Title of the Thesis

A RESPONSIBLE APPROACH BY THE BUILDING ON-SITE AIMS TO ACHIEVE A CO2 EMISSION-CONSUMPTION BALANCE DURING ITS OPERATIONAL PHASE

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ABSTRACT

Our environment is getting battered continuously by daily addition of phenomenal amount of carbon dioxide (CO2) amongst other Green House Gases. The increasing concentration of CO2 in the atmosphere is accelerating climate change and global warming. With rapid increase of urban areas worldwide, the problem of CO2 emissions and resultant climate change are becoming increasingly acute. The urban building sector is found,by all research works, to be one of the biggest consumers of energy and emitter of Carbon Dioxide (CO2). With sincere concern for climate change, this research work treads on a path to study the urban residential building CO2 emission problem and examines scope of sequestration by plantation as a mitigate tool.

Chapter1 - The need for identification of the sources of emission, its quantification and its correlation with building parameters become of primary importance to formulate any mitigation plan to reduce CO2 emission from buildings. Considering the whole life-cycle of the building, the 'operation phase' constitutes most of the emission. With a goal to investigate the quantitative and qualitative parameters of Household Carbon Footprint, this paper sets research boundaries as study of CO2 emission from the operation phase of a multi-storied and multi-tenement residential building in the urban area of Newtown, beside the city of Kolkata, in India. The research work is divided into two (2) stages. The first stage deals with CO2 emissionsfrom the urban multi-storied and multi-tenement residential buildings and aims are set as - 1) identification of causes or sources of emission in a residential building, 2) finding a logical and scientific strategy and method for quantification of CO2 emitted and 3) finding correlation between the operational stage CO2 emission and building parameters like plot area, built-up area and number of residents. Existing literature shows that the best way of mitigation of CO2 emitted by the building, is to sequester it through plants grown inside the premises. Thesecond stage of this work intends to study the scope of sequestration of CO2 by plantation grown within the plot of a multi-storied and multi-tenement residential buildings.The hypothesis is set as – 'CO2 emitted by the building can be sequestered by growing plants inside the same plot of the building'. The study further delves into the scope

of sequestrationby plantation as per present municipal rules of Newtown, scope of further addition of plantation in the premises and the sequestration of the enhanced plantation.

Chapter 2- To get a detailed view of CO2 emission and sequestration, associated information and data, this research work found it imperative to study existing literature. 'Chapter 2' of this research work presents all information, data and knowledge received from existing literature study – both primary and secondary. Study of existing literature shows that there are gaps in research methods and end results, due to wide variations in process and approach adopted for quantification of operational stage building CO2 emission, selection of sources of emission, and choice of different coefficients of CO2 emission and related factors by different agencies and research papers. These differences crop up due to difference in process of production of energy like electricity and fuel in different countries, difference in application of energy by end users and time-frame of application of such coefficients. This paper searches for coefficients, factors and standards which are more local, recent and apt and tries to find exact application of such energy by end-users.The sources of CO2 emission from residential building operational stage are studied at length and identified as - 1) Electricity consumption, 2) fuel consumption for cooking, 3) fuel consumption for vehicles, 4) respiration, 5) potable water consumption. This deduction is done totally based on existing literature study. A more detailed literature study resulted in the decision to take 1) national average annual CO2 emission factor of electricity generation and transmission, considering all forms of electricity production including renewal energy, 2) only LPG as the cooking fuel and 3) only petrol as a form of fuel for vehicles owned by residents.All information regarding emission factors related to electricity production and transmission, LPG consumption for cooking, petrol consumption by vehicles during idling time inside the premises, CO2 emission due to respiration and potable water production are identified. Consumption rates of petrol by 2-wheelers and 4-wheelers during idling time, average consumption of potable water by residents is found out from secondary literature. Similarly, CO2 sequestration rates of plants that can be grown outdoor and indoor, i.e. in open spaces at ground of the building premises, terraces or inside flats and that of green vertical gardens are also established.

Chapter 3- With an intention to secure a scientific and practical way for CO2 emission quantification, 'Chapter 3' of this research work logically examines methods of

quantification, energy consumption factors of residential units and CO2 emission factors adopted by pervious research works. The quantification units of energy consumption and emission are identified. All calculations are based on annual energy consumptions and emission and the final unit is kept as TonneCO2/annum. To have a better understanding of CO2 emission problem, the research paper divides residential buildings into three (3) categories -1) single tenement individual residential buildings, 2) individual flats in multi-storied multi-tenement buildings and 3) whole multi-storied multi-tenement buildings including common areas. To have an in-depth knowledge of pattern of emission, his research work felt the necessity of including, in the study, individual single tenement houses, which are the basic units of residential buildings. All methods of quantification of individual energy consumptions and emissions, considering all activities, previously mentioned as sources of emission from the buildings in operational stage, are logically derived and put into mathematical equations. The method of quantification of total annual CO2 emission is stated as summation of all individual emissions.

Chapter 4- It isconcluded, during the process of research, that not all information could be gathered from literature survey. quantification of consumption quantity of electricity, fuel for cooking, fuel for vehicles and CO2 emitted by respiration, need sample surveys. The fields in which information is sought from sample surveys are established. Sample survey was undertaken, information gathered and analysed and ‘chapter 4’ describes theresults of this survey. It was decided to undertake sample surveys in buildings in Newtown, our chosen site, and also in main city of Kolkata and its satellite city of Bidhannagar, to get broader view of the subject. Regarding ‘category 3’ of building types to be studied, only one (1) whole building (G+4), in Newtown, could be studied. Required information could be gathered from seven (7) out of eight (8) flats. due to non-availability of the residents in one flat. Sample study focussed on information regarding electricity consumption through annual or quarterly meter readings (as shown in electricity bills), fuel (LPG) for cooking through number of LPG cylinders consumed annually, fuel (petrol) consumption be vehicles through number of 2-wheelers and 4-wheelers owned by residents and parked inside the premises or in public spaces adjacent to the premises, and number of residents for CO2 emission through respiration.

The second part of the chapter deals with the numerical calculations of consumption of energy and CO2 emission. Consumption quantities are all calculated and emissions quantified, considering all categories of buildings and for all individual activities. The total annual CO2 emissions from each individual building, each flat in different multi-storied multi-tenement buildings and one whole muti-tenement building, including common spaces, are also quantified. The results are analysed for percentage contribution of individual activities in each category of buildings. It is found that amongst all sources of CO2 emission from urban residential buildings, considering both individual single tenement and multi-storied multi-tenement buildings, consumption of electricity is the cause of maximum emission in operation stage, followed by respiration by residents, LPG consumption for cooking, potable water consumption and lastly petrol consumption by vehicles during idling time inside the premises.

Chapter 5 - This chapter of the thesis calls for study of correlation, if any, between theCO2 emission and building parameters like plot area, building built-up or covered area and number of residents. Knowledge of correlation between parameters of the building and CO^2 emission, if any, can contribute generously to formulation of effective planning standards for building and urban agglomerate designs and associated rules and regulations. However, the results suggest that there is hardly any correlation between amount of CO2 emitted from a building and building parameters like plot area, covered area or number of residents.From the quantitative analysis of household emission, it is evident that, for single tenement buildings (category 1), CO2 emission has no correlation with plot areas or built-up areas or number of residents.The same stands true for individual flats in multi-storied multi-tenement houses or the whole building including its common areas. Two (2) sets of flats with same areas – four (4) flats each having 100 sqm. area and seven (7) flats each having 74.32 sqm. area is studied.Results showed that flats having same area were having varied CO^2 emission patterns. Considering '*emission w.r.t.plot areas'*, the mean annual CO^2 emission comes to 0.033 TonneCO^2/sqm. of plot area for a single tenement building (category 1). The same value for a multi-storied whole building in Newtown is 0.077 TonneCO^2/sqm. of plot area (category 3). Considering '*emission w.r.t. built-up areas'*, the mean value of annual CO2 emission comes 0.030 TonneCO^2/ sqm. of built-up area for a single tenement individual building (category 1), 0.038 TonneCO^2/annum/sqm. of built-up area for individual flats in multi-storied buildings (category 2) and 0.028 TonneCO^2/annum/sqm for a whole building (category 3).The mean CO^2 emission per resident comes to 1.811 TonneCO^2/ annum/person

in single tenement buildings (category 1) and almost less than half (0.834 ToneeCO^2/ annum/person) in a multistoried tenement building (category 3).The research findings says that, without any correlation between building parameters and CO^2 emission from an urban residential building during the operation stage, it is difficult to evolve a predictive model for mitigation planning of urban residential areas.

Chapter 6- Initiatives generally followed for climate change mitigation, considering residential buildings in operational stage, are restricting energy use and reducing energy-intensive materials and activities. However, sequestration by plantation inside the premises, can be a very effective tool of mitigation planning. The present rule of NKDA, the municipal authority looking after development in Newtown, states that a minimum area of 4% should be kept open to sky and not paved. That is the only rule with respect to environmental issues and climate change mitigation planning by NKDA. 'Chapter 6'of this research workintends to go beyond this municipal rule and tries to examine the possibility of an enhanced scope of plantation that can be grown inside the premises of urban multi-storied and multi-tenement residential buildings and sequestration scope of the same. Twenty (20) number of whole multi-storied and multi-tenement residential buildings in Newtown, of which, the whole building already studied for CO2 emission in previous chapters is one (referred to as Sampe 03), are chosen for sample study of plantation scope and sequestration scope. The study is segmented into two parts – 1) Scenario 1 and Scenario 2.

In 'Scenario 1', the set of twenty (20) buildings are examined for plantation scope and sequestration by the same,in 'Green Open Spaces' considering two (2) conditions – 1) green open space in only 4% area of the plot (as per the municipal rules) and 2) green open space as proposed in sanction plans. Considering condition 1, the summation of plot areas of all 20 plots come to 6229.47 sqm., the green open space area comes to 249.18 sqm. and the total CO2 sequestration volume comes to 13.15 TonneCo2/annum. Considering condition 2, the proposed green open space area comes to 292.21 sqm. and the total CO2 sequestration volume comes to 15.42 TonneCo2/annum. That there is an insignificant difference between the minimum 4% value of green open space of plot area and the green open space area provided in the sanction plans (0.69% of the total area), demonstrating there is hardly any awareness to promote green plantation area amongst residents and architects. The findings speak of lack of 'climate-change' concerns and definitely call for more efforts to increase awareness amongst residents, owners and also architects and planners who are very much responsible for educating their clients.

For Scenario 2, all 20 samples arestudied for scope of optimal level of plantation that is feasible and practical. Areas were analysed for specific uses, plotted on sanctioned site plans/ ground floor plans. Areas with scope of further plantation were demarcated, taking into consideration all sunlight and maintenance issues. The detailed examination of use of land areas of different plots show that there is much scope of increasing the 'green open space' from the stipulated 4%. The increased green space, though not significant for plots having areas ≤ 200 sqm., can go upto 9.65% of plot area (mean value) in case of plots having area > 200 sqm. and ≤ 300sqm., up to 12.565% of plot area (mean value) in case of plots having area >300 sqm. ≤ 400sqm. and 11.86% of plot area (mean value) in case of plots having areas > 400 sqm. and < 500 sqm.Considering all 20 plots together, this increase in green open space, from 292.21 sqm. as per sanction plan to 703.03 sqm. as per enhanced scope, CO2 sequestration which is 15.42 TonneCO2/annum by plantation in green open space as per sanction plan, can be increased to 37.10 TonneCO2/annum which is about 240% increase in CO2 sequestration. Similarly, CO2 sequestration by enhanced plantation of all categories, namely potted plants in paved areas in the site which are not being utilized for any other purpose, terrace gardens, green vertical gardens and indoor plants, is calculated. The total CO2 sequestration comes to 118.98 TonneCO2/annum and total annual CO2 sequestration per unit built-up area comes to 0.007 TonneCO2/annum/sqm. of built-up area. The study shows that there is lot of scope of enhanced plantation beyond the mandatory 4% green open space rule of the municipality. Vertical gardens, terrace gardens, green open spaces and potted plants in ground floor paved areas together can play a vital role in CO2 mitigation process.

Chapter – 7 This chapter of the thesis compares the amount of operational phase CO2 emitted by the building and the amount of CO2 that can be sequestered by the plantation within the premises. The mean value of annual CO2 emission/sqm. of built-up area in a whole building in Newtown (sample 03) is already quantified (0.028 TonneCO^2/ annum/sqm.) in chapter 4. The total built-up areas of each of the rest 19 buildings in Newtown area found out from sanction plans. The mean value of annual CO2 emission per unit built-up area (from sample 03) is applied to project the CO2 emission values of other samples (19 nos.).

Considering all 20 samples together, the comparative analysis shows that CO2 sequestration(15.42 TonneCO2/annum) by plantation as per sanction plans (Scenario 1) comes to only 3.44% of the total emission (448.01 TonneCO2/annum). The sequestration volume by enhanced plantation (Scenario 2) is 121.38 TonneCO2/annum. The effective CO2

emission reduction through sequestration by enhanced plantation grown within the premises of the buildings is about 27.09% of the total CO_2 emission. As per these findings, the maximum CO_2 sequestration is achieved by terrace garden (35.47%), followed by open green spaces (31.04%), green vertical gardens (22.78%), potted plants in paved areas (8.74%) and lastly indoor plants (1.97%). Though the hypothesis of this research work stands 'negative', the results are encouraging with respect to climate change mitigation initiatives and worth further studies. This CO_2 sequestration by home grown plantation within the premises, though quite less compared to the amount of CO_2 emitted by the building, will surely, add a very important value to the mitigation of CO_2 in the housing sector. Findings of this paper also calls for a better look at existing municipal rules related to green open space.

Chapter – 8 With respect to emissions and climate change scenario at present in the world, the future is generally depicted as a matter of concern and calls for serious response from everyone in this society. Chapter 8 emphasizes research gaps and that more studies are required in all fields associated with operational stage CO_2 emission from residential buildings – Methods of quantification, identification of sources of emission, factors of emission, correlation with building parameters, etc. Though a lot of research work is done on pre-operational stage of buildings, research on identification of sources of emission, emission factors and it's quantification process, particularly from the operation phase, which isthe largest emitter of CO_2 amongst all life cycle phases of the residential building, are few. Today's research work, especially in India, depends heavily on international factors and standards. Future research works related to information and data on emission sources and their emission coefficients, considering local level influencing factors, are needed.

This research work tries to find correlation between operational stage CO_2 emission from residential buildings and building parameters. There seems to be no concrete correlation. However, this can be due to limited sample size off this research work and lack of proper information in some fields associated with this research. This anomaly can be rectified with a more elaborate sample study and more in-depth research works. A data base associated with correlation between emission and building parameters like plot area, built-up area, number of residents, etc. can definitely help in setting planning standards related to urban development with an eye to climate change mitigation.

More research works are required for investigating the sequestration potential of home-grown plants in urban areas. There is little information on CO2 sequestration by home-grown local plants, especially in Indian context. Future researchers must look into this aspect of sequestration by local plants so as to make a research work more logical and exact.

The study of sample plots also shows that there is definitely fair scope of increasing green open space than what is specified by municipal rules. This calls for an elaborate study of existing rules of municipalities. For a better future in terms of climate change, awareness amongst residents, planners and architects needs to be encouraged with increased focus on benefits of home-grown plantation. This chapter also discussesother methods like designs based on climatology and sustainability, use of renewable energy, electric vehicles, solar water heaters, water harvesting, etc. for reduction of energy use.

Chapter 9 - This last chapter of the thesis, chapter 9, specifies briefly all the findings of the research work. The sources of CO2 emission from an urban multi-storied multi-tenement residential building in operation stage are described.The pattern of emission and average percentage of CO2 emission from individual sources or activities from various categories of residential buildings are discussed. The findings regarding operational stage CO2 emission and correlation with building parameters are also put forward, specifying mean values of annual CO2 emission per unit plot areas, per unit built-up areas and per number of residents. This chapter also speaks about the limitations of sequestration scope by plantation as per municipal rules or as proposed in the sanction plans of the buildings. The scope of increasing green open spaces beyond rules suggested by municipality are put forward with justified data. The scope of increasing plantation at various places and areas in the building premises are discussed. The benefits of CO2 sequestration by this enhanced plantation are also reviewed. This research work ends by suggesting that, other than increasing plantation in residential building premises, we should also increase awareness amongst residents, planners and architects, maximise use of renewable energy (RE) like solar energy, bring in new technology in electricity generation and distribution, potable water production and distribution and design and construct energy efficient buildings with more emphasis on reduction of heat gain, so as to achieve

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