

# Integrative Photovoltaic Awnings in the Natural Fusion Home: Solar Decathlon 2009

Jeff Rayl\*  
Dept. of Electrical Engineering  
The Pennsylvania State University  
221 Materials Research Building  
University Park, PA 16801  
jer5056@psu.edu

Jeffrey R. S. Brownson  
Dept. of Energy & Mineral Engineering  
The Pennsylvania State University  
224 Materials Research Building  
University Park, PA 16801  
nanomech@psu.edu

## ABSTRACT

Photovoltaic (PV) awnings provide an integrative system solution in both residential and commercial applications, as the energy produced by the PV can offset a measurable fraction of a building's energy demands and provide passive solar thermal benefits. This analysis assesses the benefits of an integrated photovoltaic operable shading system for the building market as a System Integrative Photovoltaic (SIPV) design. Here, we present the 2009 Penn State Solar Decathlon entry, Natural Fusion, as the prototype. We will demonstrate how the SIPV awning complements passive solar design techniques by blocking the high altitude summer sun, while allowing maximum light penetration during the winter. By incorporating photovoltaic modules on each of the louvers, the system generates electricity to support the tracking motors and a significant fraction of the building's internal plug loads. SIPV performance was modeled using TRNSYS, a modular FORTRAN-based energy modeling software, to provide an estimate of annual power gains for the PV awning in the Natural Fusion home set in the Pennsylvania region. Heating/cooling responses were also modeled throughout the course of a year, indicating that the awning provides an innovative passive solar design element in the Natural Fusion home.

## 1. INTRODUCTION

The original problem that Natural Fusion encountered was a need to produce all of the home's energy requirements and be architecturally appealing. Many homes in the Solar Decathlon maximize roof space in order to increase photovoltaic capacity. The solar awning was designed to have aesthetic appeal as well as functional benefits to the home. Awning systems can be mounted above windows and/or doors along southern façades to provide numerous benefits to the occupant. The student-conceived solar awning was designed in collaboration with several industry partners in materials, photovoltaics and engineering.

Incorporating photovoltaic modules on the awning allows for both the aesthetic appeal and energy production desired from the prototype. Another benefit to the awning is from tracking the sun. Figure 1 shows a representation of incident energy comparing fixed axis and tracking axis irradiance.

## 2. NOMENCLATURE

*azimuth* ( $\gamma$ ) angle of collector from South (-/+ : E/W)

*slope* ( $\beta$ ) angle of collector from horizontal

hourly integrated irradiance ( $I_{\text{meas}}$ : Wh/m<sup>2</sup>)

hourly extraterrestrial irradiance ( $I_0$ : Wh/m<sup>2</sup>)

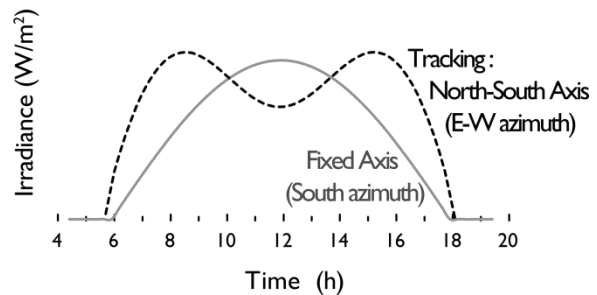


FIGURE 1: Cartoon of tracking PV (horizontal mount, E-W azimuths) to standard fixed axis PV with South azimuth. Adapted from Duffie & Beckman.<sup>1</sup>

## 2.2 METHODS

The performance of the system was simulated in the TRNSYS program. Two separate programs were used to model the electrical system performance and the heating and cooling loads for the home. The heating and cooling comparison shows the total heat transfer and average internal temperatures for the home with and without the solar awning. The electrical performance shows the estimated kilowatt-hour (kWh) production per month.

## 2.3 Data Collection: Insolation and Weather

Data were gathered from the Rock Springs station in the SURFRAD Network (Surface Radiation Budget Network; 40.72°N 77.93°W, 337 m elev.), operated and maintained by the Dept. of Meteorology at the Pennsylvania State University. The site is located about 10 km from State College, PA, and is supported by NOAA's Office of Global Programs. The data were collected in 3-minute time steps and downloaded from the SURFRAD site for processing by TRNSYS simulation (temperature, relative humidity, direct and diffuse irradiance and total irradiance on the horizontal).

### 3. RESEARCH

The overall design of the solar awning includes two main features: an operable East-West tracking system (horizontally mounted frame), and small photovoltaic modules coupled to aluminum rectangular louvers that span the frame. The system on the Natural Fusion home consists of the awning frame spanning 32' in four 8' sections along the southern façade,  $\gamma = 0^\circ$ . Along that frame are 48 louvers (each 21"x7") with individual 10 Wp solar modules composed of three mc-Si (multicrystalline silicon) cells tabbed in series (system: 480 Wp). An additional 6' non-photovoltaic section spans the western façade,  $\gamma = 90^\circ$ , above the doorway. The power generated by the system is conditioned with two micro-inverters mounted directly next to the frame of the awning. The system can be expanded to accommodate a variety of design requirements, space availability and as retrofit to current structures.

The operable portion of the awning is controlled by a 24VDC stepper motor. The motor can be programmed to meet a variety of desired tracking methods. The system on the Natural Fusion home operated incrementally across a range of East facing 30° from horizontal to West facing 30° from horizontal as shown in figure 2.

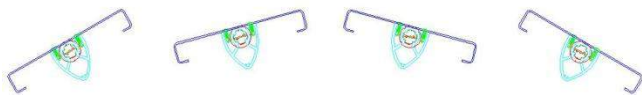


Figure 2: Cross-section view of solar awning louvers at angles to correspond with programmed times throughout the day.

#### 3.1 System Integrated Photovoltaics (SIPV):

The SIPV design concept argues that each PV is coupled via thermal and diffuse-reflective relationships between the supporting structure and the PVs.

The awning serves both for power generation and to improve passive thermal performance of the home by reducing heating and cooling loads. As the Sun's altitude changed throughout the year different levels of solar radiation will be able to penetrate into an uncovered

southern facing window. In the case of the Natural Fusion home, the southern façade is composed of four 8' sliding glass doors. The solar awning, protruding approximately 24" from the façade of the home at an elevation of 8' 6" above finished floor, blocks a significant portion of the high declination summer sun while allowing for maximum penetration of the low declination winter sun. Combined with a TPU bladder filled with water as a thermal mass in the floor, the awning controlled the light penetration aids significantly in reducing the heating and cooling loads for the home throughout the course of the year.

#### 3.2 Passive Solar Design:

A linear structure trending E-W with a glazed southern façade was deployed to obtain a significant solar gain. This would be beneficial to a home in Pennsylvania as about half of the year requires heating for most spaces and only a quarter of the year requires cooling. In addition to this, the home has an awning that can be simultaneously employed to collect solar power and convert it to electricity while blocking summer heat gain.

#### 3.3 Design Process:

The solar awning was created with the help of three different corporations. The awning was constructed by Construction Specialties™, a green design and integrated architecture firm. A modified version of their existing Sun Controls™ functioned as the frame and louver base for the photovoltaic modules.

Two companies were involved in the development of the SPI-L010-12 photovoltaic modules. The PV cells were produced by Solar Power Industries™. The multicrystalline silicon cells are approximately 15.5% efficient. Rather than using traditional ethyl vinyl acetate (EVA) as the binding agent in the modules, Bayer Material Science™ produced a thermoplastic polyurethane (TPU) encapsulant material, X2236 TPU. Figure 6 shows the performance of the PV modules at standard testing conditions (module temperature of 25°C, irradiance of 1000w/m2 and AM1.5).

#### 3.4 Context of the Solar Decathlon:

One of the greatest design constraints due to the Solar Decathlon rules was the total square footage restriction. Rather than traditional square footage measurements from the interior of the home, the competition dictated that the square footage would be measure as the total solar footprint of the home. This greatly limited the potential size of the awning as to not limit the size of the home itself.

While undergoing the research and design process on the custom photovoltaic modules for the Solar Decathlon the prototype was required to meet a variety of safety regulations. While UL listing was not necessary, the prototype was required to prove the intent of the various regulations. High potential testing, hot spot testing and fire

protection testing were all require in order for the custom modules to be allowed on the National Mall. See appendix A for testing data and results.

#### 4. RESULTS AND DISCUSSION

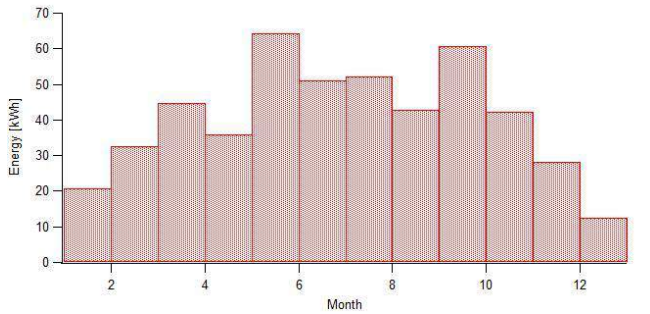


Figure 3: Simulated energy production from the photovoltaics on the awning per month. This does not account for inverter or wiring losses. The estimated yearly energy production is 487 kWh total.

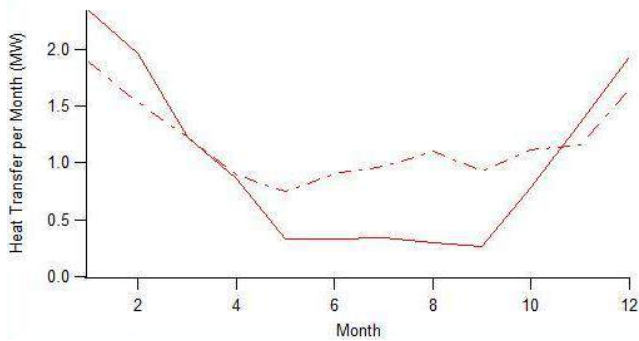


Figure 4: Total heat flow from simple TRNSYS model of Natural Fusion. Solid line: awning, dashed line: no awning in simulation.

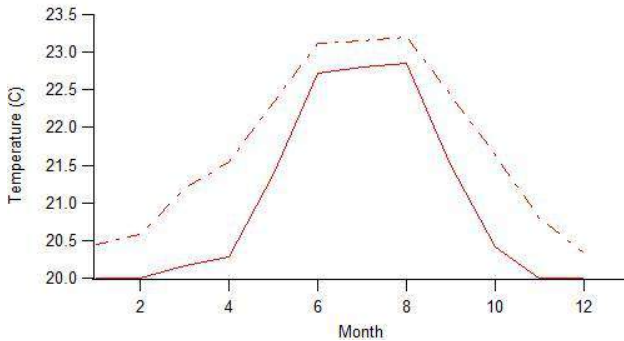


Figure 5: Average monthly internal temperature in degrees Celsius with solid line: awning, dashed line: no awning in simulation.

The total energy production from the awning throughout the year provides a significant boost in the energy production by the home. There is a relatively low level of production during the winter months. Since the awning is oriented with  $\beta = 0^\circ$  there is a low angle of incidence on the cells. This trade off was necessary to maximize the benefit in passive solar performance.

The awning provides significant decrease in heat transfer during the summer months indicating that the awning is successful in blocking a portion of the summer sun as shown in Figure 4. The heat exchange has been normalized so that both heating and cooling loads are positive valued. The total heat exchange with the home is slightly higher in the winter months but significantly lower throughout the summer months. Figure 5 further illustrates the success showing average interior temperatures for the home. The simulation assumed consistent energy consumption for conditioning between the two leaving the only dependant variable to be the presence of the awning. All of the temperature fluctuation is from passive solar. The average temperature is consistently lower in the simulation with the awning versus the simulation without the awning varying from 0.5 to 1°C in the winter to 0.2 to 0.5°C during the summer.

#### 5. CONCLUSIONS

The results indicate that the awning produces the largest portion of yearly energy during the summer months. While the total energy budget for the home was significantly higher, the awning does produce a fraction of the total energy demands.

The initial desire was to block out a significant portion of the summer sun to both produce energy and decrease heating loads. The total thermal energy required to maintain living conditions in the home are more dynamic with the awning in place. During the summer months the awning reduces the heat transfer by as much as two thirds. This also decreases the average interior air temperature.

#### 6. ACKNOWLEDGMENTS

The authors wish to thank Solar Power Industries, Construction Specialties, Bayer Material Science and the 2009 Penn State Solar Decathlon Team, *Natural Fusion* for sharing and pursuing this problem as a topic for research investigation.

## Appendix A: Cell and Module Testing

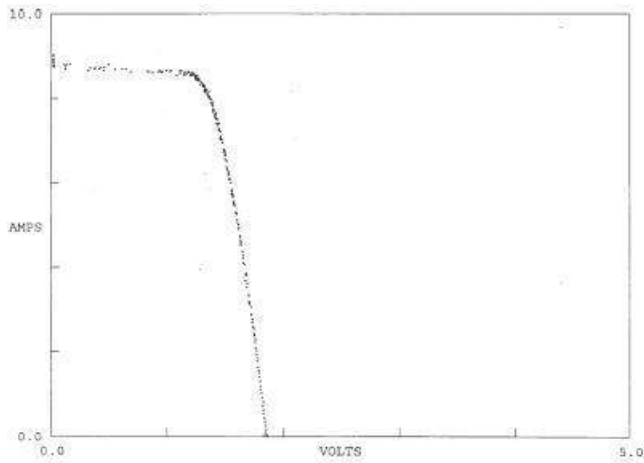


Figure 6: Current voltage curve for SPI-L010-12 photovoltaic modules.<sup>3</sup>

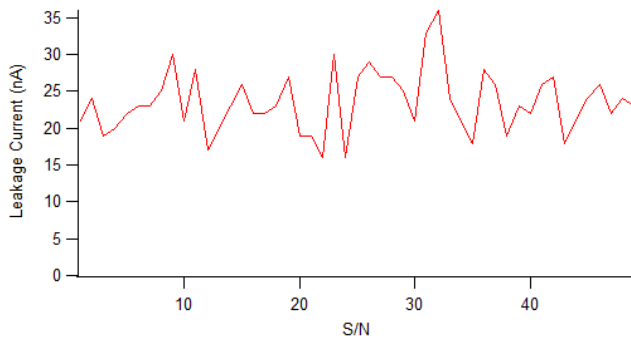


Figure 7: High potential testing performed at 2200VDC.<sup>3</sup>

### 7. REFERENCES

1. J. A. Duffie, W. A. Beckman, 2006. Solar Engineering of Thermal Processes, 3rd Edition, John Wiley & Sons, Inc., New York, pp. 21, 40.
2. L.D. Iulo, D. Riley, 2009. *The Morningstar: A Hybrid Concept for Community Building and Renewable Energy*, Solar 2009 Proceedings.
3. Robert Stoehr. *Solar Power Industries*. 10/1/09