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Energy Consumption Analysis of Construction Equipment in Building Structural Activity based on Green Construction to Reduce Carbon Emission Levels

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Abstract— Construction is an activity of planning and implementation based on a detailed contract document, especially for buildings. The implementation of construction projects that are effective, efficient, qualified, reliable, and environmentally friendly need to be supported by quality assurance of construction resources so that they can be classified as green construction. In this case, construction equipment is an important factor in every construction work, one of them is by paying attention to the specifications of construction heavy equipment and appropriate transportation equipment starting from the initial stage of project planning. This aims to reduce the carbon emissions generated from each of these tools. The location used for research, is a government office building and the data is accompanied by Bill of Quantity (BOQ) consisting of preparation, soil work, foundation work and structural work. The results showed that foundation and mobilization of construction materials required a large amount of fuel compared to others. With the greater amount of fuel used, the emissions produced will be equivalent. One of the solutions is to choose the closest construction material pick-up route during the work is in progress. Thus, the percentage of carbon can be reduced to 20% of total emissions of building structural works.

Index Terms— ***green construction, construction equipment, carbon emission, structural work, building construction.***

I. INTRODUCTION

Every job must produce carbon emissions in each of its sectors. Almost 50% of CO_2 emissions are generated by buildings, building and construction materials, and the construction industry (Figure 1).

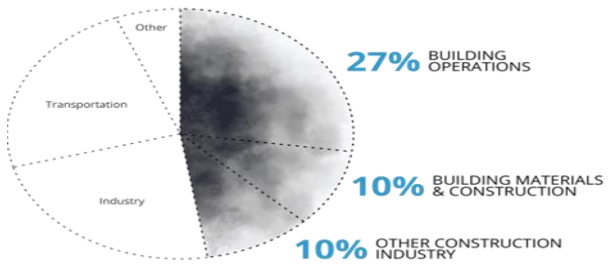

Figure 1. The World's Annual CO_2 Emissions in the Construction and Building Sector (EIA, Global Status Report, 2021)

Construction work is not only from materials for buildings, but the construction industry is also involved, therefore construction activities each year will generate 20% of world's total annual emissions.

The increasing in the number of people in the world also increases every year and it is estimated that the floor area of global buildings is expected to double by 2060 (UN Global Status Report, 2017). With this increase, construction activities will also increase, especially the construction of vertical residential buildings in city centers.

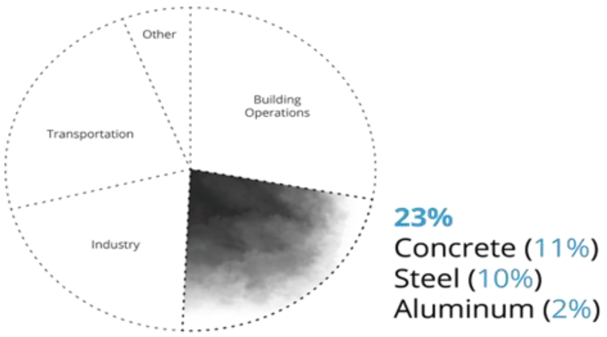

Figure 2. Percentage of World Annual CO_2 Emissions in the Construction Sector (EIA, Global Status Report, 2018)

Every year in construction activities, almost 23% of the materials used are concrete, steel and aluminum. These 3 basic materials produce large carbon emissions. If we look at the 3 construction works that use these three basic materials, the structural work that produces large carbon emissions when the construction work is carried out.

With the increasing need for buildings to support community activities in DKI Jakarta, within the last 5 years, there have been many building constructions such as residential, office, educational facilities, health facilities, and others. The development activities involve various parties, such as the central and regional governments and the private sector / individuals.

The development process that has not been effective, efficient, and unimplemented green construction principles will cause excess carbon emissions especially in the construction of buildings in DKI Jakarta. This caused by the absence of regulations that specifically regulate the principles of green construction in the construction of buildings in DKI Jakarta.

This study will formulate and provide an overview of energy needs and emissions produced in conventional construction activities of structural work in buildings, especially in construction equipment.

The results of this study will be a good beginning in the scope of construction work that can be used as a new attention and the basis for local regulations to reduce energy consumption and excessive carbon emissions.

The presence of construction equipment in carrying out a project at the development stage is very helpful for humans in achieving goals, but not just any equipment that can be used to achieve the goal. However, the equipment must be operated in accordance with working conditions and high production.

II. METHODOLOGY

A. *Research Flow*

Research activities begin with conducting literature studies and determining topics that are in accordance with current trends. After getting the topic then do the problem formulation and determine the limitations of the problem.

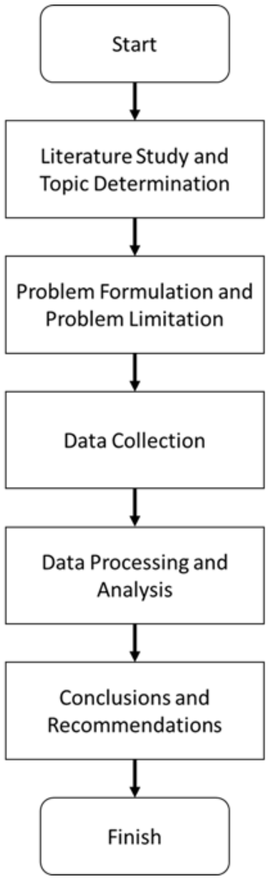

Figure 3. Research Flowchart
(Author, 2022)

Data collection in the study is carried out to be processed and analyzed which in the end to obtain conclusions and suggestions.

B. *Location Plan*

For the location used for research is one of the Government offices building at DKI Jakarta with visible images and plans (Figure 4 to Figure 6).

Figure 4. Perspective View of the Building Plan
(Central Jakarta City Government DKI Jakarta, 2019)

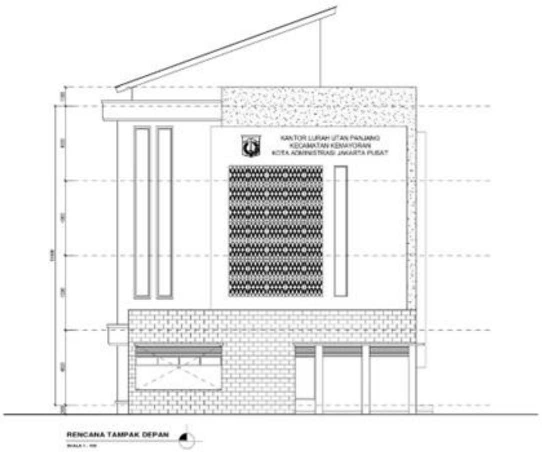

Figure 5. Front View of the Building Plan
(Central Jakarta City Government DKI Jakarta, 2019)

Figure 6. Right Side View of the Building Plan
(Central Jakarta City Government DKI Jakarta, 2019)

As for additional information on the building plan:

- Usage: Office
- Number of Floors: 4 floors
- Total Land Area: 880 m^2
- Basic Building Area: 288,74 m^2
- Total Building Area: 1.053,74 m^2
- Parking Area: 430 m^2

III. DATA

A. *Data Source*

The data source used is the Bill of Quantity (BOQ) one of the Government buildings in DKI Jakarta which consists of preparation, soil work, foundation work and structural work.

Preparation consists of installation of project signage, keet directors, mobilization/ demobilization of piles, material warehouses & workers' barracks, electrical and water work, safety corridor & cleanliness, zinc project safety fences and construction of decks & safety nets.

Soil work consists of bouw plank work, drilling, piles & pile cap, lower column concrete, masonry foundation, tie beam, stair foundation, sloof, soil management, soil compaction and floor plate work.

Structural Work consists of column, beam, floor plate, staircase, ramp, and roof work.

B. *Heavy Equipment Construction Specifications*

For heavy equipment used in this study, it uses a type of heavy equipment that is generally used in work on buildings at height of 3-4 floors.

Table 1. Heavy Equipment Specification Data Used for Calculation

Excavator		
Manufacturer	:	Komatsu PC 130F-7
Lifting Capacity [kg]	:	3200
Bucket Capacity [m^3]	:	0.55
Coef. / Bucket Factor	:	1.1
Fuel Capacity [L]	:	247
Fuel Consumption [L/hr]	:	5
Concrete Pump (Ready-mix)		
Manufacturer	:	Caterpillar Put Meister BSF
Concrete Output Cap. [m^3/h]	:	32-08.09H
Fuel Consumption [L/hr]	:	12
Soil Drilling Machine		
Manufacturer	:	Kobelco BM500
Productivity [m/hr]	:	3200
Fuel Consumption [L/hr]	:	0.55

C. *Conveyances Specifications*

For the transportation used in this study, it uses a type of transportation tool that is generally used in work on the mobilization of construction materials.

The data specifications of the transportation used in the study as the following below

Table 2. Specification Data of Conveyances Used for Calculations

Dump Truck		
Manufacturer	:	Hino FM 260 JM
Bucket Volume [m^3]	:	20
Coefficient	:	0.9
Bucket Volume × Coef. [m3]	:	18
Fuel Consumption [km/L]	:	12.52
Mixer Truck		
Manufacturer	:	Hino WM 800
Drum Mixing [m^3]	:	7
Coefficient	:	0.92
Drum Mixing x Coef. [m^3]	:	6.5
Fuel Consumption [km/L]	:	12.52
Flatbed Truck		
Manufacturer	:	Mitsubishi Colt Diesel Double
Lifting Capacity [tone]	:	5
Fuel Consumption [km/L]	:	21.7

D. Soil Type

To obtain the type of soil, it is necessary to investigate the soil in advance with cone penetration test tool. The test activities were carried out in the development area with 3 points with a capacity of 2.5 tons and carried out until it reaches the depth of the hard soil layer with a conus pressure value (QC) > 150 kg / cm2 or a maximum depth of 25 m.

Table 3. Cone Penetration Test Data

Point	Depth (m)	Description
1	9,20	QC > 150 kg/cm2
2	9,20	QC > 150 kg/cm2
3	9,20	QC > 150 kg/cm2

Source: Water Resources Investigation, Testing and Measurement Management Unit, DKI Jakarta Water Resources Agency, 2019

E. Mobilization of Construction Materials

Based on the results of a survey conducted using the help of Google Maps, one-way average mileage results were obtained for transport vehicles on mixer trucks, flatbed trucks and dump trucks.

Table 4. Mileage Data of Conveyances

Conveyances	Material	Average mileage (km)	
		Long	Short
Mixer truck	*Concrete*	21	6.5
Flatbed Truck 1	Steel	4	4
Flatbed Truck 2	Formwork	9.5	2.5
Dump Truck	Sand, Stone, Soil	9.5	2.5

F. Heavy Equipment Capacity Calculation

To calculate the estimated production capacity of the excavator can use with the following equation:

$$P = \frac{KB \times bf \times 3600 \times cf}{CT} \quad (1)$$

Where:

- P: Production (m^3/hour)
- KB: Bucket Capacity (m^3)
- bf: Bucket Factor
- cf: The Correction Factor consists of:
  - Engine Readiness Factor
  - Time Efficiency Factor
  - Operator Skill Factor
- CT: Cycle Time (s)

G. Conveyances Capacity Calculation

To calculate the need for the number of units of dump truck, flatbed truck and mixer truck can use with the following equation:

$$\mathrm{N} = \frac{V}{C} \quad (2)$$

Where:

- V: Volume of land that can be filled (m^3)
- C: Capacity (m^3)
- N: Number of Unit

H. Soil Drilling Calculation

To calculate the total working time of Soil Drilling Machine can use with the following equation:

$$\mathrm{T} = \frac{P}{V} \quad (3)$$

Where:

- P: Productivity (m/hour)
- V: Working volume (m^3)
- T: Working time (hour)

IV. RESULTS AND DISCUSSION

After the BOQ data and calculations were carried out, then the results of fuel consumption were obtained. Results obtained such as fuel requirements and total working hours of construction machines. In addition, the results of fuel consumption, fuel requirements, total trips from conveyances, total energy, and total emissions in two scenarios were also obtained.

The basic parameters that used for calculations on construction machines are capacity, bucket factor, cycle time, bucket capacity, fuel consumption and tool productivity. In addition, for the calculation of transportation equipment are carrying capacity, fuel consumption and mileage from the material producer to the job site.

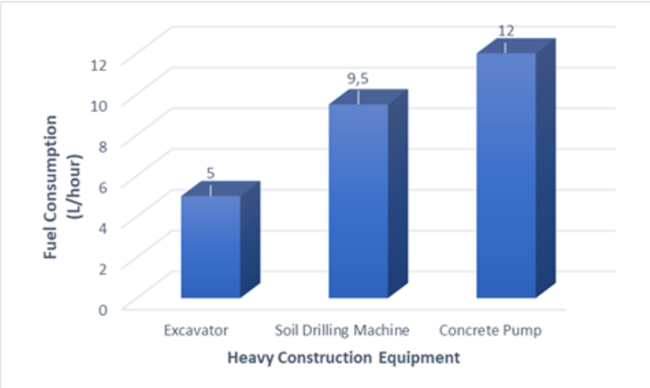

Figure 7. Fuel Consumption of Heavy Construction Equipment (Author, 2022)

The results on technical specifications of heavy equipment manufacturers, Chart 1 shows the result of fuel consumption between excavators, soil drilling machine and concrete pump. There is a significant difference in excavators and concrete *pumps*, namely 5 L/hour and 12 L/hour. Therefore, if the work is carried out at the same time, the *concrete pump* will require greater fuel emissions compared to other heavy equipment.

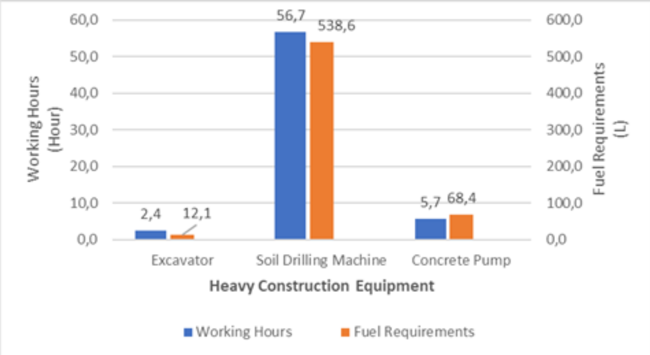

Figure 8. Fuel Requirements and Total Working Hours of Heavy Construction Equipment (Author, 2022)

In contrast to the results from Fig.7, in Fig. 8 shows that the results on the use of soil drilling machine required for almost 8 times than the fuel of the concrete pump, which is 538.6 L. This is happened because this work requires a very large volume compared to other equipment.

The capacity of tool production to the volume of work, then the total working hours on the excavator are 2.4 hours, the soil drill is 56.7 hours and the concrete pump is 5.7 hours.

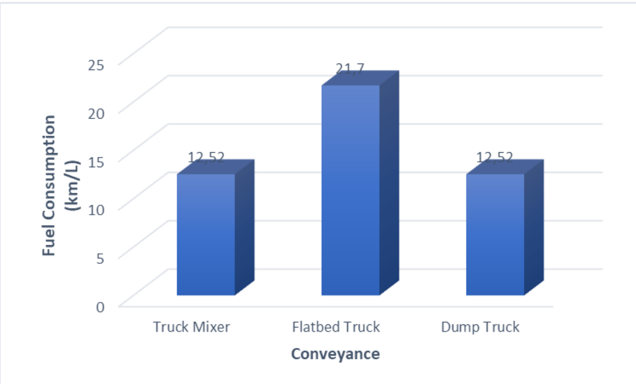

Figure 9. Fuel Consumption of Conveyances (Author, 2022)

For conveyances such as mixer trucks, flatbed trucks, and dump trucks, fuel consumption specification data is obtained as shown in Fig.9. Fuel consumption in mixer trucks and dump trucks has the same value because the type of engine and capacity are used.

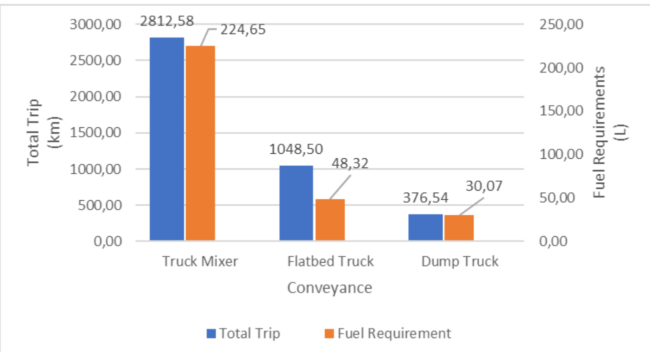

Figure 10. Fuel Requirements and Total Trip of Conveyance Scenario I (Author, 2022)

The calculation of fuel requirements is conditioned into two scenarios. The first scenario is the mileage condition of the mobilization based on the longest distance and the second scenario with the shortest distance.

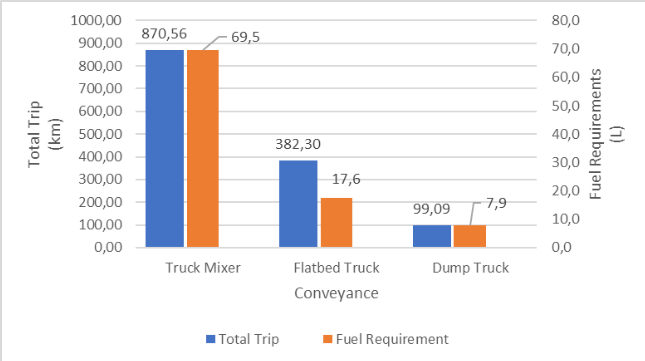

Figure 11. Fuel Requirements and Total Trip of Conveyance Scenario II (Author, 2022)

The difference in fuel requirements against mileage is clearly seen in Fig.10 and Fig.11. Mixer truck has the longest distance value (870-2812 km) compared with other conveyance. This is due to the larger volume of work contained in the mixer truck compared to other conveyance. Thus, the fuel requirement in the mixer truck becomes the largest (69.5-224.65 L).

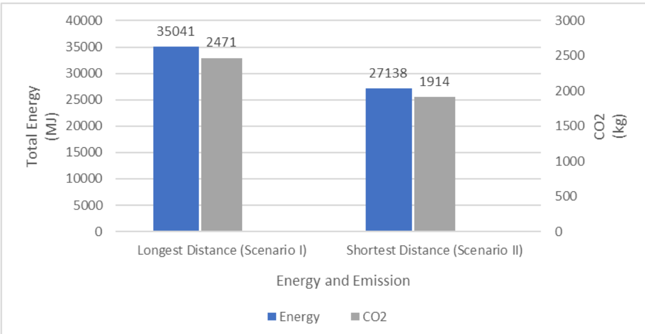

Figure 12. Total Energy Needs and Carbon Emissions in Construction Heavy Equipment and Conveyances (Author, 2022)

Fig.12 shows a comparison of total energy needs and carbon emissions on the overall use of construction equipment. By knowing the total energy needs of each construction equipment, the carbon emissions produced can also be known. The results show in Fig.12, there is a significant difference between the first scenario and the second scenario. CO_2 emissions and total energy used to see in the first scenario reached 2,471 kg with 35,041 MJ or 20% greater than in the second scenario (1,914 kg with 27,138 MJ).

The use of heavy construction equipment and conveyance in the construction work of government-owned office buildings specifically for preparation, soil work, foundation work and structural work has its own role and use.

From the BOQ in the construction work of the building, very diverse results were obtained from both heavy equipment

and conveyance. From the entire construction work, the largest fuel requirement in heavy equipment is in soil drilling machine, while in conveyance on mixer trucks.
Carbon emission and total energy produced from soil drilling machine and mixer trucks are the largest in any of its work when compared to the others.

To maximize the use of heavy equipment and transportation equipment that is effective and efficient in order to reduce excess carbon emissions, several solutions are needed that can be considered for the Government or Service Providers such as:

- Carrying out technological developments in construction heavy equipment and transportation equipment, especially in the combustion system in engines
- Increase the capacity of the conveyance to make the trip value lower by adjusting the fuel needed
- Mapping distributors of construction materials and equipment in order to reach all transportation activities on construction work more effectively and efficiently
- Using construction machines and conveyances based on hybrid or electric although it requires high investment costs

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