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Life cycle assessment and Life cycle energy analysis of buildings: A review

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Abstract

Life cycle assessment is tool to compute environmental impact. This paper review and summarize the literature on life cycle assessment and life cycle energy analysis of buildings. It highlights the need of LCA in buildings, and importance of LCA as a decision-making tool. It shows LCA methodology and discusses various case Studies to find out total life cycle energy, operational energy, and embodied energy and to find total environmental impact due to whole building life cycle, during manufacturing phase, use phase and demolition phase within last twenty years in various part of world. This review shows that generally embodied energy is 10-20% and operational energy is 80-90% of total life cycle energy. Most of the studies are from developed countries, developing countries are not well represented in literature.

Keywords: Life cycle assessment; Life cycle energy analysis; Life cycle cost analysis; Buildings; sustainability.

1. Introduction

In today's world the major problem is pollution, global warming, ozone depletion, acidification [1]. These problems are due to deforestation, use of non-degradable materials, use of toxic chemicals in industry, emission of various toxic gases from industries, only humans are responsible for this and only humans can renew [2]. According to a survey about 40% of death is due to water or air pollution. Many political actions and countries meeting are held to find the solution [3]. Concentration of CO2 is 340 ppm in 1980 and now its level increased to 409 ppm in august 2019 [4]. Which is vast increment also the hottest month since 1880 is July 2019, by these data we can imagine how the future will be? Among all these problems global warming, major source of which are CO2 emissions has been attracting attention from international community [5].

All over the world Buildings are constructed for residential, office and commercial purposes. Building sector is largest single contributor to global GHG emissions and energy consumption [6]. Construction sector accounts for a large part of the primary

energy use, which results in negative environmental impact, global warming is one of the major problems [7]. Most influencing gas for global warming is CO2 which contribute 80% out of four major gases (CO2, CH4, N2O, and chlorofluorocarbon). Worldwide, 30–40% of all primary energy is used for buildings and they are held responsible for 40–50% of greenhouse gas emissions [8]. During building construction, we divide the life cycle of a building in three phases manufacturing phase, use phase, demolition phase, in all three phase CO2 emission takes place, emission during raw material extraction, during use phase and demolition phase [9]. To reduce total carbon emission or, to make It sustainable construction industries are require to use some approach which include, use of passive or active features, use of solar energy to produce electricity, use of insulation, use of sustainable building materials, reuse or recycling of material [10].

In the next section of papers we have discussed about the literature review on Life cycle assessment, need of LCA in buildings, summary of work.

2. Literature review

2.1. Life cycle assessment (LCA)

Life cycle assessment is a procedure to recognize the environmental impact of a product through every step of its life cycle. LCA is a process in which overall material and energy flow of a system are calculated also the impact of wastes and emissions released during whole life cycle is analyzed and strategies to reduce the emissions are provided [11]. LCA involve raw material extraction, raw material processing, manufacturing, use and maintenance, disposal or recycling of a product [12]. Subsequently, a global and regional impact which mainly includes global warming, ozone depletion, eutrophication and acidification are calculated based on energy consumption, waste generation, etc [13].
There were many initiatives to standardize the methodology of LCA. The most recognized standards were the ones published by the International Standards Organization ISO [14]:

1. ISO 14040 Environmental management, LCA, Principles and framework.
2. ISO 14041 Environmental management, LCA, Goal definition and inventory analysis.
3. ISO 14042 Environmental management, LCA, Life-cycle impact assessment.
4. ISO 14043 Environmental management, LCA, Life-cycle interpretation.

ISO 14040 2006 defines four phases for any LCA which are; goal and scope definition, inventory analysis, impact assessment and interpretation.

1. Goal and scope definition – in this phase the intentional requisition and the area of the subject has to be defined. It consists what is the purpose of study [15].

2. Inventory Analysis – in this phase data is collected and application inputs and output are measured means inventory of flow. Inventory flows include inputs of water, energy, and raw materials, and releases to air, land, and water [16].

3. Impact assessment – analysis of inventory is completed in this phase [17].

4. Interpretation- purpose of this stage is to analyze results, reach conclusion, provide recommendation based on results [18].

Cradle-to-grave - Cradle-to-grave is the full Life Cycle Assessment from resource extraction ('cradle') to use phase and disposal phase ('grave').
Gate to gate- Gate-to-gate is a partial LCA looking at only one value-added process in the entire production chain

2.2. Need of LCA in buildings

Even though LCA has been usually used in the building sector since 1990, and is an important tool for assessing buildings it is not as much of established than in other industries [19]. LCA in the building sector has become a distinctive area within LCA practice. Reason behind this is not only the complexity of buildings but also some other reasons such as , first one is buildings have generally a life time of average 50 years or more so it's difficult to predict the whole life cycle of building from manufacturing phase to demolition phase [20]. Second, during its life span, the building may undergo many changes in its form and function, which can be as significant, or even more significant, than the original product [21]. Next is that most of the impact on environment occurring during its use phase. Several initiatives for harmonization and standardization of methodological developments and LCA practice in the building industry have taken place at a national level, but in general much scope remains for wider involvement and co-operation [22]

2.3. Life cycle energy Analysis of buildings

Life cycle energy analysis is an approach to measure total amount of energy utilized in whole life cycle of building [23]. All energy requirement associated with whole life cycle of a building starting from its manufacturing phase to demolition phase is called life cycle energy [24]. Life cycle energy includes embodied energy and operational energy. System boundary of life cycle energy analysis consist three phases (manufacturing phase, use phase, demolition phase) Fig 1. This analysis is performed to find out the energy utilization of each phase, so that high energy consuming phase is determined and suitable passive or active methods will be used to reduce the energy consumption [25].
Operational energy is the energy required in use phase of building which means it is the energy required for maintaining comfort condition in day-to-day life for space cooling and heating, air conditioning, ventilation, lighting, and running electrical equipment in the building [26].
Embodied energy is the Total energy used in the entire life cycle of a building, excluding the energy that is used for the operation of building [27]. Based on this approach, Embodied energy is the energy used in extraction of raw materials, transportation and refining of them, then use them for production, transportation of the products and manufacturing at the final site. Also, energy used in renovation and demolition of building is counted in in embodied energy [28].

3. LCA studies for buildings

3.1. Energy requirement in manufacturing phase

Material (cement, brick, iron rods etc.) required for construction of building are prepared by processing of impure raw materials, extraction and purification process of raw material require energy and produces waste. Cement is prepared by limestone, clay and other clay material which are heated in rotary kiln [29]. The output of rotary kiln is clinker, then clinker is mixed with gypsum to make the final product cement.in this process CO2 emission take place during DE carbonation of limestone and burning of fossil fuels, which result in global warming. The concentration of CO2 reached 411.77 ppm in July 2019(earthCO2 homepage) Emission of CO2 can be reduced by using a specific type of kiln (precalciner kiln) and using alternative fuels like biomass and waste material. Alternative fuels could have an immediate impact on carbon profile of cement industry [30]. One way to reduce the CO2 emission is to reduce the amount of clinker needed by cement and using other material in place of that such as coal ash, fly ash, risk husk etc. [31]

Many LCA study calculating the environmental impact of building material have been done in last twenty years. In 2001 a study in India focused on embodied energy in load bearing masonry buildings. A brickwork building and a soil–cement block building was compared, and the study showed that the total embodied energy can be reduced by 50% when energy efficient building materials are used [32]. Another case study performed on three flooring materials (linoleum, vinyl flooring and solid wood) in Sweden concluded that the solid wood flooring is most suitable alternative of the three materials studied, from the environmental point of view [33]. A case study on a three-bedroom house in Scotland in which in which 5 main construction material wood, aluminum, glass, concrete and ceramic tiles are considered, and detailed LCA is done on these materials. And this study concluded that embodied energy of concrete used is 65% of total embodied energy of the home, for timber and ceramic tiles it is 13% and 14% of total embodied energy [34]. A case study performed on Dutch building based on impact of reducing heat demand on embodied energy. This study concluded that the share of embodied energy use in total energy use increases from 12% in 2015 to 17% in the frozen efficiency and to 24% in the improved efficiency scenario, in 2050 [35].
Researchers compared timber and other material as a framing material in building. A case study done on a multistory building in Sweden based on timber verses concrete frame building, result of this study is that the energy requirement during production of material in concrete framed building were 60-80% more than timber framed building, this study is again reviewed by another researcher using input output based hybrid framework instead of previous one process analyzed, result found in this study is energy requirement and greenhouse gases are doubled

[36]. Even though some material used in very small quantity have large impact on environment, so every material should be considered in LCA analysis e.g. Lead

Embodied energy in BMCCs can be calculated by three method it—process analysis, input-output data calculation, and hybrid analysis [37]. However these studies are very important for progressing sustainable development, these studies are base for complete analysis of building life cycle, also provide an idea of material which are most suitable in building for better environmental condition, and low emission of GHG, overall the aim is reduce GHG emission to get a sustainable environment for better life [38].

Energy requirement in use phase

Second phase after manufacturing is use phase, it consist of energy used during day to day life in a building which include various cooling system , heaters generally in cold countries, also many food processing electrical equipment, in use phase the average life of building is defined to calculate the data, majorly as most of the researchers assume a 50 year life span, the energy used in this span is operating energy, many researcher work on this phase and majorly it is found that operating energy is about 80-90% of total energy and embodied energy is 10-15% of total energy 1% energy used in demolition phase [39]. Operating energy is highest because this is phase with longest period If operating energy is reduced it will have a major impact on total energy plus lower emission of GHG. A case study on environmental impact of three construction scenarios of an office building in Morocco is performed, appliances and lighting are considered, and result of this study is that the construction structure with insulated roof, external wall and ground is more suitable. Natural ventilation is best technique to reduce energy consumption also high glazing surface area and wide windows are most suitable in high heating demand regions. Reduction in energy consumption and GHG emission varies from 20-64% in this study [40].A case study is done on three houses in Spain to reduce CO2 emission, which provide some alternatives to reduce energy such as use of solar energy for heating water also in other heating process, use of photovoltaic solar energy in production of electric energy to fulfill the requirement of electricity in building [41].

By selecting low environmental impact building construction material in manufacturing phase, sustainable building can be produced, means building with low environmental impact, in use phase energy can be reduced by natural ventilation , use of solar energy for various purpose such as lighting, food processing and to produce electricity, use of proper insulation on floor , roof and wall. These are some methods given by various researchers to reduce environmental impact of a building [42].

Next and last phase is demolition phase in which either the wastes are recycled or disposed. It constitutes 1% of total energy. A case study is performed in china on short building lifespan up to 25-30 years, in this they concluded that if lifespans of building Is extended to 50 years, it will reduce 40% if its life cycle impact. Also, they found that environmental impact due to buildings in china (per area per year) is 2.3 times than that in UK [43].

Results of some other case studies

A case study performed in Singapore university found the methods to reduce embodied energy which include material reuse, recycling and use of low carbon building material, this university claimed to be a greenest campus of Asia [44]. A case study in Sweden compare three different type of framing materials, and result is that cross laminated timber (CLT) and modular buildings produce lowest production primary energy and higher biomass residue as compare to concrete buildings [45]. A case in Australia compared two different building i.e. timber and concrete, the GHG emission and energy consumption in timber building construction are less as compare to concrete buildings [46]. A china case study concluded that buildings with a reinforced concrete block masonry structure produce fewer emissions as compare to a reinforced concrete structure or brick concrete structure [47]. A Sweden case study on effect of thermal mass on space heating energy use in case of concrete or wood framed building, this study concluded that effect of thermal mass on space heating energy is small or wood framed building are more effective than concrete frame in term of reducing primary energy [48].wood framed buildings emit less CO_2 then concrete framed buildings [49]. A case study performed in Hong Kong to find the GHG emissions, the researchers concluded that GHG emissions will be reduced if we use recycled building material, especially reinforced steel [50].

A case study performed in Andhra Pradesh India, life cycle energy analysis of residential buildings in different conditions such as varying thickness of insulation on wall and roof, in five different climate zone of India. Study results that only alternative wall material without insulation can reduce life cycle energy up to 1.5-5%. Building under Warm and humid climate and proper insulation saves maximum life cycle energy as compare to other models, also there is limit of insulation [51]. Table 1 shows the review on case studies in different building sectors and Table 2 shows the impact categories for environmental impacts.

Table 1. Review on case studies in different building sectors

Author	Functional unit	Building Typology or material studied	Scope
[52]	MJ Whole house	LCA of five main construction materials i.e. wood, aluminum, glass, concrete and ceramic tiles	To evaluate the embodied energy of construction materials and associated environmental impacts
[53]	kWh/m2	22 academic building	To evaluate embodied energy Operational energy
[54]	kgCO2/m2	Building with reinforced concrete block masonry structure and reinforced concrete structure or block concrete structure	To evaluate the carbon emission in typical buildings
[55]	m2 (ft2)	Twelve building types, representing a range of building sizes and energy intensities, are evaluated over four study period lengths for three alternative building designs	determine the life-cycle cost-effectiveness and carbon emissions
[56]	Kwh/m2	Residential building under different envelopes and climates in Indian context	Evaluate life cycle energy of a residential building
[57]	MJ/m2	Residential buildings in the Dutch	the effect of reducing heat demand on the embodied energy use in Dutch residential buildings
[58]	(total/year, m2)	Wood flooring material in Swedish situation	environmental impact of three flooring materials solid wood, Linoleum, vinyl flooring
[59]	KgCO2/kg Embodied energy (MJ/kg)	three terraced houses built in Spain	To reduce the amount of co2 emission by choosing low environmental impact material in construction phase
[60]	MJ/kg)	wooden and a concrete framed building in Sweden	estimates of energy requirements and. greenhouse gas emissions
[61]	Pt/m2 /yr	. Six buildings in Hebei Province in China were selected as case studies to conduct life cycle environmental (LCE) impact assessment	the environmental impacts caused by buildings (per area per year) in China effect of increasing building lifespan
[62]	Kgco2/m2.year Kwh/m2.year	three construction scenarios in the six Moroccan climatic zones,	To reduce energy demand and GHG emission
[63]	kg-CO2-eq/m2	timber or concrete buildings	To evaluate GHG emission in case of timber or concrete building constructions
[64]	kWh/m2	multi storey residential building with different building systems	Primary energy use for different framing materials for multi storey residential building
[65]	Kgco2/m2	Wood frame versus concrete frame buildings	To evaluate carbon dioxide emission in wood framed and concrete framed buildings
[66]	MJ/m2 kg CO2-eq./m2	Australian commercial building	to evaluate energy consumption and greenhouse-gas emissions

[67]	(MJ/kg)	Expanded Polystyrene (EPS) Polystyrene Particles (pp) polyurethane (PU), mineral wool (MW), glass wool (GW), foam glass (FG) and phenol formaldehyde (PF)	Comparison of eight building insulating material in term of total primary energy produced and environmental emissions
[68]	5 MJ/kg	eight story residential building in Madrid	Impact of using different type of roofing on energy usage and total emissions
[69]	(kg CO2-e/kg)	building construction in Hong Kong	To evaluate GHG emission during building construction
[70]	Kgco2/Year	Wood and steel reinforced building in japan	To evaluate environmental impact of wood and steel reinforced buildings
Abbreviations: LCA, life cycle assessment; LCEA, life cycle energy assessment			

Table 2. Commonly used environmental impact categories

Impact category	**Abbreviation**	**LCI data classification**	**Characterization factor**	**Category unit**
Global warming	GW	(CO_2) (CH_3) (N_2O) (CFC11) (HFC134a) (CF_4)	Global warming potential	kg CO_2-eq.
Acidification	A	(So_2) (NO_x) (HCL) (HNO_3) (H_2SO_4)	Acidification potential	Kg SO_2-eq
Ozone depletion	OD	(HCFCs) (CFCs)	Ozone depletion potential	Kg CFC 11-eq
Eutrophication	E	(PO_4) (NO) (NO_2) (NH_4)	Eutrophication potential	kg PO_4-eq
Photochemical ozone creation	POD	NOX C_2H_4	Photochemical ozone creation potential	kg NO_x eq

4. Summary and Conclusion

LCA has been used for evaluation of environmental impact caused by a product life cycle, in this paper we reviewed various case studies performed on building sector in different countries, these studies have different system boundary, different climate condition, different building type, different local regulations, and different process used for extraction of raw materials. Due to these specific properties it's difficult to compare two case studies. A comparison can be seen in table, in which most of the case studies reviewed in this paper are listed, the important phases of LCA such as scope, life span, functional unit, building location, building typology are compared. Mostly the case studies listed here are performed in cold countries, As we see in the cold countries the fuel used for operation phase is mostly oil or gases and in most non cold/developing countries like India, Thailand, Malaysia the fossil fuels are used for electricity production such as for space cooling etc. that produce more pollution as compare to gases, also this lead to significant difference in life cycle energy of developed and developing countries. Also, most of the studies are performed in developed countries there is no case from Africa, lot of cases from Europe, Australia, Sweden and North America were available.

The analysis of cases showed in this paper that total life cycle energy is equal to sum of operating energy and embodied energy. Operating energy range from 80-90% of total life cycle energy and embodied energy id 10-20% of life cycle energy, so we can say that if we reduce the operating energy this will have a great impact on life cycle energy, operating energy can be reduced by using passive and active features in building although it may lead to a little increment in embodied energy and sometime it Is counterproductive so excessive use of passive or active features is avoided. Wood framed building is sustainable then steel framed green roofing is better to save energy consumption as compare to white roofing , use of insulation on wall provide less energy consumption, use of solar energy to produce electricity, as a solar heater, solar cooker saves a good amount of energy. Timber is better than concrete in building construction.

Despite the limitation presented in this paper LCA is a powerful tool to analysis the environmental impact, help to achieve the goal of sustainable development

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