Formulating smart integrated workspace concept to improve energy efficiency

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Abstract. The building is one of construction sector that consumes high energy and contributes to the greenhouse gas (GHG) emission. Many researchers and academics attempt to reduce the negative impact of the building by introducing alternative technology through the internet of things (IoT) and building management system (BMS). The research aims to examine components related to the workspace of building and evaluate the cost and energy usage. The study combining quantitative and qualitative approaches through energy simulation, life-cycle cost approach, and in-depth interview. The results show three components from lighting, cooling, and office equipment that can be quantified. Every component consists of equipment to tailor the concept of a smart integrated workspace. The energy per square meter from proposed concept generates 48.36 kWh per square meter or lower than the current design. Overall it requires 203,586,240 rupiahs or 18% more efficient to the current layout.

1. Introduction
Buildings consume forty percent of the world’s energy production and contribute fifty percent to the carbon dioxide (CO2) emission [1]. Public buildings identified as the most sector that submits forty percent of global greenhouse gas (GHG) emission during its total life cycle [2]. Many experts estimate CO2 emitter will increase around 42% in 2035 worldwide. The high consumption of buildings not only occurs in developed countries such as China and European Union countries [3], but also in developing countries such as Indonesia [4].

In 2014, office buildings in Indonesia spent 15.2 million GWH to power the electricity and required 250 kWh per square meter [5]. The figure shows a higher consumption usage compared to other neighboring countries such as Malaysia and Singapore with an average about 100 kWh [6]. As the energy consumption and alternative production arise exponentially during the last decades, many researchers propose the new concept to combat energy issues. The key point from users in the building suggests that efficiency in energy shall not reduce the comfort, safety and buildings flexibility [7]. The smart office is a concept that use internet of things (IoT) to support the work environment behavior and in the longer term, increase the user's productivity [8].

IoT is part of architectural programming that manages and control buildings automatically through building management system (BMS) with an integrated workspace. It operates sensors to actuators from many building components such as temperature, noise, humidity, lighting and many other aspects of
Despite its advantages, owners and developers, particularly in developing countries, hesitate to invest the concept of the construction development. The concept most likely is rejected when the technology generates more cost and compromise the length of the payback period. Green building concept also shares a similar experience in Indonesia, where it took years to be implemented by the developers and project owners [10]. The research is then attempting to examine the most potential components in the workspace and to evaluate its cost for implementation in the project. The output expected to generate more research about the smart office concept and propose an alternative concept for the related stakeholders in office buildings.

2. Methodology

The research combines quantitative and qualitative method to achieve the targeted objectives. Using both method argued as solution to increase the reliability of the research output [11, 12]. The quantitative approach will be using energy simulation and life-cycle cost approach. Components in energy simulation follow GreenMark Interior V1.1 and generate a comparison between the baseline and proposed case study expressed by KWh. The life cycle cost evaluates the proposed case study based on its initial, operation and maintenance cost. The qualitative approach uses a desk study and in-depth interview to generate the concept of smart workspace design [13]. Desk study follows a benchmarking process and a literature review from many related resources such as journals, books, public records, policies and government reports [14, 15]. The in-depth interview is used to gain input from experts related to the case study.

The respondents categorized into practitioners and academics. Practitioners shall have experience in green building or smart building and hold green professional or LEED AP certificates. Academics should have research expertise in the green building or smart building in the past three years. The semi-structured questionnaire is used for the research instrument and conducted for about 15 – 30 minutes.

![Figure 1. The building footprint as a case study.](image)

The research uses a building located in the central business district in Jakarta as a case study. It has 39 floors and six basements with gross floor area about 90,828 square meters. The building has several functions such as tenants, function hall, retail, mechanical and electrical rooms, building management and security offices. Only the 34th floor with a net area about 1,356 square meters to be simulated in the research. The forecasted headcount is about 116 persons. The floor of the case study can be seen in figure 1.
3. Result and Discussion

3.1. Workspace Components in Building

Workspace-related to four factors including behavior, lighting, cooling, and office equipment. Building management that represents the behavior component should able to monitor the energy usage and inform to the tenants. Besides, the tenant also received real-time billing, which is longer term reduce the electricity consumption. Real-time monitoring shows load demand, distribution, power consumption per floor zone and many others. The changes from manual to automatic and centralized approach required a transformation of management, so that operated smoothly and managed thoroughly.

On the other hand, current lighting system use manual on/off and scheduling system. The alternative concept proposes a combination of scheduling and sensors of on/off system based on digital addressable lighting interface (DALI). Proposed concept offers LED light with specification as about 3,700 lm for the luminous flux and power about 40.5 W. It will be supported by the recess mountable 360-degree multifunction sensor, a sensor that combines motion detector (PIR) and ambient light level detection (PE). PE sensor aims to reduce energy usage by measuring daylight level and adjust along with the system to user’s expected light level. Overall the building needs 97 points of the lamp with two gateway controllers. It acts to communicate the loop/group of lighting for on/off from the scheduling system or the user panel. The coverage area of sensors for the lighting system summarizes as figure 2.

![Figure 2. The coverage area of sensors for the lighting system.](image)

Furthermore, cooling integrates variable air volume (VAV) with the building management system. The system maintained the air supply at a constant temperature and proven to reduce energy consumption by 20 – 30% [16]. However, the primary data shows that energy saving to VAV is varied on the user density at the space and the fan speed. When the speed is 100%, the power generates 18.5 kW. On the contrary, a 17% of fan speed produce a 0.1 kW of power.

In term of office equipment such as printing devices to the multifunction devices, it should pass the energy star standard or typical electricity consumption (TEC). While, LED display follows the needs of meeting room size from small, medium, large to the conference room.
3.2. Investment and Operational Cost

The cost in the smart integrated workspace that combines lighting, cooling, and office equipment consists of investment and operational cost. Due to qualitative result, behavior aspect is excluded from the cost evaluation. Site visit generates the quantity of each equipment. Unit price follows Indonesia’s market price for the equipment. Office equipment is the largest contributor to investment cost with total 81.92%. Followed by lighting equipment and cooling equipment respectively. The initial cost for the concept design is summarized in table 1.

The operational cost is calculated by considers energy conversion from kWh to the electricity cost per year. Primary data generates the current annual kWh of each indicator from lighting, cooling, and office equipment. The interior lighting has annual usage about 863,759 kWh to accommodate 65,630 square meter office area. Meanwhile, cooling and office equipment have larger usage about 57.13% and 90.91% compared to the lighting. Thus, the annual usage for the three indicators is about 13.16 kWh per square meter, 20.7 kWh per square meter, 25.2 kWh per square meter respectively. The tariff from Indonesia’s state-owned enterprises in energy is about 1,472 rupiahs. Overall the annual operating cost of the components is about 248,634,100.

3.3. Current vs. Proposed Concept

The proposed smart integrated workspace evaluated energy efficiency and compared them from current condition. Lighting in proposed design minimizing electricity usage while maintaining lighting level through lighting control. The lighting scheduled to shut down and turn on automatically when users surpass the maximum usage. It supported by sensors and daylight harvesting concept. The quantification considers lighting spot and lamp power. Assuming the building operates for five days a week with eleven hours daily operation, the total electricity is about 10.42 kWh per square meter. Moreover, primary data shows that cooling system in the building require 4,631,146,303 Btu for 65,630 square meter with the level of temperature about 24º C. Assuming the VAV system provides 20% of efficiency compared to the other system, the proposed design produce 16.54 kWh per square meter. Last, the energy star certified office equipment generates 21.4 kWh per square meter.

| Table 1. The initial cost of the smart integrated workspace design. |
|---------------------------------------------------------------|
| Equipment | Unit Price (Rp.) | Quantity (Unit) | Cost (Rp.) |
|-----------|-----------------|-----------------|------------|
| Lighting  |                 |                 |            |
| LED lighting | 2,226,031 | 184 | 409,589,704 |
| Multi – function sensor | 2,833,380 | 53 | 150,169,140 |
| Gateway controller | 1,713,513 | 4 | 6,854,052 |
| Signal/ballast controller | 12,566,011 | 1 | 12,566,011 |
| Cooling   |                 |                 |            |
| VAV box   | 8,000,000      | 34              | 272,000,000 |
| Temperature sensor | 790,000 | 34 | 26,860,000 |
| Office equipment (Star certified) | | | |
| Laptop   | 13,340,646     | 114             | 1,520,833,644 |
| Multi – function devices | 146,740,000 | 15 | 2,201,100,000 |
| LED display |                 |                 |            |
| Type 1    | 2,361,180      | 6               | 14,167,080  |
| Type 2    | 6,923,460      | 6               | 41,540,760  |
| Type 3    | 24,612,300     | 7               | 172,286,100 |
| Voice over internet protocol | 1,336,800 | 22 | 29,409,600 |
| TOTAL     | 4,857,376,091  |                 |            |
Overall it requires smart integrated workspace and voice over internet protocol. All of them have to meet energy star certification for their related components. Every component consists of equipment to tailor the concept of a smart integrated workspace. Lighting has LED lighting, multifunction sensor, a gateway controller, and signal/ballast controller. On the other hand, cooling consists of two equipment from VAV box and temperature sensor. Last, office equipment comprises of the laptop, multi-function devices, LED display and voice over internet protocol. All of them have to meet energy star certification for further evaluation. Lighting requires 579,178,907 rupiahs or equal to 11.92% from the total initial cost. While, cooling costs 298,860,000 rupiahs (6.15%) and office equipment involves 3,979,337,184 rupiahs. In total, the additional cost to implement the concept is about 4.8 billion rupiahs. The energy per square meter from smart integrated workspace generates 48.36 kWh per square meter or lower than the current design. Overall it requires 203,586,240 rupiahs or 18% more efficient to the current design.

### Table 2. Energy and Cost Comparison between Current and Proposed Design.

| Equipment                      | Current kWh/m² | Unit price (Rp.) | Proposed Design kWh/m² | Unit price (Rp.) |
|--------------------------------|----------------|------------------|------------------------|------------------|
| Lighting                       | 13.16          | 30,470           | 10.42                  | 24,346           |
| Cooling                        | 20.7           | 37,094           | 16.54                  | 31,500           |
| Office equipment (Star certified) | 25.2           | 19,371           | 21.4                   | 15,338           |
| Total                          | 59.06          | 86,935           | 48.36                  | 71,184           |
| Annual Operating cost          | 248,634,100    |                  | 203,586,240            |                  |

The proposed concept shows a lower usage in all building components. Current design produces a total of 86,935 rupiahs per square meter while proposed concept offers 71,184 rupiahs per square meter. Overall, less annual cost about 18.12% or equal to 203,586,240 rupiahs is generated. The comparison of current design with the smart integrated workspace concept shown in Table 2.

### 4. Conclusion

Buildings consume high electricity and contribute to the increased figure of greenhouse gas (GHG) emission. Many researchers attempt to improve the power efficiency by using technology through the internet of things (IoT) and building management system (BMS) and introducing compact layout to accommodate energy saving.

The case study identifies four energy-related components includes behavior, lighting, cooling, and office equipment. However, the behavior is excluded from further analysis due to its categorization as a qualitative component. Every component consists of equipment to tailor the concept of a smart integrated workspace. Lighting has LED lighting, multifunction sensor, a gateway controller, and signal/ballast controller. On the other hand, cooling consists of two equipment from VAV box and temperature sensor. Last, office equipment comprises of the laptop, multi-function devices, LED display and voice over internet protocol. All of them have to meet energy star certification for further evaluation.

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