OPERATIONAL ENERGY LIFE CYCLE ASSESSMENT OF RESIDENTIAL HOUSES – ANALYTICAL STUDY OF AN URBAN DISTRICT OF PAKISTAN

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Abstract- Energy consumed by the buildings at their operational stage is considered one of the main factors burdening the environment. This consumed energy releases greenhouse gases (GHG) emissions due to the rising energy demands from cities' domestic and residential sectors. The domestic sector of Pakistan consumes 45.9 % of its annual energy. Heating, ventilation, air conditioning (HVAC), and lighting appliances consume about half of the total building energy. There is a rising need for more innovative and sustainable approaches to buildings operations to cope with this global issue. To fill this gap in sustainable construction and operations of residential buildings efficiently, this research was conducted based on Energy Life Cycle Assessment (ELCA) methodology for the residential houses. Researchers collected data from 13 houses in district Central of Karachi. It included information related to building envelope and operational energy details. The life cycle assessment framework was applied over the collected inventory data, and life cycle inventory analysis was performed, leading to the integration of the Life Cycle Impact assessment. The results evaluated that studied houses produce 48120 Tons of carbon footprint throughout the life cycle stages of the buildings for a reference study period of 60 years. Global warming potential was found to be the highest, followed by acidification and eutrophication potential.

Keywords- Life cycle assessment, energy efficiency, Energy, Carbon footprint

1 Introduction

The domestic sector of Pakistan consumes 45.9 % of its annual energy. About half of the total energy is consumed by buildings and/or heating, ventilation, air conditioning (HVAC), and lighting appliances [1]. With rising population demands, there is a noticeable need for energy-efficient buildings to reduce environmental impacts, such as; global warming, acidification, ozone depletion, etc. Statistics and research from the last decade reveal that the climate is changing globally [2] and will continue to do so. Overall, environmental burden of buildings can be reduced by using LCA as an instrument, which provides trade-offs associated with pressures, health and wellbeing and the consumption of natural resources [3]. Buildings play a significant role in the consumption of energy throughout the world, and the pattern of rising energy demands from this sector questions the urgency of mitigating environmental impacts caused by these buildings. This paper presents implementing an operational energy life cycle assessment framework in the district Central of Karachi in which data from 13 houses were collected and analyzed. The research was carried out by creating energy models for existing houses, and after energy auditing; results were compared with the simulation results extracted from BEM (Building Energy Model) and ELCA (Energy Life Cycle Assessment). The study will result in quantification of total carbon footprint for reference period of sixty years and the factors, which contribute towards these carbon footprints, will be analyzed.

2 Literature Review

2.1 Life Cycle Assessment

LCA is a process that quantifies and assesses the flow of energy and material within a system. Steps that include upstream (material extraction, manufacture, transport, and assembling), usage, and downstream (demolishing and disposal) of goods, products, or services network are usually inventoried first. Life cycle assessment is constantly evolving; it has been carefully constructed over the years to help manage and develop different working standards. One such development done on a global scale on quality standards is the international standard organizations (ISO) standards; 14,000 and above, with ISO 14,040 series establishing a focus on the LCA approach [4]. In the LCA approach, the information is processed through four main stages [5]: (1) Life cycle assessment (2) Life Cycle Inventory Analysis (3) Life Cycle Impact Assessment (4) Impact Categories. The impact categories, which have been observed and confirmed from various standards, handbooks, and reading materials [6], [7], [8] include; Global Warming, Climate Change, Land use, Water use, Acidification, Eutrophication, Stratospheric ozone layer depletion, Abiotic Resource Depletion Potential, Abiotic Resource Depletion potential of fossil fuels, Human Toxicity and Eco Toxicity.

2.2 Energy Life Cycle Assessment (ELCA)

The ELCA process of a building or product comprises two levels [5]. The method caters to all of a building's energy inputs throughout its life cycle. This analysis includes the energy utilization of the following phases: the manufacture, usage, destruction, and finally, disposal [6]. Usage includes all operations that the building uses throughout its life span. Manufacturing usually involves the production and transfer of building materials and engineering equipment used to install and reconstruct structures. The different types of tools and inventories available for level 1 and level 2 analysis are provided in the following sub-sections.

2.2.1 Level-1

Product comparison tools include; Building for Environmental and Economic Sustainability (BEES), National Renewable Energy Laboratory's (NREL), U.S. Life-Cycle Inventory (LCI) Database, SimaPro, Integrated Assessment, and Life Cycle Explorer.

2.2.2 Level-2

These software tools improve the decision-making process by providing a detailed project analysis. Some of these support tools are Envest 2, Eco Calculator, and Athena. These are the tools specialized in LCA and Sustainable Architecture.

3 Research Methodology

A literature review was the first step of the methodology. It was necessary to benchmark ELCA concepts, elicit secondary, data and development of ELCA framework for houses in alignment with international standards. Following the literature review was the step of energy life cycle assessment which included; gathering inventory data, calculation of annual utility consumption, identification of emission factors, identification of LCA tool, calculation of impact categories, and finally calculation of overall carbon footprint of the studied houses. The inventory data was collected for the 13 houses located in district central. The inventory data collected included; architectural plans, 12 months' utility bills (electricity, natural gas, and water), number of occupants, and covered area of the building which were used in the life cycle assessment. This data was utilized to calculate the LCA of the houses during their operational phase. Since the water, consumption data was unavailable for most of the houses, it was calculated based on water demand estimation for the district central in Karachi. As per Karachi Water and Sewage Board (KWSB), the per capita water demand is 54 gallons or 246 liters per day. The said values were used to estimate the total annual water consumption of the household based on the number of occupants in that particular house. Emission factors were taken from LCA inventory data provided in the One-Click LCA inventory (online LCA tool) which are provided in Table 1. An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with releasing that pollutant. These factors are usually expressed as the weight of the pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per mega gram of coal burned). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are averages of all available data of acceptable quality. They are generally assumed to be representative of long-term averages for all facilities in the source category *(the United States Environmental Protection Agency, n.d.).* District central of Karachi was considered as case study area for performing the analysis with the view of implicating the findings generally in other urban areas of Pakistan.

Table 1 Emission factors for Pakistan. (Values taken from One Click LCA, Bionova Ltd)

Consumption Category	Profile	Global Warming Kg CO_2	Acidification Kg SO_2	Eutrophication Kg PO2	Ozone depletion potential Kg CFC11	Formation of ozone of lower atmosphere Kg Ethene
Electricity/ KWh/Year	Electricity (World Data)	0.741675281	0.005276896	0.001199800	0.000000035742	0.000182250
Natural Gas/ Cft/Year	Natural gas	0.064132221	0.000189243	0.000012695	0.000000005045	0.000012853
Water/ Cft/ Year	Tap water, clean	0.008495054	0.000046002	0.000023274	0.000000000000	0.000002071

Special care was taken to adapt the values from the website for profiles from Pakistan. For electricity consumption, production emission factors for thermal power generation were taken from world profile. This was based on literature review findings and assumption that thermal power generation will result in similar emissions for Pakistan as well due to similarity in generation plants' technology.

4 Life Cycle Assessment Calculation

The equation that derives the LCA calculation is simple and is given below:

$$EEI = OEC \times EF \text{ -------------------- (1)}$$

Where;

EEI = Estimated Environmental Impact annually

OEC = Operational Energy Consumption

EF = Category Emission factor

The above equation gives the annual carbon emission values for the calculated household. To calculate its LCA over its operational life cycle, another variable is required i.e., the reference study period/ calculation period for LCA study. This period usually ranges between 0 to 80 years for a household, mainly depending on design life. The reference study period has been assumed 60 years for this research. For the calculations performed in studied houses, Life cycle impact values were calculated using equation (2).

$$LCI = EEI \times n \text{ -------------------- (2)}$$

Where;

EEI = Estimated Environmental Impact annually

n = study period/reference period for LCA

Table 2 shows the emissions for houses of district Central based on their Electricity consumption.

Table 2 Annual Emission Calculations for Electricity for District Central

House Code	Plot Size in yards	GWP Kg CO_2	AP Kg SO_2	EP Kg PO_2	ODP Kg CFC11	POCP Kg Ethene
H1	200	1981.76	14.10	3.21	0.000096	0.49
H2	120	2985.98	21.24	4.83	0.000144	0.73
H3	120	2750.87	19.57	4.45	0.000133	0.68
H4	100	3533.34	25.14	5.72	0.000170	0.87
H5	400	4916.57	34.98	7.95	0.000237	1.21
H6	120	2024.77	14.41	3.28	0.000098	0.50
H7	100	1288.29	9.17	2.08	0.000062	0.32
H8	80	2516.65	17.91	4.07	0.000121	0.62
H9	120	2516.65	17.91	4.07	0.000121	0.62
H10	120	2516.65	17.91	4.07	0.000121	0.62
H11	240	1948.38	13.86	3.15	0.000094	0.48
H12	240	1948.38	13.86	3.15	0.000094	0.48
H13	240	1948.38	13.86	3.15	0.000094	0.48
H14	260	1948.38	13.86	3.15	0.000094	0.48
H15	505.66	4916.57	34.98	7.95	0.000237	1.21

Table 3 shows the emissions for houses of district Central based on their Natural Gas consumption.

Table 3 Annual Emission Calculations for Natural Gas for District Central

House Code	Plot Size in yards	GWP Kg CO_2	AP Kg SO_2	EP Kg PO_2	ODP Kg CFC11	POCP Kg Ethene
H1	200	48291.56	142.50	9.56	0.003799	9.68
H2	120	75868.42	223.87	15.02	0.005968	15.20
H3	120	55730.90	164.45	11.03	0.004384	11.17
H4	100	24049.58	70.97	4.76	0.001892	4.82
H5	400	67210.57	198.33	13.30	0.005287	13.47
H6	120	56692.88	167.29	11.22	0.004460	11.36
H7	100	34246.61	101.06	6.78	0.002694	6.86
H8	80	55910.47	164.98	11.07	0.004398	11.21
H9	120	55910.47	164.98	11.07	0.004398	11.21
H10	120	55910.47	164.98	11.07	0.004398	11.21
H11	240	48291.56	142.50	9.56	0.003799	9.68
H12	240	48291.56	142.50	9.56	0.003799	9.68
H13	240	48291.56	142.50	9.56	0.003799	9.68
H14	260	48291.56	142.50	9.56	0.003799	9.68
H15	505.66	34246.61	101.06	6.78	0.002694	6.86

Table 4 shows the emissions for houses of district Central based on their Water consumption.

Table 4 Annual Emission Calculations for Water for District Central

House Code	Plot Size in yards	GWP Kg CO_2	AP Kg SO_2	EP Kg PO_2	ODP Kg CFC11	POCP Kg Ethene
H1	200	80.81	0.44	0.22	0	0.02
H2	120	53.87	0.29	0.15	0	0.01
H3	120	80.81	0.44	0.22	0	0.02
H4	100	161.62	0.88	0.44	0	0.04
H5	400	188.56	1.02	0.52	0	0.05
H6	120	161.62	0.88	0.44	0	0.04
H7	100	161.62	0.88	0.44	0	0.04
H8	80	53.87	0.29	0.15	0	0.01

House Code	Plot Size in yards	GWP Kg CO_2	AP Kg SO_2	EP Kg PO_2	ODP Kg CFC11	POCP Kg Ethene
H9	120	80.81	0.44	0.22	0	0.02
H10	120	80.81	0.44	0.22	0	0.02
H11	240	161.62	0.88	0.44	0	0.04
H12	240	161.62	0.88	0.44	0	0.04
H13	240	161.62	0.88	0.44	0	0.04
H14	260	175.09	0.95	0.48	0	0.04
H15	505.66	340.52	1.84	0.93	0	0.08

5 Results of Energy Life Cycle Assessment

Table 5 summarizes the overall carbon footprint generated by the studied houses of district Central that generate emissions of 48120 Tons. The Overall footprint is represented in the equivalent of CO_2. The reference study period for this study is 60 years, and the generated results are stated.

Table 5 Summary of Carbon Emission of district central

Carbon Metric	Central
No. of Houses	13
Global Warming CO_2 (Kg)	799081.31
Acidification SO_2 (Kg)	2528.62
Eutrophication PO_2 (Kg)	219.95
Ozone depletion CFC11 (Kgs)	0.06
Ethene (POCP) (Kgs)	162.04
Carbon Footprint/Year (Kgs of CO_2)	801991.98
Reference Study Period (Years)	60
Carbon Footprint for Life Cycle (60 Years)	48119519 Kgs
Total (In Tons)	48120

The annual overall emission results for studied houses of the district Central are graphically illustrated in Figure 1. It provides the emission results and carbon footprints per year are found to be highest while the most negligible value is of ozone depletion CFC11. CO_2 is the leading cause of Global warming that is why it is high in magnitude, which is followed by acidification and eutrophication due to suphurdioxide-ammonia reaction and deposition to the changes in the chemical composition of the soil and surface water.

6 Practical Implementation of the study

Using similar approach as presented in the study, more localities with high carbon footprints can be identified. This can help to identify energy efficiency improvement measures that can reduce carbon footprints. The authors have worked on the same idea in an extended study under same project.

7 Conclusions

After analyzing 13 houses located in the district central of Karachi 48120 tons carbon footprint was found for the reference period of 60 years. Among different parameters, which contribute in the calculation of carbon footprint, carbon dioxide (CO_2) emissions that is global warming potential ranks first, acidification (SO_2) ranks second and Eutrophication (PO_4) ranks third.

8 Recommendations

The findings of this assessment along-with similar assessment of houses studied in other districts were combined to perform building energy efficiency assessment using building information modeling, and energy analysis to propose energy efficiency improvement measures. The potential measures can reduce energy use intensity (EUI) and hence, life cycle impact of operational energy use. These measures included; using R-38 Roof Insulation, R- 2 CMU Wall for the construction, Double Glazed Window Glass, window shades of at least 1/6th of the Window height, Providing Daylight & Occupancy controls, reducing Plug Load Efficiency to 6.46 watts/m^2 or less, reducing Lighting Efficiency to 3.23 watts/m^2. It was estimated that an integrated application of improvement measures can help reduce carbon footprint of one of the houses (i.e., H12) by approx. 62%. The results obtained from this study can be used to predict the parameters for other parts of Pakistan as well by considering them as benchmark.

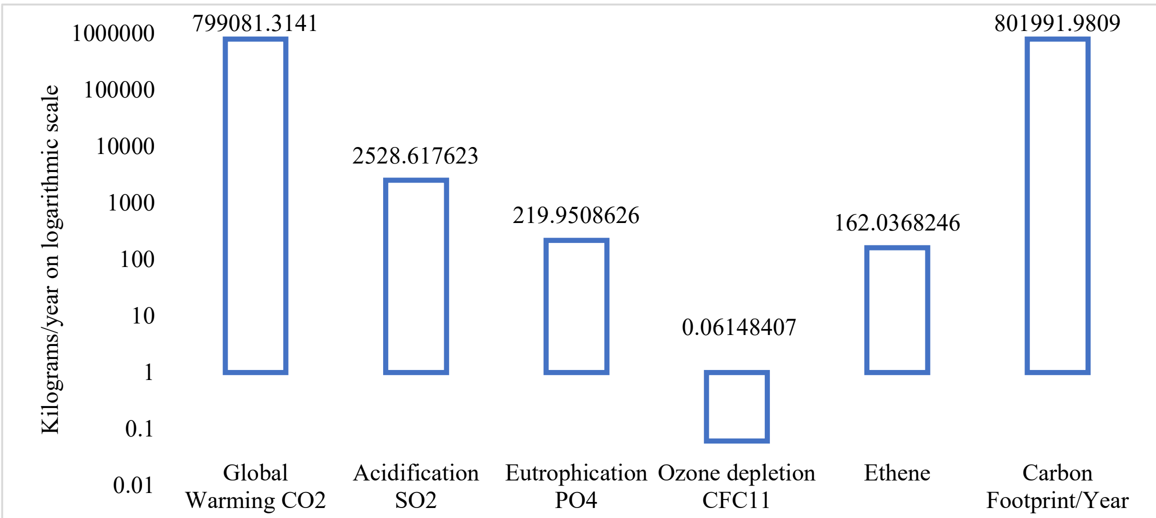

Figure 1 Emission results for houses studied in District central

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