A Study on the Energy Certified and Consuming of the Supermarkets in Taiwan

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Abstract

The European Union issued the "EPBD (Energy Performance of Building Directive)" in 2009, as a building energy consumption labeling standards. Taiwan's government to conform to the international trends, try to establish building energy certification especially for the retail store. The number of the country more than 1,000. Because the area in the supermarket is large, illuminate, air conditioning and a large number of refrigeration equipment, therefore the supermarket is the high energy consumption type. The average annual power density "EUI (Energy Use Intensity)" is 677 [kWh/(m2.yr)], the average annual consumption of electricity is up to 1,024,276 [kWh/yr] above. Due to the indoor area and different types of supermarket, we can't define a single EUI standard, this study through the "building dynamic partitioning EUI index " method, classify the space functions of supermarket six kinds of different energy densities, for: area A (arcade district), area B (warehouse and other space such as corridors, counters, stairwells, elevators, toilets, etc.), area C (refrigerated and frozen zone such as freezers area and equipment space), area D (food processing area such as kitchen), area E (office), area F (general goods area). When evaluating the future of the supermarket energy consume, as long as calculation the area and EUI through the dynamic EUI energy consumption evaluation method, we can immediately get a supermarket energy consumption standard, not only can be used to diagnose energy rationality of existing supermarkets, but also help the new supermarket energy forecast in the future.

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Research Origin and Purposes

EU issued the "Energy Performance of Building Directive" (EPBD) in 2009, enforcing the labeling of the building energy consumption level. The countries in EU are mandated to obtain the energy certificate, the building owners shall improve buildings to reach the energy-saving reference value specified by laws. They are graded so that the public can know the building energy consumption. In response to the international trend, Taiwan's government has conducted research on the building energy certification. As the "supermarket" is of high energy-consuming commercial buildings, it is ranked as preferential object of study to respond to the future trend of "EPBD". There are five major supermarket operators in Taiwan, the total number exceeds 1,000 (Table 1). Taiwan's supermarkets have long opening hours, and sell a variety of cold food. The annual energy consumption of a 24-hour opening supermarket is above 1 million [kWh/yr], and the monthly mean energy consumption is 83,000 [kWh/month], meaning that the supermarket is of high energy-consuming industry. The purposes of this study are: To survey and analyze the energy-consuming equipments and current operating condition of fresh food supermarkets, such as refrigerating equipments, air-conditioning equipments, lighting equipments, other equipments and number of visitors, to create the actual operating state of fresh food supermarkets. To analyze the above data to create the EUI (Energy Use Intensity) grading standards, to evaluate the rationality of energy consumption of the existing fresh food supermarkets, and to predict the estimation equation for the energy consumption of the future establishment, providing the business with evaluation tools and helpful to the promotion of the future Energy Certificate system.

Table 1. The supermarket operators and number in Taiwan

Supermarket operators	Taiwan Fresh	Jasons	MATSUSEI	Wellcome	Pxmart
Number	42	12	69		735

Basic survey of supermarkets

This study surveyed 38 supermarkets of representative "Taiwan Fresh" group of supermarket practitioners. The results can display the operating and energy consumption

conditions of supermarkets.

Supermarket area analysis.

The space of supermarket is divided into "sales" and "warehouse" areas, which vary with the location and establishment year of supermarket. The mean area is 1,588 m^2, the standard deviation is 548 m^2. The largest area among the samples is 3,575 m^2, the minimum total area is 627 m^2, the difference is 5.7 times. The supermarket area is mostly 1,401~1,800 m^2, accounting for 39% of total quantity (Figure 1). According to the supermarket area ratio, the sales area and warehouse area of fresh food supermarket are influenced by the site condition, establishment year and service increase. The sales area-warehouse area ratio is mainly 1.01~1.60. The stores with an area ratio higher than 2.8 times mostly have undersized back area and poor materials circulation. If the area ratio is lower than 1.0, meaning that the warehouse space exceeds sales area. The benefit is too low for the operators (Figure 2).

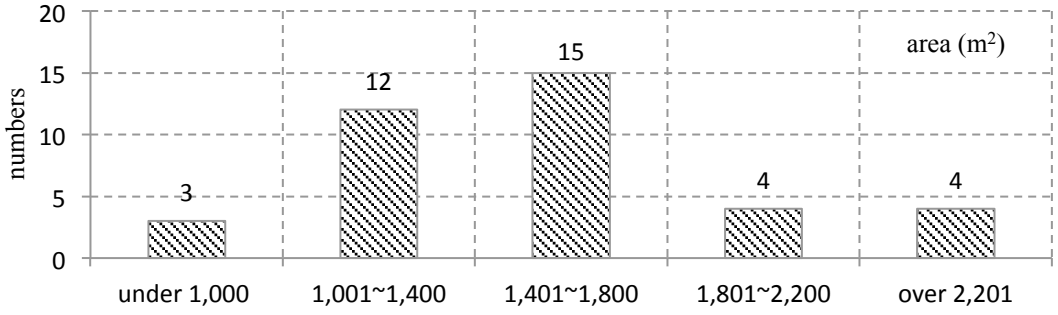


Figure 1: The supermarket area distribution

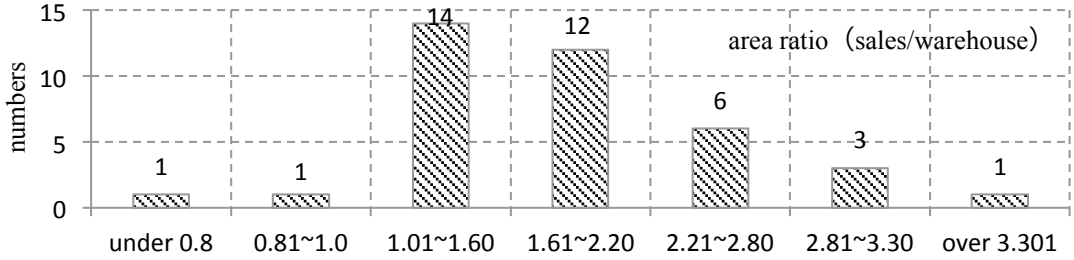


Figure 2: The supermarket sales area and warehouse area ratio

Number of supermarket visitors.

The supermarkets have different numbers of visitors as they are located in different places. The annual mean number of visitors is 349,658 person-times (about 350,000 persons), and the standard deviation is 84,606 persons. The store with the largest number of customers attracts almost 587,000 person-times annually. The store with the smallest number of customers has only two hundred thousand person-times. The mean annual number of fresh food supermarket visitors is mostly 350,000 person-times (Figure 3).

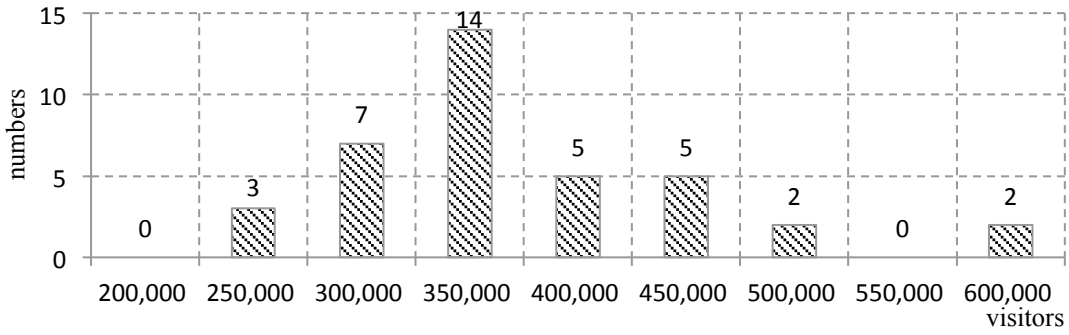


Figure 3: Number of supermarket visitors

Energy use of supermarkets

Annual energy consumption and EUI statistics of supermarkets.

There are large differences in the annual energy consumption of supermarkets due to different sales areas, numbers of visitors, equipment efficiencies and warehouse areas. The mean annual energy consumption is 959,165 [kWh/yr], and the standard deviation is 264,002 [kWh/yr]. Generally, a large supermarket has a high energy consumption. The energy consumption is positively correlated with the sales area. The correlation R is .7 (Figure 4). There is no obvious correlation between the energy consumption and the number of visitors. The correlation R is .24, meaning that the number of visitors has no significant impact on the energy consumption of fresh food supermarkets. The energy consumption is still related to the machine efficiency, quantity and operating time (Figure 5). In addition, the building energy consumption can be evaluated by the "annual EUI". The mean EUI of supermarkets is 637 [kWh /(m^2.yr)]. The EUI of 22 branches among the investigated samples is 501~700 [kWh/(m^2.yr)] (Figure 6).

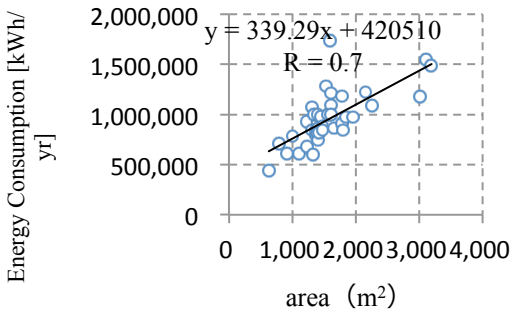


Figure 4: The correlation of supermarket area

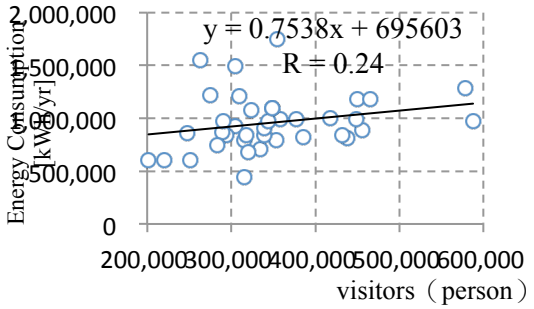


Figure 5: The correlation of visitors and energy consumption

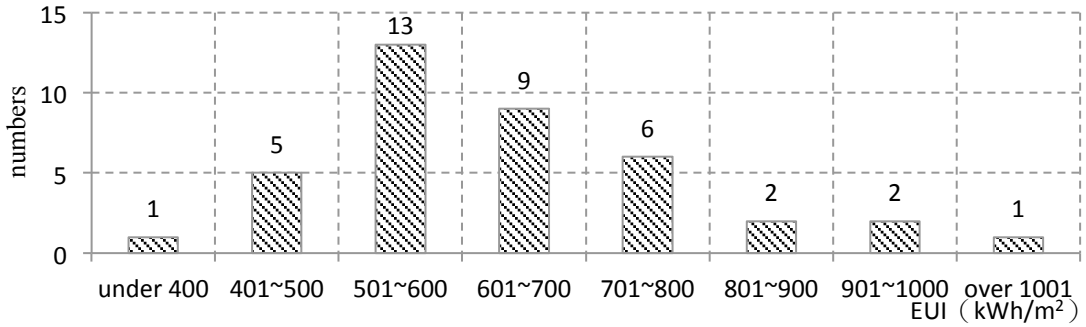


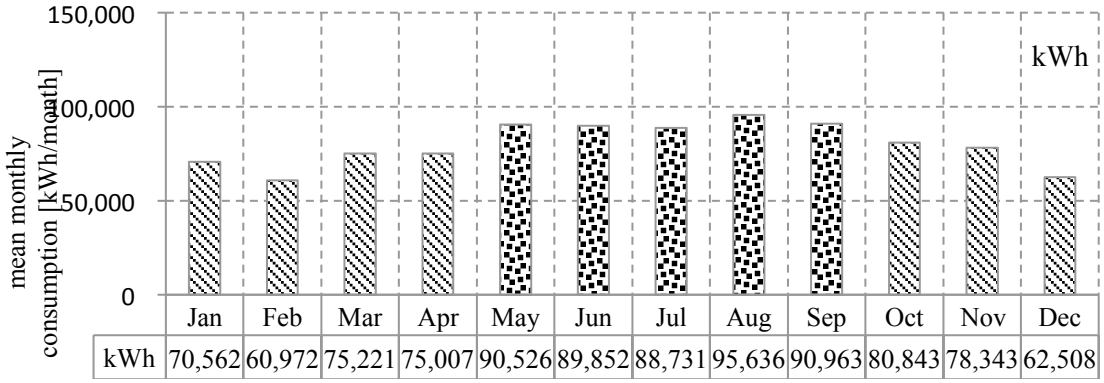
Figure 6: EUI of supermarkets distribution

Monthly energy consumption statistics of supermarkets.

The supermarkets have the highest monthly energy consumption in August. The mean monthly consumption is 95,636 [kWh/month]. The energy consumption in February is minimum 60,972 [kWh/month] (Figure 7). The mean monthly consumption in summer is 1.27 times of that in non-summer. Due to high atmospheric temperature in summer, the refrigerating equipment load is much higher than that in winter. The annual energy consumption is divided into high energy consumption, medium energy consumption and low energy consumption levels in this study. All the samples are sequenced according to annual energy consumption, the total energy consumption below 800,000 kWh is set as low energy consumption level (first 25% of samples), that between 800,000 and 1,000,000 kWh is medium energy consumption level (middle 45% of samples), and that above 1,000,000 kWh is high energy consumption level (last 30% of samples) (Figure 8).

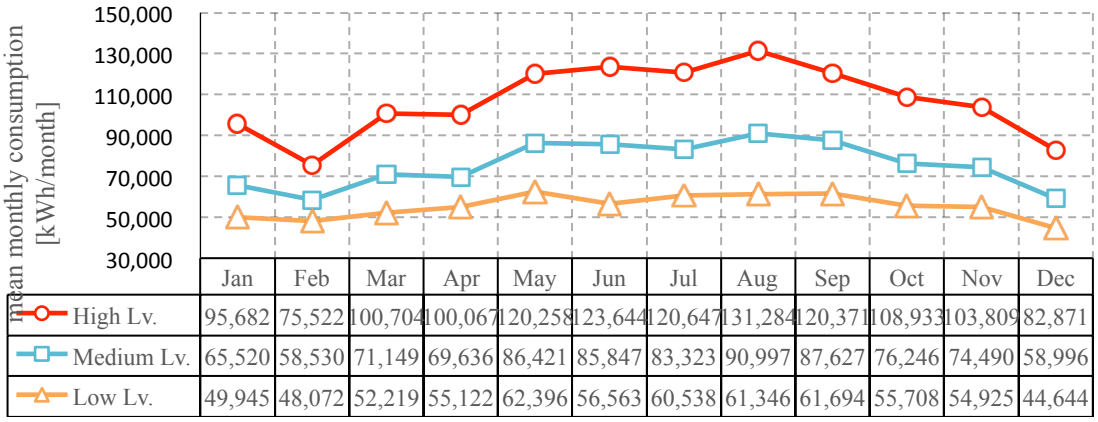
Low energy consumption level: the monthly mean energy consumption of this type of supermarket changes slightly. The mean monthly consumption is 55,264 [kWh/month],

and the mean energy consumption in summer is 1.14 times of that in non-summer. Medium energy consumption level: the mean monthly consumption of this type of supermarket is 75,732 [kWh/month], but the energy consumption peak begins in summer (May to September). The mean energy consumption in summer is 1.24 times of that in non-summer. High energy consumption level: the mean monthly consumption of this type of supermarket is 106,983 [kWh/month], and the mean energy consumption in summer is 1.26 times of that in non-summer.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh	70,562	60,972	75,221	75,007	90,526	89,852	88,731	95,636	90,963	80,843	78,343	62,508

Figure 7: Mean monthly energy consumption of supermarkets in Taiwan



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
High Lv.	95,682	75,522	100,704	100,067	120,258	123,644	120,647	131,284	120,371	108,933	103,809	82,871
Medium Lv.	65,520	58,530	71,149	69,636	86,421	85,847	83,323	90,997	87,627	76,246	74,490	58,996
Low Lv.	49,945	48,072	52,219	55,122	62,396	56,563	60,538	61,346	61,694	55,708	54,925	44,644

Figure 8: Compare the monthly energy consumption levels of supermarket

Supermarket equipment energy consumption ratio.

The electrical equipments of supermarkets are divided into four main classes: (1) air-conditioning equipments: various air conditioners, switched on/off with opening hours; (2) lighting equipments: supermarket lighting is approximately divided into two types, fluorescent lamps, metal halide lamps; (3) refrigerating equipments, large-scale low

temperature refrigerating rooms; (4) other equipments: ovens, cash registers, microwave ovens. In terms of energy consumption ratio, the air conditioning accounts for about 6.7%, lighting accounts for about 23.7%, refrigeration accounts for about 57.7%, other equipments account for about 11.9%. The refrigerating equipments have the maximum energy consumption in supermarkets (Figure 9). This study used hand-held temperature and humidity recorder to measure the temperature of the refrigeration area of supermarket. The results showed that the cold air from the open refrigerators makes the air temperature around the area at 16.0~21.2℃, which has made customers feel cold and wasted energy. The cold overflow of refrigerated cabinets is a universal problem in Taiwan's supermarkets.

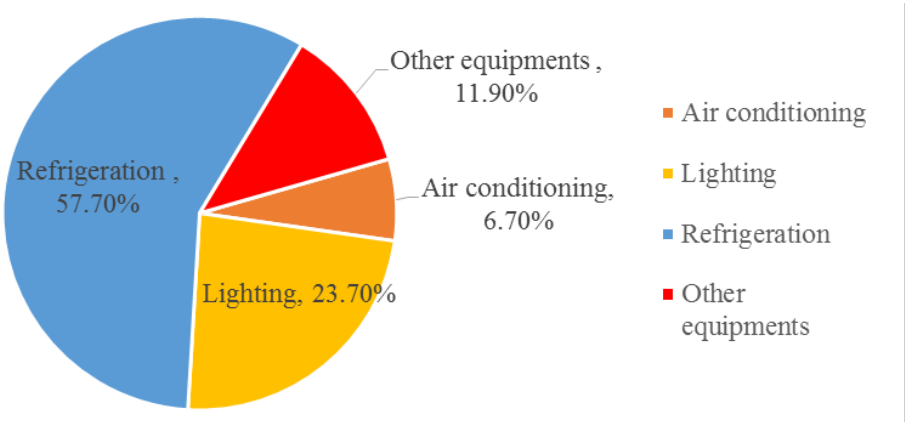


Figure 9: Energy consumption ratio of supermarkets

Indoor physical environment characteristics.

The sales area temperature range is 22.3~25.6℃, different from the standard indoor temperature 26℃ of commercial space required by Taiwan government. In other words, the air overflow from refrigerated cabinets in Taiwan's supermarkets results in too low indoor temperature. The temperature of the refrigerating cabinet area is 16.0~21.2℃, which gives people cold feeling.

A hand-held illuminance meter is used to measure the illuminance in the center of sales area and shelf area. The illuminance in the sales area is still kept at 407~567 [lx]. If the sales area is planned aiming at lighting density of 20 [W/m^2], the luminance level is acceptable.

Rapid estimation and grading of supermarket energy consumption

Dynamic EUI energy consumption evaluation method.

This study used "building dynamic EUI". The areas of different operating characteristics in the supermarket were divided, and the building energy was simulated by standardization. The EUI of six major areas in the supermarket was calculated from the standardized occupant density, equipment quantity and efficiency, operation mode, and standard building shell design. The "dynamic EUI" of the supermarket was calculated by area weighted average according to the spatial composition of supermarket. This method can estimate the energy consumption rapidly for supermarkets of different operating characteristics, more objective than the mean EUI of supermarkets. The six major areas are: Area A (arcade area), Area B (warehouse and other spaces, e.g. aisles, counters, staircases, elevators, toilets and so on), Area C (refrigeration area in sales area: the area of refrigerated cabinets in the sales area, machine rooms for backend equipments), Area D (food processing area: kitchen, cold storage for frozen food), Area E (office), Area F (dry stock area in sales area: shelf area of dry stock area) (Table 2). Take a supermarket as an example, this supermarket plane subarea usage mode is shown this figure (Figure 10). The EUI was calculated by weighting after division, and the standard EUI value of the store was 600 [kWh/(m^2.yr)]. The reasonable energy use of supermarkets can be evaluated rapidly by using this method in the future.

Table 2: Different subarea EUI of supermarket

Subarea	Division	EUI
A	Arcade area	115
B	Warehouse and other spaces (aisles, counters, staircases, elevators, toilets)	306
C	Refrigeration area in sales area: area of refrigerated cabinets, machine room for backend equipments	2000
D	Food processing area: kitchen, cold storage for frozen food	215
E	Office	130
F	Dry stock area in sales area: shelf area of dry stock area	428

Figure 10: Calculated the standard EUI of supermarket by dynamic EUI evaluation method

Supermarket energy consumption grading mode: **Relative EUI grading mode.**
This grading mode compares the "dynamic EUI value" with the "actual operation EUI value of fresh food supermarket". If the "estimated value" is greater than the "operation value", meaning that the energy consumption of store is lower than normal operation (Eq.1). The comparison value within ±5% is in reasonable range as "basic grade". A larger difference leads to a higher grade. On the contrary, if the difference is negative, the energy consumption of the evaluated store is relatively high, classified as "negative Grade I". This mode evaluates the conditions of the store, so it is "relative EUI grading" mode (Table 3).

Table 3: Supermarket relative EUI grading interval

-10.1~-15.0%	-5.1~-10.0%	±5%	5.1~10.0%	10.1~15%
Negative Grade II	Negative Grade I	Basic grade	Grade I	Grade II

$$\Delta R = \frac{Ea - Eb}{Ea} \quad \text{..... (Eq.1)}$$

ΔR: Energy consumption efficiency ratio
Ea: Estimated value: dynamic EUI value converted from area, or calculated value of EUI estimated by standard equipment energy consumption
Eb: Operation value: EUI value of actual operation of fresh food supermarket

This method uses EUI high and low points for grading, if the supermarket implements various energy-saving means to reduce energy consumption, or the supermarket has a few equipments and relatively low annual energy consumption. This mode is in the concept of normal distribution. When the mean EUI is 637 [kWh/(m^2.yr)], in positive and negative standard deviations (standard deviation 149), this range covers 97.37% of samples. Referring to EU "EPBD", the minimum and maximum EUI values of the cases are determined. The minimum to the maximum EUI are equally divided into Grades A, B, C, D, E, F and G. In this figure, darker green represents lower EUI, it is low energy-consuming fresh food supermarket. If the EUI of a supermarket is 920 [kWh/m^2.yr], it is Grade E of relatively high EUI store (Figure 11).

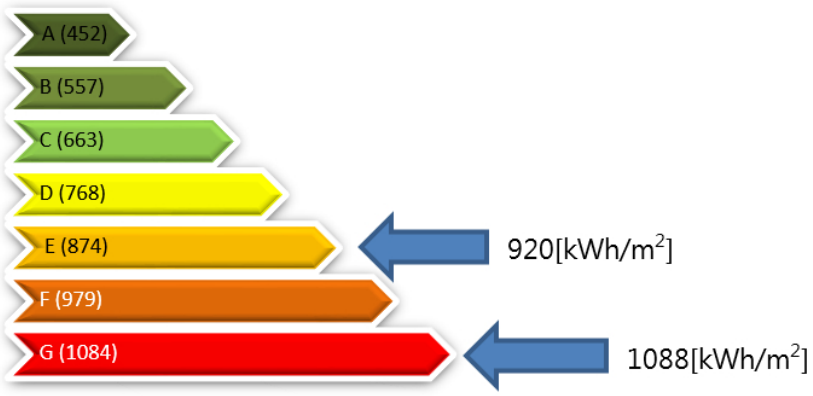


Figure 11: EUI grades of supermarket in Taiwan

Conclusion

Energy consumption characteristics of supermarkets.

The mean area of Taiwan's supermarkets is 1,100~1,600 [m^2]. The annual mean number of visitors is about 349,658 person-times (about 959 [persons/day]). Larger supermarket scale usually has higher energy consumption. The energy consumption is in highly positive correlation with sales area, but there is no obvious correlation between energy consumption and number of visitors. The average annual energy consumption of supermarkets is 959,165 [kWh], and the mean EUI is 637[kWh/(m^2.yr)]. The mean

energy consumption of supermarket at high energy consumption level in summer (June~September) is 1.33 times of the mean energy consumption in non-summer (October~December and January~ May). It is related to large increase in energy consumption of air conditioning and refrigerating equipments. The energy consumption ratios of various equipments of supermarkets are: air conditioning energy consumption 7%, lighting 35%, refrigeration 52%, other equipments 6%. The energy consumption of refrigeration accounts for over 50% of total energy consumption. The mean area of refrigeration accounts for about 27.0% of sales area.

Energy certification of supermarkets.

This study proposes two energy consumption grading modes, which are "relative EUI grading mode" and "absolute EUI grading mode". The "relative EUI grading mode" evaluates the energy consumption based on the conditions of supermarket. If the EUI of actual operation is higher than the standard value, the energy conservation can be further improved. The "absolute EUI grading mode" refers to EU "EPBD", classifying the EUI of Taiwan's supermarkets into A~G grades. The EUI of actual operation is put in comparison directly. It is a simple mode compared with "relative EUI grading mode", but this method has not considered different operating conditions of supermarkets (some supermarkets have more refrigerating equipments, some lay emphasis on general shelf area). Therefore, the "relative EUI grading mode" is recommended.

This study hopes that the preliminary survey of supermarket energy consumption can help Taiwan push the "Building Energy Certificate System" in the future to match the increasing trend of building energy consumption efficiency in the world.

References

Yang J.H. (2013). *Investigation of electrical equipment and energy analysis of Fresh Supermarkets* (Master's thesis). Taichung: Chaoyang University of Technology, Taiwan, R.O.C.

Wu Y., & Sun C.Y., & Lu S.L. (2013). EU and French building efficiency policy and financing mechanism for inspiration. *Architecture Science*, 26(2), 1-12.

Chen J.H. (2010). *The Classification Model of Energy Use Intensity Based on Building Function Types* (Master's thesis). Tainan: National Cheng Kung University, Taiwan, ROC.

Kuo P.Y. (2010). *Green convenience store energy grading mode and reform plan*. Architecture and Building Research Institute Ministry of the Interior, Taiwan

Su T.C. (2009). *A Study on the Energy Consumption Certificate of Residential Buildings* (Master's thesis). Tainan: National Cheng Kung University, Taiwan, ROC.

Haung C.C. (2003). *Effects of Refrigeration Systems on Energy Consumption of Merchandise Buildings- a Convenience Store Case Study* (Master's thesis). National Taipei University of Technology, Taiwan, ROC.

Tsai Y.C., & Lee K.P. (2002). *The energy saving manual of supermarkets.* China Technical Consultants, Inc.

Yang P.Y. (2004). *A Study on Energy Saving Techniques for Supermarkets* (Master's thesis). National Taipei University of Technology, Taiwan, ROC.

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