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Optical Performance of Polycarbonate Multi-Wall Panels in the form of Transparent Insulation Based on Long-Term Outdoor Measurements

Miroslav Čekon [1,*]

[1]Brno University of Technology, Brno, Czechia

[*]*Corresponding email: cekon.m@fce.vutbr.cz*

ABSTRACT
Buildings are subject to strongly time variable solar radiation impacts, which are phenomena that typically occur at a characteristic timescale resolution. Recent technologies and advances which are currently being used to produce polycarbonate-based materials may be used in applications where it is useful to activate the solar transmittance functions of building envelopes. In general, systems utilizing polycarbonate as a type of transparent insulation material exhibit the thermal performance of standard glazing systems. This study is focused on the optical characterization of several polycarbonate panels for buildings that are based on different numbers of chambers and differing geometries. The optical performance was analyzed in order to monitor the long-term solar properties of polycarbonate panels, by means of outdoor measurements in order to demonstrate the impact of year-round aspects on solar transmittance. This represented a specific methodical approach incorporating real full-scale components. Finally, the solar transmittance is evaluated with regard to the various outdoor time scales (hourly/daily, monthly and year-round). The studied multi-wall polycarbonate panels indicate that they may have very specific characterization from the solar transmittance perspective regarding the solar radiation that penetrates throughout their internal structure. The solar transmittance of polycarbonates, to which the timescales of the outdoor conditions respond, may significantly vary. Overall, the differences in total solar transmittance for laboratory, declared and outdoor test methods are very obvious; they differ by tens of percent. The study provides an initial insight into the optical behaviour of polycarbonate multi-wall panels and a very large set of data in order to make careful use of these parameters concerning their specificity and time dependent characteristics in thermal analysis of building integration.

KEYWORDS
Transparent insulation, Polycarbonate system, Outdoor testing, Solar transmittance

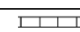
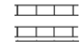
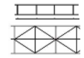
INTRODUCTION

Transparent Insulation Materials (TIMs) (Kaushika and Sumathy 2003) have the potential to be predominantly used in current concepts that are being put forward in an attempt to replace conventional insulating materials. However, their involvement in the building envelope is specific and so their application in building practice is currently rather rare. Several early studies described the benefits, disadvantages and options for the application of TIMs in the 1990´s (e.g. Braun et al. 1992). Nevertheless, they are generally too expensive, though many cheaper materials have been diffusing such as polycarbonate sheets and panels. This represents one approach involving TIMs, which may be applied either directly as a transparent part of the building envelope, or as a part of potential solar façade concepts to obtain both transparency and thermal insulation. Various types have already been developed with different numbers of chambers and differing geometries. This development is specifically concerned with improvements from the thermal aspect. Furthermore, there could be potential in the development of polycarbonates regarding their optimal optical performance and selective properties. Hence it is necessary to analyze in detail data for the materials which are already available, and their optical variation needs to be investigated from the spectral, angular and real outdoor perspectives. A variety of studies have been produced concerning different transparent glazing systems (e.g. Juráš et al. 2017), although some early studies aimed at measuring solar transmittance were performed on various honeycomb-type structures with an indoor solar simulator more than 25 years ago (Platzer 1992). In this relation, outdoor measurements using the sun as the source might be a good option. Overall, apart from Čekon et al (2017), there is a lack of information regarding real outdoor test in the literature dealing with solar transmittance measurements. Nevertheless, this may represent a very simple yet highly feasible way of measuring the total solar transmittance at a particular site, though Platzer (1992) pointed out that it is not an acceptable approach for Central European climates. Fundamental principles are already well implemented in the standard method of testing the solar transmittance of sheet materials using sunlight with detailed specification and procedures stated in ASTM (2015). In this relation, the key aim of this study is to investigate the optical performance of polycarbonate components that are primarily based upon multi-wall systems via real outdoor measurements. Based on the large quantity data obtained during long-term measurements, the aim of this study is to summarize these data with regard to their specificity and to provide time dependent characteristics.

MATERIALS AND METHODS

Three different polycarbonate systems were analyzed at the year-round scale. Table 1 shows all the measured components (PC10, PC25 and PC32) and their properties. The main difference between them lies in their overall thickness and the structure of their internal chambers. The analysis employs long-term measurements performed on vertical south-east (SE) oriented full-scale components located at the AdMaS centre operated by Brno University of Technology (Čekon et al. 2016) (longitude 16°34′, latitude 49°14′, altitude 297.23 m). Although there are many specific issues to take into account, such as inclined angular dependence, fluctuations of solar irradiation and overall solar distribution as well as cardinal point aspect, the estimation of solar transmittance via real outdoor measurements following ASTM (2015) principles was employed. This main objective is achieved via the analysis of optical performance studies carried out at different time-scale levels. The solar transmittance is then evaluated over various outdoor timescales (hourly/daily, monthly and year-round) and a comparison with values declared by the producers is provided as well.

Table 1. Description and key parameters of polycarbonate systems

	Type	Thickness [mm]	Declared T_{decl} [-]	τ_λ * ASTM G 173	Measured** ASTM E1084-86	Geometry
PC10	Clear 2walls	10	0.82	0.74	0.63	
PC10*	PC10 + prismatic glass	10+5	n/a	n/a	0.57	
PC25	Clear 3walls /diagonals	25	0.63	0.48	0.54	
PC32	Clear 6walls combined	32	0.53	0.43	0.53	

* obtained based on Čekon et al. (2017b); ** averaged values measured over 2017

Two photodiode elements were mounted in the air cavity behind each polycarbonate sample and a third additional element was left exposed to outdoor conditions. A commercial Star Pyranometer FLA 628 S was additionally used for photodiode comparison and accuracy correlations. Diode error depends on many factors and could not be directly determined. Based on the data obtained during diode circuit calibration procedures, the maximum error could be estimated at less than +/-10% of the measured value. However, a detailed analysis was conducted in relation to the measurement of solar radiant flux using a photodiode (Čekon et al 2016), its optimization and the estimation of its correction factor during measurements

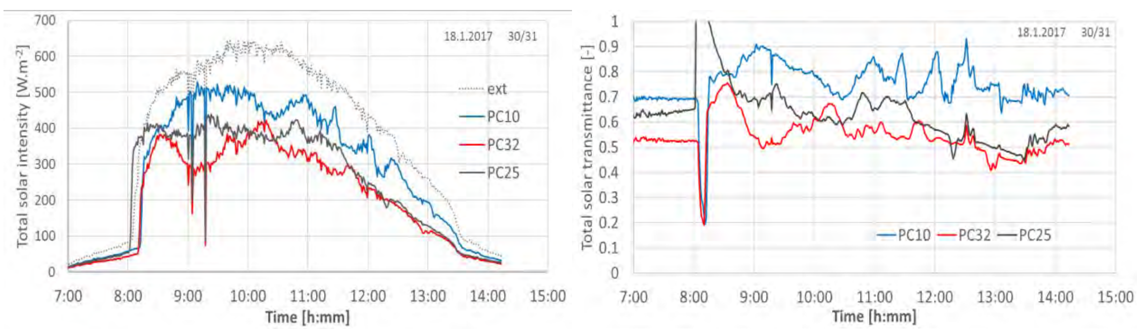
(Slávik and Čekon, 2016). Finally, the ratio between the two solar intensity rates obtained by the silicon pin photodiodes represents the solar transmittance values.

RESULTS

As the focus on the long-term monitoring of real full-scale components is to demonstrate the annual progress of the total solar transmittance and passive solar gains of multi-wall panels, the fundamental principles of a standard test method an extraordinary mode was used. This section presents results from different timescales that depend for the purpose of evaluation on variables corresponding to hourly/daily, monthly and year-round progressions.

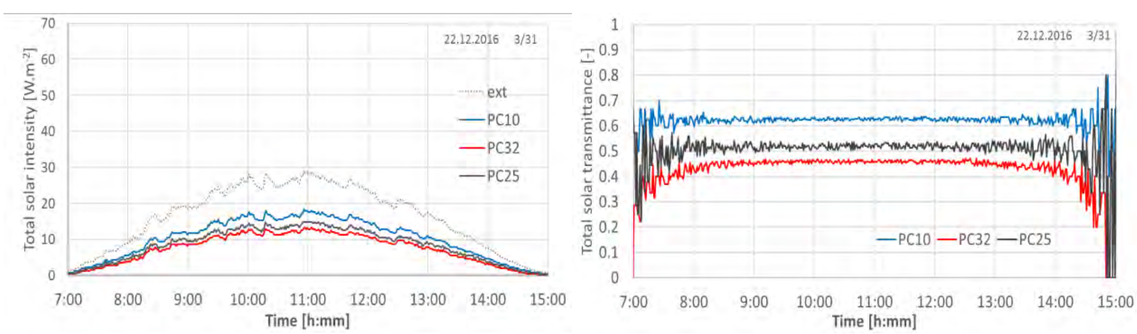
Hourly/daily-based timescale

The results presented in Figure 1 and 2 cover two different measurement days during which clear sunny and total cloud cover conditions prevailed. This corresponds to a combined hourly/diurnal time scale, where the detailed influence of polycarbonate structure can be observed. For the clear sunny period shown in Figure 1a, the results are strongly hourly sensitive due to the non-homogeneity of the tested polycarbonate systems and their internal structure (Figure 1b). This factor is demonstrated by the continuous variation in solar transmittance by several tens of percent resulting in a presence of multiple internal reflection of the incoming direct beam radiation distributed over a large-scale area towards the measurement sensor. The overall inhomogeneity and sun incident angle effect, occurring in both the parallel and perpendicular partitions over each tested structure, involve strong uniformly throughout the materials. On the other hand, very stable progressions are observed during overcast conditions (Figure 2a). For both test periods, the higher the maximum level of solar intensity, the higher the daily solar transmittance obtained.



a) b)

Figure 1. Measurements taken at an hourly/diurnal timescale under clear sky conditions; a) solar radiation rates measured; b) total solar transmittance derived.

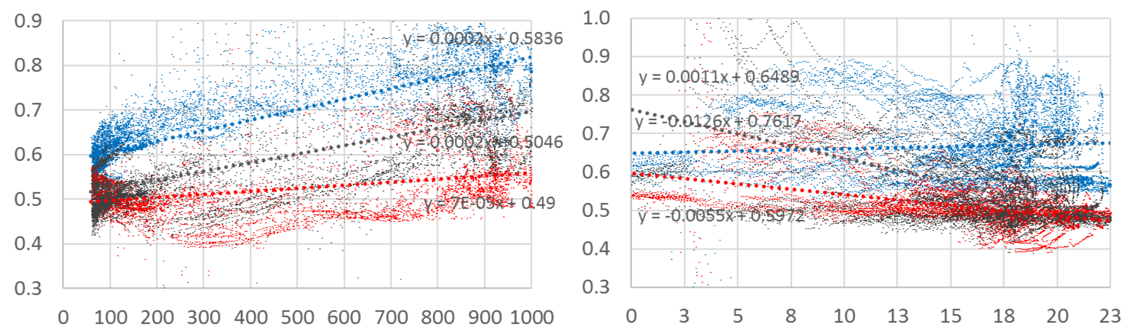


a) b)

Figure 2. Measurements taken at an hourly diurnal timescale under total cloud cover; a) solar radiation rates measured; b) total solar transmittance derived.

Monthly-based timescale

The results shown in Figure 3 are an example of monthly-based result evaluation that is dependent on solar intensity rates and the relation with the angle of incidence of the sun above the horizon (altitude α). Outdoor solar intensities greater than 60W/m^2 obtained at the vertical level of test samples are included starting at 135° from the north azimuth. The results are presented using point clouds. Linear tendencies are indicated so as to generalize these strongly time variable and numerous data. In this regard, resultant linear relation is derived, and the monthly dependencies shown in Table 2 are provided for each PC panel. It should be noted that the linear functions do not represent the measured values adequately as this is first preview gained from the analyzed data; in the case of this study it provides an initial insight.



a) b)

Figure 3. An example of measurements taken at a monthly-based timescale: a) the relation to the amount of total vertical solar radiation, b) the relation to the angle of incidence of the sun.

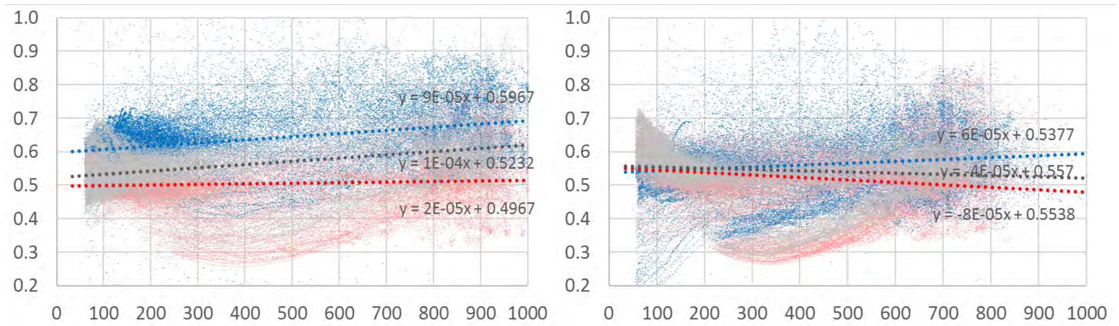
Table 2. Linear tendencies of monthly-based relations depending on solar intensity rates

2017	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE
max α	17° - 22°	22° - 31°	31° - 44°	44° - 54°	54° - 61°	61° - 64°
PC10	2E-4·*I* + 0.58	7E-5·*I* + 0.60	7E-5·*I* + 0.60	8E-5·*I* + 0.61	9E-6·*I* + 0.62	9E-5·*I* + 0.51*
PC25	2E-4·*I* + 0.50	1E-4·*I* + 0.50	1E-4·*I* + 0.50	8E-5·*I* + 0.54	-7E-6·*I* + 0.56	-4E-5·*I* + 0.55
PC32	7E-5·*I* + 0.49	2E-5·*I* + 0.50	2E-5·*I* + 0.50	2E-5·*I* + 0.50	-2E-5·*I* + 0.51	-6E-5·*I* + 0.53
2017	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
max α	64° - 59°	59° - 49°	49° - 37°	37° - 26°	26° - 18°	18° - 17°
PC10*	9E-6·*I* + 0.55*	7E-5·*I* + 0.55*	7E-5·*I* + 0.56*	7E-5·*I* + 0.55*	2E-4·*I* + 0.54*	2E-4·*I* + 0.54*
PC25	-9E-5·*I* + 0.57	-2E-5·*I* + 0.56	4E-5·*I* + 0.55	4E-5·*I* + 0.57	1E-4·*I* + 0.56	8E-5·*I* + 0.57
PC32	-1E-4·*I* + 0.57	-6E-5·*I* + 0.56	-6E-5·*I* + 0.57	-6E-5·*I* + 0.56	-6E-5·*I* + 0.58	-4E-5·*I* + 0.57

* Sample PC10 coupled with prismatic glass

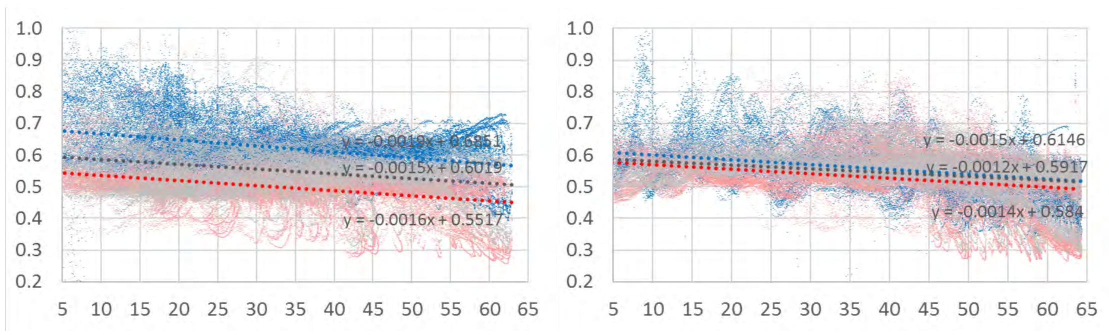
Year-round time scale

Similarly, in Figure 4 and 5, year-round progressions are interpreted based on the same visualizations, and again linear relations are derived for each polycarbonate panel. The data obtained during year-round monitoring are divided into two presented periods. One corresponds to the first half of the year, and the other to the second half; during these two periods the maximum midday height of the sun above the horizon ranged from 17° to 61° and from 64° to 17°, respectively. In both periods, not surprisingly due to the angular aspects involved, the solar transmittance decreased with higher angles of incidence of the sun (see Figure 4). If Figure 5 is studied in detail, one can observe some angular selective functions of panel PC32 as well as PC10 combined with prismatic glass (PC10*). In contrast, the solar transmittance increases with increasing solar intensity rates, and vice versa, a trend that really corresponds to the height of the sun above the horizon during the whole year. This means that the differences in the behavior of the full-scale samples in relation to solar conditions become higher with increasing solar intensity, and vice versa.



a) b)

Figure 4. Measurements taken at the year-round timescale regarding the amount of total vertical solar radiation in a) the first half year before 1st June, b) the second after 1st June.



a) b)

Figure 5. Measurements taken at the year-round timescale regarding the angle of incidence of the sun in a) the first half year before 1st June, b) the second half year after 1st June.

DISCUSSIONS

Based on the results presented, it can be observed that analyzed panels exhibit time-sensitive solar transmittance parameters. Looking at the hourly and/or daily scaled values, a continuous variation in solar transmittance of several tens of percent can be clearly detected. For the presented day with a clear sky, the obtained diurnal values are in the area of 0.79 (PC10), 0.53 (PC32) and 0.63 (PC25). This principally corresponds to the declared values (see Table 1). On the other hand, looking at the detailed hourly based progressions it can be seen that strong fluctuations occurred. This contrasts with overcast conditions, under which the average daily values are approximately 0.63 (PC10), 0.44 (PC32) and 0.52 (PC25). In this case the values correspond to those measured in the laboratory. Overall, the discrepancy in lab tests are that the incoming beam radiation is distributed disproportionately throughout the tested materials in range of approx. 15 nm diameter of spectrophotometer detector, while using outdoor tests, the transmittance is averaged over a large area. As regards the real outdoor measurements during longer timescale periods, the gained data concerning the influence of different solar intensity, angular and time dependent conditions on the solar transmittance is highly variable. The values obtained regarding solar intensity rates range from 0.50 to 0.55 (PC32), from 0.52 to 0.56 (PC25), from 0.60 to 0.67 (PC10) and from 0.54 to 0.60 (PC10*). Meanwhile, the values obtained regarding the angle of the sun above the horizon range from 0.59 to 0.49 (PC32), from 0.61 to 0.51 (PC25), from 0.68 to 0.57 (PC10) and from 0.61 to 0.52 (PC10*). However, the prevailing values show significant movement away from a linear tendency.

CONCLUSIONS

The paper presents the results of the long-term optical characterization of multi-wall panels utilizing co-extruded polycarbonate as a transparent insulation material (TIM). The study evaluated the impacts of polycarbonates with different numbers of chambers and differing geometries. The experimental monitoring of full-scale components was focused on annual optical performance as a fundamental step towards understanding overall interactions influencing the solar transfer of the presented polycarbonate TIMs. Regarding the real outdoor in-situ measurements using the sun as the source, this study applied a specific methodical approach introduced by this research using long-term solar radiation rate monitoring and its evaluation with three different multi-wall panels. This indicates that the internal structures and geometry currently used to produce polycarbonate-based materials may affect the solar transmittance functions of such components. The analysis demonstrated that from this perspective, the presented panels employ selective aspects regarding the solar radiation that penetrates throughout their internal chambers. Overall, the differences in solar transmittance for all tested periods are strongly variable; they differ by tens of percent. Finally, these results may be considered in order to make careful use of the data in thermal calculation models. Further studies should be focused on the advanced statistical analysis of obtained data in order to describe their overall dependencies more adequately.

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