Evaluating the Efficiency of a Ventilated Photovoltaic Skylight and its influence on Occupant Comfort and Building Energy Performance

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ABSTRACT: The primary aim of our research is to evaluate the effectiveness of an appropriate double-façade skylight assembly for increasing occupant comfort while pursuing a renewable energy systems approach. This would be achieved by the installation and subsequent monitoring of a double skin roof over an enclosed space. This roof will consist of thin film semitransparent photovoltaic modules and standard single pane glazing on the exterior and interior faces respectively. Convective air currents between the two layers will be monitored as to their influence on the electrical performance of the modules. The authors' attempt will be to quantify the diurnal variability of indoor conditions as affected by this ventilated photovoltaic skylight system. The ultimate photovoltaic efficiency curves and measured data points will be compared to evaluate the optimal variations of this system.

Conference Topic: 4 Innovative Low Energy Technologies
Keywords: energy, thermal comfort, photovoltaics

INTRODUCTION

The last decade saw widespread commercial application of building integrated photovoltaics, not only as an accepted system to provide point-of-use clean power, but also as a chance to showcase building owners' environmental ethics. Appropriate integration of semitransparent photovoltaic modules with architectural glazing has the potential to limit excessive solar heat gain while still allowing sufficient daylight to penetrate deep into the building. This study seeks to explore the comprehensive long-term implications of integrating a renewable energy alternative with a double-façade skylight assembly.

Photovoltaics integrated with double skin façades have been extensively studied for energy savings. Vertically oriented photovoltaic modules, however, are neither optimally positioned towards the sun, nor capable of allowing adequate views desired for occupants. Conversely, skylights with higher solar exposure and less transparency would actually work better towards minimizing solar heat gain and glare, creating an ideal photovoltaic integration area.

The study examines this prominence gaining architectural component as to its performance in a double-façade application as well as its subsequent impact on indoor building conditions. Specifics of module electrical performance, building interior surface and space temperatures, convective air flow rates and their correlation to module efficiencies and interior light levels were monitored for a range of photovoltaic integration possibilities and performance parameters adjusted to maximize the effectiveness of the system.

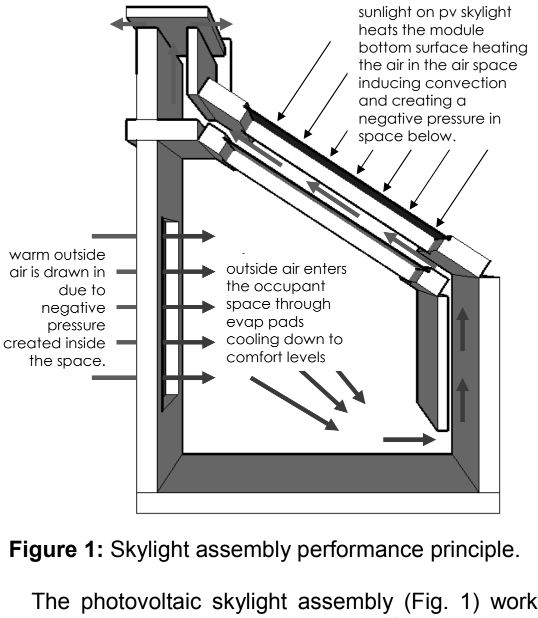

Figure 1: Skylight assembly performance principle.

The photovoltaic skylight assembly (Fig. 1) works on the principle that the pressure difference caused by thermal buoyancy creates an air current inside the air cavity. Once the air is heated after coming in contact with the hot photovoltaic modules, it becomes less dense and begins to rise up and out of the air cavity through an opening at the top of the chimney. This induces negative pressure in the space below, which draws in air through a wet pad hence cooling the air entering the space.

2. RESEARCH METHODOLOGY

2.1 Hypothesis

Recent research [1] noted that replacing conventional glass with building integrated photovoltaic modules could have adverse temporal influences on occupant thermal comfort. The underside of modules can heat up significantly, resulting in more heat being radiated into the indoor space (Fig. 2). Also, the fact that photovoltaic efficiencies are reduced with elevated operating temperatures suggests a need for investigation into alternative integration mechanisms with optimum ventilation behind the modules in order to dissipate this heat.

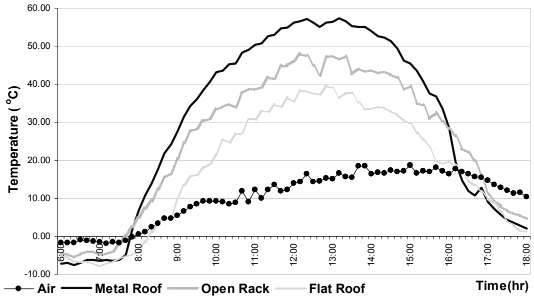

Figure 2: Typical photovoltaic module bottom surface temperatures on different setups. [1]

The authors hypothesize that a convective air cavity below the modules will permit a better performance from the photovoltaic modules by lowering their operating temperature. It is speculated that as the velocity of the air current, inside the cavity, increases then the amount of heat removed from the cavity will also increase thereby increasing the efficiency of the PV modules.

Dry outside air can further be forced to flow across wet pads enabling evaporation to take place lowering the air temperature as it enters the occupied space. This cool air would eventually enter the air cavity of the double façade where it would be heated and then rise out from the exhaust vent.

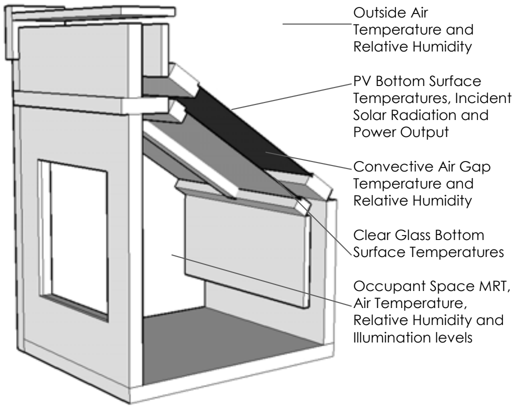

Figure 3: Study structure design and instrumentation.

2.2 Experimental Procedure

Construction, operation and testing of the study structure (Fig. 3) were completed at the Arizona State University Solar Energy Laboratory.

The double-façade skylight assembly consists of two thin-film photovoltaic modules on the outer layer and two sheets of single pane clear glazing on the inner layer, with a six-inch air cavity in between. The lower portion of the inner façade wall is constructed of Styrofoam, which stops short of the floor in order to create an entry into the air cavity. The chimney was constructed with an operable damper, which can be set to open or close in order to test variations of the assembly.

The evaporative pads are placed in a hole cut into the north wall. The water pipes and control valve are mounted on the north wall inside the occupant space. A PV powered water pump, also inside the occupant space, is controlled by a switch located on the exterior of the north wall. Finally, the entire structure is painted white in attempt to increase reflectivity and decrease heat absorption through the walls while providing uniformity.

Instrumentation was installed in place to measure the mean radiant and air temperature, relative humidity, and light levels of the interior air cavity, the interior occupied space and the outside ambient air. All instrumentation was connected to on-site data loggers and measurements were recorded for analysis. To assess the operational efficiency of the PV module, voltage and current measurements were taken in 2-hour intervals.

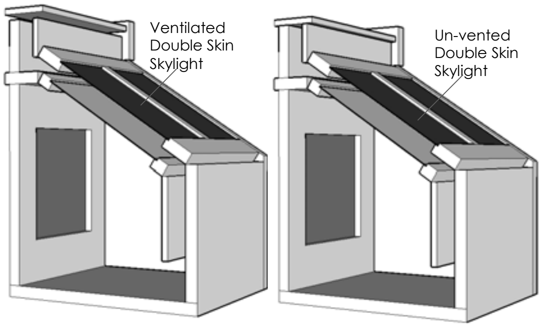

Figure 4: Studied set-up configurations.

Two variations of the photovoltaic skylight assembly (Fig. 4) were tested to analyze the dynamic module electrical and occupant space thermal performance, one with the air vent open, a second with the air vent closed. These variants were each individually tested over a 24-hour period.

After which, results from each configuration were compared to determine the effectiveness of each system. Data analysis consisted of arranging the retrieved data into manageable work-files, and using graphical images to present the performance of the installation and highlight or predict possible trends and problems.

The effect of airflow rate under the module was correlated to both the thermal and electrical performance of the photovoltaic skylight.

3. SKYLIGHT PERFORMANCE

3.1 Results

The setup was tested over a three-week period from May 25th to June 15th. Two days, May 31st, and June 14th were chosen for analyzing the experiment results based on the uniformity of solar radiation and consistency in outside air temperatures for the two variations.

Figure 5 shows the occupant space and convective air space temperatures in relation to the ambient air temperature for the two experiment setups.

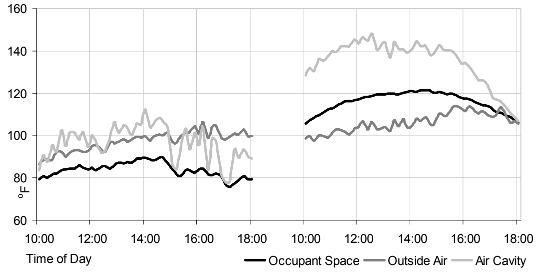

Figure 5: Occupant space thermal performance.

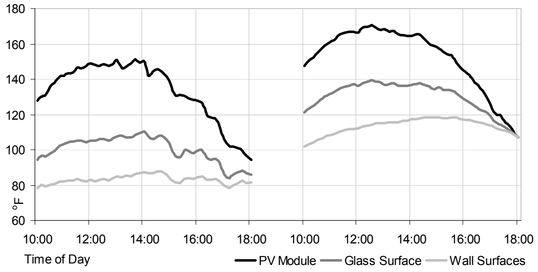

Figure 6: Assembly surface temperatures.

Figure 6 shows the trends in the surface temperatures of the PV modules and the glass bottom surface temperatures as well as the different wall surfaces in the occupant space as the setups were varied on the two days.

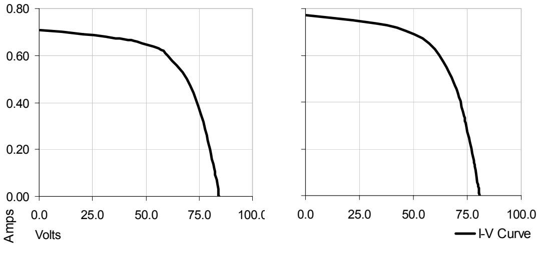

Figure 7: Photovoltaic module electrical performance.

Figure 7 shows the electrical data recorded for the PV modules at different installation setups at solar noon on the respective day. The current-voltage curve was plotted for each set of readings and maximum power output was determined. Incident solar radiation was also measured to calculate the electrical efficiency of the modules in both variations.

3.2 Analysis

The occupant space mean radiant temperature remained below 85°F on the first day even when the ambient air temperature reached 100.73°F (Fig. 8). The modules recorded a temperature of 133.38°F and photovoltaic efficiency was calculated to be 4.95%. The relative humidity inside the space rose to an acceptable 44.8% while the outside air relative humidity was at 22.4%.

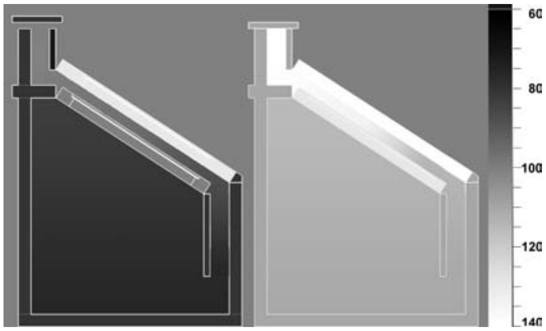

Figure 8: Thermal section of assembly variations (°F).

On the second day of testing, the air-space vent was closed stopping any convective airflow under the modules. This led to a very high air temperature of 134.9°F under the modules (Fig. 8). Also the absence any negative pressure in the occupant space led to no appreciable air intake through the wet pad heating up the space to 115.8°F when outside air was at 110.4°F. Also the module surface temperatures rose to 152°C and subsequently the electrical efficiency reduced to 4.62%.

This can be attributed to the fact that as air below the modules heats up and rises out of the vent; it draws in air through the evaporative pad thus cooling the occupant space appreciably (Fig. 9). The air movement also helps reduce the bottom surface temperatures of the modules that results in increased electrical efficiency. This predicted direction of airflow was further substantiated with a smoke test that clearly supported the hypothesis.

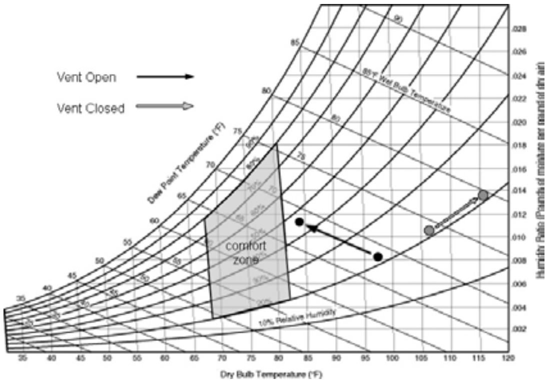

Figure 9: Psychrometric chart for comfort conditions.

The results amply state the significance of the ventilation under the PV skylight modules, both in maintaining comfort levels in the occupant space as well as for the electrical performance of the PV itself.

CONCLUSION

The exploration of photovoltaics in skylights for thermal balance modification of indoor spaces has not been a subject of much research. This study was undertaken to quantify the effects of a possible sustainable mechanism to reduce the adverse heat gain effects that are attached with the day-lighting benefits.

The authors' findings suggest confirmation of the hypothesis that appropriate mounting and integration setups can play a significant role to achieve desirable thermodynamic balances as well as photovoltaic efficiencies thus providing for more beneficial photovoltaic integration opportunities.

Test results indicate that the vented double façade construction allowed the temperature of the photovoltaic modules to be reduced as compared to the unvented façade. This can lead to the conclusion that photovoltaic modules in a vented double façade construction can allow for a better performance than from modules mounted directly on a roof as in traditional construction methods.

When the air cavity was disabled, the module temperatures elevated, reducing the modules' efficiency. In addition, the findings indicate the double façade construction reduces the solar heat gain entering the building allowing for a significantly lower mean radiant temperature inside the occupant space as compared with the unvented variation.

Therefore, the vented double façade skylight has demonstrated to be a useful construction assembly, granting improved photovoltaic module efficiency and enhanced indoor environment.

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REFERENCES

[1] Nagpal, S., Shah, S. "Effect of Photovoltaic Cover on Urban Surface Energy Balance", International Solar Energy Society, 2005.