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LIGHT GUIDE EVALUATION

HODNOCENÍ TUBUSOVÉHO SVĚTLOVODU

SHORT VERSION OF DOCTORAL THESIS
TEZE DISERTAČNÍ PRÁCE

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1 INTRODUCTION

Most people spend a majority of time during the day in indoor environment, commercial or residential. Quality of interior environment of buildings is therefore extremely important for the human physiological and psychological development. One of the monitored aspects is lighting system. Lighting is an important factor in determining the way, how we experience buildings, internal environment as well as how we are able to respond to certain tasks. It is a key element of architectural and interior design. It comprises use of natural illumination of interiors from daylight and artificial light sources.

Artificial lighting for functional and/or aesthetic purposes is a major consumer of energy worldwide. Increasing concern about energy depletion, energy conservation and cost, which has been steadily rising and also adverse environmental impact of pollution, carbon emission and global warming, has led to a reappraisal of the use of daylight as an electric lighting substitute. Lighting and HVAC are two of the major energy end uses in a building. Properly incorporating sustainable and effective lighting into the facility's design is one of the best ways for energy conservation in buildings. The reason for daylighting preference is not only energy efficiency but also a positive impact on human health.

There are many systems for daylight collection and transportation in buildings. These daylighting devices have been developed with the aim of contributing to an efficacy energy savings. One of these devices is a light guide system which is a subject of the thesis investigation.

1.1 TOPIC OF THE THESIS

Initially, light guide systems were used at random and without knowledge of their optical properties. Lighting was predicted on the basis of empirical rules and based on experience from earlier realizations. Problems have arisen mainly due to the lack of illumination under the cloudy sky conditions or, on the contrary, due the glare on bright sunny days. There was no detailed research. Today, due to energy and environmental concerns to reduce energy consumption in a lighting system, light guides have been investigated and have become one of the energy-efficiency techniques widely applied in buildings. They also have a positive influence on visual comfort.

New highly reflective materials and light tube components are tested to increase the light guide efficiency. Several methods for predicting delivery and distribution of light into the interior are being developed. Systems are continually evolving and improving, and legislation and standards are not sufficient. Therefore, there is a need to examine them further. For this reason, the selected topic of the thesis aimed at the light guide prototype evaluation is actual and in compliance with current research tasks.

1.2 AIMS OF THE THESIS

- Complete the comprehensive state of the art about the light guide systems development and overview of the evaluation methods for daylight illuminance and efficiency testing.
- Testing of the light guide prototype with mirrored concentrating head for light transmittance into the test chamber in laboratory conditions.
- Thermal evaluation of the light guide model under an infrared lamp radiation.
- Complete field daylight measurements for an evaluation of light efficiency of two light guides of same geometry and dimensions but with different roof collectors.
- Simulation case-study of daylight level on working plane for the light guides from the field measurements.
- Analysis of possible improvements of the light guide prototype for the optimised design of the daylight guide system.

2 OVERVIEWS OF THE STATE OF THE ART IN THE FIELD OF LIGHT GUIDE DAYLIGHTING

2.1 GENERALY ABOUT SOLAR RADIATION

The Sun is the source of an enormous amount of energy. A portion of this energy provides Earth with the light and heat necessary to support life. For centuries, before the advent of electricity, the sun was the primary source of light. All human activities were provided under the sun.

2.2 DAYLIGHT

Light is a primary tool for perceiving the world and communicating within it. It describes our environments. Daylight is the natural light of global solar radiation during the daytime. This includes direct sunlight, diffuse sky radiation, and often both of these reflected from the ground surface and neighbouring obstructions as buildings, trees etc.

Daylighting in buildings is influenced the by climatic conditions of the locality and seasonal time. Daylighting is the controlled admission of natural light into a space. It helps to create a visually stimulating and productive environment for building occupants. Research [1] has shown that the daylight offers high luminous efficacy compared to majority of artificial lighting.

2.3 THE DEVELOPMENT OF SOLAR LIGHT GUIDE SYSTEMS

Piping light for illumination purposes is a concept which has been around for a long time. First to design and implement hollow light guides was [2]. Many light guide designs have been patented [3-8]. Numerous theoretical models have been attempted to address the transmittance efficiency of the light guides. Early developments concentrated on light transport, tubes reflective materials, sectional shapes, tube lengths, diameters, elbows [9,10]. Technical Committee TC 3-30 Hollow Light Guides was established by the International Commission on Illumination CIE. Comprehensive investigation by a team of experts was completed and the CIE 173:2006 Tubular Daylight Guidance Systems was published [11]. Mathematical models [12] and computer simulations followed [13-16]. [17,18] reviewed innovative daylight systems, described challenges, cost, utilization, difficulties and applications limitations. Thermal behaviour was studied [19,20]. [21] presented a brief history of researches and developments into the Building core sunlighting systems (BCSS) over the last fifty years.

2.3.1 Tubular daylighting device (TDD) – light guide

Tubular daylighting device (TDD) is a device that can capture and transmit light from external artificial or natural light source to building interior for lighting purpose. Light guides can be passive, active and horizontal or vertical. Passive TDD are stationary. The illumination they provide is completely dependent on the geographical location, angle of the sun in the sky, season, time of day, the changing local weather conditions. Active systems actively follow the sun and use mirrors to drive its illumination down into a interior of building. They do not depend on the sun position in order to create illumination. There are three main components - collector, tube and diffuser.

2.3.2 Challenges of daylighting systems

The innovative daylighting systems are still facing challenges. They are the innitial cost (components and optical material prices, technology complexity), application limitations (geographical location, time of measurement, sky condition, building form), technology challengies (to deliver more daylight over further distance via smaller guides) and user acceptance [17].

2.3.3 Light guides – prediction

There are several methods describing light guide performance predictions, e.g. CIE computational method [11], Luxplot package model, Tsangrassoulis method [14], HOLIGILM (Hollow light guide interior illumination method) [15].

3 METHODS

The main task of the thesis is to test and evaluate a new special type of the light guide prototypes.

Task 1 – laboratory testing

1a) daylight measurements

- Testing a new prototype of the light guide (mirrored concentrating head) for light transmittance in the test chamber in laboratory conditions.
- Light guide model 1 type and dimensions: tube diameter – 0.52 m, concentrating head: two parabolas with mirror surface, the primary parabola: diameter 1.20 m, the secondary parabola: diameter 0.55 m.
- Test chamber made from plywood sheets on hard wood frame with internal dimensions 1.50 m x 1.50 m x 1.50 m. The light guide is installed in the central position over the chamber.
- Light sensors (luminance meters LUXTRON LX 1128 SD) are placed on top of collector glazing, above (about 200 mm) the collector and inside the chamber at floor level.

1b) thermal measurements

- Thermal measurements under infrared lamp activation.
- Temperature sensors are placed above (about 200 mm) the collector, on top of the collector, under diffuser, inside the tube and on reflective mirrors.

Measurement apparatuses:

- Data logger ALMEMO 3290-V5.
- Thermal sensors (Thermocouples of type Ni-Cr-Ni of type K).
- Infrared lamp, thermographic camera (ThermaCAM PM695).

Task 2 – field testing

- Complete field daylight measurements for an evaluation of light efficiency of two light guides of same geometry and dimensions, but with different roof concentration collectors. Testing of the temperature profile of the light guides during summer season conditions for study of possible overheating problems.
- Container 2.3 m x 4.6 m x 2.85 m was divided into two identical parts. Light guide model LG1: roof collector with parabolic concentrator, metal tube diameter 0.52 m, length 0.6 m, diffuser. Light guide model LG2: glass roof collector, metal tube diameter 0.52 m, length 0.6 m, diffuser.

Task 3 – Daylight simulations

- Simulation case-study of daylight illuminance level on a working plane for the light guides from the field measurements.
- Daylight simulations using software HOLIGILM [15] – daylight

illuminance on the working plane 2.80 m under the diffuser.

Task 4 – Results analysis

Analysis of possible improvements of the light guide prototype for the ptimized design.

- Specification of characteristic details of the atypical light guide and their installations in buildings.

4 MEASUREMENTS

4.1 LIGHT GUIDE COLLECTOR – LABORATORY TESTING

A prototype of a light guide with a mirrored parabolic head [22] was tested under laboratory conditions. The daylight illuminance measurements were carried out from April 2015 to August 2015. The readings were taken for illumination at the reference plane at 1.50 m below the diffuser in the position of the light guide vertical axis and on top of the collector glass (Fig. 4.1).

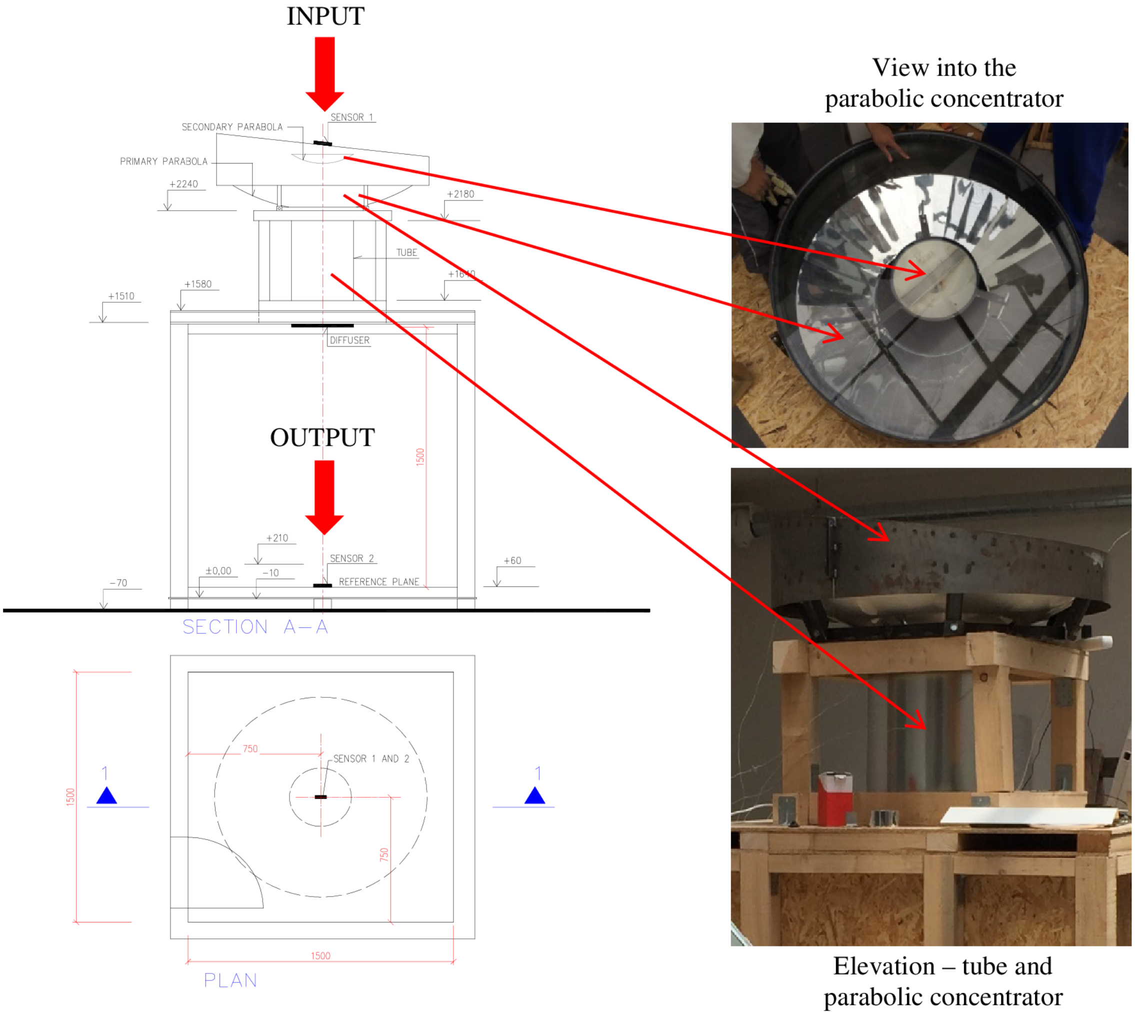


Fig. 4.1: Chamber (plan, elevation) and photographs of the light guide concentrator

4.2 Thermal evaluation of the light guide – laboratory testing

The tested prototype was mounted on the chamber. The temperature sensors were placed on the parabolic concentrator head and into the tube (Fig. 4.2). The temperature distribution on surfaces of the light guide was monitored by temperature measurements and infrared thermography monitoring. The temperature profiles were tested as provided under laboratory conditions. The light guide was also exposed to radiation of an infrared lamp.

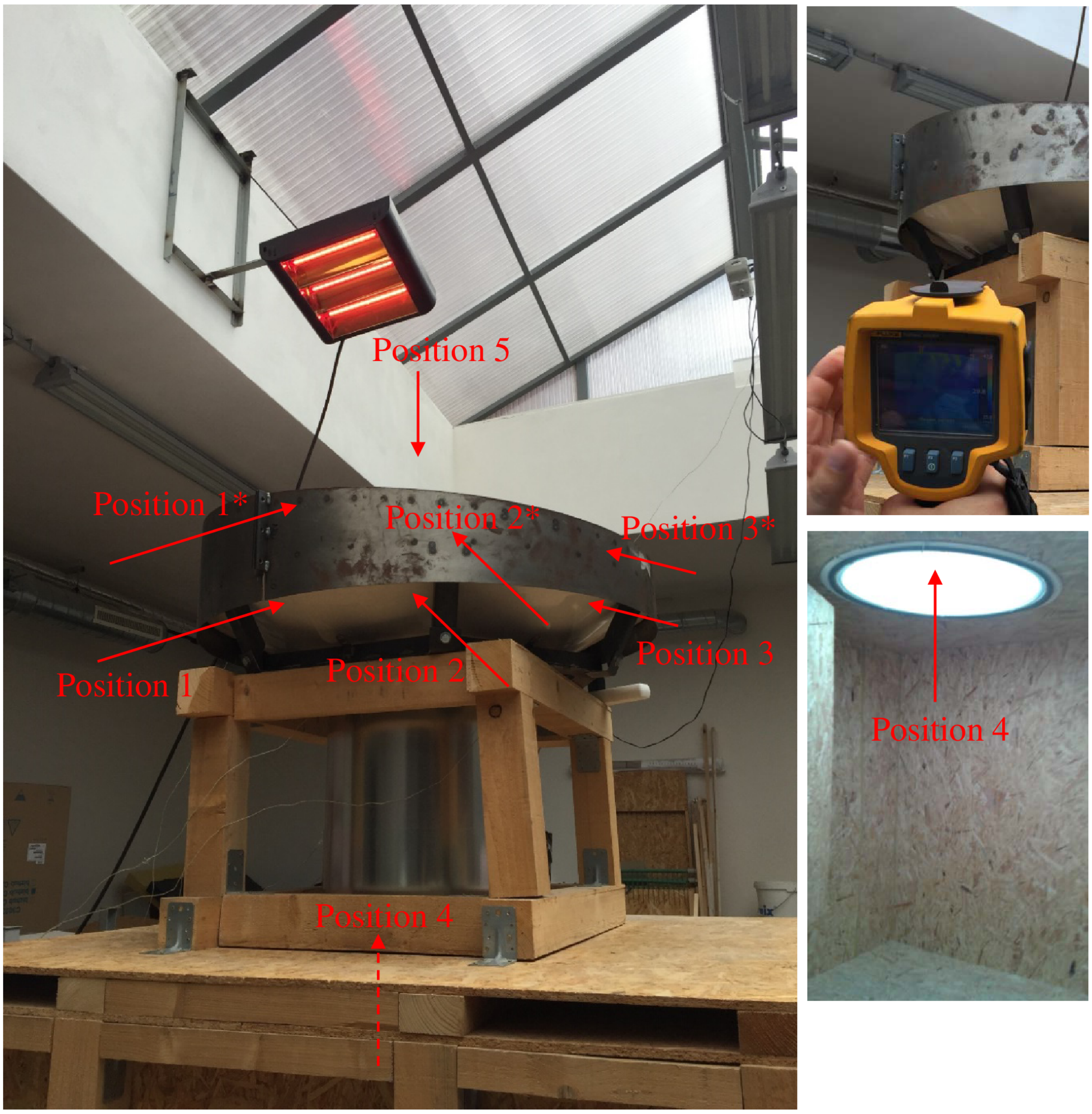


Fig. 4.2: Photograph of the light guide under the IR lamp radiation and view to the light guide diffuser (inside the chamber)
(Positions 1, 2, 3 – directions of IR camera monitoring, position 4 – on the diffuser, position 5 - placement of IR lamp [40], positions 1*, 2*, 3* - on the metal rim of the light guide head).

The infrared thermography and temperature measurements were also carried out for the light guide with additional thermal insulation 10 cm round the upper part of the light tube in the contact with the parabolic concentrator (Fig. 4.3). The thermal insulation was used to simulate the real installation of the prototype model in thermally insulated building constructions.

Fig. 4.3: Photograph of the light guide with additional thermal insulation (mineral wool)

4.3 Light guides comparative measurement – field testing

A comparative study was carried out for two light guides – one (LG1) with a concentrating mirror parabola (CMP) collector and the other one conventional (LG2). They were equipped with identical tubes of length 0.60 m and diameter 0.52 m but a different roof collector installation. LG1 has a primary mirror parabolic head with a secondary convex parabola under a flat glass cover while light guide LG2 is with a common glass roof collector (Fig. 4.4). The tube of both light guides is rigid, made from hard aluminium sheet. Its interior surface is coated with highly reflective layer. The light reflectance of the tube internal surface is $\rho = 0.95$. Both of the light guides have internal transparent plastic cover – diffuser. LG1 and LG2 were installed into a container with flat roof with internal dimensions 2.30 m x 4.60 m and clearance height 2.85 m (Fig. 4.4). The container was divided into two identical parts, separated by black curtain (Fig. 4.5). The inner walls were also covered with black cloth, so only sky component of daylight transmitted through the light guide influences indoor illuminance level. Daylight illuminance in both parts of the container was simultaneously monitored as well as external horizontal illuminance on container roof. A set of calibrated luminance meters Lutron LX-1128SD was used for the experiment. Daylight illuminance measurements were completed in one minute monitoring intervals for one month period between 22nd August and 23rd September 2017. Luminance meters were positioned in the axes of the light guide and in the distance 2.80 m from the light guide diffuser. The testing was completed in the temperate climatic region of city Brno, latitude 49°90', longitude 16°41' and altitude 246 m.

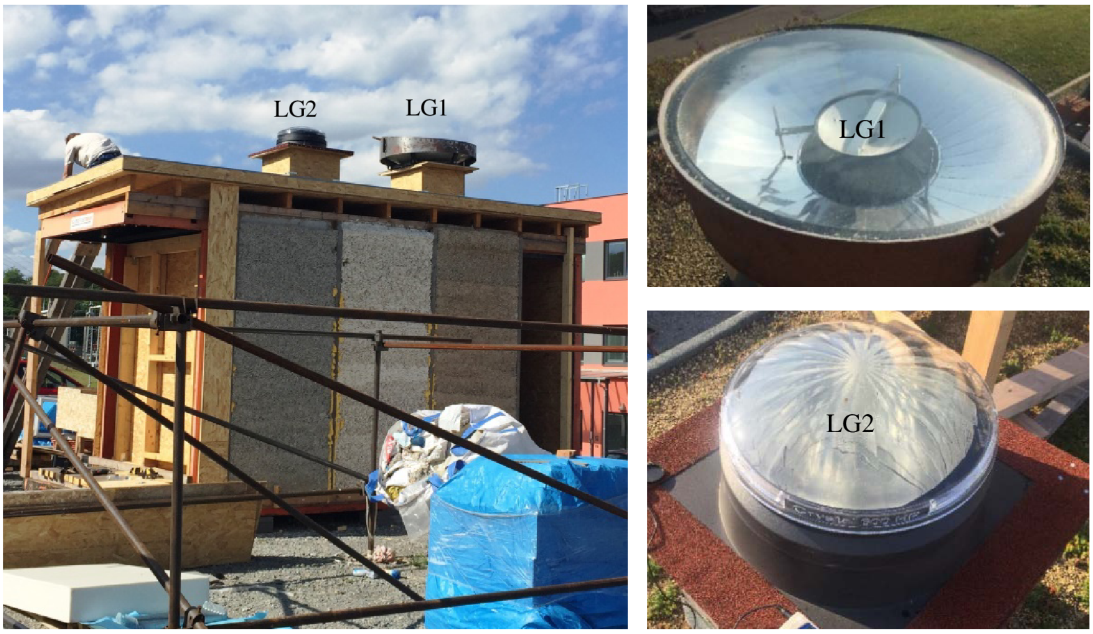


Fig. 4.4: Tested light guides LG1 and LG2 – the roof installation

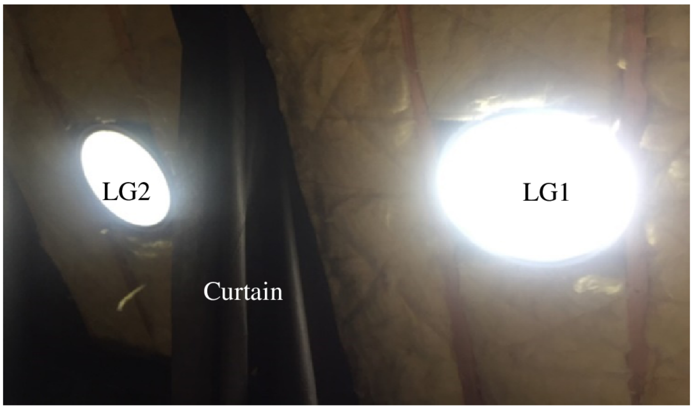


Fig. 4.5: Container's two identical parts, separated by black curtain

5 RESULTS

5.1 LABORATORY MEASUREMENTS

Light guide prototype testing

Examples of daylight illuminance measurements have been selected for the most characteristic profiles of the locality – for nearly clear sky conditions with moving random clouds at noon on 25th May (Fig. 5.1), cloudy sky conditions with time intervals of low illuminance in the morning changed with higher illuminance level in the afternoon on 2nd May (Fig. 5.2) and also for conditions of dynamic changes in external illuminance on 23rd June (Fig. 5.3) when clear sky with solar shining alternates with overcast sky due to frequent moving clouds.

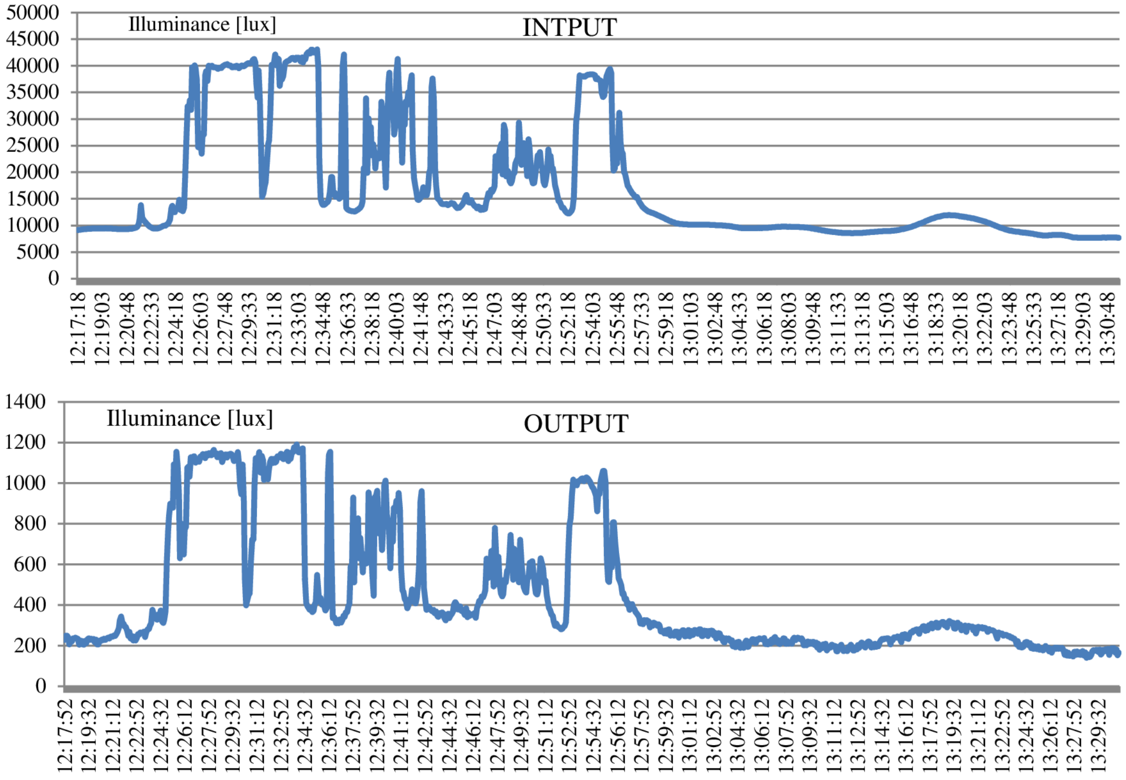


Fig. 5.1: Daylight illuminance at the input (at the entrance the the concentrating head) and output (inside of the chamber), 25/05/2015.

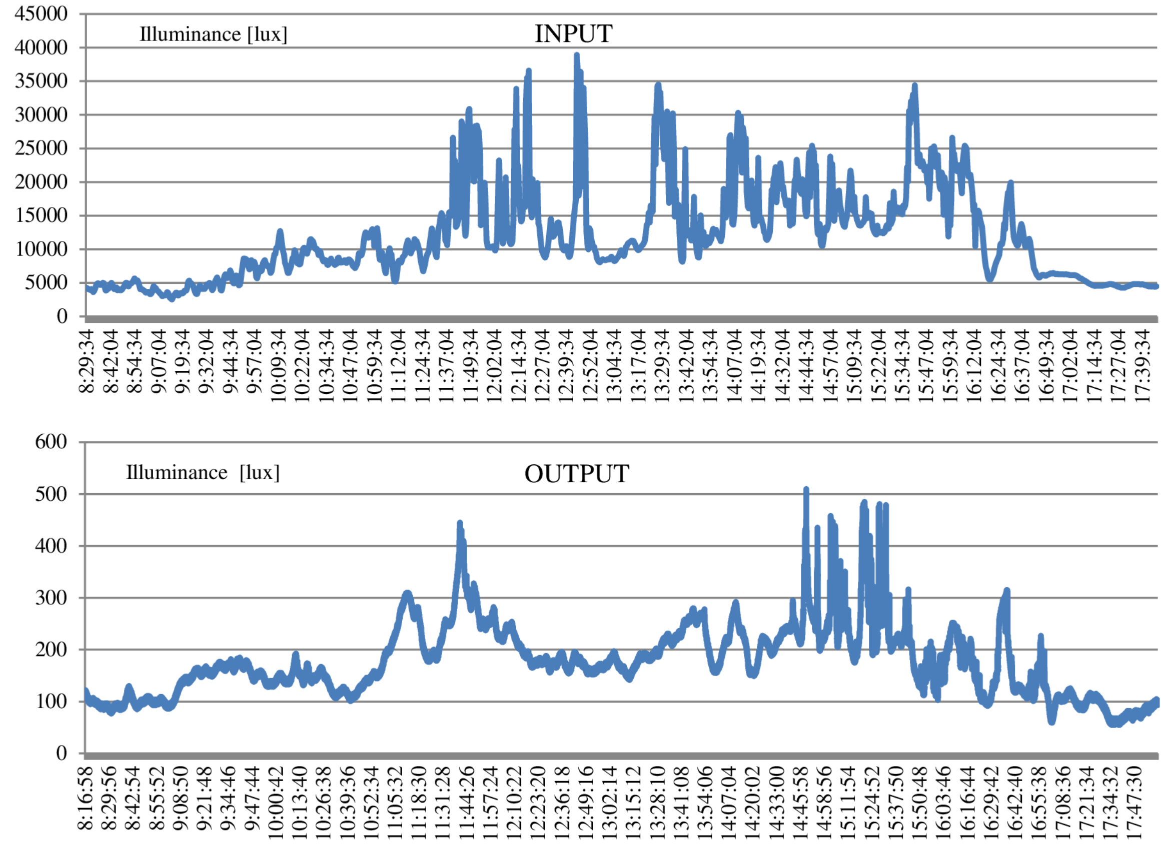


Fig. 5.2: Daily profiles of illuminance on the input and output of the light guide for cloudy sky daylight illuminance, 02/05/2015

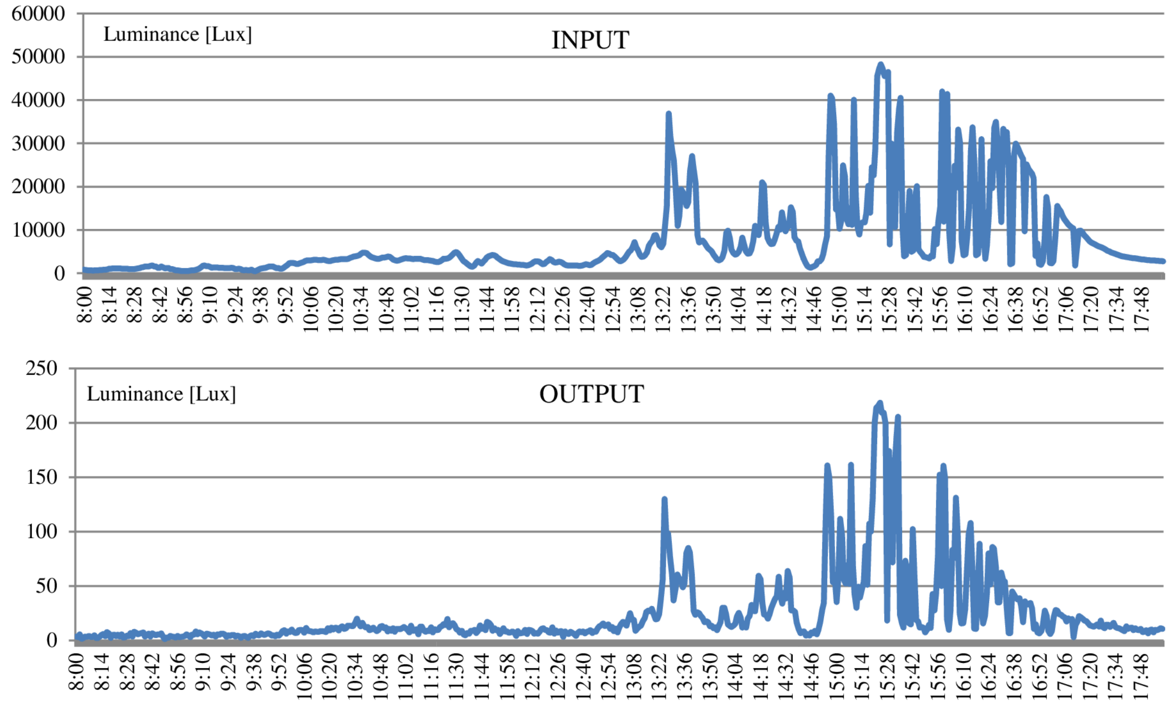


Fig. 5.3: Daily profiles of illuminance on the input and output of the light guide for dynamic changes of daylight illuminance, 23/06/2015

The input and output illuminance measurements are compared in the trend-line (Fig. 5.4) for cloudy and partly cloudy days monitoring in June.

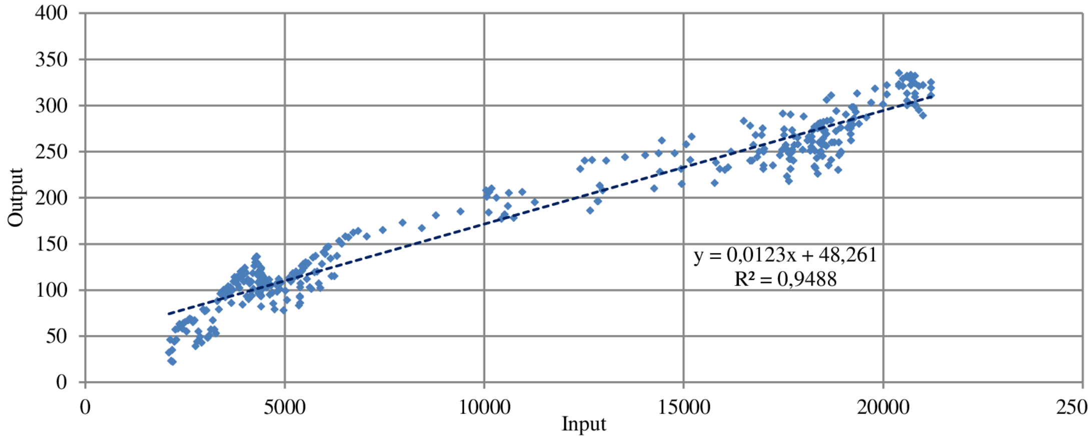


Fig. 5.4: Trend line of the input and output illuminance measurements (cloudy and partly cloudy days in June 2015)

Measured illuminance data at the input of the light guide is shown for selected days during the monitoring period in Fig. 5.5 for minimal, maximal, mean as well as median daily values.

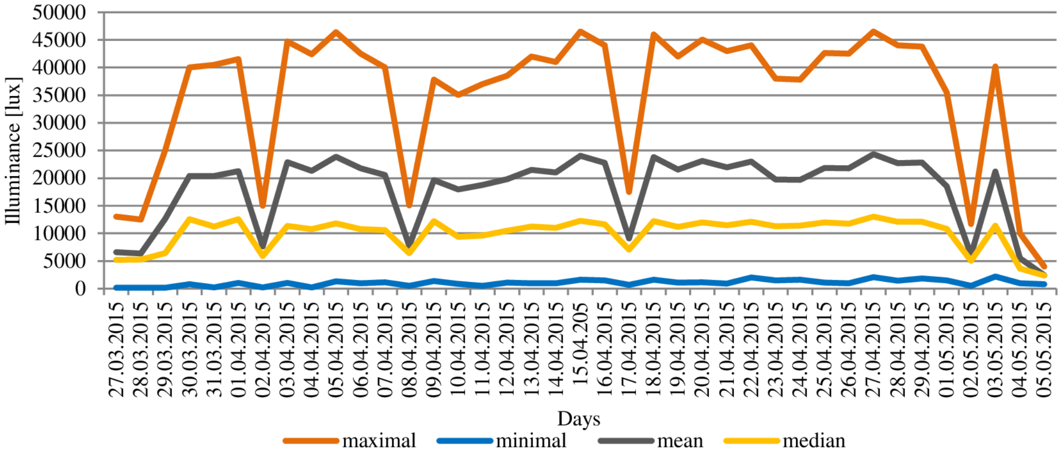
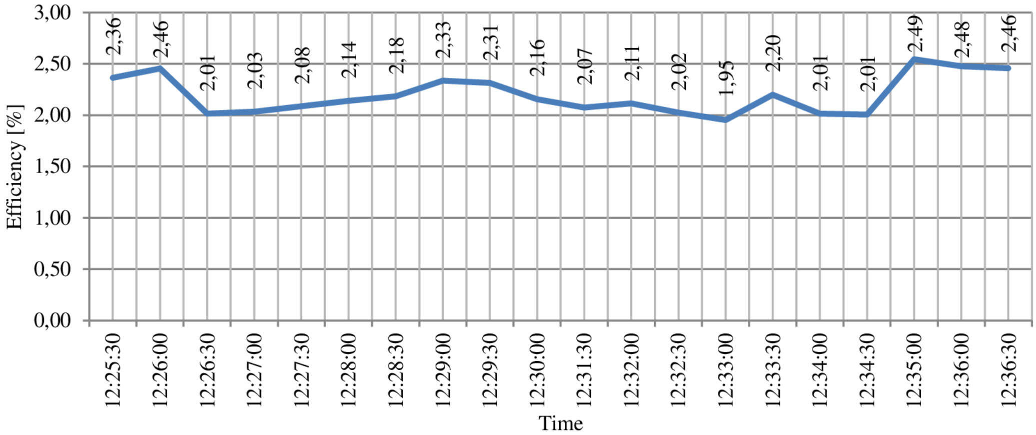


Fig. 5.5: Minimal, maximal, mean and median input illuminance

Light guide efficiency

The illuminance data processing gives information about the light guide system efficiency η [%]. The light transmittance efficiency of the light guide prototype sample was expressed for selected fragments of daily illuminance courses. The results with average values of η [%] are shown in Fig. 5.6. The results indicate that light transmittance efficiency of the guidance system with the CMP head is very sensitive for angle of incident rays. The value was only 2.49 percent. If the incident direct solar beams are not concentrated in the focus of the parabolic mirror, the high quantity of incident luminous flux is reflected back into the external space.



maximal = 2.49 %, minimal = 2.21 %, mean = 2.35%

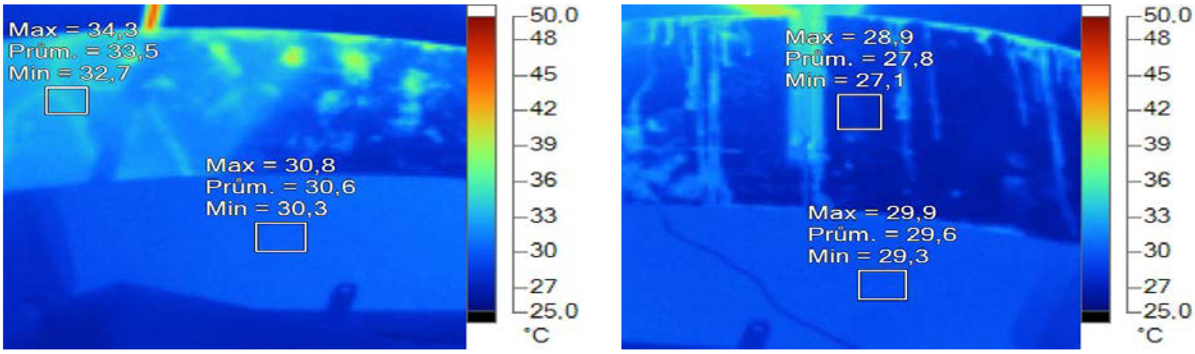
Fig. 5.6: Light guide efficiency, clear day, 25/05/2015

Infrared thermography

The infrared thermography was used for the thermal testing of the light guide. The testing was carried out for two time intervals of the infrared lamp activation: for 10 minutes and 100 minutes. The monitoring was completed for background temperature of 27 °C. An average emissivity of neighboring surfaces was 0.95. Results of the temperature monitoring for the short time interval are shown in Fig. 5.7.

Position 1 – side elevation

Position 2 – front side elevation



Position 3 – opposite side elevation

Position 4 – diffuser (interior side)

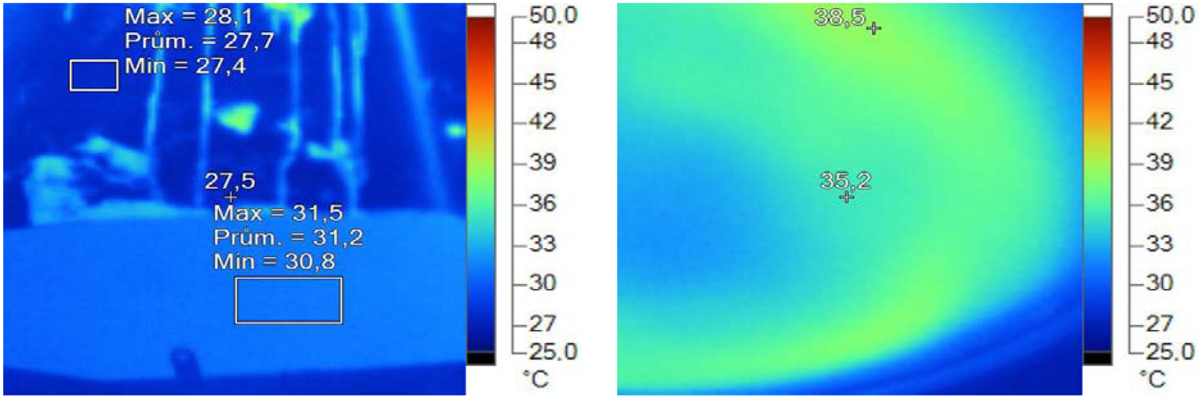
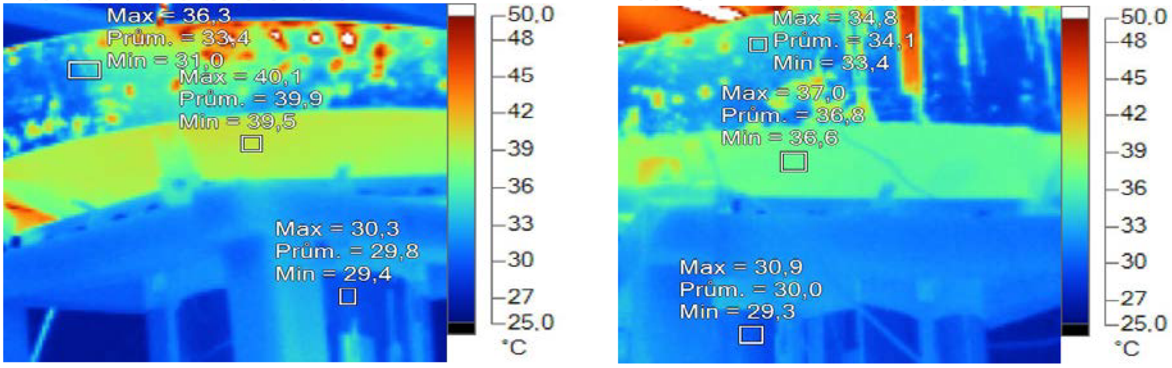
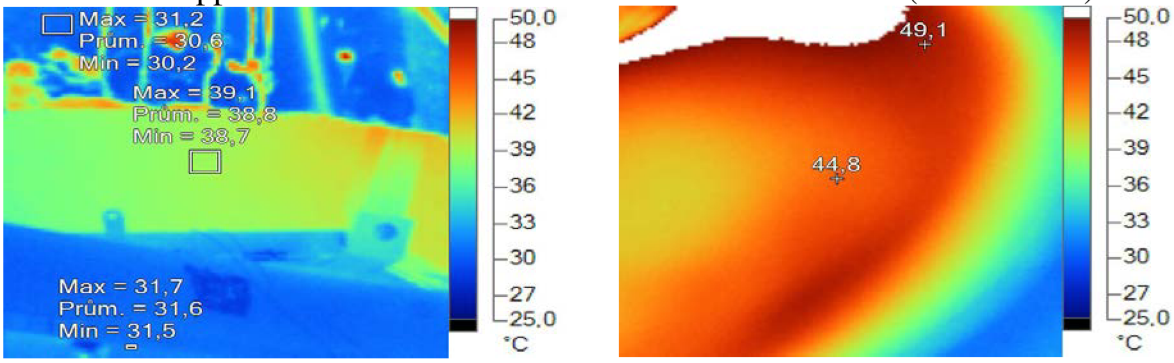


Fig. 5.7: IR thermography of the light guide head after 10 minutes activation of the IR lamp

The following measurement was carried out for the IR lamp activation for time interval of 100 minutes.


Position 1 – side elevation

Position 2 – front elevation


Position 3 – opposite side elevation

Position 4 – diffuser (interior side)

Fig. 5.8: IR thermography of the light guide head after 100 minutes activation of the IR lamp

Results of the IR thermography for the light guide monitoring from Fig. 5.7 and 5.8 are summarized in Table 1.

Table 1: Temperature distribution on the light guide – positions 1 and 2 and 3 and 4

	Surface temperature of the light guide [°C]										
	Position 1			Position 2			Position 3			Position 4	
Thermal activation	maximal	minimal	average	maximal	minimal	average	maximal	minimal	average	central	edge
10 minutes	30.8	30.3	30.6	29.9	29.3	29.6	31.5	30.8	31.2	35.2	38.5
100 minutes	40.1	39.5	39.9	37.0	36.6	36.8	39.1	38.7	38.8	44.8	49.1
Temperature rise [°C]	**9.3**	**9.2**	**9.3**	**7.1**	**7.3**	**7.2**	**7.6**	**7.9**	**7.6**	**9.6**	**10.6**
	Surface temperature of the light guide [°C]										
Thermal activation	Position 1*			Position 2*			Position 3*			Summary: Temperature rise: - parabolic concentrator (Position 1,2,3): from 7.1 to 9.3 °C -metal rim of the concentrator (Position 1*,2*,3*): from 2 to 7 °C -diffuser (inside of the box) from 9.6 to 10.6 °C	
	maximal	minimal	average	maximal	minimal	average	maximal	minimal	average		
10 minutes	34.3	32.7	33.5	28.9	27.1	27.8	28.1	27.4	27.7		
100 minutes	36.3	31.0	33.4	34.8	33.4	34.1	31.2	30.2	30.6		
Temperature rise [°C]	**2.0**	**-**	**-**	**5.9**	**6.3**	**6.3**	**3.1**	**2.8**	**2.9**		

Summary of the infrared thermography monitoring: temperature in steady state on the external surface of the parabolic head is max. 40.1° C (Table 1).

10 minutes IR lamp activation 100 minutes IR lamp activation

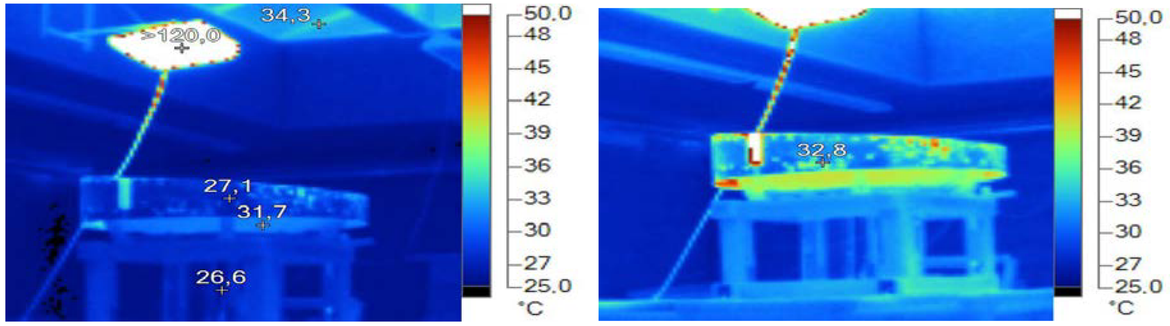


Fig. 5.9: IR thermography – distant view to the whole construction of the light guide

The thermal monitoring was repeated for the additional thermal insulation 100 mm round the upper part of the light guide in the contact with the parabolic concentrator. The temperature increased to maximal temperature rise 49.1 °C and 74.3 °C (Fig. 5.8 and Fig. 5.10).

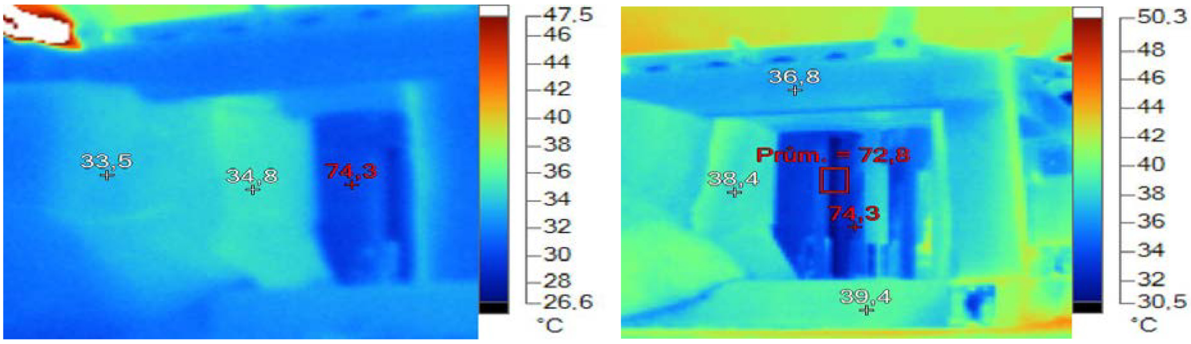


Fig. 5.10: IR thermography of the thermally insulated light guide (thermal insulation was demounted directly before the monitoring)

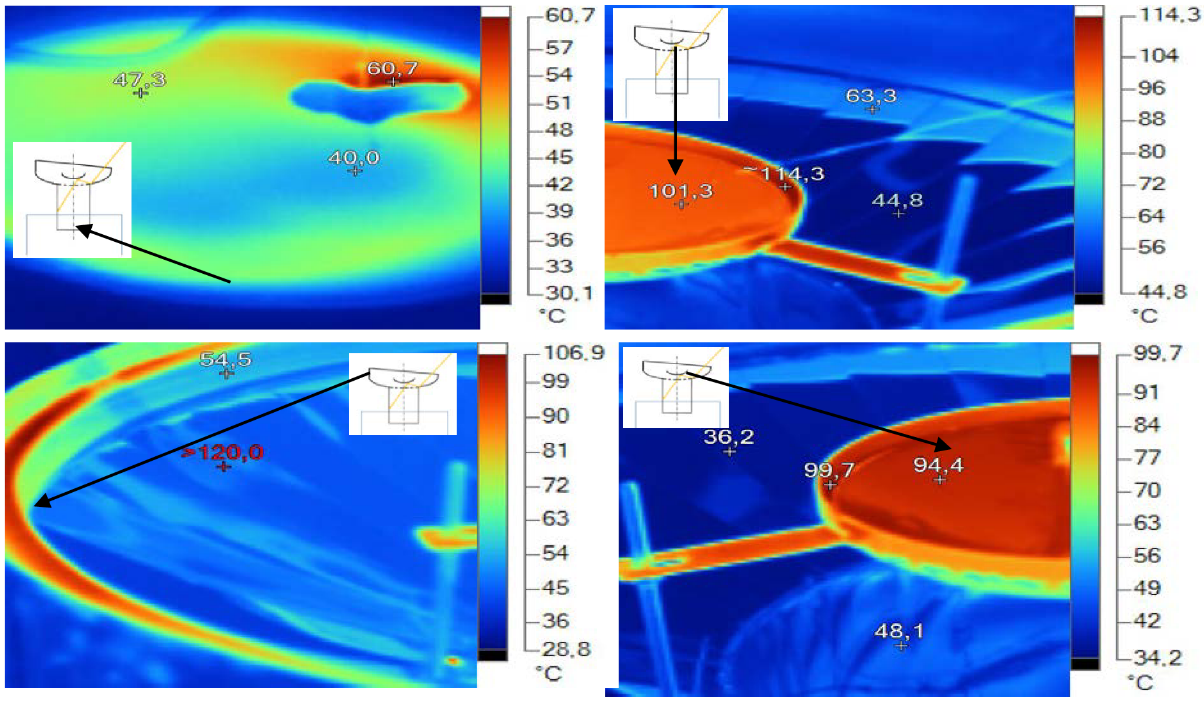
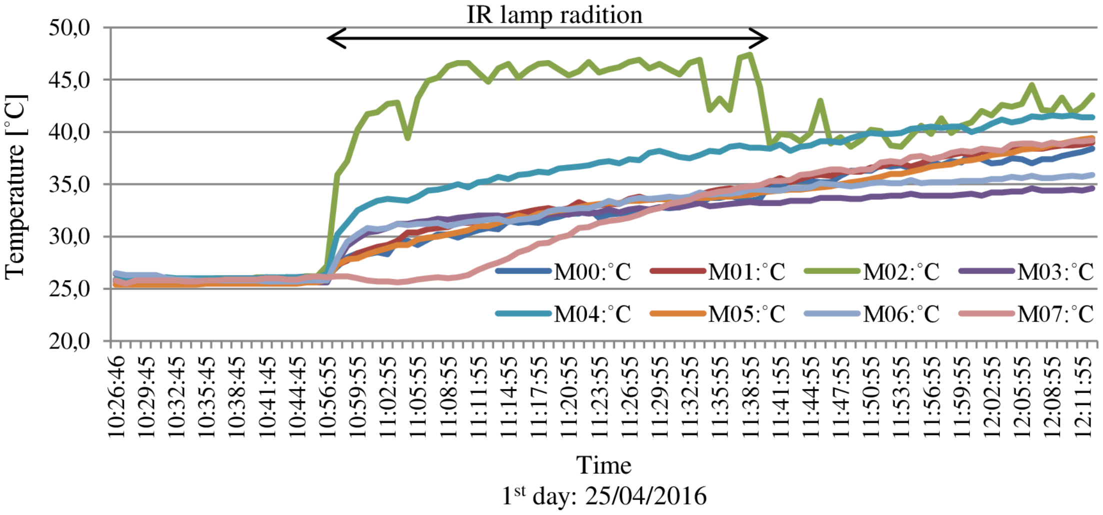


Fig. 5.11: IR camera photographs of the roof concentrating head and diffuser

The insulated light tube gives higher temperature rise. Under the IR lamp activation for 100 minutes the surface temperature on the parabolic concentrator was increased for more than 100 °C, in some parts more than 120 °C (Fig. 5.11). The difference between bottom of the concentrator (40.1 °C) and the top covered with a glass pane (120 °C) is between 60 and 80 °C.

The graph of the temperature profile measures (25/04/2016) is for the thermally insulated light guide. The temperature drop (M02 sensor, position II) on 26/04/2016 was caused by putting the thermal insulation layer on the light guide surface at 11:30 (Fig. 5.12). Less infrared radiation has been absorbed into the guide from the external side due to thermal insulation. Parabolic concentrator surface temperature rise is about 16 °C to 18 °C. Temperature close to the glass cover has increased slowly at the beginning, but finally the temperature has increased 13 °C to 15 °C, compared to the initial temperature at the start of the experiment.



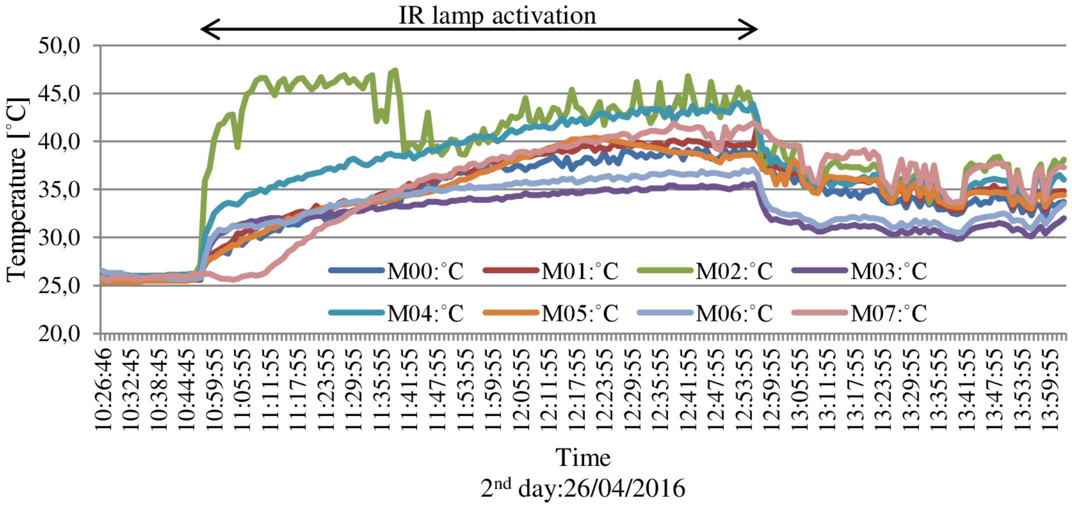


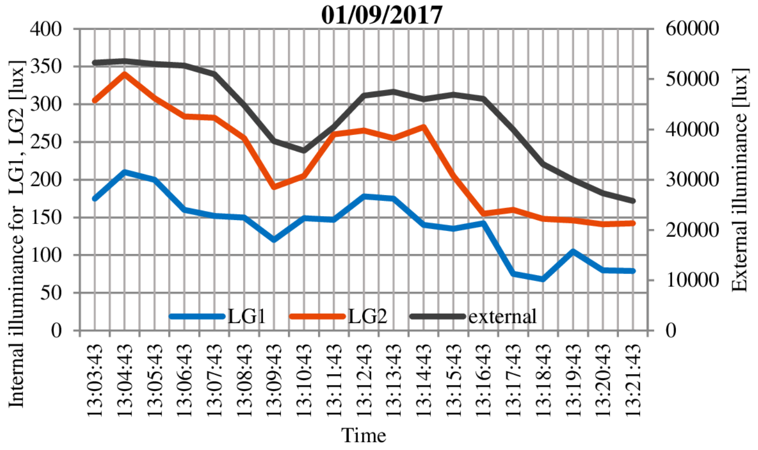
Fig. 5.12: The light guide temperature profiles

Notice: M00 – indoor air, M01 – Position I, M02 – Position II, M03 – Position III, M04 – Position IV, M05 – Position V, M06 – Position VI, M07 – Position VII.

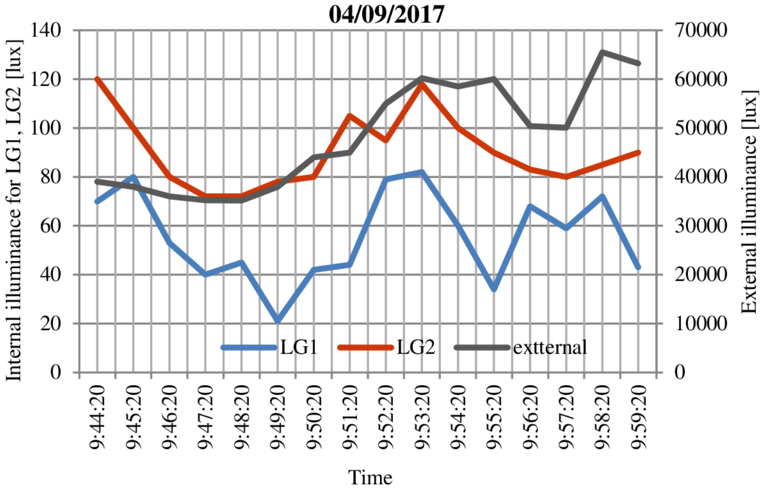
5.2 RESULTS OF IN-SITU COMPARABLE MEASUREMENTS

Light measurements were completed between August and September 2017.

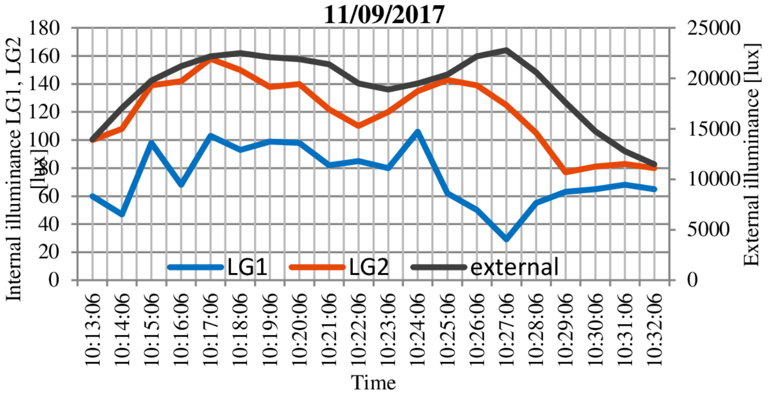
Examples of illuminance under the light guides LG1 and LG2 compared to the simultaneously measured external horizontal illuminance are shown in Fig. 5.13. It is obvious that the illuminance under the light guide LG2 is higher compared to the daylight level under the light guide LG1. This is also visible in daily illuminance profiles for the characteristic days shown in Fig. 5.14 and Fig. 5.15.



	Illuminance [lux]		
01/09	LG1	LG2	External
mean	141	242	42115
median	141	264	45850
max	213	338	53600
min	68	141	25800



	Illuminance [lux]		
04/09	LG1	LG2	External
mean	56	89	47911
median	56	88	48250
max	82	118	65500
min	21	72	33900



	Illuminance [lux]		
11/09	LG1	LG2	External
mean	77	125	19134
median	84	129	20085
max	106	158	22800
min	29	77	11500

Fig. 5.13: Examples of the internal and external horizontal illuminance

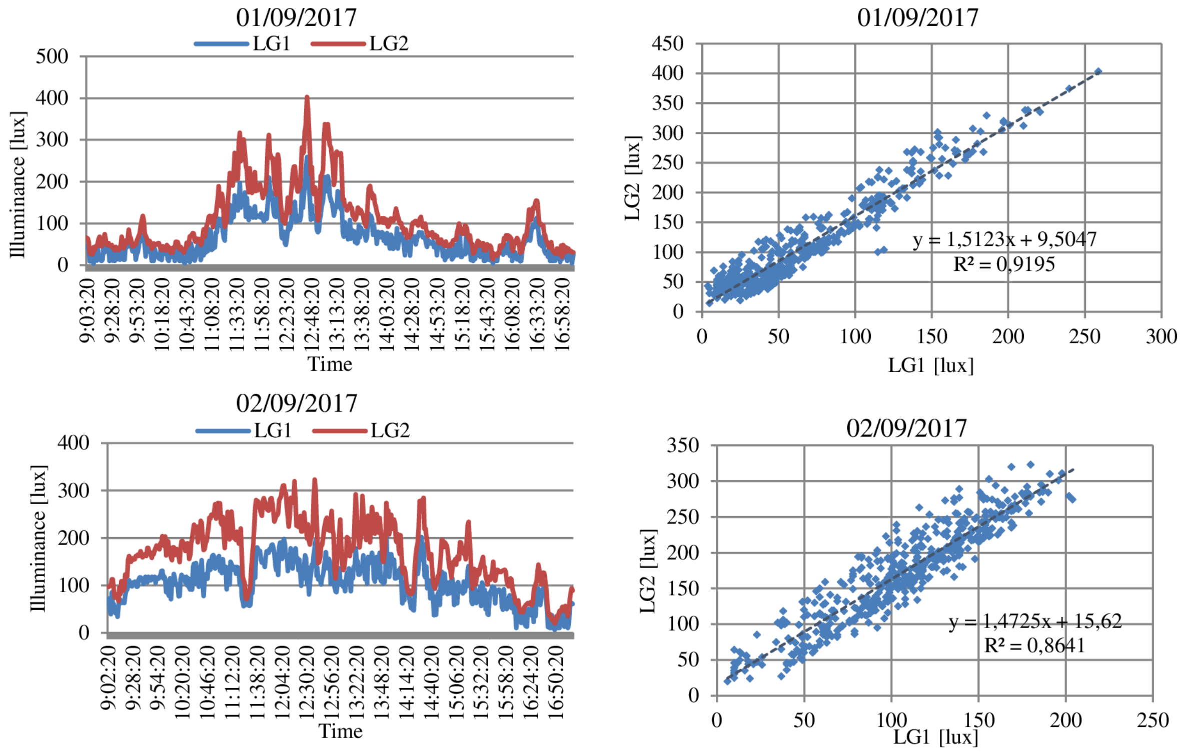


Fig. 5.14: Daily illuminance profiles and correlation graphs for illuminances of LG1 and LG2 (01/09/2017 and 02/09/2017)

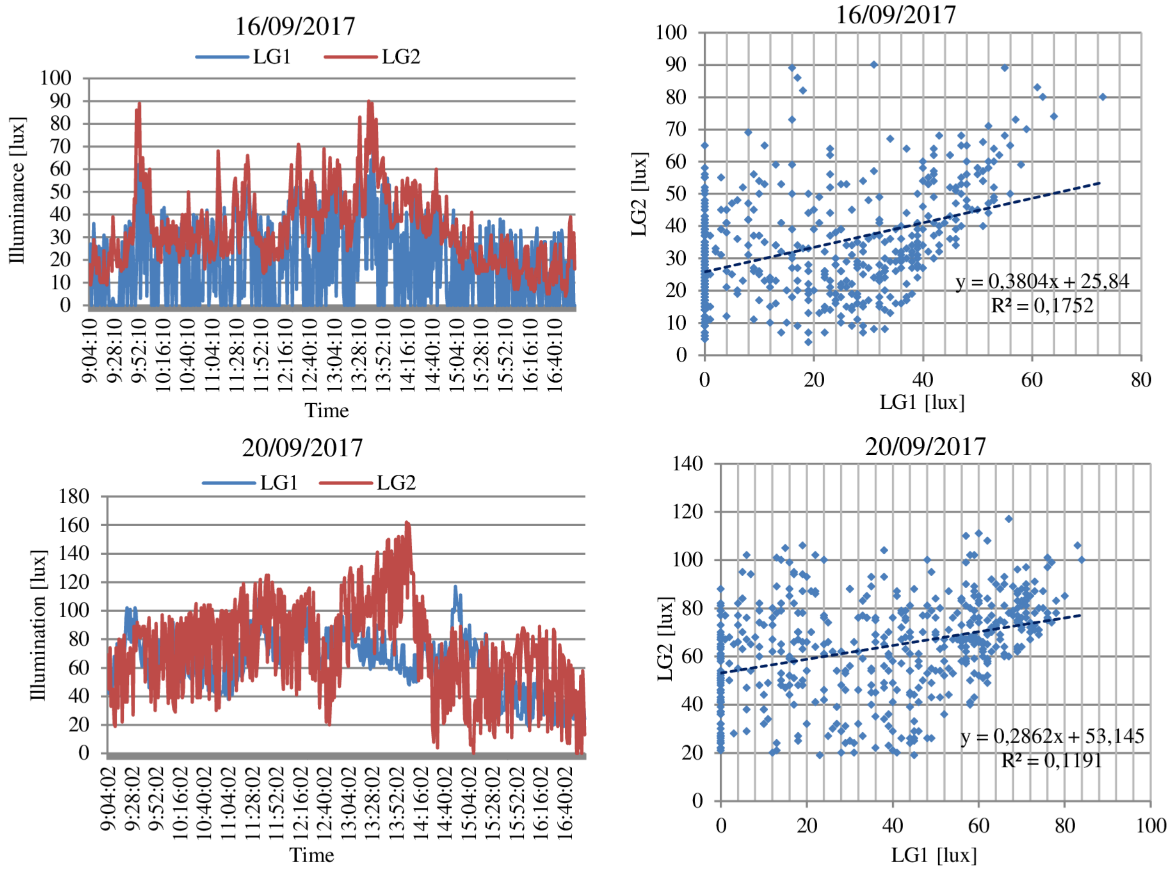


Fig. 5.15: Daily illuminance profiles and correlation graphs for illuminances of LG1 and LG2 (16/09/2017 and 20/09/2017)

Daily illuminance (from 22/08 to 23/09/2017) and percentage of the difference of mean values of LG1 and LG2 illuminance measurements are shown in Fig. 5.16 and Fig. 5.17.

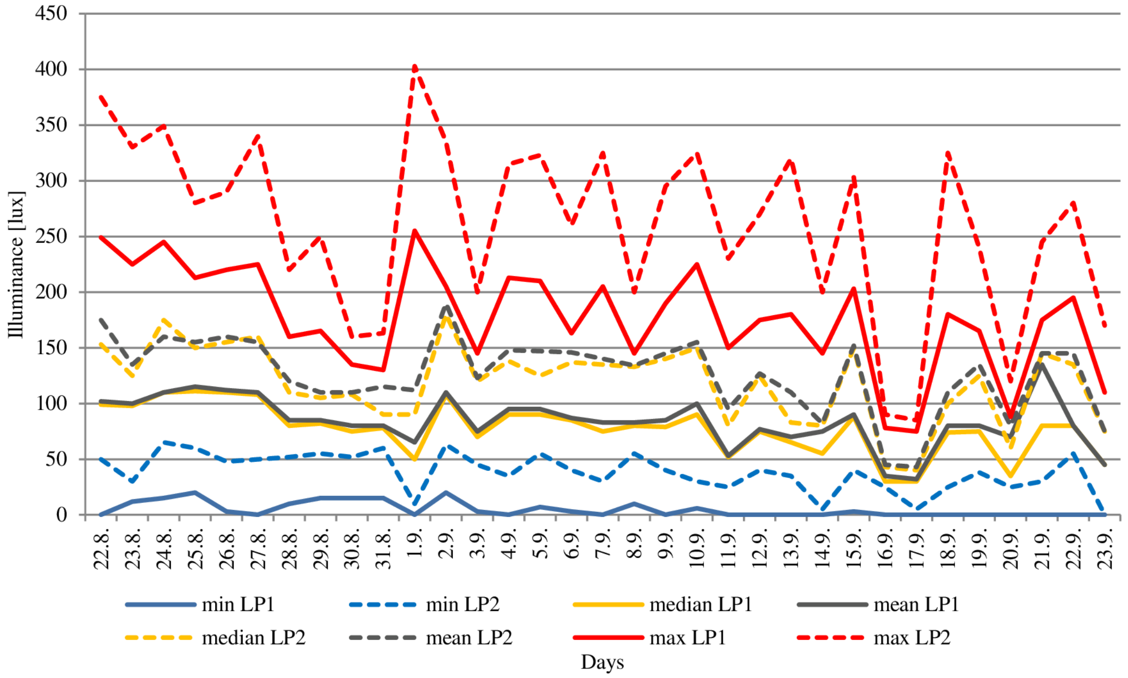


Fig. 5.16: Daily illuminance min, max, mean and median values (from 22/08 to 23/09/2017)

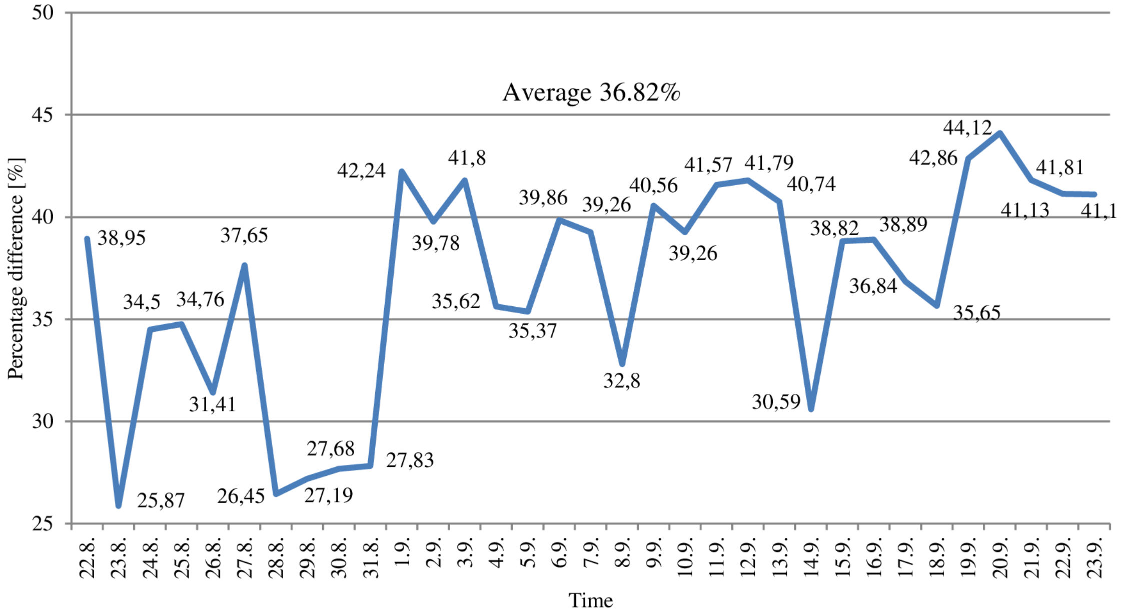


Fig. 5.17: Percentage of the difference of mean values of LG1 and LG2 illuminance measurements

Results of daylight simulations

Daylight simulations of the tested light guides LG1 and LG2 were run in software Holigilm [15]. The simulations were run on 1st September, overcast sky, to be compared with data from measurements on the same day at 12:00 (Fig. 5.18). Additionally, simulations were completed for two extreme situations in the following daylight conditions: CIE overcast sky, CIE clear sky [23] and Solstice time on 21st December and 21st June, at daytime 12:00 (Fig. 5.19). The parameters selected for the simulations are as follows:

- Dimensions of light guides LG1 and LG2 – tube length 0.60 m and diameter 0.52 m.
- Light reflectance of internal surface of the both tubes is $\rho = 0.97$.
- Light transmittance of ceiling diffusers of LG1 and LG2 is $\tau = 0.75$.
- The light transmittance of roof transparent covers of LG1 and LG2 is:
  roof collector with CMP head of LG1: $\tau_1 = 0.53$,
  roof spherical glass collector of LG2: $\tau_2 = 0.90$.

The light transmittance of the LG1 with the concentrator head is determined from the light transmittance of the glass collector decreased for reduction determined by the illuminance measurements in the test container, which is on average 37 percent. Simulation outputs of internal horizontal illuminance at level 2.8 m bellow ceiling diffusers (the container floor level). The position of the light guides LG1 and LG2 is: x = 0.92 m, y = 1.15 m, z = 2.8 m

CIE Overcast sky, 01/09, 12:00, LG1, $\tau = 0.53$ CIE Overcast sky 01/09, 12:00, LG1, $\tau = 0.90$

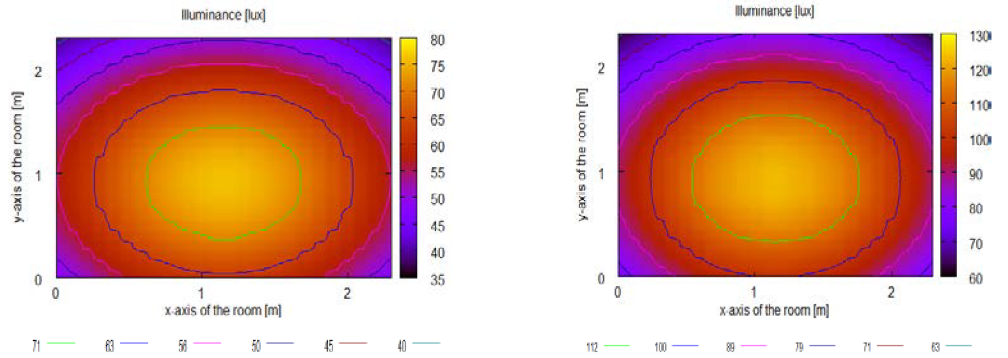
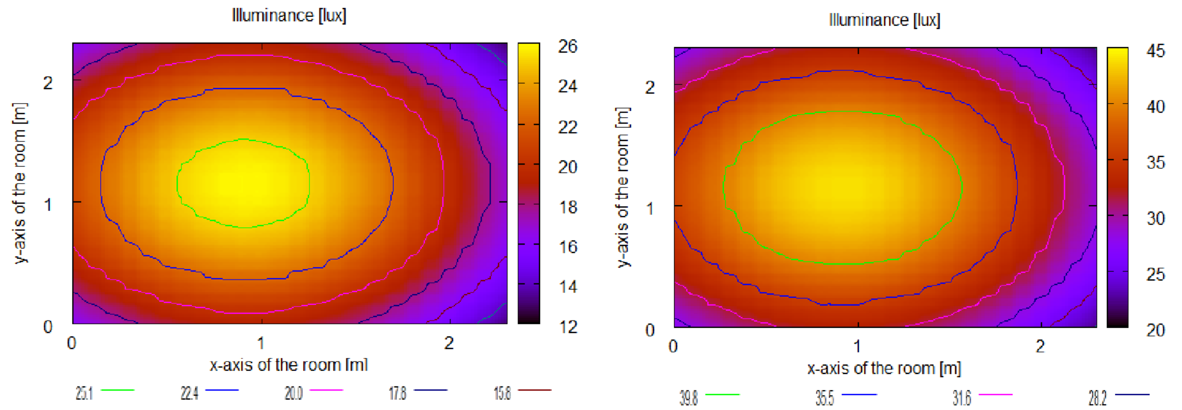


Fig. 5.18: Illuminance E [lux] under light guides LG1and LG2 on 1st September, 12:00

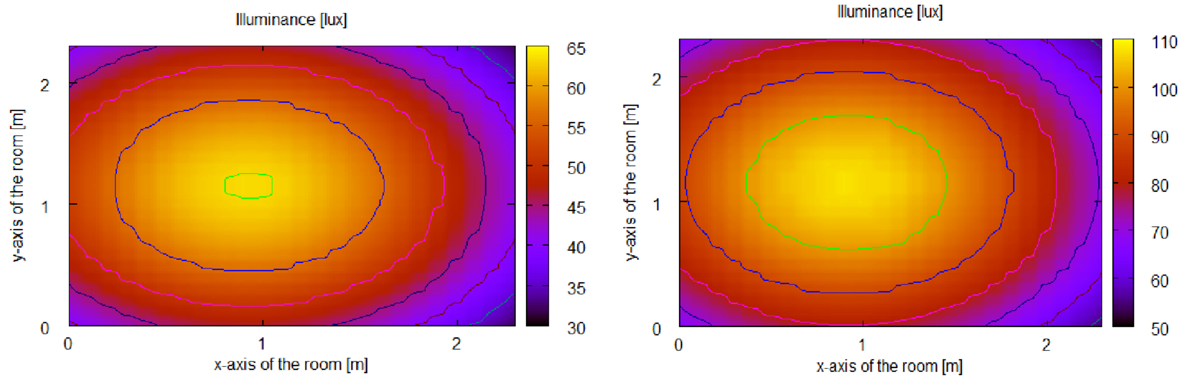
Table 2: Holigilm simulation and measured data on 01/09/2017

Holigilm simulation		
	LG1	LG2
E_{max} [lux]	71	112
E_{min} [lux]	40	63
$U = E_{min}/E_{max}$	0.56	0.56
Measured data		
E [lux]	70	131



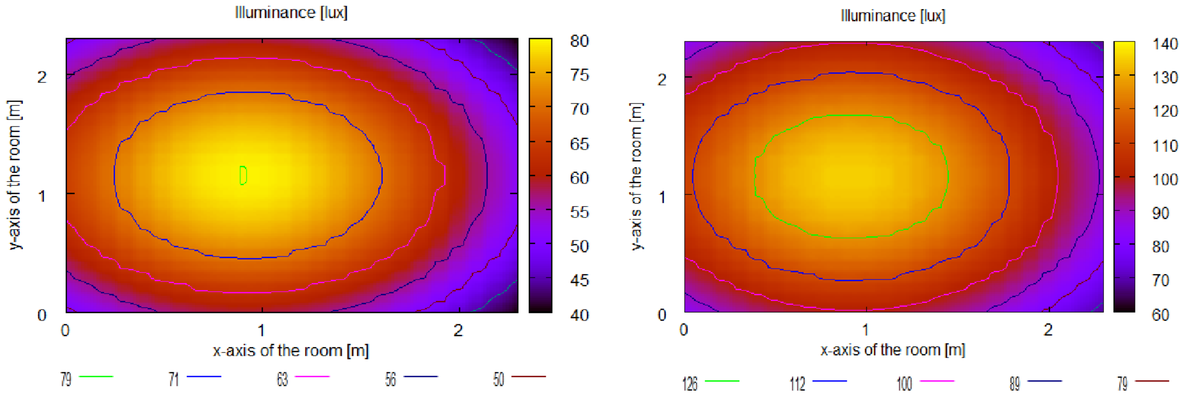
CIE Overcast sky, 21/12, 12:00, LG1, τ = 0.53

CIE Overcast sky, 21/12, 12:00, LG2, τ = 0.90



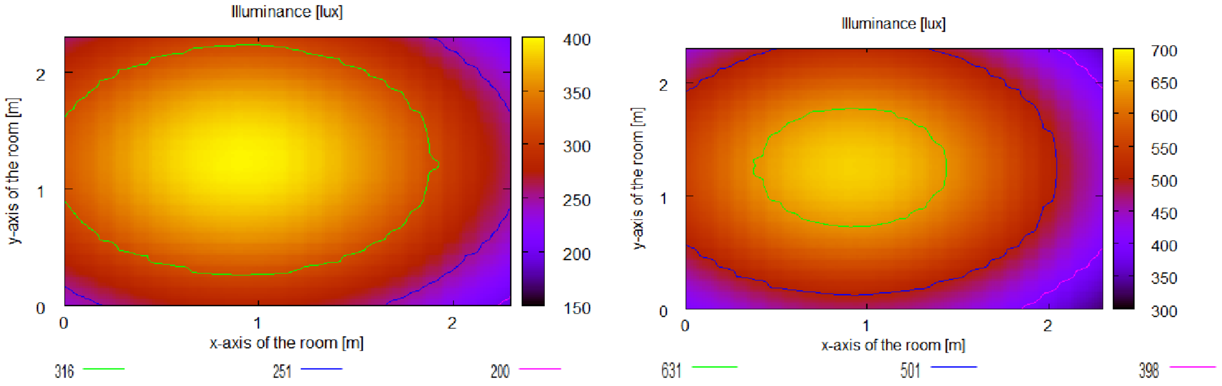
CIE Clear sky, 21/12, 12:00, LG1, τ = 0.53

CIE Clear sky, 21/12, 12:00, LG2, τ = 0.90



CIE Overcast sky, 21/06, 12:00, LG1, τ = 0.53

CIE Overcast sky, 21/06, 12:00, LG2, τ = 0.90



CIE Clear sky, 21/06, 12:00, LG1, τ = 0.53

CIE Clear sky, 21/06, 12:00, LG2, τ = 0.90

Fig. 5.19: Illuminance E [lux] of light guides LG1 and LG2, for CIE overcast and clear sky on 21st December and 21st June

The simulation outputs are in accordance with the measured data. They confirm that the light guide prototype LG1 with the CMP head is less efficient system. Compared to the conventional light guide LG2 it provides a lower level of illumination on the working plane. The concentrator’s secondary parabola represents an obstruction to daylight transmittance.

Further investigations of the light guide prototype are aimed at its installation in real buildings with different roof structures, slopes and orientations towards cardinal points. The light guide system LG1 would be most efficient in case when the light concentrator is equipped with a sun tracking system.

6 CONCLUSION

6.1 SUMMARY

The tested atypical prototype model represents a new light guiding system with a daylight concentrator device. The objective of the experiment was to solve the following tasks:

- test the light guide prototype for light transmittance,
- compare the light efficiency results of a prototype light guide with that of a conventional light guide of comparable dimensions and geometry,
- analyse the function of the prototype model and make recommendations for its possible improvement,
- find options for applications of the light guiding system in temperate climates,
- test the temperature distribution of the light guide prototype,
- specify the temperature profiles inside the light tube and near the mirror parabolic head,
- identify potential overheating problems in building applications.

6.2 ACHIEVEMENTS

The main achievement of the thesis appears to be the author's specification and implementation of the experimental method for the assessment of the atypical light guide prototype to evaluate its light transmittance and efficiency as well as its thermal behaviour. Based on the research carried out, such a comprehensive method of assessment was not found from the comprehensive review of state of the art published in studied scientific journals and databases. All author's presented experiments and data processing gave results which refer potentials of the tested light guide system in real buildings and pointed on design improvements for its practical applications.

Daylight evaluation

The prototype experiments prove that if primary parabolic mirror is not tracking the sun position only a limited part of sun rays affecting the light guide collector is redirected into the tube. When the CMP head is illuminated by the diffuse light the light transmittance efficiency is only 2.49 percent. This indicates that the secondary parabola of the light guide with the CMP head in a static horizontal position is an obstacle to diffuse daylight. The light guide will increase its efficiency in real external conditions and for time with clear sky and direct solar radiation.

Thermal testing

The thermal testing of an atypical prototype model gave an overview of temperature distribution under intensive infrared radiation. The infrared thermography photographs show very high temperature on the CMP head. Also, the diffuser temperature increased. The surface temperature rose up to 40°C due to the infrared lamp activation for light guide installation without thermal insulation. In the case of a thermally insulated light guide, the surface temperature increased to 74°C and in some places even more. The highest temperature distribution was on the CMP head (100 – 120 °C). The above mentioned findings show potential problems with the light guide overheating under intensive solar radiation in summer seasons.

Comparative field study

- The comparative field study was carried out for two light guides with different roof collector installation – a conventional light guide with a glass roof collector and a prototype with CMP head. The daylight illuminance data from measurements show differences in light efficiency of the two tested light guides. The roof installation with the glass collector was more efficient than the variation with the CMP head. Daylight illuminance level has decreased by 37 percent compared to conventional light guide. These findings apply when the CMP head is installed in a static horizontal position on a flat roof in a region with temperate climatic conditions. The evaluation was carried out for region latitude 50° with dominance of overcast and partially cloudy skies.
- Daylight simulations in software Holigilm provided an overview of the tested light guides' daylight illuminance for two days of solstice on 21st December and 21st June. Simulations have shown that a less efficient system provides a lower illuminance level on the working plane. Under defined conditions, the illuminance level is reduced by 42 percent for overcast sky and more than 45 percent in case of clear sky.

6.3 RECOMENDATIONS

Improvement suggestions of prototype efficiency are focused on increasing the prototype model performance and reduction of light guide dependence on sun elevation and azimuth angles. Suggestions are listed below.

- Removal of the overhanging edge around the primary mirror parabola.
- Elevating the CMP head above the roof structure and inclining it towards the sun rays propagation.
- A moving concentrator, system of mirror/set of mirrors, heliostats, or prismatic shells directing solar radiation into the tube during daytime would mean a positive improvement in the efficiency of this system but it would increase the investment cost of the light guiding system.
- The placement of the parabolic concentrating head in the direction of the dominant solar irradiation, i.e. towards the south and west orientation.
- A light guide passive system could be transformed into an active solar tracking system.

Simple rotating mechanism

If the prototype collector is elevated above the slope of a roof construction, it can rotate in one direction at a constant speed moving 9° every hour, completing a quarter circle in 10 hours, e.g. from 7:00 am to 5:00 pm every day. Same applies to a flat roof construction. There it can rotate at a constant speed moving 15° every hour, completing a half circle in 12 hours, e.g. from 8:00 am to 8:00 pm every day.

Advanced rotating mechanism

After testing the prototype using the simple mechanism described above, the more complex one can be tried – the sun tracking system that accurately follows the sun path to keep the collecting parabolic head perpendicular to sun's rays.

Thermal solutions

The thermal tests of the prototype model have shown an undesired effect of heat transfer along the tube. The heat, if not properly disperesed, can result in overheating problems. Therefore, appropriate ventilation and cooling techniques should be used. Some solutions to these problems are listed below:

- thermal insulation layer around the light guide tube and under the mirror parabolic head,
- double tubes (combining ventilation and illumination),
- additional thermal insulating and fire resistant glazing units inside the tube.

Testing of the light guide system application abroad

The next task for the author will be to test the application of the light guide for Nigeria’s climate conditions in collaboration with a structural engineering company in Lagos. Due to the long hours of sunshine in a tropical environment, the use of light guides that bring natural light to buildings is a great advantage. They may prove successful and should be constructed in accordance with the principles of the development postulated in the Building Energy Efficiency in Nigeria by the Federal Ministry of Power, Work and Housing [24].

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[1] The rest of the literature used is included in the full version of the thesis

8 CURRICULUM VITAE

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10 ABSTRACT

Light guide is a tubular skylight with mirrored internal surface. It is a lighting device bringing daylight into the interior of a building without windows or into rooms with insufficient daylight. It presents the potential for energy savings, opens the possibility to use places that are not well lit and improves the visual comfort of the indoor environment.

This thesis reviews the potential of light guide system as a daylighting approach in building and presents results of experiments on performance of tubular skylight prototype. The main task of the thesis is focused on comparison of traditional light guide system and newly developed prototype, examination of its light transmittance and efficiency as well as its thermal behavior in order to find possible improvements for applications in buildings.

Keywords: Lighting system, Daylighting, Tubular Skylight

Světlovod je tubusový světlovodný systém se zrcadlovým vnitřním povrchem. Jedná se o osvětlovací zařízení, které vnáší denní světlo do vnitřních prostor budovy bez oken nebo do prostoru s nedostatečným denním osvětlením. Představuje potenciál úspor energie, umožňuje využití míst, která nejsou dostatečně osvětlena a přispíva k zlepšení zrakové pohody vnitřního prostředí.

Tato práce zkoumá potenciál světlovodů jako zdroje denního osvětlení v budově a prezentuje výsledky experimentů zaměřených na světlené a tepelné posouzení prototypu tubusového světlovodu. Hlavním úkolem disertační práce je porovnání tradičního světlovodného systému a nově vyvinutého prototypu, zkoumání jeho světelné propustnosti a účinnosti a jeho tepelného chování za účelem nalezení možných vylepšení pro jeho aplikace v budovách.

Klíčová slova: Světelný systém, Denní osvětlení, Tubusový světlovod