Analyze the energy-saving benefits of Taiwan's existing advanced energy-saving strategies through energy simulation

Lin Feng-Yi[a], Su Tzu-Ching[b], Yu Pei-Yu[c]

[a] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Taiwan, itriA90070@itri.org.tw.

[b] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Taiwan, neverending1984@itri.org.tw.

[c] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Taiwan, StevenYu@itri.org.tw

Abstract. Building energy consumption accounts for more than 30% of global energy consumption. Nearly zero energy building (nZEB) is an important strategy for energy saving and carbon reduction in the building sector. nZEB design could be separated into two key strategies: "Advanced energy-saving design", which requires highly efficient envelop components and mechanical systems, and "Renewable energy", which requires renewable generations to offset building energy uses.

Taiwan's green building evaluation system provides various advanced energy-saving design strategies to achieve energy-saving beyond the codes. The purpose of this study is to explore the energy saving benefits of Taiwan's existing advanced energy-saving design strategies, especially strategies that were typically used in green buildings. This study first established two reference building energy models, a school building and an apartment, by EnergyPlus. Additionally, we formulated a series of step-by-step advanced energy-saving strategies and determined the maximal energy-saving strategy packages, which could help the two types of buildings achieve the highest rating score in the energy-saving category in Taiwan's green building evaluation system. Following, inputting the strategies into the two models, and simulating their energy efficiencies. The results show that: a school building, which implemented the maximal energy-saving strategy package that achieves the highest energy-saving score in green building evaluation system, could save about 56.2% energy when comparing with a typical school building that complies with the building codes. Regarding apartment building, applying the maximal energy-saving strategy package could reduce 51.3-54.2% apartment energy use when comparing with a typical apartment that complies with the building codes. Moreover, we found out that shading design affects the energy-saving benefits of using efficient building materials. School buildings are generally constructed with side corridors, and the shading effect of the side corridor would reduce the energy saving benefits of using efficient building materials.

Keywords. Building energy efficiency,building energy simulation, advanced energy-saving strategies.
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1. Introduction

Building energy consumption accounts for more than 30% of global energy consumption. In Taiwan, residential and commercial sectors account for 35.6% of the total electricity consumption[1]. It is the second largest power consumption category and has great potential for energy saving. Nearly zero energy building (nZEB) is an important strategy for energy saving and carbon reduction in the building sector. In order to promote energy-saving design of buildings, Taiwan has mandatory regulations and voluntary green building evaluation systems for reference. The update of "Building Technical Regulations (Building Codes)" and the green building evaluation system, as well as the formulation of the building energy efficiency evaluation system, have pushed the building towards near zero energy consumption.

There are many design strategies for energy saving and carbon reduction. Through the preliminary simulation evaluation, the project goals and implementation priorities can be determined[2]. However, there are various building styles and different usage patterns, resulting in different building energy-saving potentials. The energy-saving benefits of the same technology or material in different building cases are often different. In particular, the energy-saving effect of building materials is indirectly dependent on the air-conditioning conditions, which makes it difficult to distinguish and quantify the energy-saving effect. It is not easy for the general public to directly understand the specific energy saving or other benefits of building shading, heat insulation and equipment. In addition, Taiwan lacks typical building energy models and scenario settings with near zero energy consumption. Each study uses different building styles and usage scenarios to evaluate. When evaluating energy-saving effects, different baseline scnarios were used in different studies aswell. As a result, it often leads to a huge gap in the energy-saving benefits of the same technology or policy under different evaluation scenarios. The evaluation results can easily cause misunderstandings by non-professionals.

To effectively evaluate the energy efficiency of residential and commercial buildings and present more widely available evaluation results, the international common practice is to collect local building information and establish a typical scenario as a baseline for evaluating the energy efficiency of various technologies and assessing the potential for achieving near-zero energy consumption. Use energy simulation tools to build building models, assume building usage scenarios, and predict energy consumption of various technologies[3]. The U.S. Department of Energy combined several national laboratories to establish 16 kinds of commercial reference building models of the national building stock. Using these models and setting the situation, it can properly express the local general building style. When performing building energy analysis and evaluation, especially policy-related evaluations, the results will be consistent and representative[4]. ASHARE establishes a model for small and medium-sized offices, and sequentially adds different energy efficiency strategies to the model to quantify the impact of each strategy[2]. Attia et al. established two school baseline models to evaluate the energy performance of nZEB in practice[5]. D'Agostino and Parker used EnergyPlus to simulate and evaluate the design of new houses in 14 different climate zones in Europe. In colder climates, heat insulation and building airtightness are critical, while in warmer places, efficient electrical appliances and Lighting is the key measure[6].

2. Research Methods

This study focuses on school classrooms and multi-dwelling as the simulation object. Draw up the existing advanced energy-saving scenarios in Taiwan, and use EnergyPlus to quantify the benefits of various energy-saving scenarios.

2.1 Model establishment

The scale and form of school classrooms refer to the Taiwan's building regulations[7] and the Ministry of Education's "National Elementary and Secondary School Facilities and Equipment Standards"[8]. For multi-dwelling, refer to building regulations and government sample survey reports[9]. The model details are shown in **Tab. 1**, and the floor plan is shown in **Fig. 1**.

Tab. 1. Model scale.

Object	school classrooms	multi-dwelling
Floor area	72m^2/class room	99 m^2/ household
Height	3m	3m
Floor	3F	6F
Number of classrooms/houses per floor	3	4
Number of people	30	3
Weather data	Taipei TMY3	Taipei TMY3

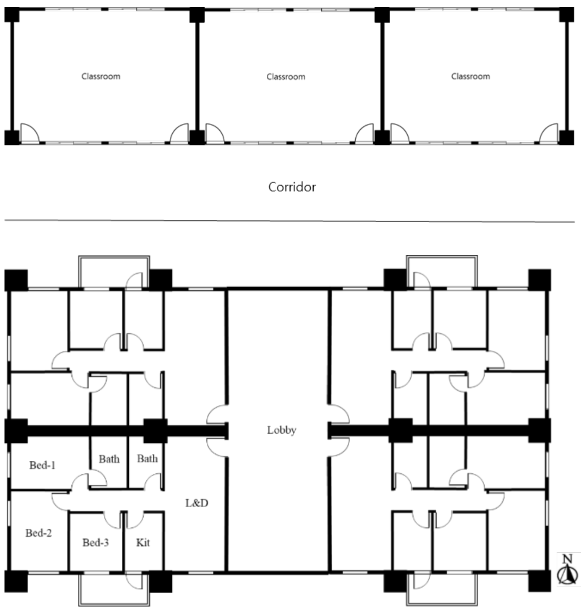


Fig. 1 - Floor plan of school and multi-dwelling.

2.2 Energy-saving scenarios

In the setting of energy-saving scenarios, refer to Taiwan's building envelope and eguipment energy performance standards and the green building evaluation system (EEWH). These two references represent Taiwan's current advanced construction practices in the energy-saving market. The baseline scenario is based on the minimum standards of building regulations, minimum energy performance standard (Meps) for air-conditioning, and fluorescent lamp design. Prioritize implementation of passive energy-saving measures, and then implement active energy-saving. The five energy-saving scenarios are shown as follows:

1. (Scenario I)Mixed ventilation: mixed use of natural ventilation and air conditioning;
2. (Scenario II)Green building envelope: improviing external shading to reach the highest grade in building envelope criterias in EEWH green building evaluation system;
3. (Scenario III)High-performance building materials: implementing advanced building materials that are beyond green building criterias, such as insulation layers and low-E glases;
4. (Scenario IV)Green building equipment- basic: air conditioning and lighting performances comply with the basic criterias in EEWH green building evaluation system;
5. (Scenario V)Green building equipment-advanced: air conditioning and lighting performances reach the highest grades in equipment criterias in EEWH green building evaluation system.

In particular, in the context of high-performance building materials, the difference between Low-e glass and heat-insulating film glass will be additionally compared for multi-dwelling. In addition to lighting power density (LPD) that meets the EEWH level, the lighting also meets the requirements of classroom illuminance 500-750lux and residential illuminance 150-300lux. The setting details of each scenario are shown in **Tab. 2** and **Tab. 3**.

Tab. 2. Classroom simulation scenario setting.

	Baseline	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V
Window rate	52%	52%	52%	52%	52%	52%
Shade depth (m)	corridor 4 balcony 0.8	corridor 4 balcony 0.8	corridor 4 balcony 2	corridor 4 balcony 2	corridor 4 balcony 2	corridor 4 balcony 2
Glass (W/m²K)	U=6.07 SHGC=0.8	U=6.07 SHGC=0.8	U=6.07 SHGC=0.8	U=1.38 SHGC=0.48	U=1.38 SHGC=0.48	U=1.38 SHGC=0.48
Roof (W/m²K)	0.8	0.8	0.8	0.467	0.467	0.467
Exterior wall (W/m²K)	3.5	3.5	3.5	1.21	1.21	1.21
LPD (W/m²)	13.5	13.5	13.5	13.5	7.8	3.6
COP	3.31~3.43	3.31~3.43	3.31~3.43	3.31~3.43	3.72	3.74~3.81
AC activation	Open all day	Turn on when the indoor temperature exceeds the upper comfort limit.				

Tab. 3. Multi-dwelling simulation scenario setting

	Baseline	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V
Window rate	38%	38%	23%	23%	23%	23%
Shade depth (m)	1.2	1.2	2	2	2	2
Glass (W/m²K)	U=6.07 SHGC=0.8	U=6.07 SHGC=0.8	U=6.07 SHGC=0.8	Low-e U=2.56 SHGC=0.26 film U=5.62 SHGC=0.48	Low-e U=2.56 SHGC=0.26 film U=5.62 SHGC=0.48	Low-e U=2.56 SHGC=0.26 film U=5.62 SHGC=0.48
Roof (W/m²K)	0.8	0.8	0.8	0.467	0.467	0.467
Exterior wall (W/m²K)	3.5	3.5	3.5	1.565	1.565	1.565
LPD (W/m²)	6	6	6	6	4.1	1.3
COP	3.63~3.93	3.63~3.93	3.63~3.93	3.63~3.93	3.87~4.21	3.9~4.58
AC activation	Open all day	Turn on when the indoor temperature exceeds the upper comfort limit.				

2.3 Principles of air conditioning activation

Regarding the setting of air-conditioning activation, air-conditioner would not be used in December-March due to the low temperature. In other monthes, air-conditioner would be turned on according to a schedule that determined by the adaptive model of ASHRAE standard 55. When the room is naturally ventilated and the temperature exceeds 90% of the comfortable upper limit, the air conditioner will be turned on. The evaluation according to equation (1).

$$T_{comf} = 0.31 \times T_{om} + 20.3 \quad (1)$$

T_{comf} is the comfortable temperature (°C); T_{om} is the monthly average outdoor temperature (°C), and the monthly average outdoor temperature in Taipei from April to November is 21.2-30.25°C.

3. Result and discussion

3.1 School classroom simulation results

The simulation results of the school classroom are shown in **Fig. 2**. The annual EUI of the classroom in the baseline scenario is 69.12kWh/m^2. When adopting mixed ventilation(Scenario I), the annual EUI was reduced to 47.52 kWh/m^2, which is 31.2% energy-saving compared to the baseline. The main reason is that air conditioning is not needed when the thermal comfort upper limit is not exceeded, and only uses natural ventilation, thus reducing the energy consumption of air conditioning by 21.6kWh/m^2. In scenario II, strengthen the shading performance on the original basis. It was found that the annual EUI was 47.50 kWh/m^2, which only reduced energy consumption by 0.03% compared with the mixed ventilation scenario. It shows that the original shading design of this classroom model comply with the building codes, and is deep enough to prevent most solar heat gains, as a result, reinforcing the shading design leads to a limited energy reduction. When the exterior walls, roofs and windows were replaced with high thermal insulation materials (Scenario III), the energy consumption of the air conditioner increased by 0.1 kWh. The annual EUI is 47.6 kWh/m^2. We found that the well-insulated building envlopes prevent the heat gains conducting both outside-in and inside-out. In the case that the indoor heat gains are more than outdoor heat gains, it would lead to a more energy-comsumed result. Since Taiwan is located in in subtropical, cooling dominated climate, when the building has deep shading, continuous improvement of the insulation performance of building materials is not much help to energy-saving. Continuously expanding the shade or using high-performance building materials not only has no obvious energy-saving effect, but also consumes unnecessary costs.

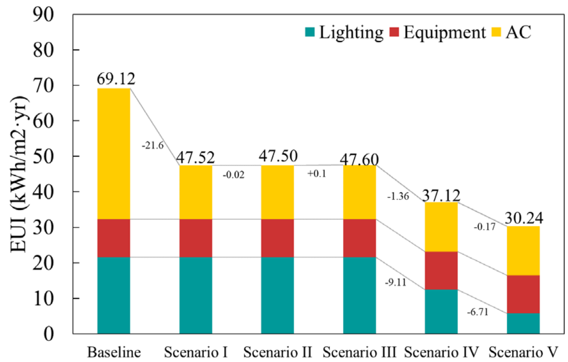


Fig. 2 - The simulation results of the school classroom.

In scenario IV, changing an air conditioner with a COP of 3.31~3.43(energy efficiency level 5) to one with a COP of 3.72 (energy efficiency level 4) reduced 1.36kWh/m^2. Replace the original lamp with a T5-fluorescent tube, the LPD is reduced from 13.5 W/m^2 to 7.8 W/m^2, led to a 9.11 kWh/m^2 energy saving. In other words, the annual EUI can be reduced to 37.12 kWh/m^2, which can save 22% energy compared with the high-performance building materials scenario. In scenario V, the air conditioner's COP is increased to 3.74~3.81(energy efficiency level 1), it can save another 0.17 kWh/m^2. Replace the tube with LED tube, the LPD can be reduced to 3.6 W/m^2, which can save energy 6.71 kWh/m^2. The annual EUI is 30.24 kWh/m^2, which is about 18.5% energy saving compared with the previous scenario. Compared with the baseline, when the envelope, air-conditioning, and lighting all reach the current best levels, energy savings can be 56.2%.

3.2 Multi-dwelling simulation results

The simulation results of the multi-dwelling are shown in **Fig. 3**. The annual EUI of the multi-dwelling in the baseline scenario is 52.59kWh/m^2. When opening windows with natural ventilation to reduce use air conditioning hours (Scenario I), the annual EUI can be reduced to 33.77kWh/m^2. It means reducing energy consumption by 35.8%. In scenario II, the original balcony depth is increased to 2m and the fenestration rate is reduced to 23%, the smaller windows would both reduce the heat gains and the opportunity of ventilation, andin this case, less ventilation led to an increase in energy consumption by 0.09 kWh/m^2, and the annual EUI became 33.86kWh/m^2, but the impact was infinitesimal. In the high-performance materials scenario (Scenario III), it has a significant energy-saving because the envlope barely has any shading devices. Compared with the previous scenario, energy saving can be 8.5-13.4%, and the annual EUI is 29.31-30.98 kWh/m^2.

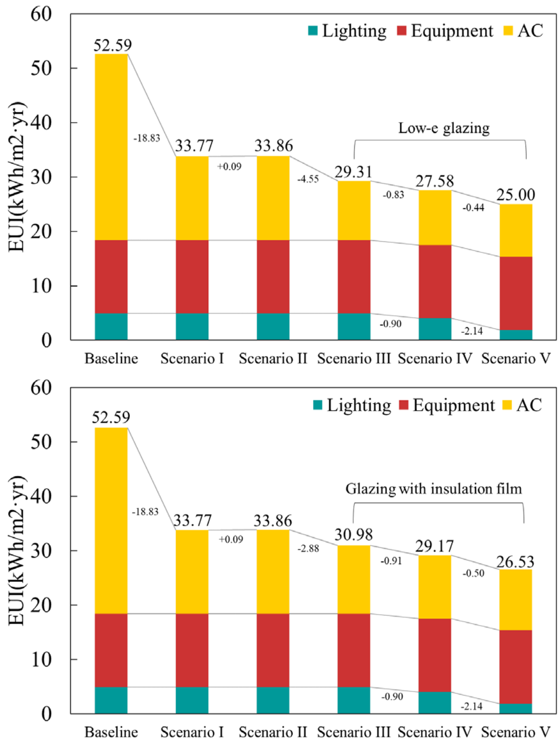
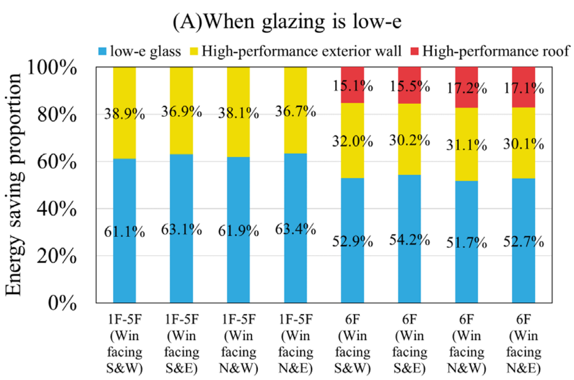


Fig. 3 - The simulation results of the multi-dwelling.

Affected by the performance of building materials, the amount of energy saving varies in different scenarios of high-performance building materials. Using air conditioners with a COP of 3.87~4.21 can reduce 0.9~0.99 kWh/m^2. When the air conditioner's COP is increased to 3.9~4.58, another 0.46~0.52kWh/m² would be reduced. Lighting is not affected by the performance of building materials. When the LPD drops to 4.1W/m², it can save 1.57kWh/m², and use LED bulbs to save more energy by 2.30kWh/m². In summary, when air conditioning and lighting meet the EEWH basic criterias (Scenario IV), energy saving is 5.0-5.3% compared to the previous scenario, and the annual EUI droped to 26.85-28.44 kWh/m². When the air-conditioning and lighting reach the best grades in EEWH equipment energy efficiency criterias (Scenario V), it can save 8.1-8.6% more energy. Compared with the baseline, when the envelope, air-conditioning, and lighting all reach the current best levels, energy savings can be 51.3-54.2%.

Further analyze the impact of roofs, exterior walls and glass on the energy saving of air-conditioning. The results show in **Fig. 4**. **Fig. 4 (A)** When the exterior walls and roof are well-insulated and the glass is replaced by a low-e glass, the energy saving per household is 3.71-5.54 kWh/m². Among windows external walls and roofs, windows have the most energy saving effect, accounting for 51.7-63.4%. External walls place the second, accounting for 30.1-38.9%. Roofs have a significant impact on the top floor dwelling units, accounting for 15.1-17.2%. On the other hand, **Fig. 4 (B)** shows a case with the same well-insulated walls and roofs, but changing the low-e window stretegy into insulation film. The energy-saving per household is 2.38-3.39 kWh/m². The energy-saving ratios of glass, exterior walls and roofs are respectively 43.2-53.3%, 37.4-47.8% and 16.2-18.1%. It is ovious that window glass has the greatest impact on the energy consumption of air-conditioning. Therefore, window would be the priority while considering building envelope energy-saving strategies in Taiwan.



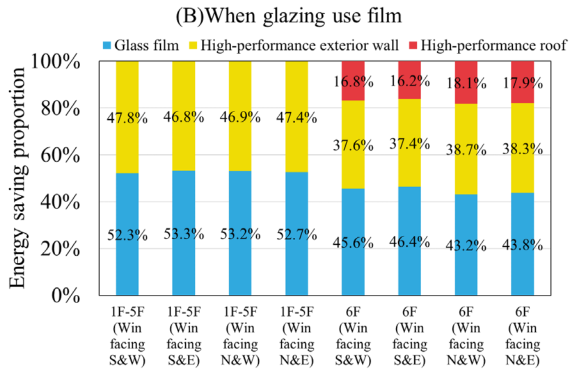


Fig. 4 - Percentage of energy-saving effects of high-performance building materials.

4. Conclusions and recommendation

There are many energy-saving design strategies for buildings. Based on the design and using type of the building, the energy-saving benefits are different. A standard and tipical building model and a series of step-by-step energy efficiency strategies will be a efficient way to evaluate the energy saving benifits. This study focused on school classroom and multi-dwelling, and evaluated the energy performance according to 5 energy-saving scenarios that based on mature but not fully widespread energy-saving technologies in Taiwan. The following are conclusions and suggestions:

1. Natural ventilation, which could reduces indoor temperature and air conditioner uses, is the most economically efficient strategy that should be considered first in any building energy saving design.
2. Well external shading design will reduce the energy-saving benifits of high performance building materials. Among windows, external walls and roofs, windows have the most energy saving benifits. It is recommended to give priority to shading and window design when considering building energy-saving strategy in Taiwan.
3. Since the mixed ventilation strategy greatly reduces the operationg hour of air conditioner, the energy saving that caused by the air conditioner efficiency improving would be reduced; however, equipment energy efficiency still has a significant energy-saving potential. Installing the most efficient level air-conditioners will save 3-5% energy when comparing with installing the basic level ones.
4. Due to the improvement of lighting performance, the LPD can be greatly reduced while maintaining the same illuminance level. Therefore, the use of LEDs can save energy by 13-33% compared with T8-fluorescent tube.
5. When comparing with baseline cases, a beyond-green-building school classroom can save 56.2% energy use, and a beyond-green-building multi-dwelling can save 51.3-54.2% energy use.
6. Compared to countries in temperate zone, Taiwan’s air conditioners and lighting performance is similar to international level.

But, the envelope performance is relatively low (compared with passive house, the U value of the outer wall is ≤0.15W/m^{2}k, and the U value of the window is ≤0.8W/m^{2}k). It is worth noting that considering Taiwan's climate and usage, when the envelope, air conditioning and lighting are all upgraded to the highest level of green building in Taiwan, the energy saving effect meets the energy saving level of 20-50% required by ZEB. The rest is to use renewable energy to reach net zero.

5. Acknowledgement

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6. References

[1] Bureau of Energy, Ministry of Economic Affairs, "Monthly Energy Statistics Report," Taiwan. 2021.

[2] ASHRAE, Advanced Energy Design Guide for Small to Medium Office Buildings Achieving Zero Energy. 2014.

[3] K.F. Woldekidan et al., "Moving Zero Energy Office Buildings to the Mainstream : Establishing Design Guidelines and Energy Targets Preprint Moving Zero Energy Office Buildings to the Mainstream : Establishing Design Guidelines and Energy Targets Preprint," no. September, 2020.

[4] M.Deru et al., "U.S. Department of Energy commercial reference building models of the national building stock," 2011.

[5] S.Attia, N.Shadmanfar, and F.Ricci, "Developing two benchmark models for nearly zero energy schools," Appl. Energy, vol. 263, no. November 2019, p. 114614, 2020, doi: 10.1016/j.apenergy.2020.114614.

[6] D.D'Agostino andD.Parker, "A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe," Energy, vol. 149, no. 2018, pp. 814–829, 2018, doi: 10.1016/j.energy.2018.02.020.

[7] Construction and Planning Agency, Ministry of the Interior, Building Technical Regulations. 2021.

[8] Ministry of Education, National elementary and junior high school facilities and equipment standards. Taiwan, 2019.

[9] Construction and Planning Agency, "Report on the Sample Survey of Housing Conditions in 2004," 2017.

Data Statement

The datasets generated during and/or analysed during the current study are not publicly available because project requirements but are/will be available confirm by email.