Session 2.6: Innovations Driving for Greener Policies and Standards – Carbon Assessment

Building Carbon Footprint (BCF) Method for Nearly Zero-Energy Building Design Assessment

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ABSTRACT

In recent years, with the global trend of greenhouse gas reduction and sustainability, the development of nearly zero energy building (nZEB) and zero carbon building (ZCB) becomes international consensus. However, some ZEB design technologies in Europe and America may not be entirely applicable to Taiwan where air condition costs a lot of energy in summer for the hot-humid climate. To face these challenges, this study provided appropriate architectural design technologies and conduct feasibility assessment of nZEB in Taiwan.

Firstly, three-oriented energy-saving technologies, including passive design, active design and renewable energy were analyzed. Then "Building Carbon footprint Method (BCF)" was used for nZEB quantify and feasibility of Taiwan's residential building. The main research results are as follows:

- In "Residential standard situations," through operating the optimizing design of building envelope and other ventilation and equipment efficiency factors, the EUI could be by 50 (kWh/ m^2.yr) down to 33 (kWh/ m^2.yr) . The total energy efficiency could rise up to 34%.
- If photovoltaics were chosen as the main renewable energy source, a single-family house with 150m2 floor areas would have the potential of reaching nZEB. However, if the house had larger scale, it needed more BIPV design and improve the conversion efficiency of solar cells to increase it s nZEB potential.
- The key point to aim at nZEB is to set specific near-zero energy targets, it not only to encourage innovative building energy efficiency design techniques, but also to promote the construction and upgrading of industrial technology.

Keywords: *green building management, energy saving, ZEB*

1. INTRODUCTION

The Nearly Zero-Energy Buildings (nZEB) refers to a low energy-consuming green building, using the renewable energy system for the building to attain the goal for energy neutralization zero energy consumption. The European Union (EU) has declared that the energy conservation standard of all of new buildings must conform to the standard of "nZEB" in 2020 . The United States Department of Energy (DOE) specified that the new commercial buildings should reach zero energy consumption by 2030, and attain the goal for zero energy consumption thoroughly by 2050. Taiwan has a mature green building evaluation system at present, but Taiwan is located in subtropical zone with wet hot climate, it depends on air conditioning energy a lot in summer, this is a big challenge to the development of zero-energy buildings in Taiwan. This study aims to appraise the feasibility of zero-energy design for green buildings under the precondition of developing nZEB in Taiwan.

2. RESEARCH PURPOSES

The main purpose of this study is to use appropriate building energy saving design technique to appraise the feasibility of nZEB, and the house building with relatively low "Energy Use Intensity (EUI)" is taken as research subject. In order to simplify the complex building energy consumption pattern, this study uses the " Standard Scenario " set by the "Building Carbon Footprint Evaluation Method (BCF)" of the Low Carbon Building Alliance (LCBA) to "standardize" the complex user, time interval and equipment by dynamic simulation of energy, and then calculates the reduction of building energy consumption with different building energy saving techniques.

3. RESEARCH METHOD

3.1 BCF method and application

The Building Carbon Footprint Evaluation Method deduced by LCBA uses a series of building materials, the statistics of building energy use and theoretical prediction equation of carbon emission to simulate the carbon footprint of buildings in 60-year life cycle, including the evaluation of five stages of life cycle, (1) building materials production and transportation; (2) construction; (3) daily use; (4) repair and renovation; (5) demolishment and discarding. The BCF uses a series of “Standard Scenario “to simulate the building carbon footprint. As the BCF method is completely established on the carbon investigation data of Taiwan's building industry, the building energy consumption analysis is developed according to Taiwan's meteorological data, the standard scenario of building use and architectural space classification are derived from precise local industry survey and academic research findings, which are indigenous, reproducible, effective and reliable.

General nZEB uses primary energy as baseline value, and only considers the energy consumption of lighting equipments, air-conditioning equipments and hot water supply equipments in "daily use" stage, the energy consumption of household appliances depends on the boundary of calculation, not always brought into calculation. At present, the studies of Taiwan's residential building energy consumption mostly use EUI (kWh/ m^2) as calculation unit. As the electricity, carbon emission and primary energy can be converted, and the routine energy consumption of BCF method is estimated by using the unit EUI of electricity (kWh/ m^2), without converting the electricity into carbon emission equivalent, this study uses the "routine energy consumption" evaluation method of BCF method to calculate the energy consumption of ZEB, which is a rapid and accurate method. Therefore, this study uses electricity (kWh) and EUI (kWh/ m^2) as the quantization units of ZEB.

3.2 "Standard Scenario" setting for residential routine energy consumption

The "Standard Scenario" means the complex users, time intervals and equipments are "standardized" by dynamic simulation of energy. The standard population of each household is set as two adults and two children, who have standardized work and rest. There is a standard situation for the service hours of household equipments (Table 1). The standard situation of residential energy consumption is: air conditioning energy consumption accounts for 20%, lighting energy consumption accounts for 30%, the energy consumption of the other household appliances accounts for 50%, the average EUI is 50 (kWh/m^2.yr) (Table 2).

Hours of operation (hr)	Annual service hours (hr/yr)		
	Air conditioning	Lighting	Business equipment
8760	1132	2920	2555

Table 1: Standard scenario of household equipments

Residential Type	Subitem EUI reference (kWh/m^2.yr)			EUI (kWh/m^2.yr)
	Air conditioning	Lighting	Electrical appliance	
Single house, townhouse, housing	10	18	22	50

Table 2: Standard residential EUI

4. BCF METHOD FOR QUANTITATIVE EVALUATION OF TAIWAN'S NEARLY ZERO-ENERGY HOUSES

4.1 Air conditioning energy conservation potential of house envelope energy conservation design

The first step of ZEB design is to use the passive energy conservation design of building envelop to reduce the indoor air conditioning heat load and the overall energy consumption of building. In the BCF method, if the energy consumption is not converted into carbon footprint equivalent (kgCO_2e), and the energy consumption (kWh/ m^2.yr) is calculated only, the estimation of the air conditioning energy consumption of specific air-conditioning system space is expressed as Equation 1:

$$\text{Annual energy consumption of specific AC system} = (\Sigma EUIai \times AFIi) \times Vac \times Bac \times SEL$$

Equation 1

$$Bac = 1.0 - (2/d) \times (1.0\text{-}EEV)$$

Equation 2

where, EUIai= Air conditioning EUI of residential space (kWh/m^2.yr)
AFIi= Indoor floor area (m^2)
Vac = Air conditioning energy consumption reduction ratio by natural ventilation
Bac= Air conditioning energy consumption reduction ratio by building envelop energy conservation
EEV= Building envelop energy-saving efficiency
SEL= Air conditioning energy label correction coefficient
2/d= Depth factor, where d is the mean depth in short direction of building (m)

The "natural ventilation air conditioning energy consumption reduction ratio Vac" means the building uses natural ventilation condition, so that the air conditioning is stopped in winter, spring and autumn to reduce the ratio of annual air conditioning energy consumption. If Vac=0.7, the natural ventilation can save 30% of air conditioning energy. The "natural ventilation air conditioning energy consumption reduction ratio Vac" is related to the "natural ventilation potential VP (Ventilation Potential)". The VP is the ratio of "naturally ventilated floor space" to "total floor space". According to the study of Building Research Institute, Cheng Kung University, Taiwan's "natural ventilation potential VP" is 0.9~0.3 . The residential spaces mostly use air conditioning at night, the maximum air conditioning energy-saving benefit is set as 70%, so the maximum Vac of residential type is 1, the VP is 0.9~0.7. The residential air conditioning energy conservation potential is discussed below by "passive energy saving technique" and "active energy saving technique".

- Discussion about passive energy conservation design benefit

According to Equation 1 and Equation 2, the "passive design" factors related to the air conditioning energy consumption estimation of specific air-conditioning system space include "building envelop energy-saving efficiency EEV", "mean depth d in short direction of building" and "natural ventilation air conditioning energy consumption reduction ratio Vac". As the BCF method encourages using natural ventilation to reduce the air conditioning energy consumption, if the EUI and total floor area are identical, this study assumes the energy-saving scenario baseline values to be VP=0.7, Vac=1, EEV=1, SEL=1 without using any shell energy conservation design technique.

The natural ventilation potential is the best when VP = 0.9, the Vac is 0.85. If EEV = 0.8, approaching the daily energy saving design value of most Taiwan's green buildings, the air conditioning energy-saving benefit increases to 22%. If EEV = 0.6, it is approximately the optimum performance value of shell energy saving of current green building design, the air conditioning energy-saving benefit is 29%, about 30% of air conditioning energy consumption can be reduced. (Figure 1).

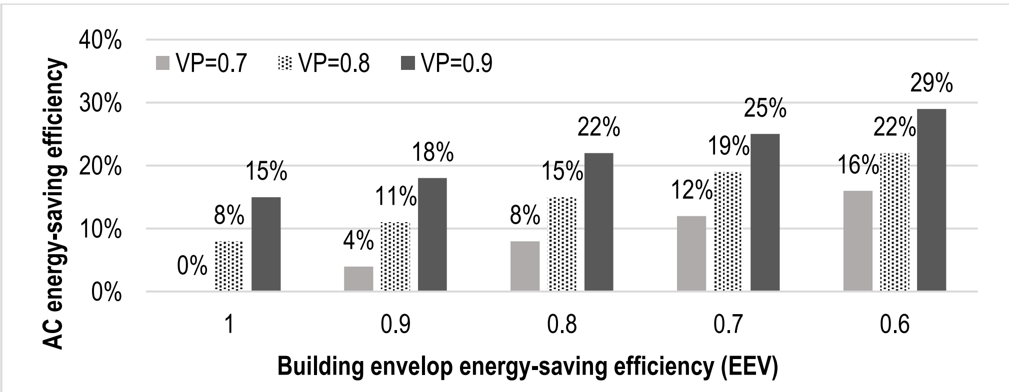

Figure 1: AC energy-saving efficiency and building envelop energy-saving efficiency EEV

- Discussion about active energy conservation design benefit

In Equation 1, the "active design" factor related to the annual energy consumption of specific air-conditioning system is the "air conditioning energy label correction coefficient SEL", the coefficient uses five "air conditioning energy label efficiency grades" of Bureau of Energy, Ministry of Economic Affairs for air conditioning energy consumption reduction. According to Figure 2, under the precondition of excellent passive energy conservation design (VP=0.9, EEV=0.6, d=5), the maximum air conditioning energy-saving benefit of different "air conditioning energy label efficiency grades" is 43%.

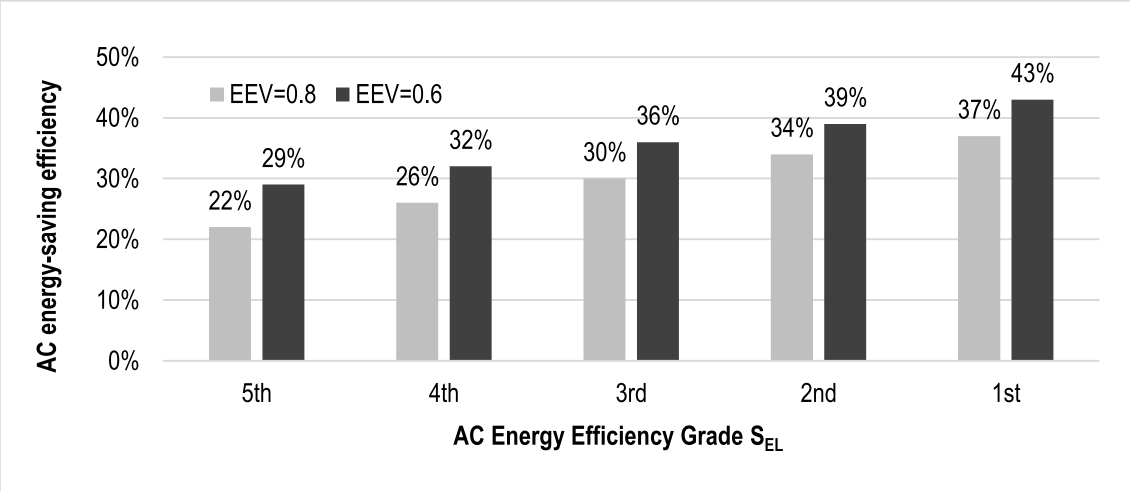

Figure 2: AC energy-saving efficiency and AC energy efficiency grade SEL

- Discussion about overall energy conservation design benefit

According to the pilot calculation of the aforesaid design influencing factors, the excellent passive design and excellent air-conditioning equipment (VP=0.9, EEV=0.6, d=5m, SEL=0.85), under the existing house design conditions of Taiwan, can reduce the routine energy consumption of residential air conditioning by 43%. Therefore, if the annual EUI of residential air conditioning is 10 (kWh/ m^2.yr), the minimum annual energy consumption is 10*0.6=6 (kWh/ m^2.yr).

4.1 Energy conservation potential of residential lighting design

The second factor influencing the residential energy consumption is the "lighting energy consumption". The BCF method estimates the lighting energy consumption as Equation 3. The EL index is the combined lighting energy-saving index about energy-saving lamps, lighting system and on-off control in Taiwan green building label EEWH.

$$\text{Annual energy consumption of lighting} = (\Sigma EUIai \times AFIi) \times EL$$

Equation 3

where, EUIli=Lighting EUI (kWh/ m^2.yr)
AFIi= Indoor floor area (m^2)
EL=The lighting system energy-saving efficiency follows the green building assessment manual EEWH - BC daily energy saving index specification

Referring to EEWH system, this study uses minimum 0.4 of EL for evaluation, namely, the minimum annual energy consumption of lighting can be 40% of standard lighting energy consumption. Therefore, if the annual EUI of residential lighting is 18 (kWh/ m^2.yr), the minimum annual energy consumption is 18*0.4=7.2 (kWh/ m^2.yr).

4.2 Energy conservation potential of household electrical equipments

The electrical equipments refer to household electric equipments with plugs, such as computer, washing machine and so on. The BCF method regards the water heater, hot drinks machine and household sauna as household appliances. The energy consumption of electrical equipments is estimated as Equation 4:

$$\text{Annual energy consumption of electrical equipment} = (\Sigma EUIai \times AFIi) \times Uei$$

Equation 4

where, EUIli=Lighting EUI (kWh/ m^2.yr)
AFIi= Indoor floor area (m^2)
Uei= Electrical equipment service management efficiency, using effective night standby power off management technique is 0.9

As the standby power consumption of household appliances accounts for about 10% of total power consumption of home, the BCF method privileges 10% of total energy consumption of electrical equipments for night standby power off management technique. Therefore, estimated by Equation 5-8, minimum value of Uei is 0.9, if the annual EUI of household electrical equipments is 22 (kWh/ m^2.yr), the minimum annual energy consumption is 22*0.9=19.8 (kWh/ m^2.yr).

4.3 Total residential energy conservation potential

According to the aforesaid subitem evaluation, under current condition of general techniques, if the residential planning and design use the optimum energy conservation design technique, the residential air conditioning EUI can be reduced from 10 (kWh/ m^2.yr) to 6 (kWh/ m^2.yr), the lighting EUI can be reduced from 18 (kWh/ m^2.yr) to 7.2 (kWh/ m^2.yr), the electrical equipment EUI can be reduced from 22 (kWh/ m^2.yr) to 19.8 (kWh/ m^2.yr), the total EUI can be reduced from 50 (kWh/ m^2.yr) to 33 (kWh/ m^2.yr), the maximum energy-saving benefit is 34%.

Title	Subitem EUI (kWh/ m^2.yr)			Total EUI (kWh/ m^2.yr)
	Air conditioning	Lighting	Electrical equipments	
Original standard value	10	18	22	50
Optimum energy-saving technique applied	6	7.2	19.8	33
Maximum energy conservation potential	40%	60%	10%	34%

Table 3: Energy-saving technique, residential EUI and maximum energy conservation potential

4.4 Substitution potential of residential renewable energy technology

The renewable energy is estimated by using photovoltaic in this study. First, local daily average solar radiation quantity (kWh/ m^2.day) is obtained from meteorological data, multiplied by photovoltaic installed capacity (kW), number of days, service life and correction coefficient 0.8 (m^2/ kWh), the annual electricity generation design value can be obtained (Equation 5).

$$\text{Photovoltaic panel electricity generation (kWh/year)} = \text{daily average solar radiation quantity (kWh/ } m^2\text{.day)} \times \text{Correction coefficient 0.8 (} m^2\text{/ kWh)} \times \text{Photovoltaic installed capacity (kW)} \times 365 \text{ (days)}$$

Equation 5

This study refers to the statistical data of Directorate General of Budget, Accounting and Statistics, Executive Yuan in 2015 , the nationwide average area per household is about 150 m^2, the EUI is 33 (kWh/ m^2.yr), the annual total power consumption is 4950 kWh. Mounting 1kW crystalline silicon photovoltaic panel needs about 10 ㎡, the annual electricity generation of 1kW photovoltaic panel in the north is about 803 kWh, that in the midland is about 949 kWh, that in the south is about 1095 kWh. Therefore, one household in the north needs at least 62 m^2 photovoltaic panel, that in the midland needs at least 52m^2 photovoltaic panel, and that in the south needs at least 45 m^2 photovoltaic panel. The specific payback period of investment is 14~19 years (Table 4).

If the individual house is a two-story building, 60%~80% of rooftop area shall be reserved for mounting photovoltaic panels. If it is a three-story building, as the rooftop area decreases, all the rooftop area shall be used, the shortage will be made up by ground area or upright space, so as to meet the goal for nZEB.

Besides the excellent energy conservation design of buildings, the application of renewable energy is the key to the success of nZEB. According to the aforesaid pilot calculation result, if a general-scale household (floor area 150 m^2) is used for nZEB design in Taiwan, under the precondition of disregarding the equipment investment cost, using the rooftop and partial area within the site to mount photovoltaic panels is potential to implement nZEB. However, the actual residential pattern is much complex, especially in large metropolitan areas, the residential pattern is mostly high density amalgamated dwelling, only using rooftop to set up photovoltaic panels to reach the balance of nZEB is hardly feasible. Therefore, only if the solar cell efficiency is further increased in the future, the concept of "Building Integrated Photovoltaic (BIPV) system" is used actively, and the photovoltaic panels are set up thoroughly on at least 70% of rooftop area, 20% of open area and the building elevation, the nZEB may be implemented.

Site	Daily average solar radiation quantity (kWh/m^2.day)	Annual power generation per unit capacity (kWh/kW)	Total installed capacity (kW)	Mounting area (m^2)	Cost recovered years (yr)
North	2.75	803	6.2	62	19
Midland	3.25	949	5.2	52	16
South	3.75	1095	4.5	45	14

Table 4: Photovoltaic substitution potential calculation (area per household 150 m^2)

5. CONCLUSION AND SUGGESTIONS

This study uses the BCF method of the "Low Carbon Building Alliance", controls the building envelop design, ventilation, lighting and household appliance factors in "residential standard situation", and calculates the "building EUI" under various energy-saving techniques, to evaluate the feasibility of nZEB. The results show that under the present general energy-saving techniques, the total residential EUI can be reduced from 50 (kWh/ m^2.yr) to 33 (kWh/ m^2.yr), the maximum energy-saving benefit is 34%.

This study uses "photovoltaic" as main renewable energy to evaluate the nZEB feasibility. The dwelling level is about 150 m^2 per household in Taiwan, under the precondition of EUI 33 (kWh/ m^2.yr), the small-scale "individual house" is potential to implement ZEB at present. However, in the case of amalgamated dwelling, the full elevation BIPV design and high conversion efficiency solar cell shall be developed, then it is potential to be ZEB.

In the promotion of related policies in the future, it is suggested to enhance the existing building energy saving reference, establish building energy label system, promote the improvement of the existing building efficiency, reward excellent green building design, and encourage the application of BIPV, so as to attain the goal for nearly ZEB.

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