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Effect of Building Orientation and Window Glazing on the Energy Consumption of HVAC System of an Office Building for Different Climate Zones

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***Abstract*— Building orientation, i.e the positioning of building on site, is an important and foremost step during the construction of building. The orientation decides the amount of daylight and natural ventilation which can enter the building. As these days, most of the office space is centrally air conditioned, this paper explores the role of building orientation and window glazing, on the energy consumption of HVAC system of an office building. This paper considers a mid-rise four floor office building in Bangalore, models the building in various geographical orientations and through simulations, and determines the best orientation of the building such that the energy expenditure in terms of cooling and ventilation is minimal. Further simulations are carried out in different temperature zones in India by simulating the same office space in different locations, across India vis New Delhi, Chennai and Ahmedabad and the best orientation for placing the building is found. On realizing the best orientation, the window glazing values are varied for four suitable values of glazing and the most energy efficient glazing providing the least load on the HVAC system is found. The paper concludes with recommendations to reduce the energy consumption of the HVAC system in different zone.**

Keywords*— Building Orientation, Solar Heat Gain Coefficient (SHGC),U-factor, Visual Transmittance(Vtis), Space Cooling, HVAC system

I. INTRODUCTION

With increasing energy consumption in housing as compared to production in rapidly urbanizing countries, it has become necessary to adapt sustainable design methods to reduce the demand on energy, especially for cooling, and to promote an environmentally sound architecture for buildings[1]. To have energy efficient buildings, there is a need to orient the buildings in the direction where less energy would be spent in maintaining thermal comfort. Orientation of building should be decided in all significant manners in order to construct a cost effective building. Amount of solar radiation falling on the building varies with its orientation, hence it also depends on the temperature zone that the building is placed in. Different temperature zones might have different requirements for orientation to achieve energy efficiency. Walls, windows and fenestrations are an important part of a building and also contribute to heat flow, in and out of the building which adds to the cooling load. In order to make the building more efficient it is important to consider the effects of windows and its glazing as well. Architecturally, the hot and humid region is one of the hardest climates to ameliorate through design. This is due to the high humidity and daytime temperatures that result in high indoor temperatures exceeding the ASHRAE summertime comfort upper limit of 26°C for most of the year. Glazed building facade imposes itself as an icon for the developing cities. This large area of glazing in each facade needs protection against overheating and sun glare in tropical region, especially when it faces east or west direction. [2]

II. BUILDING PARAMETERS

A. Building Envelope

The building envelope is the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation. By acting as a thermal barrier, the building envelope plays an important role in regulating interior temperatures and helps determine the amount of energy required to maintain thermal comfort. Minimizing heat transfer through the building envelope is crucial for reducing the need for space heating and cooling. In cold climates, the building envelope can reduce the amount of energy required for heating; in hot climates, the building envelope can reduce the amount of energy required for cooling.

B. Building Orientation

Building orientation refers to the way a building is situated on a site and the positioning of windows, rooflines, and other features. Successful orientation rotates the building to minimize energy loads and maximize free energy from the sun and wind. Orientation for solar gain will also depend on other factors such as proximity to neighbouring buildings and trees that shade the site. For solar gain, as well as considering location, orientation and window size and placement, it is also important to consider the thermal performance and solar heat gain efficiency of the glazing unit itself. If optimal orientation can be achieved, it will reduce some of the heating requirement, reduce energy costs and reduce greenhouse gas emissions. Effective solar orientation requires a good understanding of sun paths at the site at different times of the year.

C. Walls

Like roofs, the amount of energy lost or retained through walls is influenced by both design and materials. Design considerations affect the placement of windows and doors, the size and location of which can be optimized to reduce energy losses. Decisions regarding the appropriate material can be more complicated because the energy properties of the entire wall are affected by the design. Importantly, material selection and wall insulation can both affect the buildings thermal properties. A buildings thermal mass i.e., its ability to store heat is determined in part by the building materials used. Thermal mass buildings absorb energy more slowly and hold it longer, effectively reducing indoor temperature fluctuations and reducing overall heating and cooling requirements.

D. Windows, Doors and Skylight

Collectively known as fenestration, windows, exterior doors, and skylights influence both the lighting and the HVAC requirements of a building. In addition to design considerations (the placement of windows and skylights affects the amount of available natural light), materials and installation can affect the amount of energy transmitted through the window, door, or skylight, as well as the amount of air leakage around the window components. New materials, coatings, and designs all have contributed to the improved energy efficiency of high-performing windows, doors, and buildings. Some of the advances in windows include: multiple glazing, the use of two or more panes of glass or other films for insulation, which can be further improved by filling the space between the panes with a low-conductivity gas, such as argon, which will help reduce the flow of infrared energy from the building to the environment.

E. Solar Gain Heat Coefficient (SHGC)

The SHGC is the fraction of incident solar radiation admitted through a window, door, or skylight -either transmitted directly and/or absorbed, and subsequently released as heat inside a home. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the less solar heat it transmits and the greater its shading ability U-factor is the rate at which a window, door, or skylight conducts non-solar heat flow. It's usually expressed in units of Btu/hr-ft2-oF. The buildings climate, orientation, and external shading will determine the optimal SHGC for a particular window, door, or skylight.

F. Visible Transmittance (Vtis)

It is the amount of light in the visible portion of the spectrum that passes through a glazing material of a window, door, or skylight. A product with a higher Vtis transmits more visible light. Vtis is expressed as a number between 0 and 1. The Vtis required for a window, door, or skylight should be determined by the building's daylighting requirements and/or whether there is a need to reduce interior glare in a space. Visible transmittance is influenced by the glazing type, the number of panes, and any glass coatings. Visible transmittance of glazing ranges from above 90 percentage for uncoated water-white clear glass to less than 10 percentage for highly reflective coatings on tinted glass.

G. U factor

U-factor measures how well a product prevents heat from escaping a home or building. U-factor ratings generally fall between 0.15 and 1.20. The lower the U-factor, the better a product is at keeping heat inside the building. U-factor is particularly important during the winter heating season in colder climates.

III. CASE STUDY

In this paper a Mid-rise four floor office building in Bangalore is considered and the building is modelled in a software environment (eQuest) which uses DOE 2.2 as its engine. The building simulation is run for various orientations to determine the best orientation to optimize the space cooling load on the HVAC system. Further, the building energy performance is simulated for four different temperature zones in India i.e Bangalore, New Delhi, Chennai and Ahmedabad and the best orientation for the building in the various climatic zones is found [4]. To model and simulate the building for different temperature zones in India like Temperate zone (Delhi), Moderate (Bangalore) , Warm and Humid (Chennai) and Hot and Dry (Ahmedabad), weather files were used.

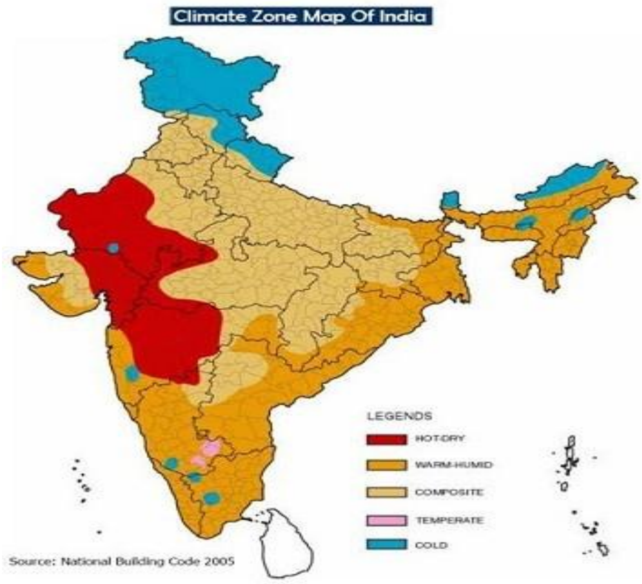

Figure 1:Climate Zone Map of India (Source: National Building Code India)

A weather file is a collection of weather related data which has been recorded and collected over a span of time which can be used for forecasting as well as for simulation purposes where the weather of a place is crucial to the outcome. The building is modelled in eQUEST which is a widely used, building energy performance design tool[6]. The chosen office space is rectangular in shape with an area of 12500 square feet per floor and has a perimeter zone depth of 15 ft. The floor to floor height and floor to ceiling height of the building are 12 ft and 9 ft respectively. As the building is considered in India which is a tropical country, it has been assumed that the walls do not have any insulation. Wall insulation is incorporated in cold countries to retain heat in the conditioned space which will not be applicable here as the places chosen for the simulation do not experience long bouts of extremely cold weather conditions. Concrete structures are considered for the walls and roofs. For the ceilings, walls and floors the default values available can be considered. The doors and windows are placed and the materials for their design are selected. In this building three types of doors have been considered vis Glass type, Revolving glass type and Sliding glass type. The window type which is considered is Single Clear quarter inch glass, mounted on an aluminium framework which has a U-value of 1.09, and a SHGC of 0.81. The window width is considered as 3 ft and the height is 5 ft with overhangs and fins of 1 ft for all the windows placed in all the exterior walls of the building. No provision for skylight roof is made in the project. Next, the activity zones, loads occupied in accordance to the activity being performed in that area and the time schedules are fed in by approximation.

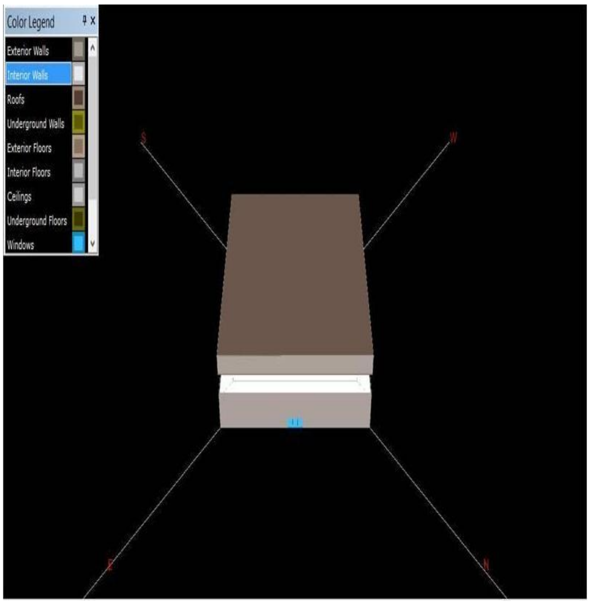

Figure 2: eQuest Model of Office Building

A multi-zone air handler with chilled water coils and ducted return air path is used for cooling purposes. The cooling set points for occupied and unoccupied conditions are specified. The cooling equipment i.e the type of chillers and pumps used and their loads are chosen in accordance to the requirement of the building. After feeding in the values for a particular orientation for a particular place with its associated weather file we simulate it to get the energy consumption values. The same is then repeated for the other seven orientations and the best orientation with the least energy consumption value is chosen and the glazing values.

Glazing type	Vtis	SHGC	U-Factor
Glazing 1	0.884	0.881	5.818
Glazing 2	0.443	0.453	1.878
Glazing 3	0.484	0.256	1.641
Glazing 4	0.415	0.233	1.654

Table I: Specifications of different glazing values

Simulations were done for different Climatic zones in India like - Hot and Dry (Ahmedabad), Moderate (Bangalore), Warm and Humid (Chennai) and Composite (New Delhi)

IV. RESULTS AND ANALYSIS

The simulation runs have been classified into four main groups as per location such as Ahmedabad, Bangalore, Chennai, New Delhi and the annual energy consumption in terms of space cooling and lighting in MTBU have been discussed below for different orientations and different glazing values. To indicate the heating and cooling ability of appliances and air conditioning and also to represent the amount of heat in fuels as a standard unit of measurement known as MTBU is used.

1. Ahmedabad – Hot & Dry Climate

Hot and dry climate is prominent by its extremely high radiation levels and ambient temperatures, accompanied by low relative humidity. Hence, it is advisable to increase the humidity in the building and prevent the infiltration of heat in the building. From figure 3, it has been observed that the building, when oriented in the North tends to be most energy efficient as it utilizes 564641 KWh of electrical energy per year for space cooling alone which saves 15.69 percentage of energy as compared to the energy spent on space cooling in other orientations.

With this orientation a monetary benefit of INR 22 lacs per annum can be obtained. Also, from figure 4, it has been observed that Glazing 4 is the most suitable glazing type that can be used whereas Glazing 1 is the least suitable option in terms of energy consumption for space cooling. But Glazing 1 is the most economical option as it can save up to INR 1.7 lac per annum.

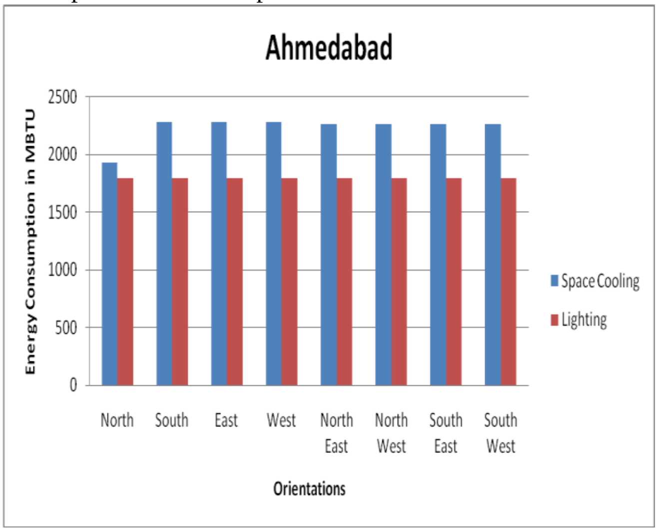

Figure 3: Energy Consumption of Building (in MBTU) for different orientations in Ahmedabad

In summer an east west orientation (i.e. longer axis along the east-west) is desirable as the north wall gets is exposed to a large amount of solar radiation in most parts of the country which results in North West rooms being at a higher temperature as compared to other rooms in other of the building.

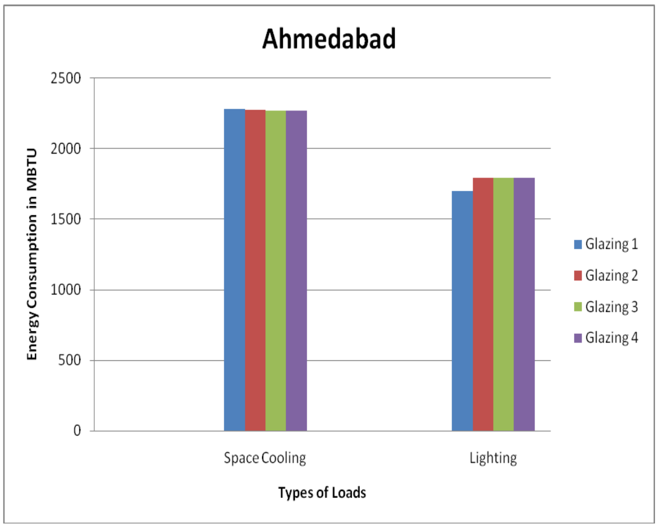

Figure 4: Energy Consumption (in MBTU) of the building in Ahmedabad for Different Glazing Values

At nights as the ambient temperatures drop cross-ventilation can be included into the building design. As the least solar radiation falls on the northern front of the building during the year more windows should be provided there in contrast with the eastern, southern and western fronts of the building. External shading devices such as fins and overhangs can be used to protect the openings of the buildings from the sun

A. Bangalore- Moderate Climate

Climatic zones having temperatures that are neither too high nor too low form Moderate Climate Zones Accordingly, to handle the heating and cooling requirements of the building, simple techniques such as cross ventilation, shading, orientation, reflective glazing, etc. are adequate.

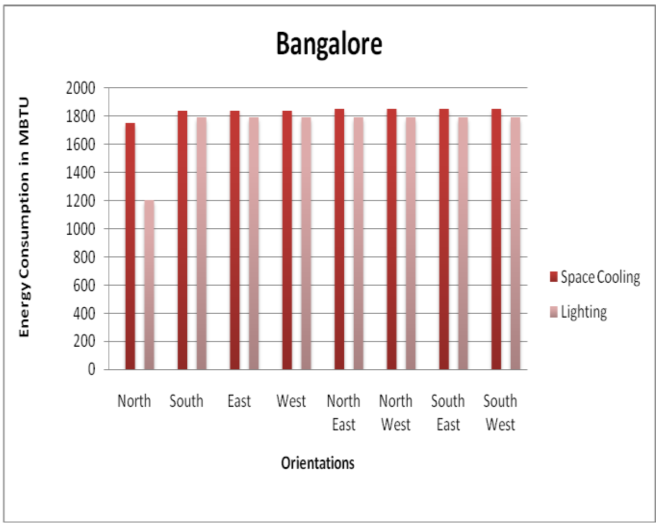

Figure 5: Energy Consumption (in MBTU) of building for different orientations in Bangalore

From figure 5, it has been observed that the building when oriented in the North tends to be most energy efficient as it utilizes 512524 KWh of electrical energy per year for space cooling alone which saves 5.64 percentage of energy as compared to the energy spent on space cooling in other orientations. With this orientation a monetary benefit of INR 18 Lac per annum can be obtained.

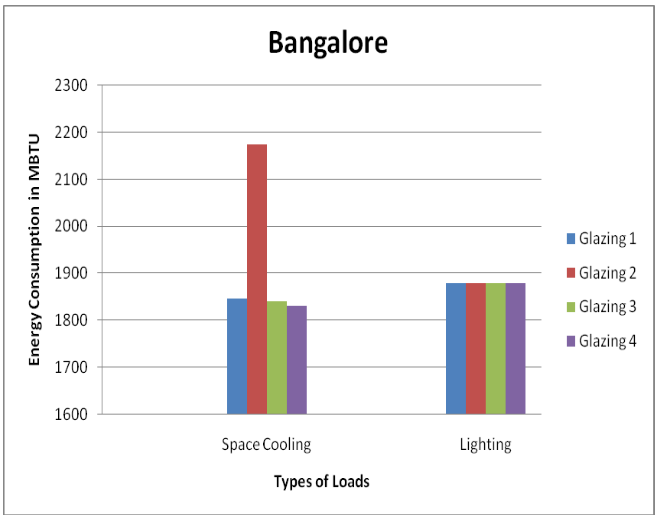

Figure 6: Energy Consumption (in MBTU) of the building in Bangalore for Different Glazing Values

Comparing the energy saving by using different types of glazing, as shown in figure 6, it can be seen that Glazing 4 is the most suitable glazing value that can be used whereas Glazing 2 is the least suitable option. But Glazing 1 is the most economical option as it can save up to INR 22.36 lac per annum. For reducing the heat gain, the placement of windows is very crucial.

The heat capacity and the thermal resistance of walls and roofs need not be high. Windows on the east, west and south must be smaller than the ones in the north. All the windows must be provided with shadings like overhangs of appropriate lengths. Low transmittance glazing should be used.

B. Chennai- Warm & Humid

Warm and humid climate is characterized by discomfort caused to persons due to high temperatures and its associated high humidity. Hence, cross ventilation is very necessary in this climatic zone. Shading can be used to ensure protection from direct high intensity solar radiation. Flexible building design plans with appropriate shading can be developed in this climatic zone as the temperature does not fluctuate a lot[3].

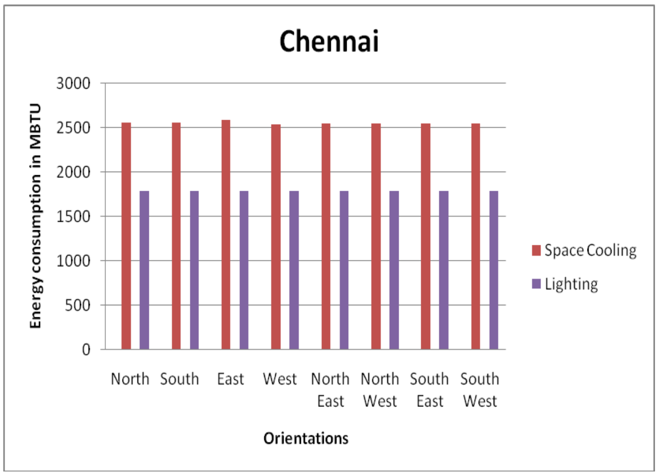

Figure 7: Energy Consumption (in MBTU) in Chennai for Different Building Orientations

From figure 7, it has been observed that the building when oriented in the West tends to be most energy efficient as it utilizes 745351 KWh of electrical energy per year for space cooling alone which saves 1.64 percentage of energy as compared to the energy spent on space cooling in other orientations. With this orientation a monetary benefit of INR 1.32 lac per annum can be obtained. Comparing the energy saving by using different types of glazing it can be seen that Glazing 4 is the most suitable glazing value that can be used whereas Glazing 1 is the least suitable option. Glazing 4 is the most economical option as it can save up to INR 1.4 lac per annum. To provide unobstructed air path for the purpose of cross ventilation which is important in hot and humid regions, the buildings are designed to be long and narrow.

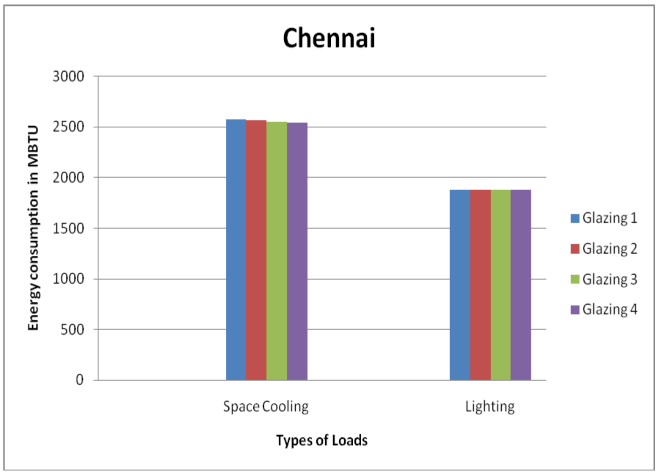

Figure 8: Energy Consumption (in MBTU) of the building in Chennai for different glazing values

To provide maximum scope for ventilation it is advisable to keep all the doors and windows open for most of the year. For control of air movement as well as to shelter the rooms from the sun and rain; blinds or louvers must be provided. Outlets at higher levels must be provided to vent hot air. External overhangs must be used to shade the openings

C. New Delhi- Composite

The characteristics of hot and dry, warm and humid as well as cold climates can be seen in Composite Climates. The longer prevailing climatic conditions are observed and recorded and used to design the buildings in this zone.

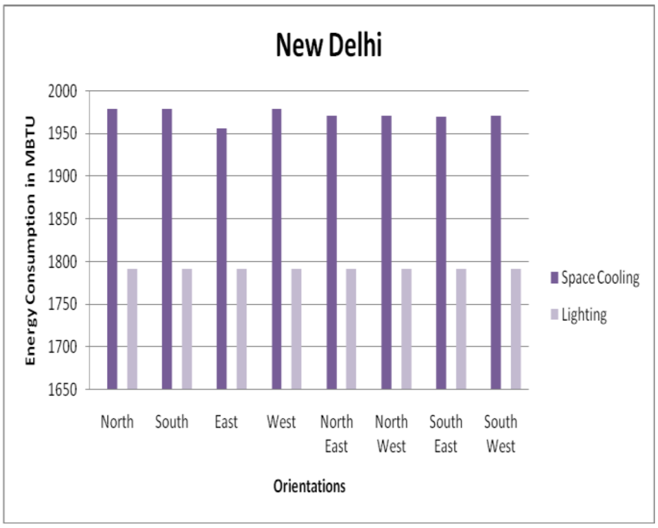

Figure 9: Energy Consumption (in MBTU) in New Delhi for Different Building Orientation

The duration of uncomfortable periods in each season are compared to obtain a suitable design for the building. As India is a tropical country, cooling takes more priority over heating and is a necessity. From figure 9, it has been observed that the building when oriented in the East tends to be most energy efficient as it utilizes 573312 KWh of electrical energy per year for space cooling alone which saves 1.12 percentage of energy as compared to the energy spent on space cooling in other orientations. With this orientation a monetary benefit of INR 1.06 lac per annum can be obtained.

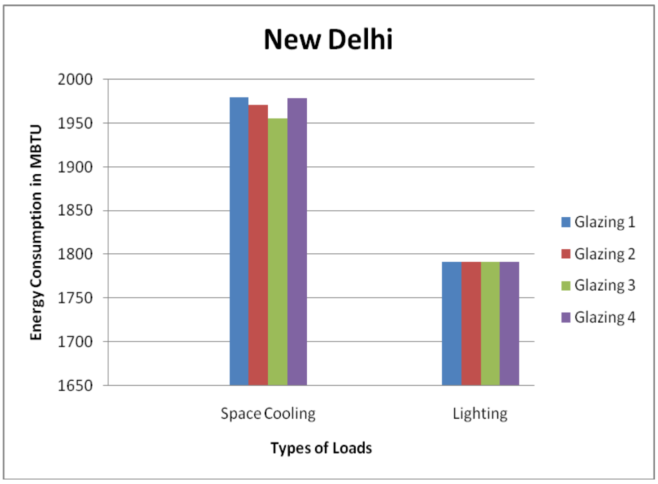

Figure 10: Energy Consumption (in MBTU) of the building in New Delhi for different glazing values

Comparing the energy saving by using different types of glazing it can be seen that Glazing 3 is the most suitable glazing value that can be used whereas Glazing 1 is the least suitable option. Glazing 3 is the most economical option as it can save up to INR 1.15 lac per annum. The general recommendations for hot and dry climates would be applicable for New Delhi for most of the year except monsoon, when ventilation is essential.

VI. CONCLUSION

Energy consumption of a building depends on many parameters, out of which its orientation and type of glazing are two such parameters. The paper studied the effect of different orientations of buildings in different climatic conditions through simulations. From the results available, it can be concluded that there is no fixed orientation for buildings which gives the best energy efficiency. The paper, through simulations also highlighted the role of glazing in energy consumption as heat load and lighting load varies depending on the type of glazing. The work, was an approach through means of simulation alone to highlight the role of these two parameters on building energy efficiency.

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