Characterization and Optimization of a PV/T Airflow Window Collector

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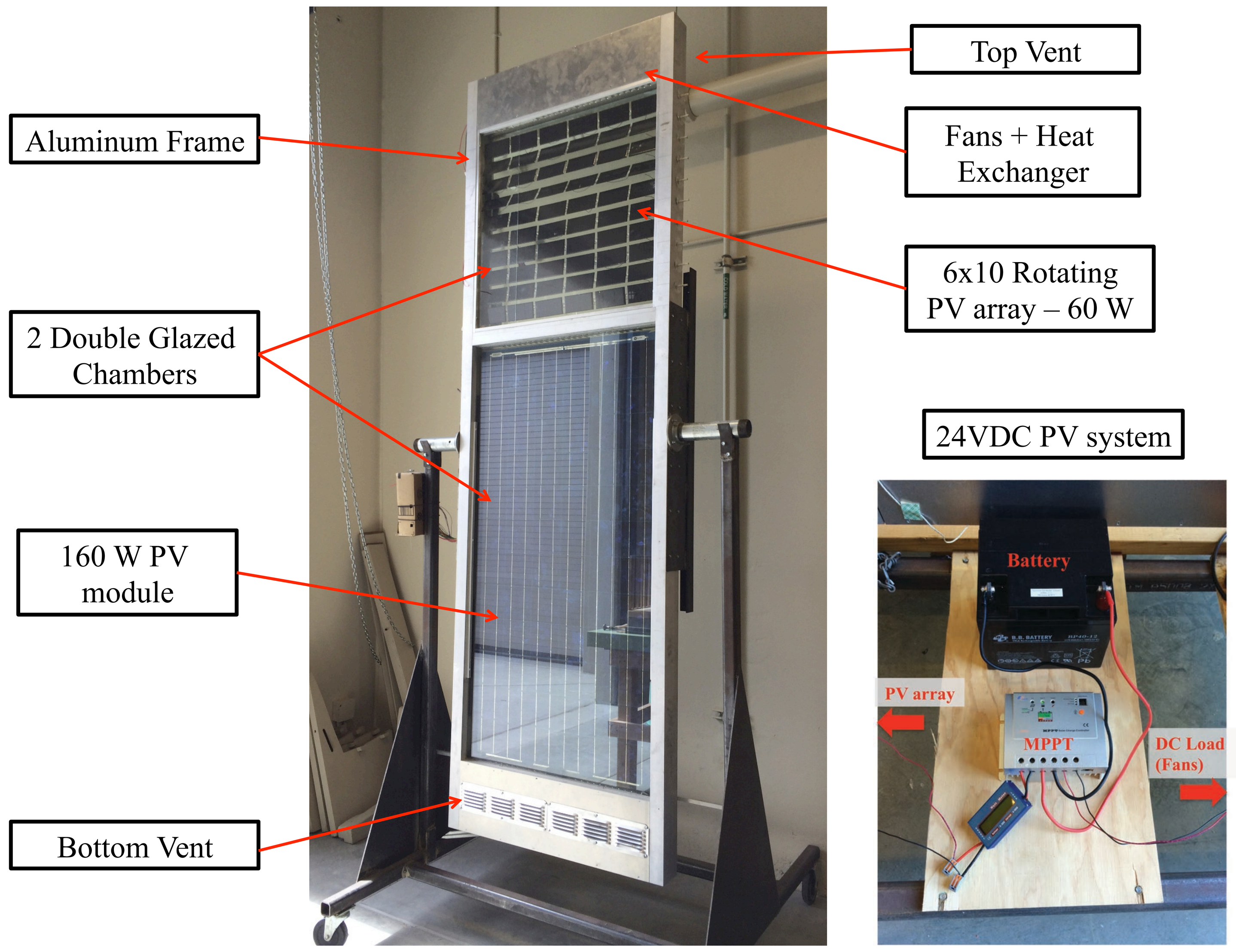
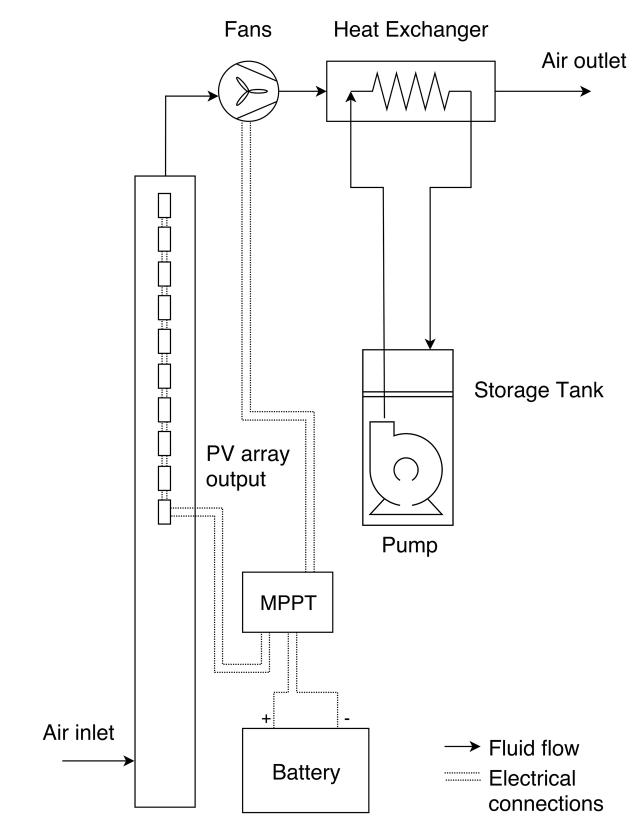
Abstract

The different elements of the building envelope such as facades, roof and windows play a central role in its thermal behaviour, and new technologies that integrate their architectural functions with energy generation are emerging. A prototype of a building-integrated photovoltaic/thermal (BIPV/T) air collector was built, which is intended to perform the functions of thermal and electrical generation, light transmission and shading control. In this work, the prototype was tested during different seasons to investigate its thermal and electrical performances. The results showed a maximum temperature rise (from bottom to top) of 31 °C and average thermal and electrical efficiencies of 31% and 7%, respectively. The experimental data were used to build 2D and 3D models in COMSOL Multiphysics, in order to assist in the optimization of the various system components for the design of the next prototype. Simulations were performed to optimize the thermal output, through the use of different improvements which included changes in frame material, glass coatings and multiple glass panes, as well as heat transfer enhancement through the addition of fins on PV modules back. The prototype was also tested under different flow rates, in order to determine the effects of a higher heat transfer coefficient between the PV modules and airstream at higher air speeds. Results showed that significant increases in temperature rise and thermal efficiency between 15 to 35% can be achieved.

Prototype Overview



System schematics

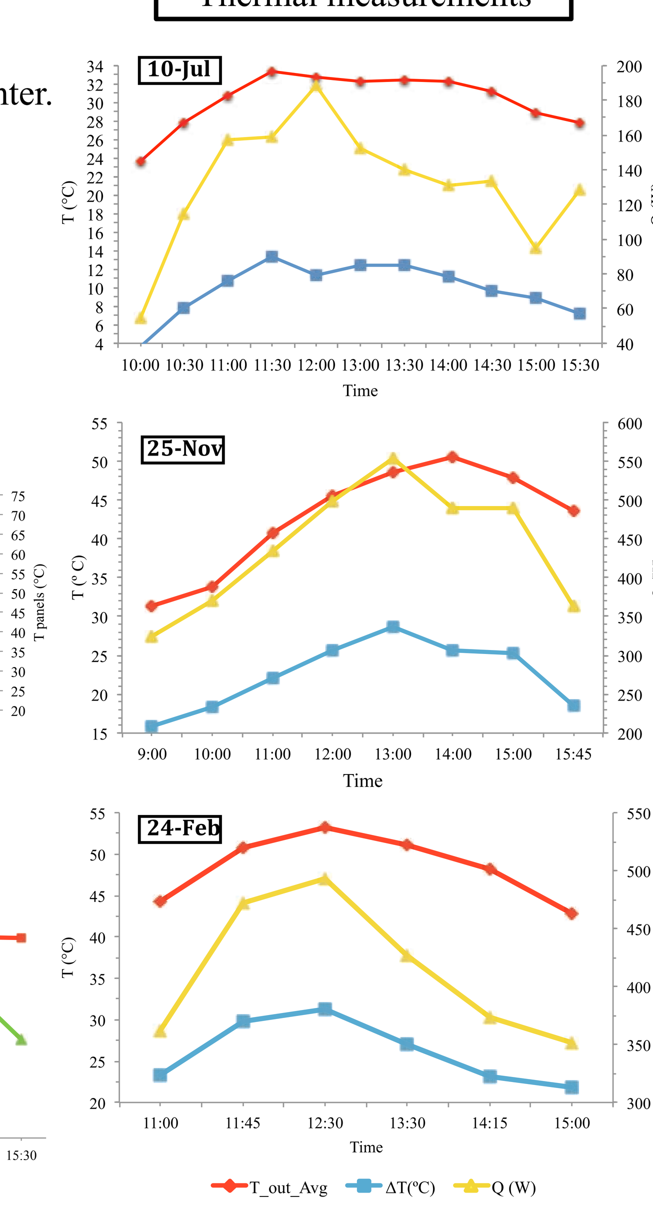


- MPPT solar charge controller
- 12 VDC, 40Ah battery
- 12VDC load (fans)
- Watt meter – PV output
- Meter for battery and load status

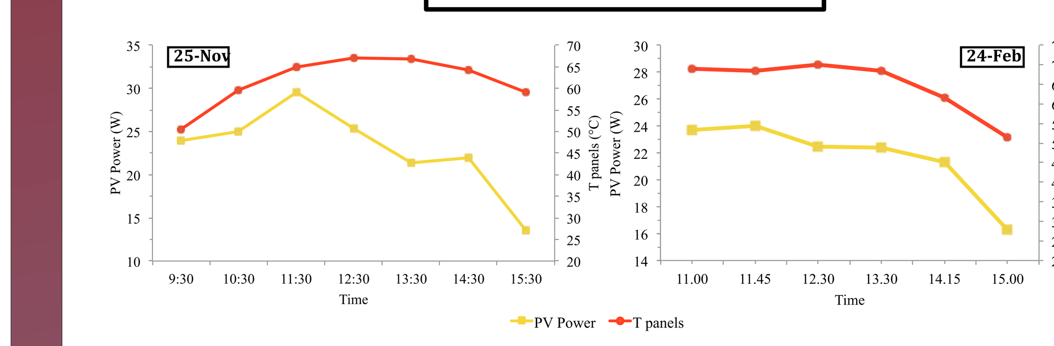
Testing Results

- Thermal and electrical measurements in summer, fall and winter.
- Maximum output air temperature 53.2 °C in winter, with a temperature rise of 31 °C.
- Thermal efficiency between 30-40% in central hours.
- Electrical power (top array): 20-25 W, with 6-8% efficiency.

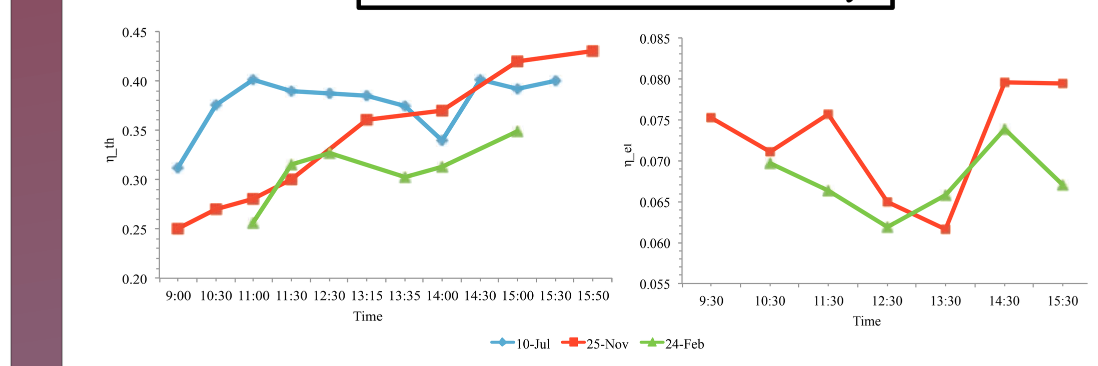
Thermal measurements



Electrical measurements



Thermal and electrical efficiency



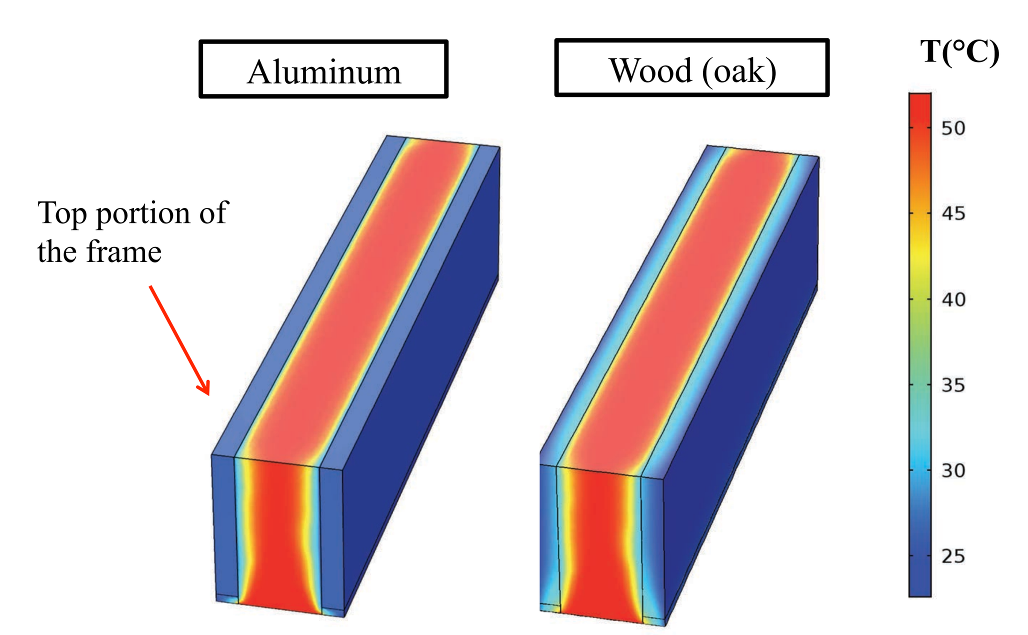
System Components Improvements

Possible improvement strategies:

- Better insulation:
  - Different frame material
  - 3 or 4 glazing layers
  - Lower conductive gas (Argon/Krypton) in insulated cavities
- Low emissivity coatings on glass surfaces
- Increased convective heat transfer between PV and air
  - Increased airflow (higher heat transfer coefficient)
  - Aluminum fins on the back of modules (more contact area)

Frame Heat Losses

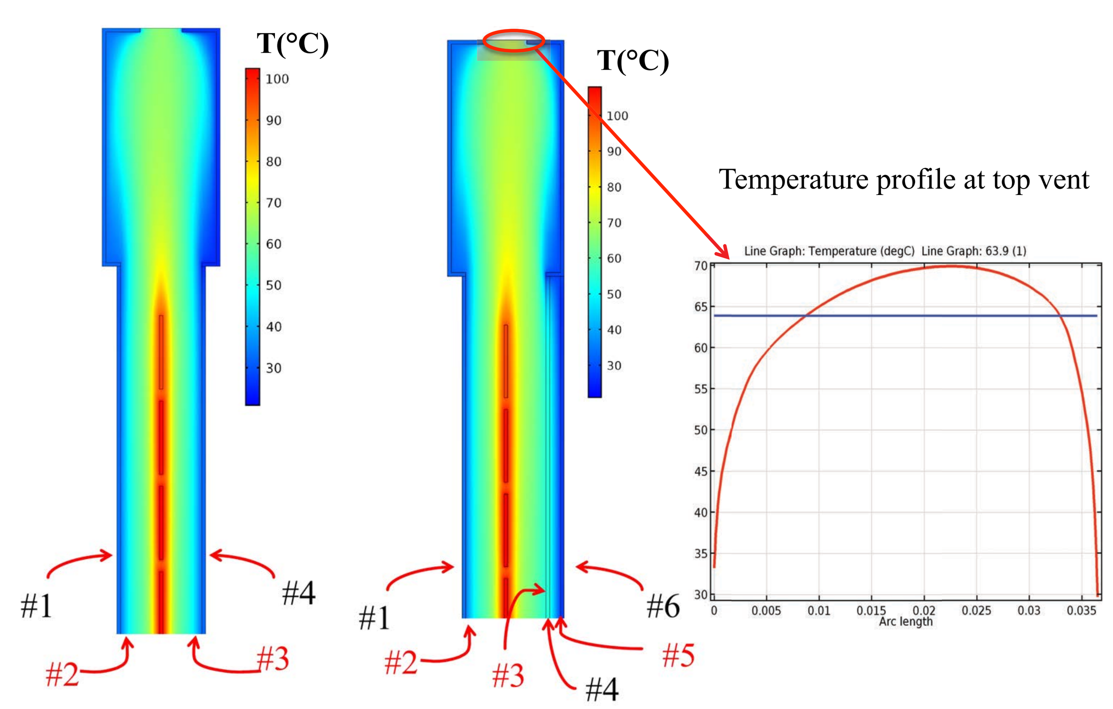
- Thermal-fluid modeling in COMSOL – material sweep



Heat losses: 40.5 W 26.1 W **35.5% decrease**

Glazing System Optimization

- Simulations with Low-e coatings, 3 and 4 glass panes and Argon filling
- Increase of output air temperature from 52.5°C up to 64-66°C, thermal efficiency from 32 up to 43-45%.



Low-e on surfaces # 2, 3 Triple glazing, Low-e on surfaces # 2, 3, 5

Configuration	Glazing	T_out (°C)	η_{th} (%)
Uncoated	Double	52.56	32.51
Low-e on surface 3	Double	57	36.6
Low-e on surface 2, 3	Double	58.66	38.1
Low-e on surface 2, 3	Triple	62.6	41.58
Low-e on surface 2, 3, 5	Triple	64.73	43.44
Low-e on surface 4, 5, 7	Quadruple	64.7	43.41
Low-e on surface 2, 3, 5, 70% NIR absorbance on surface 3	Triple	65.42	44.04
Low-e on surface 2, 3, 5, 70% NIR absorbance on surface 3, Argon filling	Triple	66.43	44.91

Heat Transfer Enhancement

Increase heat exchange from PV to air:

$$q = h \cdot A \cdot (T_{PV} - T_{air})$$

∝ Air velocity Contact area

Experimental data for different fans voltages

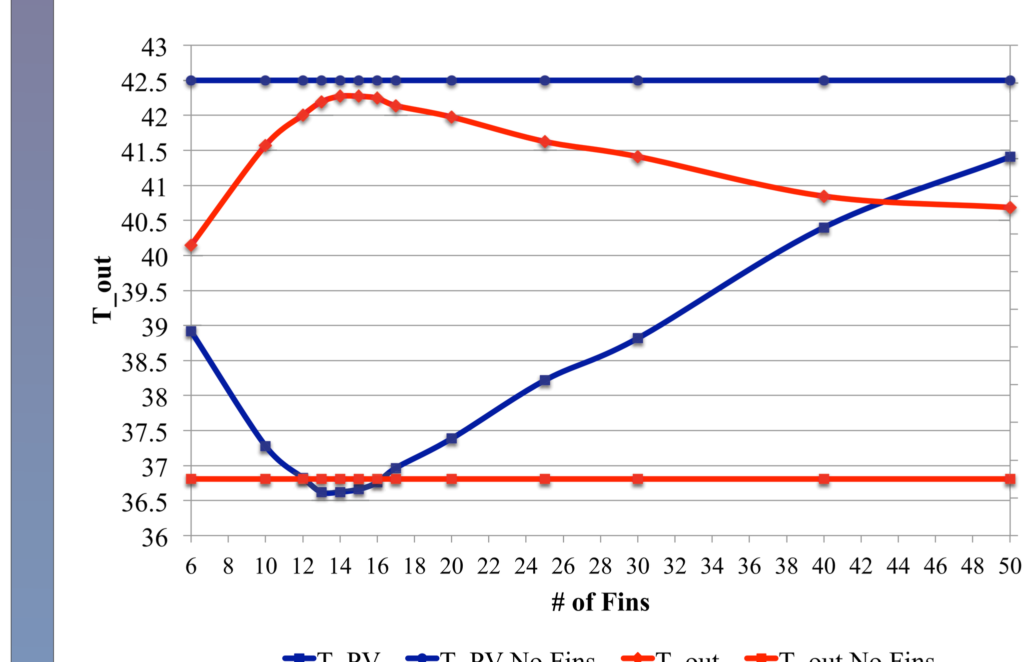
Voltage (V)	Air speed (m/s)	ΔT (°C)	Power (W)	Heat (W)	T_{out} (°C)	Thermal effic. (%)
6	0.5	25.5	19.6	340	52.9	27
7.5	0.58	26	21.7	413	48.4	31
9	0.64	22.4	20.7	400	42.3	30
12	0.8	24.4	20.4	535	47.2	42

•1) *h* enhanced

- Different air velocity tested at different fans speed.
- Thermal efficiency: increases with air speed
- Electrical power: fairly constant

•2) Increase in contact area *A*

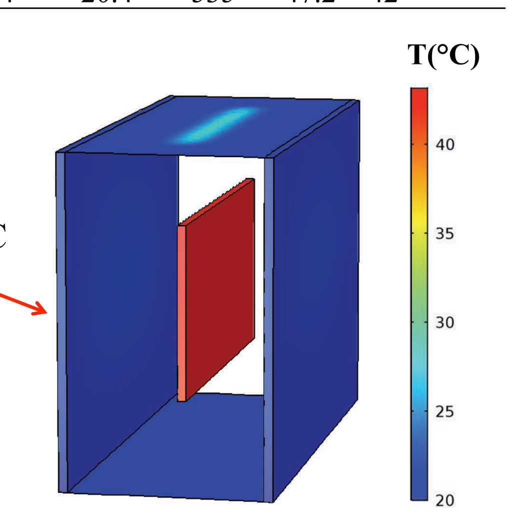
- Aluminum fins attached on PV back
- Different fins numbers simulated for 1 cm fin length
- Optimal fins #: 14



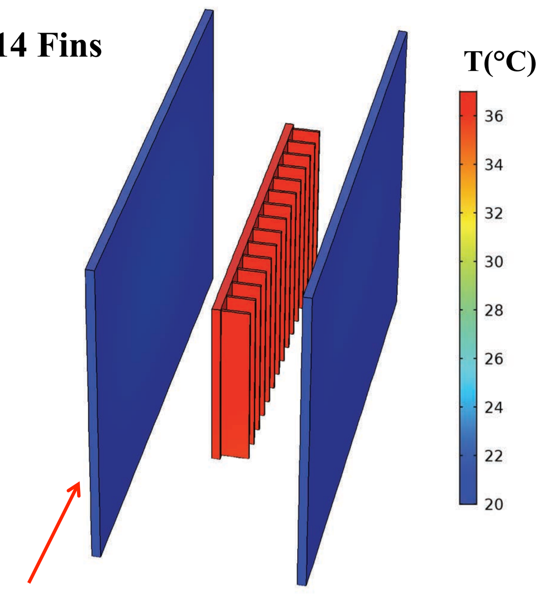
No Fins
(1 PV module)

T_PV= 42.5 °C

T_out=21.25 °C



14 Fins



T_PV= 36.62 °C **16 % increase in Δ T**

T_out=21.453 °C **26 % decrease in Δ T**

Conclusions

The thermal and electrical performances of a prototype of a BIPV/T airflow window have been tested. The results showed maximum output temperatures of 53.2°C during the winter, with a maximum temperature rise of 31°C. The thermal efficiency ranges between 25 and 40%, while the electrical one remains around 6-8%, with a generation of 20-25 W for the top PV array.

Different strategies were presented to improve the system thermal generation, including better insulation, low-emissivity coatings and convective heat transfer enhancement at the air-PV boundaries. The unit was tested at increasing air speeds, resulting in higher heat generated and higher thermal efficiency at the expense of lower output temperatures. Both 2D and 3D simulations were carried out in COMSOL Multiphysics to optimize the various system components. A 35% reduction in heat losses on the top part of the frame was possible by using wood instead of aluminum. The use of a triple pane glazing system with low-e coatings on surfaces # 2, 3 and 5 provided an increase in air temperature, temperature rise and thermal efficiency of 21.6%, 40%, and 32.8%, respectively, with respect to the experimental results. Additional aluminum fins on the PV back surfaces can further improve heat extraction, providing relative percent increase and decrease in air and PV module temperature of 16% and 26%, respectively.

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