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Study of Residential Building Orientation in Energy Consumption and Assessment of Indoor Environmental Quality

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Abstract - *The orientation of the building is one of the sustainable passive ways of reducing energy consumption and maintaining Indoor Environmental quality of a building. In India, the residential sector consumes the second-highest amount of electricity. This study highlights the impact of orientation in energy consumption, Indoor Environmental quality of Residential Building and the occupant's satisfaction regarding the orientation of residential buildings in Tamil Nadu region, India. The Energy simulation for 8 different directions for the existing residential building in Tamil Nadu, India, is presented using Design Builder software with inbuilt energy plus tool. The satisfaction of occupants in residential building was identified by investigating 160 participants in Tamil Nadu region in India by using a survey. The results indicate that the orientation of the windows towards the west, the building receives a high amount of heat gain and high energy consumption. In contrast, the building with south-oriented windows receives 40% less amount of heat gains comparatively, which leads to less usage of electricity. Energy simulation results help to identify the best and worst orientation for each space. The occupants on residence with west oriented windows have the least thermal and orientation satisfaction. Thus result established that orientation has a more significant impact on energy consumption, Indoor environmental quality and occupants satisfaction.*

Key Words*: *Orientation of Buildings, Design Builder, Occupants Satisfaction, Indoor Environmental Quality, Window Orientation, Energy Simulation, Sustainable, Passive strategy.

1.INTRODUCTION

Indoor Environmental Quality represents the quality of the environment inside the building. The Indoor Environmental quality includes the health of the occupants inside the building. The IEQ of a building depends on four main factors, namely Thermal Quality- Temperature, Humidity, Indoor Air Quality-Dust, Mold, etc. Visual Quality - Lighting, Acoustic Quality- Noise. The Factors like thermal, acoustic, visual comfort and building-related factors and occupant's factors also need to be considered to provide better IEQ and to avoid health risk both long and short term, which can give inclusive environment (1). The IEQ and energy consumption also depends on the occupant's behavior and building factors as well. The factors related to building influence the IEQ of a building are design, building space, building size, amenities, location and type of building, All the elements of IEQ should be maintained to achieve a better level of occupant's satisfaction. A better IEQ of a building can reduce a building's energy consumption level.

In India, the annual electricity consumption for the year 2019 was 1,196,309 Gwh. The industry sector in India consumes the highest amount of electricity, and the household sectors consume about 24.76 % of total electricity consumption, which is the second-highest amount of consumption (2). The average monthly consumption of electricity per hour in Tamil Nadu is 90 KWh (3). The electricity consumption in a household sector depends on the climatic conditions, thermal comfort of the region. The building factors significantly affect the psychological element of occupants. The orientation of building according to the sun direction depends upon the location and typology of the building. The impact of solar radiation varies from place to place, so the location of the building decides the effect of orientation. The climate of India varies from place to place. Majority of India lies under Hot and Humid region, which has high humidity, substantial solar heat gain and significant visual discomfort, causing a high amount of glare visual discomfort, causing a high amount of glare. This ultimately increases the use of Air conditioner leads to energy consumption in buildings.

According to Arif et al. (4) the people spend more than 90% indoors, so designers need to focus on the factors of IEQ to avoid sick building syndrome, lack of visual and acoustic comfort. The environmental factors like thermal Environment, luminous Environment, and building space affect the degree of satisfaction of occupants in a building. Comparatively building space have more impact on the degree of satisfaction. (5).

Thermal simulation is one of the best ways to analyse the consumption of energy in a building. The Consideration of building parameters during the design stage could reduce the consumption of energy in a building. (6)

Several studies have analyzed the relationship between building spaces with IEQ and energy consumption. Mark et

al. (7) reported that the building envelope of retrofitted buildings tends to be air tighter and highly insulated, so overheating may occur in the premises. This paper stated that the retrofitting technologies will not always lower the energy consumption, the energy consumption also depends on the occupant's behavior. The windows orientation and Window Wall Ratio, the size of the windows and position of windows has a more significant impact on the energy load of buildings. (8,9,10). The walls and roofs have a more significant impact on building energy consumption in Anju town, and China it can reduce energy consumption by up to 54%. (11,12). The compactness of the building has a more significant impact on reducing energy, and the pavilion type building has its advantage for compactness in Hot and Arid Regions. (13). The building types and shapes can affect energy consumption in a building (13) (14). IEQ compass (15), Arduino Boards, Data Logger (16), LCL, DOAS techniques can be used to identify the poor indoor environmental quality easily. (17,18).

Other factors were also analysed in various studies. The installation of lighting control can control the lighting, and the thermal insulation depends on the location for office buildings. (19). The usage of the green wall decreases the heat consumption of up to 60% in the buildings. The green wall helps to reduce heat load in buildings. (20). Besides, ventilation type, the use of scheduled mechanical ventilation system increases air quality and reduces energy; the calibrated models provide the most cost-effective retrofitting measures. (21). The Ventilation system in the building has an impact on occupant's satisfaction. Naturally, Ventilated buildings have a strong positive impact on thermal conditions, and the occupants are highly satisfied with IEQ. The AC buildings have a negative impact on satisfaction with IEQ. But the Mechanical Ventilated buildings have both negative and positive impact on satisfaction with IEQ and cost-effective. (22,21)

Occupants' satisfaction is closely related to the IEQ of the building. An Excellent help desk can increase the level of satisfaction of occupants and positive effect. (23) The energy consumption changes with the occupant's behavior and that the IAQ has more influences the energy consumption than other factors (24).

Weather conditions and directions influence the thermal performance of the buildings. The thermal acceptance also depends on the operative temperature of the environment. (25). In summer high solar radiation produced high external surface temperatures on the roof, eastern and western walls and was limited on the north-facing wall. In winter, the heat on the east and west was decreased. The solar radiation in the south wall is very low on both conditions. (26). The orientation of windows plays an essential role in the energy consumption of buildings. (27,28,9). The appropriate use of daylighting and shading technology, along with orientation, can reduce the energy consumption of a building (29).

Energy consumption can be evaluated using Energy Simulation software. Several studies have experimented factors like Orientation, WWR, Insulated Buildings, Daylight factor, building typology established its relationship with energy consumption using software like Design-Builder (11,12), Energy plus (9), Revit, Ecotect, GBS. (30,31,32,33)

To date, several studies have investigated the effects of orientation of building in energy consumption, but mostly the studies were on the buildings located outside India – Australia (26), Europe (27), China (11), Libya. (9). However, Prior studies have concentrated mainly on commercial buildings like office spaces. There is also a lack of studies on occupant's satisfaction and energy consumption related to the orientation of Residential Building in India.

The main objective of the study is to analyse the impact of orientation in energy consumption and Indoor Environmental quality of Residential Building using Energy Simulation tool (Energy Plus). The study will also analyse the occupant's satisfaction regarding the orientation in residential buildings. The study is limited to the Tamil Nadu region of India. The sample of 160 people from Tamil Nadu is considered for the study. The selected residence for present study simulation had it's all opening on one side; this made it more comfortable to analyse the effect of solar radiation, heat gain, temperature depending on orientation.

2. METHODS AND MATERIALS

The study has been carried out in two parts. The first part of the study includes the Energy simulation related to its orientation of a building in Tamil Nadu, India, using Design Builder software. The second part of the study focuses on occupant's satisfaction in residence by using a questionnaire survey.

2.1 Modelling and Simulation

2.1.1 Case Study Details

A Residential building located in Nagapattinam, Tamil Nadu, India is selected for the study. The building is a three-storey building. The area of the residence is 110.7 sq.m, the age of the residence is 20 years. The latitude and longitude for the site are 10.77, and 79.80 respectively. The elevation of the site is 9m above sea level. The orientation of the building is North (i.e.) having its façade on the south, with all its windows facing the west side, the east and north side have buildings, and the west side is vacant. The south side has a narrow lane of 3 meters. The building was a typical Indian brick construction, and it is plastered and painted on both sides. The external wall is 9 inches, and the internal wall was 4.5 inches. The roof slab is 6 inches thick. The living area and the hall area have marble flooring, and the other areas have vitrified tile flooring of 2' X 2'.All the windows are single glazed with a wooden frame. The equipment, Lighting, HVAC

used in the building was noted, along with its schedule details.

2.1.2 Design builder & Energy plus

To assess the energy simulation in residence the Design-Builder software with inbuilt energy plus tool, which is effective energy simulation software. The drafted AutoCAD plans of the case study building were imported in Design builder software, and the zones were created using internal partition walls.

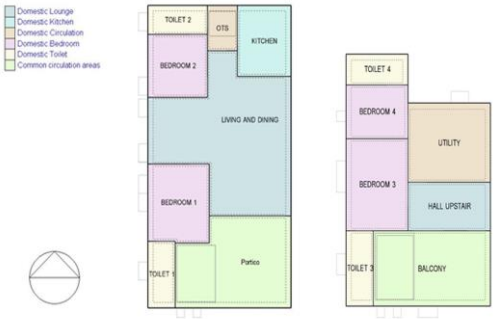

Fig -1*:* Zones according to Activity in Ground & First floor

All the collected data's regarding Location; Construction was loaded in the model. The model was divided into zones according to its usage and type. The Activity for each zone was created with their own schedules. The HVAC was scheduled according to the usage of the occupants, size of AC. The Equipment's and Lighting in each zone were loaded according to the duration of usage. The weather data for the location was downloaded from energy plus website.

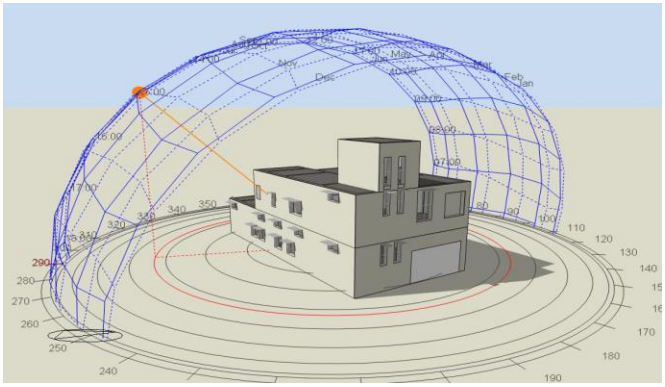

Fig -2*:* Simulation Rendered view in Design Builder

The simulation with output settings was updated in the simulation tab to analyse the energy in the building. The orientation of the site was updated from 0 to 360 degree, to obtain the energy consumption for 8 directions.

2.1.3Validation of Simulation:

The simulation results were verified with real-life data. The building was simulated for the North orientation, (i.e. the building has its main façade facing south), the energy consumption (in Kilowatt per hour) of the building was noted. The electricity bill for the year 2019, which was collected for the building, used for verifying the energy consumption result.

2.2 Questionnaire Survey

A questionnaire was prepared regarding occupants' satisfaction in residential buildings using google forms. As the climatic condition in India varies from place to place, the location of the participants (response only from Tamil Nadu) used as a basic parameter to filter out the responses. The questions like the residence type, the orientation of the house and windows were set as base questions. Questions related to solar radiation gets inside the windows due to the orientation was asked to explore the people's perception and thoughts on the direction. The satisfaction on thermal comfort, ventilation, orientation was asked to rate on scale of 1 to 5 in Likert scale.

2.3 Results and discussion

2.3.1 Results of Energy Simulation

The result of electricity consumption for the actual orientation simulated was 7643.27 kWh. The actual electricity consumption of the building was 7660 kWh. The simulated result was significant as it was under the accuracy of ± 5%. The simulated energy consumption in residence in kWh for eight directions was converted to electricity rate using TNEB unit rates tariff. The building rotated to 270 degrees, and 90 degree which is west and east direction consumes less energy comparatively. The difference between the Northside (Westside windows) and Westside (Southside windows) is INR .931.84, and the difference between the north side (West side windows) and east side (Northside windows) is INR 911.56.

Table -1: Calculated EB bill for simulated 8 directions.

Directions	Calculated EB bill in INR
North	27258.33
South	27067.01
West	26326.49
East	26346.77
Northwest	26862.77
Northeast	26843.93
Southwest	26774.86
Southeast	27012.07

The difference in energy consumption is due to solar gain and temperature inside a building. The heat gain inside the building is low when the building has its windows on North and Southside.

The Average of solar gain through windows on summertime (April – June) and the winter times (December and January) was considered to find the best and worst orientation of each zone.

Table -2: Cooling Loads in KWH of Bedrooms in 8 directions.

Bed	N	S	W	E	NW	NE	SW	SE
1	114.5	112.9	106.9	107.7	111.1	112.5	110.3	111.3
2	96.0	97.2	94.5	91.9	95.9	93.3	96.1	94.8
4	96.0	97.2	94.5	91.9	95.9	93.3	96.1	94.8

Table -2: Average Solar Heat gains through windows in W for Air-conditioned bedrooms

Spaces	N	S	W	E	NW	NE	SW	SE
B-1	53.	45.3	38.5	33.2	48.6	43.4	42.2	39
B-2	37	31.6	26.1	21.8	33.9	29.0	28.7	27
B-3	57	48.2	39.7	34.0	51.3	45.0	44.3	41
B-4	17	14.7	13.0	10.5	16.2	12.9	14.0	13
Living	105	89.5	75.6	65.5	95.6	85.5	83.6	77
Kit.	2.7	2.7	2.6	2.6	2.7	2.66	2.71	2.7

Living room - The Living room, facing west and east direction, which has the windows facing south and north direction allows the least amount of sunlight during summer times. There is 41.95% decrease in solar heat gain comparing to windows on west side oriented living room. Southwest having northeast directed windows also permits the least amount of comparatively. Overall, living room oriented towards the south, southeast with same side windows will be a better option. The second-best choice for the living room would be Northside with North facing windows. The worst orientation for the living room will be west and southwest with same side-oriented windows should be avoided.

Kitchen- The most used space in the residential building is Kitchen in India, so the thermal comfort inside the area should be maintained. The actual orientation of the Kitchen is northeast, having windows on the Northwest side. The best orientation for the Kitchen would be the south and east direction. The orientation which should be avoided for the kitchen area is Northwest, Southwest, and West having same oriented windows.

Bedrooms- The bedrooms oriented with south-facing windows receive 40% less solar gain compared to the bedrooms with west oriented windows. The best direction for the bedroom, which was analysed are East, Southeast, Northeast, and the next best orientation is North. The direction which should be avoided is West, Northwest and Southwest.

2.3.2 Results of Questionnaire Survey

The results of the survey were imported from google forms to excel. The orientation of building and orientation of windows were considered as the base parameters for the evaluation. The command "count if" was used for the cross analysing the questions. In total, 160 responds, the response with north side windows were 26, south side-25, west side-57, east side-38, Northwest-2, Northeast-6, Southwest-3, Southeast-3.The factors of IEQ were analysed according to the orientation of windows.

As a result, North and south concerned about the Air quality, West and Northeast concerned about Thermal Quality, the visual and the Noise were least concerned. As a result, about 65% of people who has the windows on the west side, feeling thermal discomfort due to their orientation of windows/house.

Table -3*:* Satisfaction Analysis according Window Direction.

Direction of House	Thermal Satisfaction (Least) (Direction of windows)	Ventilation Satisfaction (Least) (Direction of windows)	Orientation Satisfaction (Least) (Direction of windows)
North	West	West	West
South	West	West	West
West	West	West	West
East	Nil	Nil	Nil

The satisfaction rates of ventilation, orientation, thermal comfort was cross analysed with the orientation of windows for 8 direction of the house.

The other four directions (Northwest, Northeast, Southwest, and Southeast) have the least number and neutral type of response. The result of the analysis shows that despite the orientation of the building, the direction of windows affects more. The west side facing windows have more impact on thermal satisfaction and ventilation satisfaction and orientation satisfaction. People with west-facing windows having significant discomfort on thermal factors inside the residence.

At the end of the survey, people were asked about their opinion on installing new technologies. About 81.25% responds were opted to invest in new technologies, namely Thermal insulation, Air cavity and External shading devices. The External shading devices and Thermal insulation have been opted by 23% and 23% of the respondents, respectively.

Comparing the result of the survey with the result of the energy simulation, buildings in the Tamil nadu, India region should consider the orientation of windows, as the amount of solar radiation can increase the heat gain inside the building. It can lead to higher usage of the air conditioner, ultimately leads to an increase in the energy consumption of the building.

3. CONCLUSIONS

The results show that the orientation has a more significant impact on energy consumption in buildings.

1.The results of Energy Simulation confirms that there is a reduction in energy consumption when there is a change in orientation. The actual building has all the windows facing west direction, so there was high solar heat gain, which ultimately leads to high usage of electricity for an air conditioner during summer times. When, the orientation of the building is west, with all the windows facing the south direction, the building received a very least amount of sunlight and thus led to less energy consumption.

2.The results of the questionnaire survey examined that the orientation of house and windows affects the thermal comfort of the occupants. The occupants on residence with west side faced windows receives a maximum amount of sunlight and leads to having the least satisfaction on orientation and Thermal comfort.

Overall, the finding suggests that the orientation should be considered to reduce energy consumption in buildings. These results suggest that to avoid west-facing windows. This study strengthens that idea of orientation- a passive technique, in energy consumption, Indoor Environmental Quality and Occupants satisfaction.

The present study analysed the residence with a window opening on only one side; further studies can incorporate residence with openings on all sides to analyse, the effect of solar radiation, heat gain, temperature depending on orientation. More broadly, research also needs to determine the effect of orientation along with other building factors namely Size, Shape, Age, Number of floors, Window Wall Ratio etc. and other IEQ factors like Indoor Air Quality, Acoustic and Visual factors.

Further work needs to investigate regarding incorporating technologies along with the orientation to reduce the energy consumption in buildings. As implementation of technologies like Thermal Insulation materials and External shading devices are possible in existing buildings to reduce heat gain and energy consumption.

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