IMPACT OF DIFFERENT GLAZING SYSTEMS ON COOLING LOAD OF A DETACHED RESIDENTIAL BUILDING AT BHUBANESWAR, INDIA

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Abstract
For detached residential buildings located in the tropics, it is more challenging and difficult to deal with the space cooling load due to hot and humid climates. In this paper, daily and monthly computer simulations of solar heat gain and cooling load for a detached residential building are carried out using Design Builder software. Different glazing systems ranging from single glazed clear glass to double glaze with electro chromic reflective colored have been analyzed in terms of their impact on solar heat gain and cooling load. The simulation results show reductions in solar heat gain, cooling load and better thermal comfort can be achieved using proper glazing systems for a specific orientation of the building. The significance of these results stems from the fact that they are obtained under local weather conditions, a matter of importance to building architects, designers, contractors, and builders as well as air-conditioning equipment manufacturers.

1. INTRODUCTION

The last decade has witnessed a grave energy crisis in developing countries like India during summer season primarily due to cooling load requirements of building. For detached residential buildings located in the tropics, because of hot and humid climatic conditions, space cooling is normally required for up to 7–8 months in a year [Lam, 1993]. To reduce this cooling load passive cooling of buildings is the most sustainable method. Any of these passive cooling techniques can be adopted during construction of the buildings itself and also thereafter. A lot of research works on passive cooling have been done in throughout the world. Passive cooling can be defined as the removal/restriction of heat from/to the environment of building by utilizing the natural processes of rejecting heat to the ambient atmosphere by convection, evaporation, and radiation or to the adjacent earth by conduction and convection. Buildings can be designed and oriented in such a way that windows, doors, indoor spaces etc. are located and oriented to take maximum advantage of the local climate.

Solar passive cooling techniques is an active research area and has attracted large number of researcher. Performance applicability of passive and low-energy cooling systems is discussed by Givoni [1994]. Some of the known techniques for passive cooling, viz. Sky-therm [Prasad et al., 1979; Yellot and Hay, 1969], insulated roof and wall [Asan, 1998; Kumar et al., 1989; Shariah et al., 1997], roof pond [Sodha et al., 1978, 1986], earth–air tunnel [Mihalakakou et al. 1995; Sodha et al., 1989] and passive solar ventilation [Hamdy and Firky, 1998]. Impact of windows on thermal comfort and passive cooling is addressed by Chaiyapinunt et al. [2005] and Lyons et al. [1999]. Studies related to space cooling load characteristics in residential buildings located in hot and humid subtropics are reported by several researcher. These includes studies on the effects of both the thermal insulation of external wall or roof and the U-value of windows on space cooling load [Sullivan et al., 1994, Bojic et al., 2001; Shariah et al., 1997]. The discussion regarding such techniques has been widely addressed in a number of experimental and numerical studies [Duffie and Beckman, 1991; Sodha et al., 1986, 1989; Srivastava et al., 2007].

In this paper different glazing systems ranging from single glazed clear glass to double glazed with low-e and different shadings, whose optical data are available from the window manufacturers in India, have been analyzed. This paper reports on a simulation study where the effect of different glazing and shading systems on solar heat gain and residential space cooling load are investigated and analyzed using Design Builder simulation program [DesignBuilder, 2009]. The weather conditions and a detached residential building in the tropical Bhubaneswar are used in the simulation study. The premise of this study is, therefore, to provide architects and building designers with simple but effective tools to assist in proper selection of glazing systems.

2. DESCRIPTION OF THE BUILDING AND ASSUMPTIONS USED IN THE SIMULATION

A one-story residential block, which is located in the tropical region of Bhubaneswar, is used as the platform for performing the simulation study. This building is divided into nine thermal zones, which consist of two bedrooms, two bathrooms, one kitchen, one common room, one study room, one balcony and one entry room and are depicted in Fig. 1. The basic characteristics of the zones are shown in Table. 1.

2.1. Building Envelope Description

The construction details of the apartment are the required inputs to Design Builder software. These are detailed in Tables 2. Table 3 lists the physical properties of the materials used in building elements. It is assumed that the apartment is not shaded by other buildings in its close vicinity. Alternative analysis are conducted assuming north–south and east–west facings of the building. For each orientation, different types of glazing (Table 4) and different glazing areas are considered. The first case(the base case) assumes a single clear glazing with a window-to-wall ratio (WWR) of 30%. The rest of the cases represented WWR of 10, 20, 40 and 50%. The effect of window frames is not considered mainly because of the variations available in framing materials and dimensions.

2.2. Occupancy Pattern

It is occupied by a four-person family consisting of two working adults and two school children. In this simulation study, it is assumed that the common room is occupied by all family members at daytime; and one bedroom by the working adults and the other one by two child, respectively, at nighttime. The study room is occupied by the children from 7:00pm to 11:00pm. The balcony is occupied by the family members in the evening time. The kitchen is occupied by one adult during day and evening time.

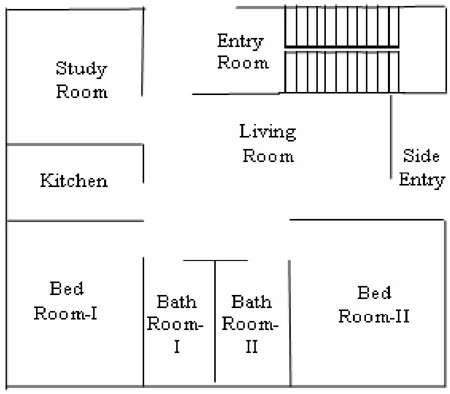

Figure 1. Floor plan of the east-west oriented residential building taken for study (not to scale)

Table 1. The zones basic characteristics

Zone	Area (m^2)	Volume (m^3)	Occupancy (people/m^2)	Venti-lation (l/s)	HVAC system
Bed room1	15.12	52.93	0.14	7.5	Split
Bed room2	17.23	60.32	0.17	7.5	Split
Com. room	34.79	121.75	0.12	7.5	Split
Study room	14.23	49.82	0.14	7.2	Split

Table 2 .Details of building elements

Building element	Layer 1 (facing outdoors)	Layer 2	Layer 3 (facing indoors)
External wall	20mm cement/sand plaster	150mm concrete	20mm gypsum plaster
Internal partitions	20mm cement/sand plaster	150mm concrete	20mm gypsum plaster
Flooring	5mm vinyl tiles	25mm screed	100mm concrete

Table 3. Physical properties of the materials

Materials	c_p (J/kg K)	ρ (kg/ m^3)	K (W/K m)
Concrete	653	2400	2.16
Cement/sand plaster	840	1860	0.72
Gypsum plaster	837	1120	0.38
Glass	-	-	0.9
Wood	2093	800	0.16

2.3. Operating Pattern of HVAC System

In this apartment, the common room and all the bedrooms are equipped with split-type air conditioners (ACs), but no air conditioning was provided in the toilet/bathrooms and the kitchen. The coefficient of performance is set to a value of 3.2 and air-temperature distribution mode is set to 1-mix i.e. air temperature within the zone is completely uniform (i.e. air is fully mixed).

2.4. Casual Gains (Internal Heat Gain)

Casual heat-gain in a building is the heat gained from electrical equipment, lighting, and/or occupants. The casual gains for lighting and equipment are usually in the form of sensible-heat gains. However, for the occupants, the activity levels of occupants are assumed to be 60W/m2 person (1.0 met for resting) when they are awake in the common room and 40W/m2 person (0.7 met for sleeping) when they are asleep in bedrooms. For lighting purpose, incandescent tubes are used which have lighting load of 15W/m^2. Two 250 watt PCs are also being used in the study room. The casual gain schedule was defined assuming that the common room was occupied by the family members only during daytime, bedrooms were occupied during 11:00pm to 7:00am and study room was occupied during 7:00pm to 11:00pm for all weekdays.

2.5. Ventilation Requirement

The ventilation rate for the common room and the bedrooms was 7.5 L/s per person as required by ASHRAE Standard 62-2001 [ASHRAE, 2001] when the rooms were conditioned.

2.6. Control

The purpose of a control function is to maintain the zone temperature and relative humidity at the specified set points. It does this by making the HVAC system inject the required heating and/or cooling sensible and/or latent load into the conditioned space to satisfy the control function. ASHRAE [ASHRAE, 2004] recommends a comfort zone based on the 90% acceptance of thermal conditions or 10% predicted percentage dissatisfaction (PPD) (Comfort class B). In our analysis, the cooling set-points chosen were 24^{0}C with a relative humidity of 50% for weekdays and 26^{0}C with a relative humidity of 50% for the weekends. The heating set-points chosen are 22^{0}C with a relative humidity of 50% for weekdays and 20^{0}C with a relative humidity of 50% for weekends.

2.7. Weather Data

Weather data is the most important input parameter for building simulation. Weather data for Bhubaneswar [ASHRAE, 2005] consists of average hourly, daily, monthly data for dry-bulb air temperature, dew point temperature, solar radiation, wind speed and direction, cloud cover, etc., for the year 2002, which was considered as the typical reference year (TRY) for Bhubaneswar. The longitude and latitude for this location were 48^0 E and 29.3^0 N respectively. Figure [2] clearly shows that the cooling season is predominant for eight months of the year. In addition, during the cooling season, the sky is clear most of the time, which implies that the effect of solar radiation on the building's cooling load could be significant.

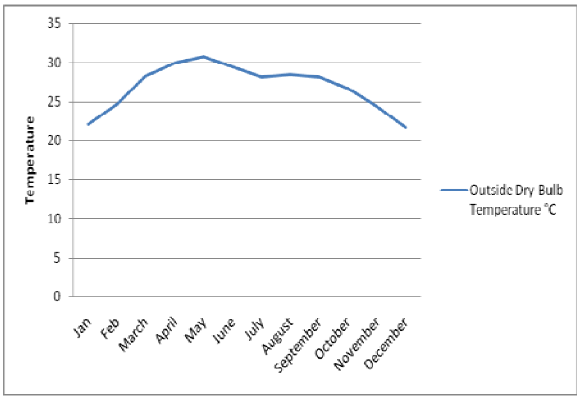

Figure 2. Plot of monthly average dry-bulb temperature for different months of the year.

Table 4. Thermal and optical properties of common glazing types considered in the analysis

Glazing type	(τ_y)	U (Wm^{-2} K^{-1})	SHGC
Single, 6 mm, clear	0.881	6.121	0.810
Single, 6 mm, reflective -A-H coated, clear	0.201	5.360	0.277
Double, 6 mm, 13mm air, clear	0.781	2.708	0.697
Double, 6 mm, low-e coated, 13mm air, clear	0.721	1.949	0.629
Double, 6 mm, reflective -A-H coated, 13mm air, clear	0.181	2.449	0.216
Double, 6 mm, Electro chromic reflective colored, 13mm air, clear	0.137	1.772	0.142

2.8. Thermal and Optical Properties of Glazing Systems Used

The main objective of this study was to analyze the effect of glazing type, wall to windows ratio(WWR) on the cooling load and solar heat gain of the residential buildings. This resulted in the development of different cases to represent different glazing types, orientations and areas. The optical properties and thermal characteristics of different glazing materials used are listed in Table 4. The reason behind selecting such glazing types was that their properties cover a wide range of commonly-used glazing, including high-performance types double Electro chromic reflective coloured.

3. RESULTS AND DISCUSSION

In order to evaluate the impact of different glazing systems on cooling load and thermal comfort pattern for the detached residential building, first the base-case model with an east–west orientation is considered. The results for the base case shown in Fig. 3 indicate that the peak cooling load for the building occurs in May (4148kWh) while the lowest occurs in December (1273kWh). It can be clearly seen that cooling is required for the entire year for this hot and humid region. Similarly simulations are also carried out to assess the effects of other glazing systems on cooling load. It is found that the peak cooling load is about 3597kWh in May when double-glazing is employed compared with 4148kWh for the base case (single glazing), which is 13.3% lower for the double electro chromic reflective colored glazing.

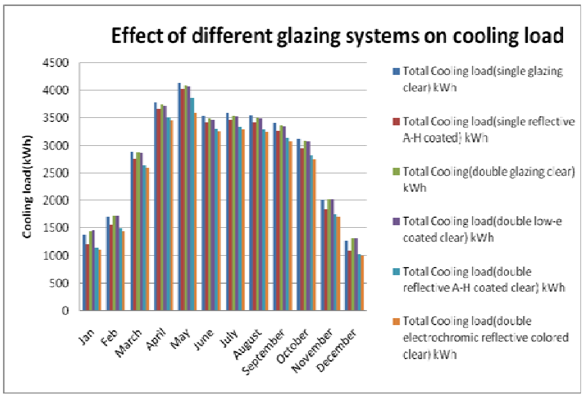

Figure 3 Monthly Cooling load profile for different glazing systems used(east-west orientation of building) with WWR of 30%

The results show that when comparing glazing with identical orientation, size and shading coefficient, higher U-value glazing often yield lower annual cooling load, but lower U-value glazing yield lower peak cooling load. This occurs because the window with higher U-value conducts more heat from inside the residence to the outside during morning and evening hours when outside air temperature is lower than inside air temperature, and a lower U-value window conducts less heat from outside to inside during summer afternoon peak cooling hours. However the absolute effects are relatively small when compared to annual total cooling load which is typically dominated by window solar heat gain effects, latent loads and internal loads.

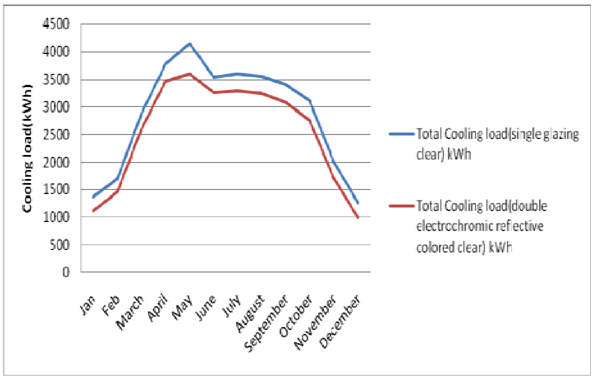

Figure 4. Comparison between Monthly Cooling load profile of single and double glazing (east-west orientation of building) with WWR of 30%.

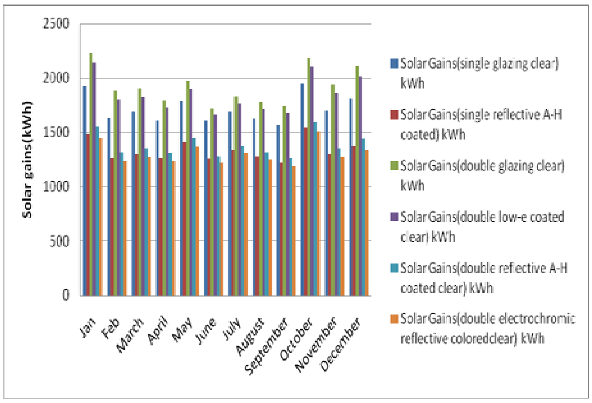

Figure 5. Monthly Solar gains profile for different glazing systems (east-west orientation of building) with WWR of 30%

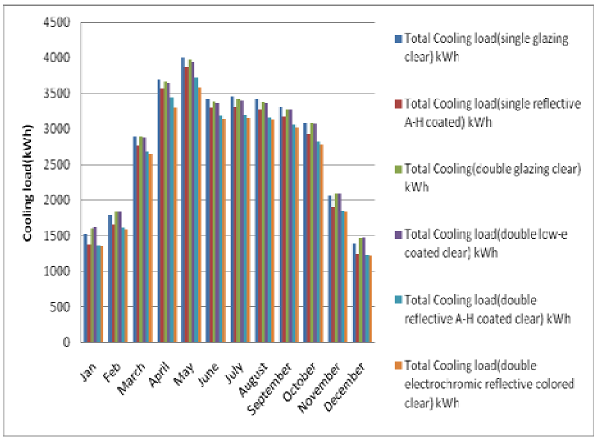

Figure 6. Monthly Cooling load profile for different glazing systems used (north-south orientation of building) with WWR of 30%

Solar heat gain from different glazing system is shown in Fig. 5. It is clear that solar heat gain varies with glazing systems used and is the minimum for double electro chromic reflective colored glazing system, which has great impact on decreasing monthly cooling load.

Similarly, simulation is also carried out for north-south orientation of the residential building. The simulation results for monthly cooling load and solar heat gain are shown in Figs. 6 and 7. Comparing the cooling load results for east-west and north-south orientations, one can see that for north-south orientation the cooling load for different glazing system is less compared to east-west orientation. For double reflective A-H coated clear glazing, peak cooling load for building having east-west orientation comes out to be 3866kWh and the peak cooling load for north-south orientation comes out to be 3732kWh, a reduction of 3.5% in cooling load. Also, it is found that the type of glazing has no effect on the cooling load in winter. This indicates that glazing is important during summer when radiation flux of over 1000 kWm-2 is observed for the months of April-July. Hence proper shading should be applied to reduce the peak cooling load.

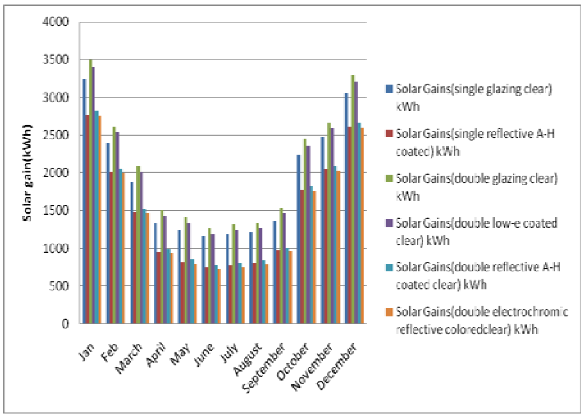

Figure 7. Monthly Solar gains profile for different glazing systems (north-south orientation of building) with WWR of 30%

The simulation results of peak cooling load with respect to the variations of WWR are shown in Figs. 9 and 10 for the north–south and east–west orientations, respectively. For different WWR, combination of north-south orientation and double electro chromic reflective colored glazing results minimum peak cooling load. It is important to note that for both the orientations, single reflective A-H coated glazing and double glazing produces almost same performance. If we set peak cooling load limit at 4000kWh, then it is clear that only the double electro chromic reflected colored clear glazing fall within the allowed limit for WWR up to 50% for east-west orientation and, both double electro chromic reflected colored clear and double reflective A-H coated glazing type fall within the allowed limit for WWR up to 50% for north-south orientation

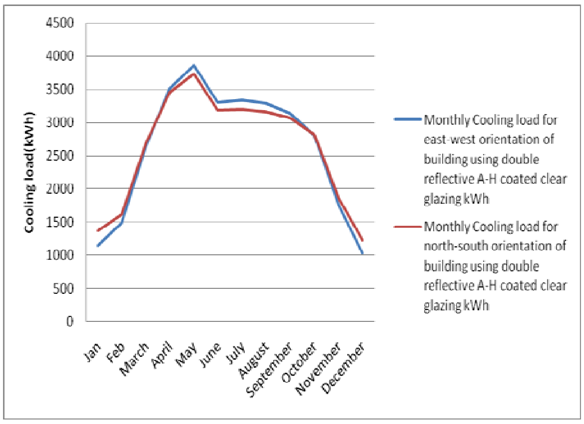

Figure 8. Comparison between Monthly Cooling load profile with WWR of 30%

4. CONCLUSION

An important objective of this study was to assess the effects of glazing type and orientation of building on the cooling load of a detached residential building located in Bhubaneswar, India. It was clear from the results that different glazing types result in significant variations in the cooling loads. Results show significant reductions in cooling load can be achieved using a suitable combination of well-established technologies such as glazing and building orientation. Using high-performance glazing, such as the double electro chromic reflected colored clear, can lead to substantial savings in the size of the A/C system and in the capital investment, which should compensate for the extra cost for the glazing. This important information can be added to the existing code to guide the effective design of detached residential buildings in the eastern part of India. It must be noted that the results presented in this paper are applicable to the type of building considered, i.e. a one-storey detached residential building which is usually located in the eastern part of India like Bhubaneswar. In addition, the study did not address the energy-consumption issue, which should also be considered in future in order to estimate the cost benefits from using such glazing systems. The present analysis can be modified to account for the effect of shading if more stringent conservation measures are implemented in future.

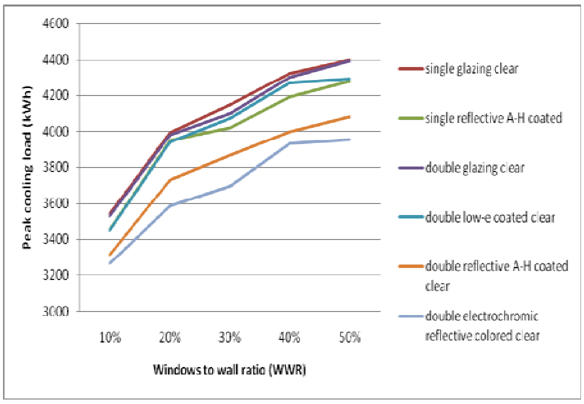

Figure 9. Variation of peak cooling load with windows to wall ratio(WWR) (east-west orientation of building)

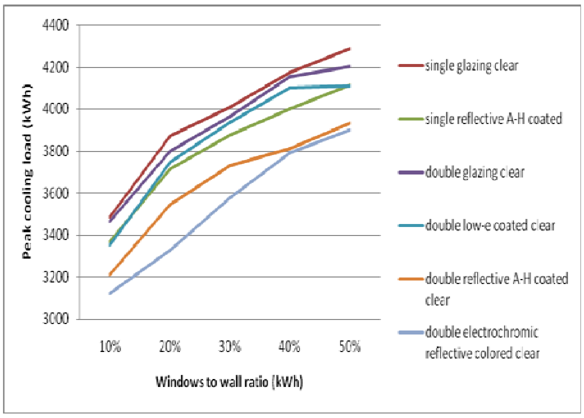

Figure 10. Variation of peak cooling load with windows to wall ratio(WWR) (north-south orientation of building)

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