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

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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.

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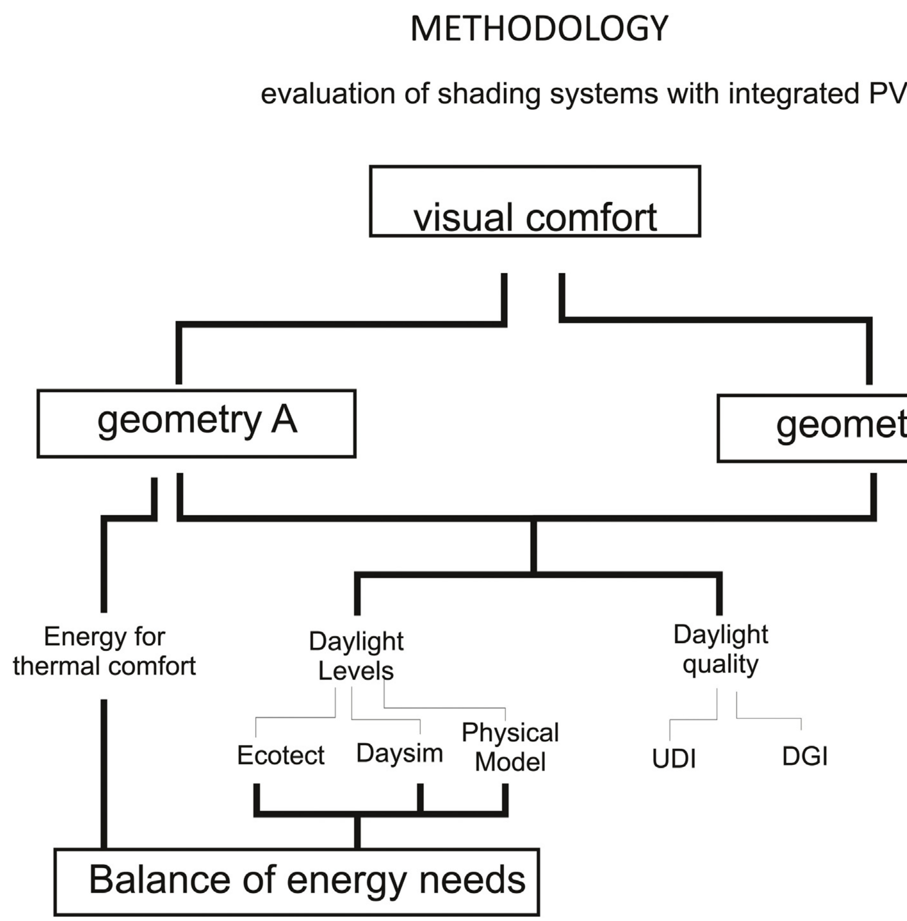


Fig. 1. Methodological diagram.

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

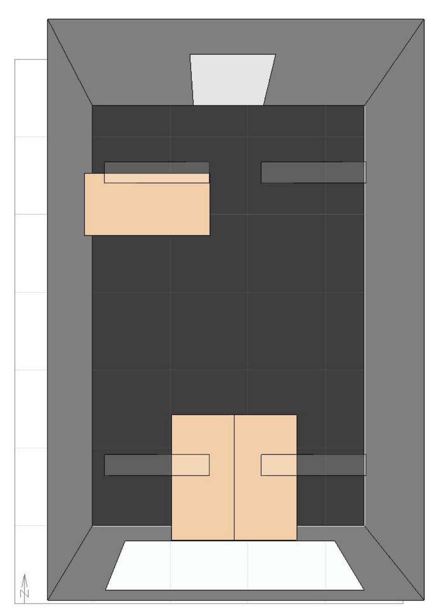


Fig. 2. Configuration of the office building examined [10].

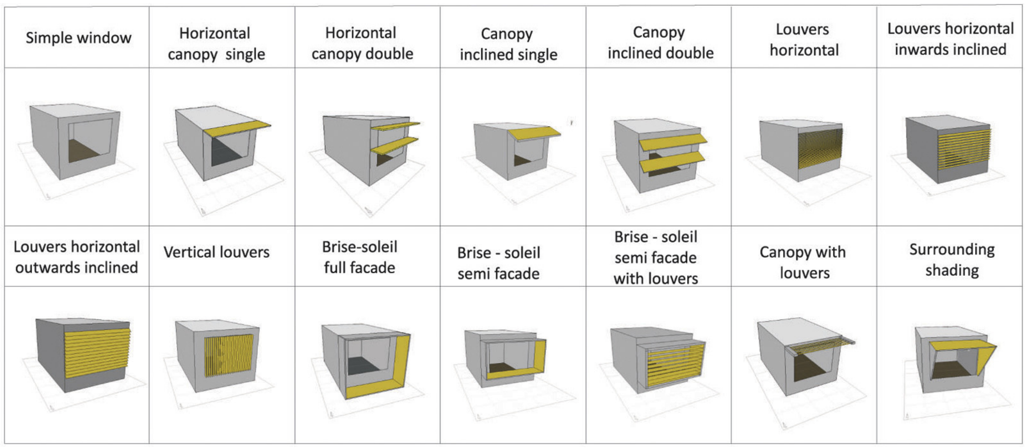


Fig. 3. Shading system examined [10].

that each office unit is part of a high rise office building and one office is repeated in high and in length. Only the wall of the facade that incorporates the window is thermally conductive. The window consists of a double glazing aluminum frame opening with thickness 0.042 m, with visible transmittance 0.898, total solar energy transmittance 0.837 and U-value 2.7 W/m^2 k.

The PV panels used as shading devices are constructed from photovoltaic composed of glass and Si polycrystalline technology [14]. The specific geometry of thirteen shading types that we examine can be seen in Fig. 3. All Shading systems are designed to exclude direct sun light during the overheated period.

2.2. Variants: geometrical factors of the integrated PV that affect the interior visual comfort conditions

In order to take into account the effect of the integration of the PV on the Shading systems, we re-evaluate the performance of thirteen types, in relation to daylight quality and to energy needs for lighting. Mandalaki et al. [10], proposed the use of framed PV systems in all shading devices. All examined elements have 3 cm of thickness (Geometry A). The thickness of the panel is crucial, especially for louvers systems. For this reason, we re-evaluated all louver systems with integrated PV of 1.5 cm thickness (Geometry B), in terms of daylight quantity and quality. Both geometries integrate the same PV technology.

The areas of the experimental approach are the following:

1. The effect of changing the thickness of the PV on the daylight levels in the interior. In order to conduct a detailed analysis we measure the daylight levels that each shading system creates in the space using both simulations and physical models.
2. The relation of the building's energy needs for electric lighting with the energy produced by the PVs.
3. The comparison of visual comfort conditions – using the following factors: Useful Daylight Illuminance (UDI) and of Daylight Glare Index (DGI) of the new shading systems (Geometry B) in relation to those already examined (Geometry A).

2.3. Examined shading systems

We categorize typical geometries of shading systems in terms of the view to outside that they provide. Analytically, we categorize them to:

a. Shading systems that allow transparency: Canopy horizontal, Canopy horizontal double, Brise–Soleil Full façade, Brise–Soleil Semi façade, Surrounding Shade, Canopy Louvers, Canopy Inclined Single.
b. Facade systems that obstruct view to outside: Canopy Inclined double, Brise–Soleil Semi Façade with Louvers, Louvers Vertical, Louvers Horizontal, Louvers Horizontal inwards inclined, Louvers Horizontal Outwards Inclined (Table 1).

3. Geometry A – energy savings

According to Mandalaki et al. [10], all examined systems can support the electricity needs during the hours when the daylight level falls below 500 lux. If the electricity produced from the PV will be used to heat and cool the internal space, the most energy efficient system (the system consuming the least energy from non renewable sources), is the system of *Surrounding Shade.* The systems of

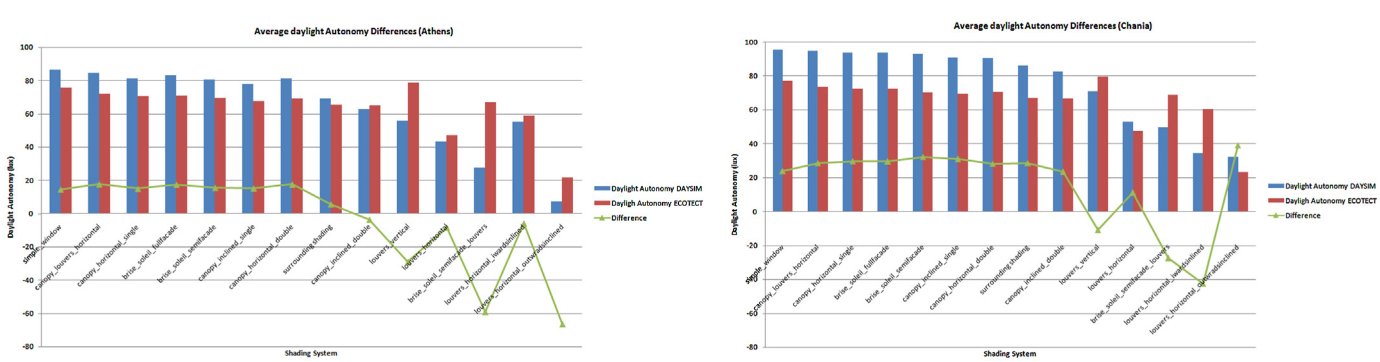


Fig. 4. Difference of calculated DA for Chania and Athens Latitude between DAYSIM and ECOTECT application software.

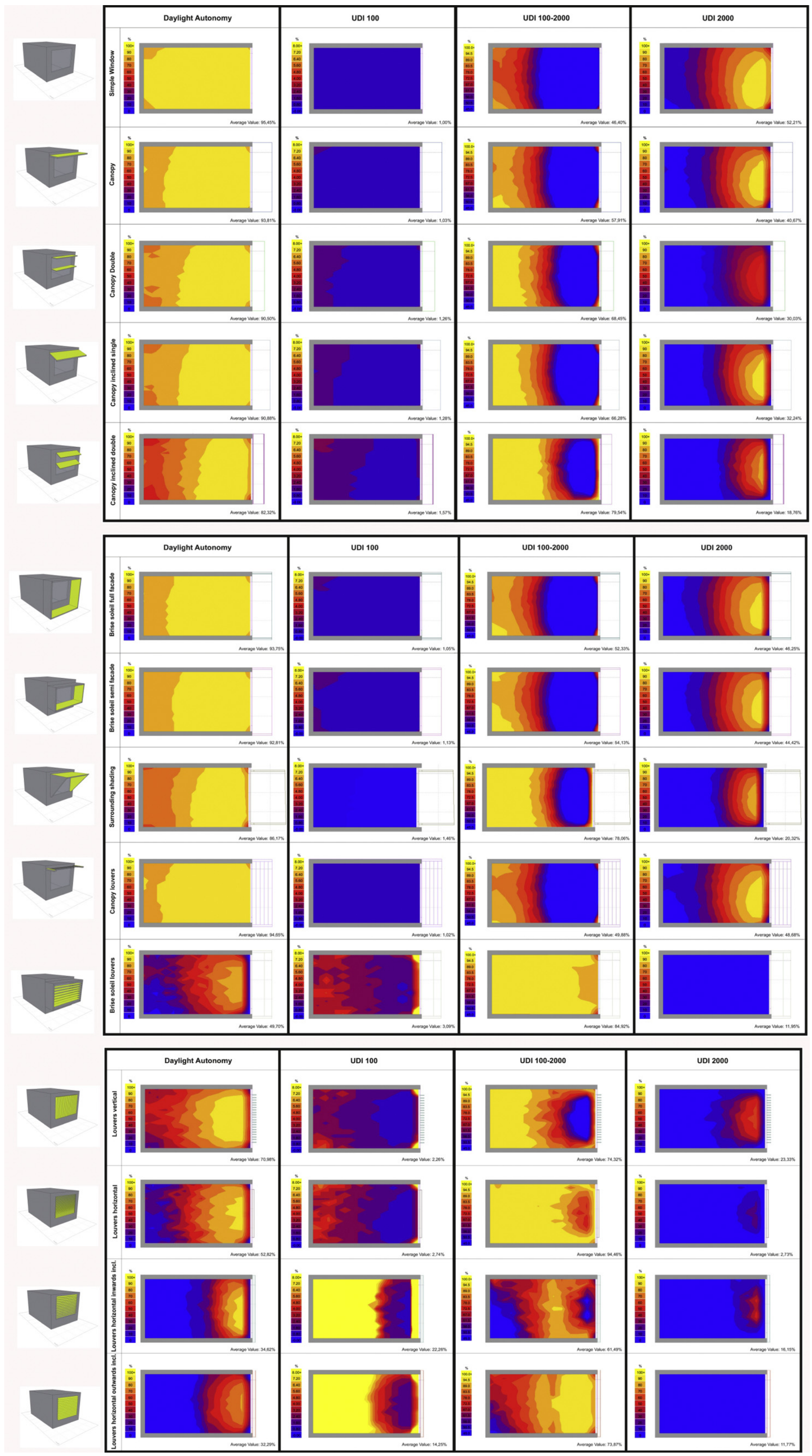


Fig. 5. Comparison of UDI values in relation to DA values for all Shading systems examined for the case of Chania.

Table 1
Groups of examined shading systems.

	Shading systems that allow transparency
GROUP 1	Canopy horizontal Canopy horizontal double Brise Soleil full façade Brise Soleil Semi façade Surrounding Shade
	Shading systems that obstruct view to outside
GROUP 2	Canopy inclined double Brise Soleil semi Façade with louvers Louvers vertical Louvers horizontal Louvers horizontal inwards inclined Louvers horizontal outwards inclined

Brise–Soleil Full facade, *Canopy inclined double* and *Canopy inclined single* are also considered to be energy efficient, in that order.

Among these systems, *Canopy inclined single* is the most efficient in terms of electricity produced in relation to the PV area installed. Similar results are presented by Hwang et al. [15] and Sun et al. [16] that when comparing the energy production per m^2 of venetian blinds outwards inclined systems and of canopy inclined, observed a 42% energy production higher in the case of canopy inclined.

4. Geometry A – evaluating visual comfort conditions

In order to evaluate visual comfort conditions, both daylight levels through the value of Daylight Autonomy Levels (DA) and daylight quality through the values of Useful Daylight Illuminance (UDI) and Daylight Glare Index (DGI) are examined.

4.1. Evaluation of DA

In order to compare in detail DA levels for the examined shading systems and to extrapolate accurate conclusions we calculated DA levels with both ECOTECT and DAYSIM. DA is defined as the percentage of year working hours (9:00–17:00) that daylight levels are above the comfort levels of 500 lux. DA is an indicator of energy needs for electric light. When DA is high, the needs for electricity used for lighting, are low.

DAYSIM calculates the annual daylight availability in arbitrary buildings based on RADIANCE backward ray tracer. It provides more accurate results than the split-flux method used by ECOTECT for daylight factor calculations. Some differences have been observed between the two methods. In most cases the DAYSIM calculates higher levels of average DA and the differences are in the range of 16%. Only for more complicated systems of venetian blind the differences are higher and are in the range of 40%. For complicated systems and for detailed analysis only the dynamic software is accurate enough (Fig. 4).

Regarding DA for daylight levels above 500 lux, transparent systems perform better than louvers systems. From this first group of shading systems (transparent systems) *Canopy louvers* and *Brise–Soleil* systems perform better while the *Surrounding Shade* has the lowest value of DA. In the second group of shading systems *Louvers vertical* and *Louvers horizontal* perform better when compared with Louvers Horizontal Outwards Inclined as we can see in Fig. 4 for Chania Latitude. The higher the DA percentage is, the lower the energy needs for electric lights are becoming. In the same Figure we can see that the systems of Canopy Louvers and Brise–Soleil are the most economical in terms of energy needs for lighting the interior space among transparent systems and the Louvers Vertical and Horizontal among the systems that obstruct view to outside.

DA is not a value that can be examined separately in order to evaluate daylight quality. It should be examined together with other daylight quality criteria. This is due to the fact that DA gives information about daylight levels over 500 lux, but does not give information about overlight areas (over 2000 lux) which can be uncomfortable or areas with lighting lower than 500 lux where lighting levels must be increased in order to reach the desired light intensity.

4.2. Other daylight quality parameters

In order to define daylight quality of the examined shading systems we additionally evaluate two factors of daylight quality: UDI that is defined by Mardaljevic [17] and the DGI defined by Baker & Steemers [18].

4.2.1. Comparison of daylight quality in terms of UDI

The daylight quality is assessed in relation to UDI. We assess three basic values: UDI 100–2000 (the mean value of the UDI), the

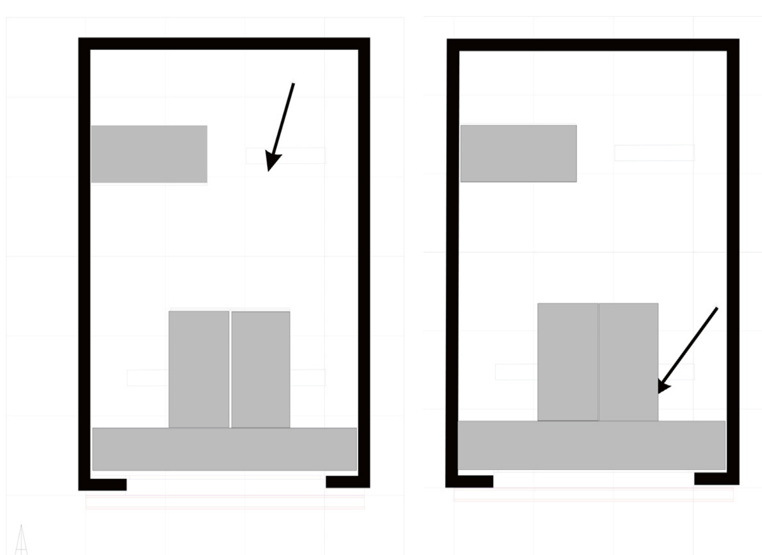


Fig. 6. Camera view for calculating DGI for South facing Shading systems (Left: away from the window, Right: near the window).

UDI 100, (the percentage of the time of the year when the space has daylight under 100 lux; this level is considered very low) and the UDI 2000, (the percentage of the time of the year that the space has daylight above 2000 lux; these levels of daylight are considered to result in uncomfortable visual conditions).

As it can be seen in Fig. 5 the *Canopy* systems (with louver or simple) have high DA value (almost 94%) but at the same time they have low UDI 100–2000 value (almost 50%), resulting in an uncomfortably daylight space. UDI 100–2000 value is the lowest in comparison to other systems. Similar results apply for *Brise–Soleil* systems. Both systems perform very low in terms of daylight quality and almost the same as the Simple unshaded window.

Amongst transparent façade systems, *Surrounding Shade* seems to perform well because it has high UDI 100–2000 values, low UDI 100 value and low UDI 2000 value in comparison to other transparent shading systems. Additionally, *Canopy Double* systems *Inclined or not* perform well in relation to the three examined UDI values, but lower than Surrounding Shade.

In general, façade shading systems perform better in terms of high percentage of UDI 100–2000. Amongst these systems, Louvers

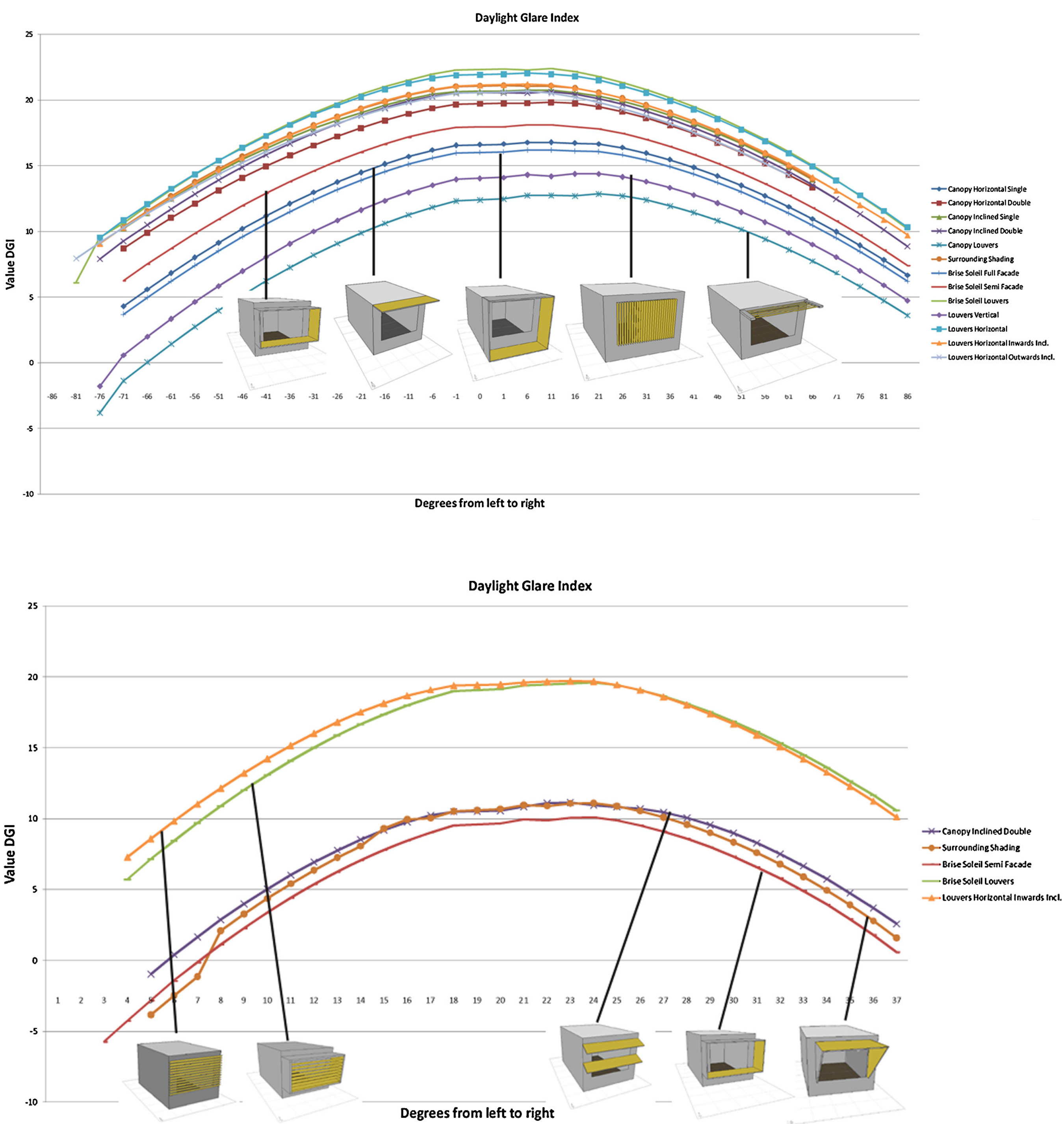


Fig. 7. DGI values for the 21 December at 12:00 o'clock for examined systems in relation to the angle of view for the camera away from window (above) and for camera near the window (below).

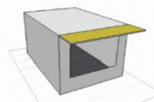
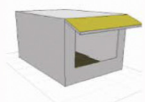
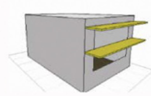
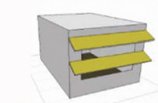
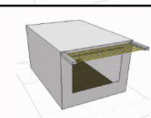
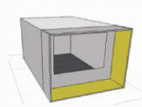
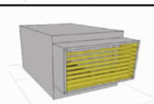
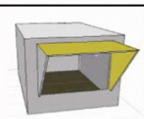
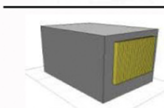
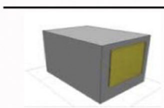
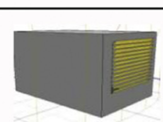
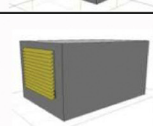
	UDI	DGI Away from window	DGI Near the window	DA	Energy Needs For H + C [6]
	LOW - 1	BEST - 2	NA	BEST - 2	LOW
	MIDDLE	LOW - 4	NA	BEST - 5	LOW - 3
	MIDDLE	MIDDLE	NA	BEST - 3	MIDDLE
	BEST	MIDDLE	MIDDLE	MIDDLE	MIDDLE
	LOW - 2	BEST	NA	BEST	LOW - 1
	MIDDLE	BEST - 3	BEST	BEST - 1	BEST - 1
	MIDDLE	MIDDLE	BEST	BEST - 1	BEST - 2
	BEST	LOW	LOW	LOW - 1	BEST - 3
	BEST	LOW - 3	MIDDLE	BEST - 3	BEST
	MIDDLE	BEST - 1	NA	LOW- 2	MIDDLE
	BEST	LOW - 1	NA	LOW- 2	MIDDLE
	LOW	LOW - 2	LOW - 1	LOW	LOW - 2
	LOW	LOW -3	NA	LOW	MIDDLE

Fig. 8. Comparative assessment of shading systems.

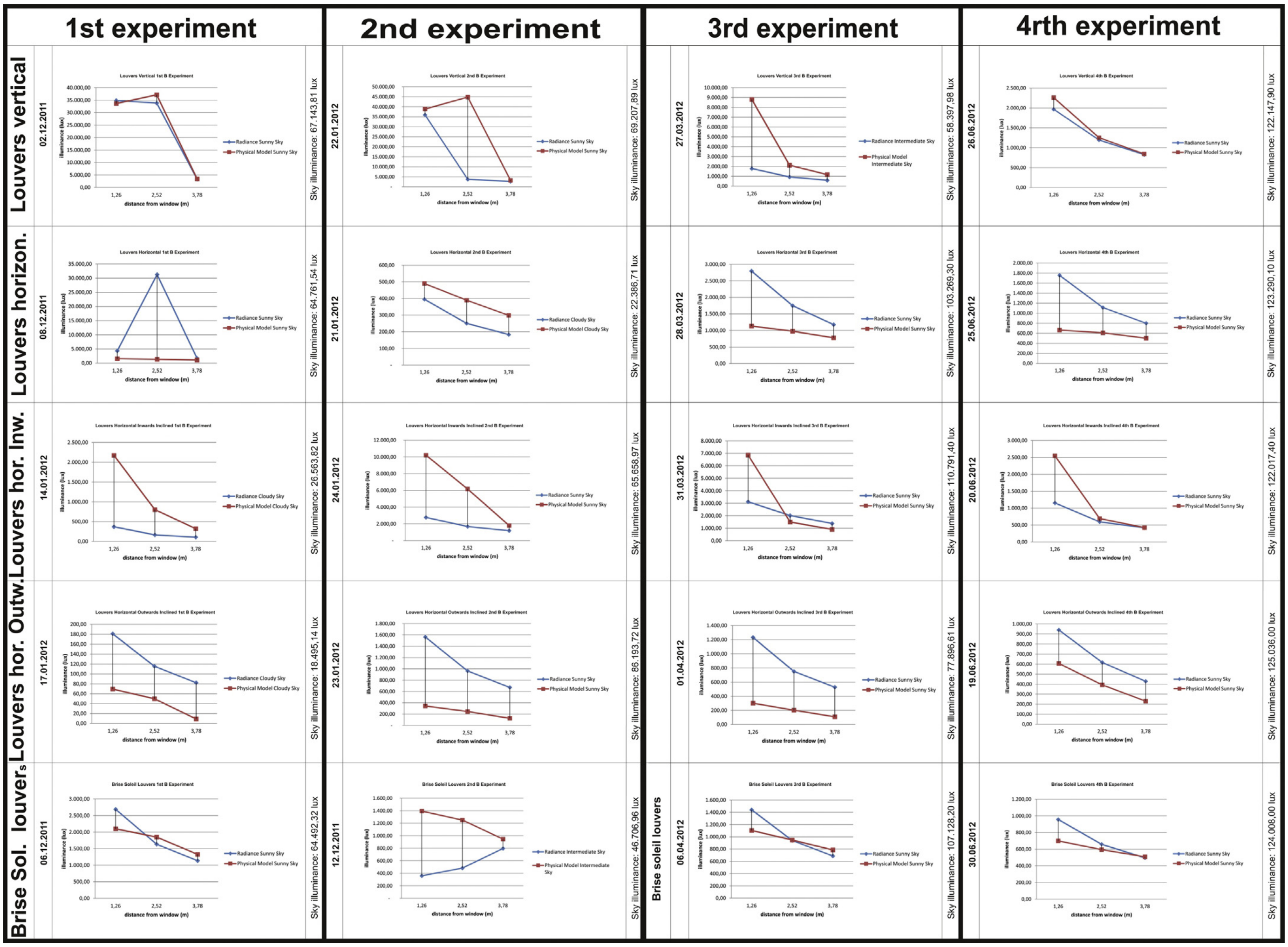


Fig. 9. Comparison of measurements (physical models) with simulation application (RADIANCE). Thickness of PVs used in simulations is 1.5 cm.

Horizontal has the highest UDI 100–2000 and simultaneously the lowest UDI 100 (resulting in uncomfortable low daylight levels) but the highest UDI 2000, near the window and this means that it might produce glare. Systems such as *Brise–Soleil Louvers and Louvers Horizontal* seem to produce a comfortable daylight environment due to their low value of UDI 100 and Low value of UDI 2000 (Fig. 5).

In conclusion, façade systems perform better in relation to UDI, as expected but not according to DA. At the same time, of course due to low DA, they result in high energy consumption for lighting. We will further on examine shading systems in terms of Glare because UDI value is an indicator of good daylight quality in terms of levels but it does not incorporate the direction of light that can generated glare.

4.2.2. Comparison of daylight quality in terms of Glare

In order to evaluate glare, the DGI factor is used. A basic table of limit values is given by Baker et al. [19]. Values below 16 are considered to result in an imperceptible visual environment.

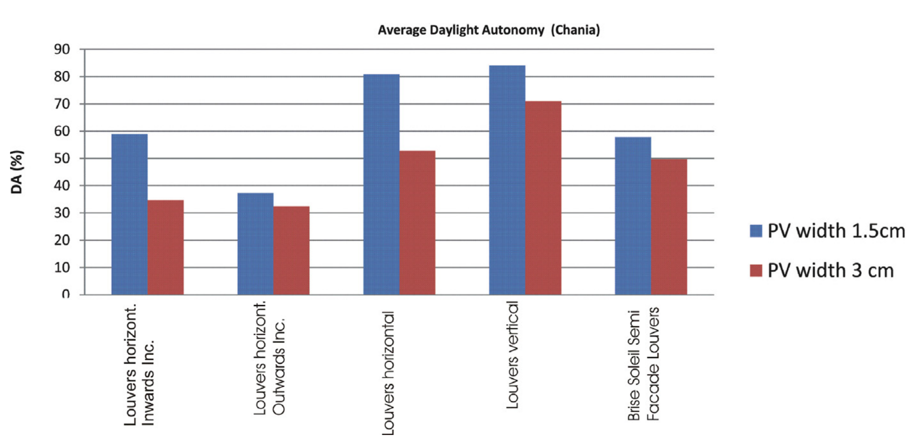


Fig. 10. Comparison of DA for two PVs' thickness (1.5 and 3 cm).

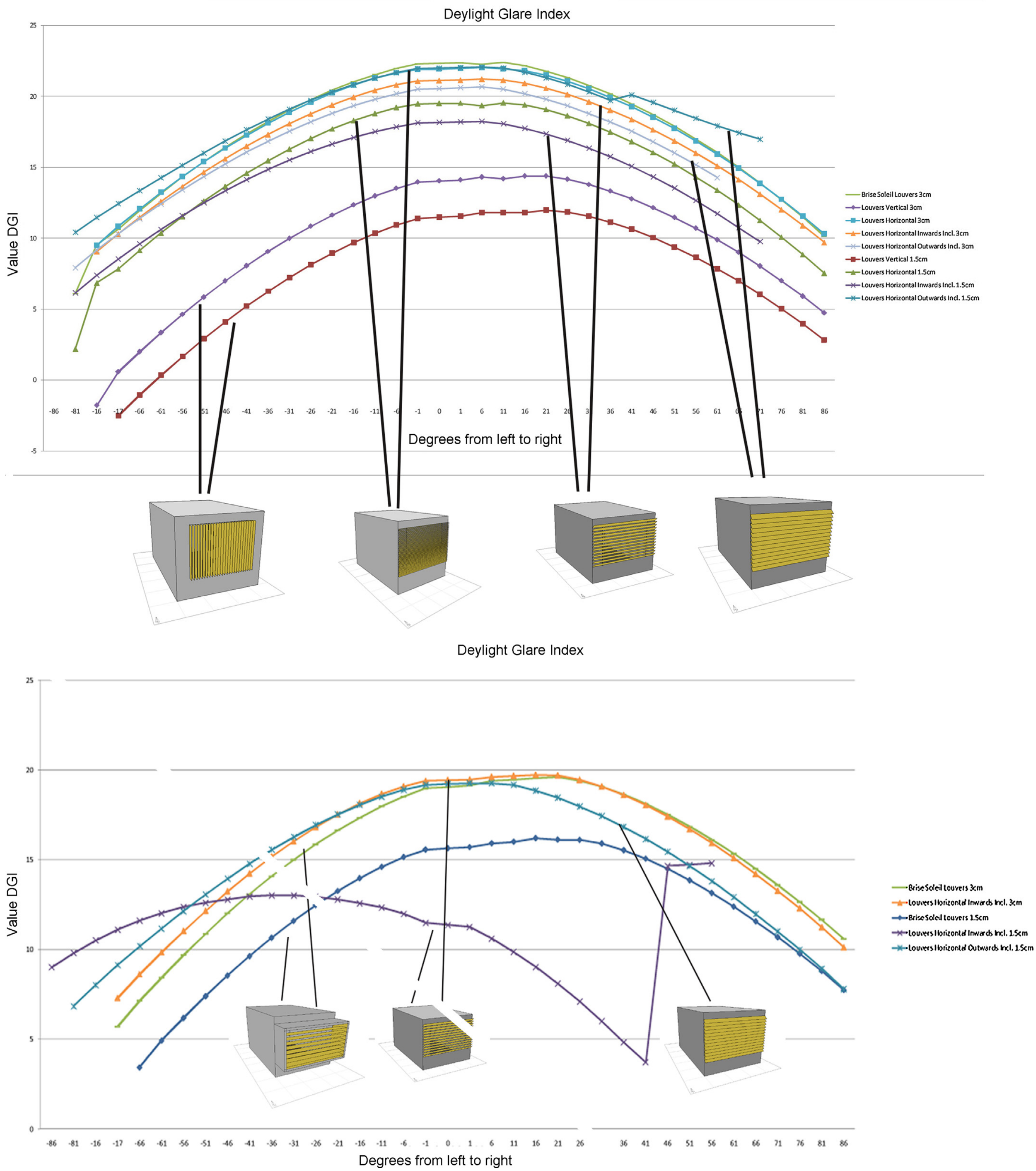


Fig. 11. Comparison of DGI values for the case of thickness 1.5 and 3 cm for camera away from the window (above) and for camera for camera near the window (below).

Originally we selected the “worst viewing position” for the simulations. In theory, the worst viewing position is the one that has the highest vertical viewing angle of the window that constitutes the main light source of the space in question, and the one with the widest viewing angle onto the surface of the window [20]. We selected this position in the model as it can be seen in Fig. 6. We additionally examine the performance of Shading systems in relation to glare for camera positions near the window, in order to evaluate visual environment in these positions (Fig. 6). All simulations are for 21st of December: The sun is in its lowest position that it can result in uncomfortable visual environment.

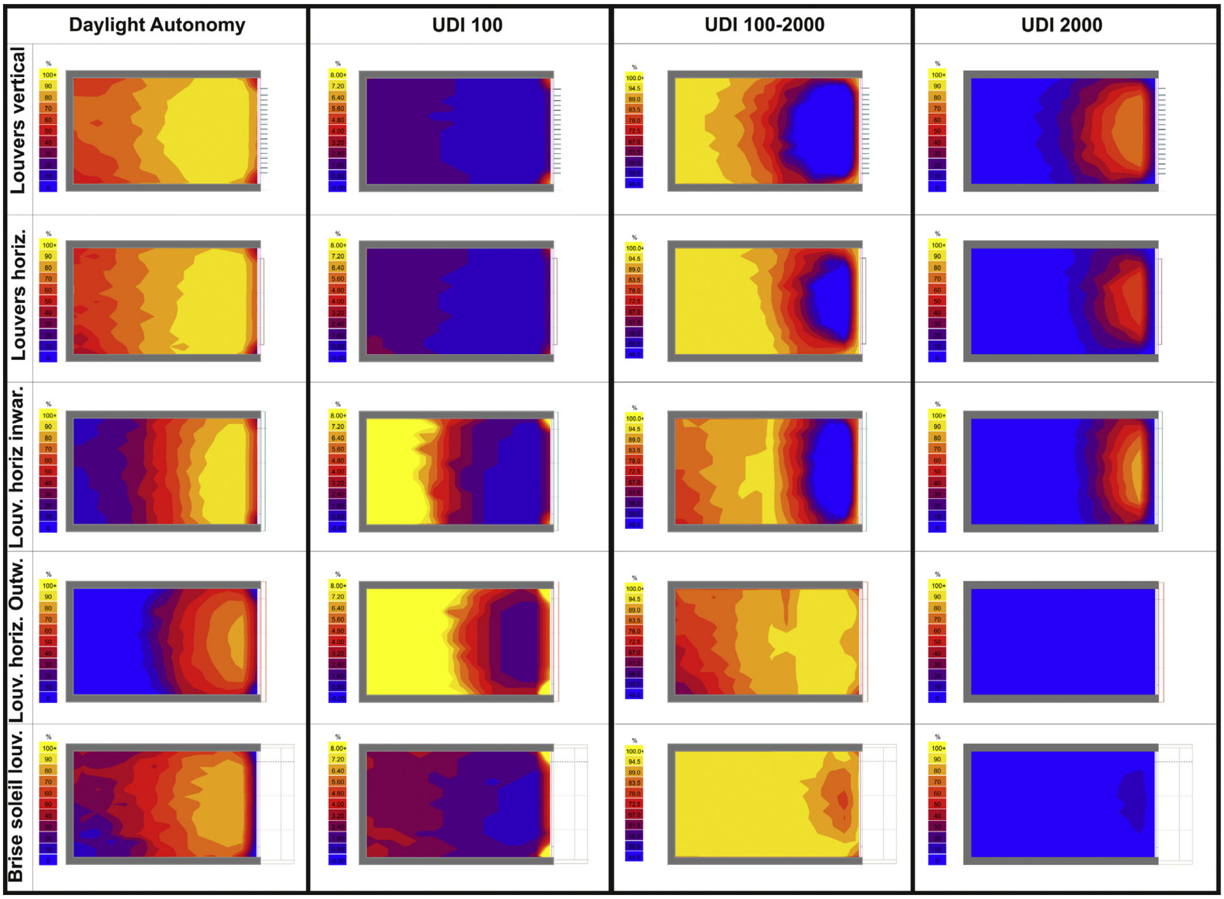


Fig. 12. DA and UDI values for Louver systems with 1.5 cm thickness.

As we can see in Fig. 7, most of the systems have DGI values above 16 for most of the viewing angles. Only some systems can result in values below 16 and these are presented here in sequence starting from the best performing (Canopy louvers, Louvers vertical, Brise–Soleil Full Façade and Canopy horizontal).

These systems, even though we showed in the previous paragraph that they do not perform very well in terms of UDI values, they perform very well in terms of low glare values and in terms of DA. Due to their high percentage of DA they can result in low energy consuming systems in relation to electric light needs.

Some systems result in perceptible glare conditions (values 16–20). These are *Brise–Soleil Semi Façade* and *Canopy Horizontal Double*. At the same time, *Canopy horizontal double* results in an acceptable level of UDI values. The rest of the examined systems result in acceptable glare conditions (values 20–24) presented in row from the worst to the best: *Brise–Soleil Louvers*, *Louvers Horizontal*, *Louvers Horizontal inwards inclined*, *Surrounding Shade*, *Canopy inclined Single*, *Canopy Inclined Double*, *and Louvers Horizontal Outwards*.

For positions near the window, as we can see in Fig. 7, systems of *Brise–Soleil Semi facade, Surrounding Shade and Canopy Incline Double* perform very well in terms of glare. We previously showed that amongst them the system of Brise Soleil Semi Facade performs well in relation to camera positions away from window. We did not manage to evaluate the rest of the systems due to probable simulation software error. Zero (0) values in Fig. 8 indicate these errors.

We concluded that Brise Soleil Semi facade system performs well for both positions of occupants (away and near to the window). This is probably due to its specific geometry that allows intereflections between their elements and prevents direct sunlight.

Generally transparent systems can result in good daylight quality for positions of occupants away from the window and some of them are performing better for position near the window. For example the systems of Surrounding Shade and Canopy Inclined Double perform better in terms of glare for positions of occupants near the window than for positions away from it.

5. Geometry A – balancing energy savings and visual comfort

In order to evaluate the performance of the examined shading systems, a table is being created that incorporates all the examined values related with visual comfort and energy savings examined in previous paragraphs (Fig. 8). This table brings together conclusions in relation to all examined factors. The measuring scale is based on three basic categories, starting from the most efficient in terms of the factor examined: Best – Middle–Low. When values of the same examined factor are very close they can belong to the same level, example two systems belongs to the BEST category for UDI factor. BEST–1 means lower quality of the examined factor and BEST–2 even lower. Their difference is not high enough to position them in a completely different level: to the MIDDLE for example. The same applies for the rest of the reference values.

The system of *Surrounding Shade* is performing extremely well in terms of low energy needs [10]. We proved that it performs well in terms of daylight quality for positions near the window and has good performance of UDI values. On the other hand, the system of *Brise–Soleil Semi facade* that is performing well in terms of energy needs for thermal comfort (but lower than the surrounding Shade) performs very well in all daylight quality values examined. Similar results can be extracted for Brise–Soleil Full facade system.

If we compare shading systems only in terms of daylight performance the system of *Canopy Louvers* has very good performance. It performs extremely well according to energy savings for lighting and according to visual comfort for positions away from window and generates acceptable visual conditions near the window. The only disadvantage is that, this system performs low in terms of energy savings for heating and cooling the space (Fig. 8). That is the reason why we cannot incorporate Canopy Louvers Shading system amongst the preferred one, when integration of PV is included in the design.

6. Geometry B – visual comfort conditions

As a next step for evaluating the potentials of integrating PV in Shading Systems we evaluated the reduction of the thickness of the PV panels and how this is affecting the interior visual conditions.

Firstly, we evaluated the influence of this change to the experimental work that we did in order to evaluate daylight levels. We compared measurements of the daylight levels calculated by Mandalaki et al. [10] to the new simulations done for louver shading systems of 1.5 cm thickness. We showed that values of daylight levels measured in the physical model and in simulation are becoming closer and in some cases are identical (Fig. 9). This means that for assessing visual environment of PV louver systems using physical model, higher thickness of louvers should be integrated than originally proposed. The overestimation in the daylight levels that the physical models are normally measuring can be reduced when the thickness of the louvers are higher than these that are going to be used in the real building (and the simulated ones). This can be expected: the observed overestimation of the daylight levels in the physical models is reduced in percentage due to higher louvers' thickness – smaller slots for entering daylight that can result in lower daylight levels.

In relation to DA we can see that, as expected, all DA values increase for all examined shading systems, and this means that the electricity needs for daylight decrease (Fig. 10).

In relation to glare values for cases away from the window it is remarkable that almost all systems with PV louvers of 1.5 cm thickness perform better than the same geometry of system with 3 cm thickness. All systems generate acceptable daylight environment (value over 16) and amongst them louvers vertical perform better (with both 3 and 1.5 cm thickness) and generate comfortable visual conditions. (Fig. 11).

However, for positions near the window almost all systems generate glare except of Brise–Soleil Louvers and Louvers Inwards Inclined of 1.5 cm thickness (Fig. 11). We conclude that Louver systems with lower thickness of PV perform better for positions near the window.

By comparing Figs. 12 and 5 we also conclude that the UDI values remain almost constant regardless the thickness of the louver, except in the case of Louvers horizontal (for UDI 100–2000).

The above mentioned facts show that reducing the thickness of the PV louvers–panels increase the daylight comfort conditions of the interior space.

7. Discussion and conclusions

We have attempted to combine the different and occasionally contradicting properties of the various shading systems with integrated PV examined in relation to their ability to save energy and to provide high quality of daylight. We have concluded that systems of *Brise–Soleil Full and Semi facade* can best achieve these two goals.

According to Mandalaki et al. [10] the most energy efficient systems are Surrounding Shading, Canopy Inclined Double, Brise Soleil Full facade and Canopy Inclined Single, in that order. Due to the fact that the first two systems do not perform well in terms of visual comfort, we exclude them from the proposed shading systems with integrated PV. On the contrary, the system of Canopy inclined single has very good performance in terms of UDI values meaning that this system can be proposed as an economical and acceptable solution when Brise–Soleil systems cannot be used.

High contradiction exists for Canopy Louvers system: even if is the best performing system in terms of visual comfort, it performs extremely low in terms of energy production and consumption. For this reason, we cannot consider it as a design and energy saving solution when integration of PV is being examined.

All systems of *Louvers* which have proved to perform very well in office units [21,22], are unsuitable for integration of PV, due to the fact that their energy production becomes very low when PVs are integrated [10]. An interesting result occurs when changing the thickness of the PV integrated to Louvers (Geometry B). First of all, the electricity needs become lower and the quality of daylight becomes better. Still, the energy production does not become high enough to rate the louver systems amongst the most efficient ones with integrated PV.

We recommend that when considering PV integration for shading systems in office buildings *Brise–Soleil systems* should be considered as a valuable solution in order to achieve visual comfort and sufficient energy production. Especially, in combination with an interior movable shading device, these systems can become valuable energy machines of comfort.

Combining the above mentioned results, further research can be done in the direction of combination of internal and external shading systems. A question will be raised wherever the use of shading systems with integrated PV that can produce the most of the electricity can be combined with an internal shading device for achieving visual comfort and can still result to an energy economical solution.

References

[1] T.Y.Y. Fung, H. Yang, Study on thermal performance of semi-transparent building-integrated photovoltaic glazings, Energy and Buildings 40 (2008) 314–350.
[2] M.F.N. Tajuddin, S.M. Ayob, Z. Salam, M.S. Saad, Evolutionary based maximum power point tracking technique using differential evolution algorithm, Energy and Buildings 67 (2013) 252–254.
[3] A. Murtaza, M. Chiaberge, F. Spertino, D. Boero, M.D. Giuseppe, A maximum power point tracking technique based on bypass diode mechanism for PV arrays under partial shading, Energy and Buildings 73 (2014) 13–25.
[4] S.H. Yoo, E.T. Lee, J.K. Lee, Building integrated photovoltaics: a Korean case Study, Solar Energy 64 (1998) 151–161.
[5] P. Eiffert, J.G. Kiss, Building – integrated photovoltaic, design for commercial and institutional structures, in: A Source Book for Architects, US Department of Commerce, Springfield, 2000.
[6] A. Hestnes, Building integration of solar energy systems, Solar Energy 67 (1999) 181–187.
[7] J. Khedaria, J. Waewsakb, W. Suphengc, J. Hirunlabha, Experimental investigation of performance of a multι – purpose PV -slat window, Solar Energy Materials and Solar Cells 82 (2004) 431–445.
[8] S. Kang, T. Hwang, J.T. Kim, Theoretical analysis of the blinds integrated Photovoltaic modules, Energy and Buildings 46 (2012) 86–91.
[9] Greek Public Power Corporation (GPPC), Wind Speed and Solar Radiation Measurements for Greece, GPPC, Athens, 1986, pp. 1980–1985.
[10] M. Mandalaki, K. Zervas, T. Tsoutsos, A. Vazakas, Assessment of fixed shading devices with integrated PV for efficient energy use, Solar Energy 86 (2012) 2561–2575.
[11] S.A. Al-Sanea, M.F. Zedan, Optimized monthly-fixed thermostat-setting scheme for maximum energy – savings and thermal comfort in air- conditioned spaces, Applied Energy 85 (2008) 246–326.
[12] P. Boyce, P. Raynham, SLL Lighting Handbook, The Society of Light and Lighting, London, 2009.
[13] H. Van Dijk, Reference office for thermal, Solar and lighting calculations, IEA Task 27, performance of solar facades components, TNO Building and Construction Research, Delft, The Netherlands, 2001.
[14] M. Mandalaki, S. Papantoniou, T. Tsoutsos, Assessment of energy production from photovoltaic modules integrated in typical shading devices, Sustainable Cities and Society (2013) (in press, available online).

[15] T. Hwang, S. Kang, J.T. Kim, Optimization of the building integrated photovoltaic system in office buildings – focus on the orientation, inclined angle and installed area, Energy and Buildings 46 (2012) 92–104.
[16] L. Sun, L. Lu, H. Yang, Optimum design of shading-type building-integrated photovoltaic claddings, Applied Energy 90 (2012) 233–240.
[17] J. Mardaljevic, The BRE-IDMP dataset: a new benchmark for the validation of illuminance prediction techniques, Lighting Research and Technology 33 (2001) 117–136.
[18] N. Baker, K. Steemers, Daylight Design of Buildings, James x James, London, 2001.
[19] N. Baker, A. Fanchiotti, K. Steemers, Daylighting in Architecture. A European Reference Book, James x James, Brussels, 1993.
[20] K. Meresi, Energy Savings in schools through daylighting, Polytechnic School of Thessaloniki, Thessaloniki, 2010.
[21] E. Bulow-Hube, Energy – efficient window systems, in: Effects on Energy Use and Daylight in Buildings, Lund University, Department of Construction and Architecture, Division of Energy and Building Design, KFS AB, Lund, 2001.
[22] M. Dubois, Impact of Shading Devices on Daylight Quality in Offices – Simulations with Radiance, Lund University, Dept. of Construction and Architecture, Lund, Sweden, 2001.