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Sustainable energy planning. Design shading devices with integrated photovoltaic systems for residential housing units.

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Abstract

The study scopes to optimize the characteristics of shading devices (SDs) with integrated photovoltaic panels (PVs) that are designed for residential building facades. The SDs are located on the external part of a window facing south, in a distance from the external wall, in order that a semi - outdoor space is created. The research deals with the integration of solar technologies in buildings. Focusing on the optimization of the relationship between the energy technologies and the architectural design. Concerning the design process we took into consideration the definition of user's visual comfort and the optimization of the design process of the final product. This experiment focuses on the integration of flexible shadings in order to use the external space as a consecution of the internal space. Methodologically the parameters of the research are defined and the decision on the type of the experiment is taken according to the summer at three different weather conditions in Crete. So, the physical model type of experiment was preferred to the computer simulation model. The results are being categorized and the process is being evaluated according to the above mentioned parameters. The research seeks to highlight how experimental shading devices with integrated PVs can achieve better view for the users while performing as energy production and reduction machines. Finally as a result the daylight analysis value is compared with the human's comfort view to outside and the energy needed for the performance of the examined unit during the day. Our main goal is to optimize the comfort in combination with the energy generated and the best suited space for the everyday activities.

Keywords: shading devices, electricity production

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1. Introduction

The electricity consumption of buildings is part of the overall energy consumption of a country. Due to this fact, together with the increase of renewable energy resources (RES), there is an interest of their integration in buildings. The assessment of local photovoltaic (PV) potential plays a critical role in the development of planning policies and financing schemes for the successful deployment of PV systems in cities [1]. A way of integrating RES in buildings is by placing PVs. PVs have been proved ideal for buildings because their placement can lead to partial or total energy independence. The possible positions of PV panels on the buildings is the facade, the roof and the shading devices. The use of shading devices is essential for south oriented facades, especially in Mediterranean climates [2]. The SDs determine the daylighting of the building and it is highly related with the visual comfort of the users. The use of daylight in buildings, with its variations, its spectral composition, and the provision for external views, is of great importance for the comfort and well-being of occupants [3].The idea of integrating SDs with Photovoltaic panels (Building Integrated Photovoltaic (BIPV)) derived from the need to cover energy needs and use RES specially in the Mediterranean area in order to produce energy and supply electricity for artificial lighting or other energy use. BIPV systems are photovoltaic modules integrated into elements of building envelope, such as the roof or the façade. These systems are very important because they serve the dual function of building skin, replacing conventional materials, and energy generator. They modify the architectural appearance of the construction [4].

Besides the large available area on vertical walls, the use of photovoltaic modules and solar collectors on facades may lead to other interesting benefits such as the combination of energy production with other functions of the buildings, such as heat insulation (Quesada et al., 2012) or illumination, by using semi-transparent photovoltaic modules on windows [2].

This research evaluates south facing SDs that were designed for a residential building facade respecting the sun glazing and the lighting. There is also a provision for the energy production.

The solar energy that reaches earth, at any time depends, on the weather conditions, the position, the orientation and the area of the surface. In fact, several factors like the global radiation on a horizontal surface, the ground reflectance and the day of the year constitute the parameters of a complex function that determine the amount of solar radiation incident on an inclined surface at any time [5]. In the text below we are going to talk about the design method of the SDs, describe the experiment process, and evaluate the results.

1.1. International scientific experience on the subject

FThe awareness of the available area on vertical walls, which in a modern city far exceeds the available area on roofs thus of setting the relatively lower irradiation falling in non-optimum inclination, has recently lead to the development of methodologies for the analysis of the solar assessment of facades (Carneiro etal.,2010;Redweiketal,2011;Hofierka and Zlocha, 2012). This paper is based on previous international research made on the subject of BIPV and especially on the research of M. Mandalaki who has constructed the basic model of the experiment in 2011, in order to test the integration of the SDs in an office building facade.

When talking about shading, there is a need to clarify the type of the building and specify the use of the space, we intend to shade. This research concerns residential housing units facing south. The demand in shading and visual comfort differs from an office building to a housing unit. The space of an office is usually limited to an exclusive use, on the contrary, the living room of a house may have several everyday uses, in variable hours of the day that require a different design approach, which will be discussed further more.

2. Methodology

2.1. General

As mentioned the living room of a house can accommodate number of activities including working as well as different number of occupants. Therefore this room is chosen to be given flexibility in daylighting and visual comfort that will encourage several activities during the day and season. Mainly living room spaces need to have external outspreads, so the SDs are positioned 2m from the building facade covering a semi-external patio. During summer in south orientation in Chania shading is a priority need. Especially the SDs will be used to shade firstly the cover patio and secondly the interior space because everyday activities in Mediterranean climates after April take place outdoors. So, the user exits the building to transform the flexible SD between two possible positions according to his need of shading or lighting, cooling or heating.

2.2. Design processing

Natural light is a vital force for human beings. Successful daylighting in buildings requires trade-offs and optimization between competing design aspects (e.g. light distribution, glare, solar gains, views, etc.), whilst also including consideration of façade layout, space configuration, internal finishes and choice/operation of shading devices [3]. The basic function of a shading device is to intercept the sun’s rays before reaching the building interior during the heating season. An external shading device requires many design consideration such as solar geometry, physical dimension of the elements, materials, finishes, control strategies, and aesthetics [6]. The design process and optimization of the SDs is not incorporated in previous research. The design is defined by the parameter of the user‘s **visual comfort** and the user‘s **personal desire** [7]. Taking for granted that the SDs have two possible positions open(down)-shut(up). The flexibility in the transformation of the SD is a main aspect of this research as it is very convenient for the different user's activity and also in terms of thermal and visual comfort as well as privacy matters. The most common reason for activation of the shading device is therefore assumed to occur if discomfort by solar heat gains or glare or the need for privacy predominates the desire for daylight and view. And the main reason for opening the shading again is assumed to occur if perceived discomfort by heat, glare or lacking privacy is reduced and the desire for daylight and view is becoming predominant [8]. As already mentioned the aim the design is to make the BIPVs more user friendly by integrating them to the facade and connect their use with the user‘s everyday activities. So the basic intention of the design it that the position of the panels reflects the inside needs in shading. Additionally it is well known that the highest production of a PV panel is achieved when the panel is vertical towards sun rays. But vertical SDs could not be transformed in a building facade so we optimized the horizontal facade by a 10° inclination to the south. 10° is the less inclination allowed so that the SDs could be located vertically in a building facade. If the inclination augments then the SDs would not be easily moved by the user.(1)

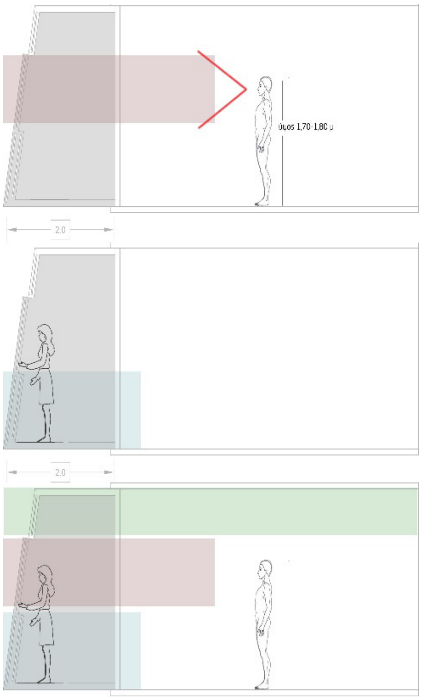


Fig. 1. Level eye view, transformable SDs

Fig. 2. Experiment box, inclination to the south

In order to eliminate any mistakes in the fabrication process a 3d model was constructed. And the two different positions of the SDs were checked as shown at the figures below.

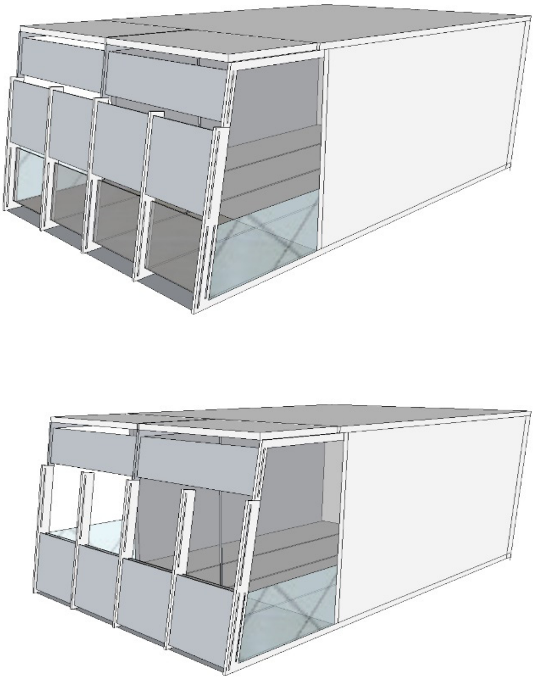


Fig. 3. In this figure we can see the 2 different positions of the SDs. a. shut (up) b. open (down). The first part of the facade is a stable PV. The second is the moving SD with integrated PV. The third is a transparent material and it is also stable.

2.3. Experiment

The parameters examined are **time** of the day, **position** of the SDs (defined by the user) and **distance** of the light source (window) inside the living room. The testing procedure takes place in a site situated in Chania Crete (35.5167° N, 24.0167° E) in a residential coastal area.(2)
In Chania the extreme positions of the sun are about 77° height in the summer and about 30° height in the winter at 12 o'clock for a south facing plane. The overheated period for this latitude point is considered to be between June to middle of September [2]. Thus we choose to realize the experiment between this period two times per day 12o' clock and 17o' clock.

In order to check the sustainability of the SD concerning the daylight production we choose to realize the evaluation through a physical model instead of using simulation software. Thus the physical method was preferred to be more accurate as it is being held on the exact under study environment. The scale of the physical model is 1/10. The physical model of 1/10 scale was constructed according to the specific instructions for making daylighting models and was tested in real sky conditions [2]. A typical room of 3.5 m 5.4 m 2.9 m (width*depth*height) is used as a reference [2]. For this investigation all windows are considered not to be shaded by opposite or neighbor buildings, this might not be realistic for all inner city locations, but it results in higher solar heat gains and is therefore a safe assumption regarding the evaluation of thermal comfort and view [11]. Methodologically and based on Mandalaki 's experiment the parameters were separated in two categories, **stable** and **variable**. The stable are the south orientation, the location and the type of glazing (sun) and the variable are the time, the position of the SD and the distance from the window.

3. Results

3.1. Illuminance

Definitions: Illuminance** is the amount of light falling on a surface, and is measured in lx.* ***Luminance is the amount of light emitted by a surface, and is measured in candelas per square meter (cd/m^2). It is a function of the light falling on a surface (it's illuminance) and the surface's reflective properties. [9].

In this research we counted the illuminance. The measurements took place at three different weather conditions during the summer 2014. The three different days are a| 1/7/2014 , b| 24/7/2014, c| 13/8/2014, at two times per day 12 o' clock, 17 o' clock in a residential building 's roof. The equipment we used is a lx meter LX 101 and the value is lx/ h, in two different positions of the SDs .(3)(4)

a) | 1 July 2014 | 22°C - 34°C - 1 Bf plain sky | *12.00* = 789 lx *17.00* = 540 lx
b) | 24 July 2014 | 23°C – 29°C - 5 Bf cloudy | *12.00* = 660 lx *17.00* = 423 lx
c) | 13 August 2014 | 23°C - 34°C - 3 Bf plain sky | *12.00* =770 lx *17.00* = 467 lx (5)

1) Obviously the position that is far from the light source in every experiment has low light values in comparison with the position near the window.
2) The highest value is 12 o' clock at the experiment C. But the lower light value is at 17 'o clock in the experiment B.

The results should be analyzed further and be compared with the human visual comfort.

Looking at the results, all the middle position of the SDs values are over 100 lx. So during the summer time in Chania there is enough light in the residential unit even in the lower position of the shutters. It is also remarkable that the values of the open and the shut position of the SDs are ranging around 100 and they are close to each other, so in the middle of the room the lighting is almost the same during sunny summer days.

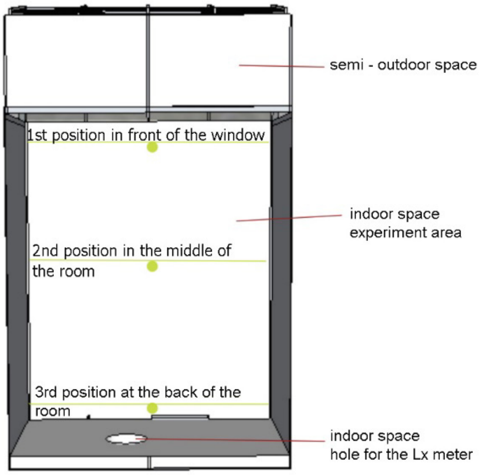
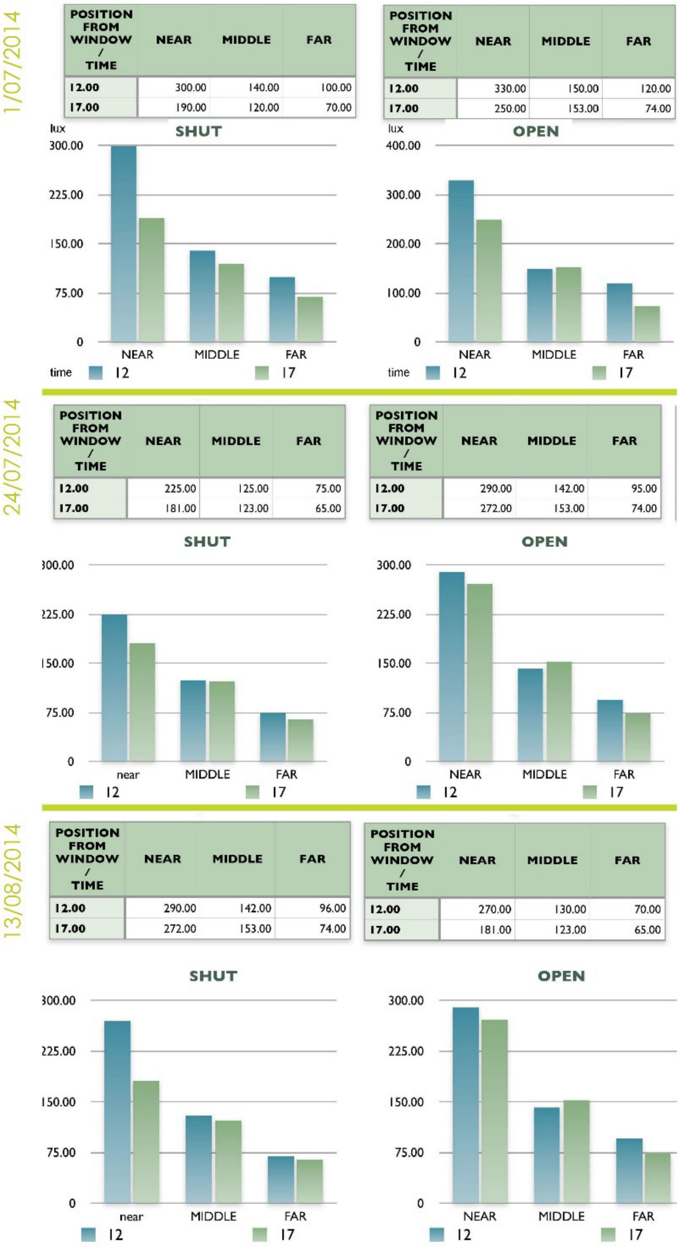


Fig. 4. In this figure we can see an axonometric plan of the residential unit examined showing the positions of the Lx meter for the three different measurements



1/07/2014

SHUT

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	300.00	140.00	100.00
17.00	190.00	120.00	70.00

OPEN

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	330.00	150.00	120.00
17.00	250.00	153.00	74.00

24/07/2014

SHUT

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	225.00	125.00	75.00
17.00	181.00	123.00	65.00

OPEN

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	290.00	142.00	95.00
17.00	272.00	153.00	74.00

13/08/2014

SHUT

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	290.00	142.00	96.00
17.00	272.00	153.00	74.00

OPEN

POSITION FROM WINDOW / TIME	NEAR	MIDDLE	FAR
12.00	270.00	130.00	70.00
17.00	181.00	123.00	65.00

Fig. 5. Experiments table, A,B,C during three different days of the summer. The results are analyzed further.

3.2. Total energy produced

The total energy produced by the PVs depends initially on the total energy radiation which reaches the surface. In case of embedded in the building PV systems solar gain actions for specific meteorological data of the region depends on the orientation of the building and the total area of PV modules that are installed on the surface.
At this research the total PVs area used is 8 panels of 0.9 X 0.70 = 0.63 m2

Total sum=8.0m x 0.63m = 5 m^2

According to the total area of our PVs we assume that we are going to need PVs of about 36 cells of 100 Watt. From an online software was calculated the energy generated (www.selasenergy.gr/solar-calculator-main.php) we have the results below:

Q=135,000 kW/h for stable south orientation.

So for further research we can compare the total annual energy production with the visual comfort.

4. Conclusions

Nowadays more and more of the everyday activities oblige people to spend time in interior environments where **natural ligh**t is very important. But in south oriented facades of Mediterranean countries natural light should be accompanied with **shading devices** during some time of the day. When the SDs include **PV panels** the solar radiation absorbed can be transformed into energy.

The task at hand for the designer is generally to identify the most appropriate properties of daylighting systems that provide adequate luminous levels and contribute to visual comfort. [3]

According to Energy Design for Architects [10] the recommended lighting level for housing units is summarized below:

- Entrances : 50-100 lx
- Dining room : 100 lx
- Living room, kitchen : 200 lx
- Offices: 300-500 lx
- Bedrooms : 150-200 lx
- Indoor activities : 200-300 lx
- Reading : 300-500 lx
- Resting : 50-150 lx

So according to the values found through this current experiment the best activity for each SD position is shown on the board below:

Open SDs : All the rooms are suitable and all the activities can be done without lack of lighting. Best room which fits the open SDs during the day is the living room, the kitchen or the bedroom. During the evening (time examined) the natural light is not sufficient.

Shut SDs : All the rooms are suitable except for the office. During the evening (time examined) only the entrances and the dining room is well suited in general the natural light is not enough.

The best position for reading activity is the one near the window where daylight is over 225 lx. In the middle of the room where daylight is quite stable during the whole day is very appropriate for indoor activities other than reading.

The patio is an exterior space which is suitable for every activity as there is plenty of natural light.

Further topics for discussion:

- Carry out the experiment during the winter, so as to find out the more suitable activity during the whole year time.
- Calculate the energy needs for lighting during the day through the year
- Test the energy produced from the SDs and how much energy can be used for artificial lighting during the night or under bad weather conditions.

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