UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Nanomaterials for energy efficiency in buildings

Ing. Alessandro Cannavale, PhD
Technical University of Bari

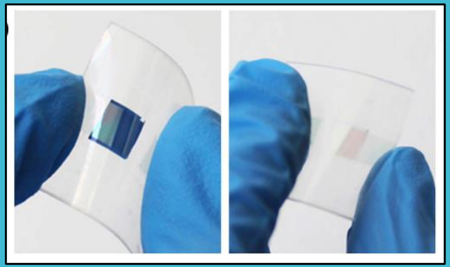
UNIONE EUROPEA
REGIONE PUGLIA
SMARTPUGLIA INTELLIGENTI DAL FUTURO
a · r · t · i
Agenzia regionale per la tecnologia e l'innovazione

Overview

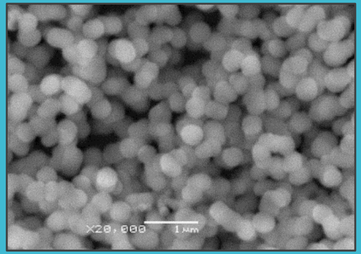
Nanomaterials for energy efficiency in buildings

Perovskite-based Photovoltaics

Solid-state Electrochromics



Bio-PCMs



1. *Perovskite-based BIPVs*
2. *Solid-state ECs*
3. *Nano Biocompatible-PCMs*

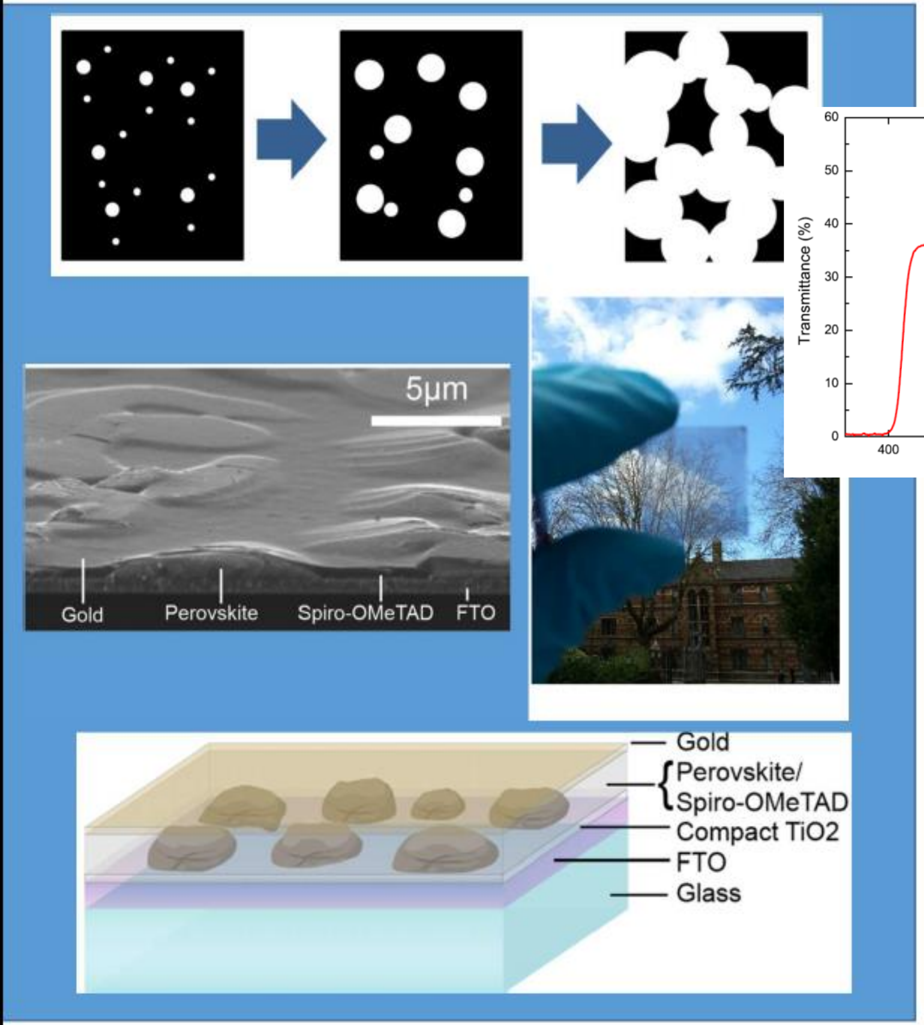
UNIONE EUROPEA

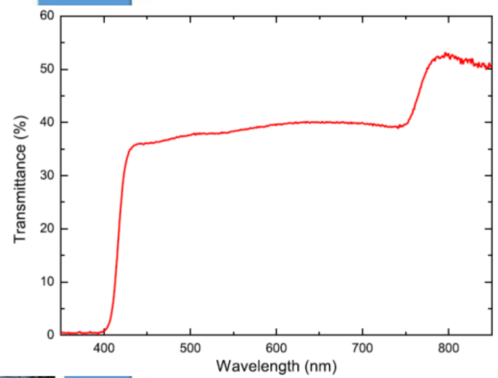
REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

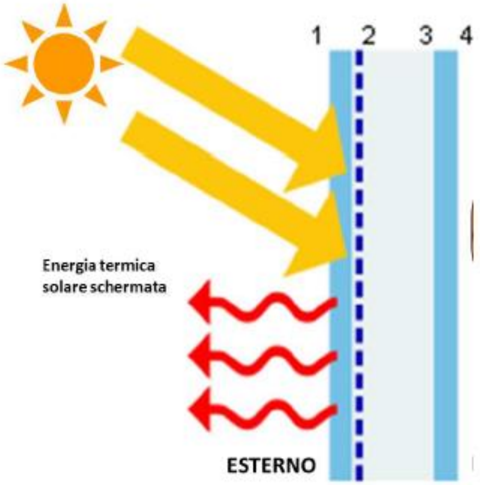
a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Caratteristiche della tecnologia fotovoltaica a microisole





Schema progettuale per applicazione in componenti edilizi



Proposta di collocazione film fotovoltaico semitrasparente a base di perovskite (Faccia 2)

Interno

Esterno

UNIVERSITY OF OXFORD

References:

Alessandro Cannavale, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, Francesco Martellotta, **Applied Energy 194 (2017) 94–107**

Conversion efficiency: 6.1%

Adv. Mater. Interfaces **2016**, 1500837

UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Perovskite-based BIPVs

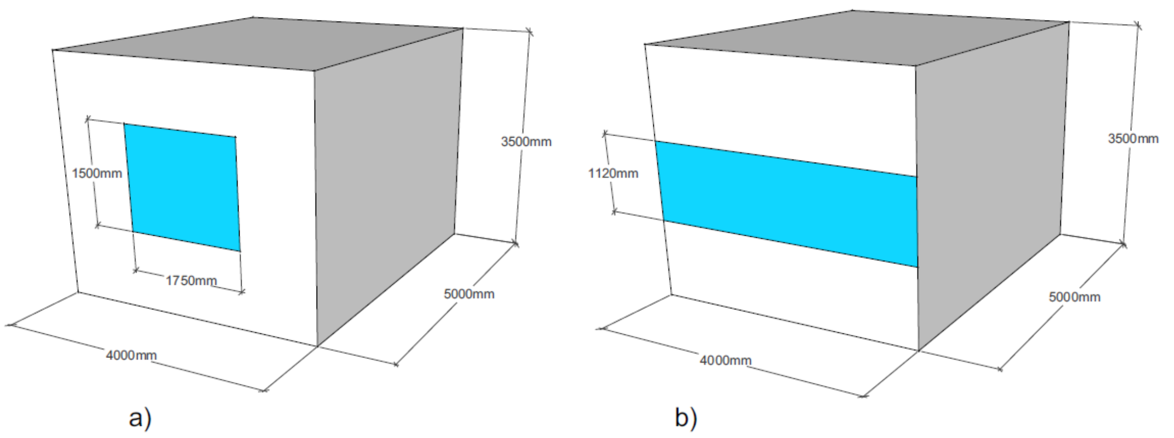


Fig. 4. View of the two room models: (a) WWR = 19%; (b) WWR = 32%.

Softwares adopted:

- EnergyPlus
- Daysim

Two values of WWR:
19% - Residential room
32% - Offices

Three locations:
- London
- Aswan
- Brindisi

Useful Daylight Illuminance (UDI): 100–2000 lx

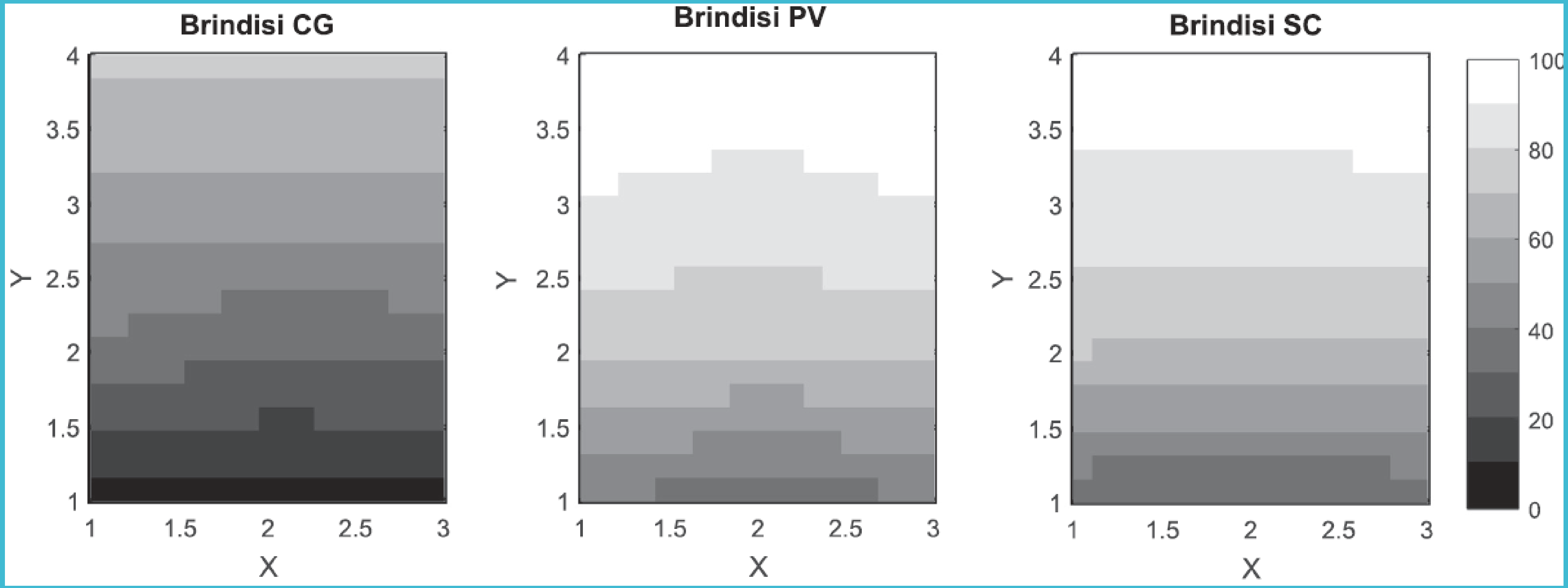
$$DGP = 5.87 \times 10^{-5} E_V + 9.18 \times 10^{-2} \log\left(1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_V^{1.87} P_i^2}\right) + 0.16$$

UNIVERSITY OF OXFORD

References:

Alessandro Cannavale, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, Francesco Martellotta, **Applied Energy 194 (2017) 94–107**

Perovskite-based BIPVs

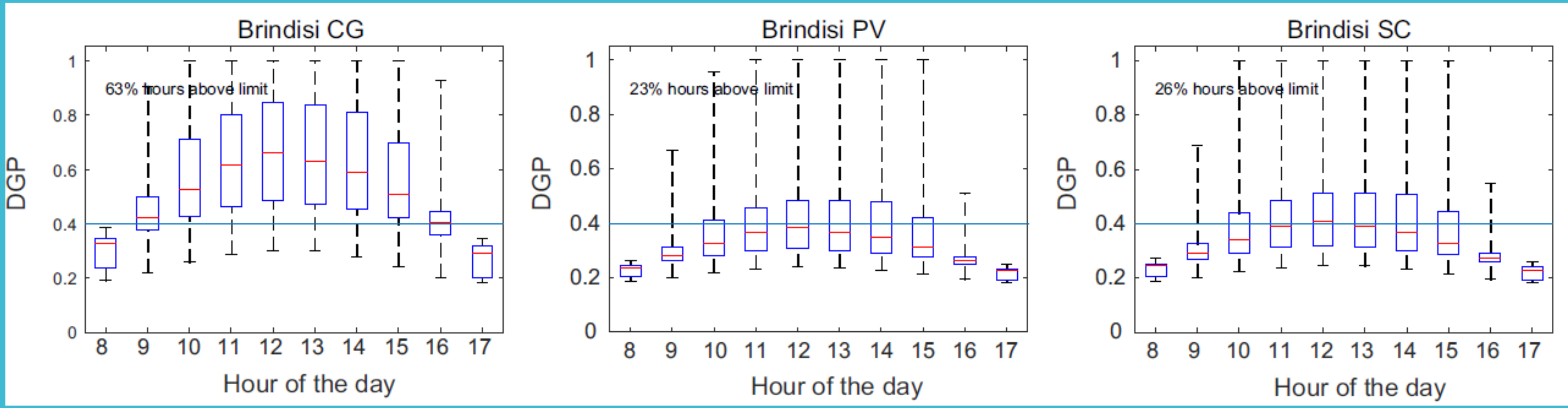


Useful Daylight Illuminance (UDI): 100–2000 lx

References:

Alessandro Cannavale, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, Francesco Martellotta, **Applied Energy 194 (2017) 94–107**

Perovskite-based BIPVs



Daylight Glare Probability (DGP)

References:

Alessandro Cannavale, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, Francesco Martellotta, **Applied Energy 194 (2017) 94–107**

UNIONE EUROPEA REGIONE PUGLIA SMARTPUGLIA INTELLIGENTI DAL FUTURO ·a·r·t·i· Agenzia regionale per la tecnologia e l'innovazione

Perovskite-based BIPVs

Use of electric lighting for offices having strip windows with a WWR = 32%. Load is meant as the annual electric lighting energy load in the test room; Yield is the Annual Electric energy yield (including temperature effect).

Location	Type of glazing	LOAD [kWh/yr]	YIELD [kWh/yr]	Yield/Load [%]
Brindisi	CG	78	–	–
	SC	108	–	–
	PV	118	129.0	109.3
London	CG	136	–	–
	SC	198	–	–
	PV	200	82.40	41.2
Aswan	CG	52	–	–
	CG	68	–	–
	PV	68	143.40	210.9

Energy Yield

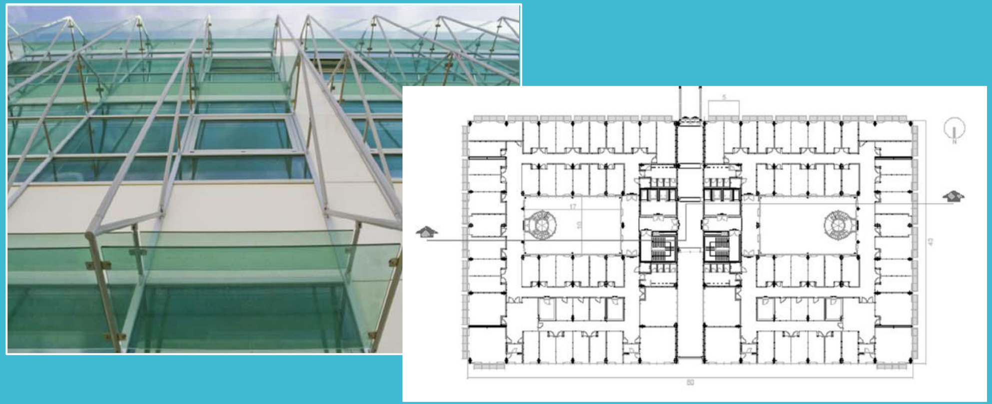
UNIVERSITY OF OXFORD

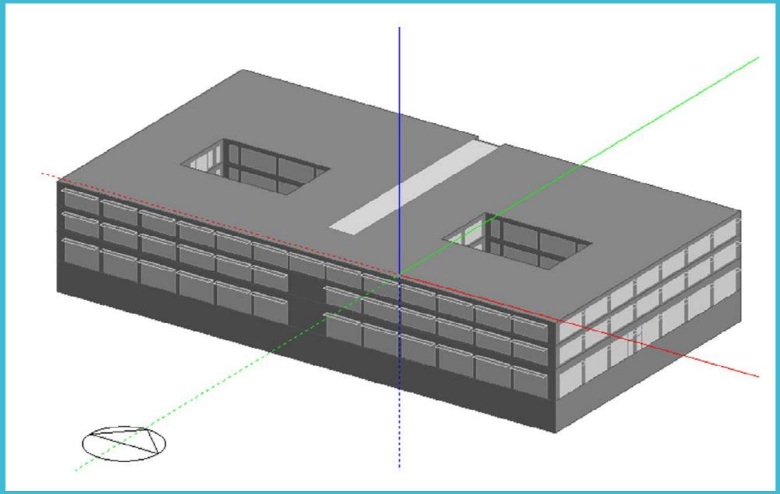
References:

Alessandro Cannavale, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Francesco Fiorito, Ubaldo Ayr, Francesco Martellotta, **Applied Energy 194 (2017) 94–107**

UNIONE EUROPEA REGIONE PUGLIA SMARTPUGLIA INTELLIGENTI DAL FUTURO a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Perovskite-based BIPVs





- BIPV solutions were investigated with reference to a tertiary building case-study.
- Energy yield of building integrated perovskite PVs showed figures up to 42.3 MWh/yr.
- Visual comfort assessment was carried out using two relevant metrics: UDI and DGP.

UNIVERSITY OF OXFORD

References:

Alessandro Cannavale, Laura Ierardi, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Ubaldo Ayr, Francesco Martellotta, Applied Energy 205 (2017) 834–846

Perovskite-based BIPVs

	Electricity consumption [MWh/year]				
	CG	CG_S	CG_SPV	PV	PV_SPV
Heating electricity consumption	38.3	39.0	40.0	49.1	51.1
Cooling electricity consumption	170.1	166.6	160.0	133.3	122.4
HVAC electricity consumption	208.4	205.6	200.0	182.4	173.5
Lighting electricity consumption	42.0	42.9	44.3	58.5	63.3
Overall variable electricity consumption	250.4	248.5	244.3	240.5	237.2
Variation		-0.8%	-2.5%	-4.0%	-5.3%

The use of a semitransparent PV layer within windows caused a 4% reduction in overall consumptions, passively.

UNIVERSITY OF OXFORD

References:

Alessandro Cannavale, Laura Ierardi, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Ubaldo Ayr, Francesco Martellotta, Applied Energy 205 (2017) 834–846

UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Perovskite-based BIPVs

Comparison of annual electricity yield [MWh/year] due to PV panels integrated in glazing and shading systems.

	PV glass			PV glass, w/Horiz. shades			Horiz. shades		
	East	South	West	East	South	West	East	South	West
Ground floor	2.51	7.13	2.68	1.75	4.44	1.86	1.65	5.62	1.59
1st and 2nd floor	1.65	4.35	1.77	0.96	2.12	1.03	1.65	5.19	1.59
Overall	5.81	15.82	6.22	3.68	8.69	3.92	4.95	15.99	4.77
Grand total [MWh/year]			27.9			16.3			25.7

*The use of PV film over the entire glazed surface of East, South, and West facades (an area of about 1100 m2) returned in total 27.9 MWh/year of electricity. This corresponds to **48% of the lighting energy demand**, to 16% of the HVAC electricity demand, or to 12% of the overall electricity demand (18% considering also opaque PV shades).*

UNIVERSITY OF OXFORD

References:

Alessandro Cannavale, Laura Ierardi, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Ubaldo Ayr, Francesco Martellotta, Applied Energy 205 (2017) 834–846

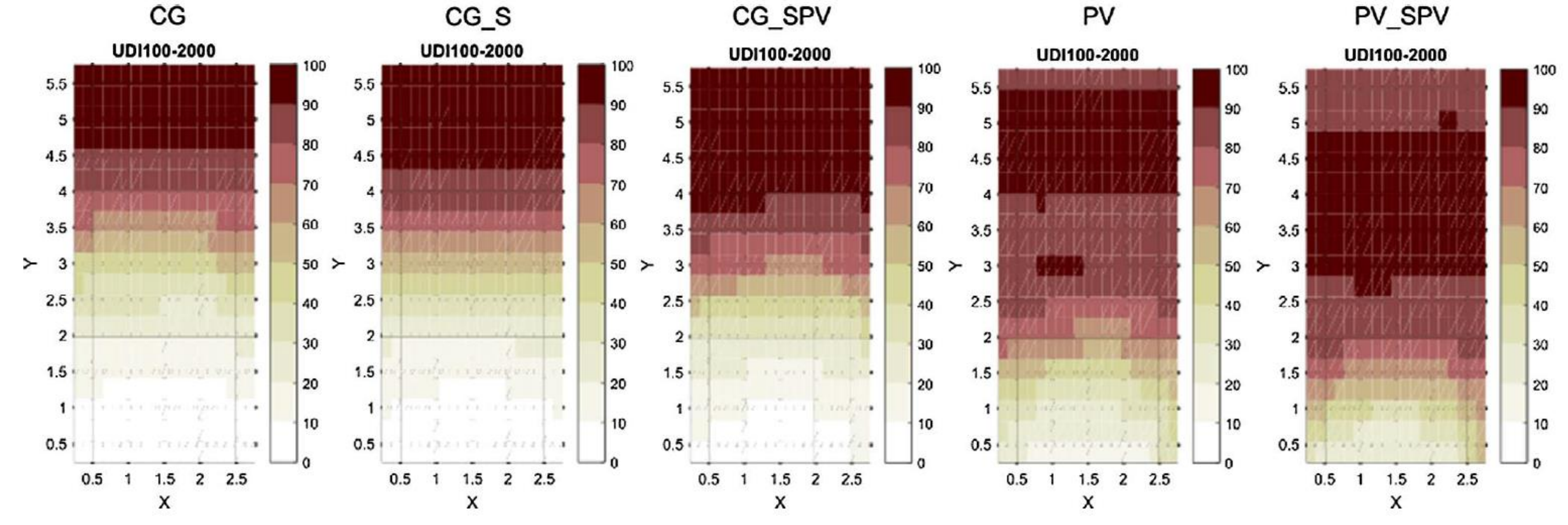
UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a · r · t · i · Agenzia regionale per la tecnologia e l'innovazione

Perovskite-based BIPVs



Useful Daylight Illuminance (UDI): 100–2000 lx

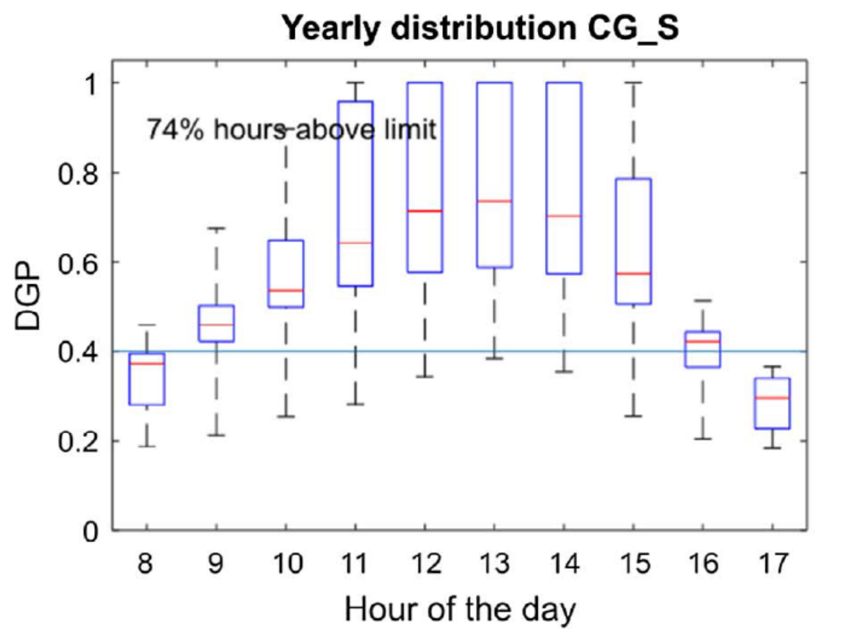
UNIVERSITY OF OXFORD

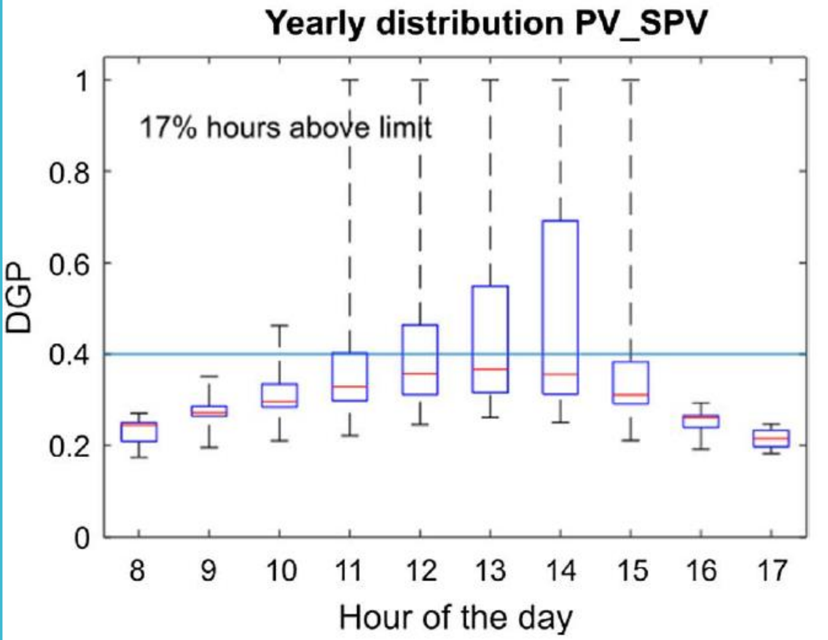
UNIVERSITY OF WASHINGTON 1861

References:

Alessandro Cannavale, Laura Ierardi, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Ubaldo Ayr, Francesco Martellotta, Applied Energy 205 (2017) 834–846

Perovskite-based BIPVs





Daylight Glare Probability (DGP)

References:

Alessandro Cannavale, Laura Ierardi, Maximilian Hörantner, Giles E. Eperon, Henry J. Snaith, Ubaldo Ayr, Francesco Martellotta, Applied Energy 205 (2017) 834–846

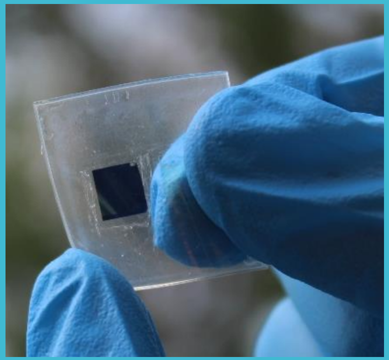
UNIONE EUROPEA

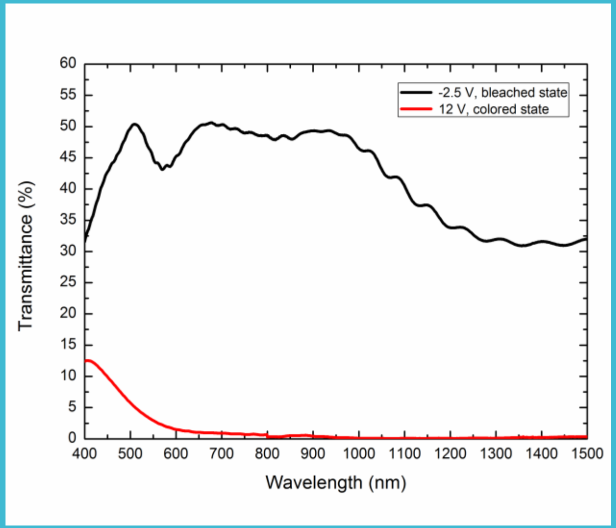
REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

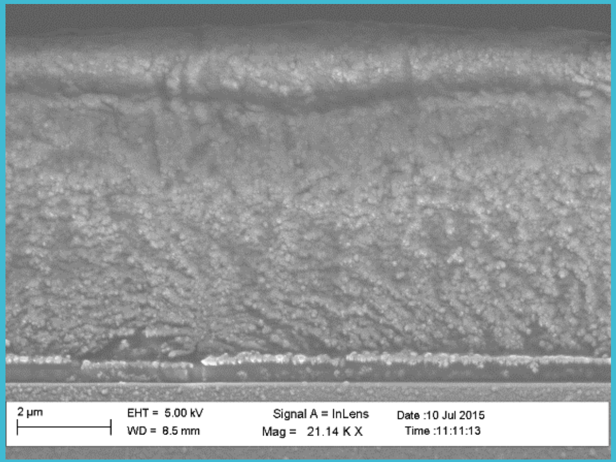
a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Solid-state ECs





Materials	Thickness	Fabrication process
PEN	0.125 mm	Commercial
ITO	150 nm	
WO_3	300 nm	Physical vacuum deposition: Electron-beam
Nafion-H^+	8 µm	Solution processing:



CNRNANOTEC INSTITUTE OF NANOTECHNOLOGY

References:

Alessandro Cannavale, Francesco Martellotta, Pierluigi Cossari, Giuseppe Gigli and Ubaldo Ayr, under revision, **Applied Energy**

Solid-state ECs

	Clear Glass				Selective Glass				CNR Electrochromic			
	L	H	C	O	L	H	C	O	L	H	C	O
LON	9.2	5.4	8.6	23.2	11.9	6.0	5.4	23.3	13.2 (10.8)	5.9 (5.4)	3.3	22.4 (19.6)
ROM	7.4	1.4	20.3	29.1	8.2	1.4	17.4	27.0	9.8 (7.8)	1.8 (1.4)	12.6	24.2 (21.7)
ASW	8.2	0.0	46.7	54.9	8.4	0.0	41.1	49.6	9.2 (8.4)	0.0 0.0	33.1	42.3 (41.5)

The total energy savings achievable with the latter solution reached 25%, compared to the clear glass reference configuration and 19% compared to selective glass reference.

References:

Alessandro Cannavale, Francesco Martellotta, Pierluigi Cossari, Giuseppe Gigli and Ubaldo Ayr, under revision, **Applied Energy**

UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

Solid-state ECs

	$UDI_{<300}$	$UDI_{300-3000}$	$UDI_{>3000}$	Glare Index < 22
CG	10.7	42.4	46.8	56.5
SG	14.9	63.9	21.2	83.5
SC	18.3	79.1	2.6	95.9
EC@500 lx	13.7	71.6	14.8	88.0
EC@300 lx	16.0	69.2	14.8	87.3
CNR-EC @ 500lx	19.4	80.4	0.1	99.9
CNR-EC @ 300lx	21.2	78.6	0.1	99.3
CNR-EC (roll. shut.) @ 500 lx	13.8	63.1	23.1	79.3
CNR-EC (roll. Shut.) @ 300 lx	15.7	63.8	20.5	81.2
CNR-EC (roll. shut. Extended)	16.8	75.4	7.8	93.6

Visual comfort assessment in terms of Useful Daylight Illuminance and Glare Index for the different technologies with reference to Rome

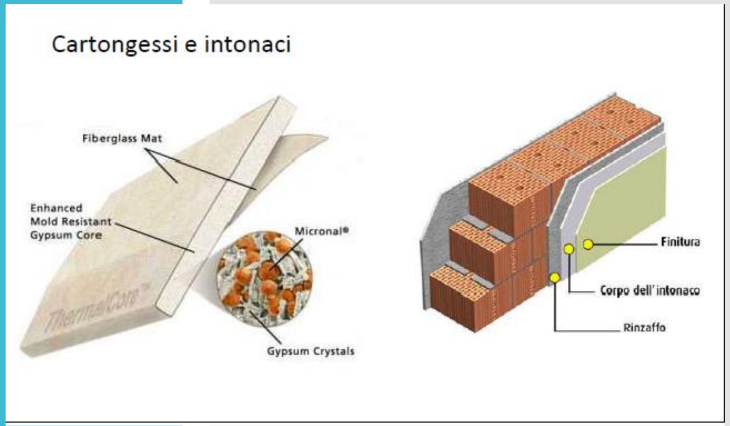
CNRNANOTEC INSTITUTE OF NANOTECHNOLOGY

References:

Alessandro Cannavale, Francesco Martellotta, Pierluigi Cossari, Giuseppe Gigli and Ubaldo Ayr, under revision, **Applied Energy**

UNIONE EUROPEA
REGIONE PUGLIA
SMARTPUGLIA INTELLIGENTI DAL FUTURO
a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

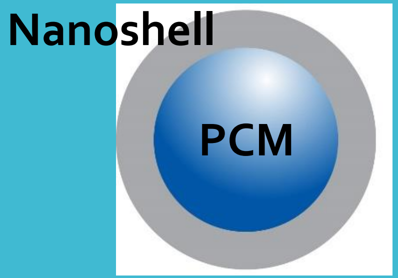
Biocompatible-PCMs



Core-shell nanostructures by solgel (Stober method)

Sol-gel method is suitable for NanoPCM with alkane, fatty acids and indium as core material and silicon dioxide as shell material.

Decanoic Acid (Capric Acid)
Molecular weight: **172,2646 g/mol**
Molecular Formula: **$CH_3(CH_2)_8COOH$**
Name: **n-Decanoic acid –** Nome comune: **Acido caprico**
Melting temperature: **27-32° C (Source: Sigma-Aldrich)**



Polyethylene Glycol (PEG600)
Molecular Weight: **570-630 g / mol**
Molecular Formula: **$H(OCH_2CH_2)_nOH$**
Name: **Polyethylene Glycol (PEG600)**
Melting temperature: **17-22° C (Source: Sigma-Aldrich)**

SiO_2@PolyethyleneGlycol600

SiO_2@Decanoic Acid

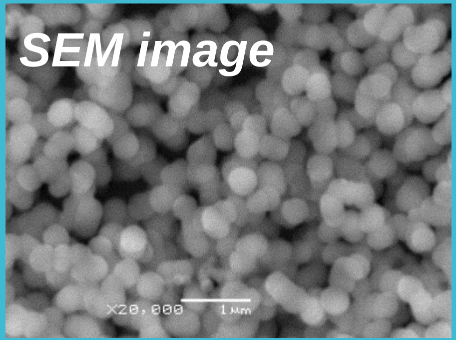
UNIVERSITÀ DEL SALENTO

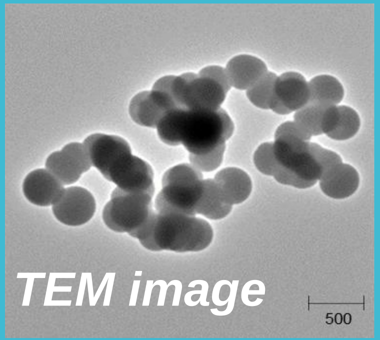
References:

A. Cannavale, V. De Matteis, F. Martellotta, U. Ayr, Manuscript in preparation

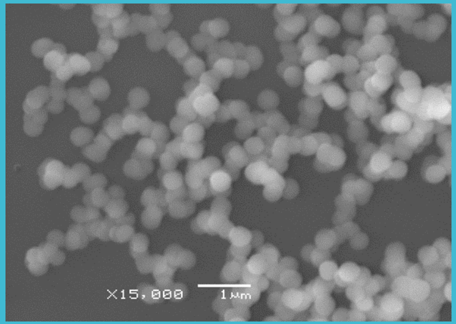
UNIONE EUROPEA REGIONE PUGLIA SMARTPUGLIA INTELLIGENTI DAL FUTURO a·r·t·i Agenzia regionale per la tecnologia e l'innovazione

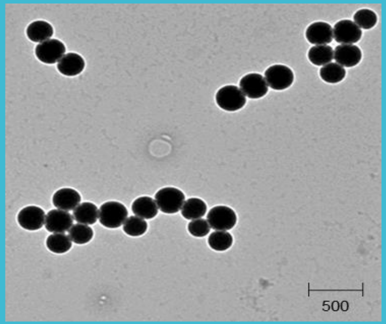
Biocompatible-PCMs





SiO_2@Decanoic Acid – 320 nm





SiO_2@PolyethyleneGlycol600 – 320 nm

UNIVERSITÀ DEL SALENTO

References:

A. Cannavale, V. De Matteis, F. Martellotta, U. Ayr, Manuscript in preparation

UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

a·r·t·i
Agenzia regionale per la tecnologia e l'innovazione

Biocompatible-PCMs

Toxicity assessment on lung epithelial cell lines (A549):

-These cells are an in vitro model to mimick inhalation exposure.
Viability assay was used to assess viability of cells after incubation with two high concentrations of our NanoPCMs (10µg/ml, 40 µg/ml) at typical timepoints for acute and chronic toxicity.

No significant variation of viability (<95%) was observed in both cases.

(Data reported as mean ±SD from three independent experiments).

UNIVERSITÀ DEL SALENTO

References:

A. Cannavale, V. De Matteis, F. Martellotta, U. Ayr, Manuscript in preparation

UNIONE EUROPEA

REGIONE PUGLIA

SMARTPUGLIA INTELLIGENTI DAL FUTURO

·a·r·t·i· Agenzia regionale per la tecnologia e l'innovazione

Biocompatible-PCMs

Material	Melting Temperature (°C)	Enthalpy of fusion (J/g)
Commercial PCM	25-26	70.22 (242)
SiO_2@Decanoic_acid	27-32	71.40 (156)
SiO_2@PEG_600	17-22	48.02 (108)

UNIVERSITÀ DEL SALENTO

References:

A. Cannavale, V. De Matteis, F. Martellotta, U. Ayr, Manuscript in preparation

UNIONE EUROPEA REGIONE PUGLIA SMARTPUGLIA INTELLIGENTI DAL FUTURO ·a·r·t·i· Agenzia regionale per la tecnologia e l'innovazione

Thank you for your kind attention!