Analysis of the Curtain Wall Photovoltaic Array on the Southern Facade of the Lillis Business Complex Atrium

Edward Clark
University of Oregon
Eugene, OR 97403
eclark@uoregon.edu

Marc Holt
University of Oregon
Eugene, OR 97403
mholt@uoregon.edu

Colin Schless
University of Oregon
Eugene, OR 97403
cschless@uoregon.edu

Alex Toevs
University of Oregon
Eugene, OR 97403
atoevs@uoregon.edu

ABSTRACT

We investigated the effects of photovoltaic array (pv) on the solar gain in the south façade of the Lillis Business Complex atrium. Insulated boxes with onset data-loggers were installed on the interior of the façade; one over a photo voltaic cell and one over unobstructed glass. Solar irradiance and surface temperate was recorded at 15 minute intervals and 10 locations on the glass. The ratio of photo voltaic cells to open glass was determined to be 24.9% Our results indicate a significant loss of solar gain due to the shading by the pv array.

1. INTRODUCTION

We have selected the Lillis business complex for our our investigations. Specifically, we focused on the photovoltaic (pv) populated South facade of the atrium space. The Lillis business complex opened in November 2003 featuring the largest pv array in the Northwest and is capable of generating 44kW. Numerous other passive solar and day lighting strategies have been employed in its design.

Our phenomenon of study is the thermal impact of Lillis' vertically oriented photovoltaic system on the main atrium space. While the photovoltaic system produces energy for the building, it also acts as a shading device, preventing solar gain.

Hypothesis: The photovoltaic array that populates the South façade of the Lillis Business Complex atrium has thermal effects on the facade itself and interior space behind it.

Fig 1: Southern Façade of Lillis Business Complex University of Oregon, Eugene

2. METHODOLOGY

We constructed two insulated cubes with the internal volumes of 0.069 ft^3. Each cube was insulated with 1" rigid insulation (Ownings Corning Formular 150). One face was left open to mate with the surface of the glass. We affixed the two insulated boxes to the window with Guerilla Tape, one behind a pv cell and the other behind and an adjacent, unobstructed portion of the window. Two onset data-loggers were placed inside each of the insulated boxes. Temperature data was recorded at a rate of one reading per minute.
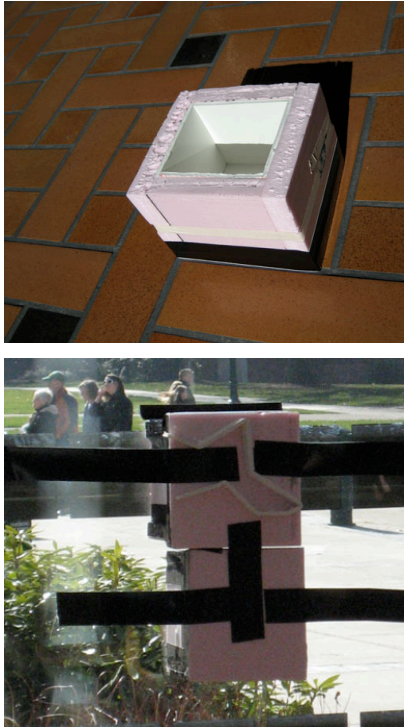
Fig 2: Insulated box (top) Insulated boxes affixed to window with Guerilla Tape (bottom)

Interior and exterior infrared and solar irradiance readings were taken at 15 minute intervals at 10 locations on the window. Temperature readings were taken with a Raytech MINI temp gun infrared thermometer. Solar irradiance was measured with a Light meter (Li-Cor LI-250A with the LI-200 pyranometer meter). All data was collected from 10:30 am until 2:00 pm on February 23rd, and 24th.

From scaled drawings and direct observation we calculated the percentage of photovoltaic panels in the glass of the South façade to be 24.9%.
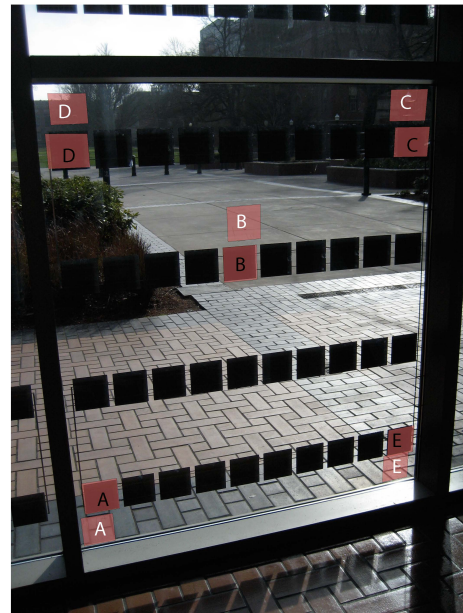
Fig. 3: Temperature and Solar Irradiance Measurement Points on South Façade Window

2. NOMENCLATURE

The sunlight that is received at the outer surface of the earth's atmosphere is approximately equal to 429 Btu's/hr per sq. ft. when measured on a plane normal to the sun's rays. This number is referred to as the **solar constant.**

On clear days the majority of the sunlight reaching the earth will pass straight through the atmosphere reaching the earth's surface as **direct solar radiation.**

The clouds and particles in the atmosphere not only absorb sunlight but scatter it in all directions. Some of this sunlight is reflected back out to space, but a portion is reflected and refracted toward the earth reaching the earth's surface as **diffuse solar radiation** coming from the entire sky. We measured this value on the surface of Lillis as **irradiance (IR).**

Surfaces that are not horizontal will receive direct radiation and diffuse radiation from the sky but will also receive some reflected sunlight from the ground. The amount of **ground reflected solar radiation** received will depend both on the tilt of the receiver and the reflectance of the ground. **Insolation** is incident solar radiation. If a surface receiving sunlight is perpendicular to the sun's rays (or "normal" to them) the amount of insolation will be maximised.

If, however, the surface is at an angle to the sun's rays, the

same amount of incoming sunlight will be spread over a greater surface area, reducing the amount of insolation per square foot of surface area.
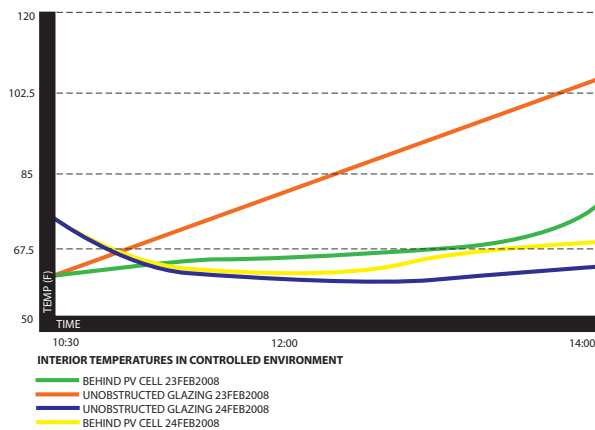
This phenomena is called the **cosine effect** due to the fact that the direct radiation is reduced by the cosine of the angle between a perpendicular to the surface and the sun's rays.

The ratio of transmitted solar radiation to the amount that is actually converted to thermal energy within the space is called the **effective room absorptance.**

The additive thermal capacitance or all of the materials and furnishings within a space is the **effective room thermal capacitance**
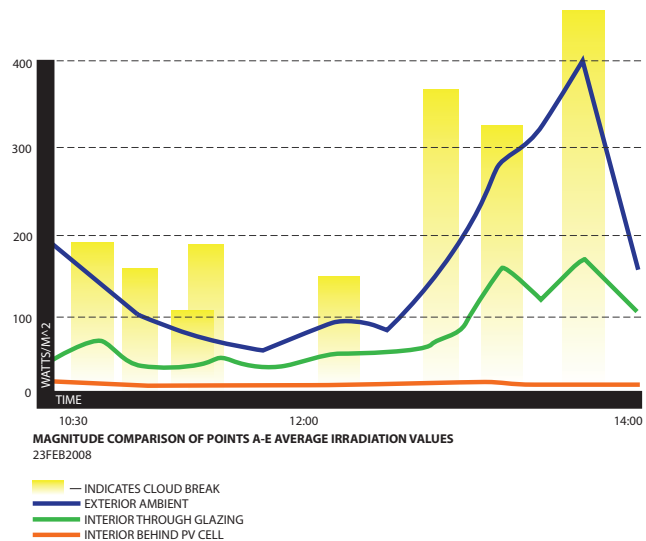
3. RESULTS

GRAPH 3.1: Summary of Interior Temps at 15 Minute Intervals

INTERIOR TEMPERATURES IN CONTROLLED ENVIRONMENT
- BEHIND PV CELL 23FEB2008
- UNOBSTRUCTED GLAZING 23FEB2008
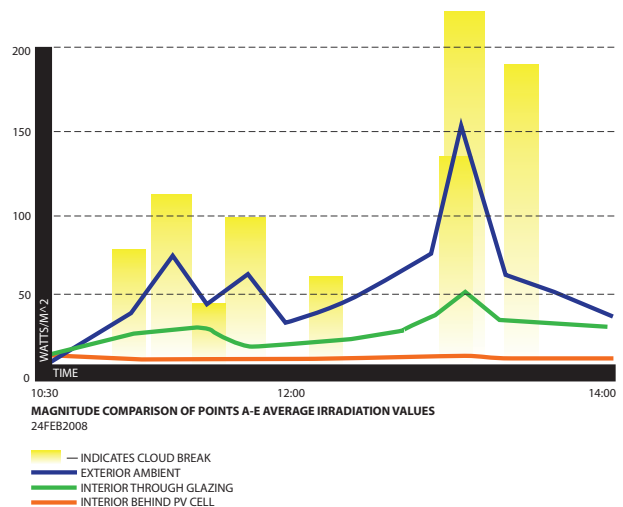- UNOBSTRUCTED GLAZING 24FEB2008
- BEHIND PV CELL 24FEB2008

Graph 3.1 compares the thermal gain (from solar radiation) between the obstructed and non obstructed isolated environments. Data indicates that on both days that the environment with unobstructed glazing experienced a greater thermal gain than the environment with obstructed glazing. The difference between the data of the two days indicates a varied amount of solar gain due to weather conditions.

GRAPH 3.2: Magnitude Comparison of Irradiation Values for Points A-E at 15 Minute Intervals for February 23, 2008

MAGNITUDE COMPARISON OF POINTS A-E AVERAGE IRRADIATION VALUES
23FEB2008

- — INDICATES CLOUD BREAK
- EXTERIOR AMBIENT
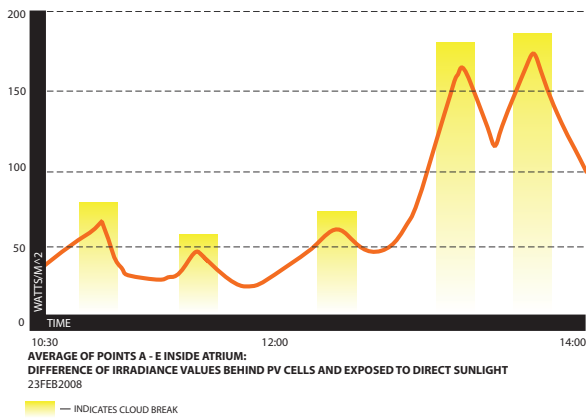- INTERIOR THROUGH GLAZING
- INTERIOR BEHIND PV CELL

Graph 3.2 and 3.3 provide an averaged comparison of irradiation values for the exterior ambient conditions, the interior conditions through the unobstructed glazing and the interior conditions behind the pv cells. Interior readings behind the pv cell remained fairly constant while the readings through the glazing generally followed the variations in exterior ambient values (although slightly reduced due to the transmittance factor of the glazing).

GRAPH 3.3: Magnitude Comparison of Irradiation Values for Points A-E at 15 Minute Intervals for February 24, 2008
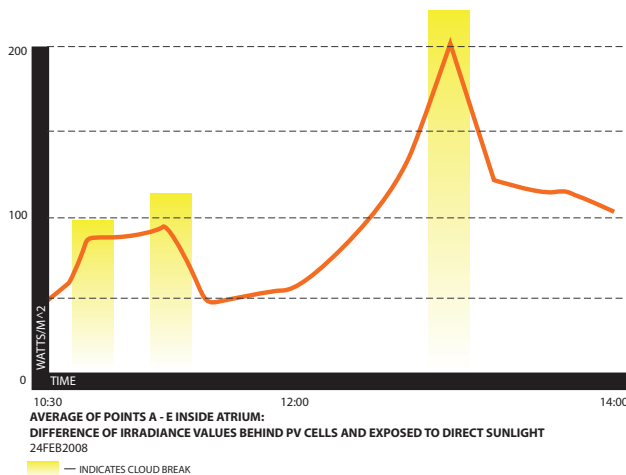

MAGNITUDE COMPARISON OF POINTS A-E AVERAGE IRRADIATION VALUES
24FEB2008

- — INDICATES CLOUD BREAK
- EXTERIOR AMBIENT
- INTERIOR THROUGH GLAZING
- INTERIOR BEHIND PV CELL

GRAPH 3.4: Difference of Irradiation Values for Interior Points A-E at 15 Minute Intervals for February 23, 2008

AVERAGE OF POINTS A - E INSIDE ATRIUM:
DIFFERENCE OF IRRADIANCE VALUES BEHIND PV CELLS AND EXPOSED TO DIRECT SUNLIGHT
23FEB2008

— INDICATES CLOUD BREAK

Graph 3.4 and 3.5 provide the averaged difference of irradiation values between the interior unobstructed glazed areas and the interior obstructed areas.

GRAPH 3.5: Difference of Irradiation Values for Interior Points A-E at 15 Minute Intervals for February 24 , 2008

AVERAGE OF POINTS A - E INSIDE ATRIUM:
DIFFERENCE OF IRRADIANCE VALUES BEHIND PV CELLS AND EXPOSED TO DIRECT SUNLIGHT
24FEB2008

— INDICATES CLOUD BREAK

Rreference the appendix for data tables used to produce all graphs.

4. DISCUSSION

Overcast skies dominated our two days of field testing. Therefore the insolation we measured was predominantly diffuse solar radiation, as opposed to direct solar radiation.

With only one irradiance meter, the team had to measure interior irradiance and exterior irradiance values at slightly different times. While moving from inside to outside of the Lillis façade only takes seconds, this time difference still meant significant changes in cloud cover. Somewhat inconsistent data resulted - the interior values do not necessarily correspond their current total available radiation. This discrepancy makes the data somewhat difficult to read as a direct graphical output - the difference between exterior available radiation and interior radiation is not always consistent and somewhat confusing.

In order to account for our inconsistency we extrapolated the *differences* between interior and exterior radiation values, and graphed that difference as a single value. However as the sun reached its zenith, the difference in solar radiation received in the interior spaces versus the total ambient radiation available spiked. Likewise, the difference in the amount of radiation that enters the atrium through glass versus the amount that enters the atrium through pv spiked as well. The graphical output of the difference extrapolates the amount of solar radiation blocked by the solar panels from otherwise convoluted data.

 Measured irradiance values behind pv panels and clear glass varied substantially. The outside insolation was found to be 126.2 W/m^2. An average value of 57.9 W/ was found behind clear glass, while areas behind pv panels was measured to be m^{2}1.9 W/m^2. Extrapolation of the data across the whole of the façade of 204.16 m^2, resulted in an outside irradiance of 25.76 kW. The percentage of pv array was determined to be 24.9%, or 50.99 m^2. A measured inside irradiance of 8.87 kW through clear glass and 0.096 kW behind the pv cells was determined, resulting in an a net irradiance of 8.96 kW. The inside irradiance was substantially lower than measured outside irradiance due the emissivity of the glass and blockage from the pv panels. Both data collection days were overcast and may have resulted in drastically understated results. If measured values were typical of the month of February, heat gains in the atrium space as well as solar gains to the pv array are almost negligible. If Eugene were dominated by cloudy weather, the investment of pv panels for the south façade may be ill placed.

In addition to comparing the irradiance transfer through pv and non-pv areas, we wanted to observe direct heat transfer through these same spots. We measured the surface temperatures on the inside and outside surfaces of the façade on pv and non-pv areas using an infrared temperature gun. While our intention was to measure heat transfer from outside to inside, we found that just the exterior surface temperature readings provided significant data to support another unintended effect of the Lillis façade. The extra heat given off from the pv panels may compromise their glass encasement. When photons strike the surface of a pv cell, they release electrons that create an electric current. The freed electrons that do not become electricity release

from the surface of the panel as heat. The effects of this released heat is particularly noticeable on Lillis' South façade.

The exterior surface temperatures of the glass directly in front of pv cells was significantly higher than the surface temperatures on plain glass by as much as 10 degrees. Overtime this heat differential could expand the glass to the extent that stress fractures form. This differential may have thermal comfort implications as well. The temperature difference between interior and exterior temperatures could result in thermal bridging and envelope inconsistencies that could complicate mechanical system sizing or energy programming.

We recorded the aggregate temperature difference between obstructed and unobstructed boxes at 18 degrees F. This is of significant interest because approx. 24.9% of the south facade is shaded by the vertical photovoltaic array. If the array was not present during cooling degree days, a method of cooling would need to be introduced into the atrium space in order maintain comfort. Conversely, the shading effect of the array prevents solar gain during heating degree days and may require additional heating to be introduced into the space to maintain comfort. A question remaining is: how much energy could the photovoltaic array potentially contribute to heating the space it shades?

5. CONCLUSION

Multiple consequences result from the photovoltaic array. Our data indicates that the pv array blocks solar radiation. In our controlled environments we observed an 18 degree F difference in temperature between the space behind the pv cells and open glass. During the two days of our experiment, atmospheric solar radiation was nominal due to cloud cover. On days with more solar insolation, the thermal effects may become more pronounced. Despite relatively low solar input, there was differential heating of the glass/pv assembly. This could cause uneven stress/strain patterns compromising the facade's integrity. Overall, our observations indicate that the PV cells that populate the south facade of the Lillis Bussiness Complex have an impact on the thermal environment inside the atrium space.

6. REFERENCES

1. Vital Signs: The Dynamic Pattern of Shading and Solar Heat Gain Through Windows. Johnston, Scott A. (pp. 2A1-2a12)