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Optimal Energy Management System in Thailand Convenience Stores

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ABSTRACT

The purpose of this research is to study and investigate the energy consumption and reduction of convenience stores. There is one retail building that is increasing rapidly in Thailand every year, and almost all of them operate 24 hours per day. There is a significant amount of energy consumption. This research is to present an updated energy portion of convenience stores through sampling at 13 stores. These stores have a sales area of 153 to 311 m^2 and operating hours of 16 to 24 hours per day. We found that energy consumption recorded from the Digital Energy Meter shows that all of them have cooling systems that use a huge portion of energy (refrigeration and air conditioning systems, 48% and 24%, respectively). Moreover, this research aims to develop a Retail Energy Management System (REMS) to increase the energy efficiency of air conditioning systems at convenience stores in Thailand while still maintaining comfort for occupants by keeping the required temperature at 26 degrees Celsius. We selected 3 of 13 stores that have the same sales area of 280 m^2 but different operating hours and numbers of air conditioners. We optimized the operating air conditioning system by data-driven with the Internet of Things system concept, which manages and controls the air conditioning system through the Programmable Logic Control (PLC) program. REMS can reduce energy consumption by 24 and 15 kWh/day, or 14.5% and 8.3%, at operating hours of 24 and 16 hours per day, respectively. There is an average return on investment (ROI) of 3-5 years, depending on the operating hours of the store. In the future, regarding the infrastructure of energy management systems, that can extend to finding some opportunity to save energy consumption in another system, for example, the refrigeration system of their convenience stores.

1. Introduction

One country that would like to have carbon neutrality in the year 2065 is Thailand. Now, they have been increasing their energy use every year, especially electrical energy consumption. The commercial sector was accountable for about 22% of all electricity use in Thailand [Energy Statistics of Thailand in 2022; www.eppo.go.th]. The improvement of energy consumption in this commercial sector was necessary and challenging for the investigation. The investigation focused on the energy

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use of retail stores, which has increased every year and is estimated to account for 13% of the energy consumption and around 7% of the GDP of the total commercial sector in Thailand [1]. Convenience stores are one of the business sectors, and they are increasing rapidly every year because the consumer lifestyle in Thailand has changed to a comfortable and easy way of life to access convenience stores. Most convenience stores are in community centers or roadside commercial buildings to provide services for selling various products that are cheap consumer goods available and located in both rural and urban centers in each community. The information updated in the year 2023 indicates that convenience store outlets in Thailand have more than 20,000 stores in the whole country. Moreover, most convenience stores are open from 16 to 24 hours, which consumes a massive amount of energy.

The energy ratios used by convenience stores in Thailand that ranked from high to low were air conditioning systems at 46.2%, equipment (for heating and refrigeration purposes) at 34.6%, and lighting at 19.2%, respectively [2]. However, convenience stores in Taiwan are like those in Thailand. They have a ratio of load equipment capacity as shown in Figure 1(a) [3] and Figure 1(b) for a department store, and the majority of energy consumption is HVAC [4], as shown in convenience stores below.

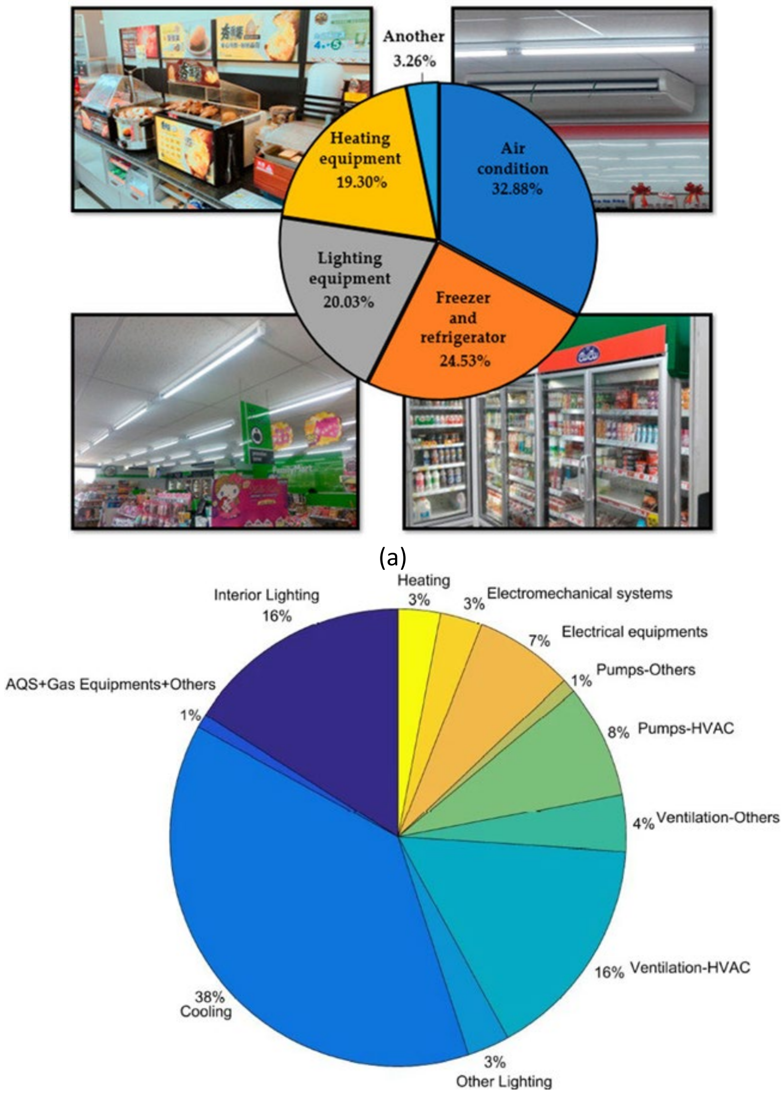


Fig. 1. Proportions of energy use (a) Convenience stores (b) Department stores

Operating smaller convenience stores (sale area <280m^2), it seems likely that the higher energy intensity supermarkets or hypermarket stores [5]. Energy consumption in convenience stores depends on the business area, size of stores, amount of equipment, especially refrigeration and freezers, and the operating time of store equipment [3].

Although energy efficiency should be developed in each system, the integration of each system is necessary. This research considered using Energy Management Control (EMCS) or Energy Management System (EMS) to save energy by integrating some parameters of management and control. EMS can be operated automatically or semiautomatically according to various control logics or developed functions and can be used to control the power usage of buildings by using the technology of the Internet of Things (IoT). We especially focused on the reduction of air conditioning systems because we would like to increase energy efficiency more than changing the type of system from fixed speed to inverter.

An EMCS is a centralized control system intended to operate a facility's equipment efficiently. These systems are also known by a variety of other names, including "energy management system" (EMS), "smart building controls," etc. A system typically has a central computer, distributed programmable controllers, and a digital communication system. The communication system may carry signals directly between the computer and the controlled equipment, or there may be tiers of communication. EMS has been applied to reduce energy consumption and monitor some parameters in homes, buildings, factories, and communities. The Home Energy Management System (HEMS), which started this research, has accomplished an idea from an energy management system. The concept of HEMS is a smart network control system that can integrate all power generation, power consumption, and management, which can improve the power efficiency of users, change the power consumption habits of communication with the grid, and provide two-way energy flow. Integration of renewable energy generation and home energy storage systems with HEMS has an architecture as shown in Figure 2 [6]. The main benefit of HEMS is saving energy costs, which meets the target aspect of comfort and convenience for occupants [7]. HEMS has monitored the behavior of the load profile in their home. The researcher's contribution to HEMS usually proposes a model to control and manage energy consumption by optimizing the scheduling of loads and integrating renewable power generation; EES, which optimizes problems by using a mathematical model such as mixed-integer linear programming (MILP) [8,9], a linear regression model with the result of saving 19% [10], PSO, and GA, which achieved 27.32% and 31.42% reductions in energy consumption, respectively. [11] Moreover, shifting load from peak to off-peak avoids a high price period. [8,12,7] The devices in the house are connected to the IOT system to enable monitoring and control. The energy consumption of the home is also consistent with the power reserved in the battery from the solar power supply. During times of high power consumption, the system will be able to effectively control the reserve power consumption, such as during the peak time of the vehicle battery charge or high power consumption from home appliances. All energy consumption is recorded on the meter. This makes it possible to know the energy consumption behavior of residents and create new solutions to reduce energy consumption by controlling the operation of the equipment. And can also reduce the cost of energy consumption to be stable as well. When the housing is larger and has more equipment and rooms that are proportional to large buildings, the energy management system developed for use in the building is called the building energy management system (BEMS). BEMS has an architecture, for example, as shown in Figure 3 [13].

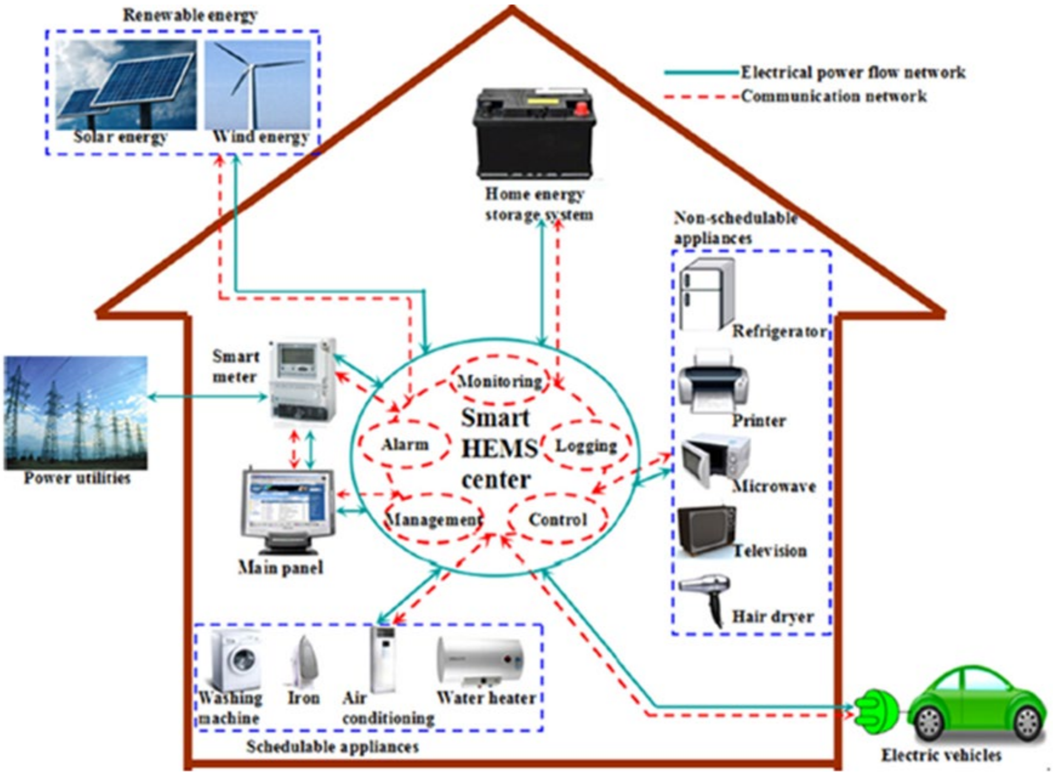


Fig. 2. Home energy management system (HEMS)

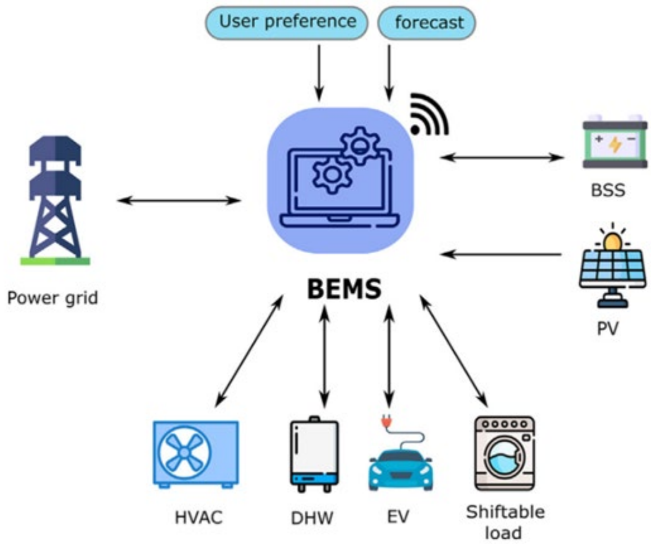


Fig.3. Building Energy Management System (BEMS)

The main objective of BEMS is to monitor, control, and manage energy consumption in buildings with higher efficiency than traditional systems. The best BEMS will make users feel comfortable when they live inside buildings. BEMS usually installed smart meters and sensors for monitoring, which used the technology of the Internet of Things (IoT) to connect their sensors and smart meters. They can communicate and receive feedback on some commands with the controller unit, which is an important unit of EMS to achieve energy reduction. BEMS is installed in large buildings that have other machines or appliances, for example, heating, ventilation, and air conditioning systems (HVAC). General HVAC in large buildings, such as chillers, is controlled to suit multiple rooms and various types of power reserves. Likewise, cold water production can be controlled by producing cold water stored in it with heat recovery during off-peak or night, which can reduce peak power consumption during the day or at peak. Buildings would like to manage demand response scheduling runs on the controller and deliver limited energy between appliances based on energy consumption data, user target price (UTP), and real-time electricity prices from their vendors. It controls the working status of all appliances in the buildings by adjusting the turn-on and off times of appliances and machines in response to variable electricity prices or to avoid peak periods of high energy prices [14]. Appliances in the building can be divided into schedulable and non-schedulable appliances. BEMS can be shifted to schedulable appliances operating at low electricity prices, but should consider the comfort index of occupants [15]. Moreover, an energy management system usually installs a sensor to measure the focused parameter for controlling the system [14] that needs to save energy consumption and improve the efficiency of the system by about 62% and 50%, respectively [16].

As presented in many research papers, BEMS has always focused on heating, ventilation, and air conditioning (HVAC) systems because this system is one of the largest energy consumers in the building. Therefore, research about energy-saving technology is essential [17]. Data-driven online energy management for HVAC systems involves streamlining the modeling process and improving the accuracy of temperature estimation, as shown in Figure 4. It also formulates a model predictive control (MPC)-based HVAC scheduling strategy to optimize HVAC operations and reduce energy consumption and peak power demand. Total energy consumption in both HVAC cooling and heating operations decreased by 4.9% and 30.2%, respectively [18].

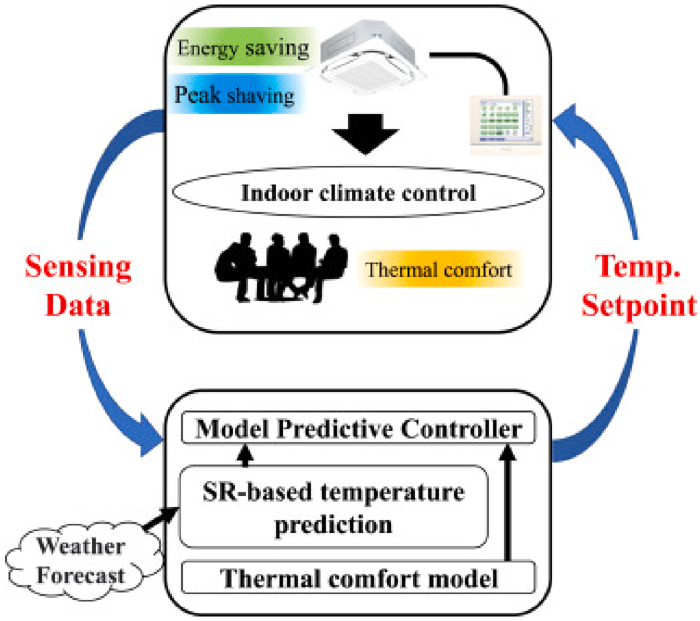


Fig. 4. Overview of HVAC energy management framework

An adaptive temperature control approach that simultaneously improves the occupant's thermal comfort at a workplace can achieve a significant energy savings of 9.98% within the desired temperature range by reducing the preferred upper limit of the temperature range by 3oC compared to current standards. The algorithm further reduces energy consumption [19]. By integrating data-driven MPC into existing BEMS, the study proposed a control modification strategy that is lightweight and replicable to increase the energy efficiency of HVAC systems in existing buildings. The average daily energy usage of the system was lowered by 24.5% [20]. In addition, model predictive control (MPC) proved to be the most efficient approach for enhancing the energy efficiency of air conditioners equipped with a variable speed drive (VSD). The proportional-integral-derivative (PID) control method yielded an energy efficiency ratio (EER) of 5.7. Through the utilization of MPC, the AI system hosted on the cloud was able to enhance the EER value to 6.22. An energy efficiency improvement of up to 9.12% was attained [21]. An energy management system that adjusts cooling levels based on occupancy can effectively reduce energy use in unoccupied rooms. The research study [22] was conducted by employing battery-powered wireless sensor nodes. After evaluating a ten-room initial deployment, they have concluded that their choice of sensors and occupancy detection algorithm can accurately detect the presence of inhabitants. By employing this occupancy data as input for a building simulation model, it is feasible to attain a decrease in HVAC energy consumption ranging from 10% to 15%.

In the last decade, there has been no research that has presented an update on the energy portion in convenience stores in Thailand and how to reduce energy consumption by using an energy management system (EMS) and the Internet of Things to help gather data and use these data to control energy consumption reduction in the air conditioning system by changing cool mode to fan mode when the desired sale area temperature meets the target. Then, in this study, we focused on it, and the result of the study can extend to implementing the same concept in another convenience store to reduce energy consumption, carbon emissions, and energy costs. Moreover, it can increase profitability on the other side for their customers.

2. Methodology

2.1 Energy Portion of Thailand Convenience Stores

This research aims to investigate and analyze the energy consumption of 13 convenience stores opened 16 to 24 hours per day, 7 days per week. There is a sale area of 153 to 311 m^2 and a typical layout as shown in Figure 5 below, which consists of inverter air conditioning (4 to 7 units), chilled and freezer refrigeration cabinets, batten LED and track light tubes, heating food appliances, an ice maker at the back of the house, a coffee maker, LED monitors, a POS system, etc. The result of this study finds that the average proportion of energy consumption in each system is total: air conditioning, refrigeration, and others, including lighting systems.

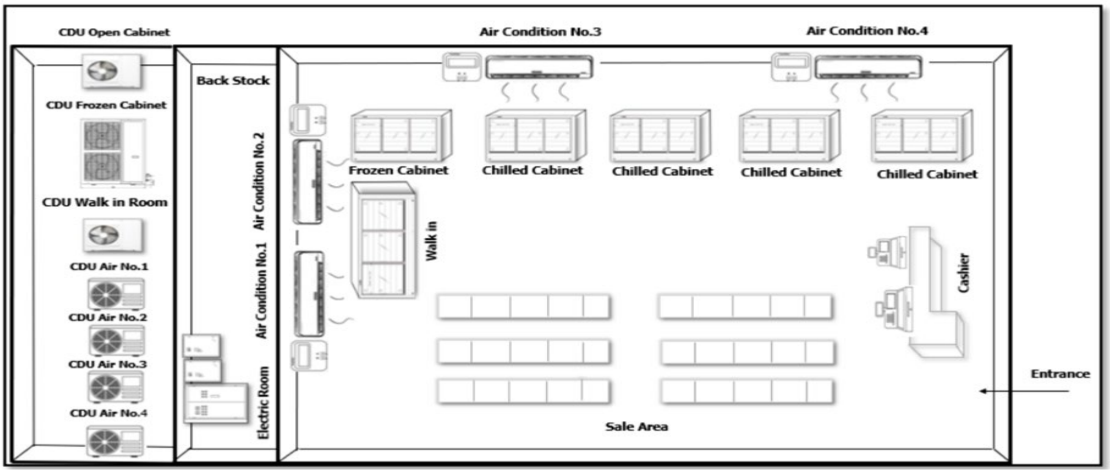


Fig. 5. Typical layout of a store focused that there is inverter air conditioning 4 units

The research installed a digital energy meter with three points that measured the energy consumption of the total air conditioning and refrigeration systems, respectively. However, the energy consumption of others, including lighting systems, can be calculated by the total deleted air conditioning and refrigeration systems. All digital meters are connected to a data logger to record their energy consumption for 7 days and send data from their stores to the cloud by using the Internet of Things system. Finally, the author can easily consolidate and calculate the average percentage energy portion of these stores.

2.2 Study Strategy for Optimization to Reduce Energy Consumption of Air Conditioning Systems

This research selected 3 of 13 focused convenience stores that have a similar sales area of 280 m^2 to study the results of the proposed optimized model for controlling and operating an air conditioning system and inverter air conditioning at 10.55 kW, whose sale area is required to be 26 degrees Celsius. Details of quantity and operating hours are given in Table 1 below.

Table1
Detail of convenience stores

Store	Quantity of A/C (Units)	Operating hours per day
A	6	24
B	7	16
C	7	16

2.2.1 Installation of hardware as proposed architecture at focused convenience stores

The energy management system proposed architecture in this research installed hardware and software of the Retail Energy Management System (REMS) for experimental purposes in this study. The main hardware materials are equipped in convenience stores as follows:

i. Indoor temperature (T_{in}) at the near center of the sale area to measure indoor temperature as a reference with measuring range 0-50 ^oC and accuracy temperature ± 0.5 ^oC.
ii. Outdoor temperature (T_{amb}) in front of the store but must not contact directly with sunlight to measure ambient temperature. This sensor is a duct temperature sensor that measures from -30 ^oC to +70 ^oC with an accuracy of ± 0.5 ^oC.
iii. A digital energy meter to measure power (kW) and energy consumption (kWh) of air conditioning, refrigeration, and a total of stores with technical specifications as detailed in the front panel mount, 96 x 96 mm. form factor, Easy Logic VAF Power and Energy meter with RS-485 communication and odd harmonics up to 15^{th} order. Complies with accuracy class 1.
iv. The interface card of the air conditioning has the function of communicating commands for operating control between the programmable logical controller and the air conditioning unit, which communicates Protocol Modbus RTU (RS485) or DIII-Net.
v. The Programmable Logical Controller (PLC) must send commands to control the air conditioning unit as per the user's requirements. This equipment is a Modbus RTU.
vi. Master Controller with Linux Server is a datalogger that can collect all energy data and record all commands of Modbus RTU equipment. At the same time, it is IoT to connect with the cloud through the Internet.
vii. Uninterruptible Power Supply (UPS) is an electrical apparatus that provides emergency power to a load when the input power source or mains power fails or power back out.

Each piece of equipment in the energy management system is connected by RS-485 communication wiring. The overview layout is shown in Figure 6, and the control cabinet is in Figure 7 below.

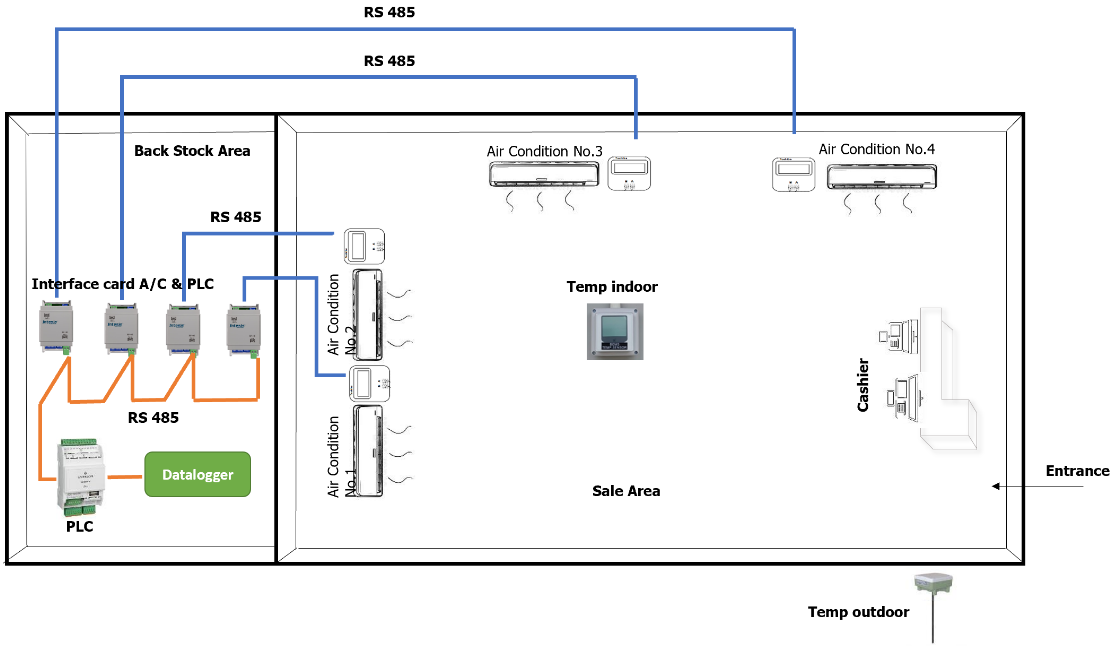


Fig. 6. Architecture of optimal Energy management system of Air conditioning system (A/C)

(a) (b)

Fig. 7. BEMS Master Controller cabinet (a) inside (b) outside with monitor of digital meters

Software installation as proposed EMS for optimal A/C operation to reduce energy Regarding the research aims to A/C energy reduction by EMS concept. The author provides logic control for A/C units in Thailand convenience stores. And study how much savings we will get from this model through installation software. Software is installed in a Programmable Logical Controller (PLC). Software called Logic Control has a flowchart for optimally operating A/C systems, as shown in Figure 8, which can explain the logic control as follows:

i. Selector EMS is turned on. All A/C units will turn on and run in cooling mode.
ii. The interface card will measure the return temperature in each A/C unit and average it. This process will occur every 30 seconds.

iii. If the average return temperature ($T_{avg, Return}$) is under the requirement temperature (26 degrees Celsius), PLC will send a command to the interface card to adjust A/C No. 1 from cooling to fan mode
iv. After that, the system averages the return temperature again, which is under the requirement temperature of 26 degrees Celsius. PLC will send a command to the interface card to adjust A/C No. 2 from cooling to fan mode. The system will check by looping until they found that the average return temperature is over the required temperature (26 degrees Celsius). PLC will send a command to the interface card to adjust A/C No. 1 from fan to cooling mode.
v. To avoid concern about the heat load and thermal comfort experience of the occupant, The system operated an A/C unit in cooling mode all the time.
vi. When the system must change from cooling to fan mode, they select an A/C unit that has the maximum working hours and the minimum return temperature.

The average return temperature of the A/C system in this study from Eq. (1) is as follows:

$$T_{avg,Return} = \frac{T_{Re,AC1} + T_{Re,AC2} + \cdots + T_{Re,ACn}}{n} \quad (1)$$

where average return temperature of the A/C system, $T_{avg,Return}$, return temperature of A/C unit number 1, $T_{Re,AC1}$, return temperature of A/C unit number n, $T_{Re,ACn}$ and quantity of A/C unit in stores, n respectively.

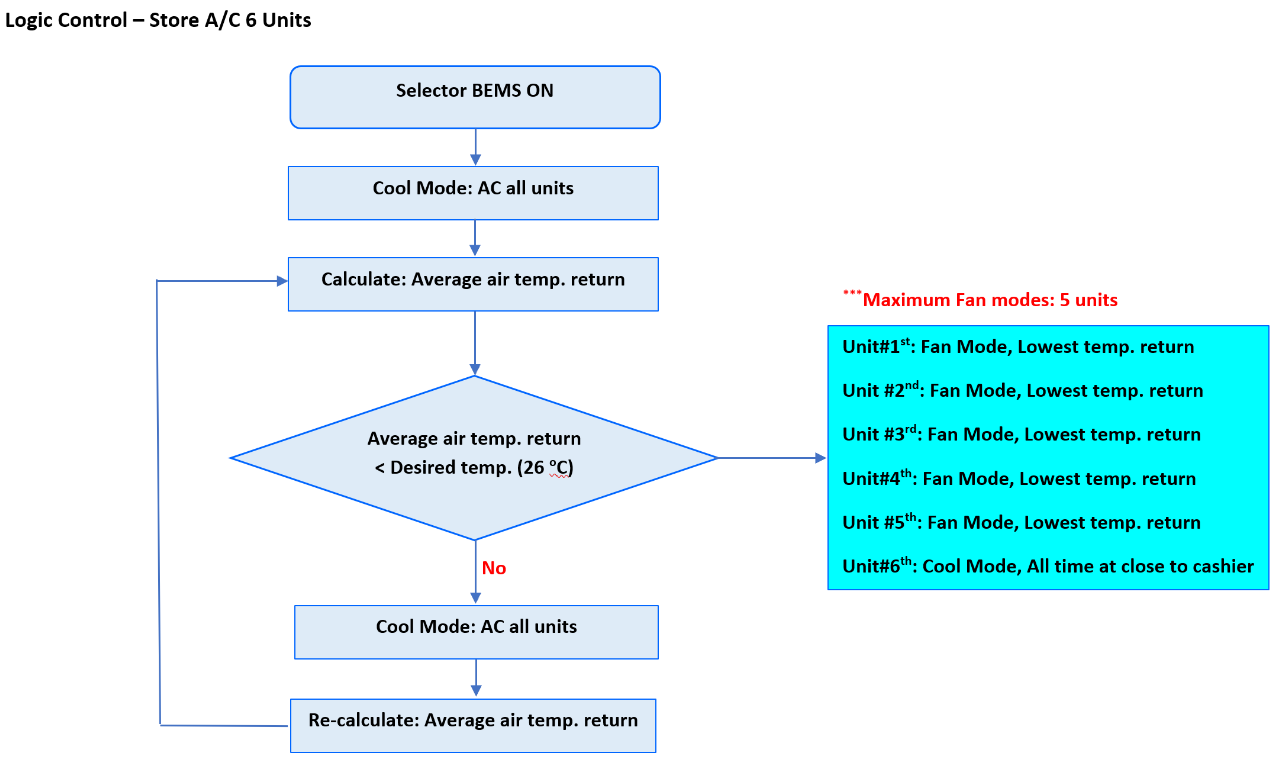


Fig. 8. Proposed Retail Energy Management System (REMS) Logic Control

2.2.2 Monitoring experiment data pre and post implemented energy management system

The author monitored and collected experiment data automatically from the cloud through the Internet system because of the benefits of the proposed Internet of Things (IoT), as shown in Figure 9 below. Data is collected, such as indoor, outdoor, and average return temperature of A/C, and the status of air conditioning (cooling or fan mode) in each unit to re-check the logic control and energy consumption (kWh) of all digital meters. Moreover, this study analyzes data only for the operating-hour period. After installation is complete, data is collected pre- and post-implementation on the strategy of the energy management system proposed by the author to find out the energy savings of this proposed model.

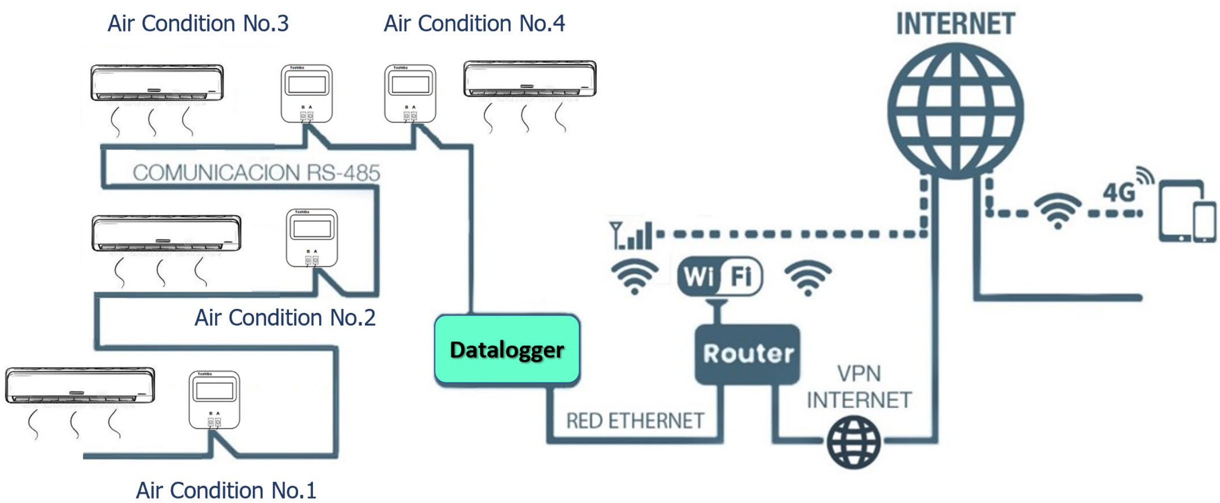
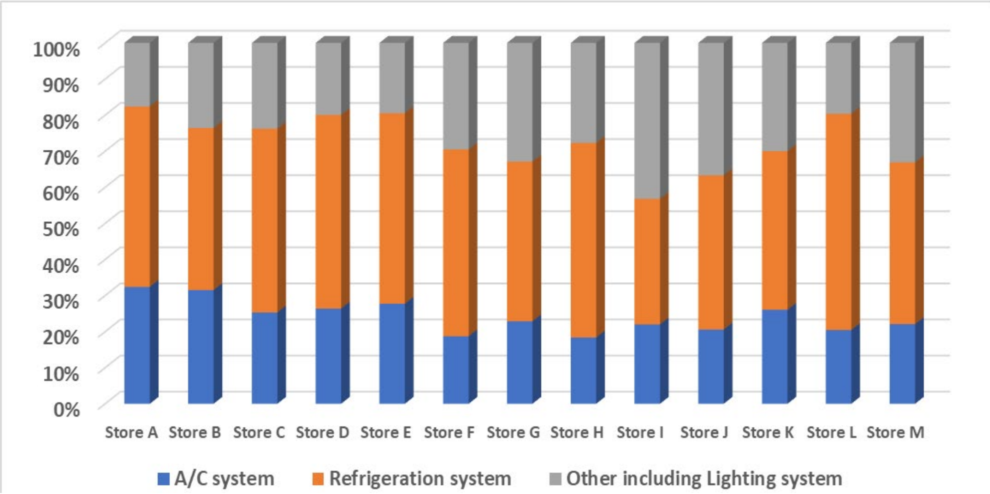


Fig. 9. Monitoring with the Internet of Things

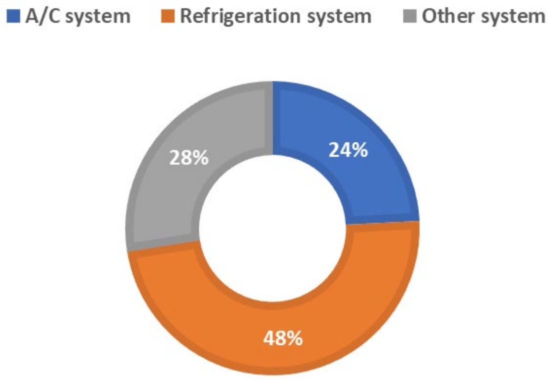
3. Results

3.1 Energy Portion

This section discussed the results of the energy portion of 13 focused convenience stores obtained from the energy consumption of the measurement study. The energy portion in each convenience store is in the same trend that can rank the average energy portion in each system from high to low, as follows: 48% refrigeration, 28% other systems, and 24% air conditioning, respectively, as shown in Figure 10 below. By the way, the average energy portion of all focused convenience stores in this research was different from other research [4–5, 16]. Recently, almost all convenience stores had energy consumption in refrigeration higher than air conditioning systems because of their lifestyles. Customers have changed that effect, so convenience stores should supply their goods sufficiently to meet customer demand. Then, the number of chilled and freezer cabinets was higher than in the past. Moreover, recently we implemented air conditioning with new technology, such as an air conditioning inverter, that can reduce energy consumption from traditional air conditioning systems such as fixed-speed compressors.



(a)

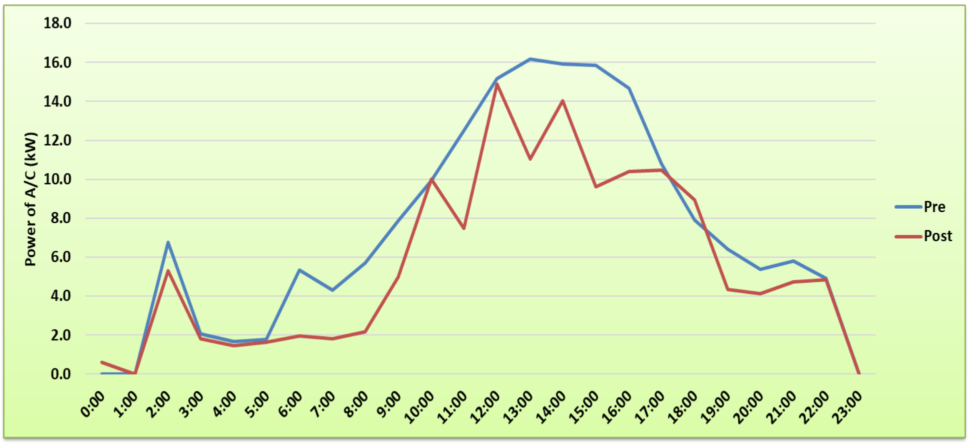


(b)

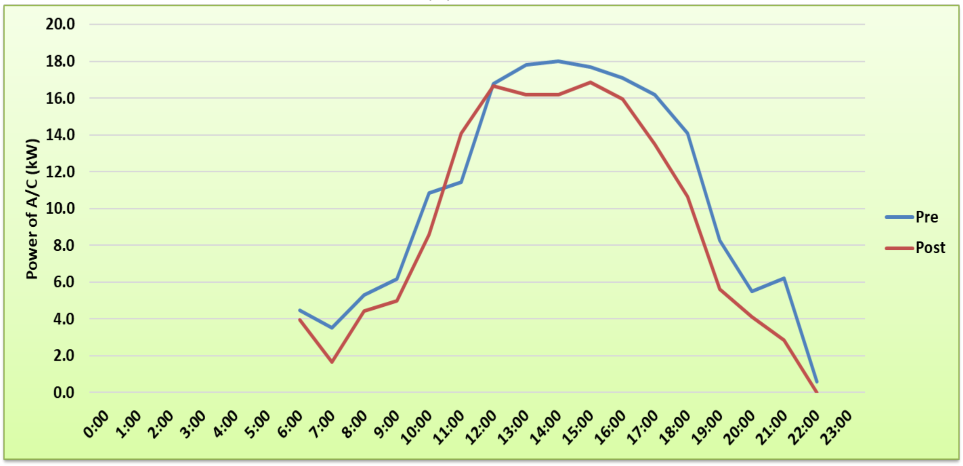
Fig. 10. Percentage energy portion (a) Detail of 13 convenience stores (b) Average energy portion

3.2 Energy Consumption of Air Conditioning System Pre and Post-Study Model Implementation

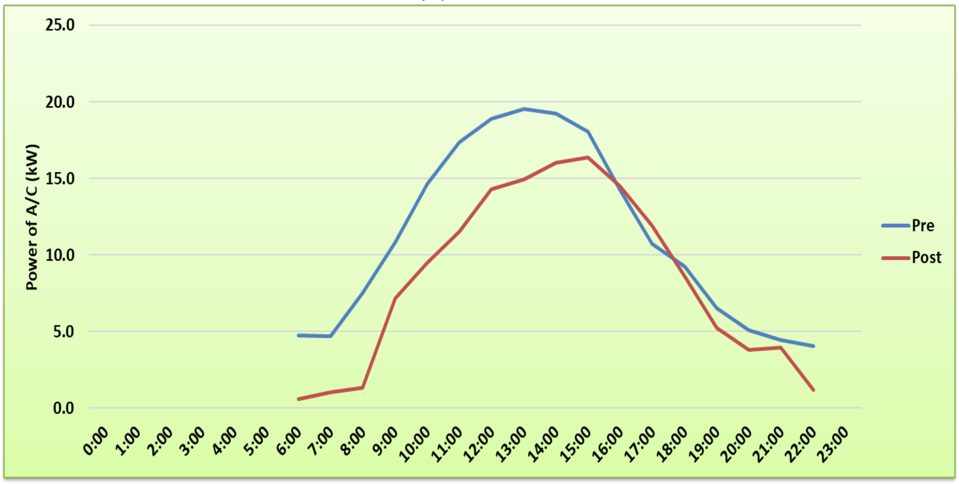
The results that show the proposed optimal energy management system of the air conditioning model can save energy consumption are different because of store operating hours, the number of air conditioning units, and the outdoor temperature in each store. All stores had pre-energy power much greater than the post-energy power shown in Figure 11(a) Store A, Figure 11(b) Store B, and Figure 11(c) Store C, respectively. Because the post-condition had a working compressor less than the pre-condition from the logic control of the proposed optimal energy management system model in this study, Figure 12, 13, and 14 show the status of the working compressor at the pre- and post-period of the experiment. In the As-Is period, the compressor turns on all the time, but the post-condition compressor turns off when the conditions meet the criteria.



(a) Store A

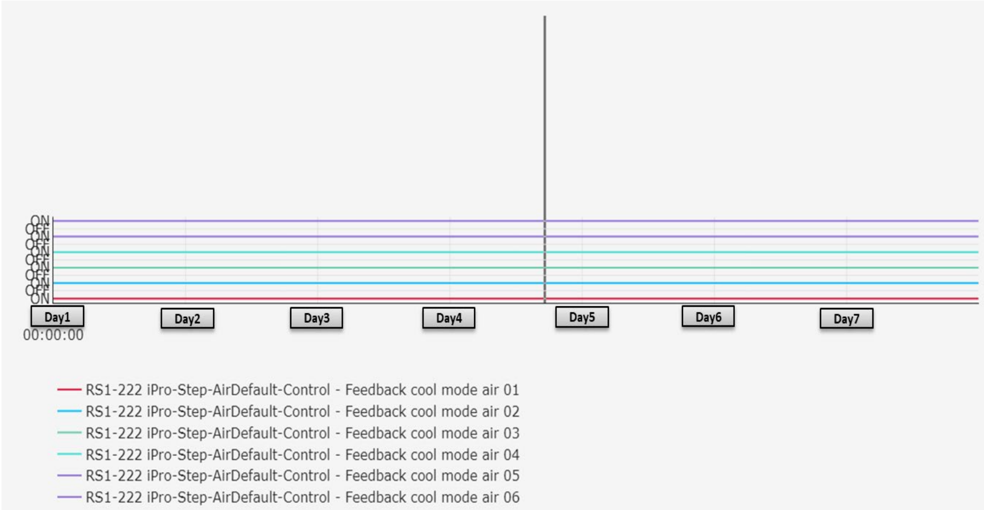


(b) Store B

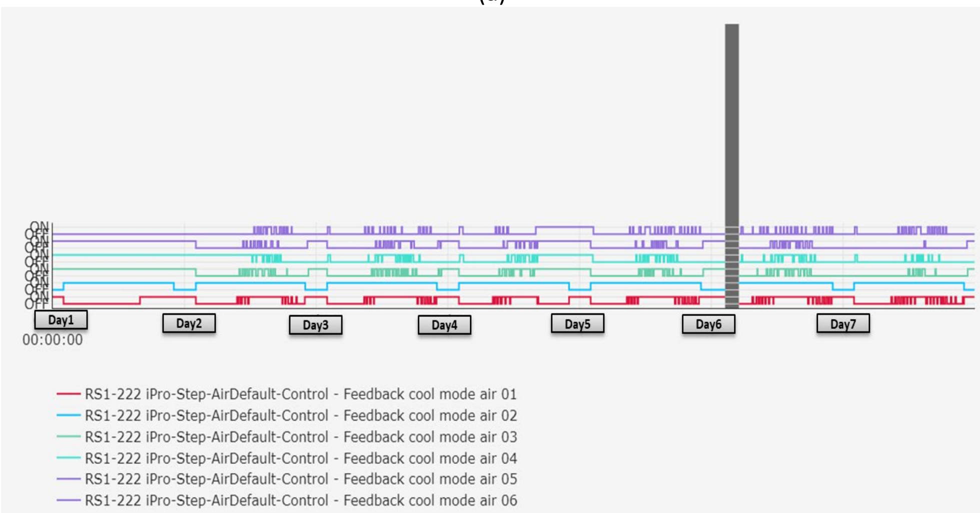


(c) Store C

Fig. 11. Energy power (kW) in each store

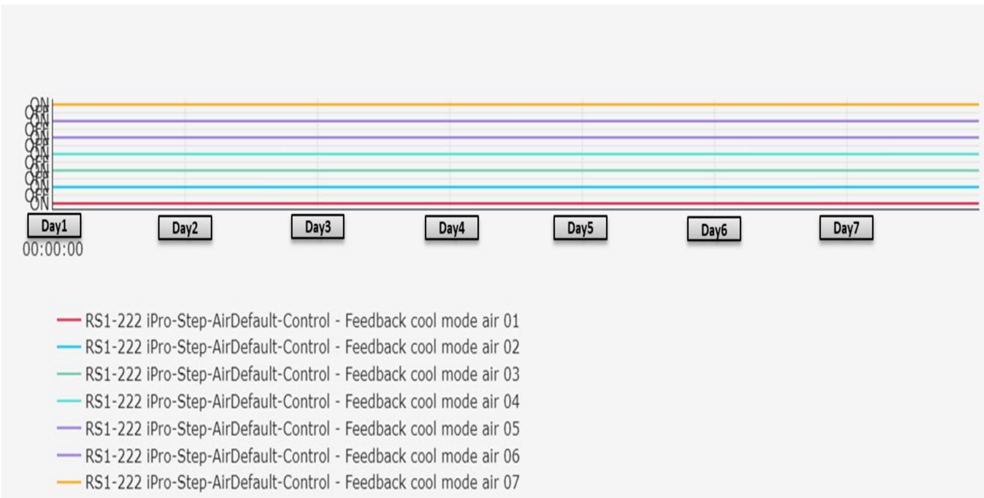


(a)

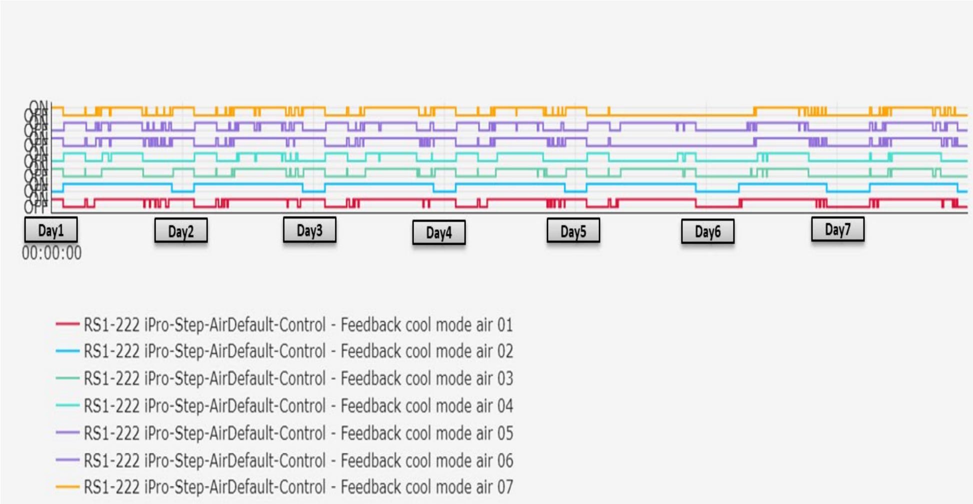


(b)

Fig. 12. Status of the working compressor at pre and post-period of Store A (a) Pre and (b) Post

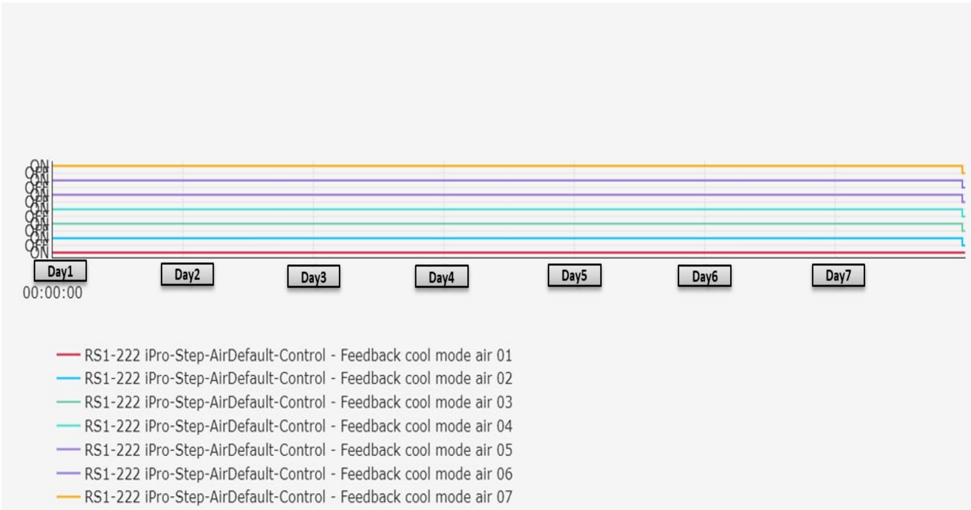


(a)

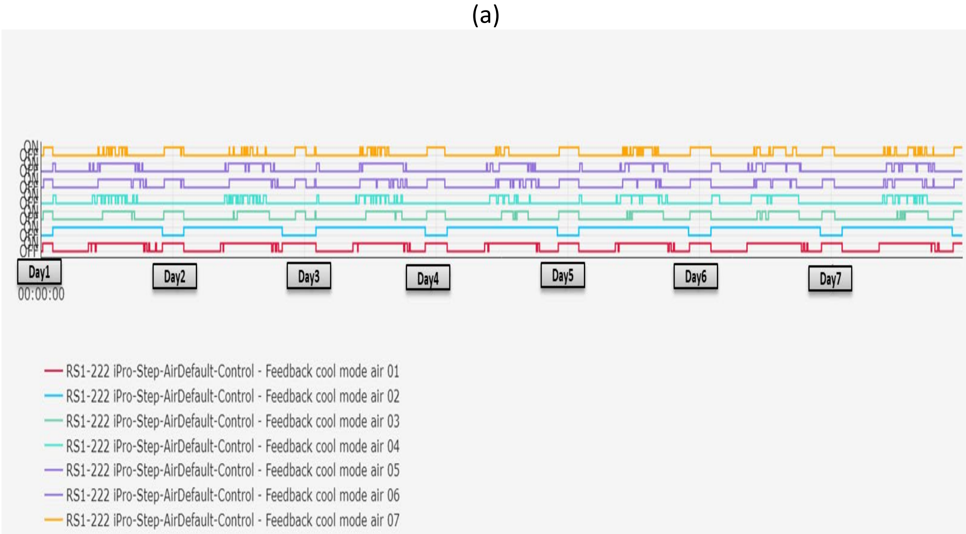


(b)

Fig. 13. Status of the working compressor at pre and post-period of Store A (a) Pre and (b) Post



(a)



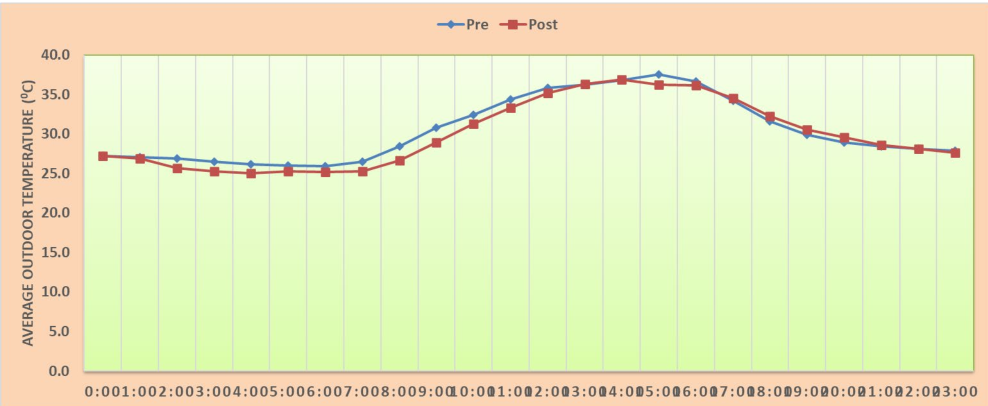
(b)

Fig. 14. Status of the working compressor at pre and post-period of Store A (a) Pre and (b) Post

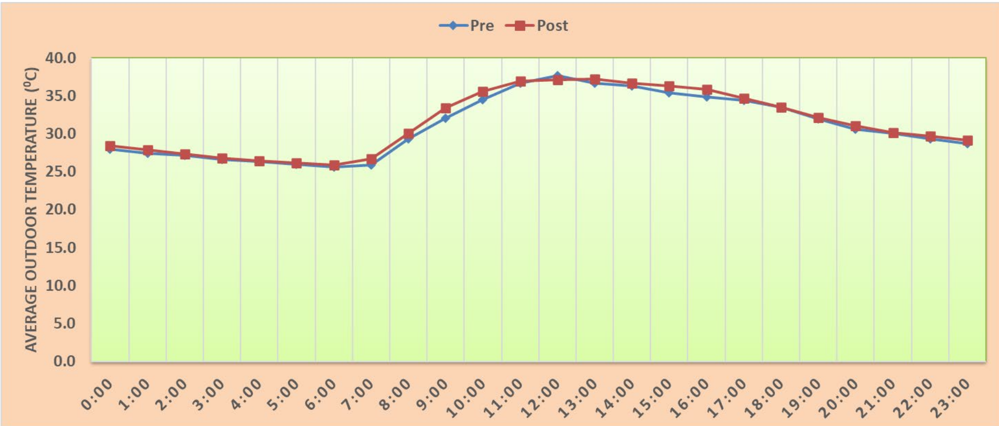
The percentage of energy saved in this study is shown in Table 2. It explained that energy savings depend on the operating hours of the store, the number of installed air conditioning units, and the outdoor temperature. Store A operated much more than Store B, so energy savings were about 9.4 kWh/day. Store C should be energy-saving close to store B, but in this study, store C had energy-savings higher than store B because store C had a pre-outdoor temperature of 6 a.m. to 3 p.m. that was higher than the post-period. Then, the saving at this interval is higher than the truth. The results of the outdoor temperature of pre- and post-period in each store are shown in Figure 15: (a) store A, (b) store B, and (c) store C, respectively.

Table2
Detail of Energy consumption and saving

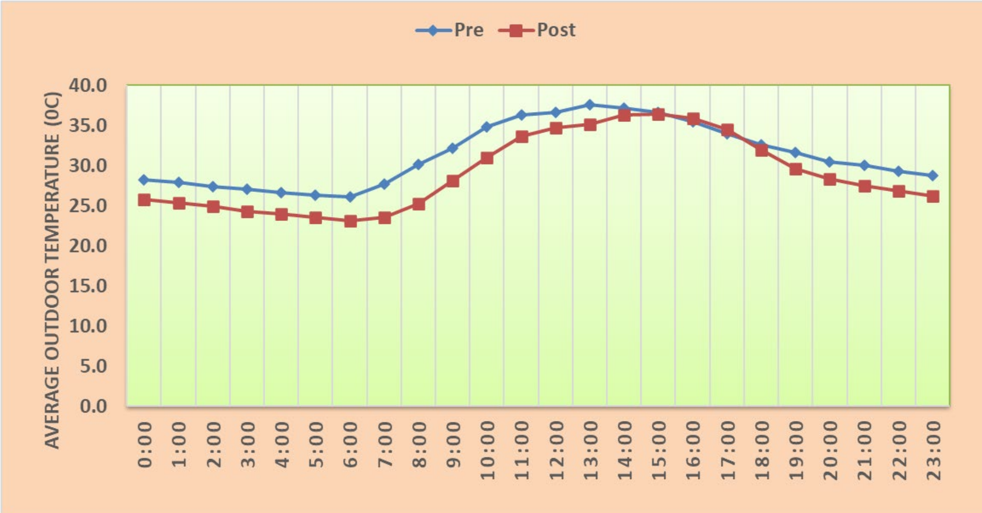
Store	Pre-Energy per day (kWh)	Post-Energy per day (kWh)	Energy saving per day (kWh)	%Energy saving
A	168.2	143.9	24.3	14.5%
B	179.2	164.3	14.9	8.3%
C	182.2	147.1	35.1	19.3%



(a) Store A



(b) Store B



(c) Store C

Fig. 15. Outdoor temperature at pre- and post-condition (°C)

4. Conclusions

The recent energy portion in convenience stores is in the same trend that can rank the average energy portion in each system from high to low, as follows: 48% refrigeration, 28% other systems, and 24% air conditioning, respectively. However, the energy portion of air conditioning is the lowest, but it is necessary to focus on energy reduction because it is operated 24 hours a day, which consumes a lot of energy. Moreover, we should be looking forward to increasing energy efficiency in the air conditioning system by integrating it with new technology. It is very important to look for new ideas to make it happen. This research is a new idea to confidently roll out widely.

The optimal energy management system that the author proposed in this study used the Internet of Things and programmable logic control to control Air conditioning was reduced by 24 and 15 kWh/day, or 14.5% and 8.3%, respectively, at operating hours of 24 and 16 hours per day, respectively, which can reduce the energy index of the air conditioning system from 0.60 to 0.51 kWh/m^2 (for 24 operating hours per day) and 0.65 to 0.57 kWh/m^2 (for 16 operating hours per day) with the desired temperature setting at the sale area at 26 degrees Celsius at the required room temperature (26 °C) in the convenience store, which had a sale area of 280 square meters. There is an average return on investment (ROI) of 3-5 years, depending on the operating hours of the store. Moreover, they can also extend to other systems within the store or other stores.

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