biological clock, biological system, and psychological state) in areas where daylight cannot be benefited sufficiently. For this purpose, the Point Illumination Calculation Method was used on the field surface. In this method, the area where the lighting will be calculated is selected and the dimensions of the warehouse area selected as the calculation area are 8 m * 16 m.

The area with dimensions of 8 m * 16 m is divided into 90 equal rectangular pieces with dimensions of 0.80 m * 1.333 m. Point Illuminance Level values were measured in the simulation environment so that they are right in the middle of the rectangular-shaped areas. Starting from the first lamp in the calculation area, point illumination calculations were made according to the observer positioned in the middle and back of the selected surface. According to the numerical values obtained in the simulation environment, a light tube was illuminated from a height of 6 m in a warehouse. In Figure 5, a view of the light tube from the bottom and from the roof is given for a warehouse.

Fig. 5. Bottom and roof top view of the light tube for a warehouse

4. SIMULATION STUDY

The ceiling height of the light tube was chosen as 6 m. Luminaires to be used in area lighting have been selected considering the level of illumination, the brightness level of the area and walls, lighting homogeneity, and economy. Calculations were determined as a result of computer calculations according to the point illuminance method (Cengiz et al. 2018). Various options are available for area-surface parameters in the simulation program used. For area-surface parameters, the lighting system (mutual lamps, cross lamps, split, single lamp, two lamps, etc.) can be selected as an area-surface class, area width, and area-surface lighting class. In-wall or suspended system lighting can be selected for lighting parameters such as distance between lamps, lamp height, lamp distance from the surface, IP protection class, pollution rate, cleaning time, maintenance factor. For lamp parameters, the angle of the lamp relative to the surface, the power of the lamp used, its life, luminous flux, ballast power can be added to the simulation. As a result, it is possible to add any lamp or light tube to the simulation (Cengiz, 2019, Cengiz 2020, Cengiz, 2021) Simulation results can be obtained with an easy and accurate calculation for the lighting system where the data is entered.

Light tubes with a luminous flux value of 17000 lumens were used in the warehouse where the study was carried out. The main thing here is the efficiency of the Light tubes. In other words, it does not make any sense whether the light tube is narrow or wide. The light tube diameter specified by the light tube manufacturers in the catalogs and the corresponding Watt value should not be taken into account. Because even if the light tube is efficient, the location and direction of the roof used, climate effects and pollution factors affect efficiency.

The light tube angle was chosen as 0, the floor reflectance coefficient of 0.10, and the maintenance factor of 0.93 (for less polluted environments that are cleaned once a year). The warehouse area with insufficient natural lighting was chosen. The 8 m wide and 16 m long warehouse area is divided into 90 points. The 8 m * 16 m was divided into 90 equal parts of 0.80 m * 1.333 m dimensions and the illuminance level (E) for each rectangular area was measured in the simulation environment. As stated in the relevant standards, an illuminance value of 50 lux should be provided for storage areas. Table 1 shows the illuminance levels for the illumination with the light tube.

Table 1. Illuminance levels for lighting with a light tube

Emin=49.427 Lx Emax=179.46 Lx Eaverage=105.02 Lx										
Meter/Meter	**0,400**	**1,200**	**2,000**	**2,800**	**3,600**	**4,400**	**5,200**	**6,000**	**6,800**	**7,600**
0,667	55,917	55,805	53,648	50,757	**49,427**	**49,429**	50,764	53,660	55,823	55,942
2,000	74,628	72,477	69,427	65,669	63,515	63,518	65,677	69,439	72,497	74,656
3,333	89,621	86,692	82,681	78,429	75,438	75,440	78,437	82,694	86,714	89,652
4,667	103,373	100,805	97,952	95,181	92,585	92,588	95,190	97,967	100,831	103,410
6,000	161,067	157,550	153,678	153,360	153,966	153,969	153,371	153,696	157,581	161,112
7,333	164,255	169,179	168,734	174,971	179,461	179,465	174,984	168,755	169,215	164,309

In this study, a solution has been found to the problem of the illuminance level in the light tubes in the simulation environment. The Daylight Factor Method, which is also accepted and in force in Turkey (TS EN 17037:2019), specified in the European Union EN 17037:2018 Standard, was used. It is recommended to use the methods in the ISO 15469:2004 standard in the calculation of the Daylight Factor Value. The evaluation of the buildings in terms of daylight performance was calculated in the simulation environment according to the horizontal luminosity of the daylight openings. Because the position of the light tube on the roof is horizontal to the roof. That is, while the window receives light vertically, the roof surface receives horizontal light. In the evaluation of the spaces that receive horizontal light and lack of daylight in terms of daylight performance, the targeted illuminance level should be provided in at least 95% of the space. According to this criterion, 50 lux value, which should be provided in the warehouse for lighting made with light tubes, should be provided at 95% of all measured points. In the calculation made according to the point calculation method, the Illuminance level value below 50 lux was observed at only 2 points out of 90 points. In other words, in the lighting made with the light tube, approximately 2% of the light has fallen below the value of 50 lux. In the light tube simulation, the illuminance level values at 88 points at a rate of 98% are above 50lux and provide the limit values in TS EN 17037:2019 or EN 17037:2018.

5. DISCUSSIONS

In addition to the use of traditional methods in architecture, it is necessary to create, develop and make widespread the use of alternative methods in order to ensure that daylight is taken into the spaces as much as possible, thus increasing the daylight effect. In addition to ensuring the integration of light tubes into existing buildings, increasing their use as an alternative in new projects affects the user positively in terms of energy consumption and economy.

Expanding the use of simple alternatives to light tubes, especially in single-story warehouses, shops, and factory buildings will contribute to energy savings.

Simple and plain light tubes will be able to reach the space both more economically and without loss in light efficiency, by enabling them to be used without the need for auxiliary systems both inside the pipe and on the roof area where the external collectors are located, due to the short path they take. In this way, regardless of direction and climatic conditions, both energy savings will be achieved, homogeneous illumination will be obtained in the interior, and negative effects such as thermal effects and glare will be prevented. In places where it is not possible to receive daylight directly in buildings with higher or more depth, it is possible to receive more daylight through support systems, that is, with solar collectors. In terms of architectural design, lighting will be easier with the daylight intervals to be created.

6. CONCLUSIONS

The light tube design made met the relevant standards in terms of illuminance level. In this way, the warehouse, which is the subject of study in the simulation environment, has been efficiently illuminated in terms of energy efficiency. The illumination level required by the circadian rhythm in terms of human health is provided. Optimum illuminance level is provided with light tubes compatible with the architecture of the building.

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