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Thermal Analysis of an Educational Building with Different Construction Materials

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Abstract

The energy consumption has been increased to an alarming rate in the current world. This scenario has raised many problems like depletion of energy resources, energy supply difficulties and increased carbon footprint (global warming, climate change). The objective of this research is to minimize the energy consumption in educational institutions. This study will help us in reducing the heating and cooling loads of building and resulting to saving cost. A prototype building was modelled in Autodesk Software, Ecotect 2011 for the climatic zone of Multan to examine the thermal performance with different construction materials. The building studied with different aspects including passive and active techniques, planning and design. These aspects were analyzed and results were evaluated. Various construction materials were listed and examined for the development of energy efficient envelope. The results showed 11.86 % decrease in energy usage including 11.76% decrease in cooling load and 46.59% in heating load with locally available building materials.

Keywords: educational building, Multan, cooling and heating load, construction materials.

Introduction

The worldwide commitment from structures towards energy consumption, both residential and private, has consistently expanded achieving figures somewhere in the range of 20% and 40% in developed countries, and has surpassed the other significant divisions: mechanical and transportation. Development in populace, increasing demand for building services and comfort levels, together with the ascent in time spent inside buildings, guarantee the upward trend in energy demand will be more in future. (Arif et al, 2012).

Consequently, energy efficiency in building is today a prime goal for energy strategy at territorial, national and universal levels. ***The development in HVAC frameworks, energy consumption is especially noteworthy (50% of building utilization and 20% of total utilization in the USA) among building services*** (Arif et al, 2012). In Pakistan, building sector consumes 50% of total energy (Bahadori et al, 2017). The statistics of population growth and increase in demand of building services indicates that buildings energy demand will increase in the future.

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Pakistan is suffering from major energy crises that needs a severe attention. This research work deals with different types of construction materials for reducing the energy consumption and HVAC loads. The city of Multan, Pakistan has been selected for analysis because of its severe hot climate. Multan has two major season winter and summer as shown in figure 1. Winter is so mild and with high humidity. The summer season remains for the long period of the year with low precipitation. While winter season is short in month of November to February. Monsoon rains in Multan are in the month of July to September.

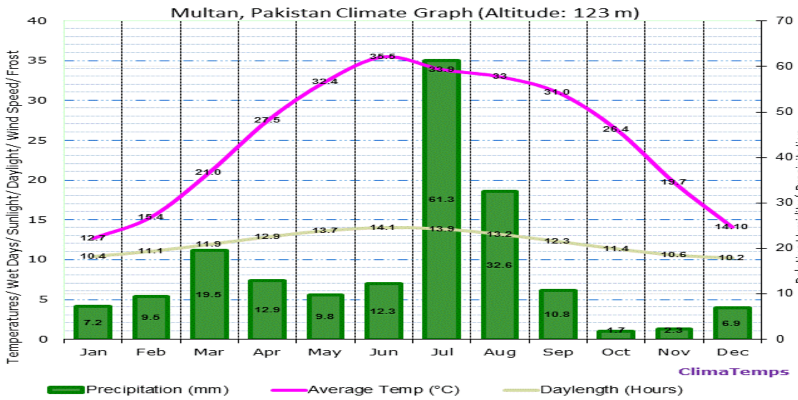

Figure 1. Multan, Pakistan climate Graph (Altitude: 123 m) [source: climatemps.com]

1.1. Building Envelope

The building envelope – otherwise called the building shell, texture or walled in area – is the limit between the inside and the outside of a building. The energy performance of building envelope including outside dividers, floors, rooftops, roofs, windows and entryways plays a significant role energy demand. The building envelope's effect on energy utilization ought not be belittled: all around, space warming and cooling represent more than 33% of all energy expended in buildings, ascending to as much as 50% in chilly atmospheres and over 60% in the residential sub-sector in chilly atmosphere countries (Bahrami, 2008). The building designers, engineers usually overlook the passive design strategies which results into the high energy demands. The building energy demand can be reduced if designed according to passive design strategies (Bahrami, 2008).

1.2. Roof

Rooftop structure and materials can lessen the measure of cooling required in hot atmospheres by expanding the measure of sun based warmth that is reflected, as opposed to retained, by the rooftop. For example, rooftops that fit the bill for energy star are assessed to decrease the interest for peak cooling by 10 to 15 percent. Appropriate insulation is additionally critical in storage rooms and building cavities adjacent to the rooftop. In addition, rooftops additionally offer a few open doors for introducing on site generation system. Sunlight based photovoltaic (PV) frameworks can either be introduced as a rooftop top exhibit over the building or a building-coordinated photovoltaic system can be incorporated into the building as material tiles or shingles. In single and double storey structures, more than 50% warmth exchange is through rooftop, in which empty mud squares were utilized as protection and were 38-63% powerful than convention system of protection (Chan and Chow, 1998). Roofs absorb maximum heat through area in which heating and cooling loss occurs (Cheung et al, 2005).

1.3. Walls

Heat exchange through walls can be minimized by wall protection. Wall insulation will decrease both cooling and heating demands of the buildings. (Muhaise, 2015). A study conducted showed a marked decrease in cooling loads up to 7-10% by doubling wall thickness on east and west sides (Pérez et al, 2008). Understanding and upgrading the warmth exchange through the walls is essential in high performance building designs. Utilizing warm mass and insulation to advantage with passive design techniques can help decrease the measure of energy that active system need to utilize. Accordingly, it is basically important to decide properly the warm transmittance of walls while surveying the energy consumption of structures. It is worth monitoring that many past examinations have affirmed the advantages of enhancing the envelope thermal properties of the consumed energy of buildings (Shaheen et al, 2016).

1.4. Windows

Energy efficient windows; double glazed with protective coating and gas filling are very helpful in maintaining indoor temperature (Sharaf and Al-Salaymeh, 2012). Window is an important component of the building envelope and if designed properly, can have a significant impact on the energy consumption. Windows are responsible for up to 60% of a building's overall energy loss. Therefore, the thermal performance of window glass must be considered during the design phase for appropriate energy consumption in future (Vijaykumar et al, 2007).

1.5. Floors

High heat retaining or mass materials that can absorb, store and release heat are important as these contribute to the total thermal mass of building. The building indoor temperature can be maintained with the help of floors. The floors contribute to mass material and can emit heat in the required time. The study conducted in University of Florida prescribed the planning of raised floors for attaining the increased air flow. In hot climate, the heat transfer is minimized by adding 1m strip of insulation material below the floor slab (Wong and Li, 2007).

2. Methodology

In this research first of all we had selected an educational building and then building was studied with different aspects including passive and active techniques, planning and design. These aspects were analyzed and results were evaluated. Different construction materials were selected and investigated in the design of an effective building envelope. Ecotect was used for thermal analysis of the building. Different cases for building with different materials were created in the software and then analyzed.

2.1. Case Study of Building

Case study building was computer engineering department which is located in Bahuddin Zakriya University Multan, Punjab, Pakistan. Total area of building is 11300 sq-ft. It is double story building with 6 class room, 3 labs, 1 kitchen, store, combined bathroom, central courtyard at each story. No sun shades are provided on windows. Thermal properties of modeled building are shown in table 1.

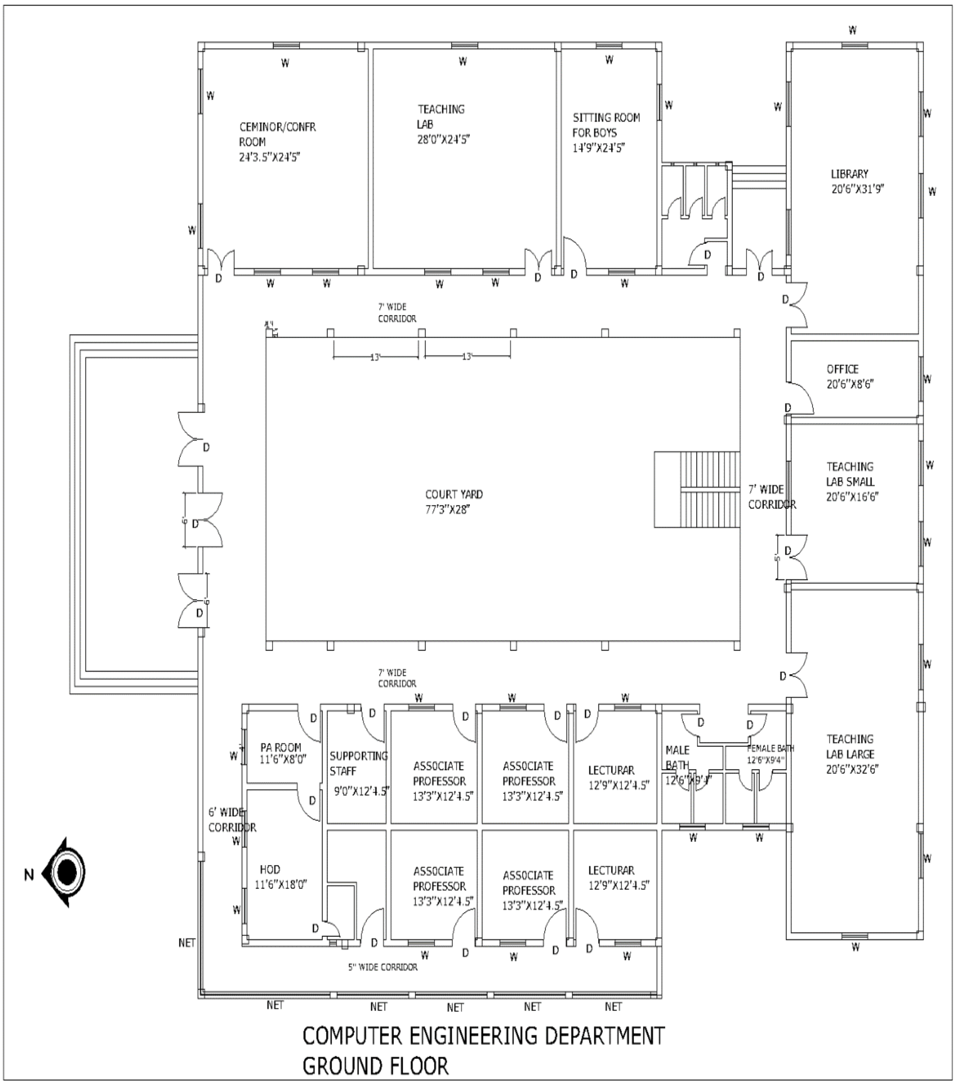

Figure 2. Computer Engineering Department (Selected Case Study Building)

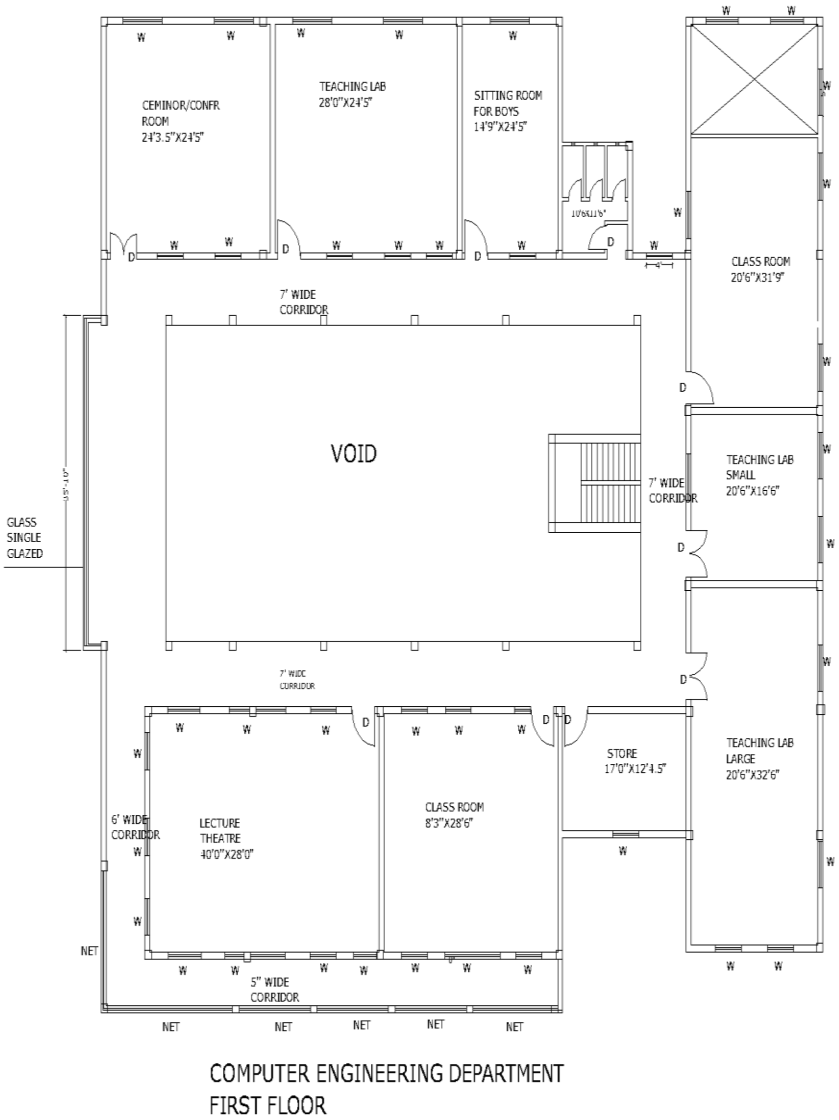

Figure 3. Selected Case Study Building

2.2. Thermal Analysis

For this research we made four cases with different materials.

2.2.1. BASE CASE: In baseline case, the building with present material was considered. Single glazed glass windows, 9'' thick brick masonry walls and concrete roof with mud and bitumen coating are used in this building.

Table 1.
Thermal Properties of Modelled Building [Source: Ecotect 2011 and www.kingspan.com]

No.	Building Element and description		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
		Roof Tiles	1 1/2"	1900	800	0.84
		Mud	3"	1900	8 80	0.520
1.	Roof U Value 0.872 (W/m²k)	Bitumen	0 3/8"	1700	1 000	0.50
		Concrete	6"	2300	656	1.046
		Ceramic Tiles	3 /8"	2000	8 50	1.2
		PCC	2"	950	656	0.209
2.	Intermediate Floor U Value 0.500	Brick blast	2"	1900	880	0.47
		Concrete	6"	2300	656	1.046
		Ceramic Tiles	3 /8 "	1900	656	0.309
		P CC	2"	2000	656	0.755
3.	Ground Floor U Value 1.330	Brick Masonry	4"	2000	8 36	0.711
		Sand	4"	2240	8 40	1.711
		Soil	9"	1300	1 046	0.837
		Plaster	3 /8"	1250	1 088	0.431
4.	Walls U Value0.324	Brick	9"	1900	880	0.47

		masonry				
		Plaster	3 /8"	1250	1 088	0.431
5.	Windows U Value 1.098	Standard Glass	1/4"	2300	8 36	1.046
		Plywood	1 /8"	530	1 400	0.140
6.	Doors U Value 2.980	Air Gap	1 5/6"	1.3	1 004	5.560
		Plywood	1 /8"	5 30	1 400	0.140

Case 1**:** In baseline case mud was used in the roof which have conductance value 0.52 w/mk but in case 1 wool resin bonded was used as an insulating material for roof which have conductance value 0.021w/mk. 1’’ thick layer of wool was used which is highly energy efficient material with low conductance value. Modified properties of materials are given in table 3.

Case 2**:** In baseline case single glazed glass was used for the windows which have U-value 1.098 w/mk but in case 2, double glazed glass was used which have U-value 0.4244 w/mk. Modified properties of materials are given in table4.

Case 3**:** Walls are also important part of structure as 40% heat comes through walls into the building. In base case, 9’’ thick brick masonry wall was used which have U-value 0.324 w/mk but in case 3, double layer of 4.5’’ thick brick masonry wall with 1’’ air gap was used which have U-value 0.236 w/mk. Double glazed windows were used in this case. Modified properties of materials are given in table 5.

Case 4**:** This was the final case in which materials of roof, walls and windows are changed. In roof 1’’ thick layer of wool resin bonded was used which have conductance value of 0.021 w/mk, cavity wall was used which have U-value 0.236 w/mk, double glazed windows were used which have U-value 0.4244 w/mk. Modified properties of materials are given in table 6.

Table 2.
Indoor design parameters as per weather file of Jaipur, India (Same Climate as Multan), Autodesk Ecotect, 2011.

Relative Humidity	67%
Wind Speed	2.31 m/s
Thermostat Range	30
HVAC System	Air-Conditioning
Air Change Rate	0.50/hr

Case study building with present materials in climate of Multan considered as a baseLINE case in which mud was used in roof, single glazed windows, 9’’thick brick masonry walls were used in this building. Autodesk Ecotect 2011 was used for analysis. In base case total energy load was 57630097 Btu/hr including 57462640 Btu/hr as cooling loads and 167457 Btu/hr as heating loads.

Case 1**:** In this case wool resin bonded was used as an insulation material in roof. Results were observed in reduction of total energy consumption. Total load of Case-I was 51761560 Btu/hr including cooling loads of 51634884 Btu/hr and of heating loads 126675 Btu/hr. A decrease was seen in energy saving incorporating 10.14% saving in cooling and 24.35% in heating burdens.

Case 2**:** In this case double glazed windows were used. Results were observed in reduction of total energy consumption. The building loads were 55734882 Btu/hr including cooling load of 55576248 Btu/hr and of heating load 158634 Btu/hr. A decrease was observed in energy saving incorporating 5.26% savings in heating and 3.28% in cooling loads.

Case 3**:** In this case cavity walls were used and double glass windows were used. Results were observed in reduction of total energy consumption more than case 2. The energy loads were reducing to 55193375 Btu/hr, including 55059948 Btu/hr in cooling and 133427 Btu/hr in heating. A decrease was observed in energy saving incorporating 4.18% Cooling load and 20.32% in heating load.

Case 4**:** we changed the material of roof, walls, windows and run analysis by Autodesk Ecotect, Results were observed in reduction of total energy consumption more than all cases. The energy loads were reducing to 50792536 Btu/hr, including 50701424 Btu/hr in cooling and 91112 Btu/hr in heating A maximum decrease was noticed in energy saving which includes a decrease of 11.76% in cooling load and a decrease of 45.59% in heating load.

Table 3.
Thermal Properties of Building Components and Material (Case 1)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
1.	**Roof U Value 0.19373(W/m²k)**	Roof Tiles	1 1/2 "	1900	800	0.84
		Mud	3 "	1900	880	0.520
		Wool, resin bonded	1’’	6.18	499	0.020
		Bitumen	0 3/8 "	1700	1000	0.50
		Concrete	6"	2300	656	1.046

Table 4.

Thermal Properties Of Building Components And Material (Case II)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
3.	Windows U Value 0.4244	Standard Glass	1 /4 "	2300	836	1.046
		Air Gap	0 3/8 "	1.3	1004	5.560
		Standard Glass	1 /4 "	2300	836	1.046

Table 5.

Thermal Properties of Building Components and Material (Case-III)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
1.	Walls U Value 0.236	Plaster	3 /8 "	1250	1088	0.431
		Brick Masonry	4.5'"	1900	880	0.47
		Air Gap	1''	1.3	1004	5.560
		Brick Masonry	4.5"	1900	880	0.47
		Brick Plaster	3 /4 "	1250	1088	0.431
3.	Windows U Value 0.4244	Standard Glass	1 /4 "	2300	8 36	1.046
		Air Gap	1''	1.3	1004	5.560
		Standard Glass	1 /4 "	2300	8 36	1.046

Table 6.
Thermal Properties of Building Components and Material (Case-IV)

No.	Building Components and Specifications		Thickness (inch)	Density (kg/m³)	Specific Heat (J/kg.K)	Conductance (W/mK)
1.	Walls U Value 0.236	Plaster	3 /8 "	1250	1088	0.431
		Brick Masonry	4.5’"	1900	880	0.47
		Air Gap	1’’	1.3	1004	5.560
		Brick	4.5"	1900	880	0.47
		Plaster	3 /4 "	1250	1088	0.431
2.	Windows U Value 0.4244	Standard Glass	1 /4 "	2300	8 36	1.046
		Air Gap	1’’	1.3	1 004	5.560
		Standard Glass	1 /4 "	2300	8 36	1.046
3.	Roof U Value 0.19373 (W/m²k)	Roof Tiles	1 1/2 "	1900	800	0.84
		Mud	3 "	1900	880	0.520
		Wool, resin bonded	1’’	6.18	499	0.020
		Bitumen	0 3/8 "	1700	1000	0.50
		Concrete	6"	2300	656	1.046

3. Conclusion

The purpose of research was to reduce the buildings HVAC loads in climatic condition of Multan. From the baseline case to the Case-IV, a marked decrease of 11.86% in energy consumption has been achieved including 11.76% decrease in cooling loads and 45.59% in heating loads. The indoor thermal environment was controlled by employing sustainable materials for construction in order to minimize the energy use. Therefore, the comfort level and favorable condition in building can be attained by introducing appropriate insulating materials.

4. Future Recommendations

This study limited up to contemporary construction materials. The future study may be on the design strategies like passive and active techniques for buildings as shading devices orientation of windows, plantations etc.

5. Limitations of Study

This research deals only with the contemporary construction materials and for the buildings which are in hot climatic zones like Multan.

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