

Estimation of solar radiation transmission for polycarbonate retractable swimming pool enclosures

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Abstract Application of retractable enclosures enables to lengthen operation periods for outdoor swimming pools operated in the moderate climate zone. Enclosures allow to diminish energy losses from water in the pool to the environment. Thermal calculations for pools with retractable enclosures are difficult to carry out because of a number of required parameters which can only be estimated. One of them is the transmission of solar radiation through the enclosure. The present paper presents the method of estimation of this parameter for swimming pool enclosures made of polycarbonate panels that have multichannels structure. In order to calculate transmission, the methodology considering the multiples of solar reflection inside the enclosure and their absorption by polycarbonate has been elaborated. Calculation results for transmission of the enclosure were verified experimentally. Analysis of results show that the transmission depends strongly on the enclosure's construction and on the direction of solar radiation on the enclosure. Mean transmission values of enclosure under research were determined both from calculations and experiment are equal to about 0.69 and 0.64, respectively. However, experimentally determined mean values of total transmission by parallel and perpendicular solar directions in relation to channel axes are equal to about 0.69 and 0.60, respectively.

Keywords: Outdoor swimming pool; Swimming pool roofing system; Pool enclosure; Polycarbonate enclosure; Solar transmission through enclosure

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1 Introduction

Rational energy consumption in various fields of activity is at present one of most important trends in the development of contemporary world. In case of outdoor swimming pools located in moderate climate zone, operating season can be prolonged due to pool water heating and/or preventing losses of heat cumulated in the water [1, 16, 17]. In order to diminish energy losses, water surface in pools is protected by covers or enclosures. Besides, enclosures are applied in order to hold down use of pool chemistry, to prevent falling down into the pool, as well as to avoid dirt deposits (leaves, pollens). Protecting sheet can be mounted just over the water surface (in direct contact with water surface), or in some distance over the water surface, as well as at the outskirts of the pool basin, in its vicinity [11, 19, 20, 22]. In case of protection directly by water surface, special covers with various construction solutions and applicability ranges are applied. They are, among others, bubble covers, foam foils, cover slats [11, 19, 20, 22]. Obvious inconvenience for the above solutions is the inaccessibility of the pool when they are spread. If protecting sheet does not remain in direct contact with the water surface, e.g., swimming pool tents, retractable swimming pool roofing system, pools can be used while they are spread over them. Most sophisticated kind of pool protection are the last one – retractable swimming pool enclosure (Fig. 1). As it was proved in paper [7], a swimming pool implemented with retractable enclosure can be used from April till October in the Middle European temperate climate zone.



Figure 1: View of swimming pool with retractable swimming pool enclosure [7].

The retractable swimming pool roofing system is supported by a frame made of aluminum profiles. Producers of pool enclosure offer various thicknesses and shapes of profiles. Such a construction is glazed, or finished with polycarbonate panels. Most frequently applied materials are multi-wall polycarbonate (twin, triple, or four-walled), and solid panels [13–15, 21].

Most frequently applied panel thicknesses are 8, 10, and 16 mm (multichannel structure), or 3 and 4 mm (solid structure). Producers offer both colorless as well as colored panels – blue, green, brown, or opaque; whereby colored panels are applied mainly in case of multi-wall polycarbonate [12, 13]. Panels are very often laminated with special coatings protecting against ultraviolet (UV) on their outer surfaces to protect people in swimming pools against the radiance. Besides, the film protects also the roofing system itself (against damages, color losses), as well as the elements beneath the pool enclosure (internal surfaces of pool's, furniture placed at the pool, etc.). In turn, inside surfaces of panels are covered with films that help condensed water to flow down on side walls of the pool enclosure instead of dropping directly down from panels [12, 13]. Glazed panels are much less frequently applied because they are heavy.

A swimming pool is an object where heat and mass exchange processes occur in a strongly unsteady state. In subject literature, information concerning models and heat calculations methodologies for objects of this type can be found [3–5, 9, 16]. In order to solve energy and mass balance equations present in the above models, knowledge of many geometric and physical parameters is required. For example, transmissivity of the cover for solar and thermal radiation, its reflexivity and absorptivity. It may, however, happen that values of the above parameters are unknown, or information given by producers of retractable enclosure or producers of polycarbonate panels applied in the swimming pool roofing system constructions is fragmentary. It is limited to visible light transmission, or to one only kind of panels (with given structure or thickness).

The present paper considers a swimming pool enclosure where not all parameters of applied materials are known. One of parameters of which the value must be given in order to carry out heat calculations is transmission of solar radiation for the enclosure. Some producers of materials applicable for enclosures print the value of this parameter in the technical data sheet of the product [24, 25]. The parameter is determined in laboratory conditions, according to relevant standards [23]. There is, however, a question if the parameter can be calculated and what is its value in real operating conditions of the enclosure. One of encountered problems is a complicated process of transmission of solar radiation through the material of enclosure which is in many cases in the form of the channel structure. Most often, an enclosure is built up of two or more walls as a supporting structure (Fig. 2). The walls are connected by short ribs which compose the channel structure. Areas among the ribs are filled by air. In longitudinal direction, the chan-

nels are not fragmented. Besides, in case of two or more walls structure of panels, thin plastic walls appear among the ribs and they divide each channel into smaller ones. Supporting structure of retractable pool enclosure closes the channels on both sides of the panel. Moreover, panels can be bent and forming an arched construction which results in irregular shapes of channels.



Figure 2: Cross section of the material of enclosure – flat polycarbonate panel with air channels: a) two-wall structure, b) four-wall structure.

It is even more difficult to create a model of transmission of solar radiation through the enclosure. Figure 3 gives an example of a flat, multi-wall enclosure with one channel next to the upper sheet of the panel. Figure shows the trajectory of solar incidence on the upper surface of enclosure. The process is similar to the process of transmission of solar radiation through covers of a solar collector [18].

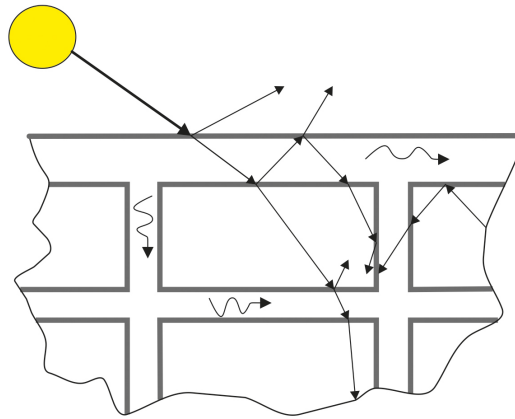


Figure 3: Scheme of transmission of solar radiation through a fragment of pool enclosure.

Solar incidence in an arbitrary angle and azimuth to the analyzed surface is partially reflected and partially refracted. The refracted part of solar radiation is transmitted through the upper sheet towards the bottom sheet and side walls of channels of the panel. It is again reflected and refracted there. During transmission through the upper sheet, part of its energy is also absorbed by the material of enclosure. There occur further reflexivity

of solar radiation and, as a result, further energy is transferred to both environment and interior of enclosure. Additionally, each channel is affected by solar radiation from neighboring channels. Information concerning calculations methodologies for transparent structures in construction industries can be found among others in [2, 10].

Essential aim in the present paper is estimating the transmission of solar radiation for chosen polycarbonate enclosure with channel structure on basis of calculations and experimental research carried out in real conditions.

2 Calculation methodology

In order to calculate transmission of solar radiation for the enclosure made of polycarbonate, calculation methodology presented in [18] was applied. This methodology can also be used in calculations for transparent covers of solar collectors.

Total transmission for a multilayer enclosure is a product of two transmissions, namely one resulting from solar absorption in polycarbonate, and the other one resulting from transmission caused by multiple of solar reflections from walls of particular channels

$$\tau_c = \tau_a \tau_r. \quad (1)$$

Transmission caused by absorption of solar radiation by polycarbonate can be determined from equation

$$\tau_a = \exp \frac{-K \delta_c}{\cos \Theta_2}, \quad (2)$$

where K is extinction coefficient, δ_c is a total thickness of enclosure, and Θ_2 is current solar refraction angle for the polycarbonate. Solar refraction angle Θ_2 can be determined from equation

$$n_1 \sin \Theta_1 = n_2 \sin \Theta_2, \quad (3)$$

where n_1, n_2 are solar refraction coefficients for air and polycarbonate, and angle Θ_1 is a current angle of incidence of solar radiation, measured in the zenith direction.

Transmission resulting from multiple solar reflections in particular walls of channel can be calculated from relation

$$\tau_r = 0.5 \left[\frac{1 - \rho_{\perp}}{1 + (2N - 1)\rho_{\perp}} + \frac{1 - \rho_{\parallel}}{1 + (2N - 1)\rho_{\parallel}} \right], \quad (4)$$

where N is the number of layers of enclosure. Equation (4) is valid for polarized light with two components – parallel and perpendicular. The components depend on reflection coefficients calculated from equations:

$$\rho_{\perp} = \frac{\sin^2(\Theta_2 - \Theta_1)}{\sin^2(\Theta_2 + \Theta_1)}, \quad (5)$$

$$\rho_{\parallel} = \frac{\tan^2(\Theta_2 - \Theta_1)}{\tan^2(\Theta_2 + \Theta_1)}. \quad (6)$$

In a most general case, the solar incidence angle (Θ_1) depends on geographical location of the pool, its incidence to horizontal plane, object azimuth, and on time (season, time of day). Pool's location is determined by means of geographical coordinates, that is latitude (Φ) and longitude (L). Pool's orientation to the south direction is determined by azimuth (γ).

Determination of enclosure's slope angle to horizontal plane (β) is possible only for enclosures that are planes themselves. For arched (or curved) planes, slope angle can be assumed to be the angle between the chord and straight line on the horizontal surface. The last of parameters decisive for solar incidence angle (Θ_1) is the hour angle of the Sun (ω), and its value depends on the season and a time of day.

Hour angle of the Sun depends on the true solar time, and so

$$\omega = 15(t - 12). \quad (7)$$

True solar time can be calculated from equation

$$t = t_{ST} + 4(L_{ST} - L) + E, \quad (8)$$

where t_{ST} is the local time related to the standard meridian, L_{ST} and L are longitudes of standard meridian and of location site of the enclosure, respectively, and E is the time equation.

Value of time equation can be determined from the pattern

$$E = 229.2 [0.000075 + 0.001868 \cos B - 0.032077 \sin B + 0.014615 \cos(2B) - 0.04089 \sin(2B)], \quad (9)$$

where $B = (n - 1)360/365$ and n is successive day of the year.

Solar incidence angle can be determined from the equation

$$\Theta_1 = 90^\circ - \alpha_1, \quad (10)$$

where altitude angle (α_1) is determined from the relation

$$\begin{aligned} \cos \alpha_1 = & \sin \delta \sin \Phi \cos \beta - \sin \delta \cos \Phi \sin \beta \cos \gamma + \\ & + \cos \delta \cos \Phi \cos \beta \cos \omega + \cos \delta \sin \Phi \sin \beta \cos \gamma \cos \omega + \\ & + \cos \delta \sin \beta \sin \gamma \sin \omega . \end{aligned} \quad (11)$$

Solar declination (δ) is determined from equation

$$\delta = 23.45 \sin \left(360 \frac{284 + n}{365} \right) . \quad (12)$$

If polycarbonate enclosure is placed horizontally, then Eq. (11) can be simplified and solar incidence angle can be determined from the pattern

$$\cos \Theta_1 = \cos \Phi \cos \delta \cos \omega + \sin \Phi \sin \delta . \quad (13)$$

Calculations results for enclosure's transmission, carried out according to calculations methodology presented in this section, have been compared with experimental research.

3 Object of research

Polycarbonate enclosure of swimming pool presented in Fig. 1 has been chosen for analysis. The swimming pool was an object of previous experimental research carried out by authors, results of which are presented in [6–8]. The pool is located in the suburbs of the city of Szczecin (Poland). Retractable enclosure is made of polycarbonate with the structure presented in Fig. 2a. Curved construction of the enclosure complicates calculations of its transmission. Because of this, it has been decided to carry out the transmission research for enclosure shaped horizontally. It has also been assumed that enclosure consists of four layers of polycarbonate. Two layers are top and bottom walls, the two remaining ones are side ribs of a single channel. The assumption is justified because phenomena of multiple reflection occur on all walls of the channel (Fig. 3).

The object of research is a sample of colorless, transparent polycarbonate with two-walls structure the dimensions of which are: 0.097 m \times 0.100 m \times 0.010 m (width \times depth \times height). The sample consists of 8 air channels with rectangular sections (dimensions 0.009 m \times 0.010 m), and length 0.100 m. On one of sample's sides, there is an incomplete channel (one wall is missing). For each channel, thicknesses of top and bottom walls are equal to 0.0006 m, and side walls are equal to 0.0005 m. The view of the sample under research is presented in Fig. 4.



Figure 4: View of the sample under research.

4 Working stand and method of research

Experimental research was carried out on the facility the scheme of which is presented in Fig. 5. Sample under research (1) was placed in the styro-foam frame of the working stand (2). The inner surface of the frame was covered with a film of black foil (3). Holes were made in the side walls of the frame in order to enable free access of air to the inside of the stand. Air flux made it possible to level temperatures between the inside of the stand and the environment. Working stand was mounted on the roof of the Department of Energy Technologies, West Pomeranian University of Technology in Szczecin for which geographical coordinates are as follows: latitude $\Phi = 53.403^\circ\text{N}$ and longitude $L = 14.529^\circ\text{E}$.

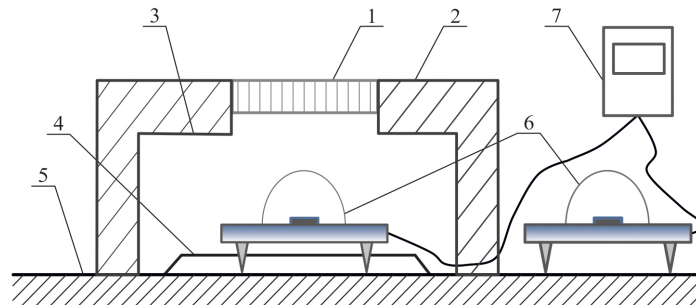


Figure 5: Scheme of working stand.

In order to measure irradiance, sensors of Kipp&Zonen pyranometers of type CMP3 (6) were placed inside and outside of the test facility. They

were connected with data acquisition unit of APAR, type AR 206 (7).

Measurements were carried out in June 2019. These were the successive three days that is 155th, 156th, and 157th of the year. Solar declinations on these days, according to Eq. (12), equaled respectively: 22.4°, 22.5°, and 22.6°. In some randomly assigned times (hours) measurements of weakening of irradiance were made. Temporary values of enclosure's transmissions were calculated as ratios of irradiance measured inside and outside of the stand, according to the following equation:

$$\tau_c^{\text{exp}} = \frac{I_{\text{out}}}{I_{\text{in}}}, \quad (14)$$

where I_{in} and I_{out} are the irradiance on the external surface and after it, respectively. On the basis of experimental research results, extinction coefficient can also be determined. According to definition, it equals common logarithm of irradiance on the external surface transparent material under research to irradiance after it passed through the material, so

$$K = \lg \frac{I_{\text{in}}}{I_{\text{out}}}. \quad (15)$$

On the first day of measurements – phase one (4th June 2019), the frame was placed so that solar radiation could reach the frame once parallel to the axis of channels, and once perpendicularly. In the second phase of measurements, in the initial moment, the frame was placed so that both axes of channels were in parallel directions (position on 5th June 2019), and in perpendicular directions (position on 6th June 2019) to the solar radiation. Next, position of the frame remained unchanged. In successive measurements, increasing inclination of solar radiation from the channel axes was observed. Thus, it should be noticed that only the first measurements in these days were valid for parallel, or perpendicular position of the frame to the solar direction. Research was carried out for various values of irradiance depending on day, day time, cloudiness. Research on first two days was carried out by almost cloudless sky. In turn, the sky was cloudy on the third day of research.

It should be noticed that received results of research are of only initial character and the experimental research requires to be continued in longer time ranges and for diversified atmospheric conditions.

5 Results

Calculations of transmission of solar radiation through a polycarbonate enclosure was carried out for the same days in which measurements were made. Tables 1–3 show values of chosen parameters calculated according to calculations methodology outlined in Section 2.

Table 1: Values of parameters required to determine total transmission of solar radiation for polycarbonate enclosure – calculations made on 4 June 2019.

No.	t_{ST}	t	ω	Θ_1	Θ_2	$\rho_{ }$	ρ_{\perp}	τ_r	τ_a
	h:min	h:min	°	°	°	–	–	–	–
1	09:35	8:39	-50.3	48.8	28.1	0.0078	0.1324	0.6955	0.9994
2	09:41	8:45	-48.8	48.0	27.7	0.0090	0.1283	0.6957	0.9994
3	09:47	8:51	-47.3	47.1	27.3	0.0102	0.1245	0.6958	0.9994
4	09:49	8:53	-46.8	46.9	27.1	0.0106	0.1233	0.6959	0.9993
5	10:27	9:31	-37.3	41.8	24.6	0.0181	0.1040	0.6948	0.9994
6	10:31	9:35	-36.3	41.4	24.4	0.0189	0.1024	0.6946	0.9996
7	10:34	9:38	-35.5	41.0	24.2	0.0195	0.1012	0.6945	0.9996
8	10:36	9:40	-35.0	40.7	24.1	0.0198	0.1005	0.6944	0.9996
9	10:40	9:44	-34.0	40.3	23.8	0.0206	0.0990	0.6943	0.9994
10	11:12	10:16	-26.0	36.7	21.9	0.0258	0.0892	0.6930	0.9995
11	11:16	10:20	-25.0	36.3	21.7	0.0264	0.0882	0.6929	0.9996
12	11:17	10:21	-24.8	36.2	21.7	0.0265	0.0879	0.6928	0.9997
13	11:55	10:59	-15.3	33.1	19.9	0.0309	0.0809	0.6919	0.9997
14	11:58	11:02	-14.5	32.9	19.8	0.0311	0.0805	0.6918	0.9997
15	12:00	11:04	-14.0	32.8	19.8	0.0313	0.0802	0.6918	0.9995
16	12:02	11:06	-13.5	32.6	19.7	0.0314	0.0800	0.6918	0.9995
17	12:30	11:34	-6.5	31.4	19.0	0.0331	0.0776	0.6915	0.9995
18	12:32	11:36	-6.0	31.3	19.0	0.0332	0.0775	0.6914	0.9995
19	12:34	11:38	-5.5	31.3	18.9	0.0332	0.0774	0.6914	0.9996
20	12:35	11:39	-5.3	31.2	18.9	0.0333	0.0773	0.6914	0.9996
21	13:03	12:07	1.7	31.0	18.8	0.0336	0.0769	0.6914	0.9996
22	13:04	12:08	2.0	31.0	18.8	0.0335	0.0769	0.6914	0.9995
23	13:35	12:39	9.7	31.9	19.3	0.0325	0.0785	0.6916	0.9995
24	13:36	12:40	10.0	31.9	19.3	0.0324	0.0786	0.6916	0.9997
25	14:00	13:04	16.0	33.3	20.1	0.0306	0.0813	0.6919	0.9996
26	14:02	13:06	16.5	33.4	20.1	0.0304	0.0816	0.6920	0.9995
27	14:30	13:34	23.5	35.7	21.4	0.0272	0.0868	0.6927	0.9995

Table 2: Values of parameters required to determine total transmission of solar radiation for polycarbonate enclosure – calculations made on 5 June 2019.

No.	t_{ST}	t	ω	Θ_1	Θ_2	$\rho_{ }$	ρ_{\perp}	τ_r	τ_a
	h:min	h:min	°	°	°	–	–	–	–
1	10:00	9:04	-44.0	45.3	26.4	0.0129	0.1166	0.6957	0.9995
2	10:02	9:06	-43.5	45.0	26.2	0.0133	0.1155	0.6957	0.9995
3	10:37	9:41	-34.8	40.5	24.0	0.0202	0.0998	0.6944	0.9995
4	10:39	9:43	-34.3	40.3	23.8	0.0205	0.0990	0.6943	0.9995
5	11:08	10:12	-27.0	37.0	22.1	0.0254	0.0899	0.6931	0.9996
6	11:10	10:14	-26.5	36.8	22.0	0.0256	0.0894	0.6930	0.9997
7	11:36	10:40	-20.0	34.4	20.7	0.0291	0.0837	0.6923	0.9996
8	11:38	10:42	-19.5	34.2	20.6	0.0293	0.0833	0.6922	0.9996
9	12:05	11:09	-12.8	32.3	19.5	0.0318	0.0794	0.6917	0.9996
10	12:30	11:34	-6.5	31.3	18.9	0.0332	0.0773	0.6914	0.9996
11	12:32	11:36	-6.0	31.2	18.9	0.0333	0.0772	0.6914	0.9996
12	13:02	12:06	1.5	30.9	18.7	0.0337	0.0767	0.6913	0.9996
13	13:04	12:08	2.0	30.9	18.7	0.0337	0.0767	0.6914	0.9996
14	13:30	12:34	8.5	31.5	19.1	0.0329	0.0779	0.6915	0.9996
15	13:32	12:36	9.0	31.6	19.1	0.0328	0.0780	0.6915	0.9995

Table 3: Values of parameters required to determine total transmission of solar radiation for polycarbonate enclosure – calculations made on 6 June 2019.

No.	t_{ST}	t	ω	Θ_1	Θ_2	$\rho_{ }$	ρ_{\perp}	τ_r	τ_a
	h:min	h:min	°	°	°	–	–	–	–
1	10:15	9:19	-40.3	43.2	25.3	0.0161	0.1087	0.6952	0.9994
2	10:17	9:21	-39.8	42.9	25.2	0.0165	0.1078	0.6952	0.9994
3	10:30	9:34	-36.5	41.3	24.4	0.0190	0.1022	0.6946	0.9995
4	10:35	9:39	-35.3	40.7	24.0	0.0199	0.1002	0.6944	0.9995
5	11:33	10:37	-20.8	34.5	20.8	0.0289	0.0840	0.6923	0.9995
6	11:35	10:39	-20.3	34.4	20.7	0.0291	0.0837	0.6923	0.9995
7	12:02	11:06	-13.5	32.4	19.6	0.0317	0.0796	0.6917	0.9995
8	12:04	11:08	-13.0	32.3	19.5	0.0319	0.0793	0.6917	0.9995
9	12:32	11:36	-6.0	31.1	18.8	0.0334	0.0770	0.6914	0.9995
10	12:34	11:38	-5.5	31.0	18.8	0.0335	0.0769	0.6914	0.9995

It was assumed for calculations that refraction coefficients were equal to $n_1 = 1$, $n_2 = 1.6$, respectively [18]. Total thickness of polycarbonate layers was $\delta_c = 0.0022$ m.

It should be noticed that knowledge of the extinction coefficient (K) is necessary to calculate transmission coefficient resulting from absorption of solar radiation by polycarbonate. The coefficient was determined in this paper on the basis of experimental research, according to Eq. (15). Figure 6 shows changes of extinction coefficient in function of time for successive days of research. On the basis of calculations, it can be stated that effect of absorption of solar radiation by polycarbonate does not influence meaningfully the total transmission of solar radiation. Thus, it can be assumed without much error that total transmission of solar radiation equals the transmission resulting from multiple of reflections of solar radiation inside the material of enclosure.

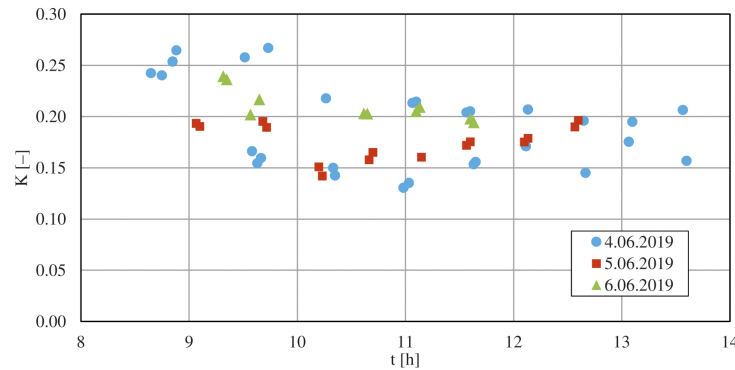


Figure 6: Extinction coefficient in function of true solar time.

Calculated temporary values of total transmission of solar radiation through the panel under research for particular days of research are presented in Fig. 7. Mean value for this parameter is about 0.69. Results of experimental research for total transmission of solar radiation through the polycarbonate enclosure under research are shown in Figs. 8 and 9, too. Figure 8 shows values of enclosure's transmission separately for parallel (\parallel), and separately for perpendicular (\perp) directions of solar radiation in relation to directions of axes of channels in the sample (obtained by means of changes of position of the frame of the stand in relation to the Sun).

In both analyzed cases, it can be stated that transmissions of solar radiation for enclosure under research change in the function of true solar time, which is shown by runs in Fig. 8. Transmission value of the enclosure rises and reaches its maximal value at noon hours. In both analyzed cases, falling trend is observed for afternoon hours. Besides, it can be clearly stated that

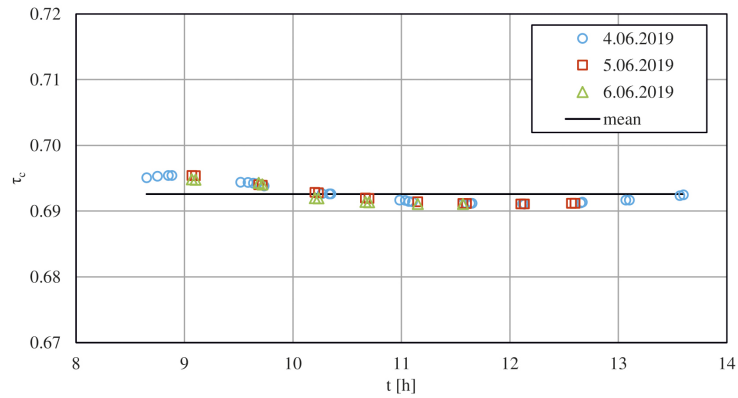


Figure 7: Results of calculations for total transmission of solar radiation through polycarbonate enclosure under research.

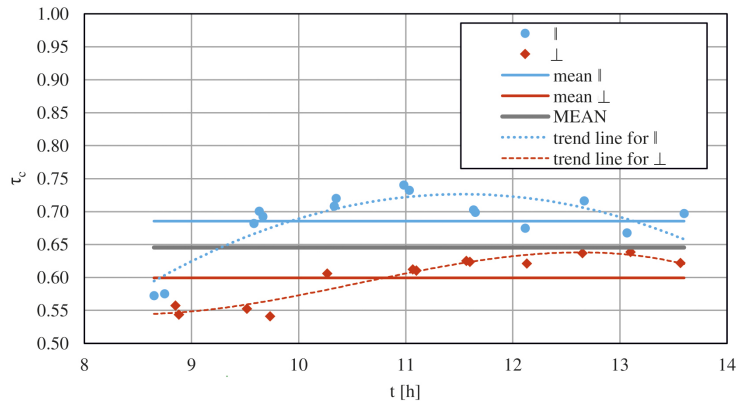


Figure 8: Temporary transmission values for pool enclosure in function of true solar time by changing position of frame of the stand.

direction of solar radiation in relation to directions of channel axes is fundamental. When direction of solar radiation is the same as directions of channel axes, values of transmission are higher than in case when direction of solar radiation is perpendicular to channel axes. In the first case, solar radiation is reflected from perpendicular walls of channels in a smaller degree and thus its dispersion is lower (Fig. 3).

In conditions of swimming pool operation, location of enclosure in relation to the Sun is optional. Besides, direction of solar radiation changes meaningfully depending on season and day time, which affects enclosure's transmission, as it was shown in the paper. Figure 8 shows the mean value

of the above parameter. For enclosure under research, transmission values are equal respectively to: 0.69 by parallel irradiance direction in relation to channel axes, and 0.60 by perpendicular direction of solar radiation in relation to channel axes. Mean value of the parameter equals 0.645.

Figure 9 shows values of transmission of solar radiation for pool enclosure for successive hours, but obtained during measurements without changing the position of the frame of the stand in relation to the Sun.

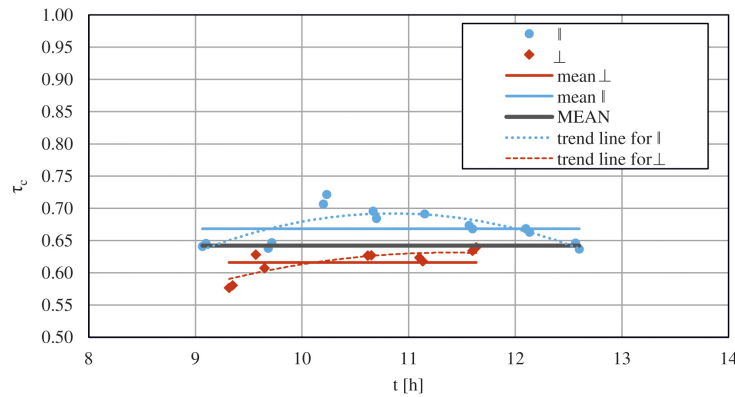


Figure 9: Temporary transmission values for pool enclosure in function of true solar time without changing the position of frame of the stand.

Received results are very close to the ones obtained during measurements in the first phase of research. For enclosure under research, mean values of transmission are respectively equal to 0.67 by initial parallel solar direction in relation to channel axes, and 0.62 by initial perpendicular irradiance direction in relation to channel axes. Mean value of transmission determined for both positions equals to 0.642. Comparing results obtained in first and in second phase, one can observe only a slight drop of mean value of transmission for the enclosure under research (from 0.69 to 0.67) by initial parallel position of channel axes of the sample under research in relation to solar direction. It results from gradual change declination of solar radiation from the initial position (parallel) in relation to the channel axis of the sample. By initial perpendicular position of channel axes of the sample under research in relation to solar direction, the opposite situation occurs. Value increase of the considered parameter is observed (from 0.60 to 0.62), because of gradual declination from the parallel position. Conclusively, it seems to be justified to assume the total transmission for enclosure equal to 0.64, for the sample under experimental research.

It can be stated by comparison of the results of calculations with experimental research that the mean total transmission from calculations is equal to the mean value of this parameter obtained on 4.06.2019 when solar direction was parallel to channel axes in the polycarbonate panel. Mean transmission values of enclosure determined from calculations and experimentally differ only slightly and they equal 0.69 and 0.64, respectively.

Evaluation of accuracy of proposed theoretical method of estimation of transmission coefficient for swimming pool cover on this stage of experimental verification is not possible. It is necessary to make experimental investigation in a wide range of time, *e.g.*, for a month or for a few chosen months of the year. Realization of the above investigations is planned for the future. Also in the future authors plan to make calculations and experimental investigations for polycarbonate plates characterized with different constructions and cell dimensions.

Advantage of proposed method of theoretical estimation of transmission coefficient for swimming pool covers is the possibility to use it in case of covers producers for the case of which their technical data are not known.

6 Conclusions

On the basis of carried out analysis of the results it can be stated that:

1. Calculations of the value of total transmission for enclosure made of multichannel polycarbonate is possible but calculations methodology is complicated.
2. For enclosure under research, the calculated value of its total transmission equals to 0.69.
3. Absorption of solar radiation by polycarbonate enclosure is very small and does not affect the total transmission of enclosure. Total transmission of enclosure depends meaningfully on transmission resulting from multiple reflections of solar radiation inside the material for particular channels.
4. Estimation of value of total transmission of the enclosure on the basis of experimental research is less complicated but it requires constructing of a test stand and registration of measurements results in longer periods.

5. Initial results of research show that total transmission of the enclosure can vary between sunrise and sunset.
6. Value of total transmission of enclosure with the channel structure is determined by direction of solar radiation to channel axes.
7. For enclosure under research, experimentally determined value of total transmission by parallel solar direction in relation to channel axes equals 0.69, and the value decreases to 0.67 with declination from the parallel direction of solar in relation to channel axes.
8. For enclosure under research, experimentally determined value of total transmission by perpendicular solar direction in relation to channel axes equals 0.60, and the value increases to 0.62 with declination from the perpendicular direction of solar in relation to channel axes.
9. For enclosure under research, it can be assumed that experimentally determined value of total transmission equals to 0.64.
10. It is advised to carry out further experimental research for longer periods (by different irradiance and different sky cloudiness).
11. It is also advised to carry out further experimental research to investigate total transmission of enclosure by its different positions in relation to the Sun in the zenith position.

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