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Investigation and analysis of power consumption in convenience stores in Taiwan

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ABSTRACT

By using a remote energy-conserving monitoring system, this study investigated the power consumption data of 30 convenience stores in northern, central, and southern Taiwan. Data collected comprised the temperature, humidity, and power consumption data of air conditioning, freezer and refrigerator, lighting, and heating equipment. In addition, factors that affected the power consumption of the stores were examined by collecting the basic information of each store, including total floor area, location, sales revenue, and number of customers visited. The results revealed that the average annual energy use intensity in a convenience store in Taiwan was 2346 kWh/m^2/year, which was significantly higher than those of office buildings and hotels. The power consumption of the four types of investigated convenience stores is arranged in a descending order as follows: convenience stores in commercial areas, residential areas, suburban areas, and strategic road areas. The demand use intensity of food storage equipment (i.e., freezers and refrigerators) was the highest among the investigated types of equipment in the convenience stores, at 88.58 W/m^2. Therefore, the first priority for improving energy conservation is to replace old and outdated food storage equipment with efficient units. Finally, a power consumption model for convenience stores was formulated through the examined power-consuming factors, and may serve as a reference for forecasting the power consumption of planned convenience stores.

1. Introduction

According to the Bureau of Energy, Taiwan's Ministry of Economic Affairs, the power consumption of business sectors in Taiwan reached 22.9 billion degree in 2005. Over the past 10 years, the average rate of increase in power consumption was approximately 5.9%, with a cumulative growth of up to 0.8 fold [1]. Specifically, the number of convenience stores in Taiwan has increased rapidly, reflecting an annual growth rate of 10%. The total power consumption of convenience stores was 1.4 billion degree, accounting for approximately 6.1% of the total power consumed in the business sector. Because convenience stores in Taiwan are open 24 h, their energy use intensity (EUI) is substantially higher than that of other business areas. In particular, the power consumption of convenience stores varies according to time period, store size, and number of customers who visited the store [2].

Taiwan has more than 10,000 convenience stores, or one per approximately every 2000 residents, which is the highest density of convenience stores in the world [1]. This number of convenience stores in Taiwan is also increasing rapidly, reflecting an annual growth rate of 10%. The total power consumption of convenience stores is 1.4 billion degrees, accounting for approximately 6.1% of the total power consumed in the business sector. Because convenience stores in Taiwan typically offer products such as food, beverages, and daily essentials, as well as provide services such as bill collection, many are open 24 h a day. Thus, their energy consumption is substantially higher than that of other businesses. In particular, the power consumption of convenience stores varies according to time period, store size, and number of customers who visit the store [2]. Therefore, convenience store employers and managers are required to investigate their current power consumption and consider energy-conserving maneuvers.

Because convenience stores are well distributed, energy-monitoring systems are required to effectively collect power consumption data of each branch store. Constructing energy-monitoring and analysis systems in these locations can facilitate power conservation [3–6]. The information technology used in

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these systems can solve complicated problems related to the power management of a building. Managers can develop power-conserving strategies through an analysis of power consumption data [7]. The benefits of convenience store energy monitoring include overseeing energy consumption and microclimate quality, increasing energy efficiency, and enhancing indoor thermal comfort [8]. Energy management systems can be operated automatically or semiautomatically according to various control logics or developed functions, and can be used to control the power usage of a building [9]. An experimental study revealed that convenience stores could reduce their power consumption by using a distributed energy management and control system operated over the Internet [10]. In this study, through wireless sensor network technology, both thermal comfort and energy conservation were achieved in four convenience stores in Taipei. The wireless monitoring system installed in the buildings collected both environmental and energy data and sent them to a web platform [11]. To determine the general outline of the multi-level building energy performance diagnostic method [12], this study examined the equipment operation and power consumption of convenience stores throughout Taiwan through an energy-monitoring system.

In general, two indicators are available for the simple evaluation of power consumption: demand use intensity (DUI) and energy use intensity (EUI). DUI measures the maximum power consumption over the total floor area (W/m^2). An example of DUI application is the evaluation of the air conditioning system or equipment power usage of a four-storied institutional building. The typical DUIs for varying systems are listed as follows: cooling system 45 W/m^2, ventilation system 5 W/m^2, lighting 15 W/m^2, and office equipment 15 W/m^2 [13]. EUI is the ratio between the yearly energy usage and the floor area, and may serve as an indicator of power consumption. Studies have compiled the EUI of various types of structures. These EUIs are listed as follows: department stores 342.78 (kWh/year)/m^2, discount stores 394.28 kWh/m^2/year, composite-style shopping malls 293.43 kWh/m^2/year [14], residential buildings 33.29 kWh/m^2/year [15], standard tourist hotels 186.3 kWh/m^2/year, and international tourist hotels 280.1 kWh/m^2/year [16]. In a previous study, the EUIs of Store A and Store B were 458.3 kWh/m^2/year and 258.3 kWh/m^2/year, respectively [17]. In a second previous study, the EUIs for three offices were 384 kWh/m^2/year, 341 kWh/m^2/year, and 237 kWh/m^2/year [18]. Annual EUI can be used as the baseline indicator for building owners and designers to set a comparable energy reduction goal for the following years [19]. The power consumption data collected in this study can be converted to DUI and EUI for evaluating power consumption in convenience stores and comparing other types of buildings.

Building energy consumption prediction is often required in the evaluation of building performance, optimization of building operation, fault detection and diagnosis, and demand side management [20]. Statistical regression models simply correlate the energy consumption or energy index with the influencing variables. These empirical models have been developed from historical performance data, which means that before training the models, sufficient historical data must be collected [21]. EUI prediction models can also be applied for new construction projects to provide a more accurate baseline and energy reduction target at the predesign stage and to facilitate evaluating basic façade design decisions [19]. In one study, the performances of Store A and B were modeled using the same building area [11]. In another study, three office buildings with different functions were selected as case studies. For these case studies, the error between the predicted and actual values of power consumption was less than 5% [18]. The present study aimed to determine the accuracy of predicted power usage of convenience stores by comparing the simulated data constructed by real factors of power consumption.

For energy-conserving maneuvers, through the implementation of new heating, cooling, and ventilation strategies, the EUIs of newly designed stores were reduced to 44% less than those of conventional stores. This was mostly accomplished by electrical strategies, space-heating strategies [17], improved door protection, defrost optimization, control settings and repairs, cost efficiency, and a relatively short payback period. By repairing current equipment and by retrofitting stores with energy efficient equipment, these improvements had short payback times of less than 1 year [22].

This study adopted a database containing information on the power-consuming equipment used in convenience stores; this database was used as the basis for energy evaluation. Subsequently, onsite testing and regression analysis of convenience stores in Taiwan were conducted, focusing on the total power consumption of these stores, the power consumption of various equipment types, and environmental factors. The results were then used to model the power consumption of the main equipment used in convenience stores. Thereafter, the environment and power consumptions of convenience stores were monitored, yielding results that can serve as a basis for establishing a convenience store power consumption evaluation system. By using this system and a spreadsheet, system users can quickly diagnose the power consumption of future branch convenience stores. The proposed system could provide recommendations for conserving energy in convenience stores that consume large amount of electricity. Thus, convenience store operators would be alerted of their high power usage and improve their power consumption models accordingly by replacing power-consuming equipment.

2. Power consumption investigation plan for convenience stores

In this study, the electrical power consumption of 30 convenience stores was monitored. Table 1 lists the attributes of convenience stores, including store area, number of customers, environmental temperature, monthly power use of various types of equipment, and energy use intensity. Subsequently, cross analysis of convenience store attributes and power consumption factors was conducted to identify the crucial factors that influence the power consumption of convenience stores.

2.1. Sample scope and survey criteria

The survey scope, subjects, and survey time employed for this study are described as follows.

1. The survey scope was primarily convenience stores in Taiwan. Survey samples contained those from the northern, central, and southern regions, including Taipei, New Taipei, Taoyuan, Hsinchu, Taichung, Nantou, Changhua, Chiayi, Tainan, Kaohsiung, Pingtung, and other cities and counties, is shown in Fig. 1.
2. The business area type in which the subject samples were established was also coded. *Business area* refers to the range and scale of potential transactions based on the convenience-store location.
   a Commercial area: mainly set in areas with numerous office buildings, where the number of employees in one office building can exceed 2000. The proportion of office workers who consume food from outside restaurants or stores is extremely high.
   b Residential area: primarily set in residential areas where the number of households is approximately 1000. If one household contains four people, the total number of potential customers can reach approximately 4000.