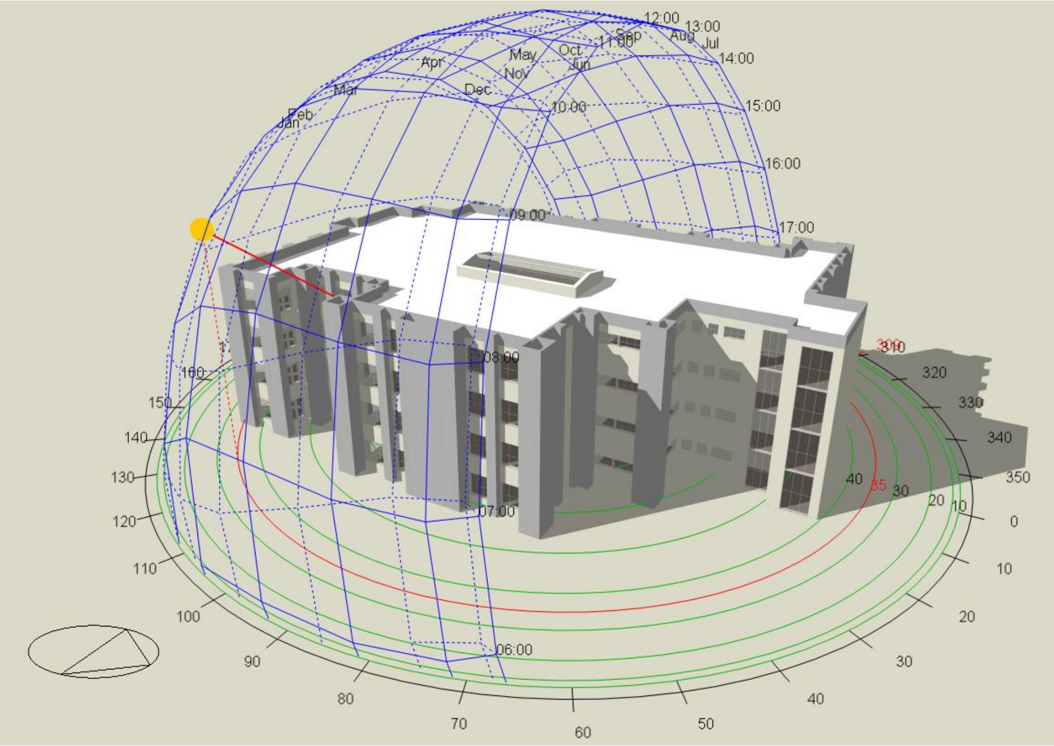
Optimising the Fabric and Service Design for a Teaching Building in South India



Project Details

Objective: Explore the architectural and system design solutions that offer the best energy performance at the lowest cost.

Building: One of 6 typical teaching buildings in a college campus, 4-storey, 5300 m^2

Location: Southern India

Climate: Hot and humid, hottest periods from March to May and Monsoon rains from June to October

Project by: PSI Energy Pvt. Ltd., New Delhi, India (www.psienergy.in)

Introduction

One of the critical challenges in design-stage decision-making is to balance the constraints and objectives related to functional, operational and maintenance requirements against project budgets and Building regulations. A clear understanding of the cost-effectiveness of the various design options and energy efficient solutions is required at the early design stages to help keep costs down and to safeguard energy efficient solutions against value engineering.

Figure 1: Teaching block buildings showing recessed windows on the North elevation

Some of the key questions asked in the project were:

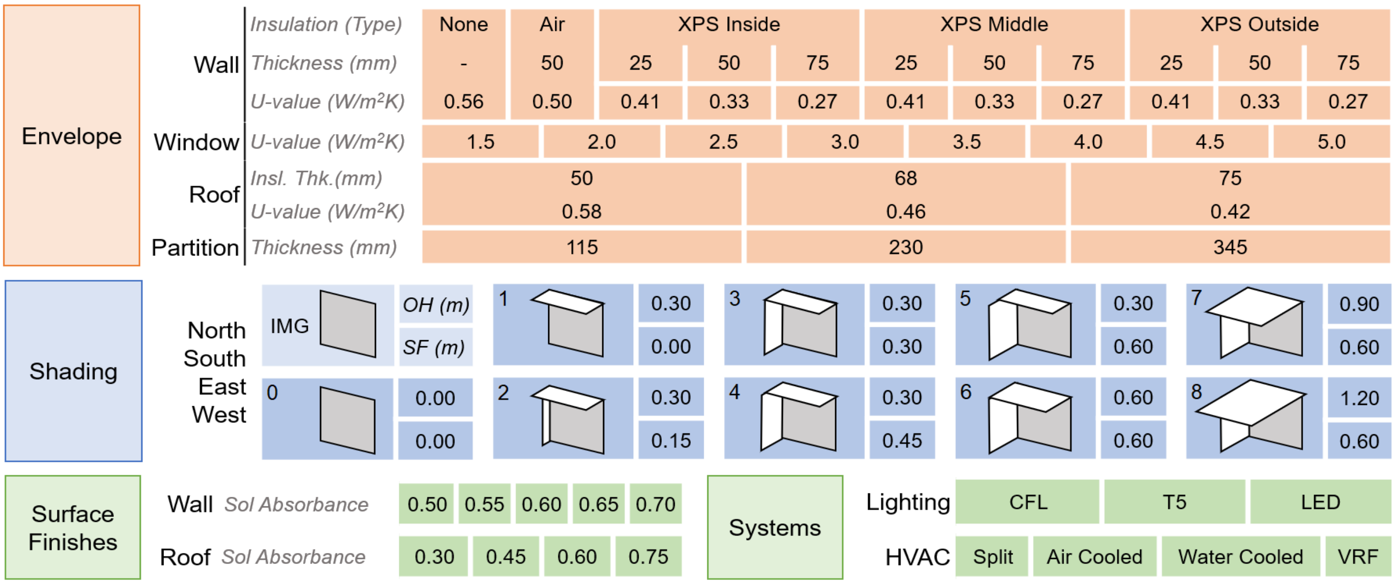
- Can the cost of the HVAC system be reduced by having a more effective envelope?
- What is the most efficient shading strategy?
- Can shading be traded against the need for a high-performance glazing solution?

The Optimisation Analysis

The building form and some of the design features were dictated by the master plan and therefore had a less-than-ideal orientation, with longer facades facing east and west. However, there was scope to vary a number of aspects of the design including wall and roof construction methods, external finishes, shading configuration, space conditioning and lighting systems.

The main factors considered in the analysis were:

- **Envelope thermal performance**: The possible envelope performance improvements were analysed by varying insulation thicknesses in the walls and roofs and the window U-values.
- **Thermal mass**: The effect of thermal mass was explored by changing the location of insulation in the external walls and varying the thickness of the brick partition wall.
- **Shading**: Various shading options were applied to limit the direct solar gains. This offers a low-cost way of reducing gains and the need for a more expensive glazing solution with solar control.
- **Surface finishes**: Reflective surfaces reduce the cooling energy use and have negligible cost implication. Surface finishes were modified by changing the solar absorptance of the outermost material of the roof and external wall surfaces.
- **Systems**: On the systems side, various lighting and HVAC systems were analysed. Lighting is a source of significant heat gains and the selection of HVAC system also involves a trade-off between capital cost and efficiency.



Envelope

Wall	*Insulation (Type)*	None	Air	XPS Inside			XPS Middle			XPS Outside	
	Thickness (mm)	-	50	25	50	75	25	50	75	25	50	75
	U-value (W/m²K)	0.56	0.50	0.41	0.33	0.27	0.41	0.33	0.27	0.41	0.33	0.27

Window	*U-value (W/m²K)*	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0

Roof	*Insl. Thk.(mm)*	50	68	75
	U-value (W/m²K)	0.58	0.46	0.42
Partition	*Thickness (mm)*	115	230	345

Shading

North South East West

IMG	*OH (m)*	*SF (m)*
0	0.00	0.00
1	0.30	0.00
2	0.30	0.15
3	0.30	0.30
4	0.30	0.45
5	0.30	0.60
6	0.60	0.60
7	0.90	0.60
8	1.20	0.60

Surface Finishes

Wall	*Sol Absorbance*	0.50	0.55	0.60	0.65	0.70
Roof	*Sol Absorbance*	0.30	0.45	0.60	0.75	

Systems

Lighting	CFL	T5	LED	
HVAC	Split	Air Cooled	Water Cooled	VRF

Figure 2: Matrix of design variables and options for the optimization analysis

In total 12 key design variables were identified. Figure 2 above summaries the main design variables considered in this analysis along with their corresponding options. Given the different options available for each variable, there were a total of 12 billion design combinations to explore! Considering the impracticality of carrying out separate simulations for each of the 12 billion design combinations, DesignBuilder's design optimisation tools were used to carry out the simulations and identify the optimum solutions without the need to simulate the entire search space.

As cooling was the predominant energy end-use, the objectives of the analysis were to simultaneously minimise annual electricity cooling energy consumption and capital cost by optimising the fabric and systems.

Optimisation Results

Instead of 12 billion simulations, the main optimal results were achieved in 3000 runs. Figure 3 shows the results of the analysis. Each dot represents one of the individual designs simulated. The red dots show the optimal solutions that occupy the Pareto front. The results and the key patterns identified from the simulations were further analysed to help identify the best overall design options for the project.

Figure 4 shows that there are four distinct clusters of results, one for each of the HVAC Systems. From the scatter graph it can be seen that the two more efficient HVAC systems, VRF and Water Cooled, offer a significant reduction in cooling energy use compared with the other options, but with only a relatively modest increase in cost.

Also, within each of the HVAC system clusters, there are sub-clusters for the 3 lighting systems. For example, in the VRF Cluster, on the Pareto front (Figure 4), we can see the impact of changing from CFL to T5 to LED, with the lower cost CFL points in dark blue towards the left of the VRF Pareto Front with slightly higher cooling energy.

Figure 5 shows the sub clusters for the 3 partition wall thickness options. The results suggest that adding more thermal mass to the partitions has minimal effect on cooling, but increases the construction cost significantly.

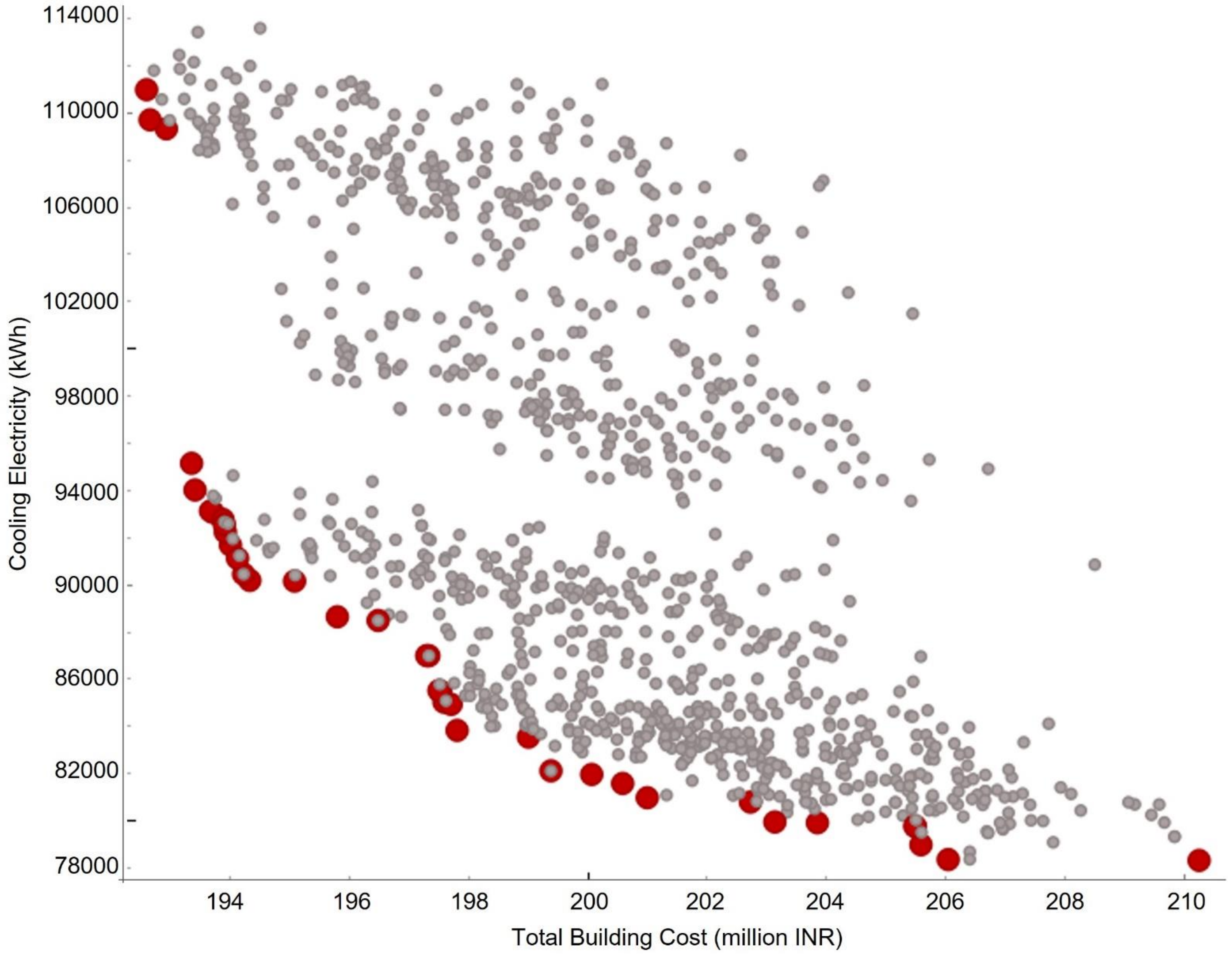


Figure 3: Pareto Front

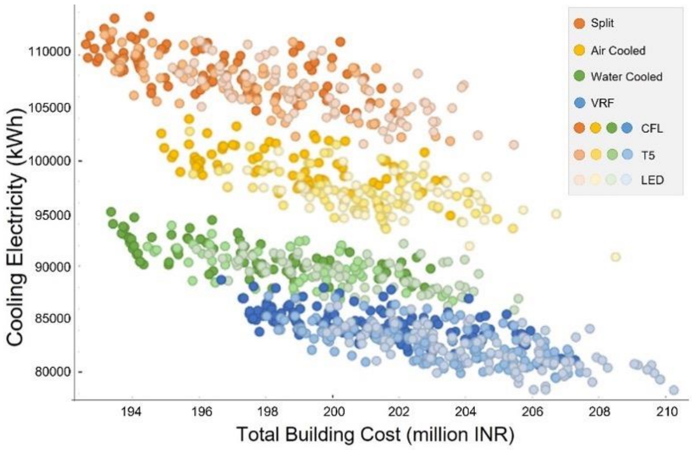


Figure 4: HVAC + Lighting Systems

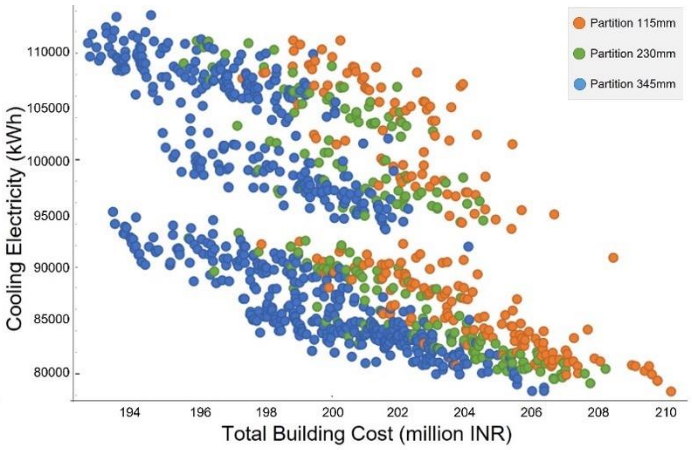


Figure 5: Partition Thickness (mm)

The effect of increasing the glazing U-value is shown in Figure 6. The trends show diminishing returns in cooling energy reductions when more expensive low U-value glazing is selected (represented in orange colours).

For shading, the trends show that it is possible to achieve a significant energy reduction for relatively low extra cost. The results for shading on the West facade, which is the most relevant one in terms of solar gains (Figure 7) show that the largest shading system 8 (ref. Figure 2) is best for this facade.

Relative trends of glazing vs shading were the most difficult to analyse because in most of the cases 2 or 3 variables were changing at the same time such as glazing, shading (on at least one of the facades) and solar absorptance values.

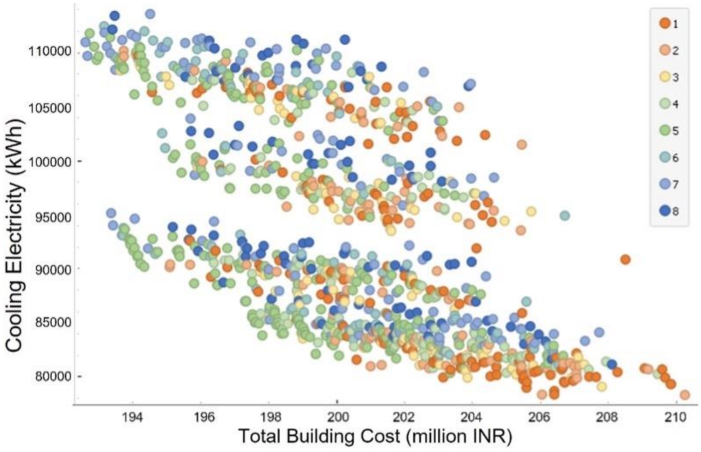


Figure 6: Glazing U-value (W/m^{2}K)

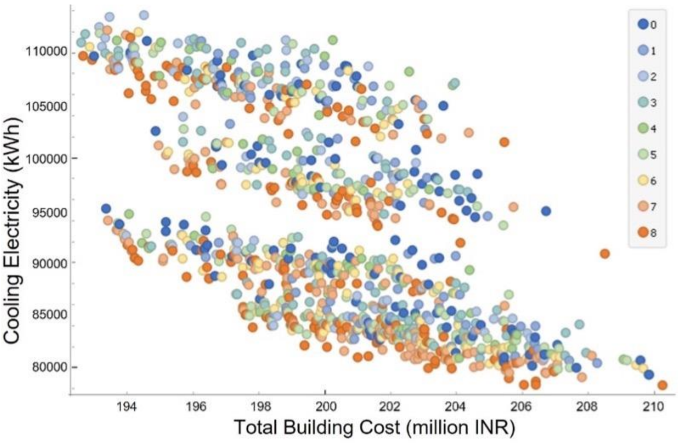


Figure 7: Shading West Façade

Increasing the insulation on the external walls and roofs significantly increases cost but has a minimal impact on cooling energy (Figures 8 and Figure 9). The most frequently selected option for the external walls was a medium U-value, cavity wall with a 50 mm air gap, and for the roof 50 mm insulation was adequate.

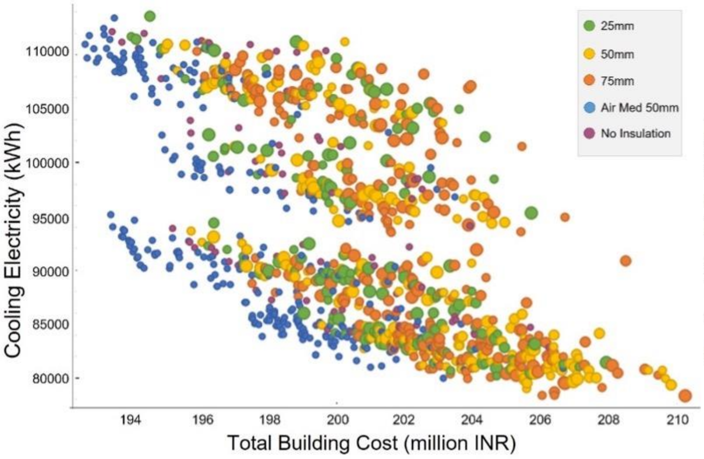


Figure 8: External Wall U-value (Insulation Thickness, mm)

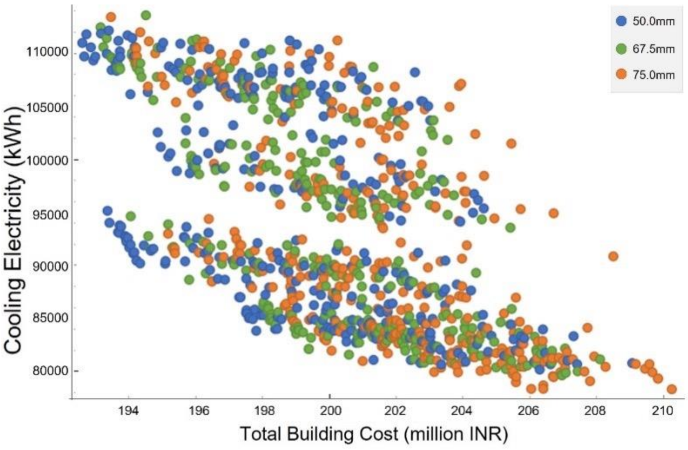


Figure 9: Roof U-value (Insulation Thickness, mm)

Design Recommendations

Based on the detailed analysis of all the design variables, the following recommendations were made to the design team.

- **HVAC system**: The choice of the HVAC system should be the decided first. Water cooled chiller and VRF based systems are the two main options. The recommended system is the water-cooled chiller because it has a significantly lower cost compared to the VRF System with only marginally higher energy use.
- **Lighting system**: CFL is considered to be the ideal solution as it provides a balanced combination of lowest cost and good performance.
- **Partition thickness**: The building has enough thermal mass through a brick and RCC construction and so a 115mm partition is sufficient.
- **Glazing U-value**: Simple double glazing with U-value between 3.0 and 4.0 W/m^2K is the recommended solution. High performance glazing is much more expensive and with diminishing returns in terms of cooling energy use reduction.
- **Shading**: For the East and West facades, which receive the highest direct solar gains, the most extensive shading options, 7 and 8 provide a significant reduction in energy demand with a relatively low additional low cost and so were recommended.
- **External Wall and Roof U-value**: Cavity walls with an air gap were selected as the optimal option for walls, and 50mm insulation was selected for the roof. Adding more insulation in both walls and roofs increases the cost much more than the resultant reduction in cooling energy use.
- **Solar Absorptance**: Specifying reflective finishes for the outermost surfaces significantly reduces cooling load with no impact on cost, and so finishes with absorptance of 0.5 and 0.3 for the walls and roof were selected.

Credits

The Case study was developed by PSI Energy (www.psienergy.in) and the project was delivered by them with support from project architects, SD Sharma & Associates (www.sdsa.co.in).

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PSI (Partnerships for Sustainable India) Energy – is a sustainable habitat and green buildings consultancy based in New Delhi. PSI Energy has experience in delivering sustainable habitat design solutions that are rooted in response to local context since 2006.

PSI Energy also conducts certification-based, training programs for university students and industry professionals on green building and sustainable habitats design (including design, thermal comfort, lighting, HVAC, solar energy systems, GRIHA, ECBC, etc.

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