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CAN THE BUILDING ENVELOPE PLAY A ROLE IN THE ENERGY TRANSITION?

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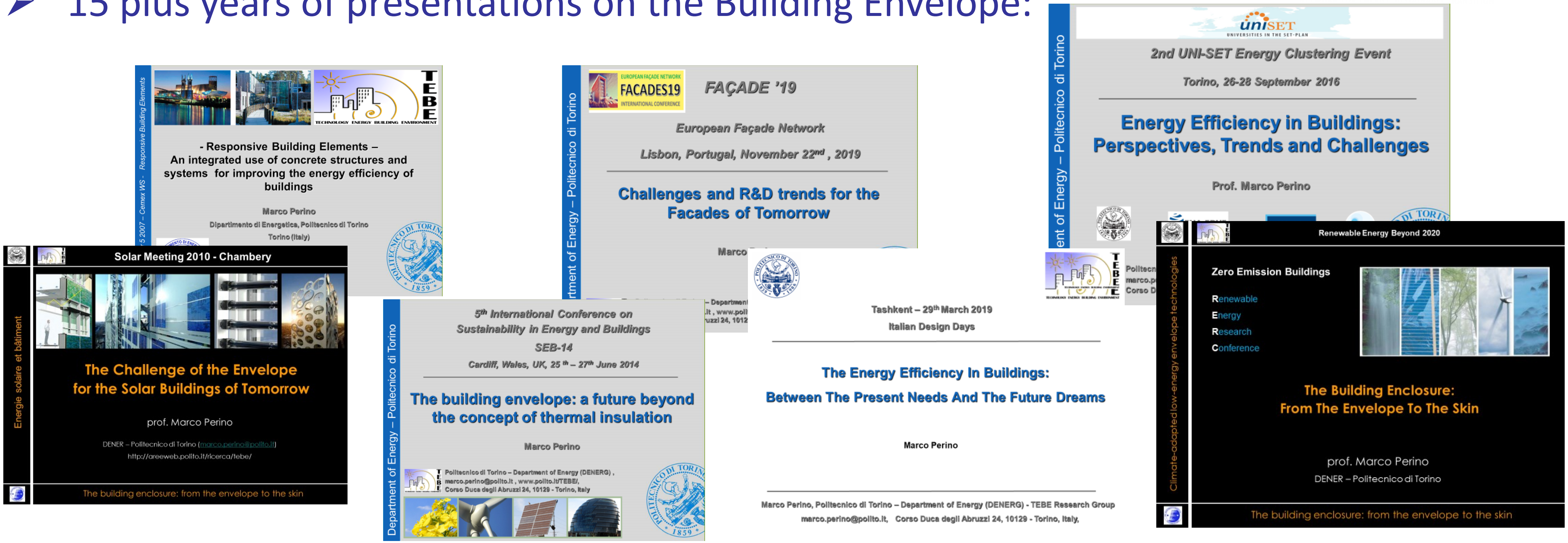
Introduction - 1

- 15 plus years of presentations on the Building Envelope:



- Is there still something to say or we are at a point where “most that can be said has already been said”?

- The question could seem to be rhetorical, but it is not and the answers are far for being trivial.

INTRODUCTION - 2

Key words for the search: “Building Envelope”, “Façade”

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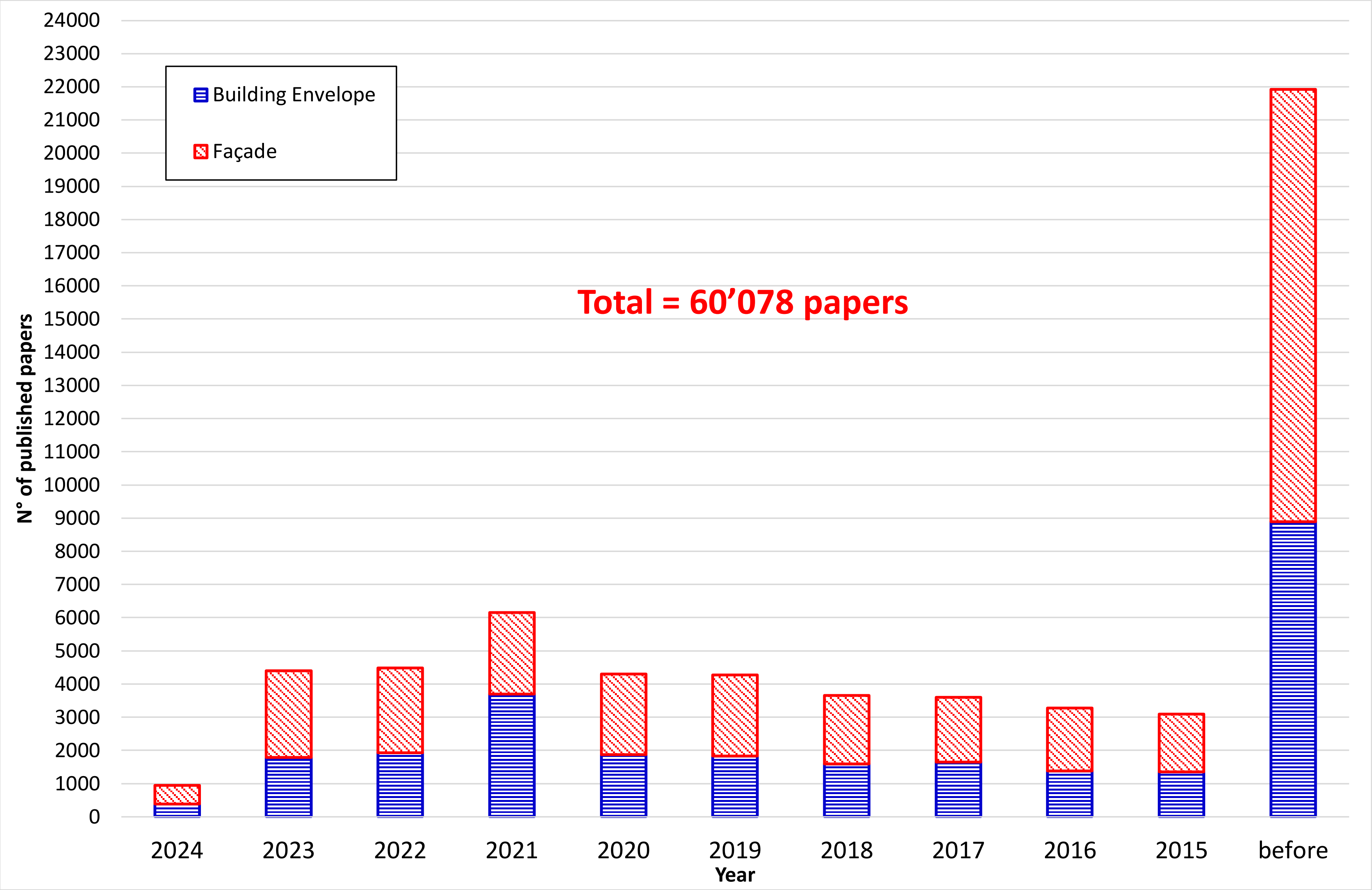
Publication type		
	Bld.env.	Facade
Journal	15692	21339
Conference Proceedings	6949	8340
Book Section	1281	2154
Book	865	375
Generic	1560	1523



Introduction - 2

Such figures suggest, that

YES

may be it is still worth focusing on

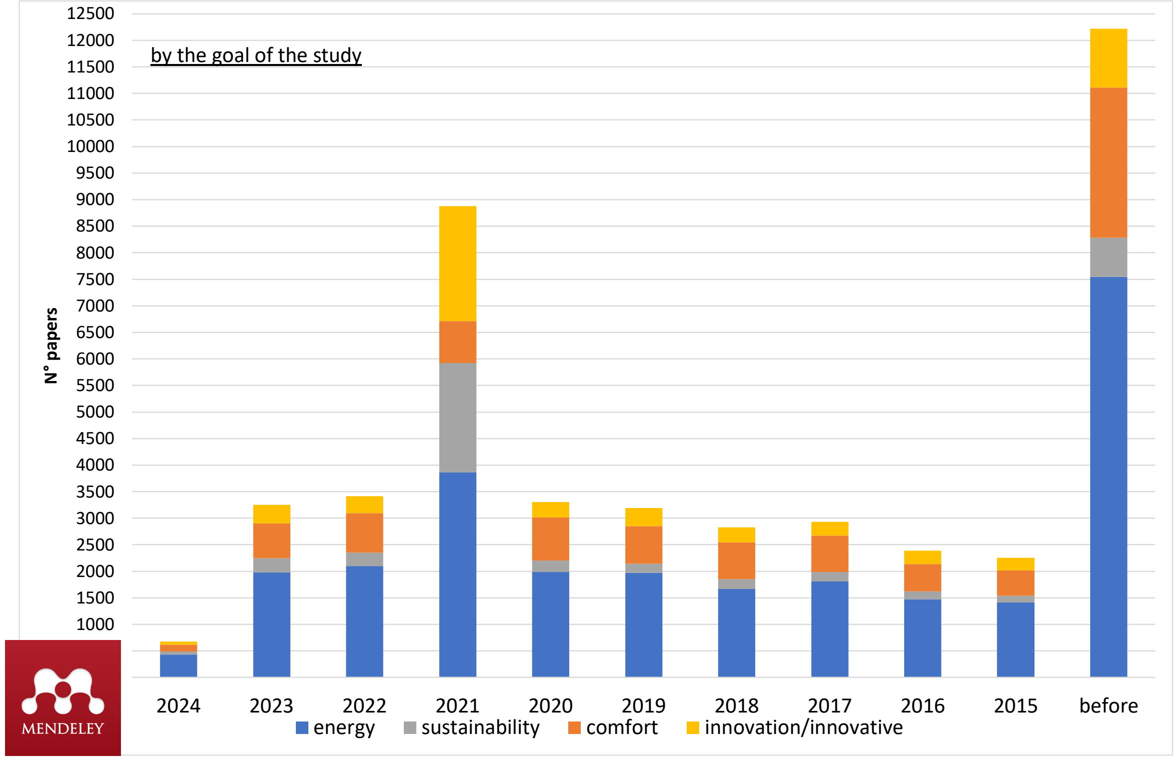
this subject

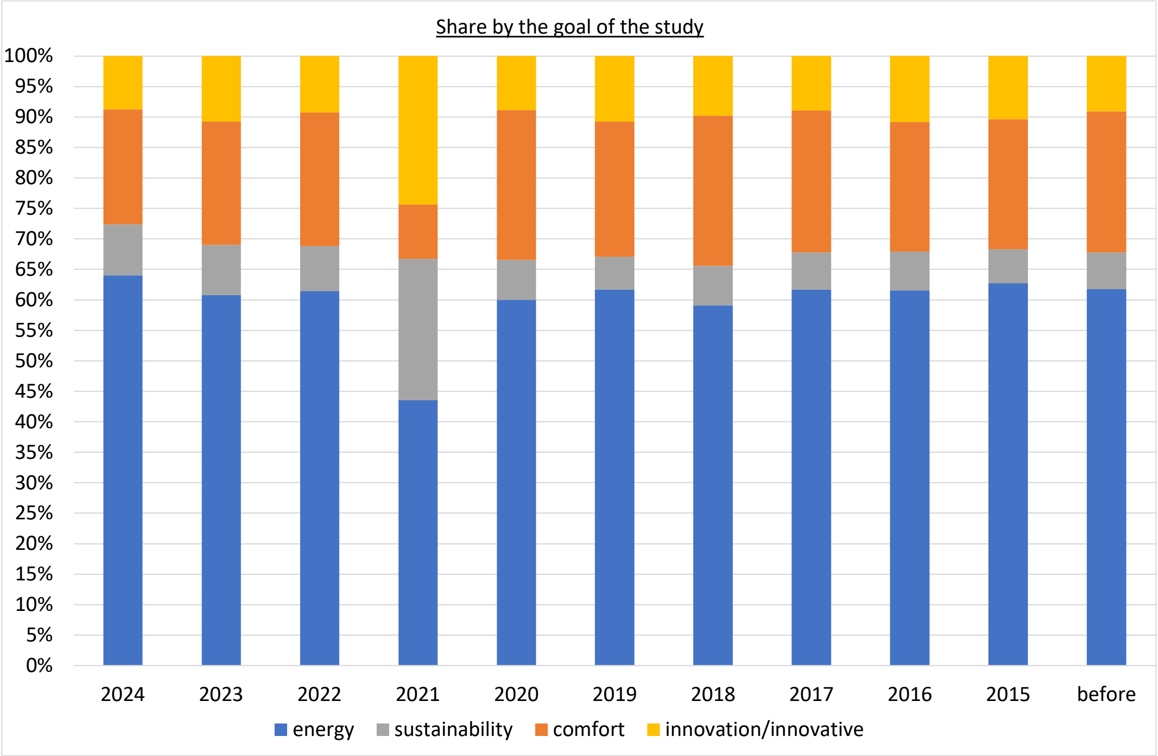
INTRODUCTION - 3

In this presentation I will try:

- To give an overview of the subjects that were popular in the Building Physics field of over the years and the ideas that drove the research on the Building Envelope,
- To understand what role can and will play the Building Envelope in the energy transition.

Motivations that drive the research – the picture:



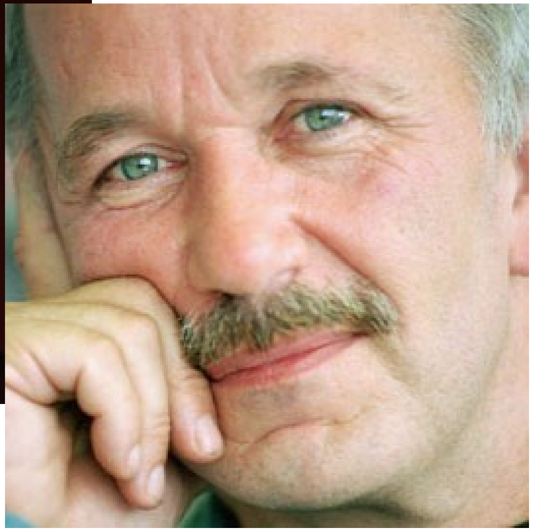


INTRODUCTION - WHAT IS THE BUILDING ENVELOPE?

- *"A building envelope or building enclosure is the physical separator between the conditioned and unconditioned environment of a building, including the resistance to air, water, heat, light, and noise transfer"* [1],
- *"It is a collection of construction components and subsystems that separates interior conditioned space from unconditioned space or the outdoors. It is the boundary through which energy and mass can be transferred"* [2],
- A building's envelope includes doors, roof, walls, foundation, insulation, seals, and windows (SEB).

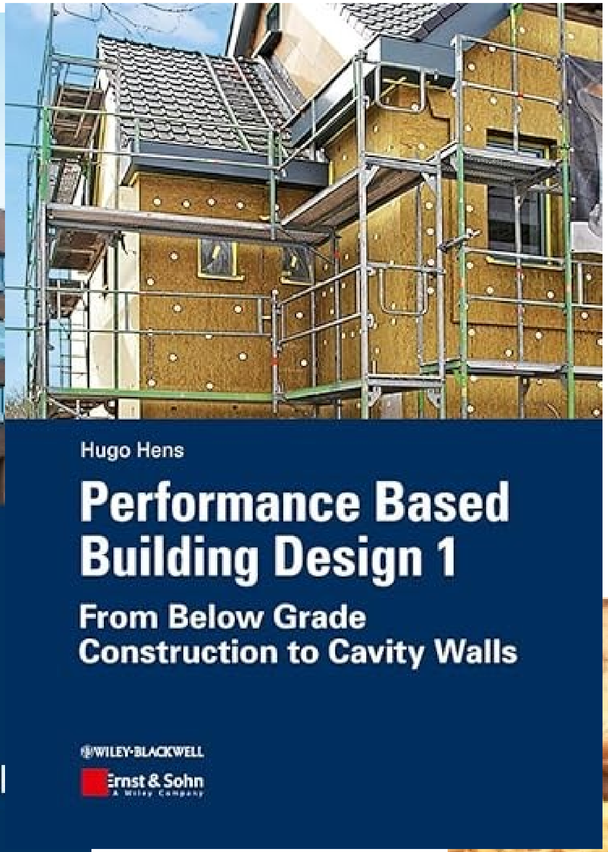
- The many functions of the building envelope can be separated into three categories:[3]
  - Support (to resist and transfer structural and dynamic loads)
  - Control (the flow of matter and energy of all types)
  - Finish (to meet desired aesthetics on the inside and outside)

THE HISTORY: ON THE SHOULDERS OF GIANTS

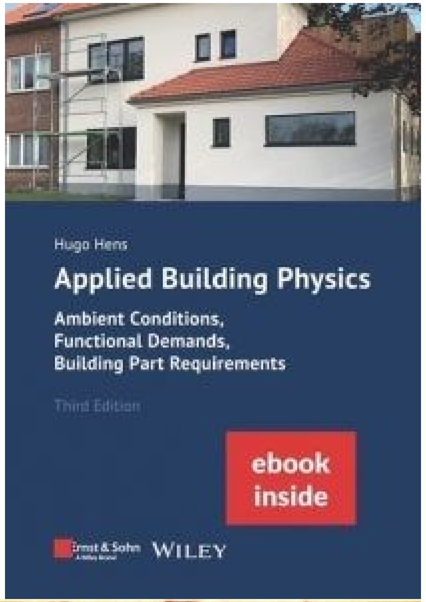


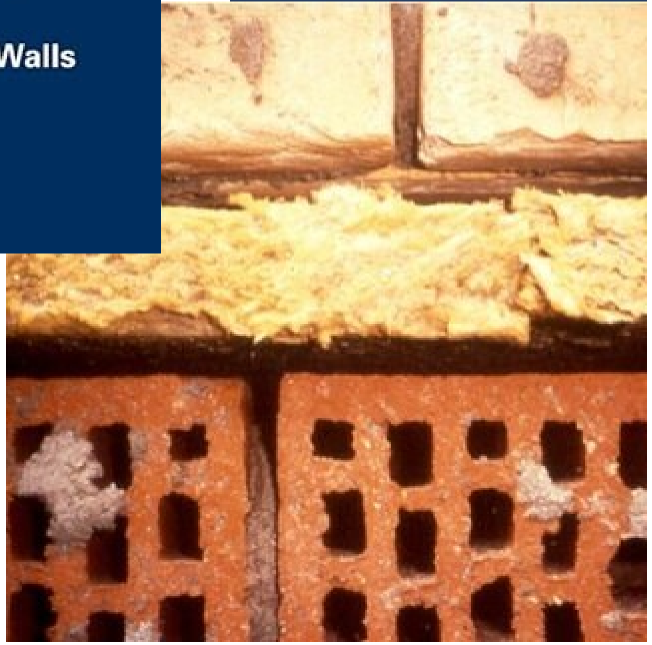
Newton, 1675 "if [we can] see further, it is by standing on the shoulders of giants”

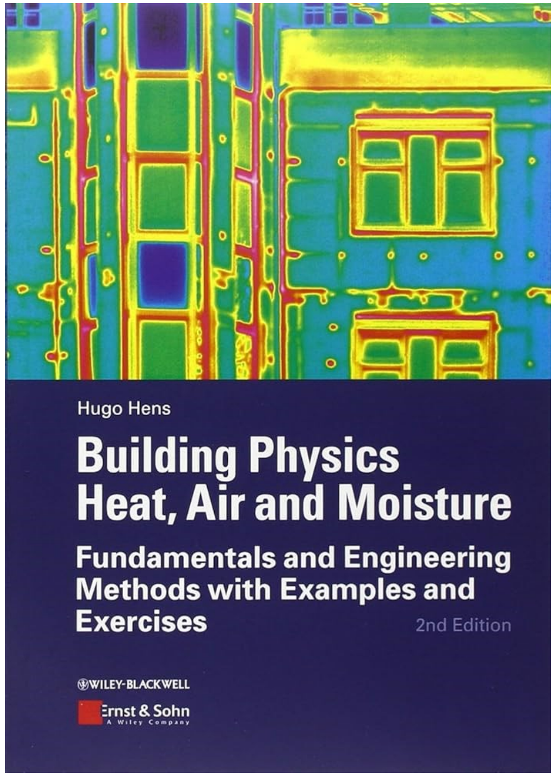
The history - traditional approach to the Building Envelope - 1



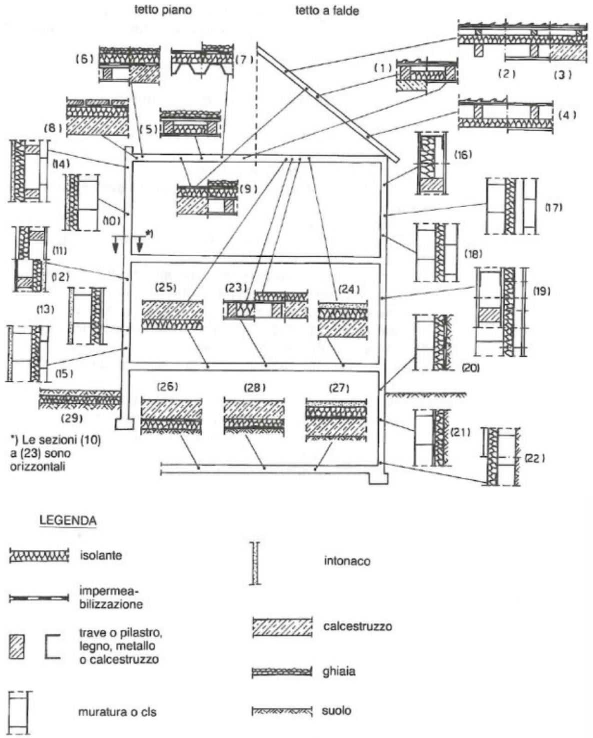
year →	1992	2006	2010	2012	2014
	U_{max}(W/(m².K)) / R_{min} (m².K				
	3.5	2.5 1.6	2.5 1.6	2.2 1.3	1.8 1.1
	0.6	0.4	0.3	0.27	0.24
	0.6/*1.0*	0.6	0.4	0.32	0.24
	3.5	2.9 1.6	2.9 1.6	2.2 1.3	2.0 1.1
	/ **1**	/ **1**	/ **1**	/**1.3**	0.4/**1.**
utdoors	0.6	0.6	0.6	0.35	0.3
e spaces	0.6	0.4 / **1**	0.4 / **1**	0.35 /**1.3**	0.3 /**1.7**
e spaces	0.9	0.4 / **1**	0.4 / **1**	0.35 /**1.3**	0.3 /**1.7**
n grade	1.2	0.4 / **1**	0.4 / **1**	0.35 /**1.3**	0.3 /**1.7**
	3.5	2.9	2.9	2.2	2.0
	1.0	1.0	1.0	1.0	1.0
en flats	1.0	1.0	1.0	1.0	1.0
frost- e pro-	/ **1**	/ **1**	/ **1**	/**1.2**	/**1.**

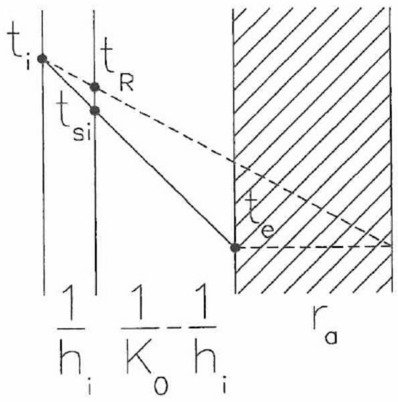






The history - traditional approach to the Building Envelope - 2





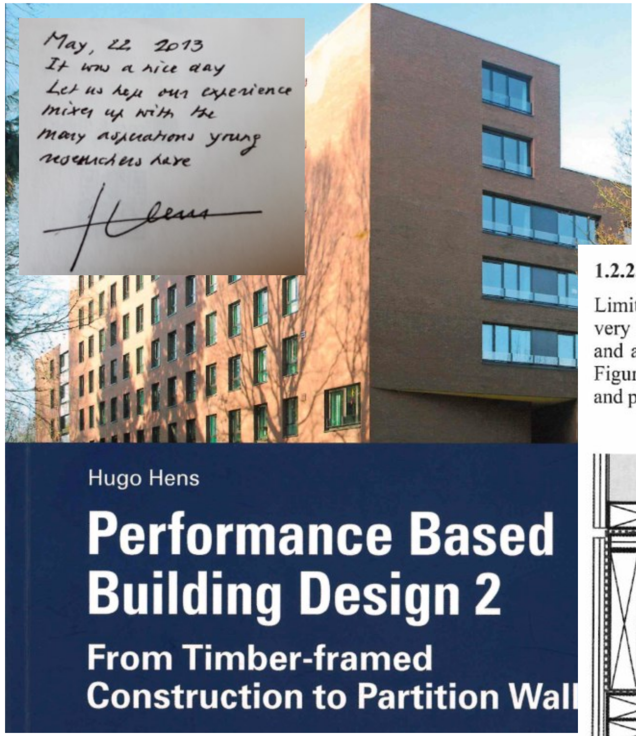
PREMESSA

L'involucro edilizio costituisce l'elemento di separazione tra l'ambiente esterno, per sua natura variabile, e l'ambiente interno, che deve invece essere caratterizzato da condizioni il più possibile stabili e rispondenti alle esigenze di comfort ambientale. All'involucro edilizio sono quindi richiesti specifici requisiti prestazionali[(1)] al fine di garantire il soddisfacimento di esigenze quali:

- sicurezza;
- benessere igrotermico;
- isolamento termico;
- isolamento acustico;
- di aspetto;
- di durabilità;
- di attrezzabilità;
- di protezione dagli agenti atmosferici;
- di protezione dall'irraggiamento solare.

In particolare al fine di garantire un comportamento dell'edificio energeticamente efficace e di assicurare il benessere igrotermico all'interno degli ambienti sono da considerare con attenzione i requisiti relativi all'isolamento termico e al controllo della condensazione nella massa.

The history - traditional approach to the Building Envelope - 3



1.2 Performance evaluation

1.2.2 Building physics: heat, air, moisture

1.2.2.1 Air tightness

Air tightness of timber-framed envelopes is not taken for granted. The outside finish, the building paper, the sheathing, as well as the insulation, all are air-permeable. Contributing factors are, for the building paper, the overlaps between the strips, for the sheathing the joints

1.2.2.5 Thermal bridges

Limited thermal bridging is a clear advantage of timber-framed c very low whole wall thermal transmittances are imposed, does on and alternative solutions for header plates, frame corners, window Figure 1.14. Metal framed construction is a different story. As Table and plate shaping and the use of thermally insulating sheathing then

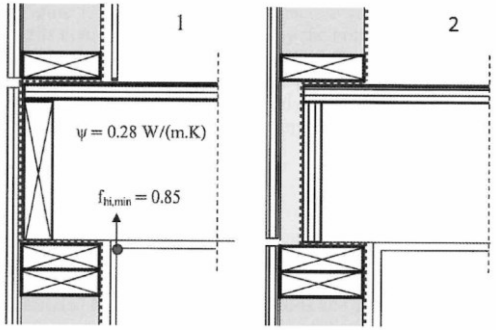


Figure 1.14. Timber-framed outer wall: adapting header plate design to avoid thermal bridging.

1.2.2.2 Thermal transmittance

The discussion relates to outer walls only. For roofs and floors, reference is made to the chapter on floors in Performance Based Building Design 1 and the chapters that follow on roofs. As always, the clear and whole wall thermal transmittances (U) differ, the last accounting for studs, top and bottom plates. In the case of an airtight outer wall, the series/parallel circuit of Figure 1.6 allows a fair guess of the whole wall thermal transmittance, as do also the following linear thermal transmittances (ψ):

Stud	Bottom plate	Top plates
$\psi = 0.017$ W/(m · K)	$\psi = 0.010$ W/(m · K)	$\psi = 0.023$ W/(m · K)

With mineral wool or cellulose as thermal insulation and a brick veneer as outside finish, the thicknesses of Table 1.4 give whole wall thermal transmittances of 0.4, 0.2 and 0.1 W/(m^2 · K) for 40 and 60 cm centred studs.

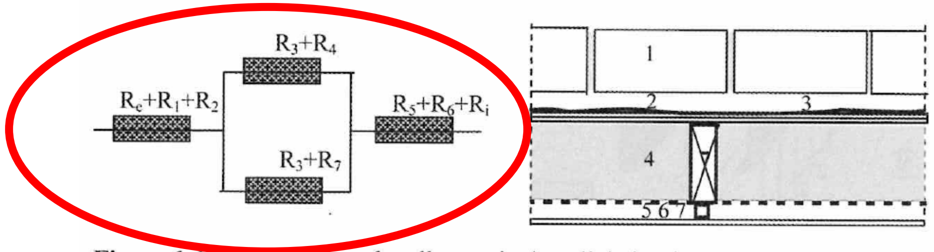


Figure 1.6. Timber framed wall as series/parallel circuit.

1.2.2.3 Transient response

On a daily basis, timber-framed outer walls have an admittance way below 3.9 W/(m^2 · K) (for a surface film coefficient indoors of 7.8 W/(m^2 · K)), while the dynamic thermal resistance hardly differs from the steady state thermal resistance and temperature damping does not even approach a value 15. Better thermal insulation hardly changes things, see Table 1.7.

Table 1.7. Temperature damping, dynamic thermal resistance, and admittance (1-day period).

Wall, brick veneer as outside finish	Temperature damping + faze –, h		Dynamic thermal resistance + faze m^2 · K/W, h		Admittance + faze W/(m^2 · K), h	
4 cm MW, U_o = 0.47 W/(m^2 · K)	2.1	7.0	2.8	4.2	0.74	2.9
14 cm EPS, U_o = 0.21 W/(m^2 · K)	4.3	9.3	6.6	5.0	0.65	4.3

1.2.2.4 Moisture tolerance

Due to water sensitivity of the softwood used, timber-framed construction is inherently less moisture tolerant than massive construction. Above a moisture ratio of 20% kg/kg the risk to see mould colonizing the timber increases sharply whereas above 30% kg/kg fungal attack and bacterial rot become likely. To avoid problems the following requirements should be fulfilled:

THE HISTORY - TRADITIONAL APPROACH TO THE BUILDING ENVELOPE - 3

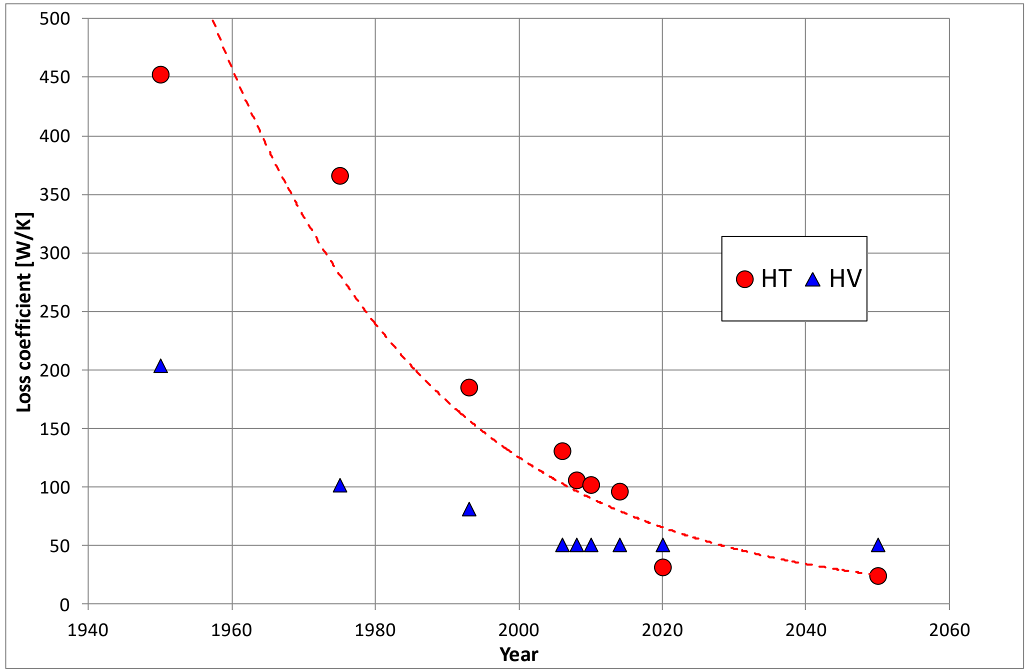
The key words that pop up:
"thermal insulation", "Protection", "Thermal Transmittance (U-value)", "Air Tightness", "Thermal bridges", "Moisture Protection".

To achieve the best possible "barrier" effect and to disconnect, as much as possible indoors and outdoors

The history - traditional approach to the Building Envelope - 4

This phase can be called the “Energy Conservation Era”, where :

- the main goal was to limit the thermal loads caused by the building envelope,
- The concern was essentially the heating energy demand,
- The idea was to maximize the solar and other free gains.



IEA Energy Conservation in Buildings & Community Systems

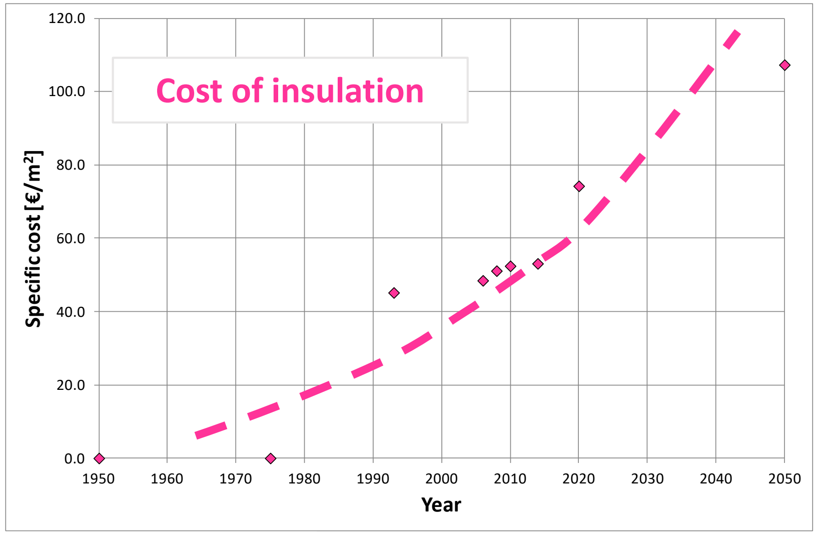
This indeed allowed to significantly improve the overall energy efficiency of buildings and to reduce the space heating …

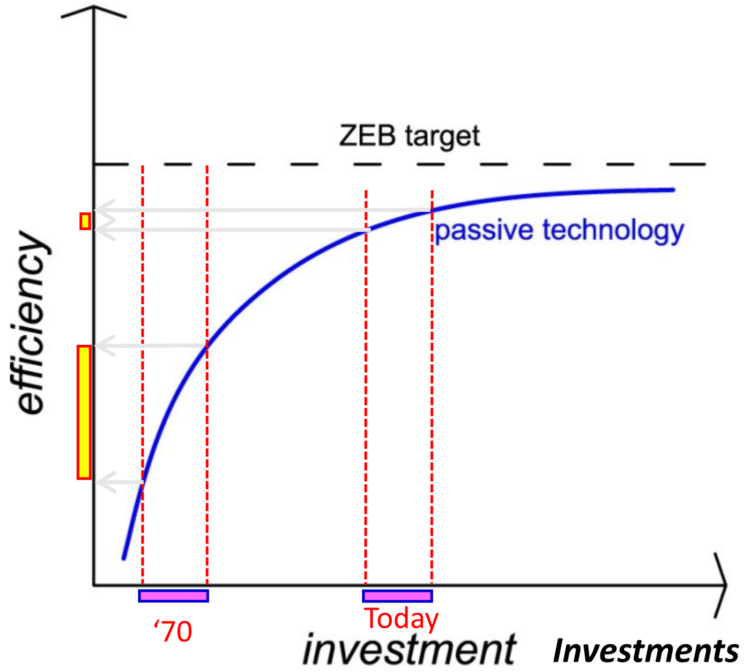
BUT ….

Limitations of the Energy Conservation approach - 1

keeping to optimize the performance just looking at a single goal (e.g. increasing the thermal insulation) leads, at a certain point, to hit the wall:

"law of diminishing returns"





Drawbacks:

Increase of energy demand for:

- Space cooling,
- Artificial lighting,
- Plug-loads.

&

- Severe problems of overheating (even in cold climates),
- Transmission losses become small compared to ventilation losses.

LIMITATIONS OF THE ENERGY CONSERVATION APPROACH - 1

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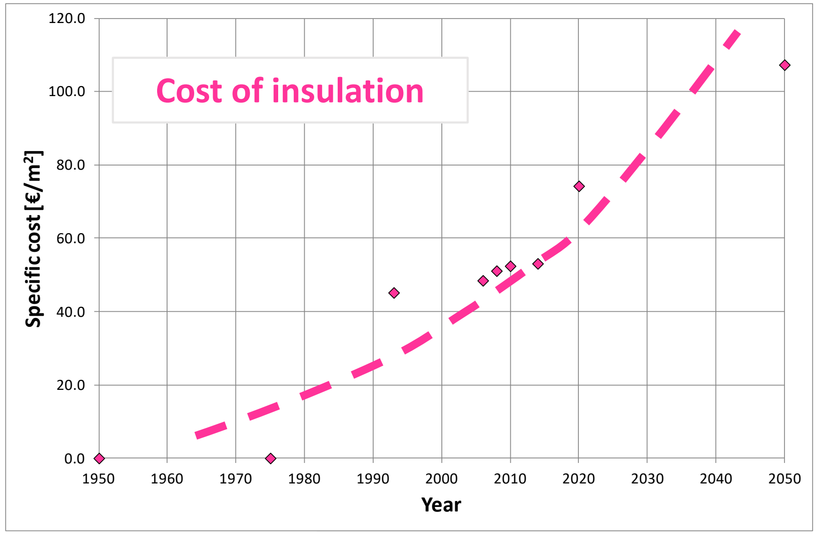

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BEYOND THE ENERGY CONSERVATION APPROACH – THE 1ST EVOLUTION - 1

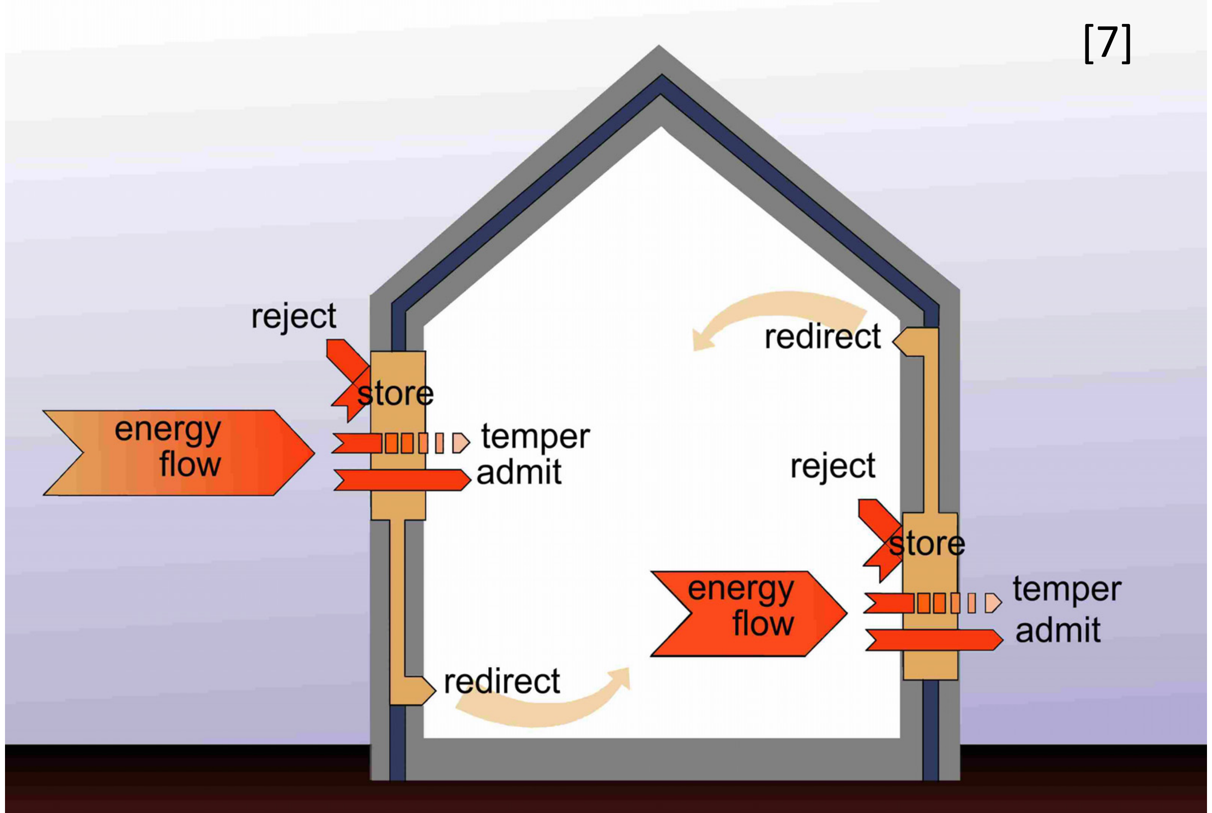
In the first decade of the 2000s there was the **need to revolutionize the concepts.**
The **dogma** of a fixed "barrier" component, that is disconnected from the other building services/functions and does not change its features, behavior and functions, started to be unsatisfactory and limiting.
The **one-size-fits-all approach was no more functional.**

The new code-words were:

- Responsivity,
- Adaptability,
- Dynamic behavior,
- Integration,

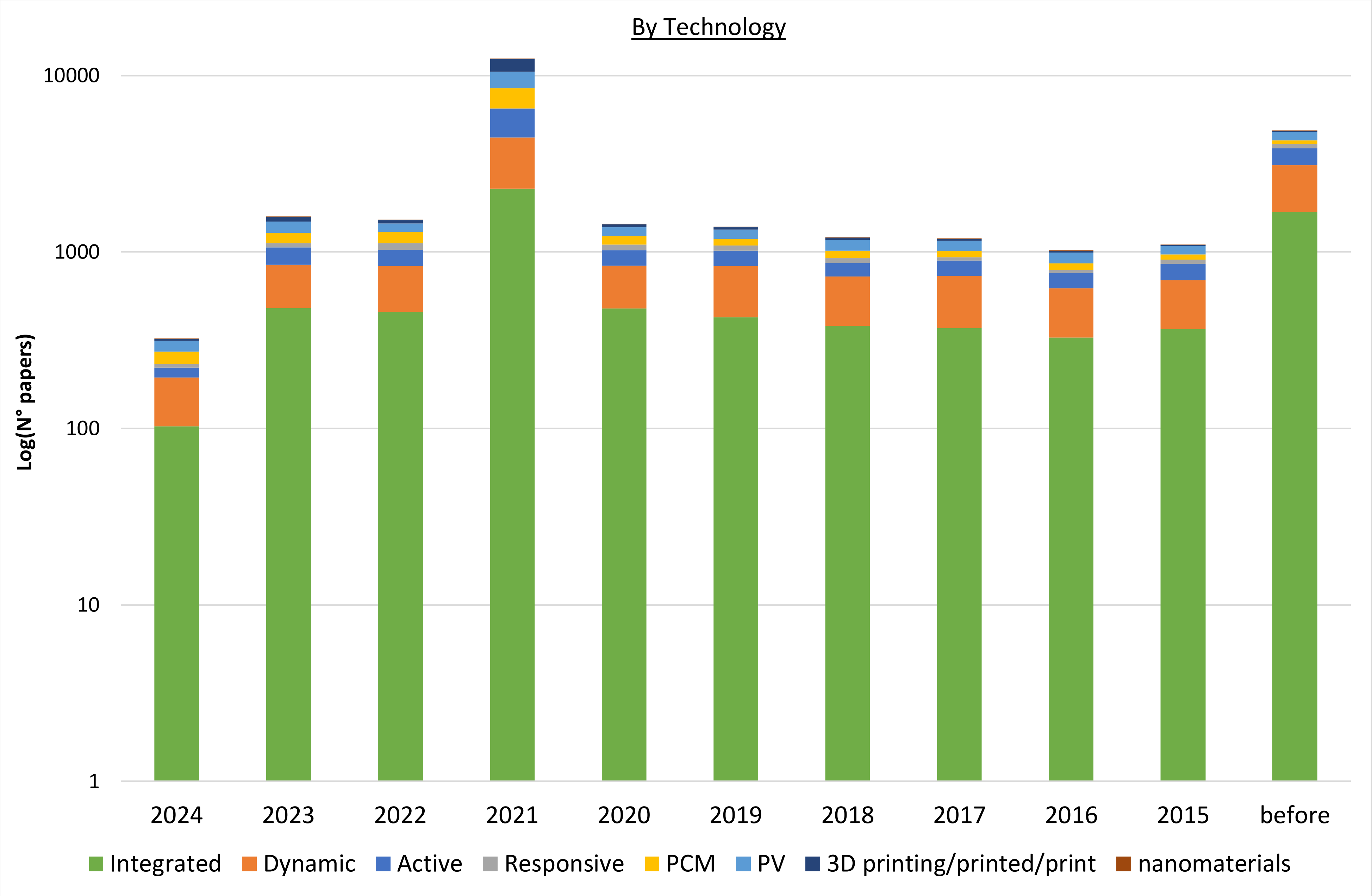
And the optimization started to be on the basis of a "**Total Energy Approach**"

[7]



IEA, Annex 44 – "Integrating Environmentally Responsive Elements in Buildings"

BEYOND THE ENERGY CONSERVATION APPROACH – THE 1ST EVOLUTION - 2



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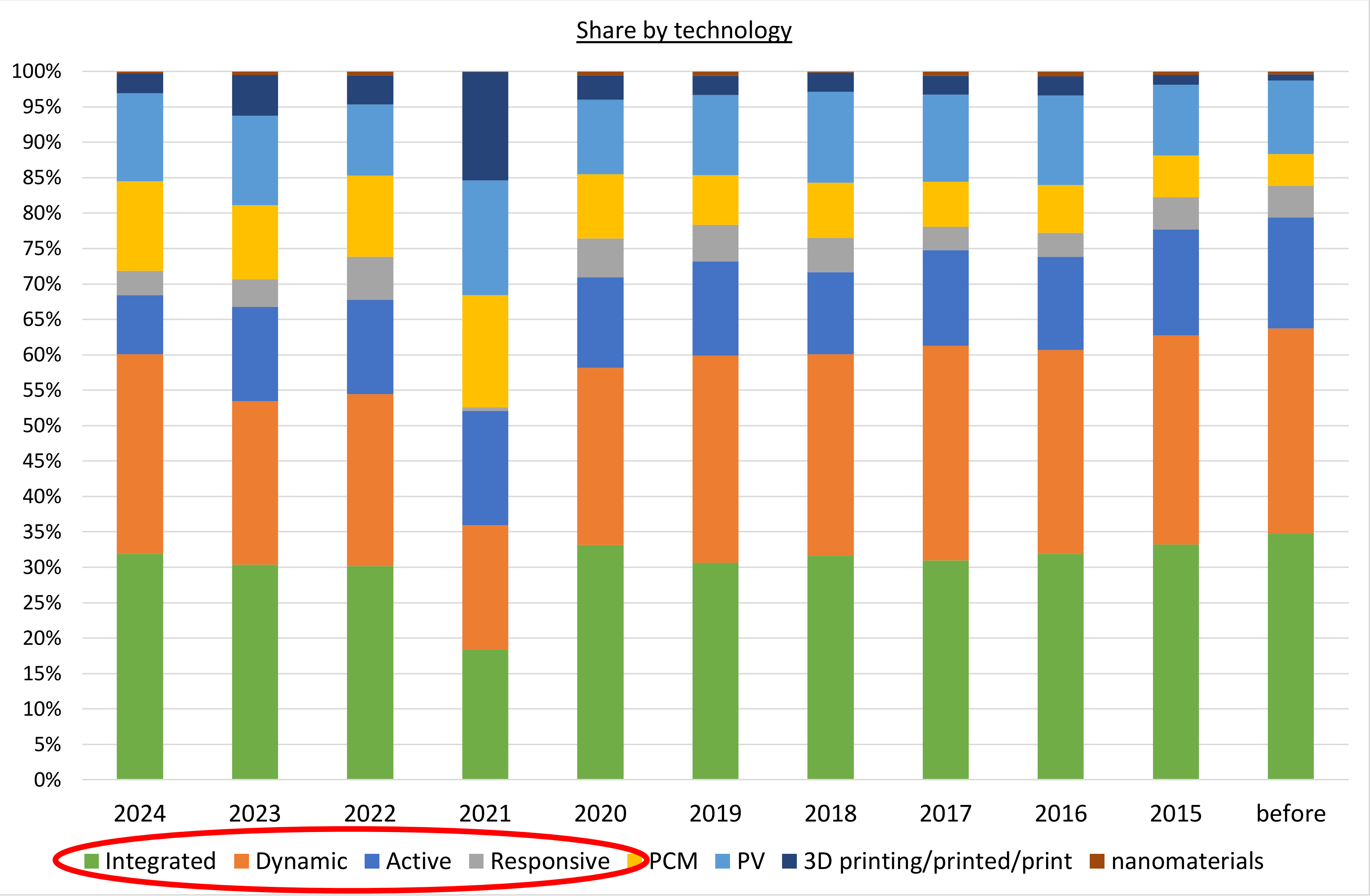
Beyond The Energy Conservation Approach – the 1st evolution - 3



BEYOND THE ENERGY CONSERVATION APPROACH – THE 1ST EVOLUTION - 1

The "Integration and Adaptability Era"

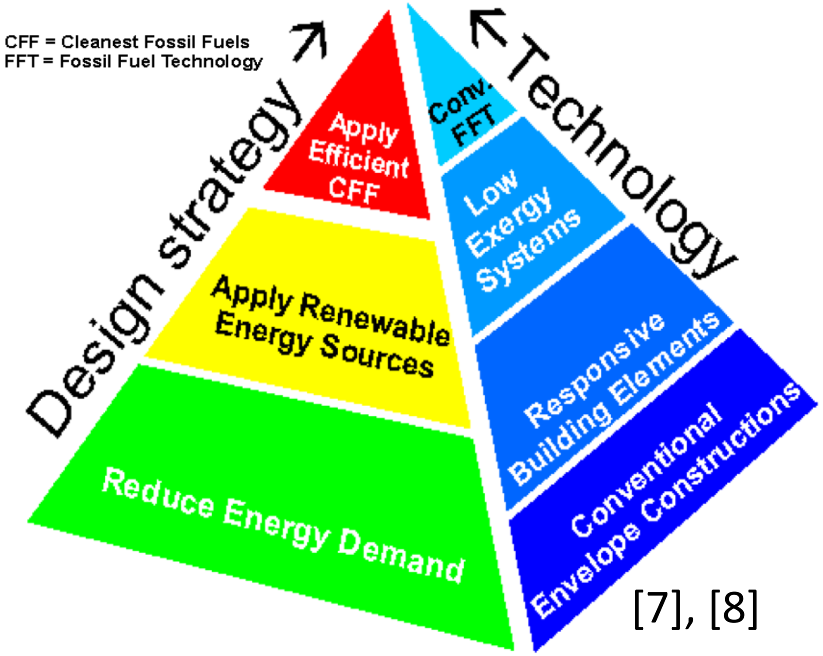
- IEA - Annex 44 "*Integrating Environmentally Responsive Elements in Buildings*"

IEA Energy Conservation in Buildings & Community Systems

EBC

Energy in Building and Communities Programme

Design Pyramid



[7], [8]

- COST Action - TU1403 "*Adaptive Facades Network*".

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

COST is supported by the EU Framework Programme Horizon 2020

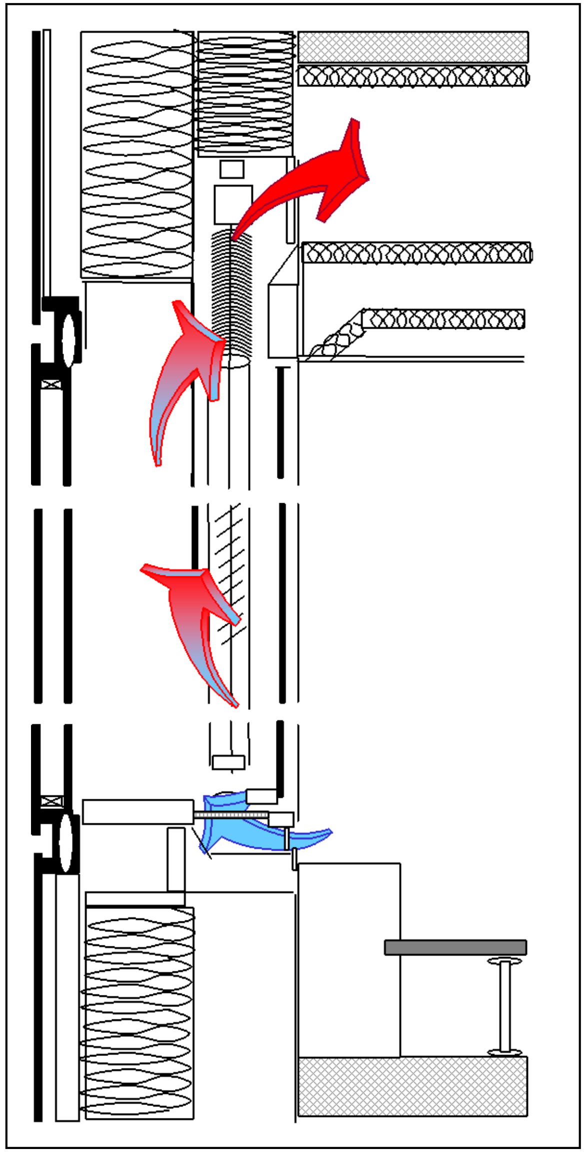
BEYOND THE ENERGY CONSERVATION APPROACH – THE 1ST EVOLUTION - 1

Typical technological expressions:

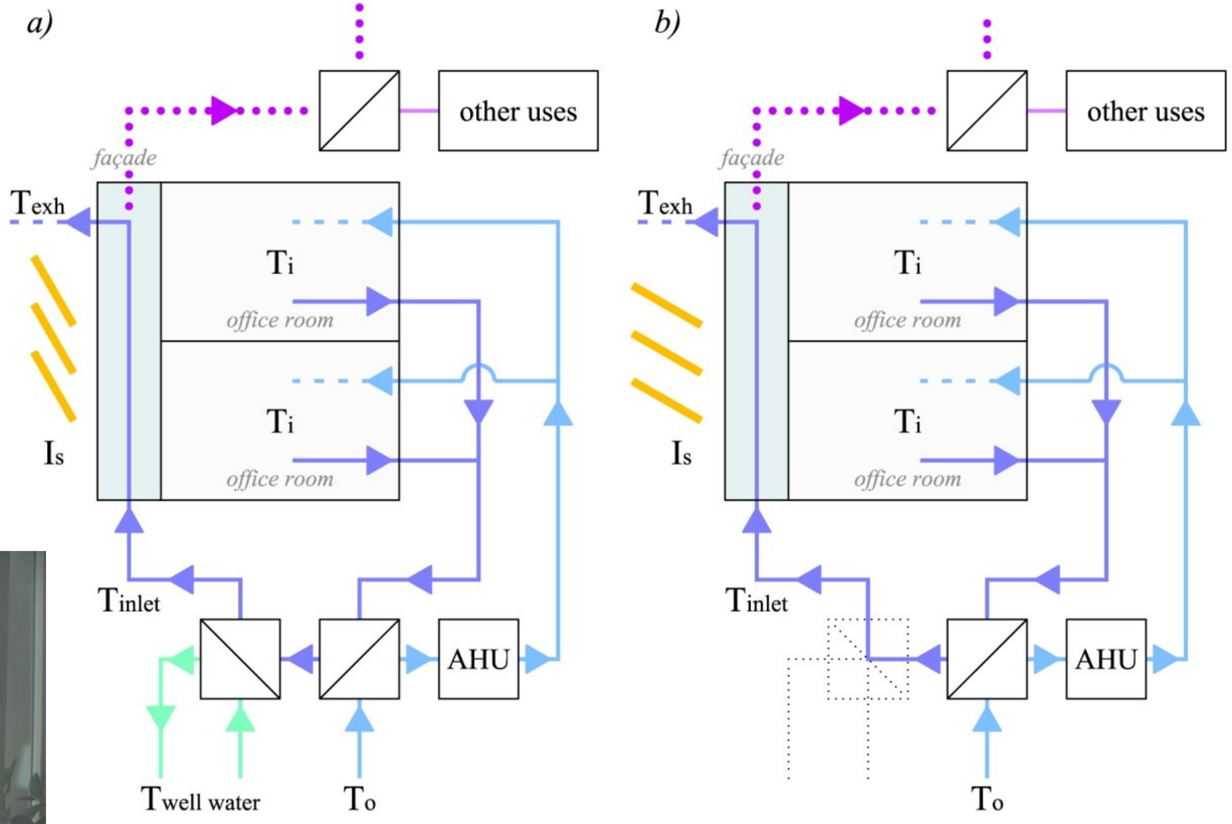
- **AIF** – Advanced Integrated façade (double skins, climate façade, ventilated façades, …),
- **KF** - Kinetics Façade - KF
- **PCM** - Phase Change Materials (integrated in opaque/transparent components),
- **SW** (Smart Windows)/**SG** - Switchable Glazing (electrochromic, thermotropic, thermochromic, chromogenic, photovoltachromic, …) and Shading Devices
- **TABE** – Thermally Activated Building Elements
- **EC** - Earth Coupling

The Integration and Adaptability phase – Examples - 1

Transparent ventilated façades:

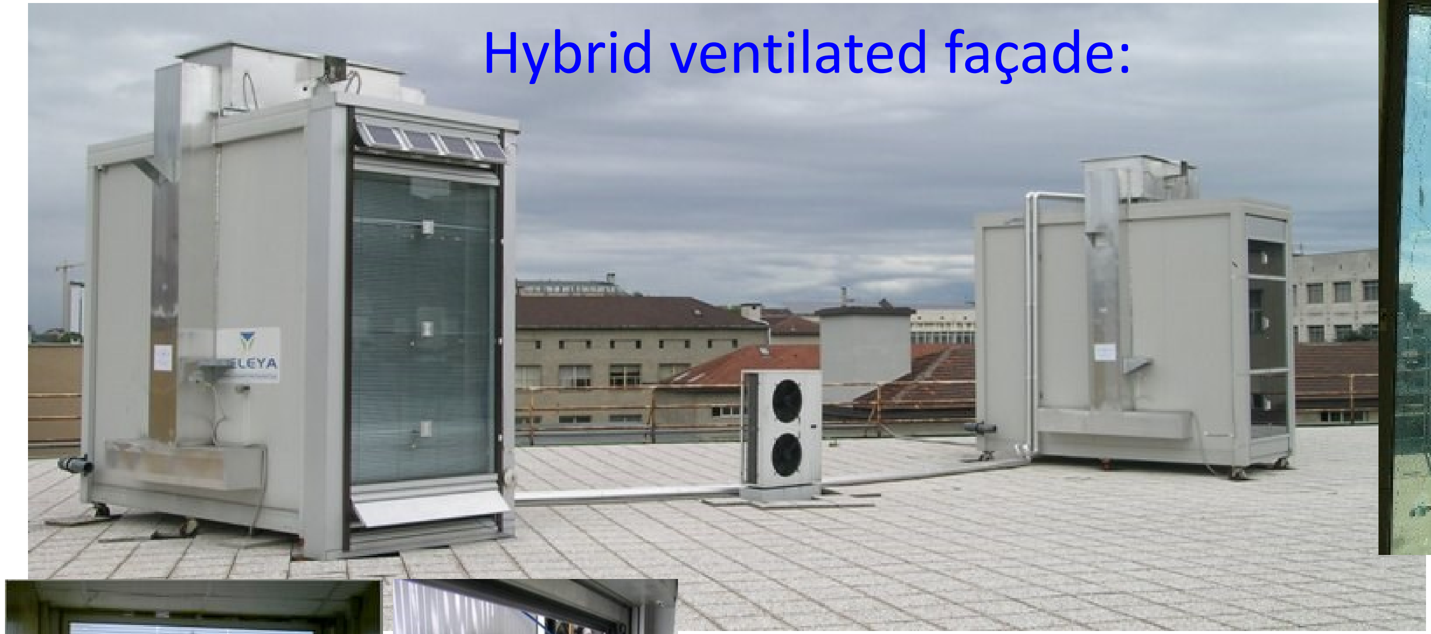


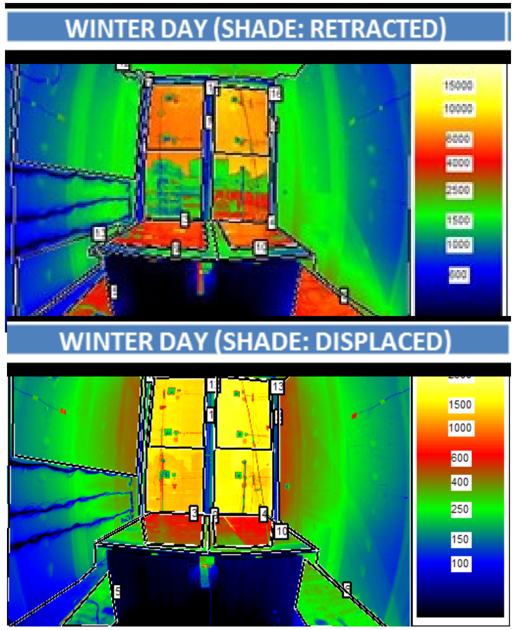
Highly integrated "climate" façade:

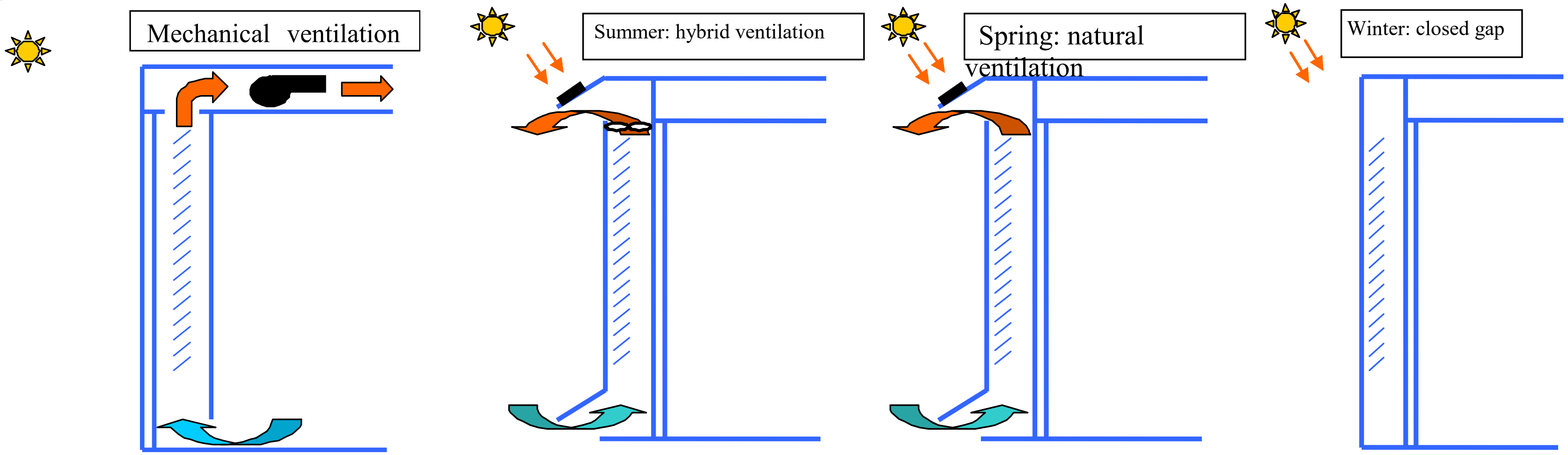


The Integration and Adaptability phase – Examples - 3

Hybrid ventilated façade & AIF prototypes:





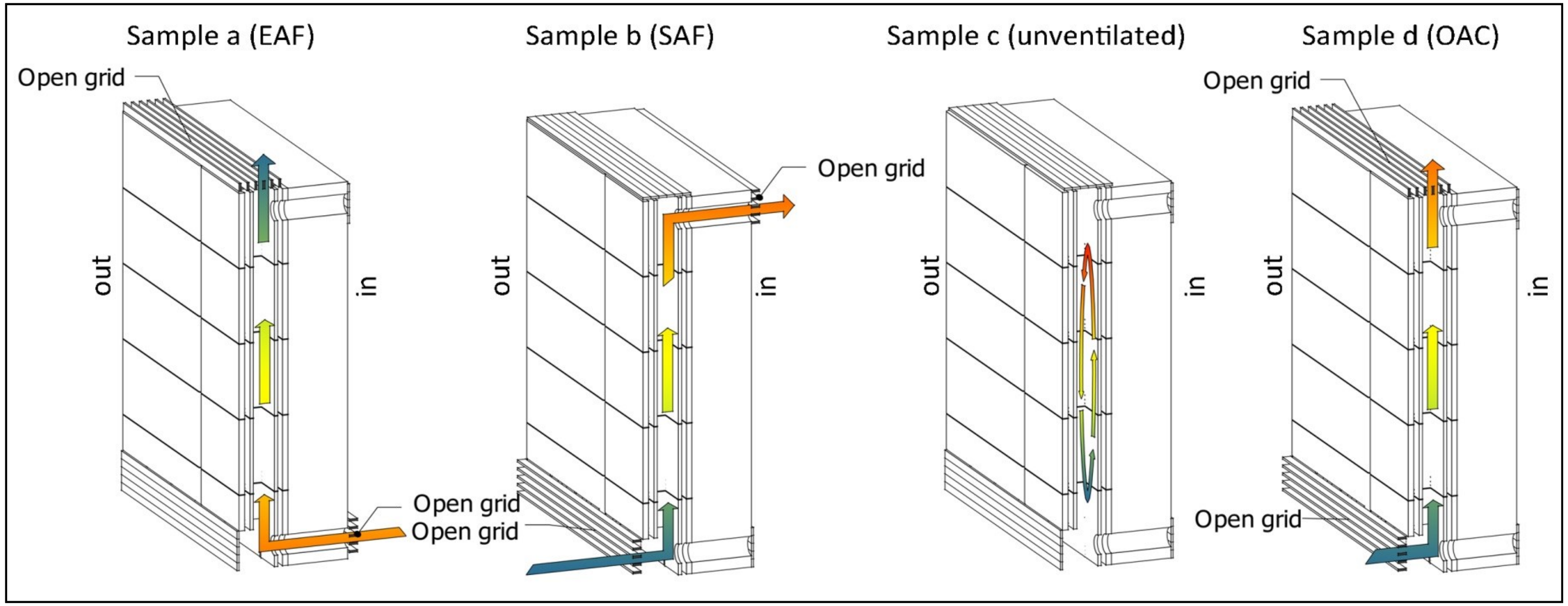


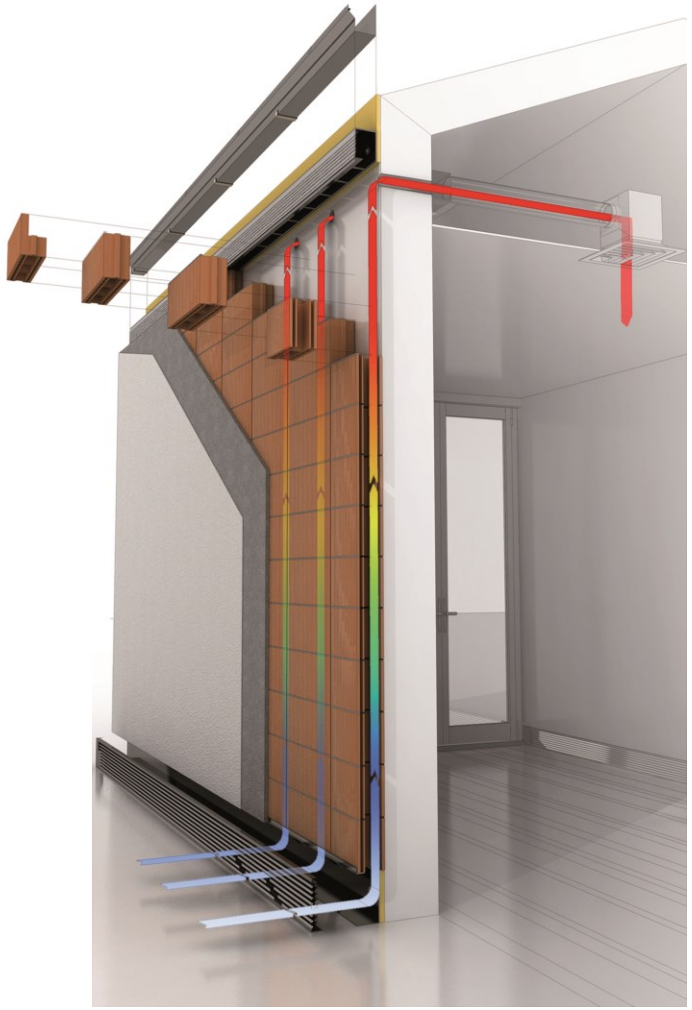
The Integration and Adaptability phase – Examples - 4

Technology Energy Building Environment

TEBE

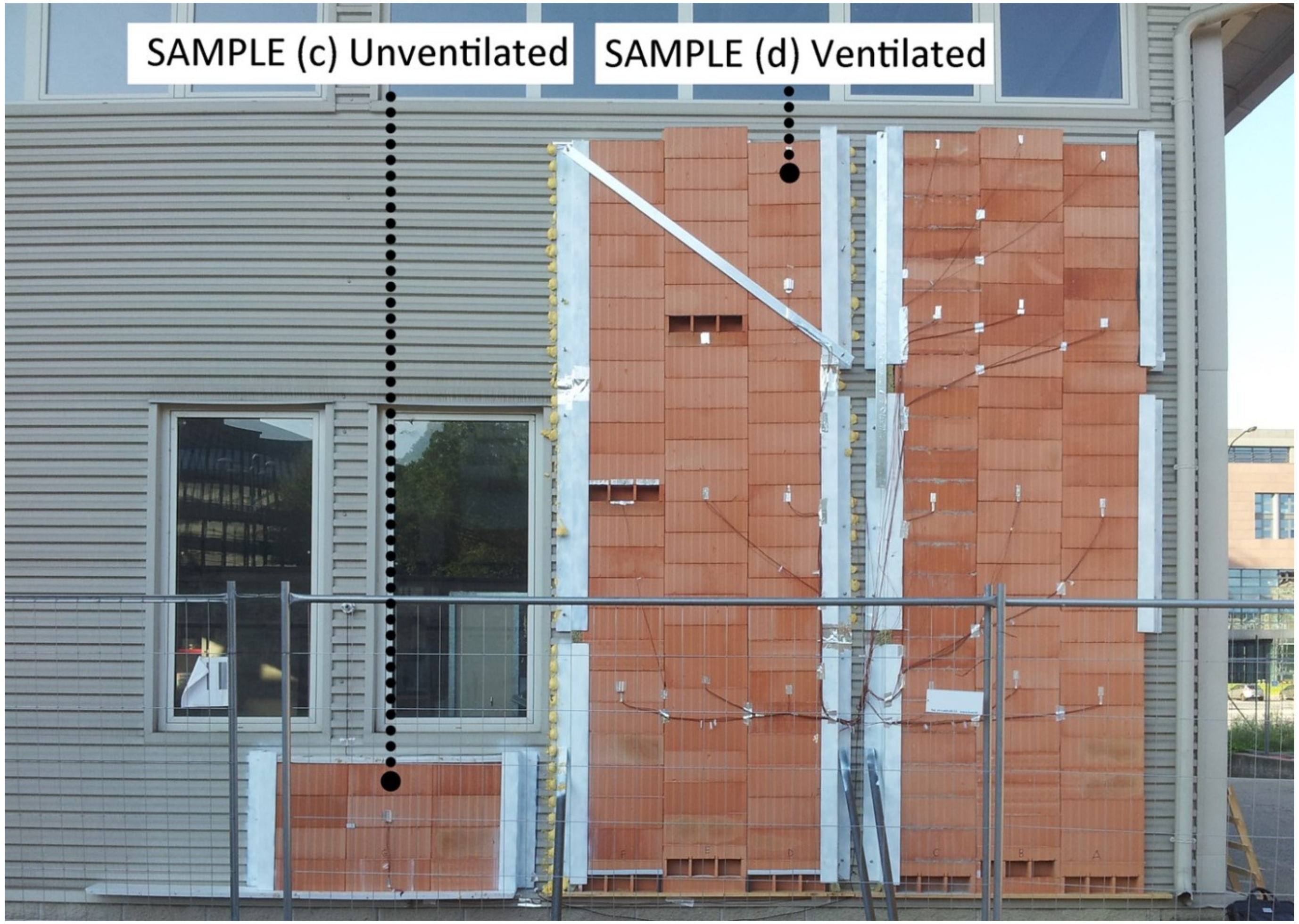
Opaque integrated façades:



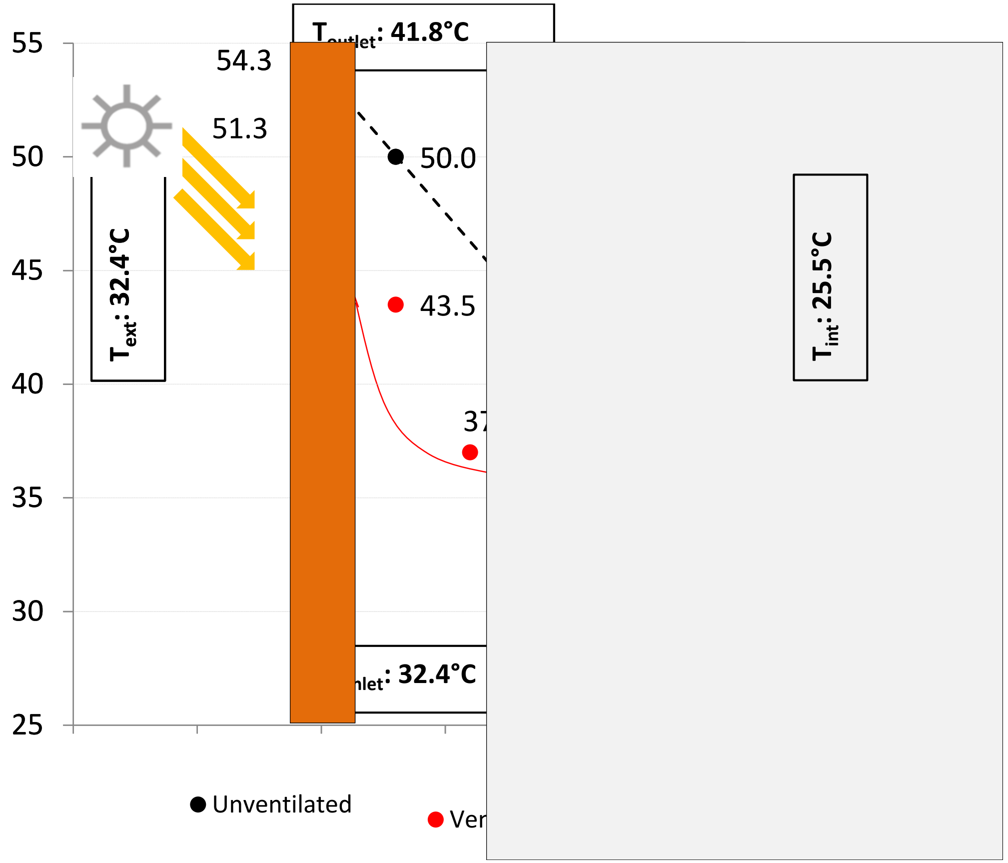


Test Sample	Ventilation Type	Experimental Condition	Air Flow Origin	Air Flow Destination
(a) EAF	MV	laboratory	interior	exterior
(b) SAF	MV	laboratory	exterior	interior
(c) RUF	unventilated	in field	-	-
(d) OAC	NV	in field	exterior	exterior

Opaque integrated façades:

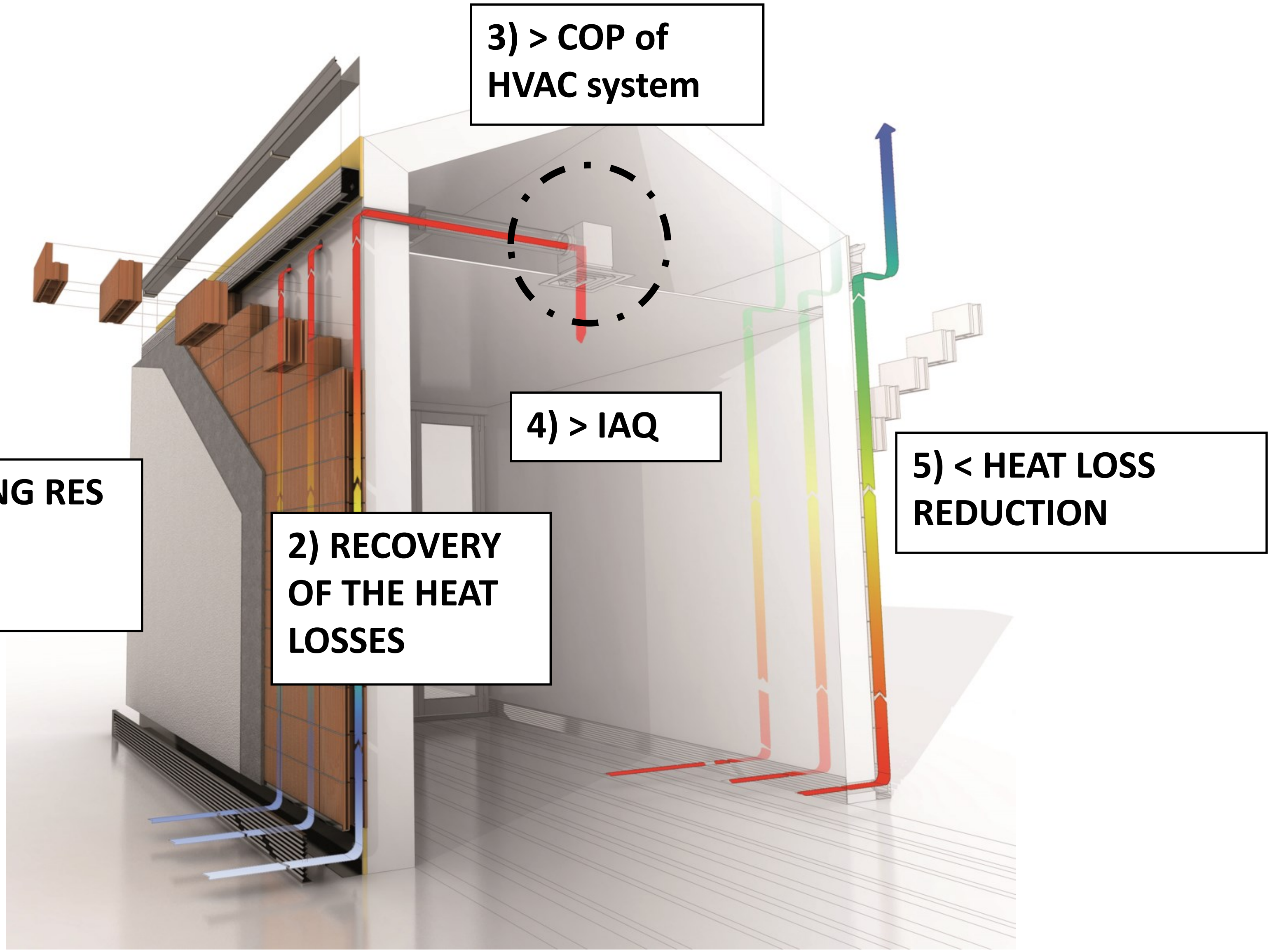


Wall temperature profile (16:00-17:00 p.m.)



THE INTEGRATION AND ADAPTABILITY PHASE – EXAMPLES - 6

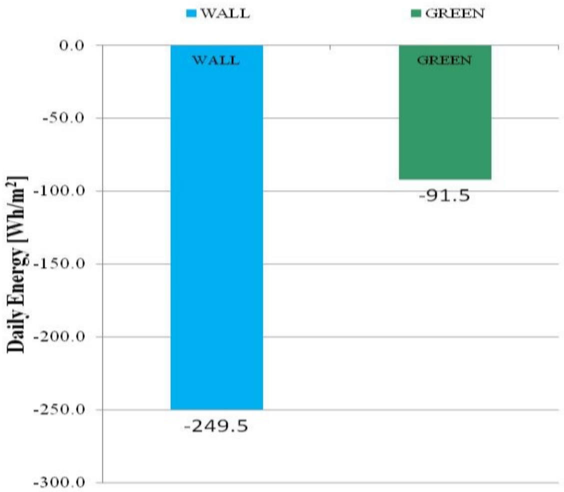
Philosophy of the total building energy approach



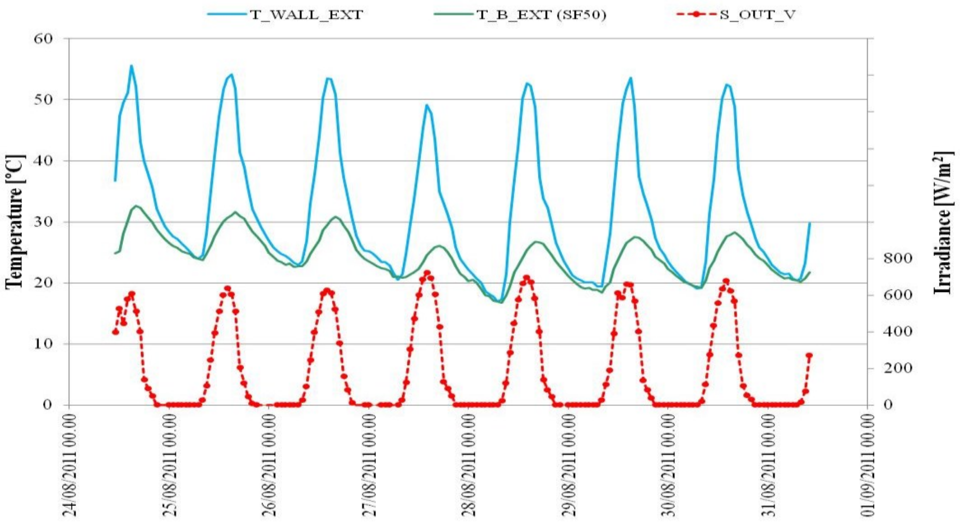
The Integration and Adaptability phase – Examples - 7

Green Walls/Roofs – Living Wall systems:

Technology Energy Building Environment



- Heat island effect mitigation,
- Extra thermal insulation (variable),
- Acoustic absorption,
- Potential air purification,
- Lower surface temperatures.

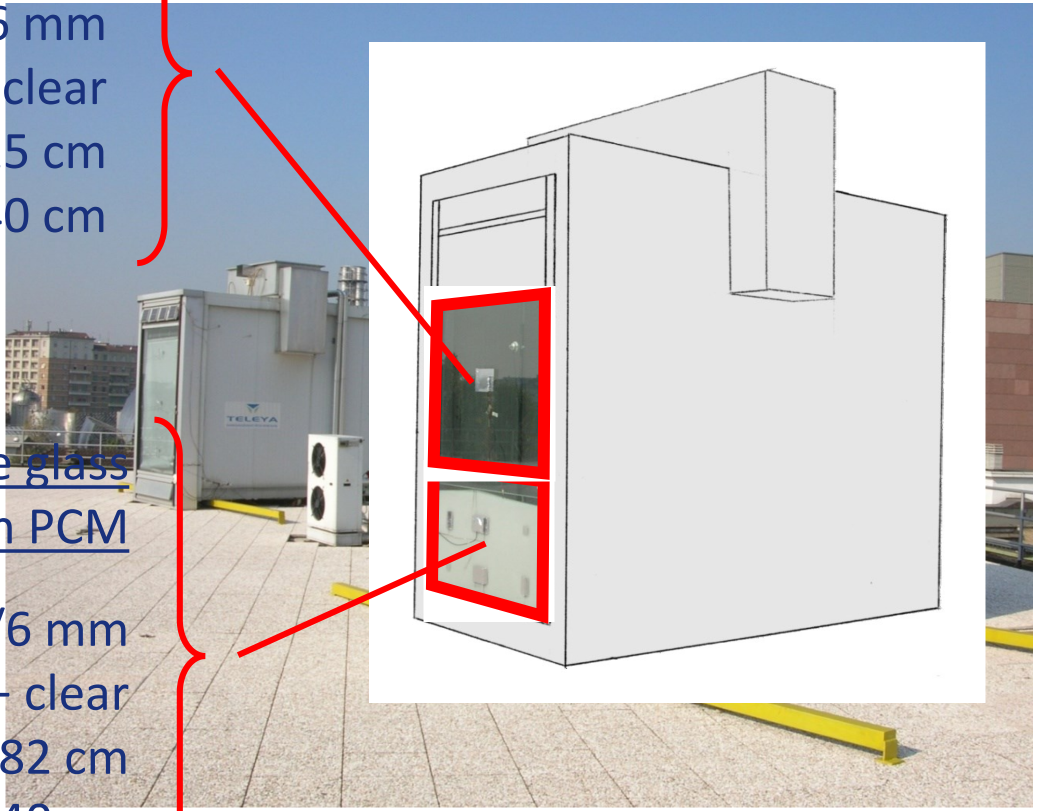


The Integration and Adaptability phase – Examples - 8

PCM in glazing and switchable glazing:

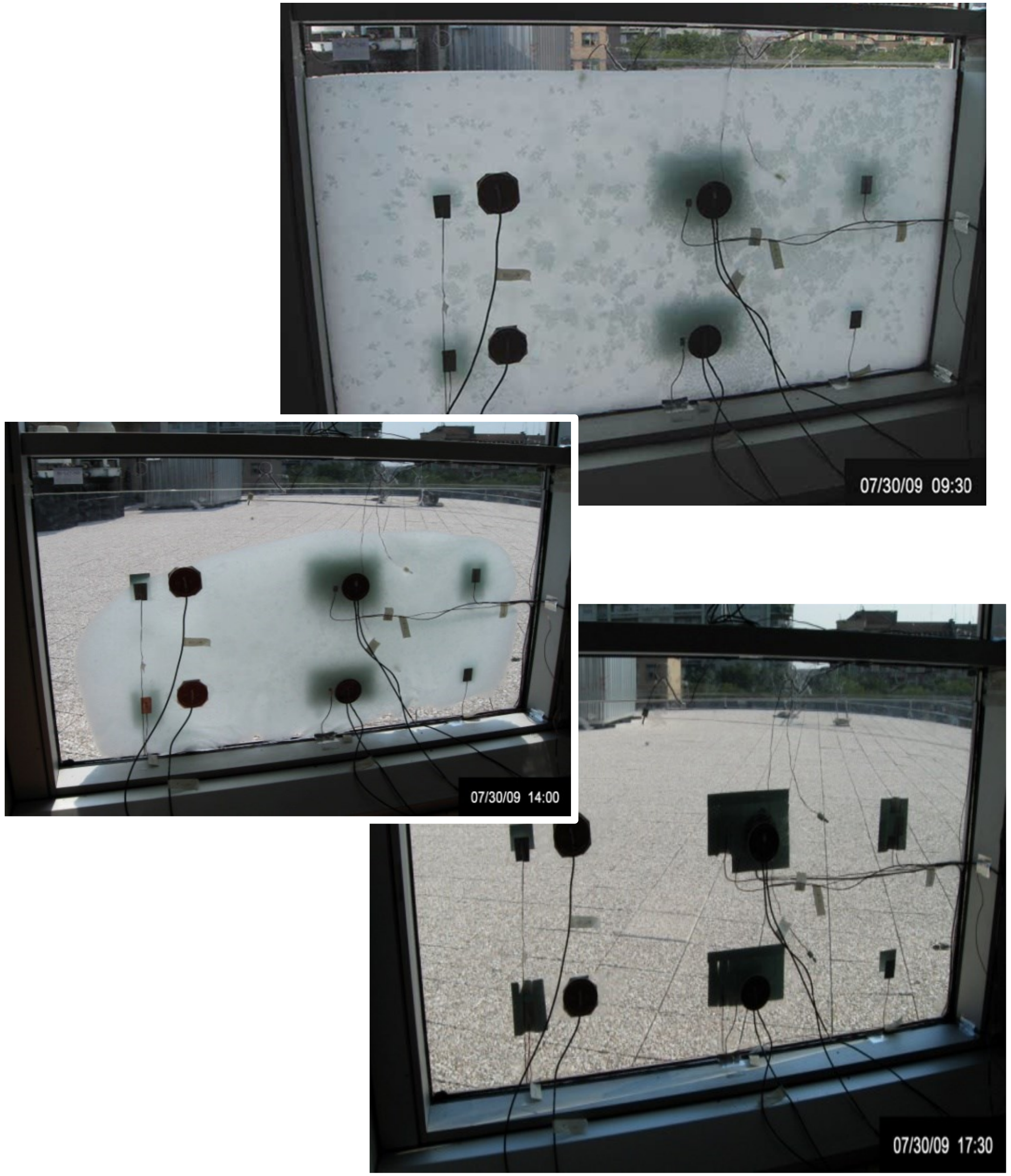
Double Glass

8/15/6 mm
clear+ clear
h: 115 cm
L: 140 cm

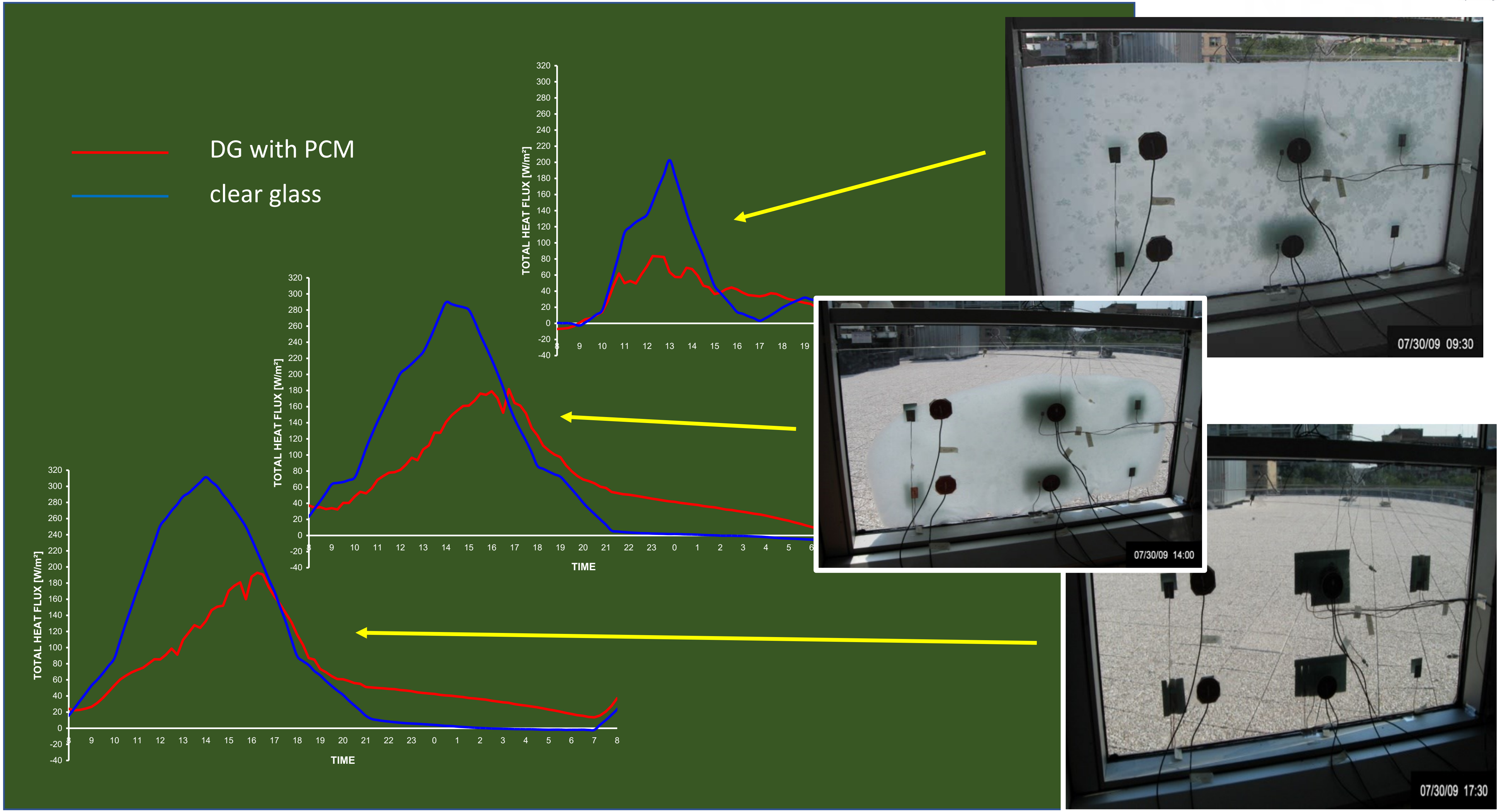


Double glass with PCM

8/15/6 mm
clear+ clear
h: 82 cm
L: 140 cm
paraffin R35

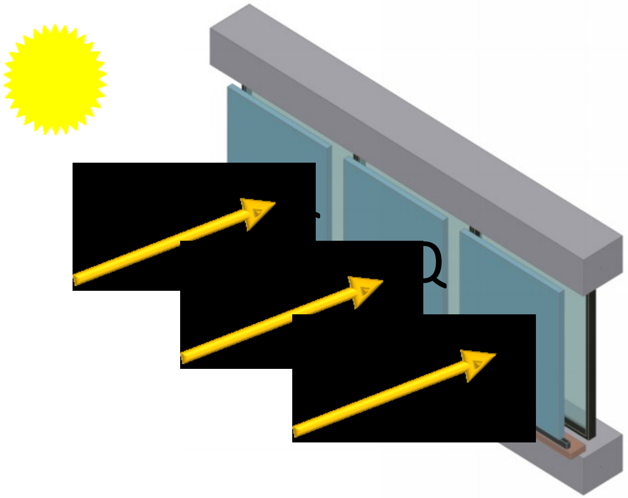


THE INTEGRATION AND ADAPTABILITY PHASE – EXAMPLES - 8

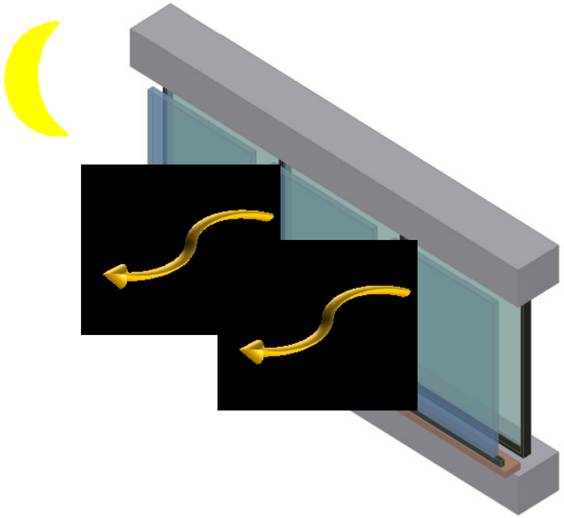


PCM in shading devices:

Summer - Daytime

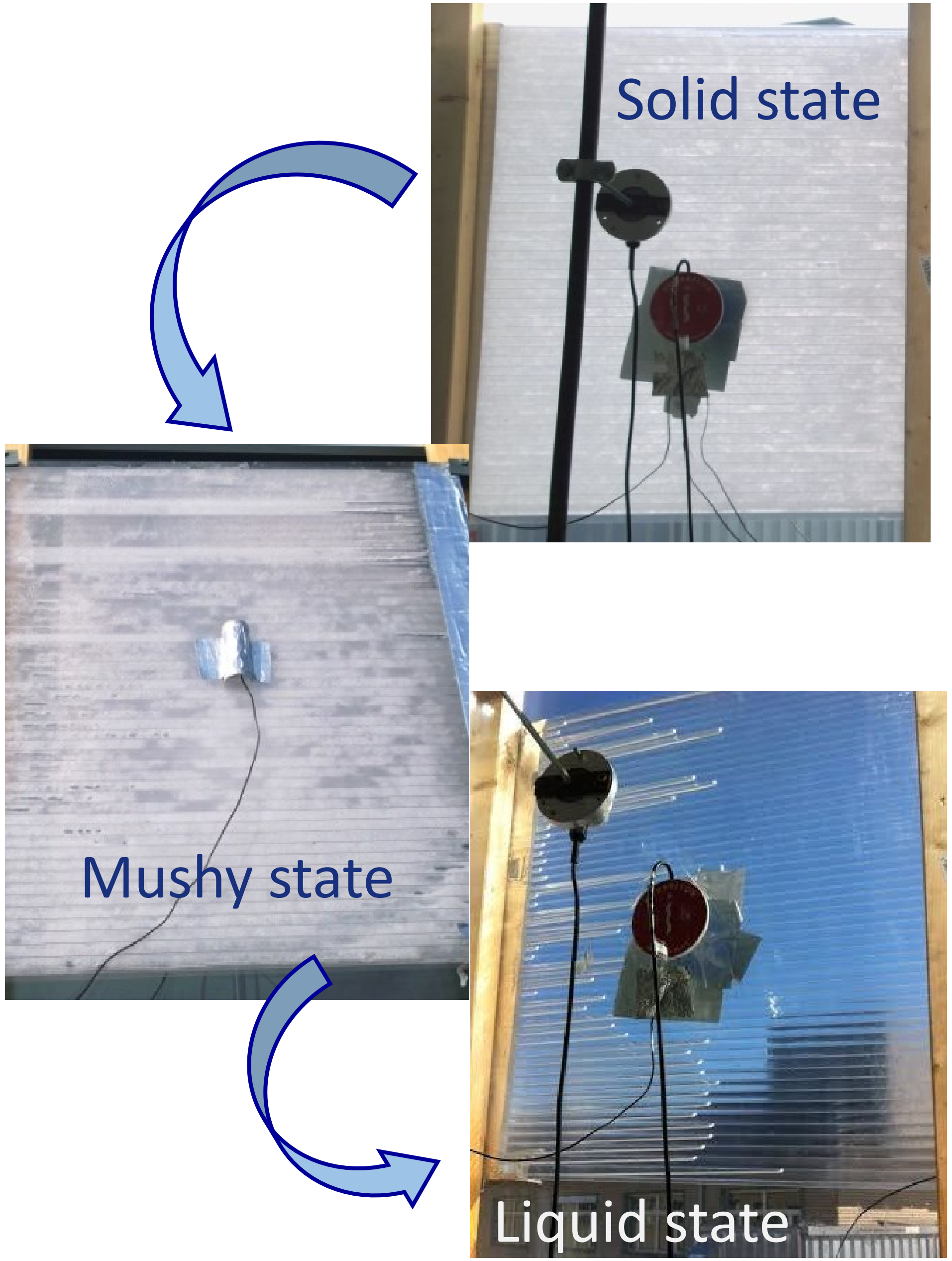


Summer - Night time



Absorption of the solar radiation ➡ Melting of the PCM. Energy is stopped and stored.

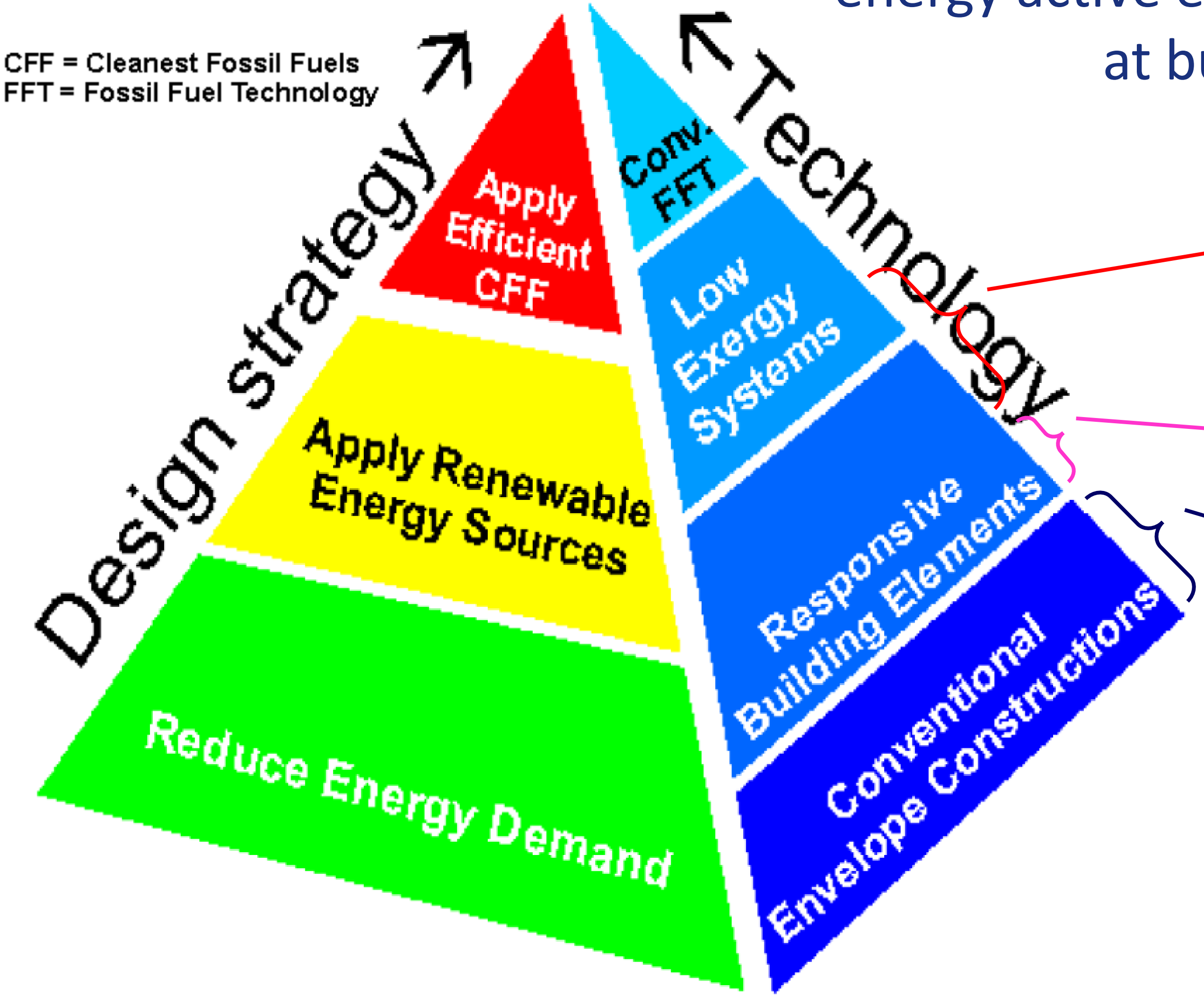
Solidification of the PCM ➡ energy is released outside the room.



THE CONCEPT EVOLUTION – FROM THE 1ST TO THE 2ND AND 3RD STEP

Annex 44 – Design Pyramid

Pursuing a deeper integration, moving from an energy passive harvester to an energy active envelope, exploiting RES at building level.



Active & Multi Functional phase
2010 - 2020

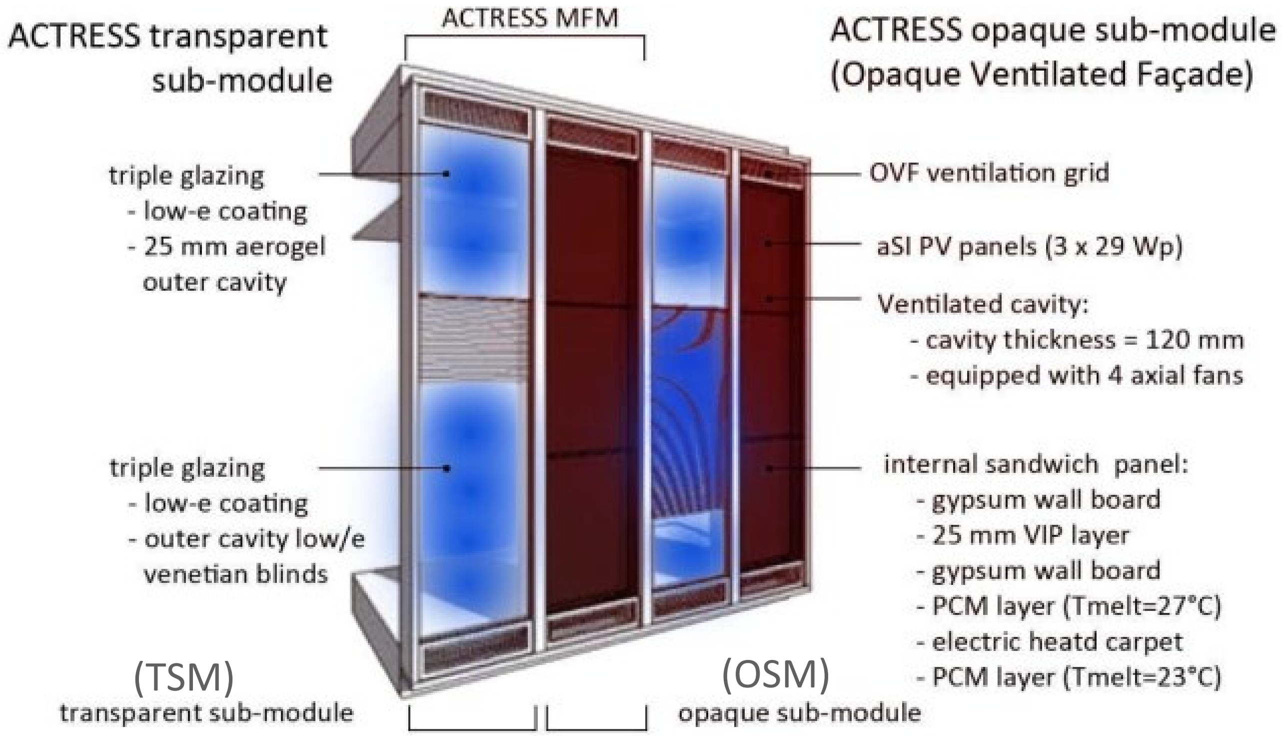
Integration and Adaptability phase
early 2000 - 2010

Energy Conservation phase
’70, ‘80, ‘90

THE ACTIVE & MULTIFUNCTIONAL PHASE – EXAMPLES - 1

Multifunctional Façade Modules (MFM) - ACTRESS

The **ACTRESS** Prototype (**ACT**ive, **RES**ponsive & **S**olar)

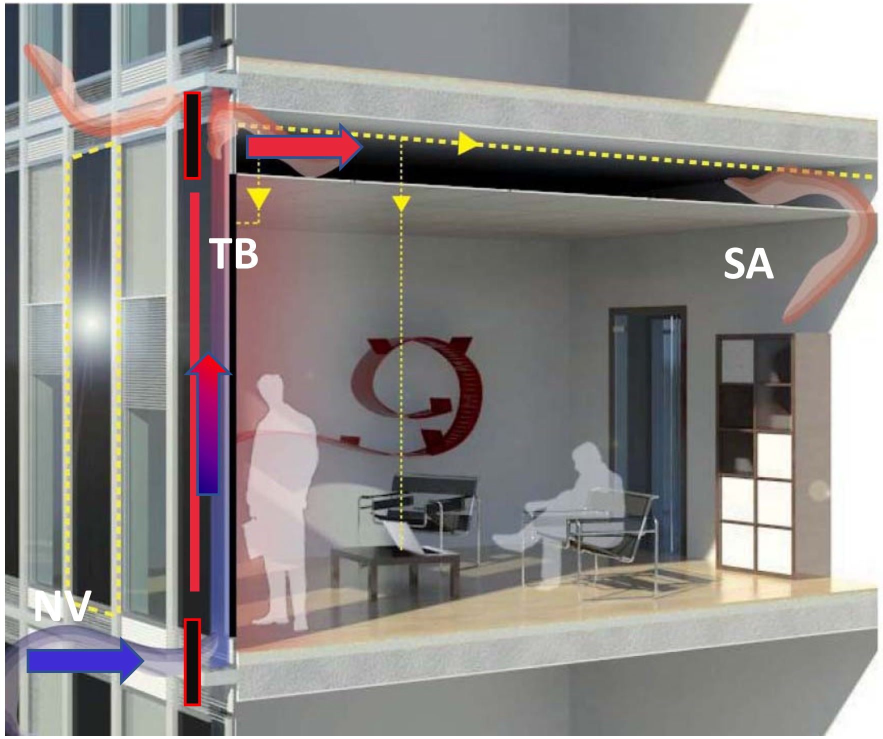


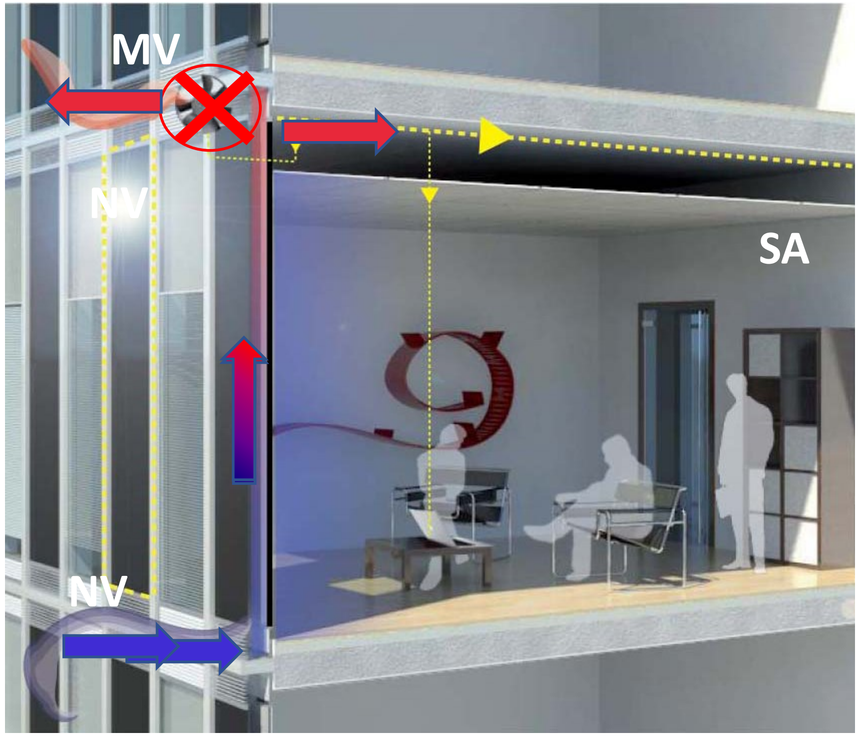
- WWR = 50 % (tot. en. optimization for Torino),
- OSM: U_{eq}= 0.08 W/(m^{2}K)
- TSM: $U_{average}$= 0.60 W/(m^{2}K), ; $U_{aerogel}$= 0.55 W/(m^{2}K)

THE ACTIVE & MULTIFUNCTIONAL PHASE – EXAMPLES - 2

Posssible **ventilation strategies** of the ACTRESS MFM - OVF Cavity:

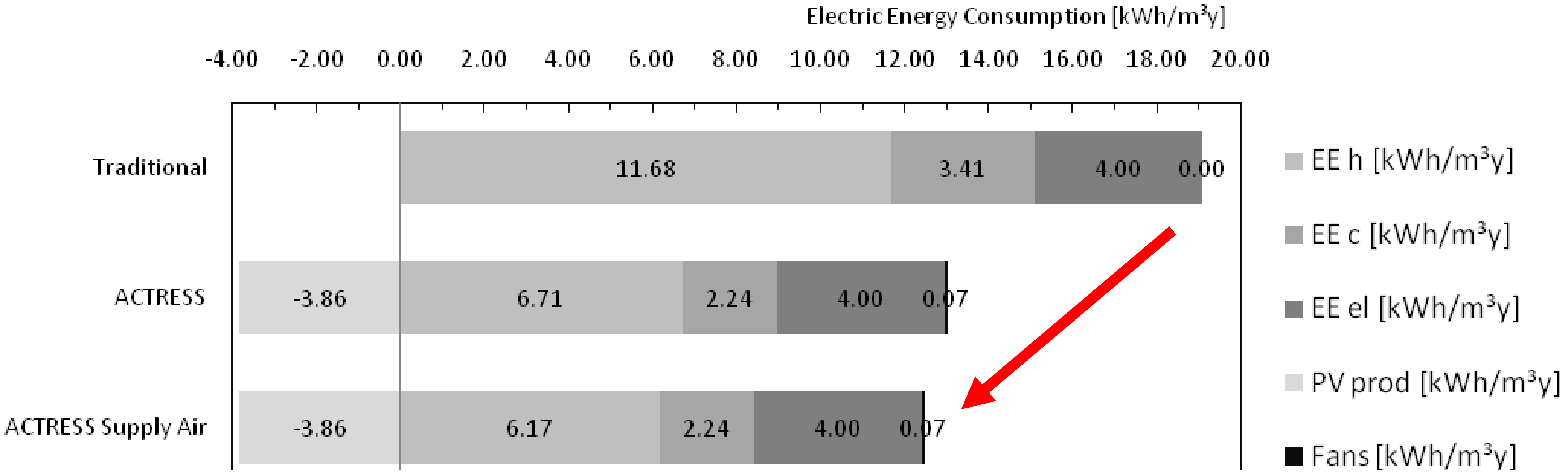
Winter: Thermal Buffer, Natural Ventilation - Supply Air
Mid Season Supply Air: Natural ventilation or Mechanical Ventilation
Summer: Outdoor air curtain: Natural Ventilation or Mechanical Ventilation





THE ACTIVE & MULTIFUNCTIONAL PHASE – EXAMPLES - 3

Yearly energy performance (total equivalent electric energy) – Simulation of a reference hypothetical office module 6 m x 5 m x 3.5 m South oriented:

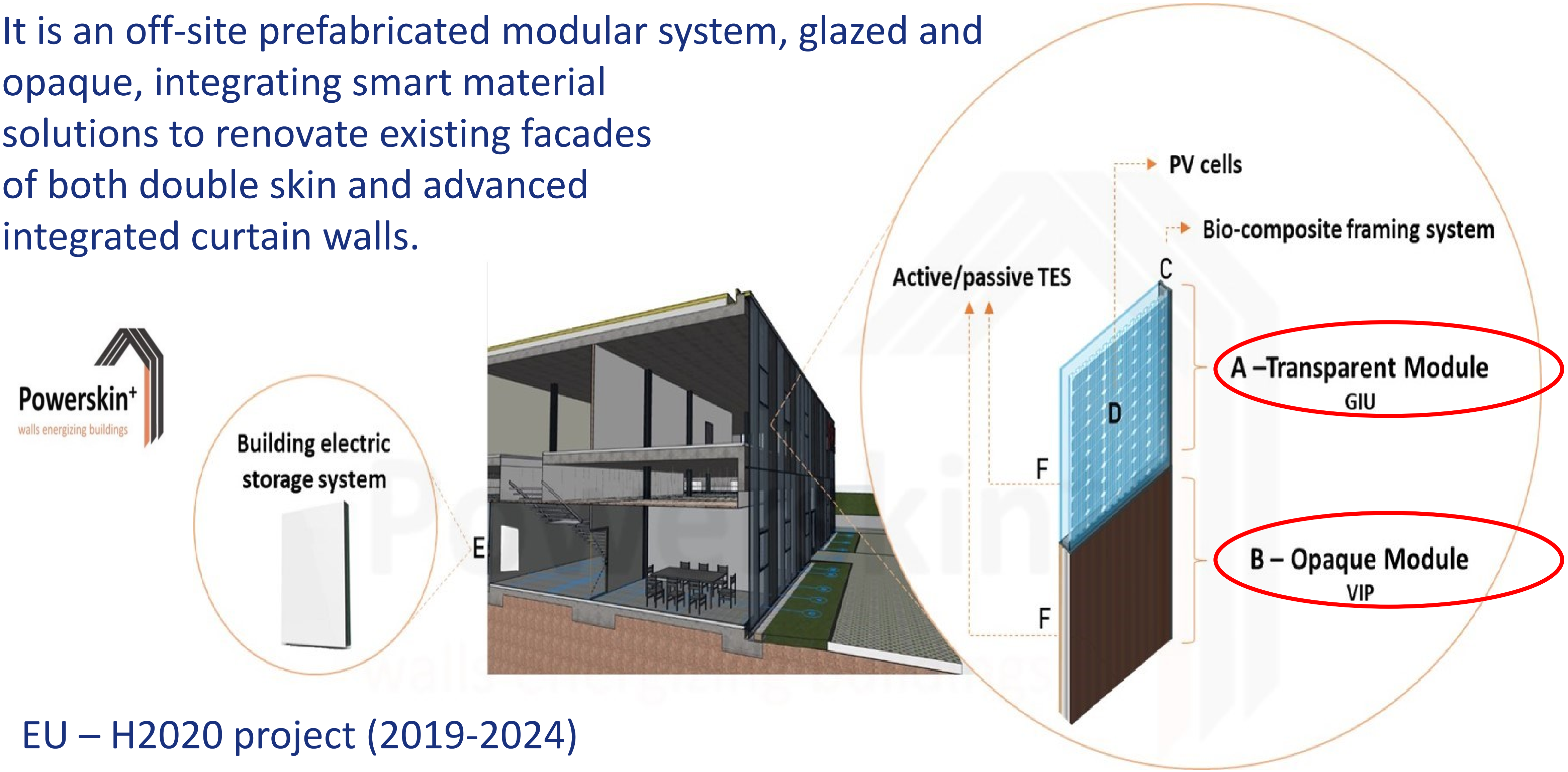


- EE reduction from 19.1 kWh/m^{3}y to 9.1 kWh/m^{3}y (≈ 52%),
- Significant reduction in heating loads EE_h, due to the use of PV energy to activate the PCM in the OSM.
- The electric (plug loads + lighting) consumption can be almost totally covered, 95% on an annual basis, by the PV production.
- Exploiting the pre-heated air (OSM supply air) during heating and mid-season allows an extra energy saving of about 8 %.

THE ACTIVE & MULTIFUNCTIONAL PHASE – EXAMPLES - 4

Going further with MFM - The POWERSKIN+ Concept:

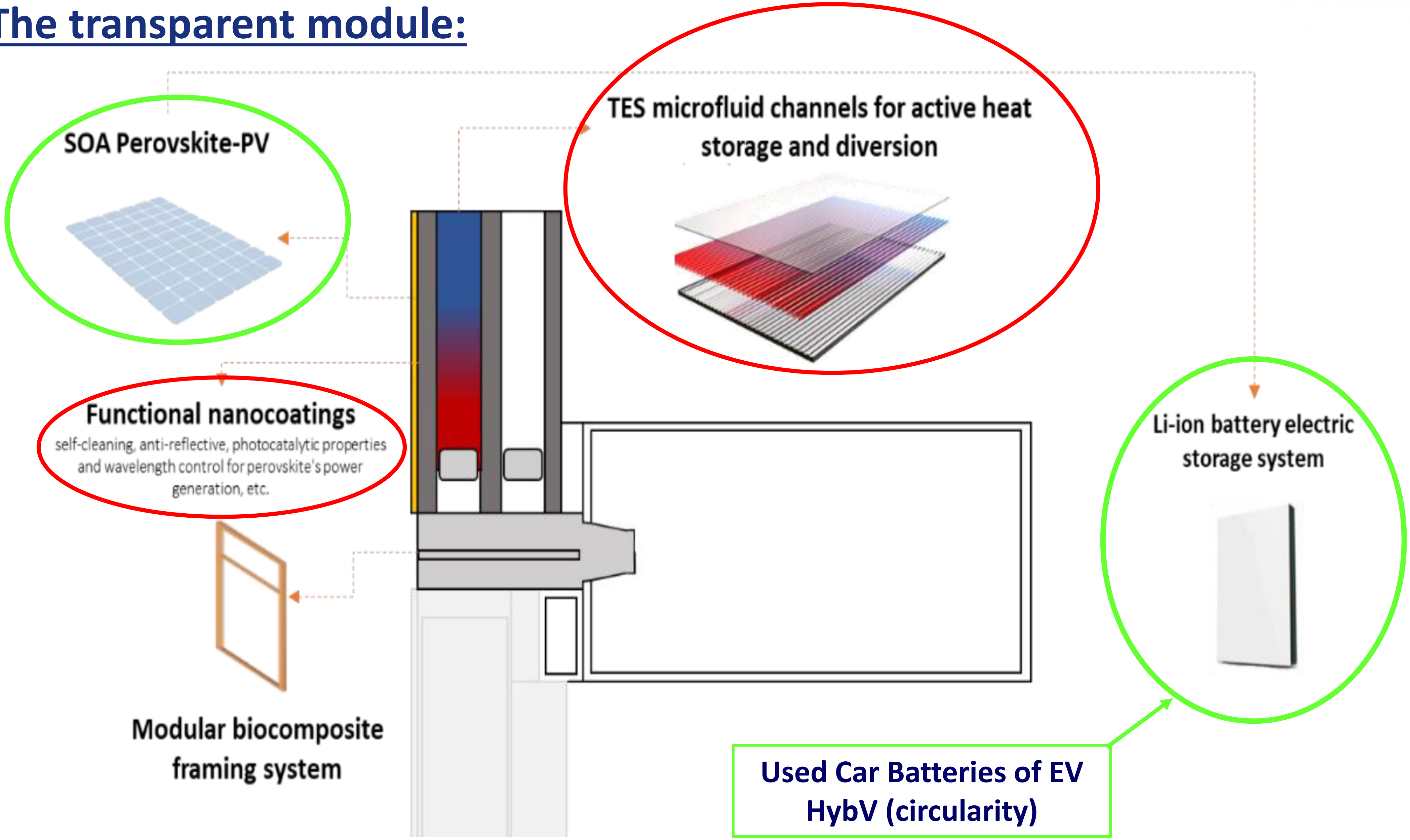
It is an off-site prefabricated modular system, glazed and opaque, integrating smart material solutions to renovate existing facades of both double skin and advanced integrated curtain walls.



EU – H2020 project (2019-2024)

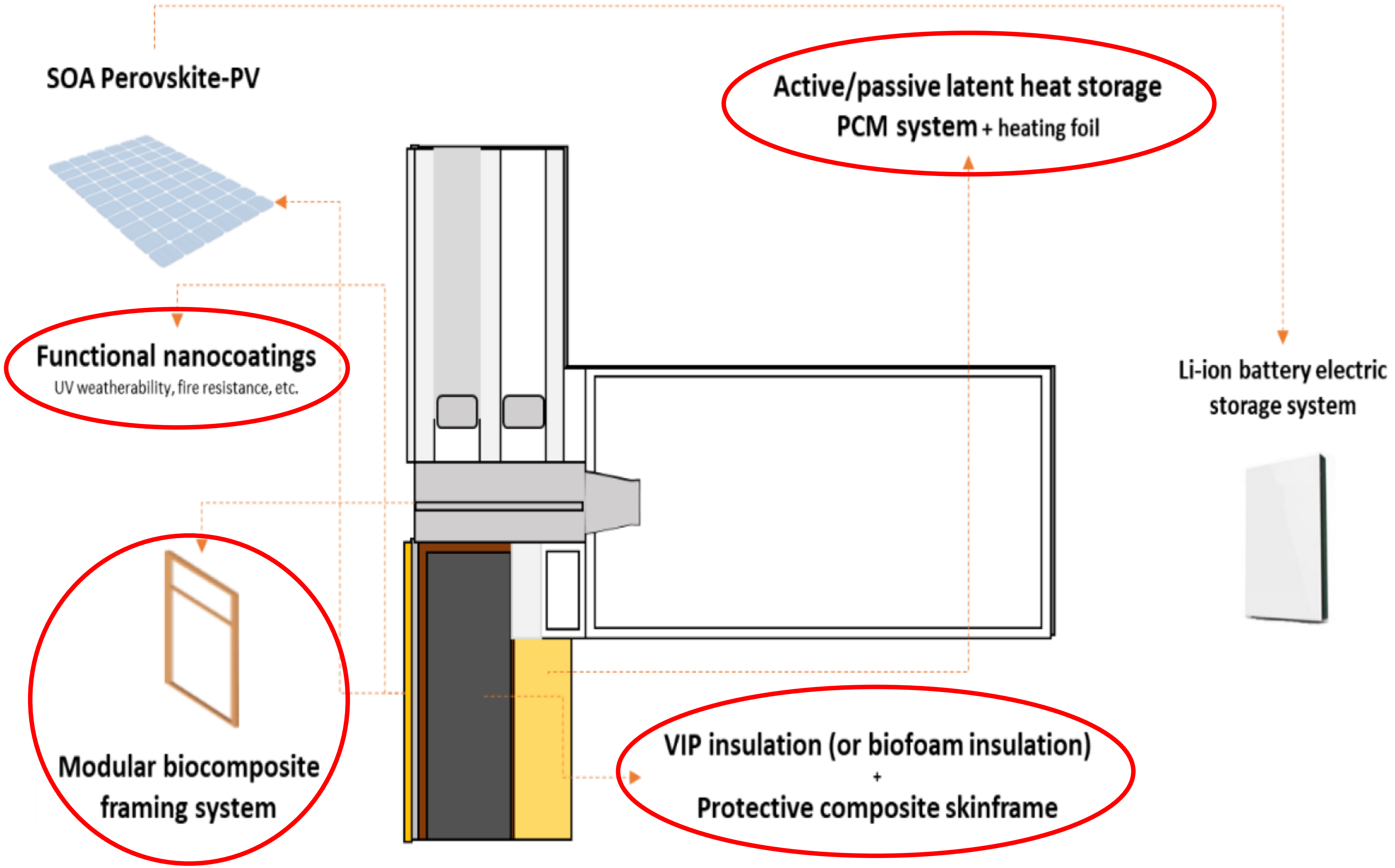
The Active & Multifunctional phase – Examples - 5

The transparent module:



The Active & Multifunctional phase – Examples - 6

The opaque module:



IMPLICATION ON MODELLING & ACHIEVEMENTS – FROM 1ST TO 3RD PHASE

Energy Conservation phase:

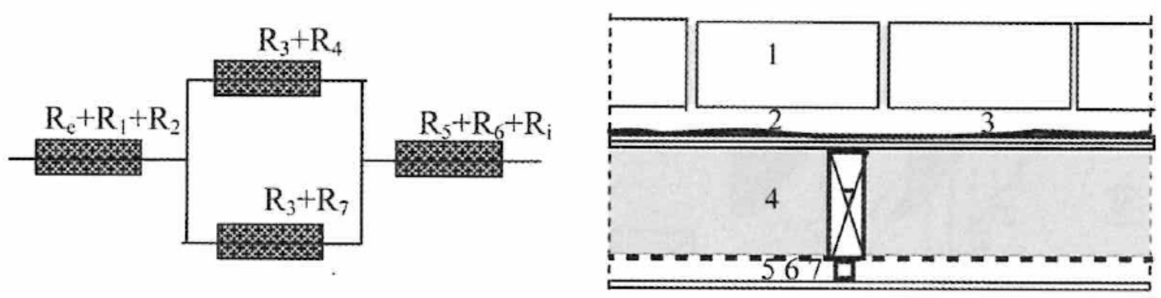
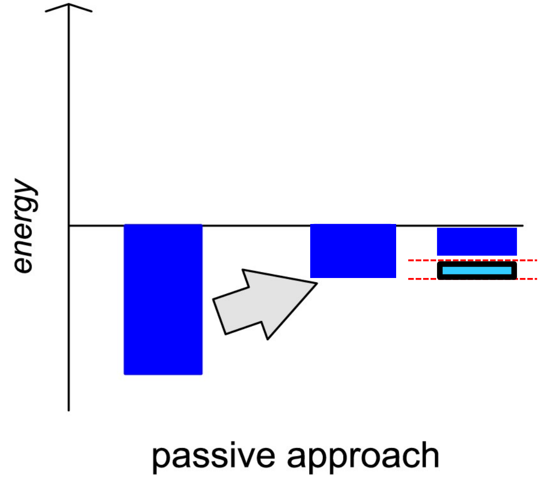
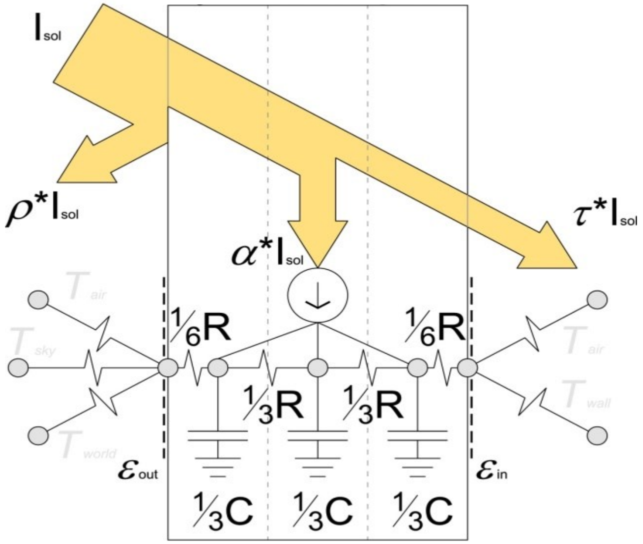


Figure 1.6. Timber framed wall as series/parallel circuit.

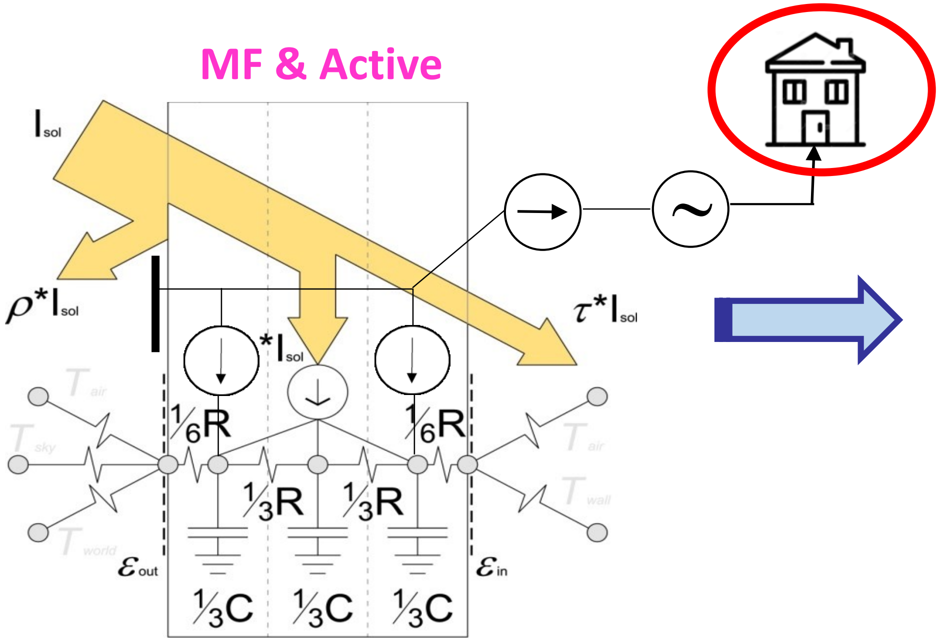


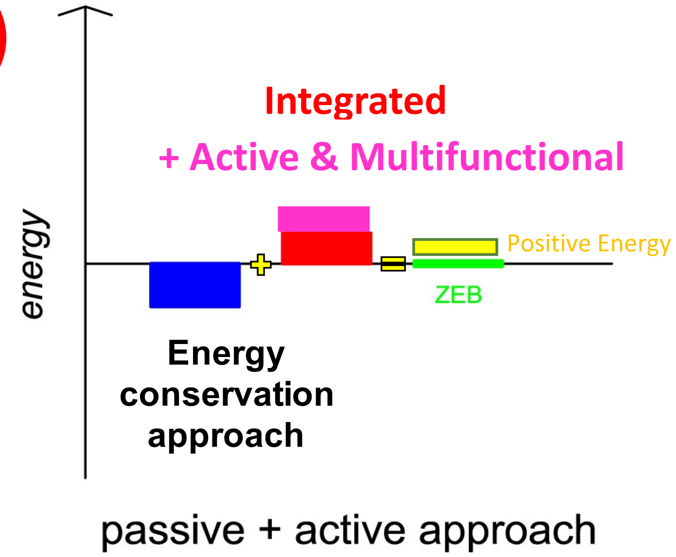
(Integration and Adaptability) + (Active & Multifunctional) phase:

Integrated Dynamic



MF & Active





IMPLICATION ON MODELLING & ACHIEVEMENTS – FROM 1ST TO 3RD PHASE

Energy Conservation phase:

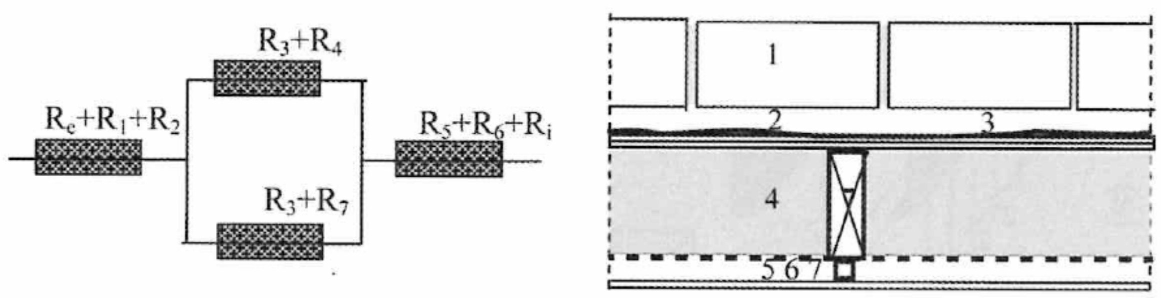
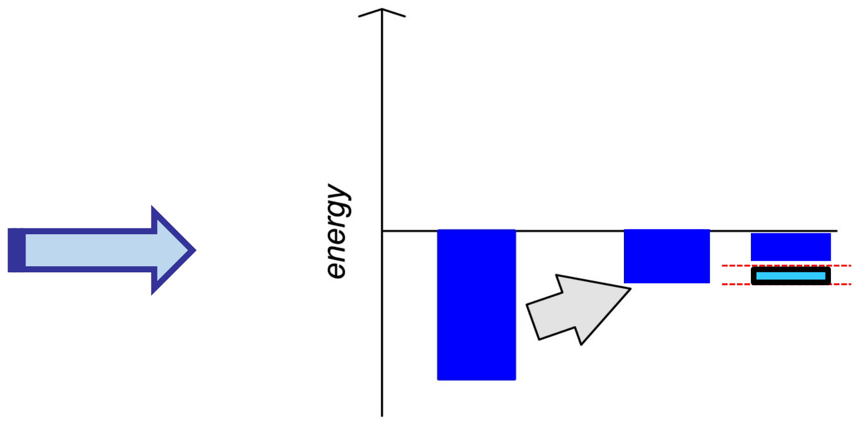
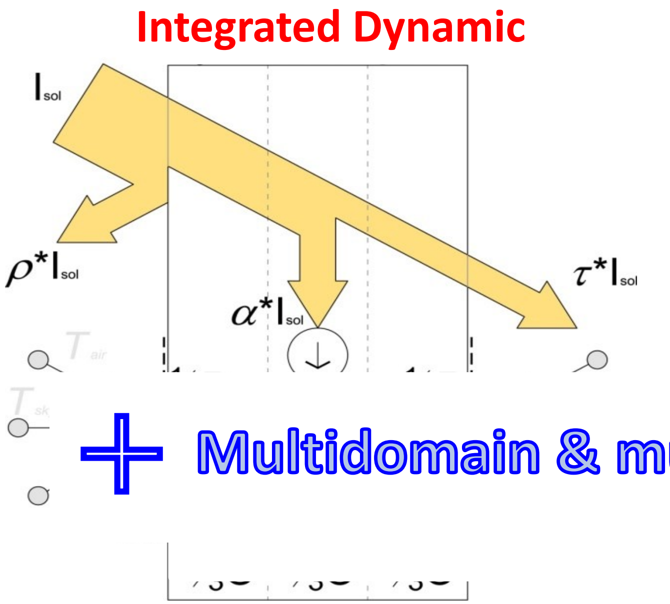
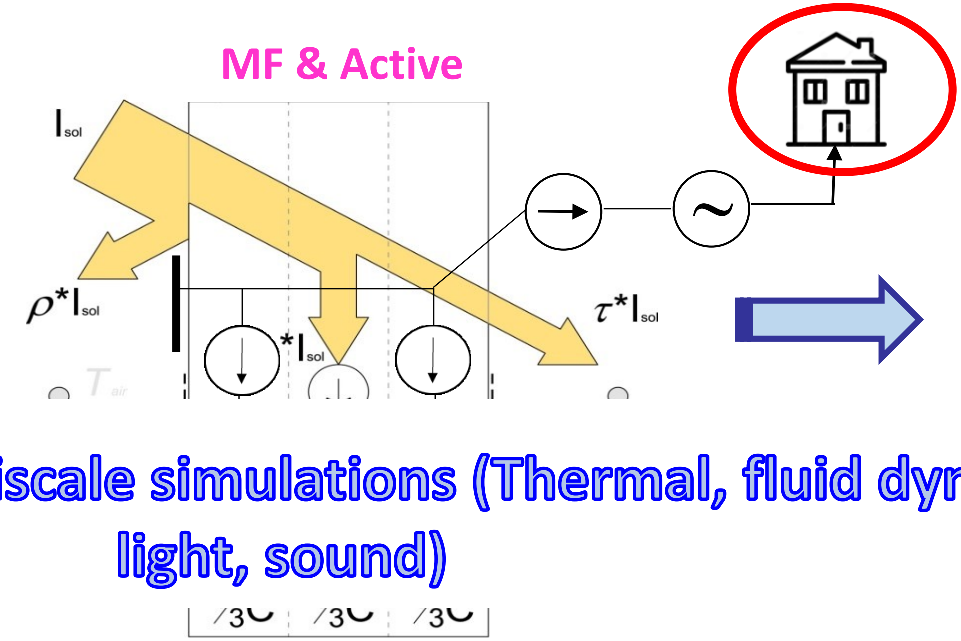


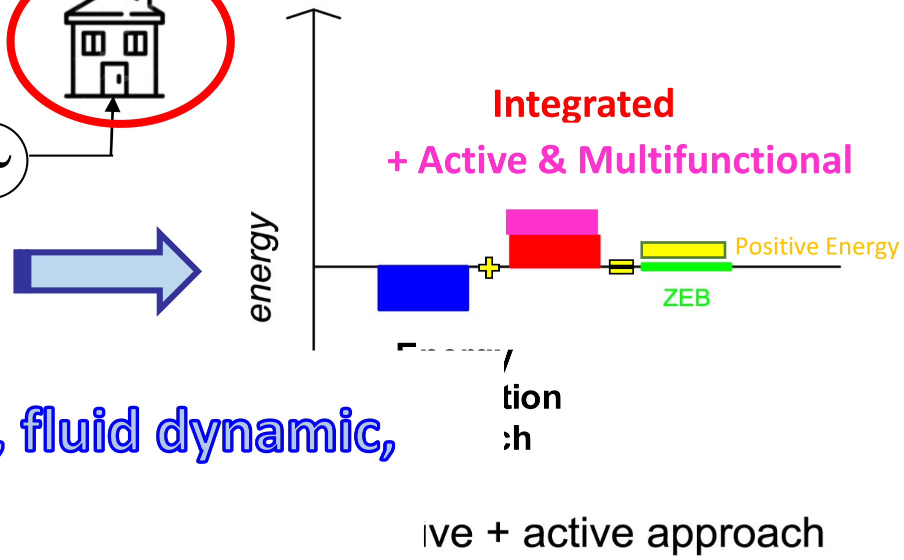
Figure 1.6. Timber framed wall as series/parallel circuit.



(Integration and Adaptability) + (Active & Multifunctional) phase:

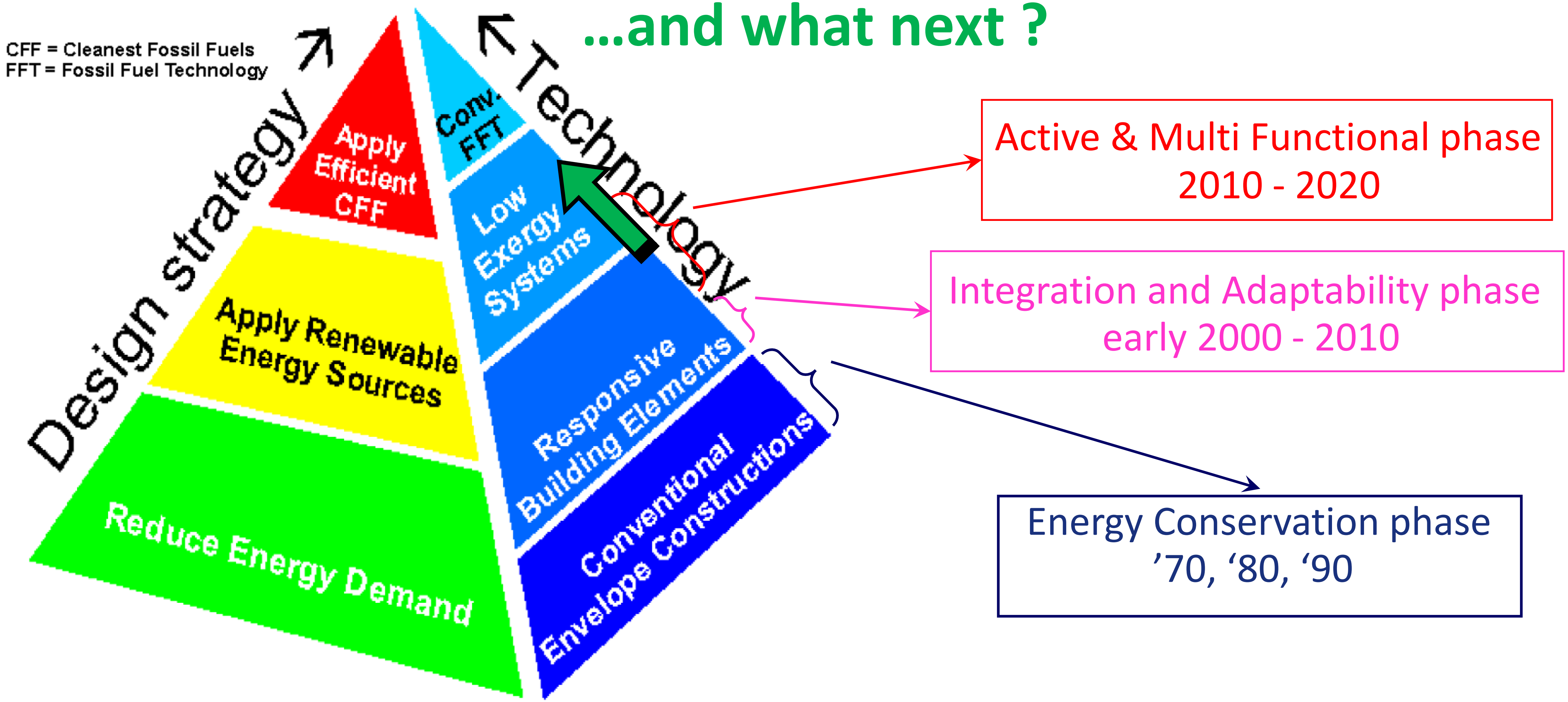






+ Multidomain & multiscale simulations (Thermal, fluid dynamic, light, sound)

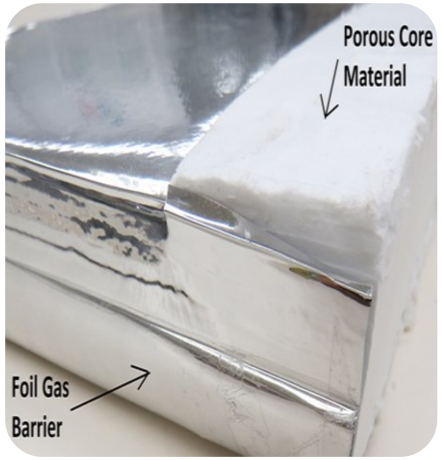
Annex 44 – Design Pyramid



EXAMPLES OF NEW RESEARCH STRANDS AND OUTLOOK - 1

New & better performing materials with added functionalities:

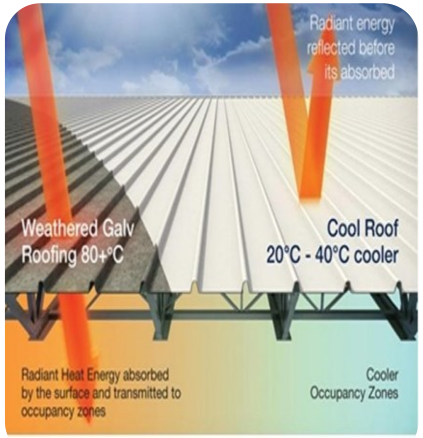
1) Vacuum Insulation Panels (VIP)



2) Adavanced Porous materials (APM)

3) Reflective insulation

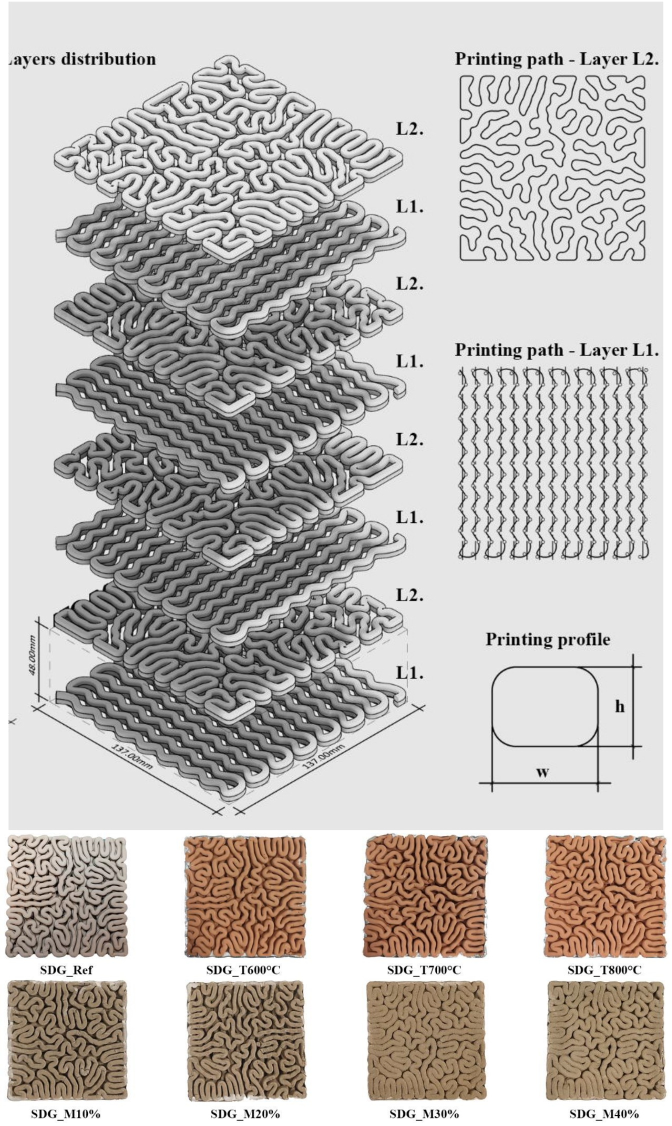
4) Cool coatings

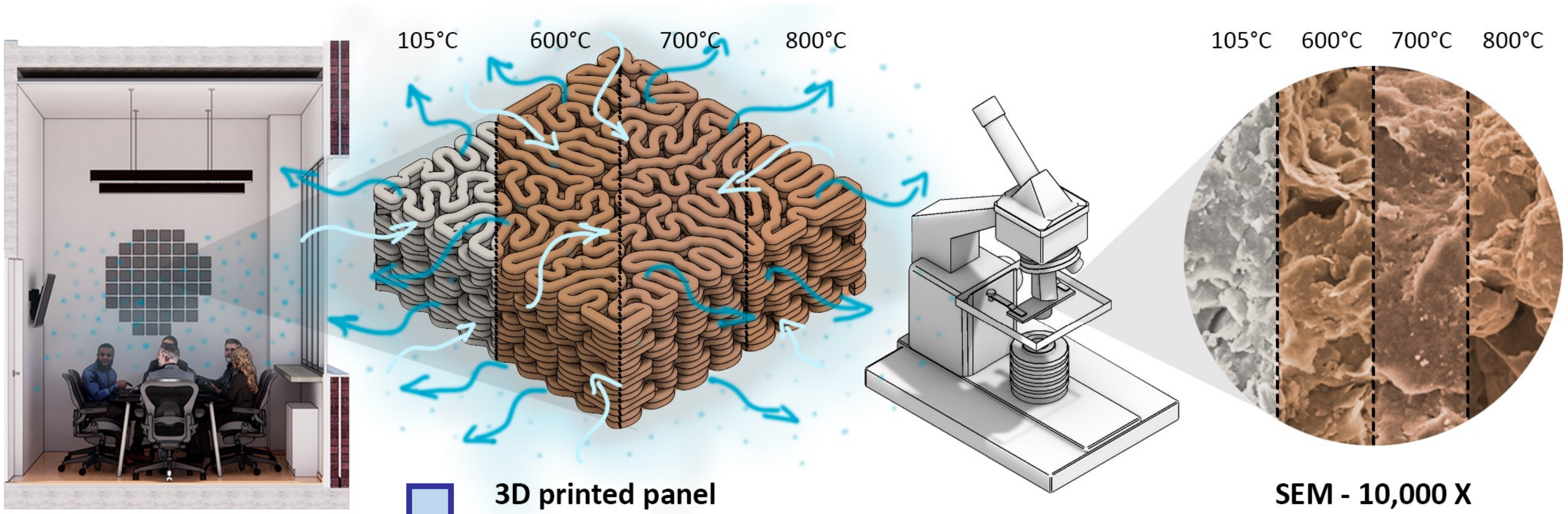


EXAMPLES OF NEW RESEARCH STRANDS AND OUTLOOK - 2

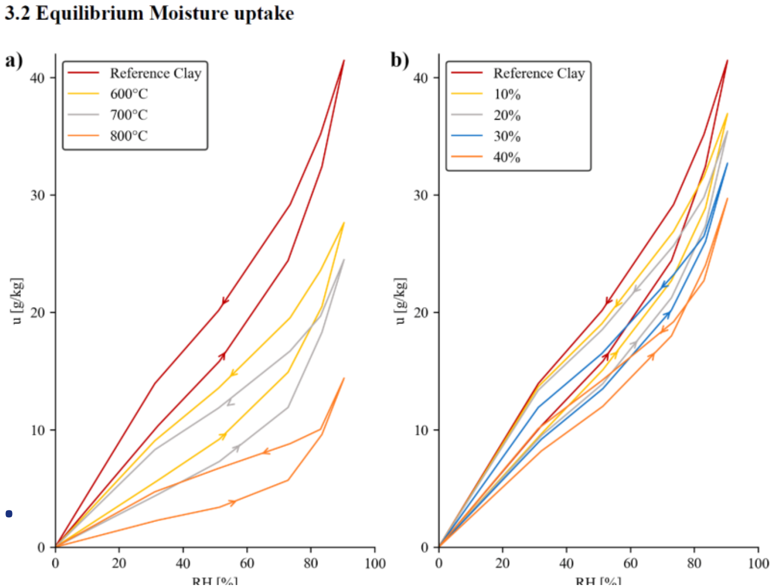
Not only thermal and lighting, but also RH control (and IAQ) :

TECHNOLOGY ENERGY BUILDING ENVIRONMENT





3D-printed clay wall components for passive indoor control of the RH and moisture buffering with high surface area.



Vincenzo Gentile, Juan Diego Vargas Velasquez, Stefano Fantucci, Giorgia Autretto, Roberta Gabrieli, Pardeep Kumar Gianchandani, Marco Armandi, Francesco Baino, «3D-printed clay components with high surface area for passive indoor moisture buffering», Journal of Building Engineering, Volume 91, 2024, https://doi.org/10.1016/j.jobe.2024.109631.

NEST

EXAMPLES OF NEW RESEARCH STRANDS AND OUTLOOK - 3

Better multifunctional integration (not only Building Physics) & 3D printing:

Image: Roman Keller

- Zero to positive operational energy consumption
- Lightweight construction, less material
- Architectural integration of renewable energy systems
- High occupant comfort

Integrating Energy Systems with Lightweight Design

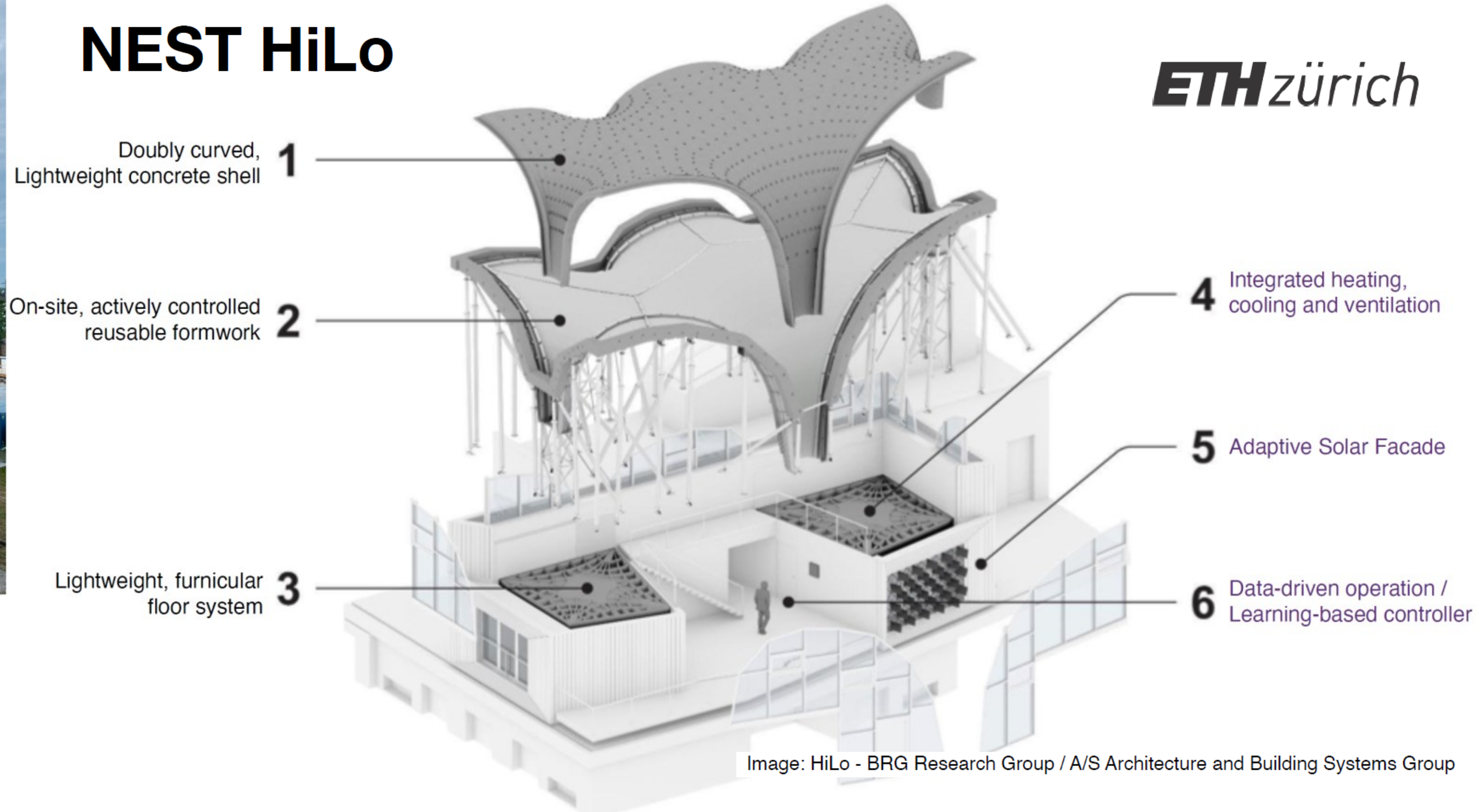


Image: HiLo - BRG Research Group / A/S Architecture and Building Systems Group

- Connection to district scale energy systems + storage

[9]

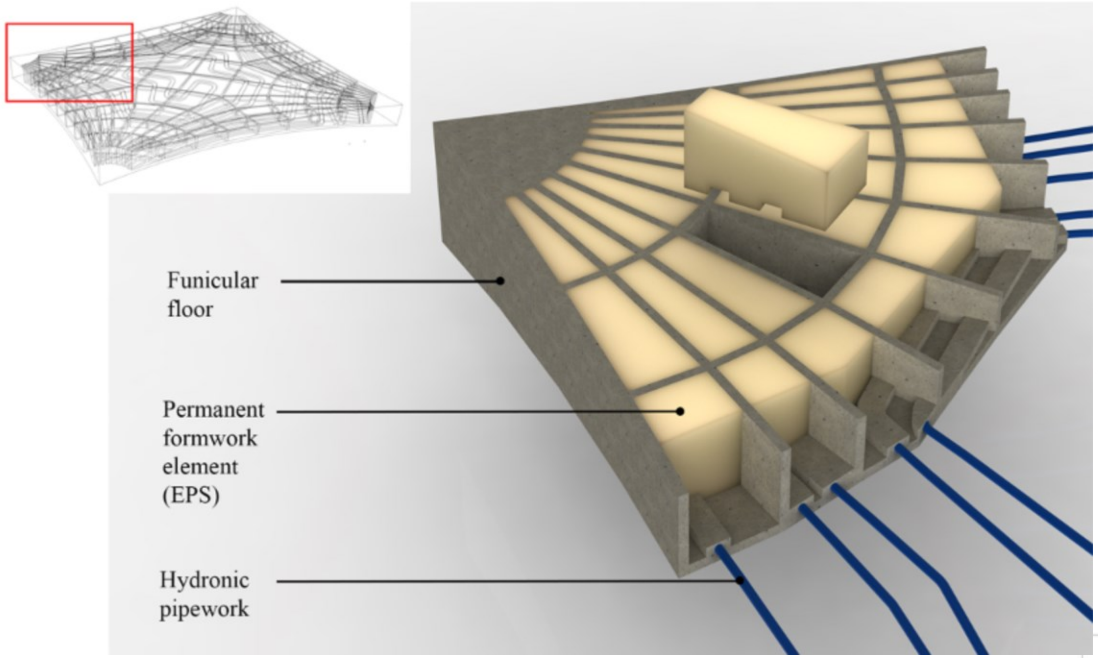
Systemic Design for Decarbonizing Buildings and Cities

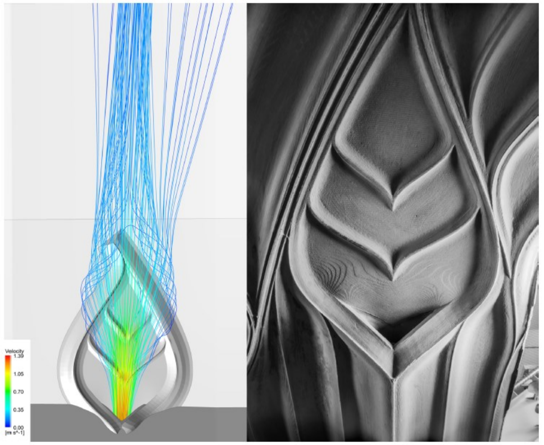
Prof. Dr. Arno Schlueter, Institute of Technology in Architecture ETH Zürich

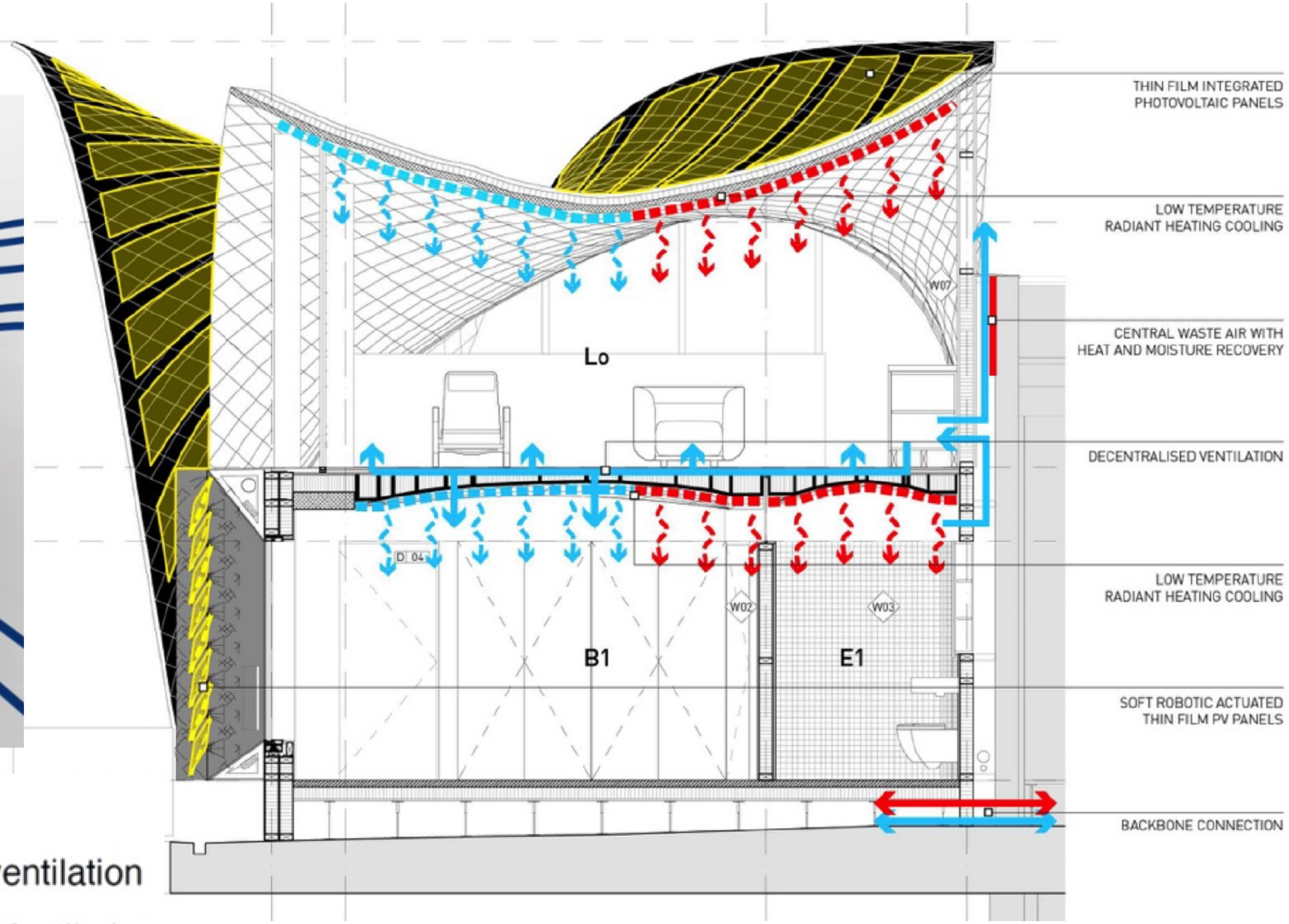
A/S Architecture and Building Systems

Examples of new research strands and outlook - 4

Integrated, Digital Design Process







Ventilation

- Manual / automated ventilation
- Decentralized Mech. Ventilation

Thermal

- Thermally Active Building Systems (TABS)
- HVRF AC Units

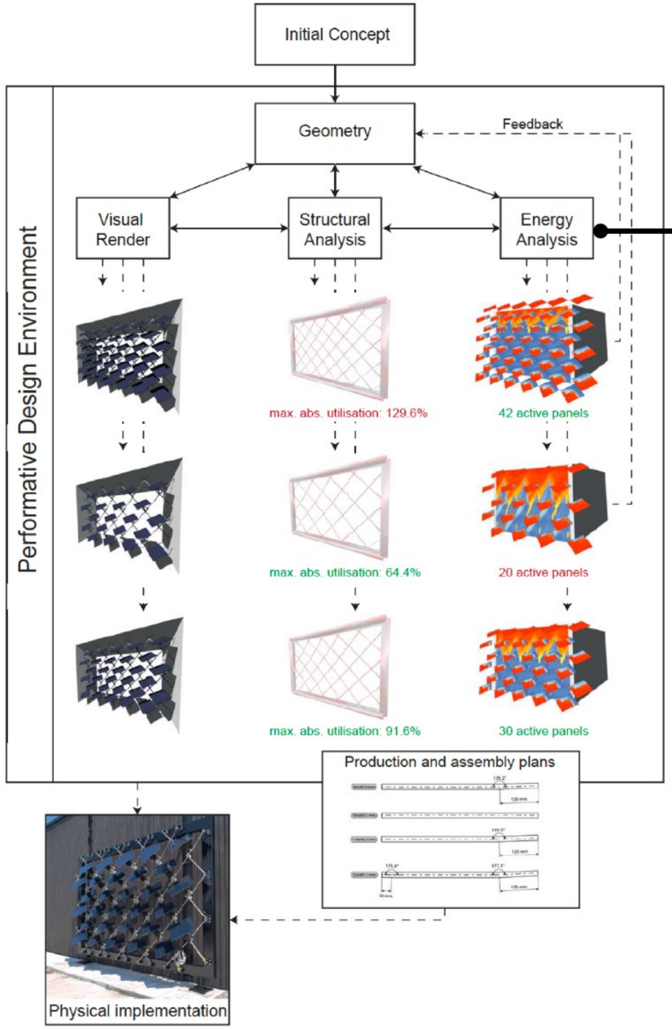
Shading / cooling

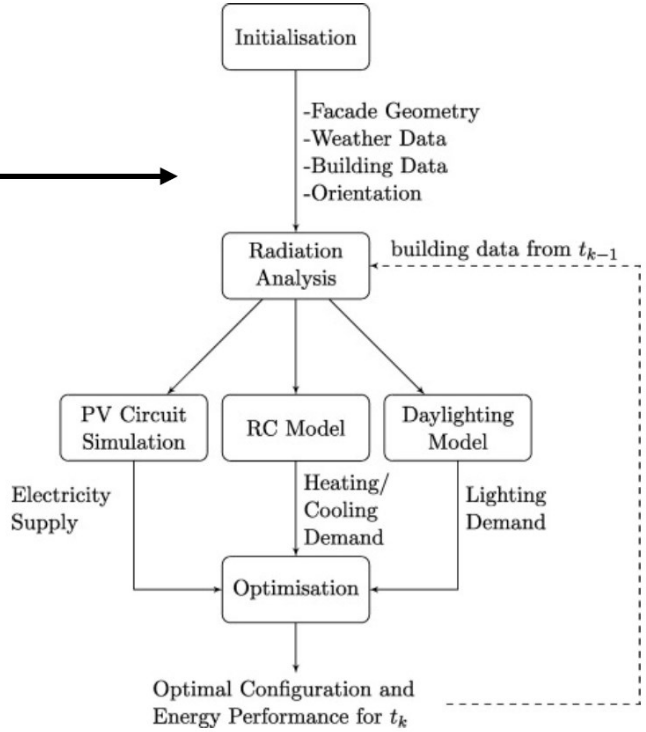
- Electrochromic Glazing
- Automated night-cooling
- Manual blinds

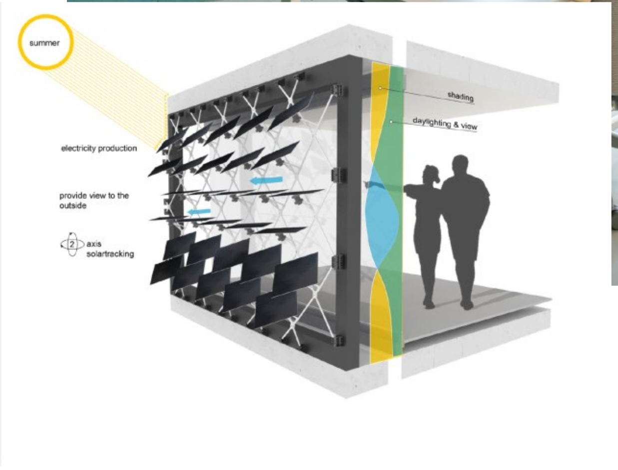
Source: Dr. Gearoid P. Lydon

EXAMPLES OF NEW RESEARCH STRANDS AND OUTLOOK - 5

Adaptive Solar Facade







Prof. Dr. Arno Schlueter, ETH zürich

Svetozarevic, Bratislav, Moritz Begle, Prageeth Jayathissa, Stefan Caranovic, Robert F. Shepherd, Zoltan Nagy, Illias Hischier, Johannes Hofer, and Arno Schlueter. 2019. '
§Dynamic Photovoltaic Building Envelopes for Adaptive Energy and Comfort Management'. Nature Energy, July, 1. https://doi.org/10.1038/s41560-019-0424-0.

Examples of new research strands and outlook - 5

Printing Performance - Towards Bespoke Facades

Personalised Features/aims

Piccioni, Valeria, Matthias Leschok, Esther Borkowski, Illias Hischier, and Arno Schlueter. 2023. 'Challenges in Modelling Thermo-Optical Performance of 3D-Printed Facades: A Cross-Domain Review'. In *Proceedings of the 18th IBPSA Conference*

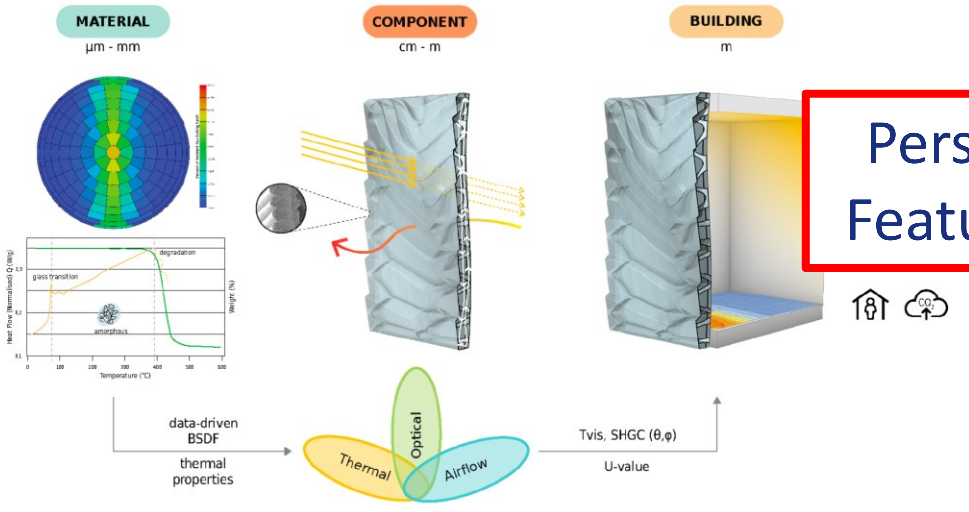
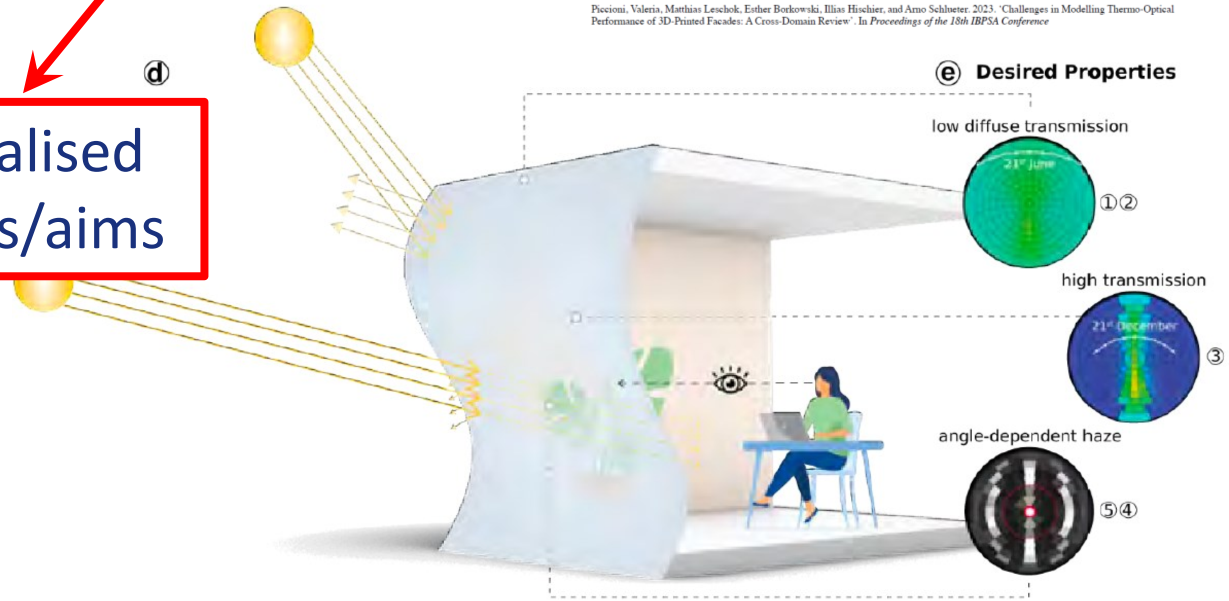
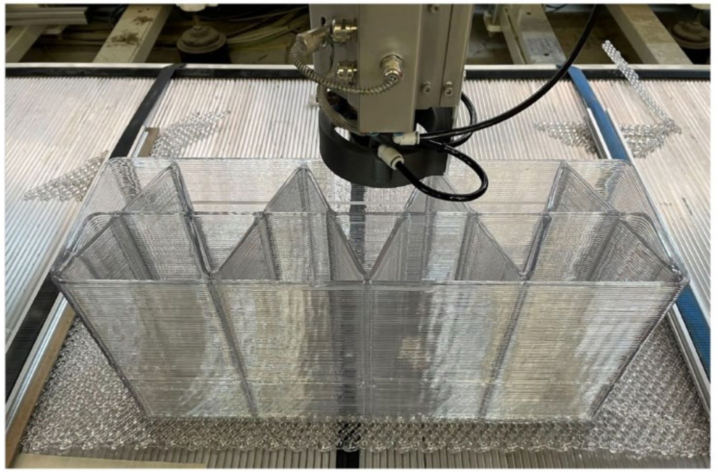
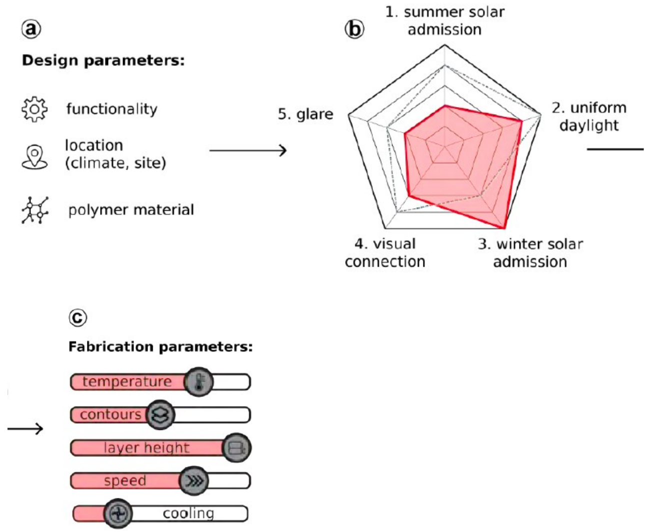
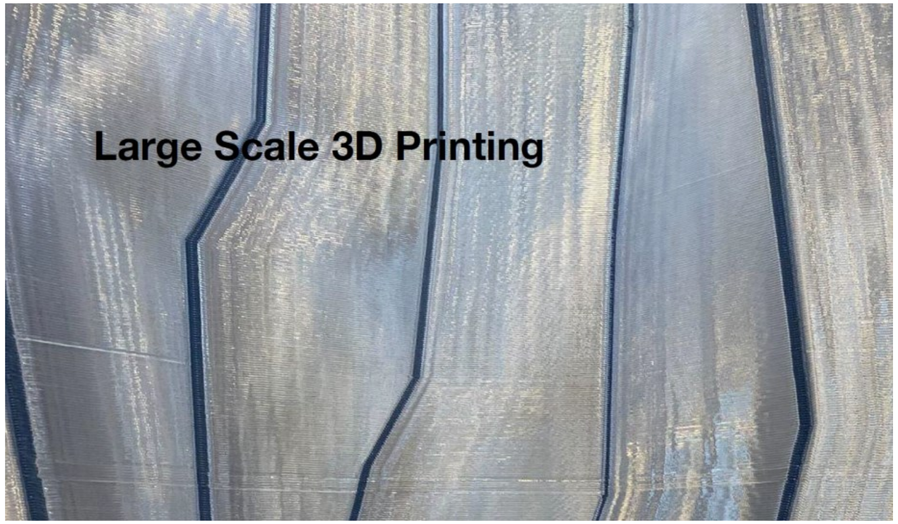


Figure 3: Concept for multiscale multiphysics approach to assess and integrate thermo-optical performance in 3DP facade systems.



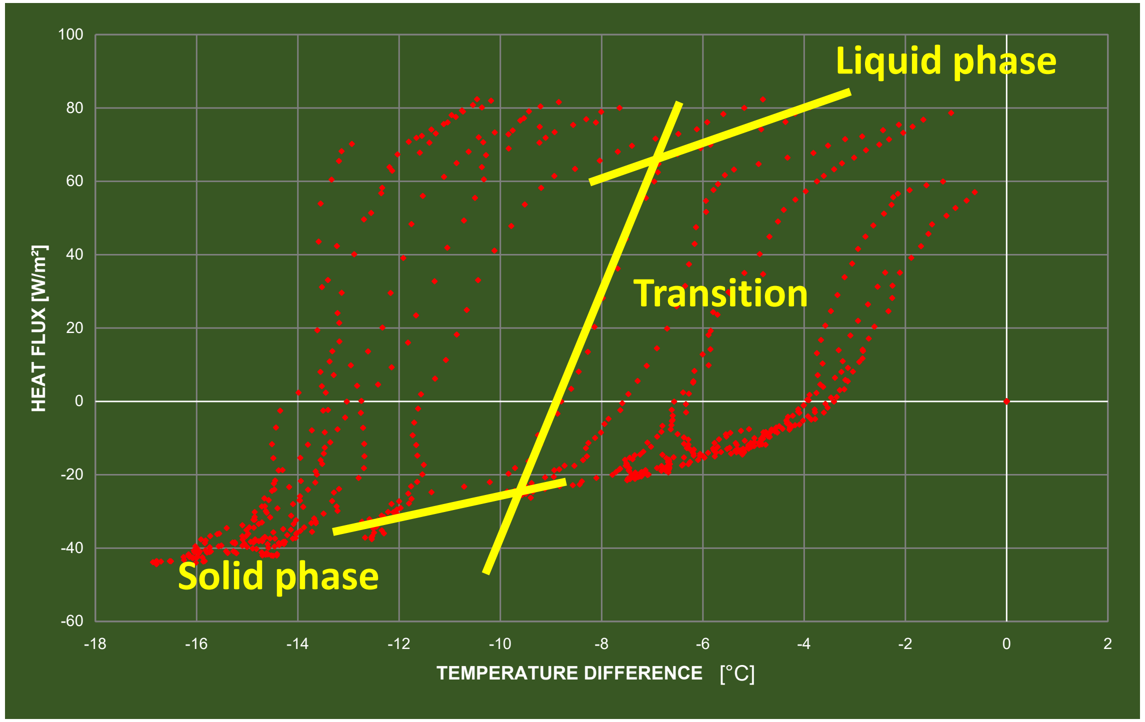






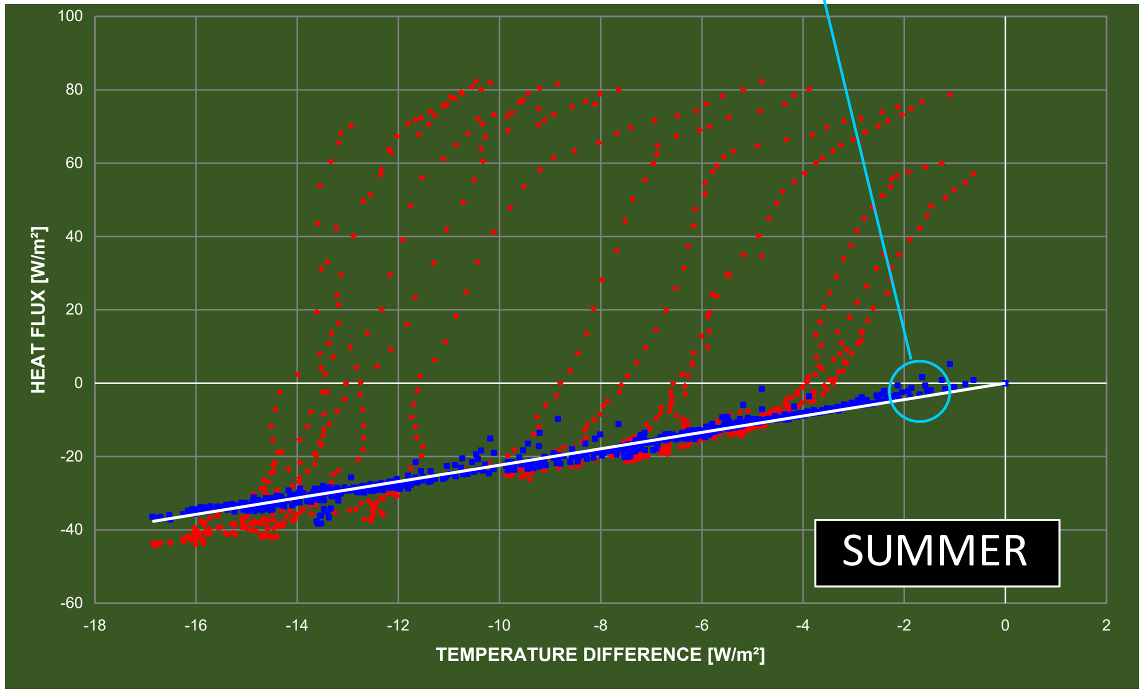
Prof. Dr. Arno Schlueter, ETH zürich

OPEN QUESTIONS OF THIS PHASES – NEW KPI NEEDED



$$U = \left(\frac{\dot{Q}}{A}\right) \Big/ \Delta T$$

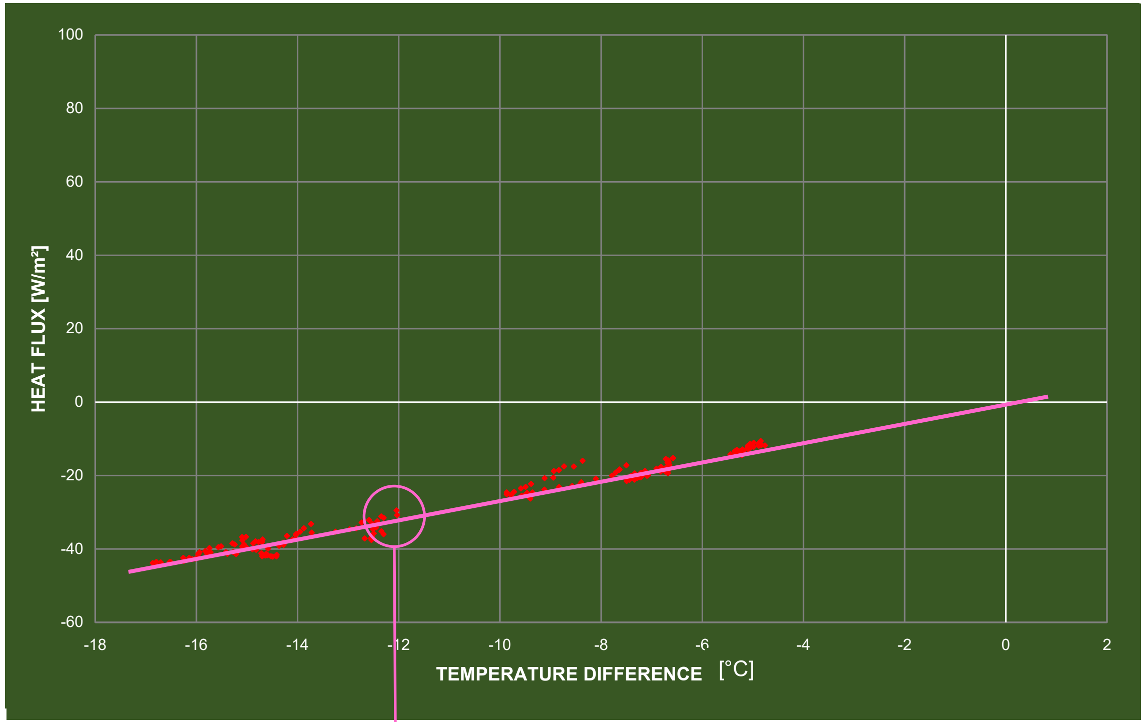
U_{night} = 2,3 W/m²K



DG with PCM

Clear double glass

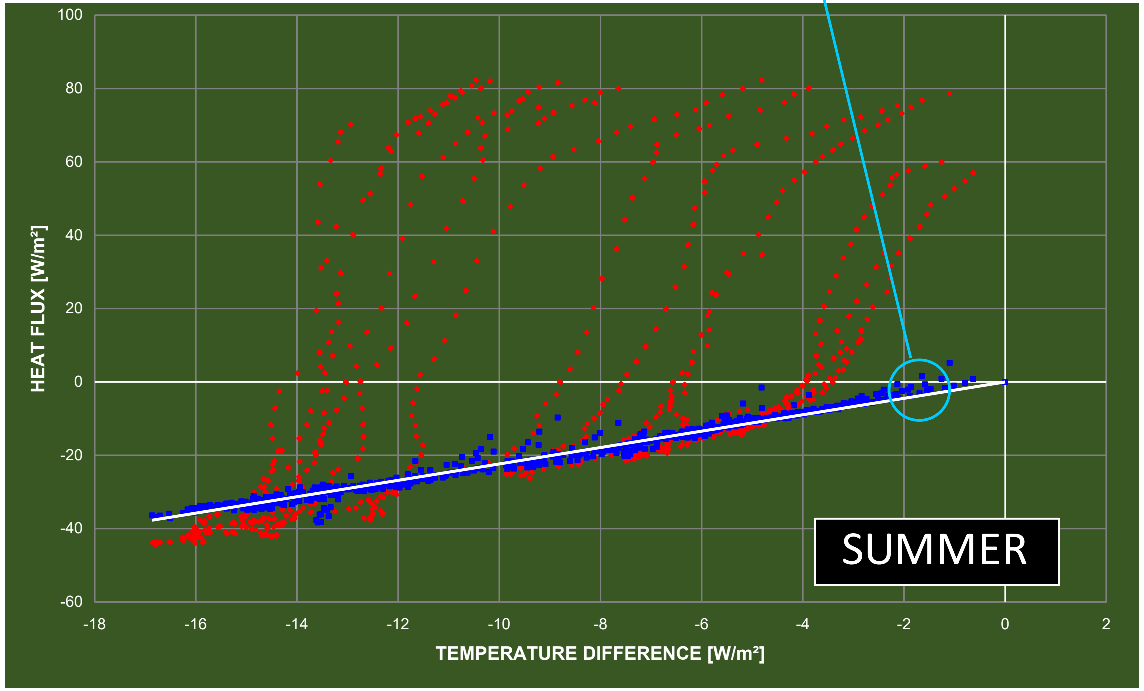
OPEN QUESTIONS OF THIS PHASES – NEW KPI NEEDED



U_{night} = 2,7 W/m²K
PCM solid phase

$$U = \left(\frac{\dot{Q}}{A}\right) \Big/ \Delta T$$

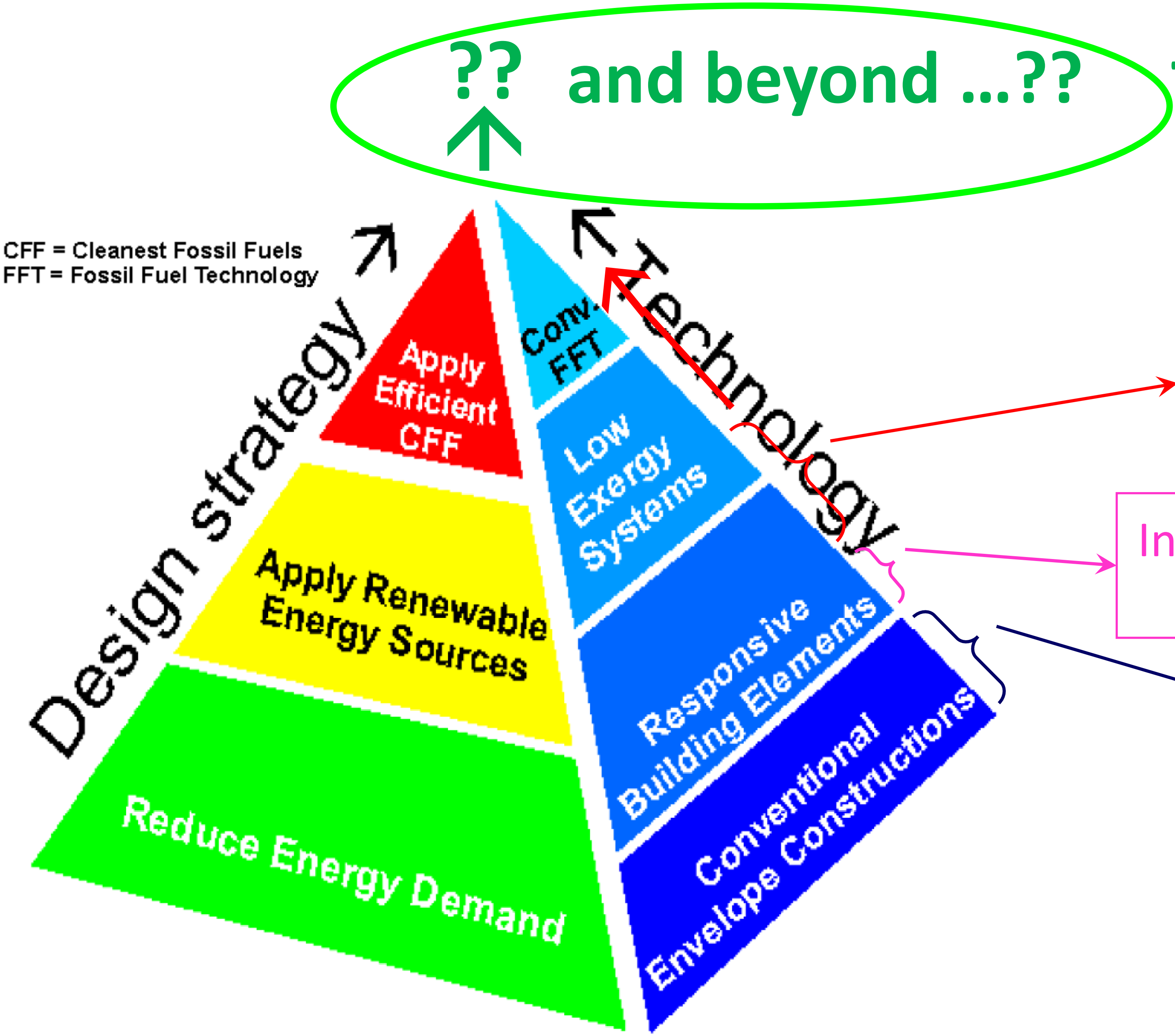
U_{night} = 2,3 W/m²K



DG with PCM

Clear double glass

The Concept Evolution – Beyond the 3RD step ?



To go there, we must be imaginative

Active & Multi Functional phase
2010 - 2020

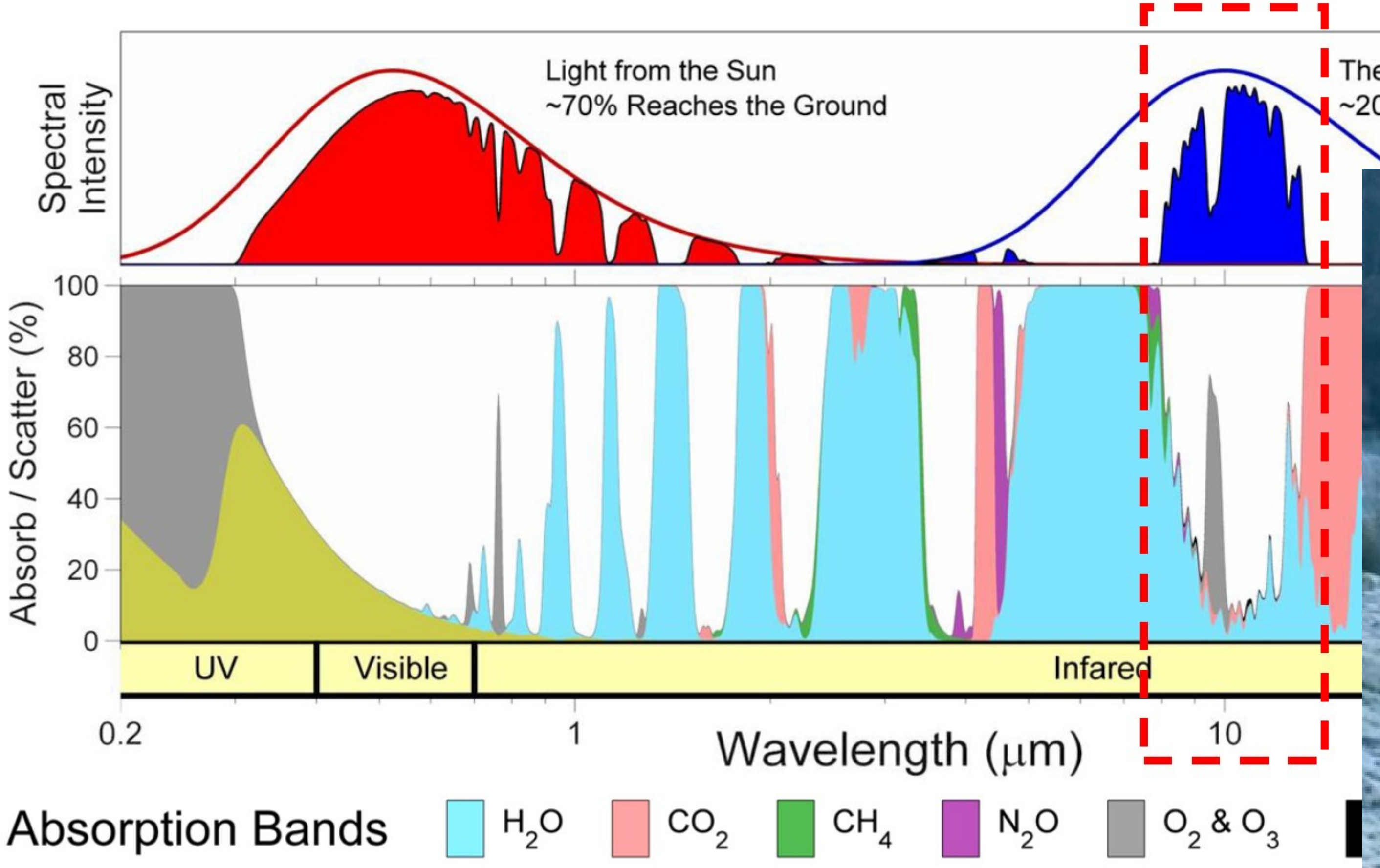
Integration and Adaptability phase
early 2000 - 2010

Energy Conservation phase
’70, ‘80, ‘90

BEYOND THE 3RD STEP – LOOKING FOR "GAME CHANGER" - 1

"Visionary" materials & Technologies:

Exploiting the "Sky transparency window"



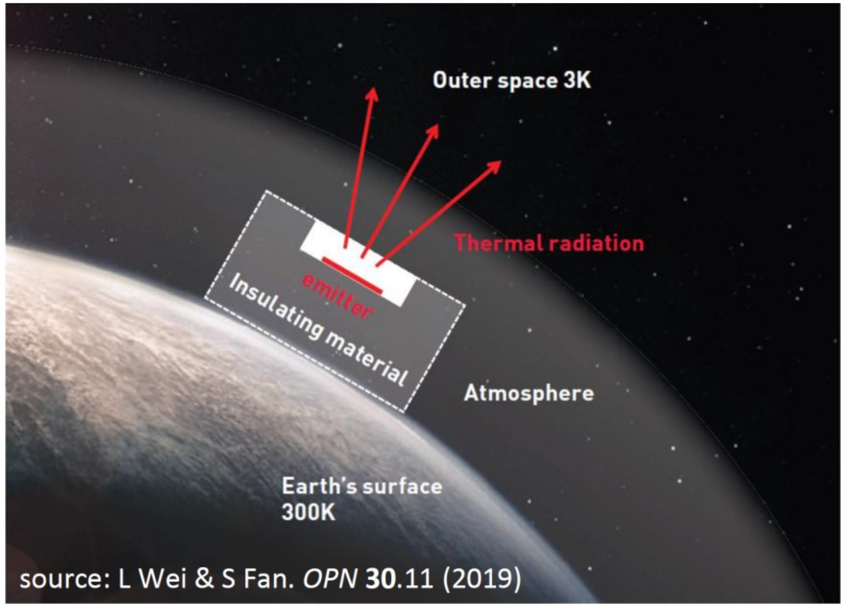
Passive radiative cooling technologies *PaRaMetric* - EURAMET project

Lorenzo Pattelli & members of PaRaMetriC
l.pattelli@inrim.it, parametric@inrim.it

PaRaMetriC [10]

BEYOND THE 3RD STEP – LOOKING FOR "GAME CHANGER" - 2

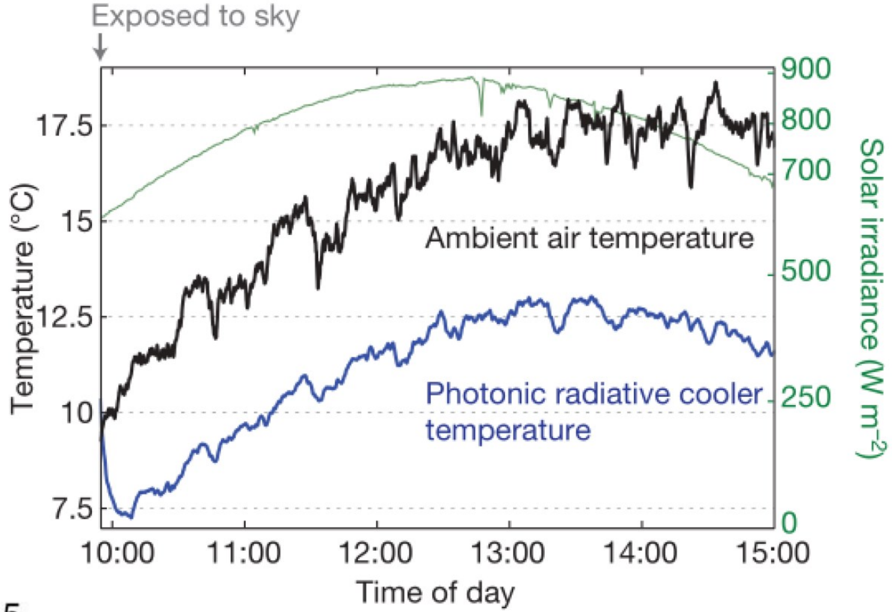
Using the (cold, 3 K) deep space as a heat sink:

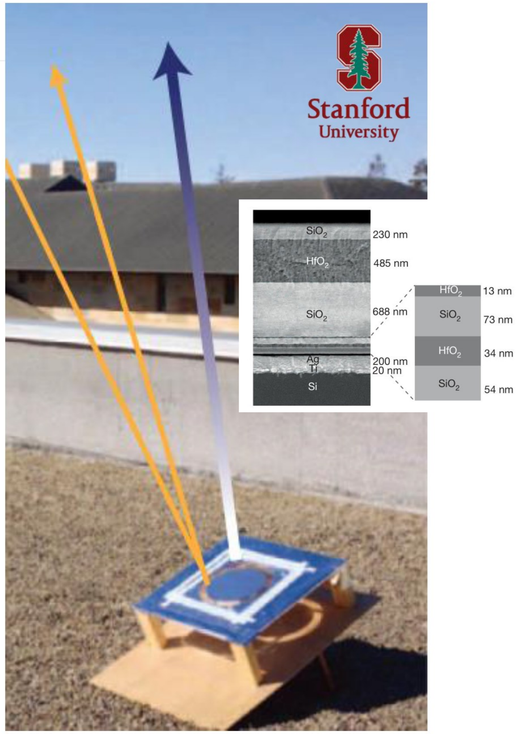


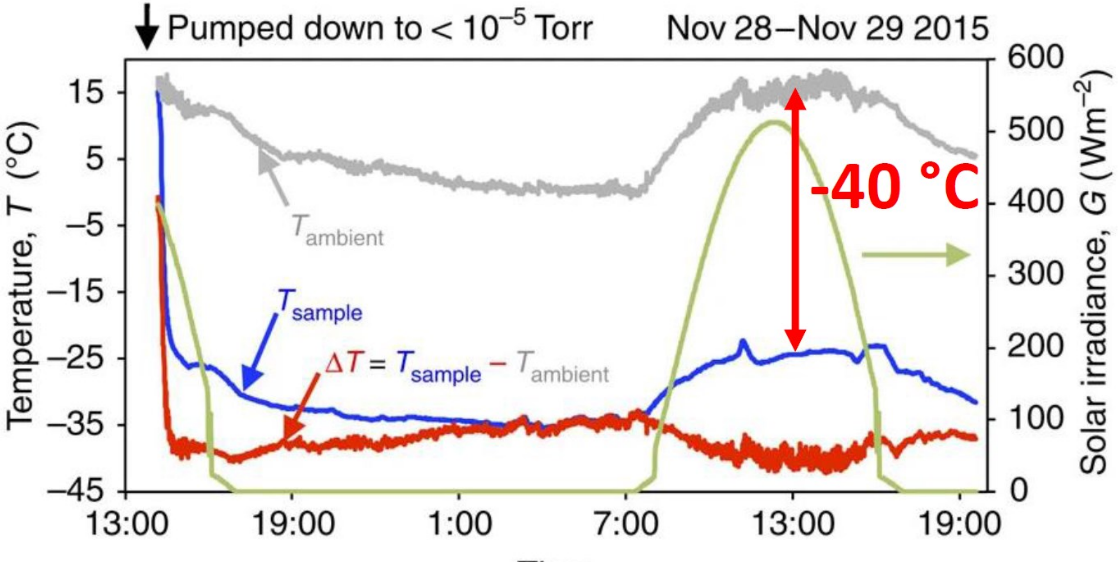
source: L Wei & S Fan. *OPN* **30**.11 (2019)

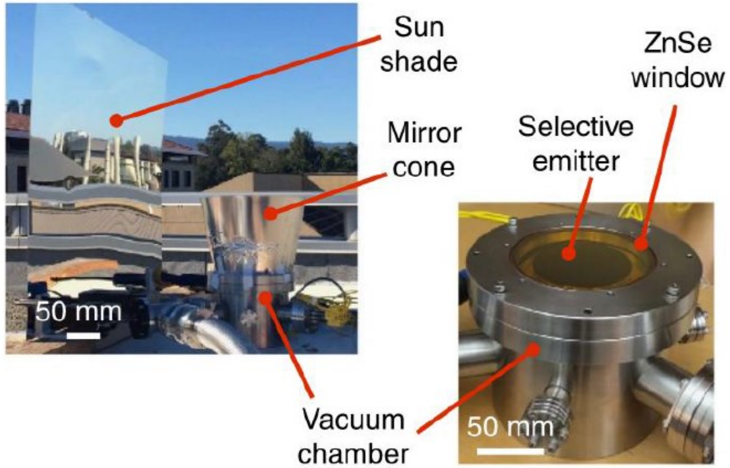
Passive radiative cooling below ambient air temperature under direct sunlight

Aaswath P. Raman[1], Marc Abou Anoma[2], Linxiao Zhu[3], Eden Rephaeli[1] & Shanhui Fan[1]

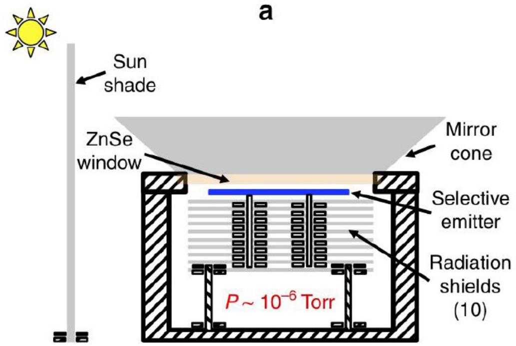








Z Chen et al., *Nat Commun* **7**.1 (2016)



BEYOND THE 3RD STEP – LOOKING FOR "GAME CHANGER" - 3

Not only Building Physics – The Building envelope as a huge "Interface" with the outdoors – the Sphere at the Venetian Resort:

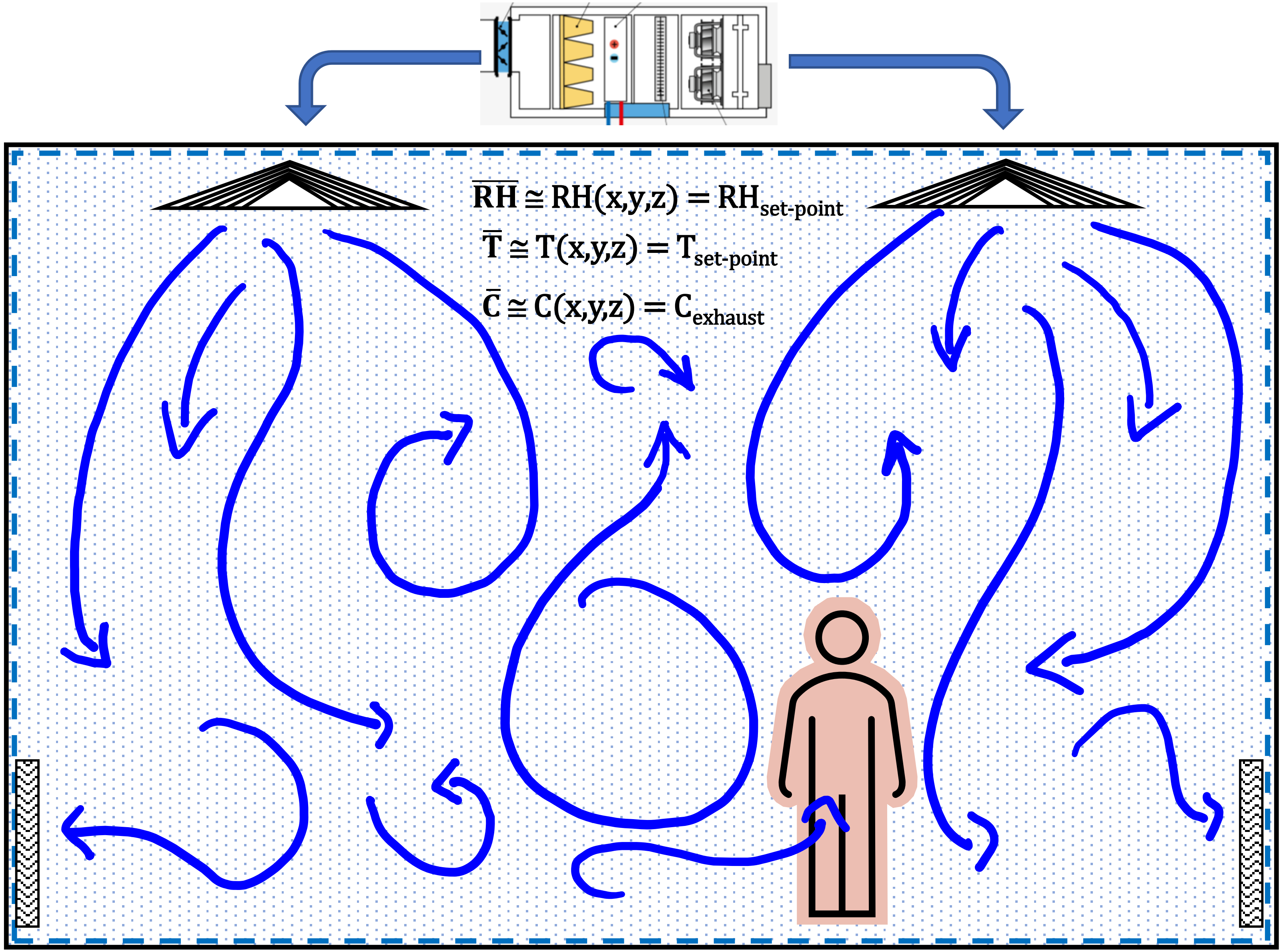
1.2 million of LED panels (2.5 x 1.2 m), resolution 14'000 x 9'000 pixels (126 Mpixels)

Beyond the 3rd step – Looking for "Game Changer" - 4

Rethinking the approach to Environmental Control:

The concept evolution:

The pristine idea



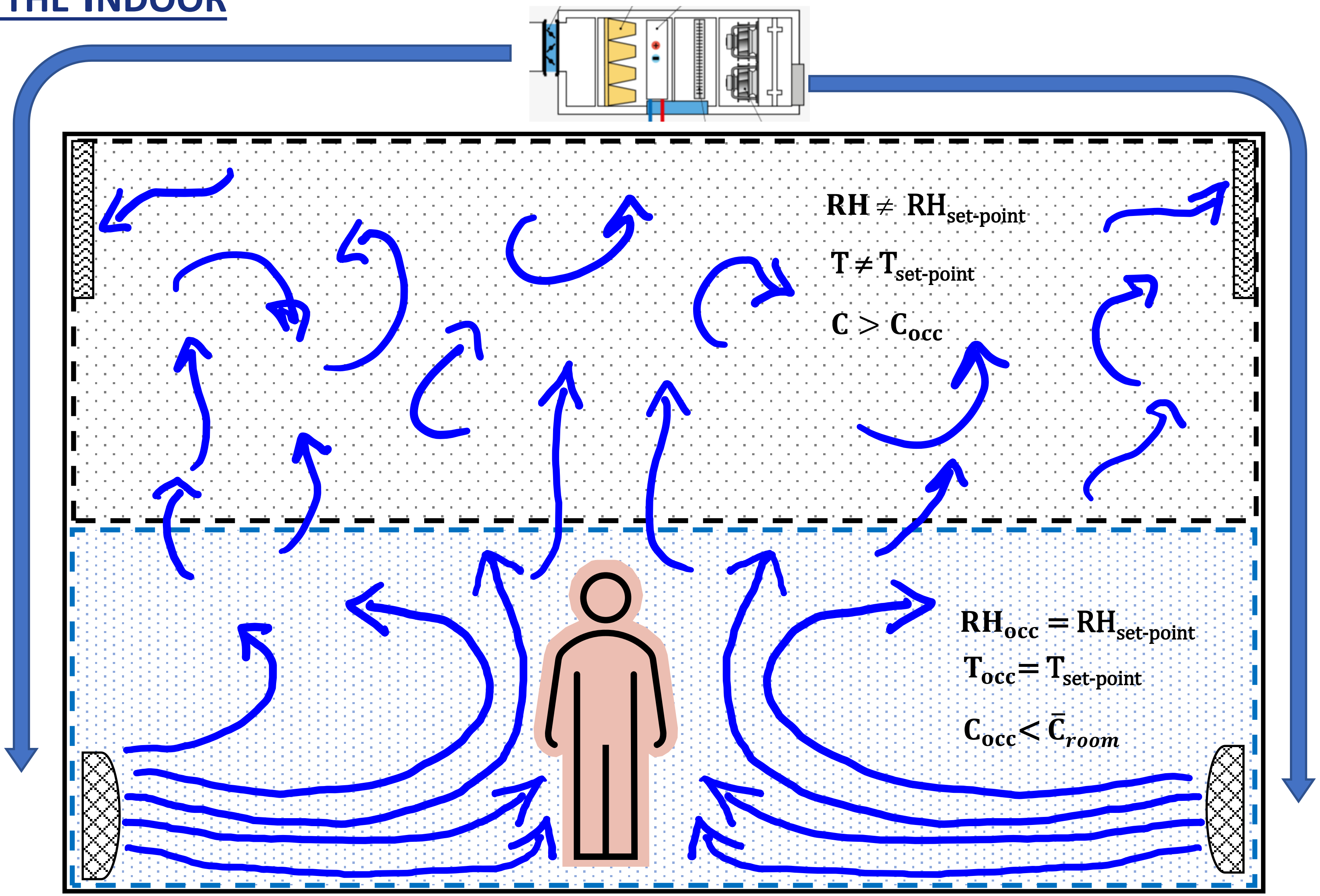
(A) Mixing system

Beyond the 3rd step – Looking for "Game Changer" - 4

Rethinking the approach to the Indoor Environmental Control:

The concept evolution:

The First evolution



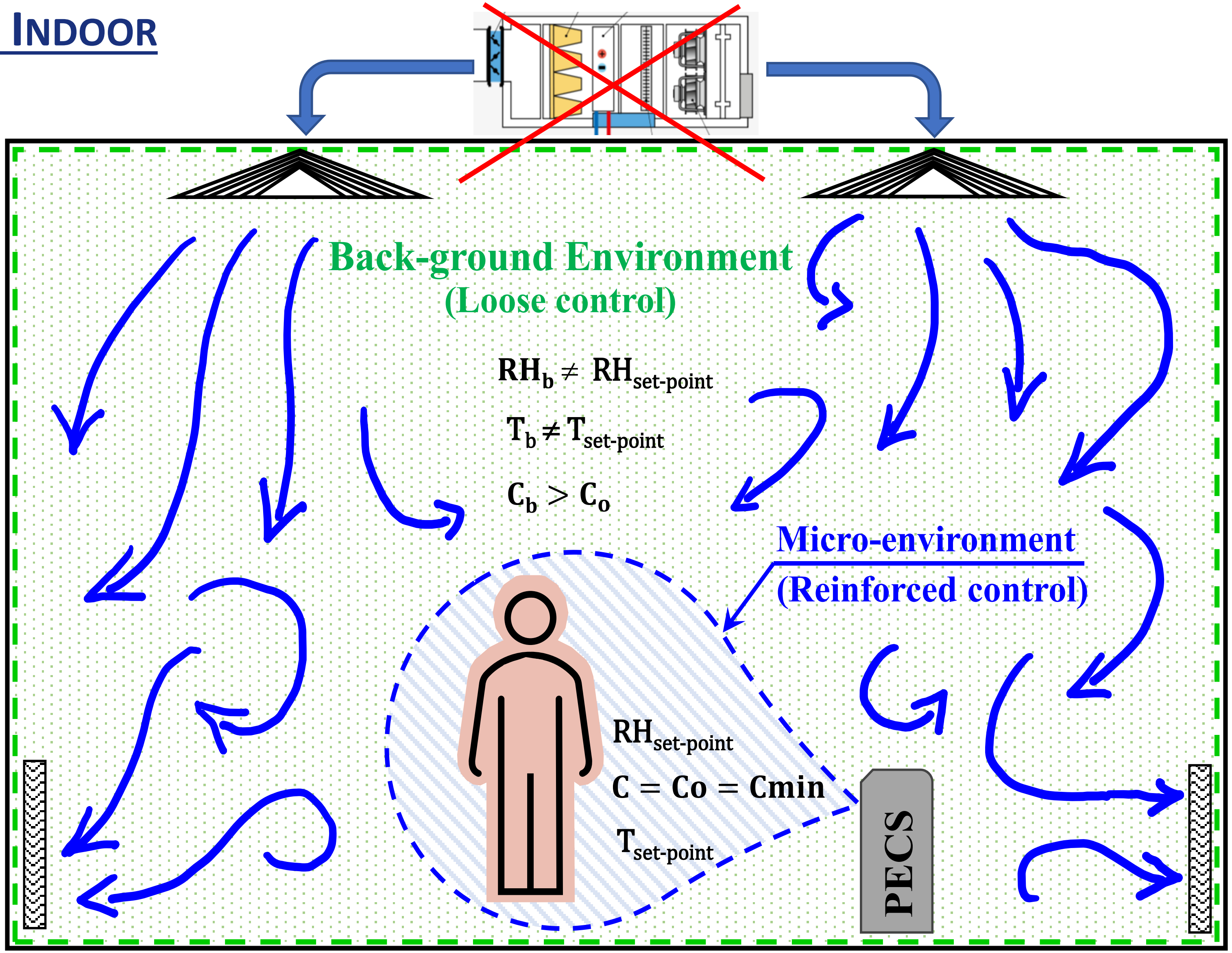
(B) Displacement system

Beyond the 3rd step – Looking for "Game Changer" - 4

Rethinking the approach to the Indoor Environmental Control:

The concept evolution:

The PECS concept



(C) PECS System

WHAT IS A PECS (PERSONALIZED ENVIRONMENTAL COMFORT SYSTEMS)?

General and unifying definition of PECS (IEA - Annex 87):

"A Personalized Environmental Control System (PECS) is a system that can provide individually controlled thermal, air quality, acoustic or luminous environments in the immediate surroundings of an occupant, without affecting directly the entire space and other occupants' environment".

This definition encompasses a number of previous classifications, like TAC, PCD, PCS, PV, PTMS.

What characterizes and unifies all these systems is ***the central idea of directly targeting the environmental control of the "personal space" instead of the entire built volume***, in contrast to conventional heating, ventilation, and air conditioning (HVAC) systems.

The new paradigm on which PECS are based is:

"making people comfortable not buildings/rooms"

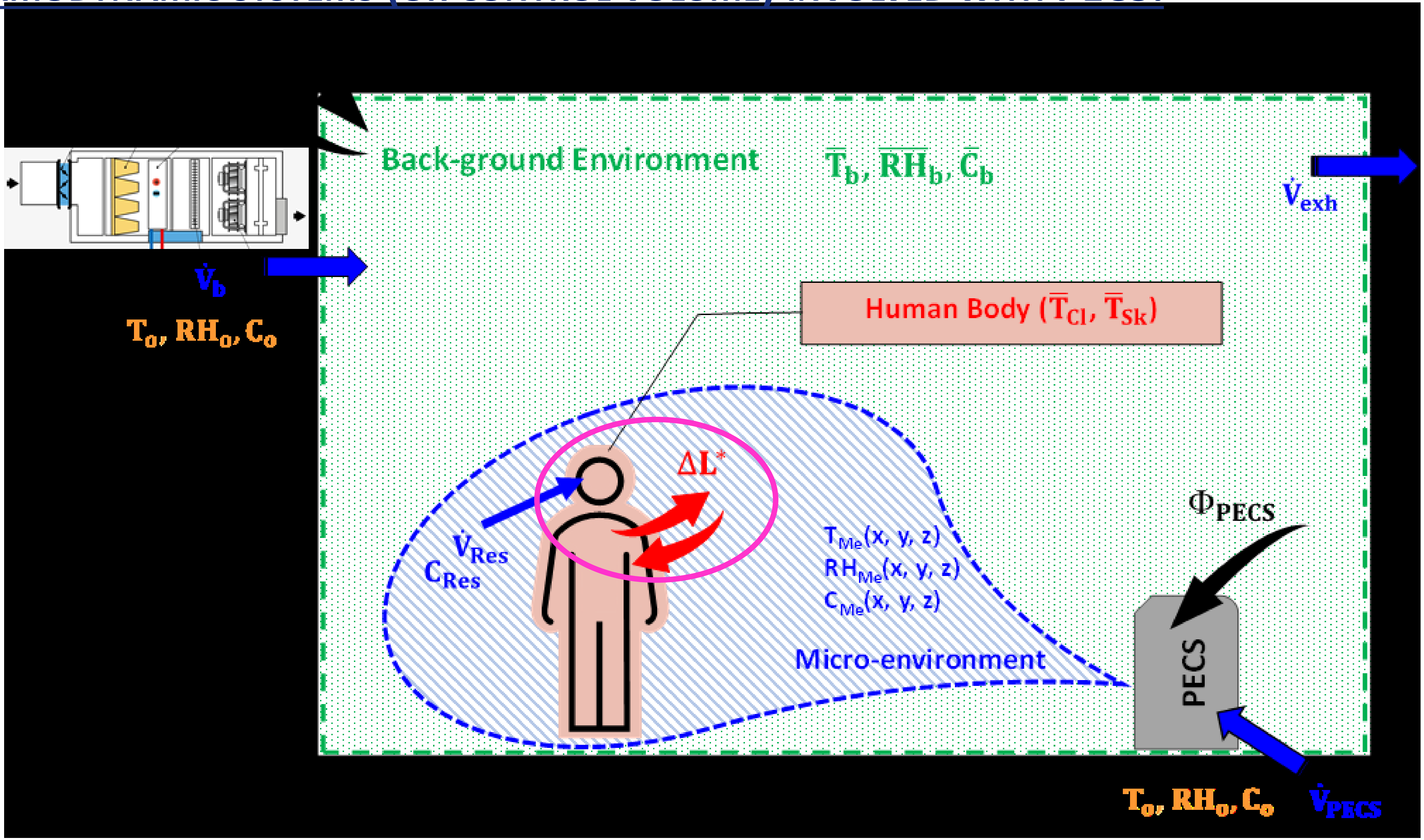
International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

ECBCS

IEA – EBC - Annex 87 - Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems (PECS)".

RETHINKING THE APPROACH TO THE INDOOR ENVIRONMENTAL CONTROL - 3

3 THERMODYNAMIC SYSTEMS (OR CONTROL VOLUME) INVOLVED WITH PECS:



WHAT SUBSTANTIALLY CHANGE IN THE METHODS FOR THE THERMO FLUID DYNAMIC ANALYSIS?

- With general, traditional HVAC systems, the enclosed space is the object towards which attention is focused. The HVAC system aims at modifying the environmental conditions.
- The relevant energy and mass exchange are those with the room environment (AHB). The comfort conditions are reached by varying the environmental parameters:

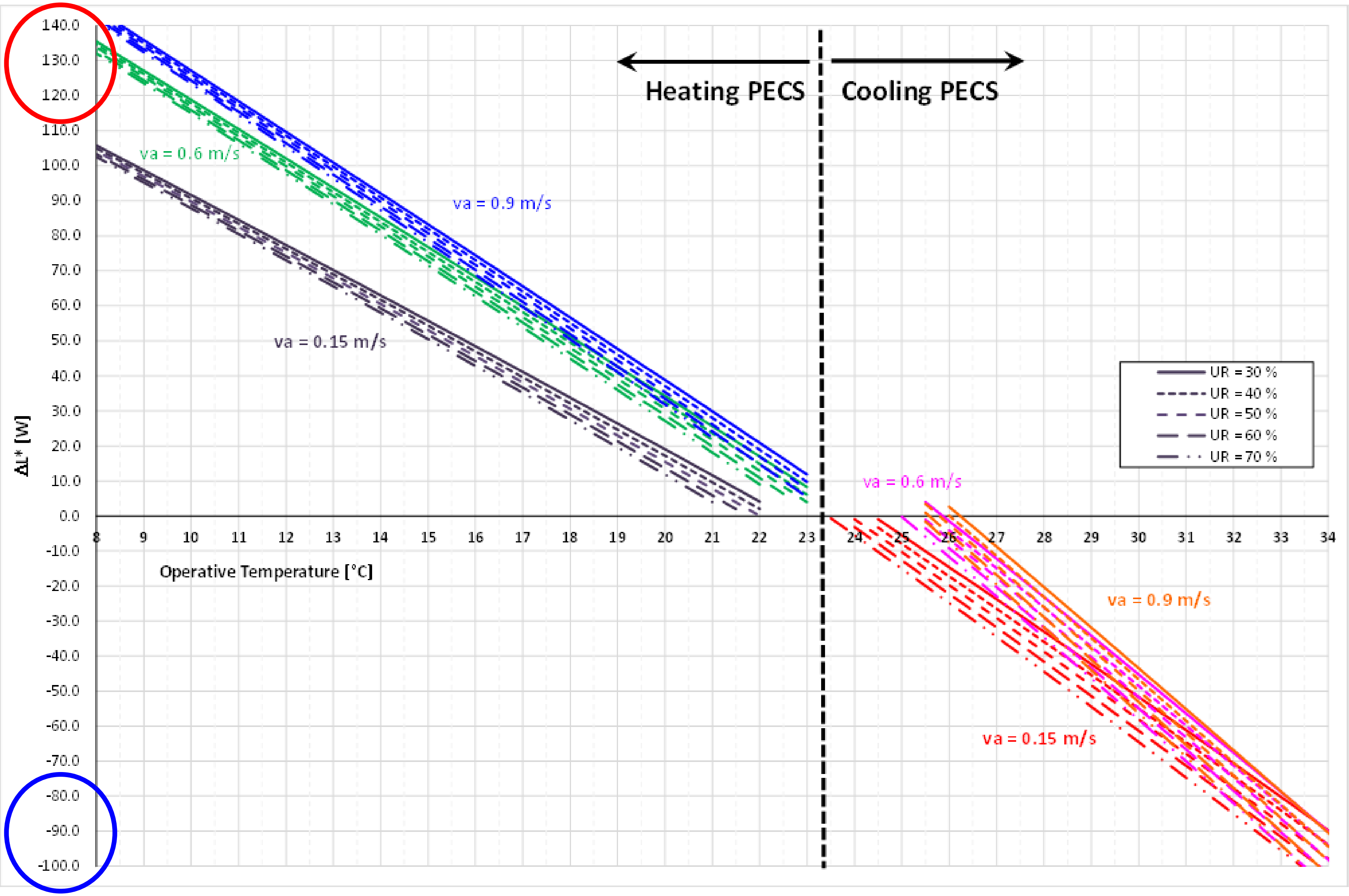
$$\Delta L = (M - W) - (C^* + R^* + C_k^* + R_{Res}^* + E_{sk}^*) \rightarrow 0$$

- With PECS the actions are focused towards the human body/skin,
- The relevant energy and mass exchanges are those with the person. Comfort conditions are reached by modulating the energy dissipation of the body (providing/extracting a certain "**Supplementary Power**", **ΔL*** [11]) and acting on the qualities of the inhaled air:

$$\Delta L = [(M - W) - (C^* + R^* + C_k^* + R_{Res}^* + E_{sk}^*)] + \Delta L^*$$

$\neq 0$

RETHINKING THE APPROACH TO THE INDOOR ENVIRONMENTAL CONTROL - 5



T_a [°C]	RH [%]	V_{ar} [m/s]
8 - 32	30-70	0.15 – 0.90

T_{mr} [°C]	I_{cl} [clo]
8.3 – 34.2	0.7 - 1

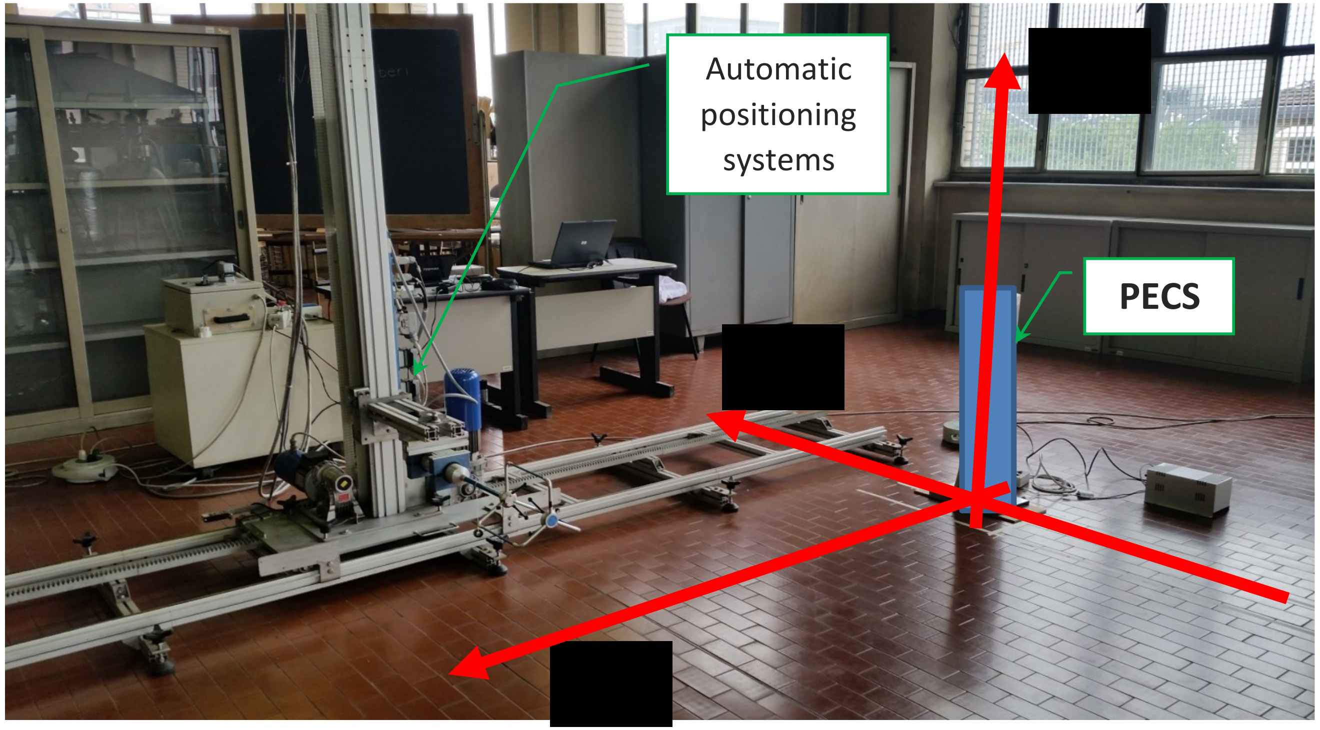
An office with 2 occupants: between 200 – 300 W (ideally) with PECS against a typical fan coil worth of some kW

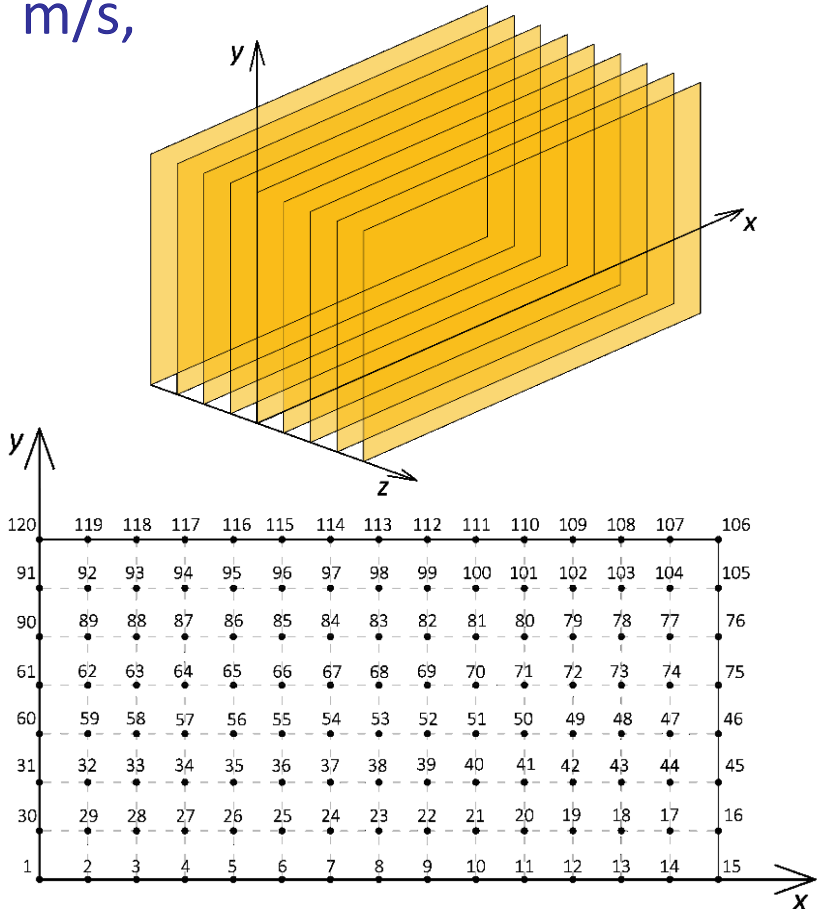
Example of the Supplementary power, ΔL^* vs operative temperature (1 person), for various environmental conditions of the background environment (Fanger model).

Rethinking the approach to the Indoor Environmental Control - 6

Example of PECS:

- Two commercially available bladeless fans were tested. The micro-environment for heating & cooling, and other metrics (η_{PECS} and the CP - Corrective Power) were measured.
- The following threshold values were chosen: v_∞ = 0.40 m/s, T_∞ = 22 °C.





Velocity **micro-environment** (“Cooling”/Isothermal Mode):

PECS “A”

PECS “B”

With PECS also the Building Envelope must evolved and adapt to this new scenario

What does “being imaginative” mean?

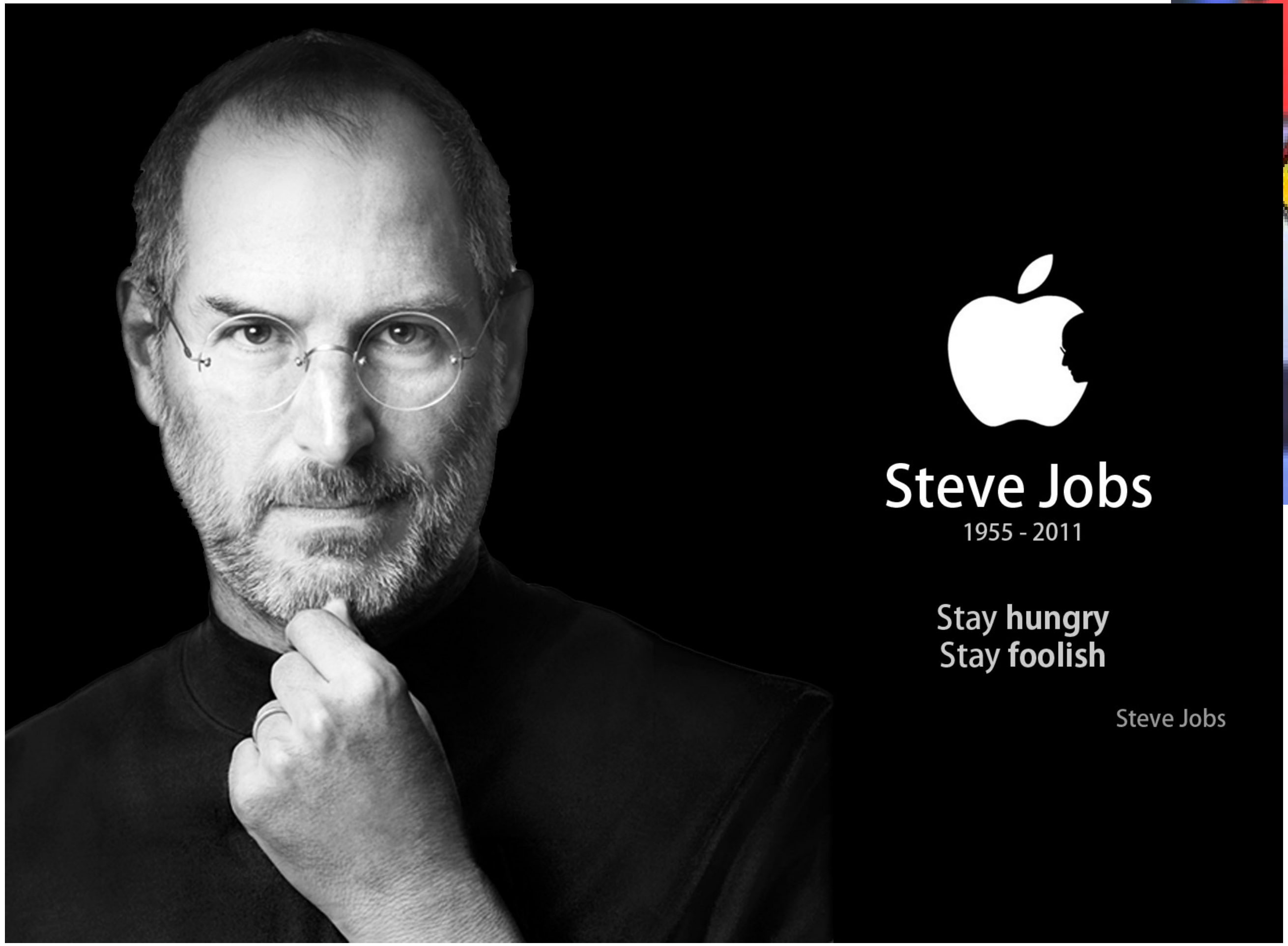
From “Blade Runner” – 1982 – Ridley Scott

Conclusions - 1

From "Blade Runner" – 1982 – Ridley Scott

What does “being imaginative” mean?

A visionary then went (far) beyond the fiction of Ridley Scott



CONCLUSIONS - 3

Can the Building Envelope Play a role in the energy transition? I think "YES"

- Reducing the final energy uses for HVAC and artificial lighting,
- In promoting the energy flexibility (space/time),
- Allowing to interface buildings each others and with other energy actors and infrastructures (Energy Communities, aiding Smart Grids management),
- A lot can still be done by continuing and deepening the traditional and current research activities (new/improved materials & technologies),
- Technical Standards must evolve and new KPI have to be conceived and used to support designers in their choice,
- Design methods must keep the pace with the new technologies and challenges,

But all this can only provide incremental innovation and development

To achieve breakthrough advancements we need to be "brave" (and may be a little "foolish") and start exploring new, visionary and disrupting solutions.

Acknowledgements

Achievements and results are never the product of one man alone … What I presented today is the outcome of numerous activities done together by many people of our research group:

THANKS FOR THE ATTENTION

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Land Acknoledgement

Toronto is in the “Dish With One Spoon” territory. The Dish With One Spoon is a treaty between the Anishinaabe, Mississaugas and Haudenosaunee that bound them to share the territory and protect the land.