Iraqi Journal of Physics,2009 *Vol.7 , No.9 , PP. 45-55*

Effect of Glass Inclination of Windows Facing East and West on Solar Radiation Transmittance into Buildings

Abbas J. H. Al-Wattar
Department of Physics, College of Science, University of Baghdad. Baghdad-Iraq.

Abstract

To reduce solar radiation transmittance into buildings through windows facing east or west during summer, a window inclination from vertical position is suggested. The inclination of the window glazing and the rate of unwanted solar radiation during summer can be calculated knowing the dialy inclination of the sun rays. The inclination of window glazing depends on the latitude of the position required. For instance in Baghdad which is at about 33^o north latitude a slope of 15^o for window glazing is sufficient to prevent about 419 MJ/m^2 of total solar radiation energy from penetration during summer for clear glazing of window facing east. This value drops to about 96 MJ/m^2 during winter. Therefore the ratio between the energy saved for cooling during summer to the energy expended in heating during winter reached 4.4:1 for window facing east and 4.0:1 for window facing west.

تأثير ميلان زجاج النوافذ المواجهة للشرق والغرب على نفاذية الأشعاع الشمسي

عباس جاسم حمادي الوتار

جامعة بغداد – كلية العلوم – قسم الفيزياء

الخلاصة

لتقليل نفاذية الأشعاع الشمسي الداخل الى المباني خلال النوافذ المواجهه للشرق او الغرب خلال فصل الصيف، فقد اقترحت طريقة لأمالة زجاج النافذة عن الوضع الشاقولي. أن مقدار امالة زجاج النافذة وكذلك معدل الأشعاع الشمسي غير المرغوب دخولة للمبنى خلال فصل الصيف يمكن حسابة بعد معرفة اتجاه سقوط الأشعة الشمسية يومياً. أن مقدار أمالة زجاج النافذة يعتمد على زاوية خط العرض للموقع المطلوب. فعلى سبيل المثال، في بغداد والتي هي على خط عرض ٣٣ شمالاً، فأن امالة قدرها ١٥ درجة عن الشاقول لزجاج النافذة يكون كافياً لمنع ٤١٩ مليون جول\مترمربع من الأشعاع الشمسي الكلي من الدخول الى زجاج النافذة الأعتيادي (غير الملون) المواجه للشرق أثناء فصل الصيف. وأن هذه القيمه تنخفض الى حوالى ٩٦ مليون جول\مترمربع خلال فصل الشتاء. ولذلك فأن النسبة بين الطاقة التي توفر للتبريد خلال فصل الصيف الى الطاقة المحجوبة والمستهلكة في التدفئة خلال الشتاء تصل الى 4.4:1 للشباك الموجه للشرق، و 4.0:1 للشباك المواجه للغرب.

Introduction

To reduce the penetration of solar radiation through glass windows during hot summer in contries` like Iraq or other Arab Gulf contries, proper methods are required to moderate the indoor temperature. One of the methods used to prevent sun rays fall on the windows is to construct a specially designed over hang to allow most of winter sun, and to prevent most of the summer sun [1]. A second method is to use of operable shading device in front of windows which has different positions in summer and winter. A third method is to use double glazing with an operable shading device called a skylid [2], or by using tinted or coated glass. An alternative method is proposed in the present work and in a previous work [3]. Where by the reflection of the incident solar radiation is increased causing the transmitted radiation to decrease. This is done by the inclination of the window by certain angle with respect to the vertical so that its lower edge is on the interior of the window sill (Fig.1). In previous work [3] a treatment for south facing window was conducted and the costwise of saving energy by utilizing such inclined windows or what may be termed as passive cooling in building was also discussed thoroughly [4]. Both methods are more efficient in preventing summer sun than winter sun due to different inclination of the sun with respect to earth between south and north. The angle of inclination of the window glazing depends on the latitude of the area in question–the smaller the latitude the smaller the angle. For hot contries between equator and latiude equal to 33^o, for example, only a small angle of inclination is needed which requires minor alteration in the construction of the window. This makes the method more suitable for such contries.

Theory

The transmittance T of a glass plate with parallel faces when absorption by the glass is neglected and multiple reflection inside the glass are taken into consideration, is given by [3] .

$$T = (1-R) / (1+R) \qquad \ldots.(1)$$

Where R is reflectance of a single air-glass interface and can be calculated from the well known Fresnel's formula, namely

$$R = \frac{1}{2}\frac{\tan^2(\phi-\phi^{/})}{\tan^2(\phi+\phi^{/})} + \frac{1}{2}\frac{Sin^2(\phi-\phi^{/})}{Sin^2(\phi+\phi^{/})} \qquad \ldots.(2)$$

Where φ , and $\varphi^{/}$ are angles of incidence and refraction respectively.

The angle of incidence, φ , of sun rays on a window glass facing east (or west) can be derived in terms of the azimuth angle A, and elevation angle E (see Fig.2) Using the direction cosines formula, namely

$$\mathbf{Cos^2}\varphi + \mathbf{Cos^2 Z} + \mathbf{Cos^2}\phi_S = \mathbf{1} \qquad \ldots.(3)$$

Where $\phi(=< POS), and\ \phi_S(=< POV)$ are the angles of incidence on planes facing east (or west) and South respectively.

Since $\cos\varphi_S = \cos E \cos A$ [3], and $\cos Z = \sin E$, then substituting these values into Eq. (3), one then gets

$$\mathbf{Cos}\varphi = \mathbf{CosE\ SinA} \qquad \ldots..(4)$$

When the window glass (facing east or west) is inclined by an angle α with respect to the vertical, the angle of in cidence φ will be modified to φ_α which is derived as :

$$\mathbf{Cos}\varphi_\alpha = \mathbf{Cos}\alpha\ \mathbf{CosE\ SinA} - \mathbf{Sin}\alpha\ \mathbf{SinE} \quad (5)$$

Using Eq.(4), then Eq.(5) can be written as

$$\mathbf{Cos}\varphi_\alpha = \mathbf{cos}\alpha\ \mathbf{cos}\varphi - \mathbf{Sin}\alpha\ \mathbf{SinE} \qquad (6)$$

Calculation of angle of incidence φ and transmittance T

The angle of incidence φ has been calculated from Eq.(4) after calculating both A and E values for Baghdad area (Latitude = 33.33^{o}N) [3-7]. The calculations have been done for oppreximately the middle of each month, between sun rise and noon, since the values E (and also φ) equal at symmetrical time intravels around the noon axis [7], i.e φ (10 a.m) $=\varphi$ (2 p.m) . The new values of the angle of incidence ϕ_α when the window glass is inclined with respect to the vertical by an angle (taken as 15^o) are calculated from Eq.(6).

The values of E,A, φ , and ϕ_α are listed in Table (1) .

The values of the transmittance T and T_α of direct sun rayp through clear window glass for vertical and inclined positions respectively were calculated from Eq(1). The values of R were calculated from Eq(2), with the values of $\varphi^{/}$ calculated from Snells law using the measured value of the refracting index of the glass which is 1.5. The absorbance of the glass (thickness ~ 3.5 mm) was found to be ~ 2%. Absorption of clear glass can therefore be neglected. Tand T_α-values are listed in Table (1).

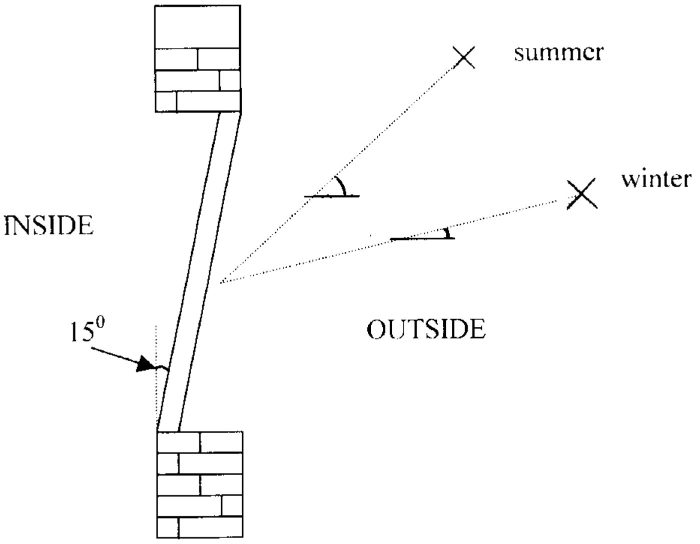
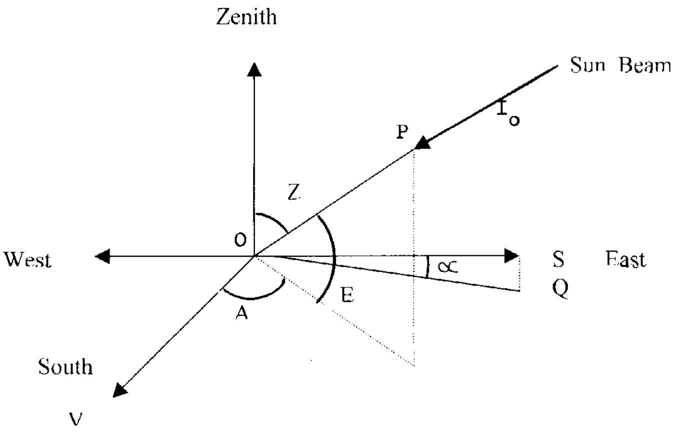


Figure (1)

Schematic view of the window



$\angle$ POS = ϕ

$\angle$ POQ = ϕ_α

Figure (2)

Angles of incidence of sun beam on window glass facing east, and other related angles: ∠POS= φ =angle of incidence for vertical position, ∠POQ= ϕ_{α} =angle of incidence for inclined position, E= Elevation angle, and A =Azimuth angle

Table (1)

Calculated values of elevation angle E, azimuthal angle A (ref.(3)), angles of incidence φ , and φ_{α} for vertical and inclined positions of window, T and T_{α} transmittances of clear glass for vertical and inclined positions of window respectively , the decrease of transmittance ΔT, direct normal solar intensity I_o (ref.(3)), and the hourly change of transmitted global intensity ΔG_t . I_o and ΔG_t are in W.h/m^2 .

The values of these quantities before 12 o'clock are for window facing East, and after 12 o'clock are for window facing west .

Day	Hour	E^o	A^o	ϕ^o	ϕ^o_{α}	T (10^{-2})	T_{α} (10^{-2})	ΔT (10^{-2})	I_o	$\Delta G_t = I_o \Delta T$
13 Dec.	7	0								
	8	10.4	53.1	38.1	44.5	91.4	90.5	0.9	160	1.44
	9	19.8	42.4	50.6	58.3	88.9	84.9	4.0	441	17.64
	10	27.2	29.6	63.9	72.2	79.8	66.4	13.4	661	88.57
	11	32.1	14.1	78.1	86.5	50.9	17.1	33.8	715	241.67
	12	33.7	0	90.0	-	-	-		778	
	13							33.8	806	272.43
	14							13.4	804	107.74
	15							4.0	792	31.68
	16							0.9	686	6.17
	17	0								
15 Jan.	7	0.6	63.8	26.2	30.2	92.1	92.0	0.1	0	0
	8	11.4	54.9	36.7	43.7	91.6	90.7	0.9	46	0.41
	9	20.9	44.2	49.4	57.6	89.3	85.4	3.9	70	2.73
	10	28.6	31.4	62.8	71.5	81.0	67.8	13.2	432	57.02
	11	33.7	16.4	76.4	85.2	55.8	23.1	32.7	520	170.04
	12	35.3	0	90.0	-	-	-		668	
	13							32.7	713	233.15
	14							13.2	785	103.62
	15							3.9	811	31.63
	16							0.9	799	7.19
	17							0.1	800	0.80

Table (1) Cont.

Day	Hour	E^o	A^o	ϕ^o	ϕ^o_α	T (10^{-2})	T_α (10^{-2})	ΔT (10^{-2})	I_o	ΔG_t
15 Feb.	7	5.4	70.2	20.5	28.3	92.2	92.1	0.1	40	0.04
	8	16.8	60.9	33.2	42.8	91.9	90.8	1.1	125	1.38
	9	27.2	49.7	47.3	57.5	89.9	85.4	4.5	236	10.62
	10	35.7	35.7	61.7	72.1	82.1	66.6	15.5	486	75.33
	11	41.5	18.4	76.3	86.7	56.1	16.2	39.9	577	230.22
	12	43.5	0	90.0	-	-	-		673	
	13							39.9	705	281.30
	14							15.5	753	116.72
	15							4.5	786	35.37
	16							1.1	783	8.61
	17							0.1	813	0.81
15 Mar.	6	0								
	7	11.6	78.7	16.1	28.8	92.3	92.1	0.2	80	0.16
	8	23.7	69.3	31.1	43.7	92.0	90.7	1.3	204	2.65
	9	35.0	57.9	46.1	58.6	90.2	84.7	5.5	401	29.65
	10	44.7	42.8	61.1	73.5	82.6	63.4	19.2	539	103.49
	11	51.7	21.8	76.7	88.9	55.0	5.5	49.5	634	313.83
	12	54.2	0	90.0	-	-	-		678	
	13							49.5	696	344.52
	14							19.2	720	138.24
	15							5.5	761	41.86
	16							1.3	767	9.97
	17							0.2	825	1.65
14 Apr.	6	5.5	97.2	9.1	21.7	92.3	92.2	0.1	21	0.02
	7	18.0	89.1	18.0	33.0	92.3	91.9	0.4	194	0.78
	8	30.5	80.3	31.9	46.5	91.9	90.1	1.8	386	6.95
	9	42.6	69.5	46.4	60.6	90.1	83.1	7.0	518	36.26
	10	53.8	54.6	61.2	75.1	82.5	59.3	23.2	589	136.65
	11	62.5	31.2	76.2	90.0	56.4	0	56.4	530	298.92
	12	65.9	0	90.0	-	-	-		594	

Table (/) Cont.

Day	Hour	E°	A°	ϕ°	ϕ°_{α}	T (10^{-2})	T_{α} (10^{-2})	ΔT (10^{-2})	I_o	ΔG_t
14 Apr.	13							56.4	697	393.11
	14							23.2	681	157.99
	15							7.0	610	42.7
	16							1.8	416	7.49
	17							0.4	113	0.45
13 May	6	10.6	105.1	18.4	29.7	92.3	92.1	0.2	98	0.20
	7	22.8	97.5	23.9	38.5	92.2	91.4	0.8	363	2.90
	8	35.3	90.0	35.3	50.3	91.7	89.0	2.7	512	13.82
	9	47.8	80.5	48.5	63.4	89.6	80.4	9.2	564	51.89
	10	59.9	67.4	62.4	77.1	81.4	53.9	27.5	559	153.73
	11	70.3	43.9	76.5	91.0	55.6	-	55.6	531	295.24
	12	75.0	0	90.0	-	-	-	-	614	
	13							55.6	696	386.98
	14							27.5	759	208.73
	15							9.2	742	68.26
	16							2.7	669	18.06
	17							0.8	649	5.19
	18							0.2	513	1.03
14 June	6	13.2	109.4	23.3	34.1	92.2	91.8	0.4	48	0.19
	7	25.2	102.3	27.9	42.0	92.1	90.9	1.2	251	3.01
	8	37.6	95.2	37.9	52.8	91.5	88.1	3.4	466	15.84
	9	50.1	87.2	50.2	65.2	89.0	78.3	10.7	597	63.88
	10	62.5	76.2	63.4	78.3	80.4	49.9	30.5	701	213.81
	11	74.0	54.8	77.0	91.8	54.2	-	54.2	777	421.13
	12	79.9	0	90.0	-	-	-	-	826	
	13							54.2	859	465.58
	14							30.5	887	270.54
	15							10.7	899	96.19
	16							3.4	923	31.38
	17							1.2	904	10.85
	18							0.4	852	3.41

Table (1) Cont.

Day	Hour	E^o	A^o	ϕ^o	ϕ^o_α	T (10^{-2})	T_α (10^{-2})	ΔT (10^{-2})	I_o	ΔG_t
14 July	6	12.4	108.0	21.7	32.7	92.2	91.9	0.3	33	1.0
	7	24.5	100.7	26.6	40.9	92.1	91.1	1.0	207	2.07
	8	37.0	93.4	37.1	52.1	91.5	88.4	3.1	373	11.56
	9	49.5	85.0	49.7	64.7	89.2	78.9	10.3	301	31.00
	10	61.8	73.2	63.1	77.9	80.7	51.2	29.5	592	174.64
	11	73.0	50.5	77.0	91.7	54.2	-	54.2	668	362.06
	12	78.6	0	90.0	-	-	-	-	721	
	13							54.2	763	413.55
	14							29.5	779	229.81
	15							10.3	800	82.40
	16							3.1	810	25.11
	17							1.0	812	8.12
	18							0.3	782	2.35
15 Aug.	6	8.5	101.0	13.9	26.0	92.3	92.1	0.2	20	0.04
	7	20.9	93.1	21.1	36.0	92.2	91.6	0.6	160	0.96
	8	33.4	84.7	33.8	48.7	91.8	89.5	2.3	458	10.53
	9	45.8	74.6	47.8	62.4	89.8	81.4	8.4	556	46.70
	10	57.5	60.0	62.3	76.7	81.5	55.0	26.5	625	165.63
	11	67.1	34.5	77.3	91.5	53.2	-	53.2	685	364.42
	12	71.1	0	90.0	-	-	-	-	760	
	13							53.2	753	400.60
	14							26.5	727	192.66
	15							8.4	706	59.30
	16							2.3	741	17.04
	17							0.6	480	2.88
	18							0.2	754	1.51
16 Sep.	7	14.8	82.3	16.6	30.7	92.3	92.0	0.3	184	0.55
	8	27.1	72.9	31.7	45.3	91.9	90.3	1.6	505	8.08
	9	38.8	61.3	46.9	60.2	90.0	83.4	6.6	571	37.69
	10	49.2	45.3	62.4	75.4	81.4	58.5	22.9	719	164.65
	11	56.9	20.1	79.2	92.1	46.9	-	46.9	782	366.76
	12	59.6	0	90.0	-	-	-	-	786	

Table (1) Cont.

Day	Hour	E^{o}	A^{o}	ϕ^{o}	ϕ^{o}_{α}	T (10^{-2})	T_{α} (10^{-2})	ΔT (10^{-2})	I_{o}	ΔG_{t}
16 Sep.	13							46.9	813	381.30
	14							22.9	797	182.51
	15							6.6	812	53.59
	16							1.6	775	12.40
	17							0.3	716	2.15
	18							0.04	876	0.35
15 Oct.	7	8.3	72.7	19.1	28.9	92.3	92.1	0.2	35	0.07
	8	20.0	63.2	33.0	43.8	91.9	90.7	1.2	222	2.66
	9	30.7	51.5	47.7	58.8	89.8	84.5	5.3	435	23.06
	10	39.8	36.2	63.0	74.2	80.8	61.7	19.1	575	109.83
	11	46.0	14.5	80.0	91.1	44.1	-	44.1	662	291.94
	12	48.1	0	90.0	-	-	-	-	697	
	13							44.1	713	314.43
	14							19.1	675	128.93
	15							5.3	630	33.39
	16							1.2	556	6.67
	17							0.2	411	0.82
15 Nov.	7	2.5	65.1	25.1	30.3	92.2	92.0	0.2	46	0.09
	8	13.5	55.8	36.5	44.3	91.6	90.6	1.0	316	3.16
	9	23.3	44.7	49.8	58.6	89.2	84.7	4.5	528	23.76
	10	31.3	30.8	64.1	73.4	79.6	63.6	16.0	651	104.16
	11	36.6	12.5	80.0	89.2	44.1	4.0	40.1	759	304.36
	12	38.3	0	90.0	-	-	-	-	793	
	13							40.1	789	316.39
	14							16.0	745	119.20
	15							4.5	765	34.43
	16							1.0	675	6.75
	17							0.2	682	1.36

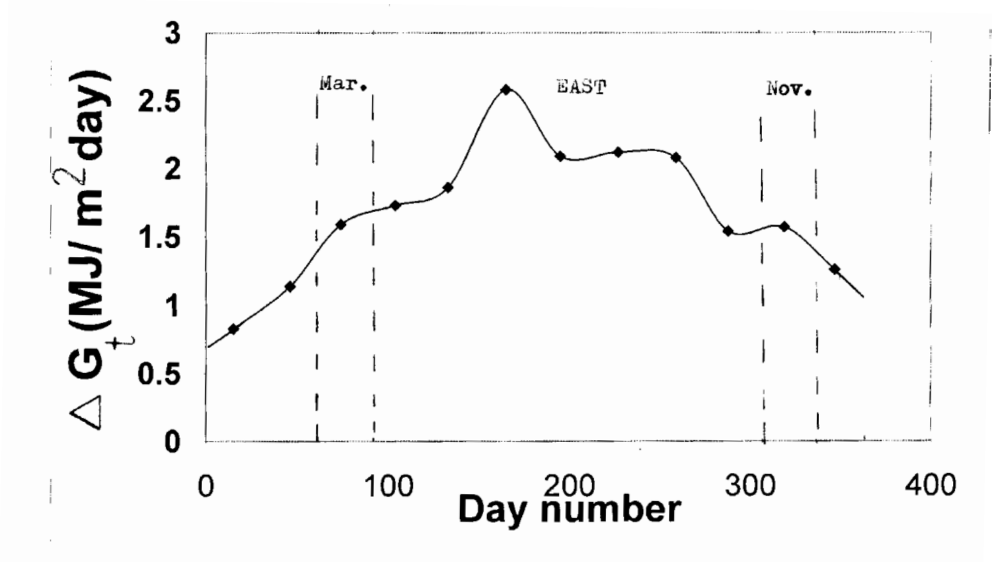


Fig. (3)

Solar radiation for clear glass versus day number. Change (decrease) of transmittance of global solar radiation ΔG_t for clear glass versus day number (window facing east).

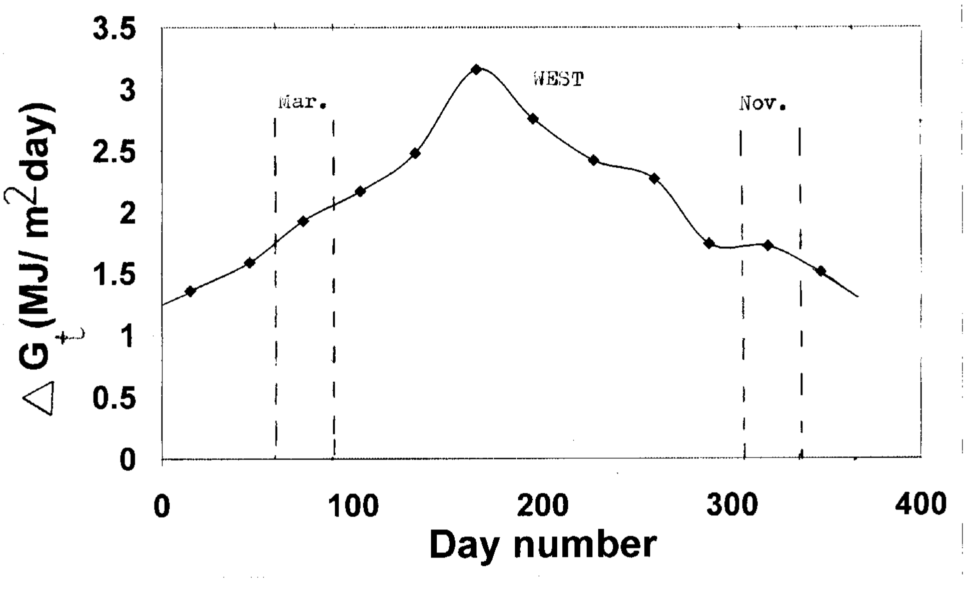


Fig. (4)

Change (decrease) of transmittance of global solar radiation ΔG_t for clear glass versus day number (window facing west).

Calculation of the change of the transmitted global solar radiation through window glass

The incident global solar radiation, G_o, in a given direction comprises two components the diffuse I_{do} and the direct I_o , i.e.

$$G_o = I_{do} + I_o \qquad \text{.... (7)}$$

And similarly the transmitted global insolution G_t may be written as

$$G_t = I_{dt} + I_t \qquad \text{.... (8)}$$

Where I_{dt} and I_t represent the transmitted diffuse and direct components respectively.

Eq. (8) can, also, be written as

$$G_t = I_{dt} + TI_t \qquad \text{......(9)}$$

Where ($T = I_t / I_o$) represents the transmittance of the direct component.

The inclination of the window glass by a 15^o from vertical causes a negligible change in the diffuse component compared to that in the direct component, since the diffuse radiation is insensitive to the direction [3,9] .

One can therefore, write for the change of the transmitted global insulation:

$$\Delta G_t \cong I_o \Delta T \qquad \text{.... (10)}$$

Table (1) shows the hourly values of direct normal intensity I_o (=I/Sin E) for Baghdad city (calculated from the measured values of direct intensity on a horizontal surface I and E-values [3]). The change (decrease) of hourly global insolation transmitted through the window glass ΔG_t, due to window inclination by 15^o from normal position, has been calculated from Eq.(10) and listed in Table (1) too. The values before 12 O'clock are for window facing east. and after 12 oclock are for window facing west. From this table the daily total change of transmitted global insulation is then found during the actual hours of sun shine for windows facing east and west and listed in Table (2). Plots of ΔG_t against day number of Table (2) are shown in Figs. (3) and (4) for both directions.

Table (2)

The daily change of the transmitted global intensity ΔG_t in $MJ/m^2 day$, for clear glass of windows facing East and West, for the given days.

Day	Day no.	ΔG_t (East)	ΔG_t (West)
15 Jan.	15	0.83	1.36
15 Feb.	46	1.14	1.59
15 Mar.	74	1.59	1.93
14 Apr.	104	1.73	2.17
13 May	133	1.86	2.48
14 Jun.	165	2.58	3.16
14 July	195	2.09	2.76
15 Aug.	227	2.12	2.42
16 Sep.	259	2.08	2.27
15 Oct.	288	1.54	1.74
15 Nov.	319	1.57	1.72
13 Dec.	347	1.26	1.51

Discussion and Conclusion

The present work is based on the variation of the intensity of the reflected and of transmitted sun light with the angle of inclination α relative to vertical position of window glass. Calculation of the reflectance R from Eq.(2) show that R increases slowly as the angle of incidence ϕ increases for low values of ϕ ($<50^o$), while increases very rapidly at higher values of ϕ . This means a very rapid decreases of the transmittance at higher values of ϕ. As suggested in the present work and a previous work [3] the inclination of the widow glass, in the direction shown in Fig.(1) causes the angle of incidence to increase (Eq.6). During the winter season, the angle of incidence is small and inclining the window would, therefore, have a small effect on transmittance and consequently a very small decrease in the transmitted sun light. While in the Summer season

The angle of incidence is large and its increase would cause a rapid decrease in the radiation transmitted into building. The results of calculations (Table 2) have shown that inclining the window facing east from the vertical position by 15^o causes a total decrease in the daily transmitted global radiation by about 0.8 MJ/m^2 day for the middle of January in winter. On the other hand the value increases to about 2.6 MJ/m^2 day for the middle of June in summer.

The total decrease in the transmitted global radiation, calculated from the area under the curve (Fig.3) is about 419 MJ/m^2, for window facing east, for the period from 1st April to 31st October which is the period when cooling of buildings in Baghdad is required. During the period from 1st December to the end of February when heating is required, the cut off is about 96 MJ/m^2. The corresponding values for window facing west (Fig.4) are 513 and 128 MJ/m^2.

This means that the ratio of energy saved for cooling during summer to the loss of energy for heating (due to decrease of transmittance) during winter is 4.4:1 for window facing east and 4.0:1 for window facing west using clear glass. Comparing these results with results obtained for window facing south, where the ratio is 18:1 for clear glass [3], suggest that the method of window inclination can be utilized with all window directions but with different energy saving ratios.

References

[1] A.J.H.Al-Wattar, and A.M.Taleb, Awindow construction for the passive use of solar energy, 4th Arab International Solar Energy Confernce-Jordan-Nov.(1995)Vol.II, pp861-874.

[2] Anderson, Solar energy fundamentals in building design, McGraw-Hill comp.,(1977), P49.

[3] A.M.Taleb, and A.J.H. Al-Wattar, Design of windows to reduce solar radiation transmittance into buildings Solar and Wind Technology, vol.5 PP503-515(1988).

[4] N.M.W. Baker and A.M.Taleb, The inclination of window method for passive cooling in buliding-Architectural Science Review, vol.45, pp51-55(2002).

[5] D.Rapp,Solar energy, Printice Hall Inc.,(1981).

[6] “On the nature and distribution of solar radiation”-Report prepared for U.S. Department of Energy, March (1978), P55.

[7] P.I.Cooper, Solar Energy, 12(1963)3.

[8] “Energy conservation in new building construction”, Texas Energy Management, Series 200, Oct. (1980), P.48.

[9] J.C.Mo Veigh, Sun power-An introduction to the applications of solar energy, Pergamon Press, (1979), pp 20, 12.