Energy and Buildings 77 (2014) 445–456

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Integrated PV in shading systems for Mediterranean countries: Balance between energy production and visual comfort

M. Mandalaki [a,*], T. Tsoutsos [a], N. Papamanolis [b]

[a] *Technical University of Crete, School of Environmental Engineering, University Campus, 73100 Chania, Crete, Greece*
[b] *Technical University of Crete, School of Architectural Engineering, Eleftheriou Venizelou street 127, 73100 Chania, Crete, Greece*

ARTICLE INFO

Article history:
Received 25 July 2013
Received in revised form 8 March 2014
Accepted 15 March 2014
Available online 29 March 2014

Keywords:
Shading systems
BIPV
Visual comfort
Energy savings

ABSTRACT

Fixed shading systems are saving energy by reducing the cooling loads of the space they shade, but can be a source of energy losses due to the increased need of daylight that they create and the increased needs for heating during winter. Aim of this paper is the comparative assessment of different typologies of buildings' shading systems with integrated photovoltaics (PV). The assessment is focused on their energy efficiency and degree of internal visual comfort conditions that they can ensure. The purpose of the comparison is to optimize the combination of shading systems and their integrated solar cells.

Shading systems are grouped and studied according to their energy savings (production and reduction of cooling loads) and to the quality of the visual interior environment. For the study, computer simulations are used for the energy loads (needs/production) and both computer simulation and experimental physical models are used for the daylighting assessment. Moreover, through this research, the effect of specific geometrical characteristic of the PV modules installed is analyzed in relation to the energy needs and to the resulting visual conditions. Systems such as Brise–Soleil are proved to be the most efficient for integration of PV modules in relation to energy saving and quality interior conditions.

1. Introduction

The issue of Building Integrated PV (BIPV) has been developed extensively since the 90s. It is still though under extensive research in relation to the transparency of the PV material, the position of the integration in the building [1] and to the tracking system used [2,3].

Integration of Photovoltaic (PV) materials to shading systems was proposed in 1998 [4]. Since then, various shading types have been used mostly according to their energy balance and less according to esthetics and interior comfort conditions [5–7]. The most of the researches though, experiments with specific simple geometries of canopy horizontal or inclined systems and louvers systems [8]. There is a gap in the research bibliography on other geometrical types of shading systems. Especially for office units, due to the specific demands for visual comfort and the increased needs for quality lighting, balancing the above mentioned facts is more crucial.

Additionally, a gap exists concerning the efficiency of PV shading systems in Mediterranean countries where the amount of solar radiation is higher than the rest of Europe. The annual solar energy at horizontal plane is exceeding 1650 kWh/m^2 [9] and encourages the installation of such shading systems.

The main objective of this paper is to evaluate various types of fixed shading systems with integrated PV facing south in Mediterranean countries according to their ability to save energy and to provide visual comfort. Measurements and experimental work has been done for two typical cities in Mediterranean area: Athens (37.58° N, 23.42° E) and Chania in Crete (35.30° N, 24.01° E). Some useful details are already presented in another publication [10]. In this paper a more detailed analysis is presented in relation to visual comfort conditions and to specific geometrical detailing of the integrated PV. We examine the resulting visual comfort conditions that most energy efficient systems can create. We additionally examine the influence of the changeability of the PV thickness to the improvement of the interior visual comfort conditions.

2. Methodology

Basic aim of the current research is to find optimization points of the shading system with integrated PV, between energy savings for heating, cooling, lighting the space and visual comfort conditions.

* Corresponding author at: Technical University of Crete, Department of Environmental Engineering, University Campus, 73100 Chania, Crete, Greece. Tel.: +30 6972328133; fax: +30 2821045229.

E-mail addresses: mandalaki@arch.tuc.gr, mamand@gmail.com (M. Mandalaki), theocharis.tsoutsos@enveng.tuc.gr (T. Tsoutsos), npapama@arch.tuc.gr (N. Papamanolis).

http://dx.doi.org/10.1016/j.enbuild.2014.03.046
0378-7788/

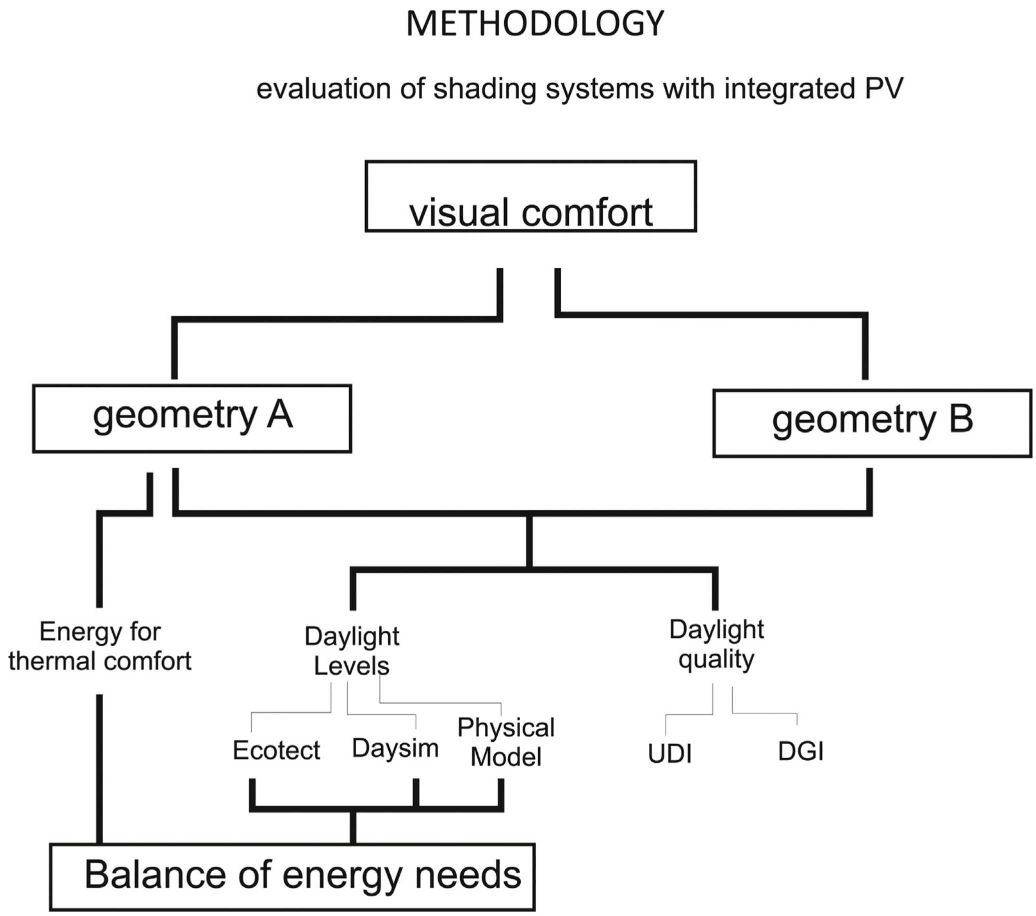

Fig. 1. Methodological diagram.

The results of Mandalaki et al. [10] are used in the part that concerns energy consumption for heating, cooling and lighting (Geometry A). Further on, different geometrical configurations of PV shading systems are examined, in order to evaluate the effect to visual comfort conditions and to energy needs for lighting (Geometry B). Finally conclusions are generated concerning the most efficient shading systems according to energy savings and visual comfort.

The methodology followed and the tools used can be seen in Fig. 1. Due to the fact that evaluating visual conditions is a complicated task, we evaluate visual comfort conditions using both simulations and physical models.

2.1. Invariants of the reference unit

We examined both energy needs for heating and cooling the space for yearly fixed thermostat settings range between 21.6 and 24.1 °C, for office hours of 9:00–17:00 for five days per week. These settings are proposed by Sanea and Zadan [11] as optimal for achieving thermal comfort with the lowest energy consumption. All weather data are for the case of the Mediterranean city of Chania, Crete.

Additionally, we examine electric light needs when daylight levels fall under 500 lux on the desk level that is considered to achieve visual comfort conditions according to Boyce and Raynham [12]. 4 of 50 W, High Frequency (HF) tubes, mirror-luminaries are being used to save electricity. We calculated the electricity needs for these lamps, which are turned on when lighting levels falls under 500 lux [13].

All parameters, description of the office unit, interior furnishing and material finishes are informed from Van Dijk [13]. More analytically, a typical office unit is 3.5 m × 5.4 m × 2.9 m (width × depth × high) with a south facing window of 2.4 m × 1.9 m (width × high). The reflectance of the material used is 0.85 for the ceiling, 0.65 for the walls and 0.20 for the floor. The position of the occupants and luminaries can be seen in Fig. 2. All surfaces of the office unit are considered to be adiabatic due to the fact

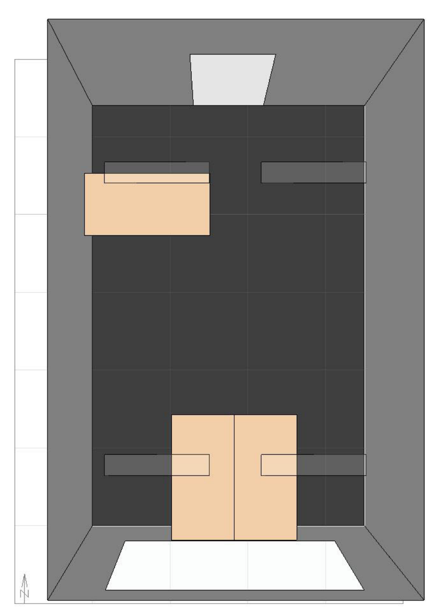

Fig. 2. Configuration of the office building examined [10].