Life cycle energy (LCE) on project life cycle (PLC): a literature review

S A K A Uda1,2, M A Wibowo 3 and J U D Hatmoko 3

1PhD Student, Civil Engineering Department, Faculty of Engineering, Diponegoro University, Jl. Prof. Soedarto, Tembalang, Semarang, Indonesia.
2Civil Engineering Department, Faculty of Engineering, Palangka Raya University, Jl. Yos Sudarso, Palangka Raya, Indonesia.
3Civil Engineering Department, Faculty of Engineering, Diponegoro University, Jl. Prof. Soedarto, Tembalang, Semarang, Indonesia
4Corresponding author: subrataaditama@student.undip.ac.id; subrataaditama@jts.upr.ac.id

Abstract. Construction activities gradually consume energy during their life cycle, namely material extrusion, transportation, production, assembly line, installation, demolition and disposal. This research aimed to identify research about energy such as embodied and operational energy. Operational energy is energy that is used during building life cycle to decrease global warming effect. This research used a qualitative method to identify and review some literature related to decreased energy construction. This study showed that 98% of researchers focus on energy efficiency in the design, construction and operational stages. Only 2% were investigating at the initiation stage. Some recommendations can be drawn suggesting that energy reduction is possible by applying optimization strategy to all project life cycle (PLC). Initiation and design phase are indirect energy optimization phase through policies and design buildings, which significantly impact energy decrease for further phases. In contrast, construction and operations phase is direct energy optimization phase through energy efficiency on each activity.

1. Introduction
Construction sector consumes 40% of energy and 16% of water per year globally [1][2]. Energy release during building operation phase in space conditioning, water heating, lighting, other tools of building operations and operational activities is called operational energy. Total energy of building, total cycle, contains operational and embodied energy [1][3]. Unlike embodied energy (EE), operational energy (OE) has a relatively higher proportion of a building's total life cycle energy [3]. Embodied energy consumption depends on the building's function, location, material utilization and working life assumption and supplied energy. This proportion tends to increase as a transitional building, from conventional to passive, low energy and almost zero energy building [4]. Environmentally friendly constructions are duty for every nation that must be undertaken. Most countries' governments are interested in preventing or missing out the activities contributing to climate change, global warming, and negative effects on the environment. Hence, the decrease in carbon emission has been an ultimate strategy for the environment around the world.
2. Life cycle project

According to Oberlender [5], 4 phases are affecting project life cycle (Figure 1). Project initiation is a phase of initiation or an initial concept of a project. In this phase, the owner has to choose the process of design and construction. There will be various choices of process and each has advantages and disadvantages. The design phase is the most important phase that needs so much time and personnel due to project types. Consultants interpret the concept as the owner desires into a sketch and suggest building components and materials specification. Construction phase or execution is mostly done together with the control phase, where project is being done, starting from purchasing materials, tools, workers and construction process, referring to each design phase output. The phase of closing or project completion is the last phase of a project. This phase contains a handover and time of building care. The handover is commonly divided into two steps: the first step is the construction work which is completed and ready to use, while another step is after the time of building care ends [5].

![Figure 1. Project life cycle](image)

3. Life cycle energy

For further sustainable building achievement in construction sector and minimizing energy consumption, a methodology called Life Cycle Energy Analysis (LCEA) is needed. This methodology is practically similar to simplified LCA (Life Cycle Analysis). The difference is that in LCEA, the only parameter used is energy. According to Dixit et al [6], building, materials and their components consume almost 40% of global energy every day in their life cycle phase, such as production and building materials' procurement, construction, operational and demolition.

3.1. Embodied energy

Embodied energy is energy consumed by all processes related to building production, starting from mine workings and natural resources processing until manufacturing, transportation and delivery. Transportation is the main element of materialized energy in construction material [7][8][9]. Building is the biggest user of materials containing high energy. Embodied energy is in accordance with production of building materials and their components, including mine works, material and tools' production. Each building is a complex combination of numerous processed materials; yet each contributes to total energy. The high level of energy implies a higher level of pollution at the end of production. Concrete, aluminum and steel are some materials that have the highest energy and take part in the high level of CO₂ emission [8].

3.2. Operational energy

Operational energy needed in building includes total energy used to maintain the environment inside the building. Operational energy often relates to stable maintenance of internal environment; energy usage target varies depending on building's needs, function and surrounding environment. Some researchers state that operational energy is the biggest contributor to total energy consumption in building’s life cycle. It is about 80% of total energy consumption in building life cycle [9]. Some researchers are recently concerned about decreasing operational energy, while embodied energy and demolition energy are less important. Some research asserts that the demolition stage's energy only represents 1% of building life cycle total energy [10].
4. Methodology
This research used a qualitative method approach by identifying and reviewing research journals related to embodied energy and operational energy on project’s construction. This research aimed to analyze previous researchers’ point of view about embodied energy, operational energy and classified research's content toward life cycle project. This research used secondary data, literature review taken from international journals through purposive sampling. The researcher reduced data and focused only topic of embodied energy and operational energy in construction sector. One hundred journals were taken as samples and analyzed on parameters and methodology within 10 years (2010 to 2019).

5. Analysis and discussion
Research data came from international journals and proceedings that were indexed Scopus, such as the journal of Energy and Buildings, the journal of Energy, the journal of Construction and Building Material, the journal of Building and Environment and the journal of Cleaner Production.

A significant increase in research about embodied energy and operational energy during 10 years and 2017 was counted as the most research publications. In early 2010, there were only 4 publications (Figure 2). England contributed to the most publications followed by USA and India. The researcher from Baht University (UK) was one of data inventory creators (ICE) about embodied energy values on some materials used in construction. This data inventory was mostly used as a reference to count the value of embodied energy on certain buildings.

Figure 3 shows research about embodied energy with higher percentage, which was 51%, while operational energy was 47% and the rest was combination of both (2%). Several researches about EE showed that researchers could optimize and decrease EE's number on construction process. Nevertheless, it is inversely proportional to the biggest volume that consumes energy, such as research in Northern and Central Europe countries [11], conventional buildings, total embodied energy consumed in materials are about 10% - 20%, while 80% - 90% are operational energy and less than 1% are EE on maintenance period and end of building’s life.

Figure 9 shows that research about energy was mostly carried out at construction stage as much as 53%, then design stage was 31% and operational stage was 14%. Research at initiation stage was carried out at least 2%. Research conducted from design, construction and operational stages reached up to...
According to construction stage activities, below are recommendations to minimize the role of energy embodied energy and operation energy.

5.1. Initiation Phase
Public policymakers must be able to establish clear and useful criteria to evaluate and encourage energy optimization. Mandley et al [12] provided useful information for United Kingdom (UK) and European Union (EU) policymakers regarding policies and rules that prioritize building design, construction and manufacturing processes throughout building sector supply chain. It is through creating a room to reduce resources consumption in sectors outside the operational phase, which can provide economic benefits and produce more competitive and sustainable sectors. Political support is needed to facilitate low carbon emissions.

**Figure 3.** Percentage of energy studies

**Figure 4.** Embodies energy and operational energy based on project life cycle (PLC)
Policymakers shall pay attention to the programming process and encourage creative solutions such as reusing old buildings concerning their specific nature. The scenario focuses on two complementary approaches for further development as protocols, namely reprogramming and designing strategies. The first considers compatibility between old buildings and the possibility of new uses and the program's ability to adapt with diverse support. The latter supports complementing rather than modifying existing structures and adjusting interventions to requirements in durability and reversibility [13]. Implementation of effective policy in the form of Energy Performance Development Guidelines can significantly reduce the operational energy while the energy contained can increase to nearly 40% of operational energy in the future [14]. It is important to formulate policies regarding ways to reduce energy in high-rise office buildings during the design phase, towards sustainable holistic energy conservation of tall buildings [15].

5.2. Design phase
Designers and technicians should consider EE together with OE as an indicator to minimize the extraction and exploitation of non-renewable materials. The results showed the importance of estimating EE in early stages of design process, in addition to potential long-term impacts and consequences of the use of different construction materials [16]. Design process must take into account the amount of energy embodied in a structure. The use of design software that considers important aspects of building, including cost, structural zone, building capability, thermal mass, service distribution, and building flexibility, will help make decisions during design phase and usually save costs [17].

5.3. Construction phase
Energy usage to manufacture and transport materials must be the primary concern in reducing embodied energy. While transportation energy requires special handling for office buildings in Hong Kong, construction industry will greatly decrease embodied energy [15]. Energy distribution at residential construction sites shall not exceed 4%. However, in reality, there is high energy consumption during construction and installation process (including usage of diesel, electricity and fuel) besides those from power tools, heavy equipment and lighting, and transportation at construction sites [18]. Choosing sustainable materials and creating low energy design during the construction stage can reduce operational energy and project waste, reducing the impact on the surrounding environment [19].

5.4. Operational phase
Ajayi et al [20] confirmed that embodied energy in building changes as different construction materials and energy use patterns applied. It implies the need for policy measures on building life evaluation methodology by paying attention to the impacts of operational toward the building. Besides being more energy-efficient during operational phase, there is an urgent need to reduce the impact of embodied energy by adopting renewable energy resources. The use of renewable energy sources for electricity production can reduce embodied energy by 57% and 83% during building operations [21]. Lolli et al [22] stated that parametric analysis tools can lead to different design conclusions, depend on the environment size or the way a building designed. Parametric analysis can identify operational energy use, realize CO₂ emission, and use energy embodied optimally through testing tools with a decent conceptual model. Parametric analysis tools can find solutions for operational energy use, embodied CO₂ emissions and energy; besides, it can be used to conduct comparative pre-assessment of various design solutions.

Based on these recommendations, the energy efficiency process, both embodied energy and energy operations, should be carried out since the initiation stage. The role of stakeholders as owners will significantly impact the design, construction, and operational processes. Commitment to implementing zero energy building instructed by stakeholders will reduce energy sustainably during construction activities. Hence, research on strategies and policies to reduce energy before the design process is very important to produce low energy consumption and environmentally friendly buildings.
6. Conclusion

This study showed that 98% of researchers focus on energy efficiency in the design, construction and operational stages. Only 2% were investigating at the initiation stage. However, when referring to the stages of project life cycle, the initiation stage is initial stage that determines the amount of energy consumed during construction activities. The implementation of energy optimization strategy effectively decreases the amount of energy in life cycle project of construction. The initiation phase has a major impact on the next stage. During initiation phase, stakeholders’ commitment to minimizing buildings impact on the environment will be tested, especially those that influence embodied energy and operational energy. Stakeholder commitment shall be realized in the form of contract documents that bind consultant planners, supervisors, contractors and building managers. Incorporating energy optimization at each stage of construction have a saving effect on building operations, especially electrical energy during building life, from operational energy consumes 80 - 90% of total energy.

Energy minimization strategy can be carried out by applying strict rules on energy usage in each construction phase, without exception during the design stage. For example, the building is redesigned to have natural lighting and maximum air circulation to minimize air conditioners usage, in addition to the selection of low-energy materials in its production process, maximizing the use of natural materials and implementing the waste management plan. Besides, optimizing the distribution of materials and construction equipment directly impacts reducing the use of fossil fuels.

Energy optimization can be performed by creating a model and pattern based on existing indicators, then develop standards and operational evaluations of construction activities for stakeholders, consultants and contractors as the executor in the scope of project life cycle (PLC).

References
[1] Abanda F H and Byers L 2016 Journal of Energy 97 517-27.
[2] Carbonaroa C, Casconeby Y, Fantuccib S, Serrab V, Perinob M and Duttoc M 2015 Energy Procedia 78 3210–15.
[3] Crowther P 1999 Energy Ecology Architecture PLEA ’99 1 95-100.
[4] Ramesh T, Prakash R and Shukla KK 2010 Energy and Buildings 42 1592–1600.
[5] Oberlender Garold D 2000 Project Management For Engineering And Construction Second Edition (American: The McGraw-Hill Companies) p. 41 – 341.
[6] Dixit M K, Solis J L F, Lavy S and Clup C H 2012 Journal of Renewable and Sustainable Energy Review 16 730– 3743.
[7] Cleveland C J and Morris C 2009 The Dictionary of Energy, Expanded Edition (American: Elsevier) p 162.
Tingley D D and Davison B 2011 Energy 164 (4) 195–204. Sattary A and Thorpe D 2012 Association of Researchers in Construction Management 1 1401-11.
[8] Larriba A B and Wolf O 2010 Analysis and Evaluation of 3 Rd Draft Criteria for Buildings and Next Steps (Institute for Prospective Technological Studies, JRC Europe Commission) p 5-20.
[9] Ramesh T, Prakash R and Shukla KK 2013 Open Journal of Energy Efficiency 2 34-41
[10] Aye L., Ngo T, Crawford R H, Gammampila R and Mendis P 2012 Energy and Buildings 47 159-68.
[11] Kotaji S, Schuurmans A and Edwards S 2003 Society of Environmental Toxicology and Chemistry Press 19 3–20.
[12] Mandley S, R. Harmsen R and Worrell E 2015Energy and Buildings 86 841–51.
[13] Fuertes P. 2017 Energy Procedia 115 431 – 39.
[14] Abanda F H, Oti A H and Tah J H M. 2017 Journal of Building Engineering 12 288 – 305
[15] Wang J, Yu C and Pan W 2018 *Energy and Buildings* **167** 152–64.
[16] Giordano R, Giovanardi M, Guglielmo G and Micono C 2017 *Energy Procedia* **134** 224-33.
[17] Goggins J, Keane T and Kelly A 2010 *Energy and Buildings* **42** 735–44.
[18] Chang Y, Ries R J and Wang Y 2011 *Energy Policy* **39** 6321–30.
Hong T, Ji C Y, Jang M H and Park H S 2014 *Journal of Management in Engineering* **30** 226-35.
[19] Pöyry A, Säynäjokia A, Heinonen J, Junnonen J M and Junnila S 2015 *Procedia Economics and Finance* **21** 355–65.
[20] Ajayi S O, Oyedele L O and Ilori O M 2019 *Journal of Building Engineering* **23** 324 – 333
[21] Chastas P, Theodosiou T, Bikas D and Kontoleon K 2017 *Procedia Environmental Sciences* **38** 554–61.
[22] Lollia N, Fufab S M and Inmanb M 2017 *Energy Procedia* **111**(C) 21-30.