

Monitoring and Data Regression of a $\Phi 450\text{mm}$ Monodraught Lightpipe

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Abstract

This paper presents monitoring of a $\Phi 450\text{mm}$ elbowed Monodraught lightpipe at a purposely built test shed with a pitched roof. The monitoring includes use of a cubic integrating box (or known as the 'BRS Integrating Sky Photometer') to determine the lumen or illuminance output of the lightpipe. The monitoring results are presented in the format of the lumen output and the illuminance ratio of the output to the external horizontal. To assist the analysis of a huge amount of monitoring data, a formula is proposed to correlate the illuminance ratio, horizontal global illuminance, solar altitude and azimuth, the diameter and length of the lightpipe and the specular reflectance. The coefficients of the formula is given by the regression of the monitoring data. The formula may be used to predict the performance of the lightpipe.

Keywords: Monitoring, data regression, lightpipe

1 Introduction

A Monodraught lightpipe is a daylighting device comprising a dome top cover, a highly reflective pipe section and a diffusion exit cover. A lightpipe can transmit daylight into the deep interior of a building where the daylight through windows can hardly reach. The field measurement of the daylighting performance in the rooms with installation of Monodraught lightpipes have been reported¹. The results indicated the substantial capacity of lightpipes to replace electrical lighting. Based on the theoretical analysis and field measurement results, some empirical formulae have been proposed to predict daylighting performance in the rooms installed with lightpipes^{2,3,4,5}. These formulae correlate the internal-to-external illuminance ratio with the dimensions of lightpipes and sky conditions. The agreement between the measured and predicted is generally satisfactory. The field monitoring of a 1m long $\Phi 250\text{mm}$ lightpipe installed in a test room of 3.2m*2.6m*3.0m has been reported recently and the internal illuminance at a 0.8m high work plane has been presented⁶. These published work has been on the daylighting performance of the rooms installed with lightpipes, so the results could be affected by the sensor position and room configuration. Our monitoring work has been designed to determine the performance of Monodraught lightpipes excluding any effect of the test room.

2 Monitoring setup

A purpose built test shed has been constructed at the School of the Built Environment, University of Nottingham to monitor the daylighting performance of a range of Monodraught lightpipes. The test shed has a 25° tilted roof facing south to enable the testing of elbowed lightpipes as shown in Figure 1. To exclude the effect of any room condition as in the field test, an integrating box (or known as the 'BRS Integrating Sky Photometer') was used with a photocell inside pointing down, which ensures all the light is collected and accounted for^{7,8}. The integrating box was 1m*1m*1m cubic with an access door and the inside of the box was painted matt white (Figure 1) which gave an internal reflectance of 0.80~0.90. The $\Phi 450\text{mm}$

Monodraught lightpipe in monitoring had a 580mm long 30° tilted section, a 30° elbow and a 2790mm vertical section.



Figure 1: The purpose built Monodraught test shed at the School of the Built Environment, University of Nottingham

Prior to the installation of the lightpipe, the outdoor monitoring of the integrating box with a $\Phi 450\text{mm}$ aperture was carried out to determine the conversion factor, which is defined as the ratio of the illuminance at the internal sensor position to the illuminance at the integrating box aperture (same as the external horizontal), i.e.:

$$CF_{box}^* = \frac{E_{in,box}}{E_{out}} \quad (\text{Eq. 1})$$

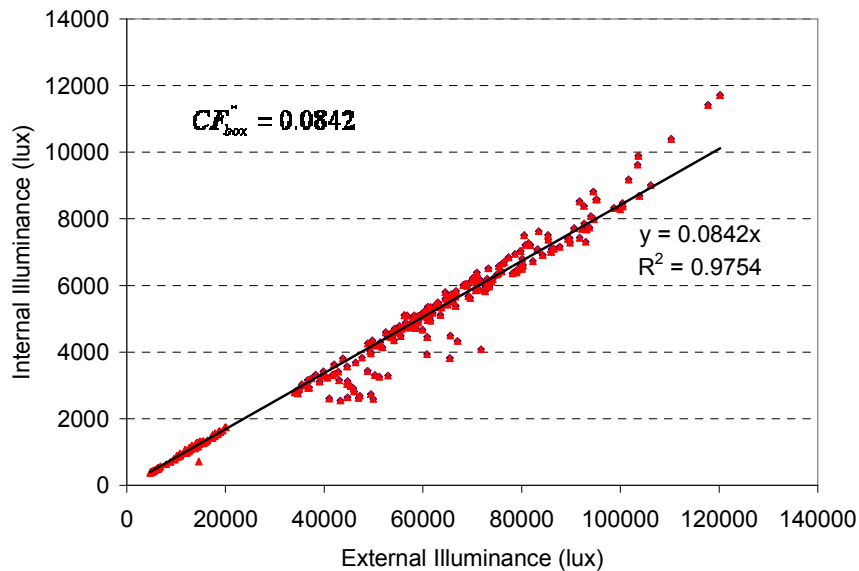


Figure 2: Conversion factor for the integrator box with a $\Phi 450\text{mm}$ aperture

The measurement was carried out in an intermediate sky condition and the results are shown in Figure 2. The average error in data regression was about 5%. It is evident the conversion factor is almost constant for a given box geometry and surface reflectance regardless of sky condition. This conversion factor could be used to calculate the average illuminance output or

lumen output of a lightpipe from the measured illuminance at the same sensor position in the integrating box, for example:

$$Lumen = E_{diffuser} \cdot \pi r^2 = \frac{E_{in,box}}{CF_{box}^*} \cdot \pi r^2 \quad (\text{Eq. 2})$$

The illuminance ratio of average output to the external horizontal, which is called the transmittance for a straight lightpipe, may be given by:

$$\tau = \frac{E_{diffuser}}{E_{out}} = \frac{E_{in,box}}{CF_{box}^* \cdot E_{out}} \quad (\text{Eq. 3})$$

3 Monitoring results and regression

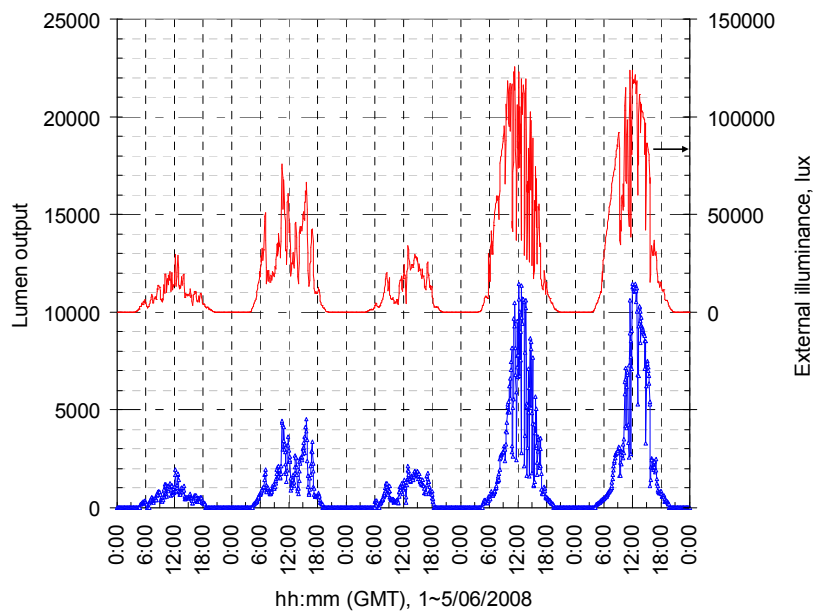


Figure 3: Lumen output of the monitored $\Phi 450\text{mm}$ Monodraught lightpipe

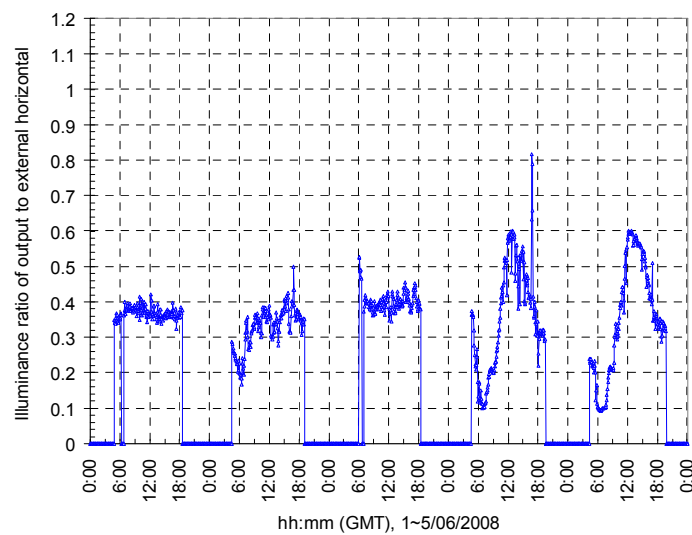


Figure 4: Illuminance ratio of output to external horizontal for the monitored $\Phi 450\text{mm}$ Monodraught lightpipe

The internal illuminance and external horizontal illuminance were recorded every 10 seconds and averaged for every 5 minutes by the datalogging programme. Figures 3 and 4 show the

lumen output and illuminance ratio calculated from the measured illuminance for a selected period which covers three sky situations: overcast, intermediate and clear skies. Some odd points might be caused by causal shade on the external sensor. For the overcast sky, the monitored $\Phi 450\text{mm}$ Monodraught lightpipe had a fairly constant illuminance ratio of about 0.4 and a lumen output around 1,000 lumen, which is equivalent to that of a 60W candescent lamp. For the clear sky, the illuminance ratio shows a large variation with the time or the sun position. At 6:00am, the illuminance ratio was as low as 0.1 due to a larger number of reflections. At the noon, the illuminance ratio was 0.6 because of less reflection and the lumen output was up to 11,000 lumen.

The theoretical analysis has indicated that the illuminance ratio may be related to the solar altitude, horizontal global illuminance, reflectance, length and diameter of a lightpipe^{2, 3, 4, 5}. For an elbowed lightpipe, the solar azimuth may be also considered. Therefore, the following equation was proposed to correlate the monitoring results:

$$\tau = (a_0 + a_1 \alpha + a_2 \beta + a_3 E + a_4 \alpha\beta + a_5 \alpha E + a_6 \beta E + a_7 \alpha^2 \beta E + a_8 \alpha \beta^2 E + a_9 \alpha \beta E^2 + a_{10} \alpha^2 \beta^2 E^2) \cdot \rho^{(b_1 \frac{L}{D} + b_2 \frac{1}{\tan \alpha} + b_3 \frac{L}{D \tan \alpha})} \quad (\text{Eq. 4})$$

Where α - solar altitude, $0^\circ \sim 90^\circ$;

β - solar azimuth; 0° (north), 90° (east), 180° (south), 270° (west)

E - horizontal global illuminance, lux ;

ρ - reflectance of lightpipe, it was determined at 0.95;

L - length of lightpipe, m ;

D - diameter of lightpipe, m ;

$a_0 \sim a_{10}, b_1 \sim b_3$ - coefficients.

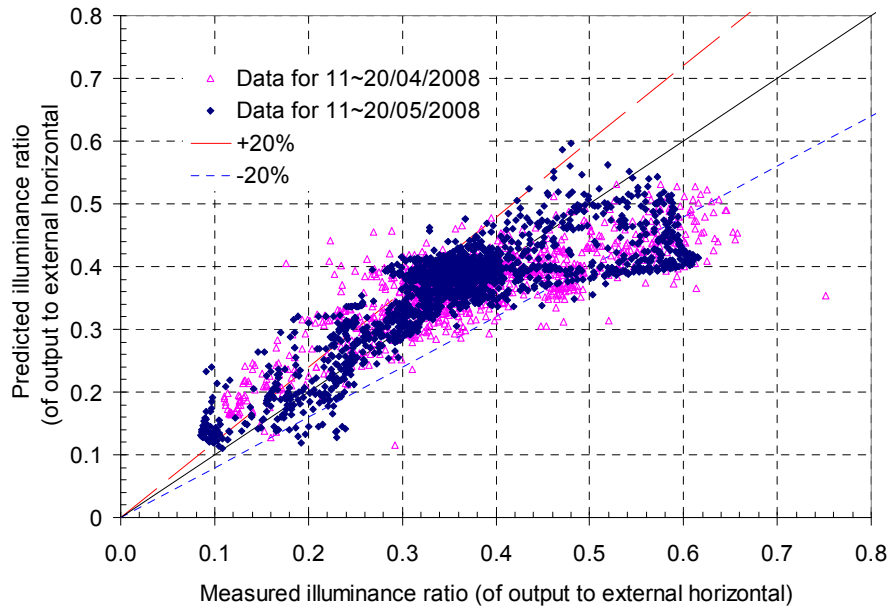


Figure 5: Comparison of predicted illuminance ratio and measured

The regression of several weeks monitoring data gave the values of the constants in Eq. 4, as below:

a0	1.1325		
a1	-5.1291E-05		
a2	9.7592E-03		
a3	-3.3996E-04		
a4	7.1482E-07		
a5	2.0186E-07		
a6	-4.8353E-05		
a7	0		
a8	-3.8255E-11	b1	2.1899E+12
a9	-1.8313E-12	b2	2.7422
a10	0	b3	-2.9242E+11

Figure 5 shows a comparison between the measured illuminance ratio and the predicted by the regression formula, Eq. 4. The average deviation is less than 20% though the maximum deviation may be quite large for some points. The agreement is relatively satisfactory.

4 Conclusions

Monitoring of a 3370mm long Φ 450mm elbowed Monodraught lightpipe has been carried out at a purposely built test shed. A cubic integrating box has been used to determine the lumen or illuminance output of the lightpipe. The monitored lightpipe has an output-to-external illuminance ratio of about 0.4 for the overcast sky and 0.1~0.6 for the clear sky in June. A formula has been proposed to correlate the illuminance ratio, horizontal global illuminance, solar altitude and azimuth, the diameter and length of the lightpipe and the specular reflectance. The regression of the monitoring data has been carried out to determine the coefficients of the formula. The formula could then be used to predict the performance of the lightpipe. It has been found that the predicted data are in a satisfactory agreement with the monitoring data.

Acknowledgements

Thanks to Monodraught Ltd. for their financial and technical supports associated with this study.

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