SOLAR RADIATION AND DAYLIGHT ILLUMINANCE MODELLING AND IMPLICATIONS FOR BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM DESIGNS

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Solar Radiation and Daylight Illuminance Modelling and Implications for Building Integrated Photovoltaic System Designs
太陽輻射與日光之模擬及其對建築物附設光伏系統設計的意義

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ABSTRACT

Recently, there has been an increasing awareness of building energy conservation. Renewable energy can produce energy without emitting pollutant and requires no fuel. Energy-efficient building designs can reduce electricity consumption and provide clean and sustainable energy via renewable energy facilities. Daylighting schemes can improve visual comfort for the building occupants and effectively reduce both artificial lighting energy and cooling load due to heat gains from artificial lighting. In many cities worldwide, particularly Hong Kong, high-rise commercial buildings are dominant in urban areas. The applications of building integrated photovoltaics (BIPV) are appropriate for these buildings in order to allow daylight penetration, reduce solar heat gain and generate electricity. The opaque and semi-transparent BIPV panels can serve as the solar façade and window glazing of the buildings, respectively. The knowledge in solar radiation and daylight illuminance on sloped surfaces can enhance the design strategies of BIPV systems. This thesis analyses the solar radiation, daylight illuminance, sky radiance and luminance data recorded from long term data measurements, develops models for predicting the solar radiation and daylight illuminance on inclined surfaces, performs field measurements and case studies for daylight-linked lighting controls and BIPV systems, and evaluates the design implications for BIPV systems in energy, environmental and financial terms.

The data measurements include the long term seven-year horizontal solar radiation and daylight illuminance (global and diffuse components), vertical solar radiation and illuminance, sky radiance and luminance distributions, and one-year sloped solar

radiation on 30°, 45° & 60° planes. The measured data were analyzed via statistical and graphical methods.

The measured data were further applied to develop models for determining solar radiation and daylight illuminance on sloped surfaces. The annual solar radiation on various inclined surfaces was determined by a sky radiance model and measured radiance data. A simple design tool for the prediction of annual solar radiation on sloped surfaces was developed based on measured horizontal solar radiation, sky radiance and sunshine duration data. The daylight availability is affected by the dynamically changing sky conditions. The determination of luminous efficacy under CIE standard skies can provide a reliable method for the calculation of daylight illuminance on inclined surfaces using recorded solar irradiance data. The performance of each prediction model has been assessed by statistical approaches.

To observe the effectiveness of utilising daylight illuminance and solar radiation, field measurements for daylighting schemes and BIPV systems were conducted to evaluate their energy performance. Measured results were analyzed systemically. It has been found that an office room integrated with daylight-linked controls can provide electric lighting energy saving at a satisfactory level of over 30% annually. Two semi-transparent BIPV systems, namely horizontal skylight and vertical glazing, can cut the solar heat gain without greatly lowering the daylight benefits. Apart from electricity generation, the semi-transparent BIPV systems can help reducing cooling load and lighting energy.

Detailed assessment of energy performance of building employing opaque BIPV and daylighting schemes has been conducted by using a building energy simulation tool. Analysis of annual energy consumption, peak cooling and electrical demand, and renewable energy generation was carried. A parametric study was performed to obtain an optimum design of building façade. Furthermore, case studies for semi-transparent BIPV systems (skylight and vertical glazing) have been completed by various calculation techniques. The evaluation is carried out in terms of the annual electricity use, cooling and lighting energy consumption, peak cooling load, electricity production, environmental and financial impacts. Design strategies are discussed based on the results.

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