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# Empirical Validation of Parameter Studies on Heat Transfer through Glazing System Using Window 6.3 Software

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**ABSTRACT**
Heat transfer through different modes from outside environment to inside occur by conduction, convection and thermal radiation. Inclusion of automatic-advance-generation-software; 'WINDOW 6.3' makes possible the detailed true picture of the impact of glazed material & its thickness/ pane spacing on its Thermal Transmittance. This software makes the user understand the thermal performance of glazing system without extensive knowledge of numerical methods of heat transfer. The U-value and solar heat gain coefficient are the key parameters to analyze heat transfer through window. However in the absence of solar radiations U-values is the only trigger. Therefore, an attempt has been made to carry out the study to calculate the U-value for different glazing systems with varying thickness/pane spacing in prevailing seasons. Composite climate of Chandigarh persisting in different season is considered for the study. The U-value obtained from simulation is validated using the guarded hot plate apparatus. After through analysis and even considering the economical effects, the authors recommended Double Glazed window with 25mm pane spacing to be perfectly used in Chandigarh region.

## I. Introduction

Heat transfer through a single/double – Glazed Window take place through three modes of heat transfer i.e. conduction, convection and radiation. Conduction occurs in window panes and convection in fluid and radiation through electromagnetic waves. Hence convection/radiation occurs in cavity and at the indoor and outdoor faces of window [1].

Window with both good looks and desired control for heat flow requires a thorough understanding of mechanism of how glass responds to solar gain and thereafter measures needs to be taken to control that heat transfer. Normal clear glass is almost transparent to high frequency solar radiation, but is a difficult to low frequency or long wave radiation [2]. The solar heat energy passing through the glazing warms up the various surrounding surface by absorption and these surrounding surface then become heat radiators of low frequency re-emitted heat which is trapped inside causing the temperature to rise. Hence ASHRAE devised method for determining heat transfer through window and presently in order to calculate the U-value & solar heat gain coefficient through windows [3].

In the developed countries, windows with glazing system or double glazed windows are used where as in India single glazed windows are used. These are being used since a long ago without proper investigation of their U-Value, SHGC (Solar Heat Gain Coefficient). Till now not much investigation has done in this field. Hence in the present investigation a single glazed and double glazed window with different pane-pane spacing is being considered.

## II. Software And Simulation

### 2.1 Software

The Window 6.3 software is used, for simulating the heat transfer through glazed windows. This software is publicly available LBNL WINDOW IBM PC compatible computer program, which is developed by the building technologies group at the Lawrence Berkeley Laboratory. It is helpful in calculating the thermal and optical properties compulsory for heat transfer analyses of fenestration products. WINDOW 6.3 is the latest in a series of programs released by the Lawrence Berkeley Laboratory, in which the new products with measured thermal and optical properties can also be added to the software database. Main parametric changes can be made in this software while modelling geometrical models of different glazing systems. The parameters which can be altered include spacing between different layers, type of glazing, environmental conditions, fluid in between the panes and so many more. Thus using different input parameters, results of various output parameters such as SHGC, U-value, $K_{eff}$, (Effective thermal conductivity) etc. can be determined. All the calculations procedures for determining various responses are available at LBNL website [4]

**2.2 Simulation**

The simulated study is intended on the basis of one factor approach to take account of the effect of control factors on response factor. The glass panes of size 635 x 635 x 3mm are selected for conducting simulation-runs for various glazing systems. A range of levels of different input simulation factors is considered as in table1.

**Table- 1:** Control Parameters

| Levels | Control Parameters | | |
|---|---|---|---|
| | Glazing Type | Pane-Pane Spacing (mm) | Climatic Conditions |
| 1 | Single | 10 | Hot-Dry |
| 2 | Double | 13 | Hot-Humid |
| 3 | | 16 | Cold-Dry |
| 4 | | 19 | |
| 5 | | 25 | |

The single response parameter U-value is measured. The full factorial approach consists of a design of total 18 experiments, as shown in table 2.

**Table 2:** Design of Experiments

| Level | Glazing | Spacing | Climate |
|---|---|---|---|
| 1 | A1 | B1 | C1 |
| 2 | A1 | B1 | C2 |
| 3 | A1 | B1 | C3 |
| 4 | A2 | B2 | C1 |
| 5 | A2 | B2 | C2 |
| 6 | A2 | B2 | C3 |
| 7 | A3 | B3 | C1 |
| 8 | A3 | B3 | C2 |
| 9 | A3 | B3 | C3 |
| 10 | A4 | B4 | C1 |
| 11 | A4 | B4 | C2 |
| 12 | A4 | B4 | C3 |
| 13 | A5 | B5 | C1 |
| 14 | A5 | B5 | C2 |
| 15 | A5 | B5 | C3 |
| 16 | A6 | B6 | C1 |
| 17 | A6 | B6 | C2 |
| 18 | A6 | B6 | C3 |

For simulation heat transfer through the chosen configuration along with the input parameters having values consequent to composite-climatic zone of India is used. Averaged wind-speed and solar radiation are obtained from the internet [5] to feed inputs to the software. The inner room temperature[6] is kept at the design conditions according to Indian climate [7]. For convectional heat transfer, ASHRAE/NFRC model and Windward Directional model are selected through the software. Both the effective sky emissivity and the effective room emissivity are assumed to be equal to 1.

The glazing systems are used to reduce the effect of U-Value. The glazing units can be categorized into single or multiple glazing layers (often known as Insulating Glazing Units IGUs) are double glazing, triple glazing, and quadruple glazing. For the present investigation, a single glazed and double glazed window with clear glass 3 mm thick is selected for the analysis of U-value [8].The selected glazing system is as below table 3.

**Table 3:** Description of selected glazing library

| S. No | Type of Glazing System | Layers | | |
|---|---|---|---|---|
| | | Layer 1 | Layer 2 | Layer 3 |
| 1. | Single | 3mm glass | | |
| 2. | Double | 3mm glass | 10mm air gap | 3mm glass |
| 3. | Double | 3mm glass | 13mm air gap | 3mm glass |
| 4. | Double | 3mm glass | 16mm air gap | 3mm glass |
| 5. | Double | 3mm glass | 19mm air gap | 3mm glass |
| 6. | Double | 3mm glass | 25mm air gap | 3mm glass |

The various solar and optical properties of clear glass are given in table 4.

**Table-4:** Solar and optical properties of glass

| Description → | | Glass |
|---|---|---|
| Solar | Trans, Front ($T_{sol}$) | 0.83 |
| | Trans, Back ($T_{sol}^2$) | 0.83 |
| | Reflection Front ($R_{sol}$) | 0.08 |
| | Reflection Back ($R_{sol}^2$) | 0.08 |
| Visible | Trans, Front ($T_{vis}$) | 0.9 |
| | Trans, Back ($T_{vis}^2$) | 0.9 |
| | Reflection Front ($R_{vis}$) | 0.08 |
| | Reflection Back ($R_{vis}$) | 0.08 |
| IR | Emis, Front (Emis1) | 0.84 |
| | Emis, Back (Emis2) | 0.84 |

The software gives freedom to select the fluid between the pane .It has the eight types of fluid:
i) Air ii) Argon iii) Krypton iv) Xeon v) Air 5% and Argon 95% vi) Air 12%, Argon 22% and Krypton 66% mix vii) Air 5% and Krypton 95% mix viii) Air 10% and Argon 90% mix.

For the present investigation air is considered .The properties of air at standard temperature and pressure is given in the below table 5.

**Table- 5:** Properties of air

| Name | Air |
|---|---|
| Type | Pure |
| Conductivity W/m-k | 0.024069 |
| Viscosity Ns/$m^2$ | 0.00017 |
| Cp J/kg-K | 1006.103271 |
| Density Kg/m3 | 1.292171 |
| Prandtl | 0.7197 |

**Table-6:** Full factorial design for evaluating U-value

| S. No | Glazing Type | Spacing (mm) | Climate | Experimental U-value | Simulated U-Value |
|---|---|---|---|---|---|
| 1 | Single | | Hot-Dry | 5.62 | 6.46 |
| 2 | Double | 10 | Hot – Dry | 2.98 | 3.35 |
| 3 | Double | 13 | Hot-Dry | 2.68 | 3.20 |
| 4 | Double | 16 | Hot – Dry | 2.87 | 3.13 |
| 5 | Double | 19 | Hot – Dry | 2.86 | 3.08 |
| 6 | Double | 25 | Hot-Dry | 2.73 | 3.07 |
| 7 | Single | | Hot – Humid | 5.11 | 5.88 |
| 8 | Double | 10 | Hot – Humid | 2.8 | 3.15 |
| 9 | Double | 13 | Hot-Humid | 2.68 | 3.02 |
| 10 | Double | 16 | Hot – Humid | 2.7 | 2.94 |
| 11 | Double | 19 | Hot-Humid | 2.67 | 2.88 |
| 12 | Double | 25 | Hot-Humid | 2.5 | 2.82 |
| 13 | Single | | Cold-Dry | 5.06 | 5.82 |
| 14 | Double | 10 | Cold - Dry | 2.59 | 2.92 |
| 15 | Double | 13 | Cold-Dry | 2.48 | 2.79 |
| 16 | Double | 16 | Cold - Dry | 2.53 | 2.75 |
| 17 | Double | 19 | Cold-Dry | 2.53 | 2.73 |
| 18 | Double | 25 | Cold-Dry | 2.44 | 2.75 |

## III. EXPERIMENTAL SET UP

The apparatus consists of primarily two copper plate's (i.e. hot copper plate, cold copper plate) water bath, copper tubes, temperature indicators of the bath, rota-meter, heaters i.e. main and guard heaters, glazing system, power supply system and other accessories. This apparatus is similar to the apparatus used by Wright and Sullivan [9]. The size of two copper plates (hot plate and cold plate) is 635x635x12.5 mm each. The plates are placed in such a arrangement so that they keep facing each other and can be maintained at constant temperatures. Both plates are held at required constant temperature by a circulating a steady flow mixture of water and glycol through a manifold of tubes attached at the back of the copper plates. The warm copper plate contains three guarded heater plates, in the vertical position at equal distance. The heat transfer that takes place over the face of each of the guarded heater can be measured. The adjustment of the electrical power supplied to the heater plate is made until zero temperature difference is achieved between the heater plate and the warm copper plate. At this position, there will be no heat transfer between the heater and the warm copper plate and all the electrical energy supplied is transferred across the gap the cold copper plate. The constant temperature baths which feed the two copper plates can be started.

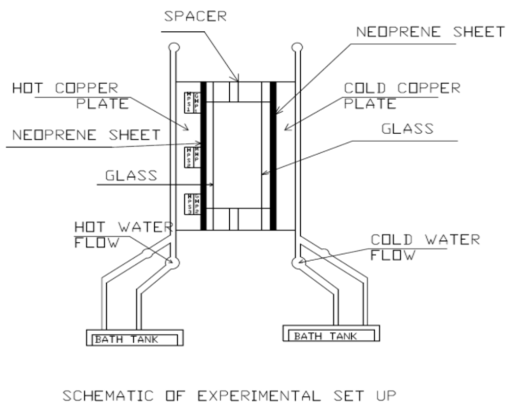


**Fig-1:** Schematic of experiment set up

### 3.1 Methodology:

The outer pane and inner pane temperature difference from simulated study is considered for temperature difference of hot and cold plate in the guarded hot plate apparatus. The sample is sandwiched between the hot and cold plates to determine its U-Value. The measuring methodology [9] used is discussed below:

For measuring the heat flux from the exposed surface of a GHP, the rate of electrical energy supplied to the heater plate Q, is determined by measuring the heater wire voltage V and current I, directly by using a digital volt meter and an ammeter.

$$Q = I * V \qquad \text{--------------- (i)}$$

The heat flux from the face of heater plate, P is then calculated by using heat flux meter output voltage, v as:

$$\mathrm{P} = (\mathrm{Q} - \mathrm{a.v})/\mathrm{Ahp} \qquad \text{--------------- (ii)}$$

Where a = heat flux meter calibration constant
$A_{hp}$ = Face area of the heater plate

After the heat flux, has been measured; the glass to glass C-value of the glazing system, can be measured as:

$$\mathrm{C} = ((\Delta \mathrm{T}/\mathrm{P}) - 2\mathrm{Rn})^{-1} \qquad \text{------------ (iii)}$$

Where ΔT = temperature difference between the warm and cold copper plate
And Rn = thermal resistance of neoprene sheet = $0.017 m^2$ C/W

The U- value based on the above measurements can finally be find out as:

$$\mathrm{U} = (C^{-1} + h1^{-1} + h2^{-1})^{-1} \qquad \text{.........(iv)}$$

Where h1= indoor heat transfer coefficient
h2= Outdoor heat transfer coefficient

In this investigation the extreme climate & temperature condition of Chandigarh, India has been considered as shown in table 7.

**Table -7:** Composite climatic condition

| Climate Condition | Composite Climate Condition | | | |
|---|---|---|---|---|
| | Tout ($^{o}$C) | Tin ($^{o}$C) | Solar radiation $W/m^2$ | Wind speed m/s |
| Hot- Dry | 43.0 | 25.0 | 6570 | 4.815 |
| Hot-Humid | 34.0 | 25.0 | 5470.0 | 4.02 |
| Cool-Dry | 5.0 | 25.0 | 3948.0 | 3.95 |

The effect influence of different parameters viz. type glazing system (single glazing, double glazing), pane-pane spacing and climatic conditions (Hot-Dry, Hot-Humid, Cold-Dry) is investigated. Observations according to full factorial design are made by keeping one parameter fix and varying the rest parameters one by one. Both the simulated and experimental response values for the planned design are shown in the table 8.

## IV. 4. Results

### 4.1 Comparison of experimental and simulated U-Values

**Table-8:** Simulated and Experimental U-Values

| S.N | Glazing Type | Spacing (mm) | Climate | Experimental U-value | Simulated U-Value |
|---|---|---|---|---|---|
| 1 | Single | | Hot - Dry | 5.62 | 6.46 |
| 2 | Double | 10 | Hot - Dry | 2.98 | 3.35 |
| 3 | Double | 13 | Hot - Dry | 2.73 | 3.20 |
| 4 | Double | 16 | Hot-Dry | 2.87 | 3.13 |
| 5 | Double | 19 | Hot-Dry | 2.86 | 3.08 |
| 6 | Double | 25 | Hot-Dry | 2.68 | 3.07 |
| 7 | Single | | Hot-Humid | 5.11 | 5.88 |
| 8 | Double | 10 | Hot-Humid | 2.8 | 3.15 |
| 9 | Double | 13 | Hot-Humid | 2.68 | 3.02 |
| 10 | Double | 16 | Hot-Humid | 2.7 | 2.94 |
| 11 | Double | 19 | Hot-Humid | 2.67 | 2.88 |
| 12 | Double | 25 | Hot-Humid | 2.5 | 2.82 |
| 13 | Single | | Cold-Dry | 5.06 | 5.82 |
| 14 | Double | 10 | Cold-Dry | 2.59 | 2.92 |
| 15 | Double | 13 | Cold-Dry | 2.48 | 2.79 |
| 16 | Double | 16 | Cold-Dry | 2.53 | 2.75 |
| 17 | Double | 19 | Cold-Dry | 2.53 | 2.73 |
| 18 | Double | 25 | Cold-Dry | 2.44 | 2.75 |

A perusal of data represented in the Table 8 shows the significant variation in the simulated software U- value due to all the three factors i.e. season, type of glazing system and pane-pane spacing (for Double glazed windows). Highest U–value is observed in single glazed window having 6.46 $W/m^2K$ in Hot-Dry season while the lowest U–value is 2.68

$W/m^2K$ in the double glazed window having 19 mm pane-pane spacing

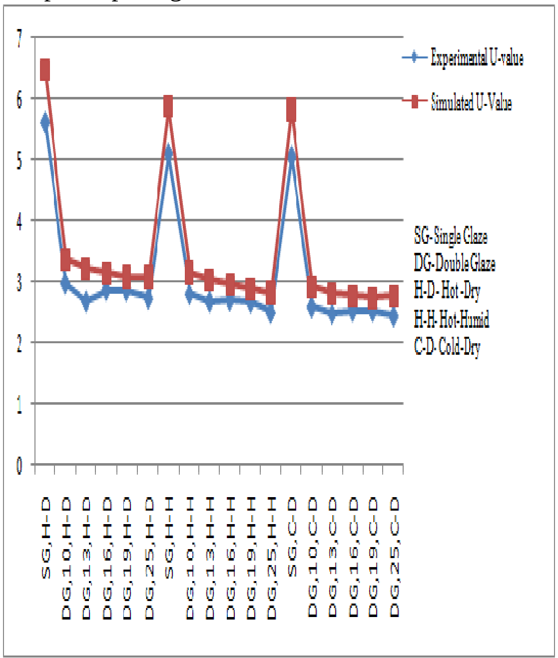


**Fig: 2** Graphical representation of Experimental and Simulated U-Value

### 4.2 The effect of spacing

It has been investigated the effect of changing pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm the U-value decreases for all climatic conditions (Hot-Dry, Hot-Humid, Cold-Dry) at different levels, whose results are listed as under:

Case1: The U-Value decreases by a minimum of 10% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Hot-Dry Conditions for double glazing system.

Case2: The U-Value decreases by a minimum of 11% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Hot-Humid Conditions for double glazing system.

Case3: The U-Value decreases by a minimum of 6% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Cold -Dry Conditions for double glazing system.

The result are similar Collins(1999) [10]

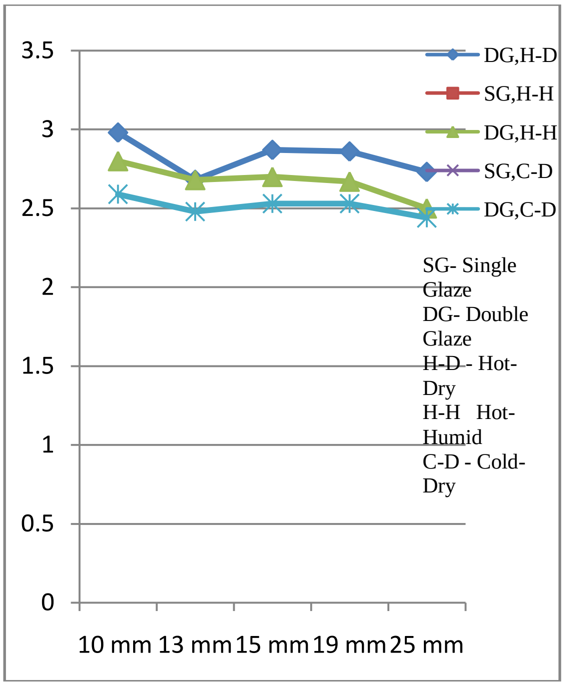


**Fig: 3** Graphical representation of the effect of Pane-Pane Spacing

### 4.3 The effect of climate

It has been observed that by changing pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm the U-value decreases for all climatic conditions (Hot-Dry, Hot-Humid, Cold-Dry) at different levels, whose results are listed as under:

Case1: The U-Value decreases by a minimum of 0.001% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Hot-Dry Conditions for double glazing system.

Case2: The U-Value decreases by a minimum of 0.001% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Hot-Humid Conditions for double glazing system.

Case3: The U-Value decreases by a minimum of 0.0005% while increasing the pane-pane spacing from 10mm to 13mm, 16mm, 19mm and then to 25 mm in Cold -Dry Conditions for double glazing system.

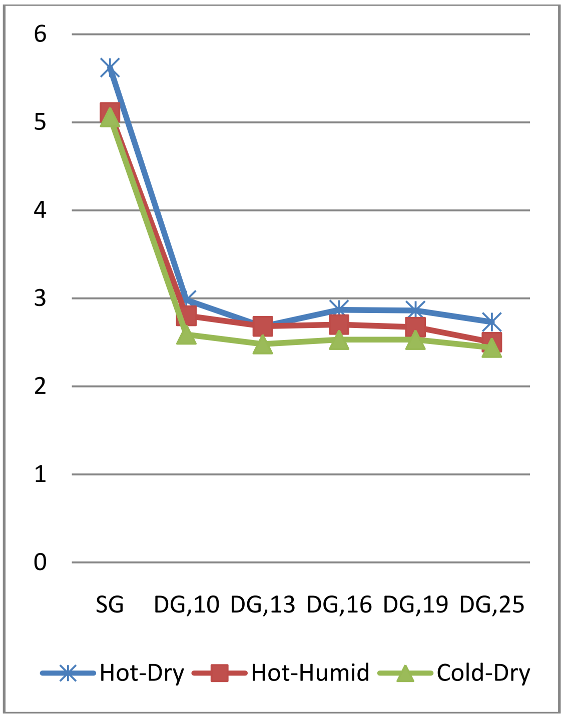


**Fig: 4** Graphical representations of effect of climate

It has been observed that the minimum U-value decreases by less than 1% in all the under taken climatic conditions, Thus climatic conditions does not have much influence on the U-Value. Hence it may be neglected.

### 4.4 The effect of different glazing systems (single glazed and double glazed)

It has been observed that by shifting from single to double glazed window, the U-Value decreases for all climatic conditions (Hot-Dry, Hot-Humid, Cold-Dry).

Case 1: The U-Value decreases from 5.62 W/m$^2$K to 2.68 W/m$^2$K , when double glazed window having pane-pane spacing 25mm is used inplace of single glazed, in Hot-Dry Climate.

Case 2: The U-Value decreases from 5.11 W/m$^2$K to 2.5 W/m$^2$K , when double glazed window having pane-pane spacing 25mm is used inplace of single glazed, in Hot-Dry Climate.

Case 3: The U-Value decreases from 5.06 W/m$^2$K to 2.44 W/m$^2$K , when double glazed window is used inplace of single glazed, in Hot-Dry Climate.

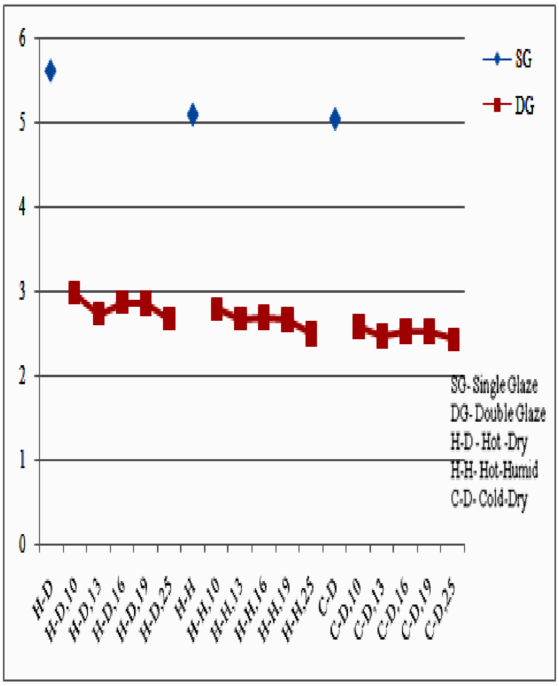


**Fig: 5** Graphical representation of the effect of glazing system on U-Value

## V. Conclusion

As lower U-value of the glazing system are desired, the following conclusions are made from the present work:

- Single glazed windows should be avoided as these have higher U-Value.
- Pane-Pane spacing has significant impact on the U-value.
- During Hot-Humid season double glazed windows with a pane-pane spacing of 25 mm is better as its U-Value is 2.5 W/m$^2$K.
- During Cold-Dry season double glazed windows with a pane-pane spacing of 25 mm is better as its U-Value is 2.44 W/m$^2$K.
- During Hot-Dry season double glazed window with a pane-pane spacing of 25 is recommend by the author as its U-Vale is 2.68 W/m$^2$K.

As most of the months in India, there is Hot-Dry/Hot-Humid climate, hence double glazed window with 25mm pane-pane spacing is recommend.

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