ADVANCED PV AND THERMAL MODELING FOR A FEASIBLE AND EFFICIENT BAPV-T SYSTEM DESIGN AND EVALUATION

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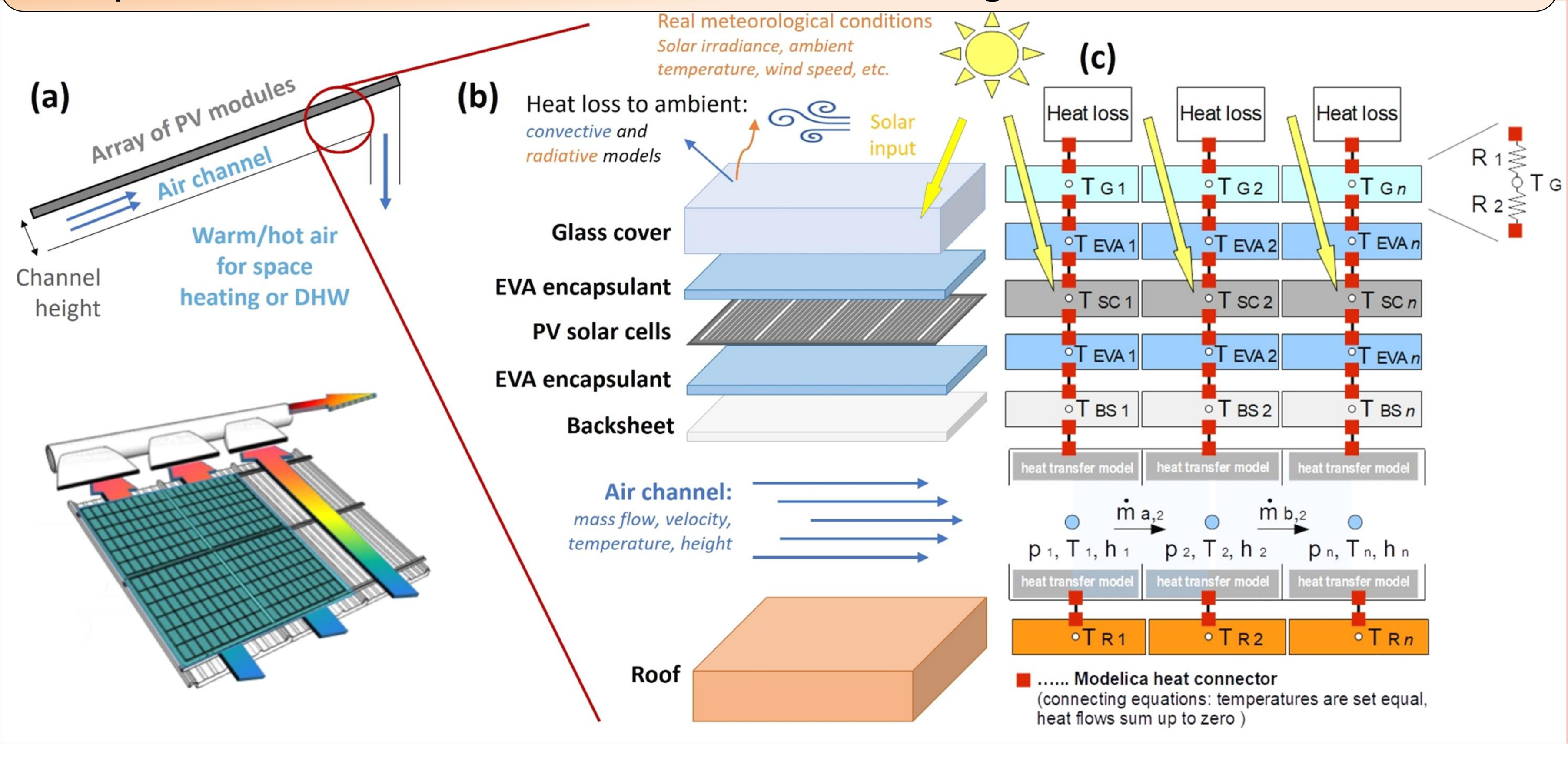
1. INTRODUCTION

- **PV-T represents a promising technology** in urban environments: limited space + high local thermal and electrical energy demands.
- This study proposes a **straightforward BAPV-T system**, by forming an air ventilation channel, which implies minimal adjustments during PV modules installation and low complexity of the equipment and control set-up.
- A simulation **model** has been developed and validated **to design the system and evaluate its performance.**

2. PV-T MODEL AND EXPERIMENTAL VALIDATION

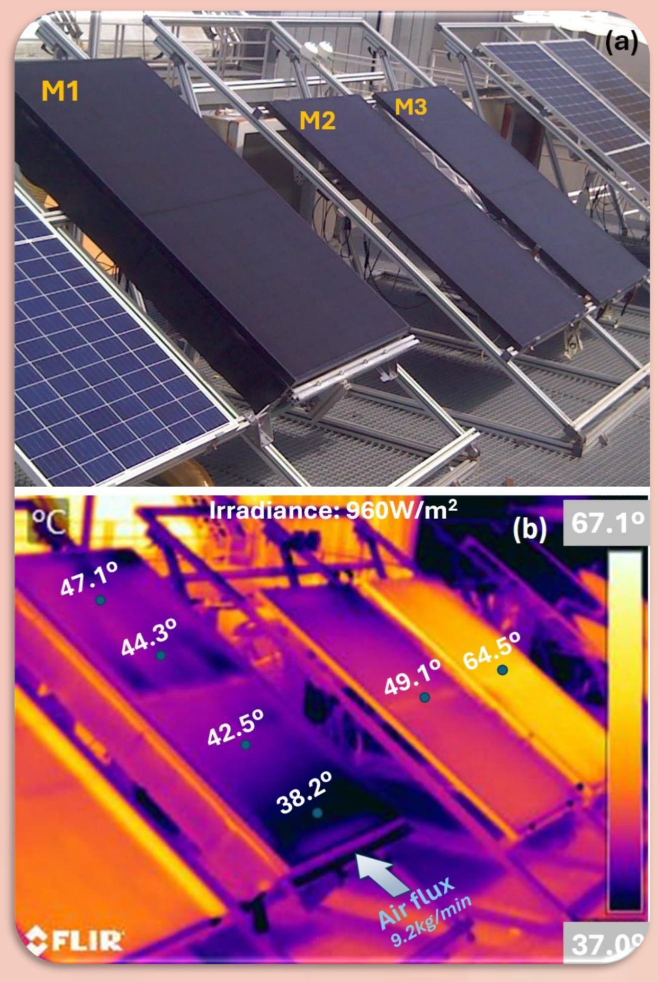
Comprehensive transient **thermal model** using the **Modelica** framework



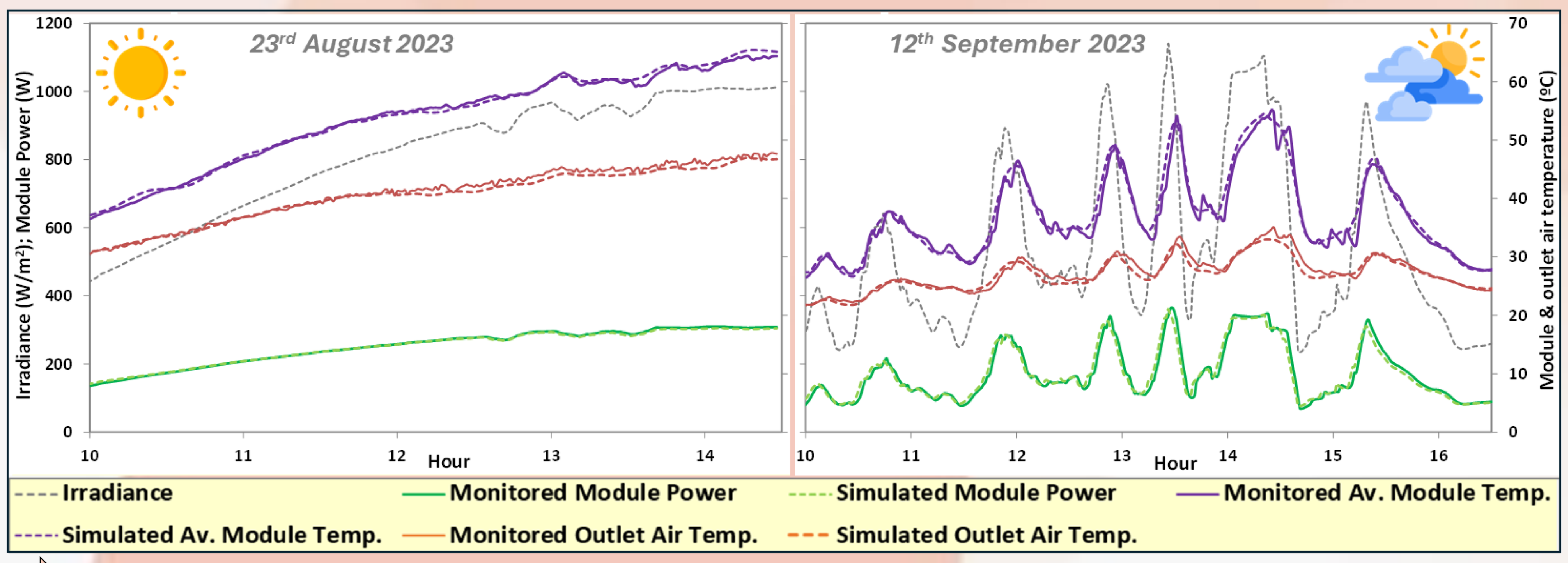
Proposed BAPV-T concept *Considered parameters/layers* *Designed 1-D conductive model*

Modelling **validation** though a 3-month **experimental campaign**

- **3 PV modules** (same model) monitored at **CENER**´s rooftop:
  - ✓ **M1:** Air ventilation channel at rear side
  - ✓ **M2:** Standard in-field configuration
  - ✓ **M3:** Thermally insulated rear side
- All **3** modules electrically **biased** at their **MPP**
- Multiple **variables** continuously monitored: global irradiance, ambient temp., wind speed, module's temp. in different areas, temp. and air velocity in the channel, module's power, etc.
- **Thermography images** periodically captured



⇨ Deep analysis shows **strong agreement** between simulated results and experimental data, even with highly fluctuating conditions



⇨ Experimental results **validate** thermal modelling at **module level**

3. REAL CASE STUDY

General simulations conditions

- **IWER building** (Pamplona, Spain), **South-east** oriented roof with 19º tilt.
- **5** in-portrait HJT **PV modules** per channel (**8.9 m x 1.0 m**).
- Typical Meteorological Year (**TMY**) of Pamplona used as meteo-input.

Preliminary simulation results: Influence of channel height & air velocity

Annual generated PV Energy improvement due to channel (%) (*)

Air velocity (m/s)	Channel height (cm): 5	10	18.5	30
5.0	4.3%	4.6%	4.6%	4.6%
2.5	3.2%	3.6%	3.6%	3.6%
1.0	1.9%	2.2%	2.3%	2.3%
0.5	1.1%	1.4%	1.5%	1.5%

Average Air temperature increase through channel (ºC) (*)

Air velocity (m/s)	Channel height (cm): 5	10	18.5	30
5.0	15.1	7.9	4.3	2.6
2.5	24.1	13.1	7.2	4.4
1.0	24.4	22.0	12.5	7.7
0.5	42.7	28.5	17.0	10.6

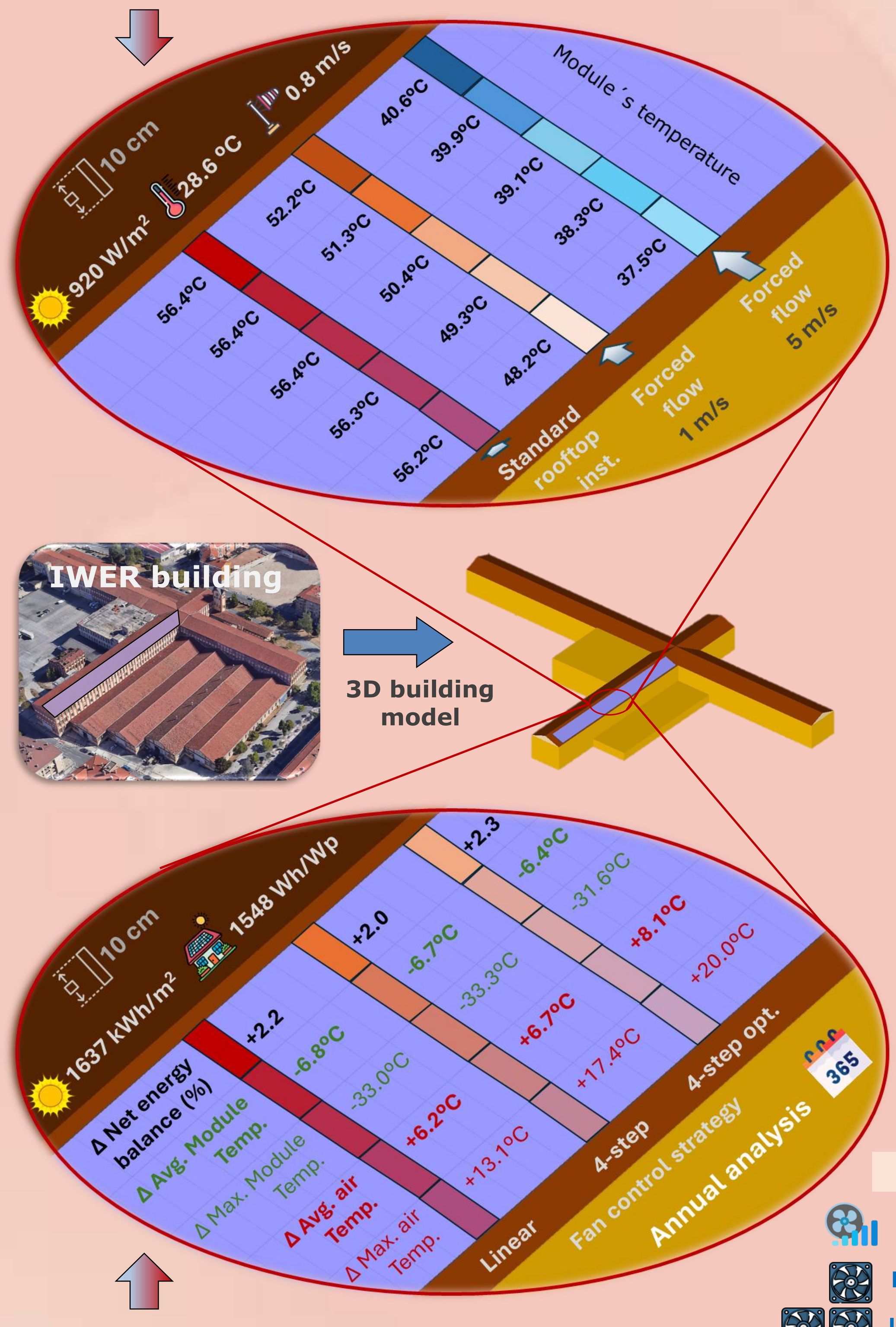
(*) Relative variation values compared to the case of rear-side insulated modules

- ⇧ Air Velocity ⇨ ⇧ PV production
- ⇧ Channel height: <10cm ⇨ ⇧ PV production; >10cm ⇨ ≈ PV production
- ⇧ Air Velocity ⇨ ⇩ Air temperature
- ⇧ Channel height ⇨ ⇩ Air temperature

Advanced simulation results: Different fan-control strategies

Channel height constant at 10 cm

Simulated modules temp. for **three air flows** during a period of high irradiance



Annual simulated **results** for **three** fan **control strategies** proposed (relative to standard rooftop installation)

Comparison different constant forced **air flows**

- Increasing forced air velocity significantly reduces module temperature (i.e. down to -19ºC with constant 5 m/s).

3 different ventilation fan-control strategies

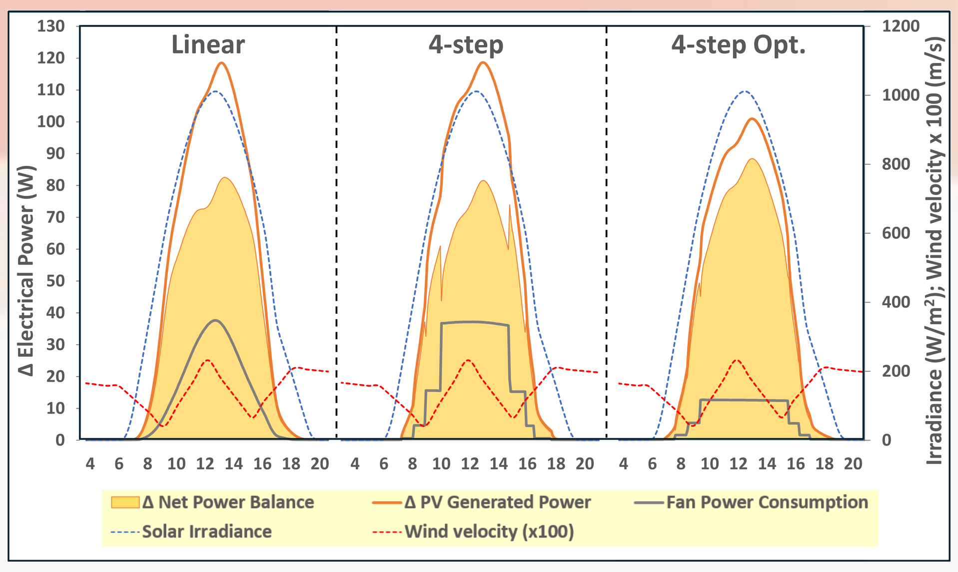
- **Linear control:** Air flow proportional to irradiance level
  - ⇨ difficult to implement.
- **4-step control: 4** low-power fans in **ON/OFF** operation
  - ⇨ number of working fans depends on equivalent steps of irradiance.
- **Optimized 4-step control:** Control-parameters values are optimized (maximizing **net energy balance**) by applying a differential evolution algorithm.

***Net energy balance** = PV generation - fan consumption*

Control strategy	Linear	4-step	4-step opt.
Max. Air velocity	3.00 m/s @ 1000 W/m²	3.00 m/s	2.11 m/s
Irradiance 1st fan ON	-	200 W/m²	96 W/m²
Irradiance 2nd fan ON	-	400 W/m²	293 W/m²
Irradiance 3rd fan ON	-	600 W/m²	490 W/m²
Irradiance 4th fan ON	-	800 W/m²	687 W/m²

- Settings from iterative optimization process allow **improving the net energy balance.**

Temporal **evolution** of solar irradiance, wind speed, and primary **energy-related** simulated results, during a **clear sunny summer day**, for the **three forced-ventilation control strategies** ⇨



4. CONCLUSIONS

- **Easily implementable system proposed, which forms a narrow air ventilation channel** between backside of PV modules and top side of roof.
- Model developed and experimentally validated demonstrating **huge potential** for assessing the system feasibility across diverse locations.
- Real case study, three fan control strategies assessed: ↑ **2.3%** in annual net energy balance; ↑ **8.1ºC** (avg.) in air temperature at the channel exit; ↓ **31.6ºC** (max.) in operating module temperature.
- **Potential extension of PV modules lifespan** due to reduction in operating temperature.
- **Future work:** 1 - further **optimization of control strategy** (wind speed, seasonal dependency); 2 - assessment of **potential uses of warm air** (space heating, DHW); 3 - **economical analysis** of the proposed solutions (cost-effectiveness through the whole lifetime).

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