Building Energy Consumption Analysis, Energy Saving Measurements and Verification by Applying HAP Software

Tauseef Aized[1], Sajid Mehmood[2], Zahid Anwar[2]

1. *Department of Mechanical Engineering, UET-Lahore,*
2. *Department of Mechanical, Mechatronics and Manufacturing Engineering, KSK-campus, UET-Lahore*

* **Corresponding Author:** E-mail: tauseef.aized@uet.edu.pk

Abstract

Energy consumption in building sector in Pakistan is almost 30 % [1] of its total energy use and it is increasing with annual growth rate of 4.7 % and 2.5 % in domestic and commercial sector respectively. Currently there is severe energy crises in Pakistan and this has adversely effected economical growth of the country. The geographical orientation of Pakistan (latitude between 24N - 35N) explains that the country remains in sunny and hot climate throughout the year. Utilization of modern energy efficient materials in existing building envelopes can help in reduction of building energy demands. In this study research effort focuses on identification of energy consumption pattern for an existing building (Lahore based) in its current and retrofitted form. A computer program (Hourly Analysis Program HAP) has been used to simulate actual operating conditions, existing cooling load of the building was estimated and possible retrofitting measures were tested in terms of their energy saving potential. Important parameters like window size, double glazing, windows orientation, and building envelop orientation, space between window frames, window frame materials, and use of shade on windows, are considered as key decision variables, these are simulated to study their effect on building energy demands. Results presented in this study suggests that significant energy saving can be obtained with slight modification in the existing building. In this study 28.6 % energy was saved by applying different retrofitting techniques.

Key Words: Energy consumption, Gymnasium, Optimization, Retrofitting, Lahore

1. Introduction

In developed countries like United States about 50% of all energy is consumed by buildings, this is mainly used for heating, cooling and lighting application. Annual energy consumption by the building sector in Pakistan is about 30%. Literature shows an increase in energy use in developing countries and part of it is coming from extended use of buildings in daily life. The reduction in energy demand will eventually help in saving money, mitigating emissions and reduced pressure on national power grid. The efficient thermal envelope (via reduced heat transmission and controlled solar penetration) results in lowering energy demand. The reduced energy demand without compromising comfort conditions would have environmental and fiscal benefits. Fast development of efficient energy modeling of buildings is, therefore, necessary to deal with exacerbating energy-crisis of Pakistan.

Ahmad et al. [2] did simulation of an office building and compared baseline and energy efficient model using e-Quest simulation software. They studied the impact of different variables like size of window, effect of glazing, energy efficient lighting, set points for thermostat and improved air conditioning equipment on buildings efficiency and performed economic analysis with payback period. By reducing the window size and window type from single glazed to brown tinted double glazed 10.5% and 5% energy can be saved respectively. Similarly, simulation results showed that setting thermostat set point temperature to 26 ^{o}C and selecting HVAC equipment with high energy efficiency ratio saves energy 12% and 16.4 % respectively. Under similar operating requirements efficient model required 37.7 % less energy than the base line model. This showed huge energy saving potential by applying small measures.

Hameed et al [3]. analyzed the energy consumption pattern of an existing commercial building using Ecotect simulation software. They suggested slight modification in the building to save significant amount of energy. They studied the solar effect on building envelop and suggested construction of cavity walls, walls with layer of insulation materials sandwiched in the cavity (and above the roof slab) to reduce the direct solar heat gain. Furthermore, they suggested LED lights to reduce energy consumption with in the building. Monthly heating, cooling load and cost benefit analysis were done before and after retrofitting and 41% of energy was saved using retrofitting techniques. This studied revealed that retrofitting has evolved as a technique to reduce energy demands of existing buildings with utilization of heat resistant low energy materials.

Tahsildoost [4] applied energy retrofit techniques on two school buildings and simulate the annual energy use by Design builder. Outcomes of the energy modelling and PBT analysis indicated that 38.29 % energy can be saved by applying different retrofit scenario like air tightening, with replacement of windows and insulation on roofs. In this study energy meter was compared before and after applying refurbishment techniques to calculate the energy conservation.

Preliminary data like annual energy consumption, building orientation and materials, mechanical and operational details of each school was collected. Thermal losses and air leakage were identified with thermal imaging (FLIR E60). Testo 400 Reference meter & logger was used to measure temperature, relative humidity and velocity of the air. The energy consumption was compared with project baseline energy use and against the established goals.

Different parameters of both buildings like air quality, air draughts, light, noise and over heat were calculated before and after refurbishment and significant reduction with comfortable level was observed after applying retrofitting techniques. Different retrofit techniques were applied like air tightening, window film, 1 pane window replacement, solar hot water, roof thermal insulation, wall thermal insulation, LED lighting and results were compared before and after refurbishment. A significant amount of primary energy like electricity and gas consumption was reduced in model and actual case after implementation.

Ahmad et al [5] performed energy analysis of residential building using e-Quest simulation software. The studied the effect of window area, glazing types, lighting, and thermostat set point, and efficiency of HVAC system for residential buildings. By reducing the window size 7.2 % energy consumption can be saved and by replacing the single glazed clear glass with brown tented glass 5.9% annual energy consumption can be decreased. Cost analysis shows that this cost can be recovered in 11 years.

HVAC system with high energy efficiency ratio 10.66 instead of 8.80 and setting thermostat at 78.8 F rather than 75 F can save energy by 19.5% and 11.7% respectively. Simulation results showed that by applying all these measures 38.5% energy can be saved as compared to base line model. And cost analysis shows that additional investment can be pay backed in first three years.

Mohammad et al. [6] applied different strategies for reducing energy consumption and potential energy conservation opportunities in a student cafeteria. They used visual DOE 4.1 simulation software, they developed an energy performance model in DOE. This model was then used for assessing various energy conservation measures for the building envelop and HVAC system design. The result showed that 66% electricity was consumed by cooling appliances while fans and lighting constituted 14% each for the baseline case. For improving energy profile various energy conservation strategies were studied including standard, single and combined energy conservation measures. These measures resulted in a combined design saving of 27.4 %.

Khan et al. [7] did comparison of building thermal loads against building orientations and concluded that appropriate orientations can offer thermally indoor conditions at lesser energy demand.

They investigated the effect of sun orientation on solar heat gains for a house with different cases of house orientation. They used the Autodesk Ecotect 2011 for estimation of the cooling demand for different orientations. For N-S oriented lot they recommended north-west and south-west oriented windows for cooling season. Based on the findings they also concluded north, east and west oriented living rooms are not feasible for the year-round performance. And east and the north living required 31% more thermal load for cooling than southern oriented living rooms and the orientations require 34% more energy to heat when compared to south oriented living in winter season or in the month of December.

A study on impact of energy efficiency measure for a conditioned space (100 m^2) for different cities of Pakistan was reported by Khalid [8], they used RETScreen for their study.

Insulation on walls and roofs, efficient windows, recovery of energy from ventilation air, and improved lighting were considered for improving house energy efficiency. The results of the simulation showed that significant saving in electricity and fuel (heating) usage can be achieved for all cities. Payback period for mountainous regions was 10 years that shows all regions of Pakistan investment in energy saving measures are economically advantageous. Thin wall and roof insulation is sufficient for mild climate cities of Pakistan.

2. Methodology

The energy interactions between thermal comfort equipment together with the appliances used in a built environment are quite complex and modeling process required many input parameters. This study has been done with HAP as this tool has all the required capability to predict the energy conservation measures with the above-stated parameters. A gymnasium building of area 34034 ft^2 was analyzed using hourly analysis program (HAP v4.8), the study is aimed on estimating the effects of adopting energy conservation methods. The methodology employed in this case study involves collection of all the necessary information like, local climatic data, material data for walls, roof, windows, door, floor, building size and layout data, Internal load characteristics were determined by the level and schedule for occupancy, lighting systems, appliances and machinery within the building. Based on collected information, a baseline case of the gymnasium building was developed using the selected energy simulation software. Various energy conservation measures were then considered and they include windows glazing, windows orientation, window size, shading, orientation of building envelop.

The Modelled Building Descriptions

The case building selected for energy modelling is of 34034 ft^2 in the east direction. It is a two-story building have one hall for sports activities and two fitness room in the north and south direction. It has spectator sitting area on the first floor in the west, north and south direction. It has some office rooms and team room as well.

Table 1: Building description

Serial No	Building Parameter	Values(ASHRAE)
1	Number of story's	two
2	Total area	34034
3	Floor height	34 ft.
4	Orientation	East
5	Indoor design temperature	26
	Building Skin	
6	Wall	3.80
7	Roof	2.88
8	Glazing	1.10
9	SC	0.9
10	Infiltration Rate	0.01 ACH
	Building system	
11	Lighting	0.9
12	Set point temperature	26
	Building Operations	
13	Schedule	6 a.m. to 11 p.m.
14	Occupancies	250
	FACTOR OF SAFETY	
15	Factor of safety	10

3. Simulations Results

3.1 Baseline Model Zone Load

Heat gain due to walls, roof, and window due to temperature difference is called external thermal load and heat generated inside the building due to people activity, electric equipment and overhead lighting is called internal thermal load. The zone load of building shows that maximum losses are due to roof followed by windows solar loads and windows transmission losses.

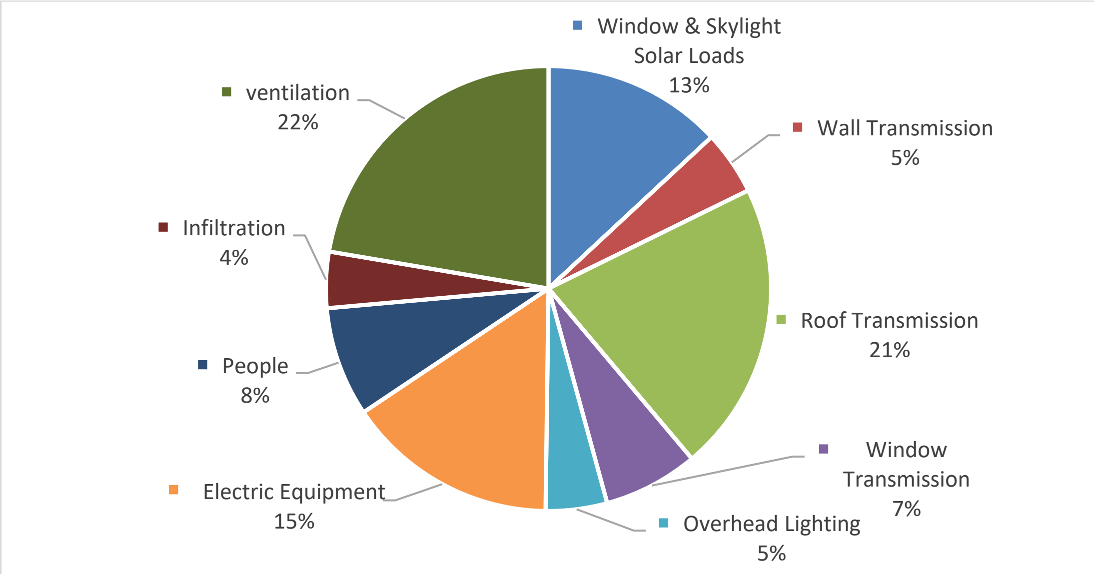

Figure 1: Zone load for baseline model

3.2 Baseline Building Envelop at Different Orientation

When the building envelope parameters are designed with the purpose of optimizing the energy performance, the size and capacity of mechanical equipment can be reduced and, consequently, the electric power distribution may also be reduced. Graph shows that there is minimum cooling load required in the direction of south. The baseline building existing orientation is in east direction and cooling load requirement for this orientation is 201 ton. The building model was designed in hourly analysis program and simulation reports were generated in varying the building envelop orientation with 22.5-degree interval. Sixteen simulation were performed such as in the direction of east, east south east, south east, south and so on. And result shows that minimum cooling load requirement is in the case of south orientation and maximum in east north east.

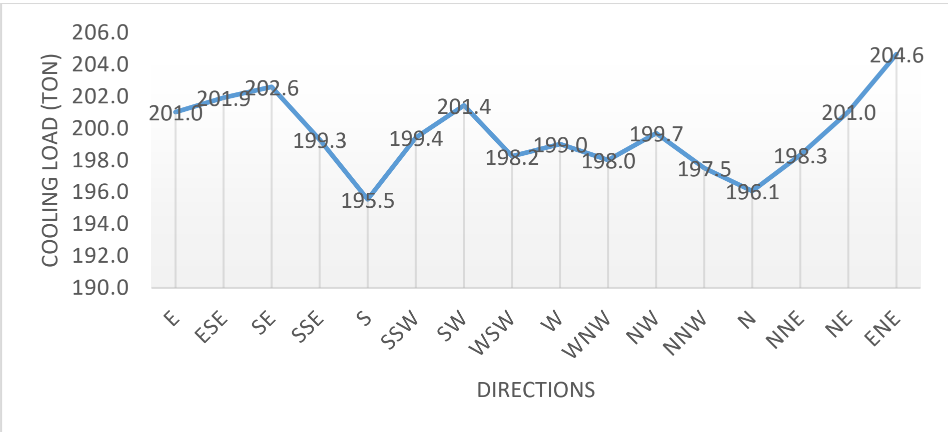

Figure 2: Variation of cooling load requirement at different building envelop orientations

3.3 Orientation of Windows

By carefully selecting the placement of windows in building envelop may save significant amount of energy resulting in financial benefits. Windows facing east or west waste more energy as compared to north and south. It is best practice that longest wall of the house should face north or south. This allows the shorter dimensions to face east or west. In graph we can see that maximum solar load is from west side followed by east side. And there is an interesting fact about windows in the South direction. It has maximum solar load in the winter when we need heat and minimum in the month of June July when there is great need of cooling. So best orientation of the window is south.

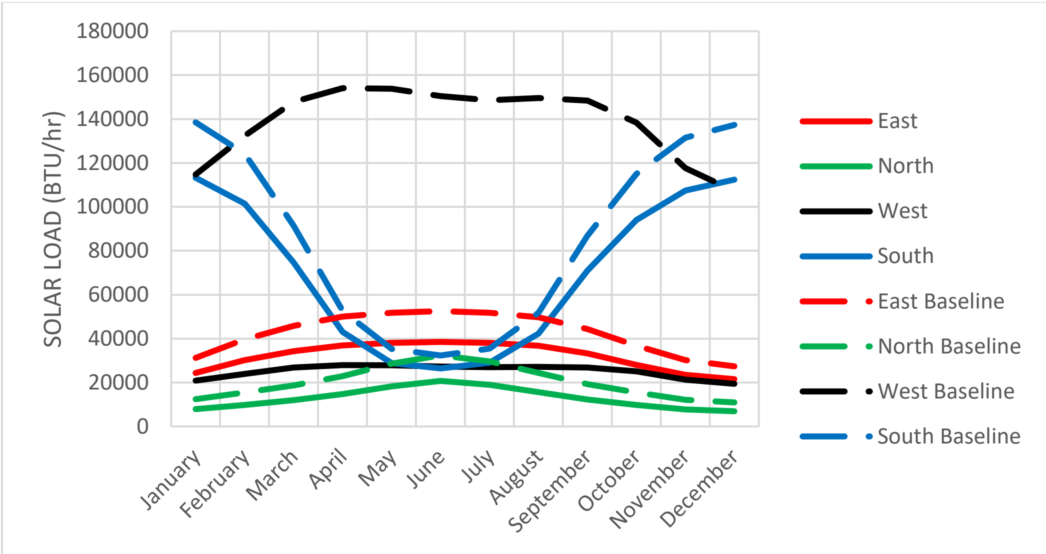

Figure 3: Variation of solar load with orientation of window in baseline model.

3.4 Baseline Model and Windows Area Energy Efficient Model Comparison Windows to Wall Percentages of Building

In the baseline case window area in the west wall is about 43.63 % which is the violation of building codes of Pakistan and it is also contributing maximum in heat gain. So, in retrofitting techniques a significant amount of energy can saved by reducing the windows area. 40.62% solar loads and 29.9 % transmission losses were reduced by this retrofitting technique.

Table 2: Window to wall area ratio for baseline and energy efficient model.

Walls	Gross Area of walls(ft^2)	Baseline window area (%)	Windows energy efficient model	% of window area reduced
East Wall	6208.5	29.19	18.43	36.86
South Wall	4632.5	37.48	28.985	22.665
West Wall	6208.5	43.63	8.57	80.35
North Wall	4632.5	25.85	15.02	41.89

3.5 Baseline Model and Double Glazing EEM Comparison

Graph is illustrating solar load on several types of windows in case of single glaze and double glaze. A significant amount of energy can be saved by using double glaze window. Double glazed windows are an ideal energy efficient choice with the added benefit of minimizing noise. The sealed air gap between the two panes acts as an added layer of insulation. This added thermal resistance reduces the amount of heat escaping in winter and keeps your home at a more comfortable temperature. Double glazing has the reverse effect in summer, preventing unwanted heat from coming into the home.

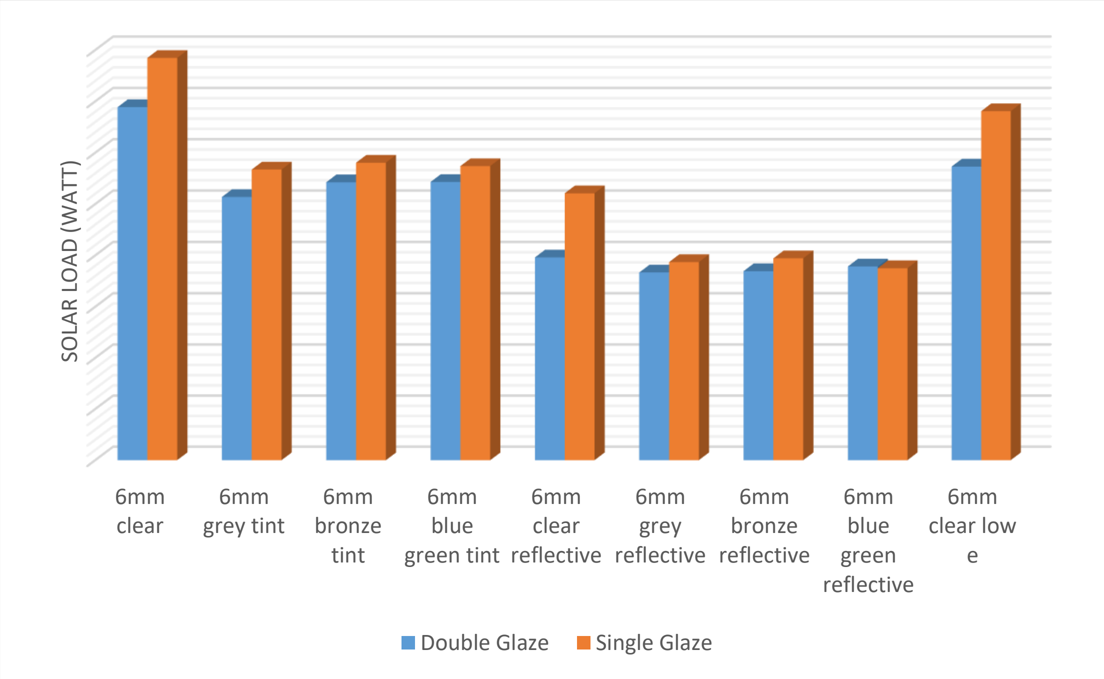

Figure 4: Variation of Solar load with single & double glaze window in baseline model.

3.5.1 By Adding Space between Double Glaze Window

The space between the panes in double glazed windows is fully sealed, it acts as an insulator, limiting the transfer of frigid air coming into your home. Thermal and acoustic performance can also be increased when gas fills this space.

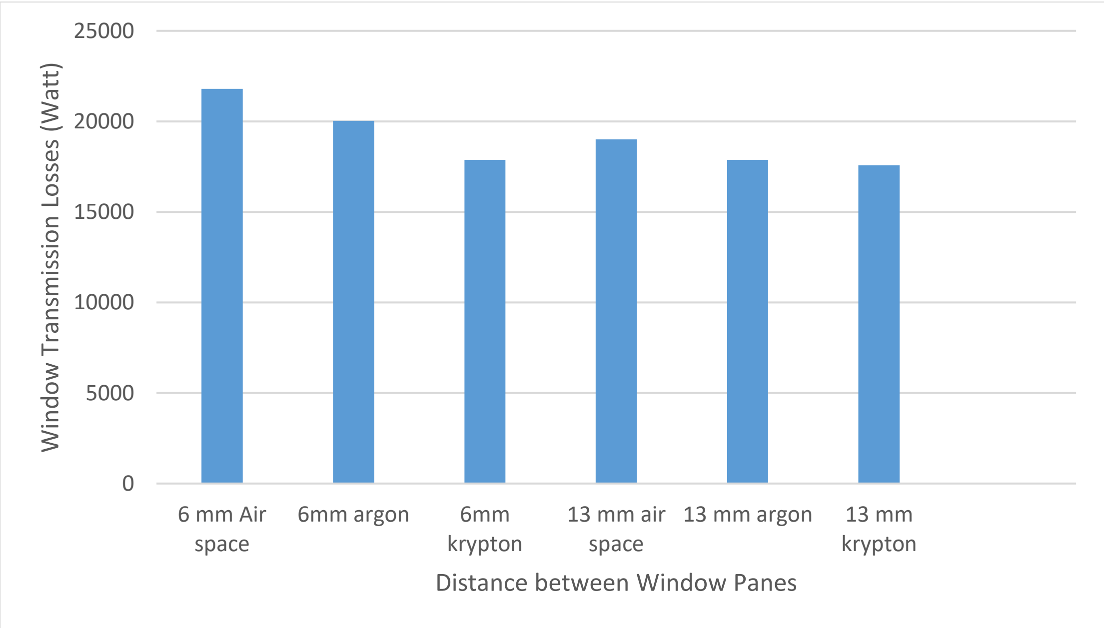

Figure 5: Variation of transmission losses with insulation gas between panes in baseline model.

3.5.2 By Changing Window Frame

Most common materials for window frames are wood, aluminum and vinyl. Aluminum is light, strong and almost maintenance free but it is poor insulator and conduct heats very rapidly. The solution of this problem is to use Aluminum frame with thermal breaks. Aluminum frame with thermal breaks have insulated material sandwich between interior and exterior pieces of aluminum frame and it is less conductive. Vinyl window frame are made of polyvinyl chloride and have best resistance against solar loads. Vinyl frame also has good resistance against moisture and don't require painting. The hollow cavities between vinyl frame serves as insulator.

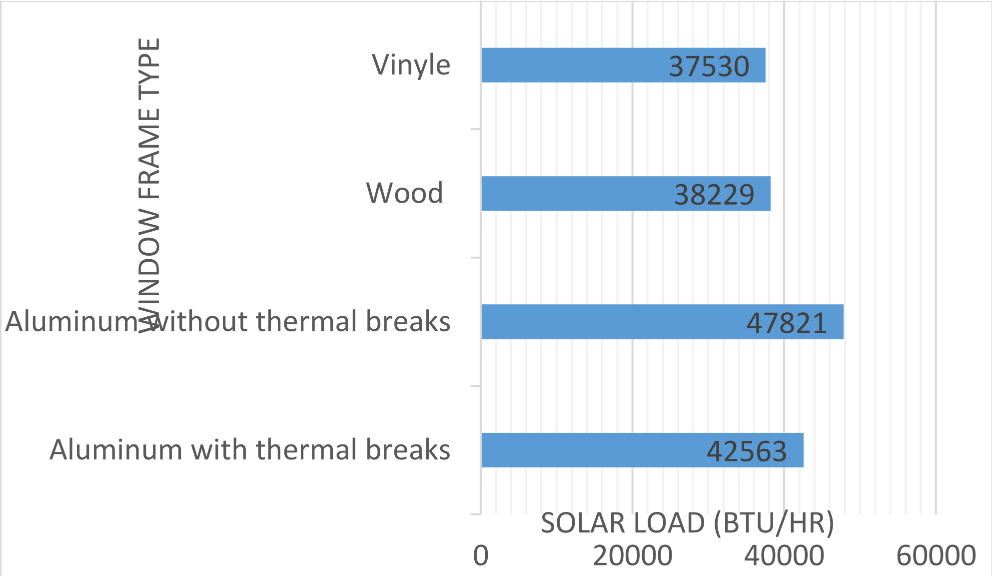

Figure 6: Variation of Solar load with window frames in baseline model.

3.6 Baseline Model and Shading of Windows EEM Comparison

For extreme sun exposures, exterior window shades are the perfect window solution. Energy cost of air conditioning can be reduced by using exterior solar screen shades. 9.13 % solar loads were reduced by applying this shade. Heat gain can be controlled by using both internal and external shade but external shade are more effective as compared to internal shades. External shade stops the sun heat to enter into the building where as internal shade minimize the effect of heat gain by reflecting the solar heat.

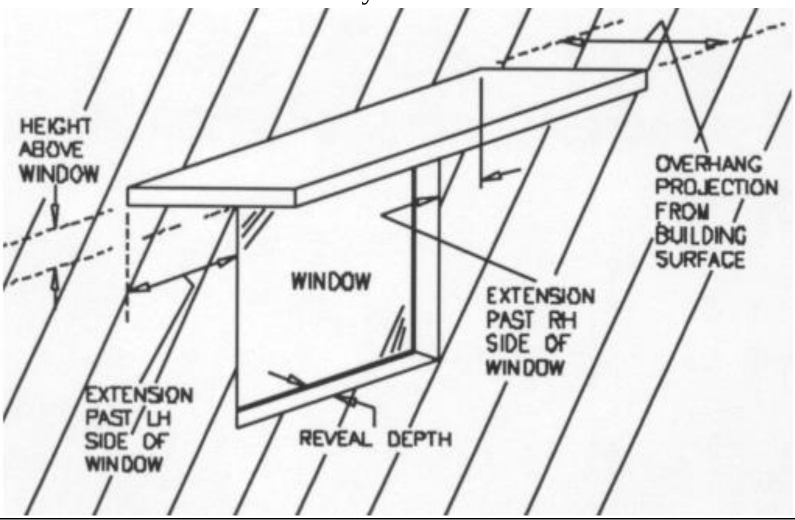

Figure 7: Horizontal external shade for windows.

3.6.1 By Applying Curtin's

There are several types of blinds drapes, curtains and shutters. Curtains block the sun rays from overheating the building. Distinct types of curtains, drapes and shutters were applied on the baseline building and their effect against solar heat gain was analyzed by applying number of simulations. Result shows that vertical blind which are available in PVC, wood and fabric is best option against solar heat gain.

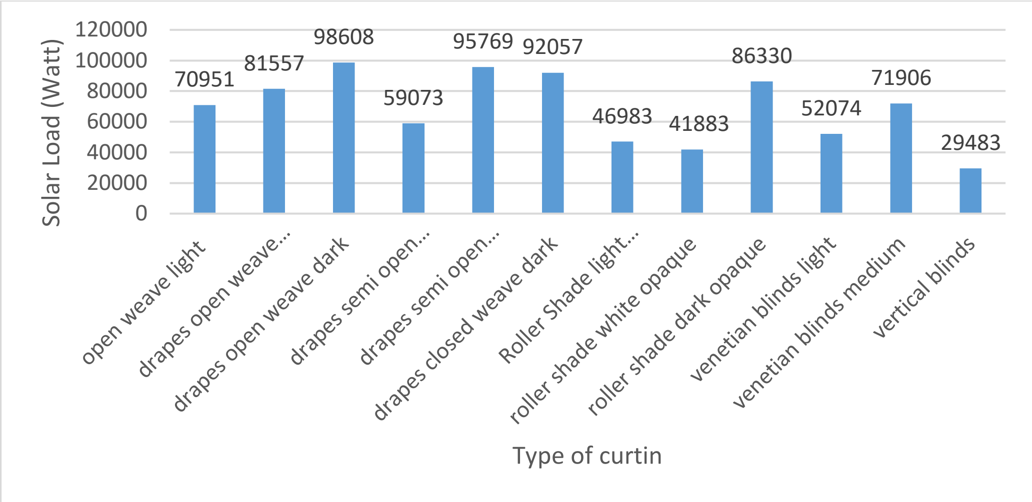

Figure 8: Variation of Solar load with internal shades in baseline model.

3.7 Baseline Model and Thermostat Management EEM Model Comparison

Graph is illustrating the cooling load requirements against the indoor design temperature and it shows that cooling load requirement has inverse relation with indoor temperature. As the indoor temperature is decreasing, cooling load requirement is increasing. Thermostat set point helps in reducing the energy consumption of building by setting it 26 C instead of frequent practice of 22 C. By setting the thermostat at 26 C almost 11.4 % cooling load requirement may be reduced

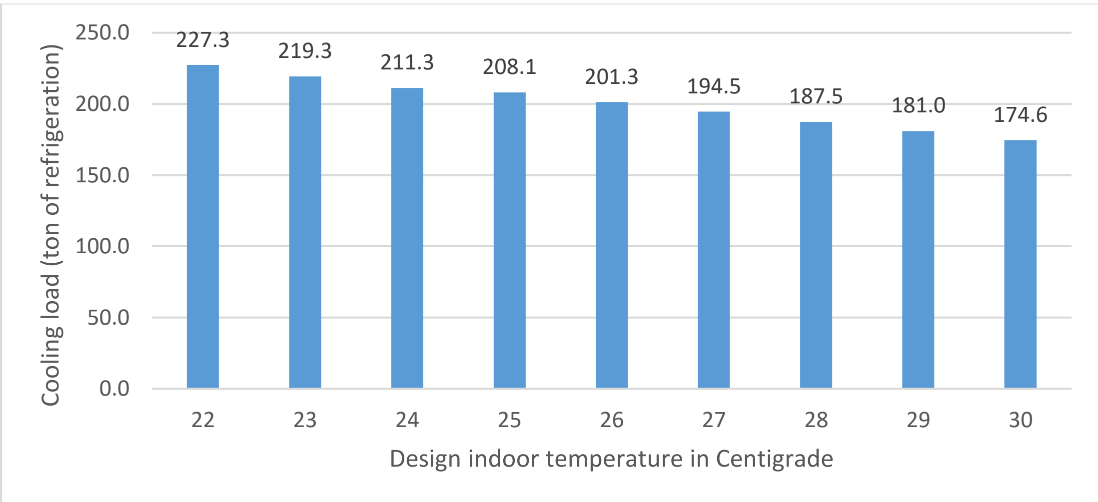

Figure 9: Variation of cooling load requirement with indoor temperature in baseline model.

3.7.1 Seasonal Variation of Cooling Load

Seasonal variation of cooling load is shown and it reflect that cooling load of building rises sharply from March and reach at its peak in the month of July and August and then start decreasing gradually.

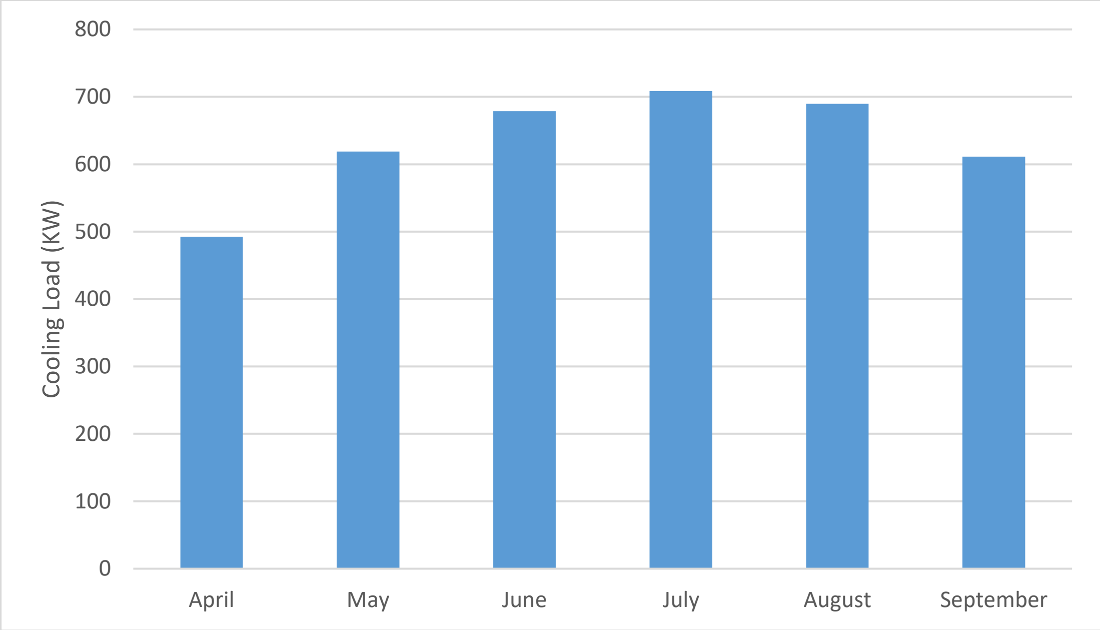

Figure 10: Variation of seasonal cooling load requirement in baseline model.

4 Discussion

Analysis of breakup of zone load provides contribution of each load on overall cooling load. The parameters for the base-case zone loads are windows & sky light solar loads, wall transmission, window transmission, overhead lighting, electric equipment, people activity, infiltration and outside air ventilation requirement. Roof transmission losses are largest share of about 21% of total zone loads, then window solar loads and window transmission losses as 13% and 7% respectively. Heat gain due to electric equipment is 15%. Infiltration is uncontrolled outside air which enters conditioned space and it has a share of 4%. These zone loads can be reduced by applying different retrofitting techniques. Reducing solar heat gain through window is clearly one of the key area. Simulation results shows that building envelop orientation plays a significant role in reducing the energy consumption of building. It was also investigated that best orientation of building is in the direction of south. By carefully selecting the placement of windows in building envelop may save significant amount of energy resulting in financial benefits. Windows facing east or west waste more energy as compared to north and south. A significant amount of energy can be saved by using double glaze window. Double glazed windows are an ideal energy efficient choice with the added benefit of minimizing noise. The space between the panes in double glazed windows is fully sealed, it acts as an insulator, limiting the transfer of frigid air coming into your home. External and internal shades also helps in reducing the penetration of sun rays and eventually energy demand for cooling. As the indoor temperature is decreased, cooling load requirement also increased.

Conclusion

Proper system design for buildings and reduction in energy consumption in buildings accounts building type and size, layout, surrounding area, the nature of activities taking place, the number of occupants, climate and other factors, making each situation distinct. Minor changes can make enormous difference from energy perspective in buildings. Making and analysing certain key measurements is essential for optimizing the building performance. Cooling load requirement varies by orientation of building envelop, orientation of windows, window type, frame, glazing, indoor design temperature, internal and external shades. External thermal loads are more than internal thermal loads. Heat gain from building envelop can be reduced by choosing appropriate building orientation, wall to window area ratio, window orientation, frame, glazing and shading.

References

[1] "http://hdip.com.pk/contents/Energy-Yearbook-2014/32.html," [Online]

[2] Ahmad, K., Badshah, S., Rafique, A. F. (2014). A simulated case study of office

building in pakistan to improve the energy efficiency. International Journal of Engineering and Advanced Technology, 04(2), 7-9.

[3] Hameed, R., Nadeem, O., Altaf, S., & Ameen, F. (2014). Improving the Energy Efficiency of Existing Commercial Buildings in Lahore Through Retrofitting Technique. Journal of Faculty of Engineering & Technology, 21(2), 95-104.

[4] Tahsildoost, M., & Zomorodian, Z. S. (2015). Energy retrofit techniques: An experimental study of two typical school buildings in Tehran. Energy and Buildings, 104, 65-72.

[5] Ahmad, K., Rafique, A. F., Badshah, S. (2014). Energy efficient residentail buildings in pakistan. Energy and Environment, 25, 991-1002.

[6] Mohammed, M. A., & Budaiwi, I. M. (2013). Strategies for reducing energy consumption in a student cafeteria in a hot-humid climate: A case study. Journal of Sustainable Development of Energy, Water and Environment Systems, 1(1), 14-26.

[7] Khan, A., Arif, S., Alamgir, K. (2012). Comparison of buildings thermal loads against building orientations for sustainable housing in pakistan. Mehran University Research Jounal of Engineering & Technology, 31, 431-436.

[8] Khalid, S. A. (2015). Economic and Environmental benefits for adopting energy efficiency methods for a typical house in Pakistan. Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan, 20(3), 25-33.