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Balancing competing parameters in search of optimal configurations for a fix louvre blade system with integrated PV

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Abstract

In this paper, a parametric analysis of the configuration of a fix louvre-blade system with integrated PV coating is presented. The study evaluates different exploitations of solar energy focusing on the competing functions associated with the system in terms of electricity conversion, and daylight availability in the room. The methodology is applied to determine the effect of the geometry of the system (louvre-blade count and tilt angle) installed in a fictitious office room in a Nordic climate, considering climatic challenges such as low solar altitude angles, and large seasonal variations of solar irradiance levels incoming on the south-facing façade plane.

Keywords: BIPV; shading system; useful daylight autonomy; daylight autonomy; parametric analysis; continuous daylight autonomy; visual comfort

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1. Introduction

Harvesting solar energy is of fundamental importance in the design and planning of low energy buildings [1]. However, this requires careful planning as different strategies for harvesting solar energy may end up competing against one another and finding an optimal solution is not trivial. While on one hand taking advantage of large surfaces of the building envelope with high solar irradiation is useful for electric conversion through PV systems, the incoming irradiation could otherwise be exploited through glazing components, allowing for improved daylighting and passive solar heating. An interesting option to overcome these competing aspects is to combine multiple functions in integrated building envelope components, thus enabling these hybrid systems to use different aspects of solar energy simultaneously. In this article, the concept of a fix louvre blade shading system with an integrated PV layer is presented. PV integration on shading systems allows achieving direct conversion of solar energy, as well as control of daylight availability and passive heat gain management. In particular, conversion of solar energy through PV-coated shading system makes use of a certain amount of solar energy that would be otherwise "lost", because falling on an element (the shading system), whose primary scope is to reject solar energy to avoid excess heat inside the building and prevent visual discomfort due to glare. Nevertheless, the design of such a system requires special attention to its geometry in order to ensure that the different uses of solar energy are well balanced such as PV-conversion, visual and thermal comfort. The work presented in the paper is a preliminary study based on extensive parametric simulations carried out in Rhinoceros environment [2], in combination with the software Grasshopper [3], along with the Diva plug-in [4] to account for the indoor environment's natural lighting conditions. Additionally, the total annual energy demands for heating and cooling are calculated in the dynamic building performance software IDA ice [5]. Focusing on the competing aspects of the system, the goal of this investigation is to find the optimal yearly configurations of the shading system in terms of geometry, e.g. number blades and tilt angle, with regard to daylight availability, risk of glare, annual solar radiation potential on the louvre-blades and energy demand.

2. State of the art

Building integrated photovoltaics were first introduced as shading devices in 1998 by Yoo and Lee [6] and have many advantages as they play a significant role in improving indoor comfort [7,8], while allowing to harvest renewable energy from the sun. Additionally, photovoltaic shading devices (PVSDs) have proven technical advantages over other types of PV installations like roof stand-alone PV systems [9]. However, the complexity of the systems and their adaptability to different contextual conditions, makes their design challenging [10]. Ibraheem et al. [11] reviewed the main influential parameters that affect the performance of buildings with PV integrated shading devices. These parameters included but were not limited to building geographical location [12], building orientation [13], type of shading devices [14], inclination angle of louvers [15] and the dimensions of the louvers [16]. Most of the recent research on PVSD has focused on implementing such systems in geographical locations close to the equator and as a result, self-shading of the system has proven to be a limiting factor in their efficiency to convert electricity [17]. However, this issue might be reduced in more extreme climates as the different sun paths do not lead to as much self-shading of the PV cells, making similar PV coated louvre-blades systems a potentially attractive technology for Nordic climates. The authors in [11] distinguish in PVSD two design sub-categories: design considerations and design configurations and apply this separation at context level (latitude and geographical location), building level (orientation and component function) and building envelope scale (design of the shading system per-se). Design considerations are the factors over which there is limited to no control but they need to be taken into account when the design process of building or the course of façade is being carried out. Design configurations, by contrast, are those elements which can be adjusted, changed or manipulated by the designer and are accounted for as a part of the project that can be shaped by the design process. Similarly, Kuhn [18] stresses the need to distinguish the design parameters (design considerations and design configurations) from the design space (effect of the system on indoor comfort) when trying to understand the impact of solar control systems on buildings.

3. Methodology

The building model that was used as a reference for this study is the Bestest Case 600, which is a 48 m^2 rectangular room with two large south facing windows [19] (Fig 1). The simulations were conducted over the period of one year with climate data for the location of Trondheim, Norway. Both windows were equipped with the louvre blade shading system, which is originally based on an existing product that doesn't have PV integrated cells [20].The optical characteristics of the glazing systems and the different surfaces in the model are summarized Table 1.

Table 1 Overview of the optical parameters used in the model (Radiance material library)

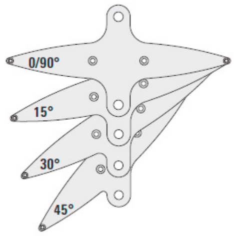
Object	Type of material	RGB reflectance
GenericCeiling_70	Opaque	0.7 ; 0.7; 0.7
GenericFloor_20	Opaque	0.2 ; 0.2; 0.2
GenericInteriorWall_50	Opaque	0.5 ; 0.5; 0.5
GenericFurniture_50	Opaque	0.5 ; 0.5; 0.5
Glazing_TriplePane_Argon90	Transparent glass	-
Aluminium_65	Opaque metal	0.65 ; 0.65; 0.65
CIGS_PV	Opaque plastic	0.1; 0.1; 0.1

The metrics assumed representative in the study were the useful daylight illumination UDI (%), the daylight autonomy DA (%), the continuous daylight autonomy cDA (%), and the annual radiation potential on the louvre-blades per m^2 of window (kWh/m^2). The UDI metric [21] separates hourly illuminance values based upon three illumination bins, 0-100 lx, 100-2000 lx, and over 2000 lx. It provides full percentage points only to hours where the illuminance values are between 100 lx and 2000 lx and assumes that horizontal illumination values outside of this range are not useful. The daylight autonomy (DA) value calculates the number of (working) hours a year a specific surface in a room receives an amount of light higher than a given threshold. The continuous daylight autonomy [22] is similarly calculated to DA but awards partial additional percentage credit to daylighting values below the given threshold. In this study, the UDI bin used is the 100-2000 lx and the threshold for the DA and cDA was set to 500 lx. Regarding the annual radiation analysis, the calculation took into account both direct and diffuse radiation incoming on the blades' surface per m^2 of window, but does not take into account PV cell conversion efficiency. For energy simulations, the building envelope components and systems were chosen to fulfill the requirements of the Norwegian technical standard TEK16 (Table 2). Internal heat gains were set to 200 W continuous [19] and the simulations were run with an ideal- heater and cooler with efficiencies of 1. The dual set point temperatures were defined as 20 ºC for heating and 26 ºC for cooling and the ventilation air inlet temperature was 16 ºC.

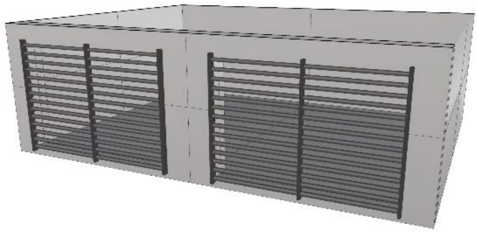
Table 2 Overview of the input used in the building model

Component	Value	Unit
External wall	0,18	$W/(m^2K)$
Roof	0,13	$W/(m^2K)$
External floor	0,15	$W/(m^2K)$
Window	0,8	$W/(m^2K)$
Air tightness	0,5	h^{-1}
AHU heat recovery efficiency	80	%
CAV rate	2	l/s

The study encompassed different designs related to the number of blades and their tilt. The configurations analyzed ranged from 10 to 22 equally spaced louvre blades and where blades have a homogenous tilt angle of 0, 15, 30 and 45° from the horizon (Fig 1.a and 1.b). The size of the blades (105 mm) and thickness were kept constant. The combination of the studied parameters yielded 52 possible configurations. The effect of each configuration was characterized on a yearly basis, using several daylighting indicators on a plane located 0.8 m above the floor level. Additionally, yearly heating and cooling demands were calculated for each configuration as well as the annual solar radiation potential reaching the surface of the louvre-blades relative to the total window area.



a)



b)

Fig 1 a) Illustration of the tilt angles for the louvre blades shading system; b) Illustration of the building model with the shading system

4. Results

The findings from the parametric study show that, as expected, the annual radiation potential increased steadily when the number of blades and the tilt angle grow. However, the different system configurations impacted the UDI in a slightly more complex manner as shown in Fig 2. For low tilt angles (0 and 15°), the UDI value lied within the range 60-65 % regardless of the number of blades; but for larger tilt angles (30 and 45°), the UDI value was below 50 % when the number of blades was respectively greater than 19 and 15 louvre-blades.

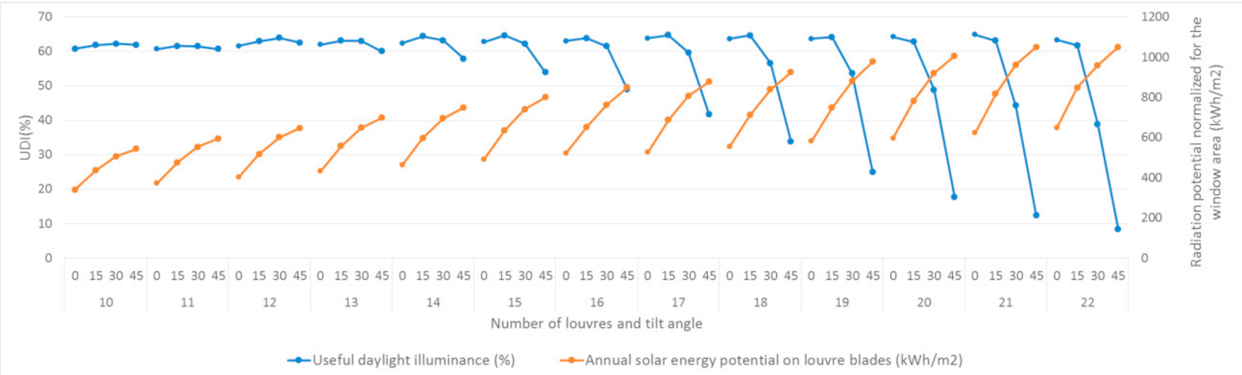


Fig 2 Impact of the system configuration on the values of the UDI and annual solar energy potential on the louvre-blades per m^2 window

The daylight autonomy decreases when the tilt angles increase in all the system configurations and is always below 50 %. The effect of the tilt angle is shown to be critical with 14 blades or more, the DA having dropped by 50 % when the angle changed from 0 to 45° (Fig 3). In terms of the cDA, any number of louvres above 13 yielded a cDA under 50 % when the tilt angle was 30° or more; and this threshold will also be breached for a 15° tilt angle when there are 17 or more louvres.

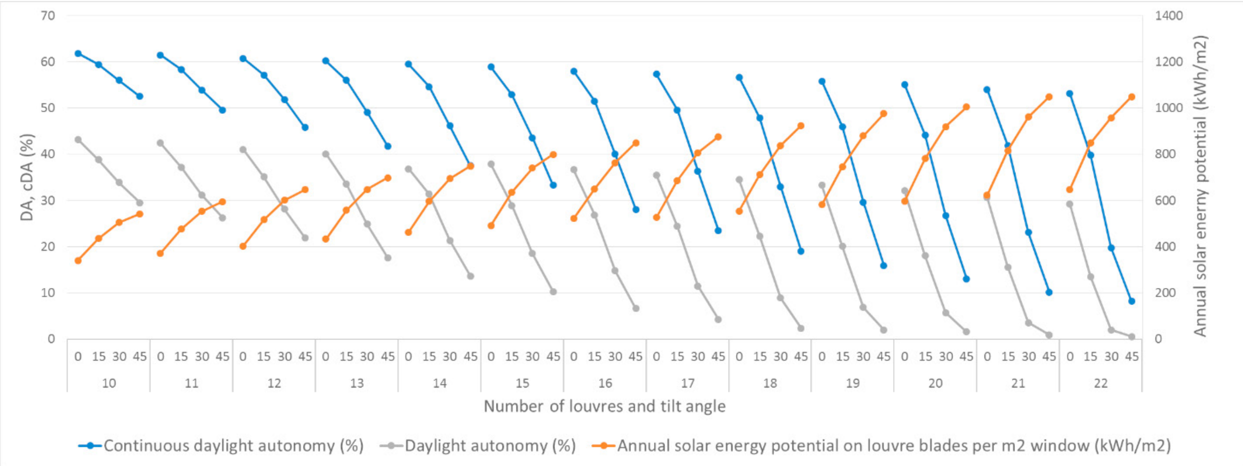


Fig 3 Effect of the system configuration on DA, cDA and annual solar energy potential on the louvre-blades per m2 window

The total heating demand for the building varied by 28 % in between extreme configurations while the cooling demand only changed by 7 %. From Fig 4, it is possible to see that the annual heating demand was dominant and the effect of the tilt angle of the shading system on the heating and cooling demand is most significant.

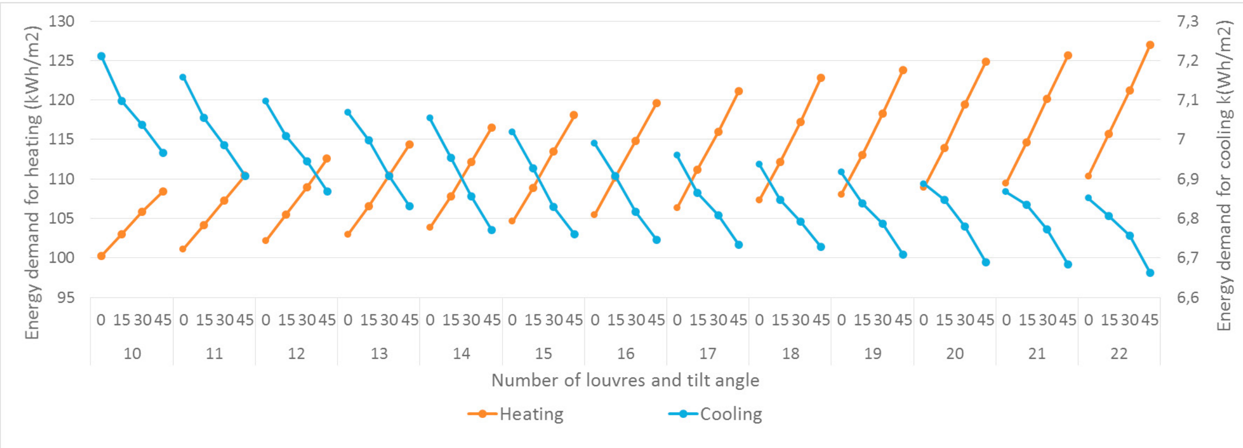


Fig 4 Impact of the system configuration on the total annual heating and cooling demand

5. Conclusion and further work

The results highlight the relation between annual solar energy conversion potential and annual visual comfort levels in the room. The DA is above 40 % for only 4 out of the 52 studied configurations which also correspond to the settings yielding the least solar energy conversion. The cDA follows a very similar trend to the DA and drops below the UDI value when the system has more than 14 louvres. This aspect indicates that there are few hours a year where the illuminance levels are slightly below 500 lx. The UDI is above 60% and almost unchanged for low tilt angles regardless of the number of louvres. This indicates that the system configuration at 15 degrees is most interesting since it significantly increases the solar energy conversion potential without compromising on the UDI. The effect of the shading system on the heating demand is more relevant than on the cooling demand, and is very sensitive to the tilt angle of the blades. According to these preliminary simulations, the two most interesting configurations are 16 louvres-blades at a tilt angle of 15° (DA= 27%; cDA= 51%; UDI= 64%; solar annual potential energy= 651 kWh/m^2) and 22 louvres at 0° (DA= 29%; cDA= 53%; UDI= 63%; solar annual potential energy= 649 kWh/m^2). Case 16_15 is the best performing option for solar energy conversion potential when the tilt is more than 0° with a cDA value above 50%. Case 22_00 performs similarly, but offers a slightly improved cDA value. This preliminary study will be improved further by investigating non-homogenous tilt angles and spacing in the solar shading system by use of optimization algorithms as well as striving to find seasonal optimal configurations instead of a yearly consideration. Additionally, an energy simulation with a more realistic case would bring more information about the energy demand of the building; especially if a control strategy for artificial lighting is implemented to quantify the additional electrical load (discounted for energy converted). Furthermore, visual and psychological parameters will be investigated.

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