EXPLORING ZERO ENERGY HOUSES DESIGNS TAILORED TO MALAYSIAN CONTEXTS

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ABSTRACT

The performance of ZEHs consists of rooftop photovoltaic (PV) power and battery (BT) storage were evaluated for typical Malaysian terrace houses through numerical simulations. Self-consumption and self-sufficiency rates, as well as the annual net energy balance, were assessed for eight different conditions with varying capacities of PV and BT.

KEY WORDS

Zero Energy House, tropical climate, self-consumption rate

1. INTRODUCTION

The construction sector is responsible for approximately 36% of final energy consumption,[1] making decarbonization and energy efficiency in this sector critical. In Malaysia, where economic development is advancing rapidly compared to other Southeast Asian nations, the construction sector consumes about 35% of the country's total energy. In response, the Malaysian government has set an ambitious goal to achieve carbon neutrality by 2050,[2] fueling growing interest in the adoption of Zero Energy Houses (ZEHs). ZEHs typically feature insulated building envelopes with energy-efficient appliances, battery (BT) storage, and rooftop photovoltaic (PV) power, enabling them to balance annual energy generation and consumption. While there has been extensive research on passive cooling strategies for Malaysian housing, studies specifically focused on ZEHs tailored to the unique context of Malaysia and other tropical Asian countries remain limited. Given these circumstances, this study aims to explore the optimal facility specifications for typical Malaysian low-rise housing, specifically terrace houses.

2. METHODOLOGY AND CONDITION SETTING

2.1 Methodology

In this study, TRNSYS18 was used as the solver of building energy simulations. By combining TRNSYS components, a model of the target residence was created to compute the time-series indoor temperatures, as well as thermal load. CONTAM, a module used to estimate flow rate of infiltration and natural ventilation due to buoyancy and wind-induced force, was coupled with TRNSYS for integrated calculations. The latest meteorological data for Malaysia, sourced from the EPW dataset was used for external weather conditions.

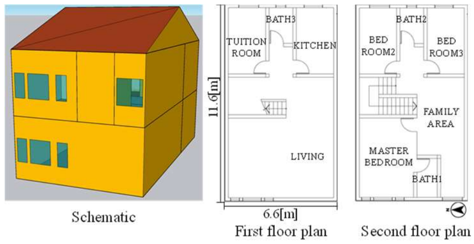

Fig.1: House model

Table1: Conditions of home facilities

Factor	Level 1	Level 2	Level 3	Level 4
PV[kW]	4.4	8.8		
BT[kWh]	0	2.5	5	7.5

2.2 Simulation setting

A middle unit of a terrace house, sandwiched between two other units as shown in Figure 1, was selected as the target. The structure is made of reinforced concrete with no insulation. The infiltration rate with closed windows was set at 0.4hr.[3] For internal heat generation from home appliances, electricity data from Zaki et al.,[4] based on actual Malaysian households, was used. Using this dataset, stochastic occupancy schedules were created, with the number of occupants in each room at each time step adjusted for differences between weekdays and weekends.

To evaluate the performance under different facility capacities, two levels of PV capacity and four levels of BT capacity, as shown in Table 1, were used for simulations.

2.3 Self-consumption and self-sufficiency rates

The time-series variations in charging, discharging, and electricity sored in battery were estimated based on Eeqs. (1) to (3).

$$P_{BT}(t)=P_{BT}(t-\Delta t) + P_{pv} - P_{cons} \quad (1)$$

$$P_{short}=|P_{BT}(t)| \text{ (s.t } P_{BT}(t)<0) \quad (2)$$

$$P_{surplus}=P_{BT}(t) - \text{Capacity (s.t } P_{BT}(t)>\text{Capacity)} \quad (3)$$

Here, the subscripts BT, PV, and cons represent the amounts charged to the battery, produced by the PV system, and consumed, respectively. The rated input/output power was set to 3kW, with the lower discharge limit set at 20% of the BT capacity. If the input/output limit of the battery exceeded 3kW, deficit would be purchased from the grid, and any surplus would be sold back to the grid. The self-consumption rate (SCR) R_{sc} and self-sufficiency rate (SSR) R_{ss} were calculated using Eqs. (4) and (5).

Table2: Annual values under each condition

PV capacity	BT capacity	SCR[-]	SSR[-]	Net energy
4.4kW	0kWh	0.57	0.24	3.48 MWh/year
	2.5kWh	0.76	0.31	
	5kWh	0.88	0.36	
	7.5kWh	0.96	0.39	
8.8kW	0kWh	0.39	0.32	-0.13 MWh/year
	2.5kWh	0.49	0.4	
	5kWh	0.58	0.48	
	7.5kWh	0.67	0.55	

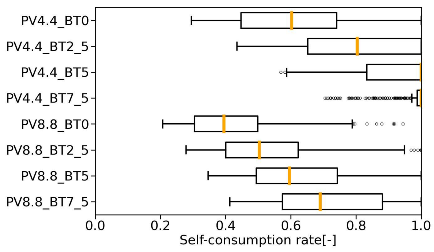

Fig.2: Boxplot of daily SCR

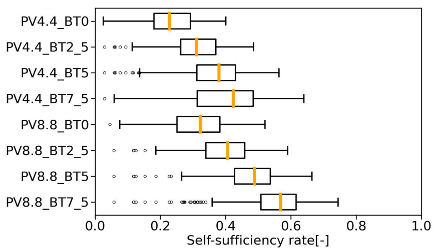

Fig.3: Boxplot of daily SSR

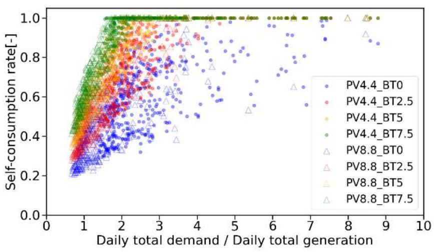

Fig.4: Relation between SCR and RDG

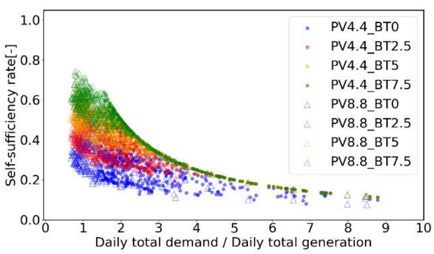

Fig.5: Relation between SSR and RDG

$$R_{sc} = \frac{\sum(P_{pv} - P_{sold})}{\sum Ppv} \quad (4)$$

$$R_{ss} = \frac{\sum(P_{pv} - P_{sell})}{\sum Demand} \quad (5)$$

Here, P_{pv} and P_{sell} represents the electricity generated by the PV system and sold to the grid.

3. RESULTS

Table 2 shows the annual SCR, SSR, and net energy, which is the difference between power demand and PV generation, for all cases. In general, as the BT capacity increases, both SCR and SSR increase. In terms of net energy, the cases with a PV capacity 8.8kW show 0.13MWh/year, achieving ZEH status. On the other hand, the generation of the cases with a PV capacity of 4.4kW is only about half of the demand, significantly falling short of achieving ZEH.

Figures 2 shows a boxplot of daily SCR. It indicates that the median- SCR of the four cases with a PV capacity of 4.4kW ranges from 57% to 100%, depending on the BT capacity. Since the median SCR of the two cases with BT capacities of 5.5kWh and 7.5kWh is close to 1, 7.5kWh can be regarded as overcapacity. For cases with PV capacity of 8.8kW, the median SCR ranges from 38% to 68%, much lower than the previous four cases as expected. Additionally, the interquartile range (IQR) of all cases, except for PV4.4_BT7.5, is about 20% to 30%, suggesting significant variation due to the different weather conditions and daily electricity demand caused by the occupants' stochastic behavior. Figure 3 shows a boxplot of daily SSR. Across the eight cases, the medians range from 23% to 55%, and IQR of each case is approximately 10%. Figures 4 and 5 show the relationship among daily power consumption, power generation, and SCR as well as SSR. The horizontal axes indicate the ratio of energy demand to power generation (RDG). In Figure 4, SCR, shows a gradual parabolic increase as RDG rises until it reaches a maximum of 1, regardless of the facility capacity conditions, though the scatter of the data points is large. When comparing all the cases, the plots with the same BT capacity but different PV capacities tends to show similar SCRs, indicating the effectiveness of RDG in assessing daily SCR.

On the other hand, the relation between SSR and RDG of all cases shows a parabolic decline with a concave shape.

4. CONCLUSION

This study explored the performance of a terrace house equipped with rooftop PV and BT, demonstrating that a PV capacity of 8.8kW can achieve annual net-zero energy, while a 4.4kW system falls short. Additionally, a BT capacity of 5.5kWh was found to be the most suitable among the conditions evaluated. A more comprehensive evaluation considering economic factors and household demand variability will be necessary in future studies to better determine the economically feasible specifications for real-world applications.

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