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Energy efficiency index as an indicator for measuring building energy performance: A review

Nur Najihah Abu Bakar [a,b], Mohammad Yusri Hassan [a,*], Hayati Abdullah [a], Hasimah Abdul Rahman [a], Md Pauzi Abdullah [a], Faridah Hussin [a], Masilah Bandi [c]

[a] Centre of Electrical Energy Systems (CEES), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bharu, Johor, Malaysia
[b] School of Electrical Systems Engineering, Universiti Malaysia Perlis, Pauh Putera Campus, 02600 Arau, Perlis, Malaysia
[c] Office of Asset and Development, Universiti Teknologi Malaysia, 81310 UTM Johor Bharu, Johor, Malaysia

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ABSTRACT

Accurate forecasting of energy consumption in a building is an important strategy in achieving the goal of reducing energy demand, as well as to improve energy efficiency. To implement this strategy, many methods and indicators have been proposed to monitor and measure energy performance in buildings. However, various factors that influence energy consumption of a building system operation, such as the types of activities carried out in the building, weather conditions, building materials, HVAC system and occupancy; contribute to the difficulty in accurately measuring a building's energy system. This paper provides a review on the Energy Efficiency Index (EEI) as an indicator used to track the performance of energy consumption in a building. Previous research works concerning this index and relevant mathematical models are also introduced. Other related methods or indicators for measuring energy consumption performance of buildings will also be presented.

Contents

* Corresponding author. Tel.: +607 5557001; fax: +607 5557005.
E-mail address: yusrihutm@gmail.com (M.Y. Hassan).

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1. Introduction

Rapid development of the building sector has led to the increase in global energy demand. The development should run in parallel with energy production and energy consumption because of the limited energy resources [1]. Rising demand for energy in the developing countries has initiated greater efforts among many organizations to balance between energy generation and energy consumption. Many research works related to consumption of total energy in buildings have been carried out to share knowledge in energy efficiency and energy conservation initiatives.

Energy efficiency plays an important role in controlling energy use, as well as reducing cost and maintaining comfortable environment in buildings [2]. Energy efficiency and energy management are closely related in terms of monitoring and controlling energy consumption in buildings. With the current increase in the global energy consumption, the main concern is not only focused on how to produce the required energy but also ways to improve energy efficiency to ensure sustainable energy supply and to be able to meet the required demand. In order to ensure optimum operation of a building's energy system, energy efficiency initiatives should be carried out regularly and continuously to verify the actual pattern of the building's energy consumption. The success factor for energy efficiency initiatives greatly depends on the method or indicators used to measure the energy performance in the buildings.

For the purpose of energy sustainability and conservation, various approaches in building energy-analysis methods have been suggested. The introduction section of this paper presents an overview of the global energy demand, total energy usage in buildings, and energy efficiency initiatives in buildings. This is followed by a discussion on the development and integration of various approaches to measure energy performance in buildings by researchers in these areas in Section 3. Section 4 discusses the utilization of the Energy Efficiency Index (EEI) as a means to measure energy performance in buildings. The recent trend in the development of mathematical models for EEI is also included in Section 4.

2. Energy consumption in buildings

Energy consumption plays a vital role as the lifeline for all activities being carried out in a building. Energy production and consumption data are essential for energy conservation purposes. To better understand the problems occurring in the energy sector and to propose effective solutions, it is important to analyse where and when energy is being consumed within the facilities.

In general, final energy consumers can be classified into several main sectors, as given in Table 1. In year 2011, transportation, industrial, residential and commercial sectors contributed to 28%, 31%, 22% and 19%, respectively, as the final energy consumers in the world [3]. The trend for energy source used by end user sector in the world is illustrated in Fig. 1.

The building sector has been identified as the largest energy consumer as it accounts for a significant percentage of a nation's energy consumption [4]. Energy use in buildings for various countries is shown in Fig. 2 ,accounting about 40% [5] for Europe, 23% for Spain [6], 25% for Japan [7], 28% for China [8], 39% for the United Kingdom [6], 42% for Brazil [9], 50% for Botswana [10], and 47% for Switzerland [11].

Worldwide energy consumption for buildings is forecasted to grow approximately 45% starting from the year 2002 to 2025 [12,13]. According to the statistical report by IEA 2007 [14], the building sector in developed nations accounts for about 40% of the primary energy consumption. From that amount, 70% of the sources used is in the form of electricity. The report by the United Nation Environment Programme (UNEP) [15], also stated that 30–40% of the energy in the world is consumed in buildings. The proportion of energy above signifies that the building sector can be considered as one of the important sectors, as it accounts for a very high percentage in national energy consumption [6]. If this trend continues, the building sector will consume almost as much as the combination of the industrial and transportation sectors [16]. Although this maybe a cause for alarm, it does provide a good opportunity for sustainable energy planning in the building sector. Therefore, there is a need to optimize a building's energy efficiency for sustainable energy management [17].

Table 1
Final energy consumers by sector in 2011.
Source: U.S Energy Information Administration (EIA).

Sector	Percentage in the world (%)
Transportation	28
Industry	31
Residential	22
Commercial	19

2.1. Energy consumption distribution

The distribution of energy consumption in the building sector involves a large set of variables. The prediction of the energy consumption in a building requires a detailed description of the building, such as construction materials, geographical location, operation schedules, energy suppliers rates, air-conditioning systems, lighting and external weather conditions as input parameters [18].

Buildings are built with different standards and come in a wide variety of sizes, shapes and purposes. The Commercial Buildings Energy Consumption Survey (CBECS) classifies buildings based on the principal activity, which includes the primary business, commerce, or function carried out within each building [19]. The break-down of energy end-use in buildings for the commercial sector is shown in Fig. 3. This figure shows that the energy consumption in a building is largely dominated by the Heating, Ventilation and Air-Conditioning system (HVAC), and followed by lighting. HVAC by far is the highest energy consumer in a building [20,21]. For this reason, the US Department of Energy (DOE), in its energy efficiency program, highlights lighting and HVAC as the most common areas in which energy efficiency measures are implemented [22].

HVAC systems have always been one of the important systems installed in buildings because of the requirements for thermal comfort in buildings [23]. Fig. 4 lists various HVAC systems installed in buildings to ensure occupant's comfort. The more comfort level is being provided to the occupants of a building, the more the energy consumption [24]. Energy can be saved to a great extent by properly managing the energy while ensuring reliability of the critical loads [19], which also minimizes the total energy consumption [25].

Other than air conditioning, lighting is a common utilized form of load. It constitutes a significant portion of total energy consumption. Because of that, the researchers are continuously thriving for better efficiency of lighting systems. Jamaludin et al. [17] highlight natural ventilation and daylighting as the two strategies that should be used to reduce energy consumption especially for cooling and lighting. The US Department of Energy (DOE) in its energy efficiency program highlights lighting and HVAC as the two