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Investigating the Use of Indoor Photovoltaic Products towards the Sustainability of a Building Environment

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Abstract

Sustainability in buildings could be mainly achieved by the incorporation of smart grid systems in a building context. These systems are based on renewable energy sources and require low production of CO_2 emissions. Additionally, product-integrated PV could also contribute in building's sustainability. The term 'product-integrated PV' (PIPV) stands for all types of products that contain solar cells in at least one of their surfaces with the objective to provide power during product's use. The use of PV products in an indoor environment is not quite developed so far, due to the low performance of those products under low levels of indoor irradiance and limited research activity in the field. However, there are PV products that are commercially available today and could be successfully used in an office environment. In this study three commercially available PV-powered products for use in an office environment; a PV-powered keyboard, a computer mouse and an office lamp, are analyzed. The results present qualitative data, with focus on users' preference to introduce PV-powered products in their daily lives, as well as their beliefs regarding the sustainability of these products. A statistical analysis is also presented, together with a comparison of the tested PV-powered products with their non-PV-powered counterparts, in order to estimate how sustainable PV products are and which is their contribution to building sustainability.

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Keywords: PIPV; indoor; PV products; sustainability; building environment; users.

1. Introduction

Sustainable design of a building is defined as the design, which aims to minimize or prevent the reduction of critical environmental resources, such as energy, water, and raw materials, prevent environmental collapse caused by

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infrastructure during their lifetime and create building environments that are accessible, secure, healthy, productive and pleasant. Building design should have positive benefits to the environment, the society and the economy in order to be considered sustainable. The application of smart grid systems in buildings could contribute in buildings' sustainability. A smart grid is an electrical grid, which includes smart meters, appliances and renewable sources of energy, which can communicate with each other and offer valuable information to users regarding the status of their electrical devices or the load of the electricity grid at a specific time. That way, users can control the production and distribution of energy and change their behavior using electrical devices more consciously.

Photovoltaic (PV) products for indoor use could also contribute in buildings' sustainability. PV cells are widely used as power sources connected to the grid or as standalone systems and can be applied in multiple indoor products such as sensors, chargers, luminaires, entertainment appliances, kitchen appliances and many others[1,2]. The integration of solar cells in commercially available consumer products started in 1976 with the PV calculator being the first commercially available product powered by solar cells[1,2]. Since then product integrated photovoltaics (PIPV) became a new category of PV products with many applications available[1].

In PIPV the solar cells receive the incident irradiance in their surface and produce electricity, which can be either stored in batteries or used directly to power a device[3]. The amount of electricity that is produced by the solar cells depends on many factors, such as the amount of incident irradiance, PV cell technology, area of the PV cell, distance of the cell from natural and artificial irradiance sources, shad(ow)ing on the PV cell, discrepancies on the cell's surface. However, one of the most important features that affect the performance of PV cells in products is irradiance. Irradiance indoors and outdoors varies greatly. On a sunny summer day in central Europe radiation outdoors can exceed 1000 W/m^2, whereas on a cloudy winter day it goes down to 100 W/m^2 [3]. A PV cell with 5 % efficiency can deliver power of 5 to 50 W/m^2. This means that a solar cell with a surface area of 100 cm^2 gives at least 50 mW, which is enough power for a portable radio. However, indoors the situation is less advantageous. Here a typical irradiance of 1 to 10 W/m^2 is expected, and the same solar cell will deliver less than 5 mW. This means that low-powered PV products in the range of μW up to a few mW could be successfully used indoors, such as sensors, luminaires, clocks and calculators[3]. In this paper three PV-powered consumer products are examined. The PV products in question are: a PV-powered mouse by a Chinese manufacturer, a PV-powered keyboard and a PV-powered luminaire, both by Swiss manufacturers.

Nomenclature

CO_2	carbon dioxide
EPBT	energy payback time
GHG	greenhouse gases
LCA	life cycle analysis
PV	photovoltaic
PIPV	product integrated photovoltaics

2. Sustainability of PV products

"Sustainable" or "ecological" design of products establishes the incorporation of environmental features within the product design aiming to improve the conservational performance of the product throughout its lifespan. By sustainable design of PIPV products, their environmental impact should become lower than that of the current alternative designs. However, this is a quite new field of research and it is still in progress. Therefore, the environmental aspects of products with integrated PV cells have not been addressed extensively so far. For this purpose a life cycle analysis (LCA) can be used [5,6].

Furthermore, other important indicators for sustainable product design are embodied energy and CO_2 emissions based on common data for materials and manufacturing processes [6,7,8]. These can be used as a rough estimation.

An LCA on small PV lighting products was carried out in South East Asia[9] aiming to examine the environmental impact of the production, use and end of critical life of these products. The study shows that solar PV lighting products have a lower environmental effect than the conservative options for lighting in South East Asia have. The