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RESEARCH PAPER

Energy Conservation Potential of Building Envelope: A Simulation based Comparative Analysis for Residential Buildings of Lahore, Pakistan

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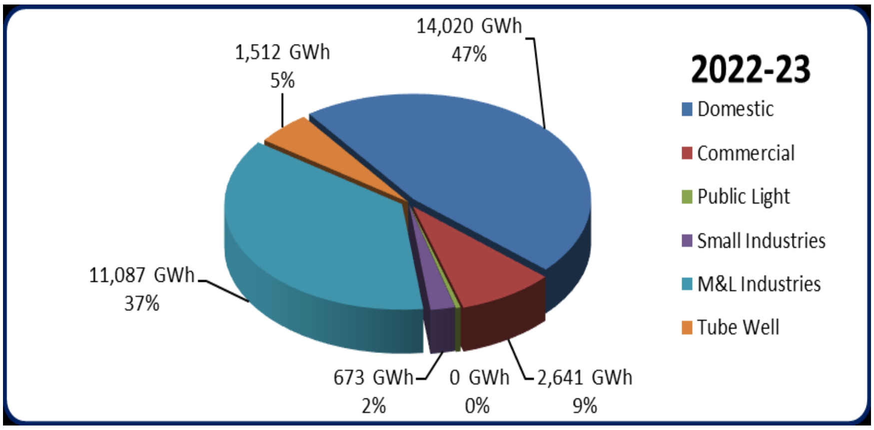
ABSTRACT

Pakistan is facing severe energy crisis like other developing countries of the world. Among different energy consumers, residential sector consumes about 47 % of total energy. The objective of this research is to find the energy conserving potential of building envelope in residential buildings. So, a prototypical detached family house has been modeled as a case study in Autodesk BIM software, Rivet 2014. In order to quantify the impact of different energy efficient techniques, cooling load analysis has been done for different building envelopes with modifications in walls, roofs and windows. It has been concluded that the building envelope has a significant potential in reducing the energy demand for a residential building. Modifications in building envelope is found to reduce energy consumption by 37 % in contemporary house. Thus, substantial energy savings are possible if designers aggressively promotes the energy efficient measures in building envelope.

KEYWORDS Building Envelope, Cooling Load, Energy, Insulation

Introduction

There is a huge concern in the world regarding energy conservation as its consumption is increasing rapidly with advancement in technology causing severe environmental hazards. Pakistan being developing country is also facing enormous problems regarding energy sources resulting in frequent load shedding's and power failures. According to the statistics of planning power National Transmission and Dispatch Company NTDC, domestic sector consumes the highest percentage i.e 47 % of electricity as compared to other sectors (Usman, 2019) as shown in figure 1. The increase in consumption of energy is mainly due to the increase in population, urbanization and increase in standards of living (Siddique, &Arif, 2016).



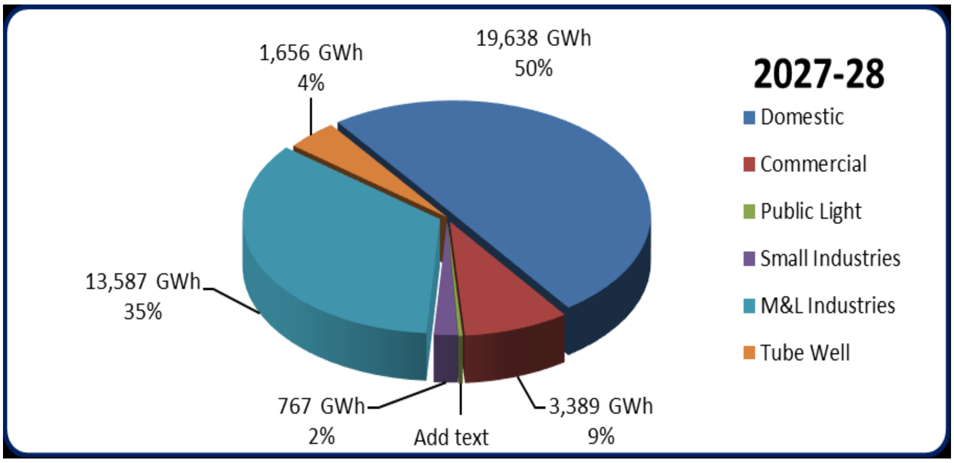


Figure 1: Sector wise distribution of electricity consumption in Pakistan. (Source: Planning Power NTDC, 2019)

Energy efficient building design techniques can serve as an alternative solution to the energy crisis problem and can help in optimization of energy consumption in buildings.. An important consideration is that building itself does consume energy rather the domestic appliances such as the lighting, heating, cooling, refrigerators and water pumps are the main consumers of energy (Jan & Mutalib, 2013) as shown in figure 2. About 39% electrical energy is consumed in cooling system of buildings. So, designing an energy efficient envelope plays an important role in reducing the energy demand in buildings (Al-Qahtani & Elgizawi, 2020). In areas like Lahore, Pakistan building indoor temperature is very high in summer due to inefficient building envelope and mechanical cooling systems are used to maintain a comfortable indoor temperature. So, there is a need of energy efficient techniques to achieve comfortable indoor environment in buildings without using substantial amount of energy especially for cooling.

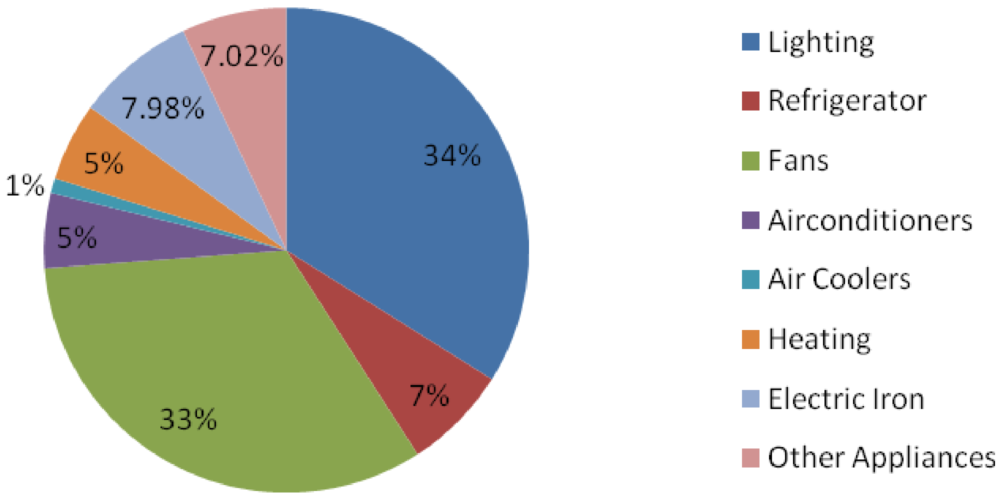


Figure 2: Electricity consumption percentage in a typical house (Source: Jan & Mutalib, 2013)

Literature Review

Considering different studies for hot and humid climate, it has been observed that the energy efficient measures have a significant energy conservation potential in reducing the electricity demand in buildings (Ahmed, Arif, Khan, &Mustaq, Jun2013). The literature review also reveals that only limited studies have done on the energy conserving potential of building envelope for the climate of Lahore, Pakistan. Thus, here is an urge to determine the potential of building envelope for the climate of Lahore as it is the second largest city of Pakistan.

Climate of Lahore

Lahore, second largest city of Pakistan is lying between latitude 31.5°N and longitude 74.3° E. It has a semi-arid climate with an average temperature 24.3° C. The hottest and coldest months are June and January with an average temperature 33.9° C and 12.8° C as shown in figure 3.

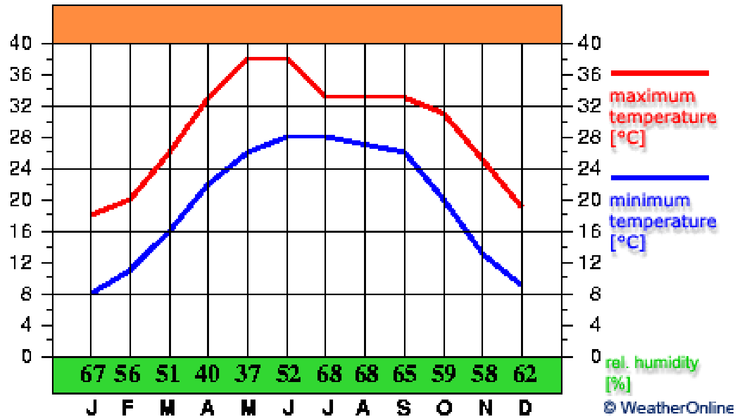


Figure 3: Climate of Lahore, Pakistan (source:Weatheronline.co.uk)

Energy conservation potential of Building Envelope

The maximum heat gain in buildings is through walls, roof and windows which are carefully examined in the study. The modifications done in these components can reduce the energy consumption in buildings.

Walls

The fundamental part in building that is exposed to external environmental conditions is the wall. Walls bear solar radiations, outside temperature, wind and precipitation. Energy efficient walls can be constructed by increasing the thickness, adding cavity inside and by insulating the walls (Taleb, 2014). Painting the walls in light color is also beneficial. Light exterior walls absorb less heat as compared to dark walls (Omrany&Marsono, 2016). Shading of buildings can reduce indoor temperatures by as much as 20°F (11°C). This can also be done by planting trees and vegetation on exterior building side. More practical is to locate trees at east and west facing walls.

Roofs

Roof is considered as the major and maximum heat gain component in the building envelope. This is also verified in the selected case study. The reason for this is the direct exposure to the sun resulting large amount of heat production. A number of design and cooling techniques are there that could lessen the heat absorption from the roofs. The literature studies show that insulation is the best way to reduce cooling load in buildings (Al-Homoud, 2004). The insulation materials are in the form of insulation sheets and boards. Another system is the roof pond which can lower down the temperature. The water pond is constructed on flat roof which is covered in day time and open during night. Shading of roof is also done in form of deciduous plants and creepers. Similarly the inverted earthen pots is a solution in traditional form of buildings (Madhumathi, Radhakrishnan, &Shanthipriya, 2016). These solutions lower down the inside temperature but somehow the roof surface becomes unusable.

Windows

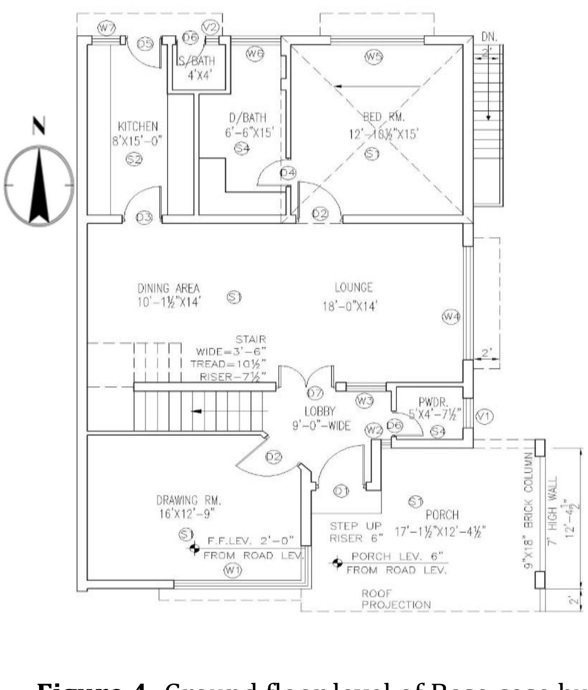
Windows are the other focused element in the building envelope generating great amount of heat. Roughly 40% of the surplus heats that affects the building come in through windows. The insulation of windows such as doubling the window glass and adding space increases its thermal resistance (Ahmad, Rafique, Badshah, & Imran, 2012). Other method used is the reflective coating of the windows that transmits the solar radiations. Moveable/ adjustable and well-designed shades provide an efficient solution for summer and winters in terms of heat gain in a building. Sun control films can also be used those are suitable for warmer climates. They can reflect about 80% of the sunlight incoming inside.

Material and Methods

Energy conservation potential of building envelope can be determined in two ways. First is based on field experimentation and second is based on software simulation. The technique adopted in this research is software simulation which is a quick and reliable method. The simulation can be repeated for various models so it can save research time and funds. The Autodesk Building information software, Rivet 2014, has been used in this study which is a reputable simulation tool for energy analysis. In order to assess reduction in the energy consumption for residences in Lahore, a prototypical residential building is defined in Autodesk Rivet 2014. Then various modifications are done in brick walls, roof and windows to determine the conservation potential of building envelope.

Selected Case Study

The residence that has been considered in the research work is a detached family house, the most common type of housing in Lahore. The building parameters that are used in base case modelled house are same as contemporary residential building. For software simulation, detailed plans were taken from Arch Sol, a well-known architectural consultancy in Lahore. The residential building was two storey and 22'-0" high with covered area of 2678 sq.ft. The architectural layout and elevation is shown in figure 4, Figure 5 and figure 6. The building orientation is 90° north.



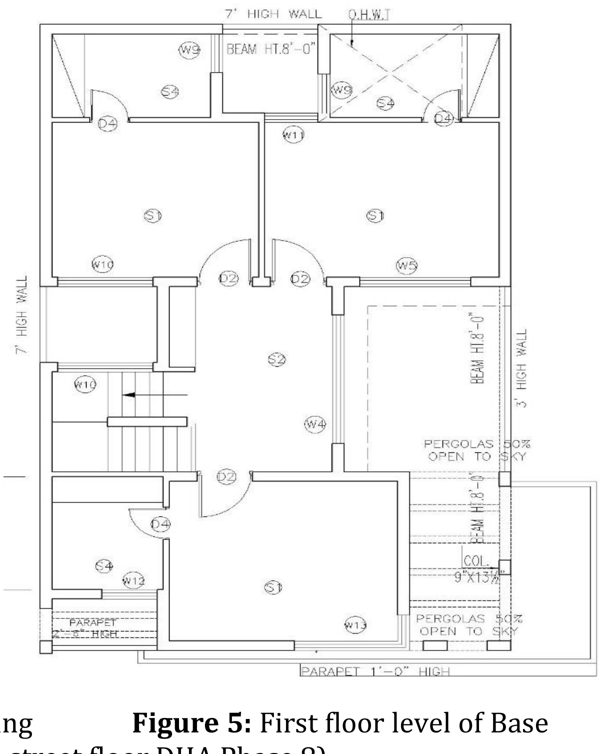


Figure 4: Ground floor level of Base case building **Figure 5:** First floor level of Base case building (Source: Arch Sol,44L commercial street floor DHA Phase 8)

Figure 6: Elevation of Base case building (Source: Arch Sol, 44L commercial street floor DHA Phase 8)

Each room in the house was modeled as an independent space**.** The construction specifications of each space are shown in table 1.The sensible and latent heat gain based on ASHRAE standards were 245 btu/hr and 145 btu/hr. The lighting and power load densities were same i.e 0.50 W/ft^2. External loads in which weather data is most important parameter was added through internet mapping service. The infiltration rate of air change was 0.3 per hour. The R-values (thermal resistances) of contemporary building are shown in table 2.

Table 1
Construction specifications of contemporary residential building

Building Location	Lahore, Pakistan
Number of stories	2
Total height	22'-0"
Total area dimensions	2275 sq.ft
Total covered area	2678 sq.ft
Type of glass	Single glazed
External walls	1/4" plaster outside + 9" thick burnt bricks + 1/4" plaster outside
Roof	6" thick Reinforced concrete slab+ 2 coats of hot bitumen + polythene sheet+ 3" mud + 1 ½" brick tiles
Floor	½" thick ceramic tiles + 1 ½ " thick Plain cement concrete+ 4" Gravel +4" sand + compacted earth
No of occupants	8 persons
Building Service	Spilt system with natural ventilation
Sensible heat gain	110 Btu/hr
Latent heat gain	185 btu/hr

Table 2
R-values of contemporary building envelope

Building Envelope Components	**R-Value**
Floor	1.85 (h.ft^2.°F)/Btu
Walls	2.545 (h.ft^2.°F)/Btu
Roof	1.81 (h.ft^2.°F)/Btu
Single glazed window	0.989 (h.ft^2.°F)/Btu

Modifications in Contemporary Building Envelope

Table 2 shows the R-values of contemporary building envelope. To design an energy efficient house parametric modelling wass done with modifications in walls, roof and windows as shown in table 3. The modifications include cavity wall with insulation, 1" thick insulation in roof, 1" thick insulation in walls and double glazed windows. The insulation materials used was Expanded Polystyrene (EPS), also known as thermopore. This is closed cell foam made from pre-expanded polystyrene beads. It is locally available in the market with high R-value that is R-5.4. Its density is 35 kg/m^3 (Thermopore).

Modifications in Walls

Two different types of modifications were done in the walls. The literature studies indicate that cavity walls have a significant impact in reducing the energy demand in buildings. So, its effect on thermal comfort was analyzed. A 1" thick cavity was provided in between 9" thick brick wall as shown in figure 7. Another modification that was applied on contemporary walls was 1" thick insulation on exterior side of 9 "thick walls as shown in figure 8.

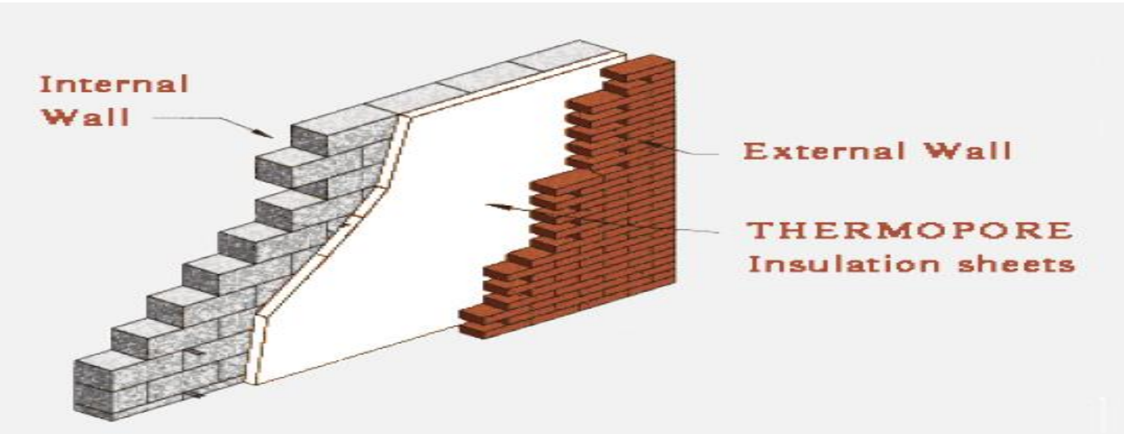


Figure 7: Cavity wall detail (Source: Thermopore)

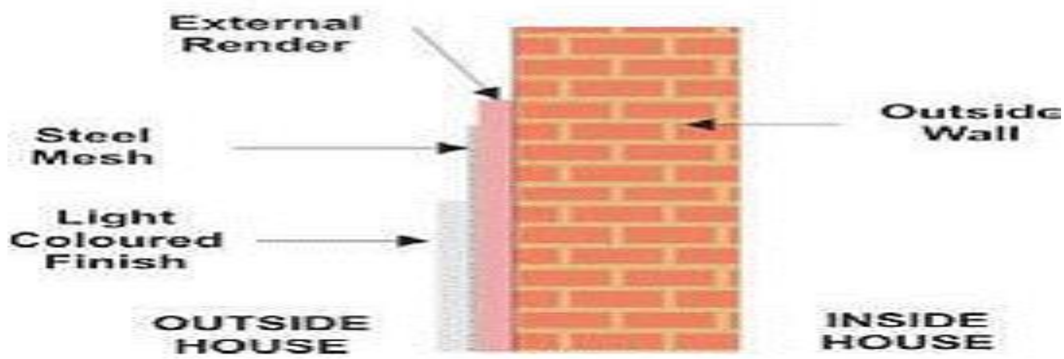


Figure 8: Insulation material on outer side of brick wall (Source :Thermopore)

Modifications in Roof

The studied literature shows that the major part of the heat gain is through roof. So, 1" insulation material was applied on contemporary roof as shown in figure 9.

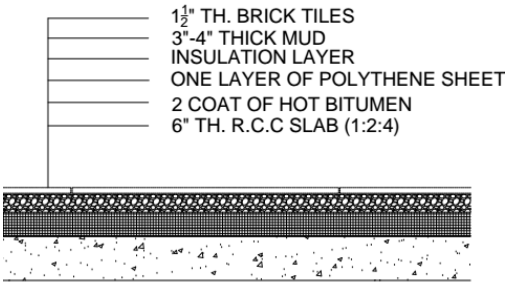


Figure 9: Sectional details of modified roof with Insulation

Modifications in Windows

Windows plays a very important role in reducing the cooling demand in buildings as they provide a weak link between the indoor and the outdoor environment. So, the window glass that is single glazed in residential buildings was replaced with double glazed glass as shown in figure 10.

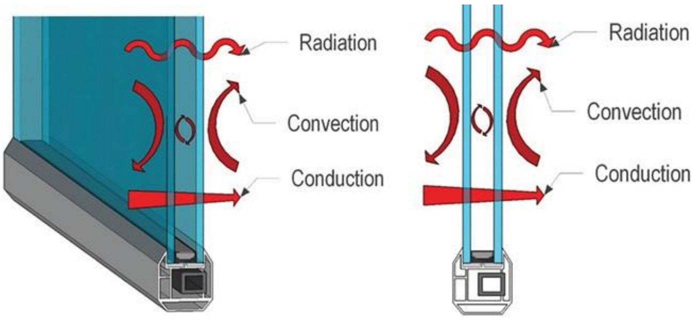


Figure 10: Working principle of double glazed glass (Source: Aguilar-Santana et al., 2019)

Table 3
R-values of contemporary building envelope (Source: Author)

Modifications in building Envelope	R-Values
Double glazed window	1.81 5(h.ft^2.°F)/Btu
Cavity Walls	7.91 (h.ft^2.°F)/Btu
Walls with 1 " thick insulation on wall exterior side	7.91 (h.ft^2.°F)/Btu
1 " Thick Insulation in roof	7.27 (h.ft^2.°F)/Btu

Results and Discussion

The contemporary building and the modified building were analyzed in Autodesk Rivet 2014 for the climate of Lahore, Pakistan. Seven parametric simulations were performed for different cases of building envelopes. The cooling load and their percentage difference were calculated for all the modifications as shown in table 4 and figure 11. The results show that building envelope has a significant potential in reducing the energy demand in buildings. The reduction in energy demand is minimum with double glazed windows i.e. 5.7%. Energy demand can be reduced up to 16.86 % with 1" thick expanded polystyrene insulation in roof. In case of Ideal building envelope, 1” thick insulation in all the four exterior sides of walls and roof with double glazed windows, energy demand can be reduced up to 37.05 %.

Table 4
Reduction in cooling load demand with modifications in building envelope

Case #	Modifications in building Envelope	Cooling load Btu/hr	Reduction in cooling Load, %
Case # 1	**Contemporary building**	134,233	------------------
Case # 2	**Double glazed window**	126,515	5.7
Case # 3	**Cavity Walls**	116,865	12.94
Case # 4	Walls with 1" **thick insulation on exterior side**	115,712	13.78
Case # 5	1" **Thick Insulation in roof**	111,592	16.86
Case # 6	**Building with insulation in walls and roofs**	93,081	30.66
Case # 7	**Ideal Building**	84,495	37.05

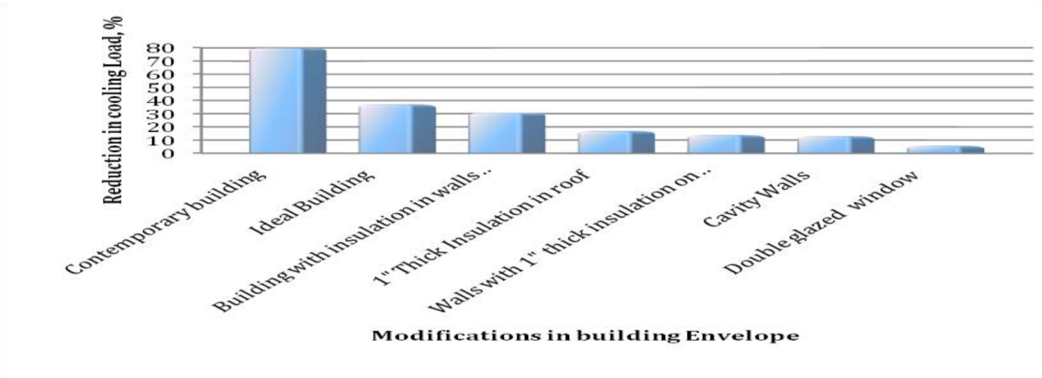


Figure 11: Graphical representation of Reduction in cooling load demand with modifications in building envelope

Conclusions

Energy efficiency is the prime concern in designing of smart buildings as they are the biggest consumer of electricity. A software simulation is done with the help Revit 2014. A prototypical house is modelled and energy efficient measures are analyzed. The cooling load is calculated for 12 months in Lahore, Pakistan. The variation done in the building envelopes includes insulation in walls, roofs, cavity walls and double glazed windows. The cooling load report provides very useful information for energy efficient house design. The result shows that the building envelope has a significant potential in reducing the energy demand in buildings. Electricity demand can be reduced up to 37% if energy efficient measures are taken into account. Thus, energy efficient design of building envelope can reduce substantial amount of energy and results in overall reduction of energy consumption.

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