Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 22 (2016) 690 – 696

Procedia Technology

9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania

Passive Tubular Daylight Guidance System Survey

Calin Ciugudeanu[a,]*, Dorin Beu[a]

[a] *Technical University of Cluj-Napoca, 28, Memorandumului, Cluj-Napoca, 400114,Romania*

Abstract

Daylight levels decrease asymptotically with distance from the window so that a disproportionate amount of daylight/solar gain must be introduced into the front of the room to achieve small increases in daylight deep inside at the back. Several systems exist to redirect daylight into areas of buildings that cannot be lit by traditional glazing. One major generic group is known as 'beam daylight' - redirects sunlight by adding reflective or refracting elements to conventional windows. The second major group is known as Tubular Daylight Guidance Systems (TDGS). Tubular daylight guidance systems are linear structures that channel daylight by means of optical interactions into the core of a building.

The paper presents a case-study for a passive TDGS installed in a residential building in Cluj-Napoca, Romania. Field measurements are presented as well as software simulation results (DIALux, Lux Calculator). Based on the official numbers of dwellings provided by the Romanian National Institute of Statistics and the energy savings presented in the case-study, some predictions were made regarding the energy saving potential of passive tubular daylight systems over Romania.

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering

Keywords: Sun pipe; Daylight; Sustainable lighting; Passive tubular daylight guidance systems.

1. Introduction

Daylight levels decrease asymptotically with distance from the traditional window so that a disproportionate amount of daylight and solar gain must be introduced into the front of the room to achieve small increases at the back. While this can increase energy savings over a larger room area by offsetting electric lighting energy, the

* Corresponding author. Tel.: +40-752-193-890; fax: +40-264-591-350.
E-mail address: calin.ciugudeanu@insta.utcluj.ro

Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2016.01.144

corresponding increase in cooling due to solar heat gain, and/or heating due to structural heat loss, can negate these savings [1]. The use of glazed areas on other parts of the building envelope including atriums, skylights and roof monitors may light some areas remote from windows but these are of limited use in lighting deep core areas [2].

The estimated lighting level was simulated with Dialux Software for a room (6*12 m) situated in Bucharest. The room has the windows orientation NE on the 6 m wall. In figure 1 it can be seen the limited amount of daylight inside a 12 m deep room. The same figure illustrates the lighting level when there are used fluorescent 36 W lamps.

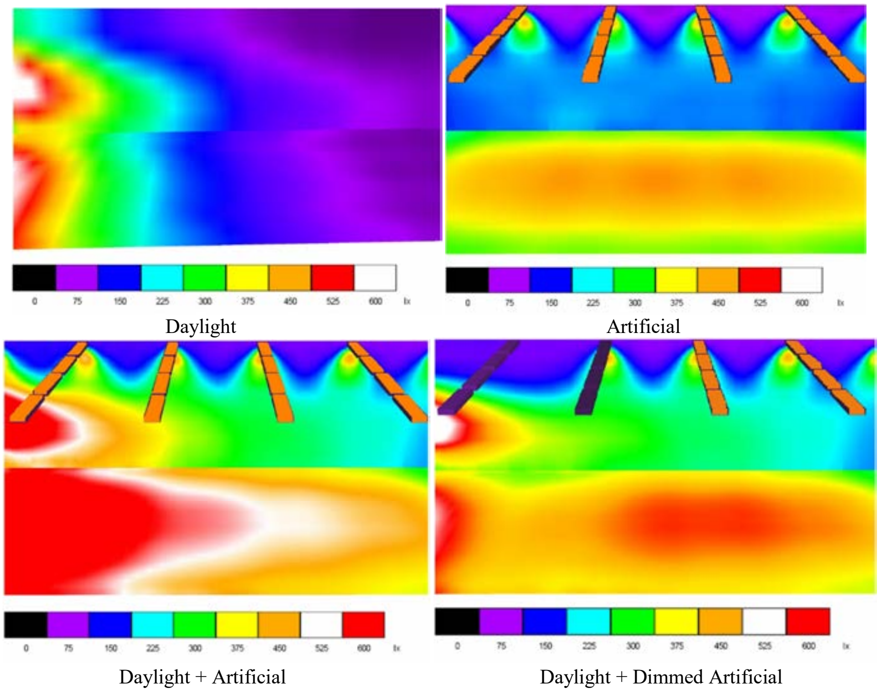

Fig. 1. Lighting levels (6 *12 m, windows on the left - NE, simulation for a building placed in Bucharest, summer time) [3]

Tubular daylight guidance systems – TDGS - consist of a light transport section with, at the outer end, some device for collecting natural light and, at the inner end, a means of distribution of light within the interior. Collectors may be either mechanical devices that actively focus and direct daylight (usually sunlight), or be passive devices that accept sunlight and skylight from part or whole sky hemisphere. The development, over the last decade, of materials with high specular reflectance has led to a large number of passive zenithal systems, the most commercially successful type of daylight guidance being installed in many parts of the world. Presently there are few methods for the illuminance prediction of daylight guidance system output within a building.

There has been a considerable research effort on TDGS over the last decade. Initially, this concentrated on light transport materials and devices, but latterly, a number of methods of predicting light delivery and/or distribution within a building interior have been developed. They form the basis of CIE173:2006 Tubular Daylight Guidance Systems – technical report. The report describes mostly the passive zenithal systems. These are, by far, the most commercially successful types of tubular daylight guidance, being manufactured and installed in large numbers in numerous countries. The design methodology presented in this report relates to passive zenithal systems only. The Report includes reviews of the technology of all generic types of daylight guidance systems, and includes case-studies. The sections on performance indices, photometry of components and systems, design methods, cost and benefits, human factors and architectural issues relate to passive zenithal systems [4].

The paper presents results of an experimental study on the performance of a passive tubular daylight system, under the climatic condition of Cluj-Napoca, Romania. A light pipe with flat collector and light-distribution diffuser was installed in a residential building. The performance of the light pipe was tested. The CIE173:2006 suggested methods of prediction were tested against measured and simulated data for the installation survey.

2. Case study - Passive TDGS installed - Cluj-Napoca

The experimental set up was installed in a residential house from Cluj-Napoca, Romania. A light pipe produced by Velux was mounted inside a 4 m * 4 m room on the first floor of the residential building, as shown in Figure 2. The house was part of a duplex situated in Cluj-Napoca. The light pipe has a length of 2.5 m and a diameter of 350 mm. A highly reflective film which has a minimum reflectivity of 95% is used for the interior surface. The top of the pipe was sealed with a clear anti-yellowing acrylic window. A white diffuser was mounted to the lower opening of the light pipe for even light distribution within the room.

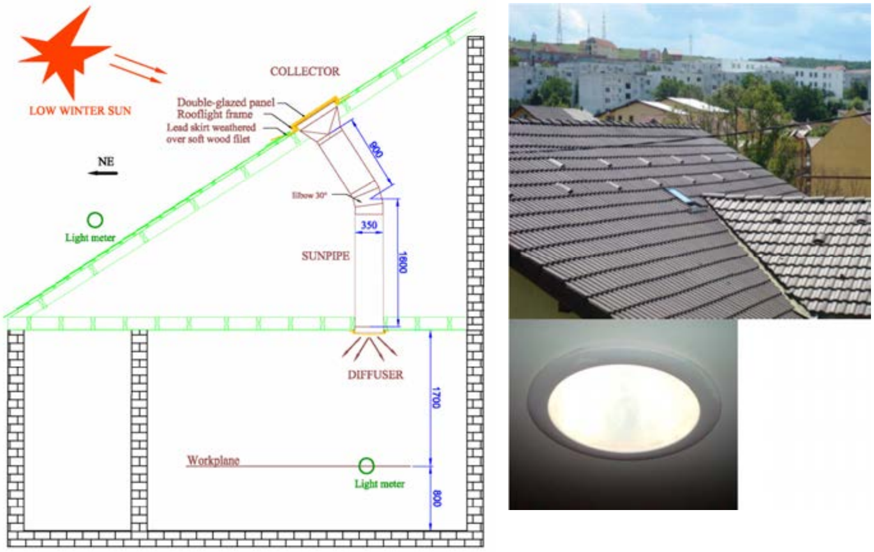

Fig. 2. The experimental set up - Velux TWR14 installed in Cluj-Napoca, Romania

Illuminance measurement was carried out using a standard light meter range 0.05- 100,000 lx. The meter was based on a photocell which has a spectral response similar to that of a standard human eye, avoiding the need for correction for various types of light sources.

Illuminance of the sun on the open field, and that within the working plane inside the room, were obtained using two separate photocells. The readings were recorded manually and cares were taken to ensure that there were no passing clouds or other significant changes of lighting condition between reading the two cells. The photocell within the room was normally placed under the diffuser, at a 0.8 m distance above the floor where the work plane is assumed to be. The data was measured for more than 30 different days, all around the year 2009.

Analyzing the measured data the maximum, minimum and average values of the indoor and outdoor illuminance were calculated. The results are presented in Table 1. For some winter days the results were not conclusive because of the layer of ice and snow covering the collector. This should ask for second thoughts regarding the shape, geometry and orientation of the flat/dome-type collectors, for northern areas with heavy winters.

Table 1 - Measurements average results

Value	Internal illuminance (work plane) [lx]	External illuminance [lx]	Internal/ external illuminance [%]	Average internal iluminance /day [lx]
Max	238	88 000	1.38	206
Min	34	3 200	0.19	65
Average	**151**	**41 926**	**0.36**	**145**

The maximum illumination achieved for the work plan was 238 lx, for the day 31.07.2009, at 13.45, corresponding to a value of external illumination of 80,000 lx. This value does not coincide with the maximum recorded external illumination, about 88 000 lx (21/07/2009, time 13.55), probably due to measurement errors. The lowest illumination value on the work plan was 34 lx registered on 04/02/2009, 14.15, overcast conditions and coincides with the minimum outdoor illumination of 3200 lx. In general the system has provided an average illumination of about 145-150 lx, with an average ratio of indoor per outdoor illumination of about 0.36, enough for many general activities according with [5].

3. DIALux simulations for the passive TDGS installed in Cluj-Napoca

The CIE 173 technical report describes three prediction methods for routine design use. The methods differ in sophistication and are as well different requiring various amounts of input data. The designer can choose the appropriate method for a particular design problem, depending on the amount of data available and the desired accuracy. The first method is a tabular method which requires only knowledge of the space to be lit, its function and its geographic location. Results give an indication of the floor area that will be usefully lit per guide. The second method is based on the "standard daylight transfer characteristic". The third method permits prediction of likely light outputs from guide systems of different configurations based on tabulated data on guide efficiencies. The CIE 173 design methodology was evaluated [6] and even being a simple calculation methodology, the delivered results were not very accurate.

DIALux 4.7 is well known among specialized software used in the calculation of interior and exterior lighting. Version 4.7 has in addition to the previous versions, the possibility to calculate the contribution of natural light inside a room. Besides the well-known interior artificial lighting systems, software includes for now only some conventional daylight systems such as windows and skylights. To achieve a simulation model close to the one studied and described above, it was used a skylight with the same geometric and structural features as the Velux TWR14 system. Although rectangular with no bends, the used section, the length of the tube and its reflection coefficient were identical. The same features and optical properties were chosen for the glass (equivalent to the collector and diffuser together). This has some implications in terms of light distribution within interior, but the overall efficiency of the collector and diffuser is identical to that of the TDGS system installed, in order not to alter the overall efficiency. The reflection coefficient for the internal surfaces, the geometry and the location of the skylight inside the room, fully respects the experimental arrangement. Also for the geographical location the software allows to choose precisely the same latitude and longitude, orientation and inclination of the collector glass for admitting the natural light. Similar the same date and time was selected as the measurements were made, to make possible to determine the software accuracy.

The calculation was performed only using the amount of indirect natural light and it was set not to take into account the direct sun rays, which would of have a big impact onto the light distribution within interior. Four different days of the year have been selected, identical to those when the experimental recordings were made, in order to compare results. In Figure 3 there are presented the overall results of the calculations. It was attempted a comparison of the maximum illumination of the working plan, corresponding to the measured values on the work plan under the diffuser.

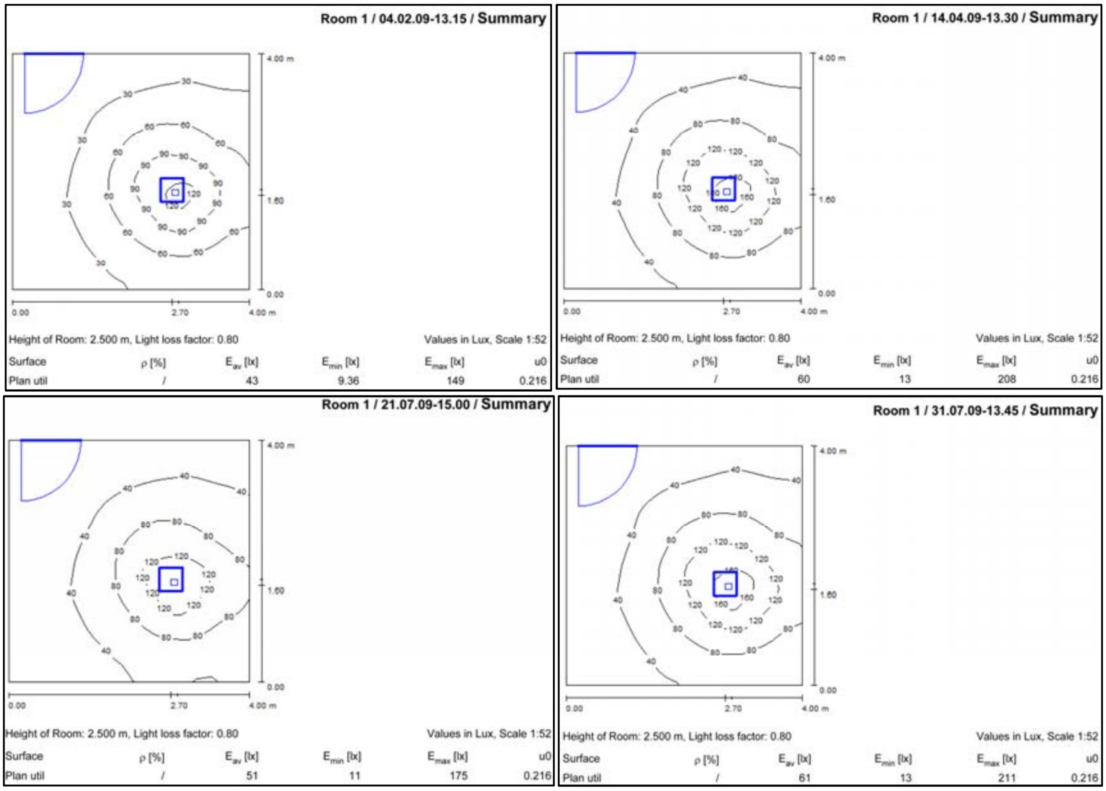

Fig. 3. Simulation results with DIALux software - four different days

Table 2 presents the compared illumination measured levels and simulated levels with the software DIALux 4.7, for the maximum horizontal illuminance on the work plane. The average relative error is about 8.7%, but note that data are comparable just for overcast simulations [6].

Table 2 - Comparison results for the maximal horizontal illuminance – measured and simulated

Date	Time	Measured illuminance [lx]	Simulated illuminance [lx]	Relative error [%]
04.02.09	13.45	135	149	9
14.04.09	13.30	200	208	4
21.07.09	15.00	160	175	9
31.07.09	13.45	238	211	13
Average relative error				8.7

It was also simulated the lighting distribution on the floor plan, for the day 31.07.2009, at 13:45. The results, Figure 4, are comparable both as values and as illuminance levels. As expected, there are certain differences because of the measurements errors or the assimilations that were made using the DIALux software.

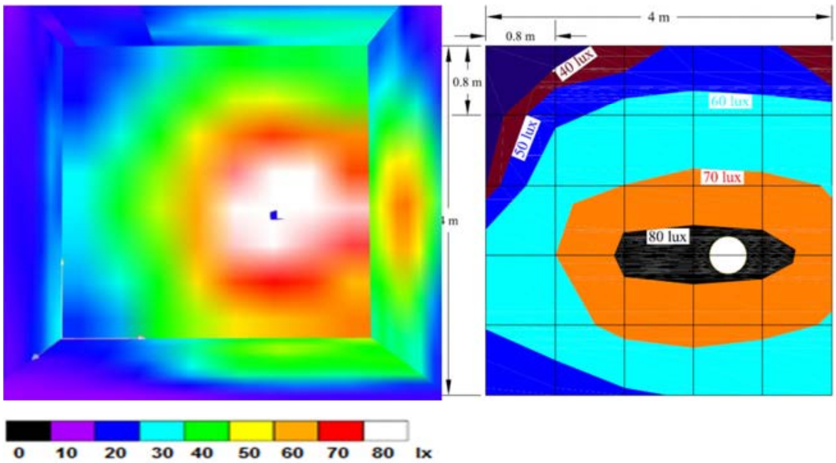

Fig. 4. Comparison results for the simulated (left) and measured (right) illuminance levels 31.07.2009 - 13:45

It can be concluded that simulated daylight calculation results with DIALux 4.7 are quite accurate. Soon it is expected that this software specialized in lighting calculations to include a TDGS module specifically dedicated, as recent versions have begun to pay increased attention to natural lighting.

4. Hybrid Tubular Daylight Guidance Systems

The Technical University of Cluj-Napoca - Lighting Engineering Laboratory – LEL [7] developed a new hybrid TDGS system that is presently under survey. The new system was developed based on the previous survey studies for a TDGS installed in Cluj-Napoca, [6].

Presently a new Hybrid TDGS is under survey. The new system is using a passive TDGSand a small photovoltaic 40W system powering LED light sources, placed next to the diffuser. The tubular daylight guidance system installed is a Velux TWF, 350 mm diameter, flexible light pipe. The photovoltaic system is geared with a 40 W photovoltaic panel 12V Poly 670×475×25mm, a BlueSolar charge controller PWM 12/24V-5A and a 12V/22Ah AGM Deep Cycle Battery providing a 10 hours autonomy for the 28 W LED. A dimming control system is used in order to maintain a certain lighting level on the work area – Figure 5.

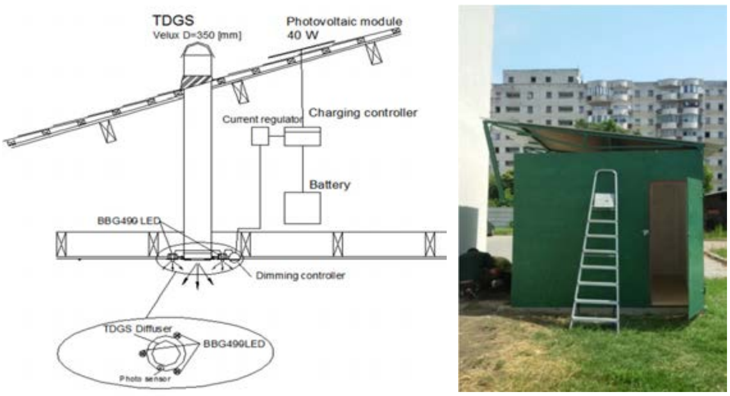

Fig. 5. Hybrid Passive Tubular Daylight Guidance System

The Hybrid Passive TDGS was installed in an outside experimental booth (3 m length, 3 m width, 2.5 m height) outside the building. The booth can provide different cardinal orientations and different roof pitches in order to provide various setups for the installed Hybrid Passive TDGS.

The designed hybrid system does not need the support of the electric network system, being suitable / adaptable for isolated areas where there is no electricity or for refurbishment solutions where new electrical wiring is not desired.

5. Conclusion

Scientists estimates electric lighting savings for the residential sector taking into consideration a non-working residential couple who spend a considerable amount of time at home with a 300 mm diameter passive TDGS installed (usually in the kitchen/hallway/bathroom). The system typically replaces the burning of 200 to 500 Watts of electric lights for 3 to 7 hours per day [8]. For this example we'll assume a 300 Watt savings for 5 hrs. per day, only 5 days per week. This leads to electric savings for a TDGS 300 mm diameter of about 390 kWh per year.

If we consider that in each 2.35 millions buildings with dwellings having non-working family head [9], at least one TDGS 300 mm diameter is suitable to be installed and taking into account the previous electrical savings example, we can assume total energy savings for residential lighting in Romania of about 916,500 MWh per year. Additionally savings can be assumed for the total number of residential buildings during the weekends (total number of residential buildings - 4.38 millions 9 * 300 Watt savings for 5 hrs. per day, only 2 days in the weekend leads to additional total electricity savings of 630,000 MWh per year). The previous predictions examples show electricity savings for the residential sector in Romania by installing in each building a TDGS 300 mm diameter of about 1.5 million MWh per year [10]. Even a greater saving potential should be available for the commercial/educational sector where usually the main activity take place during the day.

References

[1] Liu KS, Chen JL, Huang CF, Chen YC. Effects of Different Window Treatments on Energy Saving and Light Control Design. Journal for Environmental Protection and Ecology; Vol. 15; nr. 3A. 2014.

[2] Ticleanu C. Modern Daylighting Techniques. International Conference Light & Lighting 2002. Bucharest. November 2002.

[3] Ciugudeanu C, Pop F. Tubular daylight guidance systems – Energy saving potential in residential buildings in Romania. The 5thInternational Conference Energy Efficiency in Domestic Appliances and Lighting (EEDAL'09); 16-18 June 2009.

[4] CIE 173:2006.Tubular Daylight Guidance Systems. CIE Technical Committee, 3-38 of Division 3 - Interior Environment and Lighting Design. ISBN 3901906495.

[5] SR EN 12464-1:2011. Light and lighting - Lighting of work places - Part 1: Indoor work places; 2011.

[6] Ciugudeanu C, Pop F. Passive tubular daylight guidance systems, design methodology. The 6th International Conference EEDAL - Energy Efficiency in Domestic Appliances and Lighting; 2011.

[7] Pop F, Ramon S. Lighting Engineering Centre - LEC - consulting and continuous formation. Tempus Phare CMS - Compact Measures; 1999.

[8] Carter DJ. The measured and predicted performance of passive solar light guide systems. Lighting Research and Technology, 34 (1); 2002.

[9] INS. Data provided by INS – Romanian National Institute of Statistics.

[10] Beu D, Ciugudeanu C. Lighting – Between Nostalgia and Extreme Anticipation. BulLIGHT 2014 International Conference; Sozopol; Bulgaria; 10-13 June 2014.