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Measurement device for light pipe evaluation

***Abstract**. Two types of light pipes of comparable dimensions were tested. The evaluation of light guides was based on data of long-term measurements of daylight illuminance. A set of illuminance meters distributed on the reference plane under the light pipes were used. The illuminance measurements were processed using a data collecting system. The system collected data for one-year continual measurements. The measured data analysis shows differences in the tested light pipes daylighting which is relevant to their practical applications.*

Streszczenie.** Przetestowano dwa rodzaje światłowodów o porównywalnych wymiarach. Ocenę światłowodów oparto na danych z wieloletnich pomiarów natężenia oświetlenia dziennego. Zastosowano zestaw mierników natężenia oświetlenia rozmieszczonych na płaszczyźnie odniesienia pod światłowodami. Pomiary natężenia oświetlenia były przetwarzane przy użyciu systemu zbierania danych. System zbierał dane do rocznych ciągłych pomiarów. Przeprowadzona analiza danych pomiarowych wskazuje na różnice w oświetleniu badanych światłowodów, co ma znaczenie dla ich praktycznych zastosowań.* (Urządzenie pomiarowe do oceny światłowodów***)

Keywords: daylight measurements, daylighting, light pipe.
Słowa kluczowe: światłowód, urządzenie pomiarowe, natężenie oświetlenia

Introduction

Light pipes represent systems of light transport to building interiors due to multi-reflections on their internal reflective surfaces. Common light pipes consist of highly reflective tube and roof dome and ceiling diffuser. The light pipe systems found various practical applications. They are recommended for deep plan rooms and indoor places without windows like corridors. where light guide installation of could be energy saving alternative to common artificial lighting. It means the light guide systems have a big potential as sustainable resources of daylighting and integral lighting in buildings.

Light pipes were studied in research projects and case studies. Tubular daylight guidance systems were specified in the CIE technical report [1]. Applications of light pipe systems for interior daylighting were studied [2]. Achieved and predicted performance of light pipes were analysed [3]. Daylighting of internal spaces with light pipes was monitored and experimentally tested [4-8]. Mathematical models [9,10] and outputs of daylight simulations were analysed [11,12]. Additionally, light pipes were evaluated not only for light transports but also for ventilation [13,14] and temperature distribution [15] and for hybrid lighting [16,17].

Light pipe applications in real buildings influence many factors, like dimensions, optical parameters and also ways of installation in buildings. In practice, light pipe parameters are usually selected from technical documentation of light pipe products and installations are provided in accordance with empirical rules and good practice references.

Testing of light pipes based on long term daylight measurements [18] could bring data for specification of design parameters for real applications of these systems.

Selected light pipes were compared and studied for their daylight transmittance on basis of daylight illuminance measurements and spectral transmittance analysis. A simple experimental device was completed for the daylight measurements and data collection.

Daylight illuminance measurements

A case study focused on evaluation of straight light pipes daylighting was carried out. Daylight illuminance levels from two comparable light pipes was monitored. The tested light pipes are products of different contractors. The goal of the evaluation was to determine which of these comparable products is more efficient for interior daylighting.

Long term daylight measurements were provided

The light pipes were installed onto a test chamber, Figure 1. The chamber was divided into two identical boxes illuminated through the light pipes LP1 (length/radius = 2.5 m/0.265 m) and LP2 (length/radius = 2.5 m/0.275 m).

Daylight illuminance measurements were carried out due to a set of eleven illuminance meters – five internal sensors in every box and one external sensor which is protected by a plastic transparent cover. The couple of five illuminance meters set were fixed on wooden profiles located in position of a reference plane 2 m under the light guide diffuser, Figure 2. Every illuminance set consists of illuminance meters in the position of the light guide vertical axis and four illuminance metres located in four positions at distance 1 m from the central axis.

Illuminance meters CEM DT-86 (resolution 0.1 lux, accuracy +/-5%) were used for the light measurements. In total eleven illuminance meters (2 x 5 internal sensors and 1 external sensor) with electronic circuit are connected with the star network. The electronic device circuit has one-chip microcontroller ATmega168 for the transmitted signal decoding.

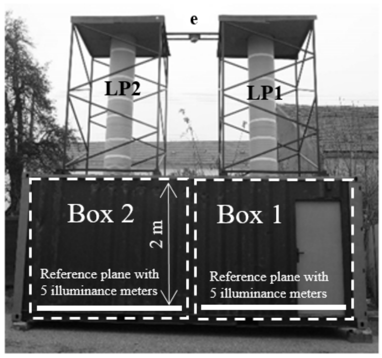

Fig.1. Test boxes with the light pipes. Photograph of the light pipes installation, e - external illuminance meter

The illuminance measurements were processed using a data collecting system, Figure 3. The electronic device collects data from illuminance meter displays. Measurement data sorting is completed due to busbar RS485 connected with illuminance meters and the computer. The busbar is standardized with specification of TIA-485-A. The measured data are sent from the busbar to a computer data logger for processing. The star network was used for the connection due to four wire cable where twelve wires are for power supply (from 9V adapter) and two ones for the data transmission.

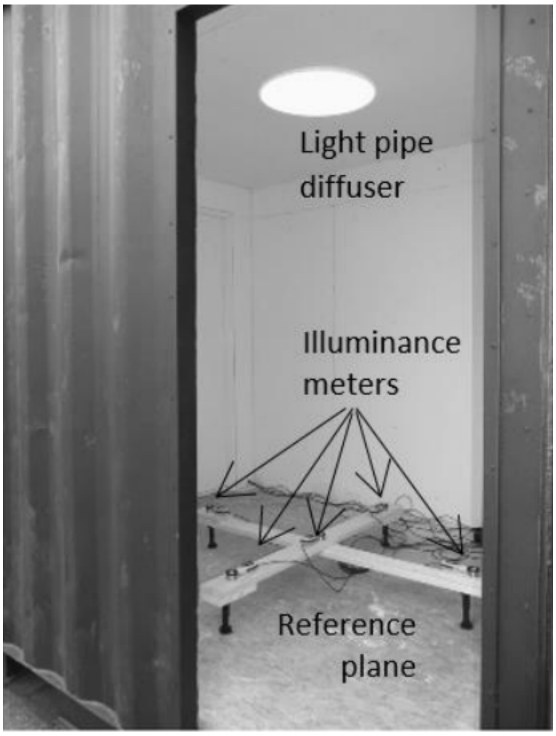

Fig.2. Illuminance meters on the reference plane - view into Box 1

The illuminance meter display data reading is for three times from the display segments. In case of three comparable readings the data digit is selected and recorded. The recording time is about 20 ms. In case that the mentioned process is not successful the procedure is repeated up to four times. In total the process duration can be prolonged from 20 ms to 100 ms. The measured data sorting software was completed in system LabVIEW for MS Windows and it is applicable for PC or notebooks.

The measurement set is connected with the computer via connector USB/RS485. The operational system gives specification to the connector and this specification is written into the measurement procedure tool. The tool gives order to all electronic circuits for measurement data monitoring on the illuminance meter display. Particular illuminance meters are ordered for the measured data records. Data transmission from all illuminance meters are recorded nearly simultaneously.

Time delay of individual readings is less than 1 s, usually less than 0.4 s. In case of measurement error, the program orders the particular illuminance meter for the corrected value. The measurement program sends order to illuminance meters to restart in every five-minute interval (the restart time is 5 seconds). The time interval of data collecting is between 1 and 5 minutes.

The tool also controls display of measured values on the PC monitor. The measured data are recorded into the text file that can Excel data be used for the MS processing.

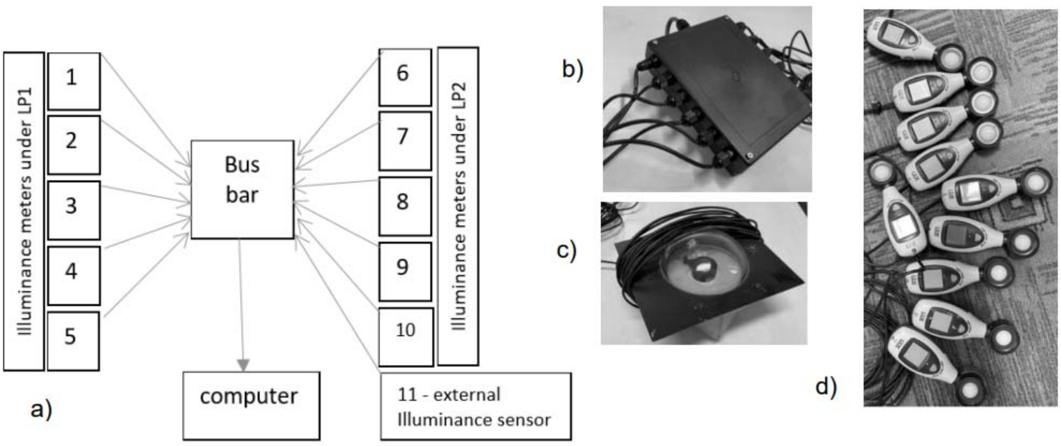

Fig.3. Data collecting system for daylight illuminance measurements
a) Scheme of the illuminance data collecting system, b) Busbar for the measured data processing, c) External illuminance sensor with transparent cover

Daylight transmittance monitoring

Light pipe efficiency depends on amount of light transmitted through the light pipe system. For this reason, a comparative evaluation of spectral light transmittance of the light pipes were carried out using camera Rollei d30 flex (objektive Rollei D Apogon 2,8-4,0/10-30 mm) with sensor 1,4 MP 2/3“ CCD.

The camera was positioned on the reference plane in the distance 2 m under the light pipe diffuser, Figure 4. The evaluation was provided in situ in the test boxes with the installed light pipes for conditions of cloudy sky in February.

Daylight illuminance

Data processing analysis from one-year illuminance measurements performs interesting results. Examples of monthly illuminance profiles are shown in Figure 5, for winter, spring and autumn climatic conditions in February, April and August. The graphs compare data of mean daily illuminance determined from the illuminance measure data.

The graphs give information about higher illuminance of box 1 with the LP1 installation compared to the LP2. It was proven for all cases of sky conditions. Higher daylight illuminance level in box 1 is because of higher light transmittance through the system of the LP1 light pipe.

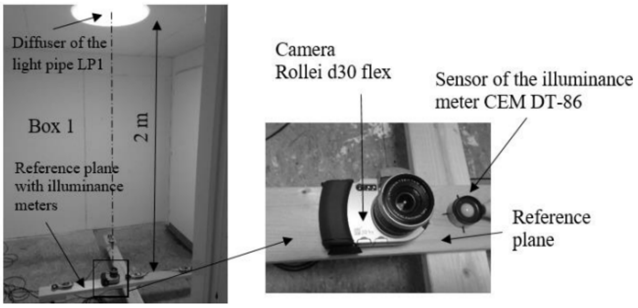

Fig.4. View into box 1 with installation Camera Rollei d30 flex on the reference plane

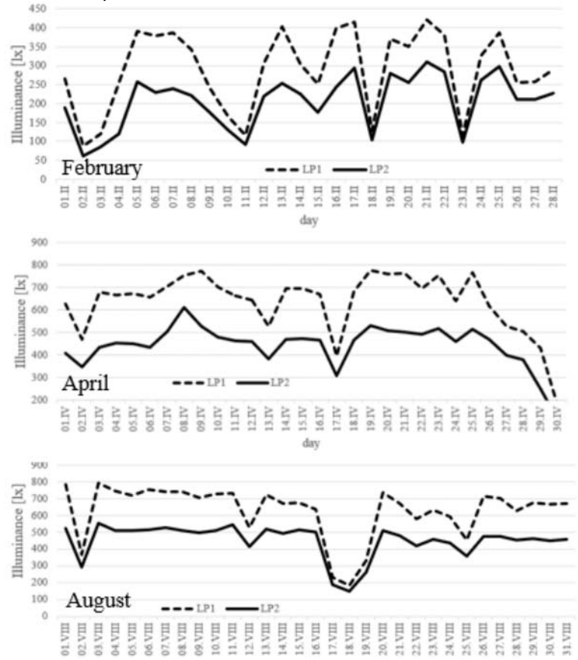

Fig.5. Daily averages of illuminance on the reference plane under light pipes LP1 and LP2

Daily profiles of illuminance under the light pipes LP1 and LP2 are shown foe partly cloudy and cloudy sky conditions in Figure 6 and for clear sky conditions in Figure 7. It is obvious that the differences in daylight levels are gigger for clear sky compared to the overcast sky conditions.

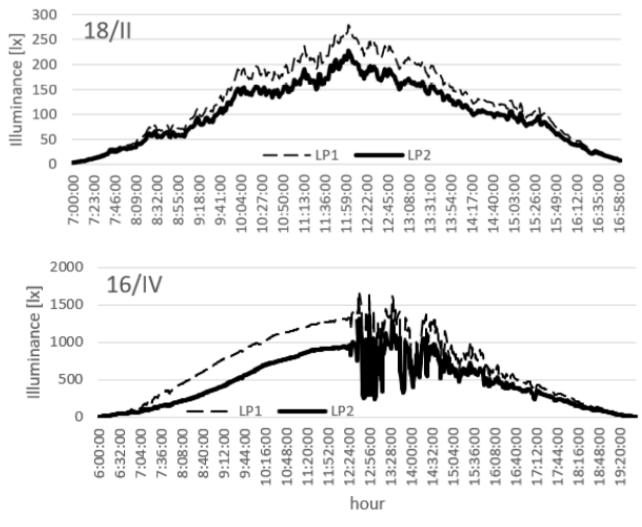

Fig. 6 Characteristic daily profiles for overcast and partly cloudy sky conditions (18th February and 16th April)

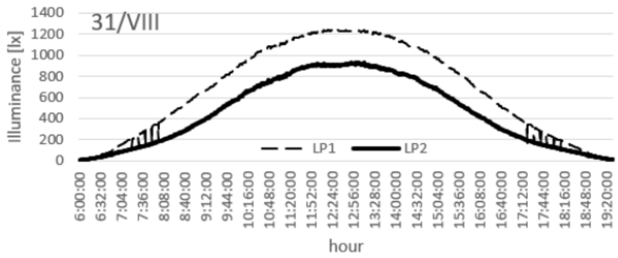

Fig. 7 Daily profile for clear sky conditions (31st August)

Spectral transmittance

The two light pipes were also studied for spectral transmittance. Spectral transmittance in the boxes under the tested light pipes LP1 and LP2 compared with the spectral distribution of natural light is shown in Figure 8. It is clear that both light pipes transmit daylight in the wide range of the visible spectrum between 380 and 780 nm. Although, the light transmittance through the light pipe is reduced. The transmittance of light pipe LP1 is higher than transmittance through light pipe LP2. This finding also confirms that the system of LP1 performs better daylight level than LP 2 light pipe.

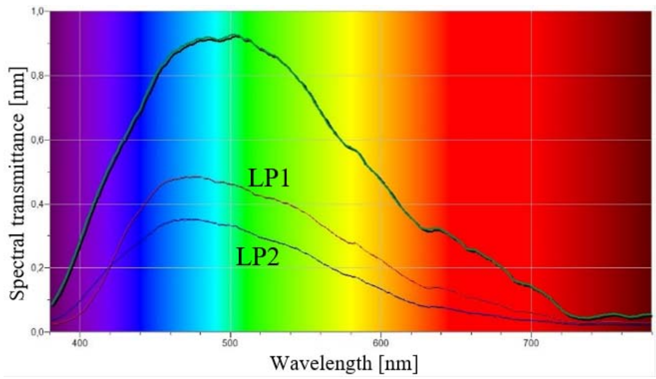

Fig.8. Spectral transmittance of light pipes LP1 a LP2 compared with spectrum of natural light

Conclusion

The method based on the analysis of one-year illuminance monitoring under light pipes was described. The selected light pipes have comparative dimensions and they are declared of similar performance in the contractors' technical documents.

Nevertheless, the light pipes support different daylight levels in the text boxes. The results of measurements brought information that the LP1 system is more efficient than the LP2 light pipe. It practically means than declared parameters of some of light pipe products are overestimated.

Finally, it was found that the light pipe LP1 has higher reflectance of pipe internal surface. Highly reflective light pipe transmits more light into interiors. The light pipe efficiency is decreased because of reduced light reflectance of its internal surface.

For the light pipes of comparable dimensions and installations, their optical properties play key role in different performance. It means light transmittance of transparent covers like roof domes and ceiling diffusers as well as light reflectance of pipes influence efficiency of the light guiding systems. Parameters of light pipes should be controlled and experimentally specified for correct design and prediction of light pipes' performance.

Long term monitoring of light pipe and data from daylight measurements represent possibility for specification of design parameters for application of these systems in buildings design [19] for electric energy savings [20] and indoor climate comfort.

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REFERENCES

[1] CIE 173:2006. Tubular daylight guidance systems. CIE Technical Report, 2006, CIE, Vienna.
[2] Rosemann, A., Kaase, H., Lightguide applications for daylighting systems. *Solar Energy*, 78 (2005), 772-780.
[3] Al-Marwaee, M. Carter, D. J., Tubular Guidance Systems for Daylight: Achieved and Predicted Installation Performances. *Applied Energy*, 83 (2006), 774–788.
[4] Li, D.H.W., et al., An analysis of light-guide system via full-scale measurements. *Applied Energy*, 87/3 (2010), 799-805.
[5] Carter, D.J., The measured and predicted performance of passive solar light pipe systems. *Lighting Research and Technology*, 33/1 (2002), 39-52.
[6] Vasilakopoulou, K. et al., Analysis of the experimental performance of light pipes. *Energy and Buildings* 151 (2017), 242–249.
[7] Darula, S. et al. Measurement of tubular light guide efficiency under the artificial sky. *Przeglad Elektrotechniczny* 86/10 (2010), 177-180.
[8] Omishore, A.; Mohelník, P.; Miček, D. Light pipe prototype testing. Przeglad Elektrotechniczny, 4 (2018), 107-112.
[9] Kocifaj, M., Darula, S., Kittler, R., HOLIGILM: hollow light guide interior illumination method – an analytic calculation approach for cylindrical light-tubes. *Solar Energy*, 82/3 (2008), 247-259.
[10] Zhang, X, Muneer, T., Mathematical model for the performance of light guides. *Lighting Research and Technology*, 32 (2000), 141–146.
[11] Tsang, EKW, Kocifaj, M., Li, DHW el al. Straight light pipes' daylighting: A case study for different climatic zones. *Solar Energy* 170 (2018), 56-63.
[12] Darula, et al. Hollow light guide efficiency and illuminance distribution on the light-tube base under overcast and clear sky conditions. *Optik*, 124/17 (2013), 3165–3169.
[13] Shao, L., Riffat, S.B., Daylighting using light pipes and its integration with solar heating and natural ventilation. *Lighting Research and Technology*, 32/3 (2000), 199-139.
[14] *A*. C. Oliveira, A. R. Silva, C. et al. *Exp*erimental and numerical analysis of natural ventilation with combined light/vent pipes, *Applied Thermal Engineering*, 21/18 (2000), 1925-1936.
[15] Šikula, O., Mohelníková, J., Plášek, J. Thermal CFD analysis of tubular light guides. *Energies*, 6/12 (2013), 6304–6321.
[16] Mayhoub, M. S. Innovative daylighting systems' challenges: A critical study, *Energy and Buildings*, 80 (2014), 394–405.
[17] Malet-Damour, B., Bigot, D., Boyer, H. Technological Review of Tubular Daylight Guide System from 1982 to 2020. *EJERS*, *European Journal of Engineering Research and Science* 5/3 (2020), 375-386.
[18] Hrbáč, R., Novák, T. et. al. Microprocessor controlled luxmeter with automatic operation and digital data recording for long-term measurements (not only) of low Illuminance. *Przeglad elektrotechniczny*. 89/6 (2013), 337-340.
[19] Šumpich, J., Novák, T. et. al. Calculation of saving possibilities in interior lighting system using both daylight and artificial light. *Przeglad elektrotechniczny*. 6 (2013), 345-347.
[20] Flimel, M. Daylight ensuring predictive buildings design, *Przeglad Elektrotechniczny* 8 (2008), 26-28.