Solving Air Conditioning Problems in a Design Project Using Energy-Efficient Daylighting Systems Based on Hollow Tubular Light Guides

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Solving Air Conditioning Problems in a Design Project Using Energy-Efficient Daylighting Systems Based on Hollow Tubular Light Guides

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Abstract. In our work we demonstrate a developed design project for lighting a 24-hour cafe at one of the largest airports in Russia. The project is based on use of energy-efficient technology for delivering natural light to rooms with constant presence of people. The existing option includes only minor artificial lighting. Employees and passengers who, for various reasons, have to stay in the terminal cafe for a long time, experience certain discomfort and fatigue for lack of natural light and continuous air conditioning in summer time. The proposed design project allows not only to radically change the interior atmosphere of the cafe due to natural sunlight and diffuse light, but also significantly save energy costs associated with continuous round-the-clock energy consuming artificial lighting and air conditioning in summer, contribute to improving the psychological comfort of people and preserving the natural environment. This statement is confirmed in this article below by the heat engineering calculation performed in Ansys calculation complex. There are no analogues to this project. Illumination calculations were performed in improved DIALux program, into which the relevant information on the applied daylighting systems was integrated. The calculation of the economic profitability of the design project confirms feasibility of material costs.

1. Introduction

Modern airports[1], built several decades ago, are being actively reconstructed. However, there are no

[1] That is how a building designed to serve passengers of air transport should be called, since the term "airport" is most often understood as a complex of structures designed for receiving, sending, basing aircraft and servicing air transportation.

current regulatory documents that focus on airports. For example, Russian Guide for the Design of Local Airlines Airports, published in 1985, does not contain specific requirements for the design and installation of engineering systems for airports. In normative documents [1], [2], [3] in addition to these requirements, issues of normative natural lighting of airport terminals are not considered. Many factors, such as weather conditions, the technical problems of aircraft, their unplanned replacement force people who make flights to stay in the terminal building for a long time. Existing problems of natural light and air conditioning are becoming apparent. We give an example of lighting of a cafe premises in airport terminal building of one of the largest cities in Russia (Fig. 1).

Figure 1. The interior of a cafe in airport terminal of one of the largest airports in Russia.

In a room space where there is practically no natural light, despite the presence of two small external window openings, passengers and working staff get tired very quickly and feel uncomfortable. Owner of the cafe, in addition to rent, is forced to pay a considerable amount of money associated with round-the-clock energy consumption of artificial lighting devices, and in the summer time – for air conditioning. We propose an original design project which involves use of technology to deliver natural light to the rooms with constant presence of people. The project allows avoid usage of air cooling systems in the summer period in this room and has no analogues in the world. This technology is based on use of hollow tubular light guides (HTLG) of various configurations. In leading scientific centers of Europe, Asia and the USA research related to the development and improvement of these systems is constantly being conducted. A lot of attention is being paid to studies of problems connected with indoor air conditioning. The research results are reflected in numeral scientific publications.

For example, article [4] discusses use of polymethylmethacrylate (PMMA) plastic fiber in a daylight system. It is confirmed here that a short-wavelength dichroic mirror can effectively filter up to 64% of high-flux infrared rays. This leads to slight loss of the visible spectrum of natural light. The presented experimental data can be used to optimize natural illumination using PMMA fibers. Scientific work [5] describes innovative devices – daylight tubes which allow to transport natural sunlight without heat transfer in dark rooms. The approach used and the results of light transportation are presented here. To evaluate the accuracy of the numerical results, various calculation programs that evaluate the experimental database were used. The results confirm the goal of developing the new model. In publication [6], problem of increasing the energy efficiency indicators of a university pool through use of HTLG is investigated. Specific feature of the heat engineering calculation is study of options of anti-condensation trays location inside the daylighting systems manufactured by Solarspot International S.r.l. company in order to find their most optimal installation points in terms of possible heat losses. Comparative thermotechnical calculation of two types of natural lighting systems was carried out in [7]: hollow tubular light guides and widespread roof zenithal skylights. In [8], [9], [10], [11], an assessment of the economic efficiency of lighting systems based on hollow tubular light guides use is made. The study [12] provides feasibility study on use of hybrid lighting (daylight +

LED luminaries) systems in Europe. Jitka Mohelnikova, Stanislav Darula, Miroslav Kocifaj in their work [17] came to a conclusion that tubular light guides are a convenient concept for illuminating with natural light rooms of buildings without window openings and represent computer simulation of daylight based on the assessment of daylight tube efficiency. D.G. Leo Samuela and colleagues in [18] consider various options for passive cooling as a viable alternative to traditional air cooling systems and provide a brief overview of energy-efficient and environmentally friendly solar cooling systems. Costs of cooling, comfort of the created environment are investigated in [19] by Wilmer Pasut, Edward Arens, Hui Zhang, Yongchao Zhai. No less interesting is article [20], where authors study social perspective and quantify costs and benefits for utility services and homeowners in Phoenix, Arizona, using large air conditioning systems.

Articles [21], [22], [23] present results of a study of direct tubular daylight guides with help of which "tropical interiors" were created; also level of illumination in the internal parts of buildings was improved and adequate visual comfort, huge energy saving potential were achieved, subject to proper design, of course.

Scientists Ran Gao, Kaikai Liu, Angui Li, Zhiyu Fang, Zhigang Yang, Beihua Cong [24] draw attention of the whole world to energy consumption in the systems for transporting and distributing air in ventilation and air conditioning ducts and offer methods to reduce local resistance in the tee of a duct using a protruding structure based on the biomimicry of the branched structure of plants. Article [25] provides a comprehensive study of a straight-line daylight tube efficiency and the distribution of illumination below the ceiling, which was performed using HOLIGILM tool. Research by Danny H.W. [26] introduces results of the daylight illumination level measuring in corridors of a building where several hollow light guides were installed. The mathematical expression used to simulate the throughput of a specular daylight tube is shown in [27]. The author found that the bifurcation of the mirrored light tube leads to significant increase in throughput, especially in the winter months.

Our analysis of the studied scientific literature shows that nowhere in the world the project we have proposed was developed and applied. Its uniqueness also confirms our assumption based on mathematical calculations that the daylighting systems simulated by us not only organically fit into the design of the premises, but also contribute to the enormous saving of energy costs associated with lighting and air conditioning of these rooms.

2. Methods

When developing our design project for natural lighting in the airport terminal building cafe we used the software for creating three-dimensional computer graphics Blender, a raster graphics editor for creating and processing raster graphics and partial support for working with vector graphics GIMP. Needed number of HTlGs, providing standard illumination requirements, their diameter was determined using the technique of Dr. G. Bracale [13]. Information on the global light parameters corresponding to the geographical latitude and longitude of Moscow was taken from the Satel-Light European database of natural and sunlight [14]. We improved the DIALux calculation program by integrating information on LEDSOLARSPOT® D.530 hybrid daylighting systems with a diameter of 530 mm used to create the model for the design project into it. This allowed us to expand the capabilities of DIALux program, checking the performed mathematical calculations and obtaining original illumination diagrams of the object studied. The heat exchange processes occurring in a hollow tubular daylight guide, typical for the climatic conditions of Russia in summer time, we studied and analyzed in Ansys calculation complex (Solid70 (Thermal mass)).

3. Results and discussion

In Fig. 2 shows a model of a new design project for the airport terminal building café, that actually exists, developed using lighting systems based on mirrored hollow tubular light guides manufactured by Solarspot International S.r.l. company.

Figure 2. The developed model of interior design of the airport terminal cafe based on the application of technology for the delivery of natural light to the rooms with constant presence of people.

The room is filled with "live" sunlight which added sense of fresh air to the interior of the airport cafe. Bright colors improved the overall design greatly. The new atmosphere optimizes physical and psychological state of people. Design of the hollow tubular light guides organically fit into the architecture of the room. They transport natural light and can significantly save energy spent on air conditioning in summer season, thereby contributing to the conservation of our environment. Light diffusers of hybrid systems are equipped with modern LED luminaries which begin to work with a decrease in natural light at the end of daylight hours. A smooth transition to artificial lighting does not distract the attention of visitors to the airport cafe.

The location scheme of the 530 mm HTLGs proposed for use in our design project is shown in Fig. 3.

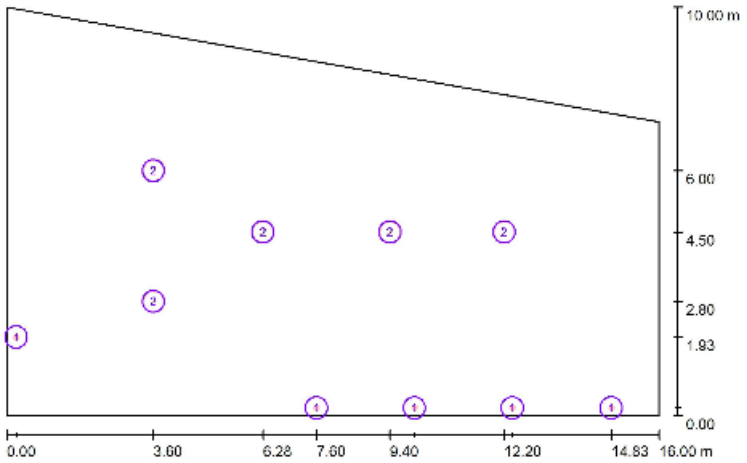

Figure 3. The layout of the fixtures (No. 1 - Bell / T LED 50v D15 4000K, No. 2 - Solarspot® D.530, scale 1: 115). Performed in the improved DIALux program.

Calculations of combined illumination (we also considered use of spotlights above the bar, in the corner of the room as an interior and additional light in the darkened areas of the terminal building cafe) gave the following results (Fig. 4, 5). Fig. 4 shows color visualization of distribution of natural light (in suites) on the floor, walls and furniture of the cafe. The level of illumination is normative. Details of the room are clearly visible.

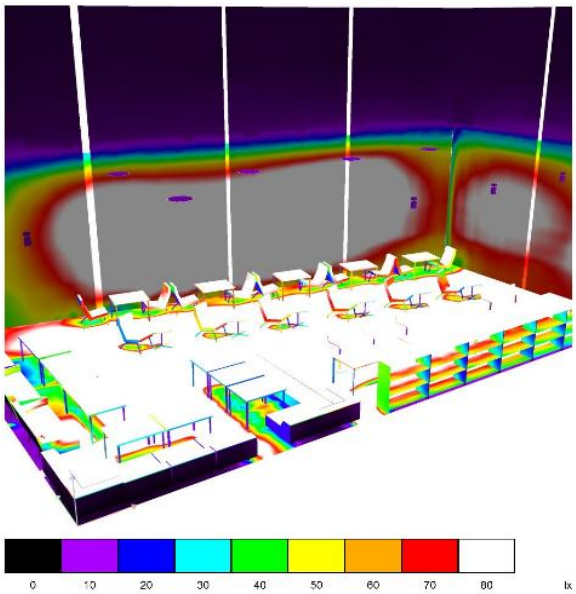

Figure 4. The illumination scheme of the terminal building cafe using Bell/T LED 50v D15 4000K lamps (5 pcs.) and LEDSOLARSPOT® D.530 hybrid HTLG (5 pcs.). Dummy colors - visualization. Performed in improved DIALux program.

In fig. 5 - a table of illumination values on working surface (in suites), adopted at the level of the cafe tables. Distribution of luminous flux of natural daylight in plane of the table surfaces is uniform and corresponds to normative.

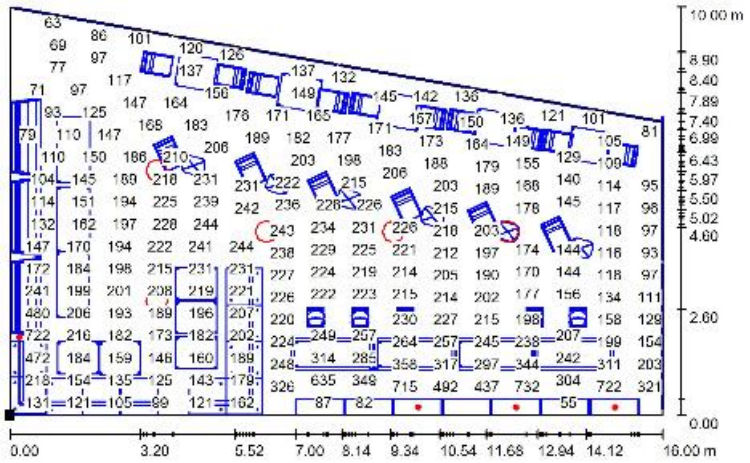

Figure 5. Table of illumination values in the airport terminal cafe. Work plane. Graph of values of E (E average value = 194 Lx; Emin = 27 Lx; Emax = 1007 Lx; Emin / E average value = 0.137; Emin / Emax = 0.026. Scale 1: 115. Developed in improved DIALux program.

While developing our design project for energy-efficient lighting of the airport terminal cafe premises, we also pursued another important goal: saving energy resources spent on air conditioning. In [6], we presented evidence of flawless operation of LEDSOLARSPOT® hybrid lighting systems in the winter climatic conditions of Russia, they are not present cold bridges. Air conditioning in summer is more expensive than heating in winter. Therefore, in the "heat problem" of the Annsys software package, we investigated other boundary conditions: the outdoor temperature is +35 °C; heat transfer coefficient of the outer surface of the building envelope is 7.91 W/m^2 · °C; indoor air temperature is +18 °C (in accordance with the requirements of Russian Building Code 118.13330.2012, p. 7.13 [15]);

heat transfer coefficient of the inner surface of the building envelope is 25.12 W/m^2 · ° C. The calculation results are shown in Fig. 6, 7.

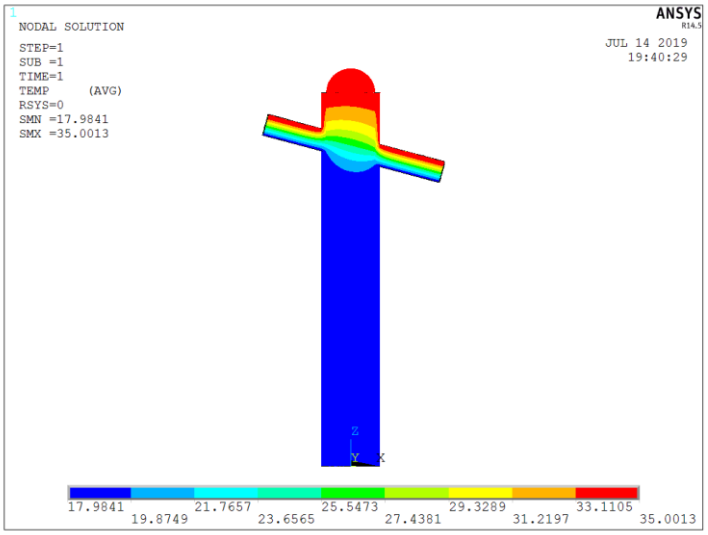

Figure 6. Temperature fields in the cross section of LEDSOLARSPOT® D.530 hybrid HTLG. The model is divided into 2704121 elements.

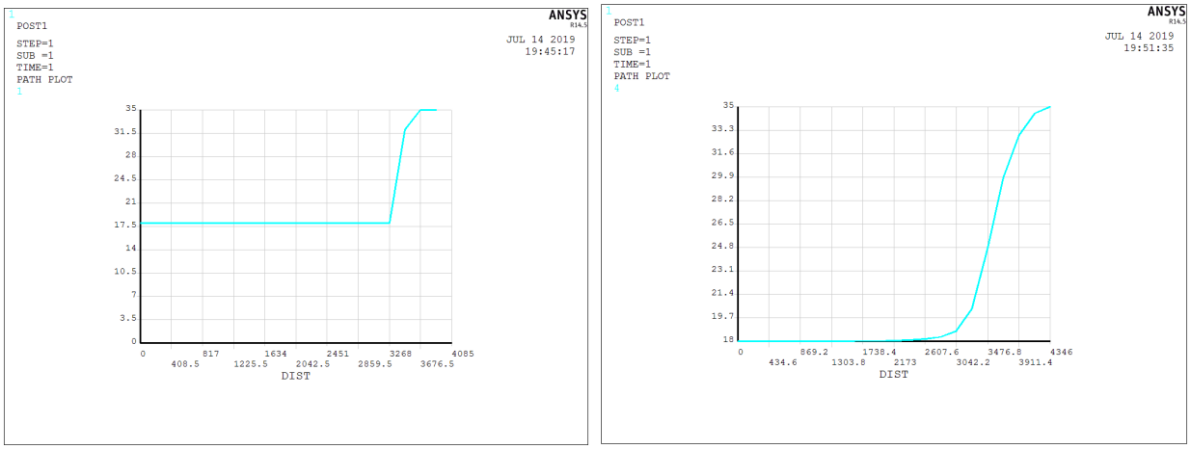

Figure 7. Temperature distribution graphs:
- along the Z axis of LEDSOLARSPOT® D.530 HTLG (X coordinate = 316 mm, Y = 0 mm) - to the left;
- along the Z axis of LEDSOLARSPOT® D.530 HTLG (coordinate X = 0 mm, Y = 0 mm) - to the right.

Analyzing the presented schemes (Fig. 6, 7), it should be concluded that the design features of the simulated hybrid lighting system LEDSOLARSPOT® D.530 completely impede penetration of heated air masses into the cafe. Design of the HTLG meets the heat engineering requirements of Russian Building Code 50.13330.2012 “Thermal protection of buildings” [16] at given temperatures of outdoor and indoor air and indoor humidity of 55%. An increase in the temperature of the internal air near the surface of the HTLG does not occur. That will contribute to a significant reduction of air conditioning cost inside the airport terminal cafe premises.

4. Calculation of cost savings associated with use of energy-efficient hybrid lighting systems based on hollow tubular light guides in the proposed design project for lighting the airport cafe

In the model of our design project for lighting the airport terminal cafe, we proposed light tinting of the outer window opening (Fig. 2), through which very little natural light enters the room, during the warm periods of the year – a lot of heat, and in winter – cold air flows. In this connection, the cafe administration is forced to use 2 modern split systems with cooling capacity of 5 kW, and heating capacity of 6 kW, seasonal energy efficiency (SEER) is 7.20 (A ++) and seasonal energy efficiency (SCOP) is 4.60 (A ++). One system cost is about €2.000, service life under the established operating mode is 2 years. The daily costs of operating split systems, excluding maintenance, repair and preventive works are about €10.

Taking into account the indicated initial data, as well as dynamics of annual increase in energy tariffs in Russia, dynamics of inflationary processes in Russia and Western Europe, significant (irrationally depending on time of the year and the prevailing climate map of the region) energy savings through use of energy-efficient natural sunlight and diffuse light delivery technology in a room with constant presence of people, we brought the dynamics of cost recovery in the developed design project (Fig. 8).

The calculations made show that it is possible to achieve a payback of own financial resources spent on the purchase of energy-efficient daylighting hybrid systems LEDSOLARSPOT® D.530 in 4 years. Investing into the project using borrowed capital is also cost-effective. Though the payback period will increase by 2-3 years.

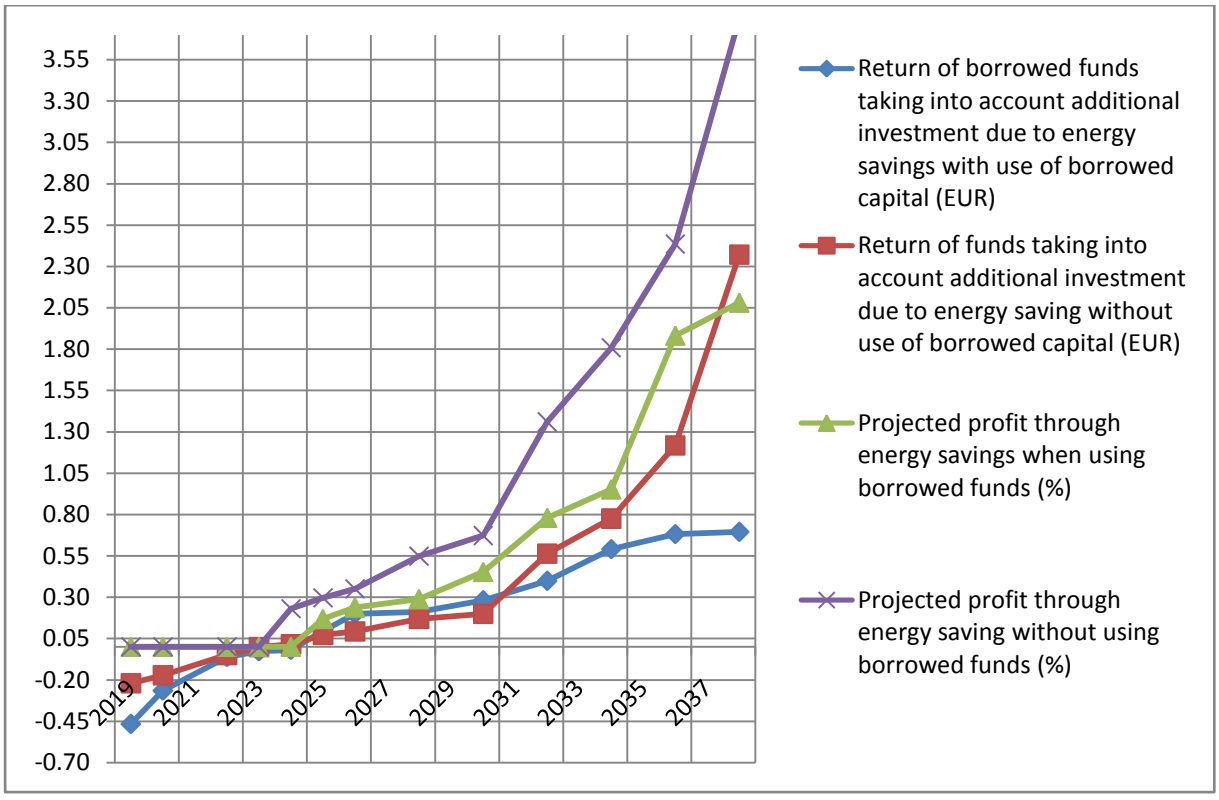

Figure 8. Calculation of the dynamics of funds return with additional investment to the project due to energy savings associated with use of energy-efficient daylighting hybrid systems LEDSOLARSPOT® D.530, along the ordinate axis – euro.

5. Conclusions

The calculations presented in this work allow us to draw the following conclusions.

1. Energy-efficient lighting systems based on hollow tubular light guides can form an integral part of design projects for lighting rooms with constant presence of people.

2. The design features of LEDSOLARSPOT® D.530 hybrid daylighting systems prevent the penetration of both cold and warm air currents into the rooms where they are installed, which can significantly save energy resources spent on heating and air conditioning and save the environment that surrounds us.

3. LEDSOLARSPOT® D.530 hybrid daylighting systems that we studied in the presented design project can help improve psychological comfort, emotional status and positive attitude of people who have to stay in these rooms for a long time.

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