

Effect of Window Glazing on Human Thermal Comfort Parameters

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ABSTRACT: In built environments human thermal comfort is achieved by maintaining a heat balance between the human body and the environment, such as walls and other surfaces, by radiative and convective heat transfer. Glazing systems have distinctly different thermal and optical properties from the walls, which severely affect the human thermal comfort in a room. The comfort of an occupant can be adversely affected by the presence of significant hot or cold windows. Window surface temperatures often fluctuate much more than those of other surfaces in a room and occupants experience discomfort as a result of radiant heat exchange with window surfaces.

In this paper a numerical simulation tool is developed to assess the performance of different types of glazing on thermal comfort distribution parameters inside a room. The basis for the program is Fanger's model of Thermal Comfort. The basic parameters used to evaluate are the Mean Radiant Temperature, PMV and PPD. To calculate the MRT and its distribution in the room, ASHRAE guidelines are employed. Based on the results the effect of the glazing is studied for the required climatic condition. The effect of non uniform radiation asymmetry created due to a particular type of glazing is incorporated.

The simulation is done for radiant temperature inside the room considering single, double, triple and quadruple with low e values. Finally the program is also validated using a case study in a non conditioned room space with respect to Chennai climate (Hot humid).

Keywords: Human Thermal Comfort, Glazing Systems, Simulation, Fanger's Model, Mean Radiant Temperature.

1. INTRODUCTION

A steady increase in energy prices has forced building designers to adopt practices where renewable energy sources like solar energy can be effectively used. Such a thrust for energy conservation has resulted in the use of enhanced fenestration areas, i.e., enhanced glazing areas, to maximize

daylight and even to capture and store solar energy for future use. Large windows always improve the aesthetic appeal of a building and also the worker efficiency. But the comfort of an occupant can be adversely affected by the presence of large hot or cold windows.

Window surface temperatures often fluctuate much more than those of other

surfaces in a room. Even when room air is maintained at a comfortable temperature, occupants may experience significant discomfort as a result of radiant heat exchange with window surfaces. On an individual room level, a design engineer needs to control the two variables the dry-bulb air and mean radiant temperatures. The dry-bulb air temperature measures the temperature of the air in the room while the T_{mrt} is a measure of the radiant energy exchange between the room surfaces and the occupant. Since the radiant energy does not directly heat the air, the dry bulb temperature does not take into account the radiant energy exchange in a room. In most design situations, only the dry bulb temperature is used, while the T_{mrt} is ignored. Hence, the goal of this paper is to incorporate the effect of window glazing systems on the T_{mrt} in the enclosed space.

Recently, researchers have carried out several studies dealing with thermal comfort simulations, especially radiant temperature. Computer simulations were done for eight different fenestration systems for both summer and winter ambient conditions in a numerical investigations conducted by Chapman and Sengupta [10]. The authors proposed “Penetration depth” and “Fenestration performance map” to evaluate the window performance. Lyons, P., D. Arasteh, and C. Huizenga [5] evaluated the window performance for 10 different window systems by simulation. The simulation results show that except in the situation where the human body is in the direct sun, the long-wave radiation is most important in determining thermal comfort. The impact of draft on comfort for residential size windows is small.

Gan, G. [7] examined a series of comfort impacts of windows by simulating more than 20 window design cases. The variables in these 20 cases include the size of the window, shape of the window (height vs. width), type of the glazing, and the effect of

a radiator. The author found that for the same size glazing, a tall and a narrow window is preferable than a square window. Replacing a large window with several smaller windows improves comfort. Atmaca I, O. Kaynakli, A. Yigit [6] investigated the local differences between body segments caused by high radiant temperature, and to analyze the interior surface temperatures for different wall and ceiling constructions with their effect on thermal comfort.

2. METHODOLOGY

2.1 Program Development

A program is developed based on Fanger model and ASHRAE standards which was then simulated to give the room model. The thermal distribution values are plotted inside the room based on the mathematical calculations of MRT, PMV and PPD.

2.2 Application of the Program

Using the program the effect of different type of glazing is plotted on a simulation model. Effect is mainly evaluated on the basis of radiation asymmetry caused due to particular type of glazing.

2.3 Validation of the Program

A suitable case is selected to study the effect of glazing on inside thermal comfort in a non conditioned space as well as conditioned space. Thermal comfort parameters are measured in the case study spaces and same room is simulated using the program developed. Both the values are compared. Thus the program is validated.

3. COMPUTATIONS

3.1 Interior surface temperature of opaque surfaces

The sol-air temperature approach is used to calculate the interior surface temperatures of the wall and ceiling. This is done by replacing the ambient temperature in the heat transfer relation through the walls and the roof by the sol-air temperature (T_s),

which is defined as the equivalent outdoor air temperature that gives the same rate of heat flow to a surface as would the combination of incident solar radiation (I), convection with the ambient air, and radiation exchange with the sky and the surrounding surfaces.

$$T_{sol} = T_o + I \alpha / h_o - \Delta q_{ir} / h_o \quad (1)$$

Where,

h_o = Surface heat transfer coefficient for radiation and convection

I = Incident Solar radiation

Δq_{ir} = Correction to infrared radiation transfer between surface and environment if sky temperature is different from the Interior Surface Temperature of Glazing

Interior surface temperature of the glazing is calculated as a function of outdoor temperature.

$$T_w = (1 - U_w / h_i) T_i + U_w / h_i T_o \quad (2)$$

Where,

T_w = Surface temperature of the glazing

U_w = U value of glazing

h_i = Surface heat transfer to the inside air

T_i = Indoor air temperature

T_o = Outdoor air temperature

3.2 ASHRAE Method of MRT calculation

To find the angle factor of the particular point to the ceiling, the ceiling is divided into four sections. 'c' being the distance of the each section from the occupant position, 'a' being the length of the section and 'b' its width, angle factor to that point is found by getting the a/c and b/c values. The corresponding angle factor is obtained from the graph A of figure 3-8. The angle factors to each section is summed up to get angle factor for the whole ceiling, F_{p-c} .

If q_{1c} , q_{2c} , q_{3c} and q_{4c} are the angle factors for each of the sections of the ceiling then F_{p-c} is given by,

$$F_{p-c} = q_{1c} + q_{2c} + q_{3c} + q_{4c} \quad (3)$$

Similarly angle factor for the window, F_{p-w} , is obtained. If q_{1w} , q_{2w} , q_{3w} and q_{4w} are the angle factors for each of the sections of the window then F_{p-w} is given by,

$$F_{p-w} = q_{1w} + q_{2w} + q_{3w} + q_{4w} \quad (4)$$

But we know that, sum of the angle factors is unity

$$F_{p-1} + F_{p-2} + \dots + F_{p-n} = 1 \quad (5)$$

$(1 - F_{p-c} - F_{p-w})$ = angle factor from the person to other surfaces of the room, excluding ceiling and window.

Multiplying the angle factors with the corresponding surface temperatures gives the radiant temperature.

F_{p-ctc} = Radiant Temperature from the ceiling of the room,

F_{p-wtw} = Radiant Temperature from the window of the room,

$(1 - F_{p-c} - F_{p-w}) t_n$ = Radiant Temperature from the other surfaces of the room, excluding ceiling and windows.

Summing up, gives the Mean Radiant Temperature.

$$T_r = F_{p-c} t_c + F_{p-w} t_w + (1 - F_{p-c} - F_{p-w}) t_n \quad (6)$$

4. APPLICATION OF THE PROGRAM

A test room of the size of 8 m x 6m x 4 m was analyzed and simulations were carried out. In the simulation, the exterior wall is the left wall of the room. All other walls including the floor and the ceiling were treated as interior walls and thus assumed bounded by other rooms. A temperature of 25°C was applied to the interior spaces.

Input Parameters :

Air Velocity	V	= 0.5 m/s
Clothing Insulation	I _{cl}	= 0.6
Humidity Ratio	WA	= 0.04
Activity	Met	= 1

Inside Temperature $T_i = 25^\circ\text{C}$
 Summer Conditions, Chennai-Month : May,
 Time : 15 hrs, $T_A = 37.6^\circ\text{C}$.

4.1 Summer conditions - Chennai

Figures 1 to 10 give the MRT plot with corresponding values for Single glazing, Double glazing, Double glazing with $e=0.1$, Triple glazing and Quadruple glazing respectively. The plots show the spatial distribution of MRT along a horizontal plane which gives an idea of the areas which are comfortable and not comfortable. Similarly the MRT graph shows how the MRT varies as the distance from window increases.

4.2 Single Glazing

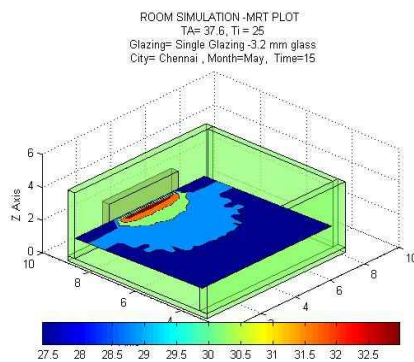


Figure 1 : MRT Contour Plot- Single glazing, Chennai Summer

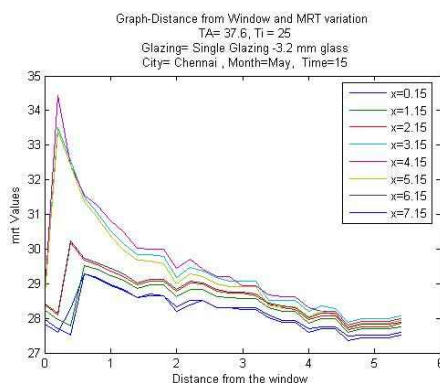


Figure 2 : MRT graph - Variation with respect to distance from the window –Single Glazing, Chennai Summer

4.3 Double Glazing

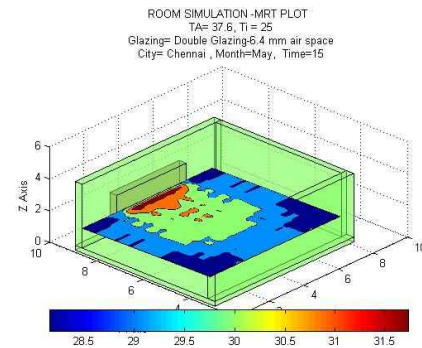


Figure 3 : MRT Contour Plot- Double glazing, Chennai Summer

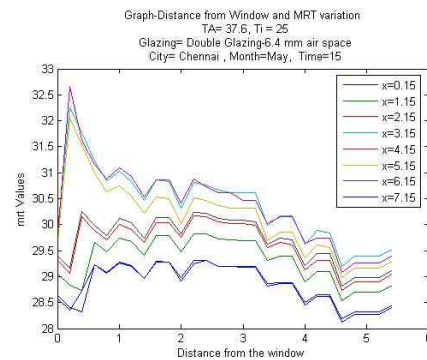


Figure 4 : MRT and PMV graph - Variation with respect to distance from the window – Double Glazing, Chennai Summer

4.4 Double Glazing, $e=0.10$

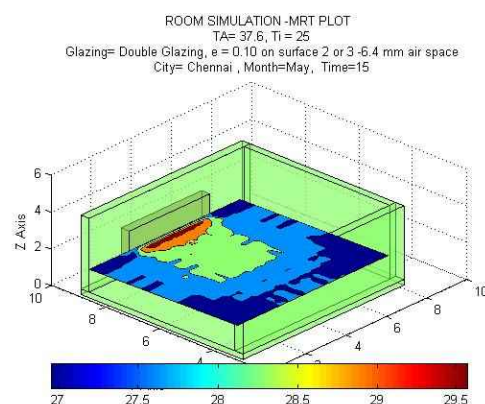


Figure 5 : MRT Contour Plot - Double glazing $e=0.10$, Chennai Summer

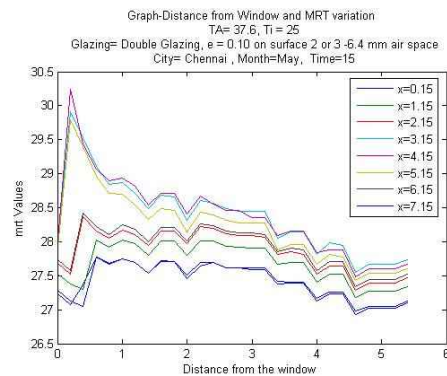


Figure 6 : MRT and PMV graph - Variation with respect to distance from the window – Double Glazing $e=0.10$, Chennai Summer

Figures 1 and 2 shows the simulation plots for single glazing and it is seen that maximum MRT reached inside the room is 34.5°C and the radiation asymmetry is 6°C . Figures 3 and 4 shows the plots for Double glazing in which the maximum MRT reached inside the room is reduced to 33.3°C and the radiation asymmetry decreased to 3.8°C . Figures 5 and 6 gives the plots for Double glazing with $e=0.1$ and it shows that maximum MRT reached inside the room for $e=0.1$ is 30.25°C . The corresponding radiation asymmetry is 2.5°C . Thus we see a reduction in MRT as we change glazing system from single glazing to double glazing by 1.2°C . A further reduction of 3°C found in case of double glazing with low e coating.

4.5 Triple Glazing- 6.4 mm air space

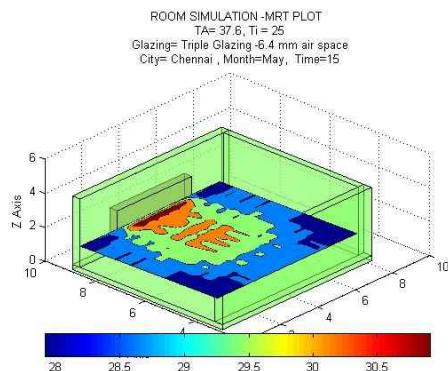


Figure 7 : MRT Contour Plot- Triple glazing-6.4 mm air space, Chennai Summer

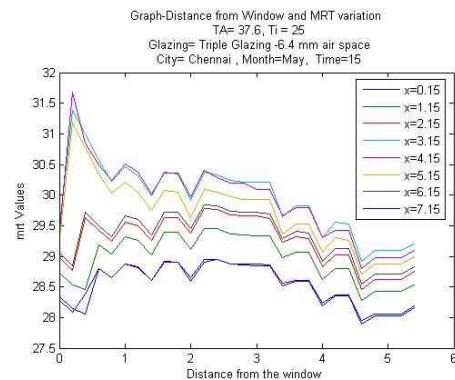


Figure 8 : MRT graph - Variation with respect to distance from the window – Triple glazing-6.4 mm air space, Chennai Summer

4.6 Quadruple Glazing – 6.4mm air space

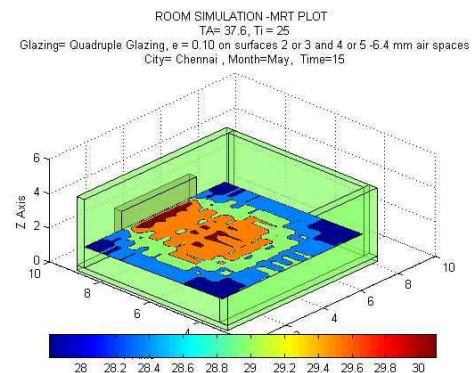


Figure 9 : MRT Contour Plot - Quadruple glazing 6.4mm air space, Chennai Summer

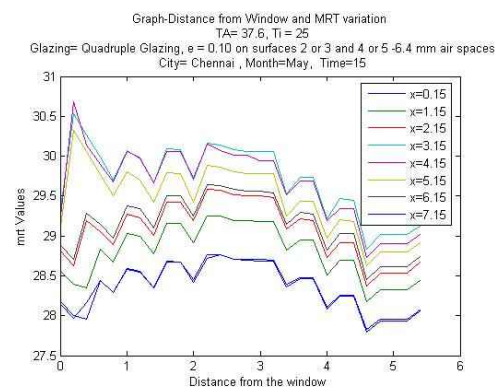


Figure 10 : MRT graph - Variation with respect to distance from the window – Quadruple glazing 6.4mm air space, Chennai Summer

From the Figures 7 and 8 showing the plots for Triple glazing with 6.4 mm air space it is seen that maximum MRT reached inside the room is 31.7°C and the radiation asymmetry is 2.2°C. Figures 9 and 10 shows the plots for quadruple glazing where the maximum MRT reached inside the room is 30.7°C and the radiation asymmetry is 1.2°C. From the simulation it is found that low e coating contributes more towards reducing MRT inside a room.

5. ANALYSIS

Analysis is carried out on the basis of type of glazing combination used. Glazing performance is analysed on the basis of

- Thickness of air layer in multi pane glazing system
- Filler gas used between the glasses
- The number of glazing layer
- Emissivity factor of the glazing system

5.1 Thickness of air layer in multiple pane glazing :

Table I : Variation of MRT and Radiant Asymmetry with respect to Thickness of air layer in Chennai Summer condition – Result from Simulation study.

Maximum MRT and Radiant Asymmetry		
Chennai- Summer		
	Maximum MRT in °C	Radiation Asymmetry in °C
Single Glazing	34.5	6
Double glazing-6.4mm air space	33.3	3.8
Double glazing-12.7mm air space	32.8	3.3
Triple glazing-6.4mm air space	31.7	2.2
Triple glazing-12.7mm air space	31.2	1.7
Quadruple glazing-6.4mm air space	30.7	1.2
Quadruple glazing-12.7mm air space	30.2	0.7

It is found that between double glazing 6.4mm air space and 12.7mm air space there is a decrease of 0.5°C. Same is seen in the case of triple glazing and quadruple glazing. Thus we can say that by increasing the depth of air layer in multi pane glazing reduce the MRT inside the room by 0.5°C. Results from the simulation study is tabulated in Table I. As thickness of air layer increases, thermal resistance increases and thus radiation effect decreases.

5.2 Filler gas used between the glasses

Table II : Variation of MRT and Radiant Asymmetry with respect to the gas fill between the glass layers in Chennai Summer condition – Result from Simulation study.

Maximum MRT and Radiant Asymmetry		
Chennai- Summer		
	Maximum MRT in oC	Radiation Asymmetry in oC
Double glazing-6.4mm air space	33.3	3.8
Double glazing-6.4mm argon space	33	3.5
Double glazing-12.7mm air space	32.8	3.3
Double glazing-12.7mm argon space	32.5	3
Triple glazing-6.4mm air space	31.7	2.2
Triple glazing-6.4mm argon space	31.4	1.9
Triple glazing-12.7mm air space	31.2	1.7
Triple glazing-12.7mm argon space	31	1.5
Quadruple glazing-6.4mm air space	30.7	1.2
Quadruple glazing-6.4mm argon space	30.2	0.7
Quadruple glazing-12.7mm air space	30.2	0.7
Quadruple glazing-12.7mm argon space	29.7	0.2

Replacing the gap by argon or krypton increase the thermal resistance which will decrease the radiation effect. Thus MRT is reduced in argon filled glazing units compared to that of air filled units because

argon is less thermal conductive. It is found from the table II that in double glazing and triple glazing the MRT reduction is only 0.25°C while in quadruple it is more than 0.5°C.

5.3 Number of of Glazing Layer :

Radiation Asymmetry is highest for Single glazed window as it transmits more solar energy. It is found to be less for double glazed as the MRT is more distributed. It is still less for triple glazing and least for quadruple glazing. The comparison is given in the table III. Hence it is found that as the layer of glazing increase from single to quadruple glazing MRT reduced from 34.5°C to 30.7°C ie., a decrease of 3.8°C.

Table III : Variation of MRT and Radiant Asymmetry with respect to the number of glazing layers in Chennai Summer condition – Result from Simulation study.

Maximum MRT and Radiant Asymmetry		
Chennai- Summer		
	Maximum MRT in oC	Radiation Asymmetry in oC
Single Glazing	34.5	6
Double glazing- 6.4 mm air space	33.3	3.8
Triple glazing-6.4mm air space	31.7	2.2
Quadruple glazing- 6.4mm air space	30.7	1.2

5.4 Emissivity factor :

It is seen that with low-e glasses, the MRT is reduced and distributed, reducing the radiation asymmetry. Table IV shows the values of Maximum MRT and Radiation Asymmetry obtained inside the given room for low e coating 0.6, 0.4, 0.2 and 0.1. From the plotted graphs in Chennai Summer condition it is found that double glazing with low e coating of 0.6 itself reduces the MRT by 2.3°C. And with emissivity as low as 0.1 the MRT reduced further by 3.05 °C.

Table IV : Variation of MRT and Radiant Asymmetry with respect to Emissivity factor of glazing in Chennai Summer condition – Result from Simulation study.

Maximum MRT and Radiant Asymmetry		
Chennai- Summer		
	Maximum MRT in °C	Radiation Asymmetry in °C
Double glazing	33.3	3.8
Double glazing,e = 0.60	31	3.25
Double glazing,e = 0.40	30.75	3
Double glazing,e = 0.20	30.5	2.75
Double glazing,e = 0.10	30.25	2.5
Triple glazing-6.4mm air space	31.75	2.25

6. VALIDATION OF THE PROGRAM

A studio space in IC&SR building of IIT campus is selected as case study which falls in Chennai climate (Hot Humid). This room is of the dimension 9m by 8m and a height of 3.5 meters. The room is situated in the topmost floor and hence the ceiling is exposed to solar radiation. Since the studio is meant for audio visual shoot, the wall are acoustically and thermally insulated. Hence there is no external heat gain through walls. Only radiation entry is through the window glazing. The window direction is North West and three windows closely placed. The wall with the window is the only external wall. MRT was measured at a 1 metre interval grid and plotted (figure 11). Same room is simulated using the program to get the MRT plot(figure 12).

From the figures 11 and 12 it is seen that the maximum MRT by simulation is 35.5 °C and the measured value is 35.8°C. At 2 metres from window, both the graphs show 35°C and at 4 metres from the window MRT from simulation showed 35°C but the measured value showed 35.5°C. At 6 metres from window both showed 34°C. Both the plots were matching to validate the program.

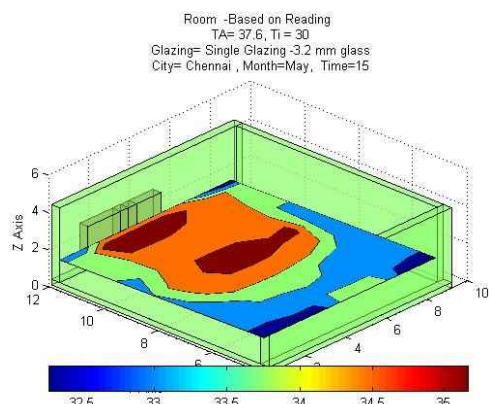


Figure 11 : MRT Plot of non conditioned room as simulated from the field measured values

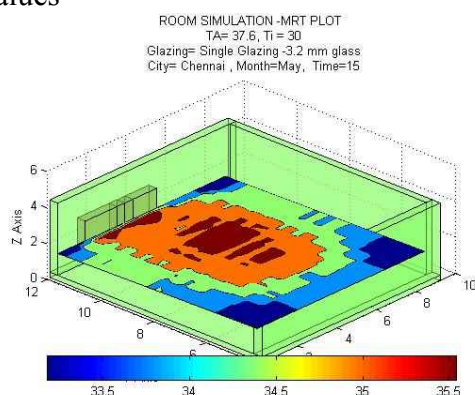


Figure 12 : MRT Plot of non conditioned space as simulated by the developed program

7. CONCLUSIONS

A simulation program has been developed using MATLAB to evaluate the MRT component inside any given enclosure. Using the program developed, the effect of various type of glazing system on the MRT generated inside a given room has been studied. Thermal performance of glazing is improved by each addition of glazing layer in multiple glazing. MRT is reduced in argon or krypton filled glazing system compared to normal air filled glazing system. Low emissivity glazing system reduces the MRT resulting in improved thermal performance.

ACKNOWLEDGEMENT

This research work is done as a part of Masters Project, May 2008 at Indian Institute of Technology, Madras, India.

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