Performance Evaluation and Optimization of a Building-Integrated Photovoltaic Thermal Air Collector

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Abstract
Integrated building elements which combine their structural and architectural functions with that of energy generation are expected to become increasingly important in the future scenario of energy efficient buildings, and they could significantly contribute to the thermal behaviour of the building envelope in order to provide energy savings. A prototype of a building-integrated photovoltaic-thermal (BIPVT) solar collector for air heating has been built by a Palo Alto start-up company, and consists on a double pane airframe window wall with photovoltaic (PV) louvers embedded in it. The unit is intended to perform the functions of both thermal and electrical generation, as well as light transmission and shading control, and its facade integration makes it more economical than installing separate collectors for the same scope. In this work, the prototype performances have been tested in different outdoor conditions and under different airflow speeds, and a maximum air temperature rise above 30 °C and average thermal efficiency of 31% have been achieved. By using inexpensive PV modules with a rated efficiency of 12.5%, an actual efficiency of 7% was recorded under the maximum operating temperatures. A two dimensional model was built in COMSOL Multiphysics to reproduce the experimental results, which has been used to optimize the glazing unit structure through the use of coatings and additional glass panels. Different configurations have been analyzed, and a 3-pane low-e coating system has been found to be the best cost-effective solution, which results in a 43°C temperature rise.

Prototype Overview

Performance Evaluation
- Thermal Output (W): \( Q = \sum_f \left( T_f - T_a \right) A_f \), where \( f \) is the spectral band.
- Thermal Efficiency: \( \eta = \frac{Q}{I_{PV} A_{PV}} \).
- Electrical Efficiency: \( \eta = \frac{P_{PV}}{I_{PV} A_{PV}} \).

Results
- Measurements on both the thermal and electrical systems were taken in summer, fall and winter months in Salinas, CA.
- Testing conditions included different orientation, tilting and air speeds. The collector was tested in south facing and tracking conditions, in vertical (90°) and 70° tilt angle, as well as under different angles between the PV array, the window and the ground.
- Latest tests are reported below and included different air speeds, produced by varying the fans voltage (from 6V to 12V).

Thermal Modeling and Optimization
- 2D modeling and thermo-fluid dynamic simulation in COMSOL.
- Reproduction of experimental results.
- Optimization of the glazing system by additional pane of glass and use of low-emissivity coatings applied to the inner surfaces of the panels.

Conclusions
The thermal and electrical performances of a prototype of an airframe window, with solar modules inside a double-glazing, have been tested. The results showed that the window performed better during the winter, when the solar elevations are smaller, and the measured output temperature exceeded a maximum of 52.2°C under the optimal air speed of 0.5 m/s, with an average of 48.4°C, corresponding to a temperature rise of around 20°C on average and 31°C maximum. The thermal efficiency ranges from 39 and 40%, while the electrical one remains quite constant to around 6.7%, with a generation of 20-25W for the top PV array. Simulations on a 2D model have shown a list of improvements through the use of low emissivity coatings, and have established an optimal configuration of the glazing system, consisting of three glass panes with low-e coatings to #2, 3 and 5 surfaces, which represents the best cost-effective solution. This setup provided an air temperature of 64°C and a rise of 45°C, with respect to the experimental conditions that yielded 52.2°C.

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