

# Retrofitting The Atrium Of CST Adm Building: To Achieve Optimum Thermal Comfort.

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## **Abstract**

Energy efficiency and renewable energy have become the twin towers of sustainable development and this ultimate goal can be achieved only if the energy conservation at all levels is efficiently practiced. Energy consumption is the world's growing concern with building sector topping the energy consumers list. The buildings with its HVAC (Heating Ventilation & Air Conditioning) components and other mechanical system have become one of the world's largest energy consumers. The building envelope evolution have shown that the wider scope of façade system and glazing options, have further led to solar responsive challenges & massive energy loss. In College of Science & Technology, there are many active means of cooling installed at every corner of the building due to its location and extreme summer heat. Atrium at the east-front of ADM building have necessarily failed in regulating diurnal temperature due to its extensive glazing ratios and areas exposed to the direct sun rays. This research is an attempt to intervene the space: at structure as well as material level to maximize its thermal comfort during daytime through a simulation approach.

**Key words** – *Retrofitting, Building Envelope, Energy Efficiency, Thermal Comfort, LoE272*

## **Introduction**

Energy is the basis of life on earth. All activities on earth are necessarily associated with energy in various forms. The consumption of energy has become a worldwide concern with advancement in new technologies and services. Dempsey & Bramley (2012), explained

energy efficiency as means to minimize the quantity of energy load to provide comfortable indoor spaces. Moreover, some further studies carried out in U.S shows that the U.S. buildings sector accounted for approximately 41% of United States primary energy consumption in 2010; more energy than any other end-use sector. Residential and commercial buildings were responsible for 22 quadrillion Btu (quads) and 18 quads of energy, respectively. In 2010, 43% of U.S. residential building energy consumption (equal to 9.5 quads of energy) was consumed for space conditioning, including both heating and cooling.

This concludes that the building sector consumes energy far more than any other sectors. Let's forget others and come to this peaceful carbon negative country where: In 2014, Bhutan consumed 650,220 TOES (Tone of Oil Equivalent is amount of energy released by burning 1 ton of crude oil) of energy (Bhutan Energy Data Directory, 2015). The maximum energy consumption was noted in the Building and Industry sectors with 78.8% of the total consumption. The Building sector consumed 270,356 TOES while the Industry sector consumed 241,972 TOES. Concluded that 41.5% is consumed by building sector.

The buildings in Bhutan are becoming more active energy oriented than energy efficient one. So, the issue is right into the structure where this work is focusing. So, it is always few steps ahead towards the energy efficiency if we make suitable solutions and interventions. Energy efficiency and renewable energy are said to be 'twin pillars' of sustainable energy policy (Brundtland Commission, 1987). So, in the right sense sustainable concept can be achieved along with energy efficient design.

Retrofitting of an existing building of any function is one of the methods to revive a space with energy and air-quality problem. According to Dascalaki & Santamouris (2002), the results of the works carried out by architectural and engineering groups to retrofit office buildings shows a cost-effective energy savings in the order of 20–30%. Retrofitting can improve the energy performance of a building. Retrofitting actions, according to Dascalaki & Santamouris (2002), involves interventions on the main energy-related aspects of the building, its outer envelope and installed systems for heating, cooling, ventilation and lighting with a simultaneous incorporation of passive

systems and techniques.

## **Problem Statement**

It was quantifiably stated in a student energy survey report, that the administration building alone demands a total energy of 21.1567 tons yearly, while its energy consumption exceeds by 36.41 tons with 46.63 tons as a current requirement. Many possible ACs (Air conditioners) have been installed and most prominently the atrium design which was to serve both thermal as well as visual comfort have failed its purpose. Many interventions were discussed and maintenance had been a serious issue with its cross heights and uncontrolled glazing towards the east façade. Hence, this research is a simulation-based attempt in intervening the existing envelope with suitable recommendations.

The building is designed with a glass facade in the three sides of the atrium through which solar heat is gained during the day time. It is being exposed to the sun for most times of day as the glass façade through which the solar heat is gained is facing south-east direction. Hence, the spaces of the atrium are found to be hardly used as it is normally very hot and humid. According to Hestnes & Kofoed (2002), the passive cooling scenarios include building envelope and structural measures. These measures are replacement or reflective coating of windows, use of solar shading systems, and exposure of thermal mass. Active cooling measures such as natural ventilation, the use of ceiling and chimney fans, and indirect evaporative cooling are also some other measures for retrofitting buildings (Hestnes & Kofoed; 2002).

## **Aims and Objectives**

The purpose of this research is to study and propose suitable retrofitting methods for the reduction of thermal heat gain through the glazed façade of administration building at College of Science & Technology (CST) facing east. It is an attempt to intervene the atrium at structure and material context to optimize its solar heat gain during peak hours of the peak seasons. Objectives of the research are, firstly to identify the parameters of energy performance in the building envelope system of the atrium. Energy performance parameters of the building

are the design determinants which are directly or indirectly involved in the solar heat gain. Secondly, to investigate the energy performance appraisal methods and document their application. Energy appraisal methods include the suitable methods of reducing solar heat gain through both structural as well as material approaches. The third one is to simulate and assess the atrium on the thermal gain and loss. Simulation and assessment procedures include the comparison of average temperature distribution in the space after and before the simulation. Fourthly, propose feasible solutions based on the simulation results and analysis. Based on the feasibility and real-time scenario, propositions have been made to optimize the solar heat gain. Finally, to validate the proposed solutions in terms of solar heat gain and loss. Validation of the data refers to the comparison of the simulated data with the general requirement of space.

### **Research Methodology**

In order to accomplish research aims and objectives, the process followed are: Identification & investigation of the energy performance parameters (Data collection & Analysis). The task is to: determine energy performance parameters for the building envelope, categorize energy performance parameters for the building envelope, define sub parameters relevant to the specific performance for each category of performance parameters. Determine interactions and relationships among performance parameters.

The task is to check on the energy performance parameters for the building envelope: define the decision issue with identified data and values, conduct feasibility study of the appraisal methods, analyze the existing model and conduct proper design interventions, experiment and compare suitable materials for the minimum thermal gain, simulation and proposition of the thermally optimized model (Data evaluation & recommendation). The task is to: Simulate the existing and proposed model, identify an appropriate software for the simulation. Explain all the necessary considerations: weather, solar angle, orientation and time of the simulation. outline the detail requirements of the software and for energy modelling, define the basic properties of the respective model and its detailed materials required for the

simulation, perform simulation based on the real time decision and factors, propose a suitable intervention model, perform comparative study of the existing and proposed model, Recommend a suitable design for the atrium.

## **Research Scope**

The primary contribution of this research is the suitable interventions made at both structure as well as material level to improve the thermal comfort of the space. The atrium with its east facing façade has full glazing surface and a suitable intervention is necessary. This research will explore all the suitable means of modifications to minimize its thermal gain.

The proposed model will be within the scope of energy modelling and building simulation based on a BIM (Building Information Management) compatible software known as Ecotect. A wide range of studies based on building envelope system, its evolution, design determinants and parameters to carefully examine its situation will be laid out.

## **Literature review**

### **Building Envelope**

An enclosure of space or a built environment, which includes walls, roofs, skylights and other fenestrations, (Gireendra Kumar & Gaurav Raheja, 2016) are called as building envelope. It can be further categorized into two different components and they are transparent & opaque components. Transparent component includes windows, glazing portions, skylight, ventilators, doors that are more than one half glazed, and glass block walls. The opaque components of the building include opaque doors, walls, roofs, slabs, basements walls

### **Role of building envelope.**

The role of building envelope has become significant as the parts form the exposed surface of the building to all the agents that directly or

indirectly affects heat flow to the space. International Journal of Research and Analytical Reviews, in India have shown 20-40%, energy saving with integration of energy efficient design and moreover it has projected 120-160 kWh, reduction from 200 kWh. Hence, the role of building envelope in energy consumption plays a vital role and its thermal performance can be linked directly to the energy saving potential

### **Typologies of Building Envelope**

In broad sense a building envelope can be generally opaque or transparent but to study the behavior of the envelope a building envelope consist of two parts:

- Single skin facade building envelope
- Double or multiple skin façade building

Single skin building envelope include single enclosure, the basic wall which provide enclosure from the surrounding. This type of building simply has walls with fenestrations and roof with inclusion of skylights. When the single layer of the wall is flanged with more layers than it becomes double or multiple skin façade building. They are usually adopted to create a thermally stable building cover system for it have to explain its sustainable and energy efficient means. In some research papers there is another building envelope system and that is the complete enclosure type envelope and very good example can be the 'mount Cenis Training Centre' located at Herne-Solingen, Germany. This enclosure can synthesis its required energy process within itself and it as well as pioneers the 'micro climatic envelope.

### **Data Collection**

#### **Location**

According to climate-data.org (2019), Phuentsholing is located in a sub-tropical region with a latitude: 26° 51' 5.90" N and Longitude: 89° 23' 18.13" E. The building is located in CST campus Rinchending,

Phuentsholing. It is the administration building of the college.

### Climate & Rainfall

Phuntsholing has warm and temperate climate. Summer receives much more rainfall than in winter. 23.2 degree celcius is the average annual temperature of Phuntsholing. Phuntsholing receives 4383 mm average rainfall annually (Climate-Data.org, 2019). December with 8mm rainfall is recorded to be the driest month of the year. The precipitation reaches its peak in july month with 1154 mm of average rainfall.

### Building Orientation

The atrium of the building has a complete glass facade on east i.e. on entrance side of the atrium and 62% of the southern façade is completely glass covered while 48% is brick wall. Likewise 62% of its northern facade is built of glass while other 48% is of brick wall with ACP(Aluminium Composite Panel) panel cladding. The plan below shows the orientation of the building clearly.



Figure 1. Contextual site plan showing its alignment along the North axis

## **Solar Study**

The figure 2. shows the direction of sun during its course of the day. The sun rises at the eastern façade and the glazing area is completely exposed to the morning sun and gets shaded when the sun crosses noon. The sun path and its azimuthal angle as well as the vertical angle as maximum and minimum is very important in the intervention as the solar heat gain is directly related with the intensity of its incident solar rays. Solar radiation can be of diffused from the surrounding via convection and radiation but more significantly the glass façade as an exposed transparent medium forms a critical layer in all sorts of solar heat transference.

## **Temperature Study of the Space**

Owing to the geographic location and the climatic conditions of the site, the weather conditions of the site is very warm and humid. The exterior glazing used as a building envelope is the main source of heat gain in the spaces of atrium, which is not required in this condition.

The temperature recorded by the device (OM-EL-USB-2) installed shows that during the morning and evening, the temperature of the office and the adjacent corridor is higher than the spaces of the atrium. However, during the mid-day, from about 11:00am and 2:00pm, the spaces in the atrium records a highest record of temperature of 31°C while the corridor measures 29°C and the office 28.5°C (1<sup>st</sup> April, 2018). The lowest temperature recorded in is at 2:00am BST where all the three-study area is at a constant temperature of 25°C.



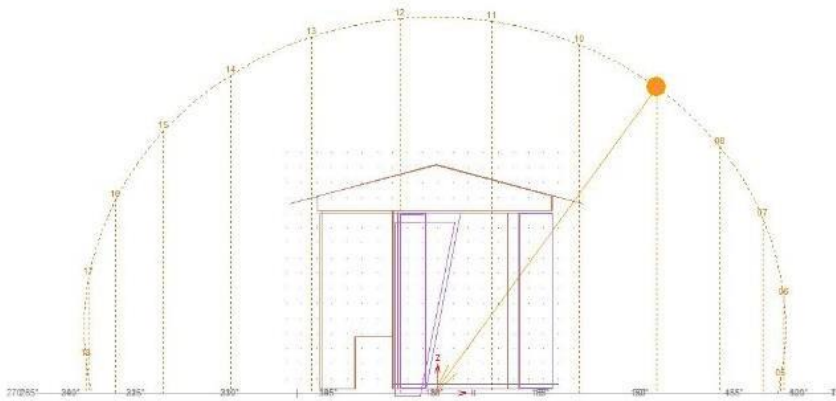


Figure 2. Image showing sun rays incidence on northern façade at 9:00 am. Source: Ecotect2011.

### Heat Transfer through a Transparent Building Envelope

Sharda and Kumar (2009), has done extensive review on heat transfer through windows. They mention that transparent part of the building envelope like windows are responsible for heat flow. Thorough understanding of mechanism responds of glass to solar heat gain and actions to control that heat transfer is essential (Sharda and Kumar; 2009). They mention that clear glass like the butterfly glazing in the atrium acts like transparent to high frequency solar radiation. Thus, the internal spaces get warmed fast.

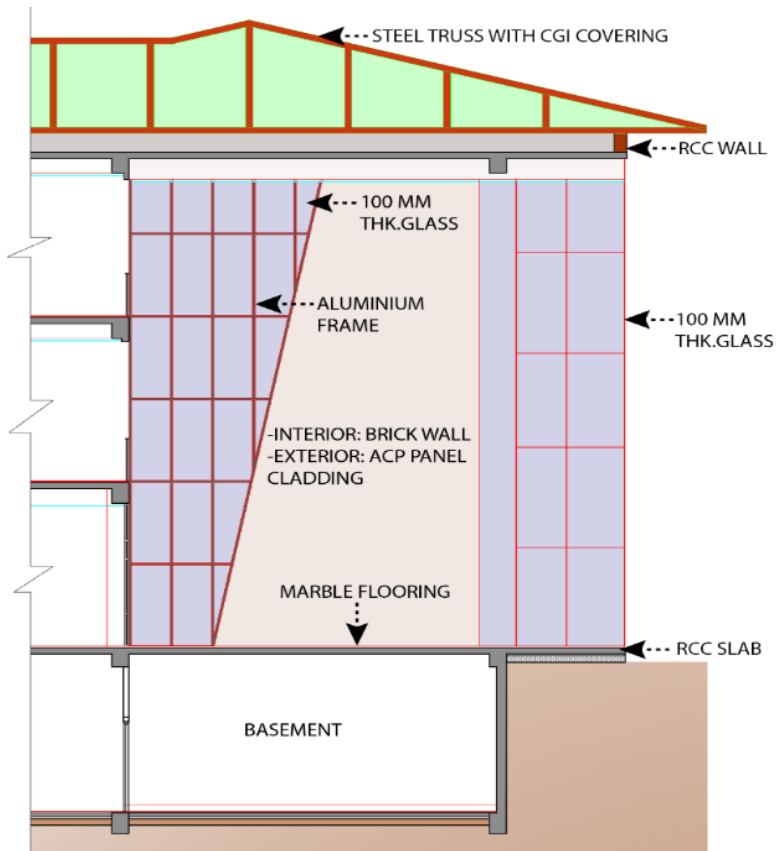


Figure 3. Sectional detail layout of material used.

## Data analysis

### Simulation Software: Ecotect

Ecotect is one of the user-friendly software with its scope for energy analysis, daylight analysis & thermal comfort analysis (Aksamija, 2015). The scope of research demands for a software, which includes thermal comfort analysis and is Building Information Management (BIM) compatible. The software interface with higher data reliability and interpretation have led to the choice of this suitable application.

Table 1. Building performance simulation software programs and their applicability for facadedesign.

Simulation tool	Energy analysis	Energy modeling	Heat transfer analysis	Combined heat and moisture analysis	Daylight analysis	Thermal comfort analysis	BIM-compatible
Ecotect	+				+		Yes
Radiance					+		
COMFEN/ EnergyPlus	+	+					
eQuest	+	+					
Green Building Studio	+	+					Yes
CBE Thermal Comfort Model						+	
WINDOW			+				
THERM			+				
WUFI				+			

### Maximum Solar Heat Gain

The data collection is based on the weather file of Rinchendding (2015-2018) and wind data is valid for 2015 and 2016 only, while rainfall data is erroneous. Before conducting any of the simulation, it is important to consider a peak average solar heat gain of the place. The data analysis average temperature shown by Ecotect for the last four years have been noted as in the figure aside. July and August are the peak solar gaining month of the year; January being the month with lowest heat gain of the year. Another conclusion based on the recorded weather data shows daily diurnal solar gain is maximum on July 9<sup>th</sup> at CST.

### Means of Heat Gain

The figures 6 shows consecutive graphs analyzed by Ecotect. The analysis shows that monthly diurnal solar heat gain varies and direct solar heat gain fluctuates in a year at the extremes. The direct heat gain is maximum in winter as the winter sun angle is lower than the summer sun. However, analysis also shows that diffuse solar gain is maximum in summer and as both the solar gain process takes place simultaneously: the combined heat gain sways away more in summer with more optimization required to reach its thermal neutrality: comfort.

The second graph shows the hourly analysis of the hottest day of the year. It can explain that in a day the building solar heat gain through various means happens from 12:00 noon to 2:00 pm.

The graph below (figure 4) shows the requirement of cooling as well as heating load (can be neglected) required to attain its thermal neutrality. The blue line shows the cooling load requirement which curves at the middle showing higher requirement during summer while its requirement during winter is almost nil. The graph also coincides with the practical experience of cool winter and hot summer of the compass.

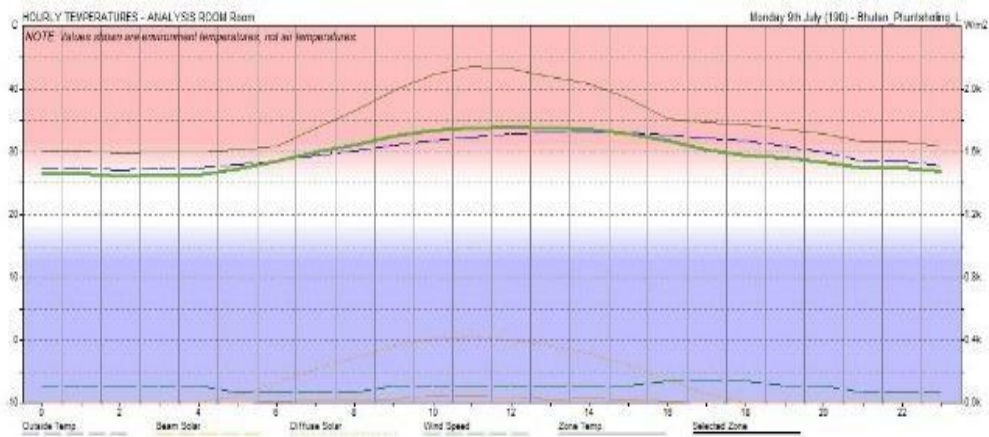


Figure 4. The daily solar heat gain of the zone with various means. Source: Ecotect

### Simulation of Existing Model

As can be noticed in the figure 5, it indicates that the atrium receives more heat gain during the mid day. The figure shows that the temperature at time 1:00 pm ranges within 36-40 degree celcius.

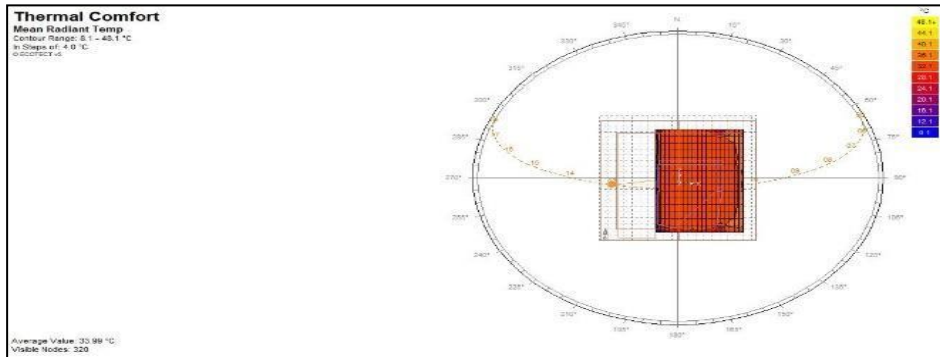


Figure 5. Image showing heat intensity at 1:00 pm. Source: Ecotect 2011.

The simulation generated the heat distribution grid, which shows the thermal gain of the existing atrium. The thermal gain of the atrium ranges between 30°C 40 °C during summer, where as human thermal comfort temperature is 27-degree Celsius

### Solar Heat Gain Pattern

The graph shown in figure 8 describes the solar thermal gain pattern annually. The yellow region shows the amount of direct solar heat gain or loss through the exposed surface while the red region shows the solar heat transfer via conduction. The negligible green bar shows the amount of thermal transfer via ventilation and the inter-zonal thermal transfer is negligible as the energy model consist of a single zone.

Solar gain is dominant with 88.5% and heat loss is maximum via conduction 89.0% and 10.8% via ventilation. This procedure is helpful in the interventions so as to minimize the thermal transfer at both direct as well as indirect conduction heat gain.

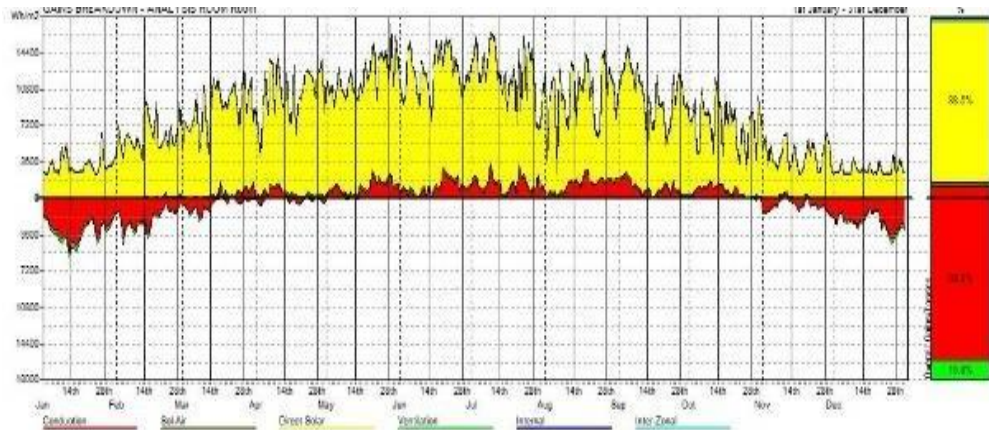


Figure 6. Annual Solar Heat Gain Pattern of the existing model.

### Thermal Comfort Analysis

The graph below (figure 9) shows thermal comfort analysis of the existing model with green continuous line showing the time period of the inner region at various temperature. The purple dotted line shows the time period of the exterior region through varying temperature of the year.

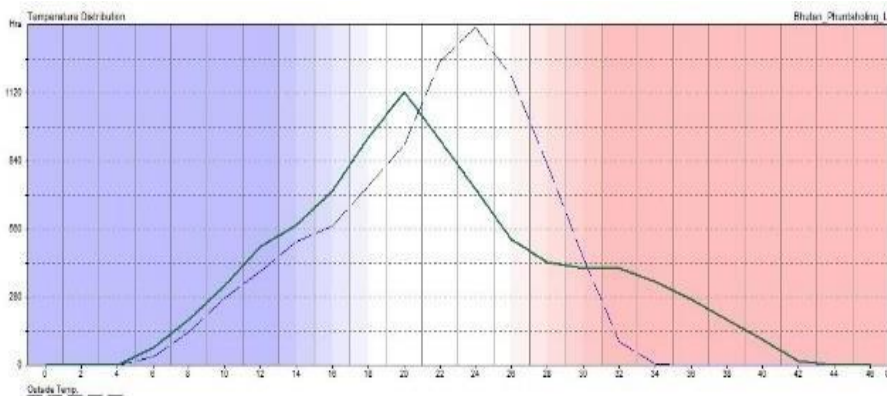


Figure 7. Thermal Comfort Graph of the Existing Model.

The comfort band as outlined in the regulations set by ECBC of India ranges between 18.0 °C to 26.0°C and the graph shows 4231 hours (176 days) which constitute 48.3 % as the comfort duration in a year.

## Design Interventions

### Replace the glazing with LoE27

LoE 272 (low emissive) cardinal glass has a low emissivity coating. It restricts the amount of ultraviolet and infrared light passing through the glass medium without compromising the amount of visible light transmitted while also reflecting heat.



Figure 8. Sectional detail of a double cardinal glazing & its real-life application

Provide shading device and louver system at best suitable height

The time considered for the louver design is only after 8:00 AM. The “adjustable vertical screens outside windows” is suitable for this situation (Sun Shading Devices, 2016). The table below shows the method of selection of suitable shading method.

Kesian Online Calculator shows that result shows that the sun angle is 80 degree at 9:00 AM on 9<sup>th</sup> July i.e., the hottest day of the year. The aluminum vertical louver with 1704 mm width, 75 mm thick and 3610 mm in height is being placed at 1306 mm center-to-center distance inclined at an angle of 30 degree with respect to north. In between the two section of vertical louvers are the Aluminum

Composite Panels (ACP) BAND OF 100 MM width to break from monotonous continuation of the vertical louvers.

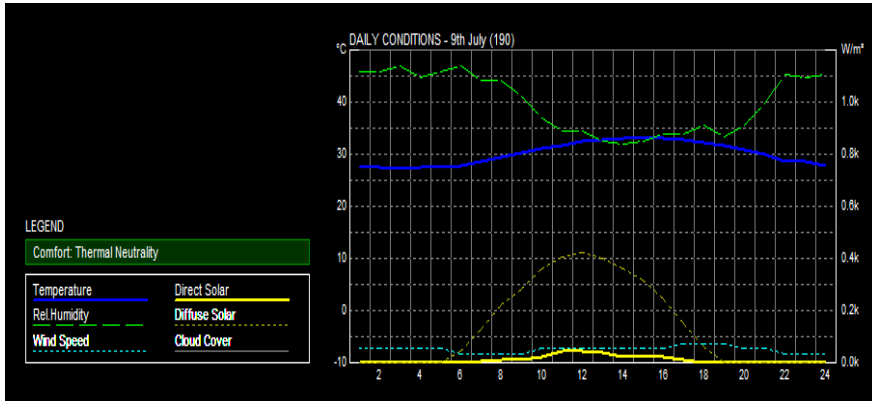


Figure 9. The temperature variation Source: Ecotect 2011.

The center-to-center distance is being kept at 0.75 of the depth of the louver (Chris Reardon, 2013). The angle is adjusted to barricade the direct sun rays of minimum sun angle aspired to keep out from the atrium. In addition, the horizontal louver with free air ventilation at the top of the atrium façade is proposed for the escape of the hot air that rises from the lower atrium space.

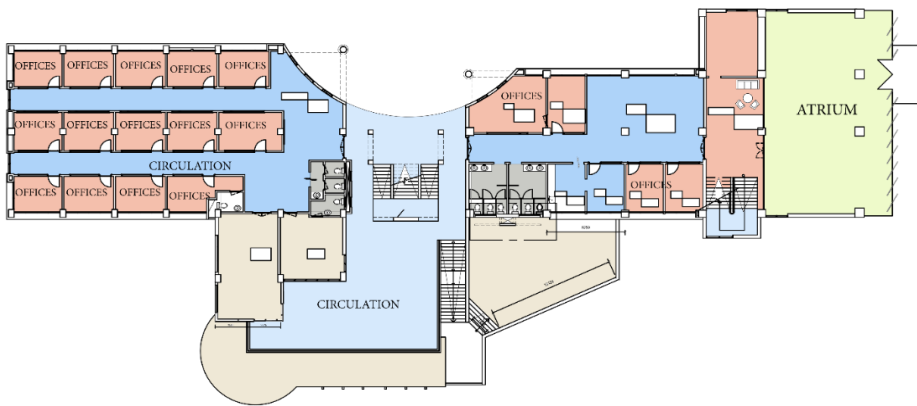


Figure 10. Overall Administration Ground Floor Plan



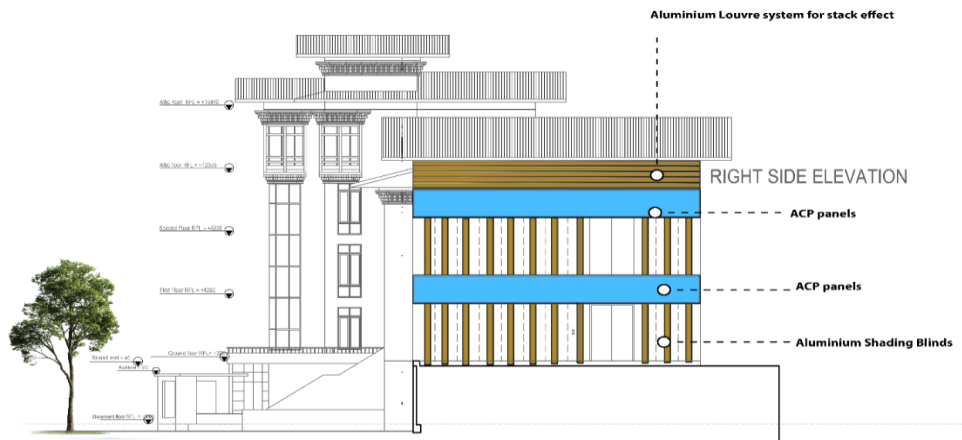


Figure 11. Administration Building Proposed Eastern façade.

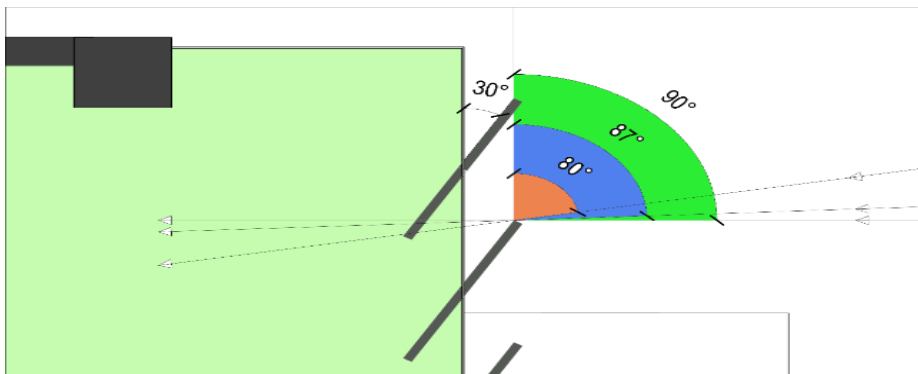


Figure 12. Image showing the direct Incidence sunrays blocked by the louvers.

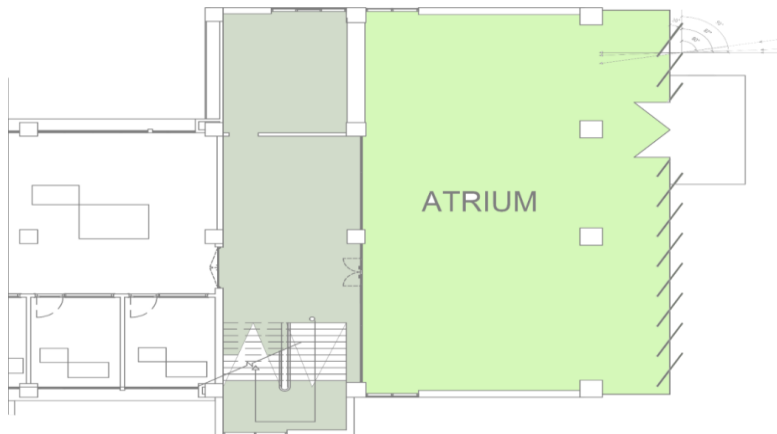


Figure 13. Atrium Plan Showing the louver layout and arrangement.

As can be seen in the figure 6. The two successive louver panels of 1306 mm wide inclined at an angle of 30 degrees can block the incidence of direct sunrays into the atrium space starting from lowest angle of bit less than 80 degrees. The direct sun rays with angle less than 30 degrees with respect to north are allowed to enter the atrium, as the rays are not yet intense until early 9:00 AM in the morning.

## Results

### Space Temperature Distribution

A combined energy modelling has been built up where the material property of the glazing has been altered (reduced from 1.04 to 0.25) and a structural model with shading device from the exterior have been proposed. The combined effect of the simulation results has been shown below.

The temperature distribution of the zone has been altered with average temperature of the zone equals to 28.68 °C at 9:00 a.m. The existing model simulation showed 32.82 °C at the same time with 4.14 °C drop in the room temperature.

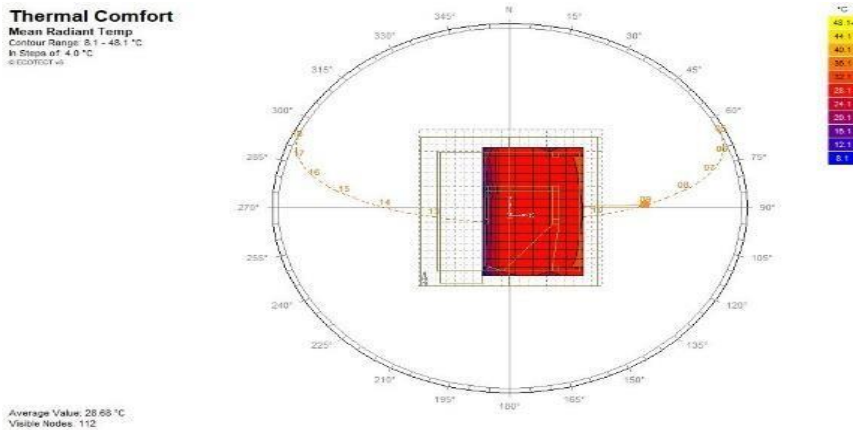


Figure 14. Temperature Distribution of the Proposed Model on July 9, 9:00 AM, Source: Ecotect 2011

Another result obtained for 1:00 pm of the 9<sup>th</sup> June, showed the room temperature as 29.26°C with its initial temperature as 33.99 °C and 4.73 °C reduction has been observed. At real case the temperature reduction will be lower than shown by the simulation results due to the other variables not accounted during the simulation. The average reduction of the temperature with the peak hours of the summer is 4.435 °C.

### Solar Heat Gain Pattern

The yellow region shows the amount of direct solar heat gain or loss through the exposed surface while the red region shows the solar heat transfer via conduction. The negligible green bar shows the amount of thermal transfer via ventilation and the inter-zonal thermal transfer is negligible as the energy model consist of a single zone. One can conclude that the direct solargain is reduced from 88.5% to 73.6 % and heat loss via conduction is reduced to 73.3% from 89.0%.

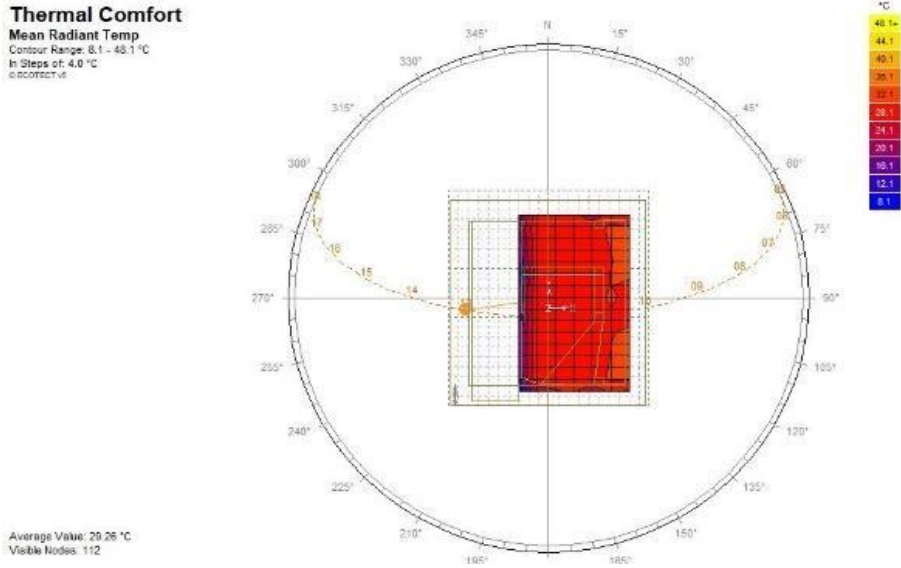


Figure 15. Temperature Distribution of the Proposed Model on July 9, 1:00 PM. Source: Ecotect 2011.

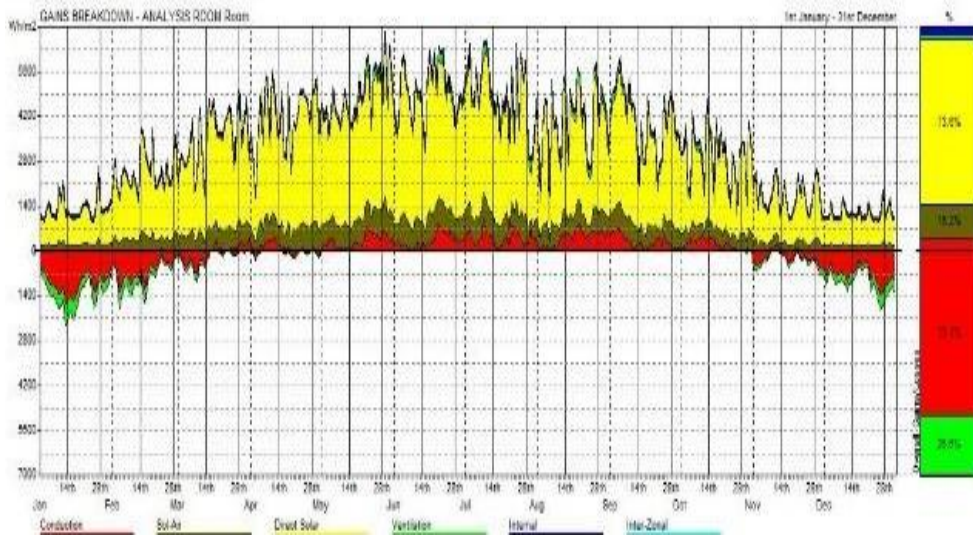


Figure 18. Solar Heat Gain Pattern of the proposed model. Source: Ecotect: 2011.

Table 2. Thermal Gain Breakdown analysis

Category	Loses	Gains
Conduction	73.3%	5.4%
Sol-air	0.0%	15.2%
Solar	0.0%	73.6%
Ventilation	26.6%	2.4%
Internal	0.1%	0.0%

### Thermal Comfort Analysis

The purple dotted line shows the time period of the exterior region through varying temperature of the year.

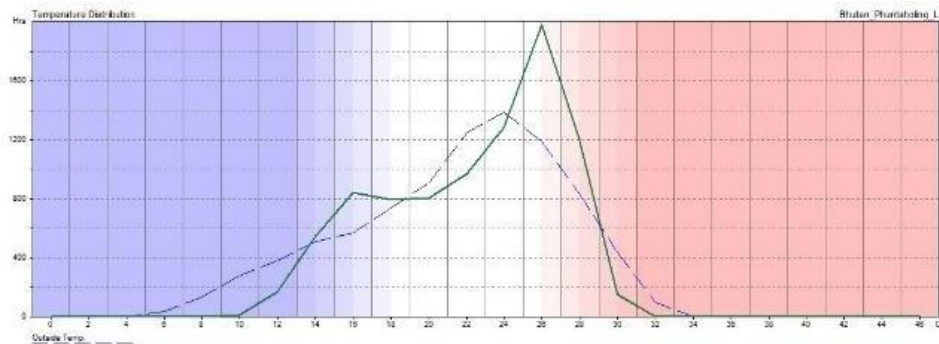


Figure 19. Temperature Comfort Analysis Graph.

The comfort band as outlined in the regulations set by ECBC of India ranges between 18.0 °C to 26.0°C and the graph shows 5830 hours which constitute 66.6 % as the comfort duration in a year.

## Comparative Analysis

The table below shows the overall output of the research. The significant parameters as identified and analyzed have been listed with its specific value shown after the decisive simulation. The specific quantity for both the existing as well as proposed model have been compared on the basis of certain parameters which are directly affecting the thermal variation of the space. The overall thermal achievement of the space is 18.3% better than the existing condition and the zone temperature reduction is achieved to 4.43 °C.

Table 3. Comparative Analysis of the simulation

Parameters	Existing Model	Proposed Model	Remarks
Exposed Area	214 square meters	18.86 square meter	Square meter area reduction
Space Av. Temp. (July 9th)	33.405 °C	28.975 °C	4.43 °C temperature reduction.
Glass U-Value	1.046 W/m <sup>2</sup> K	0.25 W/m <sup>2</sup> K	4:1 heat transfer ration
Solar Heat Gain	0.4	0.94	
Visible Light transmittance	75.3 %	70 %	
Direct Heat Gain	88.5%	73.6%	15.2% heat gain reduction

Fabric Heat Loss	89%	73.3%	15.7% heat gain reduction
Thermal Comfort (time period)	48.3%	66.6%	18.3 % comfort band improvement.

## Conclusion

Building sector has topped in overall energy consumption among many other sectors, making the people around the world concern about its energy efficiency. Administration building of College of Science and Technology have a characteristic feature of glass façade facing the east. It has been recorded that the average maximum zone temperature of the space is almost 33.4°C. The orientation of the glass façade facing towards the extreme east is one of the main factors that contributes to its extreme heat gain during the day.

The atrium in particular requires a proper and impactful interventions. There are many suitable retrofitting options available but this research shows two simple ways of intervening the system with minimum modification of the entire structure. It includes the replacement of existing 6mm clear glazing with an alternative cardinal LoE 272 glass and the installation of a carefully designed vertical aluminum shading device. The combined effect of the design has been proved better with the simulation carried out in Ecotect. It has shown that the area can achieve 18.3% rise in thermal comfort in terms of the time period and a zone temperature reduction of 4.43° C have been proved.

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## About the Authors

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