Influencing Factors of Energy Consumption in Construction: Contractor's Perspectives

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Abstract. The construction industry is one of the main contributors to global warming. The long, fragmented, and complexed process in the construction industry may inevitably increase the energy consumption of a construction project. The aim of this research is to identify the influencing factors of energy consumption in construction projects based on the perception of contractors in Indonesia. The qualitative research approach was adopted through literature studies resulting in 28 factors classified into factors related to material planning, management, and construction method. Data was collected through 1-5 Likert questionnaires distributed to 50 contractors with a response rate of 72%. This research found the top five influencing factors of energy consumption in construction projects, i.e. the construction methods, the adoption of Building Information Modelling (BIM), heavy equipment planning,the certification of material suppliers and distributors, and the workforce management. These results may help the construction stakeholders in formulating the comprehensive strategies to reduce the energy consumption in construction projects.

Keywords: Energy Consumption, Construction Industry, Construction Project, Contractor

1 Introduction

Over the past hundred years, the global surface temperature of the earth has risen by an average of 1.1°C, and the construction industry plays a great part in this global environmental problem. In 2018, 36% of total global energy was used in construction and operational activities which released 39% of CO_2 [1]. In the US, European Union and Australia the CO_2 gas emissions from construction projects were 39%, 11% and 18.1%, respectively, which was greater than the transportation and manufacturing industry [2; 3;4].

Construction activities contribute millions of tons of waste each year, which produce great emissions and consume high energy [5]. The process of energy consumption and greenhouse gas emission takes place continuously for the whole life cycle a building. As the energy consumption contributes to the emissions, the energy consumed for material production and construction processes may serve as an indicator to environmental damage. This study aims to identify the influencing factors of energy consumption in construction project based on the perception of contractors in Indonesia.

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2 Literature Review

Each stage in the building's life cycle will produce energy, such as the stage of material production, distribution to the project site, building operations, transport of waste and up to the demolition of buildings [1]. This energy life cycle includes all types of energy needed in the building life cycle, both embodied and operational energy.

2.1 Embodied Energy and Operational Energy

Embodied energy is the amount of energy consumed to produce the building, which is both directly and indirectly consumed by the building. Energy that is consumed directly includes construction activities, transportation of materials and equipment, as well as project administration, whereas indirect energy originates from the production process of the building materials, renovation, repair and demolition of buildings [7;8]. The use of fossil and non-fossil energy such as electricity and gas that is used to meet the needs of building users during building operational activities is called operational energy [6;9;10].

Operational energy is influenced by the electricity consumption during the life of the building, including the energy during maintenance. However, operational energy can be minimized if it is planned from the beginning of an energy- efficient building, which will also reduce the amount of embodied energy [5]. Most studies mention an average of above 80% to 90% of the energy consumed during building operations, while less than 20% is embodied energy [11;12;13]. Figure 1 shows system boundaries that are built based on the life cycle building include all energy consumed (Embodied Energy (EE), Operational Energy (EO), and Embodied Carbon (EC)) as a first step in identifying and assessing the energy footprint of a building.

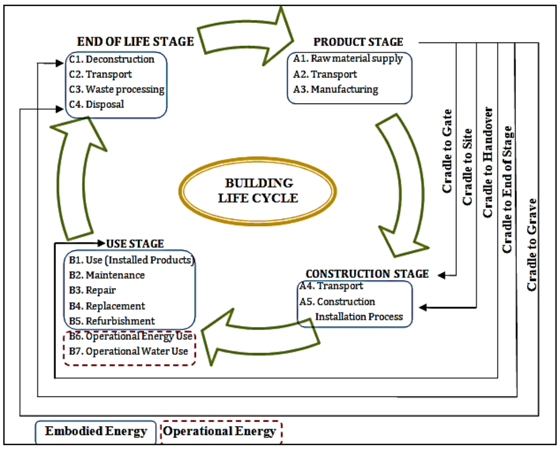

Fig.1. System Boundaries Based on Building Life Cycle [14;15;16]

The embodied energy process takes place at every stage in the life cycle of a building, that begins with the material production activities of the plant used in the construction process (cradle-to-gate**)**. The 'cradle-to-site' covers activities of distributing materials to the project site and continuing until construction, when it continues until the building can be operational is called 'cradle-to-handover', at which operational energy consumption begins. The 'cradle-to-end-of- stagecovers the process until the end of use of the building, while the 'cradle-tograve' covers the whole life cycle of the building, from the raw material supply until the disposal of the building materials. [14;15;16].

The most energy consuming is found in construction materials, where the amount of energy is calculated from production, to transportation to the project site (material supply) [7;8]. The distance between project sites and material sources will affect the amount of fuel consumption used. The need for planning in the selection of distributors of the project location, where the closer the distance to the project location the less carbon will be produced [9;17]. Berge's research states that 85-95% of the energy contained in materials during production and transportation, while 5-15% is found in the construction, maintenance and demolition of buildings. Energy in transportation depends on the mode of transportation used, such as sea, air, road or train [18].

The management system provides an important role in the sustainability of construction activities. Workforce management that is not optimal and repetitive work will influence material and energy wastage. In addition, problems of communication and sharing information is one of obstacles that hamper the construction process. For this reason, good planning is a must in determining work priorities, material, and equipment needs, to avoid waste at the project site [6;7;19;20]. The method of construction also affects the energy consumption, as it determines the effectiveness of the construction process, including the use of tools, material optimization, and minimization of waste generated [5;7;21]. Technology planning and development that takes into account energy savings at the construction, utilization and maintenance stages of a building have a significant impact on reducing carbon emissions [10;11;15]. The lean construction method is a method that is often used primarily on improving environmental quality, reducing waste and health and safety. Ogunbiyi's research shows that implementing lean construction will have positive impacts on energy, material, resource, and cost efficiency during construction activities [22].

The use of technology in construction is inevitable to boost productivity, one of which is building information modeling (BIM). BIM is a digital platform to manage resources and materials used in construction activities, including the regulation of information systems in decision making throughout the life cycle of a project, i.e. design, construction, operational, and demolition [23;24;25]. BIM can be used to calculate the total energy used in the material production process, construction implementation and transportation system in building activities [26]. The use of BIM allows the reduction of energy at early stage of the design phase, resulting significant energy savings for the whole life cycle of the building [25;26;27].

Based on the study of literature, the main influencing factors of energy consumption during construction were identified, i.e. factors related to material planning, management, and construction methods as shown in table 1.

Table 1. Influencing factors of energy consumption in material planning, management, and construction methods

Code	Influencing factors of Energy Consumption in Construction	Authors
Factors Related to Material Planning		
A1	Supply chain planning of materials	[7;8;9;17;18]
A2	Management of the transportation system for project management activities (supporting transportation), for example transport of workers, health services, etc.	[16;18;28]
A3	Selection of material suppliers that do not take into account the distance to the project location there by reducing transportation.	[7;8;17;18;21]
A4	Selection of suppliers who has no experience in product packaging and distribution ofperishable materials which can lead to repetitive	[5;7;8;13;21]

Code	Influencing factors of Energy Consumption in Construction	Authors
	material deliveries.	
A5	Transportation system planning during the construction process in an effective and efficient project environment.	[7;13;18]
A6	Certification of material suppliers and distributors who are committed to the environment.	[14;16;22;29]
Factors Related to Management		
A7	Technology planning and development related to energy savings in the construction, utilization and maintenance stages of the building.	[10;11;15]
A8	Utilization of old building structures without reducing the function and strength of the building.	[10;15;30]
A9	Construction methods	[6;7;19;20]
A10	The use of BIM to simplify the process for more effective and efficient construction activities	[24;26;27;31]
A11	Understanding on and the use of lean construction methods	[8;10;15]
A12	Selection of heavy equipment	[28;32;33;34]
Factors Related to Construction Method		
A13	Optimization of the use of heavy equipment during the construction process	[32;33;34]
A14	Implementation of the method of cleaning up waste / residual construction by sorting material (reuse & recycle)	[5;13;22]
A15	Placement of heavy equipment operators	[32;33;34]
A16	There is often a waste of heavy equipment use due to lack of field coordination.	[32;33;34]
A17	The use of electrical energy that has not been optimal during the project	[11; 12]
A18	Utilization of alternative energy that is environmentally friendly	[15;35]
A19	The frequent use of diesel energy as main electricity.	[15;16]
A20	The use of energy saving lamps as project lighting.	[15;16]
A21	Workforce management	[7;22;29]
A22	Errors of instructions and information for workers in construction process.	[6;10;22]
A23	Planning and scheduling of material and equipment	[13;22;30]
A24	Frequent errors in ordering materials and heavy equipment.	[33;34;36]
A25	Optimizing the transportation of waste material to the landfill.	[13;16]
A26	Management of waste / residual material during construction activities	[17;21;22;28]
A27	Effective in the use of heavy equipment during the construction process	[31;32;33;34;36]
A28	The availability of recycling technology for reusable materials	[7;13]

3 Research Method

This research used qualitative method based on literature studies to identify influencing variables and indicators of energy consumption in construction projects. Data was collected using questionnaires filled in by respondents of experienced contractors. Basically, the respondents were asked to fill in the questionnaire using a 1-5 Likert scale, i.e. 1= strongly disagree, 2 = disagree, 3 = quite agree, 4 = agree, 5 = strongly agree. Table 2 shows the level of influence of the factors, i.e. low, medium, high and very high, based on the mean value of each factor. The higher level simply means the higher influence of the factor in relation to energy consumption in construction projects.

Table 2. Defining level of influence based on mean values

Mean value	Level of Influence
<2	Low
2-3	Medium
3-4	High
>4	Very High

This research was conducted in Indonesia with respondents from construction companies in Central Java and Yogyakarta. There were only 36 out of 50 respondents (72%) who returned questionnaires to be analysed. Twenty contractors (56%) were from Yogyakarta, while the remaining 16 contractors (44%) were from Central Java. Based on the size level, 42% contractors are classified as large, and 58% are medium. Based on the regulations in Indonesia, this qualification determines the maximum permitted contract values. There were 17 contractors with construction work experience of 10-15 years, 16 contractors with experience above 15 years, and 3 contractors with experience less than10 years (fig 2.).Based on types of work specialization, 11 contractors were specialized in civil works (infrastructure), 18 contractors specialized in architectural and civil works (building and infrastructure), and 7 contractors specialized in architectural, civil and other constructions (building, infrastructure and other construction such as dams, factory buildings, power plants, etc) (fig 3.).

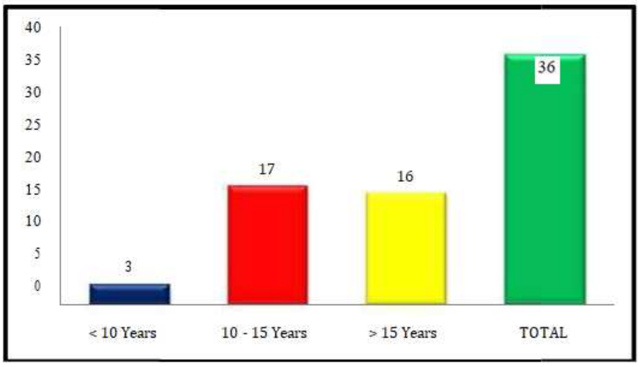

Fig 2. Working Experience of Contractor

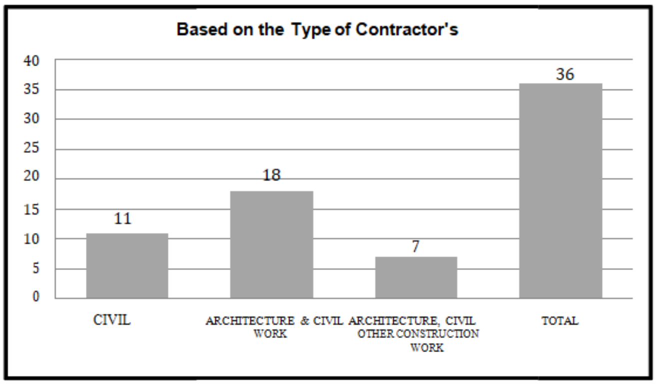

Fig.3. Specialty Contractor Work

4 Results and Discussion

Table 3 shows the rank of the influencing factors based on mean values and level of influence of each factor. It can be seen that 86% of 28 factors have high level of influence, and the rest 14% have very high level of influence. The top five influencing factors are construction method, the use of BIM, selection of heavy equipment, certification of material suppliers and distributors, and workforce management, which will be explained as follows:

Table 3. The Rank of the influencing factors of energy consumption

Code	Influencing Factors	Mean	Rank	Level
A9	Construction methods	4.31	1	Very High
A10	The use of BIM	4.28	2	Very High
A12	Selection of heavy equipment	4.22	3	Very High
A6	Certification of material suppliers and distributors	4.06	4	Very High
A21	Workforce management	4.00	5	High
A23	Planning and scheduling of material and equipment	3.94	6	High
A22	Errors of instructions and information for workers	3.86	7	High
A4	Selection of suppliers who has no experience in product packaging and distribution	3.83	8	High
A25	Optimizing the transportation of waste material to the landfill	3.81	9	High
A2	Management of the transportation system	3.81	10	High
A11	Understanding on and the use of lean construction methods	3.81	11	High
A1	Supply chain planning of materials	3.78	12	High
A16	There is often a waste of heavy equipment use	3.78	13	High
A8	Utilization of old building structures	3.72	14	High
A17	The use of electrical energy that has not been optimal	3.72	15	High
A27	Effective in the use of heavy equipment	3.69	16	High
A3	Selection of material suppliers	3.67	17	High
A5	Transportation system planning during the construction process	3.64	18	High
A24	Frequent errors in ordering materials and heavy equipment	3.61	19	High
A7	Technology planning and development	3.61	20	High
A13	Optimization of the use of heavy equipment	3.58	21	High
A28	The availability of recycling technology for reusable materials	3.56	22	High
A19	The frequent use of diesel energy	3.50	23	High
A26	Management of waste / residual material	3.50	24	High
A15	Placement of heavy equipment operators	3.42	25	High
A18	Utilization of alternative energy	3.39	26	High
A20	The use of energy saving lamps as project lighting	3.39	27	High
A14	Implementation of the method of cleaning up waste / residual construction	3.33	28	High

The first rank is construction method (A9), with a mean value of 4.31 and level of influence factor is very high. This indicates that the construction method greatly influences the construction activities, and significantly contributes to energy consumption during the procurement of materials, construction time, and operational of equipment. In other words, an ineffective method of construction will result in waste of materials, time, equipment and workers. This finding is in accordance with the results of a study, which state that the greatest energy consumption in materials comes from production and supply to the project [19]. The use of materials, electrical and fossil energy is approaching 50% of the total energy of the construction process in China [20]. Innovation in construction materials that prioritize environmentally friendly factors will have a positive impact on minimizing the amount of energy it generates [6]. The biggest materials that affect buildings are cement, steel, iron and ceramics. In addition, the use of Life Cycle Assessment (LCA) method to analyse the energy potential of both embodied energy and energy operations will be beneficial for formulating the energy efficiency strategies [8;9;10]. Most buildings use concrete and steel as the main materials, which produce almost 65% of emissions together, or 40% of emissions from the concrete alone [7;36].

The use of BIM (A10) ranks the second with a mean value of 4.28 and level of influence factor is very high. The use of BIM helps facilitating for more effective and efficient construction activities. BIM has been used to model buildings in search of elements that have the highest energy levels to lower the total energy consumption through material selections or engineering design particularly for residential buildings [23]. It provides a platform for incorporating sustainability information to create designs, which assess energy related to production materials, transportation, and building construction [24]. As an effective virtual tool for building performance analysis at the design stage, BIMcan be used to identify and assess various combinations of alternative construction materials as a solution to reduce energy consumption [26].The development of the BIM provides analytical capabilities in three dimensions as well as estimating costs, scheduling, including analysing the environmental impact of construction project activities [31]. The significant reduction of energy use and carbon footprint during the design phase has been made possible by calculating the impact of individual materials in the supply chain [25]. In addition, BIM helps rapid decision makingtowards green building, particularly in determining types and system of building technology and management of building materials [27].

The selection of heavy equipment (A12) is in the third rank with a mean value of 4.22 and level of influence factor is very high. The energy consumption and emissions are significantly influenced by the type of equipment used based on the construction method. This is true particularly for heavy equipment for earthworks and material distribution, which is criticalfor the productivity of construction workimpacting the fuel consumption and the CO2 emissions [32]. An accurate analysis of energy consumption and emissions in the construction phase must consider the characteristics of the construction method and location. Energy consumption used for earthworks requires temporary work, excavations, foundations, frameworks, and transportation in apartment projects as much as 4.03% and 3.08% of the total Global Warming Potential (GWP) [28]. The use of concrete asphalt in the flexible pavement on road construction contributed almost 50% of the total emissions, while the use of trucks as a means of transportation of materials to the project site is capable of contributing more than 35% of all construction equipment used [19]. Research on road construction projects in Korea found more than 90% of emissions activities are generated from the use of heavy equipment, especially excavators [33]. Air pollution is generated by heavy equipment nearly 500 times (130 kW) from private vehicles on especially in large scale earthworks [34].

The fourth rank is certification of material suppliers and distributors who are committed to the environment (A6) with a mean value of 4.06 and level of influence factor is very high. This factor is related to the material supply chain where the role of the supplier in providing quality material and an effective and efficient distribution system. Procurement with a certification system on materials and supply chains will positively affect the process of optimizing embodied energy [16]. As material transportation from the factory to the project site contribute significantly on embodied energy and carbon (fig.1), hence highly committed suppliers to the environment arerequired [14]. The use of sensing technology on vehicles will facilitate the monitoring and minimising delays in the supply of materials to the project location. This will assist the project manager in updating the schedule and increasing material efficiency [22]. Minimizing carbon emissions in construction activities can be done by optimizing the supply chain so as to shorten the distribution path of materials and equipment [29].

Workforce management (A21) ranks the fifth, with a mean value of 4.00 and level of influence factor is high. This factor is very closely related to all construction activities. Placement of workers according to expertise and skills will accelerate the work process with good quality, which will contribute to the efficiency of time, materials, tools, and reduce the amount of residual construction waste. This eventually will lead to reduction of the amount of energy and carbon emissions in the project. The importance of labour management is truly shown in construction, demolition, and earthworks, which require expertise and skills in sorting and operating heavy equipment so as not to cause pollution and minimize energy from fuel consumption [7;18;29]. While the top five influencing factors of energy consumption in construction has been discussed above, all the twenty-eight factors basically may serve as indicators to formulate strategy to minimise the energy consumption in construction. It is expected that the stakeholders of the construction industrycan be benefitted from the findings of this research in understanding, formulating, implementing, and evaluating the strategy of energy consumption reduction towards sustainable construction.

5 Conclusion

The embodied and operational energy is the biggest source of emission in construction, hence the optimization of construction activities is paramount to minimize energy consumption. This research identified twenty-eight influencing factors of energy consumption in construction as perceived by contractors, which are classified into factors related to material planning, management, and construction methods. In terms of influencing levels, 86% of 28 factors have high level of influence, and the rest 14% have very high level of influence. The top five influencing factors are construction method, the use of BIM, selection of heavy equipment, certification of material suppliers and distributors, and workforce management. These findings suggest the importance of making virtuous plans and management strategies for energy reduction in construction for managing the equipment, labour, materials, and supply chains with the use of BIM. Based on the research findings, future research could look into BIM-assisted innovative construction methods which are more efficient and environmentally friendly towards sustainable construction.

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