Floor Area – Carbon Emission Relationship of Multi Residential Buildings for a Typical Metropolis: A Case of Surat City

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Abstract. Energy utilized in private division in India is ever expanding, as 43 percent of all out energy is utilized for air dissemination framework in residential buildings. Be that as it may, two current advancements increment the significance of outflows stages in all structure structures they are immediate and backhanded CO2 discharges relying upon numerous boundaries. The energy execution of a home, volume of a house, number of apparatuses [electricity utilization, fuel utilizes (gas utilization), and number of occupants] are the components thought of. A field investigation of various housing forms in the Indian setting is directed to gather information dependent on different variables. Additionally, conversations on current state of energy utilization conduct in Indian abodes are featured. Based on information investigation, discharge models are created through relapse strategy to streamline arranging and planning of vitality use exercises in private homes

Keywords: Residential energy consumption models, Carbon emission model, CO2 emissions

1. INTRODUCTION

Ozone harming substance (GHG) discharges from residential structures (the creation of materials utilized in development) and the direct energy emanation from residential areas are a major issue of today’s urbanization. The outflows caused because of the immediate energy necessities of homes have additionally been a significant benefactor. Any climate change strategy has to consider how we can heat our homes, provide hot water, and power our appliances in a way that significantly reduces carbon dioxide emissions. India’s carbon footprint measures all GHG emissions (expressed in ‘carbon dioxide equivalents’) generated at home and in the production and transport of the materials which are used for construction. Our present consumption outlines are unmanageable with respect to developing requests on world's assets and its impacts on our condition. India, home to one of the largest populations, has poor or no access to energy and is also infamous for its energy wastages. One has to remember that much of the coal and oil used for electricity generation in India are imported and are highly subsidized. Subsequently, there is an earnest need to decrease the ecological impression of the structure business at the global level. This will bring the real sustainability in the world. Supportable ecological arranging ought to be done by figuring carbon dioxide radiated from the whole private part
and afterward conquering this CO2 discharge by lessening vitality use in houses. This article is legitimized through the examination factors which are answerable for carbon discharge of structures and figuring of CO2 transformation of various building structures for the utilization of direct energy utilization.

2. STUDY OBJECTIVES

Following are the study objectives.
1. To study the household electricity and gas consumption behaviour in order to identify the consumption of electrical and gas energy.
2. To shape household consumption based on different building size and shape.
3. To build up a model that can be utilized for assurance of carbon decrease.

3. DATA COLLECTION

Survey, one of the most important methodologies to study the existing scenario, of Surat city having a population of approximately 4.46 million as per 2011 census, has been taken as a case study for the research work. Firstly, inventory data was collected in the form of relevant information from various sources, such as the authorities and the municipal zonal offices. Various maps of Surat city since its evolution to the present date zonal map, showing major zones of the city of Surat; important statistical documents related to zone-wise population, area, decadal growth rate and density; details of houses in terms of area and population covered under each zone, population of each zone, and zonal details; types of building forms and even infrastructure of zones only for energy use, such as Gujarat Electricity Board and Gujarat Gas or Gas Cylinders, etc. were also included. Secondly, a questionnaire was design based on major zonal details and interviews were carried with actual users in different types of houses in all zones depending on various criteria—electricity consumption, type of heating appliances, number of residents, fuel-based equipment, major activity spaces, etc. Survey questionnaire was distributed in various residential building of different wards in each zone which comprised:

- Introductory data covered the details regarding name of the owner, number of members, and the address;
- Questions to understand the socio-economic status of an individual and community were based on occupation, designation, work place, and vehicle ownership;
- Physical planning, in terms of the house form, number of floors, space allotment; number of rooms; and its usage in terms of lights, fans, other appliances;
- Energy data in the form of the number of tube lights, fans, bulbs, CFLs or any energy saver units, number of air conditions, and their monthly/daily usage.

A survey of 1,050 households was conducted in Surat. The survey was conducted through a stratified random sampling of 150 households from all seven zones of Surat. Collected data was processed and analyzed with appropriate statistical tools.

4. STUDY AREA PROFILE

Surat is located in Gujarat on the southern bank of River Tapi. It is one of the 11 urban communities that arrived at metropolitan status in 2011 evaluation by passing one million imprints. It has encountered quick populace increment from 2001 to 2011 with a populace of 4.6 million. At the state level, Surat is underdog to the state capital Ahmedabad, which has a populace of 5.5 million. These two urban communities structure 40 percent of the all-out urban populace of the state. Surat can be extensively characterized into three sections the old city, covering a region of 8 sq. km; the internal fringe zone covering a region of 26 sq. km; and the external periphery containing the recently evolved territories, covering 112 sq. km. While the extent of populace if there should arise an occurrence of the
old city is 43 percent, for internal zone it is 34 percent, and for external outskirts, which has developed as the current focal point of populace development.

**TABLE 1** Projected population and households for the year 2021 and 2031

| Year       | Population (In Lacs) | Total Households (In Lacs) |
|------------|----------------------|---------------------------|
| 1991       | 15.19                | 2.84                      |
| 2001       | 28.12                | 4.98                      |
| 2011       | 44.62                | 5.85                      |
| 2013       | 53.56                | 7.97                      |
| 2021 projected | 69.48                | 11.03                     |
| 2031 projected | 94.65                | 12.56                     |

(Source: SMC, Surat)

Table 1 projects population and household estimates with an assumption that population growth rate will moderately increase with trends at the state level. It shows a high rate of growth as experienced in the past four decades. It is observed that the annual migration rate of increase of population in the city is estimated to be 3.5–4 per cent.

**TABLE 2** Zone-wise demographic data—Surat, 2011

| Zone       | Total population (in Lacs) | Total household (in) |
|------------|---------------------------|----------------------|
| East       | 11.87                     | 190,842              |
| West       | 4.45                      | 96,129               |
| North      | 7.09                      | 115,642              |
| South      | 9.37                      | 121,462              |
| Central    | 4.28                      | 85,371               |
| South-west | 3.90                      | 76,209               |
| South-east | 7.73                      | 111,441              |
| **Total**  | **5,356,000**             | **797,096**          |

(Source: Property Tax department, SMC Surat)

Table 2 and Figure 1 show all out populace of every one of the seven zones of Surat for the year 2014. East zone has more living arrangements (24 percent of absolute family units) though south-west zone has high salary bunch occupants with a smaller number of houses (10 percent of complete families). The structure structures, for example, cabins and duplexes are in south-west zone and west zone. Focal zone is the littlest one with respect to the quantity of family units.

![Figure 1](image_url)  
*Figure: 1 Total number of households zone wise (2011)*
5. SURVEY ANALYSIS

Analysis of the building type distribution pattern in east, west, north, south, south-west, and south-east zone in the form of percentage distribution of bungalows, row houses, duplexes, high-rise apartments, and low-rise apartments was made. Table 3 shows that majority of the bungalows are in the south-west zone (54 per cent), which only has very few low-rise apartments (6 per cent). This is because the population of the south-west zone prefers a large residential house, since they belong to the higher income group. Central zone clearly indicates that duplex, row house, and low-rise apartments are in equal proportion (30–40 per cent) in private societies of urban areas, as majority of the peoples prefer to live in gala type houses, ancient houses, etc. East zone, that is, Varachha area, has maximum number of row houses. West zone, that is, Adajan and south zone, Udhna, however, indicate the existence of all types of building forms. Row houses are the building form mostly preferred in Surat city in all zones and for all income groups; as more than 92 per cent are observed while analyzing data.

6. PER CAPITA CARBON EMISSION

Figure 2 shows that the majority of the bungalows is in the southwest zone (54%) and only few low-rise apartments (6%). As the population of the southwest zone (higher income group) preferred to have their own land with a large residential houses. Central zone clearly indicates that duplexes, row-houses and low-rise apartments are in equal proportion (30% - 40%). In private housing societies in urban area majority of the people preferred to live in row houses i.e. ancient form. East zone i.e. Varachha area is having 92% of row-houses where as west zone (Adajan) and south zone (Udhna) indicates all types of building forms. Row-houses are the building form mostly preferred in Surat city in all zones and for all income groups; as more than 64% are observed while analyzing data.

Analysis of per capita carbon emission pattern in seven different zones of Surat is shown in Table 3.

| Zone   | Per Capita CO₂ Emission (Kg/day) | Total CO₂ Emission (Kg/day) |
|--------|---------------------------------|-----------------------------|
|        | Electricity                     | Domestic Gas                |                                |
| Central| 6.9                             | 5.3                         | 12.2                          |
| East   | 9.1                             | 4.1                         | 13.2                          |
| West   | 8.9                             | 4.8                         | 13.7                          |
| North  | 10.6                            | 5.3                         | 15.9                          |

Figure: 2 Building form distribution zone wise (%)

TABLE 3 Zone-wise per capita CO₂ emission (kg/day)
Figure 3 represents that east zone and west zone is having equal (approximately 9 kg/day) per capita CO₂ emission for electricity. Now southwest zone is having less number of households though per capita CO₂ emission is very high compared to all other zones; (southwest zone is having least number of households but the building form in southwest zone i.e. bungalow form covers maximum floor area so the usage of electricity consumption and domestic gas consumption is higher). Southeast zone is having least per capita CO₂ emission.

Figure 4 represents that electricity consumption in all building forms is more than gas consumption. Bungalows and duplexes consume more energy than all other building forms because of large floor area and usage of more number of appliances. Higher floor area will emit higher carbon like bungalows, duplexes and some row-houses in southwest and west zone.

7. FLOOR AREA CARBON EMISSION BASED ON BUILDING FORM

Analysis of carbon emission based on floor area of different building forms is shown in table 4 and 5.

| Floor Area(m²) | Bungalow | Duplex | Rowhouse | Low-rise | High-rise |
|---------------|----------|--------|----------|----------|-----------|
| 100           | 157      | 69     | 64       | 36       | 34        |
| 120           | 126      | 74     | 49       | 34       | 36        |
| 150           | 120      | 104    | 70       | 33       | 64        |
| 200           | 115      | 124    | 71       | -        | 86        |

Figure: 3 Per capita carbon emission zone wise

Figure: 4 Per household CO₂ emission - building form wise (kg/day)
8. AVERAGE CONSUMPTION OF FAMILY SIZE

In India joint family prevails due to culture. Hence, in few areas more than 6 persons are staying together. Analysis of family size having average electricity consumption and domestic gas consumption per month is shown in table 6.

**TABLE 6 Energy consumption as per family size**

| Family Size | Average consumption (Kg/Day) | Total Consumption (Kg/Day) |
|-------------|------------------------------|---------------------------|
|             | Electricity                  | Domestic Gas              |
| 2           | 15                           | 15                        | 30                        |
| 3           | 27                           | 20                        | 47                        |
| 4           | 31                           | 22                        | 53                        |
| 5           | 37                           | 23                        | 60                        |
| 6           | 39                           | 25                        | 64                        |
| 7           | 45                           | 22                        | 67                        |
| 8           | 52                           | 27                        | 79                        |
| 9           | 46                           | 34                        | 80                        |
| 10          | 60                           | 41                        | 101                       |

The above figure 6 indicates that electricity consumption is almost 10% to 20% more than domestic gas consumption. As the family size increases both electricity and domestic gas consumption increases which results in increase of total energy consumed per month. Family size with 8, 9 or 10 members generally consumes more electricity and gas as their usage of appliances is more.
9. CARBON EMISSION & FLOOR AREA RELATIONSHIP

A few near diagrams are risen to examine floor territory with various range and CO₂ utilization (kg/day) through a straight relapse strategy. This is accomplished through a product application "ORIGIN Pro 8" (OriginLab Corporation, 2007). A proper direct fitting is given on the basis of contribution through this product. An additional component is "best fit model" and condition for the direct relapse is likewise done. This gives relationship between the compared parameters like floor area, total carbon emission and an R² value i.e. coefficient of determination (Devore Jay, 2011). Analysis of floor area of all the building forms having a range of 40m² to 200m² is compared to total carbon emission (kg/day).

| Floor area (40 – 200 m²) | Average total carbon emission (kg/day) |
|--------------------------|----------------------------------------|
| 40                       | 48                                     |
| 60                       | 44                                     |
| 80                       | 50                                     |
| 100                      | 53                                     |
| 120                      | 53                                     |
| 140                      | 74                                     |
| 160                      | 85                                     |
| 180                      | 110                                    |
| 200                      | 117                                    |

The above figure 7 indicates that maximum carbon emission (75 – 120 kg/day) is ranging from 140 m² to 200 m². This is on the grounds that houses with floor area of 140 m² to 200 m² are more in numbers as this scope of floor area is advantageous for a wide range of building structure. Floor area with 40m² to 100m² scope of houses is involved by lower center pay gathering of individuals in east, southeast and north zone.

10. MODEL DEVELOPMENT

Different regression models are developed based on floor area and energy data which are presented here. Different statistical tests are employed to check the validity of these proposed models. A comparison with overall forecasts, based on complex linear regression models, such as floor area ranges from 40 to 200 m² and floor area from 200 to 500 m² was performed. This shows that the developed regression models are fitting with the official projections and are based on building forms, developed as per floor area.

Three different models are predicted as given below;
1. FACE – I (Floor Area Carbon Emission model for 40 – 200 m²)
2. FACE – II (Floor Area Carbon Emission model for 260 – 550 m²)
3. BFCE (divided into five sub models) Building Form Carbon Emission model
   • Building Form Carbon Emission model for Bungalow (BFCE – B)
   • Building Form Carbon Emission model for Duplex (BFCE – D)
   • Building Form Carbon Emission model for Row house (BFCE – R)
   • Building Form Carbon Emission model for High rise apartment (BFCE - HA)
   • Building Form Carbon Emission model for Low rise apartment (BFCE - LA)

Article I. 10.1 FACE- I (Floor Area Carbon Emission model for 40 – 200 m²)

FACE I – Floor Area Carbon Emission model, an equation of consumption and floor area for households having 40 m² to 200 m² of area is developed. It is expressed in linear regression form linking the quantity of monthly usage of electricity consumption and domestic gas consumption compared to floor area observed in households of Surat city. The model takes the form of a co-efficient of determination which indicates how well data points fit a statistical model. Using intercept ‘a’ and slope ‘b’ from figure 7 of floor area 40 m² to 200 m².

\[ y = 13.9444 + 0.4708 \times x \]  
(Equation 1)

‘y’ is independent variable estimated and forecasted by a simple linear regression over the floor area ‘x’.

| Floor area (40-200) m² | Average (kg/day) | Predicted Value (kg/day) | Difference | (%) |
|------------------------|------------------|--------------------------|------------|-----|
| 40                     | 48               | 33                       | 15         | 31.25 |
| 60                     | 44               | 42                       | 2          | 4.54  |
| 80                     | 50               | 52                       | -2         | -4    |
| 100                    | 53               | 61                       | -8         | 15.09 |
| 120                    | 53               | 70                       | -17        | 32.07 |
| 140                    | 74               | 80                       | -6         | 8.10  |
| 160                    | 85               | 89                       | -4         | 4.70  |
| 180                    | 110              | 99                       | 11         | 10    |
| 200                    | 117              | 108                      | 9          | 7.69  |

It tends to be seen from the above table 7 that utilization esteem contrast between the one anticipated by the set up straight relapse model of private buildings absolute CO₂ discharge and the genuine one is very little. The outcomes affirm that this model gives 84% exactness, and the interest of things to come private structures carbon discharge anticipated by the model is solid.

Considering the above developed models accuracy of each regression is checks through error.

| S r. No. | Model | Description | Regression Equation | \( R^2 \) | Accuracy (%) |
|----------|-------|-------------|---------------------|---------|--------------|
| 1        | FACE – I | 40 m² to 200 m² | \( y = 13.94 + 0.47x \) | 0.84  | 84 %         |
| 2        | FACE – II | 260 m² to 550 m² | \( y = 143.19 + (-0.18)x \) | 0.80  | 80 %         |

Building Form Carbon Emission models

| Sr. No. | Model | Description | Regression Equation | \( R^2 \) | Accuracy (%) |
|---------|-------|-------------|---------------------|---------|--------------|
| 3       | BFCE – B | Bungalow | \( y = 169.45 + (-0.25)x \) | 0.89  | 89 %         |
| 4       | BFCE – D | Duplex  | \( y = 6.85 + 0.58x \) | 0.90  | 90 %         |
| 5       | BFCE – R | Row house | \( y = 34.5 + 0.19x \) | 0.84  | 84 %         |
| 6       | BFCE – LA | High-Rise Apartment | \( y = 3.78 + 0.28x \) | 0.91  | 91 %         |
Above Table 8 shows that models developed, predict carbon emissions accurately with the actual site condition. The models are in line with the actual data trends and helps to formulate residential building energy-saving measures and standards. Likewise, effectively advisers for sort out private development industry and assists with improving the structure of private structures. The model can give the rules to private structure vitality sparing projects and measures by anticipating the vitality utilization of private structures in Surat city. Likewise, the set up private structure vitality request models are just founded on direct vitality utilization for example power and local gas.

11. CONCLUSION

This study highlights the energy consumption behavior of residential buildings for Surat metropolitan. A survey of 500 households was conducted in Surat. East zone has more residences (24 per cent of total households) whereas south-west zone has high income group residents with less number of houses (10 per cent of total households). Central zone clearly indicates that duplex, row house, and low-rise apartments are in equal proportion (30–40 per cent). East zone, that is, Varachha area, has maximum number of row houses. West zone, that is, Adajan and south zone, Udhna, however, indicate the existence of all types of building forms. Majority of the bungalows are in the south-west zone (54 per cent). South east zone and west zone have equal (approx. 9 kg/day) per capita CO2 emission for electricity and domestic gas. East zone has per capita carbon emission is very high compared to all other zones; and south zone has least per capita CO2 emission. Family size with 8, 9, or 10 members generally consumes more electricity and gas, as their usage of appliances is more.

Floor area carbon emission models developed a strong approach for modelling the relationship between floor area and carbon emission. Floor area as dependent variable and one or more independent variables denoted as orientation of buildings, facades, shading, solar radiations and ventilation of a building. Accuracy range of 78% to 91% was observed which indicates a strong relationship between building form and carbon emission. As the consumption value for BFCE – high-rise apartments as a building form builds a firm relationship with carbon emission with 91% accuracy. Floor area and carbon emission model shows 80% to 84 % of accuracy range which shows strong relationship.

TABLE 9 Summary of floor area carbon emission relationship models

| S. No. | Model | Regression Equation | R² | 
|------|-------|---------------------|----| 
| 1    | FACE – 1 | y = 13.94+0.47x     | 0.84 | 
| 2    | FACE – 2 | y = 143.19+(-0.18)x | 0.80 | 
| 3    | BFCE – B | y = 169.45+(-0.25)x | 0.89 | 
| 4    | BFCE – D | y = 6.85+0.58x     | 0.90 | 
| 5    | BFCE – R | y = 34.5+0.19x     | 0.84 | 
| 6    | BFCE – HA | y = 3.78+0.28x | 0.91 | 
| 7    | BFCE – LA | y = 79.02+(-0.36)x | 0.78 |
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