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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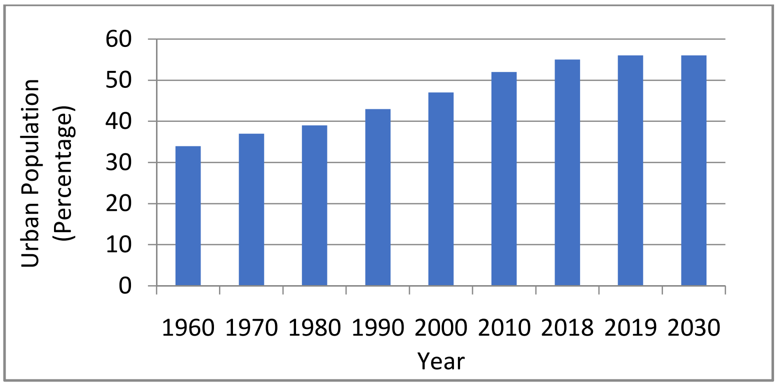
1.1 Background

1.1.1 Urbanization

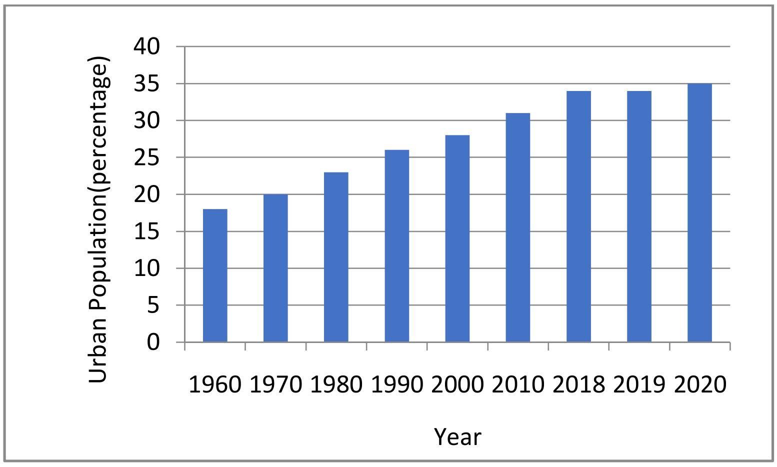
Over the last few decades, the world has seen a phenomenal increase in urbanization. The increasing attraction of commerce, the pressure of finding employment and the call for better facilities, infrastructure and high living standards have resulted in people moving in droves towards urban agglomerates. The UN World Urbanization Prospects 2018, says that in 1950 about 29% of the world population resided in urban areas, which increased to 56.2 % in 2020 (*Figure* 1) and is expected to be 68.4% in 2050, from 0.75 billion in 1950 to 4.37 billion in 2020 to projected 6.67 billion in 2050 (Nations, 2018). Urbanization in India has also seen the same trend as in the world. India, which is one of the fastest growing economies today, is also facing the urbanization process and this process is happening at a very fast rate. Urbanization, primarily propelled by the economic growth due to focus on economic liberalization, reforms in financial sector and the process of decentralization since the 1990s, have started playing an extremely important role in the economic development of the nation (TSadashivam, 2016). Percentage-wise, in 1950, 17.09% of the total population in India were living in urban areas, which increased to 34.9% in 2020 (Figure 2) and is projected to be 52.8 % in 2050 (Nations, 2018).

Figure 1 Urban Population (% of total population)- World



Source - World Bank Data 2019, Climate Transparency Report

Figure 2 Urban Population (5 of total population) - India



Source - World Bank Data 2019, Climate Transparency Report

Table 1. Decadal Urban Population Growth in India (Census of India)

Year	Total (in crores)	No. of Towns/UAs	Urban Population (in crores)	Share of Urban Population to Total Population (%)	Decadal Growth of Urban Population
1951	36.11	2,843	6.24	17.3	41.4
1961	43.92	2365	7.89	18.0	26.4
1971	54.81	2590	10.91	19.9	38.2
1981	68.33	3378	15.95	23.3	46.1
1991	84.63	3768	21.76	25.7	36.4
2001	102.86	5161	28.61	27.8	31.3
2011	121.02	7935	37.71	31.16	31.8

Source – Census of India, (T Sadashivam, 2016)

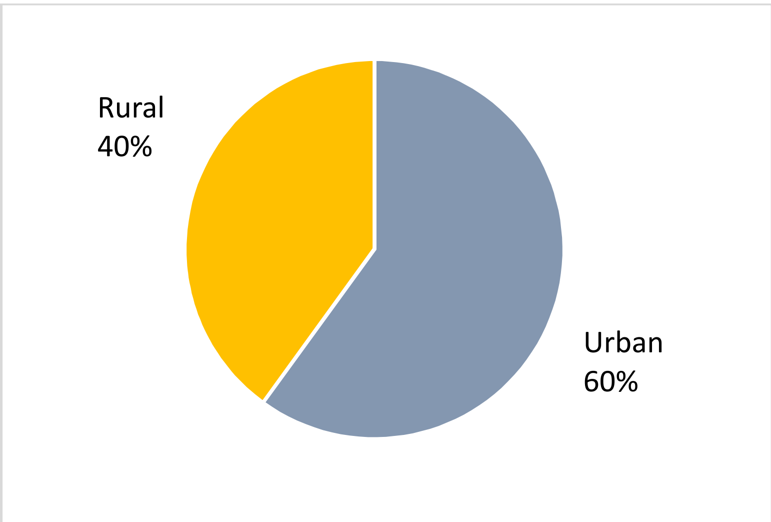
Urban Indian population has increased from 6.24 crores 1951 to 37.71 crores in 2011, number of towns/urban agglomerates increasing from 2843 to 7935 during the same period (*Table 1*). In 1951, cities with population more than one million were only five in number, which became 53 in 2011 and it is expected to become 70 cities in 2030 (T Sadashivam, 2016).Population count in India also shows that in 2011 there were only three cities with more than 10 million population, which is expected to become six cities by 2031 (T Sadashivam, 2016). Urban population in India in 1951 was 6.24 crores, which became to 37.71 crores in 2011.

Kolkata, the location for this research work, has always been one of the most populated cities of the world and that too extremely densely. The population of Kolkata urban agglomeration is projected to grow from 7329000 in 1970 to 17584000 in 2030 and it will remain amongst the most densely populated urban agglomerates of the world in near future. (Nations, 2018)

1.1.2 Effects of Urbanization

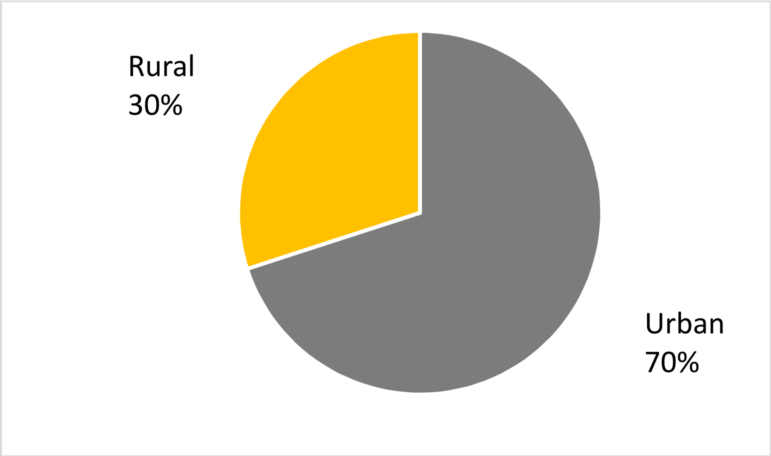
Though cities, towns and other urban areas have always been centers of knowledge and growth and helped in the evolution of civilization, the urbanization process came accompanied by number of ill-effects. One such problem which is getting out of control and putting our ecosystem at considerable risk is 'emission' of Green House Gases (GHGs). With increase in population and rapid urbanization, cities and urban agglomerates are experiencing huge increase in number of residential buildings, increase in construction of roadways, paved areas, increasing use of electrical gadgets, use of automobile, etc. Global energy demand is expected to increase at a mind-boggling rate due to increase in population, unchecked urbanization, increase in constructed buildings, increasing electrification, increasing household incomes, technology development and increase in electrical gadgets (Group), 2016). Since 2010, total global building constructed area has seen a magnum growth of over 31% and in 2024 this figure is reaching about 250 billion square meters globally, out of which residential sector constitutes approximately 80% (United Nations Environmental Programme, 2024). International Energy Agency (IEA) says 60% of the world's energy is consumed by urbanized areas (Figure 3) and more than 70% of the world's carbon emissions are caused by them (Figure 4) (Fei Zheng, 2023).

Figure 3 World energy consumption distribution



Source - Fei Zheng, 2023

Figure 4 World carbon emission distribution



Source - Fei Zheng, 2023

As per Indian Census report 2011 (CENSUS, 2011), there were 33.08 crore houses in India, out of which 11.01 crore houses were in urban areas. Of these 7.61 crore houses were purely urban residential buildings and 0.23 million houses were residential-cum-other uses buildings (Table 02). The census says there is an increase of 54% urban house from 2001 to 2011, compared to 24% increase in rural areas over the same period(CENSUS, 2011)

Table 2 - Trend in Urban & Rural Houses in India – Census 2011 (all figures in crores)

	Total	Rural	Urban
Total	33.1	22.1	11.01
Occupied	30.6	20.7	9.9
Residential	23.61	16.0	7.61
Residential-cum-other uses	0.83	0.6	0.23
Non- residential	6.2	4.1	2.1
Vacant	2.5	1.4	1.1
Number of Households	24.7	16.8	7.9

Source – Census India 2011 (CENSUS, 2011)

Table 3 Census - Urban Population, Households & Residential Houses

	Urban Population	No. of Urban Houses	No. of Urban Residential Houses	No. of Urban Residential – cum- other use houses
	(Million)	(Million)	(Million)	(Million)
India	377.11	110.14	76.13	2.3
West Bengal	29.09	8.39	6.138	0.196
Kolkata	4.50	0.96	0.94	0.022

Source – Census India 2011 (CENSUS, 2011)

West Bengal, the eastern state of India bordering Bangladesh, along with its most important the city of Kolkata, are also seeing rapid urbanization, with housing sector making the chunk of the newly constructed buildings (Table 03).

1.2 **Research Field**

1.2.1 Green House Gases (GHGs) and Climate change –

The major concern of today's world is that of Green House Gases or GHGs. Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that can absorb and emit radiations of specific wavelength emitted by the earth's surface. The Earth's surface, which is warmed by solar radiation, reflects the radiation as long-wave heat radiation. However, this radiation is partially absorbed by the atmospheric greenhouse gases and a part of that radiation is reflected back to the earth. The earth's surface and lower atmospheric layers are heated in the process. This process, referred to as the Greenhouse Effect, is adding to the earth's increasing temperature and has consequently become a thing of major concern. Carbon Dioxide (CO_2), methane (CH_4), Nitrous Dioxide (N_2O), Hydro Fluorocarbons (HFCs), per Fluorocarbons (PFCs) and Sulfur Hexafluoride (SF_6) are the major Green Houses Gases, where CO2 is the most important anthropogenic GHG – it's annual emission have grown from 21 gigatonnes (Gt) to 38 gigatonne (Gt) over a period of 1970 to 2004, itself accounting for approximately 77% of the global total CO2 equivalent GHG emission (T V Ramachandra, 2015)(Change, 2008). In order to compare the respective impact of different GHG gases on climate and their warming potential, methane and nitrous oxide are measured in CO_2 equivalents (CO2e). For this purpose, emissions are multiplied by the respective climate impact factor. The basis of all computation of GHG warming potential of CO2 is taken as one. IPCC Climate Change 2007, Synthesis Report states that the rate of growth of CO2-eq emissions during the period of 1970-1994 was 0.43 GTCO2-eq per year, which increased at a much higher rate of 0.92 GTCO2-eq per year during the recent period of 1995-2204 (Change, 2008). As per IPCC Special Report on Emissions Scenarios (SRES, 2000), the world will see an increase of global GHG emissions by 25 to 90% (CO2-eq) between 2000 and 2030 (Change, 2008).

Figure 5 Fossil Fuel Emission of the World (million Tonne)

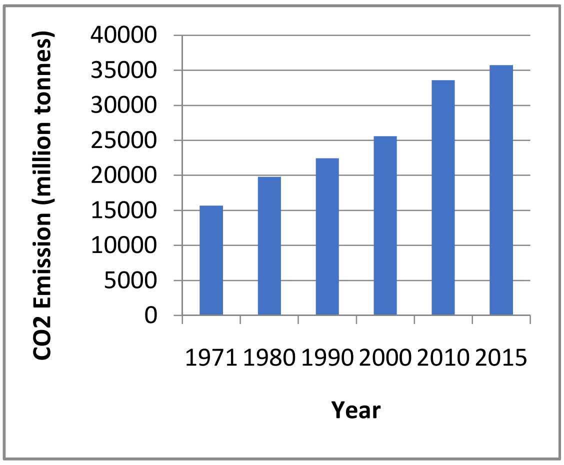
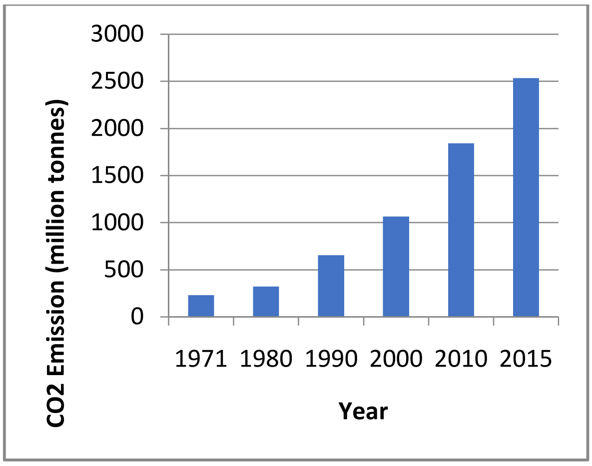


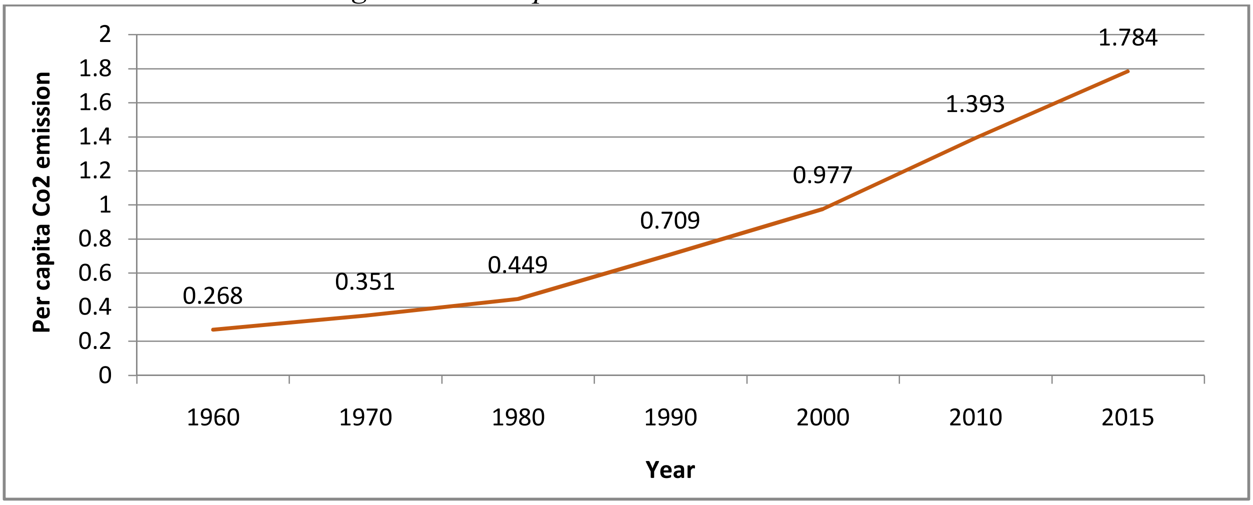
Figure 6 Fossil Fuel Emission of India (million Tonnes)



Source – Emission Database Global Atmosphere Research (RDGAR), CO2 Emission From Fuel Combustion (IEA)

Total fossil fuel emission of the world has increased from 15679 to 35753 million tonnes during the period of 1971 to 2015, i.e. an increase of 128% approximately (Figure 5). The same for India has grown from 232.19 to 2533.64 million tonnes during the same period, i.e. an increase of about 991% (Figure 6).

Figure 7 Per Capita CO2 Emission in India



Source 1 - World Bank Data 2016

It is a matter of grave concern that Carbon Dioxide emission in India has seen some rapid increase over the years (Figure 7). The graphs and data also strengthen the view that study of CO2 emission needs special emphasis and there is an urgent need for mitigation.

1.2.2 Mitigation frameworks

Excessive carbon emission is causing extreme climate change events and has become a thing of concern to people around the world. It is rapidly changing the environment we are living in. With increasing concern for reduction of GHG emission, the need for making assessment reports and methodology reports of climate change became necessary. The Inter-governmental Panel on Climate Change (IPCC) was established in 1988 by United Nations to provide policymakers with regular scientific assessments on climate change, its causes & implication and potential future risks, as well as to put forward adaptation and mitigation options. The IPCC, with 195 member countries, created by the United Nations Environment Programme (UN Environment) and the World Meteorological Organization (WMO) provides assessment reports on climate change and these are generally recognized as the most credible source of information on the subject. It also authors Methodology Reports, which guides all concerned parties for preparing inventories of greenhouse gases.

The **United Nations Framework Convention on Climate Change** (UNFCC) conference held in Rio de Janeiro in 1992 and informally known as Earth Summit, was signed by 154 nations), gave further impetus to quantification of GHG concentration in the atmosphere and quantification of emission at different source, making GHG inventory a must tool of Climate management for all participating countries. The **Kyoto Protocol** in 1997 made it binding for most countries to undertake policies so as to reduce level of GHG emission within specified limits. In the 2015 United Nations Climate Change Conference (UNCOP 21), which was held in Paris, France, and known as the 'Paris Agreement', a new framework convention on climate change, was adopted. It is the first international treaty that is legally binding, much more than the Kyoto Protocol. The 'Paris Agreement' adopted within the United Nations Framework Convention on Climate Change (UNFCC), asks all 196 participating countries to limit global average temperature rise this century to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degree Celsius (Nations, United Nations Climate Change, 2015). Since 2020, countries have been submitting their national climate actions plans, called **Nationally Determined Contribution** (**NDCs**). Each successive NDC is meant to reflect an increasing higher degree of ambition compared to the previous one.

With GHG emission inventory becoming a tool for Climate Management, there arose the need to develop a methodology to calculate and quantify emission. There are various agencies worldwide like GHG protocol, Global Reporting Initiative (GRI), International Integrated Reporting Council (IIRC), etc. which have developed standards, tools and online training that helps countries and cities track progress towards their climate control goals. Various sustainability certifications and reporting systems are based on standards set by them. GHG Protocol establishes comprehensive global standardized frameworks or accounting standards to measure greenhouse gas (GHG) emissions from private and public sector operations, value chains and mitigation actions.

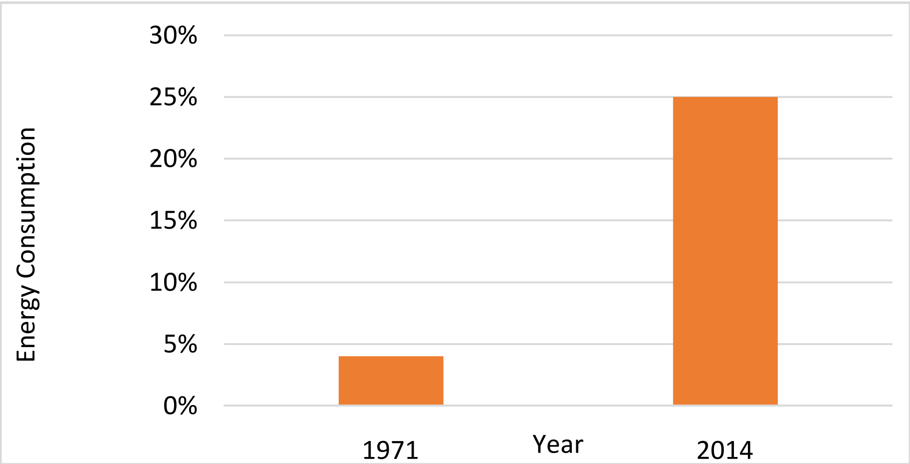
The Breakthrough Agenda Report 2023 (Champions, IRENA, & IEA, 2023), which was a report done by the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the UN Climate Change High-Level Champions, had cited that progress in mitigation has taken place at a faster rate than imagined. Primarily the focus was on deployment of renewable energy like solar photo-voltaic cells (PV) and electric vehicles which are all important solutions as countries transition to net zero emissions. However, this transition though very encouraging, is yet to reach the desired rate. The developments are happening at a planned rate in China, Europe and USA, the other areas of the world lagging behind severely.

Researchers have also played a vital role in this war against GHG emission. They have worked endlessly to contribute to this GHG accounting and mitigation process. All researchers and agencies have accepted without any debate, that to start the process of mitigation the first thing to be done is finding out the source of GHG emission and its quantification. The process of preparing GHG inventory becomes inherently necessary to understand the emission scenario and work on any policy matters.

1.2.3 Housing Sector - Energy demand - Emission

The increase in consumption of electricity and fuel is resulting in increase of CO2 emission, consequently increasing GHG gases in earth's surrounding atmosphere, thus causing changes in the climate and global warming. It is seen that in Switzerland the housing sector represents 50% of energy consumption (Zimmerman, 2005). As per PRAYAS(Group), 2016), reports of 2016 show that PRAYAS(Group), 2016.

Figure 8 Residential Electricity consumption

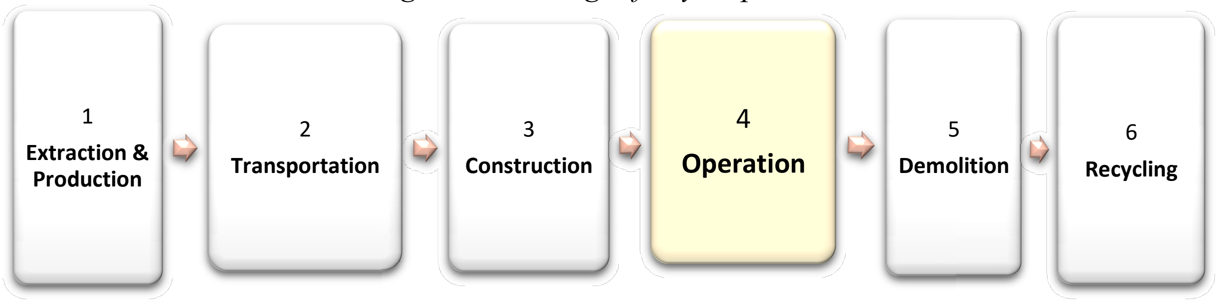


India's 'Residential Electrical Consumption' (REC), which was only 4% in 1971, is approximately 25% in 2016 (Figure 8). India's REC in 2014 was about 22% of the total 883 billion unit of electricity consumed by all sectors (Group), 2016). The energy demand of the building sector in China has grown from 26.59% of the total consumption in 1995 to 62.51% in 2012 (Lin & Liu, 2015). Chinese urban population, which is 52% of the total Chinese population, accounted for 75% of the national household carbon footprints (HCFs) in 2012 (Feng, 2016).Worldwide energy demand scenario shows that the building sector energy demand has grown by over one per cent annually between 2010 and 2022(United Nations Environmental Programme, 2024).

1.2.4 Building Life Cycle & Operation Phase

There is a need to understand and investigate the problem of household emission to implement policy intervention successfully in the field of emission control. The first step towards that goal is to find the Quantitative and Qualitative parameters of Household carbon Footprint (HCF). In order to study CO2 emission from buildings in depth, there has always been a trend by the researchers to consider the building through it's whole life-cycle - known as the 'Building Life-Cycle' theory. The building life-cycle is generally divided into several phases like 1) Extraction and production, 2) Transportation, 3) Construction, 4) Operation, 5) Demolition, 6) Recycling (Yan, 2018) (Figure 9) and emission from each phase is calculated separately. Emission from each phase is added to give the total emission from the building. Research papers have studied, either all the phases together, working on a broader view, or only one or combination of few to get a more detailed examination.

Figure 9 Building Life-cycle phases



There is no doubt that as per building life cycle theory the maximum emission comes from the 'Operation Stage' (Yan, 2018). Most of the previous research papers have found that out of all phases the 'operation phase' of the building consumes maximum energy and emits the most GHGs. Adalberth (Adalberth, 2000) found out that residential buildings built in 1990s, consumed about 85% of the life cycle energy in the operation phase, resulting in 70-90% of the environmental impact (Figure 10 & 11).

Figure 11 Building life-cycle energy consumption distribution

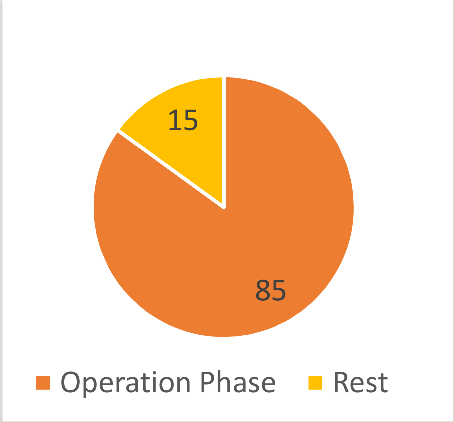
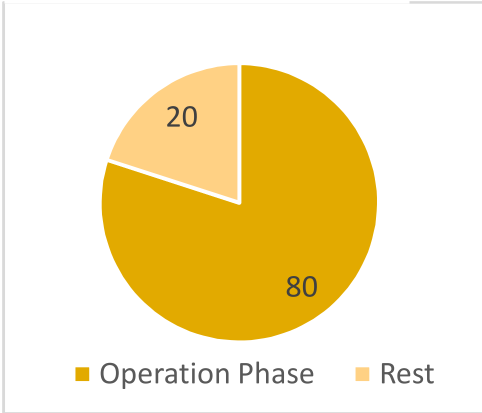
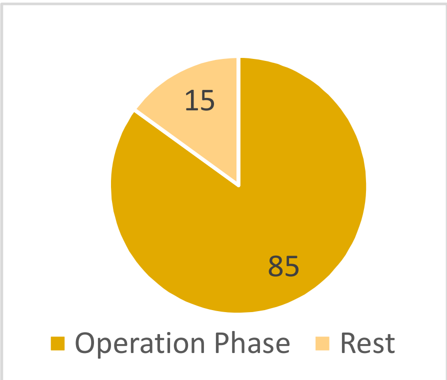
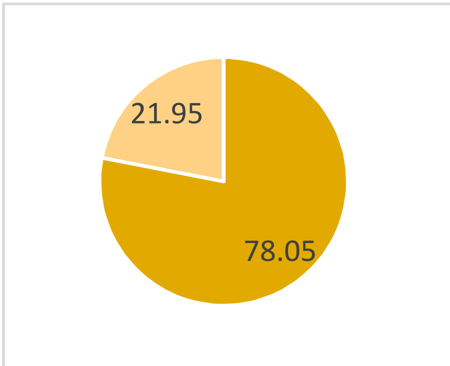


Figure 10 Building life-cycle emission distribution





(Mei Shang, 2021)



(T Ramesh, 2012)

Emission during the operation-maintenance phase of the building life cycle was found out to be 78.05 %, followed by the pre-operation phase emitting 20.59% (Mei Shang, 2021). Same results, emission during operation phase of buildings amounting to 80-90% of the life cycle emission (LCE), was calculated by (T Ramesh, 2012) when they studied life cycle analysis (LCA) of a residential building with different envelopes and climates in Indian context. In 2020 the operation phase of urban residential buildings in China accounted for 42% of the national carbon emission (Fei Zheng Y. W., 2023) Operation stage' as per 'Building Life Cycle Theory' is the maximum emitter and needs emphasis for any mitigation plan.

1.2.5 Embodied Emission

Most researchers, working on emission, especially following the building life cycle method, work on the residential emission quantification method by taking both direct and indirect components of energy consumption. The end use energy is called the 'direct energy' consumption, like the energy for lighting and space heating, whereas 'indirect energy', also referred to as ‘embodied energy’ is the energy which is used in the production process of goods and services used by households (Rui Huang, 2018).

1.2.6 CO2 Emission from Fuel Consumption of Vehicles

Along with residential electricity consumption, the use of vehicles also plays a major part in urban emission of GHGs. People all around the world, both in rural and urban areas, are compelled to use automobiles to travel from one place to another. In urban areas, it has become a necessity, making travel faster, comfortable and easy. The possession of cars and other vehicles has also become a symbol of social status. These factors are forcing almost all families in the urban area to have one or more 4 wheelers (cars) or 2-wheeler motorcycles. All these uses of automobile are adding to an increased use of automobile fuel and sometimes electricity for electric automobiles, and as a result an increased CO2 emission, which is increasing by leaps and bounds. There is an urgent need to shift to electric vehicles (EV) because that is the only way to stop burning automobile fuel. The sale of EV has been very encouraging world over and if this exponential growth rate of sale of EV continues it is possible that by 2030 we would reach a stage where from it will be easy to attain the net zero CO2 emission by 2050 (Champions, IRENA, & IEA, 2023).

Parking space has also become an integral part of a residential building. Small single tenement residential building is usually provided with one or two parking space and a small multi-tenement residential building is provided with a part or whole of its ground floor for parking. Sometimes the open areas of the plot are also allotted for parking. Double stack parking in the open areas and multi-layered basements is also becoming popular with large residential plots. Parking spaces are also consuming the open areas meant for greenery. So, when studying different factors leading to CO2 emission in a residential building during its operation time, it becomes a necessity to study emission due to consumption of fuel due to cars and motorcycles inside the particular residential plot. Though emission due to movement of vehicles inside the plot is a tiny fraction when compared to the emission outside the plot area, that is when plying on the roads of the urban area, this small fraction of emission cannot be considered negligible and calls for a more sincere study.

1.2.7 Emission - Other causes

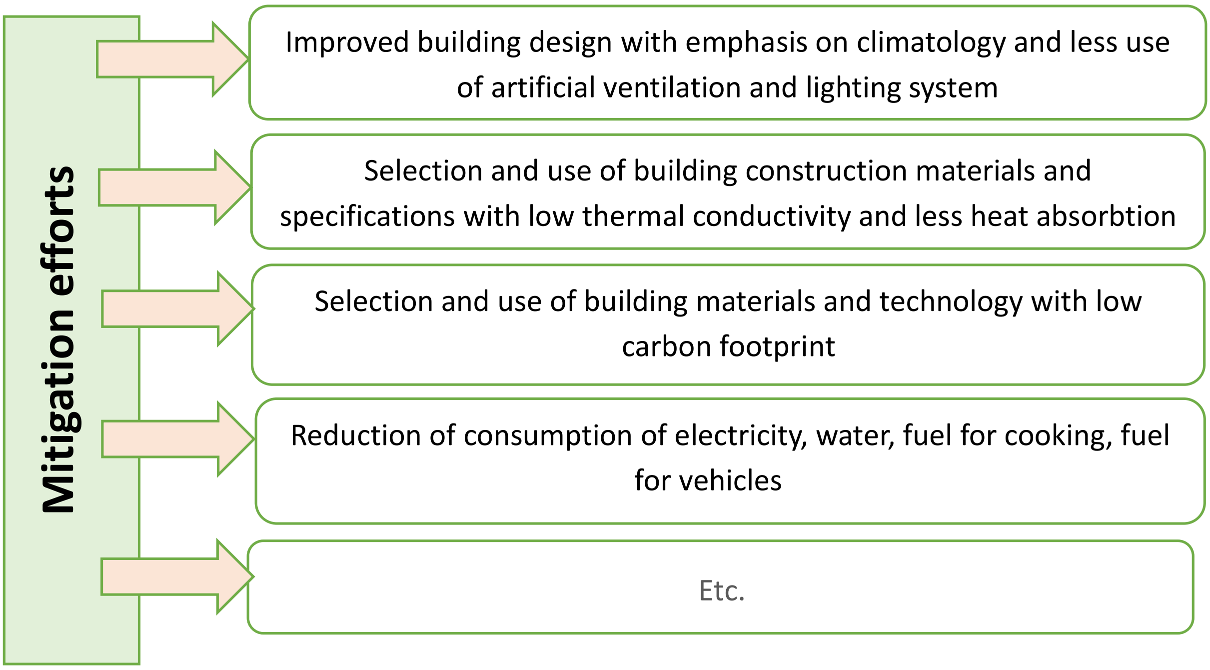
One of the primary causes of CO2 or GHG emission from urban households is cooking. Human beings need to cook most of the food he or she eats and that needs heating or firing the raw food. This cooking process involving burning of wood or cooking fuel or electricity consumes a good amount of energy (Gould & Urpelainen, 2018, November), (Lim SS, 2012 , December 15). Amongst other causes of GHG emission from urban residential buildings, many researchers have studied and claimed that the urban **Potable Water Production** (PWP) is also major cause of concern and definitely needs immediate steps for mitigation (Gui, Qi, & Wang, 2024), (Pritom Bhowmik Akash, 2024 september). Recent studies have shown that a combination of proper sewerage system and treated water supply system in the urban area can reduce water-borne diseases by 60% and is a major necessity in urban infrastructure development(Biswajit, Jan-Feb 2020). The 'Smart City' approach, introduced by the Indian Prime Minister in the year 2015, necessitates a 100% recycling in sanitation system. The Smart City sanitation system requires waste water to be treated as a resource and to be reused. It includes preserving and maintaining the natural hydrological cycle, ground water recharge, storm water storage, natural drainage system(Biswajit, Jan-Feb 2020). Urban water systems in China accounts for over 50% of the total carbon emissions from urban infrastructure operations(Gui, Qi, & Wang, 2024). The whole process of abstraction, treatment, transportation, distribution, consumption and waste water treatment involved in the urban potable water system is associated with huge consumption of energy.

Another very interesting field studied by many researchers is emission of CO2 by 'respiration' from residents and also domesticated animals or pets. This field is often skipped by many terming it as a part of the 'Carbon Cycle' and a net zero effect on environment. However, there are researchers like (Li, et al., August 2022), (Duarte, 2007), who think this CO2 emission from human, however small may be, needs to be investigated.

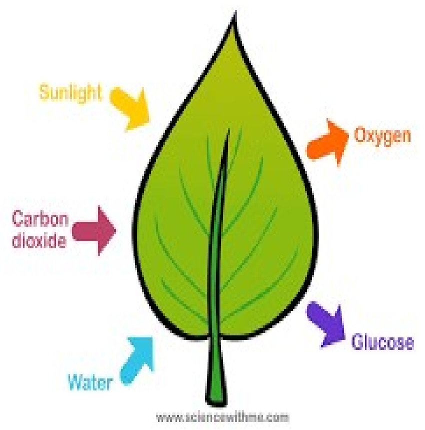
1.2.8 Mitigation efforts in residential building sector

There are various ways of mitigating CO2 emission from buildings. Considering different phases of the building, these steps can range from improved building designs, selection and use of building materials and construction technology with low carbon footprint, reduction of electricity consumption, water consumption, proper use of vehicles, etc. to reducing overall emission of buildings (Figure 12). The need of mitigation of CO2 emission at building operation phase needs to be emphasized maximum as this stage is the maximum emitting phase.

Figure 12 Mitigation efforts related to building operation stage CO2 emission



The elevated carbon dioxide (CO2) concentration in the atmosphere can be reduced by storing carbon or CO_2 in any other medium. By carbon sequestration this carbon from the atmosphere can be removed and stored in biological or geological mediums (kumar, 2006).Plants grown at micro level, that is within the plot where a building stands, can be given some investigation. Plants being the only source of carbon sequestration, can be given some importance in the building development so that it can sequester, if not the whole, a part of the CO2 that it itself emits. This paper makes comparative study of CO2 emitted by the building in operation phase and CO2 sequestered by plants grown within the campus. Home gardens (kumar, 2006) and indoor plants (Torpy, Irga, & Burchett, 2014), beside contributing to the exterior and interior visual aesthetics of residential houses, also play a very important role in purification of the indoor air quality as well as the air quality of the premises, by reducing CO2 emitted by the house. This sequestration of CO2 by home-garden and indoor



plants, however small it's contribution may be, can act as a mechanism of CO_2 reduction at source. The field of sequestration needs to be considered when calculating total CO_2 reduction at the house level.

1.3 Research boundaries

Urban buildings with their inhabitants are one of the major sources of carbon emission. Considering that buildings produce pollutants, the question arises - what are these pollutants. As per environmental standards main pollutants are carbon dioxide, carbon mono-oxide, Nitrogen oxides, Sulphur oxides, methane, ammonia, ozone, PM2.5, PM10, etc. These gases or particles are produced from different sources and have different harmful effects. However not all gases or particles are produced by the building. The fact that different pollutants are emitted in different proportions in different phases, depending upon several intrinsic properties of the building, makes the study of emission by building still more complex. So, any research on building emission should ideally lay emphasis on phases of the building, finding emission in different phases. Analysis of a research study revealed that the 75% of the total carbon footprints of urban residential buildings were from the operational stage (Xiaomei Yan, 2018). Emission from a residential building is also very different from that of a commercial or educational building. Emphasis should be given to use-group of a building when studying emission. Different fields of study of building emission are shown in Table 4.

Table 4 Various research fields associated with building emission

Locational attribute	Use Group (Occupancy)	Phases of Building	Tenement character	Gases & particles as pollutants
1. Rural	1. Residential	1. Extraction & Production	1. Single Tenement	1. CO_2 and other GHGs
2. Urban	2. Educational	2. Transportation	2. Multi - tenement	2. other GHGs
	3. Institutional	3. Operation		3. PM2.5
	4. Assembly	4. Demolition		4. PM10
	5. Mercantile	5. Recycling		Etc.
	6. Industrial	etc.		
	7. Storage			
	Etc.			

The field of study is immense and researchers are working on different aspects of the subject and adding new data and information to this vast field to make the process of mitigation better. This research work finds it prudent to draw research boundaries before-hand to make the process simple and more achievable. With the intention of doing a study that will be more precise and keeping several limitations in mind, the research boundaries are set as -

1) it studies buildings in **urban agglomerates** only and keeps those in rural setting out of the scope of study,
2) it studies only **residential buildings** and excludes buildings with all other use groups like educational, institutional, commercial, storage, etc. or mixed residential
3) it assesses only the '**operation phase'** of the building i.e. the phase when residents are living in the building and does not take into account the other phases like extraction and production phase, transportation phase, construction phase, demolition phase and recycling phase
4) the character of the building this research focuses on are only multi-storied and multi-tenanted
5) this paper studies emission of only Carbon Dioxide (CO_2)

1.4 Research Questions

The need for quantification and preparation of data base of CO_2 emitted from buildings are of primary importance for any mitigation process concerning climate change. Mitigation of CO_2 emission through sequestration also calls for quantification of plantation and sequestration volume.

Primary Questions -

1) How much CO_2 is emitted from an urban multi-storied and multi-tenement residential building in the operation phase?

2) If plants are grown inside the building plots to an optimum level, to what extent can it mitigate the total CO_2 emitted by the building?

However, there also arises other questions which get logically associated with this research process and ask for serious introspection. These questions become pertinent and hence are included in the research paper.

Secondary Questions -

1. (i) What are the sources of CO_2 emission from an urban multi-storied and

multi-tenement residential building in operation phase?

(ii) Is there any correlation between the building parameters and the quantity of CO_2 emitted?

2 (i) How can the optimal level of plantation be identified in the present scenario?

(ii) Are the present building rules pertaining to emission mitigation adequate for the purpose?

1.5 Research Topic-

Previous research works have all tried to understand the emission from buildings in details and formulate ways of mitigation. This research work focuses on various aspects of CO2 emission from an urban multi-storied and multi-tenement residential building in operation phase, tries to identify various issues concerning the topic and formulate some ways of reducing CO2 emission. The issues this research tries to study are –

1. Identification of activities emitting CO2 from a building in operation
2. Quantification of CO2 Emission by a building in operation
3. Quantification of CO2 that can be sequestered by plants grown inside the premises of the building
4. Comparison of CO2 emitted by the residential building in the operation stage and CO2 sequestered by plants grown in the premises of the building

So, the research topic is chosen as –

"A responsible approach by the building on site aiming to achieve CO2 emission – consumption balance during the operational phase"

1.6 Research aim & objectives-

1.6.1 Research Gap

A good volume of research has been done in the field of emission from the pre-operation phase of the building. Research on emission associated with materials being used for construction of the building i.e. the extraction production phase & the transportation-construction phase and the emission factors associated with these phases are well studied till now. However, research on 'operational phase' is not exhaustive and considering research on identification of sources of emission and it's quantification, from the operation phase of the residential building, are few. Identification of activities is a must for qualitative and quantitative analysis of emission. For any mitigation policy this information is sure to help immensely in formulation of building rules or town and urban planning rules and in future will help in emission control as a guideline for urban planning and building design. Research on the emission factors associated with the operation phase, like electricity generation, respiration, potable water production, LPG, etc. are few. They are difficult to retrieve from existing papers, varying considerably from paper to paper and do not follow any standardization. Information and data on these same emission sources and their emission factors at micro level, considering local level influencing factors, are also rare. Same is also true for information and data on consumption of energy at end-use point or household level.

1.6.2 Research aim

The objective of the study is to propose a system for the urban administrators, town and urban planners, architects and designers and also the urban dwellers to follow, which will contribute, to whatever extent, towards mitigation of CO2 emission. Knowing the exact sources of CO2 emission from residential buildings and their extent of contribution towards emission, effective measures can be taken to reduce the problem. Knowledge of correlation between parameters of the building and CO2 emission, if any, will contribute generously to formulation of effective planning standards for building design, rules and regulations.

A good amount of research has been done on sequestration by forests, urban and rural trees and agricultural crop lands. However, there are very few research work on urban or rural home gardens or small plants. Research work on local Indian plants regarding CO2 sequestration are non-existent. There is need and scope study on sequestration by urban home grown plantation. Existing building guidelines, standards, rules and regulations in terms of open green areas and vegetation and plantation inside the plot need a serious overhaul and proper study for the benefit of the future. Examination is required to find out whether these rules pertaining to climate change are adequate enough for reaching the mitigation goals and if not then how can plantation scenario be developed to attain the same.

1.7 Research Hypothesis

The hypothesis of this thesis is proposed as "**The amount CO2 emitted by the multi-storied and multi-tenanted Residential Building in the operation stage can be sequestered fully by the plants and trees grown inside the premises during the same**

time period". The hypothesis is true or not needs a detailed analytical and quantitative study of both the subjects – CO_2 emitted and CO_2 sequestered by the building considering the same time-frame. With respect to emissions and Climate Change scenario at present in the world, the future is generally depicted as a matter of tremendous concern and calls for responsible response from everyone in this society. Urban buildings, taken collectively, being one of the biggest contributors of this emission, the urban residents, along with planners, architects, designers of the urban buildings and also researchers need to whole-heartedly contribute to this process of mitigation. The building must do something to bring about a change in emission scenario – it must show some responsibility. The urban residential building must reduce CO_2 emission to the maximum extent and growing plants, being the only way of sequestering emitted CO_2, there should be an all-out effort to study and analyse the balance between CO_2 emitted by the building and CO_2 absorbed by plants grown inside the premises.

1.8 **Research Methodology**

The research is set into parts – 1) research considering CO_2 emission, 2) research considering CO_2 sequestration. The first part is again divided into three sub-divisions –

1) **Identification of sources of CO_2 emission** – Information and data is totally based on existing primary and secondary literature study.

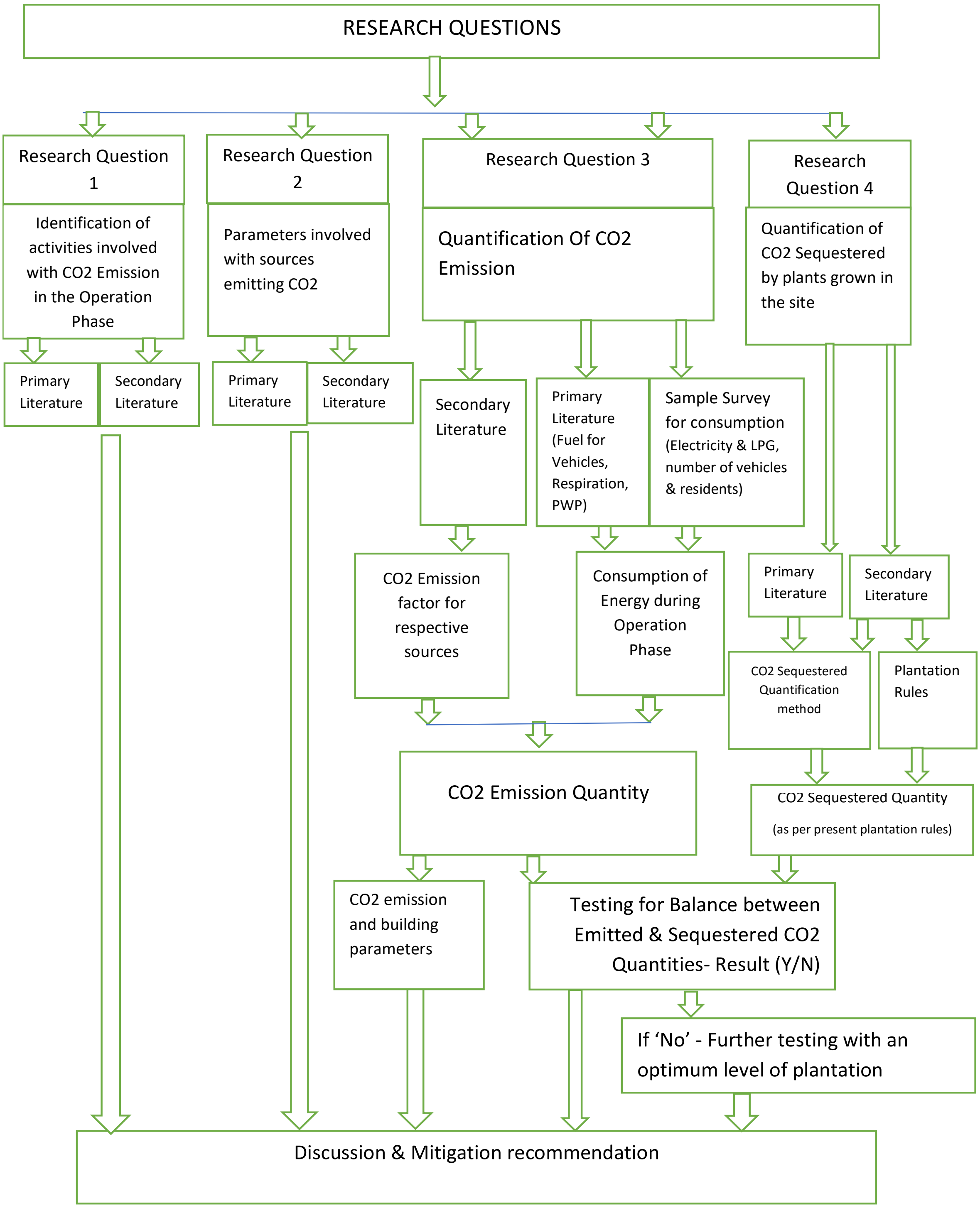
2) **Quantification of CO_2 emission** – This is also based on existing literature for a logical process of quantification and related factors and coefficients. For information on consumption of energy, a two-prong approach is adopted – mainly sample survey and to fall back on existing literature wherever information is not obtained from sample survey.

3) To follow with a comparative study of CO_2 emitted by the buildings and parameters of the building like plot area, built-up area, number of residents, etc. for any correlation.

4) Quantification of CO_2 sequestration - Information and data on this field is totally based on existing primary and secondary literature study.

5) The respective volumes of CO_2 emitted by the building and CO_2 sequestered by plants grown in the mandatory (as per building rules) open spaces of the plot are compared. If the balance between the two volumes is not achieved, a further increased scope of plantation is searched and once again CO_2 sequestered by this increased plantation is checked for emission-sequestration balance.

RESEARCH DESIGN



1.9 Study Area

Newtown (Rajarhat-NewTown) is a planned satellite city of Kolkata City in the Indian state of West Bengal (Figure 13). It is adjacent to Kolkata & Bidhan Nagar, which is also known as Saltlake and is the other planned satellite city of Kolkata. The Kolkata City, Bidhan

Nagar and Newtown all are included in Kolkata Metropolitan Area. Started in 1990, Newtown is administered by NKDA (NewTown Kolkata Development Authority). Geographically the area of Kolkata, Bidhan Nagar and Newtown sits on the lower Gangetic Delta of eastern India. Latitude and longitude of Newtown are precisely 22.64° North and 88.48° East respectively, with an average elevation varying from approximately 3.0 meters to 10.0 meters.

Figure 13 Geographical location - Newtown

Source Google Maps / NewTown Development Authority, West Benga

Table 5 Status of development in different sectors of New Town

Location	Action area-I	Action area-II	Action area-III	CBD
Area in hectares	677	1310	783	183
Progress of infrastructure development	All most complete	More than 50% work completed	Work in progress	Work in progress

Source - (Amar Biswas, May 2017)

Kolkata is an old unplanned city, developing since the 17th century whereas Bidhan Nagar and Newtown are new planned cities, construction of Bidhan Nagar starting in 1962 and Newtown starting in late 1990s. This research paper selects Newtown as the site of research study as Newtown is still in it’s infancy with huge development still left (Table 5) and there is a feasible and strong scope of urban and housing sector development with proper sustainability approach.

Newtown is one of the few planned cities in West Bengal. It is a city of future and has an immense scope of a planned sustainable approach towards development, keeping climate concerns in mind. A study on CO2 emission- sequestration by urban residential buildings can provide valuable inputs into the city's planning and development concepts.

Newtown is also one of the very few cities in India which provide a building rule governing 'Green Open Space' in residential and other building development sector. This fact, fortunately, gives this research paper a chance to probe the matter more and test the credibility of the rule.

1.10 **Research Scope & Limitations**

There is a need to understand and investigate the problem of household emission to implement policy intervention successfully in the field of emission control. The first step towards that goal is to find the Quantitative and Qualitative parameters of Household carbon Footprint (HCF). A good volume of research has been done in the field of emission from the pre-operation phase of the building. However, considering research on identification of sources of emission and it's quantification, particularly from the operation phase of the residential building, is few and not exhaustive, there is immense scope of study in this field.

Research on emission associated with materials being used for construction of the building i.e. the extraction production phase & the transportation phase and the emission factors associated with these phases are well studied till now. However, research on the emission factors associated with the operation phase, like electricity generation, respiration, potable water production, LPG, etc. are few. They are difficult to retrieve from existing papers, varying considerably from paper to paper and do not follow any standardization. Information and data on these same emission sources and their emission factors at micro level, considering local level influencing factors, is also rare. There is a huge scope of research on emission factors and consumption coefficients of sources and activities that are associated with the operation phase of the building.

Literature review of existing research papers shows that in India there is hardly any emission data inventory for the operation stage of the building. Researchers have claimed that this operation stage is the highest contributor of CO_2 emission amongst all other phase of the building. Some researchers are of the opinion that total emission from urban residential buildings in India is increasing over the years. Some research papers have claimed that it is beyond doubt that emission factors from emission sources are decreasing at the same time. However, there is not much data on weather CO_2 emission from urban residential buildings per square meters of plot or per square meters of covered area or per number of inhabitants is increasing or decreasing. There is a huge scope of a proper CO_2 emission quantification from urban residential buildings of all categories and development of a proper CO_2 emission inventory to show variations over the years and whether we are moving on the right track of emission control and mitigation.

Considering climate change and CO_2 emission from building, plants are our only well-wishers – the one and only source of sequestration of carbon that we randomly throw into the atmosphere. Existing research papers have tried to reduce the CO_2 emission from buildings by working on materials used for construction, finding more sustainable materials or materials that effectively reduce energy consumption during operation stage by reducing heat consumption or by intervention at the design planning stage taking climatological factors into consideration for effective control of heat or light or ventilation. But sadly, we have never thanked the plants properly and made serious study of their capability and contribution. Its high time we give some good research effort to do the same. Considering this fact, this research finds itself in the midst of a sea of scope to contribute to our goal of mitigation of emission control.

Existing building standards, rules and regulations in terms of open green areas and vegetation and plantation inside the plot need a serious overhaul and proper study for the benefit of the future. The contribution of plantation needs to be acknowledged. Existing rules set by the authorities, regarding eco-friendly world, needs serious checking.

There is also scope of finding few quantitative and qualitative scenarios associated with building parameters and CO_2 emission from the urban multi-storied multi-tenement residential buildings that can help planners and architects during the planning stage of the building. The findings of this research papers regarding correlation between parameters of the building like plot area, covered area or number of residents and CO_2 emission can definitely help in future for all formulation of building rules or town and urban planning, if we really consider, in future, emission control as a guideline for building design.

This research paper must be considered within the bounds of following constraints and limitations –

1) Information regarding emission factors and energy consumption of certain sources of CO_2 emission are few in existing literature. There is hardly any information regarding electricity generation emission factors at local or state level. The average CO_2 emission from electricity generation at the national level in India is provided by CEA. But the same information at the state level is missing. Considering emission factor of LPG is different in different countries due to variation in production process, there is very few data on this field. Regarding consumption of petrol by vehicles during idling time there is only one or two existing papers. There are very few studies done on CO_2 emission during respiration or from production of potable water in India. So, with all these constraints there, this research paper tries to work with whatever information is there in existing research papers. Considering that relying on international standards or factors or coefficients will give erroneous results, not true to local level or even national level investigation, there is a need for immense study on these fields, especially in India or at any country level or at the state level, so that more authentic results are drawn in a research work.
2) The sample survey is done on a very small scale due to lack of resource. This may produce some erroneous results. This research paper emphasises more on the process of investigation and prescribes a more elaborate research work over a larger scale for better results. More research on this field at the state or national level is also welcome to draw results which can be used for setting standards and rules and regulations.
3) During the process of quantification of CO_2 emission, few assumptions were considered - like for consumption of potable water per person per day this research paper takes into account information from Indian standards as there is no proper data on this field. The average time of idling time or drive inside the plot by a vehicle is also assumed due to lack of information. The consumption of LPG for cooking is also not very proper in the sense that no residing family exactly maintains a proper ledger of LPG cylinder consumption – they have an estimation on this. This paper recommends more research on these subjects for better understanding and results.
4) Regarding identification of sources of emission from an urban multi-storied and multi-tenement residential building, it can be said that almost all sources mentioned in existing literature are taken into consideration for study. Some of

them have been skipped logically like emission due to paper consumption. One very interesting point was that almost no research paper has considered indirect CO2 emission during operation phase due to introduction of all goods bought during the same phase, this research paper keeps this field outside it's scope of study due to lack of data and prescribes for further study on the same.

1.11 Conclusion

There is a need to understand and investigate the problem of household emission to implement policy intervention successfully in the field of emission control. The first step towards that goal is to find the Quantitative and Qualitative parameters of Household carbon Footprint (HCF). The building life-cycle is generally divided into several phases like 1) Extraction and production, 2) Transportation, 3) Construction, 4) Operation, 5) Demolition, 6) Recycling. Most of the previous research papers have found that out of all phases the 'operation phase' of the building consumes maximum energy and emits the most GHGs. There is a need to investigate the operation phase of residential building for CO2 emission. This research work tries to focus on –

SET - A

1) Identifying activities of a urban residential building in operation which emit CO2,
2) Finding a logical process for quantification of the CO2 emission and quantification of the same,
3) Finding correlation between Building Parameters like Covered Area, Open Area, etc. and the CO2 emission volume,

SET - B

1) Finding a logical process for Quantification of CO2 sequestration by plants grown inside the premise of the building,
2) To investigate and check whether plantation are adequate or not (plantation as per building rules),
3) To check whether an optimal plantation plan can be proposed for maximum benefit in terms of CO2 emission reduction by sequestration.

2 CHAPTER 2 – REVIEW OF EARLIER WORKS

2.1 Introduction

The study of "emission of CO_2 from urban multi-storied multi-tenement residential building in operation phase" brings into the mind a number of questions regarding household emission. To get a better look into the problem it becomes prudent to see what the earlier research studies have done. This research work, however, keeps the literature review within the scope of research boundaries already specified in the last chapter.

Initial study and discussions with varied people and experts suggested that the research work is complex and needs to be compartmentalized. For better understanding of the subject and to have a structured flow in research work, the literature review was divided into two fields –

1) **Literature review 1 - CO_2 emission from residential buildings**
2) **Literature review 2 - CO_2 sequestration by home-grown plants**

2.2 Literature review 1 – CO_2 Emission from residential buildings

2.2.1 Literature Review planning

This literature review tries to focus on primarily three aspects –

1) **Literature that has studied different 'causes' or 'sources' of CO_2 emission from urban residential buildings**. Identification of sources of CO_2 emission from urban residential buildings becomes one primary objective of this paper. Most of the research papers have worked on LCA method and worked on direct and embodied energy. Some have set a special focus on the subject of consumption of energy through electricity, and some have taken into account fuel consumption by vehicles that are personally owned by residents, considering daily travel that the residents make. Some research work have taken into account emissions from fuel consumption due to cooking or even paper consumption. There are researchers who have skipped certain causes of CO_2 emission like considering electricity and not considering cooking or considering electricity and cooking and not considering fuel. To find out and understand the causes of CO_2 emission this paper goes beyond its boundary of research – like papers dealing with not only multi-storied and multi-tenement

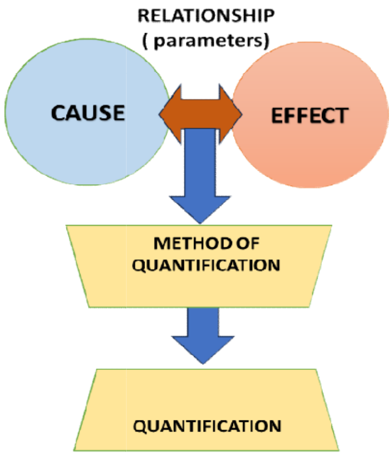
buildings but papers which study individual single-tenement buildings. Research papers on CO2 emission from respiration or potable water production were also included in the literature review.

2) **Literature that discussed and analysed how these causes are dependent on and associated with other parameters.** Most research papers have worked on the causes of CO2 emission from buildings in detail. If the cause is consumption of electricity, they have discussed at length how different electricity generation fuels can vary the CO2 emission quantitatively. Studies have found that there has been a huge change in technology of electricity generation which has, fortunately, brought about a sea change in emissions and for the better. Many researchers, considering CO2 emission from household cooking activity, have studied how changes in fuel like solid fuel LPG or natural gas can change the quantity of CO2 and other pollutants emitted and vary the indoor air quality. Researchers have investigated and produced comparative analysis of activities associated with buildings, in terms of their polluting capacity. So, the literature review was not restricted to only papers dealing with buildings and emission. Once the sources of emission were identified, studies on emission characteristics by individual sources were also taken into the purview of this research work. Primary and secondary papers regarding CO2 emission by electricity, LPG and other cooking mediums, petrol diesel and other vehicle fuels, potable water, etc. were separately studied.

3) **Method Applied for quantification of CO2 emission-** Research papers and reports that work on the process of quantification of CO2 emission from residential buildings. Different papers have applied different methods for this CO2 emission quantification – some have applied to build life cycle analysis (LCA), some have worked with population and per capita emission factors, some have worked with only direct CO2 emission, some have taken into consideration both direct emission and embodied emission, some have applied the IPCC emission factors and some have applied other coefficients derived from primary and secondary sources. As previously mentioned, there is a plethora of research papers on this subject, and considering the subject is vast and complicated, each paper is quite different from the other, interesting and unique, adopting and applying different logic and methods for identification of cause of CO2 emission, finding the associated parameters and finally quantifying the emission.

4) **Searching for emission factors** – For quantification of CO2 emission from buildings the most needed thing becomes emission coefficients and factors for different energies or associated activities. The energy consumption quantities when mathematically calculated with emission factors give the emission quantity.

This research work sums up the whole method of literature review into one known terminology – finding '**CAUSE & EFFECT**' and also studying parameters governing the "cause-effect" relationship. Identification of causes of emission, parameters governing those causes, mathematical inputs of these causes and effects of emission in terms of factors and coefficients when analysed together is expected to give us the total emission.



Literature review objectives

2.3 Literature review

2.3.1 Household emission

Xiaomei et al. (Xiaomei Yan, 2018), in their paper 'Carbon Footprints of Urban Residential Buildings: A Household Survey-Based Approach'**,** have tried to reveal emission characteristics of household buildings regarding carbon footprints, saying it is needed to achieve the goal of low-carbon cities. The community buildings' structures had been recognized, and Life Cycle Analysis estimated residential building carbon emissions. The building life cycle has six stages: First, extraction and production, then transportation, construction, operation, demolition, and recycling. This study had these objectives:1) inventory urban residential building carbon footprints, 2) define household characteristics in relation to carbon footprints, and 3) examine the relationships between energy use, residents' energy-use awareness, and household carbon footprints. Stratified random sampling was used to attain these goals, although the paper never discusses stratum properties. A face-to-face questionnaire was given to 1092 families from 46 villages in Xiamen City, China, to compute residential building carbon footprints using LCA. The questionnaire has three parts: 1) Building information, 2) household energy use, and 3) resident energy conservation. Primary data come from surveys and secondary publications. Yearbook of the Xiamen Special Economic Zone (2016) provided demographic and per capita housing data for Xiamen City. The following are the study's findings: Because of the differences in household size, the carbon footprints of the 1058 households examined ranged from 0.37 tCO_2/year to 22.45 tCO_2/year, with 90% of the houses falling between 1.65 tCO_2/year and 7.37 tCO_2/year. The study also attempts to deconstruct the HCFs into emissions per building area and per person. Additional findings from the paper include: 1) The operating stage emitted the most CO_2 (75%), followed by the pre-operational stage. 2) Greater apartment space and household size result in larger carbon footprints; 3) A larger household has a lower per capita carbon footprint. Household size has a negative correlation with per capita carbon footprints. 4) The area of apartments has a significant impact on household and per capita carbon footprints; larger flats result in higher household carbon footprints. 5) Building Age: The HCFs and per capita CFs vary depending on the age of the flats; those constructed between 1980 and 2010 had higher HCF emissions. Furthermore, compared to older or newer flats, apartments constructed between 2001 and 2010 generated larger household and per capita CFs. It's interesting to note that apartments constructed after 2010 had lower HCFs, which may be explained by the fact that people are less likely to be able to purchase large apartments due to the sharp rise in housing costs. The study's analysis also showed that urban residential structures' overall carbon footprints were 1.86 $MtCO_2$/year, primarily from the extraction and production stage (24%) and the operational stage (75%). During the operational phase, the buildings' domestic energy consumption was as follows: electricity (74%), coal (1%), natural gas (11%), and LPG (14%). Carbon footprints and energy-saving awareness did not significantly correlate, according to the authors. The authors acknowledge that there is a greater chance of inaccuracy because carbon footprints were computed using emission factors depending on the area of each apartment, despite the fact that the research is highly cautious and effectively combines primary and secondary data. The research paper also does not describe properly the research boundaries ….

Mitali Das Gupta in her research paper ‘Impact of lifestyle pattern on energy consumption and carbon emissions – A view from India’ (Gupta, 2011) said “There is a clear link between the patterns of lifestyles that individuals or households lead and its impact on energy consumption and emissions.” As per survey by ICLEI South Asia, out of 41 Indian cities, Kolkata emits the most CO_2. With 15.7 million people living in the city and metropolitan area, it is the third most populated metropolitan area in India, the thirteenth most populated urban area globally, and the eighth largest agglomeration globally (UN, 2005). She addresses the findings of Wei et al. (2007), Pachauri (2007), Bin and Dowlatabadi (2005), and Y Zhen-Hua Feng et al. (Feng et al. 2011) regarding the correlation between CO2 emissions and lifestyle patterns in her literature review. The carbon calculator offered by Clean India, a project of Development Alternatives, a prominent non-governmental organization in India that is dedicated to creating a carbon-free society, determines the carbon footprints of households. Four income classes are used for "Stratified Random Sampling": 1) low-income households with monthly incomes under Rs. 8,000, 2) lower-middle-income households from Rs. 8,000 to Rs. 20,000, 3) middle-income households from Rs. 20,000 to Rs. 60,000, and 4) high-income households from Rs. 60,000 and above. Economic characteristics, such as household size, per capita income, and carbon calculators, are the sole basis for calculating carbon equivalent emissions. However, the Calculation procedure is never mentioned. The author limits her study to Direct impact of emission only and skips indirect impact due to limited scope of paper. The study also ignores cooking as a household activity consuming energy and carbon emitter. The findings are as follows (Table 6) -

Table 6 Carbon footprint of an average household in Kolkata

Income Categories	Income Strata	TonneCO2 per Year
Low Income	< 8,000	1 - 1.3
Lower Middle Income	8,000 – 20,000	2.2 -2.5
Middle Income	20,000 – 60,000	4 - 5
High Income	< 60,000	8 – 9

The study compares Kolkata's per capita carbon footprint to that of the rest of the world. Kolkata -1.2, Kolkata (high income) -1.8, Kolkata (middle income) -0.9, Kolkata (lower middle) -0.5, Kolkata (lower) -0.3, China -3.2, USA -20.0, UK -9, and World Average -4.0. Sources utilized include UNDP and WHO (2008). The author mentions several policies practiced in Japan which are beneficial for mitigating CO2 emissions. The paper is one of the very few research papers that have worked on emission problems concerning Kolkata. However, the paper never properly clarifies the process of quantification of emissions. Though it is mentioned that only direct emission is considered and indirect skipped, however other boundaries and parameters of research are not mentioned.

Shailesh (2011) in his ARTICLE named "Carbon Footprint Calculation – A small Introduction of ISO 14064" (Telang, 2011)has very precisely explained the process to follow while calculating carbon footprint of a household. The author states that measuring greenhouse gas emissions is the first step in controlling them and defines the carbon footprint as the entire amount of all greenhouse gas emissions. The GHG Protocol, ISO 14064, "Life Cycle Assessment (LCA)", market-based mechanisms such as the "Clean Development Mechanism (CDM)", "Voluntary Carbon Standards (VCS)", and other standards and guidelines are among the methods used to assess greenhouse gas emissions, according to the author. The author restricts his discussion to ISO14064 among these. Through a schematic illustration, the article also shows how ISO 14064 aids in determining the carbon footprint of a person, product, event, or organization. The author walks us through the complete process of figuring out our individual carbon footprint at home. The article takes 1) Electricity, 2) Liquefied Petroleum Products (LPG), 3) Petrol/Diesel as the main source of emission, shows us how to tabulate and find their total use in a year, quantify the carbon emission from that data by using emission coefficients. The sources of all coefficients are also mentioned. The process is very well explained – precise and simple. This article can indeed be very useful in calculating carbon footprint. The article only shows a process of calculation of emission, but is not a document or sample-based research work, nor does it delve into applicability or accountability of the factors and coefficients applied.

An educational campus, Apex Educational Institute, of approximately 100 acres was studied by S G Deshmukh (Deshmukh, 2015) in his research paper 'Preliminary Report on Carbon Footprint of a Residential Complex'. The total CO2 emission of the campus has been calculated after taking relevant inputs like 1) Total Electrical consumption, 2) petrol consumption, 3) Diesel (as a stand-by to electricity) consumption, 4) LPG consumption, 5) others like Paper. Consumption of Electricity and diesel is based on actual, according to logbook entry, in the year 2012-2013. The consumption of LPG, Petrol, and others are estimated following basic assumptions. Carbon footprint of each category is calculated based on unit rate of emission of those products. However, the source of the rates of emission used is not mentioned. The paper also gives a plan to reduce CO2 emissions. It details a plantation plan, estimating number of trees to be planted in the next 5 years so that a part of CO2 (15%), approximately 400 tonnes of CO2, can be sequestered. Plans for Solar water heaters and Solar power for street lights are also provided with calculations. This, as per the author, will reduce electricity consumption by 20% i.e. 500 tonnes of Co2 emission. The importance of internet for information instead of paper is also important. It can reduce carbon footprint by 5% i.e. 125 tonnes of CO2. The author also feels that by educating people we can reduce approximately 100 tonnes of carbon emissions. So if all 4 actions can be taken we can very well reduce 400+500+125+100 = 1125 tonnes of Co2 emission. The calculations are based on very log-book entries and lot many assumptions, like fuel consumption in hostels, fuel consumption by vehicles, quantity of paper consumed, etc. The sources of emission factors are also not mentioned.

Rui Huang, Shaohui Zhang and Changxin Liuhave done research work that is very exhaustive and well-prepared (Rui Huang, 2018). The authors have taken almost all aspects of Carbon emission and left none for assumption. The paper studies CO2 emission of 4 megacities Beijing, Tianjin, Shanghai, and Chongqing along with its rural neighborhood. The emission data is found out with the help of existing data, coefficients, provided by different organizations, and application of simple mathematics and statistical models. The authors deal with direct and indirect emissions very systematically with in-depth study and analysis. The results conclusively show that there is a wide gap between Urban and Rural areas with respect to carbon emission. According to the study's findings, Shanghai's Direct Household Carbon Emission (HCE) rose from 48.7 MT in 2007 to 71.9 Mt in 2015, a 47.7% rise. Compared to rural direct HCE, urban direct HCE was significantly higher. In 2015, Shanghai's direct HCE was more than eighteen times greater than that of rural areas. Additionally, all trends pertaining to indirect emissions are discovered for each of the four cities. The paper also deals with Per Capita Household carbon Emission (PHCE) and finds out basic trends with regard to carbon emission. A very unique thing about the paper is that it even works on "Indirect Emission Outsourced." i.e., indirect emissions produced in other provinces to meet these cities' product demands. In 2012, Beijing's proportion of outsourced indirect emissions increased to 87.6% from 73.6% in the previous year. Another very interesting aspect of the paper is that it gives comparative data on carbon footprint of these cities and also China and other countries in different years and as cited in different research papers.

Kaveri Patil and Aparajita Chattopadhyay (Kaveri Patil, 2013) in their paper titled 'Household Energy Use and CO2 Emission: Differentials and Determinant in India' found some very important facts about consumption of energy due to cooking, lighting and electronic appliances. Primary energy demand in urban household is projected to increase by 50 % between 2005 and 2030 : 45% of this increase being in India and China. With this fact staring at us the authors feel that clean and affordable energy is a must for Indian households. About 40 to 50 percent of the energy used in India is consumed domestically, primarily for lighting, space heating, water supply, and cooking. The study examines the following factors: 1) factors that influence household energy decisions 2) Energy use and CO2 emissions in households. The authors state that the "National Sample Survey Organization (NSSO)" of the

Government of India conducted a consumer survey from July 2009 to June 2010 (66 Round NSSSO, 2010), which served as the sole source of data and methodology for their study. The NSSO conducted a sample survey of 100855 people, 41736 of whom lived in urban areas. Every five years, this survey is conducted. Other articles, such as those by Ekholm (2010), Pachuri (2007), Bhattacharyya (2006), and Gangopadhyay et al. (2005), have frequently cited the data. Monthly per capita expenditure (MPCE) is calculated using data from the NSSO survey. The urban population is divided into ten consumer groups by the authors. The source of the emission coefficients is Ventataraman et al. (2010). The study's emission coefficients are as follows:

1) Per ton of Coal Products - 1.614 tons of CO_2
2) Per ton petroleum Products - 3.102 tons of CO_2
3) Per cubic meter of natural Gas - 0.0021 tons of CO_2

In 2003–05, India's coal-based electricity generation had an emission factor of about 1214gCO_2/KWh (IEA, 2007). Nonetheless, power is also generated from other sources; in 2003–05, the average for India was 929gCO_2/kWh. In order to account for distribution losses, the authors utilize 1068gCO_2/kWh of delivered power. Among the study's conclusions are

1) 64.6% of urban households use LPG for cooking,
   19% use biomass
   6.4% use kerosene
2) 94 % of the Urban households have access to electricity
3) *Direct CO_2 emission in Urban areas = 44 kg per capita income*
4) *Indirect CO_2 emission in Urban area = 690 kg per capita income*
5) *Ratio of per capita emission in Urban top 10 % to bottom 10% = 16:1*
6) *Per capita household emission in India, Urban Area =161 kg*
7) *Per capita carbon emission varies from state to state = 268 kg in Urban Tamil Nadu*
   = 226 kg in Urban Punjab
   = 160 kg in West Bengal
8) *20% of the Urban household still rely on solid fuel for cooking*

The study's limitation is that it only looks at energy usage and CO_2 emissions from cooking, lighting, and electronic equipment. Emissions from burning automobile fuel are not included in the study.

The paper of TV Ramachandra (al, 2015) clarifies what is exactly GHG, gives a very detailed account of GHG, and limits the study to only carbon dioxide (CO2), Nitrous Oxide (NO2), and Methane (CH4). The paper justifies the need for estimation of GHG – its impact on climate change and information for future planning. Quantification of sector-specific GHG emissions and the determination of the GHG Footprint (the total of the carbon equivalent of GHG) are required. A few extremely early publications on this topic are also briefly discussed in the paper. The method of Quantification of GHG is well explained. The results show Co2 equivalent emission of different cities. For Kolkata emission was found to be 6337.11 Gg of CO2 equivalents. Carbon Dioxide equivalent emission/per capita in Kolkata was found to be 3.29 tonne.

Moti L Mittal et al. in their research work on Estimates of Emission Coal Fired Thermal Power Plants in India (Moti L Mittal, 2012)investigated emission of CO2 and other GHGs from thermal power plants in India for a period spanning from 2001-02 to 2009-10. A future estimate till 2020-21 was also provided. He discovered that diverse coal quality, combustion technology, and operating systems are used by power plants. As a result, the efficiency of power generation changes from plant to plant, as a result of which, the GHG emission rates of different plants are also changing. He also found out that CO2 emission from coal-based generation ranged from 0.82 to 1.0 KgCO2 / per KWH. However micro level investigations showed many old plants were emitting more than 1.59 KgCO2/KWH and newer advance plants were emitting 0.58 – 1.0 KgCO2/KWh, proving that data regarding emission from electricity generation is erratic and not well documented.

Table 7 Coal-based electricity generation in India

Year	Percentage
2018	58 %
2022	45 %
2027	39 %

Source 2 CEA (Central Electricity Authority, 2023)

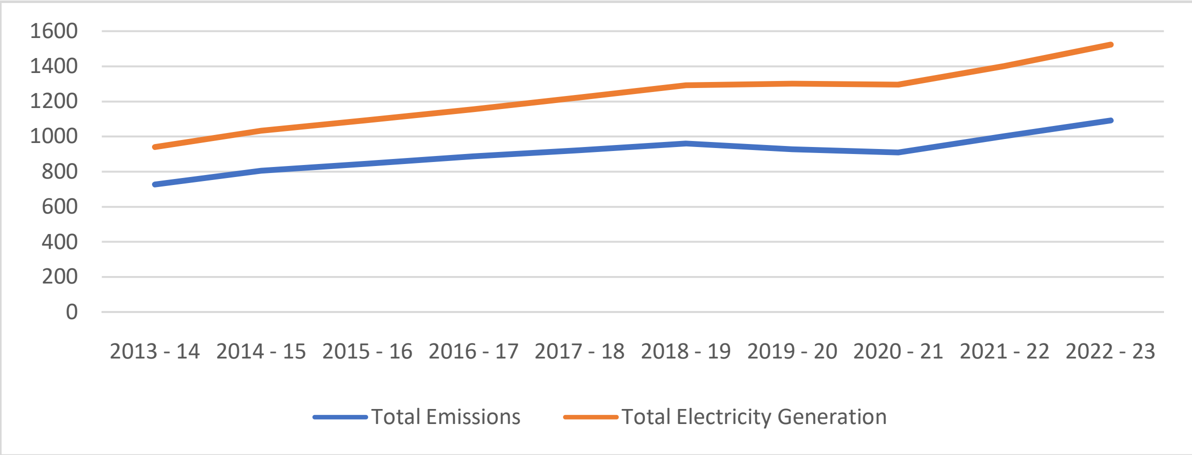
According to the Central Electricity Authority, Ministry of Power, Government of India, "CO2 Baseline Database for The Indian Power Sector," User Guide, Version 14.0, published in December 2018 (Authority, 2021) , Indian Government has also pledged to fight emissions. Following “Kyoto Protocol United Nations Framework Convention on Climate Change (UNFCCC)” and “CDM”, the Indian government is also trying to decrease emissions from electricity grids. The process of compiling database for carbon emissions from different power stations and respective grids has already started. The findings are analysed and synthesized. The results are encouraging and show that India’s Electricity Generation Management towards cleaner environment is on the right track. This has been possible by opting for better management, use of cleaner fuel, technical up-gradation generation process, use of advanced machineries, better transmission system, etc. So, the Government planned to reduce coal-based generations. Coal-based (electricity generation, which was approximately 58% of the total generation in 2011, has come down to 39% in 2022 (Table 7). It is seen that though electricity generation is increasing over time (Figure 14), emission coefficients from electricity generation, is significantly decreasing as a result of the beneficial actions made by Indian government (Figure 15). Since the advent of Renewable Energy (RE), India's average emission factor from electricity generation has significantly decreased (Table 8)

Table 8 - Weighted Average Emission Factor (Considering Renewable Energy Generation) of Indian Grid

FY	Total Emissions (Million Tonnes)	Total Electricity Generation (BU)	Average CO2 Emission Factor of Grid Electricity including RES (tCO2/ MWh)
2013 - 14	727.4	939.83	0.774
2014 - 15	805.4	1033.76	0.779
2015 - 16	846.3	1092.81	0.774
2016 - 17	888.34	1154.39	0.770
2017 - 18	922.18	1223.41	0.754
2018 - 19	960.9	1291.92	0.744
2019 - 20	928.14	1301.31	0.713
2020 - 21	910.02	1294.77	0.703
2021 - 22	1002.01	1401.01	0.715
2022 - 23	1091.962	1523.72	0.716

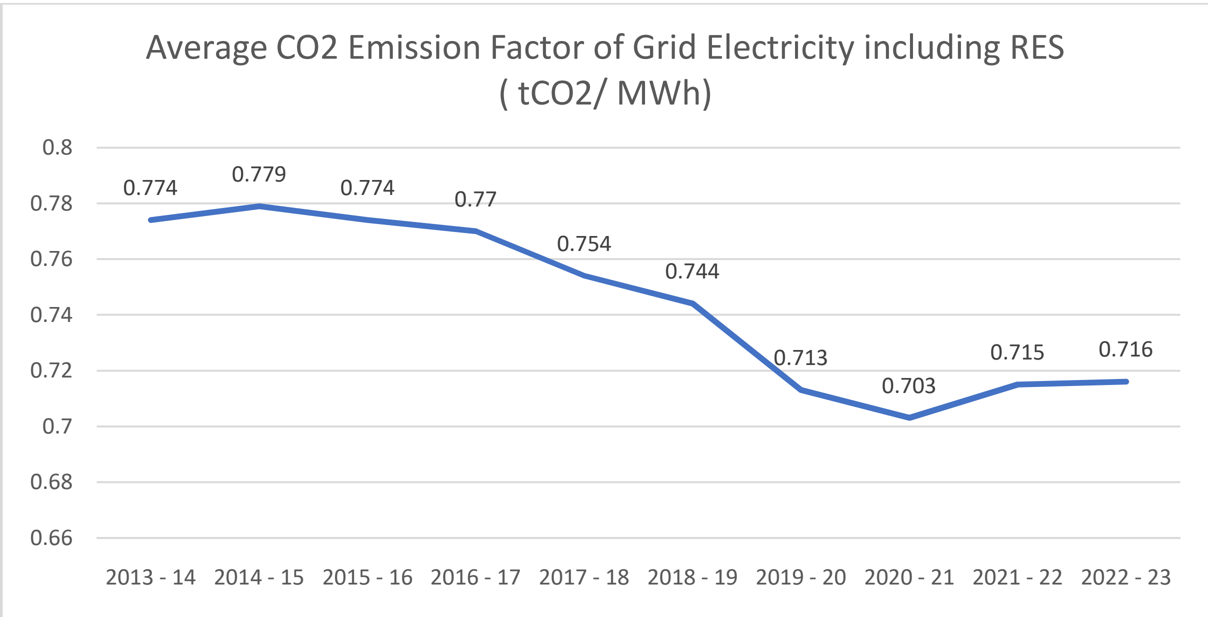
Source – CEA (Central Electricity Authority, 2023)

Figure 14 - Total Emission & Total Electricity Generation in India from 2013-14 to 2022-23



Source - CEA (Central Electricity Authority, 2023)

Figure 15 Average emission factor of grid electricity including RES (TonneCO2/MWh)



Source 3 – CEA (Central Electricity Authority, 2023)

According to cBalance Solutions Pvt. Ltd.'s 2009–10 GHG Inventory report on electricity generation and consumption in India, West Bengal's average emissions and, thus, its emission coefficient, are higher than the country's average (Central Electricity Authority, 2023) (Table 9).

Table 9 - Trends in Average Emission Coefficient in West Bengal, India

	Emission factor generation based.	Combined Emission Factor for End-User Consumption(considering AT&C loss)
	KgCO2/KWH	KgCO2/KWH
All India Average	0.89	1.1 kgCO2e/kWh
West Bengal Average	0.97	1.29 kgCO2e/KWh

Source - GHG Inventory report for Electricity generation and consumption in India 2009-10 - cBalance Solutions Pvt. Ltd (Ltd., 2009-2010)

2.3.2 Emission from Cooking Fuel

One of the most important attributes associated with Homo Sapiens is that they cook most of food that they eat which definitely differentiates them from all other living organisms. Man needs food to sustain. He cooks his food with heat or fire. This burning process associated with cooking emits CO2 to a great extent. The options for cooking fuel are the traditional ones like fire wood, coal, kerosene, dung-cakes, etc., and the non-traditional ones like LPG, Ethanol, and electricity (Gould & Urpelainen, 2018, November). Traditional solid fuel for cooking purposes is recognized globally as a severe health hazard (Lim SS, 2012 , December 15). Traditional cooking fuels cause dangerous levels of household air pollution that adversely affect the health of people staying in the house especially the women and the kids causing several respiratory disorders ((WLPGA)., 2020). According to the same estimate, indoor air pollution from the wasteful application of solid fuels and kerosene for cooking causes 4.3 million early deaths per year((WLPGA)., 2020). A comparative study of Greenhouse gas emission profile of LPG and other sources of energy in India and North America is provided in Table 10.

Table 10 GHG emission profiles: LPG & other energy sources - India, Japan, North America

Cooking Fuel	India	Japan	North America
Kerosene	1.23		
Wood (Traditional)	3.29		
Wood (Traditional) with carbon credit	0.66		
Crop Residue	5.19		
Crop Residue with carbon credit	2.01		
Dung Mud Stove	7.57		
Dung Mud with Carbon Credit	1.41		
Electric Coil	2.51		
LPG	1.00		
Induction		0.93	1.07
High Efficiency Natural Gas		0.95	0.86

Source - (Incorporated & WLPGA)

LPG provides an answer to all these ills of traditional cooking medium. As a clean burning fuel, it is much better than traditional fuel alternatives, thereby playing a vital part in developing health standards of inmates of a household. This becomes the reason that LPG, as a cooking medium, is becoming popular every day. In many regions of the world, LP Gas is one of the least carbon-emitting fuel options for cooking when compared to other fuels in terms of emissions overall and emissions per unit of energy utilized. For instance, in India, LP Gas produces 60% fewer greenhouse emissions than electric coil cooktops, 50% fewer than certain biomass stoves, and 19% fewer than kerosene stoves (Incorporated & WLPGA). According to this data, of the main energy sources, LP Gas has the lowest on-site emission rate, aside from natural gas. Since LP gas is mostly composed of butane and propane molecules, with trace amounts of other substances—the precise makeup of which changes globally—it is not a greenhouse gas when discharged into the atmosphere. Due to its lack of atmospheric persistence, LP gas vapor is often removed by natural oxidation when exposed to sunshine or knocked down by precipitation before it has a chance to mix completely and impact the climate on a global scale. There is currently no proof that emissions of propane or butane have an effect on the climate worldwide. There is currently no evidence of a global climate impact from butane or propane emissions (Incorporated & WLPGA). LPG has a “Global Warming Potential (GWP)” factor of zero since it is not a greenhouse gas, as per the United Nations “International Panel on Climate Change (IPCC)”. According to the IPCC, methane's GWP factor is 25 while CO2's is 1. (Consulting, 2009).

According to researchers T Amose and Jeyakumar T R (Amose & R, March, 2017), the Indian Government, in its stride to have a clean healthy environment, is trying, through its “Pradhan Mantri Ujjwala Yojana (PMUY)” launched in 2016, to make LPG as the only cooking fuel in India. According to the National Sample Survey 2009 10 (National Sample Survey office, 2012), the percentage of urban households employing LPG more than doubled from less than 30% to 64.5%, while the incidence of reliance on firewood for cooking has decreased from roughly 30% to 17.5% between 1993-94 and 2009-10, a decrease of more than 12 percentage points. During the same period, the incidence of reliance on kerosene has also decreased from 23.2% to 6.5%, a 72% decrease. Nowadays, LPG is a necessary component of every modern household. The fifth “National Family Survey 2019-2021 (NFHS-5)” (Ministry of Health and Family Welfare, 2021), as per research carried out by the “Ministry of Health and Family Welfare”, 89.7% of urban households cook using clean fuel. Cooking with clean fuels like LPG, PNG, or electricity is becoming more and more common. LPG is a universally accepted cooking fuel in urban households and will very soon become the only option (other than electricity – which is studied as a separate parameter in this study) as a cooking fuel.

So, with this scenario in India, this paper limits its study to only LPG as a cooking fuel in Urban households and skips all other options. Compact 5 kg cylinders of LPG are available for usage in mountainous, rural, and inconvenient locations; 14.2 kg cylinders are available for home use; and 19kg and 47.5kg cylinders are offered for commercial along with industrial utilization, respectively. For PLG calculations in this study, one LPG cylinder is assumed to hold **14.2 kg of LP gas**. The GHG Protocol Emission Factor from Cross sector Tools, March 2017 states that CO2 Emission factor for Liquified Petroleum Gas (LPG) is 1.612 Kg/Litre(Protocol, 2017).

2.3.3 CO2 Emission due to Idling Fuel Consumption of Vehicles inside a Residential Plot

One of the main contributors to the national GHG emissions—the second-largest contributor—is the transportation sector, which includes emissions from air, rail, water, and road transportation. In 2007, the industry released 142 million tonnes of CO_2 (Program, 2015). Two-wheelers and four-wheelers owned by residents are part of this huge emission in the urban areas. However, as described previously, the study of emissions by vehicles owned by the residents or household is restricted to only emissions by the same vehicles when inside the building site. The paper assumes that vehicles when inside the site are at idling phase, i.e. not moving, and for the simplicity of calculations ignore the very little amount of movement inside the site. Carrico et al. (Amanda R. Carrico, 2009) demonstrated with a wealth of data that idling a motor vehicle is a behavior or activity that should be taken into consideration by legislators. As the cars' idle period is fixed, it becomes necessary to determine how much gasoline or diesel the vehicles are using during this time. Though a lot of research paper and studies are there on consumption of petrol/diesel while the vehicle is running or moving, very few research work have been done on consumption of petrol/diesel by a vehicle during idling time i.e. when it is not moving. A comparative study of fuel consumption during idling time by various petrol vehicles is given in a research paper written by Niraj Sharma et al. (Sharma, Chalumuri, Kumar, & Singh, 2015). As per the paper, Idling Fuel consumption of vehicles in India is as follows (Table 11) –

Table 11 Summary of Mean Consumption of Petrol Vehicles tested at Idling

Sr. No.	Vehicle category	No. of vehicles Tested	Mean fuel consumption (ml/10 min)	Name of the City
1	Four wheeler	30	99.5	Bhopal
		49	88	Chandigarh
		18	107.3	Pune
		13	112.8	Chennai
		4	81.7	Kolkata
		29	98.6	Delhi
2	3 Wheeler	20	40	Bhopal
3	2 Wheeler	26	26.9	Bhopal
		22	25.3	Chandigarh
		11	22.3	Pune
		28	22.8	Chennai
		19	21.2	Vadodara
		5	27.6	Kolkata
		11	20.7	Delhi

Source - (Sharma, Chalumuri, Kumar, & Singh, 2015)

As per this paper, the mean value of consumption of petrol by motorcycles and cars across India is 0.14 litre / hour and 0.60 litre / hour (Table 12). The same study when done in Kolkata gave the mean values as 0.17 litre / hour for motorcycles and 0.49 litre / hour for cars (Table 13). The authors put the reason for variations in values of petrol consumption for the same category of automobiles to differences in engine capacity and vehicle technology. The same reason also applies to changes in consumption in different cities.

Table 12 Mean Value of Consumption of Petrol by Motorcycles and Cars in India

Mean Value of consumption of Petrol in **India**	Motorcycles (Petrol)	0.14	litre/hr
	Cars (Petrol)	0.60	litre/hr

Source - (Sharma, Chalumuri, Kumar, & Singh, 2015)

Table 13 Mean value of consumption of petrol by motorcycles and cars in Kolkata

Mean Value of consumption of Petrol in **Kolkata**	Motorcycles (Petrol)	0.17	litre/hr
	Cars (Petrol)	0.49	litre/hr

Source - (Sharma, Chalumuri, Kumar, & Singh, 2015)

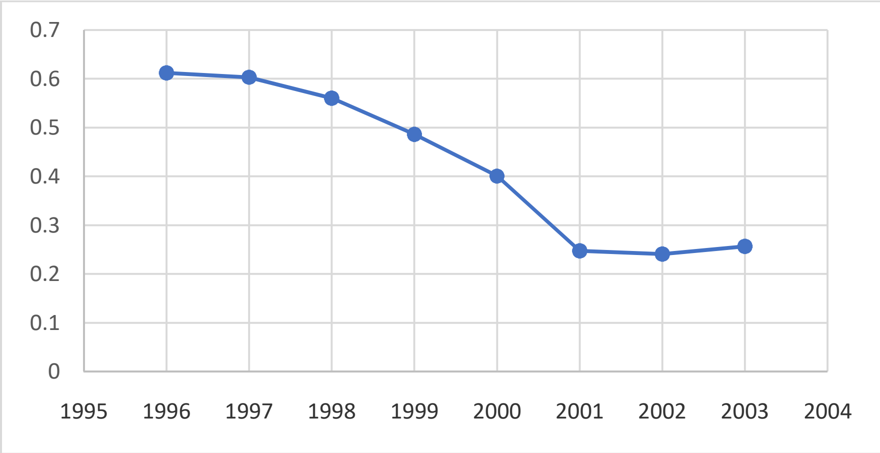
Technology is changing for the better and it applies to automobile industry also. The automobile sector is working on developing its products to give less pollution. This becomes quite clear when we investigate GHG Protocol emission calculation coefficients of petrol cars over last few years. It becomes clear from this chart (Table 14 & Figure 16) that CO2 emission factor has been reduced over the years with advancement of technology.

Table 14 CO2 emission factor of Petrol

YEAR	CO2 Emission from Petrol
1996	0.612
1997	0.603
1998	0.56
1999	0.486
2000	0.4005
2001	0.2475
2002	0.24075
2003	0.2565

http://www.ghgprotocol.org/calculation-tools/alltools

Figure 16 CO2 Emission of petrol from automobile



http://www.ghgprotocol.org/calculation-tools/alltools

The academic paper by Shailesh (Telang, 2011) titled "Carbon Footprint Calculation – A Small Introduction of ISO14064" fixes emission coefficient factor from automobile petrol consumption to 2.296 (Table 10)and puts calculation methodology as –

Emission due to Petrol= Input Value (in Litres / YR) x 2.296 (Emission Coefficient of petrol)

= Output Value (in KgCO2)

Emission due to Diesel= Input Value (in Litres / YR) x 2.653 (Emission Coefficient of diesel)

= Output Value (in KgCO2)

Emission factors included in Table 15 are used in all emissions calculations in the India GHG Program's 2015 India-specific Road Transport Emission Factors, which was authored by Stakeholder Consultation and published by the India GHG Program Secretariat.

Table 15 Emission Factor of Automobile Fuel

FUEL TYPE (Four-Wheelers)	**CO2 Emission**
Emission factor for Petrol (Motor Gasoline)	2.27 KgCO2/litre
Emission factor for Diesel	2.64 KgCO2/litre
Emission Factor for CNG	2.69 KgCO2/litre

Source (Program, 2015)

2.3.4 Emission from Respiration

CO2 is one of the common human breath components. In their research paper titled 'Human metabolic emissions of carbon dioxide and methane and their implications for carbon emissions,' the authors (Li, et al., August 2022)found that the average CO2 emission was around 28.7 g/h/person ± 2.1 g/h/person after quantifying the exhaled, dermal, and total body emission rates in a controlled environment. The authors clarify that the whole-body emission rate of CO2 varies with changes in humidity level, temperature variations, diet, and other things. This human metabolic carbon emission has a very negligible effect on the atmosphere when compared to other sources of emission. According to the authors, this emission process can be thought of as a cycle in which CO2 is taken from the atmosphere through photosynthesis, transformed into plant matter, then consumed by humans (either directly from plants or through animals that are fed plants), and finally returned to the atmosphere as CO2. The overall impact on the long-term accumulation of atmospheric CO2 is essentially insignificant because this released CO2 technically has very limited storage time in the atmosphere. However, it can be estimated at different values because there is some emission.

Y. T. Prairie and C. M. Duarte in their research paper 'Direct and indirect metabolic CO2 release by humanity' (Duarte, 2007) calculated 'direct' metabolic CO2 emission, i.e. emission due to metabolism released by humans and domesticated animals through respiration and 'indirect' metabolic CO2 emission, i.e. emission due to decomposition of their resulting wastes to find out their contribution of humanity to CO2 footprint. The authors point out that this part of emission by humans is not considered with importance by the IPCC (2001) and are not taken into account when formulating strategies for mitigation of GHG emission. They express the same concern as many other researchers that anthropogenic metabolic CO2 emission is considered as a part of a cycling process between the atmosphere, vegetation and humans and animals. The paper iterates that this component of CO2 flux must be recognized in all analysis, quantification, and mitigation of CO2 emission scenario.

Tristam O West (Tristram O. West, 2009) in their study "The human carbon budget: an estimate of the spatial distribution of metabolic carbon consumption and release in the United States," as food is now farmed in concentrated agricultural regions and transported over long distances for human consumption in metropolitan areas, they tried to support their claim that the transfer of carbon for human consumption and its emission through metabolism processes is becoming more complicated. As heterotrophic organisms, humans absorb carbon from complex carbohydrates and expel it as carbon dioxide, methane, and a variety of solid, liquid, and volatile waste products. The cyclical process is frequently regarded as an activity that contributes "no net carbon flux to the atmosphere." However, research into the spatial distribution and mobility of carbon is necessary, and as a result, the emission process must be accorded the weight it deserves.

2.3.5 Emissions from water use

One of the primary needs of urban residential buildings is potable water for its residents. Carbon emission associated with potable water production (PWP) and its supply needs to be recognized as an important concern (Pritom Bhowmik Akash, 2024 september). Many researchers have studied GHG or CO2 emissions from urban water systems- showing without any doubt that this emission is considerable and needs more research and proper mitigation. Zihan Gui, Heshuai Qi, and Shiwu Wang in their research paper titled 'Study on Carbon Emissions from an Urban Water System Based on a Life Cycle Assessment: A Case Study of a Typical Multi-Water County in China's River Network Plain' have investigated the water-carbon nexus of a small county in China called Yiwu City (Gui, Qi, & Wang, 2024). The authors clearly state that carbon emission from water system in any city or place depends a lot on the water sources and distribution system and will vary greatly from emission of water supply system of any other place due to these reasons. However, Kolkata, the location of our research, is extremely similar to Yiwu City, where the research has been conducted. Both locations are on a river plain with low-lying terrain and a wealth of surface and groundwater resources. Because of their similar topographies, it can be predicted that the emission patterns from the water supply systems in Yiwu City and Kolkata will be very similar. The results of a study conducted in Yiwu can therefore serve as a guide for a study conducted in Kolkata. Similar to a residential building, this study reveals that, when examining the life cycle of an urban water system, 86% of carbon emissions come from the supply system's operating phase, whereas only 9% come from the system's construction. According to the authors, sewage collection and treatment account for 31% of carbon emissions from the urban water system, while water treatment, distribution, and transportation account for 39%. Considering high-quality water supply scenario, the paper finds carbon footprint intensity of Yiwu City as **0.90 kgCO2eq/m3**= **0.0009 kgCO2eq/litre** of supplied water. The paper takes into account all four stages abstraction and treatment, distribution, consumption, along with wastewater treatment for quantification method.

(Pritom Bhowmik Akash, 2024 september) do a more elaborate and detailed quantification of emissions for potable water production (PWP) for a place in Chittagong Bangladesh. This research paper specifies that emissions from ground water (GW) and surface water (SW) are considerably different – emissions from SW are much higher due to more contamination than in GW. Air fallout, surface runoff, and human activities like industry and agriculture all contribute to the increased contamination of surface water. Because dirt naturally filters it, ground water is less likely to get contaminated. This paper calculates carbon footprint of potable water to 0.18 kgCO2eq/m3 from treatment of raw water, 0.37 kgCO2eq/m3 for transmission from treatment plant to booster pumps, 0.06 kgCO2eq/m3 to distribute water in the city by booster pumps, 0.02 kgCO2eq/m3 for lifting to/ overhead tanks and, lastly, the maximum share of 17.97 kgCO2eq/m3 for purification by boiling at the household level. The total, considering all stages, comes to 18.526 kgCO2eq/m3, and excluding the last two stages comes **to 0.61 kgCO2eq/m3 = 0.00061 kgCO2eq/litre**. The paper does not consider emission at the wastewater treatment phase for quantification method.

As per the "Bureau of Indian Standards", IS:1172-1993 (STANDARDS, 1993), houses with a complete flushing system shall have a minimum water supply of 200 "Liters Per Capita Per Day (LPCD)" for domestic usage. Additionally, it states that for "Low-Income Groups (LIG)" and "Economically Weaker Sections (EWS)", the amount of water that must be provided to a home might be lowered to 135 lpcd. (ABDUL SHABAN, 2007) in their paper titled 'Water Consumption Patterns in Domestic Households in Major Cities' found out water consumption patterns in different cities of India including Kolkata (Table 16). The authors suggest that water consumption by household depends strongly on water availability. Water is abundant in Kolkata and that's why the consumption of water is maximum in Kolkata.

Table 16 Domestic Water Consumption per household and per capita per day (in Litres)

Cities	Per Household	Per Capita Mean
Delhi	377.7	78.0
Mumbai	406.8	90.4
Kolkata	443.2	115.6
Hyderabad	391.8	96.2
Ahmedabad	410.9	95
Kanpur	383.7	77.1

Source - (ABDUL SHABAN, 2007)

2.4 Discussion & results - Literature Review 1 – CO2 emission

2.4.1 Sources of emission& associated parameters

The literature survey shows that the subject of emission of CO2 from urban residential buildings and in the operation, phase only is complex and needs detailed and careful investigation. There are different ways of approaching the matter and researchers have worked endlessly towards it. First, as mentioned previously, we try to set our focus on the matter of emission 'causes' or building activities emitting CO2 during operation phase investigated by different researchers. Sources which are mentioned to be probable causes of CO2 emission are electricity, fuel for cooking, fuel for vehicles, respiration, paper consumption, and water consumption (Table 17)

Table 17 Activities of Residential Building considered for study and quantification process of CO2 Emission by existing Research Papers

SL. No.	Research Paper	Note	Electricity	Fuel for cooking	Fuel for Vehicles	Paper consumption	Respiration	Potable water production	Others
1	Xiaomei et al (Xiaomei Yan, 2018)	Fields not properly mentioned							
2	(Gupta, 2011) (Gupta, 2011)	mentioned	Yes						
3	Shailesh Telang Telang, 2011	mentioned	Yes	Yes	Yes				
4	S G Deshmukh (Deshmukh, 2015)	mentioned	Yes (as per actual according to logbook entry)	Yes	(only Petrol)	Yes			Diesel (as a stand-by to electric ity)
5	Kaveri Patil and Aparajita Chattopadhyay Kaveri Patil, 2013	mentioned	Yes	Yes (electricity water supply, space heating, and lighting only)					

Table 12 shows that different research papers have taken into account varied activities connected with the building that they have thought to be the causes of CO2 emission. Some papers have put reasons for such inclusion or exclusion of activities – like making the scope of research limited or having simply not considered the activities. It is also very difficult to say whether these sources mentioned in the previous papers are the only ones that probably emit CO_2 in the operation stage of residential buildings. The papers have also quantified the CO_2 emission from different sources. They have calculated which sources emit more quantity of CO_2 and which are less emitters.

Going through information provided by the literature study, this research paper finalises to study sources of CO_2 emission from residential buildings in the operation phase as – **1) electricity, 2) fuel for cooking, 3) fuel for vehicles, 4) respiration, 5) potable water production**. Previously almost no researcher studying CO_2 emission from operation phase from residential buildings has investigated the role of respiration in CO_2 emission from residential buildings during the operation stage considering it as a part of natural CO_2 cycle where Carbon Dioxide gets transferred into carbohydrate by plants by the process of photosynthesis, that carbohydrate after consumed by human beings changes into free CO_2 in the atmosphere by the process of metabolism and again is consumed by the plant by photosynthesis. However, since this paper is also trying to quantify CO_2, emitted by the residential building during operation stage, which can be sequestered by plants and trees inside the building site, it becomes imperative to take emission from respiration into account. It is also found that very few researchers studying CO_2 emission from operation phase of residential buildings have considered potable water production in their study when investigating operation phase CO_2 emission from residential buildings. There are, however, research papers identifying the problem and studying it as a separate subject and not associating it with emissions from residential buildings.

2.5 Quantification methods& emission factors

As mentioned previously, different researchers have worked with different factors of CO_2 emission over the years. When primary and secondary papers are searched for these CO_2 emission factors, it is found that they have mostly adhered to 'emission factors' provided by previous literature or standards set by IPCC IEA CEA, or other organizations. However, when research papers are scrutinized properly, it reveals that this ' emission factor' is chosen as a standard procedure without giving importance to the parameters governing them. Emission factors depend on lot many parameters and change due to many reasons like time frame, local factors, technological aspects of production of energy, etc. A detailed look at few research papers shows that there are huge differences in emission factors chosen by them (Table 18).

Table 18 Activities of Residential Building considered for study and quantification process of CO2 Emission by existing Research Papers

SL. No.	Research Paper	Note	Electricity	Fuel for cooking	Fuel for Vehicles	Paper consumption	Respiration	Potable water production	Others
1	Xiaomei et al (Xiaomei Yan, 2018)	Fields not properly mentioned							
2	(Gupta, 2011) (Gupta, 2011)	mentioned	Yes						
3	Shailesh Telang Telang, 2011	mentioned	Yes	Yes	Yes				
4	S G Deshmukh (Deshmukh, 2015)	mentioned	Yes (as per actual according to logbook entry)	Yes	(only Petrol)	Yes			Diesel (as a stand-by to electricity)
5	Kaveri Patil and Aparajita Chattopadhyay Kaveri Patil, 2013	mentioned	Yes	Yes (electricity water supply, space heating, and lighting only)					

2.6 Literature review 2 – CO2 sequestration from residential buildings

2.6.1 Role of plants in CO2 sequestration

The Paper by Egbuche Christian Toochi (Toochi, 2018) emphasizes the huge potential of trees and plants as "Natural Scrubbers" – cleaning the atmosphere by absorbing and storing CO2 – technical term being "Carbon Sink ". In the paper 'Carbon Sequestration: How Much Can Forestry Sequester CO2?', Carbon sequestration can be explained by photosynthesis and how trees convert CO2 from the atmosphere into organic carbon. To support his argument, the document cites ARTICLE 3 of the KYOTO PROTOKOL. The author determines the total weight of CO2 that a tree sequesters in a year by calculating the tree's green weight, dry weight, total weight of carbon in the tree, and total weight of carbon sequestered in the tree. Here, the author explains that a simple equation may be employed to evaluate a tree's weight **in pounds** by utilizing two pieces of information: 1) the tree's diameter **in inches**, and 2) its height **in feet**. However, the paper never mentions the method for such calculation. Additionally, the formula or procedure for determining the tree's dry weight is never mentioned by the author. The average weight of carbon in a tree is calculated as 50% of its dry weight. The total weight of carbon stored in a tree and the total weight of CO2 stored by the tree each year are calculated through chemical analysis. The Author also gives some examples of calculating carbon sequestration in a tree and concludes by emphasizing the importance of this process of carbon sequestration to mitigate the effects of Greenhouse gases.

A 1998 research by the Energy Information Administration of the U.S. Department of Energy titled "Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings" (Administration, 1998)attempted to develop a suitable technique for estimating the amount of carbon stored by trees while accounting for a greater number of trees planted separately in urban and suburban areas. The limitations are well drawn - Method is appropriate only for calculating planted trees, such as trees typically planted in the open along streets, in yards, and in parks. The Paper presents a Worksheet to calculate Carbon Sequestration in Urban setting of Nursery raised trees. It takes into account - 1) Species Characteristics – Name of Tree, 2) Tree Type – Hardwood / Coniferous, 3) Growth rate - Slow / Moderate / fast, 4) Tree Age, 5) Number of Age 0 planted, 6) Survival factor, 7) Number of Surviving Tree, 8) Annual Sequestration Rate (lbs / year), 9) Carbon Sequestered (lbs). The process of Calculation, though complex, is precise and exhaustive.

The study lists common urban tree species in detail. The report contains a table with typical urban tree survival factors and annual carbon sequestration rates. The source of this table is not given. To demonstrate how to use the worksheet, the publication includes a sample urban forestry carbon sequestration worksheet. A very important information provided is a table specifying survival factor of some trees. This is used to calculate the number of trees to be planted to attain a specific sequestration target.

The Research generally is based on all existing / already established formulas, facts, factors, coefficients.

Rowan A. Rowntree and David J. Nowak, in their research work ‘Quantifying the role of urban forests in removing atmospheric carbon dioxide’ (Nowak, 1991) had tried to quantify the carbon sequestration in an urban area and set a model for urban foresters to use for estimation of carbon sequestration. It is exhaustive with methods adopted for calculating urban carbon sequestration very systematic and detailed. Though the empirical formulas used for calculations are based on lot of assumptions, the authors accept that and mention source of the formulas / assumptions. The method works on assumptions based on tree crown cover. However different types of trees are dealt with – hardwood, conifers, tress with different diameters, ages, etc. It also works on tree population and diameter distribution in urban areas. According to the report, over the next 50 years, the United States should plant 250 million more trees, or 5 million trees annually, increasing the average urban tree cover by 5% (from 28% to 33%). Along with replanting the 39 million additional trees that were lost to mortality, this should be done.

The paper also demonstrates an example of an organization wanting to offset their CO2 emission with trees. The “Dutchess County Environmental Management Council, located in Millbrook, New York”, occupies the building. Electric energy from various sources, such as nuclear power, natural gas, and fossil fuels, is taken into consideration when calculating the total amount of energy used. Total CO2 emitted in generation was found to be 10.1 tonnes. Applying molecular formula, carbon footprint from electricity was found to be 2.8 tonnes in 1989. Whereas carbon emitted by process of heating the building was found to be 28.1 tonnes (point to note the huge difference from carbon footprint due to electricity). Total carbon footprint was 2.8 +28.1 tonnes = 30.9 tonnes. An analysis is also provided to tackle the issue of offsetting this amount of carbon footprint. The paper also includes a unique study that tries to help individuals offset their per capita Carbon emission. The authors ask all individuals to plant as many trees as possible to tackle the emission problem.

The research paper ‘Profiling indoor plants for the amelioration of high CO2 concentrations’ by F.R. Torpy, P.J. Irga, M.D. Burchett(Torpy, Irga, & Burchett, 2014)is unique in the sense it works on CO2 sequestration of indoor plants and reduction of indoor CO2 levels due to respiration in office set-ups. The authors point out that there have been very few investigations in this field. They argue that a certain amount of indoor CO2 can be eliminated by carefully selecting indoor plant species, increasing the number of plants, and installing lighting that is particular to each plant. The paper claims that indoor light levels significantly affect how indoor plants photosynthesize, with higher light intensities resulting in higher rates of CO2 removal. The results of the experiments done with eight specific species of indoor plants, all grown in 200mm diameter pots and at different light levels (high & low), showed that CO_2 sequestration levels ranged from 47.9 to 168 mgCO_2/plant/hr. The paper specifies some information from literature study -1) highest sequestration rate is 657mgCO_2/m2 leaf area/ hr, 2) 5m2 of green wall contains - 57m2 of leaf area, 3) 68mg CO_2/m2 leaf area/h is the sequestration rate for 'areca palm'. A research paper in this field but considering Indian conditions would have been a welcome step for any quantification study of CO_2 emission – sequestration balance in urban Indian residential premises.

B M Kumar has extensively documented the unique role that tropical home gardens play in sequestering carbon (C) due to their capacity to store carbon in the soil, wood products, and standing biomass (kumar, 2006) The author justifies that this process of reduction of carbon by sequestration through home gardens is much cheaper and effective than other available processes. The structure and richness of a mature evergreen forest formation are genuinely recreated in the home garden, which includes a wide variety of plants.

An experimental research project by CRISIL ((CERE), 2021), In 2019, 2020, and 2021, In 2021, 33,368 of the 39,680 trees planted ((CERE), 2021) by a global analytical company—India's top provider of ratings, data, research, analytics, and solutions—were still alive. Additionally, 13,574 saplings were tracked at ten different locations in the cities of Pune and Mumbai, four of which had conventional plantations and six of which had Miyawaki plantations. The 33,368 trees and plants will contribute to the sequestration of 8646.29 MTCO_2 during a 15-year period, according to data obtained using a combination of geotagging and ocular observations. The creation of multiple habitats for urban biodiversity, including insects, birds, reptiles, and small mammals, is another point made by CRISIL. In addition, 135 different native tree species will be planted as part of this operation. Many members of the local villages also relied on the plantation operations and upkeep as a source of income.

2.7 Existing guidelines and building rules

2.7.1 The Department of Municipal Affairs, The Government of West Bengal

The "Ministry of Urban Development (MoUD)" launched the "Atal Mission for Rejuvenation and Transformation (AMRUT)" in 2015. The Department of Municipal Affairs, Government of West Bengal, which administers the Newtown area, launched the AMRUT in

2016. In an effort to lower emissions and other pollutants, the government of West Bengal and India has taken aggressive measures to enhance the amount of green space in urban areas. The authority has laid down certain rules and regulations which following are quite relevant to our present study –

1) To reach a green cover of 15% in the urban areas by 5 yrs from its inception
2) To make mandatory rules for all new housing schemes to have 15% green cover – this provision is to be considered during the time of sanction from urban local bodies.
3) To encourage the involvement of citizens, communities, and private sectors in the creation and maintenance of urban green space
4) To carry out tree census periodically
5) To make obligatory the role of citizens to support tree preservation and to encourage plantation through incentives.
6) To create nurseries to support plantation
7) Terrace garden to be permitted to improve green space
8) Attempt to be made to cover every building with tree lines around it

2.7.2 Newtown Kolkata Development Authority (NKDA) building rules

The NKDA has only one (1) rule regarding green open space for proposed building plots**. An open green space amounting to 4% of the site area is to be left open to sky and without any paving in plots less than 1500 sqm. as a step to counter carbon footprint**. As such, in Indian urban municipalities, there are not much legally binding rules for plot development considering plantation. Kolkata for instance, once used to have a rule of planting two (2) number small trees in all plots for building development, which is presently not there. Other cities and municipalities, in west Bengal and also in India, also do not show much interest in formulating rules regarding green open space or compulsory plantation during building development.

2.8 Discussion & results - Literature Review 2 - Co2 sequestration

It is provoking that not much research and investigation has been conducted on sequestration by plant species in tropical areas (Toochi, 2018). Some research work has been done considering Indian local trees, forestry, and agricultural lands. However, there is almost no literature on sequestration by urban home gardens The analysis faces significant challenges due to the absence of reliable inventories or estimations and inconsistencies in estimating the carbon sequestration capacity of residential gardens. (kumar, 2006). There is definitely a huge research gap in this field of carbon sequestration by plants, especially the local (West Bengal) urban home-grown small-size plants. Carbon Sequestration, as per all papers, totally depends on number of plants, volume or leaf area, the weight of plants, or physical conditions like water supply and light availability. With almost no relevant information on Carbon sequestration rates of small-size local plants, it becomes prudent enough to fall back on one or two research papers that are more appropriate and applicable considering all parameters. Out of all research papers studied the papers by Torpi et al. (Torpy, Irga, & Burchett, 2014) studying carbon sequestration by indoor plants is worth mentioning as it is the only paper that, though based on foreign conditions, gives us information about indoor plants and also small plants. The author specifies that is very difficult to actually assess the rate of sequestration by plants as it depends upon the species type, physical conditions inside the house, and most importantly the lighting conditions. However keeping aside the foreign conditions of the research study, dealing with mostly different species of trees not appropriate to tropical conditions, this research work still draws the sequestration rate factor for quantification of CO2 consumed by indoor plants based on this paper (Torpy, Irga, & Burchett, 2014) only. The paper mentions that sequestration rate for indoor plants ranges from 47.9 mgCO2/plant/hr to 168 mgCO2/plant/hr, depending upon varying light conditions and different species. To deal with this huge range, this paper considers an average of this range, i.e. **107.95 mgCO2/plant/hr = 0.001 TonneCO2/plant/year** (average of47.9 mgCO2/plant/hr and 168 mgCO2/plant/hr) as the sequestration rate for any indoor plant. The other research paper where analytical information can be used for this research work is the paper by CRISIL ((CERE), 2021). This research, though not dealing with entirely small home-grown plants, was based on entirely outdoor trees and plants in absolutely urban Indian context. There is information on small and mid-size outdoor trees and plants that are of Indian origin and are grown in urban areas with tropical hot and humid climates. A reference guideline for quantification of CO2 sequestration by plants in Indian urban scenario can be drawn from CRISIL research work. The findings of the research work can be analysed to deduce the average CO2 sequestration by plants in Indian urban context as 8646.29 MTCO2 by 33,368 trees over a span of 15 years **or 0.019 TonneCO2/per plant/year.**

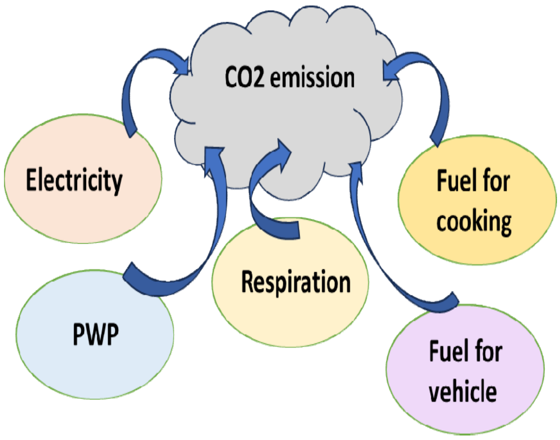
2.9 Conclusion – Literature review 1 & 2

2.10 Identification of sources of emission –

Going through information provided by the literature study, this research work identifies sources of CO_2 emission from residential buildings in the operation phase as (Figure xx)–

1) **Electricity consumption,**
2) **fuel consumption for cooking,**
3) **fuel consumption for vehicles,**
4) **respiration,**
5) **potable water production consumption**

Previously almost no researcher studying CO_2 emission from operation phase from residential buildings has investigated the role of respiration in CO_2 emission from residential buildings during the operation stage considering it as a part of natural CO_2 cycle where Carbon Dioxide gets transferred into carbohydrate by plants by the process of photosynthesis, that carbohydrate after consumed by human beings changes into free CO_2 in the atmosphere by the process of metabolism and again is consumed by the plant by photosynthesis. However, **since this paper is also trying to quantify CO_2, emitted by the residential building during operation stage, which can be sequestered by plants and trees inside the building site**, it becomes imperative to take emission from respiration into account. It is also found that very few researchers studying CO_2 emission from operation phase of residential buildings have considered potable water production in their study when investigating operation phase CO_2 emission from residential buildings. There are, however, research papers identifying the problem and studying it as a separate subject and not associating it with emissions from residential buildings.



Sources of emission mentioned in existing literature and not considered –

1) Consumption of paper - to limit scope of work

2) Consumption of diesel in generators - generators are hardly used in used in mid-size residential buildings in Study area residential buildings.

Sources of emission not mentioned in existing literature and not considered –

1) Consumption of all materials and goods during operation phase for livelihood of residents – due to non-availability of information in existing literature. This field needs proper research work.
2) Maintenance activities – to limit scope of work

2.11 CO2 Emission Factors –

2.11.1 Consumption and CO2 emission factor - Electricity

A huge difference in quantification methods & results are produced when results of literature study are analysed. The factor of CO2 emission for electricity generation and transmission ranges from 0.716 to 0.929 kgCO2/KWH, even 1.59 for coal-based generations. This is primarily because of various reasons like –

- place of generation, source of electricity (Coal/hydel/Renewable, etc.), transmission system, age of generation plant, and technical conditions adhered to during production.
- the conditions of generation in India are hugely different from those in USA China Europe, or any other place. Logically it becomes erroneous to use coefficient factor given by international and other standards. It is best to find the coefficient of emission of the electricity generation plant from where the electricity is being used. If this data is not available for any reason.
- Another primary reason for variation in CO2 emission factor is the **time frame** of the different research papers – the value of emission factor changes over time. With the government **upgrading all plants** and taking all necessary measures to reduce emission, the coefficient of emission from electric generation plants is continuously reducing.

The CEA, in 2022-23, has recorded the national average emission factor for CO2 as 0.716KgCO2/KWH, considering all types of electric generation units in India, including conventional sources like hydel and thermal power plants and renewable energy (RE) production(Central Electricity Authority, 2023) . Logically this value is a **national average and not for Kolkata or Newtown** and is not fit for application in Newtown - the chosen site for this research paper. True, it will be best suited if we can get the emission factor for the generation plant where-from electricity is drawn for the chosen site. **But in the absence of this information, this research paper opts for the projected national average (0.716KgCO2/KWH) as per CEA.**

2.11.2 Consumption & CO2 Emission Factors – LPG

Local level investigation showed that 1 cylinder of LPG contains **14.2 kg of LP Gas**. The GHG Protocol Emission Factor from Cross sector Tools, March 2017 states that CO2 Emission factor for Liquified Petroleum Gas (LPG) is **1.612 KgCO2/Litre (Protocol, 2017) = 2.985 KgCO2/kg of LPG (density of LPG = 0.54 Kg/litre).** LPG is a universally accepted cooking fuel in the urban households and will very soon become the only option (other than electricity – which is studied as a separate parameter in this study) as a cooking fuel. The fifth National Family Survey 2019-2021 (NFHS-5) (Ministry of Health and Family Welfare, 2021) carried out by the Ministry of Health and Family Welfare, 89.7 percent of Urban Household use clean fuel for cooking.

2.11.3 CO2 Emission Factors – Respiration

The CO2 emission factor for respiration by residents is taken as 28.7 g/h/person = **251.41 KgCO2/person/annum** from research paper Human metabolic emissions of carbon dioxide and methane and their implications for carbon emissions,' by authors (Li, et al., August 2022). The authors clarify that the whole-body emission rate of CO2 varies with changes in humidity level, temperature variations, diet, and other things.

2.11.4 Consumption & CO2 Emission Factors – Potable Water Distribution (PWP)

This research work decides to rely on Indian Standards and consider the average water consumption from Bureau of Indian Standards, IS:1172-1993 (STANDARDS, 1993). The average water consumption from the public water supply distribution system is taken as 200 litres/person/day.

The literature review states that carbon emission from water system in any city or place depends a lot on the water sources and distribution system and will vary greatly from emission of water supply system of any other place due to these reasons. However, Kolkata, the location of our research, is extremely similar to Yiwu City, where a research has been conducted. Both locations are on a river plain with low-lying terrain and a wealth of surface and groundwater resources. Because of their similar topographies, it can be predicted that the emission patterns from the water supply systems in Yiwu City and Kolkata will be very similar Considering high-quality water supply scenario, the paper finds carbon footprint intensity of Yiwu City as 0.90 kgCO2eq/m3 = **0.0009 kgCO2eq/litre** of supplied water.

2.12 Sequestration by plants

Indoor Plants - The paper by Torpi et al. (Torpy, Irga, & Burchett, 2014) mentions that sequestration rate for indoor plants ranges from **47.9 mgCO2/plant/hr to 168 mgCO2/plant/hr**, depending upon varying light conditions and different species. To deal with this huge range, this paper considers an average of this range, i.e. 107.95 mgCO2/plant/hr = **0.001 TonneCO2/plant/year** (average of47.9 mgCO2/plant/hr and 168 mgCO2/plant/hr) as the sequestration rate for any indoor plant.

Outdoor Plants - The other research paper where analytical information can be used for this research work is the paper by CRISIL ((CERE), 2021). This research, though not dealing with entirely small home-grown plants, was based on entirely outdoor trees and **plants in absolutely urban Indian context**. There is information on small and mid-size outdoor trees and plants that are **of Indian origin** and are grown in **urban areas with tropical hot and humid climates**. A reference guideline for quantification of CO2 sequestration by plants in Indian urban scenario can be drawn from CRISIL research work. The findings of the research work can be analysed to deduce the average CO2 sequestration by plants in Indian urban context as 8646.29 MTCO2 by 33,368 trees over a span of 15 years or **0.019 TonneCO2/per plant/year**.Information that are found to be useful for CO2 sequestration quantification in this research work and is obtained from existing literature studies are presented in Table 19 –

Table 19 Information obtained from Literature Review - CO2 Sequestration

CO2 Sequestration rate	Source	Rate/ coefficient/factor
CO2 Sequestration rate by indoor plants	(Torpy, Irga, & Burchett, 2014)	0.001 TonneCO2/plant/year
CO2 Sequestration rate by plants (as per leaf area)	(Torpy, Irga, & Burchett, 2014)	is 657mgCO2/m2 leaf area/hour,
5 sqm. of green wall contains	(Torpy, Irga, & Burchett, 2014)	57 sqm. of leaf area
CO2 sequestered by outdoor plants and small trees	CRISIL ((CERE), 2021)	0.019 TonneCO2/per plant/year

3 CHAPTER 3 - STUDY ON METHODS OF CO2 EMISSION QUANTIFICATION FROM URBAN RESIDENTIAL BUILDINGS IN OPERATION PHASE

3.1 Introduction

This research paper, as previously mentioned, intends to investigate emission from buildings. The research had further set the boundaries as study of only CO2 emission and exclude other GHGs, from only residential buildings and in urban areas, the character of the buildings being multi-tenement and structurally multi-storied. During the process of research, it was concluded that, though this paper is dealing with 'multi-tenement' and 'multi-storied' residential buildings, it would be more logical to also include single tenement individual residential houses as they form the basic unit of residential living. The study of previous research papers, have shown that most of them have followed Life Cycle Analysis (LCA) method to identify sources of CO2 emission and to quantify the amount of CO2 emission from residential buildings. Since the LCA method takes into account the whole life cycle of the building, considering all indirect and direct parameters of the emissions or ambient energy factors, it becomes logical to adopt this method for this paper also. This process involves the division of the whole cycle of the building into generally six life phases of the building – 1) Extraction and production, 2) Transportation, 3) Construction, 4) Operation, 5) Demolition, 6) Recycling (Yan, 2018). This research work fixes its research boundaries to only '**operation stage**' of the residential building and tries to find out the probable causes or sources of emission from the building, the parameters governing the emission from these sources and a logical quantification method of the CO2 emission. This research work further investigates the amount of CO2 that can be sequestered by plantation within the premises and how that plantation can be increased to have the optimal reduction of CO2 through sequestration.

3.2 Identification of sources of CO2 Emission

Previous research work has shown that some of them have considered some sources of CO2 emission from urban residential building in the operation stage and skipped few. Since this paper deals with only the CO2 emission from operation phase of the building, it was felt that all the sources mentioned in different research work should be ideally taken into consideration. To find causes or sources of CO2 emission the research was designed to wholly depend on previous and existing research papers. As previously stated, CO_2 emission from respiration by residents have never been taken into account in existing research papers - considering it as a part CO_2 Cycle. However, testing of quantitative balance between CO_2 emission by the building through different activities of the tenements and again consumption of CO_2 by the building itself by photosynthesis by plants inside the site being the primary objective of the thesis, it was decided to include respiration by the residents as a source of CO_2 emission and consider it for all quantification method. After going through all information from various primary and secondary literature, the sources of emission are identified as **1) electricity, 2) fuel for cooking, 3) fuel for vehicles, 4) respiration, 5) potable water production.**

3.3 Quantification approach

3.3.1 Background

After going through the literature survey, the research approach adopted for energy consumption quantification, was set as – 1) to obtain **energy consumption data** like electricity usage and fuel usage for cooking through *Sample Survey* of existing residential buildings in operation,2) in situations where energy consumption data cannot be obtained from sample survey (like potable water consumption), standards and factors related to consumption are retrieved from *primary and secondary literature* and quantification processed, 3) where information regarding any consumption of energy or related matters is neither available in existing research papers nor is it possible to find through survey, the quantification process is based on '*logical assumptions of some facts' like* time span of use of vehicles inside the site, 5) to calculate emission of CO_2 from respiration using information on number of residents from *sample survey* and emission factors from *existing research papers.*

3.3.2 Energy variants & associated parameters

Considering more detailed introspection of the sources of CO_2 emission from urban multi-storied and multi-tenement residential buildings it is decided to study qualitative and quantitative usage and effects of different variants of energy sources. Literature review had provided the information that in India electric generation is based of different sources, like coal, hydel and even nuclear plants and renewable energy like wind and solar. All of them have different factor of CO_2 emission. Factor of CO_2 emission also varies due to age of the electricity generation plant and the system it adopts to generate electricity. The loss of electricity due to transmission system is also to be considered when CO_2 emission factor is to be considered. Various papers have adopted different logic when considering this CO2 emission factor from electricity generation (Table 20). However, they mostly depend on secondary literature or standards set by IEA, IPCC or national level government organisation or non-government organisation. This paper also concluded that, when studying the emission of CO2 from cooking fuel consumption in urban multi-storied multi-tenement residential building, only LPG is considered and when investigating emission of CO2 from vehicle use by the tenements, only Petrol will be taken into account.

Table 20 Energy consumption and emission factors derived from literature review

Sources of Emission	Consumption Factor	Source	Emission Factor	Source
Electricity	-	-	0.716 KgCO2/KWH)	CEA (Central Electricity Authority, 2023)
Cooking Fuel (LPG)	Each Cylinder in India contains 14.2 Kg LPG	-	1.612 Kg/Litre	The GHG Protocol Emission Factor from Cross sector Tools, March 2017(Protocol, 2017)
4-wheelers Fuel consumption during Idling time (petrol)	0.6 litre/hr	Niraj Sharma et al. (Sharma, Chalumuri, Kumar, & Singh, 2015)	2.27 KgCO2/ litre	India GHG Program's 2015 India-specific Road Transport Emission Factors(Program, 2015)
4-wheelers Fuel consumption during Idling time (petrol)	0.14 litre/hr	Niraj Sharma et al. (Sharma, Chalumuri, Kumar, & Singh, 2015)	2.27 KgCO2/ litre	India GHG Program's 2015 India-specific Road Transport Emission Factors(Program, 2015)
Respiration	-	-	28.7 g/h/person = 251 KgCO2/ person/annum	(Li, et al., August 2022)
Potable Water Production				

3.4 Categorization of buildings

To investigate the quantification method of CO2 emission during the operation phase of a multi-tenement residential building in an urban area, and for a better understanding of the subject, it was decided not to restrict the study to only multi-tenement buildings, but also extend the study to single tenement buildings and individual flats. The research was designed to study different building typologies depending upon tenement sizes, building structures and location (Table 21).

Table 21 Building typology studied

Building Typology	TENEMENT TYPE
CATEGORY I	Single Tenement - Individual houses (2 storied)
CATEGORY II	Individual Flats in multi-storied and multi-tenement buildings (G+3 & G+4)
CATEGORY III	Whole Building (Entire Plot, Individual Flats and Common Areas) (Garage + 4 storied)

3.5 Calculation Units

This research paper considers the final functional unit of CO2 emission as 'TonneCO2/annum' for all quantification process of CO2 emitted by the building. This unit of calculation is taken to make all accounting results consistent and comparable with each. Most existing information, factors and coefficients regarding Co2 emission are usually in KgCO2/annum. However, all results are obtained in 'TonneCo2/annum' for calculation ease and better comparison.

Electricity consumption unit- Information from monthly or quarterly electricity consumption were added, to calculate the total yearly consumption in terms of Kilo-Watthour (KWH) in each of the buildings or flats. Emission factor in terms of KgCO2/KWH is used to quantify CO2 emission. This value is transferred to TonneCO2/ KWH/annum.

LPG consumption unit – All information is gathered in terms of number of cylinders. The information regarding number of cylinders in transferred to kilogram (Kg) of LPG. By using emission factor in terms of KgCO2/ Kg of LPG, emission of CO2 from petrol is found out in KgCO2/Kg of LPG/annum and converted to TonneCO2/Kg of LPG/ annum

Petrol consumption unit – This energy consumption is measured in litres. By using emission factor in terms of KgCO2/ litre, emission of CO2 from petrol is found out in KgCO2/ litre of petrol/annum and converted to TonneCO2/ litre of petrol/annum.

Potable water consumption unit – This energy consumption is measured in litres. By using emission factor in terms of KgCO2/ litre, emission of CO2 from potable water consumption is found out in KgCO2/ litre of potable water/ annum and converted to TonneCO2/litre of potable water/ annum.

Emission from respiration is calculated in terms of KgCO2/person/annum and converted to TonneCO2/person/annum.

3.6 Consumption-Emission quantification methods

3.6.1 Emission by consumption of Electricity

Consumption calculations: It is decided to collect data regarding consumption of electricity of residential buildings from sample survey. During sample survey it is found that there is considerable variation in consumption pattern over different seasons. Weather in Kolkata, Saltlake and Newtown being very hot and humid, the electrical consumption in summer becomes very high and in winter very low. To avoid discrepancy due to seasonal variations, it was decided to take 'annual' consumption of electricity for all quantification analytical process.

Figure 17 Annual electricity consumption (sample 12)

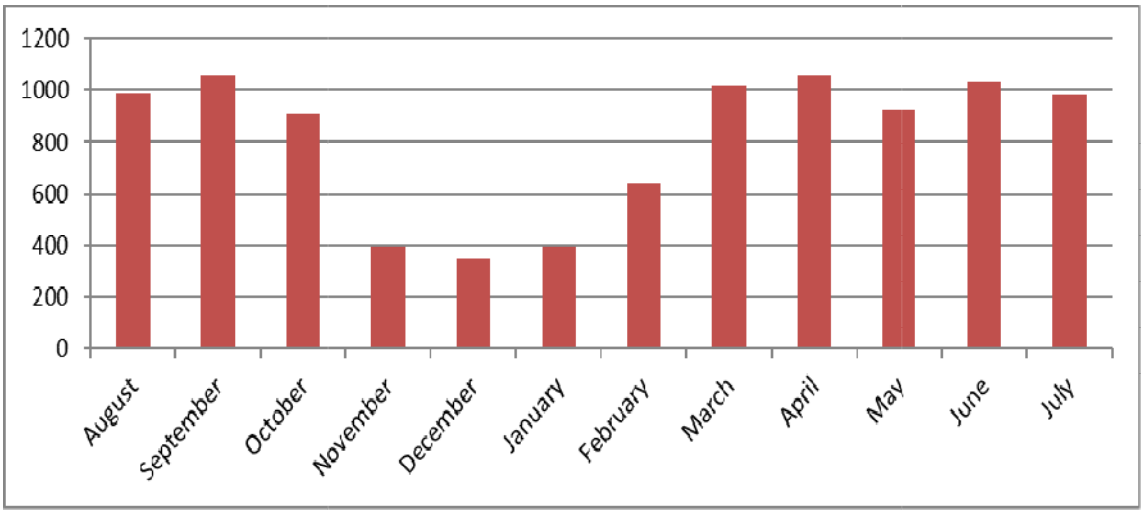
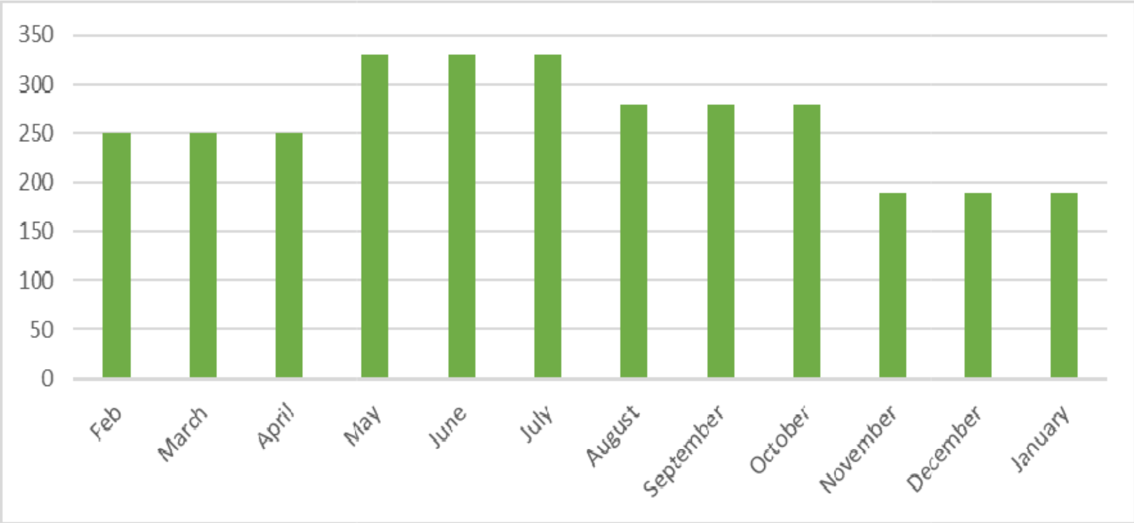


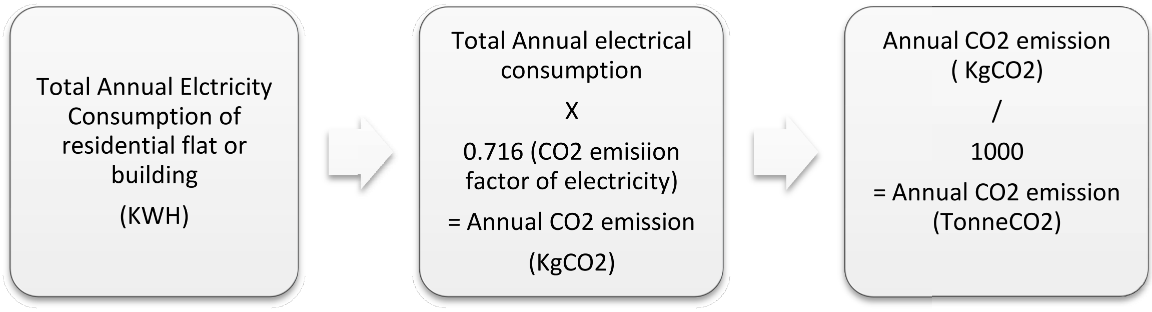
Figure 18 Annual electricity consumption (sample 5)



Data on electricity consumption from different buildings / flats was collected for 12 consecutive months to get information on total yearly consumption. The variation in consumption over different months in Sample Study 012 & Sample study 005 are tabulated and shown in Figure 17 & Figure18 respectively. Working with annual consumption of electricity also bypasses any discrepancy due to absence of the whole family or a particular member of the family during a particular time period of the year.

Emission calculations: The total yearly electricity consumption of individual single tenement and multistoried multi-tenement residential buildings in Kilowatt-hour was obtained from input data through sample survey and this yearly consumption (KWH) was multiplied by CO2 emission factor (0.716 KgCO2/KWH) of electricity generation, national average, 2023, provided by Central Electricity Authority, Government of India, to give the total annual CO2 emission from electricity consumption by the building or individual flat (Figure 19). All CO2 emission is finally converted & tabulated in terms of "**TonneCO2/annum**". Same process is also applied to find the total CO2 emission from electricity consumption from common areas of multi-tenement buildings, as in all multistoried buildings the flats and common areas are separately connected to different meters.

Figure 19 Method of quantification of CO2 emission due to electricity consumption from urban residential buildings



$$\sum E_e = \frac{(C_e \ x \ 0.716)}{1000} \qquad \text{... Eq 01}$$

Where E_e = Total annual emission from a building in the operation phase due to consumption of electricity measured (TonneCO2/annum)

C_e = Total annual consumption of electricity (KWH)

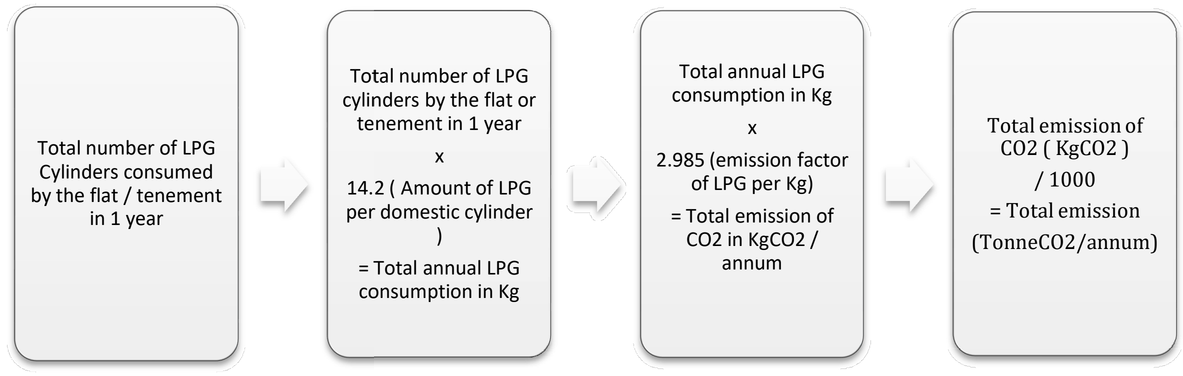
0.716 KgCO2 per KWH is the average emission factor considered for generation and transmission of electricity in India (Authority, 2021) or 0.716 KgCO2 is emitted when 1 KWH of electricity is generated and transmitted to the end user in India.

3.7 Emission by consumption of fuel for cooking (LPG)

Consumption calculation: LPG consumption, by the residentials flat / flats for cooking purpose, in terms of cylinders, were added to calculate the total yearly consumption in terms of cylinders in each tenement or flat of the buildings. The total yearly LPG consumption in terms of cylinders was multiplied by 14.2 kg (in India all domestic cylinders carry 14.2 Kg of LPG) to give total annual consumption of LPG in terms of Kilogram.

Emission calculation: The total annual consumption of LPG (Kg) is multiplied by 2.985 (emission factor of LPG = 2.985 KgCO2/ kg of LPG) to give total annual CO2 emission due to LPG consumption for cooking by that household or flats (Figure 20).

Figure 20 Method of quantification of CO2 emission from use of LPG in urban residential buildings



$\sum E_l = \frac{(C_l \ x \ 2.985)}{1000}$ .....*Eq 02*

Where E_l = total annual CO2 emission from building in operation stage from cooking using LPG measured (TonneCO2/annum)

C_l = total consumption of LPG (kg)

$$\sum C_l = N_l \ x \ 14.2$$ .... *Eq 03*

N_l = total number of LPG cylinders consumed annually

2.985 KgCO2 is the emission factor of LPG or 2.985 KgCO2 is emitted when 1 kg of LPG is burnt.

14.2 Kg is the amount of LPG in one cylinder in India

3.8 Emission by consumption of fuel for 2-wheelers & 4-Wheelers (Idling Time)

Consumption calculation: During initial discussions with residential tenements in Kolkata, it was found out that many residents, due to non-availability of car parking space inside the plot, park their cars or motorbikes permanently on the road in front of their building/plot. Though this paper aims to study all emissions by residents of a building from it's own plot, it still becomes rationale to consider all these cases of parking adjacent to the plot be included as being parked inside the plot and considered for this study. With an eye on future building designs, it can be assumed that all buildings will have enough parking space for all residents so that we can have more carriage space on the road. In some cases it was also found that some other car or motorcycle, not belonging to a resident. is parked inside the plot. As information on this issue is unpredictable and difficult to obtain, for this research paper, it is assumed that, no outside cars or motor-cycles are parked inside the site and hence they are not considered for quantification.

This Study being concerned with CO_2 emission only inside the building / plot, it becomes important to concentrate on emission effects of vehicles due to Idling time and movement inside the plot and skip, for simplicity of the study and quantification method, all emissions outside the plot. Furthermore, with limitations of this study being set to only small urban plots, the movement inside a small plot can be considered as negligible and emission due to fuel burning inside the plot can be restricted to only Idling time due to parking, i.e, when the engine is on and the car is not moving. It is generally observed that Parking Time of a car inside a small plot varies considerably and it is not feasible to find out the exact time of Idling. This research work assumes that a car takes maximum 5 minutes from start of ignition to going out of the plot and again 5 minutes from entering the plot to putting the ignition off. This makes the total times as 5+5 = 10 min for every time a car is started and taken out of the plot and again enters the plot and parks the car. It is also observed that the number of times the car is taken out of the plot and enters the building varies considerably. Again, for the simplicity of the study, it is assumed that a car is generally taken out and enters the plot two times daily. With this assumption, the total time of idling due to parking becomes 10 +10 = 20 minutes per day. So, for this particular study, which is to find out emission of CO_2 from a residential building on a small plot during its operation stage only, assumptions related to emission due to presence of automobiles, are taken as -

1) automobiles considered for calculations are all 4 wheelers cars or 2 wheelers (and not other variants as bus, trucks, vans, auto rickshaws, etc.). Other vehicles come inside the plot very rarely and are not considered for this study.

2) Since many nations including India, with the sole objective to reduce emission, are contemplating on ban on all sale of diesel cars from 2027, cars considered for calculation of emission are only **Petrol cars.**

3) Cars are generally taken out of the plot **2 times a day** on an average,

4) For all calculation, it is assumed that the cars when inside the plot and with engine running, they are not moving, i.e. they are in a **'Idling condition'**.

5) The maximum idling time for cars and motorcycles inside the plots is assumed as **5 minutes** each time it is ignited to be taken out and same 5 minutes each time it enters the plot and is parked. Same is assumed for a motorcycle. So the total time taken, every time a car or motorcycle is taken out, is 10 minutes.

6) So the total time of idling time of a vehicle inside a plot is 20 minutes per day = 20 x 365 minutes per annum = **7300 minutes per annum = 121.67 hr per annum.**

With idling time of the vehicles fixed (121.67 hour per annum), there comes the need to ascertain the consumption of petrol / diesel during this idling time of the vehicles. This is derived from research work of *Niraj Sharma and Ravi Shankar Chalumuri* (Sharma, Chalumuri, Kumar, & Singh, 2015)as shown in Table6. Annual petrol consumption by a **2-wheeler** during idling inside a plot, considering total idling time as 121.67 hours per annum (20 minutes per day) comes to 121.67 hours x 0.14 litres / hour = **17.034 litres**. Annual petrol consumption by a **4-wheeler** during idling inside a plot, considering total idling time as 121.67 hours per annum (20 minutes per day) comes to 121.67 hours x 0.60 litres / hour =**73.002 litres**.

Table 22 Mean value of consumption of petrol during idling time in India

Mean Value of consumption of Petrol in **Kolkata**	Motorcycles (Petrol)	0.14	litre/hr
	Cars (Petrol)	0.6	litre/hr

Source - Niraj Sharma and Ravi Shankar Chalumuri(Sharma, Chalumuri, Kumar, & Singh, 2015

Emission calculation for 2-wheelers: The emission factor of petrol for 2 wheelers and 4 wheelers are derived from. The India GHG Program – India specific Road Transport Emission Factors, 2015, written by Stakeholder Consultation and publishes by India GHG Program Secretariat uses emission factors as presented in Table 23 for all calculations for emissions –

FUEL TYPE (Four Wheelers)	CO2 Emission Factor
Emission factor for Petrol (Motor Gasoline)	**2.27 KgCO2/litre**

Table 23 CO2 emission factors of Petrol and Diesel

Source - (Protocol, 2017)

The rate of consumption of petrol by a 2-wheeler being 0.14 litre/ hour and total time of idling by a 2- wheeler being 121.67 hour per year, the total consumption of fuel by a 2 –

wheeler comes to 0.14 x 121.67 litre = 17.034 litres / annum. Considering CO2 emission factor as 2.27 KgCO2/litre, annual emission from petrol consumption by a 2 – wheeler comes to 17.034 litrs / annum x 2.3 KgCO2/litre = 39.18 KgCO2 per annum = 39.18 / 1000 TonneCO2/annum= 0.039 TonneCO2/annum. Information is obtained from the sample survey about the number of 2 wheelers parked by the owner of the building / flat inside the plot. The number of 2-wheelers parked inside the plot is taken and multiplied by .039 TonneCO2/annum to give the total emission of CO2 by all motor-cycles owned by the owner of the building / flat and parked inside the plot.

$$\sum E_{mp} = \frac{(N_m \ x\ 0.039)}{1000} \qquad \text{.... } Eq\ 04$$

Where E_{mp} = Total annual CO2 emission from consumption of Petrol by motorcycles owned by residents during the operation stage of the building and inside the site(TonneCO2/annum)

N_m = total number of motor cycles owned by the resident and parked inside the site.

0.039 KgCO2/motorcycle is the calculated average CO2 emitted annually by one motorcycle driven by petrol assuming that –

1) this CO2 emission is only inside the site,

2) this CO2 emission is only when the motor cycle is driven by petrol,

3) this CO2 emission calculated considering only idling time, i.e. when the engine is on but the motorcycle is not moving

4) the motorcycle is taken out of the site only two times daily considering the yearly average,

5) it takes 5 minutes to take the motorcycle from the parking lot to out of the site and again 5 minutes to enter and park it in its parking lot,

6) Emission factor of petrol is 2.27 KgCO2/litre

7) Consumption of petrol by a motorcycle during Idling time is 0.14 litre/hour

Consumption calculation for 4-wheelers: The rate of consumption of petrol by a 4-wheeler being 0.6 litre/hour and total time of idling by a 4- wheeler being 121.66 hour per year, the total consumption of fuel by a 4 – wheeler comes to 0.6 x 121.66 litre = 72.996 litres / annum. Considering CO2 emission factor as 2.27 KgCO2/ litre, annual emission from petrol consumption by a 4 – wheeler comes to 72.996 litres / annum x 2.3 KgCO2/litre = 167.89 KgCO2 per annum= 167.89 / 1000 TonneCO2/annum= **0.168 TonneCO2/annum.**

Emission calculation for 4-wheelers: Information is obtained from the sample survey about how many 4 wheelers is there parked by the owner of the building / flat inside the plot. The number of 4-wheelers parked inside the plot is taken and multiplied by 0.168 TonneCO2/annum to give the total emission of CO2 by all 4 -wheelers owned by the owner of the building / flat and parked inside the plot.

Considering 4 wheelers or precisely cars, the equation is set as -

$$\sum E_{cp} = \frac{(N_c\ x\ 0.168)}{1000} \quad \text{.... Eq 05}$$

Where E_{cp} = Total annual CO2 emission from consumption of Petrol by cars owned by residents during the operation stage of the building and inside the site (TonneCO2/annum)

N_c = total number of cars owned by the resident and parked inside the site.

0.168 KgCO2/motorcycle is the calculated average CO2 emitted annually by one car driven by petrol assuming that –

1) this CO2 emission is only inside the site,
2) this CO2 emission is only when the car is driven by petrol,
3) this CO2 emission calculated considering only idling time, i.e. when the engine is on but the car is not moving
4) the car is taken out of the site only two times daily considering the yearly average,
5) it takes 5 minutes to take the car from the parking lot to out of the site and again 5 minutes to enter and park it in its parking lot,
6) Emission factor of petrol is 2.27 KgCO2/litre
7) Consumption of petrol by a car during Idling time is 0.6 litre/hour

3.9 Emission by Respiration

Emission by respiration from human respiration inside the flat or plot is calculated by multiplying the number of residents in the flat by emission factor of 251 KgCO2/ person/annum (Li, et al., August 2022).

Emission per annum by Respiration from a single tenement building / flat

= 251 KgCO2/person/annum x number of residents in the building / flat.

$$\sum E_r = \frac{(N_r\ x\ 251)}{1000} \quad \text{.... Eq 06}$$

Where E_r = total emission by all the residents of the building (TonneCo2/annum)

N_r = total number of residents

251 KgCO2/person/annum is the Co2 emission factor from respiration

3.10 Emission by consumption of potable water (PWP)

Potable Water Production (PWP) is an intrinsic part of urban development – aa huge quantity of processed water is needed for the urban dwellers. This process of good quality potable water production involves considerable amount of energy consumption and consequently GHG emissions. The literature study, previously mentioned, showed that CO2 emission factor and quantity from PWP depends a lot on source of water, geographical conditions, distribution system, etc. This research paper finds the case study of Yiwu county in China (Gui, Qi, & Wang, 2024) for CO2 emission from PWP very interesting. The source of water for extraction in Yiwu is surface water like a network of rivers. In Newtown, which is the site for this research, potable water is also extracted from river Ganga. The other attribute, the geographical conditions of both places are also same- both being plain land with lots of water bodies. Thus, it becomes logical to adopt the results of this paper by (Gui, Qi, & Wang, 2024), for use in this research work. The CO2 emission factor of 0.90 $KgCo2/m^3$ is hence adopted for quantification process of Co2 emission from PWP in this research paper. For the calculation of CO2 emission, other than emission factor, quantity of water consumed by the residents were also required. However, Kolkata of Newtown do not have any meter system for water connection. So, recording of water consumption by individual flats or houses was not feasible. There was also no information in existing literature. This research work, in this scenario, decides to rely on Indian Standards and consider the average water consumption from Bureau of Indian Standards, IS:1172-1993 (STANDARDS, 1993). The average water consumption from the public water supply distribution system is taken as 200 litres/person/day. The total annual quantity of water consumption by the building is given by -

$$\sum C_w = N_r \ x \ 200 \ x \ 365 \qquad \text{.. Eq 07}$$

Where Cw = Total water consumption through urban potable water distribution system (Litres)

N_r = total number of residents

200 litres/ person/day is the water consumption average given by Bureau of Indian Standards

$$\sum E_w = \frac{(C_w \ x \ 0.9)}{1000} \qquad \text{.... } Eq\ 08$$

Where E_w = Total annual CO2 emission from PWP from the building due to water consumption in TonneCO2/annum

Cw = Total water consumption through urban potable water distribution system (Litres)

0.0009 KgCO2/litre is the emission factor of CO2e from potable water distribution.

3.11 Total CO2 emission Calculation

The total CO2 emission is quantified as the summation of all the individual emissions from each source. The total annual CO2 emission from a multi-storied, muti-tenement residential building during its operation phase is given by the equation –

$$\sum E_b = E_e + E_l + E_{mp} + E_{cp} + E_r + E_w \qquad \text{...Eq 09}$$

Where E_b = Total annual CO2 emission from the building in operation phase (TonneCO2/annum)

E_e = Total annual emission from a building in the operation phase due to consumption of electricity (TonneCO2/annum)

E_l = total annual CO2 emission from building in operation stage from cooking using LPG(TonneCO2/annum)

E_{mp} = Total annual CO2 emission from consumption of Petrol by motorcycles owned by residents during the operation stage of the building and inside the site (TonneCO2/annum)

E_{cp} = Total annual CO2 emission from consumption of Petrol by cars owned by residents during the operation stage of the building and inside the site (TonneCO2/annum)

E_r = total emission by all the residents of the building (TonneCo2/annum)

E_w = Total annual CO2 emission from PWP from the building due to water consumption in TonneCO2/annum

3.12 Conclusion

The method applied for identification of sources of CO2 emission from urban multi-tenement multi-storied residential buildings in operational stage is based totally on existing literature. All sources of CO2 emission or activities emitting CO2 mentioned in existing papers are more or less considered for this research paper. These activities are identified as - 1) electricity, 2) fuel for cooking, 3) fuel for vehicles, 4) respiration, 5) potable water production.

The parameters associated with these sources or activities are also identified from existing literature. For finding consumption quantities, it is decided to consider both information provided in literature study and sample survey. Information on electricity consumption (electricity supply meter readings) and LPG consumption (number of cylinders used annually) are based totally on sample survey. For calculation of vehicle fuel consumption, a combination of information from sample survey (number of vehicles) and some assumptions (idling time inside premises) are considered. For quantification of consumption of potable water, a combination of primary literature review (daily requirement of potable water as per consumption Bureau of Indian Standards, IS:1172-1993 (STANDARDS, 1993) and sample survey (number of residents) were taken. CO2 emission quantification from the building in operation was done on the basis of calculated consumption quantity and emission factors as found through literature review. The emission of CO2 from residents is based of emission factor for respiration and sample survey data (number of residents). The total emission of CO2 from the residential buildings or flats are calculated by summation of individual emissions from each source associated with the flat/building.

4 CHAPTER 4 - CO_2 EMISSION PATTERN OF URBAN RESIDENTIAL BUILDINGS

4.1 Introduction

This research had set the boundaries as study of only CO_2 emission from only operational phase of residential buildings and in urban areas, the character of the buildings being multi-tenement and structurally multi-storied. During the process of research, it is concluded that, though this paper is dealing with 'multi-tenement' and 'multi-storied' residential buildings, it would be more logical to also include single tenement individual residential houses as they form the basic unit of residential living. It is also concluded to take sample surveys in buildings in Newtown, our chosen site, and also in Kolkata and Bidhannagar to get a much broader view of the subject. The information from primary and secondary literature reviews are identified and sorted for use in this research work. The fields in which information is sought from sample surveys are established. The methods of quantification of CO_2 emitted from the buildings are also designed and discussed in the previous chapter. The next logical steps to follow are Sample Surveys and final Quantification of CO_2 emitted.

Sample Survey Design

The primary objective of this paper is to investigate Quantitative and Qualitative parameters of Household carbon Footprint. The sample surveys were carried out over a period starting from 2020 to 2024 searching for input data on variables as stated in Table 24. In order to search for input data the survey questionnaire was divided into certain variables. For the quantification process consumption quantities of different energies were required as per activities already identified in previous chapter – 1) Electricity & 2) LPG for cooking. Information on water consumption was not taken into account as there are no meters for measuring its consumption. However, since quantification of emission from water consumption needed the number of residents and also emission from respiration requires the number of residents, so information on family members was included in the questionnaire. Calculation of emission from cars and motorcycles needed the number of cars and motorcycles parked inside the plot, this information was also included in the questionnaire.

Table 24 Variable Description of Sample Survey Input

Sl. No.	Variables	Question / Description	Units	Data Source	Notes
1	Plot Area	Plot area (including covered and open areas)	Square feet	Sanction Plan / Land Deed	Respondents were all conversant with Square feet and not Square meter. Values in square feet were converted to square meter.
2	Covered Area of the Flat / Building	Covered area of building – in case of a single tenement building. Flat Area – in case of a multi-tenement building	Square feet	Sanction Plan	
3	Covered Common area (for multi-tenement buildings)	Covered Common areas including Parking areas, Staircase, common service areas.	Square feet	Sanction Plan	
4	Income	Total Income of all occupants	Rupee		
5	Electricity Consumption	Unit Consumed over a period of 12 consecutive months	KWH	Electricity Bills	Kolkata has monthly electricity bills, whereas Bidhannagar and Newtown has quarterly electricity bills. For Quarterly bills (Bidhannagar and Newtown), values of quarterly bills were converted to monthly values.
6	Fuel Consumption for cooking	Number of Cylinders consumed over a period of 12 months	Number	Count of Cylinders	Assumption by respondents as there is no exact recording
7	Fuel consumption by automobile	Number of 2-wheelers & 4-wheelers parked inside plot or on the road just outside the plot. Also number of other vehicles if parked inside the plot	Number	Count of automobiles	Parking is mostly inside the plot. However, in some cases they are parked on the road just outside the plot.
8	Emission through respiration	Number of residents	Number		

Consumption values in all these stages are found out from direct questionnaire survey and/or application of consumption factors obtained from literature review. The CO_2 emission values by these sources are quantified mathematically by using the consumption values and respective emission factors as derived and mentioned in chapter 3 namely research methods and design. Further finding correlation between CO_2 emission and building parameters, like floor area, plot area, number of residents, etc. also becomes necessary and hence it is also studied at length to find any correlation.

As discussed in the research design and methodology chapter that considering there are various types of buildings as per location, forms, structures and use groups, this sample survey limits its boundaries to 'location - Urban', 'use group - Residential' and 'Form/Structure – Multistoried & Multi-tenement'. Though Newtown is the site for this research work, it being a city developed few years back and still in infancy, the sample study was not limited to only Newtown – but extended to Kolkata and Bidhannagar also.

4.2 Distribution of building typology studied in Survey

As has been already mentioned that this research work is being done to study quantification method of CO_2 emission from a multi-tenement residential building in an urban area. However, there are other objectives like finding exact source of CO_2 emission from residential building, quantification of emission from individual sources and to find out relationship, if any, between building parameters and CO_2 emission. To do this, and for a better understanding of the subject, it was decided not to restrict the study to multi-tenement buildings only, but extend it to single tenement buildings and individual flats. The sample survey was distributed into different building typologies depending upon tenement sizes, building structures and location (Table 002). Information, as needed, was collected from a set of four (4) number single tenement individual buildings located in different parts of Kolkata and Bidhannagar, four individual flats in different multistoried buildings in Bidhannagar and one (1) whole building in Newtown, comprising of eight (8) flats and common areas (Table 25). This sample set is hereinafter referred to as 'Set-1' and the samples as Sample 01, Sample 02, Sample 03 … Sample 16. One flat in this building in Newtown could not be surveyed as the owner was not present.

Figure 21 Map showing location of samples 01, 02, 03, 04, 05, 06, 07, o8, 09, 10, 11, 12, 13, 14, 15.

Table 25 Sample Survey distribution as per Typology (Set-1)

Building Typology	TENEMENT TYPE	Sample number	Location
CATEGORY I	Single Tenement - Individual houses (2 storied)	4	Kolkata & Bidhan Nagar
CATEGORY II	Individual Flats in Multi-tenement building (4 storied)	11	Bidhan Nagar
5CATEGORY III	Whole Building (Entire Plot, Individual Flats and Common Areas) (Garage + 4 storied)	1	Newtown

Category I - For study of emission from category 1, four (4) number purely single tenement individual houses are selected in the sample survey, of which three (3) are located in Kolkata and one (1) in Bidhannagar. All of these are two (2) storied residential buildings occupied by single families. The same questionnaire is distributed in this category as in other groups.

Category II – For study of emission in category II, residential flats in multi-storied and multi-tenement buildings are selected in Bidhan Nagar and Newtown. Four (4) number flats are situated in Bidhannagar and seven (7) flats are located in Newtown. The seven (7) flats in Newtown are also part of the whole building studied for category III.

Category III - One (1) number multi-storied, multi-tenement residential building, in Newtown, could be studied fully - meaning whole building could be studied except one flat, where the owner is not present. All data of this building, related to this research study, are also obtained. The whole building, in Newtown, surveyed for sample study is a five (G+4) storied multi-storied, multi-tenement residential building with eight (8) number flats. It stands on a plot of area 271.73 sqm. The ground floor is used only for parking and service area for care-taker and the upper four (4) floors are used as residential. The ground covered area is 149.446 sqm. which is approximately 55%of the plot area, which is as per NKDA building rules the maximum ground coverage for residential plots less than 1500 sqm. The ground open space is 122.284 sq, which is about 45% of the plot area. The mandatory 'Green Open Space' (not paved) was introduced by the development authority (NKDA) to improve environmental aspects of urban areas like storm water management, heat-island, greeneries, etc. It is fixed at minimum 4% of the plot area. The green open space in this plot is 10.88 sqm, which is exactly the minimum area required (4%). The plot area, ground coverage, open spaces and other dimensions of open spaces of the plot like front open space, rear open space and side open spaces are mentioned in the Table 26. The front open space is 2.0 m, rear open space is 2.10 m, the side open spaces are 2.470 m and 1.3 m. (Figure 21 & 22))

Table 26 Particulars of whole multi-storied multi-tenement residential building studied

	Areas & Dimensions			**As per stipulated NKDA Building Rules**
	Measurements as per site		**% coverage as per Site**	
	Quantity	Units		
Plot Area	271.734	sqm		
Ground Covered Area	153.143	sqm	56.36 %	Maximum Ground Coverage for Residential Plots below 1500 sqm= 55%
Open Area	118.591	sqm	43.631 %	
Green Area	10.88	sqm	4.00 %	4 %
Open Paved Area	111.404	sqm	41.00 %	No Rules
Front Open Space	2.000	meters		1.2 M for residential buildings up to 15.1 m height
Rear Open Space	2.100	meters		2.0 M for Residential Plots upto 300 sqm and building height 15.1 M
Side Open Space (1)	2.470	meters		0.8 meters for plot area less than 300 sqm and building height less than 15.1 meters
Side Open Space (2)	1.300	meters		2.4 meters building height less than 15.1 meters
Number of stories	5 (G+4)			5
Use	Ground floor – Parking 1st, 2nd,3rd& 4th Floors - Residencial			
Total Built-up area	765.715 sqm			

Figure 22 Ground floor plan of building studied in category III

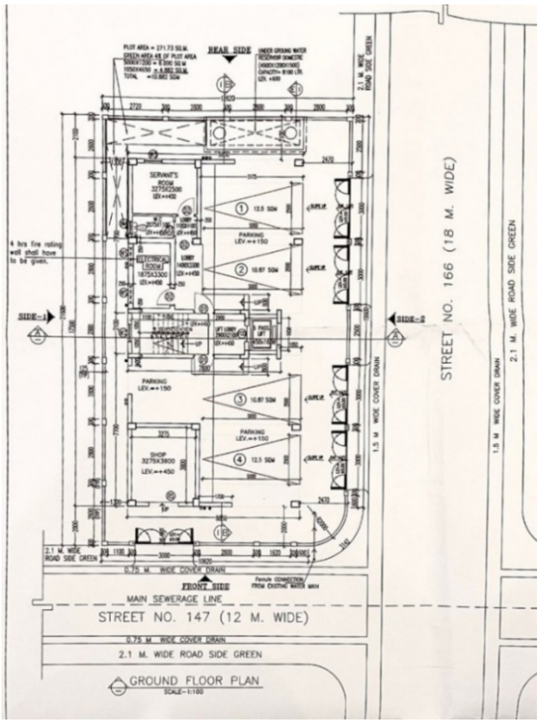
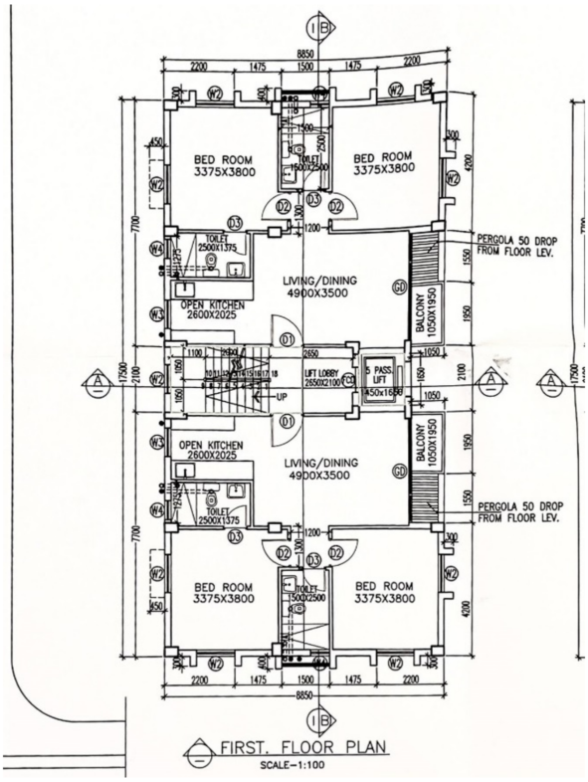


Figure 23 Typical floor plan of building studied in category III



4.3 Mode of survey

The questionnaire in digital form (Google forms) is distributed by email to all families staying in flats or buildings. The families are briefed for this survey and questionnaire explained by telephonic conversations. The filled-up forms are also collected through email. In the second stage all buildings are separately visited for reconnaissance survey, individual interview and clarification of data provided in the survey form.

4.4 Data collection & consumption quantification

4.4.1 Consumption of Electricity

Data collection for Electricity consumption– Data on electricity consumption from different buildings / flats were collected for 12 consecutive months to get information on total yearly consumption. As has been mentioned earlier in previous chapter, this was also a way to avoid discrepancy due to seasonal variations in consumption of electricity and occasional absence from staying in the flat/building. Respondents were asked to give information on electricity consumption based on Electricity Supplier provided meter reading or bills so as to get information without any discrepancy. Kolkata has monthly electricity bills, whereas Bidhannagar and Newtown has quarterly electricity bills. For Quarterly bills, average of three months were calculated.

Electricity Consumption Quantification **-** Information from monthly or quarterly electricity consumption were added to calculate the total yearly consumption in terms of Kilo-watthour in each of the buildings or flats.

4.4.2 Consumption of fuel for cooking (LPG)

Data Collection for consumption of fuel for cooking **-** This data was also taken as per 12 consecutive months to avoid discrepancy of data due to absence of whole family or a member of the family during a particular time of the year. However, during questionnaire process it was found out that no family has any record of monthly or yearly LPG consumption. In this situation it was decided to ask the respondents to give information based on their assumptions. Almost all respondents were of the opinion that this assumption would not be much wrong and the research paper can rely on the information.

*Consumption of fuel for cooking (LPG)***:** LPG consumption, by the residentials flat/flats for cooking purpose, in terms of cylinders were added to calculate the total yearly consumption in terms of cylinders in each tenement or flat of the buildings. The total yearly LPG consumption in terms of cylinders was multiplied by 14.2 kg (in India all domestic cylinders carry 14.2 Kg of LPG) to give total annual consumption of LPG in terms of Kilogram.

4.4.3 Consumption of fuel for automobile and resultant emission

Data collection: The number of 2-wheelers and 4- wheelers, belonging to each flat or building and parked inside the plot or on the road/pavement adjacent to the plot, were taken from sample survey.

Consumption of petrol: All 2-wheelers and 4- wheelers were assumed to be run on petrol. The number/s of 2-wheelers and 4- wheelers owned by the flat owner were multiplied by the consumption factor of 2-wheelers and 4- wheelers considering idling time. The petrol consumption factor for 2-wheelers during idling time is 0.14 litre/hour and that for 4-wheelers is 0.6 litre/hour (Sharma, Chalumuri, Kumar, & Singh, 2015). All consumptions are converted to annual consumptions in terms of litres/annum.

4.4.4 Consumption of potable water

Consumption of potable water: As there is no system of recording or metering consumption of potable water supplied by the municipality in Kolkata or NewTown or anywhere in West Bengal, the idea of finding quantity of consumption of supplied water in residential flats or buildings is ruled out from sample survey. In absence of any concrete way of this quantification, the national standards of 200 litres of water per person for daily consumption is assumed for all quantification. The number of residents per flat or building is obtained from the sample survey. The consumption of potable supplied water is derived by multiplying the number of residents with daily consumption rate of 200 litres/per person/day. Consumption is obtained in terms of annual value per flat or building.

4.5 CO2 emission quantification

4.5.1 Emission from electricity consumption

The total yearly electricity consumption in Kilowatt-hour was multiplied by CO2 emission factor of **0.716KgCO2/ KWH of electricity**(Central Electricity Authority, 2023) to give total annual CO_2 emission from electricity consumption by the building or individual flat. CO_2 emission is converted & tabulated in terms of "*annual emission in TonneCO2*". Same process is also applied to find the total CO_2 emission from electric consumption from common areas of multi-tenement buildings

4.5.2 Emission due to Fuel consumption (LPG)

The total consumption of LPG for cooking purpose, thus derived, in terms of kilogram, was multiplied by the emission factor of LPG i.e. **2.984 KgCO2/kg of LPG** ((Protocol, 2017). CO_2 emission is converted & tabulated in terms of "*annual emission in TonneCO2*".

Emission due to fuel consumption by automobile

The annual consumption quantity of fuel by individual flats/buildings are multiplied by emission factor of petrol for automobile i.e**. 2.27 KgCO2/litre**(Program, 2015). This emission value was again converted in terms of TonneCO2/annum.

Emission due to respiration by residents

Emission due to respiration is derived by multiplying the number of residents of a flat or building by emission factor of respiration i.e. **251 KgCO2/person/annum.** This value of emission due to respiration is also converted to Tonne/CO2/annum.

Emission due to consumption of Potable Water

4.5.3 Emission due to consumption od potable water:

The emission quantity due to consumption of potable water is calculated by multiplying the total annual consumption by the residents of the flat/building with the emission factor of potable water i.e**. 0.009 KgCO2/litre**. CO_2 emission is converted & tabulated in terms of "*annual emission in TonneCO2*".

Results of Quantification

The data received from sample survey were tabulated and quantification process of consumption of electricity, LPG, petrol for automobile, potable water were followed. Respective CO_2 emissions were derived as per methods described in chapter 3. The results of quantification of each sample are presented in the 'Appendices' section of this paper. Table 27 shows the final results of the sample survey.

Table 27 Results of sample survey - data, consumption & emission

	Sample Reference	Building Parameters							CO2 Emission Quantity					Total CO2 Emission
		Plot Area	Covered Area	No of Residents	Annual Electricty Consumption	Annual LPG consumption	No of 2 wheelers	No. of 4 wheelers	Electricity	Fuel for Cooking	Fuel consumed by Automobile	Respiration	Water consumption	
		(sqm)	(sqm)	Nos.	KWH	Kg	Nos.	Nos.	TonneCO2 / annum	TonneCO2 / annum	TonneCO2 / annum	TonneCO2 / annum	TonneCO2 / annum	TonneCO2 / annum
CATEGORY 1 Individual buildings	Sample 01	269.9	222.96	8	2600	284	1	1	1.862	0.848	0.204	2.011	0.526	5.451
	Sample 02	234.0	334.00	3	9800	213	0	1	7.017	0.636	0.166	0.754	0.197	8.770
	Sample 03	301.0	298.60	4	12200	255.6	0	2	8.735	0.763	0.331	1.006	0.263	11.098
	Sample 04	227.6	278.70	4	9800	213	0	1	7.017	0.636	0.166	1.006	0.263	9.087
CATEGORY 2 & 3 multi-storied multi-tenement buildings	Sample 05		100.00	3	3150	170.4	0	1	2.255	0.509	0.166	0.754	0.197	3.881
	Sample 06		100.00	3	3198	85.2	0	1	2.290	0.254	0.166	0.754	0.197	3.661
	Sample 07		100.00	5	5878	213	0	1	4.209	0.636	0.166	1.257	0.329	6.596
	Sample 08		100.00	5	2123	221.52	0	2	1.520	0.661	0.331	1.257	0.329	4.098
	Sample 09		74.32	3	890	127.8	0	1	0.538	0.381	0.166	0.754	0.197	2.036
	Sample 10		74.32	4	2544	170.4	1	1	1.822	0.509	0.204	1.006	0.263	3.803
	Sample 11		74.32	4	780	170.4	0	1	0.558	0.509	0.166	1.006	0.263	2.501
	Sample 12		74.32	4	1080	56.8	0	1	0.773	0.170	0.166	1.006	0.263	2.377
	Sample 13		74.32	3	480	56.8	0	1	0.344	0.170	0.166	0.754	0.197	1.630
	Sample 14		74.32	2	1042	142	1	0	0.746	0.424	0.039	0.503	0.131	1.843
	Sample 15		74.32	3	882	170.4	0	1	0.632	0.509	0.166	0.754	0.197	1.630
	TOTAL		2054.50	58	56447	2550.3	3	16	40.32	7.61	2.77	14.58	3.81	68.46

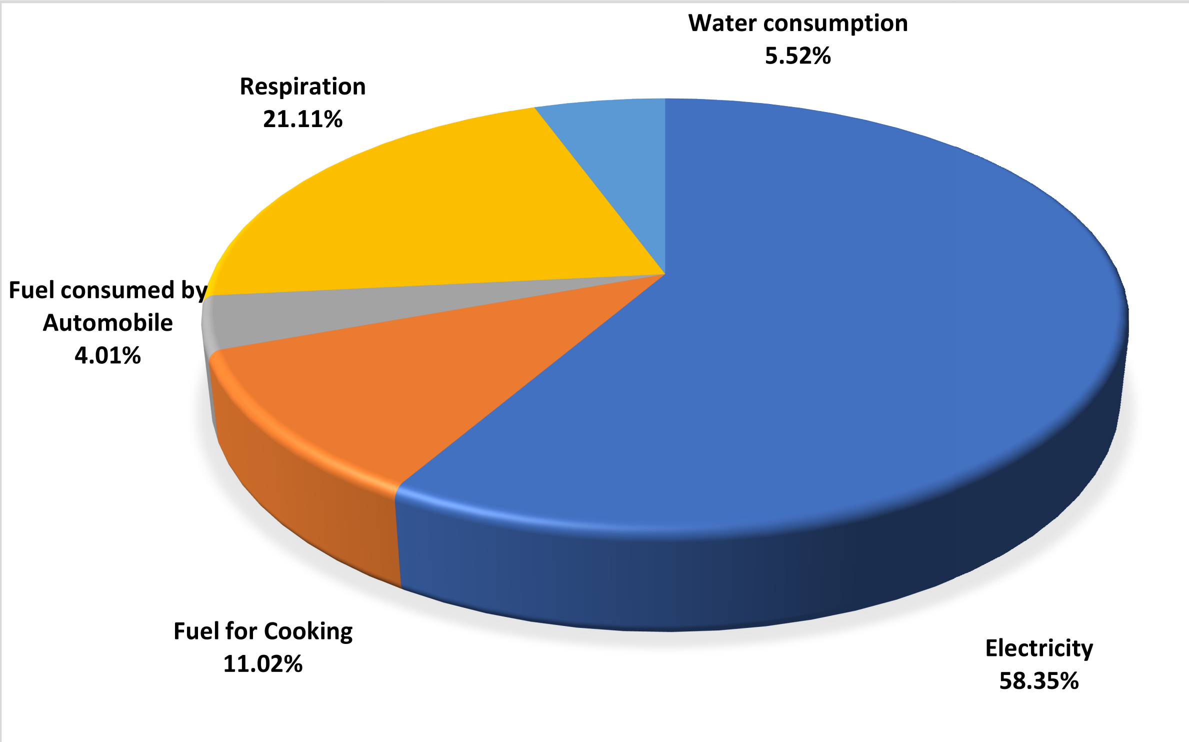
Reference - Appendices No. 01 to 15

4.6 Comparative study of amount of CO2 emission from sources

4.6.1 All categories (I, II and III) – samples 1-15

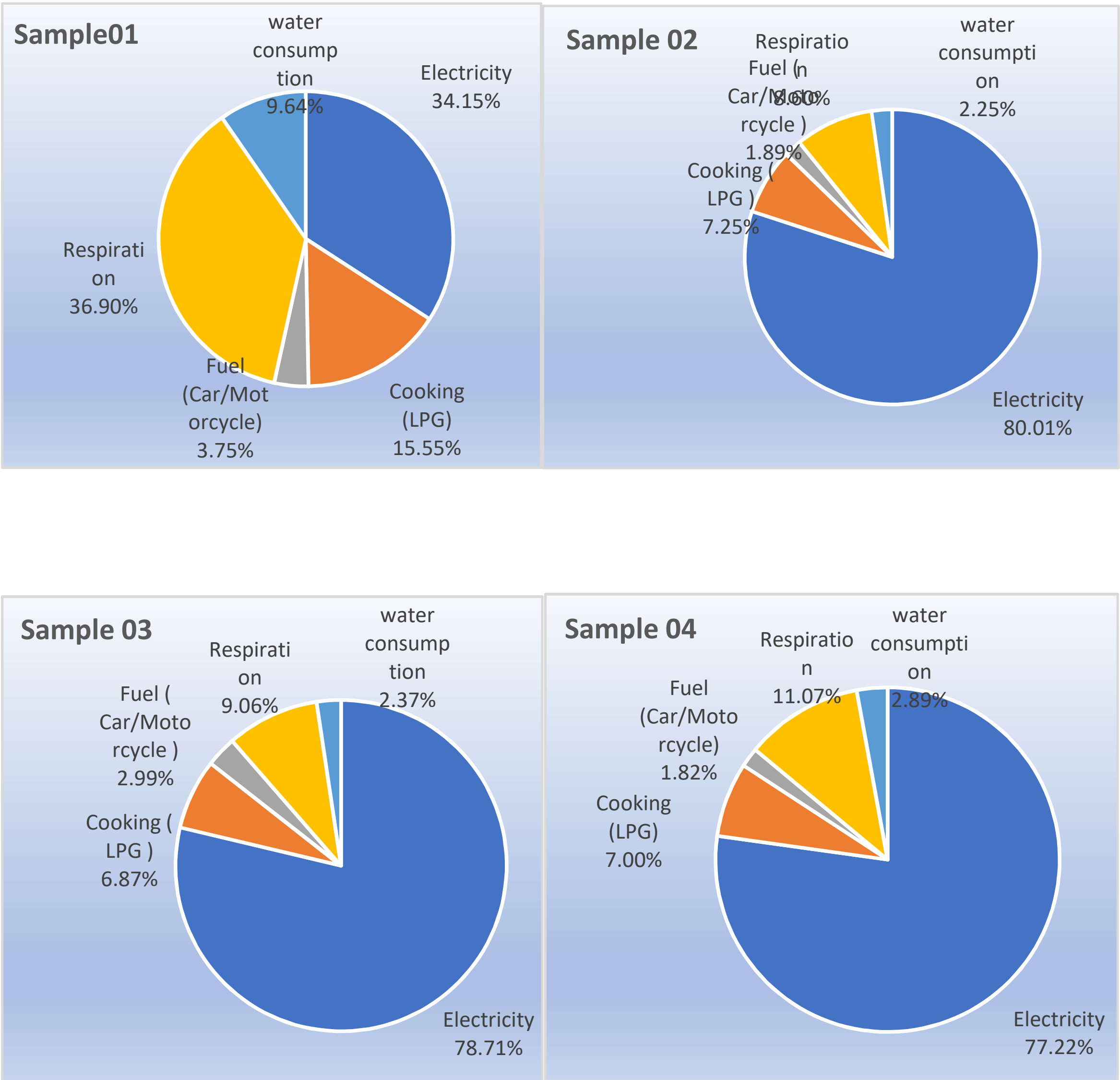
Emission from five types of different sources namely electricity, cooking, automobiles, respiration and water consumption are tabulated (Table 12) and compared. It is found that the maximum CO2 emission in almost all single tenement individual buildings and flats in multistoried buildings occur from electricity consumption followed by respiration, fuel consumption for cooking, water consumption and lastly fuel consumption by automobiles. The quantification results show that, when all samples are considered together, approximately 58.89% of the total CO2 emission is from consumption of electricity, 21.30% from respiration, 11.12% from consumption of LPG for cooking, 5.57% from water consumption and lastly 4.04% from petrol consumption by automobiles owned by the residents of residential buildings (Figure 24).

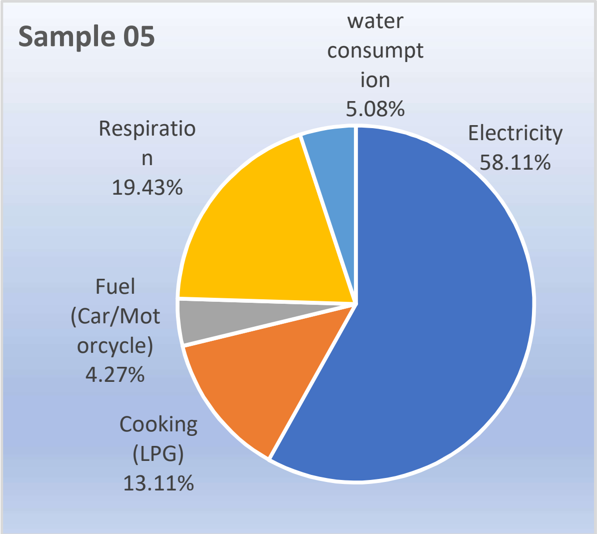
Figure 24 Percentage distribution of CO2 emission from different sources (all categories, all samples considered)

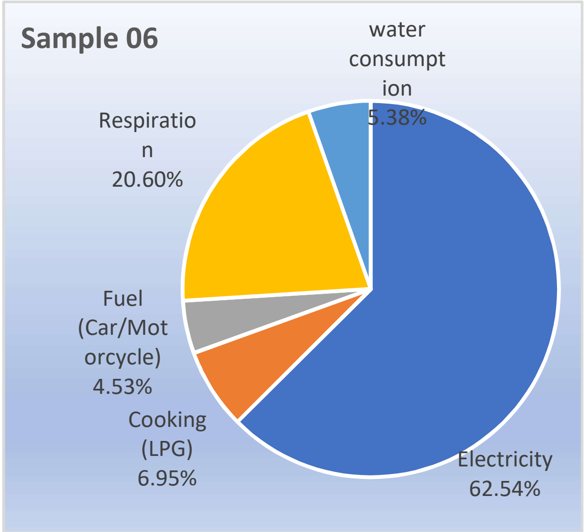


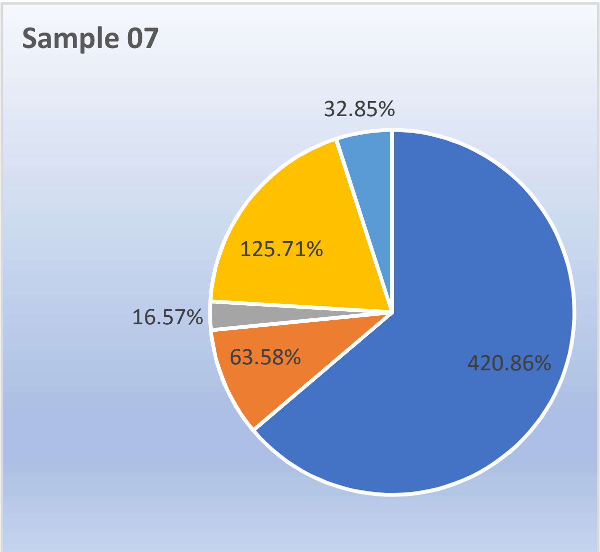
When individual samples (No. 1 to 15) are studied for this distribution of CO2 emission from different sources of individual residential buildings and flats, it is found that in some of the samples (Sample No. 1,2,3,4,5,6,7,8, 10 and 14), the general trend is that the maximum CO2 emission happens due to consumption of electricity, followed by respiration by residents, fuel consumption (LPG) for cooking, water consumption and lastly fuel (petrol) consumption by automobiles. However, in some samples (sample No. 01,09, 11, 12, 13 and 15) the maximum CO2 emission occurs from respiration by residents followed by consumption of electricity, fuel consumption (LPG) for cooking, water consumption and lastly fuel (petrol) consumption by automobiles. Graphical presentation of distribution of CO2 emission from different sources as recorded in different samples are provided in Figure 25.

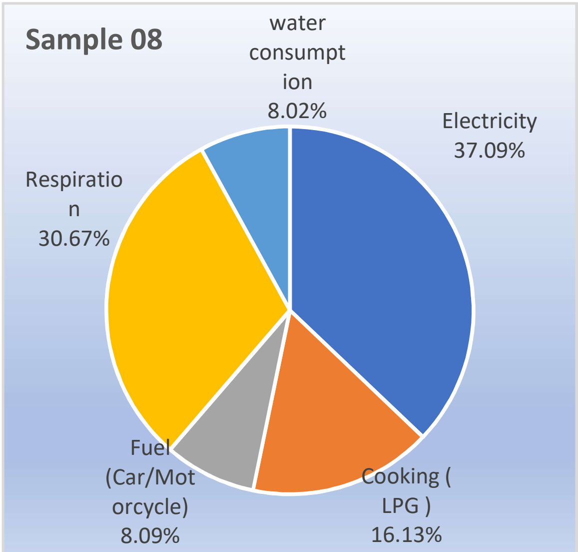
Figure 25 Graphical presentation of distribution of CO2 emission from different sources as recorded in individual samples

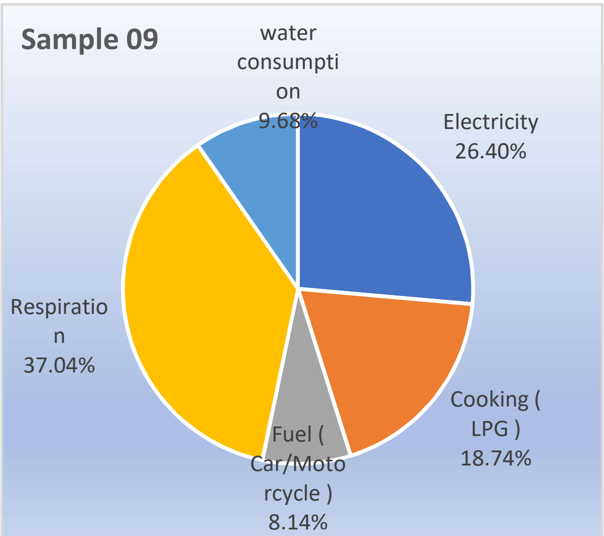


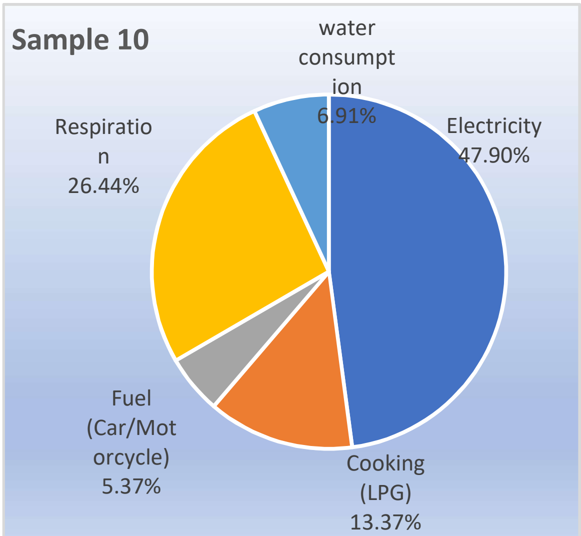

Sample 05
water consumption 5.08%
Electricity 58.11%
Respiration 19.43%
Fuel (Car/Motorcycle) 4.27%
Cooking (LPG) 13.11%

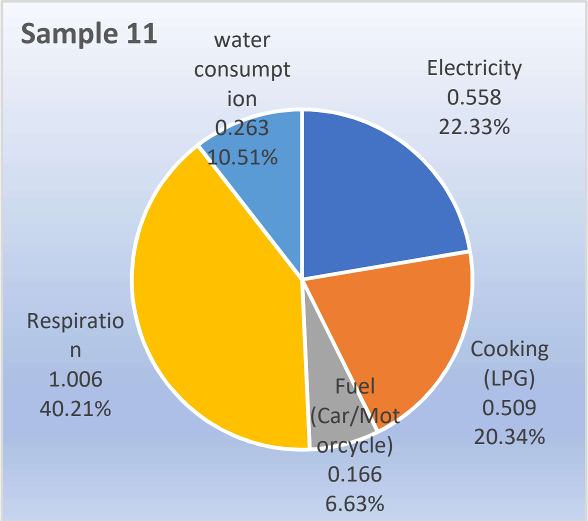

Sample 06
water consumption 5.38%
Respiration 20.60%
Fuel (Car/Motorcycle) 4.53%
Cooking (LPG) 6.95%
Electricity 62.54%

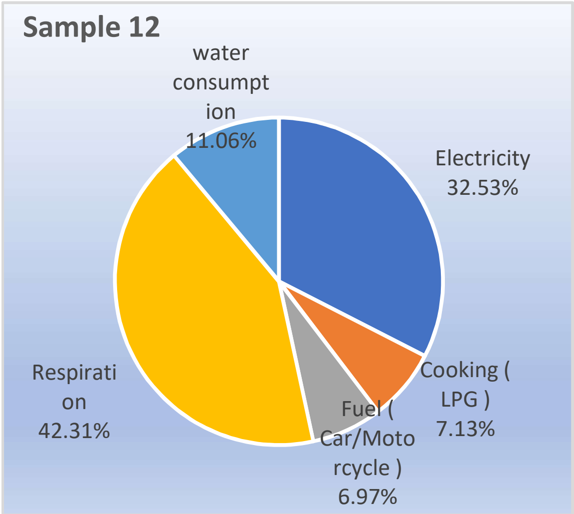

Sample 07
32.85%
125.71%
16.57%
63.58%
420.86%

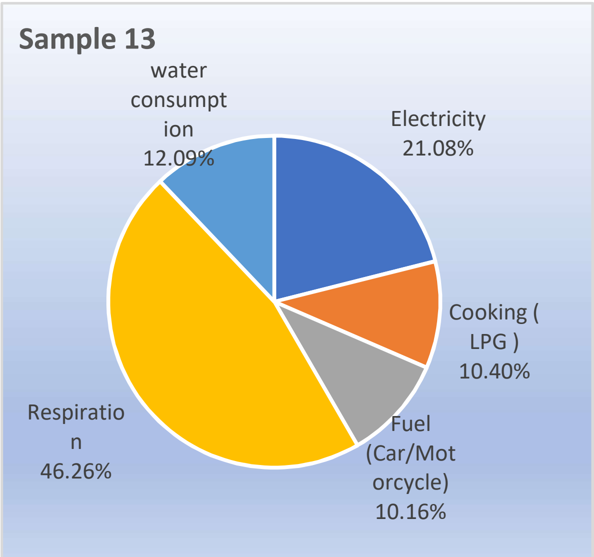

Sample 08
water consumption 8.02%
Electricity 37.09%
Respiration 30.67%
Fuel (Car/Motorcycle) 8.09%
Cooking (LPG) 16.13%

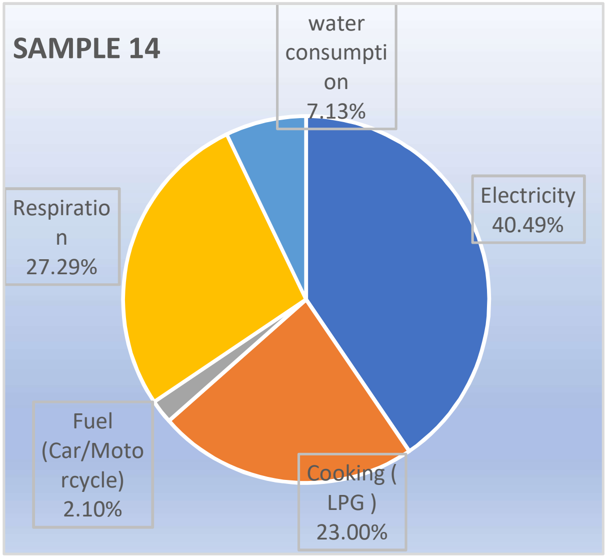

Sample 09
water consumption 9.68%
Electricity 26.40%
Respiration 37.04%
Cooking (LPG) 18.74%
Fuel (Car/Motorcycle) 8.14%

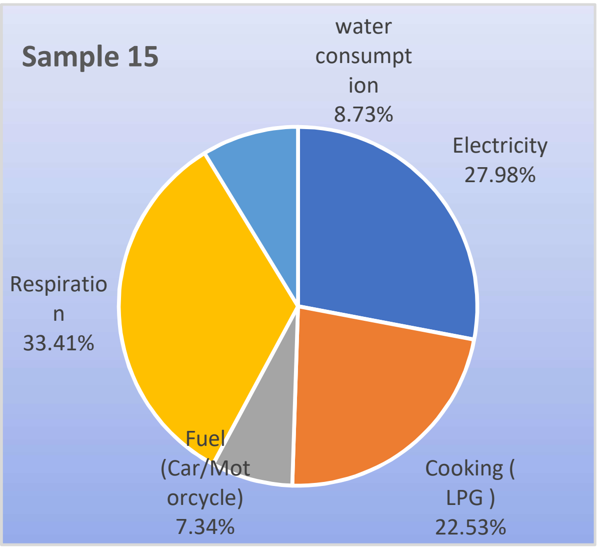

Sample 10
water consumption 6.91%
Respiration 26.44%
Electricity 47.90%
Fuel (Car/Motorcycle) 5.37%
Cooking (LPG) 13.37%


Sample 11
water
consumpt
ion
0.263
10.51%
Electricity
0.558
22.33%
Respiratio
n
1.006
40.21%
Cooking
(LPG)
0.509
20.34%
Fuel
(Car/Mot
orcycle)
0.166
6.63%


Sample 12
water
consumpt
ion
11.06%
Electricity
32.53%
Respirati
on
42.31%
Cooking (
LPG)
7.13%
Fuel (
Car/Moto
rcycle)
6.97%


Sample 13
water
consumpt
ion
12.09%
Electricity
21.08%
Cooking (
LPG)
10.40%
Respiratio
n
46.26%
Fuel
(Car/Mot
orcycle)
10.16%

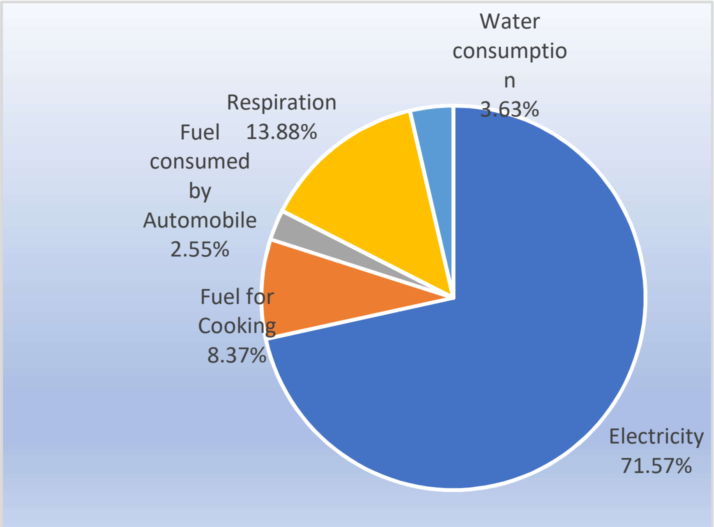

SAMPLE 14
water
consumpti
on
7.13%
Respiratio
n
27.29%
Electricity
40.49%
Fuel
(Car/Moto
rcycle)
2.10%
Cooking (
LPG)
23.00%


Sample 15
water
consumpt
ion
8.73%
Electricity
27.98%
Respiratio
n
33.41%
Fuel
(Car/Mot
orcycle)
7.34%
Cooking (
LPG)
22.53%

4.6.2 Single tenement individual buildings (category 1)

When data from only single tenement individual buildings (category 1 – sample 01,02,03 & 04) were studied for quantification, the total emission came to 34.41 TonneCO2/ annum. The total emission from electricity was 24.63 TonneCO2/ annum, 4.78 TonneCO2/annum from respiration, 2.88 TonneCO2/annum from cooking fuel, 1.25 TonneCO2/annum from water consumption and 0.87 TonneCO2/ annum from fuel consumption due to automobile idling time. The percentage distribution of emission from different sources were approximately 71.57% from electricity, 13.88% from respiration, 8.37% from cooking fuel and 3.63% from water consumption and 2.55% from automobile idling time fuel consumption (Figure 26).

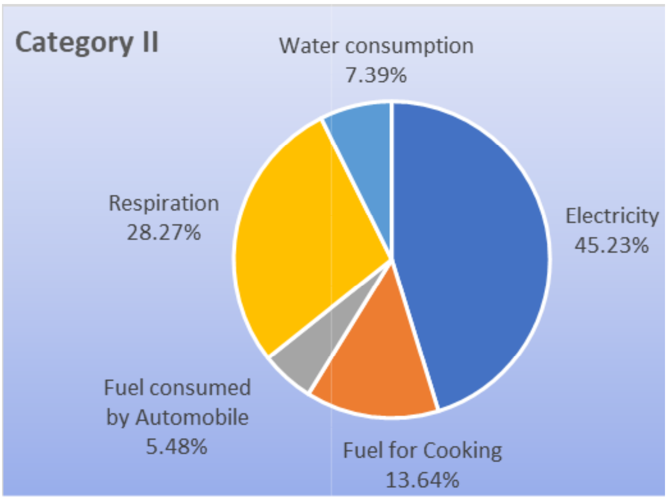
Figure 26 Percentage distribution of CO2 emission from different sources in a single tenement individual building



4.6.3 Flats in multi-tenement buildings (category 2)

Survey data from only flats in multi-tenement buildings (category 2), when tabulated, showed that the total emission came to 34.06 TonneCO2/annum. The total emission from electricity was 15.69 TonneCO2/ annum, 9.80 TonneCO2/annum from respiration, 4.73 TonneCO2/annum from cooking fuel, 2.56 TonneCO2/annum from water consumption and 1.90TonneCO2/annum from fuel consumption due to automobile idling time. The percentage

Figure 27 percentage distribution of CO2 emission from only flats in multi-storied multi-tenement residential buildings

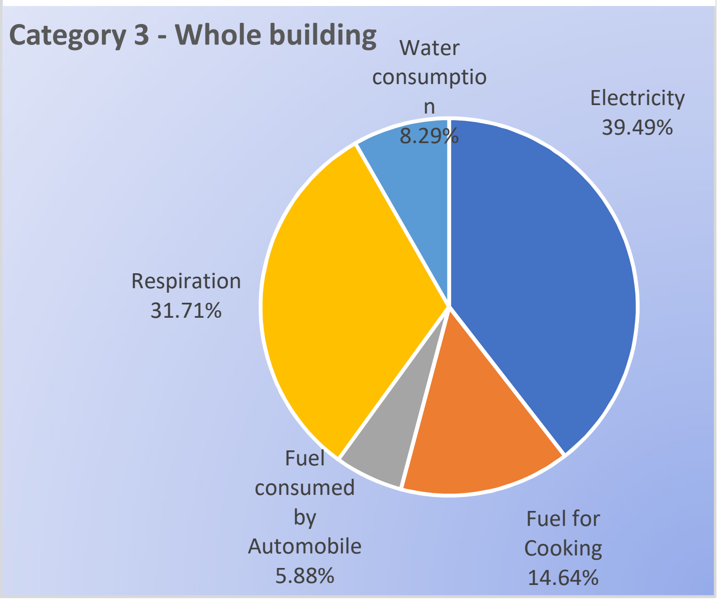


distribution of emission from different sources were approximately 46.06% from electricity, 28.79% from respiration, 13.89% from cooking fuel, 7.52% from water consumption and 5.58% from automobile idling time fuel consumption (Figure 27).

Multi-storied multi-tenement whole building (category 3)

When consideringcategory3, that is, multi-storied, multi-tenement whole buildings including common areas, field data was obtained from only one building. However, data could be collected from seven (7) flats and for one flat no data could be collected. Information or CO_2 emission value for this lone flat is calculated from the mean value of CO_2 emission from the rest of the seven flats. CO_2 emission from all common areas of the building like ground floor parking space, stair case and lift lobby, service areas in ground floor, roof areas, and by service equipment like pump is calculated. When all information, considering all eight (8) flats and common spaces are tabulated and analysed, the total emission from building comes to 20.842 TonneCO_2/ annum. The total emission from electricity is 8.33 TonneCO_2/ annum, 6.61 TonneCO_2/annum from respiration, 3.05 TonneCO_2/ annum from cooking fuel, 1.73 from water consumption and 1.22 TonneCO_2/annum from fuel consumption due to automobile idling time. The percentage distribution of emission from different sources are approximately 39.49 % from electricity, 31.71% from respiration, 14.64% from cooking fuel, 8.29% from water consumption and 5.88% from automobile idling time fuel consumption (Figure 28)

Figure 28 Distribution of CO2 emission from different sources of a whole multi-storied multi-tenement building residential building



4.7 Conclusion

Study of emission distribution from different sources of a household when compared across different categories of buildings shows that in case of a single tenement individual building the percentage of emission from electricity is quite high (71.59%). The same value for flats in multi-tenement buildings is much lesser (46.06%) and when the whole building is considered along with common areas it becomes 39.49%. The comparative values of distribution percentage of different sources from residential buildings in the operation stage, when compared across different categories are given in Table 28.

Table 28 Distribution of CO2 emission from different sources across different categories of residential buildings

Category	Description of Household	Electricity	Cooking fuel (LPG)	Fuel (petrol) consumption for automobiles	Respirati on	Water consumpti on
		(%)	(%)	(%)	(%)	(%)
Category 1	Single tenement individual buildings	71.59	8.38	2.52	13.88	3.63
Category 2	Flats in multi-storied multi-tenement building	46.06	13.89	5.58	28.79	7.52
Category 3	Whole multi-storied multi-tenement building including common areas	39.49	14.64	5.88	31.71	8.29

Considering different activities in the operation phase of urban single tenement individual buildings and flats in urban multi-storied multi-tenement buildings, maximum CO2 emission takes place from electricity consumption followed by respiration, fuel consumption for cooking, water consumption and lastly fuel consumption by automobiles.

When data from only single tenement individual buildings were studied for quantification the percentage distribution of emission from different sources were approximately 71.59% from electricity, 13.88% from respiration, 8.38% from cooking fuel and 3.63% from water consumption and 2.52% from automobile.

Survey data from only flats in multi-tenement buildings when tabulated, showed that the percentage distribution of emission from different sources were approximately 46.06% from electricity, 28.79% from respiration, 13.89% from cooking fuel, 7.52% from water consumption and 5.58% from automobile idling time fuel consumption.

Survey data when considering multi-storied, multi-tenement whole buildings with eight (8) number flats, including common areas (category 3,) were tabulated the total emission from building comes to **20.842 TonneCO2/annum**. The total emission from electricity is 8.33 TonneCO2/annum, 6.61 TonneCO2/annum from respiration, 3.05 TonneCO2/annum from cooking fuel, 1.73 from water consumption and 1.22 TonneCO2/annum from fuel consumption due to automobile idling time. The percentage distribution of emission from different sources were approximately 39.49% from electricity, 31.71% from respiration, 14.64% from cooking fuel, 8.29% from water consumption and 5.88% from automobile idling time fuel consumption (Figure 07)

5 CHAPTER 5 - FINDING CORRELATION BETWEEN CO2 EMISSION AND BUILDING PARAMETERS

5.1 Introduction

With a goal to study CO2 emission from urban multi-storied multi-tenement residential building in the operational stage, this research work, divides the research process into 4 stages –

Stage 1 - identification of the sources of emission,

Stage 2 - finding a logical data driven method for quantification of CO^2 emitted,

Stage 3 -quantification of CO2 emission

Stage 4 - finding correlation between building parameters and CO^2 emission pattern.

Stages 1, 2 and 3 are already discussed in previous chapters. The sources of CO2 emission are identified (stage 1). A justified logical method for quantification of CO2 emitted is defined (stage 2). CO2 emissions from different sources considering different categories of residential buildings are quantified and emission patterns studied (stage 3). This stage calls for study of correlation, if any, between the quantified CO2 emission and building parameters like plot area, building built-up or covered area and number of residents. The aim of the research work is to provide inputs at the planning level of urban areas and buildings with a goal of achieving mitigation of climate change. Knowledge of correlation between parameters of the building and CO^2 emission, if any, will contribute generously to formulation of effective planning standards for building design, rules and regulations.

5.2 CO2 Emission pattern w.r.t Plot area

5.2.1 Category I – single tenement individual house:

Data from questionnaire and emission quantification process were tabulated and compared to find relationship between Comparative Study of CO^2 Emission and Plot Area. The comparative data of CO^2 emission from single tenement residential plots (including all areas – building and common areas) and area of the respective plots are as shown in Table 29.

Table 29 CO2 emission per unit plot area single tenement buildings (category 1)

Sample Reference	Plot Area	Total CO2 emission / annum	CO2 emission / sqm. of plot area/annum
	(sqm.)	(TonneCO2/ annum)	(TonneCO2/sqm./annum)
Sample 01	269.88	5.451	0.020
Sample 02	234	8.770	0.037
Sample 03	301	11.098	0.037
Sample 04	227.6	9.087	0.040
Mean value			**0.033**

For urban single tenement residential buildings in operational phase (category I), the mean annual CO^2 emission comes to 0.033 TonneCO^2/sqm/annum. of the plot area of a single tenement building. It is also evident that for a single tenement building CO^2 emission has no correlation with plot area. Increase in plot area for a single tenement building does not imply an increase in CO^2 emission.

Category III – Individual flats in multi-storied buildings: For urban whole multi-storied multi-tenement residential building (category III)**,** total operational stage CO2 emission from the being 20.842 TonneCO2/annum and plot area being 271.73 sqm, annual CO2 emission per sqm. of plot area comes to 0.077TonneCO2/sqm/annum. It is noticeable that the mean value of CO2 emission in single tenement buildings (0.033 TonneCO^2/sqm./annum) is almost half the value of CO2 emission from multi-storied, multi-tenement building (0.077 TonneCO2/ sqm/annum) – ratio being 1:2.3. This is primarily because, compared to single tenement individual houses, there are more number of flats, families, residents and owned automobile per unit area of plot and hence more energy consumption per unit area of plot.

5.3 CO^2 Emission pattern w.r.t Built up area

5.3.1 Category I – single tenement individual house:

Data from sample survey were tabulated for finding a correlation between CO^2 emission and Covered area of a building. Data analysis showed that there is no proper correlation between emission and covered area of the building / flat. The comparative study of annual emission from different single tenement individual buildings (category1) are shown in Table 28. The mean annual emission from a single tenement building comes to 0.030 TonneCO^2/ sqm. of covered area. There is no correlation between annual CO^2 emission and covered area.

Table 30 Comparative study of annual CO2 emission per unit built-up area from single tenement buildings (category I)

Sample Reference	Built-up Area	Total Annual Emission	Annual CO2 Emission / sqm of the built-up area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 001	222.96	5.451	0.024
Sample 002	334.00	8.770	0.026
Sample 003	298.60	11.098	0.037
Sample 004	278.70	9.087	0.033
Mean Value			0.030

5.3.2 Category II & III – Individual flats in multi-storied buildings:

Same study of emission from different individual flats in multistoried buildings (category 2) were also tabulated. Emission from flats with the same covered areas were studied separately. The sample survey consisted of 4 number flats with the same covered area (100 sqm.) in one complex that has several multi-storied buildings in Bidhan Nagar. The sample survey also had another 8 number of flats with same area (74.32 sqm. in one single multi-storied flat in Newtown. These 2 groups were studied separately. The analysis showed that flats having the *same area were emitting different quantities of CO^2* (Table 31, Table 32 and Table 33).

Table 31 Comparative study of annual CO2 emission per unit built-up area from flats with same area (100 sqm.) in a multi-storied multi-tenement building (category II)

Sample Reference	Flat built-up Area	Total Annual Emission	Annual CO2 Emission / sqm of the built-up area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 005	100	3.333	0.033
Sample 006	100	3.108	0.031
Sample 007	100	5.611	0.056
Sample 008	100	3.536	0.035
Mean Value			**0.039**

Table 32 Comparative study of annual CO2 emission per unit built-up area from flats with same area (74.32 sqm.) in multi-storied, multi-tenement building (category II)

Sample Reference	Flat built-up Area	Total Annual Emission	Annual CO2 Emission / sqm of the built-up area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 09	74.32	2.036	0.027
Sample 10	74.32	3.803	0.051
Sample 11	74.32	2.501	0.034
Sample 12	74.32	2.377	0.032
Sample 13	74.32	1.630	0.022
Sample 14	74.32	1.843	0.025
Sample 15	74.32	2.257	0.030
Mean Value			**0.032**

Table 33 Comparative study of annual CO2 emission per unit built-up area of individual flats in multi-storied multi-tenement buildings (category II)

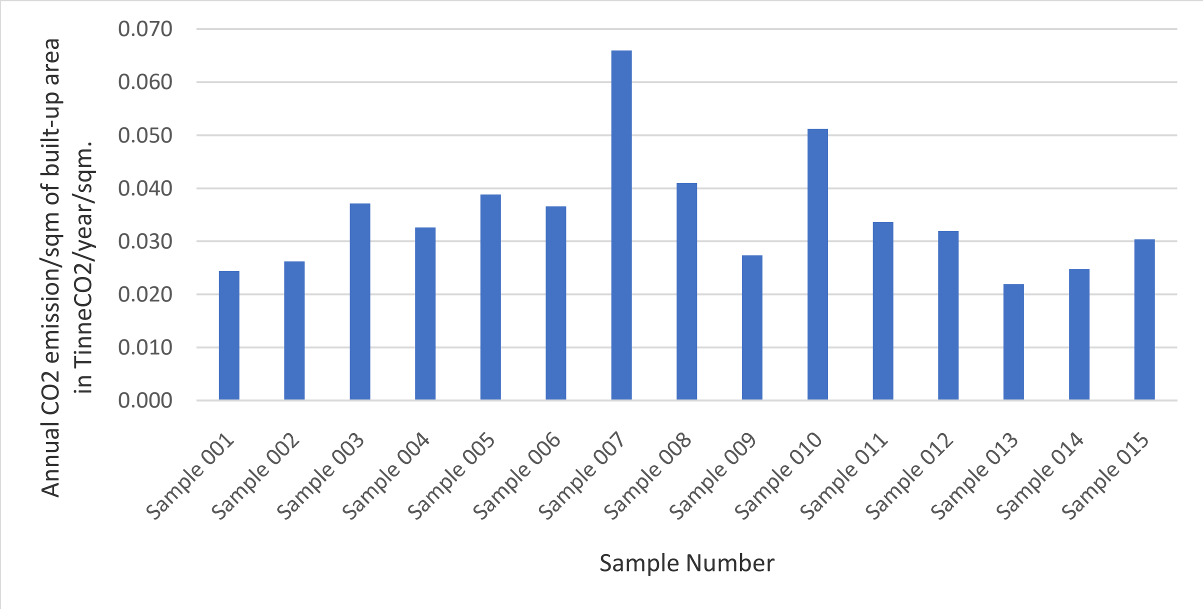
Sample Reference	Flat built-up Area	Total Annual Emission	Annual CO2 Emission / sqm of the built-up area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 005	100	3.88	0.039
Sample 006	100	3.66	0.037
Sample 007	100	6.60	0.066
Sample 008	100	4.10	0.041
Sample 009	74.32	2.04	0.027
Sample 010	74.32	3.80	0.051
Sample 011	74.32	2.50	0.034
Sample 012	74.32	2.38	0.032
Sample 013	74.32	1.63	0.022
Sample 014	74.32	1.84	0.025
Sample 015	74.32	2.26	0.030
Mean Value			**0.038**

Table 34 Comparative study of annual CO2 emission per unit built-up area from single and multi-tenement buildings (all categories combined)

Sample Reference	Flat Covered Area	Total Annual Emission	CO2 Emission / annum/ sqm of the Covered area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 001	222.96	5.451	0.024
Sample 002	334.00	8.770	0.026
Sample 003	298.60	11.098	0.037
Sample 004	278.70	9.087	0.033
Sample 005	100	3.881	0.039
Sample 006	100	3.661	0.037
Sample 007	100	6.596	0.066
Sample 008	100	4.098	0.041
Sample 009	74.32	2.036	0.027
Sample 010	74.32	3.803	0.051
Sample 011	74.32	2.501	0.034
Sample 012	74.32	2.377	0.032
Sample 013	74.32	1.630	0.022
Sample 014	74.32	1.843	0.025
Sample 015	74.32	2.257	0.030
Mean Value			**0.034**

Figure 29 is a graphical presentation of annual CO^2 emission per sqm. of covered area of different samples (15 numbers). The information from Table 34 clearly illustrates that there is no correlation between CO^2 emission and covered areas of flats / buildings. Flats with same areas produce different quantities of CO2.

Figure 29 Annual CO2 emission per unit built-up area of buildings and flats (all samples -15 numbers)



The mean value of annual CO^2 emission for a **whole multi-storied multi-tenement residential Building in operation phase, considering flat and common areas** comes to **0.028 TonneCO^2/ annum/sqm**. (Table 35)

Table 35 Comparative study of annual CO2 emission per unit built-up area from a multi-storied multi-tenement building (category III)

Sample Reference	Built-up Area	Total Annual Emission	Annual CO2 Emission / sqm of the built-up area
	(sqm)	TonneCO2/ annum	TonneCO2/ annum/sqm
Sample 09	74.32	2.036	0.027
Sample 10	74.32	3.803	0.051
Sample 11	74.32	2.501	0.034
Sample 12	74.32	2.377	0.032
Sample 13	74.32	1.630	0.022
Sample 14	74.32	1.843	0.025
Sample 15	74.32	2.257	0.030
Sample 16	74.32	2.350	0.032
Common Area	148.64	2.045	0.014
Mean Value			**0.028**

A comparative analysis of operational stage CO2 emission with respect to building built-up area across different categories are shown in Table 36.

Table 36 Comparative analysis of annual CO2 emission per unit built-up area in various categories

Category	Sample Reference	Description	Mean Value of CO^2 Emission ($TonneCO^2$/annum/sqm)
Category I	01,02,03,04	Single-tenement Individual House	0.030
Category II	05,06,07,08	Flats in a Multi-storied building (only Bidhannagar)	0.039
	09,10,11,12, 13,14,15	flats in a Multi-storied building (only Newtown)	0.032
	05,06,07,08,09, 10,11,12,13,14,15	All flats (Bidhannagar& Newtown) considered together	0.038
Categories I, II (combined)	01,02,03,04, 05,06,07,08,09, 10,11,12,13,14,15	Single tenement individual house & Flats in multistoried buildings	0.034
Category III		Whole building – flats and common areas	0.028

5.4 Comparative Study of Number of Residents and CO^2 Emission

5.4.1 Number of Family members:

Assuming that there is some bearing between number of residents in the building and CO^2 emission from the flat / building, this paper tried to analyses the data from survey to find out the authenticity of the assumption. Emphasis was given to find out average number of residents in a flat in the urban areas of Kolkata, Bidhan Nagar and Newtown. Number of family members/ residents of each individual houses and flats are shown in Table 37. The data clearly shows that irrespective of the size of the plot or covered area of the building or flat, the number of residents staying in it generally varies from 3 to 5, with very few exceptions. Flats are generally all occupied by nuclear families. Even single tenement individual buildings are also having nuclear families, barring few exceptions. The concept of joint family is almost non-existent in the urban areas. As per Census 2011 average household size in urban areas of India was 4.6 and same in West Bengal was also 4.6 Whereas, as per Ministry of Statistics and Programme Implementation, Government of India, average household size in urban areas of India in 2020-21 is 3.8 (https://www.mospi.gov.in/estimated-number-households-average-household-size-and-sex-ratio-no-female-1000-male-2), showing that household size is going down in urban areas. As per our sample survey the average household size, considering Kolkata, Bidhan Nagar and Rajarhat, comes to 3.8 (Table 35), which same as data (3.8) provided by Ministry of Statistics and Programme Implementation, Government of India, average household size in urban areas of India in 2020-21.

Table 37 Number of residents in buildings / flats in samples

Sample Reference	Number of residents
Sample 001	8
Sample 002	3
Sample 003	4
Sample 004	4
Sample 005	3
Sample 006	3
Sample 007	5
Sample 008	5
Sample 009	3
Sample 010	4
Sample 011	3
Sample 012	4
Sample 013	3
Sample 014	2
Sample 015	3
Sample 016 (average of other samples)	3
Mean Value of Number of Family members	3.8

5.4.2 Plot Area and Covered Areas per number of Residents:

To find any relationship between number of residents to plot area and covered area of a building, it is found out that, for single tenement buildings (Category 1), on an average, 54.34 sqm. of plot area is covered by a single resident. On the other hand, for a multi-storied building (category 3), a plot area of 271.73 sqm. is covered by 57 number of residents, considering all 16 flats, resulting in. So, in a single tenement building (category 1) the area of plot enjoyed by a single tenement is almost 4 times the area enjoyed by a single resident staying in a multi-tenement flat. The built-up area per resident in a single tenement building (category 1) is 58.65 sqm. whereas the covered built area per resident in a multi-tenement building is approximately half (30.975 sqm). The analysis is shown in Table 38.

Table 38 Plot area and built-up area per number of residents in different categories of samples

Category	Plot Area / resident	Built-up Area / resident
Category 1 (single tenement building)	1032.48 sqm. / 19 nos. of residents = 54.34 sqm/resident	1134.26 sqm. / 19 nos. of residents = 59.70 sqm/resident
Category 3 (multi-storied multi-tenement building)	271.73 sqm. / 25 nos. of residents = 10.87 sqm/resident	765.71 sqm. / 25 nos. of residents = 30.63 sqm/ resident

5.5 CO2 Emission and Number of Residents:

The average CO^2 emission per resident varies considerably when we calculate it across different categories of single tenement and multi-tenement buildings. The mean CO^2 emission per resident comes to 1.54 ToneeCO^2/ annum in single tenement buildings (category 1) and almost half (0.79 ToneeCO^2/ annum) in a multi-tenanted multistoried building i.e. category 2. (Table 39 and Table 40). It is also found that CO^2 emission is not directly dependent on number of persons in the flat / building. CO2 emission from respiration by inhabitants is directly dependent on number of residents – that is more the number of residents more the emission. However, the total emission from the flat / building has no correlation with the number of residents in the flat or building.

Table 39 Annual CO2 emission per number of residents in single tenement building (category)

Sample Reference	Number of Family Members	Total Annual Emission	Total Annual CO2 Emission / Number of Residents
	Numbers	TonneCO2/ annum	TonneCO2/ annum/ person
Sample 001	8	5.451	0.681
Sample 002	3	8.770	2.923
Sample 003	4	11.098	2.775
Sample 004	4	9.087	2.272
Mean Value			**1.811**

Table 40 Comparative study of annual CO2 per number of residents in flats in multi-storied multi-tenement building (category II)

Sample Reference	Number of Residents	Total Annual Emission	Annual CO2 Emission / Number of Residents
	Numbers	TonneCO2/ annum	TonneCO2/ annum/ person
Sample 005	3	3.881	1.294
Sample 006	3	3.661	1.220
Sample 007	5	6.596	1.319
Sample 008	5	4.098	0.820
Sample 009	3	2.036	0.679
Sample 010	4	3.803	0.951
Sample 011	4	2.501	0.625
Sample 012	4	2.377	0.594
Sample 013	3	1.630	0.543
Sample 014	2	1.843	0.921
Sample 015	3	2.257	0.752
Mean Value			**0.889**

Table 41 gives a comparative study of annual CO^2 emission and number of residents in all categories and as per individual samples.

Table 41 Annual CO2 emission per resident in different sample (all categories)

Sample Reference	Number of Residents	Total Annual Emission	Annual CO2 Emission / Number of Residents
	Numbers	TonneCO2/ annum	TonneCO2/ annum/ person
Sample 001	8	5.451	0.681
Sample 002	3	8.770	2.923
Sample 003	4	11.098	2.775
Sample 004	4	9.087	2.272
Sample 005	3	3.881	1.294
Sample 006	3	3.661	1.220
Sample 007	5	6.596	1.319
Sample 008	5	4.098	0.820
Sample 009	3	2.036	0.679
Sample 010	4	3.803	0.951
Sample 011	3	2.501	0.834
Sample 012	4	2.377	0.594
Sample 013	3	1.630	0.543
Sample 014	2	1.843	0.921
Sample 015	3	2.257	0.752
Mean			**1.212**

5.6 CO^2 emission Analysis of whole building (Category 3)

The information from the field survey was tabulated and analysed for finding CO^2 emission data for a whole multi-storied residential building, along with the plot. The building is a G+4storied multi-tenement residential building situated in Newtown. There are 8 number flats out of which 7 numbers could be surveyed for information. One flat is vacant and unoccupied and hence could not be surveyed. Area of the flat not surveyed is same as other flats – i.e. 74.32 sqm. The number of inhabitants (3) and annual CO^2 emission (2.076 TonneCO2) of this flat is assumed by calculation as average of the other 7 flats. Data from this survey and analysis are presented in Table 40. Annual CO^2 emission from each flat (8 numbers) were added and the total annual CO^2 emission from all 8 number flats of the building came to 12.457 $TonneCO^2$. Emissions from the common areas (ground floor parking, staircase, terrace area and water pump) were also tabulated. Cause of emission from common areas could be attributed to only electricity consumption in the common areas and is equal to 1.725 $TonneCO^2$/ annum. This, i.e. emission from common areas (1.725 TonneCO2/annum), when added to emission from all 8 number flats (12.457 $TonneCO^2$), gives the total annual CO^2 emission by the whole building. The total CO^2 emission from the whole building comes to **20.842$TonneCO^2$/ annum.**

Table 42 CO2 emission data of whole building (category III)

Sample Reference	Number of Residents	Total Annual Emission	Annual CO2 Emission / Number of Residents
	Numbers	TonneCO2/ annum	TonneCO2/ annum/ person
Sample 009	3	2.036	0.679
Sample 010	4	3.803	0.951
Sample 011	3	2.501	0.834
Sample 012	4	2.377	0.594
Sample 013	3	1.630	0.543
Sample 014	2	1.843	0.921
Sample 015	3	2.257	0.752
Sample 016* (assumed)	3	2.350	0.783
Common Area		2.045	
Total	25	20.842	
Mean			**0.834**

*Taken as average of other 7 number flats.

The total operational stage CO2 emission from this whole multi-tenement multi-storied residential building, being studied, is 20.842$TonneCO^2$/annum. Area of the total plot being

271.73 sqm. CO^2 emission from the plot comes to 0.077 TonneCO^2/annum/sqm of the plot area. Considering total covered area of the whole building as 743.73 sqm. (all areas – flats and common areas), CO^2 emission from the whole building comes to 0.028 TonneCO2/annum/sqm. of covered area. The total number of inhabitants being 25, CO^2 emission comes to 0.834TonneCO^2/annum/per person (Table 42).

Table 43 Comparative study of annual operational stage CO2 emission and building parameters for a urban multi-storied multi-tenement whole building

Total operational stage CO2Emission	20.842 TonneCO^2/ annum
Area of plot	271.73 sqm.
CO2 Emission per sqm. of Plot Area	0.077 TonneCO^2/annum/sqm of the plot area.
Total Built-up Area (all areas – flats and common areas)	743.20 sqm.
CO2 Emission per sqm. of Built-up Area	0.028 TonneCO2/annum/sqm. of covered area
Total number of Residents	25
CO2 Emission per Resident	0.834 TonneCO^2/annum/per person

A comparative analysis of 1) annual CO^2 emission per sqm. of plot area, 2) annual CO2 emission per sqm. of covered area and 3) annual CO^2 emission per person from a whole *single tenement building* (category 1) and a whole *multi-storied multi-tenement building* (category 3) are shown in Table 43 and Table 44.

Table 44 Comparative analysis of CO2 emission and building parameters of single tenement (category I) and multi-storied multi-tenement building (category III)

Category	Annual CO2 emission per sqm. of plot area	Annual CO2 emission per sqm. of built-up area	Annual CO2 emission per number of residents
	(TonneCO^2)	(TonneCO^2)	(TonneCO^2)
Category 1 (single tenement building)	0.033	0.030	1.811
Category 3 (multi-storied multi-tenement building)	0.077	0.028	0.834

5.7 Conclusion

This research work has tried to find correlation between CO2 emission during the operation phase and urban residential building parameters like plot area, covered area and number of residents. The comparative study of CO^2 emission from urban single tenement residential buildings showed that there is no correlation between CO^2 emission during the operation phase and the plot area of the building. The mean annual CO^2 emission comes to 0.033 TonneCO^2/sqm. of plot area for a single tenement building. The same value for a multi-storied whole building in Newtown is 0.077 TonneCO^2/sqm. of plot area. Data analysis showed that there is no proper correlation between emission and covered built up area of the building / flat. For a single tenement building the mean annual emission comes to 0.030 TonneCO^2/ sqm. of built-up area. For individual flats, the mean value CO^2 emission came to 0.038 TonneCO^2/annum/sqm. of built-up area. For the Sample Survey two (2) sets of flats with same built-up area were considered. Results showed that flat having same area were having varied CO^2 emission patterns. CO^2 emission quantification data also proved that the total CO^2 emission from urban residential buildings during the operation phase has no correlation with number of residents staying in the building/ flats. The mean CO^2 emission per resident comes to 1.811 ToneeCO^2/ annum in single tenement buildings (category I) and almost less than half (0.834 ToneeCO^2/ annum) in a multi-tenanted multistoried building i.e. category III. The research findings demonstrate that, without any correlation between building parameters and CO^2 emission from a urban residential building during the operation stage, it is difficult to evolve a predictive model for development guidelines of urban residential buildings based on emissions. However, mean values of CO^2 emission against plot area, built up covered area or number of residents can be used for formulating planning standards.

6 CHAPTER 6 - DETERMINING THE SEQUESTRATION POTENTIAL AND SCOPE OF PLANTATION WITHIN URBAN RESIDENTIAL PLOTS

6.1 Introduction

One way of mitigation action against CO2 emission is to sequester the emitted CO2 by plants and trees. Plants can consume CO2 from the atmosphere by way of photosynthesis to make its own food and in the process lower CO2 concentration around us. With this action plants can be a very important tool in the climate change mitigation process. It becomes our prime responsibility to use plants to the greatest extent to lower CO2 level from the earth. Architects, planners, designers and residents should also use as much plantation as possible in the building premises that they design or stay in. This research work studies quantification process of CO2 sequestration by urban plants that can be grown in sites of multi-storied multi-tenement residential buildings. It also investigates the prevalent plantation scenario in these building premises in Newtown along with further development scope of the same. To find the exact CO2 sequestration capability of home-grown plants in urban areas, there arises the need to find out – 1) exact potential of these plants to sequester CO2 and 2) scope of plantation in urban building premises. To find the exact sequestration potential of home-grown plants, first, the sequestration rates of these plants are identified. In the next step, the quantification of sequestration is carried out keeping in mind two (2) scenarios – 1) that there are plants in only 4% of the building plot area, kept as the mandatory green open space as per the present municipal rules (scenario 1) and 2) locating further plantation scope in the premises and quantifying the resultant sequestration (scenario 2).

6.2 Methods and materials

6.2.1 Identification of Sequestration rates

The methods adopted for identification of rates ofCO^2sequestration by home-grown urban plants inside the premises of a multi-storied multi-tenement urban residential building has been based completely on inputs from existing research studies (mentioned in chapter 2). The plants that can be found inside the premises are categorized into three(4) groups –

1) **out-door plants** that can be grown in the open spaces around the building, considering both, plants grown in unpaved green open spaces and plants grown in pots on paved areas and terraces,

2) **Vertical gardens** that can be put up in the premises,

3) **indoor plants** that can be grown inside the buildings, i.e. inside the flat areas or common areas, including balcony and window ledges.

For calculation of CO^2 sequestration by outdoor small and medium ranged plants, data from CRISIL ((CERE)) experiments were adhered to – '33,368 trees and plants will sequester 8646.29 $MTCO^2$ over a span of 15 years', which gives an average rate of 0.017 $MTCO^2$/plant/year = **0.019 $TonneCO^2$/plant/year**. For calculation of sequestration rate of indoor plants, data from research work of *Profiling indoor plants for the amelioration of high* CO^2 *concentrations by F.R. Torpy, P. Irga, M.D. Burchett* (F.R., P, & M.D.)were used - CO^2 sequestration level ranged from 47.9 to 168 $mgCO^2$/plant/hr for indoor plants, which means an average rate of 107.95 $mgCO^2$/plant/hr = 945642 $mgCO^2$/plant/year = 0.945 $KgCO^2$/plant/year = **0.001 $TonneCO^2$/plant/year**. Green walls becoming popular these days, the scope of sequestration of CO^2 by green walls was also considered. For this quantification, data from *Profiling indoor plants for the amelioration of high* CO^2 *concentrations F.R. Torpy, P. Irga, M.D. Burchett* (F.R., P, & M.D.) was used. This research paper by *F.R. Torpy, P. Irga, M.D. Burchett* (F.R., P, & M.D.) gives two very useful information regarding plant growth and sequestration of CO^2 by green walls – 1) **5m2 of green wall contains - 57m2 of leaf area** and 2) highest sequestration rate is 657 $mgCO^2$/m2 leaf area/ hr. This paper considers the first information as it is placed by the authors - 5m2 of green wall contains - 57m2 of leaf area or in other words **1sqm of green wall have 11.4 sqm of leaf area**. However, the second information says that this is the highest rate of sequestration by plants. So, for a more reasonable research work, a much lesser value (70% of the actual value) = 460 $mgCO^2$/m2 leaf area/hr = **0.002 $TonneCO^2$/ m2/ year** is considered as the average rate of sequestration by green walls.

6.3 Quantification of plantation scope inside the site

The number of plants that can be grown in a residential premises, inside the building or outside, is difficult to ascertain. General reconnaissance survey and literature study showed that there is a general apathy towards growing trees and plants inside the premises in urban India and in Kolkata. Reasons are numerous - like maintenance problems, damp and leakage problems in roof slabs when plants are grown in the terrace, mosquito and pest problems, lack of time, enthusiasm and support to look after plants, etc. During sample survey it was found out that most of buildings, that were surveyed, had plantations in only 4% of the plot area as per sanctioned plans or as per mandatory minimum rules for green open space. With this scenario prevailing, this research paper considers two (2) scenarios –

1) **Scenario 1 -** In scenario 1, it is assumed that the residential building restricts plantation area to only what is mandatory as per the NKDA municipal building rules. So, the plantation area is only 4% of the plot area (mentioned in literature review in chapter 2), open to sky and not paved and is termed as 'green open space'. The rule of keeping minimum 4% of plot area as 'green open space' (not paved and open to sky) was introduced by NKDA to improve environmental aspects of urban areas like storm water management, heat-island, greeneries, etc.
2) **Scenario 2 –** In scenario2, this research work investigates the possibilities of growing further plantation in the paved or unpaved areas in the plot around the building and also some terrace garden, in addition to the4% of the plot area as green space as per municipal rules. It also tries to find the scope of green vertical walls which can be accommodated in the open areas around the building or in the terrace above parapet walls and along stair-head room or overhead reservoir. Added to these, there are indoor plants in individual flats or common areas, which are also studied.

Plantation scope and CO^2 sequestration scope of each category of plants, mentioned earlier, and for both the scenarios 1 and 2 are explored, and quantified.

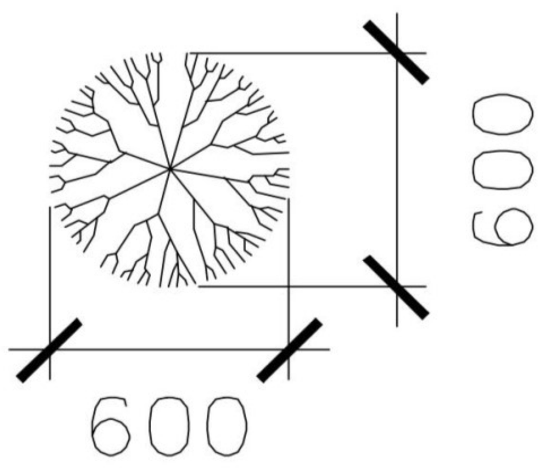
6.4 Identification of areas for further plantation scope (scenario 2)

To identify the area for further plantation in the ground floor, first the existing use of the areas are found out from the sanction plans, and plotted into drawings. The free open spaces or free top surfaces in the ground floor, that are not being used for specific purposes and have scope of ground plantation or potted plantation, are identified and located on the plans. Areas, which are paved or are being used for services like semi-underground water reservoirs, underground water supply lines or sewerage pipes or are not being used for walking, and has scope of growing potted plants, are identified in the ground floor plans. Terrace plantation area is calculated by assuming an area approximately 1.0m to 1.5m wide, as per suitability, along the parapet wall, dedicated for terrace garden. While demarcating these areas it was kept in mind that a fair amount of space is left in the terrace for other uses by the residents. These areas are plotted in terrace plans of the sample plots, checking feasibility and areas found out. Scope for suitable vertical gardens was also studied and spaces that can be used for vertical gardens were also found out. It was kept in consideration that these spaces for plantation get enough sunlight and maintenance is feasible. The option of using entire building faces, front or side or rear, facing sunlight, as vertical garden was ruled out due to maintenance and feasibility issues. Vertical gardens were mostly considered above roof parapet walls, above boundary walls and along outside walls of stairhead room sand lift rooms. For placements of all green open spaces, outdoor potted plant areas, terrace gardens and vertical gardens, availability of sunlight, maintenance ease and feasibility of vertical structures were given utmost importance. Finding number of indoor plants and plants in balcony and window ledges were difficult to ascertain. For this category, it was assumed that all flats, irrelevant of their size or orientation or other physical characteristics, are having 15 number of small indoor plants.

6.5 Number of out-door plants

As sizes of plants are not constant, meaning plants are always growing, a definite size of plants had to be assumed to find number of plants in a specific area. The number of outdoor plants that can be grown in the specific green open area (scenario 1 & 2) are calculated by dividing the value of the area for plantation by 0.36 sqm – assuming each home-grown mid-size plant to cover 0.6 m by 0.6 m area (Figure 30).

Figure 30 Assumed size of each outdoor plant in green open spaces, paved areas and terrace gardens



The same procedure is also applied to find number of mid-size plants grown in other areas like paved areas in ground floor and terrace garden.

6.6 Quantification of sequestration

The annual sequestration volume of CO2 by mid-size outdoor plants in green open spaces is quantified by multiplication of number of plants with the sequestration rate of a mid-size plant i.e. 0.019 TonneCO^2/plant/year. The same procedure is applied for quantification of sequestration by outdoor midsize plants grown in pots on paved areas. Sequestration rate of a mid-size potted plants in the terrace is taken as 0.019 TonneCO^2/plant/yeartide. same as plants in green open space in ground floor. The annual sequestration volume of CO2 by mid-size plants in in the terrace is quantified by the same procedure - multiplication of number of plants with the sequestration rate of a mid-size plant i.e. 0.019 TonneCO^2/plant/year.

For, vertical gardens, leaf area (sqm.) is first found out by multiplying the wall area value in sqm. with11.4 sqm assuming 1sqm of green wall have **11.4 sqm of leaf area**. This value (area of leaf in sqm.) is multiplied by **0.002 TonneCO^2/m2/ year** to find the sequestration volume of CO2 by vertical gardens.CO2 sequestration volume by indoor plants is obtained by multiplication of number of indoor plants with sequestration factor of indoor plants i.e. **0.001 TonneCO^2/plant/year**. Total volume of CO2 sequestration is obtained by summation of all these CO2 sequestration volumes i.e. sequestration volume of CO2 by mid-size plants in green open spaces, by potted mid-size plants in areas in ground floor other that green open spaces, by mid-size plants in the terrace, by vertical gardens inside the plot and by indoor plants in the window ledges, balconies and inside the flats and common spaces.

The quantification process of CO^2 sequestration is as follows –

1) CO^2 sequestration from mid-size outdoor plants in green open space

   = Number of plants x 0.019 TonneCO^2/plant/year

2) CO^2 sequestration from mid-size outdoor plants – potted and on paved areas

   = Number of plants x 0.019 TonneCO^2/plant/year

3) CO^2 sequestration by potted plants at terrace

   = Number of plants x 0.019 TonneCO^2/plant/year

4) 1 sqm of green wall = 11.4 sqm of leaf area

   CO^2 sequestration by green wall

   = Green wall area(sqm) x 11.4 x 0.002 TonneC02/annum

5) CO^2 sequestration by indoor plants

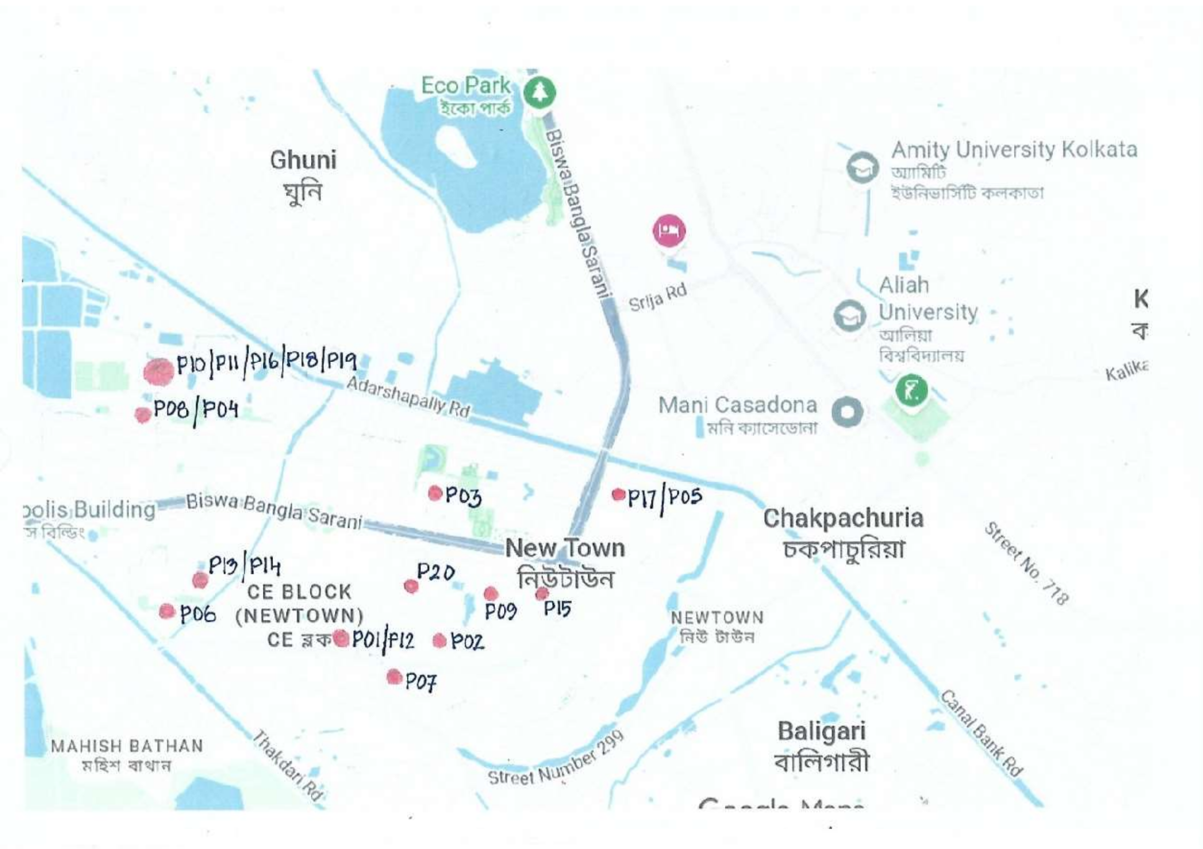
   = No. of plants x 0.001 TonneCO^2/year

6.7 Sample Survey

6.7.1 Scenario 1

Twenty (20) number of whole multi-storied and multi-tenement residential buildings in Newtown are chosen for study of plantation and sequestration scope. These samples are henceforth referred to as P01, P02, P03, P04, …. P20 and the sample set as 'Set-2'. The whole multi-storied and multi-tenement (G+4) residential building in Newtown already chosen and mentioned in sample survey in previous chapters 3, 4 and 5 and whose total CO2 emission has already been calculated, is a part of this sample set – hereinafter mentioned as sample number P03. The green open space in this plot (sample P03) is 10.88 sqm, which is exactly the minimum area required (4%). Similarly, for all samples in this Set-2, sanction plans are collected and analysed for plot area, minimum green open spaces of 4%. Sample location, New Town (Set 2) are shown in figure 31.

Figure 31 Map showing sample location in Newtown (Set 2)



6.7.2 Scenario 2

The same set samples (Set-2) are also selected for quantification of optimum feasible plantation area (Scenario - 2). For quantification of optimal level of plantation in these plots, the process as mentioned in methods sections applied - existing ground space utilization, in all these plots are examined as per sanction plans, plotted in drawings and percentage coverage calculated. Ground floor open space utilization is categorized into 1) drive ways, 2) other paved areas, 3) areas utilized for services mainly plumbing and sanitary and 4) mandatory green open spaces as per municipality stipulations. To investigate scope of further plantation in ground open space, areas which are not being utilized for any specific purpose but which have scope of green open space are found out and plotted. Areas which are being used for different purposes but has scope of having potted plants are also plotted. The terrace areas are examined for plantations with potted plants in all samples. Vertical gardens are marked in ground floor areas and terrace areas, considering suitable locations with proper sunlight. Number of indoor plants are assumed as 15 per flat.

6.8 Results &Analysis

6.8.1 Scenario 1-

Scenario 01 –Set 2- Sample P03: Quantification of sequestration considering plants in only 4% green space for plants as per existing building rules shows that green open space in sample P03 is only 10.88 sqm. This is only area where there is plantation. Considering that there are only mid-size plants, each on an average covering 0.6m x 0.6 m = 0.36 sqm approximately, there can be approximately 30 number such plants in the site. Considering them as outdoor plants with CO^2 sequestration rate as 0.019 $TonneCO^2$/plant/year, the annual total CO^2 sequestration from the building comes to **0.57 $TonneCO^2$/annum**.

Scenario 01 –Set 2 – other samples: Applying the same quantification method and same assumption that there are no plantations other than what is there in the stipulated open green spaces (4%) the sequestration potential of all 20 samples (including sample P03)is found out. The sequestration scope of green open space as per mandatory rules of all 8 samples are shown in Table 01.

The analysis shows that keeping only 4% green open space and restricting plantation scope to only that space, i.e. considering all 20 number sample plots together and having plantation in 249.18 sqm. out of 6229.47 sqm of land area, the total sequestration of CO2 is

13.15 TonneCO2/annum. However, considering green open spaces as per sanction plans of these samples (Set-2), the total green open space from all these sample plots taken together (total area of plot = 6229.47 sqm) increases to 292.21 sqm. Quantification volume of the total amount of CO2 sequestration by plantation in green open space as shown in sanction comes to 15.42 TonneCo2/annum (Table 45)

Table 45 Sequestration by plantation in green open space restricted to only 4% of plot area

Sample No.	**Plot area**	**Open green Space** (considering green open space restricted to only 4% of plot area)			**CO2 Sequestration** (sequestration by plantation in green open space restricted to inly 4% of the plot area)
	(sqm.)	(sqm.)	% of plot area	No. of plants (projected)	TonneCO2/ annum
P-01	200.53	8.02	4.00	22	0.42
P-02	266.64	10.67	4.00	30	0.56
P-03	271.73	10.87	4.00	30	0.57
P-04	299.67	11.99	4.00	33	0.63
P-05	335.84	13.43	4.00	37	0.71
P-06	361.37	14.45	4.00	40	0.76
P-07	400.96	16.04	4.00	45	0.85
P-08	399.50	15.98	4.00	44	0.84
P-09	335.13	13.41	4.00	37	0.71
P-10	399.15	15.97	4.00	44	0.84
P-11	400.03	16.00	4.00	44	0.84
P-12	399.50	15.98	4.00	44	0.84
P-13	201.34	8.05	4.00	22	0.43
P-14	402.08	16.08	4.00	45	0.85
P-15	200.00	8.00	4.00	22	0.42
P-16	200.87	8.03	4.00	22	0.42
P-17	335.58	13.42	4.00	37	0.71
P-18	150.10	6.00	4.00	17	0.32
P-19	335.17	13.41	4.00	37	0.71
P-20	334.28	13.37	4.00	37	0.71
TOTAL	**6229.47**	**249.18**			**13.15**

Table 46 CO2 sequestration by plantation in green open space as provided in sanction plans (Set-2)

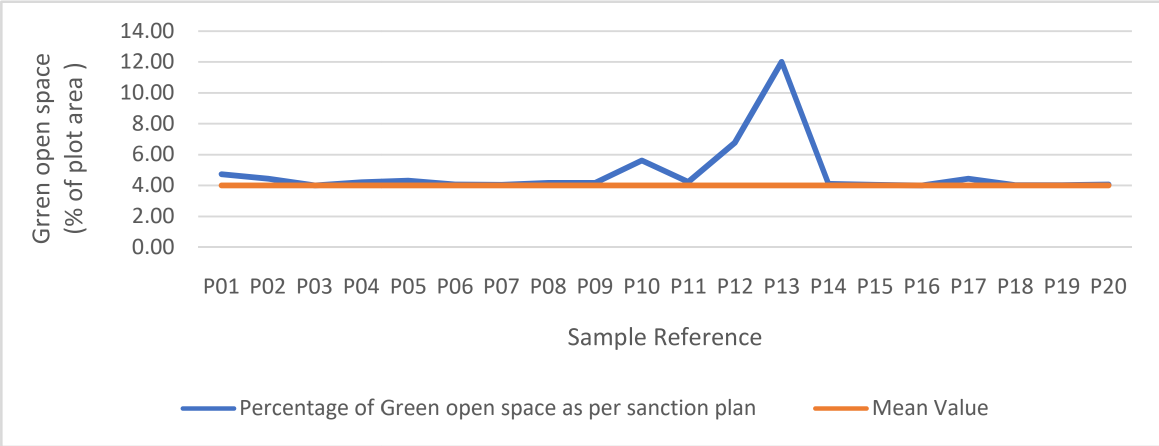
Sample No.	**Plot area**	**Open green Space** (as per sanction plan - following stipulation of minimum 4% of plot area)			**CO2 emission reduction** (through sequestration by plantation in green open space provided as per sanction plan)
	(sqm.)	(sqm.)	% of plot area	No. of plants (projected)	TonneCO2/ annum
P-01	200.53	9.50	4.73	26	0.50
P-02	266.64	11.83	4.44	33	0.62
P-03	271.73	10.88	4.00	30	0.57
P-04	299.67	12.63	4.21	35	0.67
P-05	335.84	14.50	4.32	40	0.77
P-06	361.37	14.70	4.07	41	0.78
P-07	400.96	16.20	4.04	45	0.86
P-08	399.50	16.70	4.18	46	0.88
P-09	335.13	13.98	4.17	39	0.74
P-10	399.15	22.41	5.62	62	1.18
P-11	400.03	16.93	4.23	47	0.89
P-12	399.50	27.11	6.79	75	1.43
P-13	201.34	24.17	12.00	67	1.28
P-14	402.08	16.50	4.10	46	0.87
P-15	200.00	8.08	4.04	22	0.43
P-16	200.87	8.05	4.01	22	0.42
P-17	335.58	14.90	4.44	41	0.79
P-18	150.10	6.05	4.03	17	0.32
P-19	335.17	13.50	4.03	38	0.71
P-20	334.28	13.60	4.07	38	0.72
TOTAL	**6229.47**	**292.21**			**15.42**

Comparison of Table 46 & 47 show that, when all samples of Set-2 are considered for green open space, there is hardly any difference between the minimum 4% value of green open space of plot area and the green open space area provided in the sanction plans.

Table 47 Green Open Space as per minimum 4% rule and as per provided in sanction plans

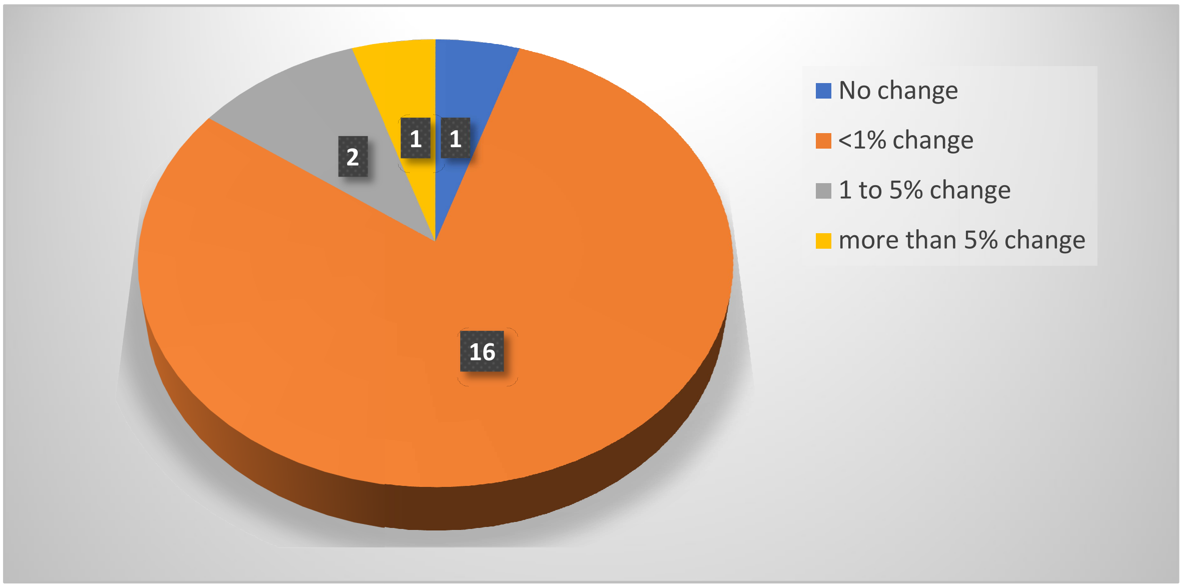
Sample Number (Set 2)	Premises No.	Plot Area	Green open space as per 4%	Green open space as per sanction plan	Change	
		(sqm.)	(sqm.)	(sqm.)	(sqm.)	(%)
P-01	CE-1A	200.53	8.02	9.50	1.47	0.73
P-02	CD-85	266.64	10.67	11.83	1.16	0.44
P-03	BC-62	271.73	10.87	10.88	0.01	0.00
P-04	AC-84	299.67	11.99	12.63	0.64	0.21
P-05	DC-216	335.84	13.43	14.50	1.07	0.32
P-06	AK-106	361.37	14.45	14.70	0.25	0.07
P-07	DA-96	400.96	16.04	16.20	0.16	0.04
P-08	AC-195	399.50	15.98	16.70	0.72	0.18
P-09	CB 68	335.13	13.41	13.98	0.57	0.17
P-10	AA-6	399.15	15.97	22.41	6.45	1.62
P-11	AA-178	400.03	16.00	16.93	0.93	0.23
P-12	CE-1/C-86	399.50	15.98	27.11	11.13	2.79
P-13	AL/1/A/3	201.34	8.05	24.17	16.11	**8.00**
P-14	AL/1/C/12	402.08	16.08	16.50	0.42	0.10
P-15	CC 167	200.00	8.00	8.08	0.07	0.04
P-16	AA 107	200.87	8.03	8.05	0.02	0.01
P-17	DC 54	335.58	13.42	14.90	1.48	0.44
P-18	AA 143	150.10	6.00	6.05	0.05	0.03
P-19	AA-1C	335.17	13.41	13.50	0.09	0.03
P-20	CA-225	334.28	13.37	13.60	0.23	0.07
TOTAL		6229.47	249.18	292.21	**43.03**	**0.69**

Figure 32 Green Open Space provided as per sanction plans with respect to Municipality Rule of 4% of the plot area



The table 47 and Figure 31 demonstrates that green open space provided as per sanction plan is just marginally more than the stipulated minimum 4% of plot area – considering all 20 sample plots of set 2, the minimum area (4%) to be kept aside for green open space is 249.18 sqm, whereas green open space provided as per sanction plan is 292.21 sqm, which only 43.03 sqm more and approximately just 0.69% of the total area.

Figure 33 Distribution of sample plots as per green open space provided beyond stipulated minimum 4% area of plot



Out of 20 sample plots, one (1) number plot has provided exactly 4% green open space; sixteen (16) number plots have proposed green open space just over 4% of plot area with less than 1% more increase; two (2) number plots have proposed more than 1% and less than 5%

increase, and only one (1) plot, i.e. sample plot 13, have proposed a reasonable increase of more than 5% of the plot area – beyond the stipulated minimum 4% rule (Figure 32).

This definitely proves lack of awareness amongst residents and architects to provide any extra space for plantation beyond the stipulated rules. It is a matter of grave concern that, except sample P13 – which has by choice allotted approximately 12% of the plot area as green open space during sanction, there are none, amongst all these twenty (20) samples, that have given, on its own, more area for green open space than the stipulated minimum 4% as per rules. The findings speak of lack of 'climate-change' concerns and definitely call for more efforts to increase awareness amongst residents and owners and also architects and planners who are very much responsible for educating their clients. The concern for climate change and mitigation responsibilities should be communicated to residents and architects at every level for a better future.

6.9 Scenario 2

6.9.1 Enhanced scope of green open space -Scenario 02 – Set 2 -all samples

Reconnaissance survey in Newtown showed that there are many multi-storied multi-tenement urban residential buildings where there are, other than love for plants, a higher degree of awareness and appreciation for benefits of keeping plants inside the site. There are many premises which grow plants and trees more than what is typically prescribed by the law. As a hypothetical case this paper considers the same plots (Set-2), being studied in Newtown, with increased number of plants than what can be accommodated in the minimum 4%.

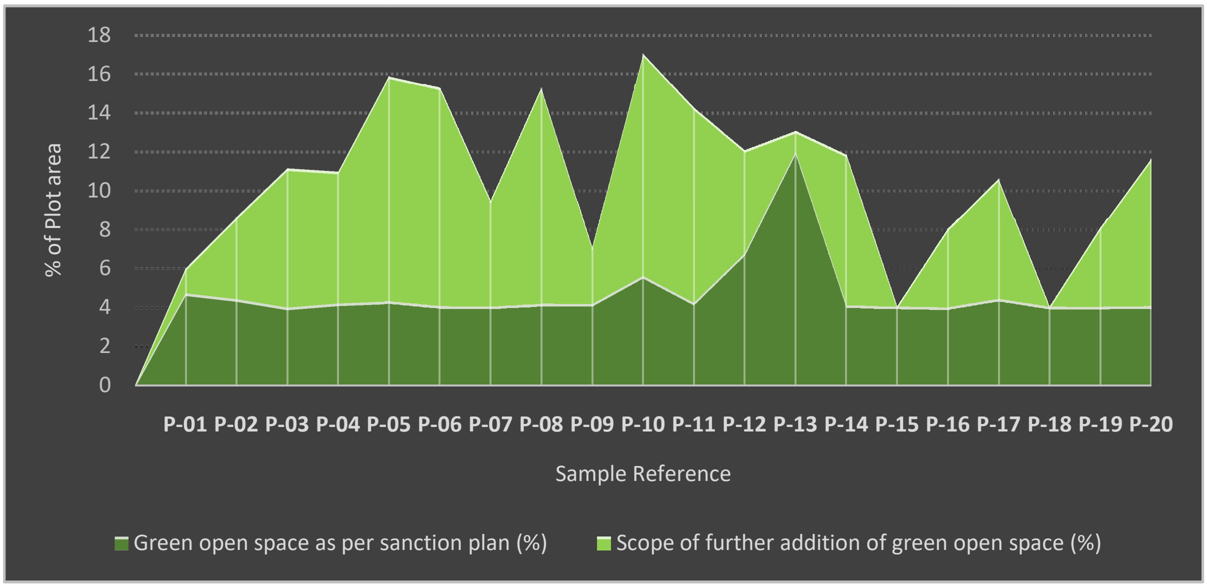
The plots (Set-2) were studied for existing green open spaces as per the NKDA rule of mandatory 4% of plot areas also for other areas having some scope of growing plantation. The ground floor plans, as per sanction plans, were plotted and all areas used for mandatory green open space, parking, driveways, service areas and paved areas marked. Areas in ground floor which were lying unutilized i.e. not used for any exact purpose like parking, driveways, services or not under mandatory 4% green open space were demarcated. Areas having scope of further plantation in the form of green open space or potted plants are carefully investigated, mapped in drawing and tabulated (Table 48 & Appendix 02).

Table 48 Area distribution as per sanction plan and scope of further green open space in sites of Sample Survey (Set-2)

SL.No	Premises No.	Plot Area	Covered area		Open Area		Boundary wall		Driveway + Paved		Services				Green Open Space		Further scope of open green		Total Green open space	Space remaining	
											Hard Surface / Raised		Underground								
		Area	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%	Area	% (A)	Area	% (B)	% (A+B)	Area	%
		(sqm.)	(sqm.)		(sqm.)		(sqm.)		(sqm.)		(sqm.)		(sqm.)		(sqm.)		(sqm.)			(sqm.)	
P - 01	CE - 1A	200.53	110.44	55.07	90.09	44.93	7.30	3.64	39.54	19.72	6.29	3.14	23.33	11.63	9.50	4.73	2.56	1.28	**6.01**	1.58	0.79
P - 02	CD - 85	266.64	148.50	55.69	118.14	44.31	8.00	3.00	53.33	20.00	8.50	3.19	23.69	8.88	11.83	4.44	11.20	4.20	**8.64**	1.59	0.60
P - 03	BC- 62	271.73	150.49	55.38	121.24	44.62	7.94	2.92	47.51	17.48	8.33	3.07	16.04	5.90	10.88	4.00	19.40	7.14	**11.14**	11.14	4.10
P - 04	AC - 84	299.65	167.12	55.77	132.53	44.23	8.76	2.92	43.02	14.36	7.60	2.54	27.55	9.19	12.63	4.22	20.26	6.76	**10.98**	12.71	4.24
P - 05	DC - 216	335.84	183.00	54.49	152.84	45.51	9.13	2.72	40.06	11.93	5.50	1.64	19.34	5.76	14.50	4.32	38.86	11.57	**15.89**	25.45	7.58
P - 06	AK - 106	361.37	198.72	54.99	162.65	45.01	9.81	2.71	11.61	3.21	8.00	2.21	34.53	9.56	14.70	4.07	40.60	11.24	**15.30**	43.40	12.01
P - 07	DA - 96	400.96	220.30	54.94	180.66	45.06	10.40	2.59	87.89	21.92	5.50	1.37	17.07	4.26	16.20	4.04	21.77	5.43	**9.47**	21.84	5.45
P - 08	AC - 195	399.50	219.41	54.92	180.09	45.08	9.91	2.48	69.17	17.31	7.59	1.90	26.86	6.72	16.70	4.18	44.39	11.11	**15.29**	5.48	1.37
P - 09	CB-68	335.13	170.12	50.76	165.01	49.24	9.29	2.77	120.09	35.83	0.00	0.00	6.15	1.84	13.98	4.17	9.67	2.89	**7.06**	5.83	1.74
P - 10	AA-6	399.15	203.81	51.06	195.34	48.94	10.40	2.61	63.09	15.81	8.64	2.16	41.74	10.46	22.41	5.62	45.63	11.43	**17.05**	3.43	0.86
P - 11	AA- 178	400.03	209.51	52.37	190.52	47.63	10.00	2.50	21.43	5.36	11.13	2.78	53.65	13.41	16.93	4.23	40.12	10.03	**14.26**	37.26	9.31
P - 12	CE-1/C-86	399.50	208.22	52.12	191.28	47.88	10.34	2.59	82.03	20.53	11.13	2.79	37.50	9.39	27.11	6.79	6.81	1.70	**8.49**	16.36	4.10
P - 13	AL/1/A/3	201.34	96.09	47.72	105.25	52.28	7.26	3.61	26.67	13.25	7.24	3.60	22.00	10.93	24.17	12.00	15.17	7.53	**19.54**	2.74	1.36
P - 14	AL/1/C/12	402.08	207.73	51.66	194.35	48.34	10.32	2.57	94.47	23.50	9.06	2.25	23.64	5.88	16.50	4.10	31.13	7.74	**11.85**	9.23	2.29
P - 15	CC-167	200.00	100.62	50.31	99.39	49.69	7.44	3.72	60.66	30.33	5.18	2.59	11.02	5.51	8.08	4.04	0.00	0.00	**4.04**	7.01	3.51
P - 16	AA- 107	200.87	110.42	54.97	90.45	45.03	7.28	3.62	3.73	1.86	3.00	1.49	33.08	16.47	8.05	4.01	8.11	4.04	**8.05**	27.20	13.54
P - 17	DC-54	335.58	173.35	51.66	162.23	48.34	9.18	2.74	73.10	21.78	8.64	2.57	22.17	6.61	14.90	4.44	20.77	6.19	**10.63**	13.47	4.01
P - 18	AA- 143	150.10	71.74	47.79	78.36	52.21	6.19	4.12	38.55	25.68	5.34	3.56	10.81	7.20	6.05	4.03	0.00	0.00	**4.03**	11.42	7.61
P - 19	AA-1C	335.17	173.77	51.85	161.40	48.15	9.20	2.74	68.50	20.44	10.00	2.98	35.50	10.59	13.50	4.03	13.63	4.07	**8.09**	11.07	3.30
P - 20	CA-225	334.28	173.61	51.94	160.67	48.06	9.20	2.75	55.98	16.75	10.00	2.99	26.95	8.06	13.60	4.07	25.39	7.60	**11.66**	19.55	5.85

The detailed examination of use of land areas of different plots (Table04) shows that there is much scope of increasing the 'green open space' from the stipulated 4%. The further addition of green open space in some plots can be nil or very negligible, but in most plots it can be achieved by considerable extent. The total green open space in most of the samples surveyed can be raised from mandatory 4% to the range of 6-17% of the plot area (Figure 33).

Figure 34 Scope of addition of green open space in sample plots



Planners, architects and the authorities should also understand that, with judicious planning of driveways and parking facilities, there can be more scope of green open space. There are many plots in the sample survey that have wasted land area by bad planning of parking and driveways or even service facilities.

Scope of enhancement of green open space in multi-tenement multi-storied urban residential buildings, when studied through sample plots of Set 2, it was felt that further analysis requires categorization of plots as per area. The sample set of 20 plots were divided into 4 categories – 1) area less or equal to 200 sqm. 2) plot area more than 200 sqm and less than or equal to 300 sqm. 3)plot area more than 300 sqm and less than or equal to 400 sqm. and 4) plot area more than 400 sqm and less than or equal to 500 sqm. The results of scope of addition of green open space in these sample plots were tabulated as per the categorization mentioned above (Table 49).

Table 49 Scope of further addition of green open space as per category of plots

Sample Reference			Land Area	Green Open Space as per sanction plan	Green open space as per further addition	Mean value
			(sqm)	(sqm)	sam	
Category 1	≤200 sqm	P-18	150.10	4.03	4.03	4.03
		P-15	200.00	4.04	4.04	
Category 2	>200 sqm ≤300 sqm	P-01	200.53	4.73	6.01	9.65
		P-16	200.87	4.01	8.04	
		P-13	201.34	12.00	13.07	
		P-02	266.64	4.44	8.64	
		P-03	271.73	4.00	11.14	
		P-04	299.67	4.21	10.98	
Category 3	>300 sqm ≤400 sqm	P-20	334.28	4.07	11.66	12.56
		P-09	335.13	4.17	7.06	
		P-19	335.17	4.03	8.09	
		P-17	335.58	4.44	10.63	
		P-05	335.84	4.32	15.89	
		P-06	361.37	4.07	15.30	
		P-10	399.15	5.62	17.05	
		P-08	399.50	4.18	15.29	
		P-12	399.50	6.79	12.09	
Category 4	>400 sqm < 500 sqm	P-11	400.03	4.23	14.26	11.86
		P-14	402.08	4.10	11.85	
		P-07	400.96	4.04	9.47	

Analysis shows that there is almost no scope of increasing (beyond stipulated 4%) green open space in category 1, i.e. the smallest size of plots less than or equal to 100 sqm. However, there is quite considerable scope of increasing green open space in other categories 2,3 and 4. Considering these categories of plots, the green open space can very well be increased to 9.65% of plot area (mean value) in case of category 1, to 12.565% of plot area(mean value) in case of category 3 and 11.86% of plot area (mean value) in case of category 4 (Figure 34, Figure 35, Figure 36 & Figure 37).

Figure 35 Comparative study of maximum enhanced green open space as per different category of plots

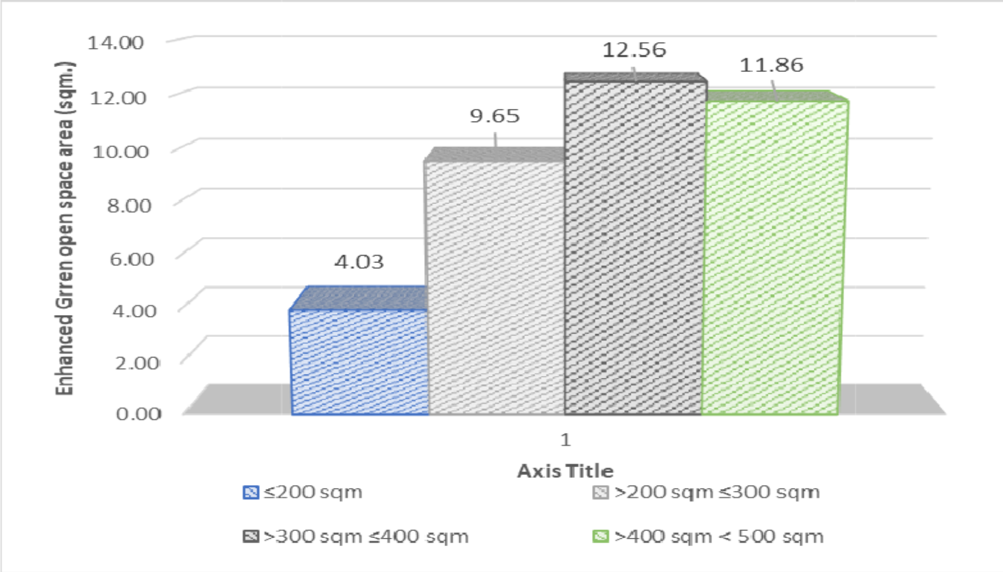


Figure 36 Maximum enhanced scope of green open space in plot size ranging from 200 sqm to 300 sqm

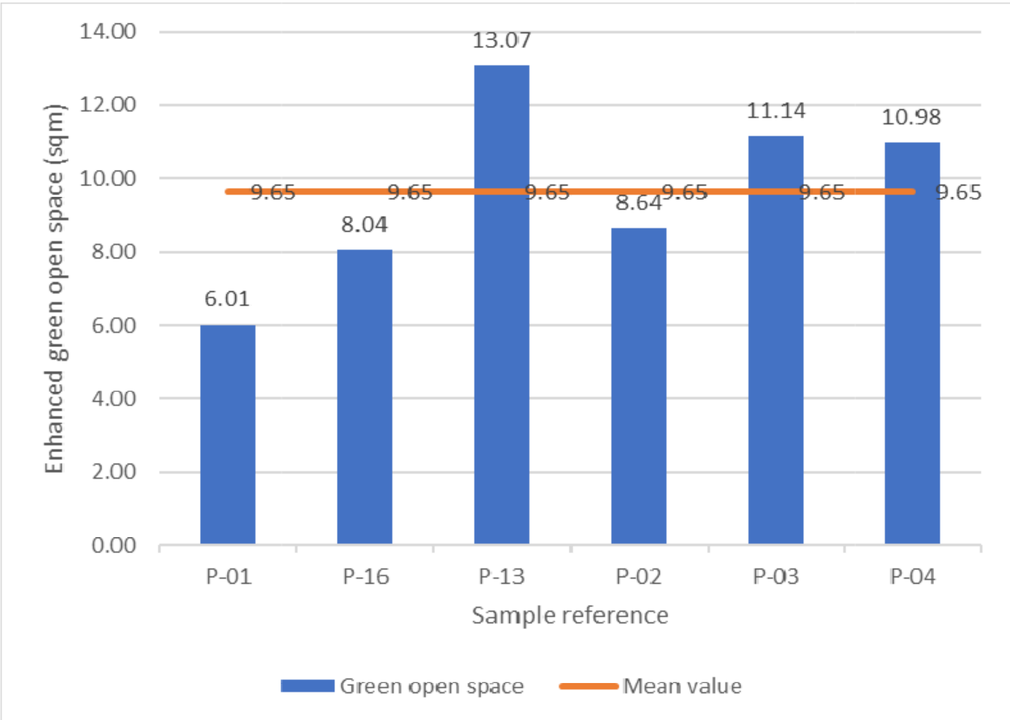


Figure 37 Maximum enhanced scope of green open space in plots ranging from 300 sqm to 400 sqm

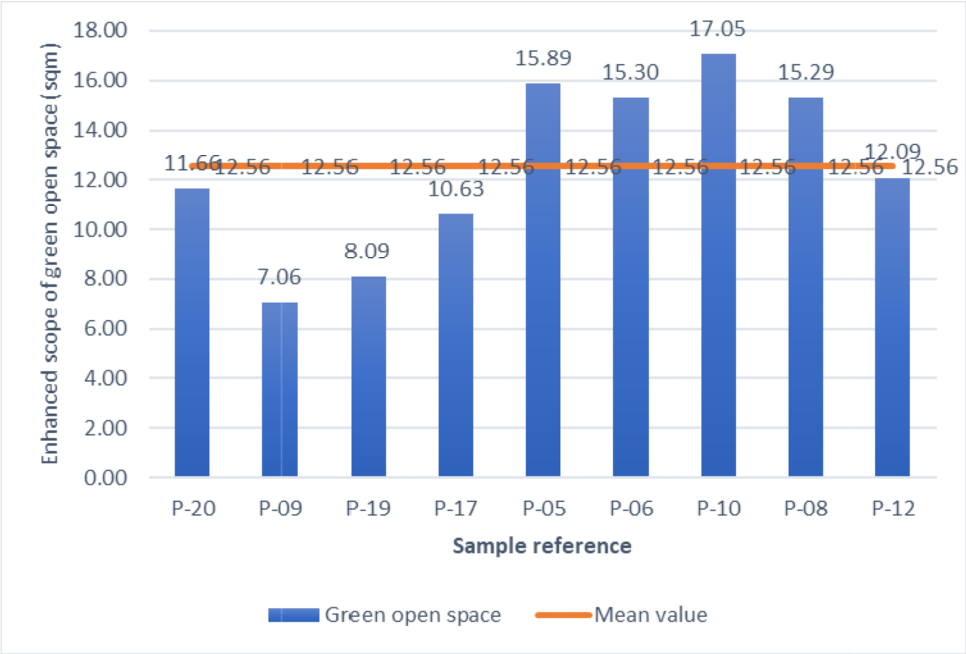
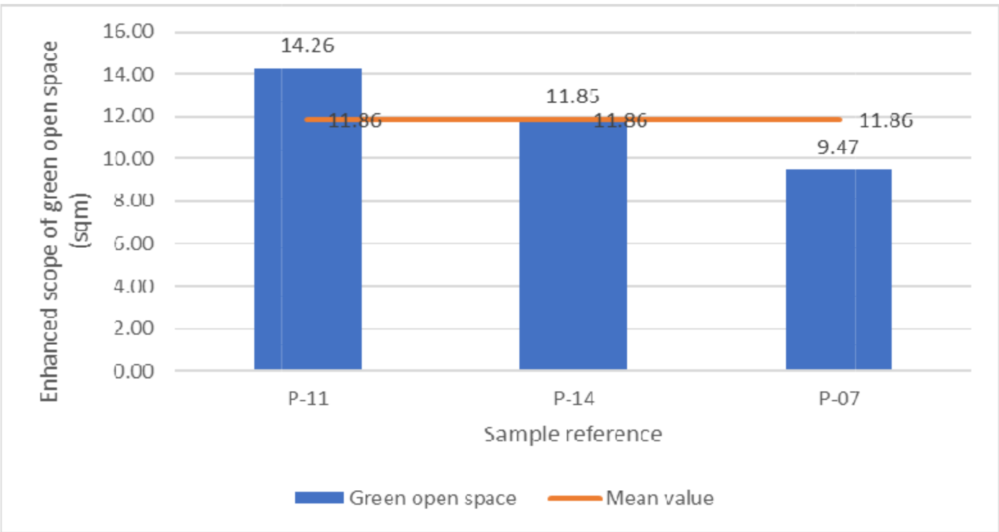


Figure 38 Enhanced scope of green open space in plot size 400 sqm to 500 sqm



6.9.2 Scope of sequestration through increased 'green open space'

The scope of further plantation, when investigated in these sample plots (Set-2), shows that plantation can be increased to a considerable extent in the ground areas through increased green open spaces (discussed earlier) and potted plants in paved surfaces. Vacant spaces suitable for plantation are located and mapped sanction plan drawings and areas tabulated. The results are encouraging and show a fair amount of sequestration potential from enhanced green open space. (Table 50).

Table 50 Scope of CO2 sequestration in enhanced green space scenario

Sample No.	Plot area	Open green Space					CO2 Sequestration
		existing - as per sanction plan	Further scope of green open space	Total Green Open Space (as per 4% + proposed additional space)			
	(sqm.)	(sqm.)	(sqm.)	(sqm.)	% of plot area	Total number of mid-size plants	Tonne CO2/ annum
P-01	200.53	9.50	2.56	12.06	6.01	33	0.64
P-02	266.64	11.83	11.20	23.03	8.64	64	1.22
P-03	271.73	10.88	19.40	30.28	11.14	84	1.60
P-04	299.67	12.63	20.26	32.89	10.98	91	1.74
P-05	335.84	14.50	38.86	53.36	15.89	148	2.82
P-06	361.37	14.70	40.60	55.30	15.30	154	2.92
P-07	400.96	16.20	21.77	37.97	9.47	105	2.00
P-08	399.50	16.70	44.39	61.09	15.29	170	3.22
P-09	335.13	13.98	9.67	23.65	7.06	66	1.25
P-10	399.15	22.41	45.63	68.04	17.05	189	3.59
P-11	400.03	16.93	40.12	57.06	14.26	158	3.01
P-12	399.50	27.11	15.17	42.28	10.58	117	2.23
P-13	201.34	24.17	2.16	26.33	13.07	73	1.39
P-14	402.08	16.50	31.13	47.63	11.85	132	2.51
P-15	200.00	8.08	0.00	8.08	4.04	22	0.43
P-16	200.87	8.05	8.11	16.16	8.04	45	0.85
P-17	335.58	14.90	20.77	35.67	10.63	99	1.88
P-18	150.10	6.05	0.00	6.05	4.03	17	0.32
P-19	335.17	13.50	13.63	27.13	8.09	75	1.43
P-20	334.28	13.60	25.39	38.99	11.66	108	2.06
TOTAL	**6229.47**	**292.21**	**410.82**	**703.03**			**37.10**

Comparative study of sequestration potential by plantation in green open space in only 4% plot area as per municipality rules (condition 1), green open space as provided in the sanction plans (condition 2) and enhanced green open space as found out by this research paper (condition 3) is shown in Table 49.

Table 51 Comparative study of CO_2 sequestration scope by plantation in varying green open spaces

	Green open space in only 4% of the plot area	Green open space as shown in sanction plan	Increased Green open space as found out by this research
Total area provided (sqm.)	249.18	292.21	703.03
Total CO2 Sequestration (TonneCO2/annum)	13.15	15.42	37.10

Table 49 shows that, considering all sample plots together, with proper planning, approximately 410.82 sqm. of green open space can be added to the existing green open space of 292.21 sqm. as per sanction plans and the total green open space can be increased to 703.03 sqm. With this increase in green open space, CO_2 sequestration which is 15.42 TonneCO2/annum by plantation in green open space as per sanction plan, can be increased to 37.10TonneCO2/annum which is about 240% increase in CO_2 sequestration.

6.9.3 Enhanced scope of plantation (all categories)

As has been mentioned earlier, in methods and materials part of this chapter (2.3), all spaces and areas suitable for plantation, considering all categories like outdoor plants in green open space, potted outdoor plants on paved areas, terrace gardens, vertical green walls and indoors plants, are feasible, keeping in mind for sunlight and ease of maintenance, are plotted in the sanction plan drawings, areas found and number of plants calculated. The CO_2 sequestration volumes by each category of plants in respective building premises are also quantified with the help of sequestration factors found out from the literature review. The results, as shown in Table 52, clearly demonstrates that with enhanced plantation technique in the building premises a considerable amount CO_2 can be sequestered.

Table 52 Quantification of CO2 sequestration by increased plantation in the site

Sample No.	Plot area	Open green Space						Potted Plants in areas other than green open space in ground floor			Potted Plants in terrace			Green vertical wall			Indoor Plants		Total CO2 Sequestration
		existing - as per sanction plan	Further scope of green open space	Total Green Open Space (as per 4% + proposed additional space)			emission reduction	Potted mid-size plants in areas other than green open space		emission reduction	Potted mid-size plants in terrace		emission reduction	Area for vertical wall	leaf area	emission reduction	No. of plants assumed	emission reduction	
	(sqm.)	(sqm.)	(sqm.)	(sqm.)	% of plot area	Total number of mid-size plants	Tonne CO2/ annum	(sqm.)	Total number of mid-size plants	Tonne CO2/ annum	(sqm.)	Total number of mid-size plants	Tonne CO2/ annum	(sqm.)	(sqm.)	Tonne CO2/ annum	Numbers	Tonne CO2/ annum	Tonne CO2/ annum
P-01	200.53	9.50	2.56	12.06	6.01	33	0.64	8.33	23	0.44	44	122	2.32	30.2	344.28	0.69	120	0.12	4.21
P-02	266.64	11.83	11.20	23.03	8.64	64	1.22	24.86	69	1.31	45.5	126	2.40	81.1	924.54	1.85	120	0.12	6.90
P-03	271.73	10.88	19.40	30.28	11.14	84	1.60	14.90	41	0.79		0	0.00	60.2	686.28	1.37	120	0.12	3.88
P-04	299.67	12.63	20.26	32.89	10.98	91	1.74	16.00	44	0.84	49	136	2.59	59.19	674.77	1.35	120	0.12	6.64
P-05	335.84	14.50	38.86	53.36	15.89	148	2.82	19.50	54	1.03	69.8	194	3.68	58.7	669.18	1.34	120	0.12	8.98
P-06	361.37	14.70	40.60	55.30	15.30	154	2.92	23.80	66	1.26	53.4	148	2.82	73.86	842	1.68	120	0.12	8.80
P-07	400.96	16.20	21.77	37.97	9.47	105	2.00	13.20	37	0.70	52	144	2.74	70.64	805.3	1.61	120	0.12	7.18
P-08	399.50	16.70	44.39	61.09	15.29	170	3.22	19.75	55	1.04	27.8	77	1.47	38.4	437.76	0.88	120	0.12	6.73
P-09	335.13	13.98	9.67	23.65	7.06	66	1.25	5.90	16	0.31	53.3	148	2.81	66.55	758.67	1.52	120	0.12	6.01
P-10	399.15	22.41	45.63	68.04	17.05	189	3.59	6.00	17	0.32	48.6	135	2.57	77.4	882.36	1.76	120	0.12	8.36
P-11	400.03	16.93	40.12	57.06	14.26	158	3.01	6.00	17	0.32	49.4	137	2.61	71.6	816.24	1.63	120	0.12	7.69
P-12	399.50	27.11	21.17	48.28	12.09	134	2.55	12.40	34	0.65	48.8	135	2.57	71.54	815.56	1.63	120	0.12	7.53
P-13	201.34	24.17	2.16	26.33	13.07	73	1.39	0.00	0	0.00	20.5	57	1.08	41.5	473.1	0.95	120	0.12	3.54
P-14	402.08	16.50	31.13	47.63	11.85	132	2.51	3.00	8	0.16	52.1	145	2.75	59.75	681.15	1.36	120	0.12	6.91
P-15	200.00	8.08	0.00	8.08	4.04	22	0.43	3.00	8	0.16	31.2	87	1.65	50.81	579.19	1.16	120	0.12	3.51
P-16	200.87	8.05	8.11	16.16	8.04	45	0.85	9.90	28	0.52	23.4	65	1.24	31.56	359.78	0.72	120	0.12	3.45
P-17	335.58	14.90	20.77	35.67	10.63	99	1.88	3.00	8	0.16	38.4	107	2.03	76	866.4	1.73	120	0.12	5.92
P-18	150.10	6.05	0.00	6.05	4.03	17	0.32	3.00	8	0.16	18.3	51	0.97	52.7	600.78	1.20	120	0.12	2.77
P-19	335.17	13.50	13.63	27.13	8.09	75	1.43	6.00	17	0.32	49.8	138	2.63	66.8	761.52	1.52	120	0.12	6.02
P-20	334.28	13.60	25.39	38.99	11.66	108	2.06	3.00	8	0.16	43.1	120	2.27	77.8	886.92	1.77	120	0.12	6.38
TOTAL	**6229.47**						**37.42**			**10.64**			**43.19**			**27.73**		**2.40**	**121.38**

Taking into account all twenty (20) sample plots together, CO2 sequestration, which was only 13.15 TonneCO2/sqm. considering plantation in only 4% of the plot area as per municipal rules, can be increased to 121.38 TonneCO2/annum, with an enhanced plantation scenario. Plants grown in increased green open spaces, potted plants in paved areas, terrace gardens and indoor plants can increase the CO2 sequestration potential of the building premises by about 900%.

6.10 Sequestration as per building parameters

The results and analysis demonstrate that enough scope of increasing plantation scenario in a urban multi-tenement multi-storied residential building. To draw standards of sequestration by plantation as per building parameters, the results were analysed further. The results show that considering all 20 sample plots, having a total plot area as 6229.47 sqm. total sequestration through plantation in enhanced green open space is 37.42 TonneCO2/annum, which is about 0.006 TonneCO2/annum/ sqm of plot area. Sequestration through plantation in potted plants in the ground areas other than green open space is 10.64 TonneCO2/annum, that is about 0.0016 TonneCO2/annum/ sqm of plot area. The total built up area, considering of all 20 sample plots, is 16000.49 sqm. Total sequestration through terrace garden is 43.19TonneCO2/annum. The CO2 sequestration through terrace garden is 0.0027 TonneCO2/annum/ sqm of built-up area. CO2 sequestration through vertical gardens being 27.73 TonneCO2/annum, it comes to 0.002 TonneCO2/annum/sqm. of built-up area. CO2 sequestration through indoor plants is almost negligible compared to other forms of plantation sequestration and may be avoided for calculation purposes. The total CO2 sequestration being 118.98 TonneCO2/annum, total annual CO2 sequestration per unit built-up area comes to 0.007 TonneCO2/annum/sqm. of built-up area.

6.11 Conclusion

This study of CO2 sequestration by home-grown plants in multi-storied multi-tenement residential building premises along with investigation of optimal plantation scope in the same premises, show that the roles played by the enhanced green open space, potted plants in the ground floor and terrace, vertical gardens, and indoor plants are encouraging and emission reduction by them, adds up to make a creditable amount. There is lot of scope of enhanced plantation beyond the mandatory 4% green open scape as per municipality rule. Vertical gardens, terrace gardens, green open spaces and potted plants in ground floor paved areas together can play avital role in CO2 mitigation process.

7 CHAPTER 7- COMPARATIVE STUDY OF CO2 EMISSION-SEQUESTRATION BALANCE IN URBAN RESIDENTIAL PLOTS

7.1 Introduction

This thesis intends to study the comparative balance between operational stage CO2 emission from the urban multi-storied multi-tenement residential building and the sequestration potential of plantation grown within the same building sites. As has been mentioned in 'Research Hypothesis' in the introduction chapter of this research work, this research work proposed - "the amount CO2 emitted by the multi-storied and multi-tenanted residential building in the operation stage can be sequestered fully by the plants and trees grown inside the premises during the same time period". In order to validate this hypothesis, there arises a need to compare 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. Quantification methods of CO2 emitted during the operation stage of urban multi-storied and multi-tenanted residential buildings, considering electricity consumption, LPG use for cooking, petrol consumption by vehicles, potable water consumption, has been discussed at length in previous chapters 2, 3, 4 & 5. Operational stage CO2 emission from various single tenement individual buildings, flats in multi-storied buildings and one (1) whole building has been quantified (**set-1**). Quantification of CO2 sequestration by plantation within the premises, have been individually found out, through detailed study of sanction plans, in the last chapter for a set of twenty (20) buildings (**Set-2**).With CO2 sequestration data in hand, the next step of research asks for quantification of CO2 emission from these 20 buildings of sample survey Set-2 and further comparison and analysis of CO2 emission-sequestration volumes.

7.2 Quantification of CO2 emission in Set-2

Due to various difficulties, data needed for quantification of CO2 emission from samples in Set-2 could not be obtained from most of the flats. Only one whole building in Newtown (as mentioned in chapters 4 and 5 and referred to as sample P03 in Set-2 in chapter 6) could be fully studied. Necessary information could be received from all flats (except one which is unoccupied) in this building. The total operational phase CO2 emission from this G+4 multi-tenement residential building in Newtown (sample P03 in Set-2) is **20.842**

TonneCO2/annum (ref. - chapter 4).The mean value of annual CO^2 emission per unit built-up area for a whole building in operation phase, considering all flats and common areas comes to **0.028 TonneCO^2/ annum/sqm.** (Chapter 5 – Table 07).

The However, in case of other buildings in sample Set-2, information from all flats could not be obtained. Due to this lack of complete information, the methods of CO2 emission quantification that were followed in case of sample 3 of set 2 (mentioned in chapter 3 and 4), could not be applied for quantification of CO2 emission from other buildings. For quantification of operational phase CO2 emission in these samples plots of Set-2, mean value of annual CO2 emission per unit built-up area for the whole building (sample P03, Set-2) studied in Newtown, is utilized to quantify the emission from rest of the nineteen (19) buildings. *The quantification results show that, considering all twenty (20) buildings of Set-2 together, with total built-up area as 16000.49 sqm, including all flats and common areas, and taking annual mean operational CO2 emission as 0.028 TonneCO^2/annum/sqm. the total operational stage CO2 emission considering all buildings of Set-2 comes to448.01TonneCO2/annum.*

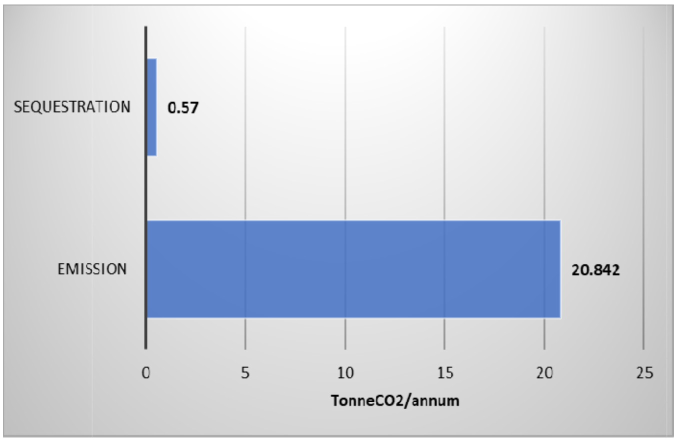
7.3 CO2 Emission – Sequestration balance check

7.3.1 Scenario 01 – Green open space as per sanction plan

7.3.1.1 Sample P03

For this study, first, the multi-storied multi-tenement urban residential building (sample P03), surveyed and analysed in this paper, is taken for consideration. The total CO^2 emission from this residential building, considering the whole building with eight (8) number flats and common areas, as quantified previously, is **20.84 TonneCO^2/annum**. Quantification of sequestration by plantation in sample plot P03, as per sanction plan, results in **0.57 TonneCO^2/annum** (mentioned in the last chapter) (Figure 38). Considering that there are no other plants in the site, this quantity of CO^2 sequestered when compared to the total annual CO^2 emitted by the building (20.842 TonneCO^2/annum) becomes too negligible. The amount of CO^2 sequestered by plants grown inside the site comes to only 2.74% of the total annual CO^2 emission.

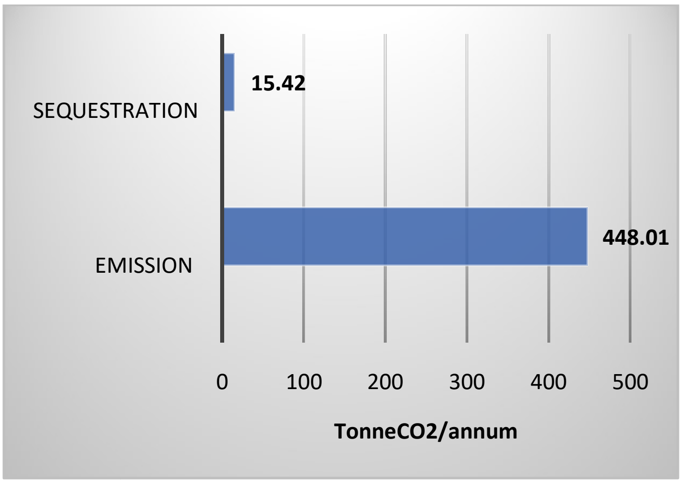
Figure 39 Comparison of annual CO2 Emission -Sequestration balance (Sample 03)



7.3.2 Sample plot - Set 2 – all samples -green open space as per sanction plans

Similarly, the comparison is done considering all samples of Set-2. The CO_2 sequestration potential of plantation considering all these 20 number buildings of Set 2, with plantation as per sanction plan following the rule of 4% mandatory green open space, is 15.42 TonneCO_2/annum (ref: Chapter 6 - table 02). The total annual CO_2 emission for all buildings in Set-2 are also found out in this chapter and is equal to 448.01 TonneCO_2/annum. The comparative analysis is presented here in Figure 39. CO_2 emission reduction (15.42 TonneCO_2/annum) for the entire set-2 comes to 3.44% of the total emission (448.01 TonneCO_2/annum).

Figure 40 Comparison of CO2 Emission-Sequestration balance (Set2- all samples)

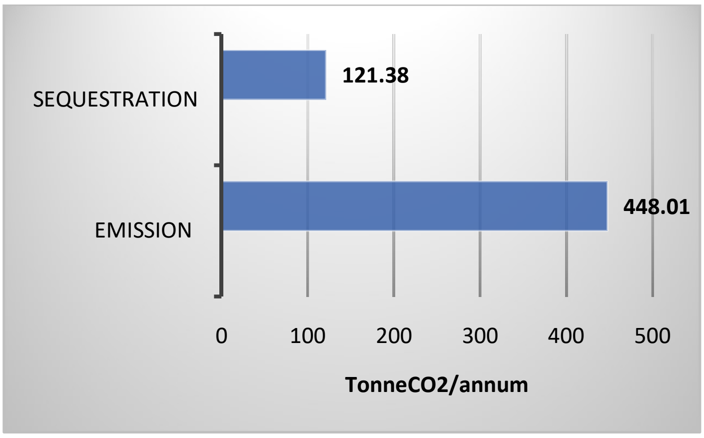


It is evident from this analysis that mean value of annual emission reduction by the process of sequestration of CO_2 carried out by plantation in 4% area of the respective plots is only 3.44% of the total annual CO_2 emission by the building or in other terms the plantation provided in sample plots, as per sanction plan following the rule of minimum 4% open green space, can annually sequester approximately 3.44% of the total annual CO_2 emission by the building itself.

7.4 Scenario 02 – enhanced plantation – Set 2

The detailed examination of use of land area of different plots studied in sample survey showed that there is much scope of increasing the green open space from the stipulated 4% (Chapter 6 -Table 3). The quantity of CO_2 emitted by these buildings are already calculated(Table 01). The sequestration potential values, considering enhanced scope of plantation in these plots, are also tabulated (Chapter 6 –Table 05).The comparative analysis of the respective CO_2 emission and sequestration from same building plots show that CO_2 emission reduction through sequestration by plants can be increased to a great extent. The total operational stage CO_2 emission from all plots together is **448.01 TonneCO2/annum** and the total CO_2 sequestration by plants, considering an enhanced plantation scenario, is**121.38 TonneCO2/annum** (ref: Chapter-6,Table-06) (Figure 40). **The effective CO_2 emission reduction through sequestration by plantation grown within the premises of the buildings is about 27.09% of the total CO_2 emission**.

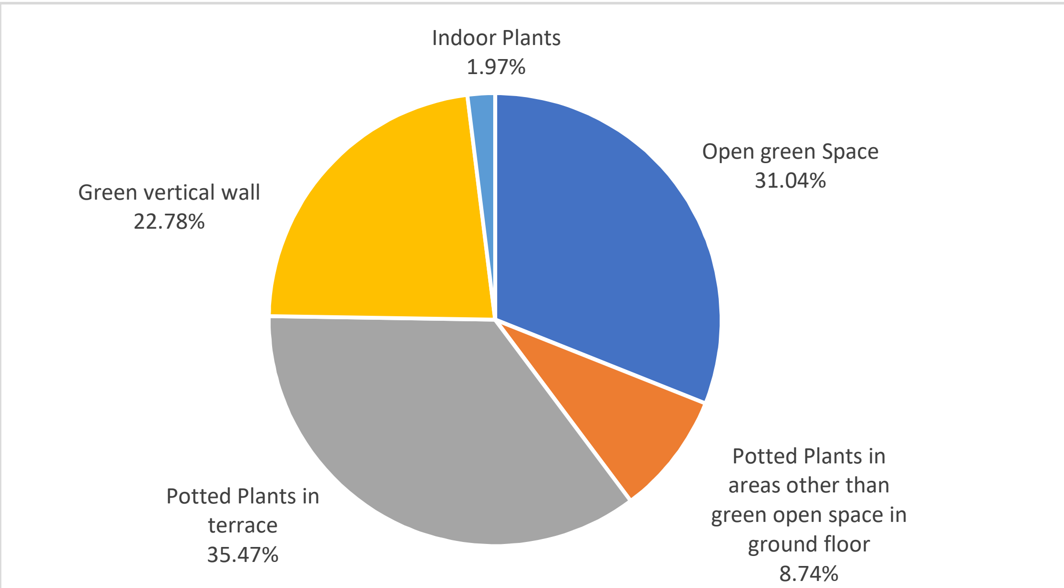
Figure 41 CO2 emission - Sequestration balance in enhanced plantation condition



The analysis also shows that the roles played by the enhanced green open spaces, potted plants in the ground floor and terrace, vertical gardens, and indoor plants are encouraging and CO_2 emission reduction by them, though negligible by themselves, add up to make a creditable amount. 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%)

(Figure 41). The areas allotted for green open spaces and potted plants in paved areas are done logically, through a process of identification of existing land use and scope of further enhancement and can be said to be optimal, without much scope of further increase. However, areas allotted for green vertical gardens in urban multi-storied residential buildings can be increased from what has been selected in this research work, considering faces of buildings, front boundary wall are not considered for green vertical walls. more areas of terrace as plantation, etc. are not considered. The results also show that role played by indoor plants in CO2 sequestration is almost negligible (1.97%).

Figure 42 Comparative study of CO2 sequestration by various category of plantation in a urban multi-storied multi-tenanted residential building



7.5 Conclusion

As per findings of this paper, the mandatory green open space of 4%, as stipulated by the municipal authority (NKDA) of Newtown, is being able to sequester only about 3.44% of the CO^2 being emitted by the building in the same plot, whereas with an increased plantation scenario, considering increased green open space, potted plants in paved areas, terrace gardens, vertical gardens and indoor plants, this CO2 emission reduction can be almost 27.09%. Though the hypothesis of this research work stands 'negative', the results are encouraging and worth further study. 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 the stipulated minimum green open space of 4% by the municipal authority. Considering mitigation scope of CO_2 emission, this rule is not effective. There is a need to carry out a detailed investigation of this rule and formulate more effective home grown plantation planning standards.

8 CHAPTER 8 - AVENUES FOR FUTURE WORKS

8.1 Future Research work

This research paper concludes that there is a dearth of research work and consequently information on certain fields associated with CO_2 emission from urban residential buildings. 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. More studies are required in all fields associated with it – operational stage CO_2 emissions, factors of emission, identification of sources of emission, correlation with building parameters, etc. A good volume of research has been done in the field of emission from the pre-operation phase of the building. Research on identification of sources of emission and it's quantification, particularly from the operation phase of the residential building, is few and not exhaustive. However, 'operation stage' being the largest emitter of CO_2 amongst all life cycle phases, it needs more emphasis in future for a sustained mitigation process. Research on the emission factors associated with the operation phase, like electricity generation, respiration, potable water production, LPG, etc. are few. Emission factors are difficult to retrieve from existing papers, varying considerably from paper to paper and do not follow any standardization or time line. There is a need for more scientific approach to emission factor database. Information and data on emission sources and their emission factors at micro level, considering local level influencing factors, is also rare. Today's research work, especially in India, depends heavily on international factors and standards. Research on these avenues are pending and welcome. There is not much data in existing literature on building operational CO_2 emission from urban residential buildings per unit area of plot or built-up area or with respect to number of inhabitants / residents. There is scope of research in this field so that this information can be used during planning stage of urban agglomerates, or even simple building design with a concern for mitigation and climate change.

There is considerable scope of finding sequestration capability of plants associated with residential and other building sites. Sequestration is the only way of absorbing emitted CO_2. Considering climate change and CO_2 emission from building, plants are our only well-wishers – the one and only source of sequestration of carbon that we randomly throw into the atmosphere. More research works are required for investigating this potential of plants. There are also very few information on CO_2 sequestration by home-grown local plants at the local level, especially in India. Future researchers must look into this aspect of sequestration by local plants so as to make a research work more logical and exact. Research work studying role of plants by category – green open space, potted, terrace garden, vertical garden, indoor plant also needs attention in future. The analysis for reduction of CO2 emission with enhanced plantation plan, shows that maximum reduction is performed by terrace gardens (35.47%), green open space (31.04%), green vertical walls (22.71%), followed by potted plants paved areas (8.74%) and lastly indoor plants (1.97%).The findings call for an increased emphasis on plantation in terrace gardens, green open space and vertical green walls.

This research work demonstrates that there is no logical understanding behind green open space rule of many municipalities. NKDA, the municipal authority looking after development of Newtown needs to do an elaborate study of the minimum green open space rule. The current rule of leaving 4% of the plot area as open space is not producing effective results in terms of climate mitigation efforts. The study of sanction plans of sample plots also shows that there is definitely fair scope of increasing green open space. Plantation in other parts of the building premises, like potted plants in paved areas, terrace gardens vertical green walls and indoor gardens also need more emphasis. 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.

8.2 Need for emphasis on other avenues of mitigation

With a reduction of approximately 27.09**%** of the total CO2 emission from a residential building through sequestration by plantation grown inside the premises, there arises the responsibility of finding mitigation scope through other means so that a net-zero emission building can be achieved. This paper finds from literature review that better designs based on climatology and sustainability reduces the Operational Energy (OPE) to a great extent.

- Use of alternate materials with low thermal conductivity and proper insulation of roof
- The maximum emission of CO2 being from use of electricity and use of fuel for automobiles, there comes the need to reduce use of energies like electricity and fuel for automobiles. Replace conventional energy with *Renewable Energy (RE) and Electric vehicles***.** The need of the hour is to cut down on all kinds of fossil fuel use for running automobiles, cooking and heating purpose.

- There is huge scope of reduction of CO2 emission in the field of Potable Water Production (PWP) by reducing energy consumption during production, distribution and end-use phases. Building household activities like *use of solar energy for water heating, optimal use of water, reduction of leakage, reuse of reclaimed water, efficient water harvesting, etc*. can reduce emission immensely. To save the world, a very conscious and scientific effort consisting of various mitigation approaches are required – and the building can play a very important part in it.

9 CHAPTER 9 - CONCLUDING REMARKS

This paper identifies sources of CO_2 emission from residential buildings in the operation phase as – 1) Electricity consumption, 2) fuel consumption for cooking, 3) fuel consumption for vehicles, 4) respiration, 5) potable water production consumption. This is concluded completely based on existing literature study. There are mentions of some more activities in residential buildings that emit CO_2 like consumption of materials for livelihood or maintenance work or diesel for generators. However, this research paper does not consider these activities for information limitations. This paper also iterates that there are possibilities of more activities emitting CO_2 and calls for further studies.

The results and analysis of this research work shows that for urban residential buildings, the maximum CO_2 emission takes place due to consumption of electricity. Considering urban single tenement individual buildings (category 1), consumption of electricity produces the maximum CO_2 emission (71.59%), followed by respiration by residents (13.88%), consumption of LPG as cooking fuel (8.38%), consumption of potable water (3.63%) and lastly petrol for automobile during it's idling time inside the plot (2.52%). Similarly, for flats in a urban multi-storied multi-tenement residential building (category 2) the emission proportions are – electricity (46.06%), respiration by residents (28.79%), consumption of LPG as cooking fuel (13.89%), consumption of potable water (7.52%) and petrol for automobile during it's idling time inside the plot (5.58%). For a whole urban multi-storied multi-tenement residential building the proportions of CO_2 emission are -electricity (39.49%), respiration by residents (31.71%), consumption of LPG as cooking fuel (14.64%), consumption of potable water (8.29%) and petrol for automobile during it's idling time inside the plot (5.88%). The results definitely demonstrate that electricity is the main source of CO_2 emission and need maximum emphasis during any mitigation planning.

Existing research works have studied CO_2 emission from residential buildings considering several activities producing the emission. Literature study showed that these activities are not fixed. The inclusion and omission of several activities and selection of variable emission factors are resulting in considerable variations in quantification results. There is a need for research in this field for a more definite conclusion. This research paper tries to select almost all activities related to operation stage of the building that are mentioned in existing literature. The variation in quantification results also indicates a more extensive study on emission activities and emission coefficients/factors considering local parameters. However, though quantification results from different research works contradict each other and show varying percentage distribution of emission from different activities during operational stage of buildings, almost all have identified electricity as the main contributor of CO_2 emission. The findings of this research work finds itself compliant with the same.

Some of the existing literatures have considered respiration by residents as a source of CO_2 emission and some have not, taking respiration as a part of 'natural carbon cycle' (ref- 2.4.1 – Literature Review – Sources of emission & associated parameter'. This research work has considered respiration by residents as a source of emission as it studies CO_2 sequestration by plants inside the site. This also produces variation in quantification results of emitted CO_2 and percentage distribution of emission from different activities and consequent correlation factors with building parameters, when compared with other research works.

This paper also tries to find correlation between CO_2 emission during the operation phase and urban residential building parameters like plot area, covered area and number of residents. The comparative study of CO_2 emission from urban single tenement residential buildings showed that there is no correlation between CO_2 emission during the operation phase and the plot area of the building, or built-up area or number of residents. CO_2 emission is quite independent of these factors. Four (4) number flats with same area (100 sqm.) and seven (7) number flats with same area (74.32 sqm.) were studied for CO_2 emission and it was found out that emissions from flats with identical areas were varying by considerable margins. However, for the benefit of further research works and for setting planning standards, the mean annual CO_2 emission with respect to building parameters for different category of residential buildings, as found by this research paper, are studied (Table 53).

Table 53 Mean annual CO_2 emission with respect to building parameters in different category of buildings

category	annual CO2 emission per sqm. of plot area	annual CO2 emission per sqm. of built-up area	annual CO2 emission per number of residents
	(TonneCO2/ annum/sqm.)	(TonneCO2/ annum/sqm.)	(TonneCO2/ annum/sqm.)
Category 1 (single tenement individual building)	0.033	0.030	1.811
Category 3 (whole multi-storied multi-tenement building including common areas)	0.052	0.028	0.834

Existing literature show that there are several studies on CO2 emission from residential buildings - though same from the operational stage are few. There are also many research work on plants and trees. However, research combining both the fields is rare. There is a need for research work on study of CO2 sequestration from urban residential buildings, considering all local parameters and the scope of maximum CO2 sequestration by the building site for a more sustainable future.

As per findings of this paper, the mandatory green open space of **4% of plot area**, as stipulated by the municipal authority (NKDA) of Newtown, is being able to sequester only about 3.44% of the CO2 being emitted by the building in the same plot. A detailed study of ground coverage distribution of multi-storied and multi-tenement residential building plots, in Newtown, shows that there is quite a fair scope of increasing area designated for green open space, from the stipulated 4%, in all building sites, leaving aside all spaces for boundary walls, driveways, paved areas or walkways, areas designated for services, etc. For residential plots, whose areas range from 200 sqm. to 300 sqm. the mandatory 4% green open space can be increased to a mean value of 9.65%, ranging from 6% to 10.98%**.** For residential plots, whose areas range from 300 sqm. to 400 sqm. the mandatory 4% green open space can be increased to a mean value of 12.56%, ranging from 7% to 15.89%. For residential plots, whose areas range from 400 sqm. to 500 sqm. the mandatory 4% green open space can be increased to a mean value of 11.86%, ranging from 9.47% to 14.26%.With this increase in green open space, CO_2 sequestration level increases from 15.42 TonneCO_2/annum, considering green open space as per sanction plans, to about 37.30 TonneCO_2/annum which is almost double the previous value. This CO_2 sequestration by plantation in only green open space, though small and almost nothing compared to the amount of CO_2 emitted by the building, will, for sure, add a very important value to the mitigation of CO_2. Increase in 'green open space' area in residential plots is definitely more than welcome. Apart from the increased CO_2 sequestration this will also add to better storm water management, heat-island reduction, greeneries and aesthetic value. Findings of this paper definitely call for a better look at the stipulated minimum green open space of 4% by the municipal authority.

This paper also suggests that in case of an increased plantation scenario, added to the plantation in 4% green open spaces, i.e. plants grown in pots on some paved areas or service areas of the site, over under-ground water reservoir, in the terrace, some vertical gardens and indoor plants inside flats, the CO_2 sequestration level can be increased to as high as 27.09% of the CO_2 emitted by the building itself. Though, the hypothesis of the research work stands negative, the findings of the work are definitely encouraging. A reduction of 27.09% of the operation stage emission by the building through sequestration by plantation grown within the premise is quite important as far as climate change mitigation process is concerned. Analysis has showed that, with the increased plantation technique followed by this research work, the maximum CO_2 emission reduction through sequestration is achieved by terrace gardens (35.47%), followed by green open space (31.04%), green vertical gardens (22.78%), potted plants in ground area other than green open spaces (8.74%) and lastly by indoor plants (1.97%), In this situation, increased number of plantations inside multi-storied multi-tenement residential building premises, involving green open spaces, potted plants in ground space other than green open spaces, terrace gardens, indoor plants and vertical gardens are to be encouraged to the maximum. There is a need to instil awareness amongst residents and planner and architects to provide maximum plantation in residential buildings -because that is the most effective way of reducing CO_2 emitted by the building itself.

With a reduction of 27.09% of the CO_2 emission by process of sequestration with plants grown in own premises, residents, along with architects, planners and builders, get further scope to target other avenues for a better CO_2 emission-consumption balance during the operation stage of the building. The climate change mitigation concern calls for an all-out effort to cut-down CO_2 and other GHG emissions and hence makes it mandatory to look into all avenues of emission reduction options. Other research works have shown that a huge reduction in operation stage energy consumption and emission reduction can be achieved by application of alternative materials and insulation in building envelope (Lief Gustavsson), (Utama & Gheewala). Materials with low thermal conductivity, i.e. good resistance to heat flow from outside to inside of the building and vice-versa can, by itself, reduce operation stage energy demand by 1.5-5%. A well-designed envelope with layers of insulation in roof and external walls can cut down heat gain and loss considerably, resulting in a reduction of emission by 10-30%, the maximum reduction being achieved in hot and humid climate (Ramesh, Prakash, & Shukla). Research work by (Cho & Chae) established that, considering whole life cycle, emission per unit area from Low-Carbon-Buildings were 25% less than conventional building. Layered envelopes, double walls, clay-brick walls, hollow concrete walls, gypsum internal cavity walls, clay houses, etc. play a vital role in reduction of building operation stage energy demand (Ramesh, Prakash, & Shukla), (Lief Gustavsson), (VanGeem, 2008). Researchers have established that by providing thicker external walls and by adding different layers to the same, though an initial increase in embodied energy (EE) is incurred because increase in mass, however, over a longer period of building life cycle, a huge reduction in operating energy (OPE) demand can be achieved (Mithraratne & Vale). A research work studying Buildings envelope with Integrated Green Plants (BIGP) in China, says that energy saving by such a building is about 18% in winter and 25% in summer (Tan, Hao, & Hu). Based on all these research works, we can very well assume that by applying a energy-efficient building envelope and system, using materials with low thermal conductivity, providing internal cavity walls, well designed fenestrations and proper orientation of the building, a better scenario can be achieved were the annual operational energy consumption will be reduced bya great extent.

Emission reduction by Technology innovation of electricity generation and use of renewable energy-

Apart from energy efficient building design, the other area which plays a vital role in reduction of GHG emission from building industry is the Electricity generation sector. Electricity makes up the most part of emission from building sector almost as high as 59.88% (this study). Hence the main emphasis of Climate change mitigation policies involves bringing a change in the field of energy production – mainly by replacing conventional electricity generation with Renewable Energy (RE) like solar energy, wind energy, hydel power, etc. and also by bringing in new technology in generation and distribution. At present the main initiative of reduction of GHG is electrification of all households, energy efficiency and providing renewable energy. Renewable energy, which makes up about 25% of the total energy production in Europe, is projected to reach approximately 85% in 2050 (Gielena, et al., April 2019). The Energy Performance of Buildings Directive 2010/31/EU (EPBD) (Tenhunen), which is a legal instrument for decarbonization of building stock in member states in Europe, had set a target in 2012 of attaining almost 'Zero Energy Building' or net zero emission from operational energy of buildings in Europe by 2020. Electric Vehicles (EVs) are also being popularized to cut down use of fossil fuels.

Research work is also being done in the PWP sector – trying to find ways to reduce energy consumption in this field, during production stage, distribution stage and at end user level.(Nair, Hashim, Hannon, & Clifford), in their paper have cited that maximum energy is consumed for heating of water which is almost as high as 30% of the total energy use. This paper (Nair, Hashim, Hannon, & Clifford, 2018) cites that solar energy can provide for 60% of the water heating demand in a residential building and by proper management of hot water use, controlling hot water heat loss, minimal pump start-ups, etc. most of the grid electricity supply can be replaced by solar power. Measures like optimal use of water, reduction of leakage, reuse of reclaimed waste water, proper rainwater harvesting and improved water treatment processes will drastically reduce consumption of energy in PWP and resultant CO_2 emission (Gui, Qi, & Wang, 2024), (MohammadT.Alresheedi, Haider, Shafiquzzaman, & AlSaleem).

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11 APPENDICES

Appendix 1 Calculation of CO2 emission for sample 01

	SAMPLE 01							
	Owners name	Asish Pal					House Type	Residential
	Address	10, Amrapali, Garia Station Road, Kolkata 700084					Tenement Typology	Single
	Location	Kolkata, West Bengal					No.of Stories -	2
	Land Area	270	sqm				Covered Area	
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Building & Common Area				2600	0.716	1861.6	1.862
2	**Emission due to LPG Consumption for cooking - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	20	14.2			284	2.985	847.74	0.848
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	1	121.67	0.14	17.03	2.3	39.178	0.039
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.905	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	8					251.41	2011.28	2.011
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	8		200	73000	584000	0.0009	525.6	0.526
					TOTAL ANNUAL CO2 EMISSION			**5.453**

Appendix 2 Calculation of CO2 emission for sample 02

	SAMPLE 02							
	Owners name	Sugato Ghosh					House Type	Residential
	Address	B 352 Lake Gardens					Tenement Typology	Single
	Location	Kolkata, West Bengal					No.of Stories -	2
	Land Area	234	sqm				Covered Area	334
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Building & Common Area				9800	0.716	7016.8	7.017
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	15	14.2			213	2.985	635.805	0.636
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3					251.41	754.23	0.754
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3		200	73000	219000	0.0009	197.1	0.197
					TOTAL ANNUAL CO2 EMISSION			**8.772**

Appendix 3 Calculation of CO_2 emission for sample 03

	SAMPLE 03							
	Owners name	Sabyashachi Bhattacharya					House Type	Residential
	Address	384, Lakae Gardens					Tenement Typology	Single
	Location	Kolkata 700045, West Bengal					No.of Stories -	2
	Land Area	301	sqm				Covered Area	278.7 sqm
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Building & Common Area				12200	0.716	8735.2	8.735
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	18	14.2			255.6	2.985	762.966	0.763
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	2	243.33	0.6	146.00	2.3	335.80	0.336
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4					251.41	1005.64	1.006
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4		200	73000	292000	0.0009	262.8	0.263
					TOTAL ANNUAL CO2 EMISSION			**11.102**

Appendix 4 Calculation of CO2 emission of sample 04

	SAMPLE 04							
	Owners name	Manish Chakraborty					House Type	Residential
	Address	AA 171A Saltlake					Tenement Typology	Single
	Location	Kolkata 700064, West Bengal					No.of Stories -	2
	Land Area	228	sqm				Covered Area (sqm)	278.70
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Building & Common Area				9800	0.716	7016.8	7.017
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	15	14.2			213	2.985	635.805	0.636
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4					251.41	1005.64	1.006
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4		200	73000	292000	0.0009	262.8	0.263
					TOTAL ANNUAL CO2 EMISSION			**9.089**

Appendix 5 Calculation of CO2 emission of sample 05

	SAMPLE 05							
	Owners name	Nabarun Sen					House Type	Residential
	Address	KB02 / 02					Tenement Typology	Multi-tenement
	Location	Saltlake, Kolkata 700106, West Bengal					No.of Stories -	
	Land Area		sqm				Covered Area (sqm)	100
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				3150	0.716	2255.4	2.255
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	12	14.2			170.4	2.985	508.644	0.509
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3					251.41	754.23	0.754
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3		200	73000	219000	0.0009	197.1	0.197
					TOTAL ANNUAL CO2 EMISSION			**3.883**

Appendix 6 Calculation of CO2 emission of sample 06

	SAMPLE 06							
	Owners name	Suvendu Roy					House Type	Residential
	Address	KB02 / 08					Tenement Typology	Multi-tenement
	Location	Saltlake, Kolkata 700106, West Bengal					No.of Stories -	
	Land Area		sqm				Covered Area (sqm)	100
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				3198	0.716	2289.768	2.290
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	6	14.2			85.2	2.985	254.322	0.254
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3					251.41	754.23	0.754
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3		200	73000	219000	0.0009	197.1	0.197
					TOTAL ANNUAL CO2 EMISSION			**3.663**

Appendix 7 Calculation of CO2 emission of sample 07

	SAMPLE 07							
	Owners name	D Basu					House Type	Residential
	Address	KB10/5					Tenement Typology	Multi-tenement
	Location	Saltlake, Kolkata 700106, West Bengal					No.of Stories -	
	Land Area		sqm				Covered Area (sqm)	100
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				5878	0.716	4209	4.209
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	15	14.2			213	2.985	635.805	0.636
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre **)**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	5					251.41	1257.05	1.257
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	5		200	73000	365000	0.0009	328.5	0.329
					TOTAL ANNUAL CO2 EMISSION			**6.598**

Appendix 8 Calculation of CO2 emission of sample 08

	SAMPLE 08							
	Owners name	Malabika Ghosh					House Type	Residential
	Address	KB10/6					Tenement Typology	Multi-tenement
	Location	Saltlake, Kolkata 700106, West Bengal					No.of Stories -	
	Land Area		sqm				Covered Area (sqm)	100
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				2123	0.716	1520	1.520
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	15.6	14.2			221.52	2.985	661.2372	0.661
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	2	243.33	0.6	146.00	2.3	335.80	0.336
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	5					251.41	1257.05	1.257
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	5		200	73000	365000	0.0009	328.5	0.329
					TOTAL ANNUAL CO2 EMISSION			**4.103**

Appendix 9 Calculation of CO2 emission of sample 09

	SAMPLE 09							
	Owners name	Ashoke Kumar Dey					House Type	Residential
	Address	Flat No. S1, BC, Street No. 166					Tenement Typology	Multi-tenement
	Location	Action Area 1B,NewTown, Kolkata, West Bengal					No.of Stories -	4 (G+3)
	Land Area	27.592	sqm				Flat Covered Area (sqm)	74.32
	No of Flats	6						
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				890	0.604	538	0.538
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	9	14.2			127.8	2.985	381.483	0.381
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3					251.41	754.23	0.754
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3		200	73000	219000	0.0009	197.1	0.197
					TOTAL ANNUAL CO2 EMISSION			**2.038**

Appendix 10 Calculation of CO2 emission of sample 10

	SAMPLE 10							
	Owners name	Sanjoy Biswas					House Type	Residential
	Address	Flat No. S3, BC, Street No. 166					Tenement Typology	Multi-tenement
	Location	Action Area 1B,NewTown, Kolkata, West Bengal					No.of Stories -	4 (G+3)
	Land Area	27.592	sqm				Flat Covered Area (sqm)	74.32
	No of Flats	6						
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				2544	0.716	1822	1.822
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	12	14.2			170.4	2.985	508.644	0.509
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	1	121.667	0.14	17.03	2.3	39.18	0.039
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4					251.41	1005.64	1.006
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4		200	73000	292000	0.0009	262.8	0.263
					TOTAL ANNUAL CO2 EMISSION			**3.806**

Appendix 11 Calculation of CO_2 emission of sample 11

	SAMPLE 11							
	Owners name	Biblab Majumder					House Type	Residential
	Address	Flat No. S4, BC, Street No. 166					Tenement Typology	Multi-tenement
	Location	Action Area 1B,NewTown, Kolkata, West Bengal					No.of Stories -	4 (G+3)
	Land Area	27.592	sqm				Flat Covered Area (sqm)	74.32
	No of Flats	6						
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				780	0.716	558	0.558
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	12	14.2			170.4	2.985	508.644	0.509
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor (kg/litre)**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4					251.41	1005.64	1.006
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4		200	73000	292000	0.0009	262.8	0.263
					TOTAL ANNUAL CO2 EMISSION			**2.503**

Appendix 12 Calculation of CO_2 emission of sample 12

	SAMPLE 12							
	Owners name	Debashish Sarkar					House Type	Residential
	Address	Flat No. N4, BC, Street No. 166					Tenement Typology	Multi-tenement
	Location	Action Area 1B,NewTown, Kolkata, West Bengal					No.of Stories -	4 (G+3)
	Land Area	#####	sqm				Flat Covered Area (sqm)	74.32
	No of Flats	6						
1	**Emission due to Electric Consumption - TonneCO2e / annum**							
					Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only				1080	0.716	773	0.773
2	**Emission due to LPG Consumption - TonneCO2 / annum**							
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg			Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4	14.2			56.8	2.985	169.548	0.170
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**							
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)	**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor** (kg/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14	0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6	73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**							
	No.of Family members					**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4					251.41	1005.64	1.006
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**							
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)	Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	4		200	73000	292000	0.0009	262.8	0.263
					TOTAL ANNUAL CO2 EMISSION			**2.379**

Appendix 13 Calculation of CO2 emission of sample 13

	SAMPLE 13								
	Owners name	Santanu Biswas						House Type	Residential
	Address	Flat No. N1, BC, Street No. 166						Tenement Typology	Multi-tenement
	Location	Action Area 1B,NewTown, Kolkata, West Bengal						No.of Stories -	4 (G+3)
	Land Area	27.592	sqm					Flat Covered Area (sqm)	74.32
	No of Flats	6							
1	**Emission due to Electric Consumption - TonneCO2e / annum**								
						Yearly Consumption (KWH)	**Emission Factor**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	Consumption by flat Area only					480	0.716	344	0.344
2	**Emission due to LPG Consumption - TonneCO2 / annum**								
	No.of LPG Cylinders used per annum (No.)	LPG in each Cylinder in Kg				Yearly LPG Consumption in Kg	**Emission Factor**	**Emission in KgCO2** per annum	**Emission in TonneCO2** (per annum)
	4	14.2				56.8	2.985	169.548	0.170
3	**Emission from Fuel Consumption due to idling - TonneCO2 / annum**								
	Automobile Type	**No.**	**yearly Idling Time (hr)** assuming 20 minutes per day	**Consumption Factor** (Lt / hr)		**Fuel consumption yearly (assuming 20 minutes idling time per day)** litres	**Emission Factor (kg/litre)**	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	2 wheelers	0	0	0.14		0.00	2.3	0.00	0.000
	4 wheelers (cars)	1	121.67	0.6		73.00	2.3	167.90	0.168
4	**Emission due to Respiration of Family members - TonneCO2 / annum**								
	No.of Family members						**Emission Factor** (KgCo2/annum /person)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3						251.41	754.23	0.754
5	**Emission due to Water consumption by Family members - TonneCO2 / annum**								
	No.of Family members		Water consumption per person per day (litre)	Water consumption per person per year (litre)		Total water consumptionby residents (litres/annum)	**Emission Factor** (KgCo2/litre)	**Emission in KgCO2** (per annum)	**Emission in TonneCO2** (per annum)
	3		200	73000		219000	0.0009	197.1	0.197
						TOTAL ANNUAL CO2 EMISSION			**1.632**

Appendix 14 Existing land use and further plantation scope in ground space and terrace (Sample P05)

SAMPLE NO. P-05

LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMDING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	

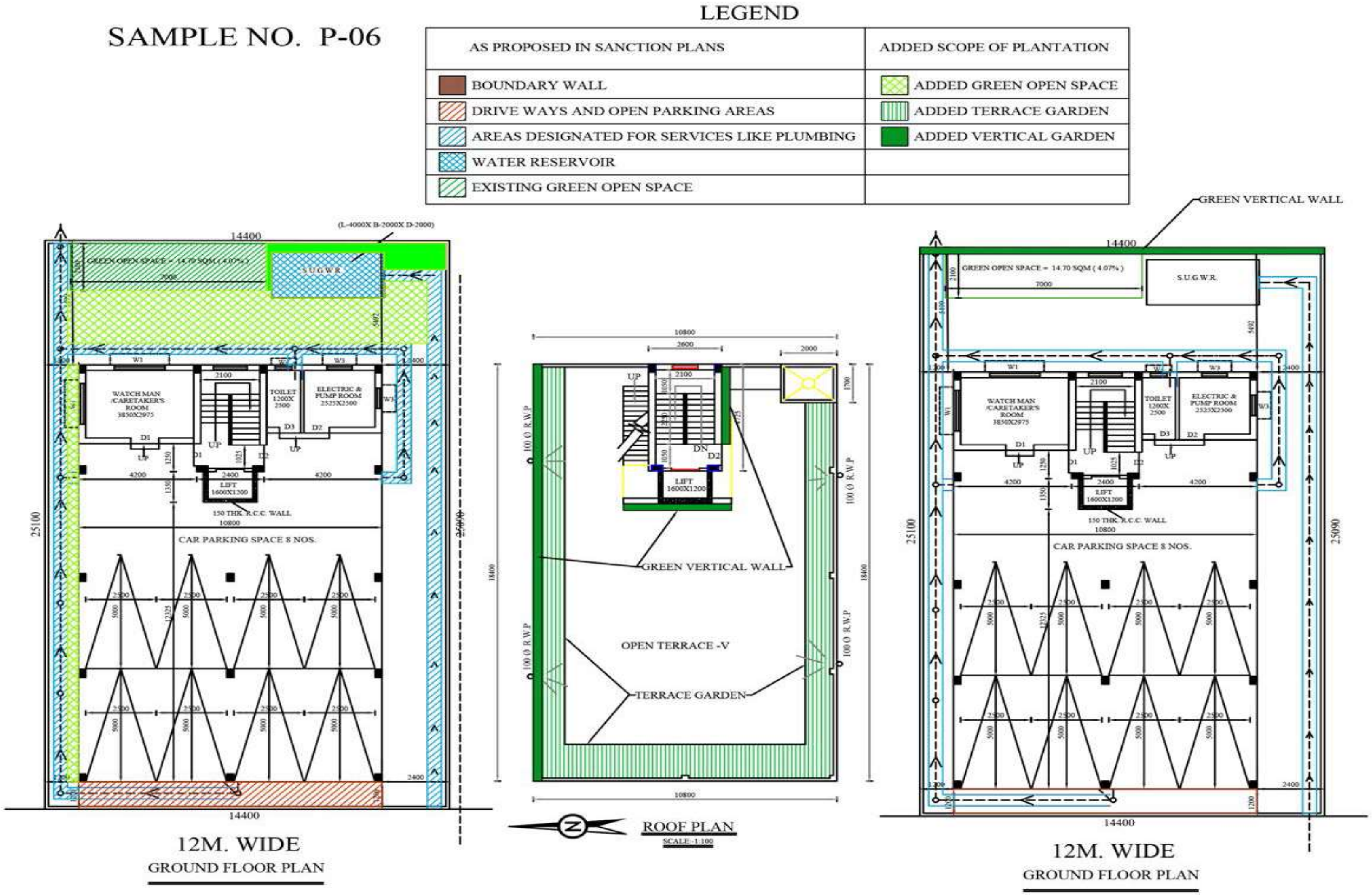
12 M WIDE

GROUND FLOOR PLAN

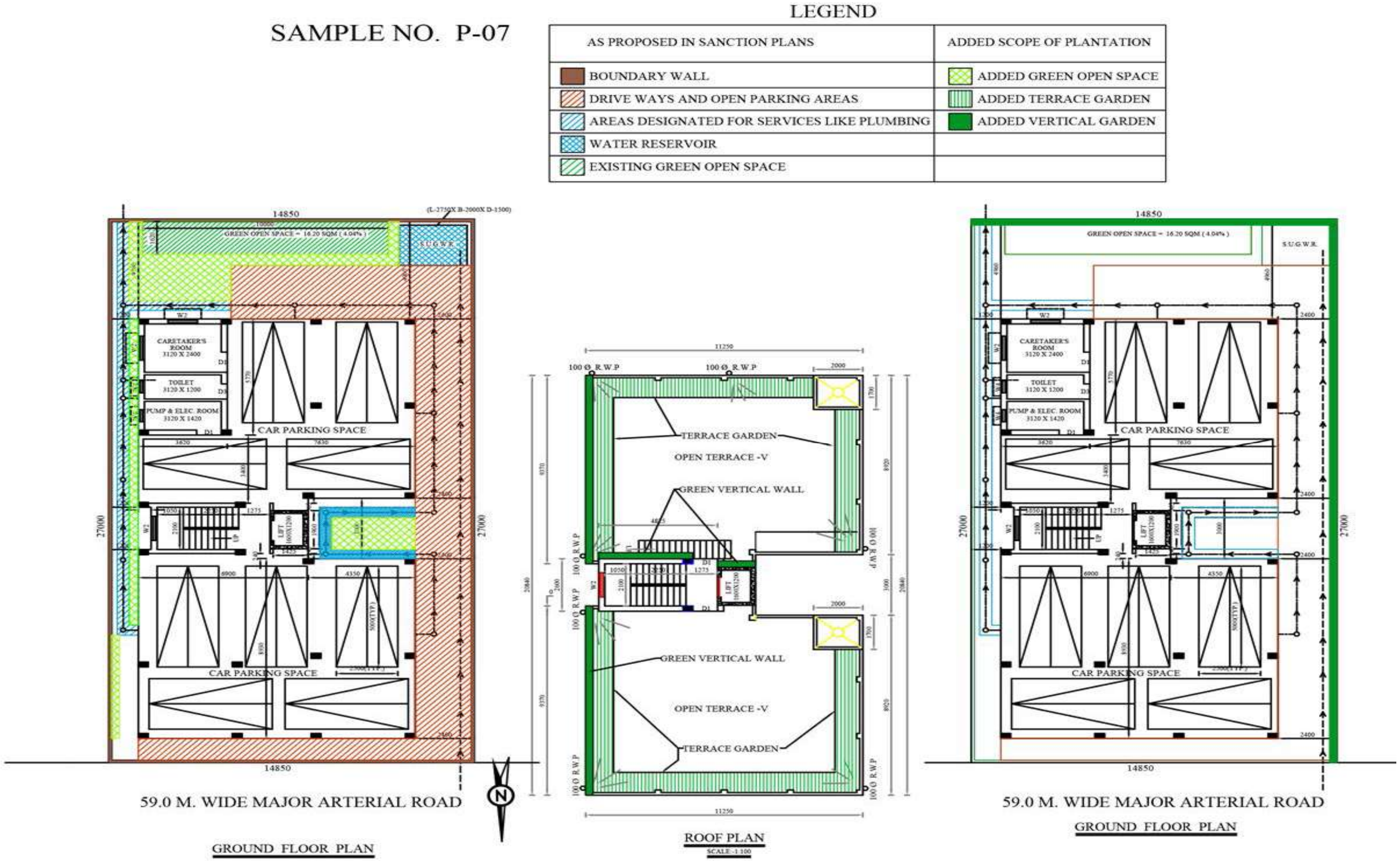
12 M WIDE

GROUND FLOOR PLAN

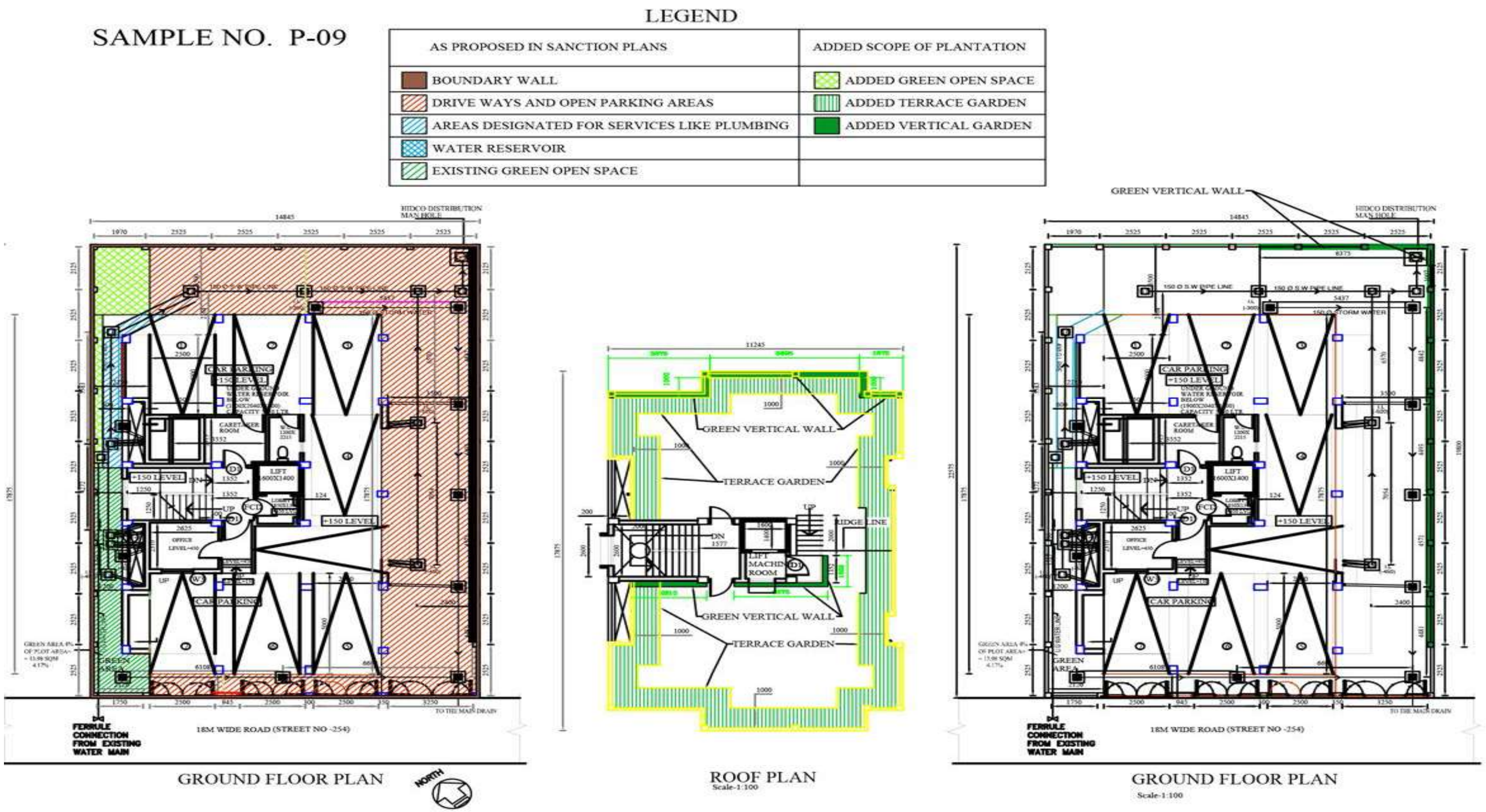
Appendix 15 Existing land use and further scope of plantation in ground space and terrace (Sample P06)



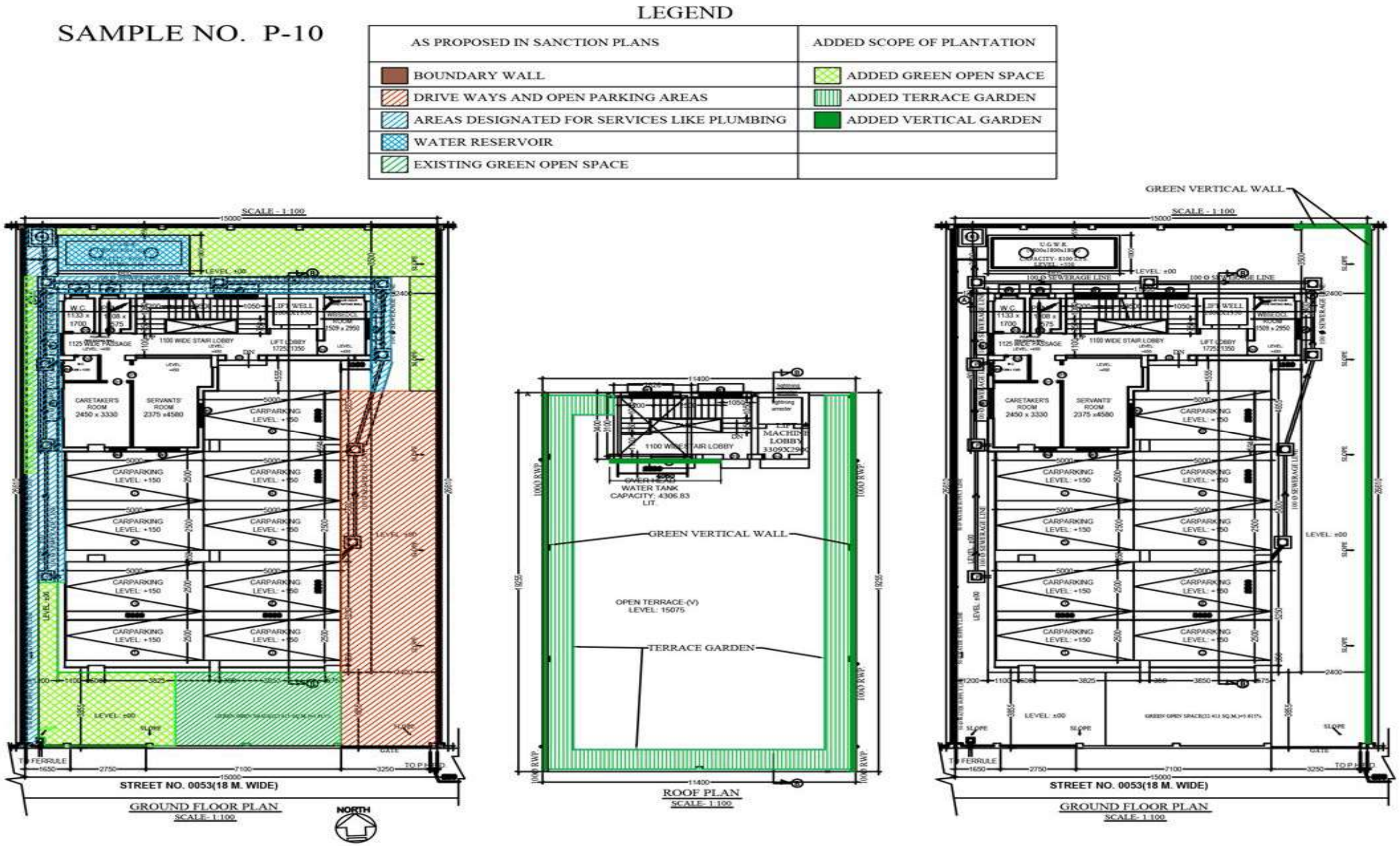
Appendix 16 Existing Ground space and further scope of plantation in ground space and terrace (Sample P07)



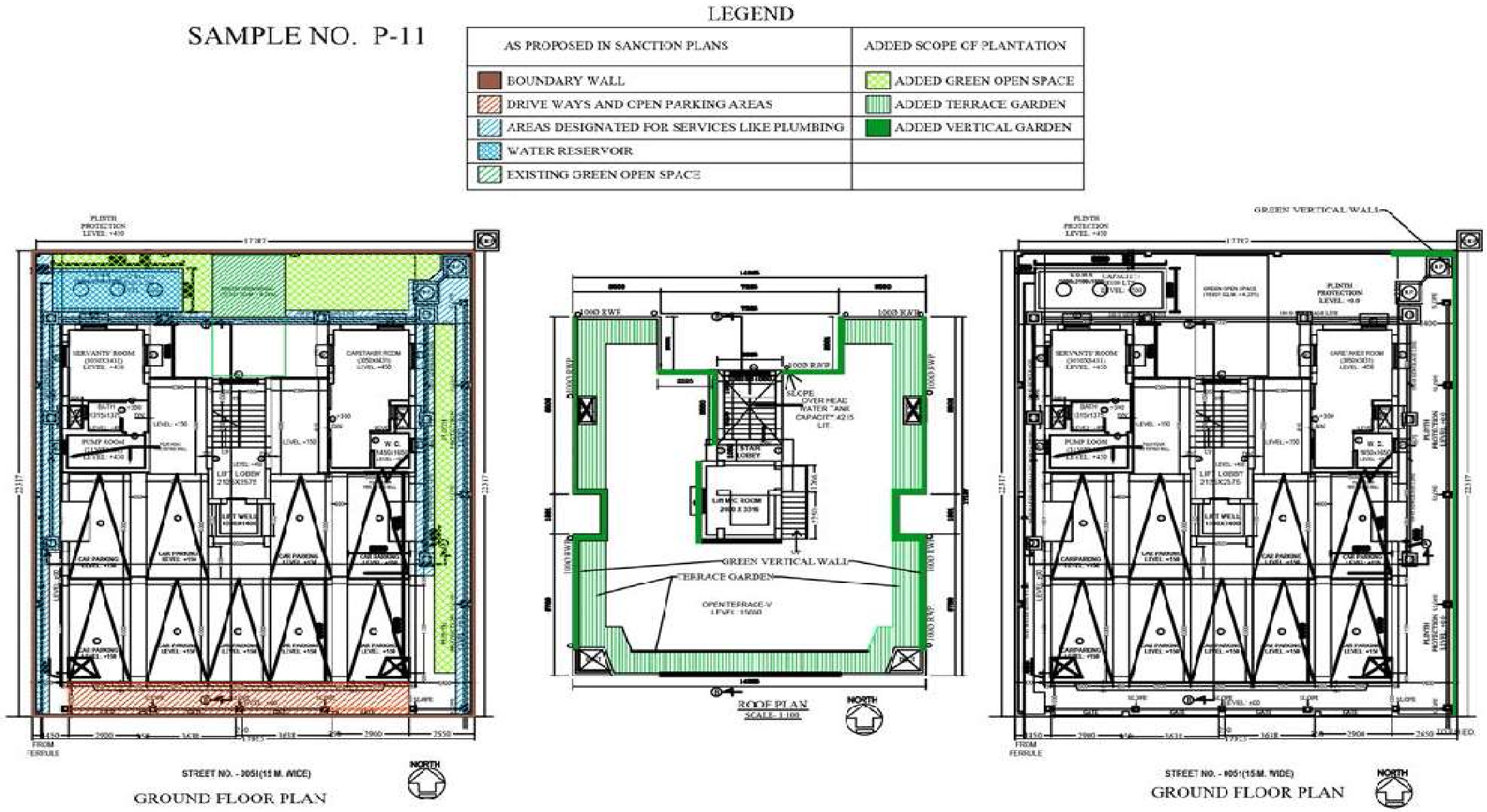
Appendix 17 Existing land use and further scope of plantation in ground space and terrace (Sample P08)



Appendix 18 Existing land use and further scope of plantation in ground space and terrace (Sample 10)



Appendix 19 Existing land use and further scope of plantation in ground space and terrace (Sample P11)

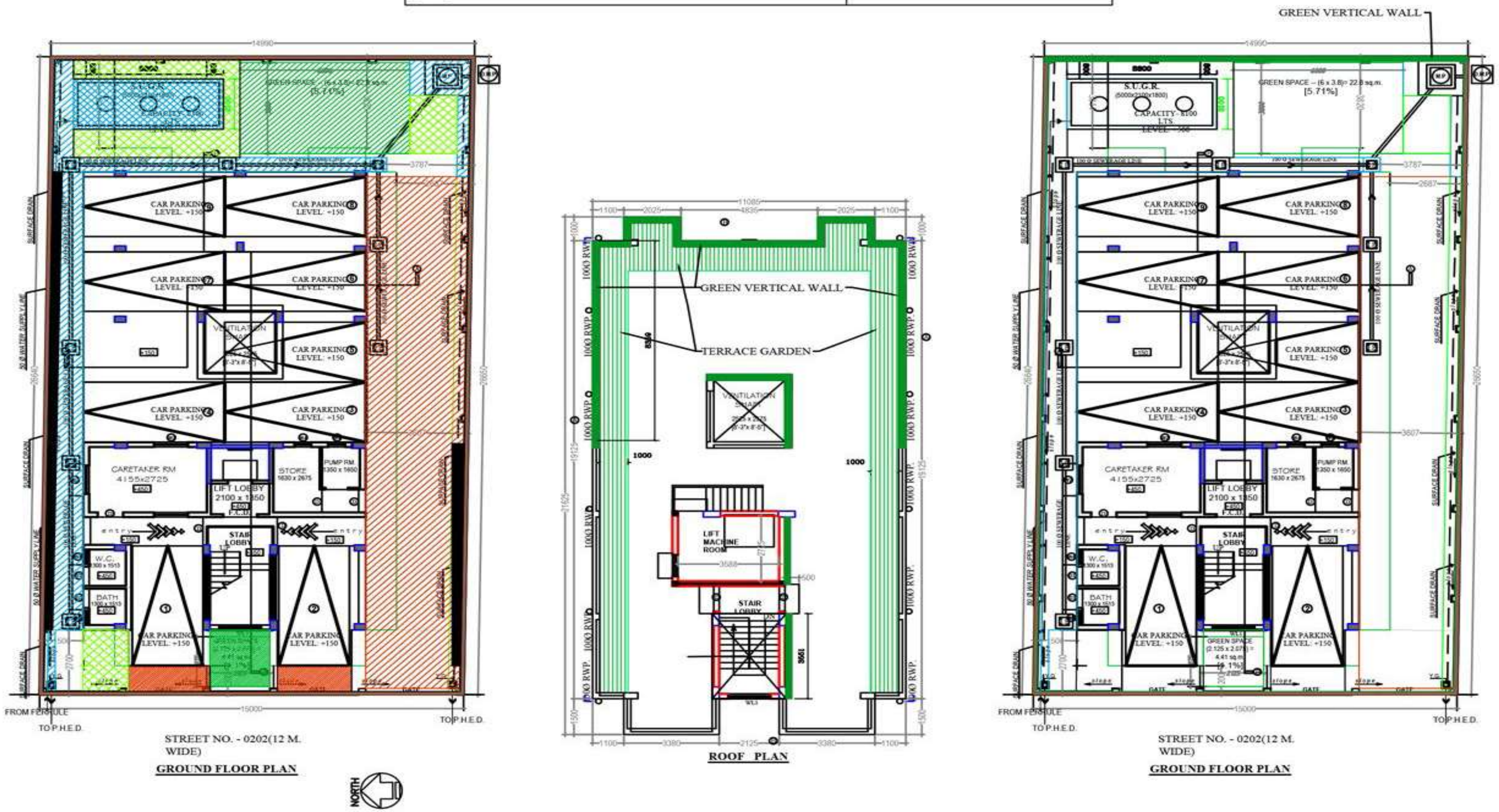


Appendix 20 Existing land use and further scope of plantation in ground space and terrace (Sample P12)

SAMPLE NO. P-12

LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	

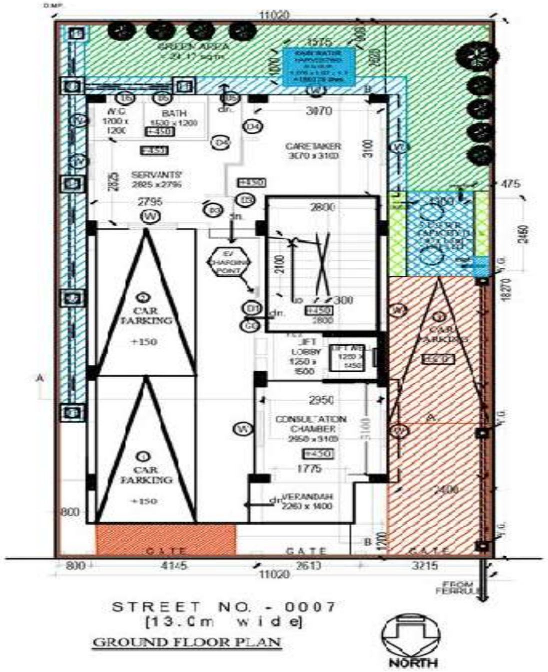


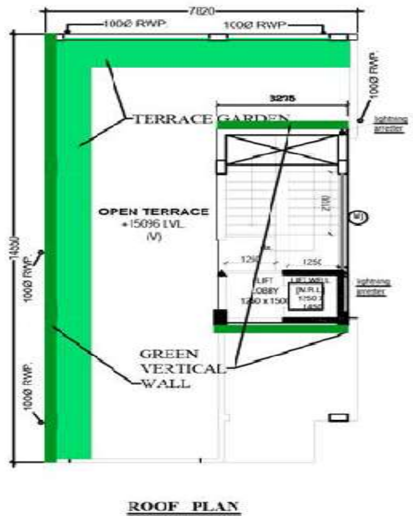
Appendix 21 Existing Land use and further scope of plantation in ground space and terrace (Sample P13)

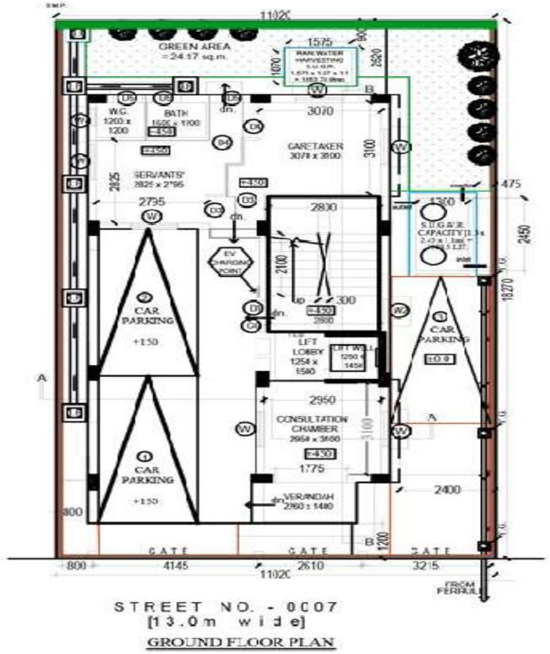
SAMPLE NO. P-13

LEGEND

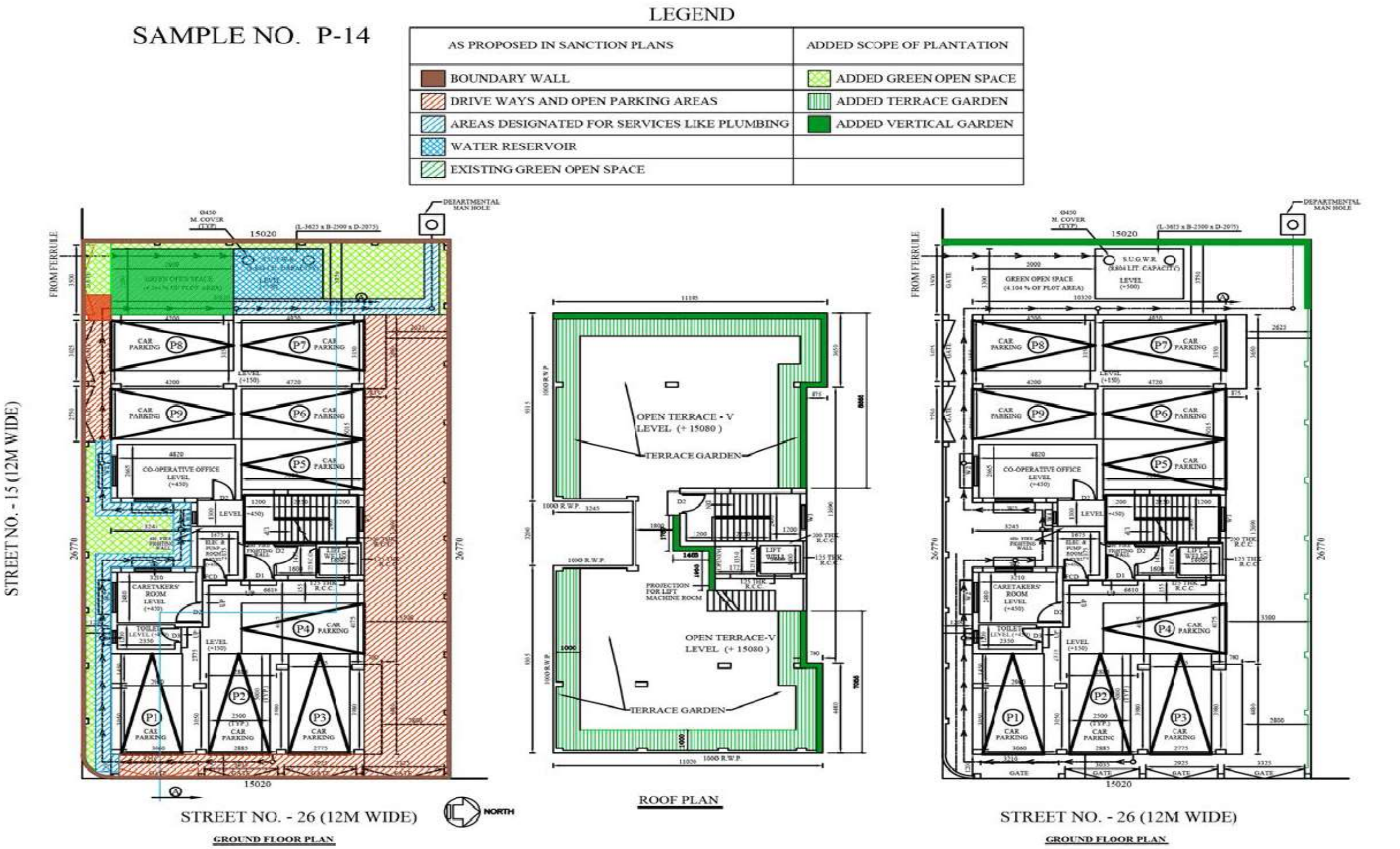
AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	



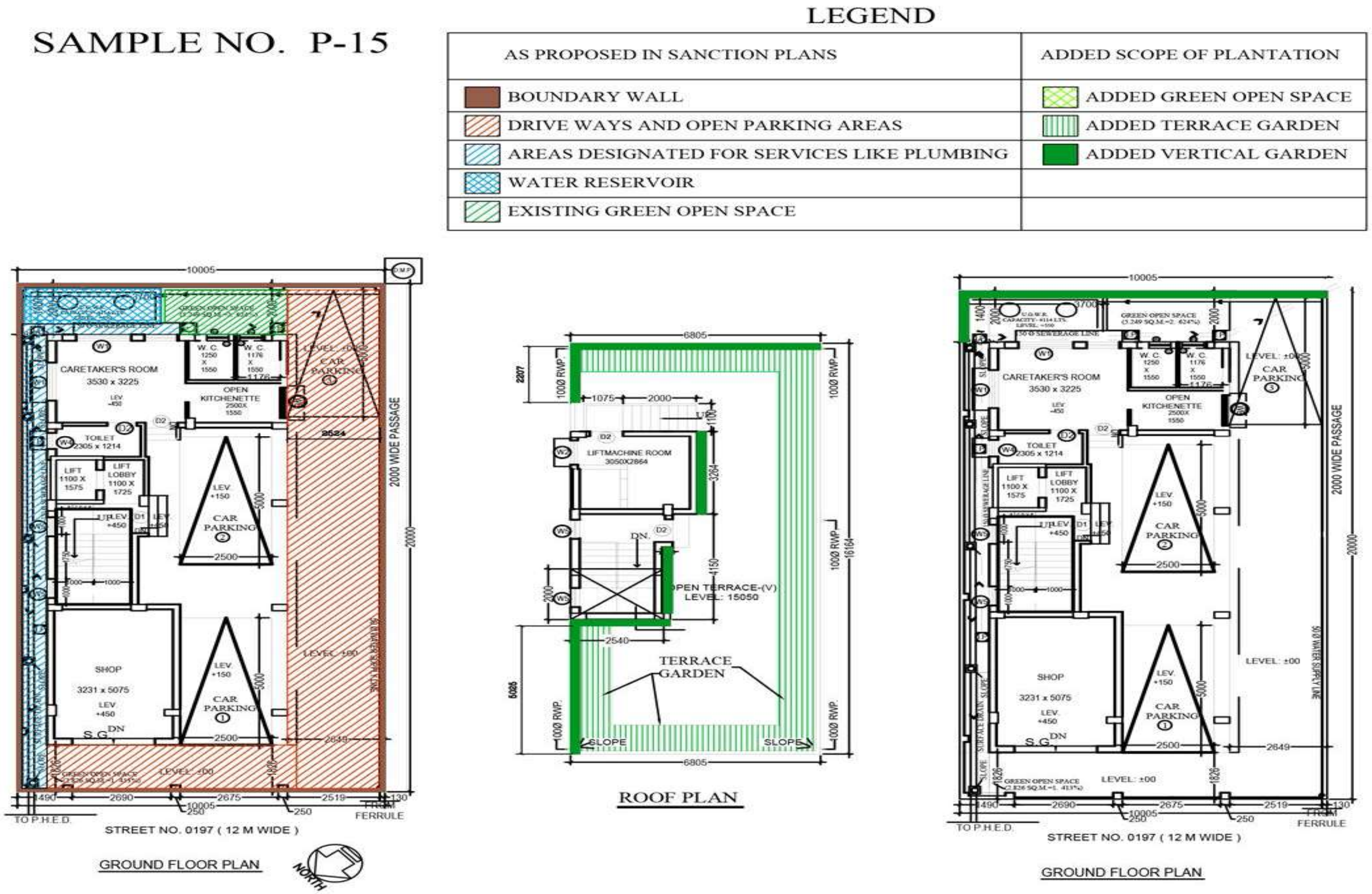




Appendix 22 Existing land use and further scope of plantation in ground space and terrace (Sample P14)



Appendix 23 Existing land use and further scope of plantation in ground space and terrace (Sample P15)

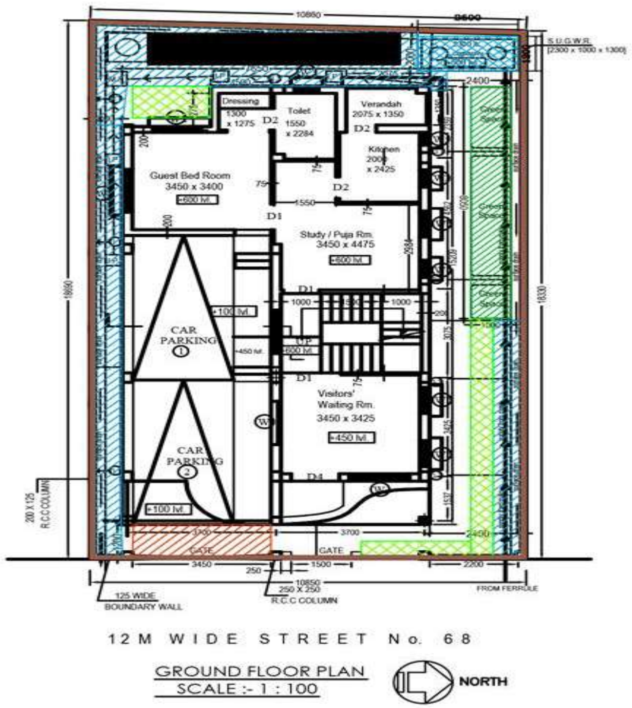


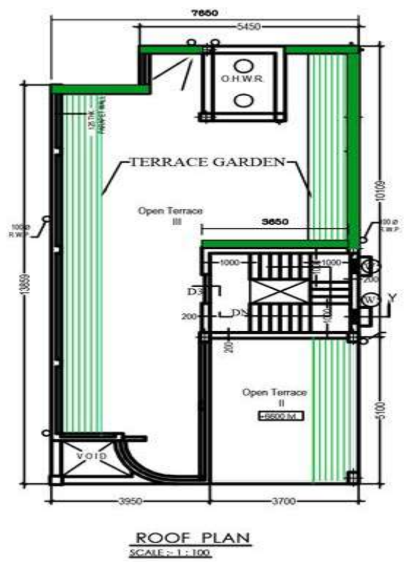
Appendix 24 Existing land use and further scope of plantation in ground space and terrace (Sample P16)

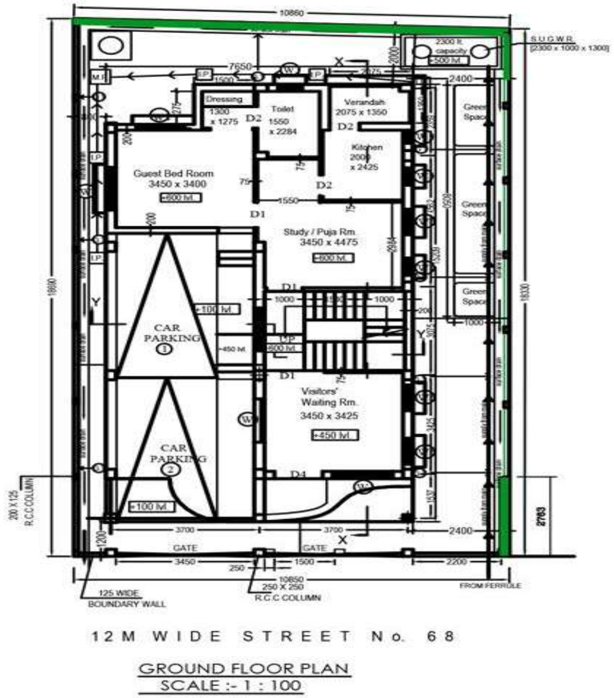
SAMPLE NO. P-16

LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	





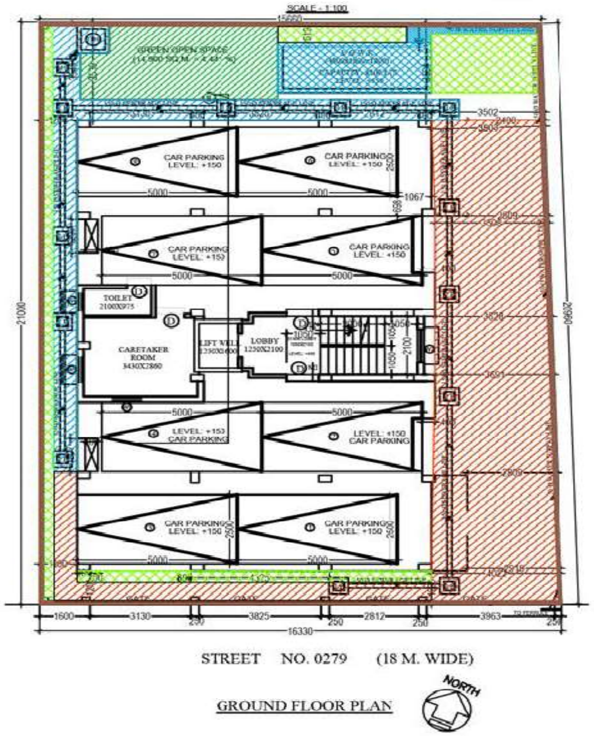


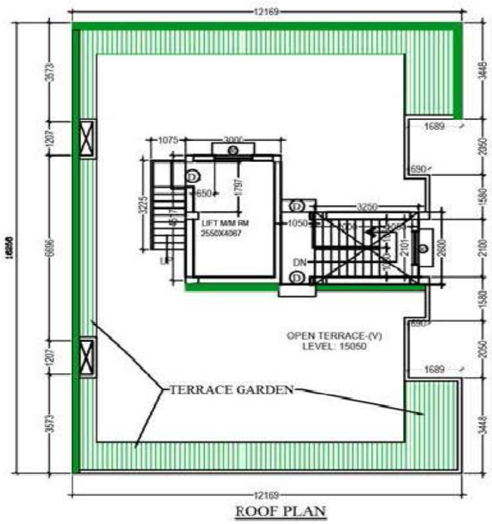
Appendix 25 Existing land use and further scope of plantation in ground space and terrace (Sample 17)

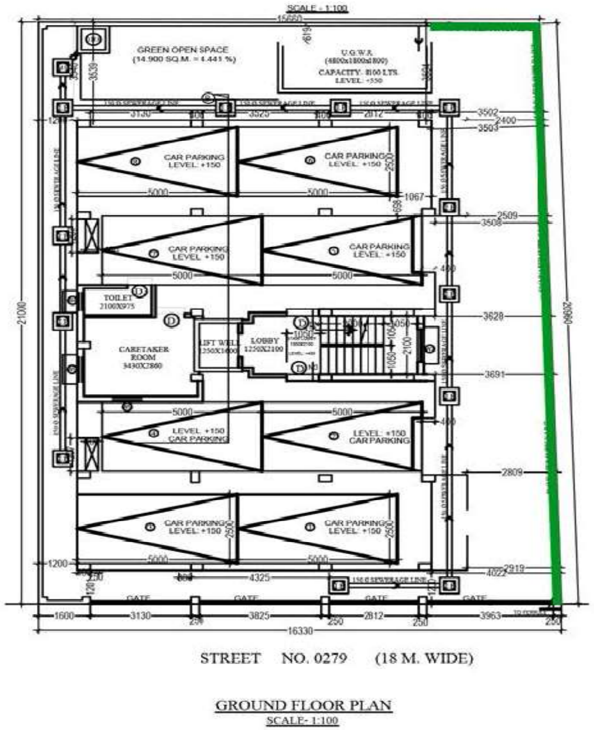
SAMPLE NO. P-17

LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	





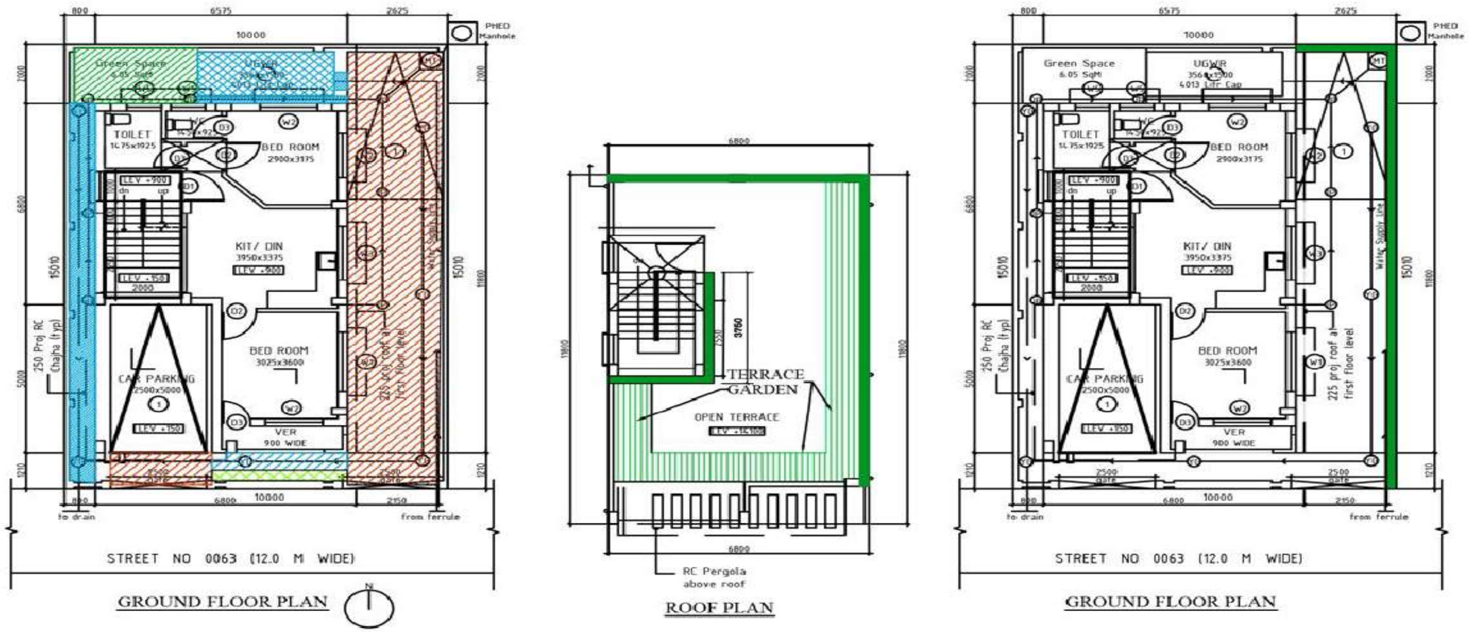


Appendix 26 Existing land use and further scope of plantation in ground space and terrace (Sample P18)

SAMPLE NO. P-18

LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	

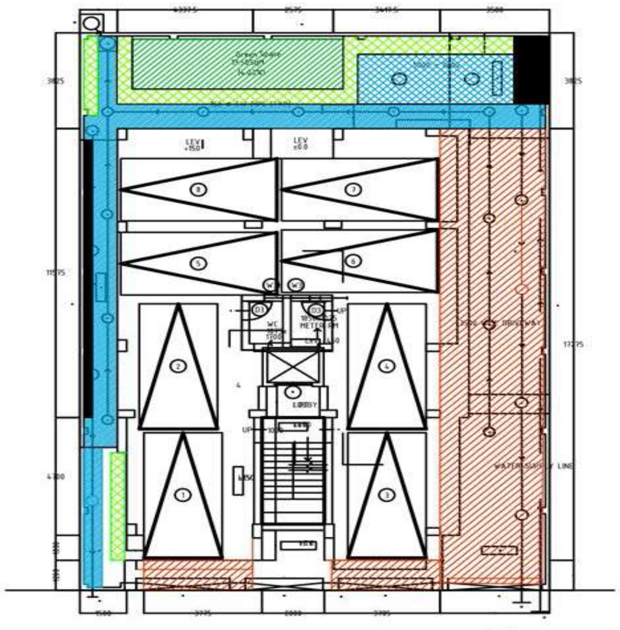


Appendix 27 Existing land use and further scope of plantation in ground space and terrace (Sample P19)

SAMPLE NO. P-19

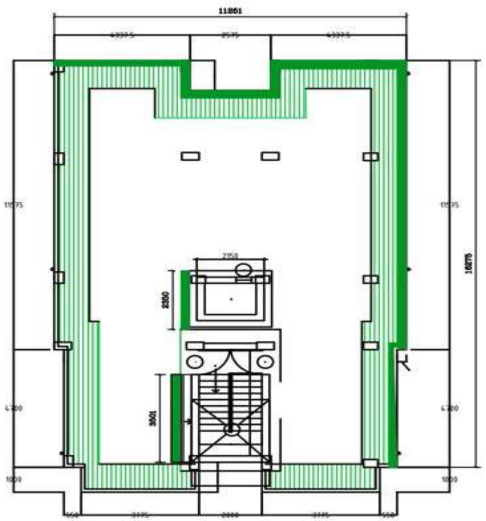
LEGEND

AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	

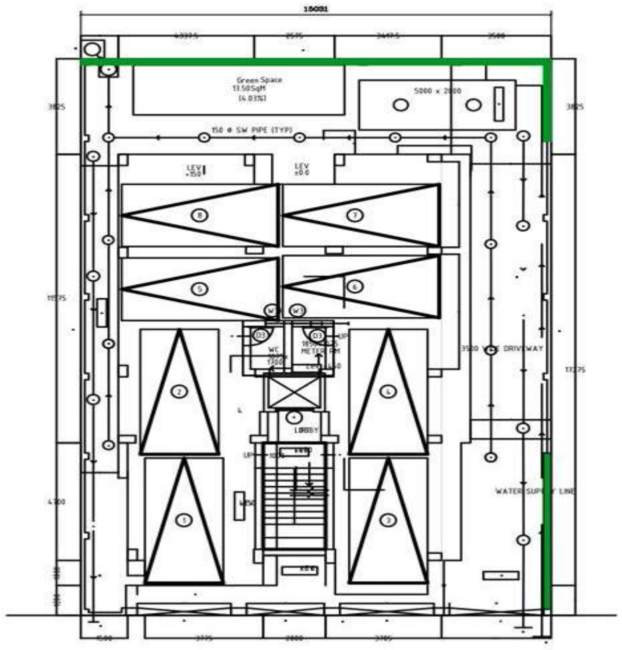


STREET NO 0215 (12.0 M WIDE)

GROUND FLOOR PLAN



ROOF PLAN



STREET NO 0215 (12.0 M WIDE)

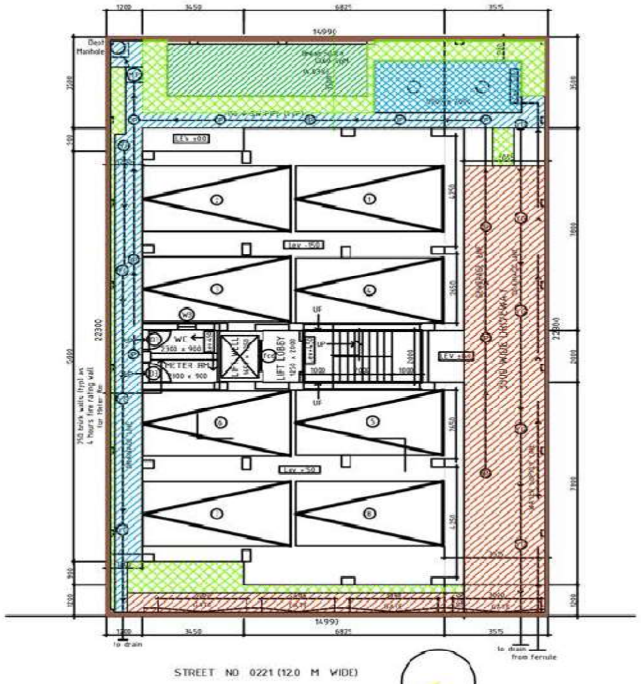
GROUND FLOOR PLAN

Appendix 28 Existing land use and further scope of plantation in ground space and terrace (Sample P20)

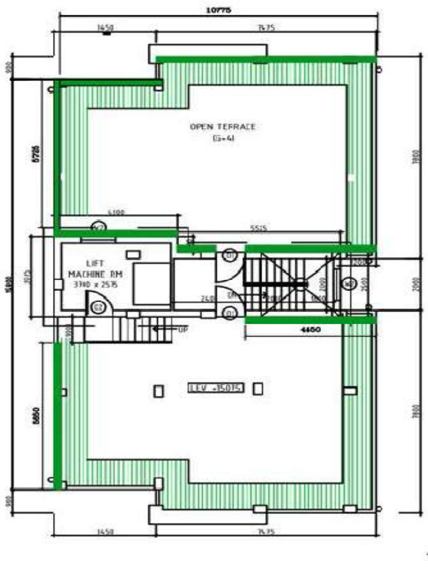
SAMPLE NO. P-20

LEGEND

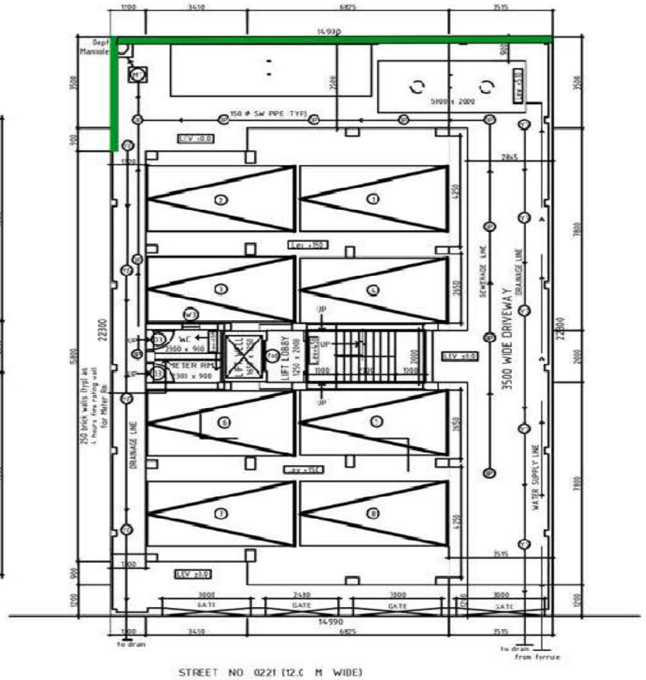
AS PROPOSED IN SANCTION PLANS	ADDED SCOPE OF PLANTATION
BOUNDARY WALL	ADDED GREEN OPEN SPACE
DRIVE WAYS AND OPEN PARKING AREAS	ADDED TERRACE GARDEN
AREAS DESIGNATED FOR SERVICES LIKE PLUMBING	ADDED VERTICAL GARDEN
WATER RESERVOIR	
EXISTING GREEN OPEN SPACE	



GROUND FLOOR PLAN



ROOF PLAN



GROUND FLOOR PLAN

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