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Convenience store: The unintended large energy consumers in urban Taiwan

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Abstract: In Taiwan, the average of convenient store's Energy Use Intensity (EUI) is high at a 1501 (kWh/m^2/year) which is 3 times higher than department stores, 7times higher than central air conditioning office buildings and 38times higher than housing due to operational hours, internal loads and a poorly designed building envelope. Unexpectedly, communities use convenience stores as thermal comfort refuges during summer. This study utilised a dataset of 251 convenience stores in Taiwan from the largest leading retailer to obtain data on the physical, construction elements, energy use and siting of convenience stores. Sample analysis results analysed the architectural features and main locations, urban setting of the convenience store for a base case design. The dynamic software IES-VE (2016) is used to simulate different envelope improvement techniques to understand cooling demand and indoor thermal performance in relation to an urban setting. The dataset energy loads were used to validate the simulation results. The simulation results show that the most efficient building envelope improvement type is an insulation roof with shading. It saves 17% of cooling load in arterial roads while saving up to 18% of cooling load in residential areas.
Keywords: Convenience store, Energy consumption, Building envelopes.

■1. INTRODUCTION

In Taiwan, the average of convenient store's Energy Use Intensity (EUI) is 1501 to 2346 (kWh/m^2/ year) [1, 2] which is 3 times higher than department stores, 7 times higher than central air conditioning office buildings and 38 times higher than housing. Taiwan is a country that possesses a significant density of convenience stores. There were 10,199 convenience stores serving 23 million people in Taiwan (Statistical information obtained at the end of 2016), which means there is one store for every 2,304 person. This study aims to investigate the energy consumption of stand-alone convenience stores in Taiwan in two different urban settings. It seeks to investigate and propose energy reduction strategies for new development and refurbished convenience stores.

Nowadays, retailers develop their stores with more space to provide more facilities to increase consumers' footfall. According to the retailer's annual report (2016) the convenience stores with a designated seating plan and coffee shop incur better sales.

Currently, retailers tend to construct and refurbish existing shops to increase the visual connection between outside and the inside of shops and leading to an all glazed facade regardless of urban setting orientation (Fig. 1). However, this change of building envelope influences the indoor atmosphere and energy consumption. Researchers note that the indoor atmosphere can change occupants' behaviours and energy performance. [3,4]. Heat loads on building envelopes due to the intensity of solar radiation and less temperature fluctuations and a high level of humidity in the Taiwanese hot humid climate contributes as one of the major factors that have a direct impact on indoor thermal comfort.

Figure 1: Convenience store façade.

■2. CONENIENCE STORE IN TAIWAN

As convenience stores continued to penetrate the Taiwanese market and competition increased, the existing stores designed ways to ensure their survival.

The stores offered a wide range of convenient products that met customers' specific needs. To manage the high competition, Taiwanese convenience stores developed strategies that led to the introduction of hybrid convenience stores that provides other facilities such as neighbourhood meeting places, toilets and seating areas [5]. While these stores offered fast foods, they appreciated the need for dining furniture and facilities that enabled customers to enjoy the services and products and an extended stay indoors

2.1 Convenience store buildings in Taiwan

A new convenience store design introduced to Taiwan's customer in 2012. The new convenience stores with a designated seating plan and coffee shop incur better sales. The stand-alone convenience store has more space than others and has developed into the fundamental convenience store architectural type in Taiwan. It is an ongoing challenge to improve a building's energy efficiency without compromising its indoor environmental quality. Nowadays, a convenience store is not only a place for shopping but also a community place for the neighbourhood.

The light steel buildings are palpable in Taiwan and are deemed desirable due to the inexpensive construction; the building fabric is constructed of reusable and recyclable fast to build materials. However, the light steel buildings lack insulation, which causes the indoor temperature to reach 40℃ in the summertime [5]. To counter such temperatures, air conditioning systems are used to improve the indoor thermal environment, which leads to a heightened consumption of energy.

2.2 The influence of store design on user

Shopping is not just about retrieving items from shelves according to one's needs; it is an experience that one desires to enjoy. The retail store atmosphere can influence emotional responses, such as pleasure, arousal and dominance [6]. The importance of the time spent in the shop relates to a comfortable or an enjoyable experience. The significant element of retail environment is the ambient condition, such as lighting, temperature and noise [7]. However, thermal comfort is the condition of mind that expresses satisfaction with the thermal environment; therefore, it is strongly related to psychology [8].

■3. METHODS

The largest leading retailer provided a dataset of 1,416 stores. The following sources were included: region, address, operation type, electricity number, district type, dimension of the store (total dimension, business area and storehouse), annual power expense, monthly customer flow, equipment type and equipment quantities. The obtained information was organised into a spreadsheet database and the chief facilities engineer was consulted. After examining the retailer's database, there were 251 stand-alone convenience stores with complete data. A previous study was used Google Maps to determinate convenience store building types in Taiwan [1]. This study used Google Maps street view to understand convenience store's architectural feature such as window's orientation, structure, urban street settings, determining the road classification, adjacent and surrounding building's height. Sample analysis results provide the architectural features and main locations, urban setting of convenience store for base case design. The dataset analysis shows over 82% of stand-alone convenience stores were located in the arterial road and residential area and 98% of 251 stand-alone convenience stores were steel roof and steel construction with single glazing buildings. The dynamic software (IES-VE) is used to simulate different envelope improvement techniques to understand the

cooling demand and indoor thermal performance in relation to urban setting.

■4. STAND-ALONE CONVENIENCE STORE ENERGY CONSUMPTION

Convenience stores in Taiwan tend to use the large floor to ceiling single glazing as buildings' façade to visually attract people and to display products. However, the large single glazing areas can increase heat gain during the summertime. Table 1 shows the results of statistical tests of two sided and three sided window convenience store. Generally, the two sided window stores have marginally larger store sizes, which lead to lower EUI. Table 1 indicates that the three side window convenience stores can attract more customers than two side window stores but it also increases annual store electricity consumption. However, the three side window stores tend to have more customers and higher EUI and energy consumption than two side window stores.

Table 1: Comparison of two sided and three sided windows stores information.

Number Of windows	Store size (m^2)	Annual power consumption (kWh)	Customer	EUI (kWh/m^2/year)
Two-sided	138.1	175,211	319,290	1,344.0
Three-sided	128.6	176,164	339,494	1,432.0

The database indicates variations of architectural shading overhangs of the convenience stores. Stores varied in the provision of overhangs that provides a space for customers to rest and a smoking area for smokers without optimization of its dimensions to deal with the onslaught of direct solar radiation. Table 2 shows that stores with three sides overhang have the highest EUI due to smaller store size. The one side overhang stores have the lowest EUI because it tend to be adjacent to other buildings, which causes less heat gain.

Table 2: Energy consumption comparison of store with shading.

Overhang	Store Size (m^2)	Energy consumption (kWh)	Customers	EUI (kWh/m^2/year)
Without	140.7	176,618.9	346,038	1,363.9
One side	135.0	169,945.1	318,399	1,323.9
Two side	139.2	175,784.5	321,135	1,339.9
Three side	131.1	176,442.0	355,196	1,418.8

The thermal environment of the store and its surrounding largely influences the energy consumption of respective appliances. For instance, during summer, the electricity consumption of air conditioning, and freezing and refrigeration appliances increases during summer. The energy measurement data shows that the cooling energy consumption in summer is six times higher than winter. Table 3 shows the building's envelope setting detail and Table 4 shows the internal gain equipment list of the base model.

Table 3: Information of simulation base case.

Built up area	105m^2
Entrance	East
Window orientation	East and south
Number of Storeys	1
Floor to Floor Height	3.5m
External Walls	Tile + Brick wall+ 15 mm of timber board
Internal Walls	Brick wall + 15 mm of timer board
Glazing	8 mm single glass
Roof	1mm metal cladding+ 15mm timber board
Ceiling	15 mm Plasterboard
Infiltration rate	4.5 $m^3/h/m^2$
Lighting	2272w
Occupancy	7
Cooling set point	26°C

Table 4: Internal gain equipment list.

Equipment	Wattage	Quantities
Microwave	1800	2
Hotdog machine	900	1
Oden machine	900	2
Coffee machine	3080	2
Tea eggs cooker	800	2
Water dispenser	2800	1
Computer and POS system	500	2
ATM	4300	1
Copy machine and multiple media kiosk	200	1

The existing store's roof only uses metal cladding and adds a timber panel in inner surface to reduce the noise from raining seasons. The store has a

large configuration of glazing. There is no possibility of opening windows at the convenience store as they are all sealed for security, air quality and reduction of outdoor sound.

During the examination of the surfaces of the envelope, various aspects will be signified during the process of simulation. These include internal gain, occupation and equipment, and lighting. In cooling mode, the key focus is placed on sensible heat; the impact of latent heat is so low that it is insignificant. All effective parameters in the assessment of the building envelope are considered in connection with the Hsinchu City climate.

According to monitored data, during the summertime, the highest indoor temperature in non air cooled space can reach 46.1°C at 14:00 in the summertime. The simulation base case result shows that the highest temperature in the summertime was 48.59°C, which was over estimated the indoor temperature by 2.5°C, but creates a standard base case for comparison. The existing building simulation result shows that the mean percentage of people dissatisfied is 80.89%

The study simulates two most common stand-alone convenience store urban settings: arterial road and residential area. Each urban setting simulation includes four types store exposure: one side, two side, three side and four side exposure (Fig. 3).

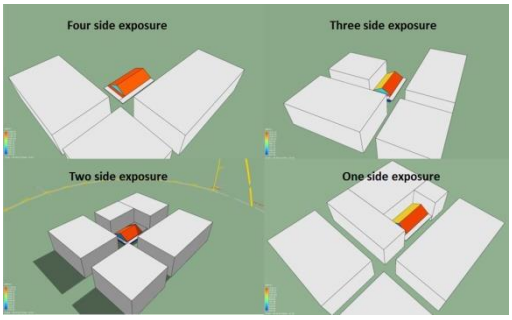

Figure 3: IES-VE modelled view of the building exposure.

■5. STORE'S ENVELOPE IMPROVEMENT

The base case is a stand-alone convenience store (in what urban setting) for simulation as it present over 80% of existing convenience stores condition such as structure, store size and architectural form (two side windows with veranda or shading) and can use it to validate with simulation work (Fig. 4). This study simulates two urban settings: arterial road and residential area. The arterial road stores were surrounded by 3.2m low rise buildings and 2.8m width roads while the residential area stores were surrounded by 12m height buildings and 4.5m width road.

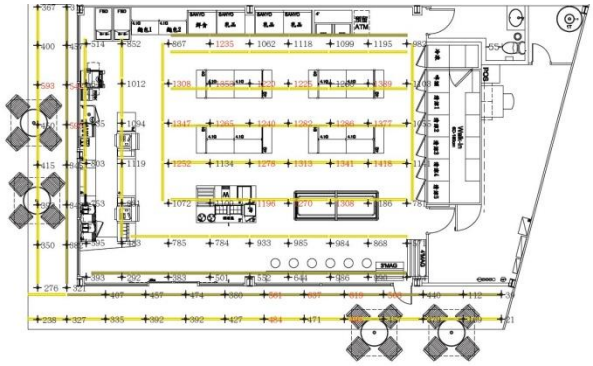

Figure 4: Base case store floor plan.

5.1 Roof insulation improvement simulation

This section presents the simulation result of the insulated roof. as the convenience store buildings are not subject to compliance with building thermal performance regulations in Taiwan, the existing building roofs are; 1 mm metal cladding, 15mm timber board and 15 mm plasterboard without any insulation.

The simulation model added two types common insulation material between the metal cladding and timber board. First, insulation material is a 50 mm insulation board, and second is 30 mm of polystyrene foam (see Table 5). Those insulation materials are widely used for roof insulation on buildings in Taiwan, such as resident buildings, office buildings and schools.

Table 5: The construction template of insulation roof.

External Walls	Tile + brick wall+ 15 mm of timer board
Internal Walls	Brick wall + 15 mm of timer board
Glazing	8 mm single glass
Roof	1mm metal cladding + 50mm insulation board + 30mm polystyrene foam+ 15mm timer board
Ceiling	15 mm Plasterboard

Table 6 shows that the roof insulation significantly reduced indoor temperature. In general, the mean temperature can significantly reduce from 33.51°C to 27.9°C. Moreover, the mean number of people dissatisfied also reduced from 80.89% to 52.87%. The store with insulation roof can save cooling load up to 13%.

Table 6: The simulation result of insulation roof in arterial road.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	27.9	27.93	27.92	27.93
Mean people dissatisfied (%)	52.87	53.1	53.03	53.1
Cooling load(kWh)				

Table 7 shows that the insulation material adds on a residential urban setting can significantly reduce mean temperature from 33.51°C to 27.79°C. Moreover, the mean number of people dissatisfied also reduced from 80.89% to 51.75%. It save cooling energy consumption up to 15%.

Table 7: The simulation result of insulation roof in residential area.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	27.8	27.92	27.79	27.92
Mean people dissatisfied (%)	51.89	53.02	51.75	53.03

5.2 Optimizing the wall sections environmental performance

The shading device is an economic technique to reduce the solar gain. Most of convenience stores have the shading device. However, the designer placed the shading device too high and it cannot shade the ceiling to floor glazing properly (Fig. 5). This study simulated insulation roof with shading device. The louver shading device is placed at 2.3m above ground allows for airflow to reduce thermal stratification on the façade (Fig. 6).

Figure 5: Shading device of convenience store.

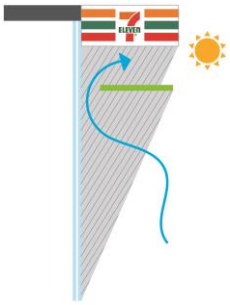

Figure 6: Louver shading device.

Generally, the mean temperature in arterial road store can decline from 33.51°C to 25.22°C and the mean people dissatisfied also reduce from 80.89% to 39.18% (Table 8). It save cooling load about 17%.

Table 8: The simulation result of optimizing the wall sections environment in arterial road.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	26.84	26.91	25.82	25.22
Mean people dissatisfied (%)	42.39	43.14	39.56	39.18

Table 9 presents that the mean temperature of store in residential area can decline from 33.51°C to 25.87°C and the mean people dissatisfied also reduce from 80.89% to 39.14%. The insulation roof with louver shading device can save cooling energy up to 18% in residential area.

Table 9: The simulation result of optimizing the wall sections environment in residential area.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	26.13	26.85	25.94	25.87
Mean people dissatisfied (%)	40.77	42.56	39.62	39.14

5.3 Double glazing performance

The large configuration of glazing makes convenience stores brighter and transparent but also increases the heat gain. According to the previous

studies [9, 10] double glazing can keep the building transparent, but reduce the heat gain and improve the indoor thermal environment. This study changed the existing 8 mm single glass to 8 mm reflective glass with 10mm argon cavity between two glazing. Table 10 shows the simulation result of store added double-glazing on an arterial road urban setting. The mean temperature can significantly reduce from 33.51°C to 27.94°C. Table 11 shows the simulation result of double glazing in an arterial road urban setting. The mean temperature can significantly reduce from 33.51°C to 27.92°C. The double glazing envelope improvement can save cooling energy consumption up to 11% in both urban settings.

Table 10: The simulation result of double glazing in arterial road.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	28.03	28.07	27.94	28.07
Mean people dissatisfied (%)	54.19	54.52	53.22	54.52

Table 11: The simulation result of double glazing in residential area.

Exposure	Four sides	Three sides	Two sides	One side
Mean temperature (°C)	28.02	28.05	27.92	28.05
Mean people dissatisfied (%)	54.02	54.34	53.04	54.34

■ CONCLUSION

Statistical analysis shows that the three sided window stores tend to attract more customers and higher EUI and energy consumption than two sided window stores. It can be concluded that three sided window stores can increase perceptions of spaciousness by linking interior and exterior visually for customers, which results in attracting more customers. About one in six of convenience stores in Taiwan are standalone convenience store. The store's envelope improvement can save energy up to 2,033kWh/year at a stand-alone convenience store which means saving 3,429,000 kWh per year in Taiwan. Provision of overhangs and insulated roofs proves to be the preferred architectural configuration to save energy while keeping the glazed areas. This study however didn't find using double glazing to provide substantial energy savings, indicating that for economies of scale the single glazing is a viable option to maintain connectedness of indoors and outdoors visually.

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