Abstract: In this study, a Building Integrated Photovoltaics (BIPV) system installed at Yasar University, Izmir, Turkey, which also achieved TS EN ISO 50001:2011 (Energy Management System Standard) certification as the first university in Turkey on 5 January 2016, was introduced first. A comparison between the theoretical and experimental (on-site measurements) values was then made. Finally, the results obtained were presented and discussed. The authors expect that the study will be very beneficial to those, who are involved or interested in the design, analysis, simulation, and performance evaluation of BIPV systems.

Keywords: Buildings, Building Integrated PV, Photovoltaics, PV, BIPV,

Introduction
Photovoltaics (PV) is a fast growing market. More than any other energy technology, solar PV has grown at an amazing pace. In this regard, a number of studies have been conducted on this topic while numerous installations have been realized worldwide. As part of these studies, Building Integrated PV (BIPV) systems play an important role in generating electricity.
BIPV systems are considered multi-functional building elements that combine electricity generation with other functions of the building envelope. These systems appear as a promising strategy and the most rapidly emerging technology within the solar industry to help in achieving the ambitious goals set by the European energy policies as for the nearly-zero energy buildings (nZEB) foreseen in the energy performance of buildings directive 2010/31/EU (Maturi et al., 2015). The efficiency loss with rising temperature in a PV module is mainly due to a globally with an estimated capacity growth of about 50% or more from 2011 to 2017 [1].

Ventilated BIPV had been studied theoretically and experimentally, while various methods of PV cooling have been proposed by different investigators, as reported by ElSayed [2].

Lai and Lin [3] integrated PV system, building structure, and heat flow mechanism to propose the notion of ventilated BIPV walls. They investigated the energy-saving potential of the ventilated BIPV walls via engineering considerations and using computational fluid dynamics (CFD) simulations. CFD simulations of flow patterns and temperature distributions of the ventilated BIPV walls were conducted under the conditions of three outdoor wind velocities, four airflow channel widths and six indoor vent heights. It concluded that a wider airflow channel resulted in a lower heat removal rate for the ventilated BIPV wall while the heat removal rate and indoor heat gain were not significantly affected by indoor vent height. The effects of outdoor wind velocity and channel width on the heat removal rate and indoor heat gain were also introduced.

Saadon et al. [4] numerically simulated a partially transparent, ventilated PV façade designed for cooling in summer (by natural convection) and for heat recovery in winter (with the aid of mechanical ventilation). For both configurations, air in the cavity between the two building skins (photovoltaic façade and the primary building wall) was heated by transmission through transparent glazed sections, and by convective and radiative exchange. It was reported that BIPV/T systems were relevant components for near net-zero energy houses and provided significant potential for reducing the cooling needs.

Chatzipanagi et al. [5] presented the results of a demonstrative BIPV system installed in Lugano where five BiPV modules with different integration solutions (fully integrated as Double Glaze Units and ventilated), different inclinations (30° and 90°) and different technologies (double junction amorphous silicon (a-Si/a-Si) and crystalline silicon (c-Si)) were investigated. Fully integrated modules exhibited higher temperatures. In terms of performance, the integrated c-Si modules, regardless of their inclination, ranked lower – in terms of energy yield – than the integrated and ventilated a-Si/a-Si modules, for which the high operating temperatures proved to be beneficial. The inclination of 90° was found to be ideal for Lugano for both c-Si and a-Si/a-Si modules.

The simplest strategy to cool down the modules – well documented in literature – is the natural retro-ventilation of PV, which could achieved with the presence of a suitable air gap between the module back surface and the building envelope structure [6]. This approach has been used in the REELCOOP project. Within the framework of a European Commission project, the so-called REELCOOP, it is aimed at significantly enhancing research cooperation and knowledge creation on renewable electricity generation, involving Mediterranean partner countries, while at the same time developing and testing new renewable electricity generation systems. One of three novel prototype systems to be developed and tested in the project is prototype 1, which is related to a BIPV system.
Measuring System

Many measuring devices have been installed on the BIPV system for evaluating the system performance. The PV surface temperature has been measured at 24 points using T-type thermocouples. The air temperature behind the PVs on the upper side has been measured at 12 points, of which two have been made using thermo-anemometers while the rest has been measured by T-type thermocouples. Due to the shading effects on the façade, the solar irradiation has been measured at 6 locations (4 of them are in the corners and the remainder is in the middle of each string). A weather-station has been located just next to the upper string. The wind velocity and direction, the air temperature and humidity have been measured at this point. Some pictures and their locations of the measuring devices are indicated in Figures 1 and 2 while their range and accuracy values are listed in Table 1.

Figure 1. Pictures of the measuring devices (Upper left: weather station, Lower left: Anemometers, Right: pyranometer). Note that the thermocouples are behind the PV panels.

Figure 2. Locations of the measuring devices.
Table 1. Specifications of the measuring devices.

<table>
<thead>
<tr>
<th>Name</th>
<th>Instrument</th>
<th>Measurement range</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface temperature measurement</td>
<td>T-type thermocouples</td>
<td>0 ÷ 100 °C</td>
<td>± 0.5 °C</td>
</tr>
<tr>
<td>Thermo-anemometers</td>
<td>Temperature</td>
<td>-10 ÷ + 60°C</td>
<td>± 0.3 °C</td>
</tr>
<tr>
<td></td>
<td>Air velocity</td>
<td>0 ÷ 2 m/s</td>
<td>± (0.06 m/s + 2% of measurement)</td>
</tr>
<tr>
<td>Global radiation sensor</td>
<td>Pyranometers</td>
<td>0 ÷ 1500 W/m²</td>
<td>Sensitivity : 6.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total uncertainty : 0.34%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Expected uncertainty : 0.67%</td>
</tr>
<tr>
<td>Weather station</td>
<td>Temperature</td>
<td>-40 ÷ + 60°C</td>
<td>± 0.1 °C</td>
</tr>
<tr>
<td></td>
<td>Relative humidity</td>
<td>0 ÷ 100%Rh</td>
<td>± 2% f.s.</td>
</tr>
<tr>
<td></td>
<td>Wind speed</td>
<td>0.28 ÷ 50 m/s</td>
<td>&lt; 0.1 m/s</td>
</tr>
<tr>
<td></td>
<td>Wind direction</td>
<td>0 ÷ 360°</td>
<td>± 0.3°</td>
</tr>
</tbody>
</table>

**Figure 3.** Datalogger.

**Datalogger:** A 60-channel HIOKI data logger has been mounted in the suspended ceiling of one of the classrooms located behind the façade. All the sensors have been connected to the datalogger and the data have been recorded continuously.

**Virtual PC for data storage:** The IT department of Yasar University has created a virtual PC with one processor, 4 GB RAM and 100 GB Hard Disk, to store data. The data logger has been connected to the local area network (LAN) of the university through Ethernet cable. The picture of the data logger is given in Figure 3.

The BIPV electricity generation data have been measured by the SMA inverter itself. The electrical data have been sent to the SMA Sunny Portal web-based cloud services through the cluster controller with 15 minute intervals. This allows us to connect to Sunny Portal and monitor all the electricity generation data on the instant, daily, monthly and yearly bases.
Analysis

The influence of the PV module temperature on the electrical efficiency is considered using the following equation [7]:

\[
\eta_T = \eta_{\text{stc}} \times \left(1 - \beta \times (T - T_{\text{stc}})\right)
\]

(1)

where \(\eta_{\text{stc}}\) represents the efficiency of the PV module under standard test conditions and \(\eta_T\) stands for the efficiency of the models under irradiation level equal to 1000 W/m² and the PV module temperature equal to \(T\) (°C).

According to the manufacturer information, the temperature coefficient (\(\beta\)) is taken to be equal to 0.0045 K⁻¹.

In addition, the influence of the total irradiation level on the electrical efficiency of the PV modules is considered using the following equation.

\[
\eta_{\text{irr-A}} = \alpha \times \eta_{\text{stc}}
\]

(2)

where, \(\eta_{\text{irr-A}}\) stands for the electrical efficiency of the module under irradiation level equal to ‘A’ (W/m²) and the PV module temperature equal to 25 °C. According to the manufacturer information, the irradiation coefficient (\(\alpha\)) values are provided in Table 2.

<table>
<thead>
<tr>
<th>Irradiation level (W/m²)</th>
<th>Irradiation coefficient (\alpha) (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>92%</td>
</tr>
<tr>
<td>200</td>
<td>97%</td>
</tr>
<tr>
<td>400</td>
<td>99%</td>
</tr>
<tr>
<td>700</td>
<td>102%</td>
</tr>
<tr>
<td>1000</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2. Irradiation related coefficients for the electrical efficiency of the PV modules [7].

Results

The values for daily irradiation level and environment temperature on 21 April 2016 are illustrated in Figure 4. It is obvious from the figure that the environment temperatures vary between 16.5 °C and 22.5 °C while the maximum irradiation level of 594 W/m² has been recorded at 10.15 a.m.

Figure 4. Values for daily Irradiation level and environment temperature on 21 April 2016.
Hourly electrical power generation values dated 21 April 2016 are illustrated in Figure 5. As can be seen in the figure, these values have been recorded between 7 a.m and 8 p.m., reaching a maximum value of 4 kW at about 11 a.m.

**Figure 5.** Hourly electrical power generation values on 21 April 2016

Daily electrical energy generation values in April 2016 are indicated in Figure 6. It is clear in the figure that these values are in the range of 11 kWh to 23 kWh, reaching a maximum value on 21 April 2016.

**Figure 6.** Daily variation of energy generation values in April 2016.

The BIPV system was commissioned on 9 February 2016 and since then, the system has been successfully operated. As seen in Figure 7, the highest energy production value belongs to the month of April at 547 kWh, being totally 2113 kWh as of 22 June 2016.

**Figure 7.** Monthly energy generation values.
Hourly energy efficiency values based on the PV and cell areas are shown in Figure 8 while they are maximum 12% and 16%, respectively.

Figure 8. Variation of hourly energy efficiency values.

Concluding Remarks

In this study, a BIPV system installed at Yasar University was considered and analyzed using the preliminary results. Some conclusions may be drawn from the results of the present study over a period of 5 months from February to June 2016 as follows:

a) The maximum irradiation level is recorded to be 594 W/m².
b) A maximum electrical power generation value of 4 kW is obtained.
c) The highest energy production value is observed in April at 547 kWh.
d) Hourly energy efficiency values based on the PV and cell areas are maximum 12% and 16%, respectively.

References


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