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프리즘창의 이차원 투과계수 평가에 관한 연구

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Bi-Directional Transmission Assessment Study of Angular Solar Selective Panels

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Abstract

빛이 입사각별로 태양투과율이 제어되어지는 첨단 창과 같은 물체를 통과할 때 투과되는 성분은 직달투과와 산란투과성분으로 볼 수 있다. 직달투과는 물체를 통과하면서 일정한 방향으로 굴절되어 투과되는 성질을 말하고, 산란투과는 직달투과를 제외한 나머지 방향의 성분들의 형태를 말한다. 이러한 첨단 창의 냉난방부하에 미치는 에너지성능을 평가하기 위해서는 산란투과에 대한 정보가 필요하고, 이에 대한 물리적 변수는 입사각, 출력각, 양방향 투과율 분산함수인 BTDF로 정의된다.
본 논문에서는 3개의 서로 다른 첨단 창 :(1) 42°/5° 프리즘 창 판넬, (2) 레이저 컷 판넬 (3) 45° 프리즘 3M 필름의 BTDF 데이터 획득을 위한 실험 방안을 소개하고, 실험을 통해 획득한 정보를 이용하여 계산식과 비교 검증을 하였다. 따라서 이 검증된 방안을 이용하여 지역별 냉난방 부하를 최소화 할 수 있는 입사각별로 태양 투과율 제어 판넬을 선정할 수 있게 되었다.

Keywards : 입사각 태양선택 판넬(Angular Solar Selective Panels), BTDF(Bi-Directional Transmission Distribution Function), 프리즘 창(Prism Glazing), 프리즘 필름(Prism Film)

NOMENCLATURE

(θ1, Φ1) : polar coordinates of the incoming light flux
(θ2, Φ2) : polar coordinates of the outgoing light flux
L1(θ1, Φ1) : luminance of the incoming element of light flux (cd m-2)
L2(θ1, Φ1, θ2, Φ2) : luminance of the outgoing element of light flux (cd m-2)
dω1 : solid angle subtended by the incoming

light flux (sr)

$E_1(\theta_1)$: illuminance of the fenestration material, due to the incoming light flux (lx)

1. Introduction

Efficient collection or redistribution of direct sunlight for optimal visual and thermal comfort conditions in buildings remains a major objective of fenestration systems. They can improve the penetration of daylight into deep rooms to reduce electricity consumption and lead to larger solar gains in winter combined with lower solar loads in summer, which also significantly increase energy savings.[1]

The daylight distribution, inside buildings has to be optimized, in order to reduce energy consumption and improve visual comfort. However the light behavior expectations can only be considered with a full knowledge of incoming and outgoing photometric characteristics of daylighting systems like prismatic glazing of advanced angular glazing selective systems.[2] Precise knowledge and objective measurements of the photometric properties have, therefore, to be handled to control the daylighting performances of the building.

A very important quantity for transparent insulating materials in solar energy applications is naturally the solar transmittance. The light transmittance and reflectance are important for visual evaluation of a daylighting system. The directional-hemispherical quantities are needed for energy consideration, and the complete bi-directional characteristics are important for daylighting.[3]

Advanced windows, including novel solar blinds, new glazing materials and daylight-redirecting devices, of course, play an essential role in this field.[1] A complete and precise knowledge of their directional photometric properties is indispensable to control the daylighting performances of buildings. The required information is provided by the Bi-directional Transmission Distribution Function (BTDF), also called luminance coefficient q(sr^{-1}) in the CIE[4] nomenclature.

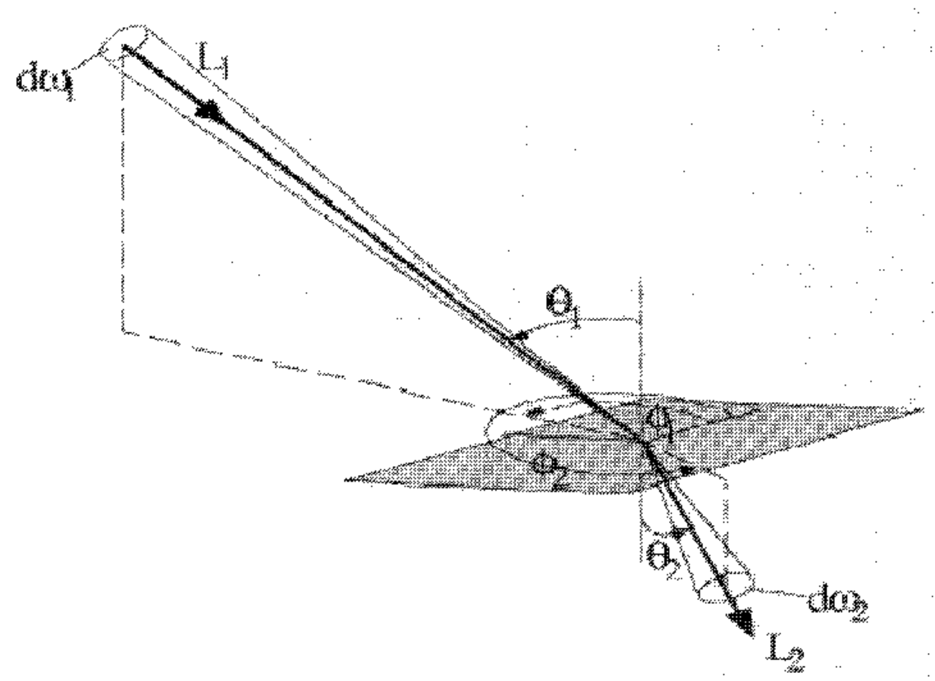


Fig 1. photometric and geometric quantities used to define the "BTDF" of fenestration material

$$BTDF(\theta_1, \phi_1, \theta_2, \phi_2) = \frac{L2(\theta1, \phi1, \theta2, \phi2)}{L1(\theta_1, \phi_1)\cos\theta_1 d\omega_1} = \frac{L2(\theta_1, \phi_1, \theta_2, \phi_2)}{E_1(\theta_1)} \quad (1)$$

The BTDF is defined by the following (Equation 1) and the associated photometric and geometric quantities are shown in **Fig 1.**

The "BTDF" can also define as the luminance coefficient q (cd m^{-2} lx^{-1}) as the quotient of the luminance of a surface element in a given direction, by the illuminance incident on the sample. This definition allows a very easy and direct application of numeric values of BTDF to practical cases. Indeed to know how much light comes out from a certain area of the sample along a particular direction (θ_2, ϕ_2) and with particular direction of sun (θ_1, ϕ_1), one only needs to multiply the known BTDF by a realistic illuminance.[5]

Bi-directional photogoniometric device has been used to experimentally assess BTDFs for prismatic glazing 42°(shallow side)/5° (deep side), Prism 45° 3M film, and laser cut panels. The usual way to measure bi-directional transmission functions is based on point per point mapping of the emerging hemisphere with a device-specific detector. The operating principle of the photogoniometer based on the observation of a mobile projection screen, from which transmitted light is reflected into a calibrated CCD camera. This technique allows a considerable reduction of the time needed to perform BTDF measurements.[2]

As the data have been assessed by the digital imaging-based bi-directional photogoniometer, developed at the LESO-PB in Swiss federal technical university, a particular image processing has been developed as well as to take the benefit from continuous information about the transmitted light distribution, moreover provided at a very high spatial accuracy. This paper introduces the concept of BTDF, describes the key solar angular selective panels and makes analysis to select a right solar panel for a given location.

2. Description of Three Angular Selective Panels

For the evaluation of daylight distribution through entrance of the system, different types of angular selective solar panels are used to collect the maximum amount of sunlight possible and direct into the room efficiently. These solar glazing panels can also be used to direct sunlight in to a room, to prevent glare and colour dispersion.[6] The 42°/5° prismatic glazing panel, laser cut panel and 45° prismatic 3M film with particular angle specification are specially used for the analysis of bi-directional distribution function (BTDF) of transmittance(τ). These panels have total solar energy transmission coefficients, which are composed of the coefficients of direct solar transmission and of secondary heat transfer. The direct solar transmission coefficient specifies that part of solar radiation incident on glazing surface is directly transmitted towards inside. "The secondary heat transfer coefficient signifies that part of incident solar radiation, which is transferred towards inside by convection and longwave IR-radiation through the individual glass sheets, and prisms, which cause to produce heat inside the building by, absorbed radiations".[7] The following three systems were used for the analysis of BTDF and transmittance properties with same area and different thickness as shown in the following **Table 1**.

Table 1. Dimensional specifications of three systems

S.N	Material Name	Area	Thickness
1	Prism 42°/5°	78.54 ㎠	1.2 cm
2	Laser Cut Panel	78.54 ㎠	0.6 cm
3	Prismatic 3M film	78.54 ㎠	0.6 cm

The 42°/5° degree sawtooth prismatic panels with particular angle specification (42°/5°) redirect or refract the sunlight inside the building and provide superior protection against solar radiation and comfortable glare during the whole day. There are two refracting angles 42° and 5°. These panels reflect light coming from a certain range of angles while transmitting light coming from other angles. For deep penetration of sunlight, these prismatic panels could accommodate wide range of solar altitudes. The refracted light could emerge at an angle less than 15° above horizontal to obtain maximum penetration without creating descending rays of glare sunlight. Occurrence of refraction due to these panels is used to change the direction of transmitted light rays.[8]

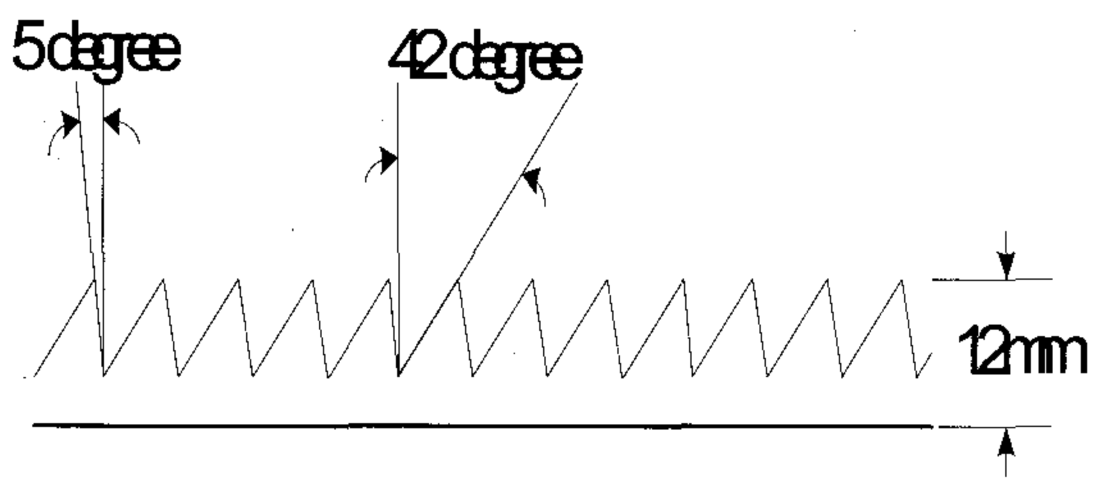
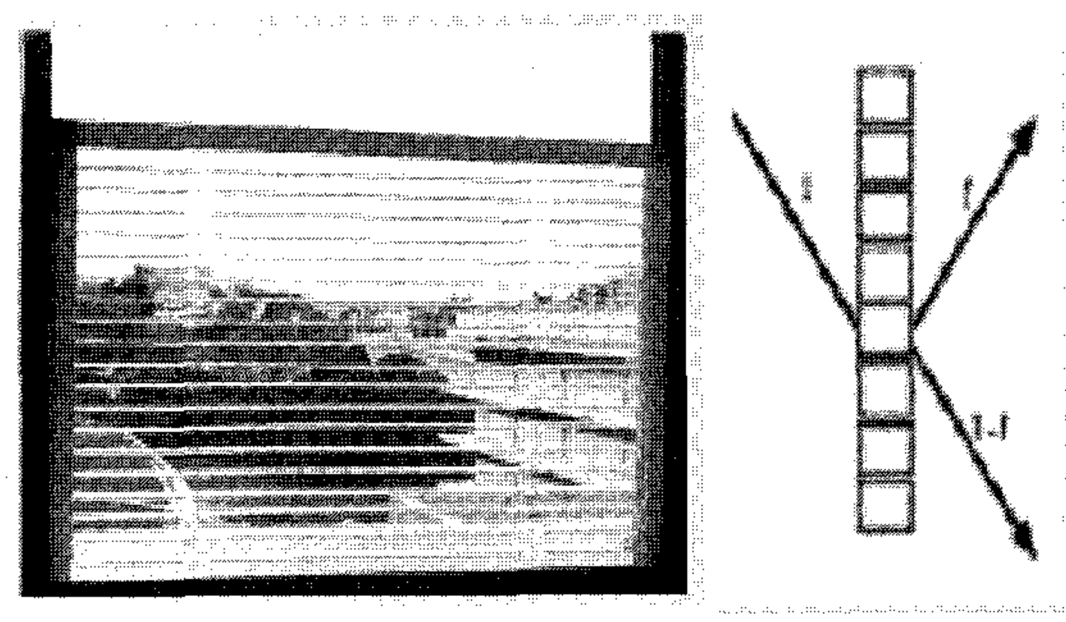


Fig 2. 42°/5° Prism glazing with particular geometrical shape

The principle underlying prismatic glazing is the alteration of incoming daylight by means of refraction and reflection. Sawtooth prismatic panels (**Fig 2**) were used for the study of "BTDF" (measured by LESO-PB Photogoniometer) and transmittance values.



(a) (b)

Fig 3. Laser cut panel(a) and fraction of light deflected in a laser cut panel(b)

The laser cut panel, (LCP), is an optical material produced by making laser cuts in a thin panel of clear acrylic material. The surface of each laser cut becomes a small internal mirror, which deflects light passing through the panel. The principal characteristics are very high proportion of light deflected through a large angle (>120 degrees) and maintain of through the panel.

An LCP is a thin panel, which has been divided into an array of rectangular elements by laser cutting. Light is deflected in each element by refraction then total internal reflection and again by refraction as in **Fig 3**.

As each deflection works in the same direction, the deflecting power is high due to which deflection is highly efficient. The panels may be used as an external glazing if the cut surface is protected by lamination between glass sheet. More usually the panel is fixed inside existing glazing. Normally the panels are cut at an angle perpendicular to the surface, to gain more control over the direction of the deflected light.[9]

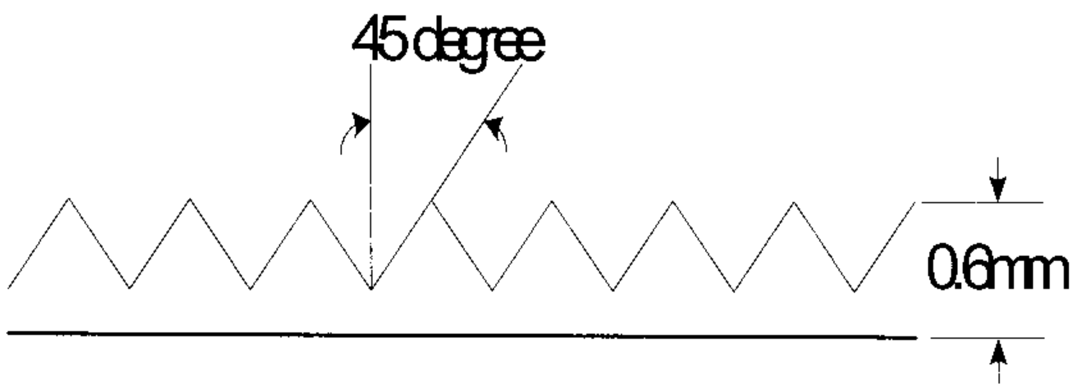


Fig 4. 45° Prism glazing with particular geometrical shape

The prismatic glazing 3M films are produced from acrylic polymer and these panels are partially coated with an aluminum film with high specular reflection on one surface of each prism. Refraction and total internal reflection can be used to change the direction of transmitted light rays, the fraction of reflected, refracted and transmitted light depend upon the angle of incidence (Fig 4).

3. Analysis of Transmittance from BTDF Data

With a complete BTDF data set provided, it is possible to calculate the hemispherical light transmittance $\tau(\theta_1, \Phi_1)$. This information is effectively of great importance in the validation of the measurements on one side and in the qualification of the global photometric behavior of a fenestration material on the other side.

A validation of the BTDF values through a comparison of the hemispherical transmittances can be calculated from a numerical integration of electronic data using the following equation.[10]

$$\tau(\theta_1, \phi_1) = \Delta\theta_2 \Delta\phi_2 \sum_{n=1}^{N-out} BTDF_n(\theta_1, \phi_1, \theta_{2n}, \phi_{2n}) \cdot Cos\theta_{2n} \sin\theta_{2n} \qquad (2)$$

The value of transmittance from the BTDF electronic data file, which was collected by using the photogonimeter, has been calculated by using above equation 2 for three systems 1) prismatic glazing 42°/5° panel, 2) laser cut panel and 3) prism 45° 3M film at an altitude angle of 40° (winter time as see in Table 2) and at an altitude angle of 90° (summer time as see in Table 3) for an output angular resolution $(\Delta\theta_2, \Delta\Phi_2)$ = (5°,15°).

The assessment of $\tau(\theta_1, \Phi_1)$, in consequence, requires an extrapolation of the data for extream values of θ_2. During the creation of the final data file the light transmittance is thus calculated by using the above equation.

If we compare the values of transmittance of light collected by photogoniometer as in Table 4 and the values of transmittance calculated by using the equation 2, it is clear that there is a small difference in these values which shows the validation of the BTDF result.

Table 2. Transmittance comparison for angular solar selective samples solar noon (winter time)

Altitude angle	Prismatic 42/5 degree panel		Laser cut panel		Prismatic 45 dgree 3M panel	
θ2	BTDF avg.	Transmittance	BTDF avg.	Transmittance	BTDF avg.	Transmittance
95	13.953	1.212	0.001	0.0001	0.839	0.073
100	104.792	17.921	1.017	0.174	1.205	0.206
105	49.927	12.482	2.303	0.576	1.476	0.369
110	3.654	1.174	3.139	1.009	1.496	0.481
115	2.932	1.123	3.341	1.28	1.397	0.535
120	3.784	1.639	3.741	1.608	1.326	0.574
125	10.716	5.035	5.69	2.673	1.315	0.618
130	88.277	43.468	14.59	7.184	1.354	0.667
135	13.293	6.647	61.563	30.782	1.379	0.69
140	4.237	2.086	66.987	32.985	1.305	0.643
145	3.143	1.477	21.378	10.044	1.206	0.567
150	2.893	1.253	7.937	3.452	1.029	0.446
155	2.758	1.056	5.187	1.987	0.938	0.36
160	3.101	0.997	5.616	1.805	0.955	0.307
165	3.468	0.867	4.934	1.234	2.131	0.533
170	3.711	0.635	3.306	0.565	16.905	2.891
175	8.879	0.771	1.206	0.105	1.943	0.169
	Transmittance =75%		Transmittance =73.1%		Transmittance =7.60%	

Table 3. Transmittance comparison for angular solar selective samples solar noon (summer time)

Altitude angle	Prismatic 42/5 degree panel		Laser cut panel		Prismatic 45 dgree 3M panel	
θ2	BTDF avg.	Transmittance	BTDF avg.	Transmittance	BTDF avg.	Transmittance
95	6.657	0.578	23.936	2.078	0	0
100	9.413	1.61	37.647	6.438	0.766	0.131
105	22.277	5.569	43.406	10.851	1.279	0.32
110	168.007	53.996	35.825	11.514	1.885	0.606
115	40.991	15.7	23.944	9.171	2.965	1.136
120	9.014	3.903	13.92	6.027	4.388	1.9
125	4.455	2.093	8.252	3.877	13.589	6.385
130	2.413	1.188	6.105	3.006	70.285	34.609
135	1.499	0.75	5.2	2.6	5.786	2.893
140	1.453	0.7155	5.068	2.496	2.817	1.387
145	0.957	0.45	3.845	1.806	1.643	0.772
150	0.777	0.337	2.303	0.997	1.451	0.628
155	0.928	0.355	1.543	0.591	2.558	0.98
160	1.409	0.453	0.875	0.281	21.399	6.877
165	1.761	0.44	0.027	0.00675	34.543	8.636
170	20.932	3.58	0	0	3.588	0.614
175	27.09	2.352	0	0	1.468	0.127
	Transmittance =71%		Transmittance =46.3%		Transmittance =51%	

Result shows that the transmittance of light not only depends upon the material but also on the altitude angle.

Table 4. Comparisons of measured and calculated values of transmittance for three samples (winter and summer time)

		1	2	3
Material Name		Prism 42°/5° sample	Laser cut smaple	Prism 45° 3M film sample
Area (㎠)		78.54	78.54	78.54
Thickness (㎝)		12	0.6	0.6
Transmittance (Winter)	Measured	76%	74%	8%
	Calculated	75%	73.1%	7.60%
Transmittance (Summer)	Measured	72%	47%	52%
	Calculated	71%	46.3%	51%

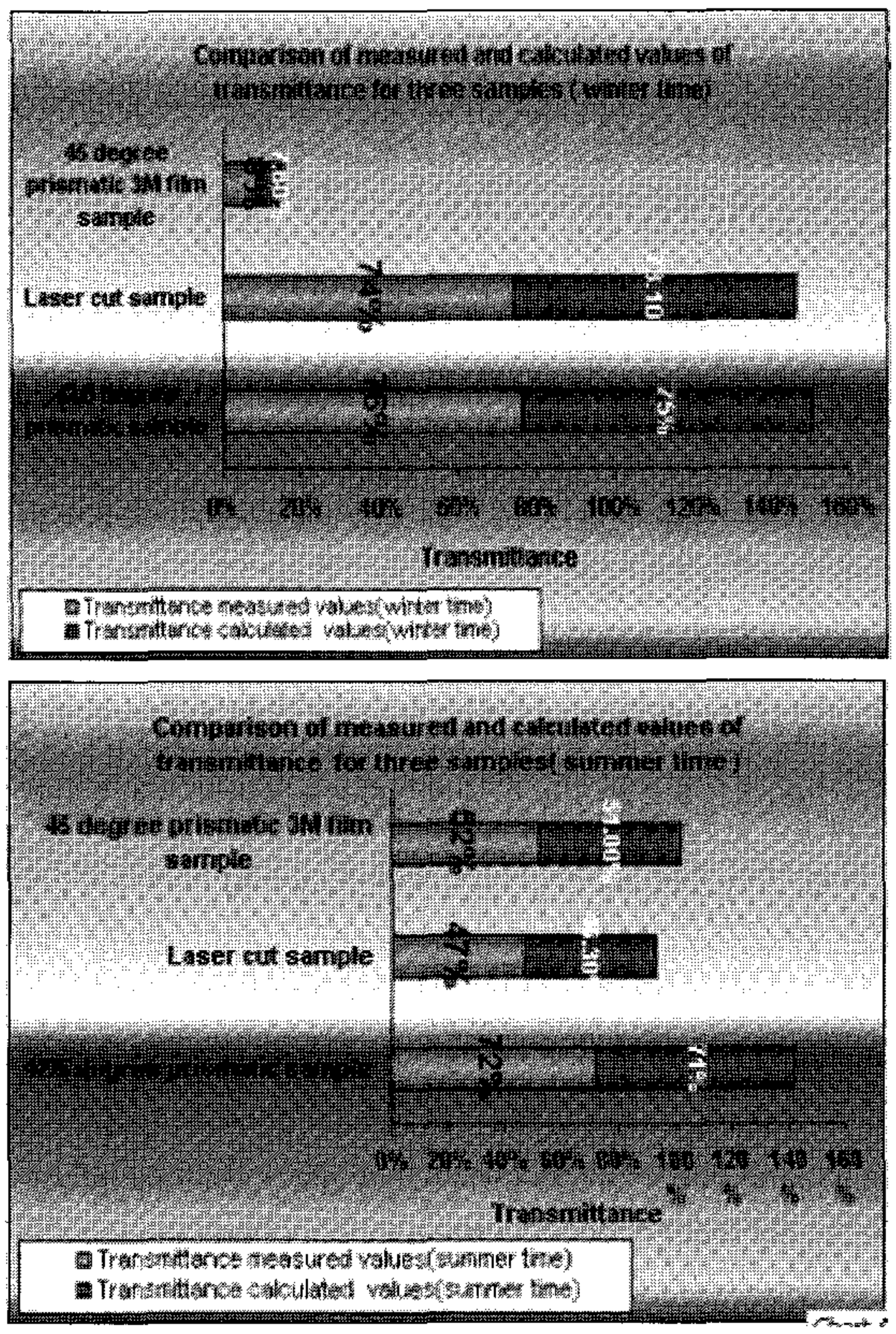


Fig 5. Comparison of measured and calculated values of transmittance for three samples in winter and summer solar noon time

4. Result and Discussion

The transmittance values from BTDF data file have been calculated for summer and winter times at different altitude and azimuth angles for 1) prismatic panel 42°/5°, 2) Laser cut panels and 3) prismatic 3M films. In these three cases, the difference in transmittance values has been observed. This change in transmittance values depends upon the altitude angle and also on the geometrical shape of the sample, i.e. slope angle of prismatic glazing 42°/5° (depth=12mm and space between two peaks =8mm), laser cut (width=20mm and thickness=6mm), and prismatic 3M films (depth=12mm and space between two peaks =10mm)

From the results of transmittance values, it is clear that the prismatic glazing 42°/5° panels have high value of transmittance in winter as well as in summer time. The main reason of this high transmittance is that the prismatic 42°/5° panel controls the sun light by reflecting and refraction and transmitting the maximum sun light through the panel. Therefore the transmittance efficiency lies between 76% to 72% depending on the solar altitude angles. It is clear from the results that change in altitude angles (i.e. in winter and summer time) causes a little change in transmittance values i.e. about 2%.

Whereas result of transmittance of laser cut panels show that the transmittance value for altitude angle 40°(winter time) is 74% and for summer time this value decreases to 47% due to changes in altitude angles (see table 2 & 3).

The main reason of high transmittance value 74% in winter time is that the laser cut panels can deflect the maximum sunlight due to total internal reflection at low altitude angle. In winter, the effectiveness of laser cut panel strongly depended on the space of the laser cut. Due to slope angle of laser cut panel and low altitude angle the transmittance is about 74%. This value of transmittance of light could decrease to 47% due to higher altitude angle i.e. summer time. The main reason of this decrease is that there is difference in slope angle of laser cut panel and azimuth angles.

The results of prism 3M films show that transmittance of light is about 8% in winter time and about 52% in summer time as in table 2 and 3. As the tilted prismatic film sheet has one face of each prism coated with aluminum, so that the light from the areas of sky where the sun could be will be reflected back out side at low altitude angle. Whereas the diffuse light from higher altitude (summer time) is admitted and refracted on to the ceiling by the inner vertically fixed prismatic sheet. In term of the lighting performance of a skylight, the two most important properties are how much light to pass through (transmittance) and how much to diffuse the sun light. The choice of glazing also effects the amount of heat that passes both in and out of the skylight. There are two important characteristics here, the relative proportion of the solar radiation that is blocked by the glazing material, measured by solar heat gain coefficient (SHGC) and overall resistance of the skylight unit to all types of heat flow, measured by R-value.

Glazing is one of the most important factors in good skylight design so, the penetration of light depends upon the glazing efficiency, which is measure of how much light penetrates all the layers of glazing in relation to how much solar heat gets through. It is more specially referred to as the "light to solar gain relation". It is the relation of the visible transmittance to the solar heat gain coefficient (SHGC) of the glazing.[(11)] The solar heat gain factor and daylight factor could depend upon the prismatic angles.

Due to high value of transmittance, prismatic panels transmit directly input solar thermal range radiations increases. This increase in temperature some time produce thermal discomfort effect on some part of the building. It is clear from transmittance results of three systems that laser cut panels have transmittance value of about 47% in summer which is low as compare to the prismatic panel 42°/5° and prismatic 3M films. Good thermal conditions therefore can be produced in winter and summer by using the laser cut panels.

5. Conclusion

The development of advanced fenestration systems (prismatic glazing and daylight redirecting device) can significantly contribute to reduce energy consumption of buildings and can improve visual comfort conditions for users. However, full knowledge of the light distribution through a window is necessary to optimize its performance, i.e. to deepen the propagation of daylight in to the building or to increase solar gain in winter and decrease solar loads in summer. The above three daylighting systems have been investigated to analyse the "BTDF" values with updates DB. Special attention has been paid to all data processing to provide an easy and synthetic approach of the light transmission properties of the materials. Results of transmittance showed that the laser cut panels can increase solar gains in winter and decrease solar load in summer. By using the laser cut panels, we can get more visual performance and good thermal conditions both in summer and in winter.

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