ELSEVIER

Applied Energy 67 (2000) 293–306

APPLIED ENERGY

www.elsevier.com/locate/apenergy

Simulation of the behaviour of transparent insulation materials in buildings in northern China

Hongxing Yang [a,*], Zuojin Zhu [b], John Burnett [a]

[a]*Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong*
[b]*Department of Thermal Science and Energy Engineering, University of Science and Technology of China, Anhui, Hefei, 230026, PR China*

Received 5 November 1999; received in revised form 25 February 2000; accepted 26 February 2000

Abstract

A simulation model has been developed to analyze the potential of the application of transparent insulation for passive solar buildings in northern China. The potential advantages of using transparent insulation materials in buildings are estimated, in which the effects of variations in solar radiation have been taken into account. By simulating the monthly auxiliary energy requirement of the building and the solar fraction variation due to transparent insulation, it is found that if the traditional south brick walls are covered by a 10 cm thickness layer of honeycomb material in the Beijing area, an increase of solar fraction will be around 39%, corresponding to a solar heat gain of around 137 kW/m^2 year.

1. Introduction

Historically, the function of thermal insulation of honeycombed structures was first reported by Veinberg [1], no matter whether the material for the honeycomb was transparent or not. Application of transparent honeycombs in solar collectors has been found to have the advantage of convection suppression [2], and infrared radiation reduction. A previous study indicated that thermal insulation with transparent

* Corresponding author. Tel.: +852-2766-5863; fax: +852-2774-6146.
E-mail address: behxyang@polyu.edu.hk (H. Yang).

PII: S0306-2619(00)00022-2

Nomenclature

A_c	area of window collector, m^2
A_r	insulation area for the south facing wall, m^2
C_0	empirical constant for transmitance
C_1	empirical constant for transmitance
C_b	capacitance of the building room, J/K
C_p	specific capacity of the wall material, J/kg K
DD	degree-days K
D_h	cell width of square honeycomb mm
f	monthly solar fraction
f_i	monthly solar fraction to a infinitive capacitance system
$\bar{H}_b$	monthly average daily beam radiation on a horizontal surface, GJ
$\bar{H}_d$	monthly average daily diffuse radiation, GJ
$\bar{H}$	equals $\bar{H}_b + \bar{H}_d = \bar{K}_T \bar{H}_0$, here $\bar{K}_T$ is the monthly average clearness index, GJ
i	the night insulation time fraction
I_{T_c}	the critical radiation level, W/K
k_w	the wall thermal conductivity, W/m K
L_{ad}	the monthly heating load if an adiabatic wall is instead of the collector-storage wall, GJ
L_w	the monthly energy loss through the collector-storage wall, GJ
L_{in}	the insulation thickness mm
n	the average day of month
N	the number of days in a month
P	parameter for evaluating the solar fraction
Q_D	the energy that would be dumped, GJ
Q_i	the overall net heat transfer through the rooms, GJ
Q_{Ti}	the net heat transfer into the rooms through the storage wall, GJ
$\bar{R}_b$	the ratio of the average daily beam radiation on the tilt surface to that on a horizontal surface for the month
$\bar{S}$	radiation absorbed by the transparent insulation wall, GJ
S_b	building's thermal capacity for a month, GJ
S_w	the storage wall's capacity for a month, GJ
$\bar{T}_a$	the monthly average ambient temperature, K
$\bar{T}_b$	the balance point temperature, K
$\bar{T}_r$	the room temperature, K
$\bar{T}_w$	the average wall temperature, K
$\bar{T}_{yr}$	the annually average ambient temperature, K
(UA)	the total load coefficient including that of windows, W/K
$(UA)_{ad}$	partial load coefficient, W/K
U_w	the wall conductance, W/m^2 K
U_i	inside heat coefficient, W/m^2 K

U_L	the loss coefficient without night insulation, W/m^2 K
$\bar{U}_L$	the loss coefficient with night insulation, W/m^2 K
$\bar{X}_c$	a monthly average critical radiation level
Y	a dimensionless storage-dump ratio

Greek symbols

β	the slope of the solar collector
δ	the declination of the sun at solar noon
δ_w	the wall thickness, m
θ_b	the incident angle of beam radiation
$\bar{\phi}$	the monthly average daily utilizability
$(\overline{\tau\alpha})_b$	a monthly average transmittance-absorptance product for beam radiation
$(\overline{\tau\alpha})_d$	the product for diffuse radiation
$(\overline{\tau\alpha})_g$	the product for diffuse reflection by the surroundings
$(\overline{\tau\alpha})_{win}$	the product for windows
ω_s'	the sunset angle for a tilt surface
ρg	the diffuse reflectance for the total radiation by the surroundings
$\rho\omega$	the mass density of the wall kg/m^3
σ_m	the standard deviation of the monthly average ambient temperature, K
σ_{yr}	the standard deviation of the annual average ambient temperature, K
ω	hour angle
ω_s	the sunset angle

Subscripts

a	auxiliary
ad	adiabatic
b	balance point
b	beam
c	collector
d	diffuse
L	loss
n	noon
r	room
w	wall

insulation material (TIM) in buildings could increase the room temperature of buildings in northern China [3]. A recent study of Braun and his coworkers [4] has revealed that the transparent insulation of a vertical sun-facing wall is characterized by higher solar conversion efficiency. The solar energy gains per year can be up to 200 kWh/m^2 year. A comparative study reported by Peuportier and Michel [5] indicated that transparent insulation can increase the productivity of air collectors by 25%, when compared with less expensive covers. However, the gain of a Trombe wall structure is doubled when compared with that of a non-insulated one. New technological improvements can achieve a higher solar fraction (30–45%) within reasonable cost. However, few studies on the application of transparent insulation in buildings in China have been reported, even though in northern China, space heating accounts for the majority of energy consumption in buildings.

This paper describes the potential for TIM applications in buildings in northern China, especially for the Beijing area. The simulation model developed is based on the unutilizability design method of collector-storage gain for passive systems [6].

2. The simulation model

Most residential buildings in northern China are 4–6 story buildings facing south. A typical apartment from such a building is chosen for simulation purpose. It has a floor area of 4×4×2.4 m, a 0.9×1.9 m entrance door and a window of size 0.8×1.2 m, as shown in Fig. 1. The exterior walls face south and west, and are constructed with common bricks of 240 mm thickness. Table 1 shows the basic data used in analyzing such a building system to examine the potential of transparent insulation applications for two types of windows, that is single and double glazing. For each type of window, three cases are considered: a massive wall without TIM cover; a massive wall covered by 4cm TIM, and a massive wall covered by 10 cm TIM.

The direct effect of transparent insulation application in a building is less heat loss to the surroundings, and greater solar energy absorption. The insulation potentiality can be estimated by a method based on the concept of unutilizability developed by Monson et al. [7,8] for passive systems. For collector-storage wall systems, the monthly auxiliary energy required is calculated from:

$$L_A = (L_{\mathrm{ad}} + L_{\mathrm{w}})(1 - f) \tag{1}$$

where L_{ad} and L_{w} are the monthly heating loads for an adiabatic wall, and for a collector storage wall, respectively; f is the monthly solar fraction; L_{ad} is estimated in terms of partial load coefficient $(UA)_{\mathrm{ad}}$ and degree-days (DD):

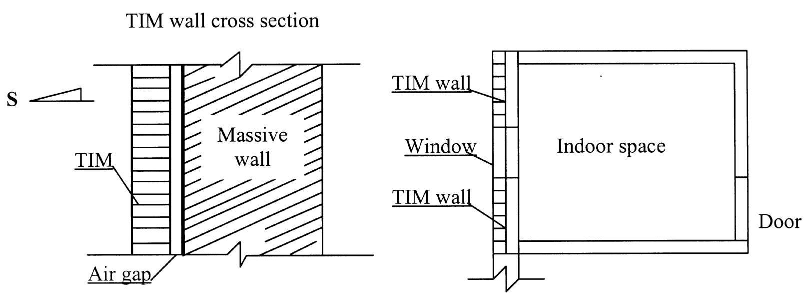

Fig. 1. A cross-section of the TIM wall and a layout of the simulated TIM room unit.

Table 1
Preliminary data for simulation

		Single glazing			Double glazing				
		NI[a]	TI[b]	TI[c]	NI[a]	TI[b]	TI[c]	Unit	
	(UA)	49.9			48.75			(W/K)	
	$(UA)_{ad}$		34.01	34.01		32.86	32.86	(W/K)	
	$(U)_{win}$	3.7	3.7	3.7	2.5	2.5	2.5	(W/m^{2}K)	
	$(U)_L$		4.43	1.42		4.43	1.42	(W/m^{2}K)	
ρ_g	A_c	A_r	C_b	C_p	T_r	ΔT_b	δ_w	k_w	ρ_w
	m^2	m^2	MJ/K	kJ/K	K	K	m	(W/mK)	kg/m^3
0.3	0.96	8.64	7.5	0.84	18.3	6	0.24	0.70	1800

[a] Without insulation.
[b] Transparent insulation thickness: 4 cm.
[c] Transparent insulation thickness: 10 cm.

$$L_{ad} = (UA)_{ad}(DD) \tag{2}$$

L_w is the monthly energy loss from the building through the collector-storage wall:

$$L_w = U_w A_r (DD) \tag{3}$$

where A_r is the area of transparent insulation, and U_w is the wall conductance:

$$U_w = \frac{1}{\dfrac{1}{\bar{U}_L} + \dfrac{\delta_w}{k_w} + \dfrac{1}{U_i}} \tag{4}$$

where $U_i = 8.3$ W/m^2 K is the inside heat transfer coefficient between the inner wall surface and the air in the room. The wall thickness is δ_w and its thermal conductivity is k_w. $\bar{U}_L$ Is the average heat loss coefficient from the outside surface of the wall, through the transparent insulation material, to the ambient environment. If night-time insulation is considered, $\bar{U}_L$ can be estimated as a time-average of day and night conductances:

$$\bar{U}_L = (1-i)U_L + i\left(\frac{U_L}{1 + R_N U_L}\right) \tag{5}$$

where U_L is the heat loss coefficient without night insulation; R_N is the thermal resistance of the night insulation, and i is the fraction for the 24 h. DD is calculated from Erbs' Equation. [9]:

$$DD = \sigma_m N^{1.5}\left[h + \frac{\ln[\cosh(1.698h)]}{3.396} + 0.2041\right] \tag{6}$$

where

$$h = \frac{T_b - \bar{T}_a}{\sigma_m \sqrt{N}}$$
$$\sigma_m = 1.45 - 0.0290\bar{T}_a + 0.0664\sigma_{yr}$$
$$\sigma_{yr} = \sqrt{\frac{\sum_{i=1}^{12}\left(\bar{T}_{a,i} - \bar{T}_{a,yr}\right)^2}{12}} \tag{7}$$

N, $\bar{T}_a$ and σ_{yr} are respectively the number of days in the month, the monthly average ambient temperature and the annual average temperature. σ_m Is the standard deviation of the monthly average ambient temperature. The DD value in Table 2 was calculated with regard to the 47 years before the year of 1999 meteorological data for the ambient temperature determination.

The equation for solar fraction is

$$f = \min\left\{Pf_i + 0.88 \times (1 - P)[1 - \exp(11.26f_i)], 1\right\}$$
$$\text{where } P = [1 - \exp(-0.144Y)]^{0.53} \tag{8}$$

where Y is a dimensionless storage-dump ratio, defined as the ratio of weighted storage capacity of the building and wall, to the energy that would be dumped by a building having zero heat capacitance:

$$Y = \frac{S_b + 0.047S_w}{Q_D} \tag{9}$$

Table 2
The meterological and $(\overline{\tau\alpha})$ data

Month	$\bar{T}_a$ °C	DD K	$\bar{H}_0$ MJ/m^2	$\bar{H}$ MJ/m^2	$\bar{S}$ MJ/m^2	$\bar{H}_T$ MJ/m^2	$(\overline{\tau\alpha})$	$(\overline{\tau\alpha})_{win}$
January	−3.46	674.6	15.3	9.20	12.535	17.680	0.7090	0.450
February	−1.04	541.6	20.3	11.77	11.149	16.419	0.6791	0.420
March	5.79	388.9	27.4	15.89	9.354	14.996	0.6237	0.384
April	9	282.0	34.6	20.07	7.335	12.845	0.5710	0.350
May	14	151.1	39.7	23.03	6.192	11.282	0.5489	0.335
June	19	48.6	41.7	24.19	5.615	10.617	0.5289	0.323
July	23	15.6	40.6	23.55	5.635	10.840	0.5198	0.316
August	22	21.5	36.4	21.11	6.552	11.989	0.5465	0.333
September	17	80.5	29.8	17.28	8.402	13.914	0.6039	0.364
October	11	232.9	22.4	12.99	10.578	15.657	0.6756	0.423
November	5.4	387.9	16.4	9.51	11.619	16.582	0.7007	0.442
December	−1.24	605.8	13.7	7.95	11.754	16.415	0.7160	0.459
Year	10.04	3430.7						

f_i is the solar fraction corresponding to an infinite capacitance system:

$$f_i = \frac{L_{\mathrm{w}} + Q_i}{L_{\mathrm{ad}} + L_{\mathrm{w}}} \tag{10}$$

Q_D is the energy that would be dumped:

$$Q_D = \frac{U_k A_{\mathrm{r}}(\overline{\tau\alpha}) + (U_k + U_{\mathrm{L}})A_{\mathrm{c}}(\overline{\tau\alpha})_{\mathrm{win}}}{U_k + U_{\mathrm{L}}} \frac{N\overline{S\phi}}{(\overline{\tau\alpha})} \tag{11}$$

where A_{c} and $(\overline{\tau\alpha})_{\mathrm{win}}$ are the area and average transmittance and absorptance product of the windows. In addition, the numerator in the right-hand term of Eq. (9) is the weighted storage capacity of the building, in which S_{b} and S_{W} are evaluated from:

$$S_{\mathrm{b}} = C_{\mathrm{b}}(\Delta T_{\mathrm{b}})N$$

$$S_{\mathrm{w}} = \frac{\rho_{\mathrm{w}}}{2k_{\mathrm{w}}} \frac{C_{\mathrm{p}}\delta_{\mathrm{w}}^2}{\delta t} Q_{Ti} \tag{12}$$

and ΔT_{b} is the temperature swing with the net heat transfer into the rooms through the storage wall. Q_{Ti} is given by

$$Q_{Ti} = U_k A_{\mathrm{r}}\left(\bar{T}_{\mathrm{w}} - T_{\mathrm{r}}\right)N\delta t$$

$$\text{where } \bar{T}_{\mathrm{w}} = \frac{\bar{S} + \left(U_k T_{\mathrm{r}} + \bar{U}_{\mathrm{L}}\bar{T}_{\mathrm{a}}\right)\delta t}{\left(U_k + \bar{U}_{\mathrm{L}}\right)\delta t} \tag{13}$$

and $\delta t = 24 \times 3600$ s. However, the calculation of the dumping energy needs to use a monthly absorbed radiation and a monthly solar energy utilizability $\bar{\phi}$. If the diffuse and ground-reflected radiations are assumed to be isotropic, the monthly absorbed radiation $\bar{S}$ can be calculated from:

$$\bar{S} = \bar{H}_{\mathrm{b}}\bar{R}_{\mathrm{b}}(\overline{\tau\alpha})_{\mathrm{b}} + \bar{H}_{\mathrm{d}}(\overline{\tau\alpha})_{\mathrm{d}}\left(\frac{1+\cos\beta}{2}\right) + \bar{H}_{\rho g}(\overline{\tau\alpha})_g\left(\frac{1-\cos\beta}{2}\right) \tag{14}$$

Table 2 shows the monthly meterological data in the Beijing area and the TIM's $\overline{\tau\alpha}$ data, accompanied by the monthly absorbed radiation $\bar{S}$ calculated from the above equations.

Klein [10] obtained the monthly average daily utilizability $\bar{\phi}$ as a function of a monthly average critical radiation level $\bar{X}_{\mathrm{c}}$, defined as, at that level, the gains just offset the losses. The critical radiation level is given by:

$$I_{T_{\mathrm{c}}} = \frac{U_{\mathrm{L}}A_{\mathrm{r}}\left(T_{\mathrm{r}} - \bar{T}_{\mathrm{a}}\right) + (U_k + U_{\mathrm{L}})(UA)_{\mathrm{ad}}\left(T_{\mathrm{b}} - \bar{T}_{\mathrm{a}}\right)}{U_k A_{\mathrm{r}}(\overline{\tau\alpha}) + (U_k + U_{\mathrm{L}})A_{\mathrm{c}}(\overline{\tau\alpha})_{\mathrm{win}}} \tag{15}$$

where the conductance from the outer wall surface to the room is given by:

$$U_k = \frac{U_i k_\mathrm{w}}{U_i \delta_\mathrm{w} + k_\mathrm{w}} \tag{16}$$

The transmittance of the transparent insulation material (τ) is given by the following empirical expression proposed by Yang [11]

$$\tau = C_0 \exp\left(-\frac{C_1 L_\mathrm{in}}{D_\mathrm{in}} \tan\theta_\mathrm{b}\right) \tag{17}$$

For AREL[1] material with insulation thickness $L_\mathrm{in} = 100$ mm, the cell width of square honeycomb $D_h = 4$ mm:

$$C_0 = 0.586, \quad C_1 = 0.172$$

For OKALUX[2] material with insulation thickness $L_\mathrm{in} = 40$ mm, the cell diameter D_h of the honeycomb = 3 mm:

$$C_0 = 0.674, \quad C_1 = 0.215$$

where in expression (17), θ_b is the incident angle of the beam radiation. In terms of I_{T_c}, the monthly radiation level is given by:

$$\bar{X}_\mathrm{c} = \frac{I_{T_\mathrm{c}}}{r_{t,\mathrm{n}} R_\mathrm{n} \bar{H}} \tag{18}$$

Then, the utilizability can be calculated from:

$$\bar{\phi} = \exp\left[a_0 + b_0\left(R_\mathrm{n}/\bar{R}\right)\right]\left[\bar{X}_\mathrm{c} + c_0 \bar{X}_\mathrm{c}^2\right] \tag{19}$$

By using the monthly average clearness index $\bar{K}_T$, the three coefficients are written as:

$$\begin{aligned} a_0 &= 2.943 = 9.271\bar{K}_T + 4.031\bar{K}_T^2 \\ b_0 &= -4.345 + 8.853\bar{K}_T - 3.602\bar{K}_T^2 \\ c_0 &= -0.170 - 0.306\bar{K}_T - 2.936\bar{K}_T^2 \end{aligned} \tag{20}$$

The parameter R_n is defined as the ratio for the hour, centred at noon, of radiation on a tilted surface, to that on a horizontal surface for the average day of month. It can be calculated from:

---

[1] Square honeycomb TIM made in Israel with 4 mm cell width.

[2] Capillary honeycomb TIM made in Germany with 3 mm diameter pores.

$$R_{\mathrm{n}} = \left(1 - \frac{r_{\mathrm{d,n}}\bar{H}_{\mathrm{d}}}{r_{\mathrm{t,n}}\bar{H}}\right)\bar{R}_{\mathrm{b,n}} + \left(\frac{r_{\mathrm{d,n}}\bar{H}_{\mathrm{d}}}{r_{\mathrm{t,n}}\bar{H}}\right)\left(\frac{1+\cos\beta}{2}\right) + \rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{21}$$

where $r_{\mathrm{d,n}}$ is the ratio of the diffuse radiation at noon to the daily diffuse radiation, r_{n} is the ratio of the total radiation at noon to the daily total radiation and $r_{\mathrm{t,n}}$ is the ratio of the hourly total radiation at noon to the daily total radiation. They can be calculated by the equations given by Collares-Pereira and Rabl [12]:

$$\begin{aligned} r_{\mathrm{t,n}} &= \frac{\pi}{24}(a_1 + b_1\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega - \omega_s\cos\omega} \\ r_{\mathrm{d,n}} &= \frac{\pi}{24}\frac{\cos\omega - \cos\omega_s}{\sin\omega - \omega_s\cos\omega} \end{aligned} \tag{22}$$

where $\omega = 0$ at noon. The coefficients a_1 and b_1 are given by:

$$\begin{aligned} a_1 &= 0.409 + 0.5016\sin\left(\omega_s - \frac{2\pi}{3}\right) \\ b_1 &= 0.6609 - 0.4767\sin\left(\omega - \frac{2\pi}{3}\right) \end{aligned} \tag{23}$$

For the northern hemisphere, the ratio of the average daily beam radiation on a tilted surface, to that on a horizontal surface at solar noon for south facing surfaces (i.e. surface azimuth angle $\gamma = 0$), $\bar{R}_{\mathrm{b,n}}$, can be calculated by:

$$\bar{R}_{\mathrm{b,n}} = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s' + \omega_s'\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + \omega_s\sin\phi\sin\delta} \tag{24}$$

where ω_s' is a sunset hour angle for the tilted surface for the mean day of the month, which is given by

$$\omega_s' = \min\left(\frac{\cos^{-1}(-\tan\phi\tan\delta)}{\cos^{-1}(-\tan(\phi-\beta)\tan\delta)}\right) \tag{25}$$

while the sunset hour angle for a horizontal surface for the mean day of the month is

$$\omega_s = \cos^{-1}(-\tan\phi)\tan\delta) \tag{26}$$

where δ and ϕ are respectively the declination of the sun and latitude. The declination is calculated from the equation derived by Cooper [13]

$$\delta = \frac{23.45\pi}{180}\sin\left(2\pi\frac{284+n}{365}\right) \tag{27}$$

where n is the day of the year.

It should be noted that the solar energy absorbed by a collector is closely dependent upon the average product of transmittance and absorptance. A glazing window has different values of $(\overline{\tau\alpha})$ from that of the transparent insulation material.

3. Results and discussions

The annual heating loads are obtained for the six cases, including the annual heat gains from solar radiation, the auxiliary energy needed and the solar fractions, as shown in Table 3.

The gross reference load is clearly reduced as a result of transparent insulation, no matter whether the window is single glazing or double glazing (see Table 3). It is found that when 4 cm and 10 cm insulation layers were used on the exterior wall, the solar fraction, including the solar collecting contribution of the 0.96 m^2 window, reaches 38–62%. However, Table 3 also illustrates that the solar fractions without insulation is about 22%.

Excluding the radiation absorbed by the windows, the transparent insulation per square metre can provide solar gains of about 70 kWh/m^2 year and 137 kWh/m^2 year, for the two cases with different thickness of TIMs. If the shading effect is included, the solar gain value may be smaller. This feature will be investigated in future work.

Transparent insulation also results in a reduction of annual auxiliary energy needed for the room in the building. Table 3 has shown that for a wall with 4 cm thickness TIM, the annual energy saved is about 4.2 GJ, and 7.8 GJ can be achieved if the TIM thickness is 10 cm. The potential of transparent insulation is significant, although it is not as optimistic as reported by Braun et al. [4], who illustrated a solar gains of 100–200 kWh/m^2 year, using a simulation method embedded in the software TRNSYS.

Table 3
Annual gross reference loads, auxiliary energy and solar fractions for six cases

The gross reference load						
Single glazing			Double glazing			
NI[a]	TI[b]	TI[c]	NI[a]	TI[b]	TI[c]	Unit
15.5	13.7	12.3	15.1	13.4	11.9	GJ
The annual auxiliary energy needed						
NI[a]	TI[b]	TI[c]	NI[a]	TI[b]	TI[c]	Unit
12.6	8.5	4.8	12.3	8.1	4.5	GJ
The annual solar energy fraction (%)						
NI[a]	TI[b]	TI[c]	NI[a]	TI[b]	TI[c]	
21.8	38.6	60.7	22.3	39.4	62.0	

[a] Without insulation.
[b] Transparent insulation thickness 4 cm.
[c] Transparent insulation thickness 10 cm.

Table 3 also shows that a 4 cm insulation of transparent material for south facing walls gives a 17% increase of annual solar friction and 39% increase for a 10 cm insulation. However, the potential of double glazing is just a 1% improvement of the annual solar fraction, if TIM is not used.

As shown in Fig. 2, the auxiliary energy becomes larger in winter, during which the monthly solar fraction remains relatively small. Fig. 3 shows the monthly solar fraction. For about six months, i.e. May–October, space heating is unnecessary because, during these months, the solar energy utilized is unity. In other months, when the monthly solar utilizability is less than unity, auxiliary energy is required.

The monthly average transmittance and absorptance product for glass windows and TIM walls are shown in Fig. 4. This shows that the product for the TIM wall is about 66% of the product for windows.

Fig. 5 illustrates the monthly absorbed radiation calculated from Eq. (14), which indicates that a vertical surface absorbs less solar energy in summer than that in winter.

The potentiality of transparent insulation can be seen from Figs. 6, 7 and 8. The solar fraction, the auxiliary energy and gross reference load under different conditions are illustrated. It is seen that better insulation will no doubt achieve a higher solar fraction, and reduce the amounts of the auxiliary energy needed for the space heating of buildings.

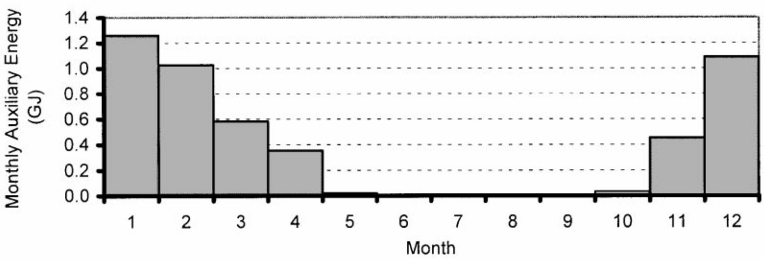

Fig. 2. Monthly auxillary energy requirements when the thickness of the TIM layer is 100 mm with a single glazed window.

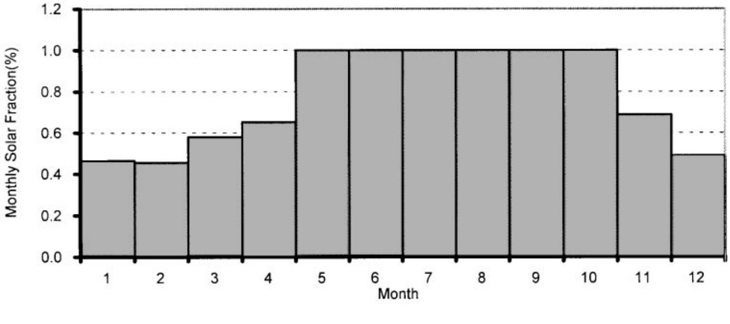

Fig. 3. Monthly solar fraction when the thickness of TIM layer is 10 mm with a single glazed window.

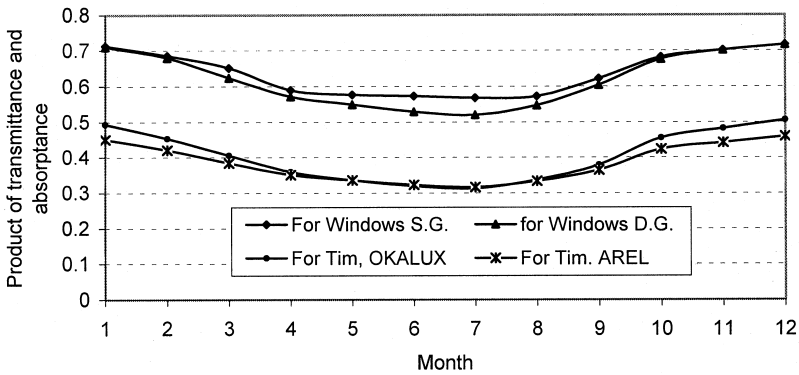

Fig. 4. Monthly transmittance and absorptance products (S.G.: single glazing; D.G.: double glazing).

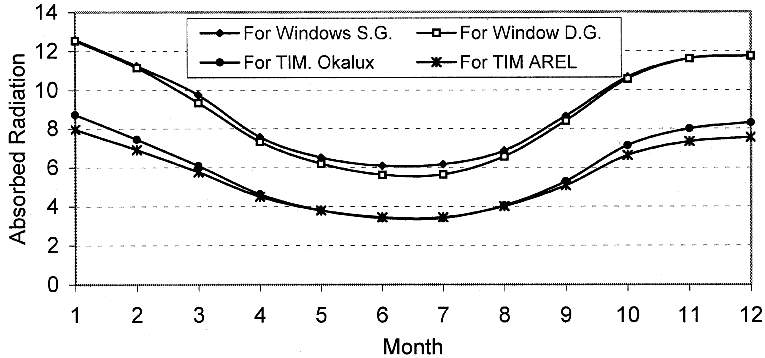

Fig. 5. Absorbed solar radiation by windows and TIM walls (S.G.: single glazing; D.G.: double glazing).

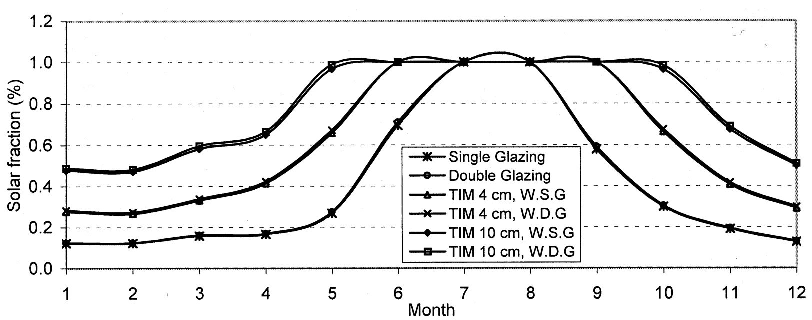

Fig. 6. Monthly solar fraction for different walls (W.S.G.: single glazing window; W.D.G.: double glazing window).

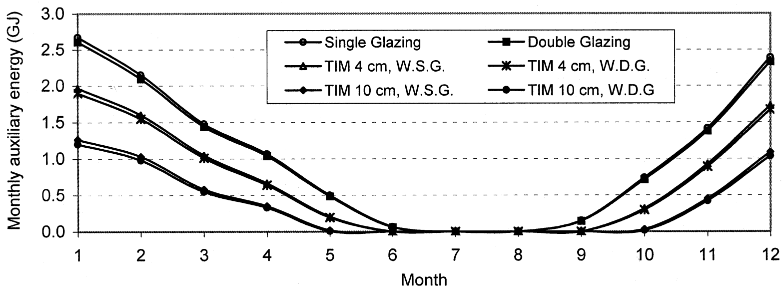

Fig. 7. Monthly auxillary energy needed for different walls (W.S.G.: single glazing window; W.D.G.: double glazing window).

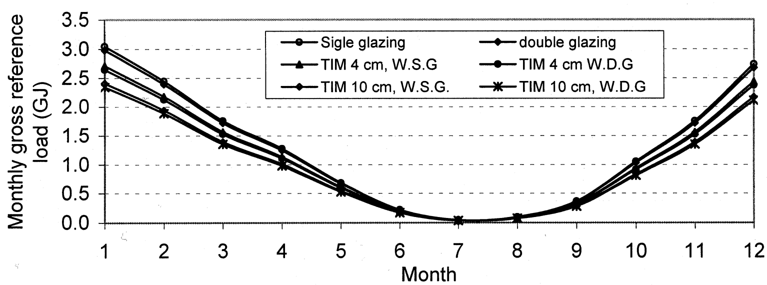

Fig. 8. Monthly gross reference load for different walls (W.S.G.: single glazing window; W.D.G.: double glazing window).

4. Conclusions

Using the simulation model, a comparative study gives the following results:

1. Much higher solar fractions can be achieved by TIM applications in buildings.
2. Transparent insulation has greater potential than that of double glazing. A 10 cm thickness honeycomb insulation for a south facing wall of a building leads to an increase of the solar fraction by about 38%, while the double glazing merely produces about 1% of solar fraction lift when compared with single glazing.
3. The solar gains from the 4 and 10 cm thickness transparent insulations are about 70 and 137 Wh/m^2 year, respectively.

Acknowledgements

This work was supported from the Industrial Support Fund of the Industry Department of the Hong Kong SAR Government and in part from the National Science Foundation of China via Grant No. 19872062.

References

[1] Veingberg VB. Optics in equipment for the utilization of solar energy. State publishing house of defense industry, 1959, Moscow (English translation).
[2] Hollands KGT. Honeycomb devices in flat plate solar collectors. Solar Energy 1965;9(3):159–64.
[3] Yang HX, Brinkworth BJ, Marshall RH. The potential utilization of TIM in passive solar building in China. In: Proceedings of the 1991 Solar World Progress, Denver, USA, 1991, Vol. 3 Part 1, p. 2945–50.
[4] Braun PO, Goetzberger A, Schmid J, Stahl W. Transparent insulation of building facades — steps from research to commercial applications. Solar Energy 1992;49(5):413–27.
[5] Peuportier B, Michel J. Comparative analysis of active and passive solar heating systems with transparent insulation. Solar Energy 1995;54(1):13–18.
[6] Duffie JA, Beckman WA. Solar engineering of thermal process. 2nd Ed. New York: Wiley, 1991 pp. 733–76.
[7] Monson WA, Klein SA, Beckman WA. Prediction of direct gain solar heating system performance. Solar Energy 1981;27:143.
[8] Monson WA, Klein SA, Beckman WA. the unutilizability design method for collector-storage walls. Solar Energy 1982;29:421.
[9] Erbs DG, Klein SA, Beckman WA. Estimation of degree-days and ambient temperature bin data from monthly average temperatures ASHRAE J 1983, June, p. 60.
[10] Klein SA, Theilacker JC. An algorithm for calculating monthly-average radiation on inclined surfaces. ASME, Journal of Solar Energy Engineering 1981;103:29.
[11] Yang HX. A transient test method to determine thermal and optical properties of transparent insulation. PhD thesis, University of Wales College of Cardiff, Cardiff, UK, 1993.
[12] Collares-Pereira M, Rabl A. The average distribution of solar radiation-correlations between diffuse and hemispherical and between daily and hourly insolation values. Solar Energy 1979;22:155.
[13] Cooper PI. The absorption of solar radiation in solar stills. Solar Energy 1969;12:3.