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The Issue of the Daylighting Intensity by Light Guides

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The Issue of the Daylighting Intensity by Light Guides

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Abstract. The issue of the efficiency of use and determination of the operational efficiency of the designed light sources is relevant during the process of lighting design. The contribution deals with the illumination of the interior by the tubular light guides during design and operation itself. The measurement of the luminance, the illumination of the exterior and the interior was carried out on experimental wooden building in Brno belonging to VUT FAST (Czech Republic). In one case, the brightness of the sky was also measured. The assessed tubular light guides Sunizer with the length of tube 2 m and with the diameter of 320 mm passes through the roof structure and through the ceiling structure into the interior corridor of the wooden building. Prior to the start of the measurement, the measuring sensors were placed in the center of the diffusers of the two measured tubular light guides at the floor level. Another one sensor was placed at the midpoint between the diffusers at the floor level. Subsequently, another sensor was placed on the roof of the building in the exterior. The sensor is placed next to the dome of the light guide so that it is not overshadowed. The sensors were connected to the datalogger and the 5-minute measurement was performed at all four locations simultaneously at time intervals after one minute. The values of the sky brightness always in four directions were determined were determined before the measurement, in the middle of the measurement and at the end of the measurement. The sky type was determined visually for some of the measurements. Finally, the measured data from the luxmeter was stored and the ratios of illumination of the interior and exterior were calculated. Subsequently, the measured data are compared with the simulations obtained from the software Holigilm and Velux Daylight Visualizer. The benchmark is the ratio between indoor and outdoor illumination, the so-called daylight factor. Finally, there is an evaluation, a graph showing the difference between these values and the explanation of the differences of results between the real measured values and the outputs from the simulation programs.

1. Introduction

In the lighting design there is an issue of use efficiency and operating effectiveness determination of the sources designed. This research deals with the measurements of the illumination of spaces by means of light guides. Technical light measurements were carried out three times during a year on two light guides installed in the experimental wooden building, belonging to VUT FAST in Brno, Czech Republic. The illumination of the exterior and interior and in one case also the brightness of the sky were measured. The tubular light guide by the Sunitor brand is a tube with the length of 2 m, 320 mm in diameter, which passes through the roof and the ceiling structure into the interior of the hall.

2. Measurement description, light guide and measured space specification

Firstly, the measuring sensors were placed in the centres of the diffusers (two measured light guides) and one between the diffusers, all at the floor level, as shown in Figure 2. Then, the other sensor was placed outdoors on the roof of the building so, that it is not shaded. The sensors were connected to the datalogger and five-minute measurements were taken at all four locations simultaneously at one-minute intervals. The sky brightness was determined before the measurements of illumination, in the middle and after the measurements were completed, always in each of four directions. For one of the measurements, the sky type was determined visually. Finally, the measured data from the luxmeter were saved.

The measured values were then compared with the ones obtained from the computer simulations in Velux Daylight Visualizer and Holigilm applications using illuminance ratios.

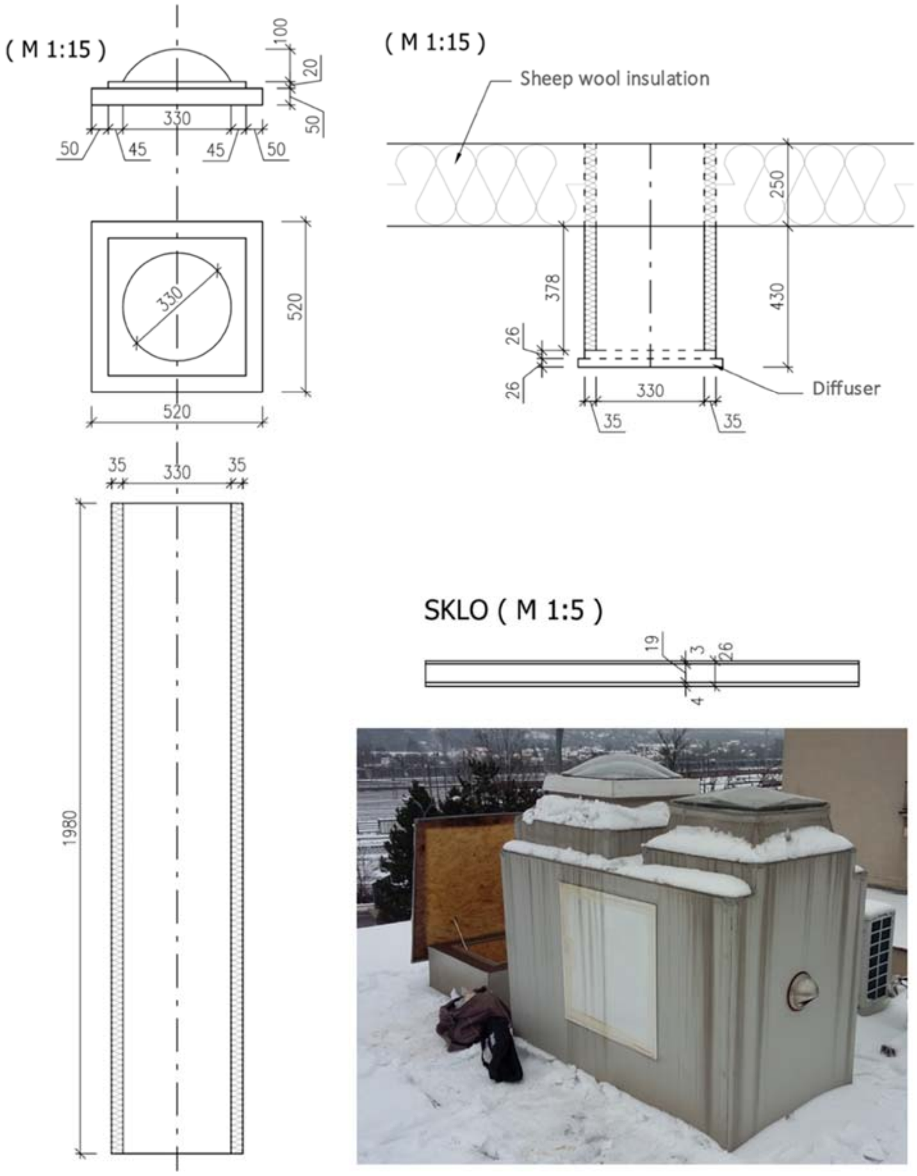

Figure 1. Measured space floor plan scheme

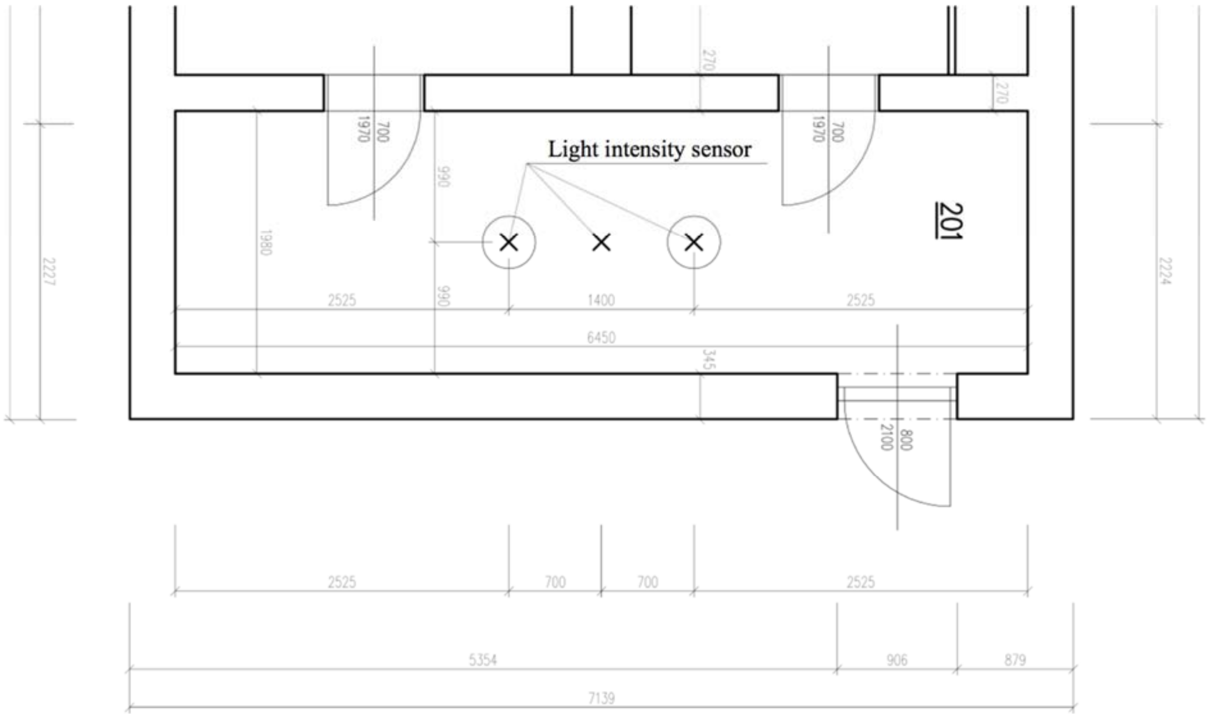

Figure 2. Measured space floor plan scheme

3. Measurements

The illumination was measured in the interior under the light guide and in the exterior on the roof of the building. In one case, the brightness of the sky was also measured. The following devices were used for the measurements:

- Ahlborn ALMEMO 2590-4S Datalogger: This is a compact device with a universal input for connection with different sensors and a large 2-line segment LCD display for demonstrating the immediate and maximum values.
- Probe for measuring illuminance: Ahlborn FLA623VL. This device has measuring ranges: 1st channel 0 to 20,000 lx, 2nd channel 0 to 170 klx. The sensor has a 5% accuracy of the measured value and spectral sensitivity: 380 to 720 nm, maximum 555 nm. [1]
- Gossen MAVO-SPOT 2 lightmeter: This lightmeter is a class B precision device according to the German standard. It provides measures from 1m to infinity. The device also has an LCD display and measured data are read from the viewfinder. There is a tripod thread on the bottom. [2]

General measurements data and surface characteristics are shown in the Table 1.

Table 1. Basic measurement data

Introduction to measurements	
Purpose of measurement	Measurements of illumination from light guides
Light guide manufacturer	Sunizer, American Bohemian Corporation
Illumination radius	1,5 mm (Light guide type SZ 330)
Specifications of lighting system components	Dome: Polygonal dome: 1st layer of acrylate, 95% transparency; 2nd layer of acrylate Tubes: Reflection 99.7%, Ø 330 mm Diffusors: Lambert's cosine, transparency of the diffuser is 0.75, transparency of thermal insulating double glazing is 0.98 and the total one is 0.735, Fresnel special optical lenses, Ø 400 mm
Rules and standards	ČSN 73 0580
General information	
Place of measurements	Kulkova 4045/8, Brno 61500 (49°12´40,0´´N, 16°38´55,0´´E)
Measured building	Experimental wooden building VUT FAST in Brno
Measured space	Hall
Date of measurements	First measurement: 10.7.2015, Second measurement: 7.1.2016
Measurement time	First Measurement: 8:56 - 9:00, Second Measurement: 10:59 - 11:03
Sky type	First measurement: 9, Second measurement: 1
Measuring devices	
Type and manufacturer of the measuring device	Ahlborn 2490-2
Accuracy	+ - 0.03% of the measured value + - 2 digits
Other measuring devices and their specifications	Light intensity sensors FLA623VL Gossen MAVO-SPOT 2 USB
Spectral sensitivity	380 to 720 nm, maximum at 555 nm
Characteristics of interior surfaces	
Walls, ceiling and floors color	Walls - white painting, ceiling – white gypsum cardboard, floor OSB boards
Ceiling, wall and floor reflectivity	Walls 65%, ceiling 55%, floor 25%
Walls surface, ceiling and floor state	New, slightly dusty floor
Measuring devices location	
Sensor position	Position 1 - On the floor under the light guide diffuser 1 Position 2 - On the floor between light diffusers 1 and 2 Position 3 - On the floor under the light guide diffuser 2 Position 4 - On a tripod on the roof of a building at unshaded height

4. In-situ measurement and computer simulations results

This chapter contains measured values of illumination and brightness of the sky recorded in the tables and resulting simulations from the computer applications Holigilm and Velux Daylight Visualizer.

Table 2. Measured illumination in [lx] and conversion to illuminance ratios [%] - 10.7.2015

Measurement time	Illumination values E [lx]				Calculated illuminance ratio e [%]			
	E_{P4}	E_{P1}	E_{P2}	E_{P3}	e_{P4}	e_{P1}	e_{P2}	e_{P3}
8:56	52230	172	177	175	100	0,329	0,339	0,335
8:57	43680	144	151	150	100	0,330	0,346	0,343
8:58	39440	149	157	154	100	0,378	0,398	0,390
8:59	38840	148	155	153	100	0,381	0,399	0,394
9:00	40270	148	155	152	100	0,368	0,385	0,377

Table 3. Measured illumination in [lx] and conversion to daylight factor [%] - 7.1.2016

Measurement time	Illumination values E [lx]				Calculated daylight factor D [%]			
	E_{P4}	E_{P1}	E_{P2}	E_{P3}	D_{P4}	D_{P1}	D_{P2}	D_{P3}
10:59	10153	57	63	53	100	0,561	0,621	0,522
11:00	10094	56	61	53	100	0,555	0,604	0,525
11:01	10006	56	61	52	100	0,56	0,61	0,52
11:02	10057	56	61	52	100	0,557	0,607	0,517
11:03	10295	57	63	53	100	0,554	0,612	0,515

Determination of the daylight factor values under the conditions of uniform sky was based on the ratio 1:

$$D = \frac{E}{E_h} \tag{1}$$

where:
E interior illumination [lx
E_h exterior illumination [lx] [3]

ČSN 361100-2 specifies that the sky brightness is checked at the zenith - brightness Lz [cd / m2] (at the angle 90 °) and in places with an altitude 15 ° and 45 ° - L15 and L45 in cd / m2. For the valid measurements, the ratio of the brightness must be within the ratio tolerances specified by the standard. According to the standard ČSN 360011-2 for uniform sky and light terrain: L15 / Lz = 0.3-0.7; L45 / Lz = 0.7-0.9; and for dark terrain: L15 / Lz = 0.3-0.6; L45 / Lz = 0.7 - 0.85. [3] The sky brightness values were determined before the measurement of illumination, in the middle and after the measurement was completed, in each of four directions as illustrated. Since the terrain and roof were snow-covered, the calculated brightness ratios were compared with the brightness ratios determined by the standard for the light terrain. It can be seen, that the most calculated brightness ratios satisfy the standard ones, only at some moments the calculated ratios are higher. So, most of the time the sky adjusted to the sky type 1 (uniform sky). At the first measurement, the sky type was determined visually.

Figure 3 shows the directions of the sky brightness measurements and in Figures 4 and 5 there are computer application outputs.

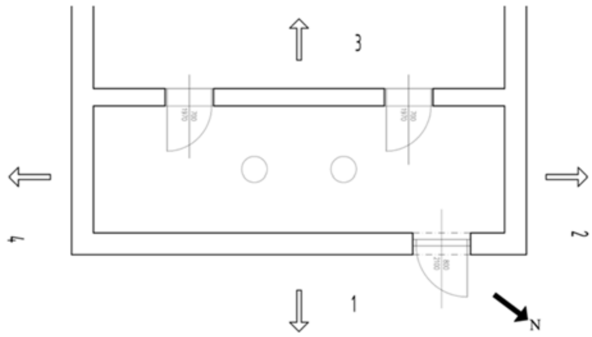

Figure 3. Sky brightness measurements directions

Table 4. Measured sky brightness values 7.1.2016

Time			in direction 1	in direction 2	in direction 3	in direction 4
10:55	Measured brightness at different angles [cd · m^{-2}]	90° = 3965	45° = 3037	45° = 3134	45° = 3355	45° = 3336
		90° = 3951	15° = 2659	15° = 2640	15° = 2696	15° = 2682
	Calculated brightness ratios		0,766	0,790	0,846	0,841
			0,673	0,668	0,682	0,679
11:03	Measured brightness at different angles [cd · m^{-2}]	90° = 3763	45° = 3380	45° = 3202	45° = 3617	45° = 3559
		90° = 3784	15° = 2797	15° = 2887	15° = 2922	15° = 2572
	Calculated brightness ratios		0,898	0,851	0,961	0,946
			0,739	0,763	0,772	0,680
11:08	Measured brightness at different angles [cd · m^{-2}]	90° = 4165	45° = 3728	45° = 3385	45° = 3897	45° = 3651
		90° = 4085	15° = 2708	15° = 2620	15° = 2498	15° = 2578
	Calculated brightness ratios		0.895	0.813	0.936	0.877
			0.663	0.641	0.612	0.631

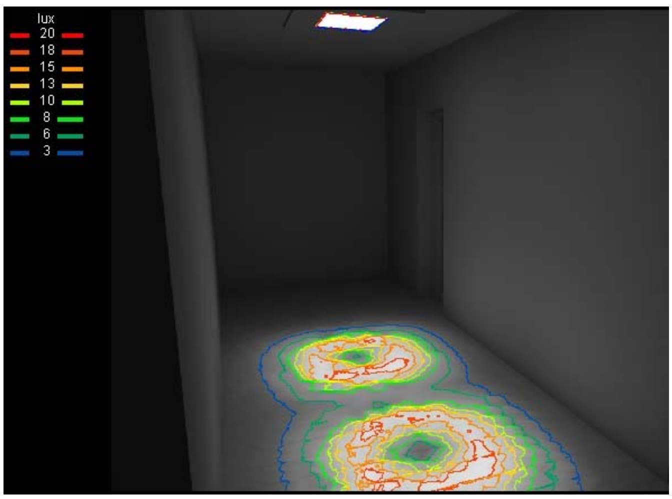

Figure 4. 3D Simulation of measured space in software Velux Daylight Visualizer obtained on 10.7.2015

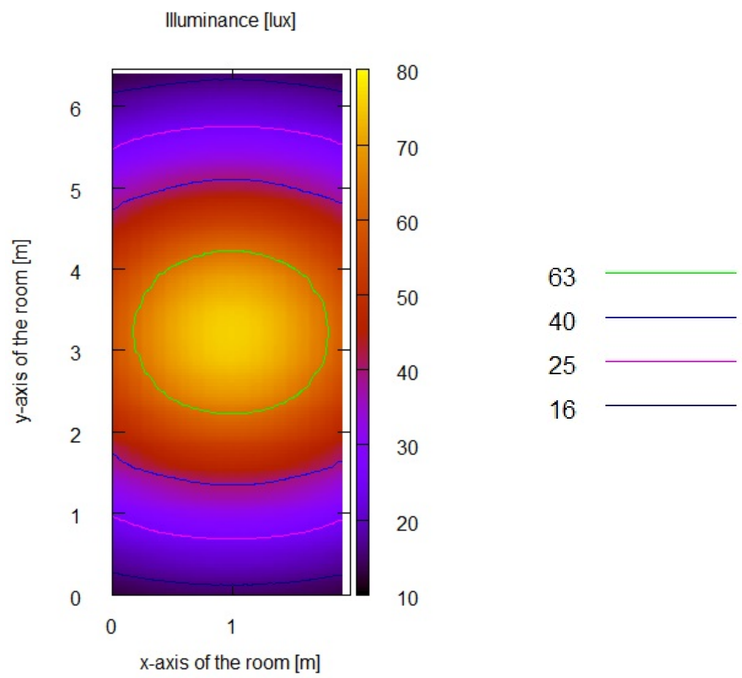

Figure 5. Floor illumination under the light guide from the software Holigilm obtained on 10.7.2015

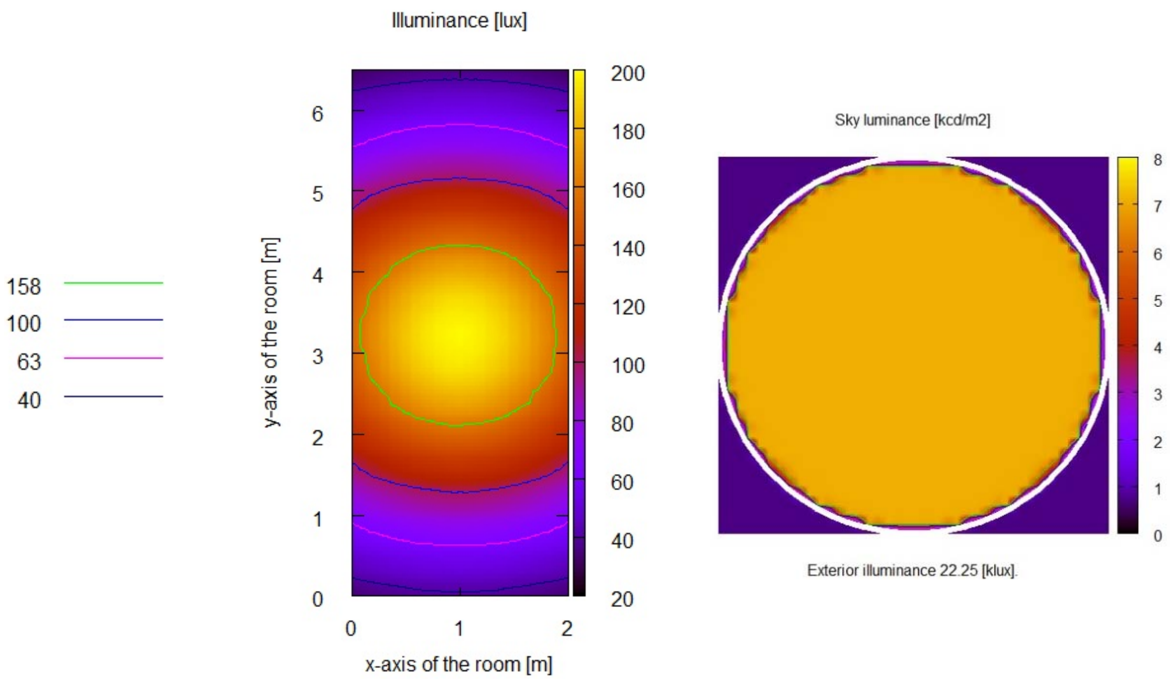

Figure 6. Sky luminance and exterior illuminance from the software Holigilm obtained on 7.1.2016

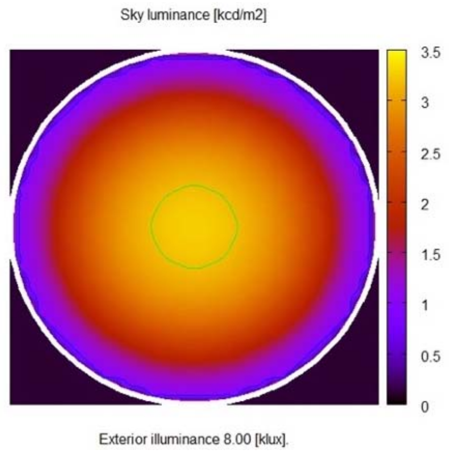

Figure 7. Floor illumination under the light guide from the software Holigilm obtained on 7.1.2016

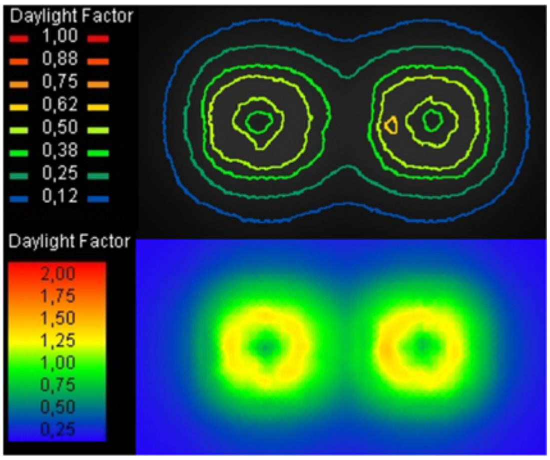

Figure 8. Daylight factor on the floor under the light guide from the software Velux Daylight Visualizer obtained on 7.1.2016

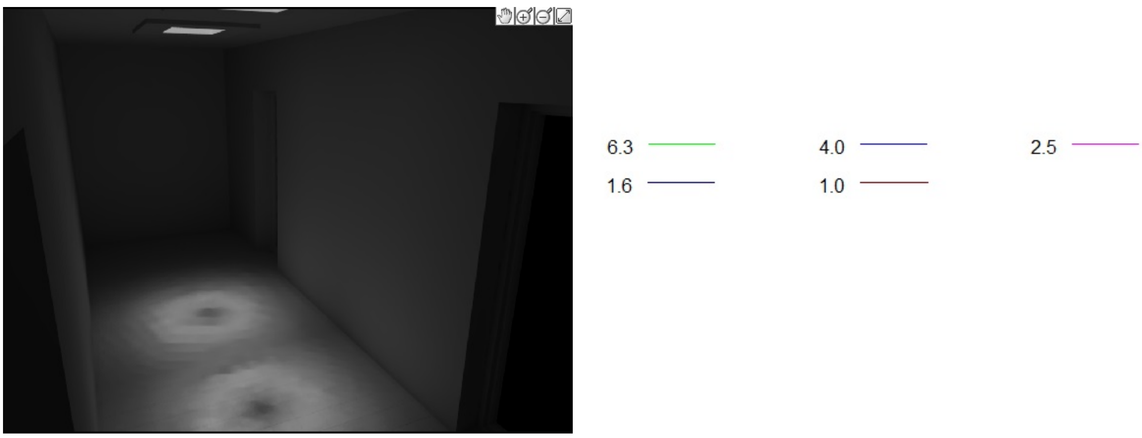

Figure 9. 3D simulation of measured space in software Velux Daylight Visualizer obtained on 7.1.2016

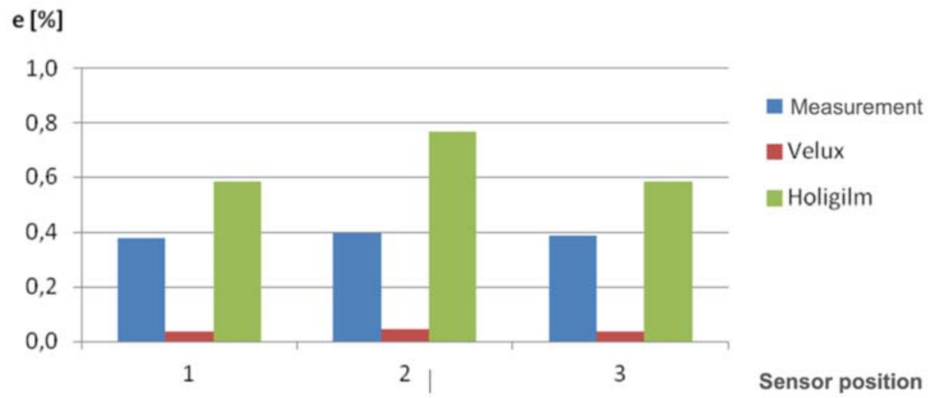

Figure 10. Evaluation and comparison of illuminance ratios (daylight factors) obtained on 10.7.2015

5. Conclusion

The comparison of the illuminance ratios obtained on 10.7.2015 is shown in the graph (figure 10) created in MS Excel. The results from the simulation in the software Holigilm differ from reality because of the setting geographic location only by the latitude (49 °) and the choice of only some of the sky types, where for the visually determined sky type 12 the nearest possible sky type was 5. When setting parameters there were also considered the manufacturer's declared values of light reflection factors in the tube and the diffuser and dome transparency. In fact, these values are likely to be lower, e.g. due to pollution. The reflectivity values of walls, floors and ceilings in the hall are determined only visually, according to the material and the surface finishes. After setting the date, time and other parameters, an outdoor illumination of 22,250 lx was calculated instead of a measured average outdoor illumination of 39,440 lx. Due to these differences, the resulting daylight factor values from the software Holigilm are higher than ones from the measurements.

The software Velux Daylight Visualizer does not have the option of a light guide. For this reason, it must be modelled using the skylights, which are among the software options with a minimum diameter of 600mm, and fenced with walls of the appropriate height. The difference between the values calculated by the software Velux Daylight Visualizer and the measured values can be caused by the formation of a square shape of the tube which does not produce such perfect light reflections as a circular cross-section one. Furthermore, the sky type was determined only visually, and the program allows to set the measurement date only as the 21st day of the selected month. The origin of significantly lower values calculated by the software Velux Daylight Visualizer in relation to measured values and the software Holigilm results can be the fact that, unlike the Holigilm, the Velux Daylight Visualizer determines illumination for all sky types only by illumination from the sky and does not include illumination from direct sunlight, as has been reported in the book " Daylighting on the working plane in oriented attic rooms under overcast and clear sky ". [4]. In addition, the software Velux Daylight Visualizer does not show numerically what exterior illumination for the current day and sky type it is working with, and the ratio of indoor and outdoor illumination (daylight factor) is set only for the uniform sky (ie CIE sky type 1). For these reasons, the value of the exterior illumination taken from the software Holigilm was used in the calculation of the illuminance ratio in Velux Daylight Visualizer. Therefore, the program works with a different illumination and thus its resulting values are lower than the measured ones.

Table 5. Illuminance ratios e [%] 7.1.2016

Sensor position	Illuminance ratio e [%]		
	Measurement	Velux Daylight Visualizer	Holigilm
1	0,378	0,036	0,584
2	0,398	0,045	0,764
3	0,390	0,036	0,584

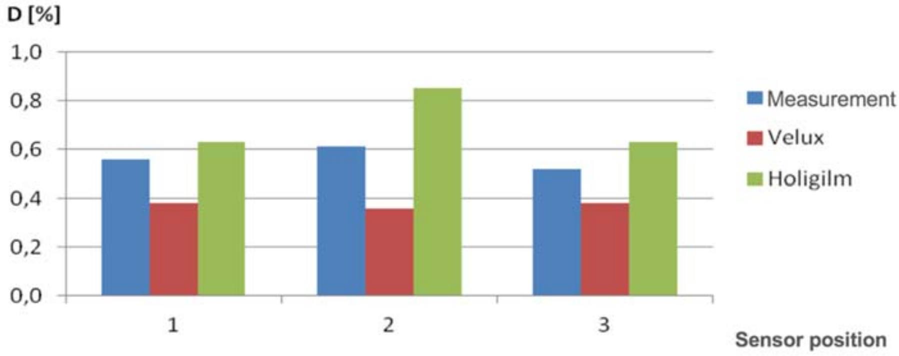

Figure 11. Evaluation and comparison of the illuminance ratios (daylight factors) obtained on 7.1.2016

A comparison of the individual illuminance factors obtained on 7.2016 is shown in the graph (Figure 11). The results from the simulation in the software Holigilm differ from reality because of the setting geographic location only by the latitude (49 °). When setting parameters there were also considered the manufacturer's declared values of light reflection factors in the tube and the diffuser and dome transparency. In fact, these values are likely to be lower, e.g. due to pollution. The reflectivity values of walls, floors and ceilings in the hall are determined only visually, according to the material and the surface finishes. After setting the date, time and other parameters, an exterior illuminance of 8000 lx was calculated instead of a measured average exterior illuminance of 10006 lx. Because of the mentioned differences, the Holigilm resulting values of the daylight factor are higher than the measurements ones. The software Velux Daylight Visualizer does not have the option of a light guide. For this reason, it must be modelled using the skylights, which are among the software options with a minimum diameter of 600 mm and fenced with walls of the appropriate height. The difference between the values calculated by the software Velux Daylight Visualizer and the measured values can be caused by the considering of the skylight in the calculation model and thus the formation of a square shape of the tube which does not produce such perfect light reflections as a circular cross-section one. The program allows to set the measurement date only as the 21st day of the selected month. For the mentioned reasons, there was a difference from reality and the resulting program values were lower than the measured ones. For a uniform sky, the Velux Daylight Visualizer directly calculates the daylight factors, so in this evaluation daylight factors calculated in the Velux Daylight Visualizer were used. In Fig. 5 is a graph illustrating the comparison of illuminance ratios.

Table 6. Comparison of measured data and computer simulations for 7.1.2016

Sensor position	Daylight factor D [%]		
	Measurement	Velux Daylight Visualizer	Holigilm
1	0.560	0.380	0.630
2	0.610	0.360	0.854
3	0.520	0.380	0.630

Acknowledgements
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