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An experimental study on the annual surface temperature characteristics of amorphous silicon BIPV window

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ABSTRACT

In this study, a mock-up facility equipped with both BIPV windows and normal clear windows was installed to carry out the actual measurement of long-term surface temperature characteristics as the preliminary step for analyzing the impact of the surface temperature rise of thin film BIPV modules on the PV performance. The measurement was carried out for clear double windows and BIPV double windows simultaneously for each inclined angle (0°, 30°, and 90°) for one year, and various statistical analyses were carried out for the collected annual surface temperature data to investigate the surface temperature characteristics of BIPV windows. The analysis result shows that the temperature of windows applied on the vertical plane rises significantly during the winter season, and the temperature of windows applied on the horizontal plane and the inclined plane rises significantly during the summer season with high solar altitude. Regarding indoor surface temperature of windows which is closely related with the thermal comfort of indoor occupants, the surface temperature of BIPV windows with low solar heat gain coefficient was 1 °C lower than that of normal windows during the day time in summer season and was approximately 2 °C higher during the night time in winter season due to the thermal insulation effect.

1. Introduction

Thin film solar cells have lower energy conversion efficiency than crystalline solar cells but have very high flexibility in the integration with a building so that these solar cells have received increasing attentions in BIPV field during the last decades. Especially, transparent thin film solar cells which enable day-light penetration can provide multiple functions including power generation as well as day-lighting, shading and heat radiation and thus it is considered as a field of technology with very high potential.

In order to apply transparent thin film solar cells to BIPV effectively, it is necessary to review comprehensive aspects such as power generation capacity, shading, lighting, heat and sound radiation. Especially, the surface temperature of the modules greatly affects the power generation efficiency of solar cells and building load, and thus it should be taken into account. Generally, the surface temperature of PV modules is affected by solar radiation, outdoor temperature, wind speed, wind direction, building material properties and installation method of modules [1]. Among them, solar radiation has the highest impact. On the other hand, the temperature of PV modules rises and drops slowly, indicating that there is a time lag affect between the PV module temperature and the solar radiation [2].

5–20% of the solar radiation is converted into electricity. The remainder of the solar radiation is contributes to the increase of the PV module temperature by either the absorption of infrared solar radiation or the internal heat generation from transparent electrode (TCO) and high reflectance coating.

When applying this PV module to a building in the form of double or triple pane windows, questions including how the temperature characteristics of PV module changes as well as how indoor thermal environment will be influenced by changes in the temperature of PV modules should be evaluated. The surface temperature of BIPV modules can have various impacts on indoor cooling and heating energy consumption, and the possibility of thermal cracking due to the overheating of PV modules under different situations should be taken into account. Therefore, the surface temperature of PV modules can be considered as a very important influential factor for the proper installation and operation of BIPV modules, and thus it is necessary to have a clear understanding of the temperature change characteristics of modules before applying PV modules to a building.

However, previous studies regarding PV or BIPV modules are mainly focused on the actual measurement of generation performance such as the generation efficiency drop due to the temperature rise of module [3], methodology for reducing temperature rise through the ventilation strategy on the rear side of the

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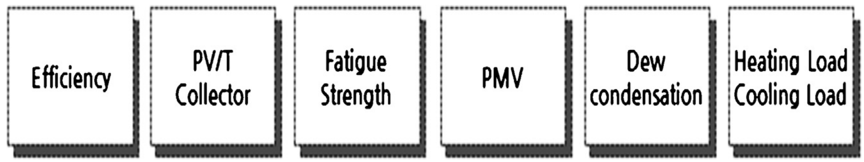

Fig. 1. Considerations according to the temperature characteristics of PV module.

module [4], PV/T system [5,6], and simulation evaluations for light and thermal environments due to the BIPV application [7,8]. The generation capacity and prediction by simulation are important for applying actually effective BIPV, and thus various studies on the generation performance based on actual measurements are also required. Furthermore, it is necessary to examine the temperature characteristics of module greatly affecting the generation performance, but studies with actual measurement have not been carried out sufficiently thus far.

Therefore, mock-up facility equipped with both BIPV windows and normal clear windows was installed to carry out the actual measurement of long-term surface temperature characteristics as the preliminary step for analyzing the impact of the surface temperature rise of thin film BIPV modules on the PV performance in this study. The measurement was carried out for clear double windows and BIPV double windows simultaneously for each inclined angle (0°, 30°, and 90°) for one year, and various statistical analyses were carried out for the collected annual surface temperature data to investigate the surface temperature characteristics of BIPV windows.

2. Theoretical review

For highly efficient transparent thin film PV modules, transparent conductive oxide (TCO) layer with rough surface is deposited on a flat glass plate to increase the amount of light absorption. However, when the amount of light absorption is increased, the surface temperature of the module rises, decreasing the generation efficiency. In case of crystalline silicon solar cells, approximately 0.5% of generation efficiency decreases when the surface temperature increases by 1 °C, and in case of non-crystalline thin film solar cells, approximately 0.2% of generation efficiency decreases by the temperature rise of 1 °C [9]. Therefore, the temperature rise in solar cells is closely related to the power efficiency, and thus it is a very important factor when applying BIPV system. A variety of factors directly connected to the surface temperature of the module are shown in Fig. 1.

Recently with regard to the surface temperature of crystalline solar cells, the development of PV-thermal hybrid module which reduces the temperature rise has been developed actively. The solar heat system normally converts only a little portion of solar radiation into electricity and the rest will be emitted as heat, but the PV-thermal hybrid system effectively retrieves this heat to maximize the overall efficiency. In this case, the rear surface of the PV plate will be cooled down so that the generation efficiency of PV can be increased by approximately 10%.

In addition, when applying BIPV windows which replace glass skin of a building, the surface temperature rise will affect not only the thermal environment of indoor occupants but also the cooling and heating load of the building. And also, due to the characteristics of BIPV windows with low penetration ratio, it is necessary to adopt the automated lighting control system to predict the impact on the lighting energy consumption as well as changes in cooling and heating energy consumption due to the heat emitted from the artificial lighting.

Furthermore, the issue of surface temperature rise of BIPV windows may be extended to the safety problems, i.e., relevant module problems should also be taken into account such as thermal stress due to continuous heat energy accumulation into the module, heat damage by the high temperature difference between the center portion and other portions of glass and the damage due to the mechanical resistance drop because of the glass surface temperature increase.

Finally, BIPV modules also have transparency which is a basic property of windows and is deposited on the normal glass materials, indicating that thermal radiation will be emitted under different levels of surface temperature rise and drop just like normal windows. This radiant heat becomes the main influential factor of the thermal comfort of indoor occupants, indicating that it is necessary to evaluate the changes in the mean radiant temperature (MRT) due to heat loss and gain near windows and corresponding thermal comfort.

3. Results of surface temperature characteristics of BIPV windows

3.1. Overview of mock-up facility and BIPV window

In order to install BIPV windows to mock-up, 10 mm PV single plate module was produced for non-crystalline transparent thin film solar cells. The size of the module is 980 mm wide and 950 mm long, and one PV module is connected with 108 cells in series. A BIPV window applied in this study is composed of 10 mm PV single sheet module + 12 mm air space + 5 mm clear glass as illustrated in Fig. 2.

As schematized in Figs. 3 and 4, the mock-up model is a shape of 8 m wide, 5 m long and 3.5 m high combined with a 30° inclined roof and horizontal roof. It south-oriented for the solar radiation absorption and is located in Yongin, Gyeonggi-Do, South Korea [5]. BIPV windows were installed on the horizontal plane (tilt angle of 0°), inclined plane (tilt angle of 30°) and vertical plane (tilt angle of 90°), and clear windows were installed in the same angles in order to carry out the comparative performance analysis with BIPV windows.

The measured parameters and equipment details such as the accuracy are summarized in Table 1.

The visible transmittance and the solar heat gain coefficient (SHGC) of BIPV windows are 7.5% and 0.185, and 81.5% and 0.075 for clear windows, respectively.

During the measurement period, no HVAC system was operated, and the statistical analysis for temperature data measured in each installation angle for 10 months from November 2006 to August 2007 was performed. During the measurement, the average value for every 10 min was computed, and the statistic analysis was carried out for total 363,216 data. The analysis result was schematized in forms of Box & Whisker graph for arithmetic mean, standard deviation, maximum and minimum.

The measured data of outdoor air temperature and solar radiation on vertical, horizontal and inclined planes were presented in Fig. 5.