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Comparison of Transparent Insulated and Non-Insulated Solar Cell

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Abstract: In today's world, non-renewable sources such as coal, petroleum, and natural gas have become unreliable sources of fuel for energy production because of price volatility caused by geo-political issues and the depletion of these resources. Nonetheless, there's a rapid increase in energy consumption globally. Therefore, alternate energy sources are seriously required if the above challenges are to be resolved. These alternate energy sources are wind power, hydropower, solar energy, biomass, biofuel, and geothermal energy. In the Turkish Republic of North Cyprus (TRNC), weather conditions favor solar energy applications. However, the efficiency of solar cells is negatively affected by high temperatures. Therefore, transparent insulation materials are applied to the solar cell. Transparent or translucent insulation materials (TIM) represent a new class of materials with a high potential for increasing the efficiency of solar thermal systems. This paper investigates the advantages of applying transparent insulation materials to solar cells with respect to their efficiency by theoretical and experimental analysis. The cells are attached to a levered plane with a protractor that acted like a "see-saw" to adjust the angle of the solar cells to the Sun. Around the plane, a column of cardboard was constructed with black fabric covering the inside and bottom surfaces to prevent unwanted reflections. The time of day, temperature, voltage, and current were recorded in the experimental analysis. Using Microsoft Excel, the data (voltage, current, and calculated power) was graphed with respect to time. In the result, we compare solar cells with TIM and solar cells without (TIM). The results of the investigation show that solar cells with TIM have better efficiency compared to solar cells without TIM.

Keywords: Solar energy, Solar cell, Transparent insulation materials.

Introduction

Solar cell (photovoltaic cell or photoelectric cell) is a solid-state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The energy of light is transmitted by photons-small packets or quanta of light. Electrical energy is stored in electromagnetic fields, which in turn can make a current of electrons flow. Assemblies of solar cells are used to make solar modules which are used to capture energy from sunlight. When multiple modules are assembled together (such as prior to the installation of one pole-mounted tracker system), the resulting integrated group of modules all oriented in one plane is referred as a solar panel. The electrical energy generated from the modules is an example of solar energy. Photovoltaic is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight. Cells are described as photovoltaic cells when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example, infrared detectors, or measurement of light intensity.

History and Development of Solar Cell Technology

The development of solar cell technology began with the 1839 research of French physicist Antoine-César Becquerel. Becquerel observed the photovoltaic effect while experimenting with a solid electrode in an

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electrolyte solution when he saw a voltage develop when the light fell upon the electrode. The major events are discussed briefly below, and other milestones can be accessed by clicking on the image shown below.

- Charles Frits **- First Solar Cell**: The first genuine solar cell was built around 1883 by Charles Frits, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold. The device was only about 1 percent efficient.
- Albert Einstein **- Photoelectric Effect:** Albert Einstein explained the photoelectric effect in 1905 for which he received the Nobel Prize in Physics in 1921.
- Russell Oh l **- Silicon Solar Cell:** Early solar cells, however, had energy conversion efficiencies of under one percent. In 1941, the silicon solar cell was invented by Russell Oh 1.

Gerald Pearson, Calvin Fuller, and Daryl Chapin **- Efficient Solar Cells:** In 1954, three American researchers, Gerald Pearson, Calvin Fuller, and Daryl Chapin, designed a silicon solar cell capable of a six percent energy conversion efficiency with direct sunlight. They created the first solar panels. Bell Laboratories in New York announced the prototype manufacture of a new solar battery. Bell had funded the research. The first public service trial of the Bell Solar Battery began with a telephone carrier system (Americus, Georgia) on October 4, 1955 (Khoja,2013).

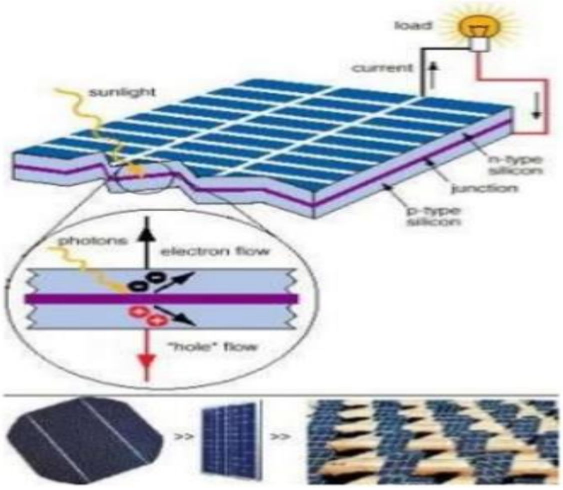

Figure 1. Photovoltaic cell or photoelectric cell (Khoja, 2013).

How Solar Cells Work - Components & Operation of Solar Cells

Since a solar cell is the only generator in a solar PV system, it is one of the most important parts of a solar PV system. In the following paragraphs, a simple introduction of a solar cell and how it operates is discussed (Miller, 2013). A solar cell is an electronic device that directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power.

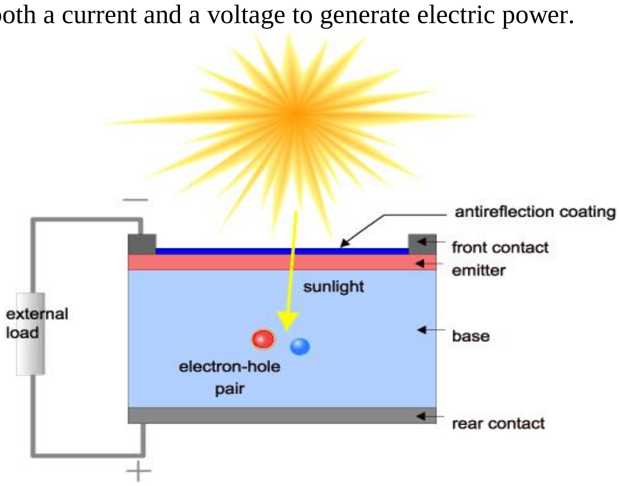

Figure 2. Solar cell structure (Miller, 2013).

This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice, nearly all photovoltaic energy conversion uses semiconductor materials in the form of a *p-n* junction (Maxwell,2011). A solar cell structure is shown in figure 2 and a solar panel configuration is in figure 3.

The basic steps in the operation of a solar cell are:

- The generation of light-generated carriers;
- The collection of the light-generated carries to generate a current;
- The generation of a large voltage across the solar cell; and
- The dissipation of power in the load and in parasitic resistances.

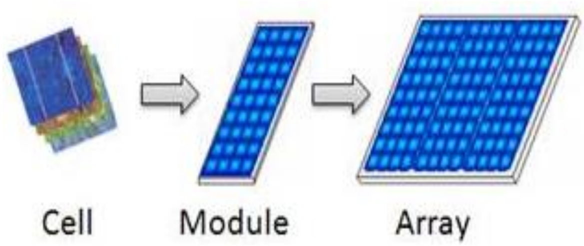

Figure 3. Solar panel configuration (Miller, 2013).

Light-Generated Current

The generation of current in a solar cell, known as the "light-generated current", involves two key processes. The first process is the absorption of incident photons to create electron-hole pairs. Electron-hole pairs will be generated in the solar cell provided that the incident photon has an energy greater than that of the band gap. However, electrons (in the *p*-type material), and holes (in the *n*-type material) are meta-stable and will only exist, on average, for a length of time equal to the minority carrier lifetime before they recombine. If the carrier recombines, then the light-generated electron-hole pair is lost and no current or power can be generated.

A second process, the collection of these carriers by the *p-n* junction, prevents this recombination by using a *p-n* junction to spatially separate the electron and the hole. The carriers are separated by the action of the electric field existing at the *p-n* junction. If the light-generated minority carrier reaches the *p-n* junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the solar cell are connected together (i.e., if the solar cell is short-circuited), the light-generated carriers flow through the external circuit. The ideal flow at a short circuit is shown in Figure 4(Finch, 2003). The absorption of a photon creates an electron-hole pair. Ideally, the minority carrier (in this case a hole) makes it across the junction and becomes a majority carrier. After passing through the load the electron meets up with a hole and completes the circuit.

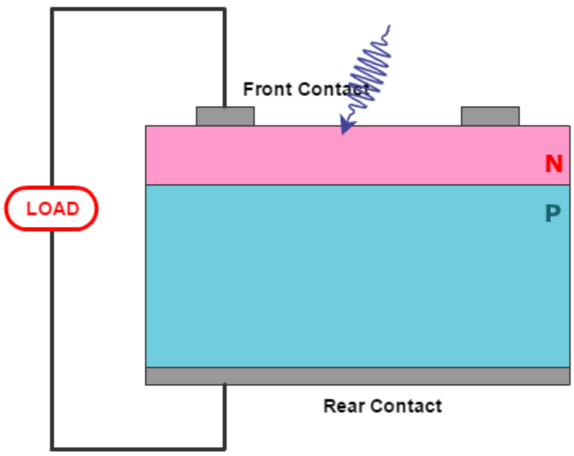

Figure 4. The ideal short circuit flow of electrons and holes at a p-n junction (Finch,2003).

Materials Used in Solar Cell

Various materials display varying efficiencies and have varying costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth’s surface. However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light-absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms. Materials presently used for photovoltaic solar cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenite/sulfide. Many currently available solar cells are made from bulk materials that are cut into wafers between 180 to 240 micrometers thick that are then processed like other semiconductors. Other materials are made as thin-films layers, organic dyes, and organic polymers that are deposited on supporting substrates. A third group is made from Nanocrystals and used as quantum dots (electron-confined nanoparticles). Silicon remains the only material that is well-researched in both bulk and thin-film forms. Examples: Crystalline silicon, Thin films, Cadmium telluride solar cells, Copper indium gallium selenite, Gallium arsenide multifunction, Silicon thin films…etc. (Khoja, 2013).

Transparent Insulation Material (TIM)

The input object “Surface Control: Movable Insulation” allows modeling Transparent Insulation Materials (TIM) that were originally designed for use in solar collector systems, where there was a need to increase the insulation in the solar collector without dramatically reducing solar energy transmittance. Transparent Insulation provides both these properties, insulation from heat loss and transmittance of solar energy. The combination of these properties is achieved because Transparent Insulation is a transmitter of short-wave radiation but a barrier to long-wave radiation. Therefore, short-wave solar radiation passes through the Transparent Insulation, and long-wave heat radiation is insulated by the transparent insulation. Incident solar energy falling on the transparent insulation is reflected and re-reflected within the material and eventually falls on the absorber. In addition, transparent insulation materials also have increased thermal resistance due to conduction in comparison to standard glass. Honeycomb transparent insulation was first developed in the 1960s to enhance the insulation value of glazing systems with minimal loss to light transmission. Over the past 25 years, transparent insulation materials (TIMs) have been applied to windows, walls, skylights, roofs, and high-performance solar collectors.

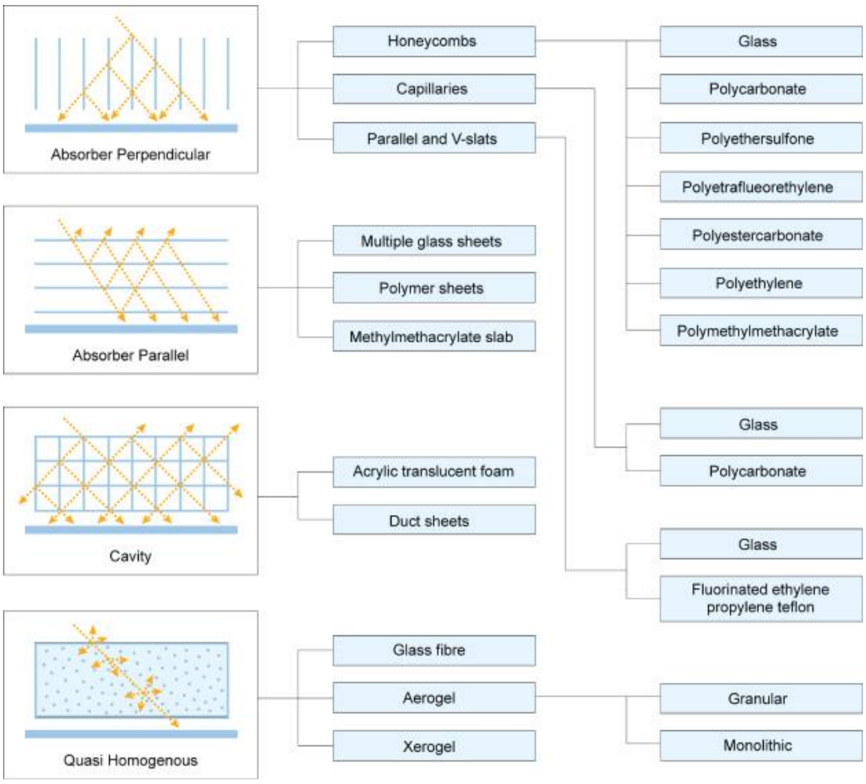

Figure 5. Types of transparent insulation (Happold, 2022).

Transparent insulation materials perform a similar function to opaque insulation, but they have the ability to transmit daylight and solar energy, reducing the need for artificial light and heating. They transmit heat, mainly through conduction and radiation, but convection is usually suppressed. The thermal and optical properties of transparent insulation materials depend on the material, its structure, thickness, quality, and uniformity. They typically consist of either glass or plastic arranged in a honeycomb, capillary or closed-cell construction. Alternatively, granular or monolithic silica aerogel can be used to achieve higher insulation values. Depending on the structure of the material, its arrangement can be classified as:

- Absorber perpendicular.
- Absorber parallel.
- Cavity.
- Quasi-homogeneous.

Figure 6 (below) compares the thermal conductivity of various transparent insulation materials and other insulation products. Okalux Glass Honeycomb is a commercially produced absorber perpendicular TIM with a thermal conductivity of 0.039W/m.K. Translucent silica aerogel, a quasi-homogenous TIM, has the lowest thermal conductance of any known solid at 0.004-0.018W/m.K. Only vacuum technology is comparable with thermal conductivities in the region of 0.005W/m.K.

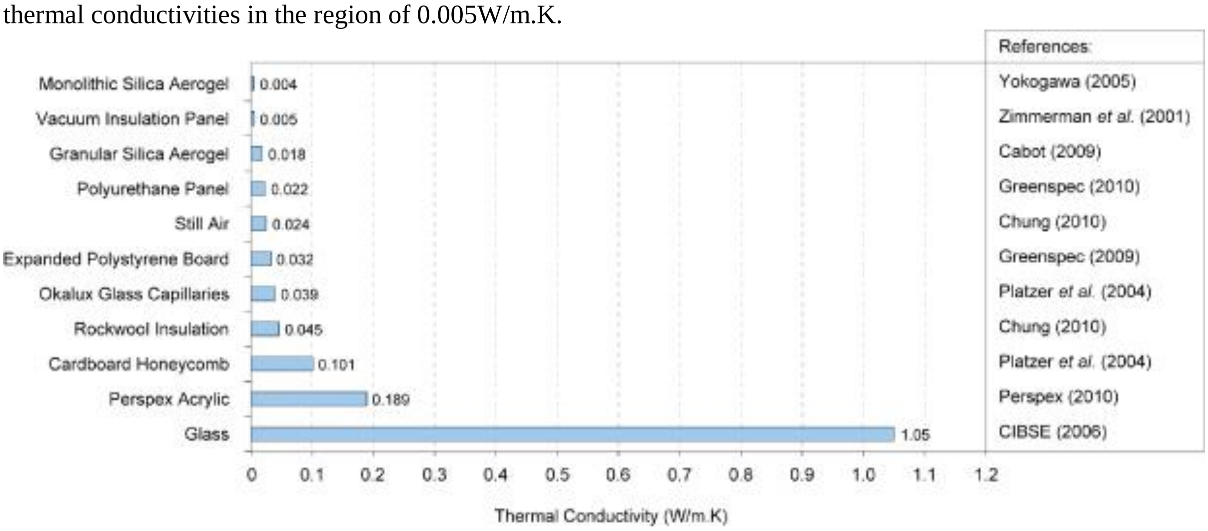

Figure 6. Thermal conductivities of insulation materials (Happold, 2022).

The Experiment of a Solar Cell

Solar cells convert light energy into electrical energy. With a few simple tools on a sunny day, you can measure how efficient a solar cell is at transforming sunlight into electricity by taking a reading from the multimeter. Here are the few equipment required

- Solar cell
- Multimeter
- Crocodile clips
- Tapes
- Wooden or Cardboard base for the inclination of the solar cell
- Transparent layer

Calibration

The most important setting is to calibrate the measuring instrument and in this, it is a multimeter. These are the steps to calibrate a multimeter

- Set the multimeter to the highest resistance range by turning the dial to the highest "ohm" setting.
- Touch the test probes of your digital multimeter together. The digital display of the multimeter should read "0 ohms."

Press the calibration knob until the display reads "0" on the digital multimeter if you don't see "0 ohms" initially.

Investigation

Working outside, in a sunny place, set the multimeter to the DC voltage scale so it can measure a few volts. Using the clip lead, connect the positive terminal of the meter to the positive terminal of the solar cell. Then use the black clip lead to connect the common (COM) terminal of the meter to the negative terminal of the solar cell (see photos below). Measure the open circuit voltage and current across the solar cell.

Figure 7. Solar cell set up without transparent layer

Then repeat the same process for the solar cell with the transparent layer on it.

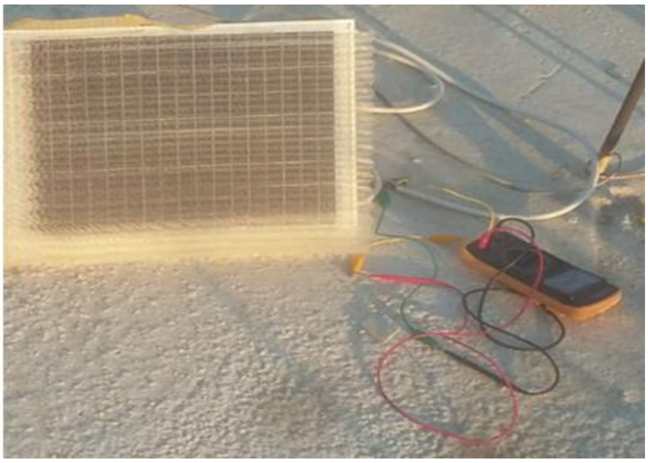

Figure 8. Solar cell set up with transparent layer.

Figure 9. Solar cell set up

The values of the voltage and current after being recorded are substituted into the formula of power which is

Power = Voltage (volts) × Current (amp)

The graph is then plotted in comparison of the values attained by solar with the transparent layer and without the transparent layer. I would like to thank Muhammad ABID KHAN and Taha BIN IMAM for their help

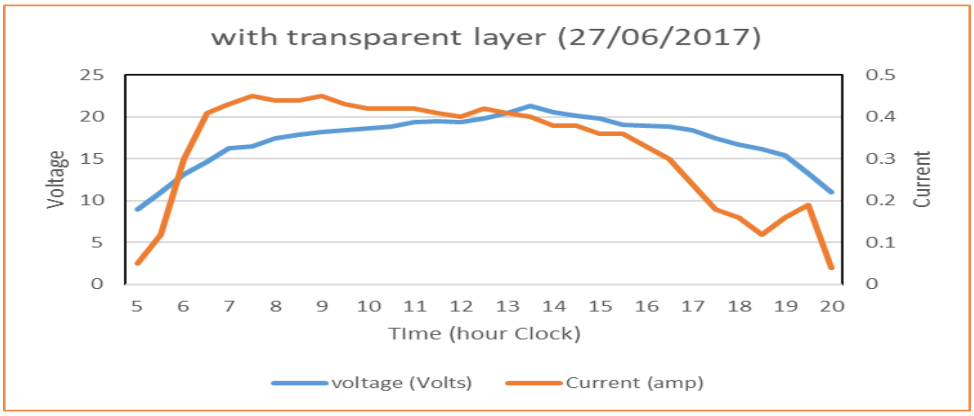

Figure 10. Trend of current and voltage with the transparent layer

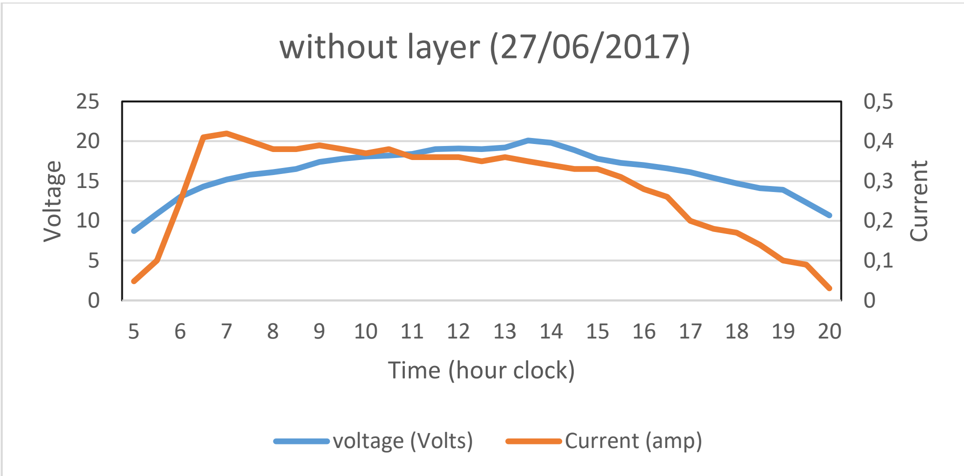

Figure 11. Trend of current and voltage without the transparent layer

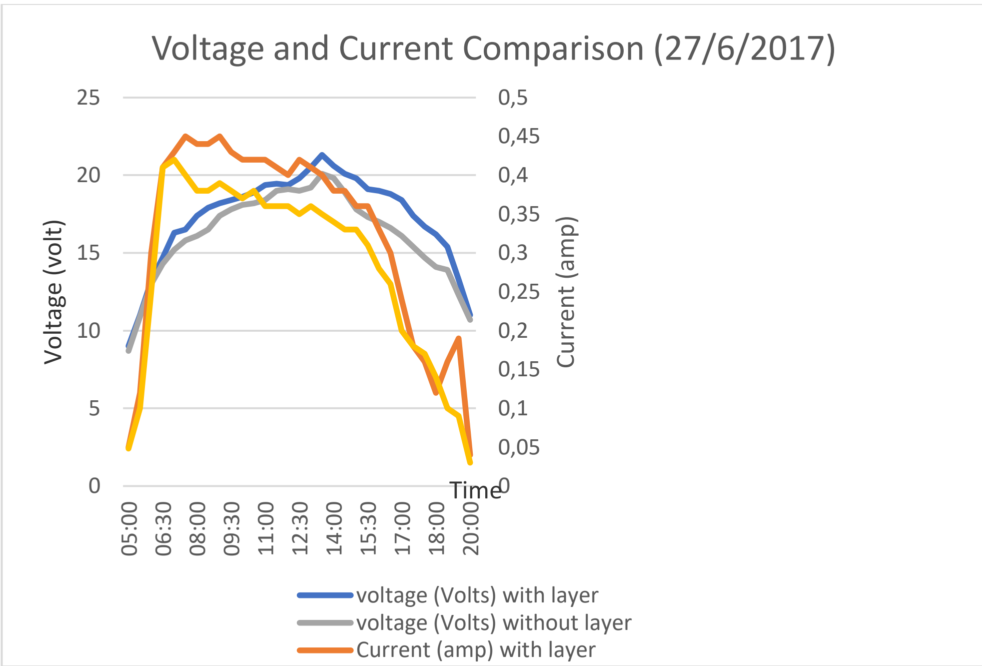

Figure 12. Graphical comparison of voltage and current

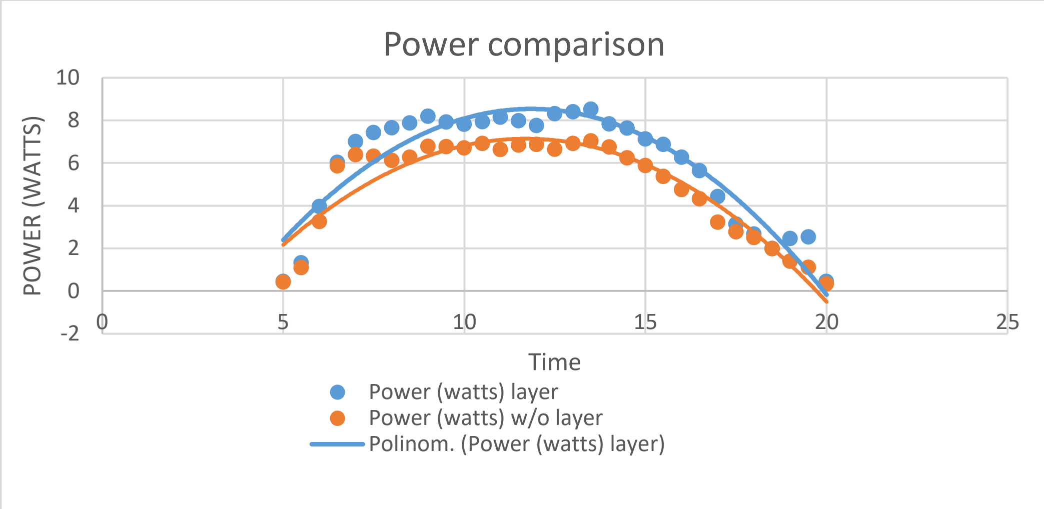

Figure 13. Graph of power for with and without layer

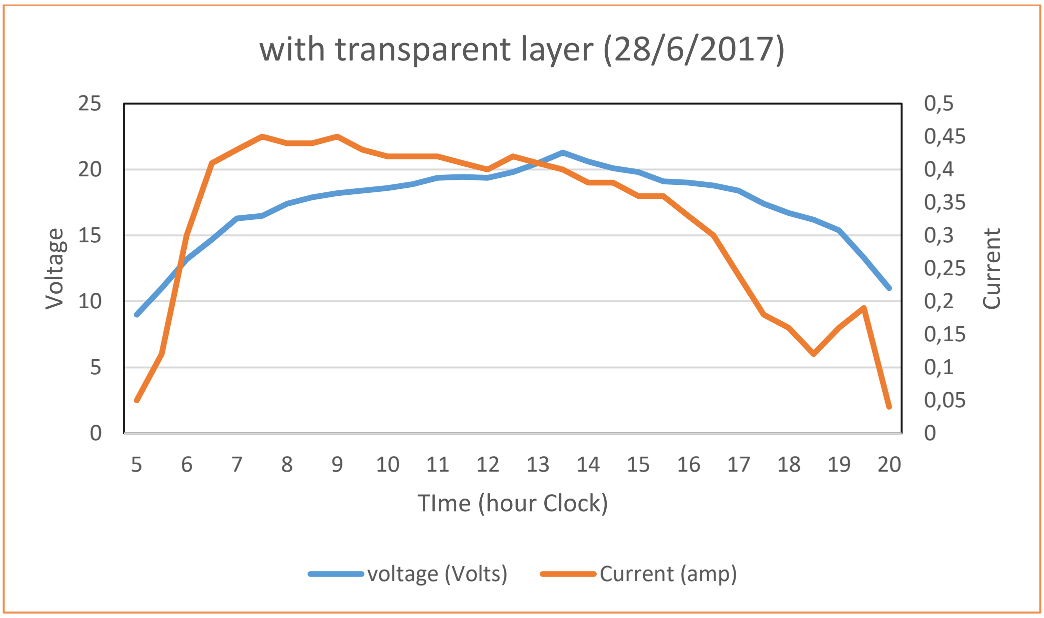

Figure 14. Graph of voltage and current with layer

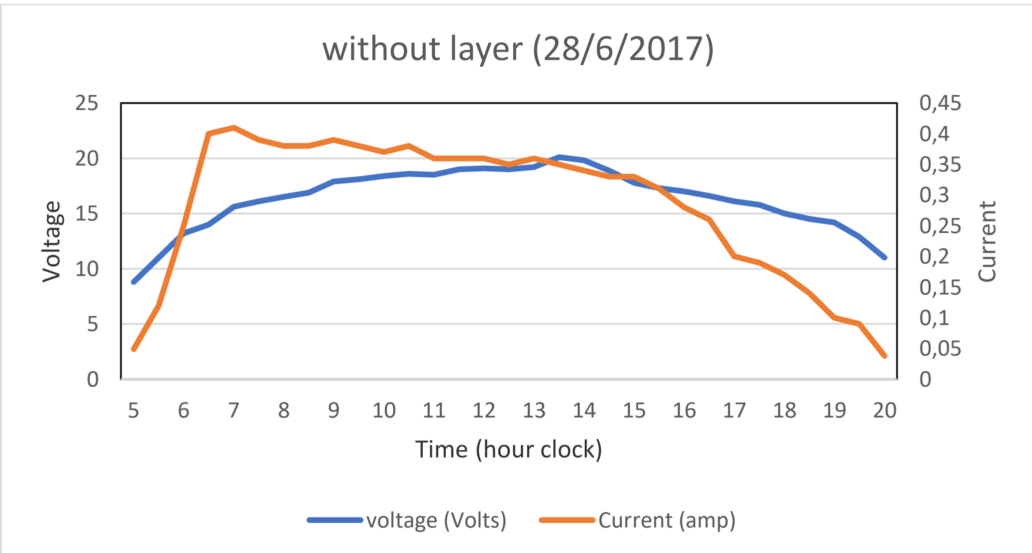

Figure 15. Graph of voltage and current without layer

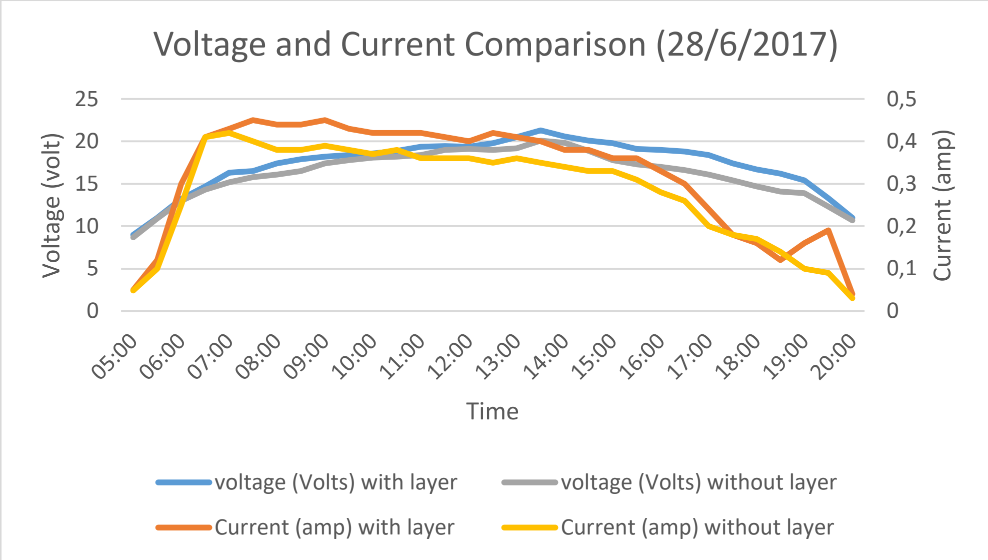

Figure 16. Graphical comparison of current and voltage with and without layer

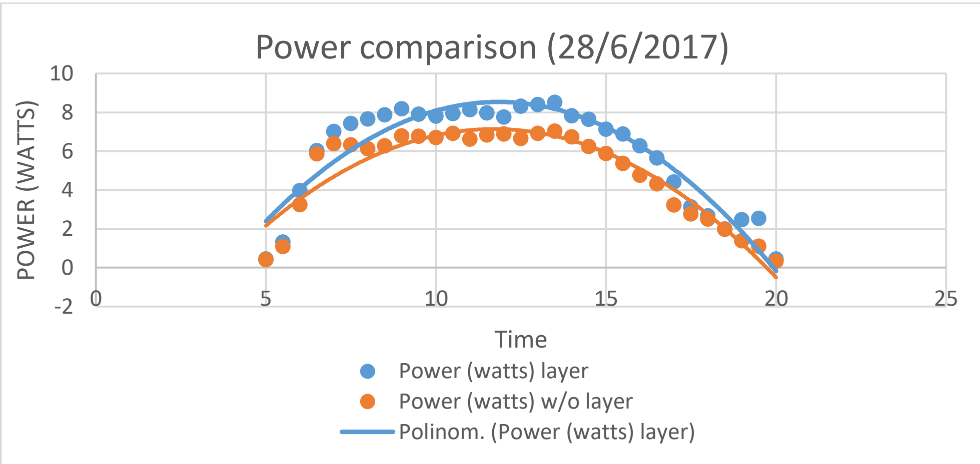

Figure 17. Graphical comparison of power

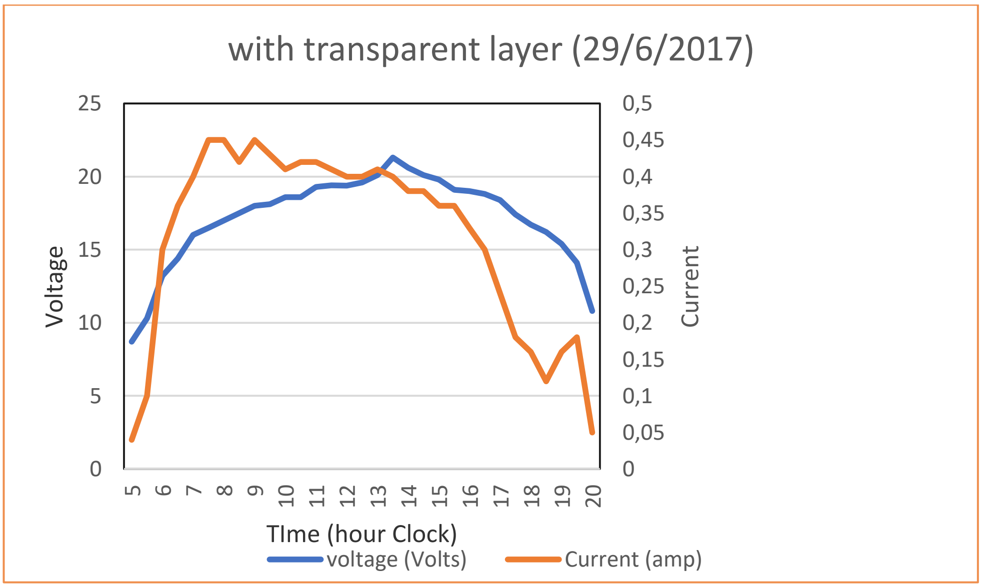

Figure 18. Graphical analysis of voltage and current with transparent layer

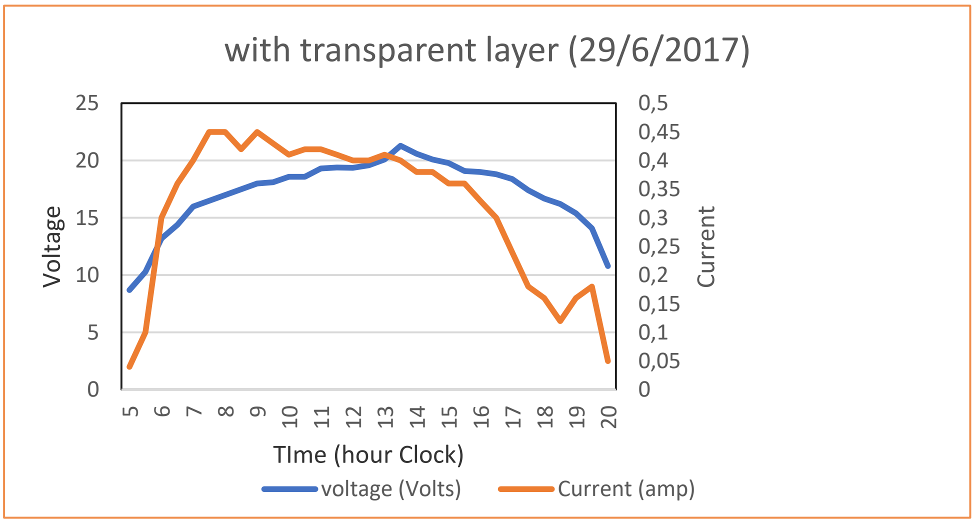

Figure 19. Graphical with transparent layer

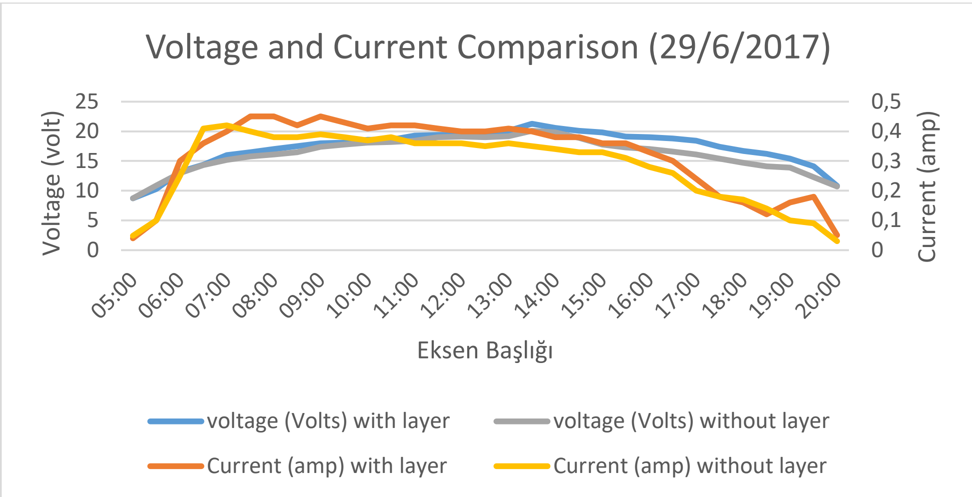

Figure 20. Graphical comparison of current and voltage with and without layer

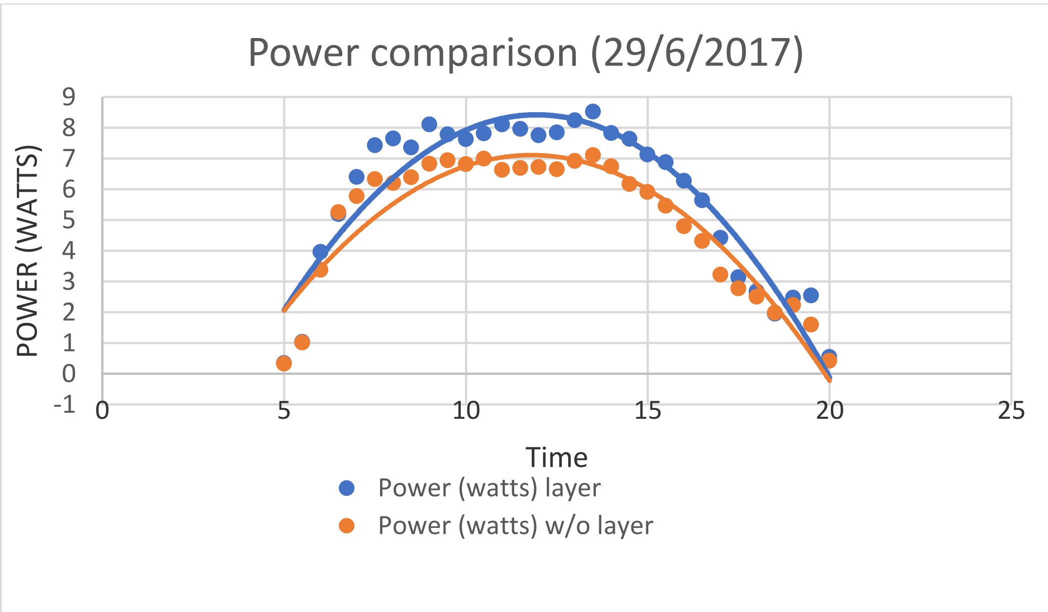

Figure 21. Graphical comparison of power with and without layer

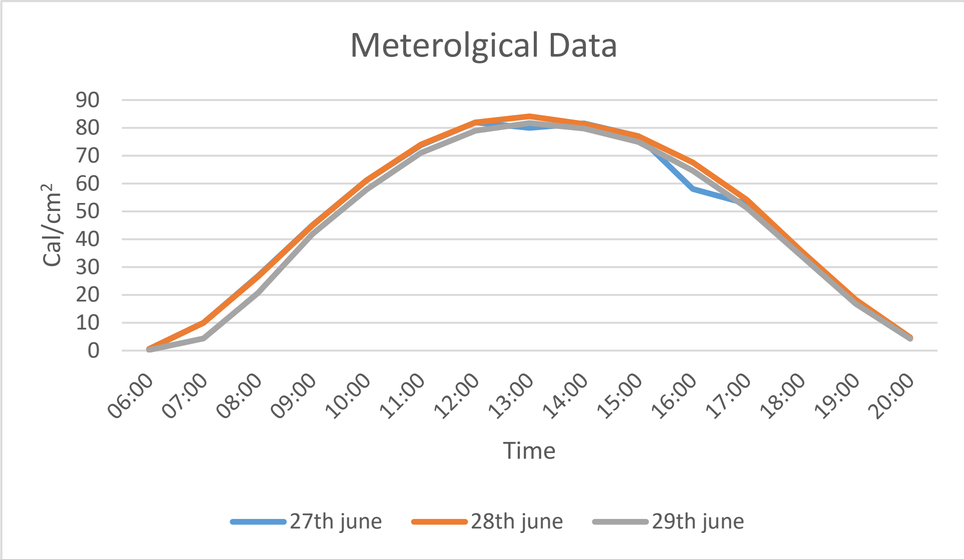

Figure 22. Graphical analysis of meteorological data

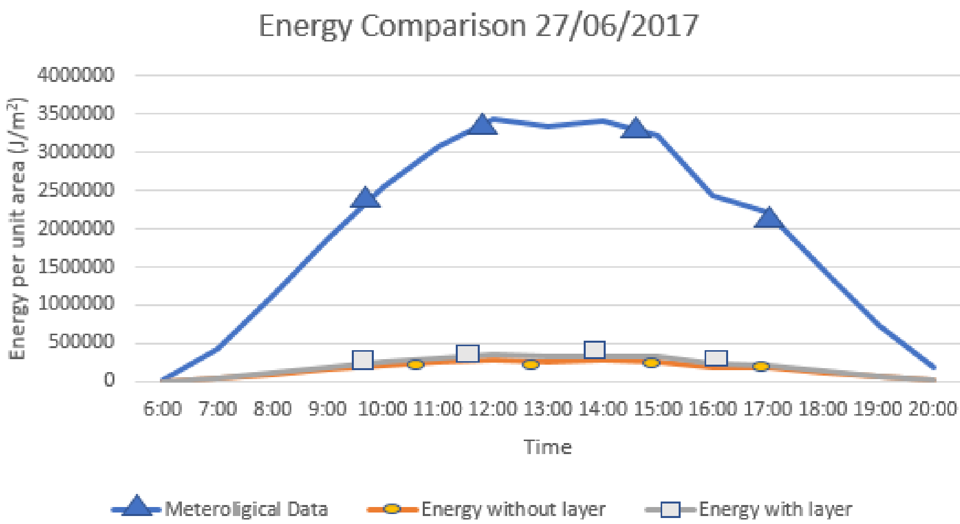

Figure 23. Graphical analysis of meteorological data and power reading

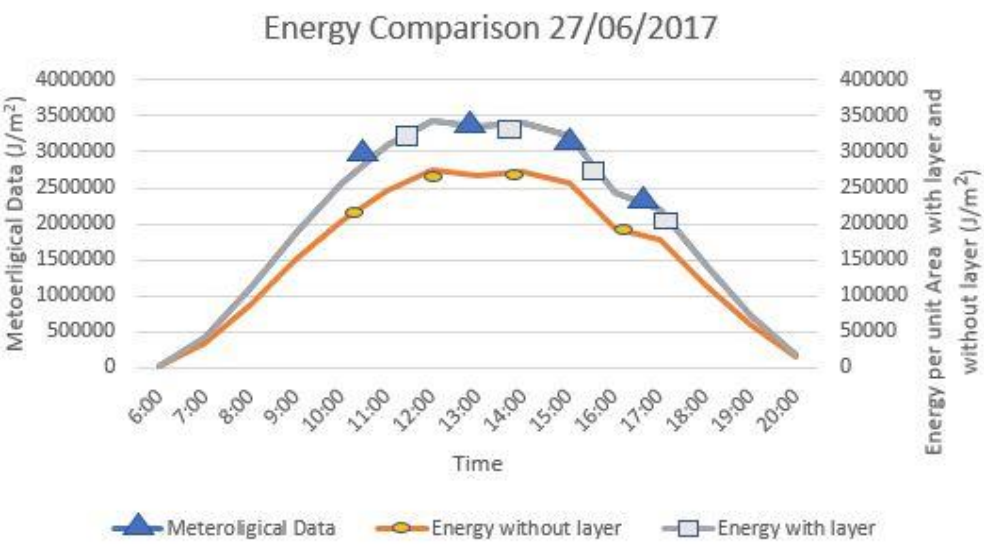

Figure 24. Graphical analysis of meteorological data and power reading

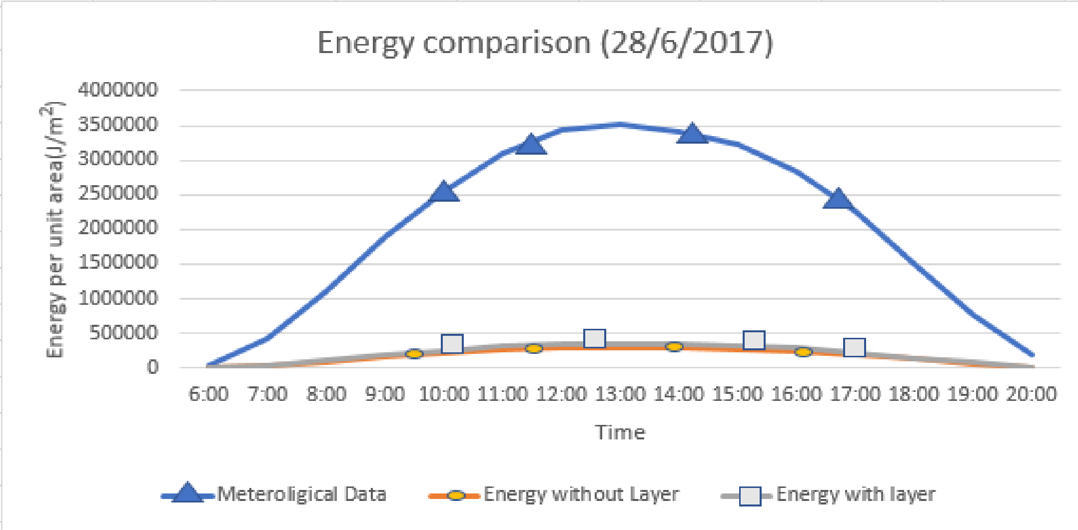

Figure 25. Graphical analysis of meteorological data and power reading

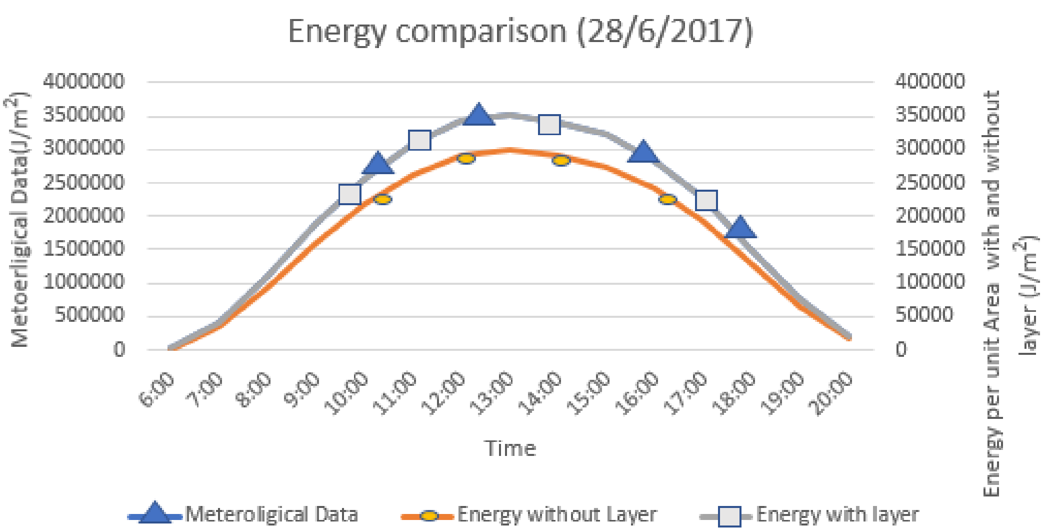

Figure 26. Graphical analysis of meteorological data and power reading

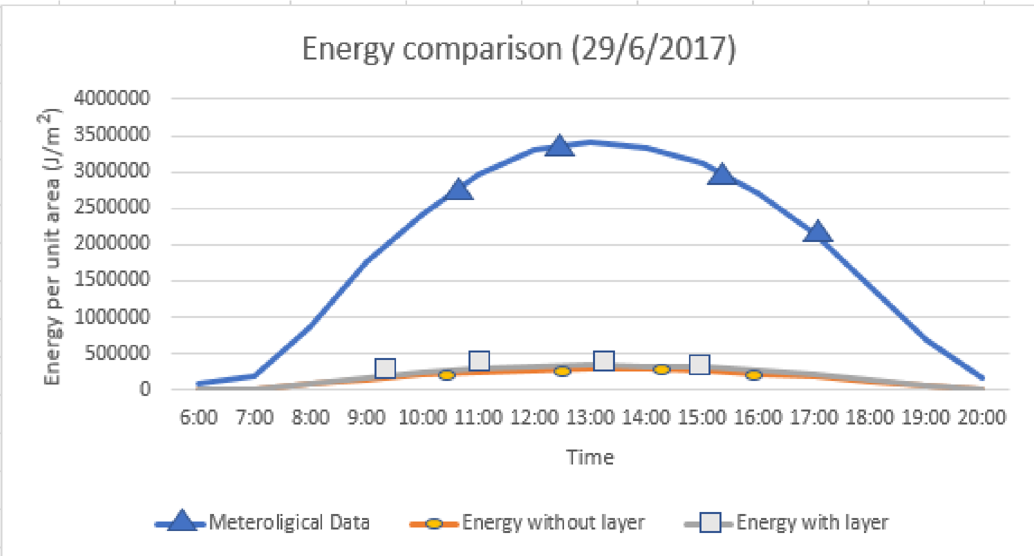

Figure 27. Graphical analysis of meteorological data and power reading

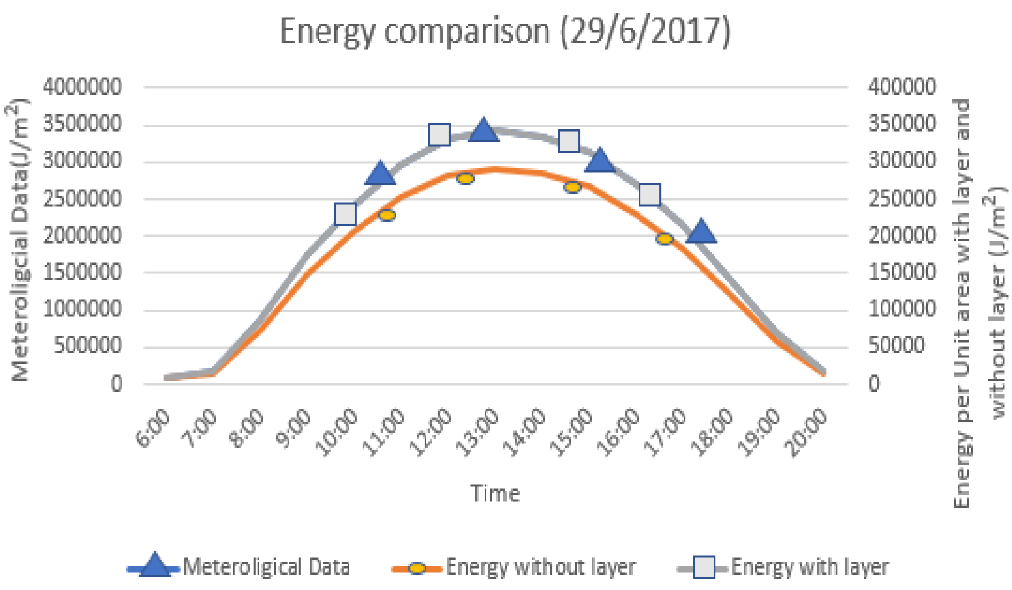

Figure 28. Graphical analysis of meteorological data and power reading

Conclusion

After the extensive investigation, we found that the performance of solar cells is affected by the transparent insulation. As the transparent insulation is put in place, the power output is observed to increase compared to non-insulated solar cell. It is observed that the difference between the metrology data and solar cell was 10 times. The world is rapidly gravitating towards renewable energy applications. Therefore, any technology such as transparent or translucent insulation materials which seeks to improve renewable energy harvesting and utilization is greatly welcomed. This reduces the use of fossil fuels and thereby minimizes the destruction of the environment. Transparent or translucent insulation materials are a new class of materials that are now in development and in some instances already on the market. They may have important applications in improving the energy balance of buildings. The definition of such a material is that it has a high transmission of solar radiation and good thermal insulation qualities. For future recommendations, the effect of temperature and the effect of resistance must take into account for taking solar readings and the insulation reading must be recorded in a controlled temperature system. As the values are recorded manually the chances of human error increases so to avoid such a scenario a continuous data logger can be used to record values on every instance.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to authors.

Acknowledgements or Notes

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