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Evaluating the impact of photovoltaic systems on the thermal performance of buildings and its implication to building energy code. A case study in subtropical Hong Kong

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ABSTRACT

For promoting energy-efficient building design, various green building certification schemes such as BREEAM, LEED, DGNB, Green Mark, BEAM Plus, ASHRAE Standard 90.1, Code of Practice for OTTV, etc. have been developed around the world. In recent years, photovoltaic system is widely adopted in building application. This system can offer double benefits: (i) generating electricity by absorbing and transforming solar energy; (ii) reducing heat gain transmitted into a building through building envelope. Since the current building certification schemes were originally developed for buildings constructed with conventional building materials, the reduction in heat gain resulted from the application of photovoltaic systems cannot be properly reflected in these building certification schemes. This study investigates the effect of photovoltaic systems on the thermal performance of buildings. Three existing buildings located in subtropical Hong Kong were used as case study. It was found that the effect of photovoltaic glazing system on the reduction in heat gain was significant (ranging from −13.59% to −38.78%). Based on the findings from this study, it is recommended to incorporate the effect of photovoltaic glazing system into the OTTV regulation in Hong Kong. The methodology developed in this study can be applied to other building certification schemes and energy codes.

1. Introduction

Nowadays, there is a joint effort from worldwide scientists and engineers to reduce the emission of greenhouse gas (GHG), with an aim at mitigating the adverse impact of GHG on human health and retarding the rate of climate change. Minimization of energy use is one of the effective approaches to foster GHG reduction. Building, as one of the largest electricity consumers in a modern city, can make a marked contribution to energy conservation as well as GHG reduction by sophisticated building design. For promoting green building design, there are various green building certification schemes developed around the world. Some of these widely adopted schemes have been reviewed, with a focus on building energy efficiency, as outlined below.

1.1. BREEAM

BREEAM (Building Research Establishment's Environmental Assessment Method) is the first sustainability rating scheme for the built environment in the world. It was first launched in 1990 by the Building Research Establishment (BRE) in the United Kingdom. The first version of the BREEAM for New Offices was released in 1993 (Prior, 1993). After about two decades, the latest version of BREEAM New Construction was published in 2016 (BRE, 2016). BREEAM adopts a scoring system in which credits are awarded under ten categories including Management, Health and Wellbeing, Energy, Transport, Water, Materials, Waste, Land Use and Ecology, Pollution, and Innovation.

In the Energy category, procurement of energy-efficient equipment is encouraged to ensure optimum performance and energy savings in building operation. Under the section *Ene 08 Energy Efficient Equipment*, two credits can be awarded to a building if it can demonstrate a meaningful reduction in annual equipment energy consumption. Moreover, another two credits are allocated within the *Ene 04: Low Carbon Design* for building project that makes an appropriate use of renewable energy.

In passive building design, energy saving is promoted through appropriate selection/design in building fabric, thermal mass, building form, layout, orientation, etc. as stated in *Ene 04 Low Carbon Design*. In addition, reduction of heat gain/loss through building envelope is indirectly encouraged through an Energy Performance Ratio (EPR_{INC}) outlined in *Ene 01 Reduction of Energy Use and Carbon Emission*. A building under evaluation is firstly modeled to demonstrate compliance

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with local building regulations (e.g. L2A Conservation of Fuel and Power in New Buildings other than Dwellings (HM Government, 2013)). Then the building model is updated as a notional building by using the information from *Ene 01 Reduction of Energy Use and Carbon Emissions*. After that, the simulated energy demand (MJ/m^2), primary energy consumption (kWh/m^2) and emission rate ($kgCO_2/m^2$) of the building under evaluation, notional building and a BREEAM best practice building will be entered into a scoring and reporting tool to get an EPR_{INC}. According to the calculated value of the EPR_{INC}, a maximum of 15 credits are allocated to recognize and encourage buildings designed to minimize operational energy demand.

BREEAM has been widely used in Europe. Moreover, country-specific schemes have been developed in a number of countries such as Austria, Germany, Netherlands, Norway, Spain, and Sweden. BREEAM has been used to certify over 530,000 building projects and is being applied in over 70 countries.

1.2. LEED

Leadership in Energy & Environmental Design (LEED) is a sustainability rating system created by the US Green Building Council (USGBC) in the United States of America. It is a point-based assessment program for building projects. All LEED projects are evaluated per each criterion which is either a 'Prerequisite' or 'Credit'. Each building project is awarded scores against a standard set of credits and the sum of the points awarded determines the level of certification.

The current version of LEED v4 for Building Design and Construction was updated in July 2017 (USGBC, 2017). It covers various building types including New Construction, Core and Shell, Schools, Retail, Data Centers, Warehouses and Distribution Centers, Hospitality and Healthcare. In LEED v4, there are eight categories involved: Location and Transportation, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation, and Regional Priority.

The category: Energy and Atmosphere in LEED v4 intents for building projects to reduce the environmental burden by achieving a certain level of energy efficiency. The first part is a prerequisite on the *EA Minimum Energy Performance Requirement*. A building under evaluation must demonstrate that it can comply with the mandatory and prescriptive requirements of ANSI/ASHRAE/IESNA Standard 90.1–2016 (ASHRAE, 2016); or it can show an improvement of 5% for new construction projects in the proposed building performance rating compared with a baseline building performance rating which is calculated according to ANSI/ASHRAE/IESNA Standard 90.1–2016.

Then, up to 20 credits can be awarded under the *EA Credit: Optimize Energy Performance* if a building project can demonstrate increasing levels of energy performance beyond the prerequisite standard, either through whole building energy simulation or prescriptive compliance with the ASHRAE Advanced Energy Design Guide.

In the prescriptive approach, consideration of the building envelop heat gain/loss is evaluated through the number of credits awarded for the design of building elements. An example of small to medium office buildings is shown as follows.

ASHRAE 50% Advanced Energy Design Guide for Small to Medium Office Buildings:

- Building envelope, opaque: roofs, walls, floors, slabs, doors, and continuous air barriers (1 point)
- Building envelope, glazing: vertical fenestration (1 point)

Moreover, up to 3 points can be achieved in the *EA Credit: Renewable Energy Production* by using renewable energy systems to reduce the environmental burden associated with consumption of fossil fuel.

LEED has become one of the dominant sustainability rating systems globally and is commonly used in the USA, Canada, Mexico, Central and South America, and India. It is also widely used in China and the Gulf region as well as Western Europe.

1.3. DGNB

DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) was launched by the German Sustainable Building Council which was founded in 2007. The objective is to develop and promote materials, means, and solutions for the planning, construction and operation processes of buildings to meet the criteria of sustainability. In this scheme, six areas of evaluation are involved: Environmental Quality, Economic Quality, Sociocultural and Functional Quality, Technical Quality, Process Quality, and Site Quality. The DGNB is widely adopted in countries including Germany, Austria, Switzerland, Denmark, Bulgaria and China.

In the DGNB green building certification scheme, the primary energy requirement of a building is evaluated under the area Environmental Quality – *Resource Consumption and Waste Generation* (DGNB, 2014a). Checklist points are placed on the reduction in overall primary energy consumption and the utilization of renewable energy. Three energy indicators, namely Non-renewable Primary Energy Demand, Total Primary Energy Demand and Proportion of Renewable Primary Energy will be calculated by building energy simulation for the design building and a reference building. The number of checklist points to be awarded depends on the ratios of these three energy indicators between the design and reference buildings.

The quality of building envelope is governed by a DGNB Criterion *TEC 1.3 Building Envelope Quality* (under the Technical Quality), with an aim at reducing space heating demand (DGNB, 2014b). The evaluation is undertaken by comparing the existing performance of mean thermal transmittance of building envelope (including opaque and transparent external building components, glass roof, and rows of windows) to the required performance parameters as calculated according to the EN ISO 6946 standard (ISO, 2017). A maximum of 30 checklist points can be awarded in this part of evaluation.

1.4. Green Mark

The Green Mark scheme was established in 2005 as Singapore Government's initiative to promote sustainability in the built environment (BCA, 2016). The development of this Green Mark scheme is largely based on a *Code for Environmental Sustainability of Buildings* (BCA, 2012) which was also promulgated by the Singapore Government.

In the Green Mark scheme, 30 credits are allocated for building energy performance including:

- Energy Efficiency (11 points) in air-conditioning, lighting, car park systems, and receptacle load efficiency.
- Energy Effectiveness of Building Energy (11 points): to generate a percentage improvement in energy consumption of the design building against a notional reference building.
- Renewable Energy (8 points)

For controlling the heat gain/loss through building envelope, a building with aggregated area exceeding $500\,m^2$ has to cope with the requirements of Envelope Thermal Transfer Value (ETTV) set out in a *Code on Envelope Thermal Performance for Buildings* (BCA, 2008). ETTV was developed according to a review on the Overall Thermal Transfer Value (OTTV) regulation in Singapore which was originally implemented. It is claimed that the new ETTV can provide a more accurate measure of the building thermal performance.

ETTV is a measure of heat gain through building envelope. It takes into account the three basic components of heat gain through the external walls and windows of a building. These are (i) heat conduction through opaque wall; (ii) heat conduction through glass window, and (iii) solar radiation through glass window.