



Climate Change, Ventilation and Resilience

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## Full-scale facility for night and day-time passive radiative cooling system assessment

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### Introduction

- The **escalating demand for cooling energy, driven by global warming and increased urbanization**, poses a significant challenge to the sustainability of the built environment.
- **Traditional air conditioning systems** contribute to greenhouse gas emissions and high energy consumption.
- **Passive cooling technologies** are increasingly used to reduce building heat loads. **Passive radiative cooling (PRC)** is especially promising because it dissipates heat to outer space without external energy.
- New **PRC materials can reach sub-ambient temperatures** during both nighttime and daytime under direct sunlight.

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## Objective

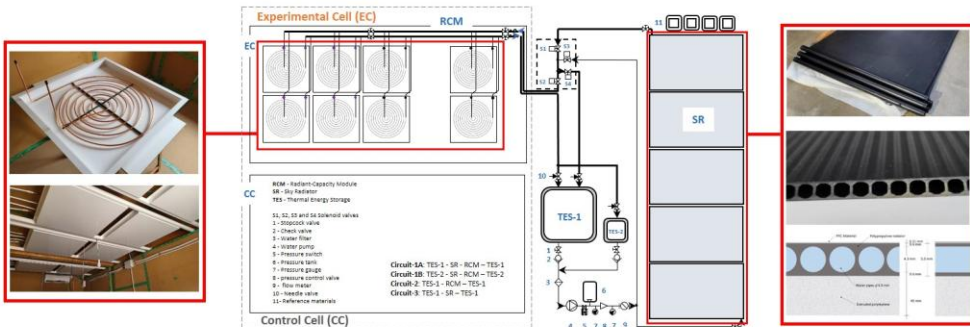
- This study aims to quantify the cooling potential of the sky radiator with and without PRC material. To achieve this, a methodology based on multiple correlation models is proposed, incorporating the most influential factors in determining the cooling potential of sky radiators ( $CP_{SR}$ ).
- The primary aim is to establish a practical methodology for comparatively assessing the cooling capacity of sky radiator arrays across experiments conducted under diverse climatic conditions.

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## Methodology

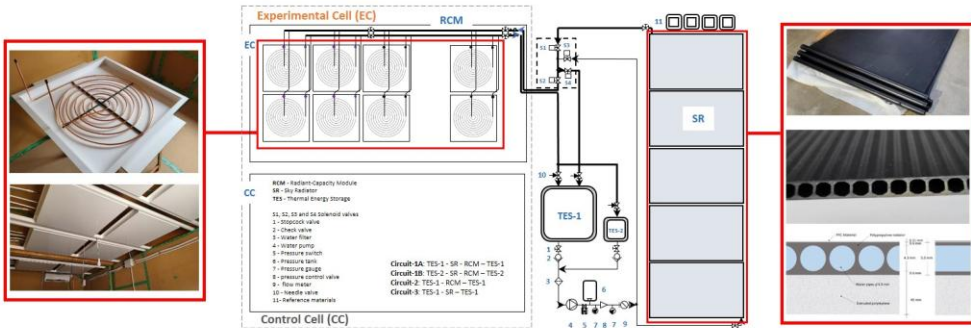
### The Radiant-Capacitive Cooling System (RCCS) - Components

**PaRaMetriC Project**  
The Radiant-Capacity Cooling System at the full-scale facility of the IETCC-CSIC in Arganda del Rey.

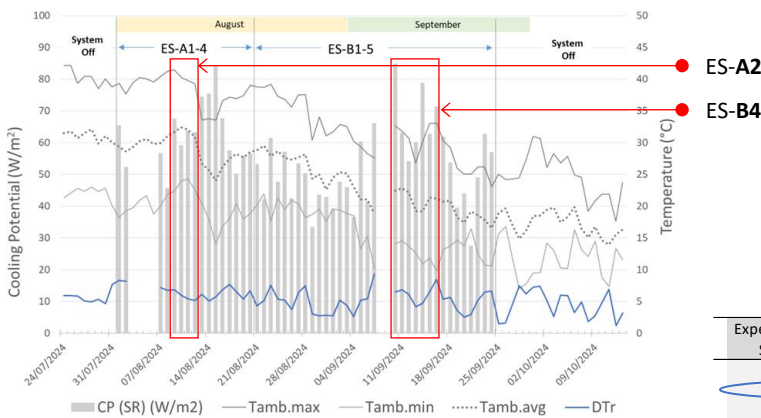


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**PaRaMetriC Project**  
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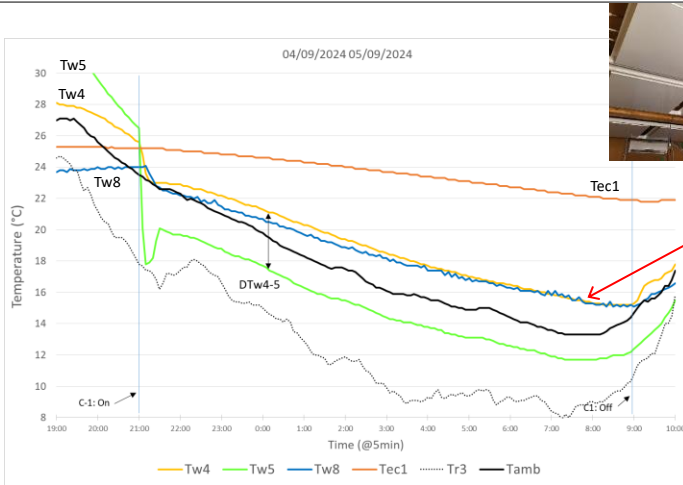
Nine experimental series were conducted to evaluate the cooling performance under various operating configurations.

Configurations involved modifications to the **water flow rate**, **energy storage capacity**, and **the number of radiant-capacity modules** in both radiator conditions.

Experimental Series	Circuit-1	TES-1	TES-2	WFR (l/h)	8-RCM	4-RCM
ES-A1	10h	X		183	X	
ES-A2	10h	X		387	X	
ES-A3	10h		X	396	X	
ES-A4	10h		X	380		X
ES-B1	12h		X	363	X	
ES-B2	12h		X	170	X	
ES-B3	12h		X	158		X
ES-B4	12h	X		376	X	
ES-B5	15h	X		376	X	

Daily mean CP<sub>SR</sub> values for each experimental series and their relationship with the ambient air maximum, mean, and minimum temperatures, as well as with the corresponding reference temperature depression.

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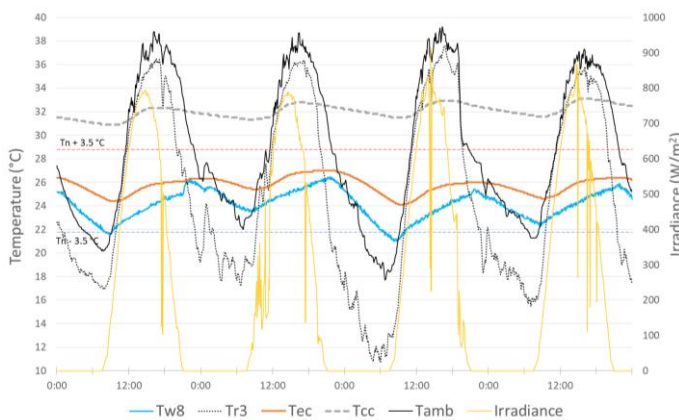


Monitored values:

- ambient (**Tamb**) and reference (**Tr3**) temperatures
- radiator inlet and outlet water temperatures (**Tw4**; **Tw5**)
- RCM inlet and outlet water temperatures (**Tw6**; **Tw9**)
- water in the RCMs (**Tw8**)
- indoor temperature (**Tec1**)

$DT_{avg} T_{cc}-T_{ec} = 7.3 \text{ } ^\circ\text{C}$ ;  $DT_{avg} T_{amb}-T_{ec1} = -2.1 \text{ } ^\circ\text{C}$ ;  $DT_{max} T_{amb}-T_{ec1} = 4.8 \text{ } ^\circ\text{C}$   
 $DT_{avg} T_{amb}-T_{r3} = 5.3 \text{ } ^\circ\text{C}$ ;  $CP_{SR} avg = 60.5 \text{ W/m}^2$

**ES-B1** – Circuit-1 (9 pm to 9 am -12h) - TES2 - 8 RCM - 363 l/h



The indoor temperature difference between CC and EC was **6.3°C**,

Drop of maximum indoor temperature relative to outdoors ( $DT_{max}$ ), is **11.9 K**.

Monitored values:

- ambient (**Tamb**) and reference (**Tr3**) temperatures
- indoor EC (**Tec1**) and indoor CC (**Tcc**) temperatures
- water temperature in the RCMs (**Tw8**)
- Solar irradiance
- calculated adaptive comfort range

$DT_{avg} T_{cc}-T_{ec} = 6.3 \text{ } ^\circ\text{C}$ ;  $DT_{avg} T_{amb}-T_{ec1} = 3 \text{ } ^\circ\text{C}$ ;  $DT_{max} T_{amb}-T_{ec1} = 11.9 \text{ } ^\circ\text{C}$   
 $DT_{avg} T_{amb}-T_{r3} = 5.6 \text{ } ^\circ\text{C}$ ;  $CP_{SR} avg = 51.2 \text{ W/m}^2$

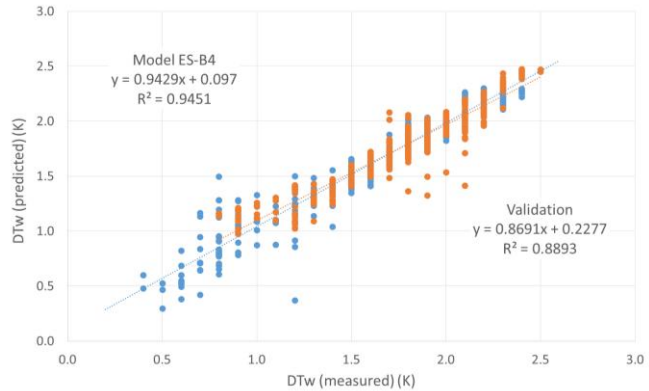
**ES-B4 model**

A multiple regression model was developed based on the first four nights of **ES-B4**, incorporating **Tamb, Tsky, Tr3, Tw4-Tr3**.

$$Y=0.24725-0.13482*T_{amb}-0.02919*T_{sky}+0.16729*Tr3+0.15197*(Tw4-Tr3)$$

CC = 0.9719; R<sup>2</sup> = 0.9446; RMSE = 0.119 °C; MAPE = 6.20%

validation: R<sup>2</sup> = 0.8893



ES-B4 model validation.  
DTw measured vs. predicted.

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**Comparative Analysis of Cooling Potential in Series B4-A2**

The generated models allow us to estimate the water temperature drop as it passes through the radiators, i.e., the temperature difference between the inlet and outlet of the radiators, expressed as DTw. Based on this temperature drop, we determine the cooling potential per unit area of the sky radiators (CP<sub>SR</sub>) as follows:

$$CP_{SR} = \dot{m} \times cp \times DTw / A \quad (W/m^2)$$

Where:  $\dot{m}$  (kg/s) is the mass flow rate of water;  $cp$  (J/kg.K) is the specific heat of the water;  $DTw$  (K) is the difference in water temperature and  $A$  (m<sup>2</sup>) is the area of the sky radiator.

- The **ES-B4** regression model was used to predict **DTw** using the data from series **A2**.

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## Results and discussion

Average temperature differences between the radiator inlet and outlet and corresponding **measured and predicted  $CP_{SR}$  values.**

Dates	Series	Real data		Predicted with data A2		TES	WFR	8-RCM
		$DT_w$ (K)	$CP_{SR}$ ( $W/m^2$ )	$DT_w$ (K)	$CP_{SR}$ ( $W/m^2$ )			
		Avg	Avg	Avg	Avg			
09/08 to 12/08	A2	1.61	63.8	2.00	77.0	1	387	X
10/09 to 16/09	B4	1.77	68.1	2.00	77.0	1	376	X

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## Conclusions

- **Polypropylene and PRC-coated radiators** reached similar nocturnal stagnation temperatures, but the **PRC coating** extended the cooling period.
- **Mean cooling potential ( $CP_{SR}$ )** ranged from **43.4 to 74.3  $W/m^2$** , mainly driven by the temperature difference between inlet water and the radiator surface.
- **The validated multiple correlation model** improved system performance in **ES-B4** compared with **ES-A2**.
- **Indoor temperatures in the experimental cell** were reduced by up to **7 K** versus the control cell and by up to **12 K** versus outdoor conditions, confirming the **RCCS** potential as a passive cooling strategy.

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## Acknowledgements

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**THANK YOU**  
**ANY QUESTION?**



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