International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 2, Mar-Apr 2024
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Life Cycle Assessment of Existing Structures and Retrofitting Tools

Mrunal Amle, Dr. Smita Patil
Civil Department, Datta Meghe College of Engineering, Airoli -Navi Mumbai
Email: Mrunal.amle@viit.ac.in
Civil Department, Datta Meghe College of Engineering, Airoli -Navi Mumbai
Email:smita.patil@dmce.ac.in

--************************----------------------------------

Abstract:
This paper presents the results of a study of the environmental performance of two case study houses, one refurbished and one newly constructed. An analysis of the assembly, use, and end-of-life phases during 50 and 80-year life cycles was used to determine the environmental performance of retrofits and new construction. The environmental impact of each stage is modeled using raw information, LCA software and LCA database. In both case studies, the operational phase was found to be the largest source of environmental damage, followed by the assembly phase and the end-of-life phase. As the lifetime increases, the relative importance of the assembly and end-of-life phases decreases. It was found that the reconstructed dwellings studied outperformed new construction during the assembly and operational phases, while new construction performed better at the end-of-life phase.

Keywords **—Energy conservation; Rehabilitation, reclamation & renovation; Sustainability.**

--************************----------------------------------

I. INTRODUCTION

In recent years, there has been a growing emphasis on sustainable development, driven by global leaders' efforts to reduce anthropogenic environmental impacts, such as climate change. The UK Government, through the Climate Change Act (2008), has committed to legally binding targets of reducing greenhouse gas emissions by 34% by 2020 and by 80% by 2050, based on 1990 levels. To achieve these ambitious goals, reductions in CO2 emissions from sectors like industry, transport, and construction have been identified and presented in various government strategies. The housing sector is a significant contributor, accounting for over a quarter of total annual UK CO2 emissions (Energy Saving Trust, 2010). The Energy Performance of Buildings Directive (2010) aims to improve the energy efficiency of buildings, requiring public and new buildings to be nearly zero energy by 2018 and 2020, respectively, with certification based on life cycle analyses. The UK also aims for all new homes to be zero-carbon by 2016, with the recently updated definition focusing on mitigating emissions from regulated energy use. Initiatives such as the installation of smart meters in all homes by 2020 aim to enable homeowners to monitor energy consumption. However, these initiatives alone are insufficient to achieve the required 80% reduction in CO2 emissions, as a significant portion of homes in 2050 will have been built before the implementation of these strategies (Energy Saving Trust, 2010; Department of Energy & Climate Change, 2011). The existing housing stock is aging and underperforming, with average energy efficiency ratings in Northern Ireland and England falling below the desired level. To reach the 80% reduction target by 2050, the majority of housing will need to achieve energy efficiency ratings above a 'B,' equivalent to a minimum SAP rating of 81. Various studies, conducted by organizations like BRE and the Environment Agency, have explored different approaches to improving the housing stock, including increased rates of demolition and new construction or high-quality retrofitting of existing homes. These studies, summarized by the Environmental Change Institute (2006) and Power (2008), discuss the merits and weaknesses of these approaches. However, they lack a systematic assessment of the environmental performance and potential energy savings associated with each solution. To address this gap, a research project focused on conducting a comprehensive analysis of the environmental performance and potential energy savings. This paper provides a summary of the research findings to inform the development of a well-informed and appropriate strategy to achieve the 80% reduction in CO2 emissions by 2050. The paper begins with an introduction to the life cycle assessment (LCA) framework, a widely used methodology for evaluating environmental impacts and sustainability, particularly within the EU. The two case studies that formed the basis of the analysis are then described, including the life cycle stages of assembly, operation, and end-of-life disposal, which are discussed and analyzed. The results are compared to draw conclusions regarding the environmental impact and potential energy savings by 2050.

II. Scope of Work

The study focuses on the assessment of existing structures, including buildings and infrastructure, and their retrofitting possibilities. The analysis will primarily consider the environmental impacts throughout the life cycle stages of these structures, including raw material extraction, construction, operation, and end-of-life. The research will encompass a range of retrofitting tools and strategies, such as energy-efficient systems, renewable energy integration, and material substitution. However, it is important to note that economic and social aspects of retrofitting will be considered only to the extent that they directly influence the environmental performance. The study acknowledges that retrofitting may have varying effectiveness depending on the specific context and characteristics of the structures being assessed. Overall, this research aims to contribute to the body of knowledge on life cycle assessment of existing structures and the role of retrofitting tools in achieving environmental sustainability in the built environment

III. Background of Life Cycle Assessment

A. Life cycle assessment (LCA)

The LCA is a methodology used to assess the environmental impacts of a product throughout its entire life cycle, from raw material extraction to disposal. While LCA was initially developed for simpler products, applying it to buildings is a complex task due to their long lifespan and multifunctional nature. This section provides an overview of the specific aspects involved in conducting a life cycle analysis of buildings and explains the methodological choices made in developing the LCA model.

B. Structural System of Buildings

In order to achieve harmony between environmental and structural criteria in building design, the proposed approach aims to optimize resource usage and minimize environmental impacts while meeting necessary safety requirements. The structural system of a building, by mass, typically outweighs other components of the building. Structural engineers play a key role in the design process, as they have the ability to choose the materials and structural systems used.

C. Life Cycle Assessment Background Life Cycle Assessment.

(LCA) is a methodology used to quantitatively assess the resource consumption, emissions, and environmental impacts of a product. It considers the entire life cycle of a product, including resource extraction, manufacturing processes, use, and eventual disposal. The ISO 14040 series provides international standardization for LCA, but it lacked technical detail, resulting in a wide range of choices for LCA practitioners. To supplement the ISO standards, best practices were developed by organizations such as the Society of Environmental Toxicology and Chemistry. Additionally, the International Reference Life Cycle Data System is currently being developed to establish a robust, consistent, and prescriptive framework with enhanced quality assurance (EC JRC, 2010).

IV. REVIEW OF LITERATURE

In their case study, Lee et al. [7] created an LCA for the building's planning stage. The program's aim, scope, and inventory analysis phases are designed to support the sustainable building LCA program. The outcomes included impact evaluation, improvement analysis, and purpose analysis.

In contrast, Ximenes and Grant [1] examined the benefits of wood vs other building materials in Australia and discovered that replacing the original floor and subfloor materials with wood resulted in a reduction in greenhouse gas emissions.

Wu et al. [2] employed a "green tax-based weighting" approach to undertake a life cycle assessment (LCA) of several concrete and steel types that are commonly used in the Chinese construction industry.

In the meantime, Asdrubali [3] looked into the effects on the environment of switching to sustainable substitutes for traditional thermal and sound insulation materials. Because of this material substitution, their life-cycle assessment (LCA) demonstrated considerable advantages with respect to the environmental impact of the building's various life-cycle phases.

In 1996, Adalberth et al. [4] conducted a life cycle assessment (LCA) on four apartment complexes erected in Sweden. The purpose of the study was to examine the four buildings' various life-cycle phases and determine which had the biggest influence on the environment. The research took into account the following stages: production, transportation, erection, use, renovation, demolition, and removal. The use phase, the scientists found, accounted for roughly 70–90% of the buildings' overall environmental impact.

An LCA was carried out on an RC office building in Thailand by Kofoworola and Gheewala [5]. They discovered that the materials with the most environmental effects were steel and concrete, which accounted for 52% of the energy used during the course of the entire life cycle.

An LCA was carried out by Blengini [6] on a structure that was destroyed by controlled explosion. This study examined both the demolition phase and its potential for recycling. According to the research, recycling construction debris is not profitable from an economic standpoint, but it has minimal environmental and energy impact.

V. METHODOLOGY

While the methodology of life cycle assessment (LCA) is well-defined, journal articles are not obligated to adhere to the requirements of ISO 14040. As a result, the literature often lacks comparability due to varying assumptions and methodological choices. After examining 20 journal articles' compliance with ISO 14041, Optis & Wild (2010) came to the conclusion that the majority of them lacked sufficient information, which limited their applicability to others and slowed the development of LCA. In this paper, efforts were made to reduce uncertainty by adhering to international standards and guidelines such as ISO 14040, Guinée et al. (2002), and ILCD (2010), with any deviations from these standards being explicitly noted.

A. System Boundary and Assumptions

The European Standard BS EN 15643-1:2010, which focuses on the sustainability assessment of buildings, provides a framework for evaluating the environmental, economic, and social performance of buildings using a life cycle approach. This standard recommends dividing the building life cycle into three stages: the assembly stage (before use), the operational stage (during use), and the end-of-life stage. In this study, the assembly stage refers to the activities related to raw materials, transportation, manufacturing processes, and construction processes. The operational stage includes 17 maintenance, material replacement rates, and operational energy consumption, including heating, lighting, appliances, and hot water heating. The end-of-life stage encompasses the demolition/deconstruction process and the possibilities of material reuse, recycling, or refusal. It illustrates the system boundaries used in the modeling process. Items outside the thick broken line were excluded from the modeling, while items inside the line were included. Although some of the excluded items, such as operational water use, operational waste production, waste transport, and reprocessing of recyclable materials, could have environmental significance, primary data for these aspects could not be obtained for both case studies. Therefore, these items were not included in the modeling process. Including them would have required numerous assumptions, which would have compromised any meaningful comparison between the two buildings.

B. Life cycle inventory and data assumptions

Assembly materials Bills of quantities and design drawings for both the retrofit and newly constructed homes were acquired for the assembling materials. To assess the life cycle inventory, the SimaPro 7.2 LCA software application was utilized. Primary data from the obtained documents was combined with secondary data sourced from the Ecoinvent database, which contains a comprehensive collection of products and services from Swiss and Western European manufacturers and service providers (more information available at www.ecoinvent.ch). The Ecoinvent database includes information on construction materials, processes, raw material usage, extraction, production, transportation, and associated environmental impacts such as air and water emissions. Approximately 30 processes from the Ecoinvent database were selected and utilized to model the life cycle inventory of the retrofit and new build case studies. It should be noted that while the Ecoinvent database may not be a perfect fit for the UK, as it predominantly represents mid-European processes, the lack of comprehensive and transparent life cycle assessment details for UK processes necessitated its use. However, an exception was made for.

The operational consumption: The operational consumption of both the retrofit and new build houses, including space heating, domestic hot water (DHW), and electricity consumption, is presented . According to thorough calculations based on the Standard Assessment Procedure (SAP), estimated energy consumption and electricity production from the PV roof panel were available for the retrofit case.As for the new build, the operational consumption was determined using the Dwelling Energy Assessment Procedure (DEAP), similar to the UK SAP. The new build achieved a B2 rating, equivalent to a consumption of 125 kWh/m2/year. However, a detailed breakdown of energy consumption was not available. To estimate the split between electricity and space heating/DHW, average Irish household consumption patterns were considered, with a ratio of 78% for electricity and 22% for space heating and DHW, as suggested by Sustainable Energy Ireland(2008).

The retrofit house incorporates a photovoltaic (PV) system that offsets a portion of its electricity demand. It generates approximately 15 kWh/m2/year of surplus electricity, which is fed back into the grid. Although this renewable energy source provides a net environmental benefit, it falls outside the system boundary of the project and is not considered in the analysis.

B. Life cycle impact assesment

In the life cycle impact assessment (LCIA), the ReCiPe Midpoint and Endpoint methods were employed, as mentioned earlier. The hierarchist perspective was adopted for the ReCiPe Endpoint method, with an average weighting applied. By utilizing these average weighting factors, the endpoint damage categories were combined to generate a single score representing The overall environmental impact of each stage on a point scale.

VI. RESULTS

The life cycle assessment (LCA) results, evaluating the environmental performance of the retrofit and new build houses, were analyzed using the ReCiPe method at both midpoint and endpoint levels. In the analysis, the New Build house is denoted as NB, while the Retrofit house is denoted as R.

Additionally, the environmental performance of both houses during the assembly and operational stages was assessed using the ReCiPe Endpoint method, which provides easily interpretable results. Furthermore, a comparison was made between the embodied and operational energies of the new build and retrofit houses in relation to the operational energy of the pre-retrofit house.

VII. CONCLUSIONS

Comparison of the new build house with the retrofitted house. The environmental goods of the functional stage of all case studies modelled far overbalanced either the assembly or end of life stage. As similar, it's felt that reducing the functional stage energy demand in so far as possible is a worthwhile bid. The results reported in this paper show the perceptivity of the build house to the optimal position of refurbishment. Overall, the results would favor the relinquishment of a high-quality retrofitting scheme to remediate being stock issues. It should be noted that the build accepted is of a veritably high quality and is aprotrusive and laborious process. The play of the being embodied energy in the build structure allows for the specification of high grades of sequestration and other energy saving bias, similar as the photovoltaic panels whilst still achieving a lower assembly stage impact than the new figure. It must also be noted that the optimal functional position of the new figure house mustn't be neglected. The new figure house, though achieving a fairly good environmental performance standing, could potentially achieve an advanced performance standing through a more focused low energy and embodied energy design. The new figure house may surpass the build if the energy consumption, which is 78 kWh/ m2/time, were changed without significantly changing the environmental effects of the assembly or end-of-life stages. Overall, these are only two case studies and farther case studies on new figure and build systems should be accepted to understand further the influence of new accoutrements and technologies on the overall energy and carbon performance of new and living casing stock. Benefits of retrofitting the case studies reviewed in this paper reveals that retrofitting will vastly reduce the energy demand of a house over its life time. The energy' pay- reverse' period for retrofitting was shown to be around 4 times for the exemplifications considered in this exploration. Given that the current casing stock is underperforming, immediate action would allow for optimal savings and go towards the required carbon reductions by 2050. Significance of functional energy reductions Given the long-life spans of houses in the UK the functional energy conditions accumulate annually. As the current casing stock is presently underperforming with poor SAP conditions the effect of energy inefficiency is replicated across the UK with large energy losses rephrasing to dispensable environmental impacts. perfecting the condition of the casing affords a better quality of life for the inhabitants eradicating issues similar as energy poverty whilst also fulfilling the conditions of the Climate Change Act. significance of decarbonizing the grid The energy generation blend of the UK as modelled is 35 heavily fossil energy dependent. If the energy blend in the UK had larger renewable or nuclear ingredients also the associated environmental impacts of the functional stage of both case studies would be significantly different with the eventuality for the assembly and end of life stage to increase in relative significance. The validity of the results presented in this paper would be affected by such a change to the energy blend with lesser focus needed for the increased environmental impacts of the assembly and end of life stages.

ACKNOWLEDGMENT

I take this opportunity to express my deep sense of gratitude to my dear guid Dr. Smita Patil for her guidance and kind encouragement.

I would like to express my endless gratitude to my dear mother Vaishali Amle who has been an aspirational leader, warrior and gave me everything she could to enable me to pursue post- graduation.

REFERENCES

[1] Ximenes, F.A.; Grant, T. Quantifying the greenhouse benefits of the use of wood products in two popular house designs in Sydney, Australia. Int. J. Life Cycle Assess. 2013, 18, 891–908. [Google Scholar] [CrossRef]

[2] Wu, X.; Zhang, Z.; Chen, Y. Study of the environmental impacts based on the green tax—Applied to several types of building materials. Build. Environ. 2005, 2, 227–237. [Google Scholar] [CrossRef]

[3] Asdrubali, F. The role of life cycle assessment (LCA) in the design of sustainable buildings: Thermal and sound insulating materials. In Proceedings of the Euronoise 2009, Edinburgh, UK, 26–28 October 2009.

[4] Adalberth, K.; Almgren, A.; Petersen, E.H. Life cycle assessment of four multi-family buildings. Int. J. Low Energy Sustain. Build. 2001, 2, 1–21. [Google Scholar]

[5] Kofoworola, O.F.; Gheewala, S.H. Environmental life cycle assessment of a commercial office building in Thailand. Int. J. Life Cycle Assess. 2008, 6, 498–511. [Google Scholar] [CrossRef]

[6] Blengini, G.A. Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy. Build. Environ. 2009, 2, 319–330. [Google Scholar] [CrossRef]

[7] Lee, K., Tae, S., & Shin, S. (2009). Development of a life cycle assessment program for building (SUSB-LCA) in South Korea. Renewable and Sustainable Energy Reviews, 13(8), 1994-2002

[8] De Gracia, A., Rincón L., Castell, A., Jiménez, M., Boer, D., Medrano, M. & Cabeza, L.F. (2010) Life Cycle Assessment of the Inclusion of Phase Change Materials (PCM) in Experimental Buildings. Energy & Buildings 42, 1517-1523.

