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# KEY PREDICTORS OF ANNUAL ELECTRICITY USE IN HIGH-RISE RESIDENTIAL APARTMENTS IN DHAKA, BANGLADESH

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**Abstract.** This paper describes a study that examines the influence of building design and household characteristics on the annual electricity use of apartments in high-rise residential buildings of Dhaka, Bangladesh. To do this, 342 apartments in different high-rise residential buildings were studied. Their electricity use records were collected and the apartments were also surveyed to collect data of building design characteristics. Data on the building design characteristics include floor level, floor areas of the apartments, effective canyon ratio, window area, shading depth, window-to-wall area ratio (WWR) and window-to-floor area ratio (WFR) and shape coefficient of the apartments. Household characteristics include household size and number of air conditioners (ACs). The analysis methods used in this study include descriptive statistics, correlations and linear regression analysis with SPSS. The results show that among the different variables studied, of the design characteristics, total window area and total WFR per apartment are the key predictors of annual electricity if the effect of the influence of household characteristics such as household size and number of ACs are excluded. If household characteristics are included in the linear regression models, effective canyon ratio, household size and number of ACs are the predictors of annual electricity use in addition to total window area and total WFR per apartment.

**Keywords.** High-rise residential buildings; apartments; building design characteristics; electricity use; household characteristics

## 1. Introduction

Bangladesh is small in geographical area, but one of the most densely populated countries in the world. In 2006, Dhaka, the capital was ranked 11th among the world's megacities with a population of 12.4 million (United Nations 2006). Increasing urbanization together with rapid population growth has created a huge pressure on the housing sector of Dhaka (Bhuiyan, 2011). Urbanization has reached a grave point by exceeding the supply of infrastructure and services (Rahman, 2011). High-rise residential apartments in Dhaka have thus become increasingly popular as the answer to housing needs over the last twenty years. The present trend in Dhaka is to construct high-rise residential buildings that are 12-20 floors (Kamruzzaman and Ogura, 2007), while the average height of high-rise residential buildings in Dhaka is 16 floors (Kamruzzaman, 2007)

Worldwide, the residential building sector accounts for over one-third of total final energy consumption (IEA, 2013) and the situation in Dhaka is no different. In Dhaka, residential buildings consume more than 50% of the total energy consumption (DESCO, 2013). The electricity consumption of the residential sector of Dhaka has almost doubled from 2005 to 2011 (Mondal and Denich, 2010). As the demand of electricity continues to outstrip supply, load shedding has increased (Mondal and Denich 2010), especially during the summer months when it is hot and humid thus creating excessive discomfort and driving many people to use air conditioners. Much of the increased demand for electricity is also due to the increased standard of living (Unnayan Shamannay, 2006).

At present there is an absence of any kind of clear and verifiable assessment measures of electricity use in high-rise residential apartments in Dhaka. The purpose of this research is to identify the factors that predict the electricity use in high-rise residential apartments in Dhaka. In order to find the predictors of the electricity use in those high-rise apartments, the design characteristics and electricity use within the apartments need to be identified first.

## 2. Review of Previous Studies

### 2.1. STUDIES ON ELECTRICITY USE IN HIGH-RISE RESIDENTIAL BUILDINGS

Wan and Yik (2004) presented the findings of energy end-use and building characteristics of high-rise residential buildings in Hong Kong. The building characteristics surveyed include apartment size, ratio of the area of living and dining to total apartment size, average number of floor levels, window-to-wall area ratio, type of fenestration and external shading devices. Though the study presented the findings of building characteristics and energy end-use data, it did not study the influence of the building characteristics on energy use.

Touchie et al (2013) examined correlations between building characteristics and energy use. The building characteristics included building height, size, vintage, fenestration ratio, glazing type, thermal conductance of glazing and mechanical system details and occupancy type. The study found that there appeared to be no correlation between energy use and building height or size. The building characteristics that exhibited the strongest correlations with energy use were fenestration ratio and boiler efficiency. Energy use was also attributed to differences in building operation.

Besides depending on the building envelope, electricity use may also depend on apartment size, canyon ratio, building shape coefficient and floor level. The effect of apartment size, canyon ratio, building shape coefficient and floor level on cooling electricity use was studied by Yun and Steemers (2011), Strømann-Andersen and Sattrup (2011), Depecker et al (2001) and (Hachem et al 2014) respectively.

## 2.2. DESIGN CHARACTERISTICS OF RESIDENTIAL BUILDINGS IN DHAKA

The average floor area of the apartments is 142 square metres (Seraj, 2012). On average, there can be either two or three bedroom apartments. Apartment size or number of rooms depends mainly on the socio-economic status and also the size of the family (Kamruzzaman, 2007). According to BBS (2001), the average household size in Dhaka is four.

Table 1. Summary of building design characteristics of residential buildings in Dhaka (Ahsan, 2009)

| **Building design characteristics** | **Mean** |
|---|---|
| Master bedroom | 13 $m^2$ |
| Bedroom 2 | 12 $m^2$ |
| Bedroom 3 | 10 $m^2$ |
| Dining room | 16 $m^2$ |
| Living room | 13 $m^2$ |
| Kitchen | 7 $m^2$ |
| Total window area | 20 $m^2$ |
| Window-to-wall area ratio (WWR) per apartment | 0.28 |
| Window-to-floor area ratio (WFR) per apartment | 0.24 |
| Shading depth | 0.7 m |

Ahsan (2009) studied the design features of residential apartments in Dhaka. Data on the size of different rooms, window-to-wall area (WWR), window-to-floor area (WFR) and shading device have been summarized in Table 1. Most external walls of residential buildings in Dhaka are of 125 mm solid brick. 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 for uplifting the front facade. In general, residential buildings in Dhaka do not have insulations because it is considered expensive, difficult to maintain and not appropriate in terms of climate. Roofs are flat, about 100 mm thick, made of reinforced concrete slab with weathering course and neat cement finish. The windows are sliding with aluminium frames and usually have 5 mm thickness tinted glass. The opening of these sliding windows is limited to 50% of the window size.

### 2.3. STUDIES ON ELECTRICITY USE IN HIGH-RISE RESIDENTIAL BUILDINGS

Analysis of household survey data by World Bank (2013) suggests that 77% of the urban households in Dhaka consumed between 100-400 kWh of electricity per month in 2010. About 19% of the households in the richest quintile consumed more than 400 kWh per month and this accounts for almost 22% of total monthly electricity consumption. In a previous limited study, Ahsan (2009) found the average cooling, lighting and appliances electricity used by apartments in Dhaka in a typical summer month to be about 42%, 41% and 17% respectively of the total electricity consumed. The study was representative of residential buildings with six floors inhabited by upper middle-income groups in Dhaka.

## 3. Method

It is hypothesized that the electricity use in the high-rise apartments in Dhaka is influenced by building design and household characteristics. In order to test this hypothesis and identify the factors that can predict the electricity use in existing high-rise apartments in Dhaka, the research applied a case study method. The selection of the case study buildings was based on the following criteria:

- Buildings are representative of typical multi-unit high-rise residential apartments in Dhaka
- Data for one year of electricity use from 01/2012 to 12/2012 were available
- Buildings were accessible
- Architectural drawings of the apartments were available.

At the end, 342 high-rise apartments in 8 case study buildings were identified as suitable for the research. In the first stage of the research, electricity use data from these apartments were collected.

Based on the findings from the literature review, seven building design characteristics, namely floor level, apartment size, window area, shading depth, window to wall area ratio (WWR, defined as the ratio of the area of window to the area of the wall in each room), window to floor area ratio (WFR, defined as the ratio of the area of window to the area of the floor), and shape coefficient of the apartments, were identified as key features that might play a role in influencing the electricity use. Shape coefficient is defined as the ratio of the area of building's outer-surface to its inclusive volume (Depecker et al 2001; Enshen 2005). Shape coefficient represents the amount of exposed surface of buildings and therefore, their potential for interacting with the climate through natural ventilation, day lighting, etc. (Ratti et al 2003).

The above building design characteristics were surveyed in the 342 apartments during the second stage of the study. It should be noted that, as residential buildings in Dhaka have the same building materials, i.e. uninsulated brick walls and single glazed windows, glazing type and thermal insulation were not included in the study although they were noted.

The effective canyon aspect ratios around each building were also calculated. The canyon aspect ratio (H/W) is defined as the ratio of the buildings' height (H) to their separation (W) at ground level. While a canyon ratio is not a design characteristic of the building itself, it is an important factor to indicate urban density (Oke, 1987) which may have an influence in the cooling energy of the apartments. In this study, the effective canyon ratio was calculated for each external wall on the relevant floor level by taking into account the height of the top of the building directly opposite of that wall, from that floor and the gap between the two buildings (see Figure 1).

In addition to building design characteristics, two household characteristics were also identified as factors that may affect electricity use in high-rise buildings in Dhaka. These were household size and number of air conditioners (ACs) in each apartment.

Descriptive statistics, correlations and linear regression analysis with SPPS (Version 20) are the different analysis methods that are used in this study. Descriptive statistics have been used to summarize electricity use data by finding the mean and standard deviation. Pearson correlations are used to to explore the strength of the relationship between two variables, i.e. annual electricity use and a design characteristic. Pearson correlations give an indication of both the direction (positive or negative) and the strength of the relationship (Pallant, 2011). A positive correlation indicates that as one variable increases, so does the other. A negative correlation indicates that as one variable increases, the other decreases.

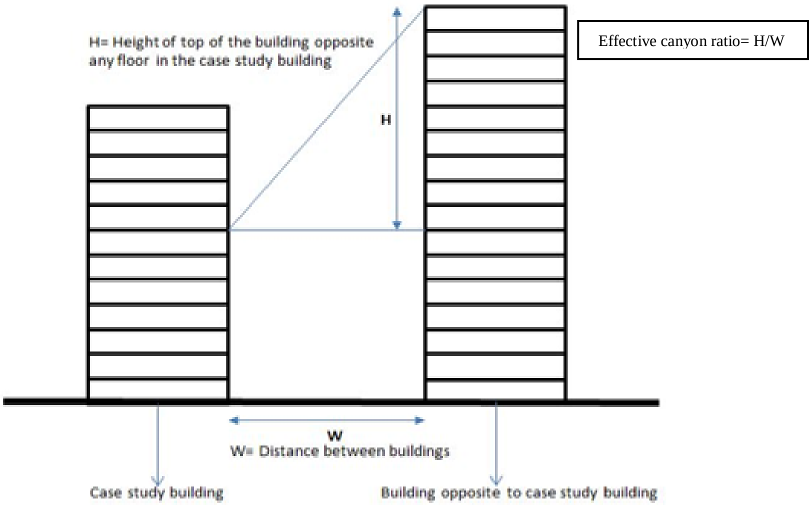


*Figure 1. Method of calculating effective canyon ratio*

The statistical technique of regression analysis may be used to relate a dependent variable with an independent variable (Lam et al, 1997).The objective of a linear regression analysis used in this study is to predict the independent variables (design characteristics and household characteristics) that affect the dependent variable, annual electricity use. In other words, a linear regression analysis is used to analyze the influence of building design and household characteristics on annual electricity use. In this study, to determine the effect of household characteristics in the model, the regression analysis was carried out in two steps in order to control for building design characteristics.

## 4. Results

### 4.1 BUILDING DESIGN CHARACTERISTICS

Table 2 provides a summary of the descriptive statistics for each of the building design characteristics.

Table 2. Descriptive statistics of building design characteristics of 342 apartments

| **Building design characteristics** | **Minimum** | **Maximum** | **Mean** | **Standard Deviation** |
|---|---|---|---|---|
| Floor level | 2 | 20 | 10 | 4 |
| Apartment size | 88 $m^2$ | 204 $m^2$ | 117 $m^2$ | 17 |
| Master bedroom | 10 | 21 | 14 | 1.5 |
| Bedroom 2 | 9 $m^2$ | 16 $m^2$ | 12 $m^2$ | 1.3 |
| Bedroom 3 | 8 $m^2$ | 14 $m^2$ | 8 $m^2$ | 3.8 |
| Dining room | 7 $m^2$ | 27 $m^2$ | 14 $m^2$ | 3.5 |
| Living room | 10 $m^2$ | 21 $m^2$ | 13 $m^2$ | 2.6 |
| Kitchen | 4 $m^2$ | 10 $m^2$ | 7 $m^2$ | 1.5 |
| Total window area | 11$m^2$ | 28 $m^2$ | 21 $m^2$ | 6 |
| Window-to-wall area ratio (WWR) per apartment | 0.2 | 0.4 | 0.3 | 0.03 |
| Window-to-floor area ratio (WFR) per apartment | 0.2 | 0.4 | 0.3 | 0.07 |
| Shading depth | 0.1 m | 1 m | 0.6 m | 0.2 |
| Effective canyon ratio | 0.1 | 34 | 5.3 | 5.2 |
| Shape coefficient | 0.1 $m^{-1}$ | 0.5 $m^{-1}$ | 0.3 $m^{-1}$ | 0.1 |

## 4.2. ELECTRICITY USE OF APARTMENTS IN HIGH-RISE RESIDENTIAL BUILDINGS IN DHAKA

### *4.2.1. Total annual electricity use*

Based on the annual electricity bill records of the 342 apartments, the average annual electricity use was calculated to be 3775 kWh while the average annual electricity for the usable floor area of 342 apartments was 32 kWh/$m^2$. Table 3 shows the descriptive statistics for annual electricity use of the 342 apartments.

Table 3. Descriptive statistics for annual electricity use of 342 apartments

| **Electricity use** | **Minimum** | **Maximum** | **Mean** | **Standard. Deviation** |
|---|---|---|---|---|
| Annual electricity (kWh) | 1246 | 8431 | 3775 | 1327 |
| Annual electricity (kWh/m2) | 9.5 | 64 | 32 | 11 |

## 4.3. ELECTRICITY USE AND BUILDING DESIGN AND HOUSEHOLD CHARACTERISTICS OF APARTMENTS IN HIGH-RISE RESIDENTIAL BUILDINGS

### *4.3.1. Correlations between design characteristics and annual electricity use*

Out of all the building design characteristics studied in the 342 apartments (n= 342), annual electricity use (kWh) was found to have correlations with high significance ($p<0.05$) with apartment size, effective canyon ratio (H/W), total window area, shading depth, total WFR per apartment and compactness as shown in Table 4.

Table 4. Correlations between building design characteristics and annual electricity use of 342 apartments

| **Design characteristics** | **Relationship** | **R2** | **Significance (p value)** |
|---|---|---|---|
| Apartment size | + | 0.076 | 0.000 |
| Effective canyon ratio(H/W) | - | 0.023 | 0.005 |
| Total window area | + | 0.074 | 0.000 |
| Shading depth | + | 0.019 | 0.011 |
| Total WFR per apartment | + | 0.027 | 0.002 |
| Compactness | + | 0.042 | 0.000 |

It can be noted that the significance of r is strongly influenced by the size of the sample, for instance, in large samples (n=100+), very small correlations (e.g. $R^2$=0.02) may still reach statistical significance (Pallant, 2011).

### *4.3.2. Regression techniques*

The primary objective of the regression analysis in this research was to determine the building design characteristics that influence annual electricity use. The next objective was to analyse to what extent household characteristics such as household size and number of ACs, explained the variations in annual electricity use. Therefore, for the dependent variable annual electricity use, the regression analysis was conducted twice. At first, only the design characteristics were taken as the independent variables to understand the influence of their influence on electricity use. For the second regression analysis, household size and number of ACs were added to the list of independent variables to explore their influence of ACs on annual electricity use.

### *4.3.3. Regression model for prediction of annual electricity use*

Based on the first linear stepwise regression analysis, the total WFR and total window area were found to be the only two design variables that affected annual electricity use. The result shows that annual electricity use would increase as the total window area increases and it would decrease as total WFR increases ($R^2$ =0.13, $p<0.05$). Table 5 shows the equation for the first regression model with the constant and unstandardized beta (β) coefficients.

Table 5. First regression models for annual electricity and building design characteristics

| Regression Models | Equation to predict annual electricity (y) using the constant (C) and beta (β) values: y= C+ β x |
|---|---|
| Total window area | y= 3233 + (198x total window area) - (11696 x total WFR per apartment) |
| Total WFR per apartment | |

When both household size and number of ACs were included in the second regression analysis along with the building design characteristics, the number of ACs, effective canyon ratio, household size, total WFR per apartment and total window area were found to be affecting annual electricity use, showing that annual electricity use would increase with the increases in effective canyon ratio (density), total window area, household size and number of ACs and it would decrease as total WFR increases ($R^2$ =0.32, $p<0.05$). Table 6 presents the equation for the second regression model with the constant and unstandardized beta (β) coefficients.

Table 6. Second regression models for annual electricity and building design and household characteristics

| Regression Models | Equation to predict annual electricity (y) using the constant (C) and beta (β) values: y= C+ β x |
|---|---|
| Effective canyon ratio | y= 1484 + (105x effective canyon ratio) + (237x total window area) - (14263 x total WFR per apartment) + (230x household size) + (475x number of ACs) |
| Total window area | |
| Total WFR per apartment | |
| Household size | |
| Number of ACs | |

## 6. Discussion

The correlation analysis between annual electricity use and effective canyon ratio (H/W) shows a negative correlation, meaning that electricity use decreases as effective canyon ratio increases. This can be explained as narrow streets and high buildings create a larger shaded area in the urban canyon. Annual electricity use decreases as the shadowing effects leads to a lower temperature during the day and a consequently lowering cooling electricity use. When the regression analysis is done using only the building design characteristics, the coefficient for effective canyon ratio is negative, though not significant. As the independent variables household size and number of AC are added to the second regression analysis along with all other building design characteristics, the coefficient for the effective canyon ratio becomes positive as shown in Table 6. It can thus be concluded that the influence of household size and number of ACs is strong that after their inclusion to the regression analysis, an increase in effective canyon ratio (density) results in an increase of annual electricity use. Household size or the number of persons in an apartment is crucial because of the anthropogenic heat released is a potential heat source for an apartment (Oke, 1987). This heat released inside the apartments can be a by-product of activities (cooking, lighting, electrical appliances, etc) and it includes the metabolic releases of the occupants inside the apartment. It can be concluded that an increase in household size would increase the anthropogenic heat released inside the apartment. In order to dissipate this heat from the apartment, the dependence on artificial cooling such as air conditioners is increasing. The need for natural ventilation or air exchange also increases with the onset of household size. As ventilation is highly influenced by the layout of building, spacing between and height of the surrounding buildings, highly dense areas would affect the potential for natural ventilation. When natural ventilation cannot be achieved, the likelihood of using air conditioners increases and this in turn increases the annual electricity use.

## 7. Conclusion

Total window area and total window-to-floor area ratio per apartment are the key predictors of annual electricity if the effect of the influence of household characteristics such as household size and number of ACs are excluded. Annual electricity is seen to increase with increase in window area. However, an increase in window-to-floor area ratio decreases annual electricity use. This implies that window area on its own increases electricity use, but window area in relation to floor/room area would decrease electricity use. If the window area is very small compared to the floor/room area, electricity use can be expected to increase as the small sized windows would not be enough to provide air exchange for thermal comfort and hence the dependence on air conditioners would eventually increase electricity use. Also small sized windows in relation to larger floor area would not admit sufficient daylight, resulting in the use of artificial lights and this would increase the electricity used for lighting which would contribute to an increase to in the total electricity use.

The influence of household characteristics particularly household size and number of ACs also strong and when they are added to the list of design characteristics in the regression model, they become the predictors of annual electricity use. While planners and architects cannot control the household size and the number of ACs installed in each apartment, they need to take into account the influence of these factors when developing and designing high rise residential buildings in Dhaka. It is expected that careful considerations of all of the above significant factors will lead to lowering electricity use from these buildings.

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