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The effect of the type of illumination on the energy harvesting performance of solar cells

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Abstract

This paper presents the effect of the illumination type on the performance of photovoltaic energy harvesting for application in buildings. A range of different types of solar cells are available to suit differing illumination sources and intensities. Modules made from polycrystalline silicon, amorphous silicon and dye-sensitized TiO_2 were investigated under illumination from incandescent, fluorescent, white light LED and RGB colour-controllable LED light sources in this paper. It is shown that it is important to select the solar cell to suit the type of light. In this paper, the maximum power points of four types of solar cell have been investigated under three different electrical light sources for various illumination levels allowing the selection of the optimum solar cell type for a given combination of electrical light source and a particular illumination level. An analysis of the effect of varying the spectral composition of the illumination is achieved by using a colour-controllable LED to provide the primary colours of white light. Generally, most power is harvested by solar cells under incandescent illumination sources followed by compact fluorescent (CFL) and then LED. The amorphous-Si solar cells tested show a similar power output under all three illumination sources, therefore a device using these should perform consistently under all lighting sources, whereas the poly-crystalline silicon solar cell tested shows a significant difference between incandescent and CFL/white light LED sources which could restrict operation to just incandescent lighting.

Keywords: Building environment; Energy harvesting; Solar cell; LED; Maximum power point

1. Introduction

Energy harvesting powered devices have the potential for widespread use in buildings as sensors in building management systems (Grabham et al., 2011; Matiko et al., 2014). For mains powered devices, harvesters offer an alternative which avoids the installation and material costs of power supply cables. For battery powered installations, harvesters offer more environmentally friendly solutions and do not need periodic replacement since long lifetimes can be achieved (Beeby et al., 2006). Maintenance costs associated with the replacement of batteries and service interruptions due to depletion of batteries can be avoided by employing self-powered devices. A harvester-based approach also improves the flexibility of a building management system; for example a sensor node can be easily relocated with minimal effort as there is no fixed wiring to alter and the location information of the corresponding sensor can be easily updated in the control software with no need to change the fixed infrastructure. However, clearly the operation of self-powered devices is limited by the amount of ambient energy that they can harvest from their local environment.

The most prevalent ambient energy source available in buildings is light, which can be harvested using

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photovoltaic devices (Li et al., 2013). The light can be from both natural and electrical sources and a range of different types of solar cell are available to suit differing light sources and intensities. These must be selected to suit the type of light and its intensity. Inside buildings, there is limited or no natural light in some locations or at some times. When natural solar energy is not available, photovoltaic devices must rely on electrical light sources and therefore the solar cell must operate efficiently under electrical lighting. The nature of electrical light sources is changing over time from incandescent sources, through fluorescent lights, with LED lights currently attracting significant interest due to energy savings. This impacts on the selection of the solar cell to achieve an optimum solution since the spectrum and intensity of the light source depends on its type.

For illumination systems in buildings, the light level should be constant irrespective of the type of source used, but the amount of energy harvested by a photovoltaic device will change depending on the light source type, even for an identical light intensity. Of major importance to energy harvesting powered devices is that the solar harvester selected will harvest sufficient energy when deployed irrespective of the light source providing the illumination. A danger is that a solar cell based energy harvester will work perfectly with a specific light source, upon installation, but, when the building occupant changes the type of light source, for example when the bulb expires, the harvester produces insufficient energy for operation. This paper provides general guidelines in harvester design to mitigate this risk.

An investigation of the difference in the energy harvested, caused by changing the electrical lighting source is presented in detail in this paper. This work investigates the output power achievable from four types of solar cell under three different electrical illumination sources: incandescent (halogen), compact fluorescent lamp (CFL) and LED (white light LED and colour-controllable LED), typically encountered within buildings, for various illumination levels. Within the LED lighting category both a standard white light LED device and an RGB colour-controllable LED have been utilised. The use of the RGB source permits the analysis of the effect of varying the illumination spectra from a nominally white spectrum.

In Section 2, the types of illumination sources and solar cells used in this work are described in detail and their light spectral characteristics compared. Section 3 describes the experimental procedure. The measured output power densities under different illumination sources are detailed in Section 4, followed by conclusions in Section 5.

2. Types of illumination light sources and solar cells used

2.1. Electrical illumination sources

The luminous intensity of illumination systems within a building is designed or adjusted to achieve a satisfactory level for the occupants; the illumination level is commonly measured in lux. Lux levels represent a measure of the light luminous intensity as perceived by the human eye. In office environments, the lux level at the desktop should be around 300–500 lx which allows the human eye to work in a comfortable and relaxed state for typical office-based tasks (Richman, 2012).

In buildings the illumination system accounts for approximately 9% of residential electricity use and 40% of commercial electricity use (Halonen et al., 2010). Incandescent light bulbs waste over 90% of their input energy as heat (Cheng and Cheng, 2006). By upgrading incandescent lamps to CFL or white light LED, on average 70% or 85%, respectively of the previous energy consumption, can be saved (Howard et al., 2012). Therefore in many situations lighting installations are being upgraded from incandescent lamps to save both energy and money.

Examples of the typical illumination sources used in this work are shown in Fig. 1.

Because the different lamp types used utilise different emission methods to produce their illumination, the spectral content of the emitted light varies between the lamp types. The 20 W incandescent dichroic reflector lamp has a colour temperature (CCT) of 2800 K, the 11 W CFL lamp has a CCT of 6400 K, and the 1 W white light LED lamp has a CCT of 3500 K. For comparison purposes in this paper the natural solar light is measured indoors in an open plan office space with the light passing through double glazed windows with glass that is treated to reduce solar heating effects, the glazing in the area used for these tests is specified as T80 double glazing with BM TRADA Q-Mark 012/001-03 certificated glass (BM TRADA, 2012). The spectral distribution of each light source was therefore measured for representative light sources using a spectrometer (Ocean Optics USB2000 with 10.0 nm resolution) and is shown in Fig. 2.

The spectrometer presents spectral data as raw counts detected by each of the sensor pixels, with the number of photos per count dependant on the response of the sensor, and the recorded spectra are therefore relative not absolute spectra. Due to a limitation in the illumination levels that can be measured by the spectral measurement device used, the output levels from natural light between 469 nm and 626 nm and from CFL light between 542 nm and 550 nm have saturated the sensor at its maximum level. However,

Fig. 1. Typical illumination sources, from left to right: 20 W incandescent lamp, 11 W CFL lamp, 1 W white light LED lamp, 6 W RGB colour-controllable LED lamp.