Assessment of performance of building shading device with integrated photovoltaics in different urban scenarios.

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Abstract—Shading devices are an important aspect of many energy-efficient building design strategies: they can help in reducing the amount of energy required for cooling and artificial lighting. Shading devices can also integrate photovoltaics: the performance of the PV is influenced by the tilt angle and especially by any partial shading that can be caused by surrounding buildings. This paper presents a combined study of building energy consumption and the electricity production from a PV system integrated into a shading device for different surrounding building configurations and tilt angles.

I. INTRODUCTION

There are many reasons for controlling amount of sunlight that is admitted into a building. In warm, sunny climates excess solar gain may result in high cooling loads, in cold and temperate climates winter sun entering south-facing windows can positively contribute to space heating and in nearly all climates controlling and diffusing sunlight as it enters the building will improve daylighting and reduce lighting loads. A combined study of overall building energy demand and supply has been undertaken for a shading system that integrates photovoltaics into the shading device itself. The effects of the shading device and the PV system have been simulated for an urban context with different tilt angles and surrounding buildings.

The real urban texture is highly complex and difficult to model. In order to limit these complexities some archetypes were defined and these simplified types are used especially for energy use studies (Ratti et al., 2003). In this assessment two generic urban types were chosen: separated and continuous units. The separated unit, defined by geometrical ratios, can be seen in figure1.

Fig. 1. The separated form structure H, D, L2, refer to the height, depth, frontal length of each unit, L1 refers to the spacing between the units and W refers to the width of the street (Shashua-Bar L, Hoffman ME, Tzamir Y).[1]

Three dimensional urban quarter simulation has been undertaken for different generic urban form and geometrical ratios. To calculate the daylight illuminance the raytracing program Radiance was used. The room was also equipped with artificial lighting. The placement of the artificial lighting system in
the test office and the luminary lamp properties can be seen in the figure 2. Total luminous fluxes of lamps are 2600 lm and efficiency is 72.8%. Each luminary power is 32 W. A daylight responsive dimming system is integrated into model. The annual electricity consumption with a daylight responsive control system was simulated in radiance based on the lighting program Daysim (Reinhart, 2006)[2].

![Image](image1)

**Fig. 2. Artificial Lighting System Placement.**

### III. PHOTOVOLTAIC MODEL DESCRIPTION

The model used represents a building integrated photovoltaic (BIPV) module of 40Wp at STC. The amount of energy produced by the PV cells is calculated using the one-diode model and the system model is built up from sub-models of individual cells and modules to properly represent cell mismatch resulting from partial shading. The shading device incorporates 32 BIPV modules of 40Wp @STC. Each cell has a current source that represents the photocurrent generated by the amount of radiation available and its value comes from:

\[
I_{SCt} = I_{SCR} \left( \frac{G_t}{G_R} \right)
\]

where \( I_{SCt} \) is the short circuit current (maximum current available from a solar cell) at the time \( t \); \( I_{SCR} \) is the short circuit current measured at the STC (=1000 W/m², 25 C) and \( G_t \) is the value of the global radiation at the time \( t \) incident on the cell; \( G_R \) is the radiation at the STC (=100 W/m²)[3]. The value of \( G_t \) is calculated by using EnergyPlus: the shading device has been divided in small objects corresponding to each solar cell and respecting their distance in a way to exactly reproducing the photovoltaic array cell by cell(figure 3). Energy plus calculates the average of the global radiation (direct beam plus diffuse beam plus reflected from the surrounding building) on each surface as function of the time. The time step for the simulation has been set at 15 minutes.

#### A. Simulation details

The analysis in PSpice has been developed as we can scan the I-V characteristic from the array for each 15 minutes: with a transient analysis on time, the configured array (parallel connection of two strings of 16 modules series connected) has been connected to an ideal variable load and in 1 second the value of current and voltage (as well as the power) can be measured from the simulation, within 200 steps. The values of the each cells current (ie the equivalent global radiation) must remain constant while the simulation is scanning the I-V characteristic.

The current sources in PSpice (to represent the photocurrent of each cell) have an output driven by a .txt file. This .txt file has to be created from the output of EnergyPlus: a .csv file that contains the names of the overall cells and their incident global radiation during the year 2009 with a time step of 15 minutes.

A script has been developed to create a single .txt file for each cell named with the name that corresponds to their position and the value of the current calculated in (1). The time in PSpice cannot be specified as day and time of the day, so the script has to create each .txt file with the time in seconds and maintains the value of the current constant for each second the I-V characteristic is measured. See Appendix 1a.

The simulation produces the I-V and P-V characteristic: only the I-V and P-V characteristic where the radiation is constant has to be selected.

![Image](image2)

**Fig. 3. Shading device with photovoltaics integrated and particular of one module on the top.**

Another script has been developed to select acceptable results. Once all the simulations have been completed the parameters of interest is the maximum power and the current @MPP. These values have been detected using another script. See appendix 1b.

To make the simulations and the compiling of the scripts easy and faster each simulation is undertaken month by month.

![Image](image3)

**Fig. 4. Example of the output from PSpice: only the first characteristic is valid.**
IV. RESULTS

The simulated thermal and electricity energy performance of the office with different $L_1/L_2$ ratios were investigated in terms of total annual consumption (loads, kWh/m²). The simulated annual electricity lighting consumption without daylighting control is 29.58 kWh/m². With daylighting control, annual electricity loads decrease to 6.14 kWh/m² which is about 20% of total lighting consumption without any shading effect from neighboring buildings.

Fig. 5. The energy performance (demand) calculation results as a function of the in built form $t$ (spacing distance to the frontal length ($L_1/L_2$)).

When the shading effect due to the surrounding buildings is included in the evaluation, less electric lighting energy savings are observed from simulation results. The cooling energy demand is also affected by daylight responsive controlled artificial lighting fixtures. It results in less heat gain generated by artificial lighting and small fall in heating energy demand concerning internal gains. In the figure5 the observed affects was caused by external obstructions.

The shading affect is decreased with growth of the $L_1/L_2$ ratio and it results in an increased cooling requirement by reason of the decrease in solar gains. On the other hand, as natural daylighting decreases, the electric lighting consumption and relatively the cooling demand due to artificial lighting usage increases. figure5 shows also average useful daylight illuminance level which is the degree of occurrence of illuminances in the range of 500 to 2,000 lux on the working level of the office room (80cm height) in order to distance between buildings [4] figure6 shows the annual lighting electricity consumption per m² variation both in cardinal direction and three levels of aspect ratios ($H/W$). The electricity energy reduction due to daylighting for is more apparent than $L_1/L_2$ affect. The range of aspect ratio effect is about 3.7 kWh/m² in the south facing office however the spacing distance to the frontal length ratio effect ($L_1/L_2$) is just 0.57 kWh/m². The building depth to frontal length ratio ($D/L_2$) effect on annual electricity lighting consumption can be seen in figure7.

The performances of photovoltaics integrated into a shading device are drastically reduced by the shading created by the surrounding buildings.

From the analysis of the results, the electricity production is mostly reduced by the ratio $H/W$: increasing the height of the surrounding buildings, the percentage of shading on the south facing photovoltaic increases, resulting in a lower electricity production. The other aspect $L_1/L_2$ (as well as $D/L_2$) has not the same impact as $H/W$ but increasing the distance between the buildings, the shading created by the nearby building on the photovoltaics decreases permitting to quantify the effects due to the buildings on the left and right of the building in front of the shading device.

The winter and the Autumn are the seasons which mostly influence the performance of photovoltaic due to the declination angle: due to the lower position of the sun with the horintal plane (solar azimuth), the shape of the shading on the photovoltaics increases for higher ratio of $H/W$ and decreases for higher ratio of $L_1/L_2$.

The results show even the effect of tilt angle: the best tilt angle for all the configurations is 20°, even if for this site the tilt angle that maximize the incidend solar radiation for the whole year is the tilted 35°. Increasing the tilt angle means increasing the incident solar radiation but this increases the shape of the shading too. The more significant result in these terms is for the aspect ratio of $H/W=2$ where a tilt angle of 35°is less efficient than the horizontal one: that means the effect of the shading is bigger than the increase of the incident solar radiation.

A. Discussion

This study examines the energy performance of office buildings in an urban context with different dimensional ratios representing the various generic urban forms. The cases deal with daylight responsive controlled electricity lighting consumption and the thermal performance of the buildings. For a sample office room the annual electricity lighting saving
increases from 0.41 kWh/m² to 3.48 kWh/m² as a function of the dimensional ratios for the urban structures. Within this work, the thermal performance of building under which is the L1/L2 ratios effect was evaluated. Further analysis will be extended to investigate the whole building energy performance under H/W ratios and D/L2 ratios. A photovoltaic system was integrated into the shading device.
to analyse how much the surrounding buildings can affect its performance: in the cases analysed it needs to pay attention on the installation of photovoltaics, considering the shape of the shading in function of the surrounding building and the tilt angles.

V. CONCLUSION

The first calculation showed that between 4.5% and 35% of electricity consumption could be prevented by site design. On the other hand the heating and cooling consumption can be optimized in the same time. Many aspects of the urban design, from the layout of the roads to the building shape, will crucially affect the energy performance of the buildings. If solar access is taken into account at the earliest planning stages, it is usually possible to ensure that the majority of buildings on a site are orientated to have good solar access for daylighting and reducing the heating demand. For this type of settlements, the cooling load can be minimized by installing optimized shading devices. For summer dominated climate conditions, the site design can be helpful to reduce the cooling load but in design phase always the daylighting situation and the lighting loads should be considered. By taking early focus on site design, many business districts can reduce their energy demand significantly.

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Appendix

1a.

```bash
#!/bin/bash
for file in $B:
do
  mkdir hw15-NN.d
  for ((i=${H[0]}))
do
    name=$(cat bw.csv | awk -F',' 'NR == i {print $2$1}'| sed 's/\(.*\):\(.*\)/\1/')
echo $name
cat $file | awk -F',' 'NR == i {print 2*NR-4 "$1+$2*0.00479";}'
  print 2*NR-3 "$1+$2*0.00479";>
hw.d/$name.txt;
done;
done;
```

1b.

```bash
#!/bin/bash
for file in $B:
do
  mkdir $file.d;
cat $file | awk '{BEGIN{i=0; Fmax=0} NR=i {i++;} if (Fmax<4.0) {
    if (Fmax>Fmin) {
      Fmax=Fmax; Fmax=0;
    }
  } else(i++); print $1 "Fmax" "Imax" "Fmax=0";}

  }>$file.d/main_parameter.csv;
done;
```