Development of Residential Carbon Emission Assessment Models

Carbon Emission Models

Devansi Hemant Nagarsheth[1]
Research Scholar
Department of Civil Engineering
Surat, Gujarat, India

Dr. J. E. M Macwan[2]
Professor
Department of Civil Engineering
Surat, Gujarat, India

***Abstract*—This paper describes the models which are developed to predict carbon emissions to explore technological feasibility of achieving CO_2 emission reductions in the Indian residential sector. Recent analysis indicates that these reductions are likely to be required across number of countries in order to stabilize the atmospheric CO_2 concentration and weaken the effects of climate change. In order to investigate this problem, energy and CO_2 emission model of Indian residential sector has been developed. This paper covers both energy demand and supply to develop three realistic scenarios of energy use and CO_2 emissions; carbon emission reductions appear feasible even with a considerable increase in total number of Indian households, an increase in thermal comfort standards and a significant increase in the standards of services that occupants are likely to expect.**

Keywords—CO_2 emission model; Energy consumption model; Residential emission model, detached dwelling carbon emission model, semi-detached dwelling carbon emission model.

I. Introduction

This paper provides an understanding of the greenhouse has (GHG) emissions from both house building (the production of materials used in construction) and the direct energy emission from the residence. The emission caused due to the direct energy requirements of homes have also been a significant contributor. In India, consumption patterns are unmanageable, with growing demands on the world's resources and its impact on our environment. As one of the largest populous country with poor or no access to energy it is also famous for energy wastage. Hence, there is an urgent need to reduce the environmental footprint of the building industry at global level. Sustainable environmental planning should be done by calculating carbon dioxide emitted from the entire residential sector and then overcoming this CO2 emission by reducing energy use in houses is the answer to above question.

This paper needs to be justified through the study indicators which are responsible for carbon emission of buildings and calculation of CO2 conversion of different building forms for the use of direct energy consumption. Residential carbon emission models namely: "FACE (0-200)" model, which represents a relationship between floor area and total carbon emitted by end-use efficiency and carbon intensity for electricity generation and use of natural gas; "FACE (200-600)" model, which represents a relationship between floor area and total carbon emitted by end electricity and natural gas; and "BFCE" model, which represents a relationship between building forms of different types and total carbon emission.

II. Objectives

- To study the different forms of energy used by the household of study area.
- To examine the level of energy consumption of the study area.
- To develop the model that can be used for determination of the carbon reduction.

III. Literature Study

The energy consumption of the building and that caused by their location to transport, account for more than half of all global CO2 emissions. Over the past two decades, emissions have grown five times as fast as the global average. The population increase, rapid urbanization and the extensive building constructions will continue in coming years. Buildings account for nearly 50% of all greenhouse gases globally. However, two current developments increase the importance of the construction phase emissions and the embodied emissions of the building materials. At first, improvements in energy efficiency of buildings increases the comparative share of the construction phase emissions. Secondly, sequential allocation of emissions increases the importance of carbon emission from construction. Yao and Steemers [11] presented formulated a method for UK households space heating for different types of houses by using thermal dynamic model. Snakin [8] presented an assessing space heating energies and related greenhouse gas emissions model based on energy consumption to improve the quality and quantity of heating energy and emission data. Antti Säynäjoki, Jukka Heinonen and Seppo Junnila [2] calculates the carbon emitted by a residential construction project in Finland through a hybrid life cycle assessment of 220 homes development project were 60,000 tons of carbon is emitted in which 90% from actual buildings and 10% from infrastructure. In this paper, we analyze the implications of low-carbon residential construction on the life cycle emissions of a residential area with a case study based on housing demand in mega cities of India, development of models for forecasting energy use and CO2 emissions and its assessment scenario based on climate change.

IV. STUDY AREA PROFILE

Surat is an Indian city with a population of 2.1 million at 2001 census and 4.6 million in 2011 census (fig.1.1). It is the 8th largest city and 9th largest metropolitan area of India. Surat has experienced a rapid population increase in last two census decades (1971–81 and 1981–91). In the following decades the city again witnessed a remarkably high population growth rate of 66.01%. Seven zones of the city with its current area, population and household is given in table I.

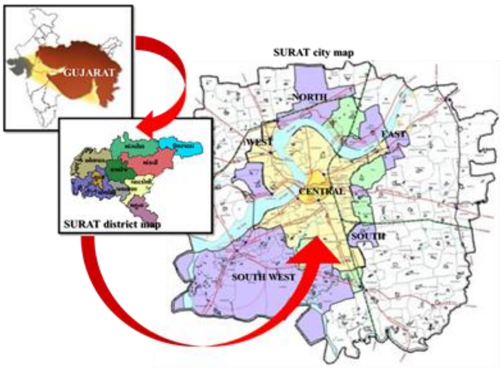


FIG 1.1 MAP OF SURAT, GUJARAT WITH SEVEN ZONES
(Source: SMC, Surat)

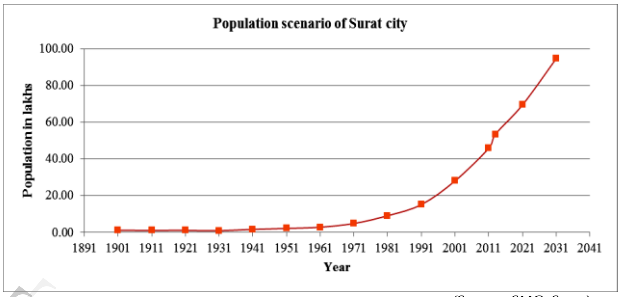
TABLE I. DEMOGRAPHIC DATA ZONE WISE - SURAT, 2011

Zone	Total Pop.(lakhs)	Total Household
East Zone	11. 87	1,90,842
West Zone	4.45	96,129
North Zone	7.09	1,15,642
South Zone	9.37	1,21,462
Central Zone	4.28	85,371
South West	3.90	76,209
South East	7.73	1,11,441
Total	**53,56,000**	**797096**

(Source: Property Tax department, SMC Surat)

Surat is one of the 11 cities in the country which attain metropolitan status in 2011 census by crossing the one million mark from last two censuses. It has experienced a rapid population increase from 2001 to 2011; with a population of 4.6 million. At the state level Surat ranks second only to the capital Ahmedabad, which has a population of 32.98 lakhs (Census of India, 1991). These two cities account for 34% of the total urban population of the state. The city experienced an increase in the density of population despite an increase in area between 1971 and 1981. However, in 1991, the density declined due to a proportionally larger increase in the area compared to the population. In 1991, the population was spread over an area of 111.16 sq. km resulting in a density of 13,483 persons / sq. km. In 2001, the density increased to 21,677 persons / sq. km. but it decreased to 8,582 persons / sq. km. in 2006. Surat city can be broadly classified into three parts; the old city covering an area of 8.18 sq. km; the inner periphery and Rander zone spread over an area of 47.37 sq. km and the outer periphery comprising of the newly developed areas covering 55.61 sq. km. Although the population and density in the inner city had increased from 1971 to 1981 a decreasing trend has been observed in these variables in 1991. This resulted in a corresponding increase in the density in the inner periphery. This trend points out the shift of population from the inner city due to extreme congestion, dilapidated buildings, over-stressed civic infrastructure and an overall deteriorating quality of life along with increasing land values [1].

Despite these processes the inner city still has the highest density among the three zones with as many as 51,929 persons per sq. km. The inner periphery and the Rander zone have emerged as the focus of population concentration during 1981 - 91 with the population and density almost doubling during the same period. While the proportion of population in case of the inner city decreased from 77 per cent in 1971 to 28% in 1991, it increased in the inner periphery from 23% to 43% during the same period. The outer periphery which has emerged as the current focus of population growth accounted for 29% of the total city population and has the lowest density with 7,911 persons per sq. km [1].



(Source: SMC, Surat)

GRAPH 1. POPULATION SCENARIO OF SURAT CITY (LAKHS) FOR THE YEAR 1891 TO 2041 (PROJECTED)

TABLE II PROJECTED POPULATION AND HOUSEHOLDS FOR THE YEAR 2021 AND 2031

Year	Population (lakhs)	Total Households (lakhs)
1991	15.19	2.84
2001	28.12	4.91
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)

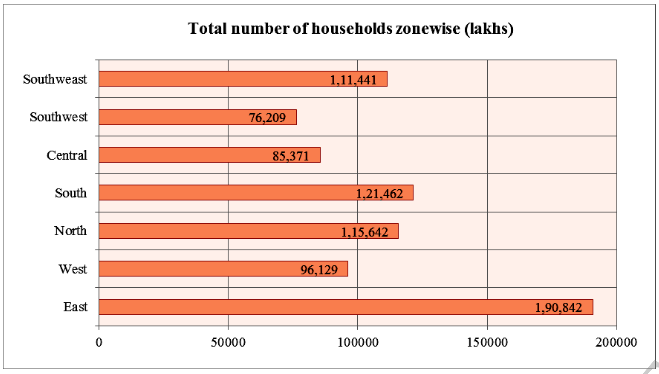
Surat area include private sector (Piplod, Ghod Dod, Athwalines, City Light Nanpura, Mahidharpura, Ring Road, Salabatpura, Sony Falia, Adajan, Rander, Katargam, Varachha, Laldarvaja, Sumuldairy, Saiyadpura, Kapodra). Private household area lies about 40 to 500 Sq Mt. In private sector some areas are completely residential and some are residential cum commercial. Housing in north zone, south zone and southeast covers 0.65 to 1.1 lakhs household in 2001 where as in 2011 this household count increases to 1.15 to 1.2 lakhs and floor area lies between 80 to 300 Sq Mt. This area is on the outskirt of Surat city and majority house are of row house with ground floor and first floor and low rise apartment of approximate four floors. Housing in central zone is mainly gala type house (row house) with only 0.74 lakhs households in 2001, due to space constrain in CBD area this count of household's only increases to 0.85 lakhs. Now southwest and west zone extends their limit as per development plan in 2011 the total households in southwest is 0.76 lakhs and in west zone 0.96 lakhs with a building form having vast floor area i.e. bungalow, duplex and high rise apartment. Both the zones have very high income, high income and upper middle income group of population.

GRAPH. 2. SHOWS TOTAL NUMBER OF HOUESHOLDS ZONE WISE (2011)

TABLE III. DEMOGRAPHIC DATA ZONE WISE - SURAT, 2011

Zone	Total Population (lakhs)	Total Household
East Zone	11. 87	1,90,842
West Zone	4.45	96,129
North Zone	7.09	1,15,642
South Zone	9.37	1,21,462
Central Zone	4.28	85,371
South West Zone	3.90	76,209
South East Zone	7.73	1,11,441
Total	53,56,000	797096

(Source: Property Tax department, SMC Surat)



The above table and figure shows total population of all seven zones of Surat city for the year 2011. East zone is having more residences (25% of total households of all seven zones) whereas southwest zone is having high income group people with less number of houses (only 76209 (9%) of total households) and the building form is bungalow and duplex, area of southwest zone (athwa) and west zone (adajan) are the largest one and central zone (muglisara) and southeast zone (limbayat) is the smallest.

Data collection

Stratified random survey of 350 households was undertaken through a structured questionnaire in seven zones of city to extract information related to household energy consumption for cooking, water heating, natural gas, etc. survey has been carried out in 400 households. Questionnaire was designed to compile data covering various parameters such as satisfaction with overall environment, residential status, building type, kind of facilities in home and energy consumption behavior of households. A carbon emission due to electricity and natural gas consumption is computed by the use of emission factors.

V. MODELS DEVELOPED

The models which are developed is made to understand residential carbon emission present in life cycle energy profile of a residential building covering the embodied, operational and all energy aspects in the Indian context with an example of the fastest growing city.

Parameters of model:

Population, GDP, technology efficiency, energy resource, energy price, sector output, to keep three models in line with same analysis framework. Because these models are different in analysis mechanisms and have different input and output parameters, it is useful to use each other's data.There are three principal approaches to forecast energy demand and supply to develop three realistic scenarios of energy use and CO2 emissions are as follows;

A. Floor Area Carbon Emission Model

1) Model I ***FACE (0-200)***

Floor Area Carbon Emission model 0 – 200 sq m

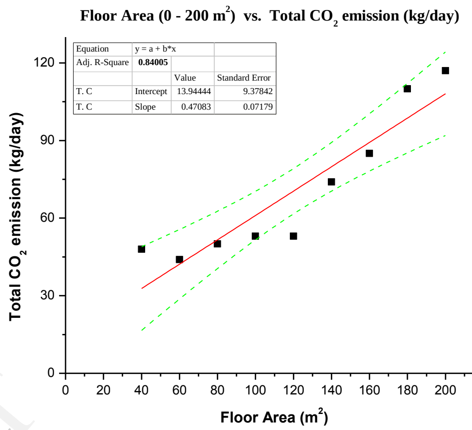


FIG 1.2 FLOOR AREA (RANGE 0 TO 200 SQ M.) VS TOTAL CARBON EMISSION (KG/DAY)

Y =13.9444 + 0.4708*X …… (EQ. 1)

2) Model II ***FACE (200-600)***

Floor Area Carbon Emission model 200 – 600 sq m

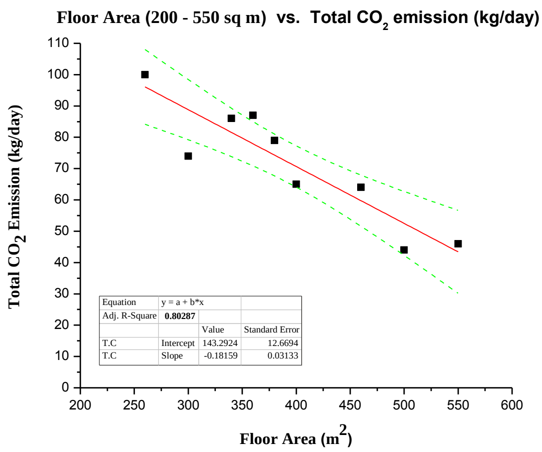


FIG 1.3 FLOOR AREA (RANGE 0 TO 200 SQ M.) VS TOTAL CARBON EMISSION (KG/DAY)

Y =13.9444 + 0.4708*X …… (EQ. 1)

Several comparative graphs are made to analyze floor area with different range and CO2 consumption (kg/day) through a linear regression method; which is achieved through a *software application "Origin Pro 8". A suitable linear fitting is provided on the basis of input through this software. An added feature is "best fit model" and equation for the linear regression is also done. This gives relationship between the compared parameters like floor area of all different building forms, total carbon emission as per building form. And an R2 value i.e. coefficient of determination which indicates how well data points fit a statistical model. Thus, R2 = 1 indicates that the fitted model explains all variability in y, while R2 = 0 indicates no 'linear' relationship, R2 = 0.7 means 70% of the variation in the response variable can be explained by the explanatory variables and remaining 30% can be attributed to unknown.*

Figure 1.2 indicates maximum carbon emission with floor area of 140 sq m to 200 sq m is convenient for all types of building form whereas floor area with 40 sq m to 100 sq m range of houses is occupied by lower middle income group of people in east, southeast and north zone. Figure 1.3 indicates maximum carbon emission in the area ranging from 260 sq m to 380 sq m is more; as they are large high rise apartments, bungalow and duplexes in west zone, southwest zone and central zone respectively.

B. BFCE III (divided into five sub models) - Building Form Carbon Emission model

Building form of five different types is considered as per the case of Surat city in Indian context. Bungalow i.e. detached building with walls and roofs independent of any other building and with open spaces on all four sides. Duplex and row house means semi-detached building having one or more side attached with wall and roof with other building. Apartments are of two types high rise apartments having more than 5 floors upto 10 or more and low-rise apartments having maximum 5 floors and minimum 3 floors. (Source GDCR Surat Municipal Corporation)

1) BFCE – B(bungalow)

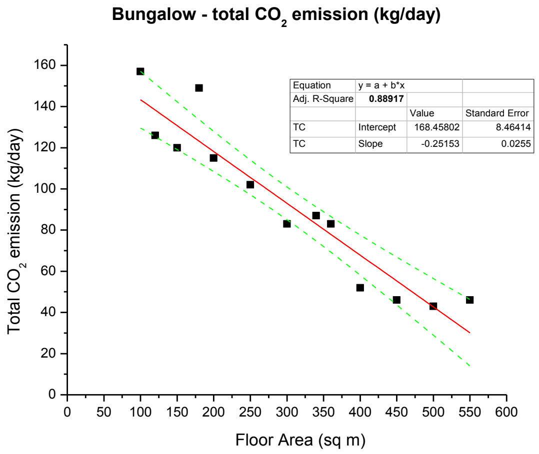


FIG 1.4 BUNGALOW – TOTAL CARBON EMISSION (KG/DAY)

Y =169.4580+ (-0.2515)*X …… (EQ. 3)

2) BFCE – D (duplex)

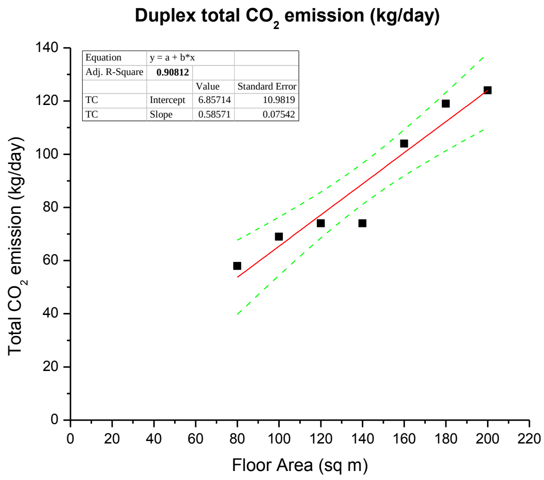


FIG 1.5 DUPLEX – TOTAL CARBON EMISSION (KG/DAY)

Y =6.8571+ 0.5857*X …… (EQ. 4)

3) BFCE – R (rowhouse)

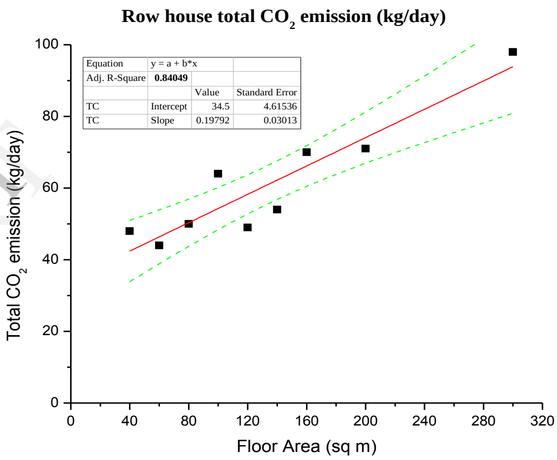


FIG 1.6 ROW HOUSE – TOTAL CARBON EMISSION (KG/DAY)

Y =34.5+ 0.1979*X …… (EQ. 5)

4) BFCE – HA (highrise apartment)

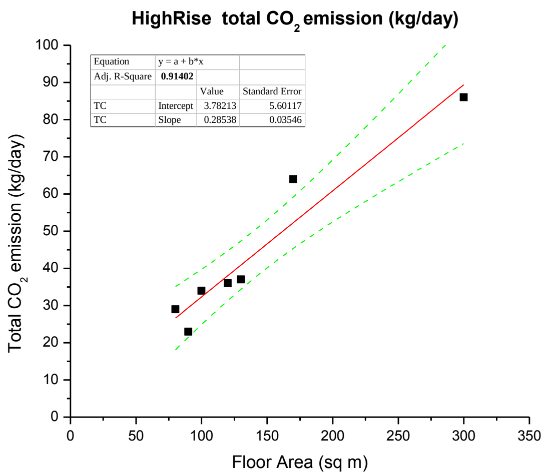


FIG 1.7 HIGH-RISE – TOTAL CARBON EMISSION (KG/DAY)

Y =3.7821+ 0.2853*X …… (EQ. 6)

5) BFCE – LA (lowrise apartment)

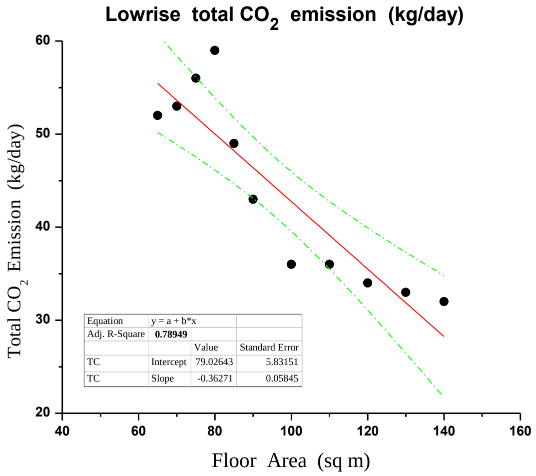


FIG 1.8 LOW-RISE – TOTAL CARBON EMISSION (KG/DAY)

Y =79.0264 + (-0.3627)*X …… (EQ. 7)

As we can see from the above graphs, the consumption value difference between the one predicted by the established linear regression model of residential building total carbon emission and the actual one is quite small, with an error of less than 1%. The results confirm that this model provides accurate results, and demand for future residential buildings carbon emission predicted by the model is consistent.

VI. VALIDATION OF MODELS

To validate the developed model, the study performed 400 households. Results showed that the error of the prediction were 84, 80, 88, 90, 84, 91 and 78% respectively, in each of the cases, and CO2 emissions of energy usage in residential buildings could be estimated prior to design completion. It is expected that model developed will be a useful tool in the decision-making process on design alternatives that consider CO2 emission reduction in residential development.

TABLE IV. SHOWS COMPARISON OF MODELS BASED ON LINEAR REGRESSION RELATIONSHIP BETWEEN FLOOR AREA, BUILDING FORM AND TOTAL CARBON EMISSION.

Model Name	Model Formulae	R2	Parameters
FACE (1-200)	y =13.9444 + 0.4708*x	0.84	Floor area from 1 to 200 sq. m.
FACE (200-600)	y =143.1924 + (-0.1815)*x	0.80	Floor area from 200 to 600 sq. m.
BFCE - Bungalow	y =169.4580+ (-0.2515)*x	0.88	Detached building form
BFCE - Duplex	y =6.8571+ 0.5857*x	0.90	Semidetached building form
BFCE – Row house	y =34.5+ 0.1979*x	0.84	Row of semidetached dwellings
BFCE - High rise	y =3.7821+ 0.2853*x	0.91	More than four floors
BFCE – Low rise	y =79.0264 + (-0.3627)*x	0.78	Upto four floors

VII. CONCLUSION

The predicted results from above models show that increase in carbon emission model is accurate and reliable. The model is in line with the actual data trends and helps formulate residential building energy-saving measures and standards and correctly guide and organize residential construction industry and helps to optimize the structure of residential buildings. The model can provide the guidelines for residential building energy-saving programs and measures by predicting the energy consumption of residential buildings in Surat city. In addition, the established residential building energy demand model is only based on direct energy consumption i.e. electricity and domestic gas.

REFERENCES

[1] Anna Pagès, Massimo Palme, Helena Coch, Toni Isalgué (2006); "Energy consumption and CO2 emissions in the construction and use of flats according to floor area", Mechanical and Industrial Engineering Department of the University of Rome.

[2] Antti Säynäjoki, Jukka Heinonen and Seppo Junnila (2011); "Carbon Footprint Assessment of a Residential Development Project", International Journal of Environmental Science and Development, Vol. 2, No. 2.

[3] Archana Ghosh (1998); "Management of Urban Environment: A Study on Post-Plague Initiatives of Surat Municipal Corporation", Institute of Social Sciences, New Delhi.

[4] Jacob N. Hacker, Tom P. De Saulles, Andrew J. Minson &Michael J. Holmes (2008); "Embodied and operational carbon dioxide emissions from housing: A case study on the effects of thermal mass and climate change", Energy and Buildings, Elsevier.

[5] John Eakins (2013); "An Analysis of the Determinants of Household Energy Expenditures: Empirical Evidence from the Irish Household Budget Survey", Survey Energy Economics Centre (SEEC), School of Economics, University of Surrey Guildford, Surrey GU2 7XH, UK.

[6] Lei, Y.R. (2008); 'The Study on Chongqing Residential Building Energy Consumption Forecast Method"; Master Thesis, Chongqing University, Chongqing, China; pp. 18–26.

[7] O'Neal, D.L., & Hirst E. (1980); "An energy use model of the residential sector"; IEEE Trans. Syst. Man Cybern, 10, 749–755.

[8] Snakin JPA, 2000. An engineering model for heating energy and emission assessment: The case of North Karelia, Finland. Applied Energy67, pp: 353-381.

[9] Vishnu Bajpai, Gouri Kulkarni, Sun Sheng Han & Ramachandra T. V (2012); "Carbon Emissions due to Electricity Consumption in the Residential sector", National Conference on Conservation and Management of Wetland Ecosystems, Kottayam, Kerala.

[10] Wei Yu, Baizhan Li, Yarong Lei & Meng Liu (2011); "Analysis of a Residential Building Energy Consumption Demand Model"; Energies, vol. 4, 475-487.

[11] Yao R, Steemers K., 2005. A method of formulating energy load profile for domestic buildings in the UK. Energy and Buildings 37, pp: 663–671.