The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan

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Abstract

Commercial and residential sector buildings consume up to 40% of world's energy production. It is estimated that the developing countries will consume up to 65% of world's energy by 2040. Pakistan is one of the developing countries which is facing a huge gap in supply and demand of electricity. Residential sector is the largest consumer of electricity in Pakistan which currently consumes 47% of total electricity production. The process of energy consumption can be made more efficient by using an energy efficient home design. In Pakistan, the lack of basic understanding of a sustainable home and a higher upfront cost of sustainable design are two biggest barriers hindering the implementation of green solutions. The purpose of this research study was to develop typical single family detached home designs for Pakistan and apply different Energy Efficiency Measures (EEMs) to study their impact on electricity consumption. For home modeling, data related to climatic conditions, home designs, construction materials and electricity rates was collected from Lahore, Pakistan. eQUEST® (Quick Energy Simulation Tool) was used for baseline modeling and running energy simulations. Four different home designs within size range of 75 m^2 to 475 m^2 were modeled. A baseline design was first developed in accordance with typically used construction practices in Pakistan. In energy efficiency designs, several energy efficiency measures were separately applied to baseline design to see their impact on electricity consumption. Results showed that by applying these energy efficiency measures, there is a potential of reducing electricity costs by up to 26%. It was observed that lighting-power density, roof color, roof insulation and wall insulation result in most reduction in electricity consumption. It is suggested that government, housing authorities, designers, contractors and home owners help in promoting these energy efficiency measures to achieve maximum energy savings in the residential sector.

Keywords

Energy efficient design, Residential construction, Green home, Energy simulations

1. Introduction

Start The International Energy Agency (IEA) estimated that residential, commercial and public buildings account for up to 40% of the world's energy consumption (Woody, 2013). These numbers are even higher for developing countries and recent estimates suggest that developing countries may consume up to 65% of the world's energy by 2040 (Woody, 2013). Pakistan, a developing country in South Asia, is facing a huge gap in supply and demand of electricity. Energy crisis is one of the top three issues that are significantly impacting the lives of people in Pakistan (PewGlobal, 2017). In the last decade, Pakistan has been badly affected by the shortfall in energy because of economic growth and better living standards. The electric power deficit had crossed the level of 7,000 MW/day at many points during the years 2011 through 2016 (Aftab, 2014). The persistent shortage of electricity in the country has adversely affected the national economy. Industrial production has been severely hit; and also triggered social unrest which sometimes turns violent thus, thereby creating law and order problems in many urban centers in the country (Aftab, 2014). According to recent studies, the power shortages have resulted in an annual loss of about 2% of GDP, and total industrial output loss in the range of 12%-37% (Siddiqui, 2011).

Energy efficiency in the built environment is vital to achieving climate energy, and development objectives in emerging economies. There is increased recognition that the cost of reducing energy consumption is much lower than the cost of generating new energy (Managan *et al.*, 2011). Energy-efficient buildings bring many benefits to their owners, their occupants, and the society as a whole. Owners benefit from lower operating costs due to reduced energy usage, and occupants benefit from greater comfort through better insulation and lighting. Benefits to society include reducing greenhouse gas emissions, increased energy security, and improving air quality through lower consumption of electricity, the majority of which comes from burning fossil fuels (Managan *et al.*, 2011).

In Pakistan, there is a need to develop design and construction standards and practices for energy efficient buildings and homes. Moreover, the life cycle cost analysis of different energy efficient designs is needed so that the owners have a better idea why they should incorporate these energy efficient designs even though these improvements typically result in higher initial investment costs. A green building is designed to use less energy and water and to reduce the life-cycle environmental impacts of the materials used. This is achieved through better site planning, design, material selection, construction, operation maintenance, removal, and possible reuse (Azad and Akbar, 2015). There are several modeling and energy simulation tools available for designing the buildings more efficiently. These tools enable us to incorporate energy efficiency measures in the building design stage and evaluate their impact on building performance. One of the biggest recent developments for the design and construction industry is Building Information Modeling (BIM). BIM is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure (Azhar, 2011). BIM is a platform that can provide a comprehensive and interactive assembly of the components in a building to create an interactive energy model. This virtual model becomes more and more closer to the real world building as more information is added to BIM for each individual part of the building. Using BIM one can model the similar conditions of the actual buildings and run energy simulations based on actual design, construction and climatic data (Azhar, 2011).

The aim of this research study is to use Building Information Modeling (BIM) based energy simulations to develop energy efficient designs for single family detached homes in Pakistan. The research tested various energy efficiency improvement measures and identified the ones that result in best performance. This research is limited to design development of single family detached homes in Pakistan. Size of these homes ranges from 75 m2 to 475 m2. The weather conditions considered for this research are of hot climate areas, since the major portion of population in Pakistan is in the hot climate region. Moreover, the focus city for this research is Lahore (31° 32′ 59″ N, 74° 20′ 37″ E) which is the second largest city of Pakistan and lies in hot climatic region where summer season dictates the type of home design. Summer spans from mid-April to mid-September. The hottest month is June, where average highs routinely exceed 40 °C (104 °F). The coldest month is January where average temperature is in the range of 6-10°C (43-50°F).

2. Literature Review

Worldwide, individuals and organizations have responded to the increased demand for energy efficient buildings. The terms energy-efficient, green and high performance buildings are typically used interchangeably. According to the Office of Energy Efficiency and Renewable Energy (EERE) of the US Department of Energy, a high performance building "…uses whole-building design to achieve energy, economic, and environmental performance that is substantially better than standard practice". The creation of high performance buildings is best addressed through effective building design, which integrates three general approaches: (1) designing a building envelope that is highly resistant to conductive, convective, and radiant heat transfer; (2) fully implementing passive design; and (3) employing renewable energy resources. Passive design employs such strategies as building geometry, orientation, window design, and mass to condition the structure using natural and climatologic features such as the site's solar insolation, prevailing winds, local topography, microclimate, and landscaping (Kibert, 2012).

In Pakistan, the residential sector is the largest consumer of electricity, consuming approximately 45.6% of total electricity supply, followed by Industrial (28.4%), Agriculture (11.8%), Commercial buildings (7.4%), Public buildings (6.2%), and Street lights (0.6%) (Nasir *et al*., 2008). These numbers indicate that buildings and homes together consume approximately 60% of total electricity produced in Pakistan. The total capacity of electric power generation in Pakistan is approximately 19,681 MW/day, whereas the peak demand is approximately 26,520 MW/day (Nasir *et al*., 2008). Even a 10% electricity savings in buildings and homes could result in an overall savings of approximately 1,200-1,500 MW/day which is equivalent to a daily power generation of 3-4 medium size coal power plants (Kibert, 2012).

The majority of urban homes in Pakistan are constructed using masonry walls and reinforced concrete roof, whereas reinforced concrete frame with masonry partition walls is typical in public and commercial buildings. In most cases, the builders construct homes and buildings without any thermal insulation for higher return. A significant amount of energy is wasted due to the heat gain/loss through non-insulated walls and roofs. On average, 36% electricity is utilized for space heating/cooling, 35% for lighting, and 29% for home/office appliances in Pakistan (Masood and Shah, 2012). By constructing energy-efficient and passive buildings, maximizing daylighting, and using high-efficiency appliances, significant savings can be achieved.

In Pakistan, there have been some attempts to promote energy efficient design. For example, the National Energy Conservation Center (ENERCON) developed the "Building Energy Code of Pakistan" in 1990. This code was mostly based on American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) standards. The code provided minimum performance standards for building windows and openings, heating, ventilating and air conditioning (HVAC) equipment, and lighting. The Building Energy Code was non-mandatory and over the years did not result in any significant improvements in local design practices. In 2011, ENERCON and Pakistan Engineering Council (PEC) thoroughly revised this code and made it an integral part of the Pakistan Building Code of 1986 (i.e. Energy Provisions-2011). These Energy Provisions shall apply to buildings and building clusters that have a total connected load of 100 kW or greater, or a contract demand of 125 kVA, or a conditioned area of 900 m2 or unconditioned buildings of covered area of 1,200 m2 or more. At this point, no published data are available for evaluating the usefulness and applicability of these energy provisions. Furthermore, it is important to realize that most buildings in the country are too small to be covered by this code, but use much energy because of their numbers (Masood and Shah, 2012).

3. Research Design and Methodology

The research design is outlined in Figure 1 which is divided into three phases. In the first phase, modeling of baseline homes was completed using design and construction data from Lahore, Pakistan. It was followed by energy simulations and applying energy efficiency measures to compare the results with the baseline design. In the last phase, the cost and feasibility of energy-efficient design features was evaluated and final recommendations are made.

Four typical home designs; Home A, B, C and D were selected from Lahore, Pakistan (Table 1). The floor plans of these homes are shown in Figure 2. These floor plans comply with the locally enforced residential by-laws. Typical construction of the home was composed of brick masonry and RCC slab.

Figure 1. Research design

Table 1: Selected home sizes for the research study

Home	Local Designation	No. of Floors	Covered Area	
			m^2	ft^2
Home A	5 Marla	1	75	815
Home B	10 Marla	1	125	1325
Home C	1 Kanal	1	230	2500
Home D	2 Kanal	1	475	5100

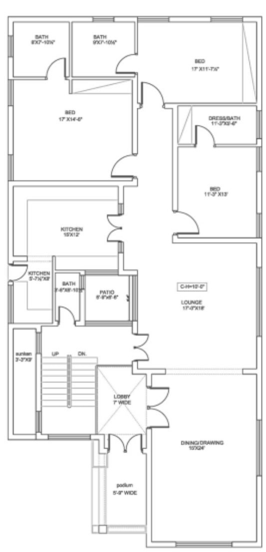
As described previously, modeling and energy simulations were carried out in Revit® and eQUEST®. In eQUEST®, the modeling is performed through wizards called "Schematic Design Wizard" and "Design Development Wizard". The baseline modeling process followed the following major steps:

1. First the general information about the project was added. It included project name, type and location. Weather data file is added into the project via a .BIN file which stores the local yearly weather data. Home's area, floors and type of air conditioning equipment were also selected in this step.
2. Next, the footprint of the home was defined. This was achieved by importing a Revit® file and then defining custom areas and zones. Floor height as well as building orientation were defined. Moreover, the air-conditioned and non-air-conditioned zones were defined.
3. In this step, properties of building envelope were defined. It included roof details, exterior wall details and ground floor construction details. The roof and wall construction allowed us to select appropriate type of materials involved in the construction of the home. Custom roof and wall sections can be made to depict the actual design as accurately as possible. In this study, roof was composed of 15 cm (6 inches) thick RCC slab with sand and tile insulation. Walls were made up of bricks with plaster layer on both sides.
4. After the creation of the building model, exterior doors and windows were added. The doors and windows size and type were selected as per local design and placement was made on each wall according to the plan. The window-wall ratio of walls on each side were also defined.
5. Next, the home's operation schedule was defined. In this step, it was assumed that home will be unoccupied for 6-8 hours during the day. However, that is not the case in actual conditions. This was only done to limit the operational hours of the HVAC system because in local homes air-conditioning is mostly used during the nights and in day time its use is limited.
6. After that, various activity areas were defined (e.g. living areas, bedrooms, etc.) followed by allocation of non-HVAC and HVAC loads to these areas. For this study, HVAC split system was used because this is the common system used in residential homes in Pakistan. DX Coils were selected which represent split system. The air path was assumed to be direct rather than duct system since a separate split system is used in each zone. The cooling temperature for summer was selected as 26 °C (78 °F). The Seasonal Energy Efficiency Ratio (SEER) of 6 was selected. The number of

split AC systems assumed for Home A, B, C and D were one, two, three and five respectively. Each system had cooling capacity of 1 Ton (12,000 Btu/h). It was assumed that ACs in bedrooms operate 8 hours a day and remaining ACs run 4 hours a day.

7. After the modeling process, energy simulations were run on the baseline design. These simulations gave the results of total monthly and yearly energy consumption of the homes in kWh. The results were validated against actual electricity bills and minor refinements were made.
8. After performing energy simulations for the base designs, the following Energy Efficiency Measures (EEMs) were added into the base models one by one: (a) Roof and wall insulation; (b) Change of roof color; (c) Windows size reduction; (d) Energy efficient glass for windows; (e) Windows glass color; (f) Windows shading; and (g) Adjustments in lighting power density.
9. After reviewing the simulation results and incorporating EEMs, comparison results were obtained to analyze the effect of each EEM. In this step different, the best EEMs were shortlisted.
10. Based on the energy simulations, a set of recommendations is prepared for the designers and constructors as well as various government agencies.

Home A **Home B**



Home C **Home D**

Figure 2. Floor Plans of Selected Home Designs

4. Results and Discussion

The energy simulation results indicated that the following four energy efficiency measures; Lighting Power (LED usage), White Paint on Roof, Roof Insulation and Wall Insulation had a significant impact on annual electricity consumption. Table 2 shows the percentage reduction in annual electricity consumption for first four energy efficiency designs when compared with the baseline designs. The other four measures; Windows Size Reduction, Double Glazed Tinted Glass, Single Glazed Bronze Tint and Windows Overhang had negligible impact on annual electricity consumption.

Table 2: Reduction in Annual Electricity Consumption compared to Baseline Designs

Energy Efficiency Measure	Home A	Home B	Home C	Home D
Lighting Power (LED usage)	-12%	-8%	-11%	-17%
White Paint on Roof	-10%	-6%	-7%	-8%
Roof Insulation	-5%	-3%	-4%	-3%
Exterior Wall Insulation	-0.3%	-1.8%	-1.4%	-1.1%

The results from energy simulations indicated that replacing the CFLs with LEDs has the biggest impact on reduction in electricity consumption. This was due to reduced area lighting loads while the cooling loads remained similar as baseline designs. The area lighting loads decreased significantly when CFLs were replaced with LEDs. The annual reduction in electricity consumption ranged from 56% to 66%. A previous case study has shown that replacing CFLs with LEDs reduces electricity usage by 54%. The LEDs had higher initial cost but the lifetime money savings were twice as many as CFLs. This was because of a longer lifespan of LEDs. As the LED technology is improving costs are decreasing and LEDs are becoming more efficient (Soni and Devendra, 2008).

For reduction in cooling loads, the most effective energy efficiency measure was found to be application of white paint on roof. Table 3 shows percentage reduction in cooling loads using white paint, roof insulation and wall insulation. These results comply with a case study conducted in Islamabad, Pakistan (UNHabitat, 2010). This study measured inside temperature of a house with no roof treatment and compared it with inside temperature of house with white paint/lime wash on roof. This process was carried out for a month. Results showed a temperature reduction of 4.1°C (8 °F) with the application of white paint on roof (UNHabitat, 2010). A lower inside temperature meant that cooling load will be decreased to achieve the desired cooling temperature. The cooling loads were also decreased for all homes with the introduction of roof insulation. These results comply with aforementioned case study conducted in Islamabad, Pakistan. This study measured inside temperature of a house with no roof treatment and compared it with inside temperature of house with 2” thick *Diamond Jumbolon Insulation*^{TM} on roof. This process was also carried out for a month. Results showed a temperature reduction of 4.7°C (9 °F) with the introduction of insulation on roof (UNHabitat, 2010).

Table 3: Annual Cooling Loads for Baseline and Energy Efficient Designs

Home	Cooling Loads (kWh)						
	Baseline	White Paint on Roof	% Reduction	Roof Insulation	% Reduction	Wall Insulation	% Reduction
Home A	2511	2096	17%	2292	9%	2498	1%
Home B	4484	4009	11%	4288	4%	4344	3%
Home C	5460	4760	13%	5120	6%	5350	2%
Home D	9830	8190	17%	9160	7%	9510	3%

The last four measures; Windows Size Reduction, Double Glazed Tinted Glass, Single Glazed Bronze Tint and Windows Overhang had negligible impact on the annual electricity consumption. The windows size was reduced by 20%. The Window-Wall Ratio (WWR) in the baseline designs was 15%, while in energy efficiency designs it was 10%. This was in accordance to a previous research study which showed that changing WWR from 15% to 10% resulted in 1.5% reduction in annual energy consumption (Kim et al., 2016). The double glazed window glass had no significant impact on energy consumption either. These results complied with a previous research conducted for a house design in Miami, Florida (Hot Climate City) which indicated that, “In hot climates, window insulation has virtually no influence in home heating and cooling energy consumption” and there will be no energy benefit provided by multiple glazing of windows (Kim et al., 2016). This is also the case with single glazed tinted glass which did not provide substantial benefits. Tinted glass may be used to control solar heat gain but typically provides limited insulation benefit (AWS, 2017). The last measure was the introduction of window overhang which did not provide any significant savings in electricity consumption. The overhang provided in this research study was 45 cm (1.5 ft) wide over an 240x180 cm (8x6 ft) window. A previous study conducted for a house design in Calcutta, India showed results of 0.5m (1.6 ft) wide window overhang over a 320x200 cm (10.5 x 6.5 ft) window. The results showed an average reduction of 2% in energy consumption. Although, this reduction became significant when overhang size was increased up to 1.5m (5 ft) (Shaik, 2016). Table 4 summarizes the total potential percentage reduction in annual electricity consumption if all of these measures are applied simultaneously on baseline designs. The results show that on average, electricity consumption can be reduced by up to 26%.

Table 4: Total Potential Reduction in Electricity Consumption

Energy Efficiency Measure	Home A	Home B	Home C	Home D
Lighting Power (LED usage)	-12%	-8%	-11%	-17%
White Paint on Roof	-10%	-6%	-7%	-8%
Roof Insulation	-5%	-3%	-4%	-3%
Exterior Wall Insulation	-0.3%	-1.8%	-1.4%	-1.1%
Windows Size Reduction	-0.0%	-0.1%	-0.2%	-0.2%
Double Glazed Tinted Glass	-0.0%	-0.4%	-0.5%	-0.3%
Single Glazed Bronze Tint	-0.0%	-0.3%	-0.4%	-0.3%
Windows Overhang	-0.0%	-0.2%	-0.1%	-0.4%
TOTAL	-28.1%	-19.5%	-24.8%	-30.3%

5. Conclusions and Recommendations

This paper presented development, testing and life cycle cost analysis of energy efficient designs for typical single family detached homes in Pakistan. Residential sector in Pakistan consumes approximately 47% of produced electricity. Electricity must be used more efficiently in order to reduce its consumption. This can be achieved by applying energy efficiency measures in design and construction phase of the homes. Results of this study shows that there is a potential of reducing electricity consumption by up to 26% using various energy efficiency measures. The energy simulation results showed that replacing Incandescent and CFL light fixtures with the LED fixtures had the biggest impact on electricity and money savings. It is very important to incorporate LEDs in residential sector as LED technology is improving and its cost is also decreasing. Secondly, roof treatment in the form of application of white paint on roof substantially decreased the electricity consumption with relatively lower initial investment. Moreover, thermal insulation on roof and external walls resulted in lower electricity consumption although their initial investment is relatively higher. The results of the Life Cycle Cost Analysis (LCCA) showed that combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years of home’s service life. It is strongly recommended that various energy efficiency measures are implemented in residential designs in Pakistan. Implementation process will require continuous effort from government, housing authorities, designers, contractors and home owners. Government officials should help organize workshops that promote energy efficient practices. Another way to promote this knowledge is through social and print media. Social media can significantly help expanding this message across wider range of public. It is the responsibility of local housing authorities in Pakistan to make sure these measures are implemented. It can be achieved by including these energy efficiency measures in residential by-laws and codes. Some of the energy efficiency measures like LED usage and White Paint on roof can be made mandatory in house construction as they have lower initial cost and biggest savings. Moreover, home owners and builders should consider these energy efficiency measures in the planning phase because they will save their money in the long run and also save country's electricity production. Ultimately, it will result in surplus electricity rather than a shortfall and overall living standards will be improved.

6. Acknowledgment

This research study is funded by the US Department of State and the Higher Education Commission of Pakistan (HEC) under the joint Pakistan-U.S. Science and Technology Cooperation Program (Phase 6).

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