IoT-BASED POWER MONITORING SYSTEMS TOWARDS HIGH ENERGY EFFICIENCY IN SCHOOL BUILDINGS

HỆ THỐNG GIÁM SÁT ĐIỆN NĂNG TRÊN NỀN IoT HƯỚNG TỚI HIỆU SUẤT NĂNG LƯỢNG CAO TRONG CÁC TÒA NHÀ TRƯỜNG HỌC

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ABSTRACT

The fast expansion of urban areas in developing countries like Vietnam significantly increments new modern buildings. Additionally, many intelligent electrical appliances are being used in that built environment. Thus, total energy demand is being raised tremendously. Understanding energy usage in such buildings is essential to operate them efficiently. Recent Internet of Things technologies makes the supervision of power usage more convenient and possible to do remotely. In this work, we have developed a power monitoring system to observe the energy consumption in a school building. The system collects information at different locations in the buildings and subsequently enables data analysis. The initial results help to understand the current situation in an existing building, and thus would be helpful for the operators to plan appropriate schemes to optimize the operation and then obtain the most energy savings.

Keywords: *Internet of Things, smart buildings, energy efficiency, power monitoring.*

TÓM TẮT

Tốc độ đô thị hóa nhanh chóng ở các nước đang phát triển như Việt Nam dẫn đến sự gia tăng số lượng các tòa nhà hiện đại. Thêm vào đó, số lượng các thiết bị điện thông minh cũng đang được sử dụng ngày càng nhiều trong môi trường trong nhà, do đó nhu cầu năng lượng cũng rất lớn. Hiểu được nhu cầu sử dụng năng lượng trong các tòa nhà này là một yêu cầu cấp thiết để có thể vận hành các tòa nhà một cách hiệu quả. Sự phát triển công nghệ Internet vạn vật gần đây cho phép việc theo dõi công suất tiêu thụ điện từ xa trở nên thuận tiện và dễ dàng hơn. Trong nghiên cứu này, chúng tôi đã phát triển một hệ thống giám sát năng lượng để theo dõi năng lượng tiêu thụ trong một tòa nhà trường học. Hệ thống tiến hành thu thập dữ liệu ở các vị trí khác nhau trong tòa nhà và cho phép phân tích các dữ liệu này. Các kết quả phân tích ban đầu giúp cho người vận hành có thể lên kế hoạch sử dụng các trang thiết bị điện trong tòa nhà một cách tối ưu và tiết kiệm tối đa năng lượng.

Từ khóa: *Internet vạn vật, tòa nhà thông minh, hiệu suất năng lượng, giám sát năng lượng.*

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1. INTRODUCTION

Throughout history, an introduction and implementation of innovation on a large scale often engender latent complexities that sometimes possess profound alternative potential. The upscaling of manufactured structures, or in other words, the creation and enlargement of buildings, is one instantiation of this pattern. The larger the buildings became, the more variables there had to be in their energy models, and thus, the more complex energy management became.

Although buildings of all types, whether public (schools, libraries, government buildings) or private (apartment buildings), have existed for a long time, scientific research into energy consumption and its distribution in buildings was relatively recent. According to a data-science-based literature review of building energy, the annual number of scientific studies published and recorded in the ELSEVIER database on power in buildings has increased from under 50 in the 1980s to more than 3000 in 2019 [1].

The substantial increase in the number of studies on building energy, especially energy efficiency, correlates with an increase in energy efficiency, with the growth rate of energy consumption (1%) falling behind that of floor area expansion (2%) which can be attributed to the resultant birth of building energy regulations from the studies [2]. The building energy benchmarking report by Singapore's Building and Construction Authority details the overall energy consumption of five types of buildings, including commercial, healthcare, educational, civic, and entertainment buildings. According to the report, with the rate of ground floor area increases far exceeding that of power consumption, the overall energy use intensity (EUI, measured in kWh/m^2) of buildings experienced a 21% decrease from 2008 to 2020. For school buildings specifically, the EUI decrease was lower than average but high nonetheless, standing at 19% [3]. However, according to extrapolations from the IEA, this positive development is insufficient to meet the Net Zero goal in 2050 [2]. In [4] and [5], The UN environment program (UNEP) reported that in 2019, buildings' electricity consumption made up a high

55% of all electricity consumption. In 2020, their final energy consumption took up 36% of all energy consumption. Of this 36%, 22% were contributed by residential buildings, and 8% by non-residential structures, as shown in Fig. 1. Consequently, the total emissions from buildings reached up to 37% of all emissions in 2020. With the necessity of efficient energy usage within facilities established, the background on the progress made in managing electricity consumption in buildings shall be briefly discussed.

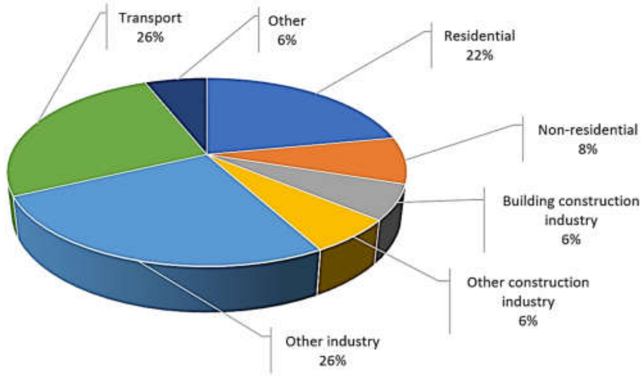

Figure 1. Energy consumption ratio among different buildings [5]

Conventionally, the primary energy loads in a building can be categorized into lighting, HVAC, and domestic appliances loads. Data analysis from different sources shows a repeated pattern of energy consumption distribution. The most energy is spent on the HVAC load, and the second highest amount of energy is consumed by lighting loads. HVAC energy consumption regularly doubles that of lighting and appliances, especially in developed countries [6-8].

As mentioned previously, there has been extensive research into building energy consumption and efficiency. For most energy auditing and modeling research, however, the data collection phase is primary. Mantha et al listed the various types of parameters that impact the final energy consumption of a building and analyzed five different data acquisition methods in terms of their applicability to these types of parameters [9]. The handling of data acquired with sensor-based plans is to be transferred to a database to be analyzed. There have been several studies into utilizing IoT technology for this task. In [10], for example, an IoT network with the Contiki operating system and the CoAP IoT protocol is simulated and analyzed. Or in [11], where a software architecture is designed to integrate heterogeneous data of building energy, enabling various features that were not feasible with only homogenous making energy data, such as a detailed geographical information system (GIS) map of residential areas that includes building energy supply and demand.

Research into the efficient energy consumption of buildings is also numerous. There are studies on the prediction of energy consumption in a building, the assessment of energy efficiency in a building, and various methods to maximize building energy efficiency. Energy forecasting per se is a topic of study with rapidly growing popularity, facilitated by the growth of Big Data, IoT, and machine learning [12]. Energy prediction technology is helpful for the proactive planning of energy distribution, generation, etc., maximizing general energy efficiency. This prediction can be performed using many techniques, whether statistical or machine-learning-based. For machine-learning-based procedures, many variations of neural networks, such as artificial neural networks, adaptive neural networks, recurrent neural networks, etc., have been utilized in predicting energy consumption with varying success [13-15]. A compilation and detailed analysis of different energy prediction methods can be found in [16, 17], and a publication focusing entirely on probabilistic forecasting can be found in [18]. Regarding efficiency assessment, Langevin et al. simulated and calculated the scaled impact of the best building efficiency measures [19]. In addition, Bakar et al. contrived the Energy Efficiency Index to evaluate the energy each student consumes with the HVAC system per square meter of a classroom [20]. This study also investigates the effectiveness of simply reorganizing classroom occupants' distribution in reducing energy consumption.

In this work, we have developed a system to acquire information on a typical floor in a school building. The system is being deployed and operated to obtain electrical information. It helps as a research testbed for energy data analysis in a specific building category. In section 2, the description of the system is presented. The hardware design of the field devices is introduced in section 3. The data collection scheme is provided in section 4. We discuss the analysis results in section 5. The work is concluded in section 6.

2. SYSTEM DESCRIPTION

2.1. The buildings

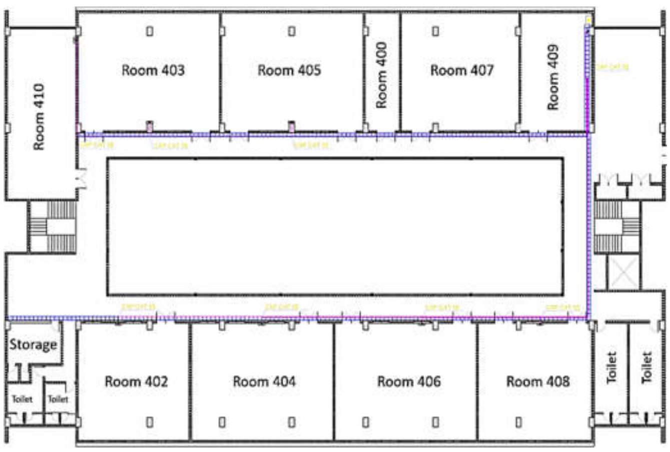

Figure 2. Floor layout under supervision

The monitored objects in this research are the school buildings in the Hanoi Vocational College of High Technology. The monitoring system was installed and operated on the campus's fourth floor of block D. There are eight classrooms, four toilets, and three additional rooms on this floor, as shown in Fig. 2. The eight classrooms, around 80 to 160- square meters, are the main focus of the systems.

The rooms are regular classrooms and laboratories where students conduct experiments to consolidate knowledge from the main class. Thus, besides the single-phase loads such as ceiling fans or lighting systems, they are also equipped with three-phase equipment like induction motors. Typical loads of the rooms are listed in table 1.

Table 1. Typical electrical loads in each room

Load	Rated power [W]	Number of phases
Ceiling fan	80	One
Fluorescent lamps	40	One
Desktop computers	60	One
Projector	300	One
Induction motor	200 ÷ 1500	Three
Experiment accessories	20 ÷ 200	Mix
Split air conditioner	5000 ÷ 6000	One

2.2. The system architecture

The system's overall architecture is presented in Fig. 3. The system includes field devices at the distribution board of each room, an embedded computer acting as a gateway, and a remote server. The field devices perform the tasks of monitoring and controlling the main power. They then send data to the central server via the gateway, which acts as an intermediate station in the network. A Raspberry Pi 4 is selected to work as the gateway. The last component in the system is the server which consists of the server applications and a server database.

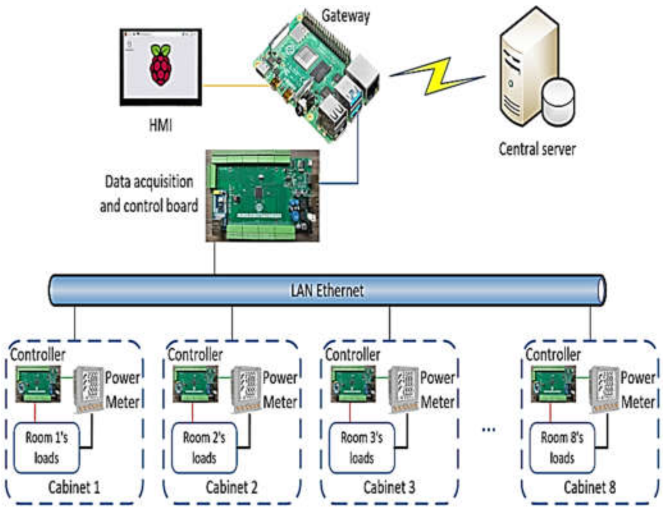

Figure 3. The overall architecture of the energy monitoring system

3. HARDWARE SETUP

The field devices are mentioned in Section 2.2. include power meters connected to a self-developed Data Acquisition and Control (DAQC) board, as shown in Fig. 4a. The board is equipped with a microcontroller unit, an Ethernet module, and a power supply unit, as illustrated in Fig. 4b. The Selec MFM384-C multifunctional meter is utilized in this study to measure various electrical parameters such as single-phase or three-phase voltages, currents, power factor, active power, reactive power, etc. In addition, contractors can switch on/off the main power of single-phase and three-phase loads remotely via the DAQC board. Due to the current distribution system installation within the buildings and the requirement of load operation, the control task is not yet fully activated.

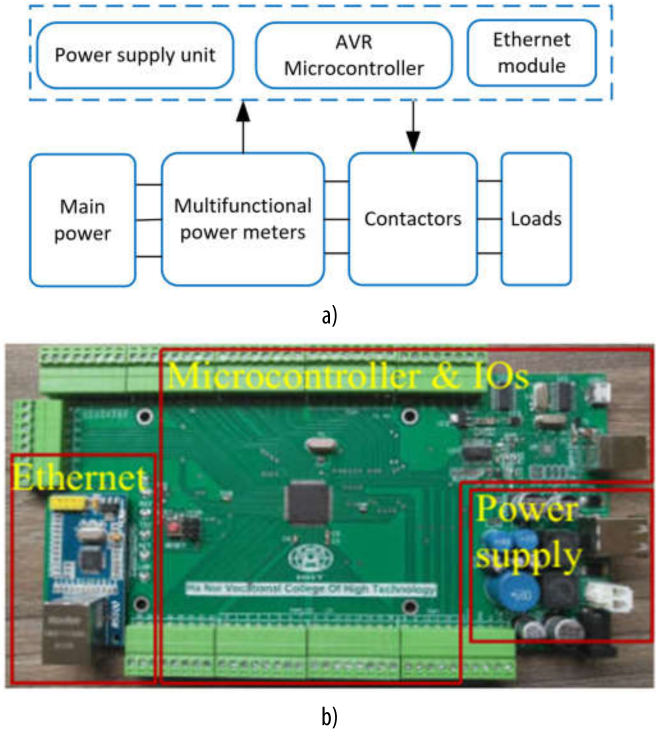

Figure 4. (a) Field device connection and (b) Data acquisition and control board

4. DATA COLLECTION SCHEME

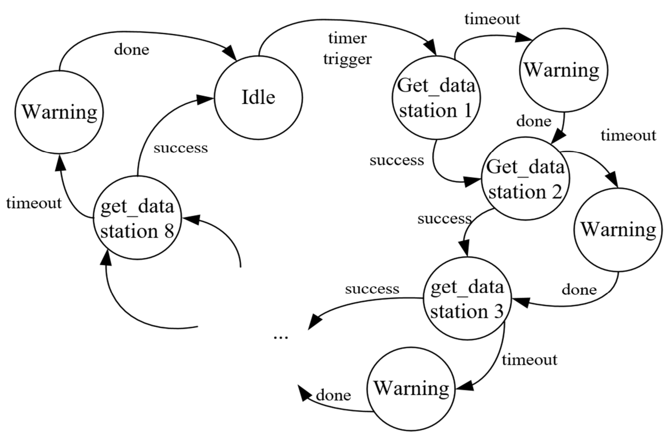

Figure 5. Round-robin transition to poll DAQC board

Data collection is performed in a round-robin approach, in which the server periodically polls each DAQC board in a preset sequence, as shown in Fig. 5. The board then acquires sensor measurements from the power meters over Modbus RTU via RS-485. The values are packed into a single message and transferred to the gateway. A Python-based application is deployed in the gateway to gather the data from different DAQC boards and forward it to the central server.

The data is also stored locally at the gateway in case the connection to the server is lost. A MySQL database is adapted to keep the information locally and on the central server. The database schema is illustrated in Fig. 6, which includes four tables. The table named building_info consists of metadata on the distribution board where our devices are installed. Each distribution board may contain a few sub-meters and contactors to observe and control the power of different rooms or different parts of the rooms. Measurements of each sub-meter are stored in a separate table. The control actions performed by the DAQC boards are also recorded with their respective timestamp.

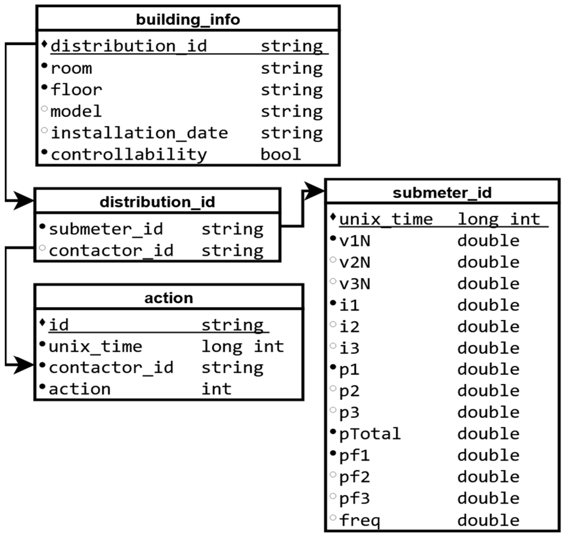

Figure 6. Database schema at the gateway and the central server

5. DATA ANALYSIS AND DISCUSSION

The data for the area of interest has been collected over three months. The system was installed and operated during the summer, so some rooms were under-utilized. Fig. 7 shows the daily energy consumption of the two rooms being monitored. Room 402 was sometimes used for meetings, while room 403 was used more often for teaching activities and conducting experiments.

The hourly power consumption of eight rooms is shown in Fig. 8. Generally, for typical school buildings, the loads in all the rooms consumed the most power during working hours, from 8AM to around 6PM. However, the usage patterns vary from room to room as they are employed for different purposes and contain other electrical loads. The proportion of energy consumed in the eight rooms are illustrated in Fig. 9. Another pattern can be observed: significant power consumption after working hours. This consumption can be attributed to parasitic loads or to the fact that critical loads like computers and air-conditioners were kept on, with the latter serving to maintain a proper temperature and humidity to obtain good ambient conditions for experiment equipment. This finding requires the building operator to look for energy-saving solutions. Potential approaches can be to optimize the current system's operation by increasing the temperature set point whenever possible or enhancing the air conditioning and ventilation system with a better coefficient of performance (COP).

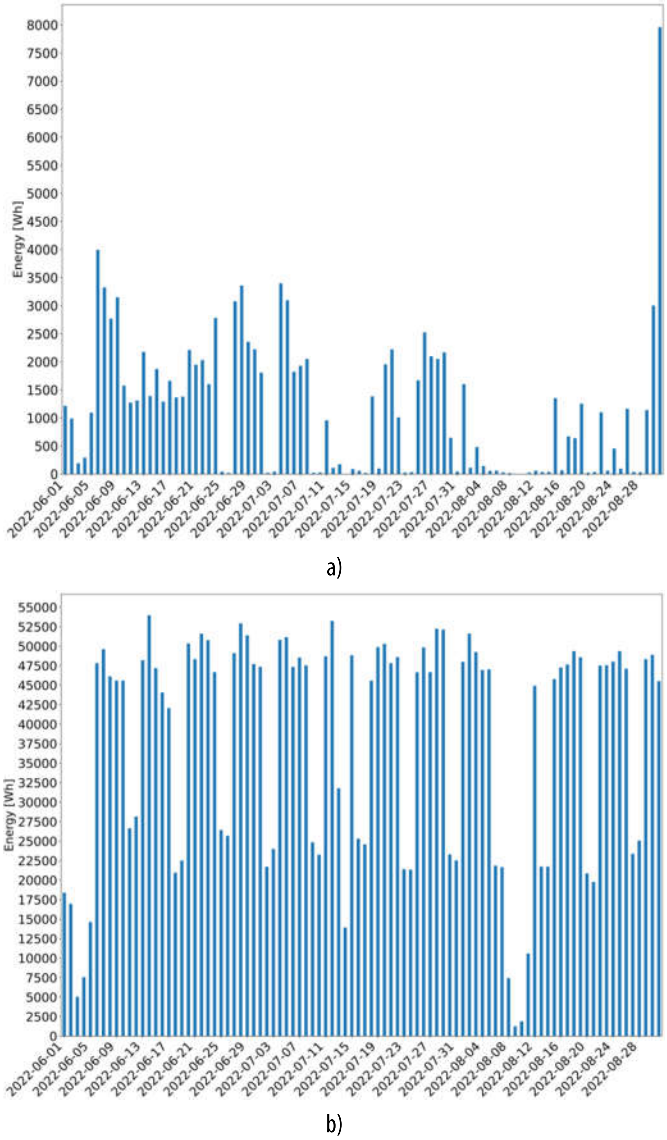

Figure 7. Daily energy consumption of Room 402 (a) and Room 403 (b)

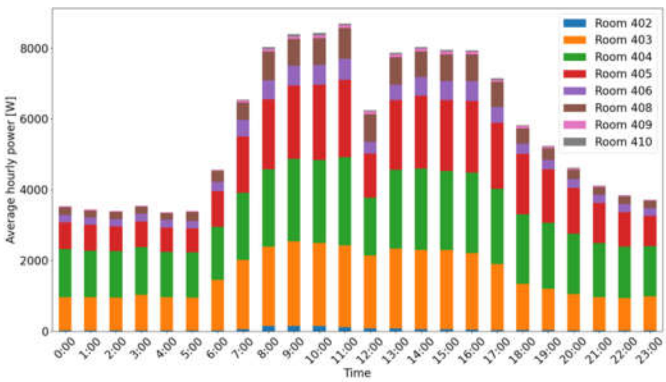

Figure 8. Hourly power consumption of different rooms on the 4th floor over three months

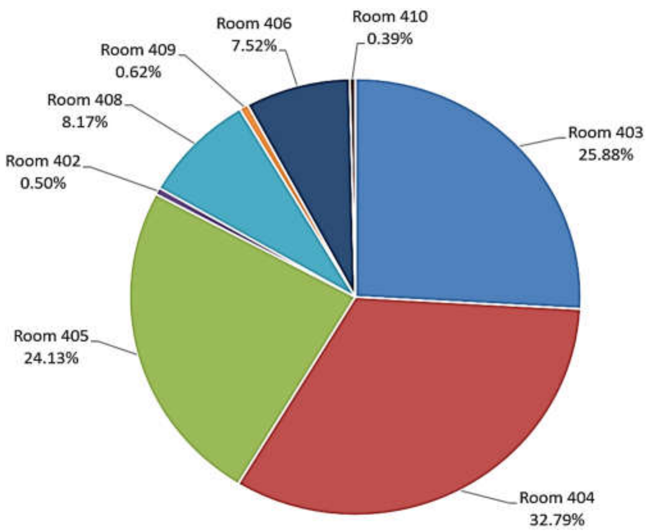

Figure 9. Energy consumption ratio of the eight rooms in August 2022

6. CONCLUSIONS

In this work, a power monitoring system has been developed. The data set of a school building is collected. The initial analysis helps the building operators and users understand the current energy consumption situation. Further extension of the system will be carried out to collect information on all the buildings and the campus of our college. The comprehensive data set over more extended periods can be opened to the public for exploration of the behavior of the institution building type. Future research also includes applying machine learning techniques to diagnose the problems in the distribution network and predict the energy demand.

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