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PASSIVE DESIGN FEATURES FOR ENERGY EFFICIENT RESIDENTIAL BUILDING IN HOT CLIMATE

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Abstract- The rapidly growing use of energy has raised concerns for depleting energy resources and the resulting heavy environmental impacts. The contribution from the buildings towards energy consumption has steadily increased over the past few decades. Growth in the population, increase in the use of technology, increasing demand for building services, enhanced comfort levels, as well as increase in the time spent inside the buildings depicts an upward trend in energy demand. For this reason, energy efficiency in building sector is of prime importance today. The reduction in energy consumption in buildings can be achieved by simple methods and techniques such as using passive design features and renewable resources. Climate responsive design of buildings and energy efficient systems and technologies such as passive solar systems can reduce the energy demand in buildings. This research is aimed to make contribution in the designing of energy-efficient residential buildings. This study provided guidelines for designing the energy-efficient residential building with passive design features and suggested environmental friendly materials in the context of Rahim Yar Khan, Pakistan. A model house was designed with passive design features and using climate responsive design strategies, evaluated with Ecotect software to analyze the efficiency of suggested passive design features which showed promising results in terms of energy efficiency.

Keywords- Energy-efficient Buildings, Passive Design, Renewable Resources, Residential Building Design

1. INTRODUCTION

Energy is considered to be the life line of any economy, the most vital instrument of socio-economic development and has been recognized as one of the most important strategic commodities. One of the opportunity costs of civilization is increase in the amount of consumption of energy per capita per year [1]. The turning of the world into a global village with modern technologies and their rapidly increasing demand for energy indicates that energy will be one of the biggest problems of the world in the future [2]. This requires use of the alternative sources of energy preferably renewable resources along with the economical utilization of present energy sources [3].

Pakistan is rapidly urbanizing and it is expected that over 40 million more people will be living in urban areas in Pakistan by the year 2025 [4]. This represents a tremendous leap from traditional buildings to new dwelling with more mechanical systems and less passive design features. Many parts of the country face temperatures over 40 degree Celsius in summers. Pakistan has been facing the challenge of inverse energy supply and demand scenarios resulting in load shedding periods in the summer months [5]. This challenge can be overcome by designing buildings with green materials and technologies to reduce operational costs, reliance on electricity and enhance human comfort [6]. Pakistan's energy producing resources are still developing. There has always been an energy crisis in Pakistan due to high energy demand in peak summer months and low supply of electricity. This is a consequence of no serious efforts being made to install new power generation plants. Some of the significant constraints leading to severe energy shortage are; increase in population, circular debt, weak financial position of energy companies, falling gas production, high dependence on oil/gas (over 80%), and low exploitation of indigenous coal and hydel resources, unutilized power generation capacity [7].

Various researchers have worked on the energy saving potential of architectural design by incorporating passive design features. Building plan (shape), envelope, orientation [8], type of glazing were used as passive design features for building design in hot climate which showed considerable saving in energy and reduced the building cooling loads [9]. In one study, architectural design features such as building orientation, shape and complexity of the building plan and the type of glazing

used in windows were found to have maximum impact on cooling loads in hot climate [10]. Atrium is another such example which has shown promising results in terms of natural lighting and energy saving up to 15.7% [7].

The use of energy in the residential sector is increasing day by day [11]. According to Hydrocarbon Development Institute of Pakistan, in the total consumption of electricity, the share of household, commercial and other government sector has increased while share of industrial and agriculture sector has decreased over 1993-94 to 2011-12. According to Pakistan Water & Power Development Authority (WAPDA), among all the consumers of electrical power, domestic consumers are consuming electricity at the highest level. There is lot of potential for energy conservation in the domestic sector of Pakistan. In order to conserve energy at domestic sector, it is the important to design energy efficient residential buildings [12]. This work demonstrates the dire need to rely more on passive design features in residential building design in hot climate (Rahim Yar Khan city of Pakistan) to minimize the energy consumption. The climate analysis of Rahim Yar Khan was performed followed by the site analysis. A study was conducted on a residential colony of Rahim Yar Khan to analyze the passive design features used in residential buildings. The studied features were then utilized in the design of a model house incorporating suitable materials according to the climate. Energy analysis of the model house was performed through Ecotect software. The results show that the applied passive design techniques are effective during daytime, during extreme temperatures, in the summer season. But, they will create slight uncomfortable conditions at mid-night; that would be balanced by night-purge cooling effect. The designed shading devices are effective in controlling the heat gain through windows. The lighting analysis performed showed maximum admittance of natural light through openings, which will reduce dependence on artificial light. Hence the study showed promising results and can be utilized to minimize energy consumption in residential sector by the use of passive features in building design.

2. PROBLEM STATEMENT AND RESEARCH AIM

In Rahim Yar Khan, large infrastructure development has been seen during the recent years. Many housing societies are being developed on the outskirts of Rahim Yar Khan city. All this new residential development will cause the energy consumption to rise. Due to increase in urban population and improvement in living standards, the consumption of electricity is increasing by residential sector. Air conditioner usage in the residential buildings, particularly in hot climate, has tremendously increased the energy demands.

By observing many residential buildings in Rahim Yar Khan, it is concluded that buildings are not designed with the aim of energy conservation. The orientation of buildings is not given due importance in the design and most buildings are constructed without proper insulation, with large window-to-wall ratio (WWR), with extensive use of glass, with windows having no appropriate shading. This results in additional heating/cooling loads. Designs of residential buildings are not responsive to the requirements of climate. Dependence on artificial lighting and mechanical systems is common in buildings. Interruptions in the supply of power due to power deficit is a big problem. As the residential buildings are not designed in accordance to the climate, they fail to take advantage from natural climatic features. They become extremely uncomfortable in harsh weather conditions, particularly during periods of load-shedding. It seems that architects are not aware how they can design energy-efficient buildings. They lack in knowledge about basics of energy-efficient building design. On the other hand, developers and clients stress that residential buildings must be designed with maximum space utilization resulting in project economy. They cannot apply energy efficient building techniques independently. They have to convince the developers and clients first.

This study was particularly aimed at; suggesting passive design features for the residential buildings of Rahim Yar Khan (for hot climate) to make them energy-efficient in the context of hot climate; suggesting suitable local, energy-efficient and eco-friendly materials for different building elements; designing a model house by incorporating the suggested passive design features and then evaluating the building for thermal analysis by using Ecotect software. A case study is used to demonstrate the resulting benefits of passive design strategies. Based on the present energy situation, construction practices, increase in number of residential buildings, change in the life style, it is essential to evolve energy-efficient building designs. Passive design of buildings should be first and foremost preference rather than relying completely on active means. This shift of attitude towards energy conservation will help in saving the depleting energy resources. There is a lot of potential for energy conservation in residential sector. The research will contribute in this reference in designing an energy efficient house on small scale. This study can help the stakeholders of the building construction industry including designers, evaluators, building control agencies and energy professionals to put additional efforts to produce more passive design buildings to reduce the burden on the end consumer by reducing energy consumption in residential buildings. The study will also provide guidelines to enable the architects in the design of energy-efficient houses in Rahim Yar Khan.

3. RESEARCH METHODOLOGY

The main objective of the research was to design a model energy–efficient house for the hot climate. To find out what kind of passive design strategies have been incorporated in the residential buildings of Rahim Yar Khan, an observational study of a residential colony was carried out. The architectural features which were fabricated in the houses for protecting the indoor environment from harsh weather conditions (extreme heat or cold) were studied. Whole design process was followed for designing a model energy-efficient house [13], which included the following steps; climate analysis of Rahim Yar Khan, site analysis [14], house design with passive design strategies and passive design elements, selection of suitable materials, analysis [15] of the house designed through the Ecotect software [10].

4. DATA COLLECTION AND ANALYSIS

The climatic data of Rahim Yar Khan City is obtained from the laboratory of Fatima Fertilizer Company Limited, located in Goth Machi, Sadiqabad, where weather conditions are monitored on daily basis. The climate of Rahim Yar Khan is mostly hot and dry in summer season. In winter season, the weather gets cold, dry and pleasant. The warmest month of the year is June. The maximum temperature reaches above 45°C. In January, the average temperature is 13.3 °C. The summer season is longer than the winter season. The summer season starts from April and it continues till the month of October. November to March are considered as months of winter season. The driest month is October with 1 mm rain. Mostly, rainfall occurs in the month of August, around 27 mm. The occurrence of dust storms is very common in summer (May/June). The average annual temperature in Rahim Yar Khan is 26.2°C. So, climate of Rahim Yar Khan can be classified as Hot and Dry.

To find out what kind of passive design strategies have been incorporated in the residential buildings of Rahim Yar Khan, an observational study of a residential colony was carried out. The architectural features which were used in the houses for protecting the indoor environment from harsh weather conditions (extreme heat or cold) were studied. This observational study was analyzed on the basis of theory of Climatic Responsive Design. Problems found during the study are as follows; the orientation is not given any due consideration; the shades which have been provided on the windows are given mainly for aesthetic purpose and they don't serve the purpose of shading, which results in additional heating /cooling loads; the houses are not designed according to the climate; extensive use of glass was seen; reflective type of glass has also been used. For designing the model energy-efficient house with passive design features, a plot from housing society 'Abbassia town' was selected. Abbassia town is a large, newly developed housing society located in the outskirts of Rahim Yar Khan City. The copy of the bye-laws for the buildings was first obtained from the TMA Rahim Yar Khan.

5. RESIDENTIAL BUILDING DESIGN

Whole design process was followed for designing a model energy-efficient house, which included the following steps; climate analysis; site analysis; house design with passive design strategies and passive design elements; selection of suitable materials; analysis of the house designed through the software Ecotect [16]. An actual site was selected from a newly developed housing society in Rahim Yar Khan for designing a model house. Climate data was collected as in Figure 1 and site analysis was done in the start of the deign process. Based on the theoretical knowledge; a model house was designed with focus on passive design features with Ecotect software as in Figure 2. The designed house was then analyzed though the software Ecotect, to demonstrate the benefits resulting from incorporation of suggested passive features [17]. Use of alternate renewable source of energy was also explored in the local context. Suitable eco-friendly materials have also been proposed and discussed in detail. A two-story house has been designed.

From the climate analysis, it can be seen that there is a difference of about 20°C between day-time and night-time temperatures. In summers, the temperature reaches above 45°C and summers are longer than the winter months. The main factor to tackle in the energy-efficient design of the house will be the cooling load. Concept of passive design has been incorporated into the house plan, with passive cooling and passive ventilation strategies. The main aim was to design a house in such a way as to reduce the heat gain in extremely high temperatures and ultimately the cooling load. Following strategies have been used while designing an energy-efficient house; air movement; cooling breezes; convective air movement; radiative cooling. A lawn has been designed on the North side as coolth pond. Sunken garden with depth 3 feet has been given, which is a classic example of a coolth pond, into which the cooler air, during the night-time will descend. Garden walls will act as pond walls. In this way, the cooler air will enter the house through openings, at night. The direction

of the wind is North-South during the summer months and dust storms are common during this season. As a lawn is designed at the North side, the air will be passed over naturally planted ground cover, which will reduce the dust levels.

UN-HABITAT in partnership with Ministry of Environment, Capital Development Authority (CDA, ENERCON National Energy Conservation Centre (ENERCON) and manufacturers and suppliers conducted an energy efficient housing project which has been used for the selection of materials for the model house. Materials are proposed for the designed house based on following factors; availability, maintenance, energy-efficiency, impacts on natural environment, durability, recyclable and obtained from renewable resources. Clay bricks were proposed for walls as they are locally fabricated in Rahim Yar Khan [18]. Double-glazed windows [8] with low-solar-gain, low-E glass with argon gas fill is proposed for the windows [19]. Polyvinyl chloride (PVC) frames has high R–value (Resistance value) and low maintenance (high performance commercial buildings). So, PVC frames are proposed for the window frames [20]. Cavity walls are proposed for walls [21]. Polystyrene (Jumbolon) with plain concrete screed is selected as proposed insulation technique for the roof slab of the designed house [19].

The delimitations of this work include; the study was delimited to residential buildings; as multistory-apartments/flats are not common in Rahim Yar Khan, the study was delimited to separate units that is single story, multi-story houses; the study was confined to the energy use in the operational phase of the house; the study was restricted to suggesting passive design strategies for new houses.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	30.5 (86.9)	35.5 (95.9)	41.4 (106.5)	45.8 (114.4)	47.3 (117.1)	47.5 (117.5)	44.2 (111.6)	42.9 (109.2)	42.3 (108.1)	40.4 (104.7)	36.8 (98.2)	31.3 (88.3)	47.5 (117.5)
Average high °C (°F)	23.0 (73.4)	25.5 (77.9)	31.8 (89.2)	38.2 (100.8)	41.7 (107.1)	41.6 (106.9)	37.8 (100)	36.6 (97.9)	36.7 (98.1)	36.2 (97.2)	30.7 (87.3)	25.3 (77.5)	33.76 (92.78)
Daily mean °C (°F)	14.3 (57.7)	17.1 (62.8)	23.4 (74.1)	30.2 (86.4)	34.3 (93.7)	35.2 (95.4)	32.8 (91)	31.7 (89.1)	30.7 (87.3)	27.7 (81.9)	21.5 (70.7)	16.1 (61)	26.25 (79.26)
Average low °C (°F)	5.6 (42.1)	8.8 (47.8)	15.0 (59)	22.1 (71.8)	26.8 (80.2)	28.8 (83.8)	27.7 (81.9)	26.8 (80.2)	24.7 (76.5)	19.1 (66.4)	12.1 (53.8)	6.9 (44.4)	18.7 (65.66)
Record low °C (°F)	−0.9 (30.4)	−2.7 (27.1)	3.7 (38.7)	12.0 (53.6)	15.8 (60.4)	19.8 (67.6)	20.3 (68.5)	20.4 (68.7)	16.3 (61.3)	10.2 (50.4)	3.3 (37.9)	−0.9 (30.4)	−2.7 (27.1)
Precipitation mm (inches)	5.7 (0.224)	7.8 (0.307)	6.3 (0.248)	11.9 (0.469)	15.9 (0.626)	33.0 (1.299)	91.1 (3.587)	82.6 (3.252)	40.8 (1.606)	10.1 (0.398)	1.9 (0.075)	3.0 (0.118)	310.1 (12.209
Avg. precipitation days	0.8	1.0	1.5	0.9	2.6	3.2	6.6	5.6	3.0	0.6	0.3	0.5	26.6
% humidity	49	43	34	25	27	39	58	61	52	36	40	48	42.7

Figure 1 Climate data of Bikaner-India (reference data for Rahim Yar Khan, Pakistan)

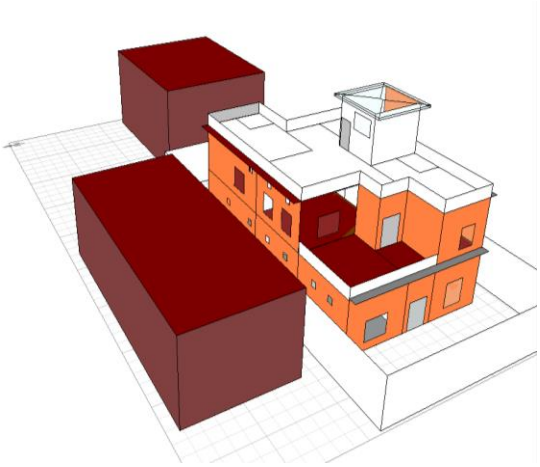
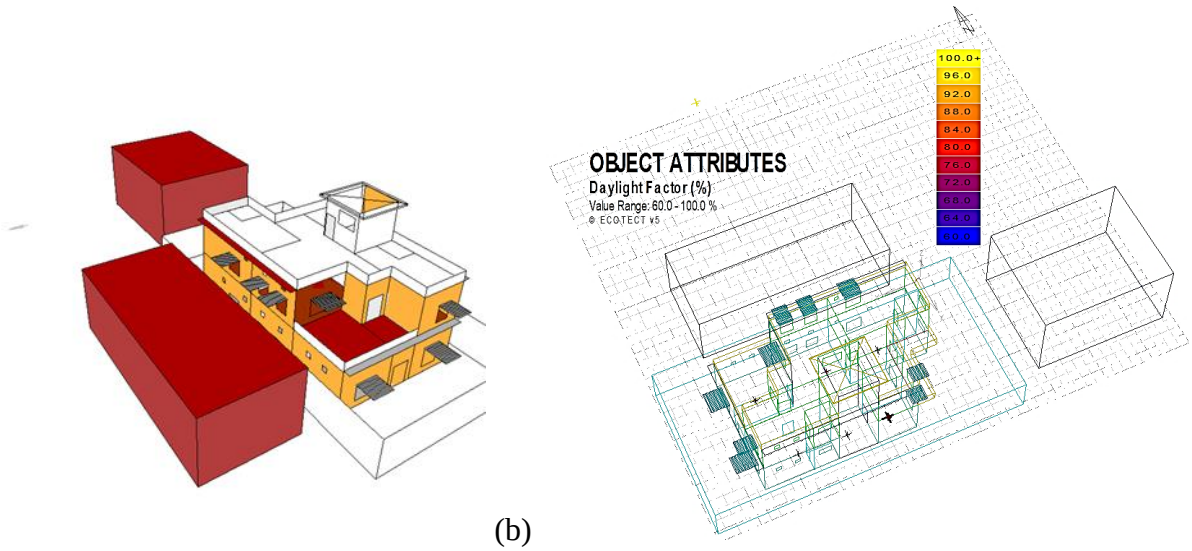


Figure 2 Model of house designed with adjacent houses

6. RESULTS

The results showed that the applied Passive design techniques will be effective during day-time, during extreme temperatures, in the summer season. But they will create slight uncomfortable conditions at mid-night that would be balanced by night-purge cooling effect. The designed shading devices will be effective in controlling the heat gain through windows. The lighting analysis shows maximum admittance of natural light through openings, which will reduce dependence on artificial light. The daylight analysis was done with Ecotect after designing the shading devices for the windows as presented in Figure 3 (a) and (b) respectively. Whereas, Figure 4 depicts the hourly temperature graph which shows the internal temperatures of all visible thermal zones in the model over a 24-hour period. It has been calculated for the hottest day (average) that is, May 16th, for all the visible zones. The graph shows that during the day time, the temperatures inside the zones will be less than the outside temperature. Here, the graph also depicts that during mid-night; inside temperatures are more than the outside temperature, which is due to the heat gained by the fabric during the day. Then the night-time cooling will cool the mass and will help to lower the inside temperatures. The daylight analysis was done with Ecotect after designing the shading devices for the windows as presented in Figure 3 (a) and (b) respectively. Figure 3 (b) shows that the daylight factor for inner zones is more than 80% that will reduce the use of artificial lighting.



(a) (b)

Figure 3 (a) Shading devices designed for windows of house through Ecotect (b) Ecotect daylight analysis

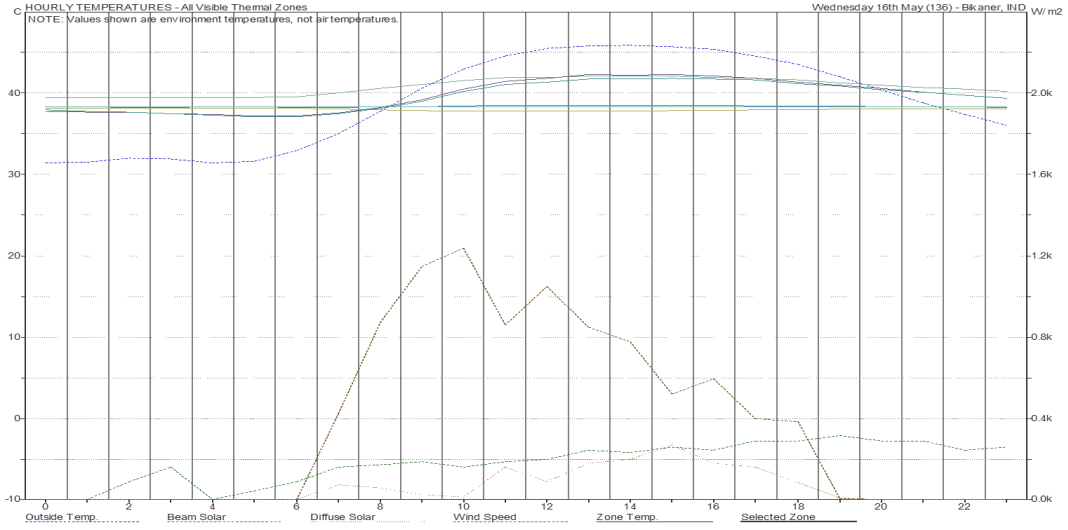


Figure 4 Hourly temperature analysis with Ecotect

7. PRACTICAL IMPLEMENTATION OF RESEARCH

The house with passive design features was modeled and analyzed in Ecotect software. The model house was designed with carefully selected materials based on the climate analysis of Rahim Yar Khan city and the site analysis. This analysis can be performed by the designer and the energy professionals by incorporating new materials and by adding or removing the various passive design features as per the requirements of the stakeholders of the building construction industry. The results can depict the amount of energy saved by relying more on passive means rather than active means. These results can be utilized as a benchmark for designing other buildings in various different climates by incorporating the relevant weather data files in Ecotect.

8. CONCLUSION AND RECOMMENDATIONS

The traditional house constructed with lime mortar and lime plaster, having a central courtyard, verandahs for passive ventilation, thick and massive walls acting as insulation, clay roof with white washing providing additional insulation and reflectance properties, double height ceilings with ventilators at the top to allow accumulated heat to escape provided a comfortable environment without relying much on mechanical means. However, with the advancement of technologies and adoption of air-conditioner and a sealed building system with fixed windows; the traditional design concepts and passive means were gradually discarded. Designers can now reach for the energy solutions to climate modification with ease, passing on running costs to consumers and designing buildings without concern. This present approach of designers has resulted in increase of energy consumption by buildings. The results of this study showed that the applied passive design techniques will be effective during day-time, during extreme temperatures, in the summer season. But they will create slight uncomfortable conditions at mid-night which would be balanced by night-purge cooling effect. The designed shading devices will be effective in controlling the heat gain through windows. The lighting analysis shows maximum admittance of natural light through openings, which will reduce dependence on artificial light.

In order to design a building, which is responsive to the climate of the area and operate without much dependence on artificial means, the process of designing such building should include following steps; study of climate of the area where site for the building is located; study of the site of the building; identifying passive design features ,suitable for the site specific climate; selection of suitable, local and recyclable materials with low embodied energy and integrating the identified features effectively in the building design.

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