Energy Efficient Design Features for Residential Buildings in Tropical Climates: The Context of Dhaka, Bangladesh

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Abstract

This study aimed at identifying passive design features through literature study that can be incorporated in residential buildings of Dhaka to make them energy efficient. The study also aimed at identifying changes in the design process that can affect energy efficiency in residential buildings. It has analyzed the present electric energy use for cooling and lighting typical residential buildings of upper middle income households in Dhaka through a case study conducted in Dhaka. It has also calculated the possible energy savings by adopting certain energy efficient features in the case study building.

The findings from this study indicate that doubling the thickness of external walls on east and west of the building, use of hollow clay tiles instead of weathering course for roofs and use of appropriate horizontal overhang ratios for all four orientations can reduce the cooling load of the case study building by 64% and thus reduce the total energy use of the building by 26%. Finally, it can be concluded that the process of designing energy efficient residential buildings is not a 'one-man's show'. Architects, developers, interior designers and clients are the other actors who can bring a change in the design practice.

Keywords: *Energy- efficient; passive design features; residential building; tropical climate*

1 Introduction

Bangladesh with an area of 55,598 square miles is a small but one of the most densely populated countries in the world. The population of Bangladesh was estimated at 129,194,224 in July of 2000 (Encyclopaedia of the Nations, 2010).The climate of Dhaka can be categorized as tropical monsoon type with high temperatures, high humidity most of the year, and distinctly marked seasonal variations in precipitation.

The energy infrastructure of Bangladesh is quite small, insufficient and poorly managed (Temple in Mozumder and Marathe, 2007). 82% of the country's electricity is generated from natural gas, 9% from oil, 4% from hydro and 5% from coal (Tuhin, 2008). According to Tuhin (2008), only 42% of the population is served with electricity and per capita electricity use is about 160 kWh. The demand for electricity is growing at a rate of 10% per year (USAID in Mozumder and Marathe, 2007) without any well-designed plan to meet the demand. According to the report of Dhaka Mirror (2009), the country has been experiencing a shortfall of about 1200 MW of electricity against the demand of 4500 MW. Dhaka alone is being provided with 1185 MWs against a demand for about 1800 MWs.

Worldwide, 30% to 40% of all primary energy is used in buildings (UNEP, 2007). Energy efficiency in residential buildings is crucial, especially for a country like Bangladesh where the demand for electricity, as already stated, is growing at a rate of 10% per year. According to BBS (2008), the electricity used by the industrial, residential, commercial and other sectors in the year 2006-2007 was about 21181 GWh. Out of this, 42% was used by the residential sector alone (BBS, 2008). Much of the increased demand for electricity is due to the increased standard of living (People's Report 2004-2005, 2006) among the wealthier income groups. One of the major factors in the increased use of electricity by the higher income group is the use of air conditioning units, which has only recently become quite popular (Hancock, 2006). To make matters worse, a study of the regulations in the national building code of Bangladesh shows that the government of Bangladesh has not adopted building energy codes in any form for building construction. In addition, simple observation of most of the residential buildings in Dhaka shows that developers, architects and interior designers are still not aware of the role they can play in designing energy efficient buildings.

1.1 Aim

The aim of this study is to identify passive energy efficient features for residential buildings in the context of tropical climates such as Dhaka to make a contribution in the field of architecture, by developing and designing energy-efficient residential buildings. Given the specific problems in the preceding section, it can therefore be attributed that there are probably large potentials for improvements in the energy sector and built environment. However, this research focuses on those attributes that can be attained through changes in the practices of architects. This study, based on a case study residential building in Dhaka, is thus expected to answer the following research questions in order to achieve the goals of this study:

1. What is the present electric energy use for cooling and lighting typical residential buildings inhabited by upper middle income households in Dhaka?
2. What are the passive design features that can be incorporated in residential buildings of Dhaka to make them energy-efficient ?
3. What are the possible energy savings in the case study residential building by adopting these energy efficient features?

In terms of the various categories of buildings that are there in Dhaka, this research was delimited to a case study on multi-unit residential buildings and not on a statistical sample. This study confined itself in considering energy use at the operational phase of the building. The study was oriented towards the residential buildings inhabited by upper middle-income groups in Dhaka. This study is delimited to the upper middle-income group, since they use more and more energy as they have increased their standard of living and are becoming increasingly accustomed to the use of air conditioners. The study is restricted to making new residential buildings energy-efficient and does not consider the existing housing stock. Reza (2008) notes that Dhaka city, with an annual growth rate of about 4%, adds half a million people to its population each year. He also states that to accommodate the growing population, the city would need at least 10 million new units/flats by the year 2015 and thus, Dhaka would not be able to cater the energy needs of these new units.

2 Methodology

2.1 Research Methodology

This research is based on a single case study and through literature review to explore the problems specified and seek answers to the research questions. A literature review consisting of books, journal papers, researches and documents defined the theoretical framework for this study by identifying energy efficient design principles that could be used for the context of Dhaka. In addition, it identified the methodology of analysis and issues that were investigated in the case study. The case study is a multi-unit residential building that is representative of inefficient energy buildings in Dhaka city. A fieldwork in Dhaka consisted of visits to the case study building and interviews with the residents. Quantitative and qualitative data were collected from the case study building. The data on energy use of different flats/units in the building were analyzed quantitatively and the design features of the apartment were analyzed both quantitatively and qualitatively. Energy efficient principles that were identified through literature review were summarized and analyzed quantitatively to determine the energy savings of all the features that could be applied in the context of Dhaka. Calculations were then made to see how much energy the flats surveyed in the case study building could save, by adopting the energy efficient design principles.

2.2 Selection of case study

The selection of the case study building was based on the following criteria:

- It is representative of typical multi-unit residential building design in Dhaka
- The architectural drawings of the apartments were available
- It was accessible
- The households were cooperative.

2.3 Issues Investigated

Apart from the design aspects that were identified in the theoretical framework, the following issues in the case study apartment have also been investigated:

- energy use practices of households (appliances used, energy used by those appliances)
- energy use for cooling and lighing in typical multi-unit residential buildings of Dhaka
- general living pattern of the households

2.4 Data gathering strategies

Data gathering strategies were divided into a mixture of qualitative and quantitative approaches. The following different combinations of data gathering strategies were adopted:

- qualitative and quantitative physical survey of the case study building
- qualitative and quantitative semi-structured interviews that have open and closed questions
- quantitative calculation of energy use
- qualitative and quantitative architectural drawings of the case
- archival records of computerized quantitative statistics on the climate of Bangladesh
- quantitative statistics from newspaper clippings.
- photographs (qualitative and quantitative)

3 Theoretical Framework

3.1 Energy efficient residential buildings

Well-designed energy efficient buildings maintain the best environment for human habitation while minimizing the cost of energy. According to the Development and Land Use Policy Manual for Australia (2000), the objective of energy efficient buildings is are to improve the comfort levels of the occupants by reducing energy use for heating, cooling and lighting. United Nations (1991) defines energy efficient buildings to have minimum levels of energy inputs.

3.2 Basic principles in energy efficient building design

It is evident from the above section that energy efficiency in buildings is vital for many reasons. Having justified the needs for energy efficiency it is now important to focus on the basic principles that can bring about energy efficiency in residential buildings of Dhaka. An extensive literature review consisting of different journals, books, researches and related websites was undertaken to establish the basic passive principles for designing energy efficient residential buildings. It must also be stressed that as this study focuses on those passive that quantify the energy savings. Below is the list of aspects for energy efficient residential buildings that show a percentage reduction in energy use and that has been arrived at from the literature review and is based on the context of Dhaka:
Building envelope:

- External wall
- Roof
- Windows
- Shading device

3.3 Building Envelope

3.3.1 External wall

The field measurements and computational energy simulations to examine the effectiveness of passive climate control methods such as facade construction in a typical 14 storey residential building of Singapore by Wong and Li (2007) reveal that the use of thicker construction on east and west external walls can reduce the solar radiation heat gain. It was found that the cooling load can be reduced by 7%-10 % when the thickness of external wall is doubled (229 mm concrete hollow block instead of 114 mm concrete hollow block).

Residential buildings in Dhaka have 125 mm thick external walls made of brick to make most of the floor area and to reduce construction costs. It should be noted that older buildings had thicker walls ranging from 250 mm to 500mm. With the advent of multi-unit residential buildings due to increasing pressure on building land and structural system, these thick walls were replaced with 125 mm walls. The design option put forward by Wong and Li uses concrete for external walls, but concrete is expensive in Dhaka. The local building material for external walls in Dhaka is burnt brick and it is much cheaper when compared to the cost of concrete. According to Gut and Ackerknecht (1993), the transmittance value or U value (measurement of heat transfer through a given building material) of 250 mm hollow concrete block whitewashed externally is 1.7 W/m^2. The U value of a 280 mm brick wall (115 mm brick + 50 mm air gap + 115 mm brick) including an air cavity of 50 mm and whitewashed externally is also 1.7 W/m^2. These U values suggest that energy savings from using brick instead of using concrete should be roughly the same as calculated by Wong and Li. Hence, for Dhaka's context 280 mm brick walls including an air cavity of 50 mm can be used instead of hollow concrete blocks on east and west facades to reduce energy use.

3.3.2 Roof

The roof is an important element of design when it comes to conserving energy because this part of the building receives most of the solar radiation and its shading is not easy. Nahar and Sharma in Tang and Etzion (2004), Vijaykumar et al. (2007) and Alvarado and Martinez (2008) conclude that the heat entering into the building structure through roof is the major cause for discomfort in case of non air-conditioned building or the major load for the air-conditioned building. Vijaykumar and Srinivasan in Vijaykumar et al. (2007) have advised the use of hollow clay tiles (HCT) in place of weathering course for roofs. They have claimed that the use of such a system can save 18% - 30% of energy used in an air conditioned building. Application of hollow clay tiles as suggested by Vijaykumar and Srinivasan is easily feasible in the residential buildings of Dhaka as the cost of hollow clay tiles is not significantly higher compared to the cost of the weathering course for roofs.

3.3.3 Windows

3.3.3.1 Shading device Ossen et al. (2005) carried out a study using computer simulation to explore the effect of six different alternatives on incident solar radiation, transmitted solar heat gain, natural light penetration and energy use. Their main objective was to assess and compare the impact of horizontal shading devices in reducing the unwanted solar heat gain and the amount of natural light penetration into office buildings in Malaysia.. The base-case model developed for the study was a single unit office room with dimensions of 6 metres for length and depth and a height of 2.8 metres. The size of the window was taken to be 4.4 metres in length and 1.82 metres height (from sill to ceiling line). The window area was assumed to be 50% of the net external wall area .The corresponding window to floor area ratio was 22%.The depth of the overhang (external horizontal shading device) was the main variable in this study. A range of overhang depths was investigated to determine the optimum shading for reducing the maximum solar heat gain from form direct solar radiation. Table 1 outlines the various overhang depth studied and the relative overhang ratio (OHR).

Table 1. Description of Tested Cases for Independent Variable

OHR= D/H D= Overhang depth H= Fenestration height	Overhang Depth (Metres)
0.4	0.73
0.6	1.09
0.8	1.46
1	1.82
1.4	2.55
1.6	2.92

Source: Ossen, D.R., Ahmad, M.H. & Madros, N.H. 2005.

Their study reveals that horizontal overhang ratios of 1.3, 1.2, 1 and 1 for east, west, north and south orientations respectively have optimum total energy savings of 14%, 11%, 6% and 8%. Ossen et al. (2005) conclude that in hot and humid climates, external solar shading is the best option to optimize total energy use, considering the trade off between total heat gain and natural light penetration. Even though this study considered orientations and height of opening when determining the depth of the overhang hang, it did not consider horizontal shadow angles, vertical shadow angles and width of openings.

It is therefore reasonable and logical to accept the proposal of Ossen et al. (2005) for the context of Dhaka for three reasons. Firstly, because of the similarities in the two climates, secondly, because of the parameters they have considered in determining the length of shading device and finally because they have also considered the trade off between total heat gain and natural light penetration when calculating total energy savings.

4 Results: Case Study Findings and Data Analysis

4.1 An overview of the case study building

The building is in Lalmatia residential area (Fig. 1), an upper-income neighbourhood, located at the heart of the city. Mohammadpur and Sher-e-Bangla Nagar to the north, Raja Bazar to the east and Dhanmondi and Rayerbazar to the south surround Lalmatia.

Figure. 1. Location of the case study building in Lalmatia, Dhaka Source: Google Map

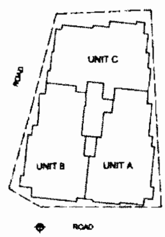

Figure. 2. The Case Study Building Figure. 3. Location of different units

The case study building (Fig. 2) is a typical six-storied multi-unit residential building with three flats on each floor and fifteen households. The three different flats/units in the building are: Type A, Type B and Type C (Fig. 3). The sizes of flat Type A, B and C are 120, 122 and 120 square metres respectively. Type A is surrounded by a road on the southern side and by a residential building on the eastern side. Two roads, one on the western side and the other on the south, surround Type B. Type C is surrounded by a road on the west side and a residential apartment on the north.

Seven out of fifteen households were surveyed. These households are A2, A3, B2, B4, B5, C1 and C5.The residents of C1 are tenants; all other flats surveyed are owned by the households.

4.2 Design features of the case study building

4.2.1 Building envelope

4.2.1.1 External wall All external walls are of 125 mm solid brick. The owner of flat B4 who was the owner of the land now regrets the limited thickness of external walls. During the interview, she complained that the heat gain on the western side of the building is profuse and unbearable. She claimed that the developers had suggested 125 mm wall thickness to reduce the construction costs of the building. She now feels that the heat gain on the western side would have been less if the external walls were 250 mm. She has admitted that the extra costs of using 250 mm wall thickness and the reduced indoor floor area as a result of the increased external wall would have been worthwhile.

Both external and internal walls have a cement plaster over the brick and white wall finishes. Some exterior walls that face the roadside are clad with light coloured facing bricks.

4.2.1.2 Roof The roof is flat, about 100 mm thick. It is made of reinforced concrete slab with weathering course, a course laid on the top surface of RCC roof slab to protect it against weather elements like rain, heat etc and neat cement finish. The roof has one big room that functions as a community room. The roof is also used by the residents for hanging laundry and as a community space.

4.2.1.3 Windows

Shading devices

Shading devices are needed in Dhaka to ensure protection from the rain and solar heat gain. The depth of the shading device for different orientations of windows in all rooms of the different unit types (A, B and C) was calculated.

The analysis of shading devices for windows (Tables 4- 6) demonstrate that shading devices are either absent or their sizes are much less than the recommended value. This analysis together with simple observation on shading devices represents the general scenario of shading devices in typical residential buildings of Dhaka.

Table 4. Shading device analysis of Flat Type A

Room	Window orientation	Window size (In metres)	Window to wall area ratio (WWR)	Recommended horizontal shading (In metres)	Actual horizontal shading (In metres)
Master bed	East wall	1.5 x 1.4	0.24	1.8	-
Master bed	South wall	1.5 x 2	0.24	2	0.78
Bed 2	South wall	1.3 x 2	0.27	2	0.78
Bed 3	East wall	1.8 x 1.4	0.28	1.8	-
Living	East wall	1.5 x 1.4	0.24	1.8	0.25
Dining	Central void	1.8 x 1.4	0.18		
Kitchen	East wall	1.1 x 1.4	0.18	1.8	-

Table 5. Shading device analysis of Flat Type B

Room	Window orientation	Window size(In metres)	Window to wall area ratio (WWR)	Recommended horizontal shading (In metres)	Actual horizontal shading (In metres)
Master bed	West wall	1.67 x 2	0.38	2.4	-
Master bed	South wall	1.5 x 2	0.25	2	1.16
Bed 2	South wall	1.3 x 2	0.28	2	0.9
Bed 3	West wall	1.5 x 2	0.39	2.4	0.25
Living	West wall	3 x 2	0.70	2.4	-
Dining	Central void	1.8 x 1.4	0.13		
Kitchen	West wall	1.3 x 2	0.26	2.4	0.5

Table 6. Shading device analysis of Flat Type C

Room	Window orientation	Window size (In metres)	Window to wall area ratio(WWR)	Recommended horizontal shading (In metres)	Actual horizontal shading (In metres)
Master bed	West wall	1.8 x 2	0.31	2.4	0.78
Master bed	North wall	1.65x 1.4	0.24	1.4	0.5
Bed 2	West wall	1.7 x 2	0.27	2.4	1.4
Bed 3	East wall	1.09 x 1.4	0.28	1.8	0.9
Living	East wall	1.65 x 1.4	0.24	1.8	0.7
Dining	Indirect windo	1.8 x 1.4	0.18		
Kitchen	North wall	1.3 x 1.4	0.18	1.4	-

4.3 Energy usage of the case study flats

4.3.1 Total energy usage

The energy use of the case study flats depend on the household size, occupancy pattern, appliances used, the power rating of the appliances and the duration for which they are used. The study does not take into account the energy efficiency of the different appliances and energy efficiency related to every day habits that cannot be influenced by design because the study focuses on the energy efficiency aspects that can be addressed through planning and design. The energy use of the households has been calculated for a typical summer month, when the maximum temperature can be as high as 34° C. The monthly total energy use for a typical summer month for all the units studied is given in Table 7. A break up of the energy use pattern (in percentage) of the case study flats for a typical summer month has been outlined in Table 8. Analysis of energy use in Table 8 shows that the energy required for cooling and lighting takes up the largest share of the energy used by a flat. Unit C1 has very low energy use compared to the other units because the household size is small and it does not use excessive fixtures for lighting or air conditioners for cooling. The average cooling and lighting energy used by all the units of the case study in a typical summer month has been calculated as 40% and 39% respectively of the total energy use.

Table 7. Monthly total energy use

	Unit A2 1 A.C	Unit A3 1 A.C	Unit B2 1 A.C	Unit B4 2 A.Cs	Unit B5 2 A.Cs	Unit C1 No AC	Unit C5 2 A.Cs
Monthly total energy use for a typical summer month (kWh)	1762	1401	900	1263	1356	450	1316

Table 8. Break-up of monthly total energy use

Energy used (%)	Unit A2	Unit A3	Unit B2	Unit B4	Unit B5	Unit C1	Unit C5
Cooling (A.C)	25.2 1 A.C	36 1 A.C	16.7 1 A.C	29 2 A.Cs	29.7 2 A.Cs	No AC	37.1 2 A.Cs
Cooling (Fan)	10.89	14.4	18.6	10.7	7.4	19.2	12.8
Lighting	46	30	40	41	42	56	29
Refrigeration	10.05	6.2	19.7	14.1	13.10	19.3	13.5

Other appliances	7.66	13.4	4.8	4.2	7.4	5.10	7.4
Ventilation in toilet & kitchen	0.18	0.22	0.2	0.34	0.05		0.1

4.3.2 Energy usage for cooling

Using the data in Table 9, the average cooling energy as a percentage of the total energy used by all the units of the case study has been calculated as 40 % and the average energy use for air conditioners as a percentage of the total cooling energy alone is 24%. The percentage of total cooling energy for Units A3 and C5 is 50% because they are more dependent on air conditioners as compared to other units in the building; Unit A3 uses 36% of cooling energy for air conditioners and Unit C5 uses 37%. On the other hand, the percentage of total cooling for Unit C1 is extremely low when compared to other units because this household does not have air conditioners.

Table 9. Energy used for cooling

Energy used	Unit A2	Unit A3	Unit B2	Unit B4	Unit B	Unit C1	Unit C5
Cooling (A.C) in kWh	444 1 A.C	499.5 1 A.C	150 1 A.C	366 2 A.Cs	402 2 A.Cs	- No AC	488.25 2 A.Cs
Cooling (A.C) in %	25.2	36	16.7	29	29.7	-	37.1
Cooling (Fan) in kWh	192	202	168	134.4	100.8	86	168
Cooling (Fan) in %	10.89	14.4	18.6	10.7	7.4	19.2	12.8
Total for cooling (kWh)	636	702	318	500	503	86	656
Total in kWh	1762	1401	900	1263	1356	450	1316
Total for cooling in %	36	50	35	40	37	19	50

The energy used by air conditioners depends on their capacity, type, power rating, and usage and setpoint temperatures. Table 10 shows the energy use of air conditioners based on their capacity, type and power rating. According to Tham (1993), a rise of one degree Celsius in setpoint represents a saving of 6% in energy required for cooling.

Table 10. Energy use of air conditioners based on their capacity, type, usage and power rating

Units/ Flats	Air conditioner (A.C)	No.	Rating (W)	Estimated total load for appliance (kW)	Usage per day (h)	Daily energy use during used period (kWh)	Monthly energy usage of A.C (kWh)
A2	Split 1.5 ton	1	1850	1.85	8	14.8	444
A3	Split 1.5 ton	1	1850	1.85	9	16.65	499.5
B2	Split 1 ton	1	1250	1.25	4	5	150
B4	Split 1.5 ton	1	1850	1.85	4	7.4	222
	Split 2 ton	1	2400	2.4	2	4.8	144
B5	Split 1.5 ton	1	1850	1.85	4	7.4	222
	Split 2 ton	1	2400	2.4	2.5	6	180
C1	None						
C5	Split 1 ton	1	1250	1.25	1.5	1.875	56.25
	Split 2 ton	1	2400	2.4	6	14.4	432

Units A2, A3 and B2 have one air conditioner each and that alone is used for 8, 9 and 4 hours a day respectively. Units B4, B5 and C5 have two air conditioners each and both air conditioners in each unit is used for 6, 6.5 and 7.5 hours respectively.

It can be observed that in flats, such as A3, B2 and C5 which are occupied by the households (excluding the housekeeper) throughout the day use air conditioners in the afternoon and at night. This can be interpreted as such that overheated periods that cause discomfort due to solar radiation on the building envelope extend from 10 am in the morning to 8 pm at night. Solar radiation incident on the building envelope raises the temperature of the exterior surface of the envelope, thereby creating a temperature gradient across the thickness of the envelope. As a result, heat is conducted through the inefficiently designed building envelope, causing a rise in the interior surface temperature. Ample ventilation is needed to dissipate this stored heat at night (Gut and Ackerknecht, 1993). As this stored heat cannot be dissipated outside due to inadequate cross-ventilation and placement of openings, it causes the occupants of the flats to swelter in poor ventilation and high temperatures.

Comparison of the energy use for flats with and without air conditioners (Table 7) shows that case study flats without air conditioners use much less energy. This highlights the necessity in paying attention to architectural characteristics and trends that can address the thermal comfort demands of the households without increasing the dependency of air conditioners. Although fans are also used for cooling, the energy used by them is not as significant as the energy use of air conditioners (Table 9).

It must be emphasized that the case study building is representative of upper middle-income households who have a minimum of one air conditioner. The value for the share of energy utilized for cooling by air conditioners would be much more for lower upper and upper upper- income groups who live in four bed-roomed flats and have air conditioners in all their rooms.

4.3.3 Energy usage for lighting

There are substantial variations in energy used for lighting residential buildings. In the United States, lighting uses 12% of the energy used by a residential building (UNEP, 2007) and 9% of energy used in residential buildings of India contributes to lighting (UNEP, 2007). Residential buildings of Taiwan, on the other hand use 40% of the total residential sector electricity use for lighting (Yang and Hwang, 1993). Using the data in Table 9, the average lighting energy used by all the units of the case study has been calculated as 39%.

Table 11. Different types of lights and energy used for lighting

Type of lighting	Unit A2	Unit A3	Unit B2	Unit B4	Unit B5	Unit C1	Unit C5
Incandescent	16	6	6	16	30	8	9
Fluorescent	12	12	11	11	12	10	9
Energy saving	2	16	16	7	3	None	7
Spot	11	5	None	6	4	None	2
Total number of artificial lights	41	39	33	40	49	18	27
Total energy for lighting (kWh)	810.6	422.4	360	518.25	574.35	252	382.8
Energy used for lighting (%)	46	30	40	41	42	56	29

The energy use for lighting in the households is seen to vary with type of lighting, the number of lights, power rating and the usage of lights. Table 11 shows the different types of lights, the total number of lights and the share of energy use for lighting. Analysis of the different types of lights and the energy use of each type of light is illustrates that incandescent lights use more energy than fluorescent lights. The analysis also shows that energy saving lights use less energy. Nagarajan (2006) states that compact fluorescent light (CFL) or energy saving light as it is commonly called is energy efficient and consumes 80% less electricity when compared to incandescent light.

Developers in Bangladesh generally provide a minimum of two average quality wall mountable lighting fixtures, but not the lights. The households studied in this building did not use the lighting fixtures provided by the developers. Instead, they purchased a multitude of lighting fixtures and lights of their own choice or as suggested by the interior designers who were responsible for the interior design of the flats. The number of lights in all flats except unit C1 and C5 are much more than what is needed for strictly practical reasons. Units C1 and C5 are good examples to show that use of excessive lights are not a necessity. It is possible to use fewer lights and have good indoor artificial lighting conditions. The superfluous lights in the remaining households are for aesthetic purposes and to some extent, to signify the status of the households. Gut and Ackerknecht (1993) have advised against the use of unnecessary lighting as it adds up to internal heat gain.

Even though Unit C1 has the least number of lights compared to the other units, energy used for lighting in unit C1 is more than 50% because this household does not use air conditioners and other major energy consuming appliances. Lighting alone contributes to more than 50% of the share of energy used by this household. It is thus seen that percentages are not relevant on their own, but only in relation to a total.

5 Discussion

5.1 Energy efficient design features

The theoretical framework in this study identified energy efficient design features that can meet the purpose of this study and can be applied in the context of Dhaka. The features that have been selected pertain only to the building envelope, reduce heat gain by the buildings, and they mainly reduce the energy use for cooling. It needs to be strictly emphasized that the chosen features reduce only the cooling energy; the features do not influence the energy used for electrical appliances. The research front has been summarized in Table 12 to formulate the energy efficient design features that can be applied in the context of Dhaka.

Table 12. Energy efficient design features

Feature	Application	Reduction/Saving	Reference
External wall	**Doubling the thickness of external walls with 280 mm brick walls including an air cavity of 50 mm on east and west facades.**	**7% - 10%**	**Modified by the author**
Roof	The use of hollow clay	18% - 30%	Vijaykumar and

	tiles (HCT) in place of weathering course for roofs		Srinivasan in Vijaykumar et al. (2007)
Shading device	**Horizontal overhang ratios of 1.3 for east**	**14 %**	**Ossen et al. (2005)**
	Horizontal overhang ratios of 1.2 for west	11 %	Ossen et al. (2005)
	Horizontal overhang ratios of 1 for north	**6 %**	**Ossen et al. (2005)**
	Horizontal overhang ratios of 1.3 for south	8 %	Ossen et al. (2005)

Assuming that the energy savings estimated by the authors above are roughly correct, then addition of the lower range energy saving values of all the features above gives a total energy savings of 64% (7% + 18% + 39%) for cooling. Given the concrete features of the case study building, the energy efficient design features listed above can be recommended for the context of Dhaka and lies within the field of influence of the architect.

5.2 Energy use of the flats in the case study on adoption of the energy efficient features

The energy use of each flat in the case study building has been delineated in section 4.3. Out of all the energy use that the households use, only the cooling energy of each flat has been reduced because the design measures are not connected to energy use for lighting and other appliances. If the building were to adopt the energy efficient features discussed above, then the cooling energy use of the surveyed flats in the case study building would be reduced by 64%. As explained above, the 64% reduction is a summation of the lower range energy saving values of all the energy efficient features.

Table 13. Reduced energy use of the flats

Energy use		Unit A2	Unit A3	Unit B2	Unit B4	Unit B5	Unit C1	Unit C5
Energy use (kWh)	Cooling	636	702	318	500	503	86	656
	Electrical appliances	1126	700	582	753	853	364	660
	Total Energy	1762	1402	900	1253	1356	450	1316
Net energy use after	64 % reduction on	229	253	114	180	181	31	236

adopting design features. (kWh)	cooling energy							
	Electrical appliances	1126	700	582	753	853	364	660
	Total energy	1355	953	696	933	1034	395	896
Percentage reduction in total energy use		23%	32%	23%	26%	24%	12%	32%

Table 13 above illustrates total energy used by the flats before and after adopting the energy efficient features, assuming that the comfort level of the households remaining unchanged. Since the design features reduce the cooling load, 64% was deducted from the cooling energy of each unit or flat. During the calculation of the reduced energy of the flats, the energy used by electrical appliances has been left unchanged as shown by the values in the second row of the table For example, the cooling energy of Unit A2 was 636 kWh before the reduction and it is 229 kWh after a reduction of 64%. The total energy used by Unit A2 was 1762 kWh before the reduction on the cooling energy. After the cooling energy of Unit A2 is reduced to 229 kWh, the consequent reduction in total energy use of Unit A2 is 1355 kWh as compared to the initial value of 1762 kWh. This is a reduction of 23% in the total energy use of Unit A2. The percentage reduction was calculated by subtracting the difference in energy use before and after reduction of 64% and then dividing this value by the total energy use before the reduction.

In a similar way, the percentage reduction on the total energy use of Units A2, A3, B2, B4, B5, C1 and C5 is calculated as 23%, 32%, and 23%, 26%, 24%, 12% and 32% respectively. This is an average reduction of 26% on the total energy use of the building. This average reduction was found by adding the total energy use of all the units before (8439 kWh) and after the reduction of 64% in cooling energy (6262 kWh). The difference of these two values (2177 kWh) is divided by the total energy use before the reduction of 64% (8439 kWh) and then multiplied by 100 to give the average percentage reduction of 26% on the total energy use of the units surveyed.

The percentage reduction in cooling energy is seen to be more in Units A3 and C5 because these units use 50% of the total energy in cooling (shown earlier in Section 5.3.2). Whereas, the percentage reduction in cooling energy of Unit C1 is only 12% as it uses only 19% of the total energy for cooling. It was shown in Section 5.3.2 that units A3 and C5 are more dependent on air conditioners as compared to other units in the building and Unit C1 does not use air conditioners. The unit without air conditioners (Unit C1) is not as benefitted as those that have air conditioners because the reduction in energy use was directed at those who have air conditioners and are very much dependent on them. Nevertheless, households of Unit C1 would have a better indoor climate with lower indoor temperatures and with lower energy use for cooling by fans and lower costs.

It can thus be concluded that a 64% reduction in cooling energy literally implies that more than half of the devices that were used for cooling are no longer used. Households would use the fans for a lesser period of time or to enhance cross ventilation or when there is no air flow. It would also mean that those who are dependent on air conditioners might use it for a lesser period of time or probably do not need air conditioners.

Further reduction in total energy use is possible if the energy required for lighting is reduced by using energy efficient lights. However, discussions on reducing energy use for lighting are outside the scope of this study as mentioned in Section 1.3.2.

6 Conclusion and Recommendation

This study has identified the following energy efficient building features for the context of Dhaka:

- Doubling the thickness of external walls with 280 mm brick walls including an air cavity of 50 mm on east and west.
- The use of hollow clay tiles (HCT) in place of weathering course for roofs.
- Horizontal overhang ratio of 1.3 for east orientations, 1.2 for west orientations, 1 for north orientations and 1 for south orientations respectively.

All the features that were analysed in this study for adoption in the case study building reduce the energy use for cooling. The study shows that it is possible to reduce the cooling load of the flats studied by 60-70% and hence reduce the total energy use of the flats surveyed by 26-30%.

Dhaka City Building Construction Act need to develop building codes to promote and influence energy efficiency in buildings. The focus of the codes should be to incorporate energy efficient design features right from the design stage.

Considering the significant amount of energy used by the residential buildings in general and the prevailing energy crisis in Dhaka, it is important to adopt the reasonably simple energy efficient design features highlighted in this study. These features can reduce the total energy use of the flats in the case study building by a factor of one fourth and also provide increased comfort to the households. Energy efficient design features not only improve the energy efficiency of residential buildings, but can also provide reduced energy costs to users and play a role in improving the overall energy situation of the country

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