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Optimizing Windowpane Performance in Terms of Solar Radiation and Thermal Conductivity for Balancing Lighting and Thermal Models in Architectural Spaces

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Abstract

This study optimizes the number of windowpanes in terms of the integrity of daily lighting and heat transfer and solar radiation in architectural spaces. The study tests single pane, double pane, and triple pane windows in terms of solar energy gain and loss by radiation and thermal conductance. Due to high interconnectivity amongst building façade parameters, daylight and heat gain are much affected by the transmittance factors of windowpanes. Accordingly, this study seeks integral formulas that correlate daylight levels and heat gain in spaces. It seeks for the optimal number of window layers that prevent heat loss in winter without reduction in solar radiation or light through windows. The study used Radiance software for lighting analysis to simulate daylighting levels in spaces using single, double, and triple-pane windows. In parallel to daylight performance, the heat conductance of the three cases of windowpanes was compared with the solar transmittance to reach optimal solutions for energy efficient building envelope in terms of heat gain and daylight inside architectural spaces.

Keywords*:* Daylight; Building facade; Radiance; Optimal solution; solar transmittance; Building envelope.

INTRODUCTION

Good illuminance levels and comfortable temperatures in spaces are influential factors for improving occupants' productivity in buildings. To achieve high level of visual and thermal comfort in spaces, many factors should be carefully handled such as window size, building geometry, wall reflectance, and shading devices. The interdependency among lighting and heat variables in spaces necessitates deep investigation for optimal solutions that keep acceptable illuminance levels in spaces without surplus heat gain in summer.

An amount of electromagnetic (visible and infrared) radiation energy from the sun equal to 1340 J/second passes perpendicularly through each 1 m^2 at the extra-terrestrial region right at the edge of the earth's atmosphere [1]. Building designers have utilized this tremendous source of energy in many useful ways, and have dealt with energy by following different strategies for energy saving in architectural spaces. One of the common treatments in buildings is using double and triple pane windows.

This study focuses on finding the optimal number of windowpanes that increases the energy saving in buildings within acceptable ranges of illuminance levels without affecting the amount of solar radiation gain in winter.

Multi-layer windows in buildings.

Using multi layer windows in buildings is a good strategy for energy saving. The higher the number of glass layers in windows means less of the heat lost by conduction from the windows [2].

According to Heinrich [3], "Evacuated double glazing can achieve similar or even lower thermal transmittances than advanced triple glazing offering at the same time higher solar energy transmittance and lower overall thickness and weight".

Manz et al. [4], suggest that "the use of the triple vacuum glazing concept can significantly reduce the thermal transmittances achieved by the best insulation glazing units". According to this study, "the triple vacuum-glazing concept holds considerable potential for low-energy building applications". In cold regions using triple pane windows is more efficient than using it in temperate regions [5].

A dual-gasflow window with triple glazing can also conserve more energy than a single gasflow window because the former works like a cross-counter flow heat exchanger [6].

In computer simulation, Carriere et al. [7] have used the popular DOE-2 software to study the efficiency of window glazing in reducing solar heat gain of buildings. One of their key issues showed that cooling loads decreases proportionally with the number of glazing panes resulting in the overall reduction in energy consuming in buildings [8].

Double skin facades.

Similar to double pane windows, double skin faces are also efficient in energy saving in buildings. Neveen Hamza [10] defined double skin facades as "two layers of facade separated by an air gap that varies in its depth creating a solar chimney effect where warm air rises by buoyancy" [10]. The double skin faces is a system engaged with the addition of a second glazed envelope, which can create opportunities of maximizing daily light and advancing energy presentation

[9]. Double skin façes (DSF) are growing for their ability to reduce solar heat gain in buildings [8]. According to [12] buildings constructed with double skin faces can have better thermal performance than the conventional single skin face [12], the application of double skin faces in buildings can reduce the heat transmission as well as the electricity consumption of the air-conditioning system [12].

According to Yılmaz and Ferit [9] double skin faces has a great result on heat loss in buildings; heat loss through single skin face is 40% higher than double skin faces.

Hien et al. [11], in their simulation showed that double glazed faces with natural ventilation were efficient in minimizing energy consumption and enhancing the thermal comfort in spaces [11]. However, a double skin faces might not lead to major energy savings if it is distorted or not installed properly. On the other hand, based on experimental results on a double skin faces configuration, Saelens [13] finished off that transparent double-skin face in moderate climates are effective than single-skin face.

METHODOLOGY

The authors followed two research approaches to test the performance of multi-pane windows. A computational method was used to estimate the heat gain and loss by conduction from windows and a simulation method were used to examine the performance of windowpanes in terms of lighting and solar radiation.

Computational method.

This method was followed to compute the radiated and absorbed energy through the window glass layers. It deals with glass layers and the filled gaps between glass layers.

Multi-layered windows.

In multi-layered window, the energy of solar radiation that enters the window depends on the angle of incidence (θ) and the medium material as well as the thickness of the glass layer. Assuming the radiation energy incident on the plane of separation between media 1 and 2 with an angle of incidence θ_1 is U_1. Part of this energy will be reflected at the plane of separation, while the rest will be transmitted through the surface between media 1 and 2, see Figure 1. Where S_1, S_2, …, S_7 are the temperature of medium 1, 2, …, medium 7 consequently, θ_1, θ_2, …., θ_6, are the angle of incidence of the electromagnetic waves on medium 2, 3, …, medium 7 respectively.

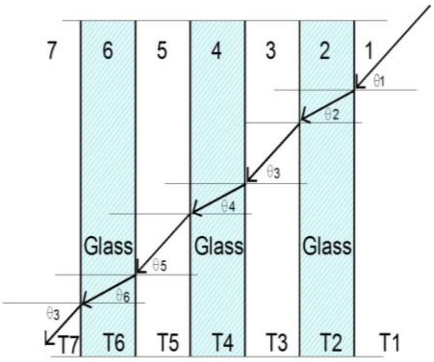


Figure 1: Multi-pane window with air and gas gaps

The incident, reflected, and transmitted electromagnetic wave lies in the same plane known as the plane of incidence; each electromagnetic wave consists of electric field is perpendicular to the magnetic field and these fields are perpendicular to the propagation direction of the electromagnetic wave itself. Upon this relation, the electric and magnetic fields each can be in general decomposed into two components, one is parallel to the plane of incidence, and the other is perpendicular to this plane. So they can be electric written as [14] :

$$\overrightarrow{E} = \overrightarrow{E_{||}} + \overrightarrow{E_{\perp}}$$

$$\overrightarrow{B} = \overrightarrow{B_{||}} + \overrightarrow{B_{\perp}}$$

Where

E :is the electric field of the electromagnetic wave.

B: is the magnetic field of the electromagnetic wave.

The electric field $\vec{E}$ and the magnetic field $\vec{B}$ lie in the same plane (wave front).

Φi indicates the angle between either the electric field or magnetic field and an axis parallel to both the plane of incidence and the interface (plane separating two different media).

Notice that the wave front makes an angle of α with the interface (angle of incidence).

$E_{||} = E\cos\Phi\text{i}$ and $E_{\perp} = E\sin\Phi\text{i}$, $B_{||} = B\sin\Phi\text{i}$ and $B_{\perp} = B\cos\Phi\text{i}$ (see Figure 2).

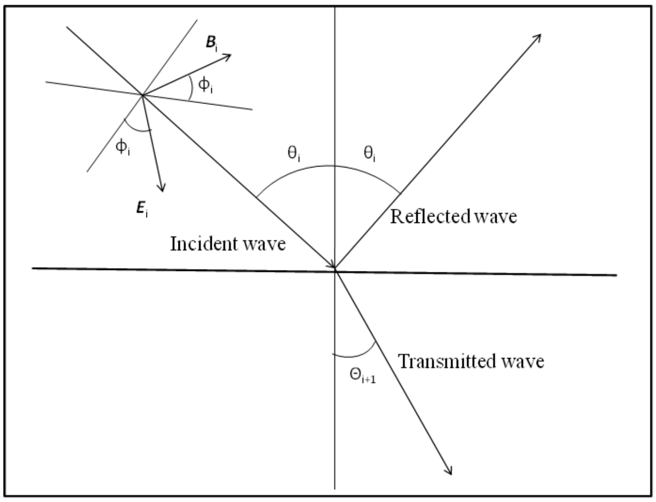


Figure 2: Analysis of the electrical and magnetic field

Because of that, the electromagnetic energy will have two parts, the first part comes from the parallel components of $\vec{E}$ and $\vec{B}$, and the second part comes from perpendicular components of $\vec{E}$ and $\vec{B}$ to the plane of incidence. Since the electromagnetic energy is proportional to E^2 and B^2, then the angle Φ has no effect at the end. So the total transmitted electromagnetic energy in medium 5 (double windowpane) and medium 7 (triple windowpane) is then the sum of the transmitted energy from the parallel and perpendicular components of the electric and magnetic fields.

$$U_{tot} = U_{\parallel} + U_{\perp}$$

U_{tot} is the total energy incident per meter squared per second and equal to 1340 j/m^2.s from the sun before entering any medium.

$$U_{\parallel} = {U_{tot}}/{2}$$

$$U_{\perp} = {U_{tot}}/{2}$$

Parallel Component.

The following equation is used for the parallel component:

$$(U_{\parallel})_5 = (T_{\parallel})_1 (T_{\parallel})_2 (T_{\parallel})_3 (T_{\parallel})_4 (U_{\parallel})_1 (1 - e_2 - e_3 - e_4 + e_2 e_3 + e_2 e_4 + e_3 e_4 - e_2 e_3 e_4)$$

$$(U_{\parallel})_5 = \prod_{i=1}^{4} (T_{\parallel})_i \; (U_{\parallel})_1 (1 - e_2 - e_3 - e_4 + e_2 e_3 + e_2 e_4 + e_3 e_4 - e_2 e_3 e_4) \qquad 1$$

$$\begin{aligned}(U_{\parallel})_7 = \prod_{i=1}^{6} (T_{\parallel})_i \; (U_{\parallel})_1 \Bigg(& 1 - \sum_{i=2}^{6} e_i + e_2 \sum_{i=3}^{6} e_i + e_3 \sum_{i=4}^{6} e_i + e_4 \sum_{i=5}^{6} e_i + e_5 e_6 - e_2 e_3 \sum_{i=4}^{6} e_i - e_2 e_4 \sum_{i=5}^{6} e_i - e_2 e_5 e_6 \\ & - e_3 e_4 e_5 - e_3 e_4 e_6 \\ & - e_3 e_5 e_6 - e_4 e_5 e_6 + e_2 e_3 e_4 e_5 + e_2 e_3 e_4 e_6 + e_2 e_3 e_5 e_6 + e_2 e_4 e_5 e_6 + e_3 e_4 e_5 e_6 - e_2 e_3 e_4 e_5 e_6 \Bigg)\end{aligned} \qquad 2$$

Where e_i is the absorbance or emissivity of ith layer, where *i* represents the air, glass, Argon, and xenon, which is almost zero, so the upper equation is reduced to the following for double pane window:

$$(U_{\parallel})_5 = \prod_{i=1}^{4} (T_{\parallel})_i \, (U_{\parallel})_1$$

The following equation will be for triple pane window:

$$(U_{\parallel})_7 = \prod_{i=1}^{6} (T_{\parallel})_i (U_{\parallel})_1$$

Where : $(T_{\parallel})_i$ is the transmittance (ratio of passing energy to the incident energy) of ith layer produced from the parallel components of the electric field.
And for triple window pane the following equations is used:

Perpendicular component.

The same derivation used for the double windowpane with using $(T_{\perp})_i$, so for double windowpane the following equation is used:

$$\begin{aligned}(U_{\perp})_5 = \prod_{i=1}^{4} (T_{\perp})_i \; (U_{\perp})_1 (1 - e_2 - e_3 - e_4 + e_2 e_3 + e_2 e_4 \\ + e_3 e_4 - e_2 e_3 e_4)\end{aligned}$$

For $e_i = 0$, the equation can be written as follows for double pane windows:

$$(U_{\perp})_5 = \prod_{i=1}^{4} (T_{\perp})_i \; (U_{\perp})_1$$

$$(U_\perp)_7 = \prod_{i=1}^{6}(T_\perp)_i\ (U_\perp)_1 \Bigg(1 - \sum_{i=2}^{6} e_i + e_2 \sum_{i=3}^{6} e_i + e_3 \sum_{i=4}^{6} e_i + e_4 \sum_{i=5}^{6} e_i + e_5 e_6 - e_2 e_3 \sum_{i=4}^{6} e_i - e_2 e_4 \sum_{i=5}^{6} e_i - e_2 e_5 e_6 \\ - e_3 e_4 e_5 - e_3 e_4 e_6 \\ - e_3 e_5 e_6 - e_4 e_5 e_6 + e_2 e_3 e_4 e_5 + e_2 e_3 e_4 e_6 + e_2 e_3 e_5 e_6 + e_2 e_4 e_5 e_6 + e_3 e_4 e_5 e_6 - e_2 e_3 e_4 e_5 e_6\Bigg) \qquad 3$$

For emissivity $e_i = 0$, the above equation is reduced to the following:

$$(U_\perp)_7 = \prod_{i=1}^{6}(T_\perp)_i\ (U_\perp)_1$$

Where: $(T_\perp)_i$ is the transmittance (ratio of passing energy to the incident energy) of ith layer produced from the perpendicular components of the electric field.

The total fraction of transmitted energy is the sum of the parallel and perpendicular components.

$$U_7 = (U_\parallel)_7 + (U_\perp)_7$$

Where: $(U_\parallel)_7$ and $(U_\perp)_7$ are given by equations 2, and 3 respectively.

The transmittance of the ith layer of the parallel component is given by the following equation:

$$(T_\parallel)_i = \frac{4 Z_i Z_{i+1} \cos\theta_i \cos\theta_{i+1}}{(Z_i \cos\theta_i + Z_{i+1}\cos\theta_{i+1})^2}$$

And the transmittance of the ith layer of the perpendicular component is given by.

$$(T_\perp)_i = \frac{4 Z_i Z_{i+1} \cos\theta_i \cos\theta_{i+1}}{(Z_{i+1} \cos\theta_i + Z_i\cos\theta_{i+1})^2}$$

Where:

$$Z_i = \sqrt{\frac{\mu_i}{\epsilon_i}}$$

Z_i: *is the optical impedance of the ith medium.*

μ_i: *is the permeability of the ith medium.*

ϵ_i: *is the permitivity of the ith medium.*

And

$$\frac{Z_i}{Z_{i+1}} = \left(\frac{\mu_i}{\mu_{i+1}}\right)\frac{n_{i+1}}{n_i}$$

n_i : *the refractive index of the ith medium.*

The total transmitted energy is the sum of the fractions of parallel and perpendicular components of the incident light passing through the windowpanes.

Thermal conductivity. The thermal energy flow rate of a material of thickness *L,* area *A,* and thermal conductivity *k* is given by the following equation:

$$P = \frac{kA(T_h - T_c)}{L}$$

Where:

k: The thermal conductivity of material measured in $\frac{W}{m\cdot K}$

A: The surface area of the material in m^2.

T$_c$: Outside temperature.

T$_h$: Inside temperature, $T_h > T_c$.

L: Thickness of the material.

The thermal resistance of the material (R) as shown in Figure 3 is defined by

$$R = \frac{L}{k}$$

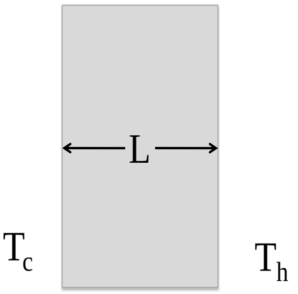


Figure 3: material layer with thickness L.

For multi layers of the same area A, the thermal energy flow rate (Figure 4) is given by the following:

$$P = \frac{A(T_h - T_c)}{\sum_{i=1}^{n}\frac{L_i}{k_i}}$$

k_i: The thermal conductivity of *ith* layer measured in $\frac{W}{m\cdot K}$

A: The area of each layer in m^2.

T_c: Outside temperature.

T_h: Inside temperature, $T_h > T_c$.

L_i: The thickness of *ith* layer.

The thermal resistance of *ith* layer is given by the following equation:

$$R_i = \frac{L_i}{k_i}$$

Accordingly, the total resistance of *nth* layers is given by:

$$R_T = \sum_{i=1}^{n} R_i$$

Based on that the total energy flow rate from interior to exterior can be written as

$$P = \frac{A(T_h - T_c)}{R_T}$$

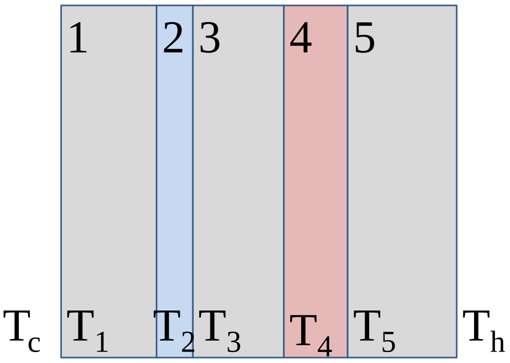


Figure 4: Multi- layer window with external temperature T_c and internal temperature T_h.

Simulation conditions.

In addition to the computational method, The well-known computer software for lighting analyses (RADIANCE) was used to measure the daylight in spaces for different cases of windowpanes. to explore the effect of window layers on the attenuation of solar radiation in architectural spaces.

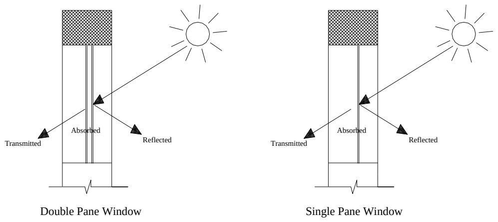


Figure 5: Window types used in the simulation

A typical office was used to measure the daylight levels with different numbers of windowpanes. The office was 6 m by 4 m in plan with a 3 m ceiling height. Only one window and one door were assumed in this office. The reflectance factor of the internal walls was assumed to be zero so that only the direct illuminance level was considered in the lighting measurements. Five lighting sensors were placed at the midline linking the window with the opposite wall with one meter apart. The distance

Figure 5: Window types used in the simulation between the window and the first sensor is1.5 m, (see figure 5).

The window panes were assumed to be made of glass with thickness of 8mm all air gaps were assumed to be 6 mm.

To test the conductivity of the window layers, two inert gases (xenon, argon) were used to fill the gaps between the glass layers. These gases are assumed to decrease the heat transfer coefficient (U-value) of the combination of glass layers with the gas-filled layers.

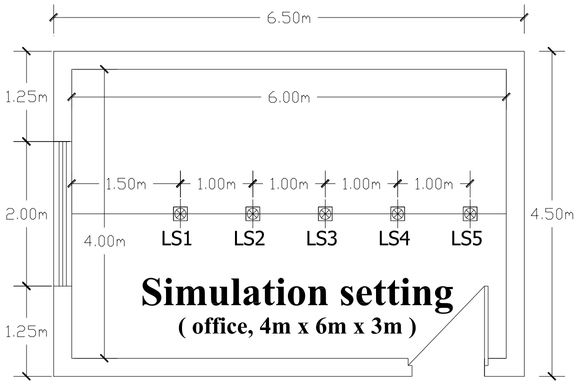


Figure 6: A plan for a typical office plan used for the simulation setting

RESULTS AND DISCUSSIONS

The analyses were conducted for solar energy and lighting in spaces to find the optimal number of glass panes on a window that prevents heat loss by conduction without affecting the solar heat gain in winter by radiation.

Solar heat gain by radiation.

The results show that the integration between lighting, heat loss, and solar radiation for multilayered windows is achievable. Installing triple panes in windows is not an optimal solution if the value of illuminance and the loss of solar radiation in buildings are considered. A high number of glass layers was not found to be efficient because it decreases the light levels and the amount of solar radiation which contributes positively to heating loads in winter. In the case of double pane windows, the illuminance level is decreased by 20% compared to the base case of a single layer. As this loss of light level is associated with the solar radiation, it is important to investigate the loss of radiation and how much heat loss happens by conduction for each combination of window layers.

The solar energy in space per second through a square meter window by radiation is estimated for single, double, and triple pane windows, and for filling gases of air, Argon, and Xenon in the spaces between glass panes. The angle of incidence is important in determining the amount of radiation. As the angle of incidence increases, the amount of heat gain by radiation drastically decreases. Figure 7 shows a plot of the solar power versus the angle of incidence for Xenon filling for single, double, and triple layers.

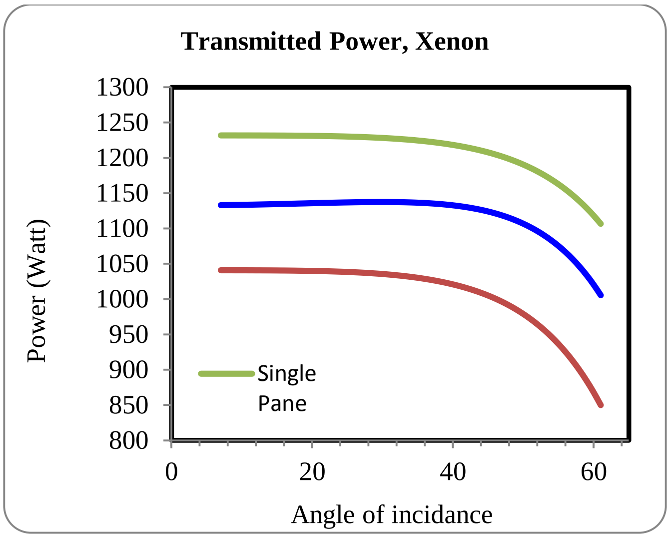


Figure 7: Transmitted power vs. the angle of incidence for Xenon Filling Gas.

The amount of solar heat gain by radiation is different for each case of window panes, it is the lowest in case of triple pane window with xenon filling gas. Figure 8 is a plot of the differences of solar heat gain by radiation between single layer and double layer, single layer and triple layer, and double layer and triple layer in the case of Xenon filling. As the angle of incidence increases, the difference also increases; for example, at angle zero, the difference between single and double pane is about 190 watts; it increases to become 250 at angle 60° (see Figure 8).

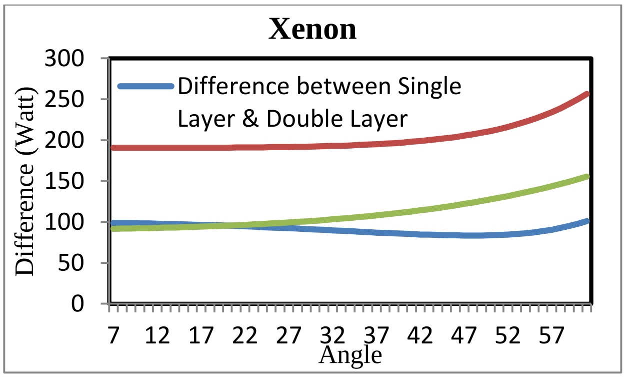


Figure 8: Difference in Transmittance between Single Layer & Double Layer

The transmitted solar power from window layers also depends on the angle of incidence and the number of glass layers as well as the filling gas between the glass panes. Changing the glass layers will increase or decrease the percentage of transmitted solar power in the architectural space. For example, changing from single to triple decreases the transmitted solar power in spaces at incident angle 60° to 23 percent.

Changing from double to triple glass layers decreases the solar power at incident angle of 60° to 14 percent. Figure 9 shows a plot of the percent ratio single to double, single to triple, and double to triple in case of Xenon as filling gas between the glass layers.

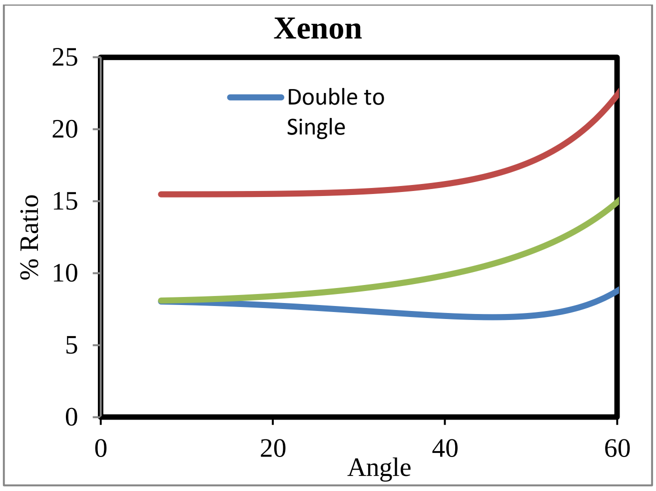


Figure 9: The Ratio of Transmitted Power

The analyses also show that the type of filling gas between the glass panes does not make big difference. The air, argon, and xenon almost have the same transmittance value. Figure 10 shows a comparison of the transmitted power (Watts) from the 1.2 m^2 tested window with double panes for filling gas of Air, Argon, and Xenon. The graph shows the transmittance for angles from 7° up to 40° and the difference in transmitted power of the three filling gases. As shown in the figure, Xenon has the highest transmittance at angle of incidence 30°.

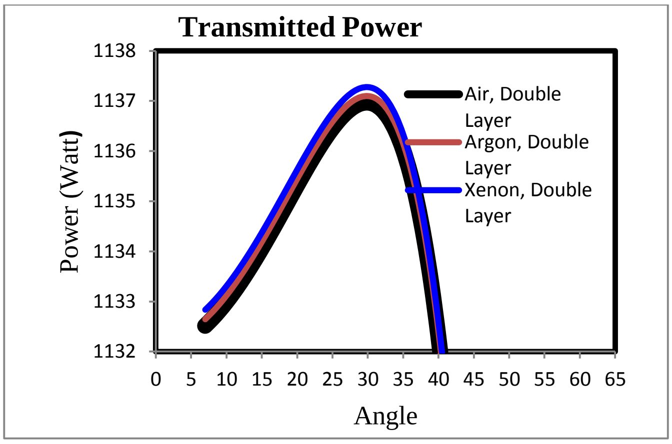


Figure 10: The Transmitted Power for Air, Argon, and Xenon as filling gases in case of double layer.

The amount of energy entering through a one square meter window by radiation per 10 hours/ day for angle of incident running from 7° up to 61° are shown in Table 1 in units of Mega Joule (MJ). While Table 2 shows the change in energy from single pane to double pane, single pane to triple, and double pane to triple pane windows.

Table 1: The Average Energy for 10 hours day light entering by radiation.

Average Energy (MJ)			
Filled Gas	**Single Layer**	**Double Layer**	**Triple Layer**
Air	43.52	40.23	36.22
Argon	43.52	40.24	36.23
Xenon	43.52	40.25	36.23

Table 2: The change in average solar radiation energy from single, double, and triple.

Change in Energy (MJ)			
Filled Gas	**Single to Double**	**Single to Triple**	**Double to Triple**
Air	3.29	7.30	4.01
Argon	3.28	7.29	4.01
Xenon	3.28	7.29	4.02

Heat loss by conduction.

The heat loss by conduction per square meter per second was calculated using the following equation:

$$P = \frac{A(T_i - T_o)}{\sum_{i=1}^{n} \frac{L_i}{k_i}}$$

Where:

P: The heat loss

A: Area of window

T_i: Inside temperature

T_o: Outside temperature

L_i: The thickness of ith window layer

K_i: The conductivity of ith layer

The equation was used for single, double, and triple pane windows with filling gases of air, Argon, and Xenon. Also the amount of heat loss from inside to outside per day from a the tested window was calculated and averaged for temperature difference between inside and outside running from 0 up to 25 Kelvin. Each glass pane has a thickness of 8 mm while the thickness of each filling space is 6 mm.

Figures 11 shows the relation between the heat losses by conduction in watts (W) of single, double, and triple panes filled with argon with the temperature difference.

It is apparent that double and triple layer window is much effective in preventing the heat loss compared to that of single layer. However, the difference in heat loss between double and triple layers is not considerable; for example, at temperature difference 25 C°, the difference in heat loss is about 25 watts/m^2; while the difference in solar heat by radiation between double and triple window is 100 watts/m^2. Accordingly, it is not good to use triple pane windows in winter because the solar radiation loss is higher than the saved heat by conduction when using triple panes.

The type of filling gas is very important in determining the heat loss; the best filling gas is xenon. Figure 12 is a comparison of the heat loss from double layer window between Air, Argon, and Xenon filling gases. As noticed in this figure, the lowest heat loss at all degrees of temperature difference happens when the filling gas is xenon and ranges from zero to 20 watts/m^2.

The total energy consumption for all temperature difference between 0 and 25 C° is shown in Table 3. It is the amount of heat loss through a one square meter window in case of single, double, and triple panes filled with argon, xenon, and natural air between the glass panes. It is clear that xenon is the best in heat insulation for double and triple layers; the total amount of heat loss in case of xenon is 0.98 MJ compared to 3.04 MJ and 4.4 MJ for argon and natural air respectively. The drastic drop in heat loss happens in changing from single layer to double and triple layers. The heat loss in single layer windows is 129.6 MJ; it drops to 0.98 MJ in case of double layers with xenon, and 0.49 in case of triple layers with xenon, see Table 3.

Table 4 shows the difference in heat loss for the same window by conduction for single, double, and triple panes for natural air, argon, and xenon. For example, changing from single to triple panes leads to energy savings of 127.36 MJ when natural gas filled between the glass panes. This savings is increased to 129.11 MJ in case of using xenon as filling gas between the glass panes. However, changing from double layers to triple layers does not lead to considerable energy saving by conduction. Therefore, using triple layers is not efficient because it reduces the solar radiation for heating and has almost the same thermal resistance as double layers, see Table 4.

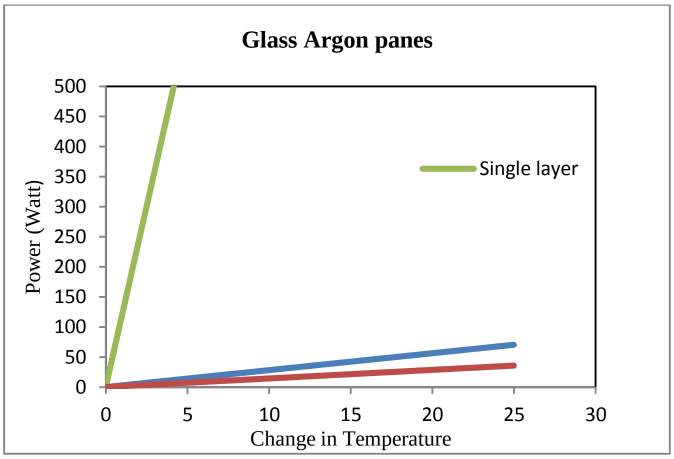


Figure 11: Heat loss by conduction for single, double, and triple pane with argon filling gas per square meter.

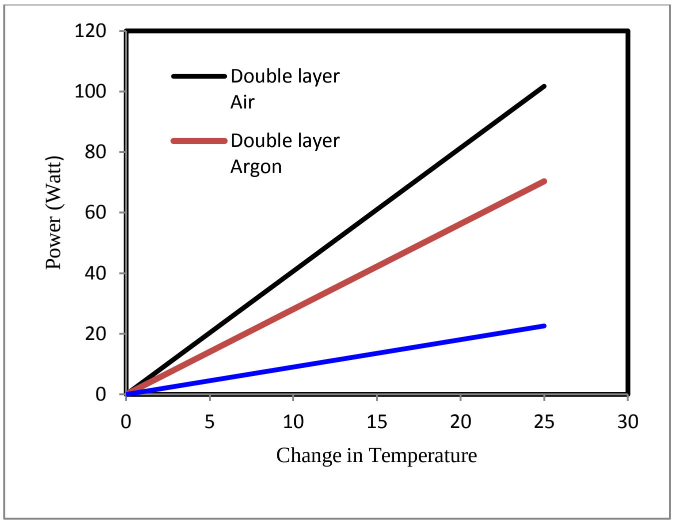


Figure 12: Power lost by conductivity for double layer of, Air, Argon, and Xenon

Table 3: The daily Average Energy for 24 hours leaving by conduction.

Average Energy (MJ)			
Filled Gas	**Single Layer**	**Double Layer**	**Triple Layer**
Air	129.60	4.40	2.24
Argon	129.60	3.04	1.54
Xenon	129.60	0.98	0.49

Table 4: The change in average energy from single, double, and triple.

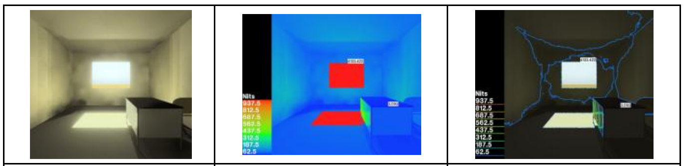
Change in Energy (MJ)			
Filled Gas	**Single to Double**	**Single to Triple**	**Double to Triple**
Air	125.20	127.36	2.16
Argon	126.56	128.06	1.50
Xenon	128.62	129.11	0.49

In summary, there is large amount of energy lost by conduction through a one square meter window in the case of single layer. The difference in energy saving between single layer and double layer as shown in Table 4 is high, but the difference between the energy saving between double layer and triple layer is not high. The average energy saved when flipping from single to double is about 125.2 MJ while the amount saved from single to triple is about 127.36 MJ. This shows that the third layer saved only 2.16 MJ. However, the lost in solar radiation due to the third layer is about 4.1 MJ (see Table 2). .

A comparison between the average energy gained by radiation and the average energy lost by conduction, suggests that it is better to adopt two glass layers instead of three layers. Accordingly, it is recommended to use double layer windows which have very little difference from triple layer, while the cost triple layer windows would be greater than double layer.

Lighting results.

The lighting analyses were conducted using the RADIANCE software. The analyses included illuminance levels at different distances for different glass layers; single, double, and triple, (Figure 13).

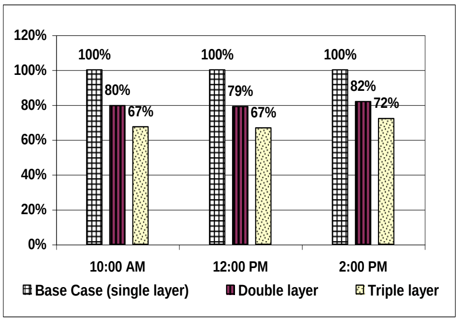


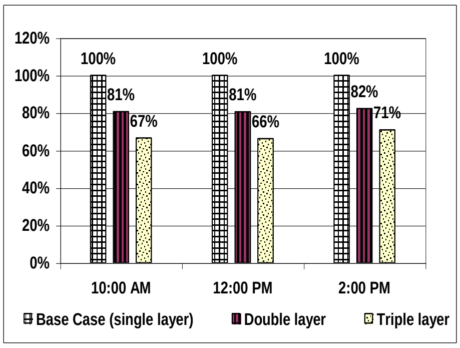
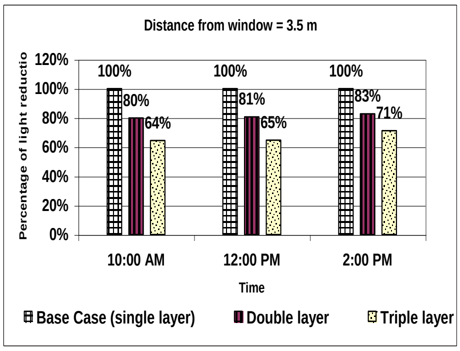
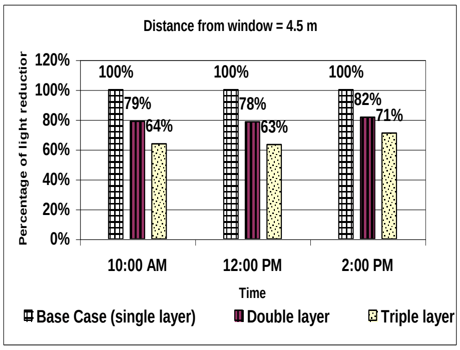
a) Normal | **b) False colour** | **c) Iso contour**

Figure 13: analyses of lighting distribution in the studied office conducted by Radiance software.

Compared to the results in heating and radiation, the illuminance level is not highly affected by adding more layers to the windows. Using a single layer window as a base case, the reduction in light levels ranges from 20% in case of double layers to 37% in case of triple layer window. For example, at a distance of 4.5 meters from the window, the illuminance level at 12 pm decreases to 80% in case of double layers and 63% in case of triple layers, see Table 5.

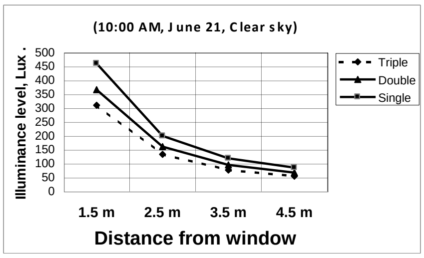
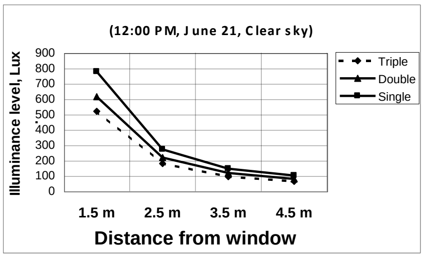
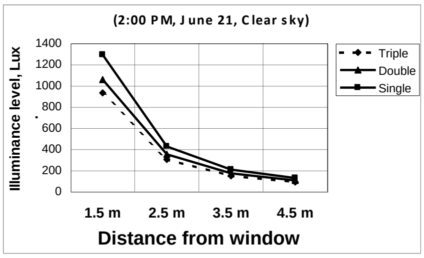
Table 5: Reduction in illuminance levels with respect to the number of windowpanes

Distance from window	Illustration
1.5 m	

2.5 m	
3.5 m	
4.5 m	

The illuminance level for all combinations glass panes were also measured; at a distance of 1.5 meters from the window at 12 pm, the illuminance level was 800 lux for single layer, 360 lux for double layer, and 310 for triple layer. The largest drop appears in changing from single to double; while changing from double layers to triple layers result in a reduction of light of less than 12%, (see Table 6).

Table 6: Illuminance levels with respect to the number of windowpanes

Description	Simulation graph
-Time: 10 am -Date: June 21 -City : Irbid -Latitude: 32° N -Longitude: 36° E	
-Time: 12 pm -Date: June 21 -City: Irbid -Latitude: 32° N -Longitude: 36° E	
-Time: 2 pm -Date: June 21 -City: Irbid -Latitude: 32° N -Longitude: 36° E	

CONCLUSIONS

As shown in the above results, the number of window panes used in severe weather areas should be well studied. As some architectural designers think that adding window panes to the window has no limit, it is shown by this study that adding a third layer to the window decrease the solar radiation significantly. This decrease contributes negatively to heating loads in winter especially in cold climate regions like Northern Europe and North America.

The benefit from adding more layers to the window to prevent heat loss by conduction is much less than the solar radiation loss due to the unneeded glass layers.

It is important to optimize the number of window layers in architectural design and specify the exact number of window glass layers based on the weather conditions.

Designers should calculate the window glass layers based on the climatic conditions and the temperature difference between outside and inside.

In this study the temperature difference ranges from 10 to 25 degrees Celsius; this indicates that the optimal number of window glass panes is two layers. The third layers in this study will decrease considerably the solar heat gain in winter despite the little benefit from preventing the heat loss by conduction.

Transmittance of radiation entering the window is a function of angle of incidence, Xenon has the highest transmittance between other filling gases for double and triple layer because Xenon has the lowest optical impedance. The difference in transmittance between single layer and double layer, single layer and triple layer, and double layer and triple layer is not constant instead the difference starts rising for angles greater than 40° as shown in figure 2 for all filling gases which means the difference is a function of the angle of incidence.

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