Analysis of a Structure for Efficient Energy Utilization Using Design Builder

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Abstract. A major concern for the Indian Construction industry is its negligence of energy efficiency aspects of the various building projects being undertaken nowadays. Moreover, it is a concern for the citizens as well. Heat island and climate change phenomenon has led to a massive increment in the ambient temperatures, intensified reliance on energy resources, created discomfort conditions. By 2030, India's dependence on energy imports is expected to exceed 53% of the country's total energy consumption [5]. As growth is inevitable, a multifaceted and scalable solution is needed to temper the environmental impacts of growing cities. The growth in the cities leads to hot urban environments. The temperature variation between urban areas and adjacent rural areas is called the “heat island phenomenon”. It is found that the heat island phenomenon triples the peak electricity demand, doubles the building’s cooling load, and reduces the mechanical cooling system’s coefficient of performance by 25% [5]. To ease our lives in such a climate we need to invent the cooling techniques and those too are energy and cost-efficient. Many of the environmentalists and architects are putting forward their contributions toward it, suggesting solutions to make use of more and more sustainable systems of energy not like those being practiced in earlier times like courtyards and cavities but newer techniques which merges out with the present form of architecture, few of which are namely, the green roof techniques, terracotta pot, outdoor cooling systems. In this paper, we have analysed the Academic Block 4 building of our college and estimated the size of an outdoor cooling plant based on weather data, occupancy, and constructional details of the building such as heat absorbed by various facades due to internal and solar gains, etc

1. INTRODUCTION

Analyzing the building from a structural point of view and ensuring the safety of various joints, beams, columns, slabs is an important task in construction but, these days due to rising environmental atrocities and phenomena like heat island and climate change analyzing the buildings from an energy efficiency point of view is also very important. It ensures less amount of energy consumption during the lifecycle of the building and fewer emissions consequently. Energy efficiency analysis is also important in getting LEED (Leadership in Energy and Environmental Design) and GRIHA (Green Rating for Integrated Habitat Assessment). Considering India especially, which has a hot climate for major duration of year and keeping in view the kind of architecture being practiced here one can easily predict that there is a great demand for passive or energy efficient cooling techniques. Design Builder is an Energy Plus based software tool used for energy, carbon, lighting and comfort measurement and control. Design Builder combines the fast three-dimensional building modelling with dynamic energy simulations along with its unique simple use. It is considered a novel software tool to make and evaluate building designs. Energy Plus
is a modern building performance simulation program that combines the best features from BLAST and DOE-2 along with some new capabilities [2].

We first created a model geometry of the building under analysis i.e. Department of Civil Engineering of JSS Academy of Technical Education. Weather data depending upon the location of the building was assigned to the structure for realistic analysis. The dimensions of the various facades, constructional details such as wall thickness, type of bricks, mortar, paints used, and windows openings were properly set up in the model in the most realistic way for obtaining accurate results from the simulation.

For creating the model geometry, we used Design Builder and for running the simulations and estimating the size of the cooling plant we used Energy Plus as the simulation engine. Design Builder allows complex buildings to be modelled in a simple fast way even by non-expert users. Design Builder is the first and most comprehensive program that creates a graphical interface to an Energy Plus dynamic thermal simulation engine. This graphical interface makes the design of the buildings, their energy performance, and CFD simulations allow them to be displayed in 3D to provide support for examination. Design Builder uses the latest version of the Energy Plus simulation engine for calculating the energy performance of buildings. The resulting data can be filtered as desired and presented in graphs or can be exported in tabular format for use in other applications.

**METHODOLOGY:**

Before starting to make the model geometry we had to set the site location so that weather data such as outside dry bulb temperature, humidity, solar gains, etc. which would be useful in the energy efficiency analysis can be assigned to our model.

Design Builder provides inbuilt weather data files that can be imported into the model from the libraries or these files can be downloaded from the internet as well. In this case, we have used an inbuilt weather data file of New Delhi – Safdarjung as this place is close to the building, we have analysed and has similar weather, similar sunrise and sunset timings, similar day and night temperatures for accurate results.

Using the different tools available for creating the geometry of the building we created a 3D model of Academic Block 4 which would be used for simulations further.

![Figure 1: Model Geometry - Academic Block 4 building](image)
Then in the next step, the constructional details of the various building components were customized and assigned respectively to the components. For example, in the picture below we can see the constructional details of the external walls of the AB4 building showing wall thickness, plaster, and paint details.

Figure 2: Constructional details of exterior walls

Figure 3: Constructional details of partition walls.

Figure 4: Floor slab details.
Figure 5: Details of a window, door frames

Different building materials have different tendencies to absorb, emit, or retain heat. How well a building material resists or conducts heat is judged based on R-Value and U-Value respectively. R-Values are additive for layers of materials. The higher the R-Value the better is the thermal performance of the material. Similarly, low U-Values indicate high levels of insulation. Analysing the building materials based on these values is a useful way of predicting the composite behaviour of an entire building element rather than relying on the properties of individual materials.

Based on the materials used the R-Value of external walls was found to be 0.582 meter squared kelvin per watt and the U-Value for the same was 1.718 watt per meter squared kelvin. The U, R-Values of internal partition walls were found to be 2.143 and 0.467.

Similarly, the details of windows such as window to wall percentage, the height of windows from the ground, type of glass used in windowpanes and its thickness, opening and closing schedules of windows, etc were set up:
The occupancy density and the number of days per week the building would be occupied is also set up by the ‘Activity Tab’. Metabolic activities also affect the heat gain in a building due to the heat released in the form of carbon dioxide in the process of metabolism taking place within the occupants of a building.

Other important parameters that can be set up using this tab are the environmental controls such as the heating and cooling set-point temperatures and gains through office equipment and computers which play a major role in the design of a cooling plant and analyzing the heat gains because they release heat.

This completes the data entry portion for our model. After this step, we ran simulations and cooling design calculations for sizing the cooling plant. We have carried out the calculations for summer design day which is supposed to be the hottest day of the year so that results automatically fit in and be valid for other days of the year.
RESULT AND CONCLUSION:

Table 1: Cooling Design Calculations for 15 July (hottest day of the year for our site location)

| Zone                                      | Design Capacity (kW) | Air Temp (˚C) | Time of Max Cooling | Max Op Temp in Day (˚C) | Outside Dry-Bulb Temperature |
|-------------------------------------------|----------------------|---------------|---------------------|-------------------------|-----------------------------|
| Ground Floor: Surveying X Geology Lab    | 24.23                | 23            | Jul 16:00           | 27.1                    | 41.6                        |
| Ground Floor: CAD Lab                    | 25.35                | 23            | Jul 10:00           | 26                      | 38.6                        |
| Ground Floor: BMC and Transportation Lab | 24.18                | 23            | Jul 16:00           | 27.2                    | 41.6                        |
| Ground Floor: Geotechnical and Environment Lab | 22.58            | 23            | Jul 10:00           | 26                      | 38.6                        |
| First Floor: Seminar Hall                | 42.8                 | 24            | Jul 15:30           | 29                      | 41.9                        |
| First Floor: Computer Desks              | 9.4                  | 24            | Jul 14:00           | 28.1                    | 42.2                        |
| First Floor: Senior Professor Office     | 7.5                  | 24            | Jul 09:00           | 29.1                    | 36.9                        |
| First Floor: HOD Office                  | 7.56                 | 24            | Jul 09:00           | 29.2                    | 36.9                        |
| First Floor: Department Library          | 18.72                | 24            | Jul 14:00           | 28.2                    | 42.2                        |
| First Floor: Presentation Room           | 14.64                | 24            | Jul 09:00           | 29.3                    | 36.9                        |
| First Floor: Staff Room                  | 33.51                | 24            | Jul 15:30           | 29.1                    | 41.9                        |
The final rendered image of the model created with the help of Design-Builder is shown below:

![Final rendered image of AB 4](image)

**Table:**

| Second Floor: Room 204 | 17.92 | 23 | Jul 14:00 | 29.0 | 42.2 |
|------------------------|-------|----|-----------|------|------|
| Second Floor: Room 202 | 21.84 | 23 | Jul 09:00 | 29.5 | 36.9 |
| Second Floor: Room 206 | 23.72 | 23 | Jul 16:00 | 30.1 | 41.6 |
| Second Floor: Room 205 | 23.68 | 23 | Jul 16:00 | 30.0 | 41.6 |
| Second Floor: Room 203 | 17.74 | 23 | Jul 14:00 | 28.9 | 42.2 |
| Second Floor: Room 201 | 21.89 | 23 | Jul 09:00 | 29.5 | 36.9 |
| Overall                | 357.26 |    |           |      |      |

The final rendered image of the model created with the help of Design-Builder is shown below:

![Final rendered image of AB 4](image)

After carrying out the cooling design calculation for the design summer day i.e. 15 July the size of the cooling plant was estimated to be 357.26 kW or 102 tonnes. Keeping in mind the relation:

\[
1 \text{ tonne} = 3.504 \text{ kW}
\]

A design margin of 15% is included in this result keeping in mind extra occupancy or extremely hot weather conditions which may develop accidentally.
These energy calculations were done by the EnergyPlus simulation engine incorporated in the software.

Figure 9: Graph of Variations of various gains and cooling with time.

This graph shows the variation of solar gains and internal gains to time for the Ground Floor CAD Lab. The yellow line represents the solar gains through the exterior windows. We can see how it starts from a point of time when the sun rises and continues to go up till the cooling plant is turned on as per the schedule. As the zone sensible cooling i.e., the blue line increases the solar gains decrease which can be seen by the downward slope of the yellow line. The heat gains due to various types of equipment such as computer systems, fans, etc. can be seen to remain at a fairly constant value throughout. These loads ultimately go down along with the gains due to occupancy when the building starts getting evacuated by the occupants after 4 o’clock in the evening.

Figure 10: Graph of Simulation results for a design summer week.

Here, we can see the variation of various internal gains such as solar gains, heat gains due to various appliances such as fans, bulbs and tube lights, computer systems, and other laboratory machines such as electric oven and other testing machines for one week. It is evident from the graphical data how the gains remain fairly constant or tend to follow the same pattern for five days of the week i.e. two peaks of solar gains in the morning and evening respectively whereas lesser gains are seen while on the sixth
day as the building is occupied or is in use for a lesser time duration the graph’s peak at lower levels. Other gains such as lighting and equipment rise steadily during the start of the day as these things are turned on and attain a constant level and then again go down as they are turned off in the evening. On Saturday lesser occupancy is seen due to half-day hence a reduction in gains is seen along with the cooling loads. On Sunday only solar gains can be seen as the building remains unoccupied and computers and other appliances are not in use for the whole day. It is important to note that the line representing zone sensible heating remains flat throughout because we have not provided a heating plant since it was not necessary as per the weather conditions and requirements.

The above graph is for design summer week which means the results would not exceed these values for any other week during the rest of the year. Hence, reliable data is generated using the simulation techniques. Also, by analyzing the different gains through the simulation results we can determine the areas where which we can tackle to reduce the gains and make our cooling or heating plant extra energy and fuel-efficient.

Figure 11: Sun-path diagram for a random instance.

The above sun path and shadow diagram is for 1 June 2:30 pm. We can see the shadows generated due to the position of the sun and also analyze through these diagrams which portion or façade of the building experiences solar gains at what time and for what duration of time. Various such diagrams can be generated with the help of the software corresponding to different dates and times of all the months in a year for an effective analysis. These diagrams help in designing the overhangs and side fins for the external windows of different facades.

USEFUL CHANGES WHICH MAY LEAD TO ENERGY EFFICIENCY:

With the help of these sun-path diagrams for different months of the year we can see that the major solar gains are experienced by the front, top, and rear façade of the building. In the previous simulations and cooling design calculations and investigations, we have found out that the major gain in the building is solar gain. Hence, to reduce the solar gains and consequently reduce the size of the cooling plant for better economics we would suggest that external blinds be used on these walls or window glazing be reduced from single to double glazing of vacuum type.

Double-glazed windows have two glass panes set parallel to each other in such a way that there is a little space or air column between them which acts as an insulating layer. Double glazed windows are essentially two panes of glass with a vacuum between them. The trapped air creates insulation that prevents heat loss or gains through the window because the air temperature cannot penetrate the vacuum and therefore bounces back. From our analysis, we could conclude that Double glazed
windows cut down heat gains/loss by 30% in comparison to single glazed windows. Standard B rated double glazing saved four to five thousand rupees per year in cooling costs.

It was also noticed that providing a green roof instead of providing only the normal concrete slab also improves the energy efficiency of the building to a noticeable extent. Green roofs improve the microclimate by cooling and humidifying surrounding air. This cooling effect significantly increases the performance of air conditioning systems and reduces carbon emissions. It also binds dust and toxic particles such as smog; it also helps in rainwater retention. It protects the roof membrane and its waterproofing layer. While using a green roof in the analysis it was seen that temperature variations were reduced up to 4-5 degrees Celsius. Approximately 100 tonnes/year of carbon emission was reduced. A significant fall in air conditioning loads in summers was seen but not much difference in monsoons was observed in cooling loads.

The analysis of shadows generated on various facades with the help of sun path diagrams helps us in deciding the size of overhangs and side fins of windows in such a way that for most of the time the facades remain in shade and consequently lesser heat gains leading to lesser consumption of energy can be observed ultimately increasing the efficiency of the air conditioning system of the building.

CONCLUSION:
From the results it is evident that it is extremely necessary to realize the importance of energy prospects of a building rather than only concentrating on and ensuring the structural safety and serviceability. It is necessary to state the useful role played by software in making our analysis easier and faster during calculations. Learning software like this always helps in the long run in terms of carrier growth and making effective analysis for educational purposes as well. We conclude that we have learned how to analyze the simulation results and developed a better understanding of it during the course of our work. Through our investigations and studies, we have designed the capacity of a fully functional cooling plant for the Academic Block 4. Also, our analysis has led us to a place from where we have suggested what useful changes in the construction of the building can be made to make it more energy efficient i.e., use less amount of energy for the same or a better output. Also, having faced the wrath of itchy and tiresome summers while attending lectures in the building due to the absence of cooling systems, we realize the necessity of conditioning and energy needs. This project made it possible for us to give back something valuable to our department and faculties and also provide for a comfortable environment by showing that an energy and cost efficient cooling system is possible to be installed in the Department of Civil Engineering, Academic Block 4.

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