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Long-Term Performance of Super-Insulating Materials in Building Components & Systems

NANJING TECH UNIVERSITY
23 September 2015

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- Context & Challenge
- Heat transfer
- Thermal Conductivity
- Main issues about ageing for SIM
- Applications
- Conclusion

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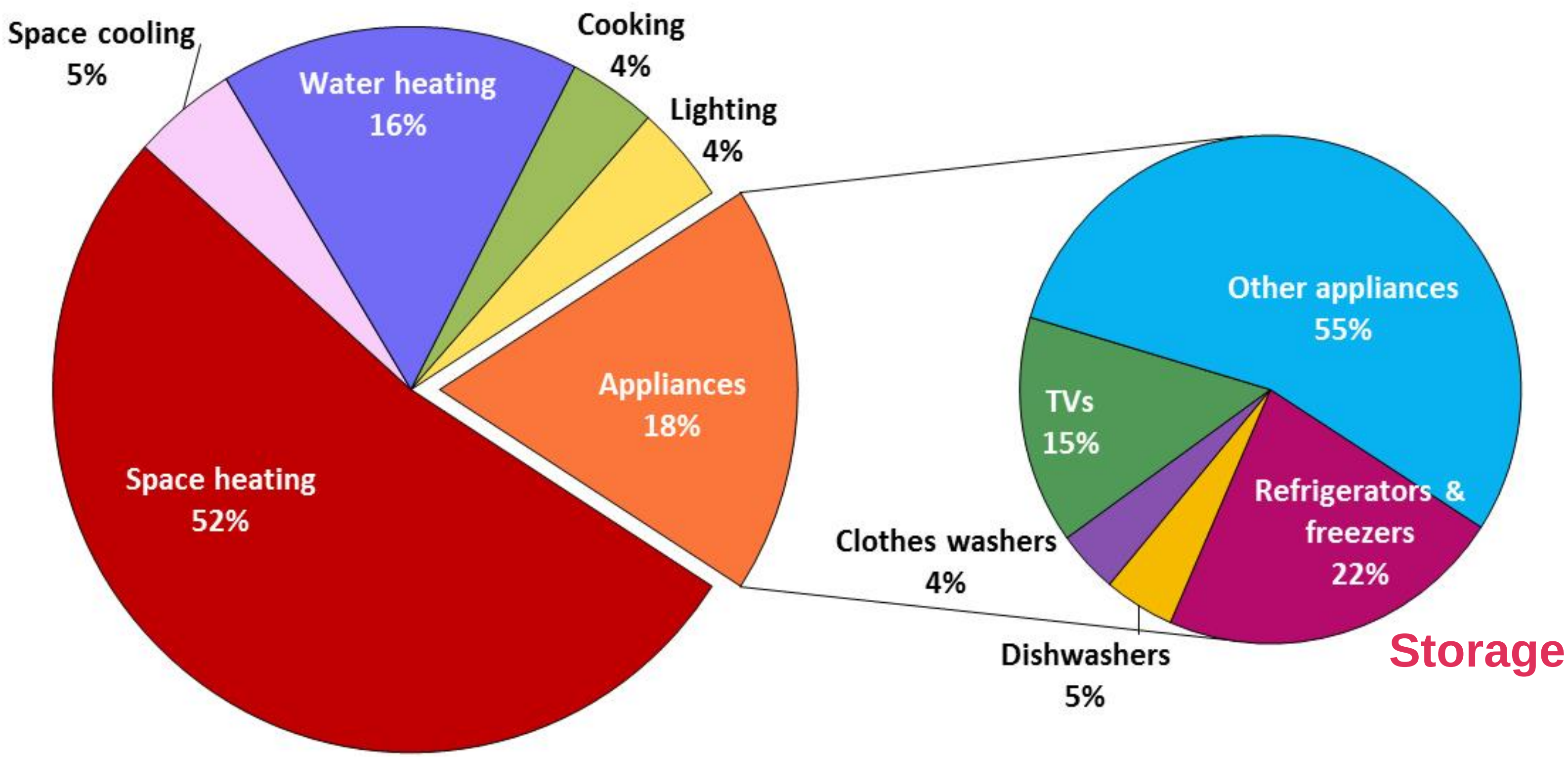
What drives energy consumption in households?

19 OECD member countries



Heating ~ 70 %

Breakdown of OECD energy consumption in the residential sector (2011)

Source: IEA energy efficiency indicators database 2014

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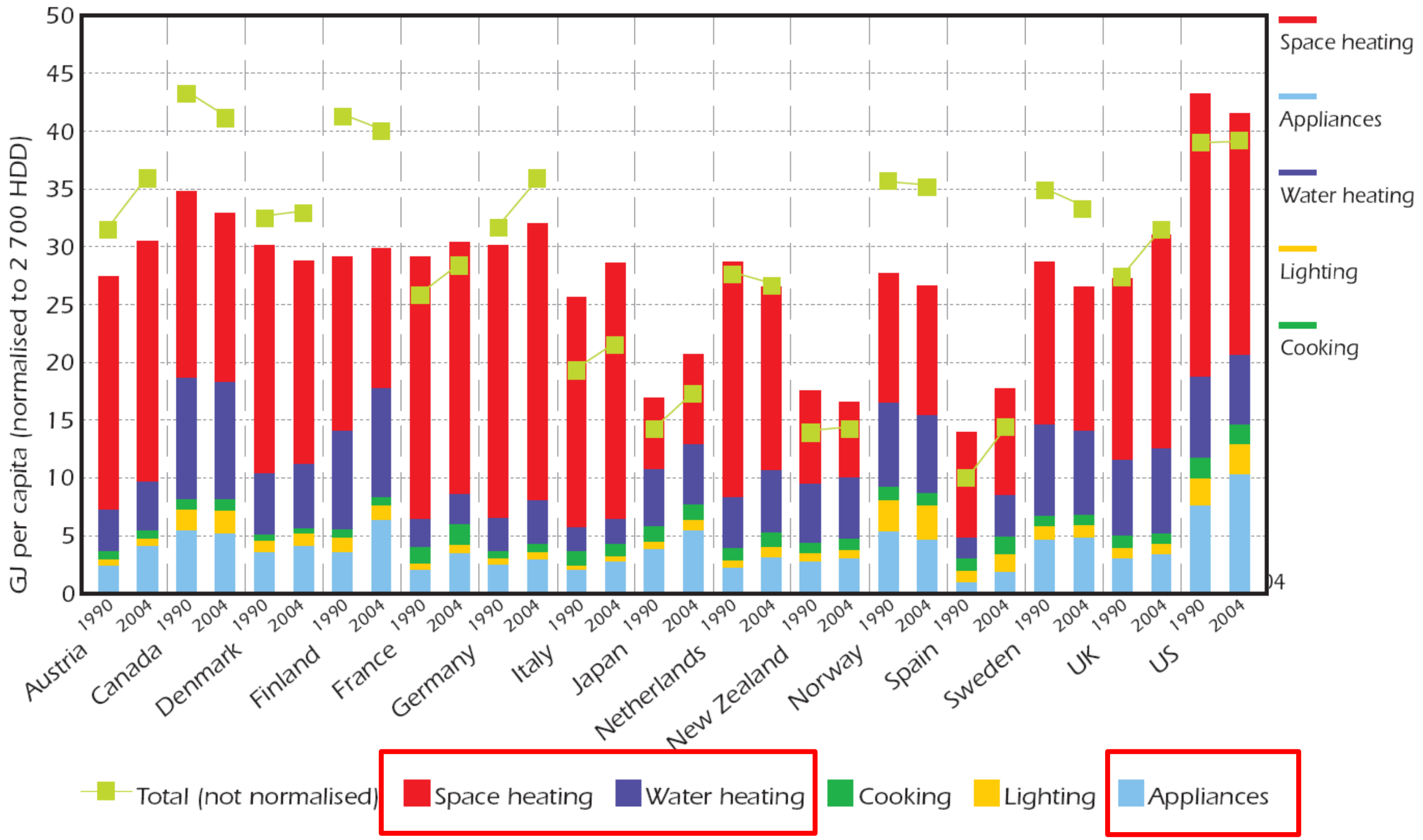
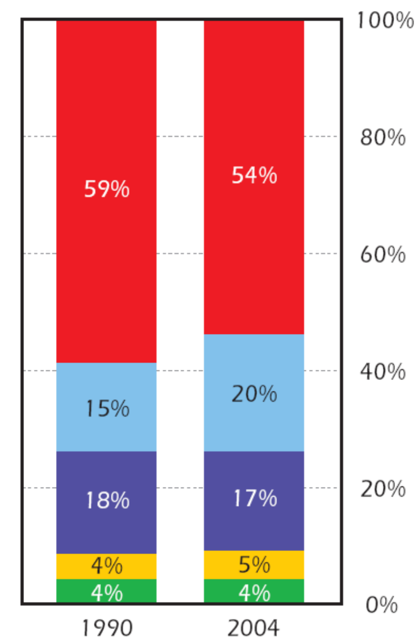
The Building Context
Three main energy users

waste

Figure 4.13 ▶ *Household Energy ~~Use~~ per Capita*





60 to 80 %

Source : IEA - Millennium

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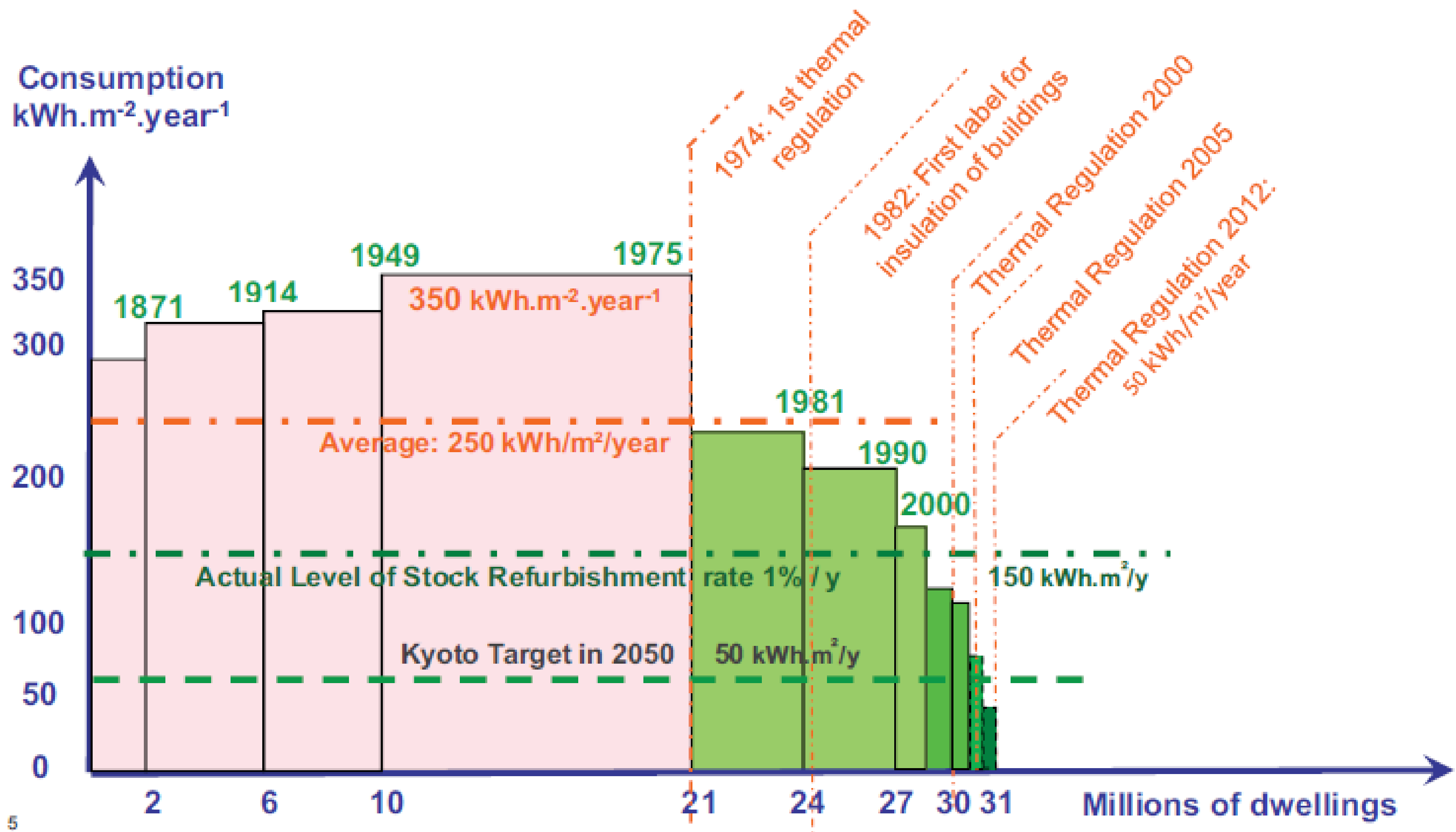
FRENCH BUILDINGs - EXISTING STOCK



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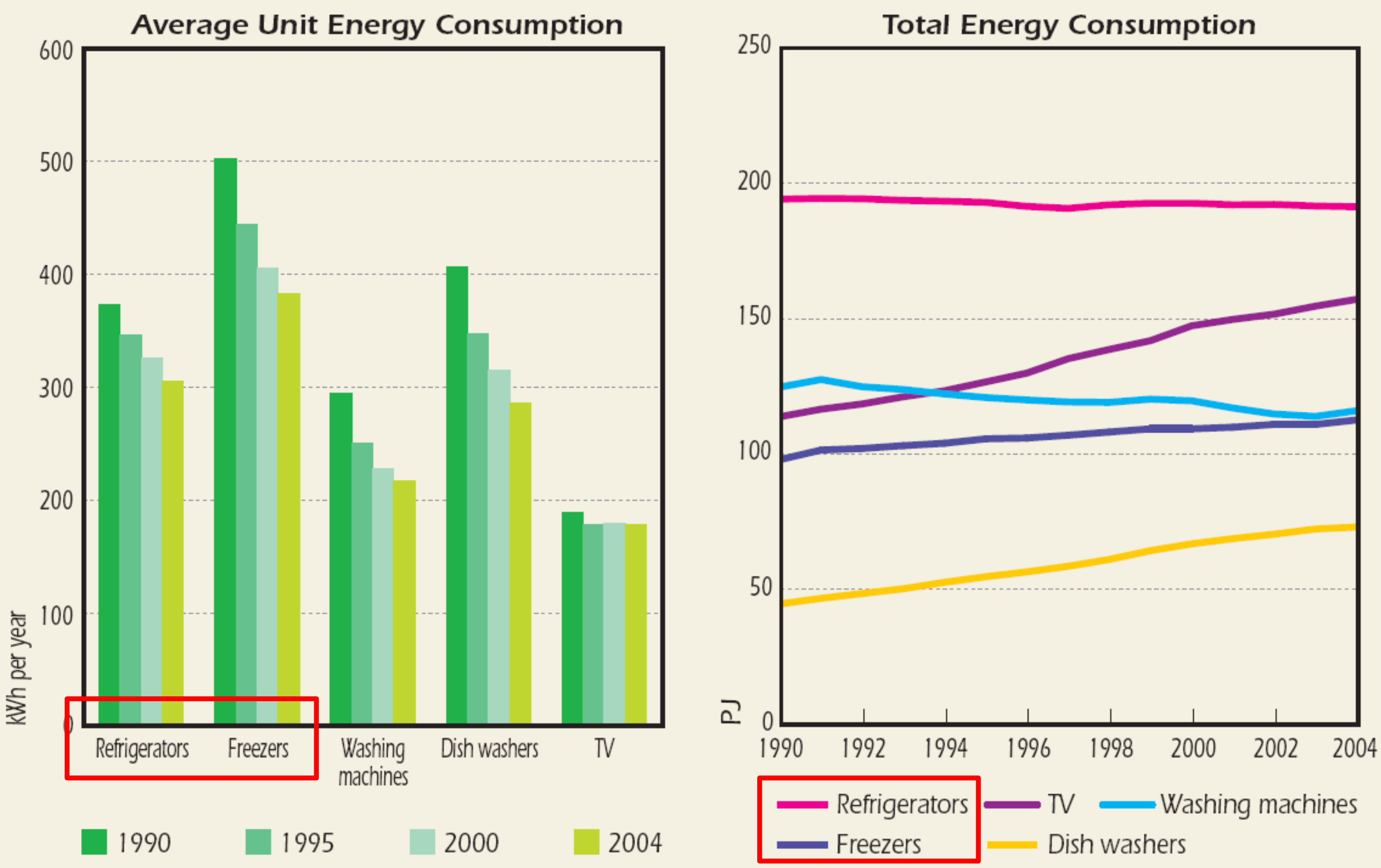
Cold Storage : freezer & refrigerator

Figure 4.8 ▶ ***Energy Consumption of Large Appliances, EU15***



Source: ODYSSEE Energy Efficiency Indicators.

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Energy Performance of Buildings Directive (EPBD),

The principle of nearly zero energy buildings

"nearly zero-energy building" means a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby

The principle of cost optimality

giving guidance for the energy performance requirements of new and existing buildings undergoing major renovation

Source : E2APT-RICS-ACE

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Buildings in the European Union

210 million buildings in the European Union
Approximately 53 billion square meters of usable indoor space

Type	Number constructed before 1973	Number constructed after 1973	Overall percentage of total stock
Individual Private Residences	42,840,000	28,560,000	34
Private Apartment Buildings	17,640,000	11,760,000	14
Public (Social) Housing	16,800,000	8,400,000	12
Commercial Buildings	18,900,000	44,100,000	30
Public Buildings	5,040,000	11,760,000	8
Other (Leisure, Industrial…)	1,890,000	2,310,000	2
Totals:	**103,110,000**	**106,890,000**	**100**

60%

40 %

new buildings : 10 % to 20 % of the additional energy consumption by 2050
building stock: more than 80%

Source : E2APT-RICS-ACE

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Potential energy savings in Building … as much as transport today

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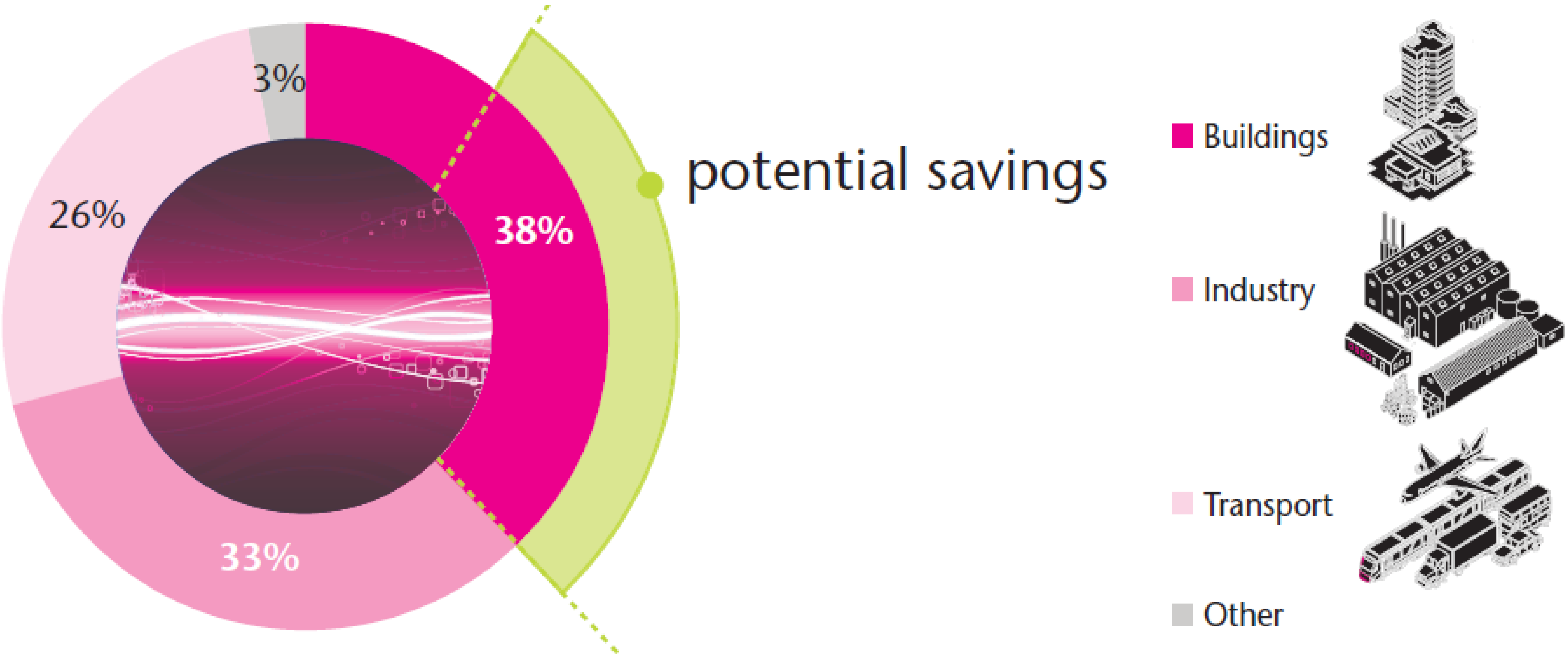

Source WBCSD

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EUROPE : Challenges in the Building Sector

Renovation/Retrofitting

- Building stock : more than 80% of energy consumption.
- 75% to 90% of current buildings will still be standing in 2050

New Buildings

- NZEB (Net or Nearly Zero Energy Building)
- only 10 % to 20 % of additional energy consumption (2050)

Energy Efficiency

- Through Building Envelope & Thermal Insulation (IEA Roadmap)

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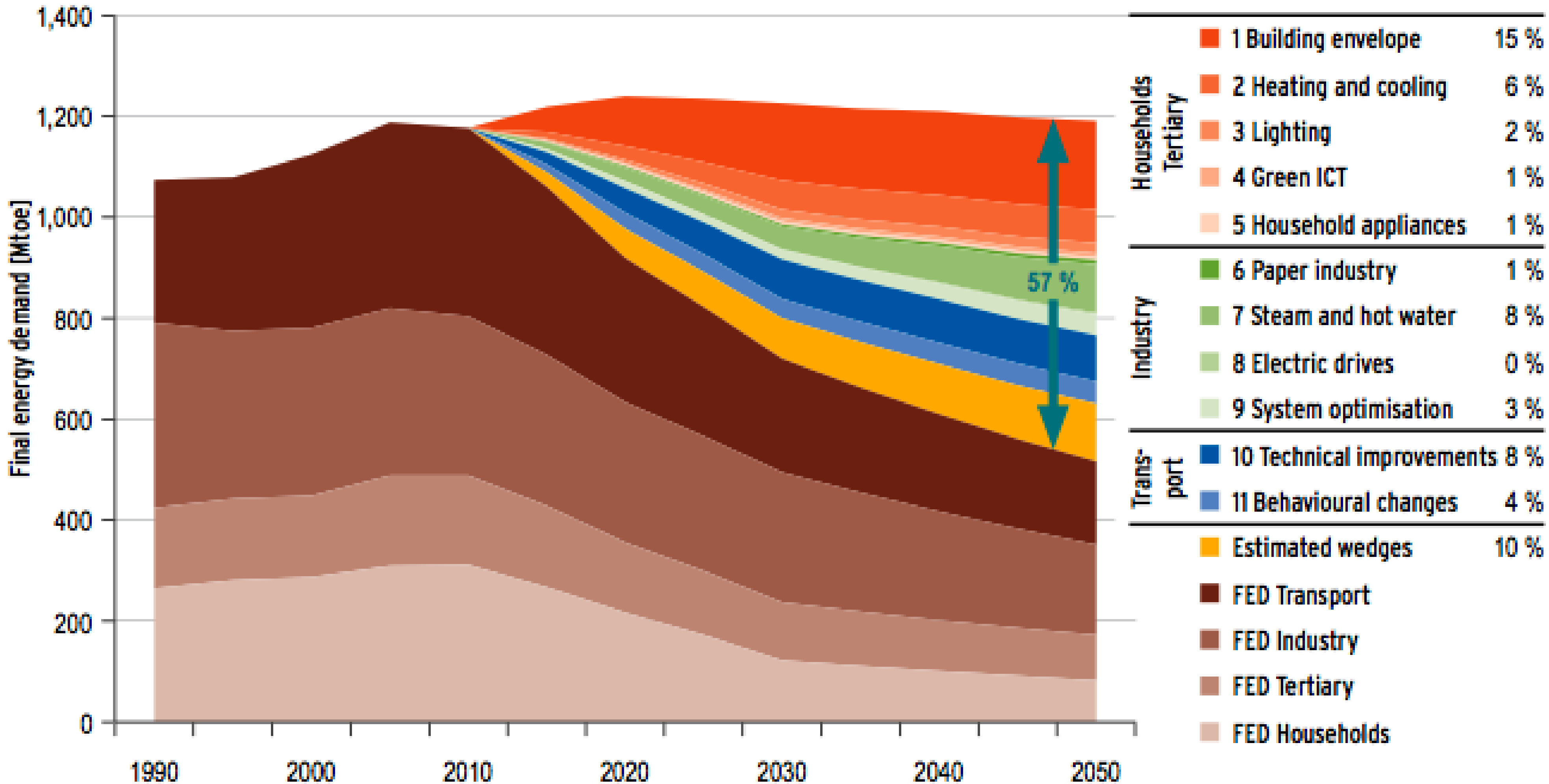
Thermal Performance of the Building Envelope is a top priority



Source : http://www.energy-efficiency-watch.org/fileadmin/eew_documents/images/Event_pictures/EEW2_Logos/EEW-Final_Report.pdf

Source: FhG-ISI et al. 2012

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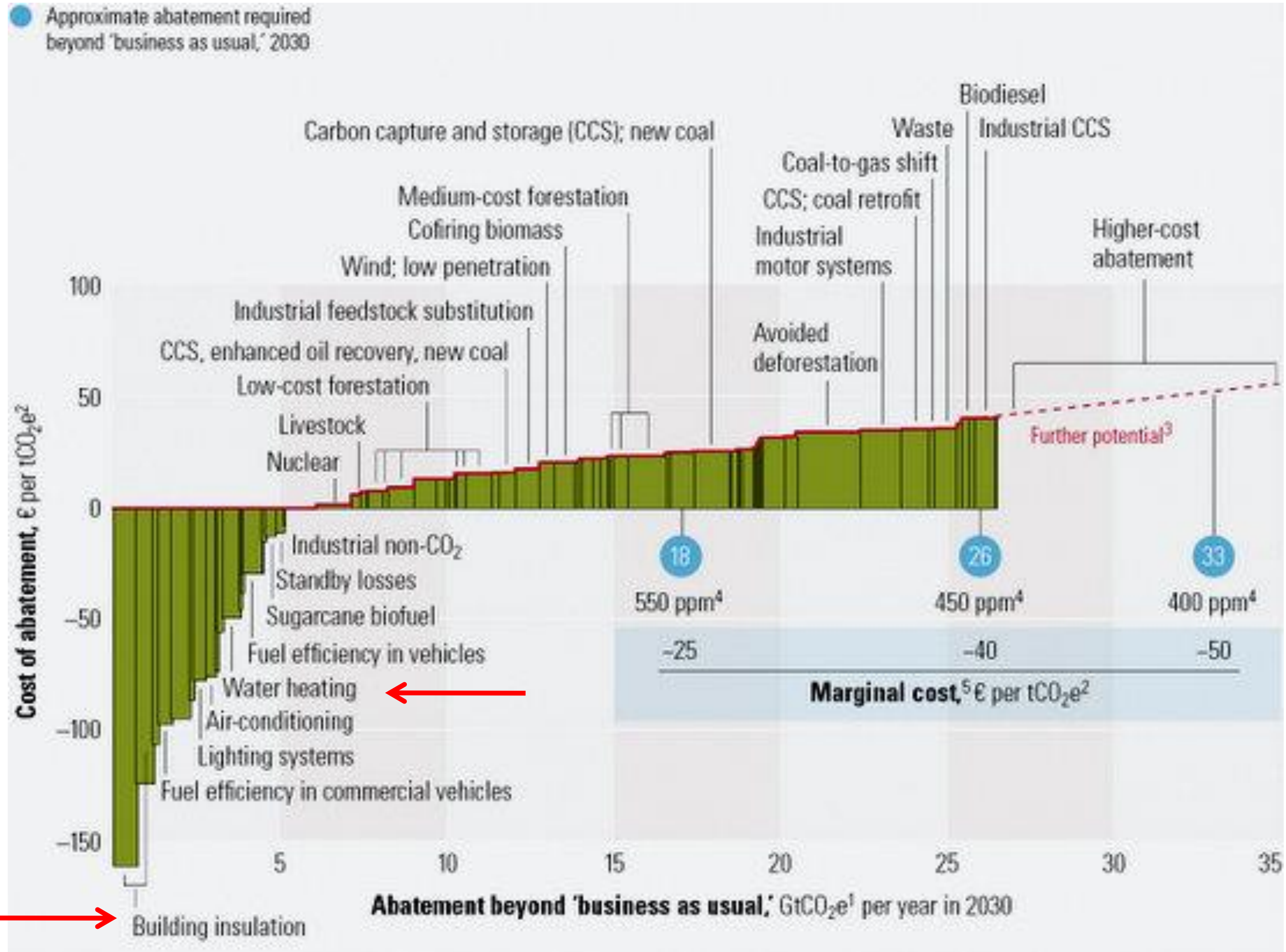
Building Insulation & Water Heating Saving are among the most cost-effective carbon abatement measures



Global cost curve for greenhouse gas abatement measures beyond "business as usual".

Source : Mc Kinsey

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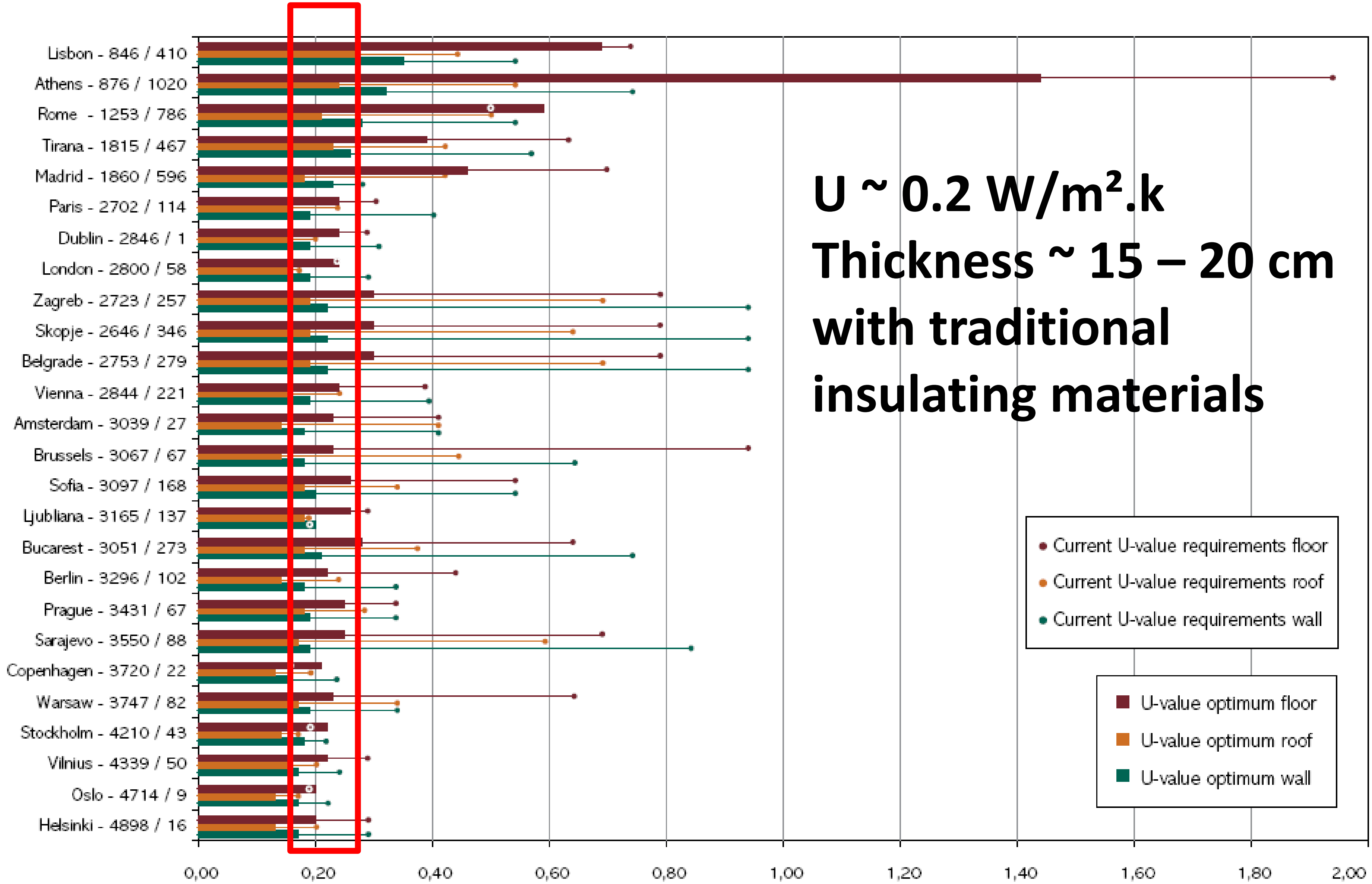
Optimum U-value



U ~ 0.2 W/m².k
Thickness ~ 15 – 20 cm
with traditional insulating materials

Source : EURIMA-ECOFYS

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Thermal Conductivity of Building Materials

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Building Materials
Thermal Conductivity vs Density

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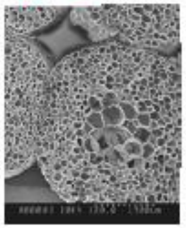
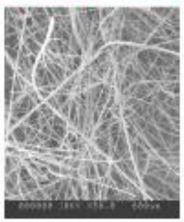
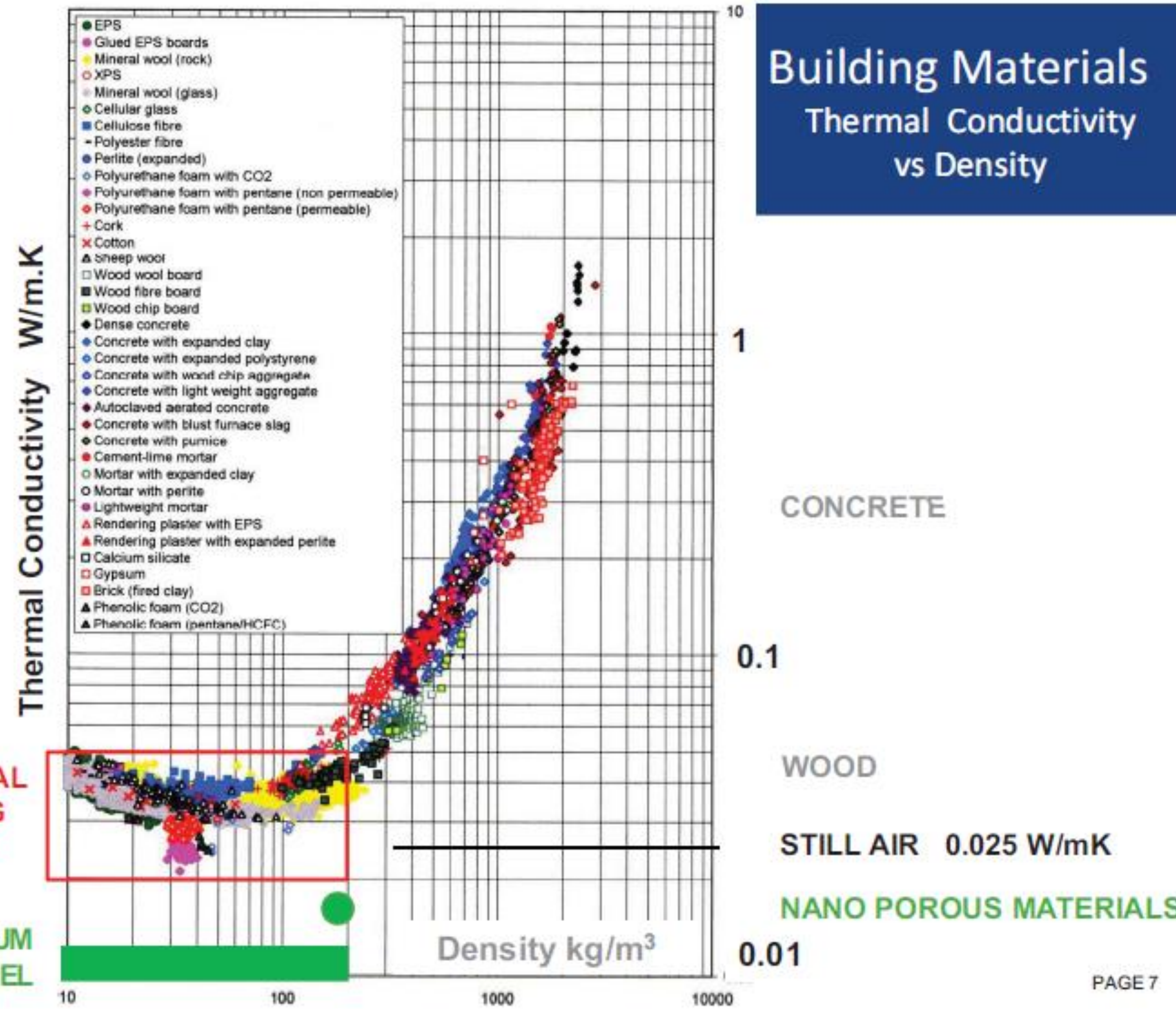


Glass Wool





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Equivalent Thermal Conductivity λ_e

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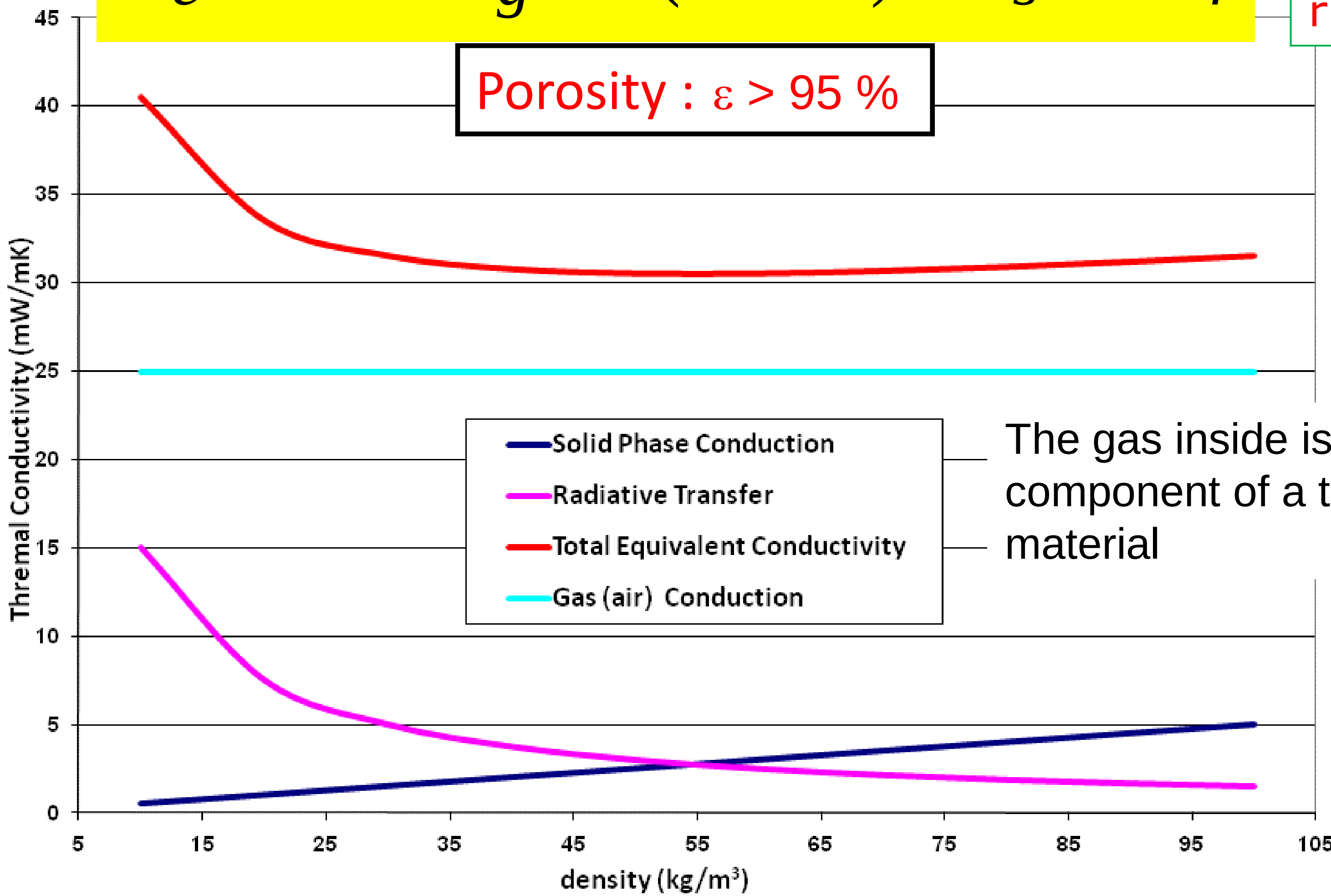
$$\lambda_e = \varepsilon \cdot \lambda_g + (1-\varepsilon) \cdot \lambda_s + \lambda_r$$

g : gas
s : solid
r : radiation

Porosity : $\varepsilon > 95\ \%$



The gas inside is the main component of a thermal insulating material

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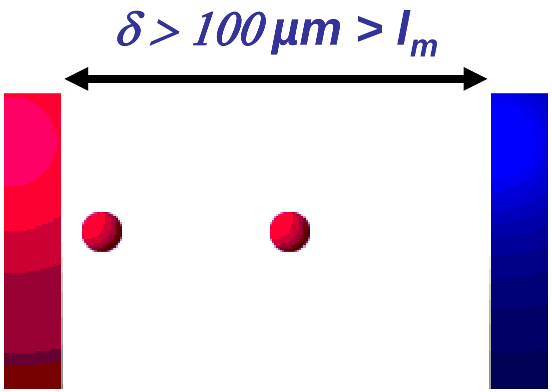
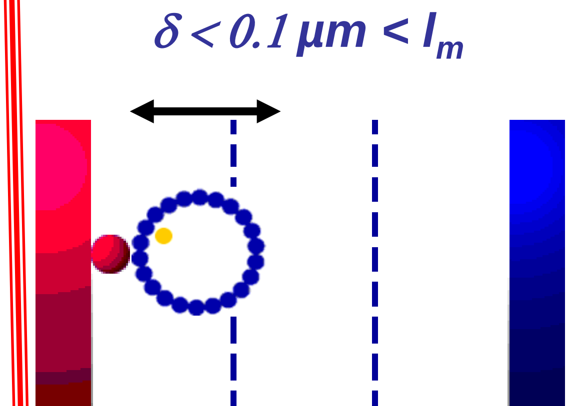
$$\lambda_e = (1-\varepsilon)\cdot\lambda_s + \varepsilon\cdot\lambda_g + \lambda_r$$

Equivalent Thermal Conductivity



Gas Conduction

$$\lambda_g = \cdot\frac{\lambda_{g0}}{1 + C\cdot\dfrac{T}{\delta\cdot P}}$$



Radiation

$$\lambda_r = \frac{16}{3}\cdot\frac{\sigma\cdot T^3}{\rho\cdot E}$$

- δ : Characteristic size of cavities
- P : Pressure
- ρ : Density kg/m3
- E : Extinction Coefficient
- T : Temperature
- σ : Boltzmann's Constant

Source : Microtherm

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The main trends to lower thermal conductivity

Reduction of radiative transfer (15% - 50 %)

- « low-emissivity barriers » : films, powders …

$$\lambda_r = \frac{16}{3} \cdot \frac{\sigma \cdot T^3}{\rho \cdot E}$$

Reduction of gas conduction (60 % - 80 %)

1 : « heavy gas » , lower λ_{g0}

2 : low pressure P

3 : confinement - cavity size δ lower than l_m

$$\lambda_g = \cdot \frac{\lambda_{g0}}{1 + C \cdot \frac{T}{\delta \cdot P}}$$

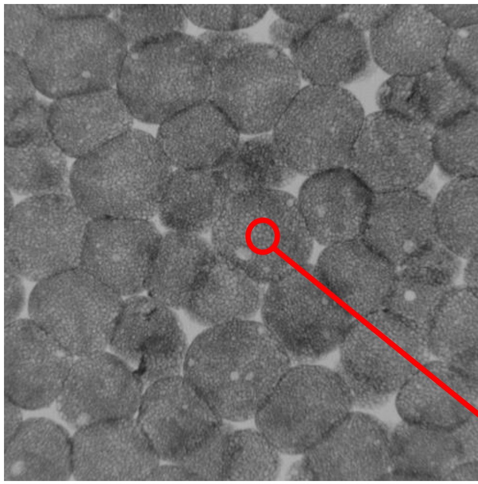
Change of Gas

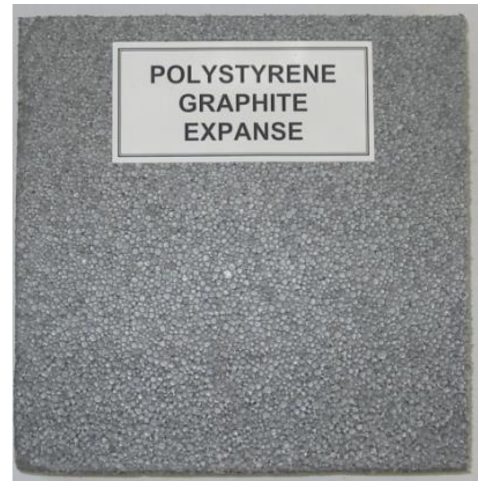
Gas	Molecular Weight *kg/mole*	Thermal Conductivity λ *W/m .K* - 24 °C
Air	29	0.026
Water Vapor	18	0.0187
CO_2	44	0.0168
~~CFC11~~	~~137~~	~~0.008~~
HCFC 141b		0.010
HFC		0.011
n-Pentane C_5H_{12}	72	0.0135
c-Pentane		0.015
Ar	40	0.0179
Kr	84	0.0123
Xe	131	0.0055

banned

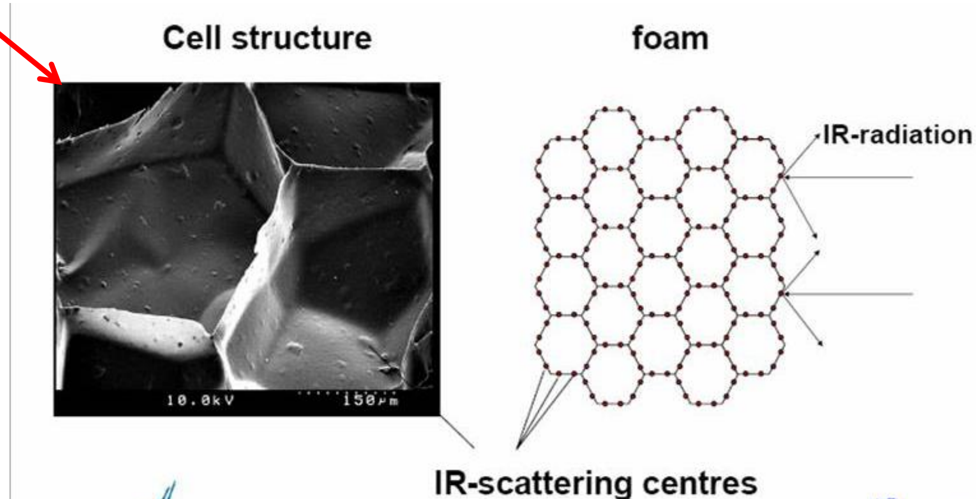
Use in double-glazing

Reduction of Radiative Transfer by opacifiers use





EPS



Opacifiers
- **Graphite Powder**
- **Aluminium Powder**

Plastics
Imagine the potential

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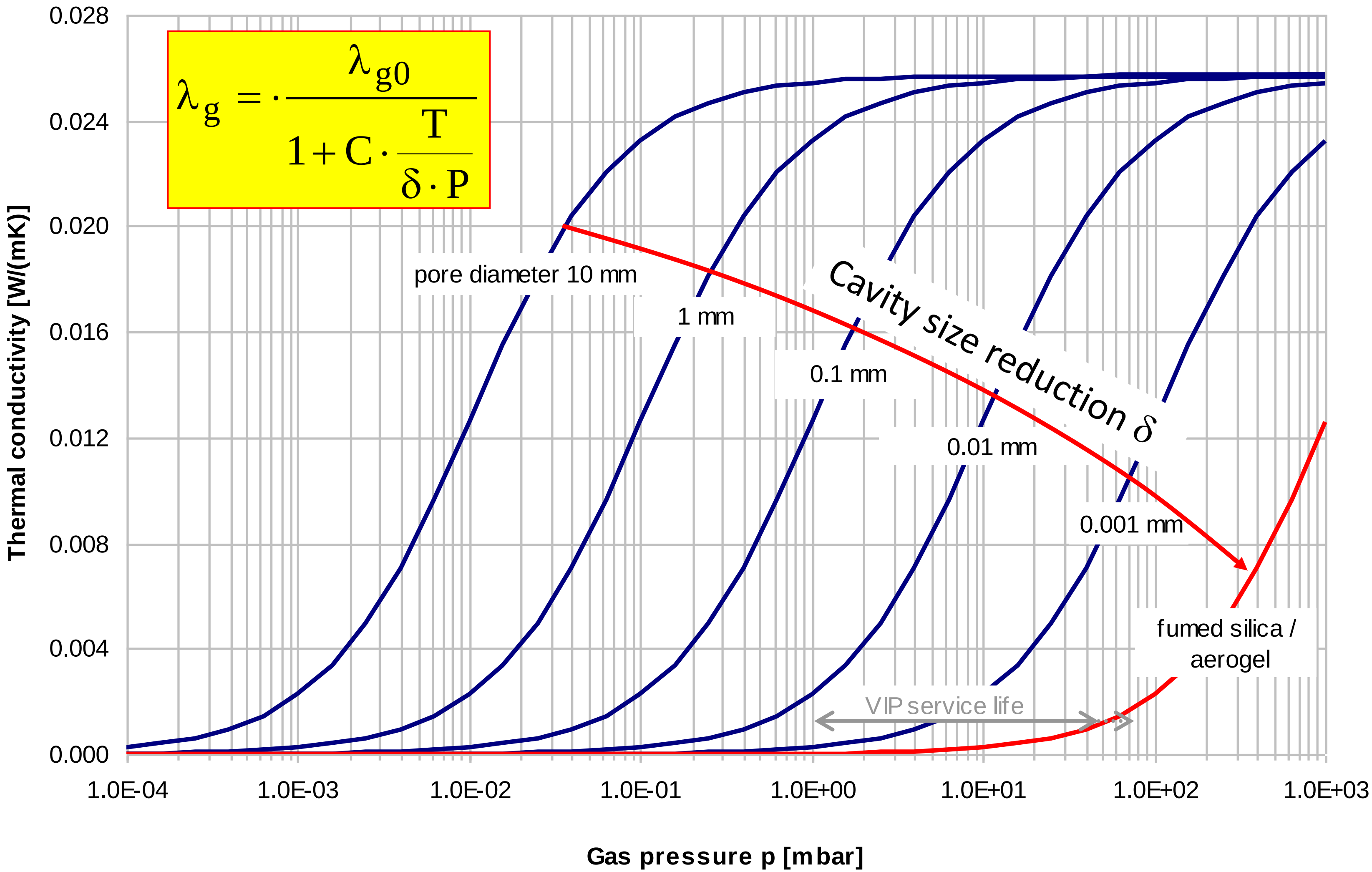
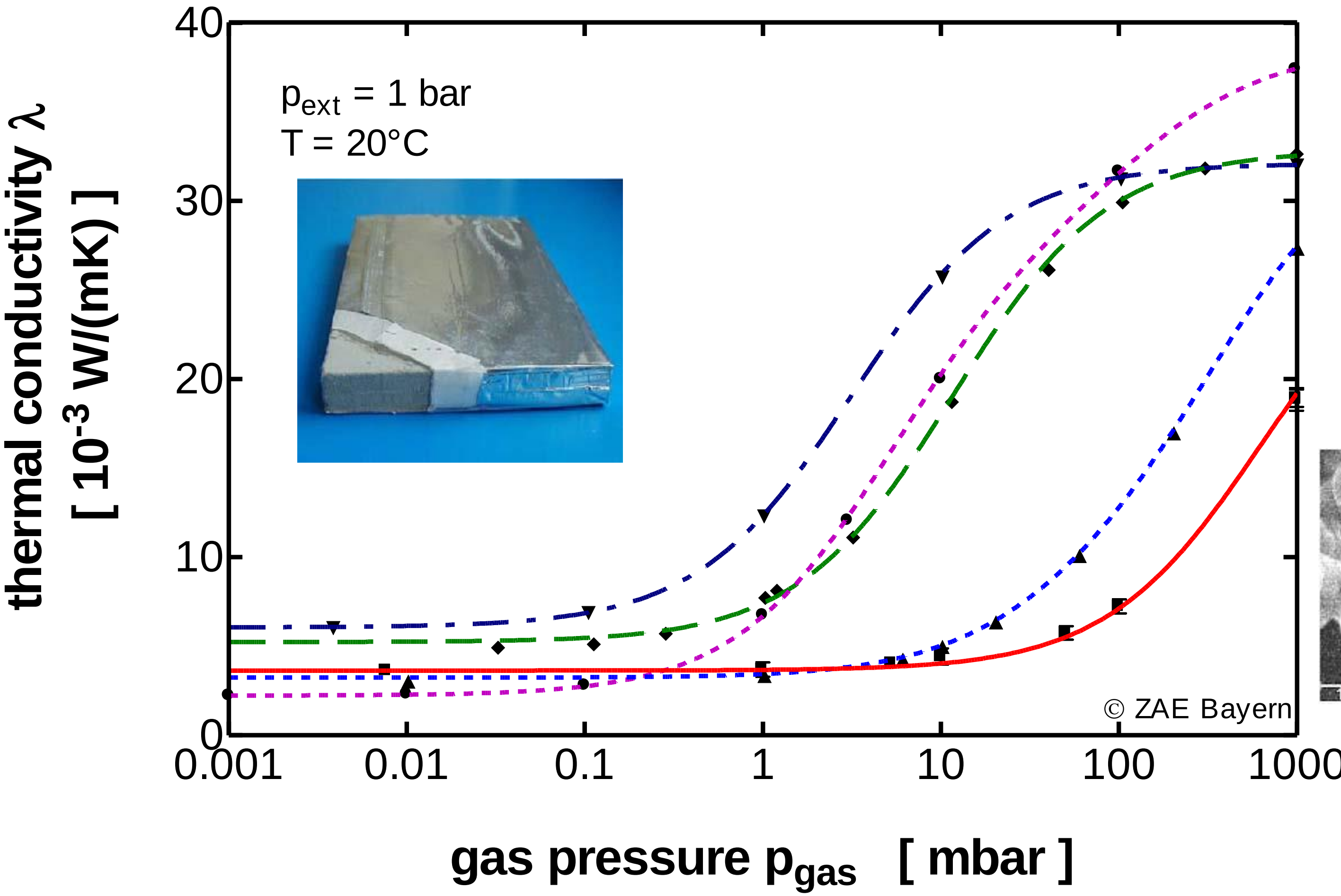
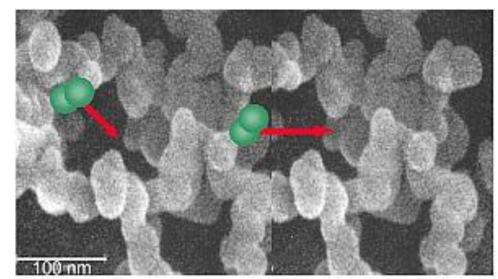
Source BASF

Confinement & Low Pressure



VIP : Vacuum Insulation Panel





$\delta < l_m = 0.1\ \mu m$

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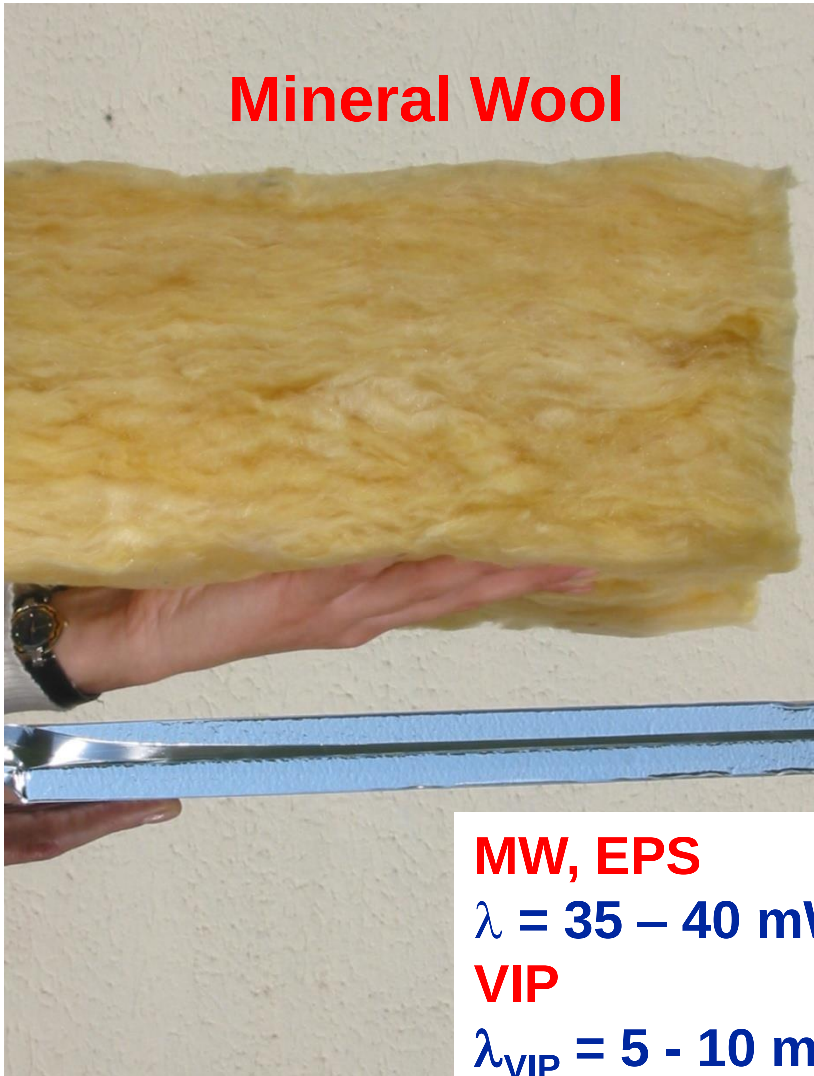
Traditional Insulating Materials vs Nano-Porous Materials at Low Pressure



µn-porous Core Material
Fumed Silica / Aerogel

Airtight Foil

MW, EPS

λ = 35 – 40 mW/mK

VIP

λ_{VIP} = 5 - 10 mW.mK

VIP

Vacuum Insulation Materials

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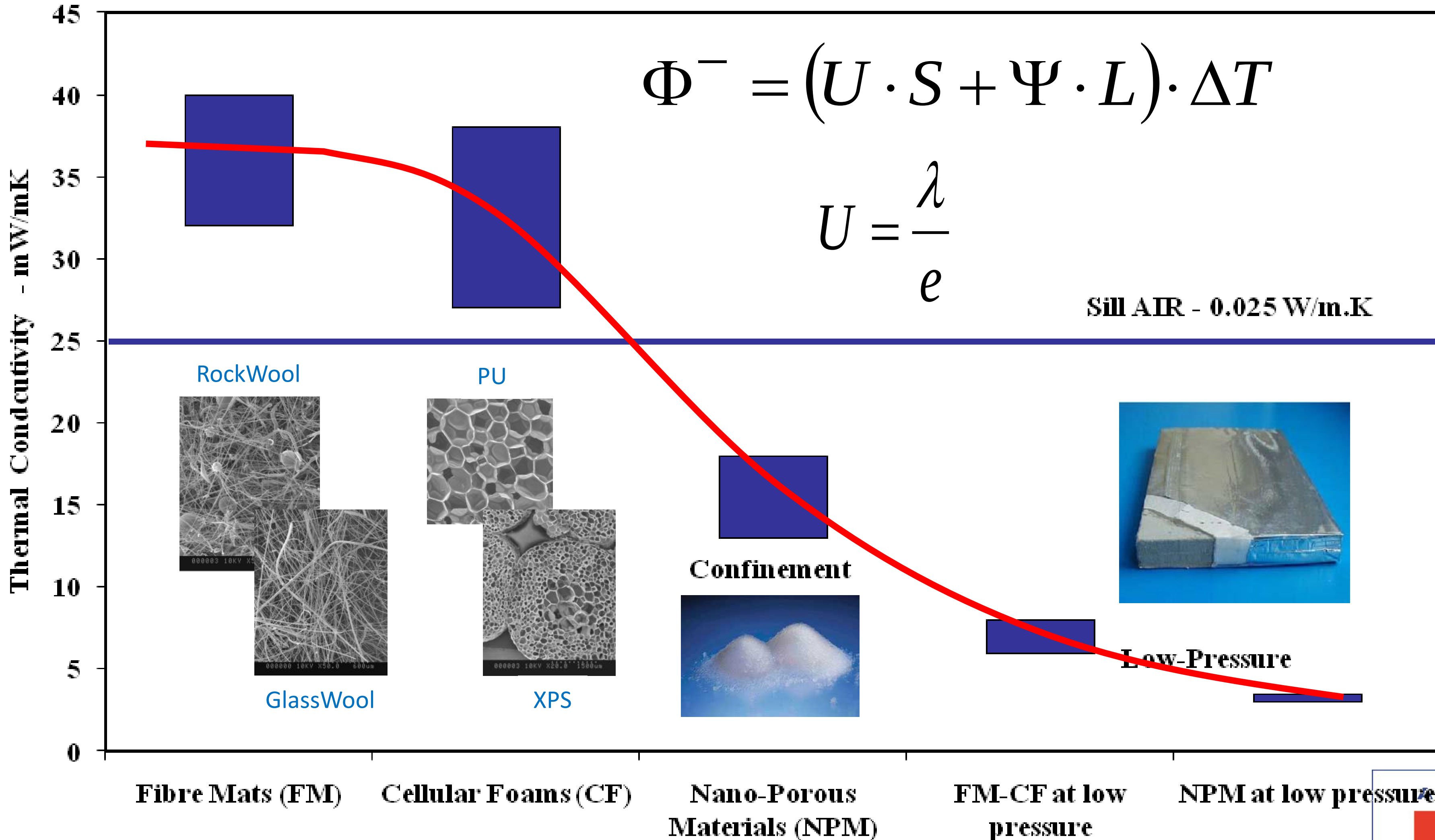
From Traditional Insulating Materials to Super Insulating Materials (SIM)



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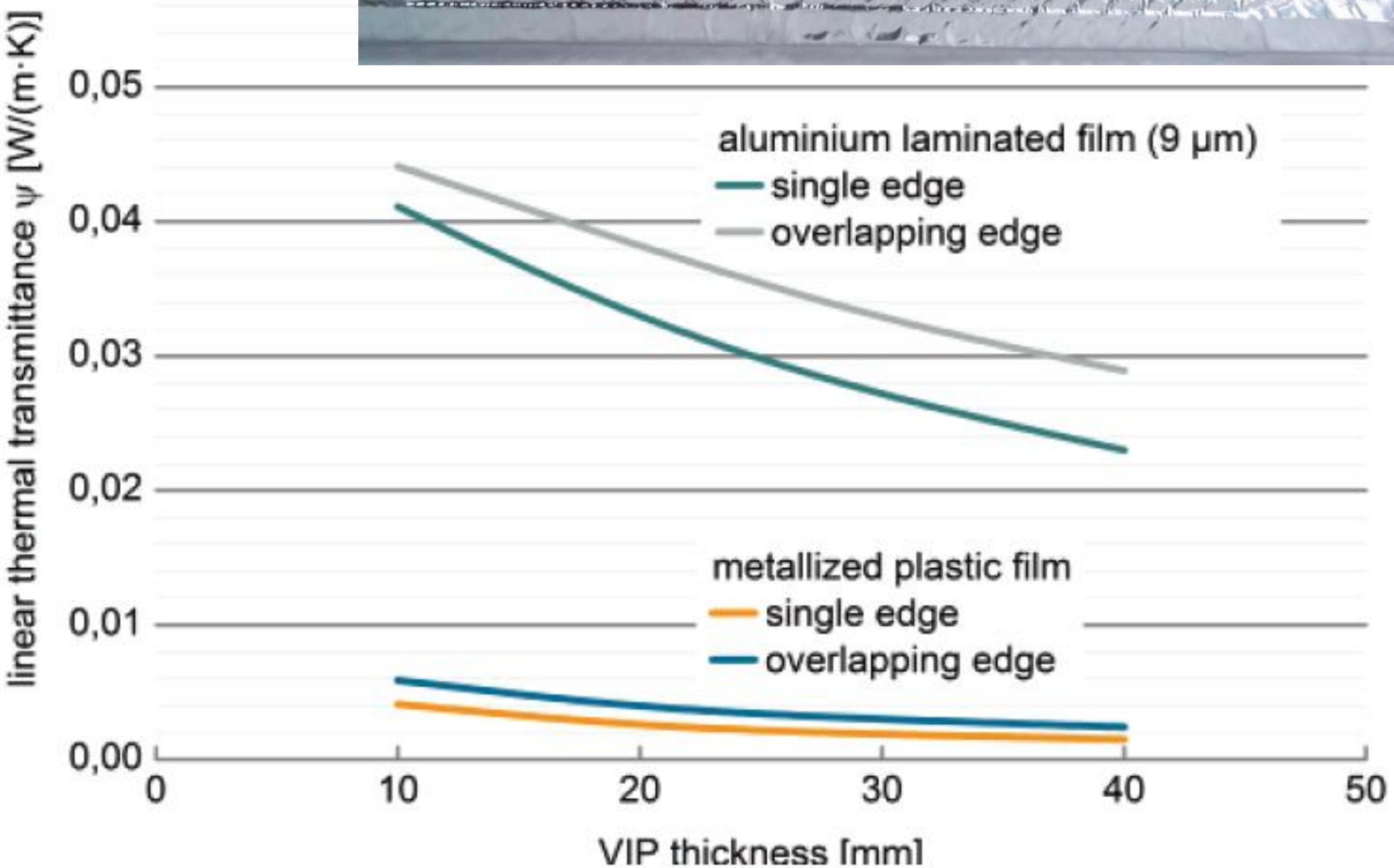
Thermal Bridge



Source : FIW – C. Sprengard

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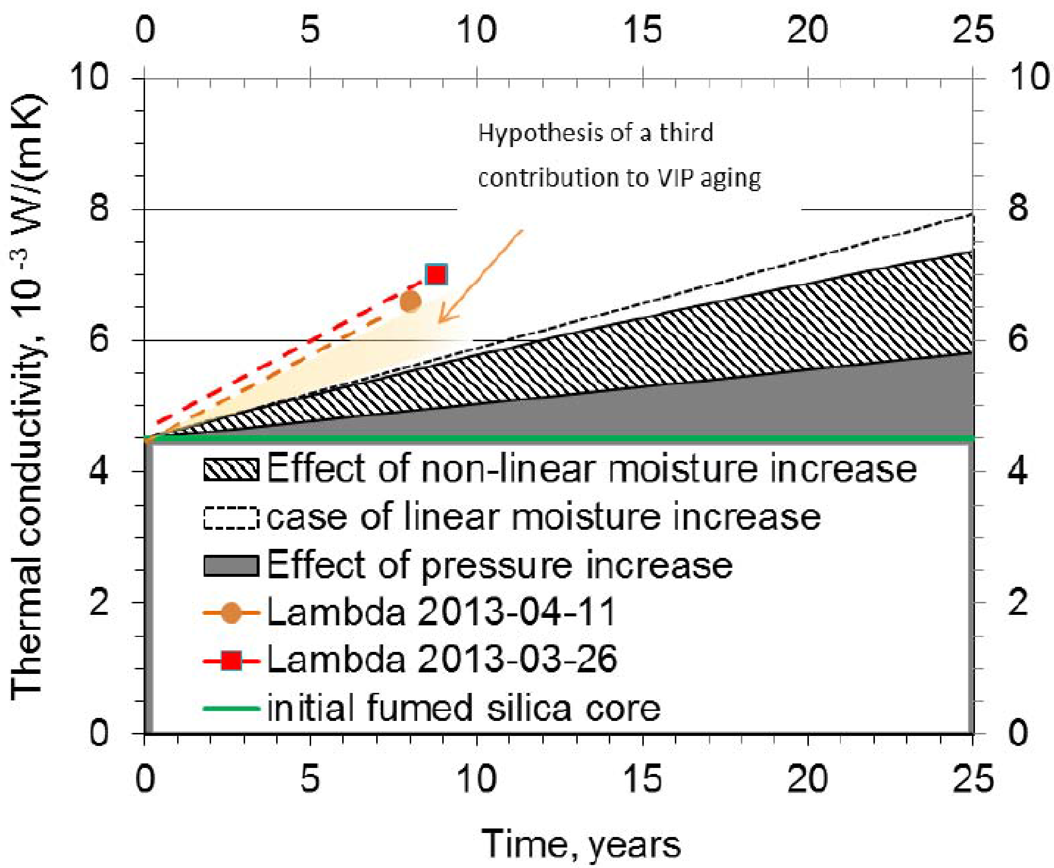
Basic Phenomena of VIP ageing



Pressure increasing due to gas transfer through the film

Solid conductivity increasing due to water adsorption

Solid conductivity increasing due to densification

Source EMPA

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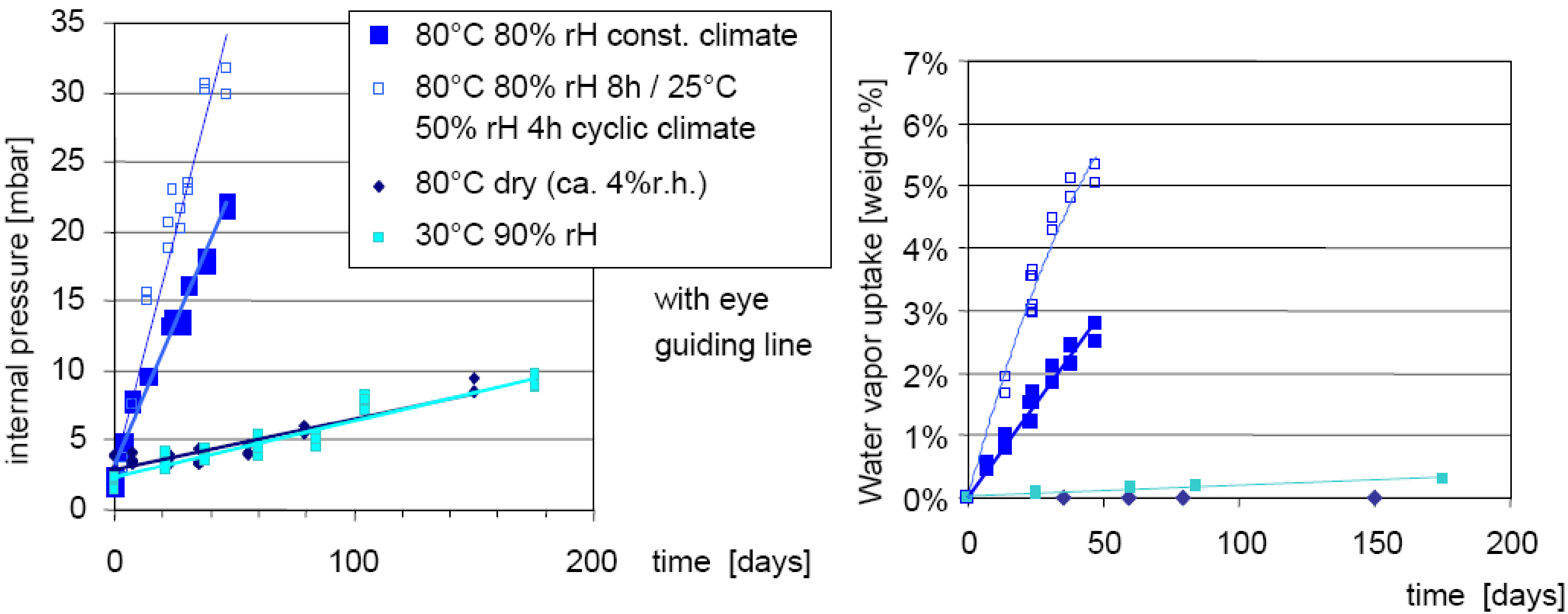
Ageing

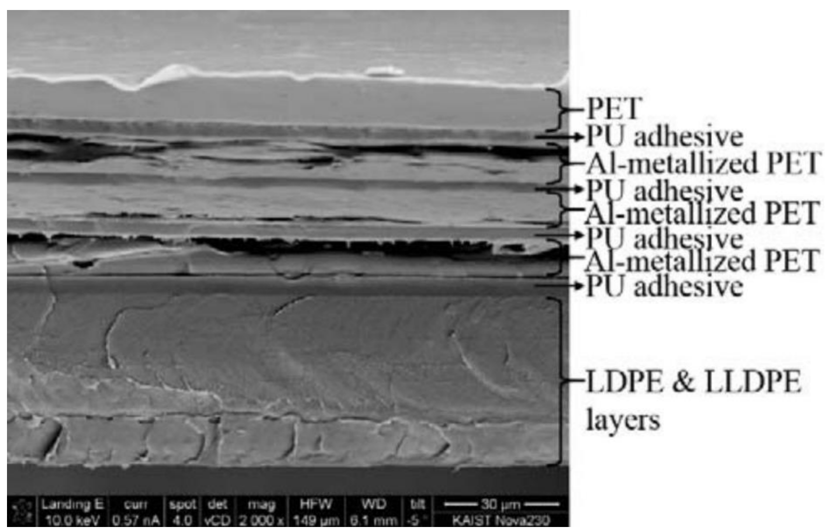


Source : Vacuum insulation panels for building application basic properties, aging mechanisms and service life
H. Simmler , S. Brunner - Energy and Buildings 37 (2005) 1122–1131

Film performance
Air permeability / Water vapour diffusion

Important points :

- Barrier performance of VIP-envelope before and after VIP production not comparable (folding, welding, sealing …)
- Values not comparable unless all the measurement conditions are the same (Temperature, Humidity, measurement duration, …)
- Limitation of measurement capacity when using commercially available devices for permeation



Source : FhG IVV – Esra Kucukpinar

Porous Core Materials
Identification of basic degradation phenomena

Nano means huge !

High Specific Area

- several 100 of m²/g

Small Pore Size

- < 0.1 µm

High Gas adsorption - (H_2O)

High capillary pressure (P~1/r)

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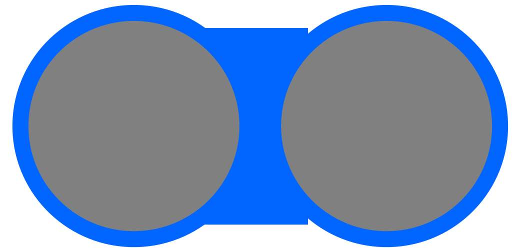
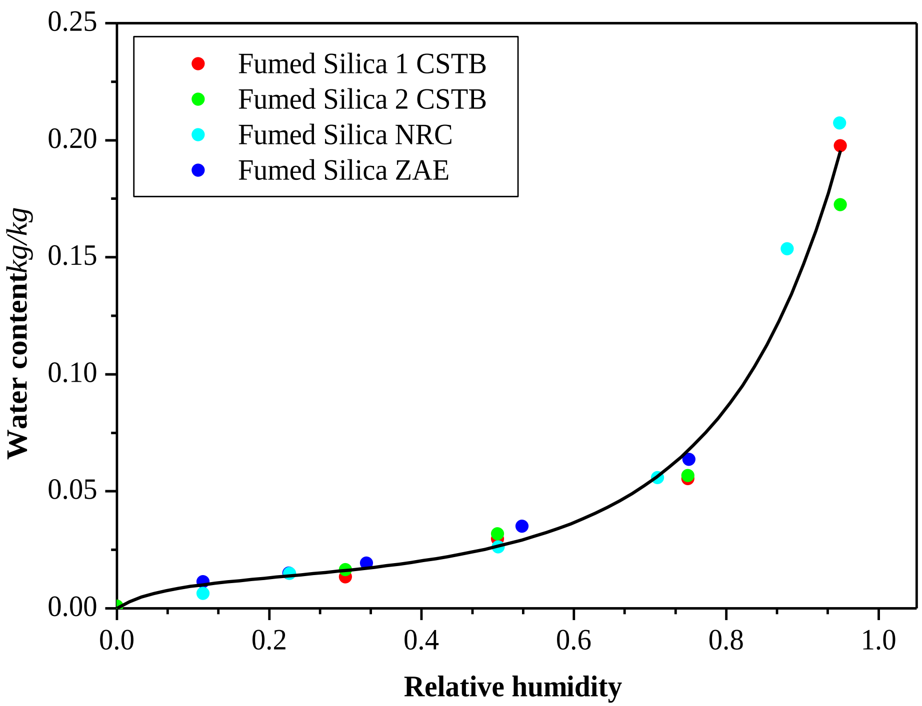
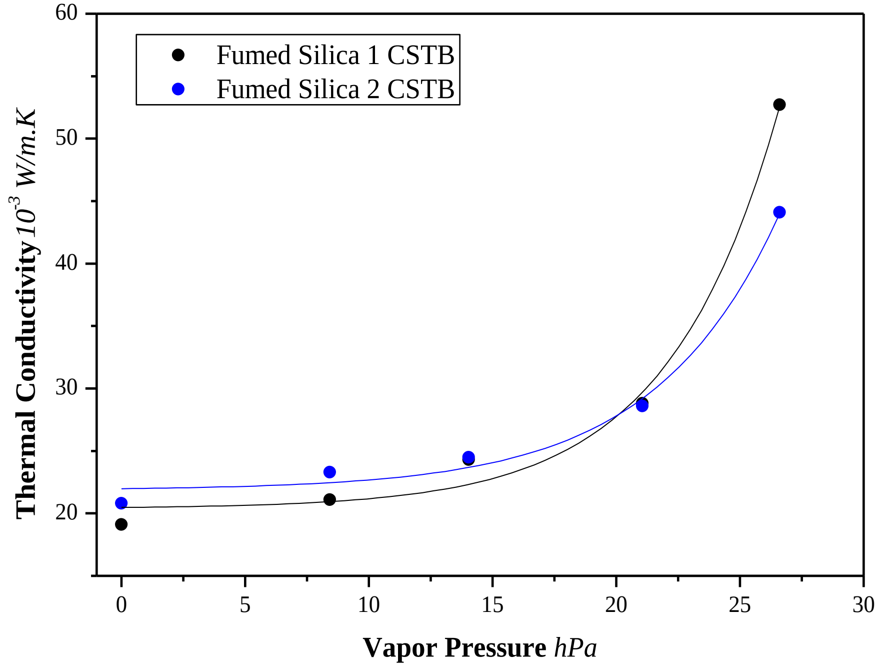
Water absorption







Source : CSTB

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Porous Core Materials
basic degradation phenomena

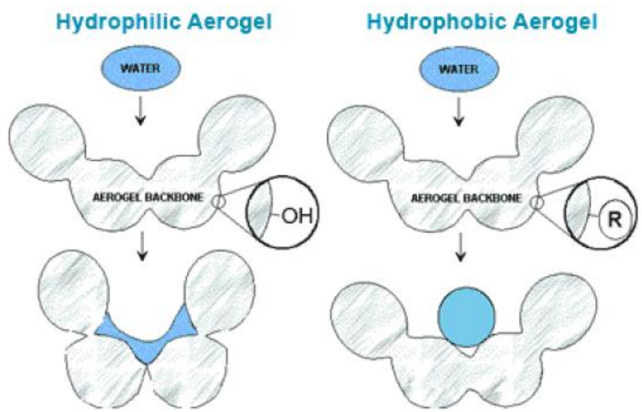
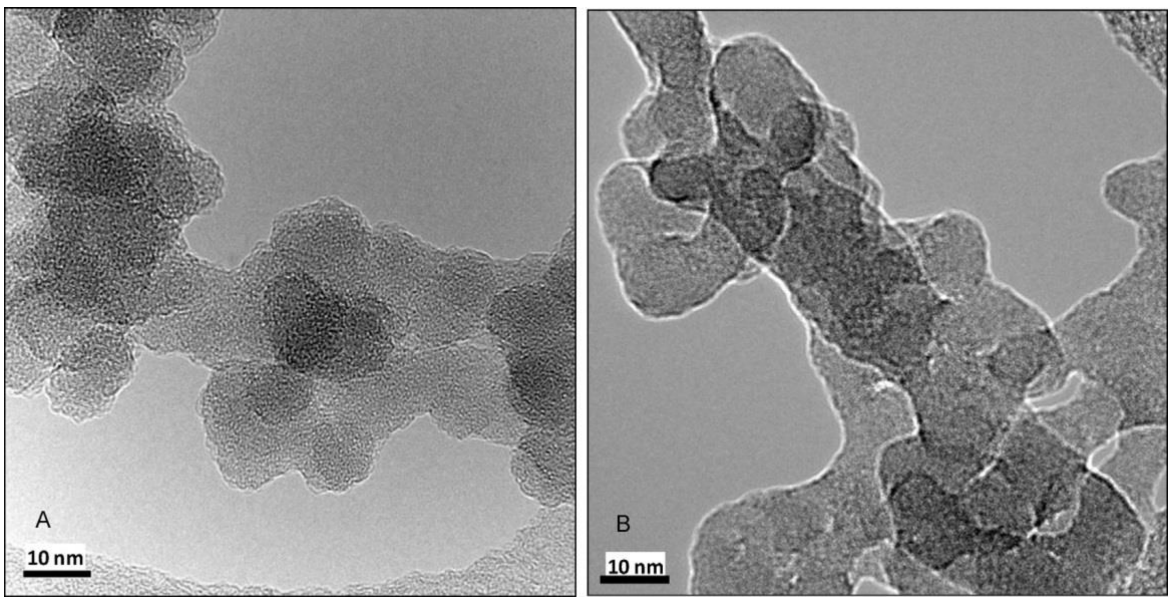


Figure 14: Comparison between hydrophilic and hydrophobic aerogels (Chemistry, 2012)

- Surface smoothing
- Reduction of S_{BET}
- Inter particles neck growth



Lang Huang - KTH : Feasability study of Using Silica Aerogel as insulation fro buildings
B; Morel : Pyrogenic silica ageing under humid atmosphere - Powder Technology 190 (2009) 225–229

Ageing analysis of SIM
Identification of degradation processes

- **VIP ageing :**
  - four components should be considered with regard to life time:
    - barrier envelope (air permeability, water vapour diffusion)
    - core material (porous silica, MW)
    - sample thickness
    - service conditions (T, HR, loads)

- **APM :**
  - four components should be considered with regard to life time:
    - core material (pore size & specific surface)
    - hydrophobic treatment
    - sample thickness
    - service conditions (T, HR)

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Cabot LUMIRA aerogel in polycarbonate

Thermal Insulation / Light Diffusion / Reduction of noise impact

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SUBTASK III : Design & Installation
Leader : Chalmers

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Listing of critical points :

Handling & Transportation
Installation / fixing
…

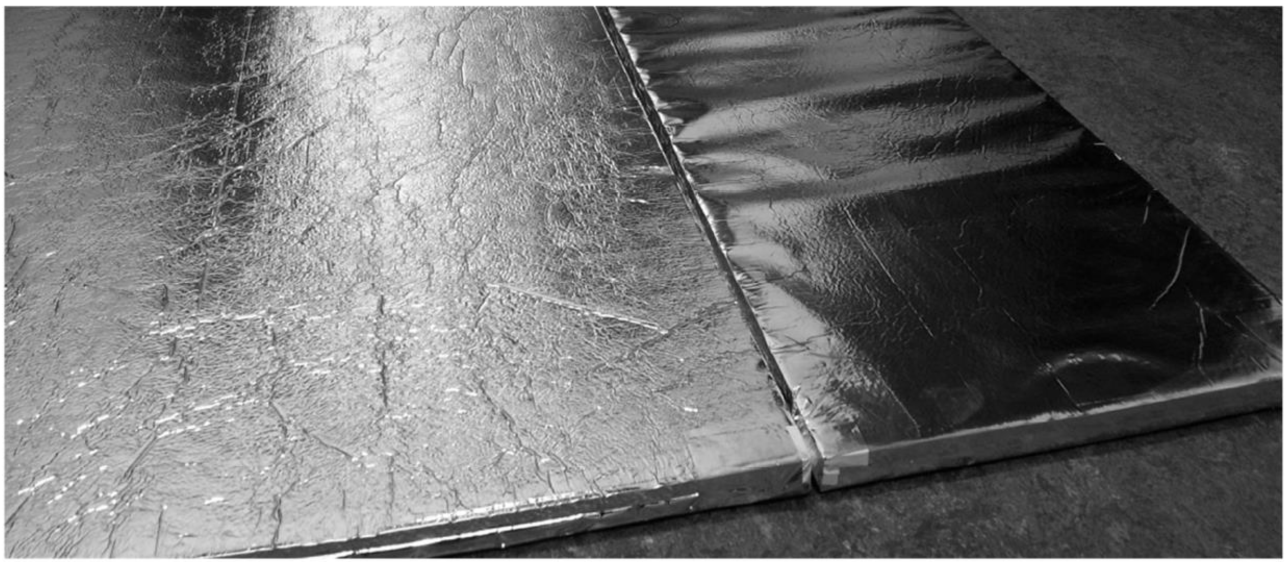
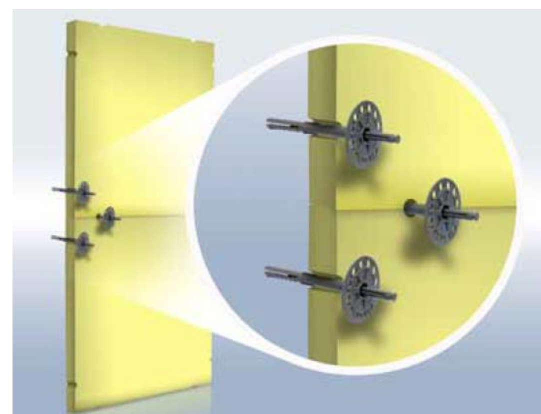


Figure 2.9. Evacuated VIP compared to the one where a laminate has been damaged. It is clear that the laminate is loose from the core in the second case (Photo: Axel Berge).



Source : Chalmers – va Q tec

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SUBTASK III
Case studies

Thun, Switzerland
30 km south of Swiss capital Bern

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SUBTASK III
Case studies

Maison de l'Alsace - Paris

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http://www.maison-alsace.com/suivez-les-travaux-en-direct/novembre-2014

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Maison de l'Alsace - Paris

Source ISOLPRODUCTS – M. Koenig

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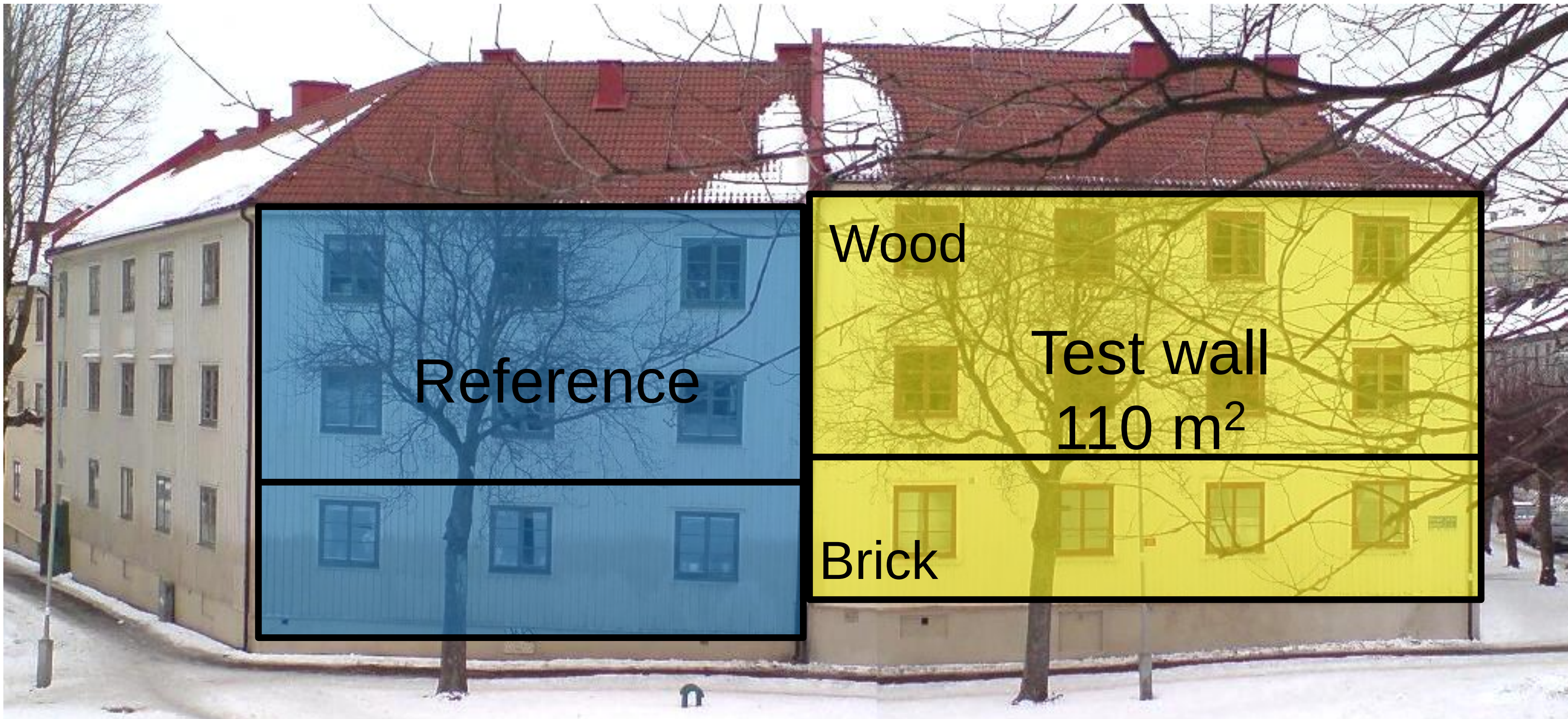
SUBTASK III
Case studies



Landshövdingehus from 1930 - SWEDEN

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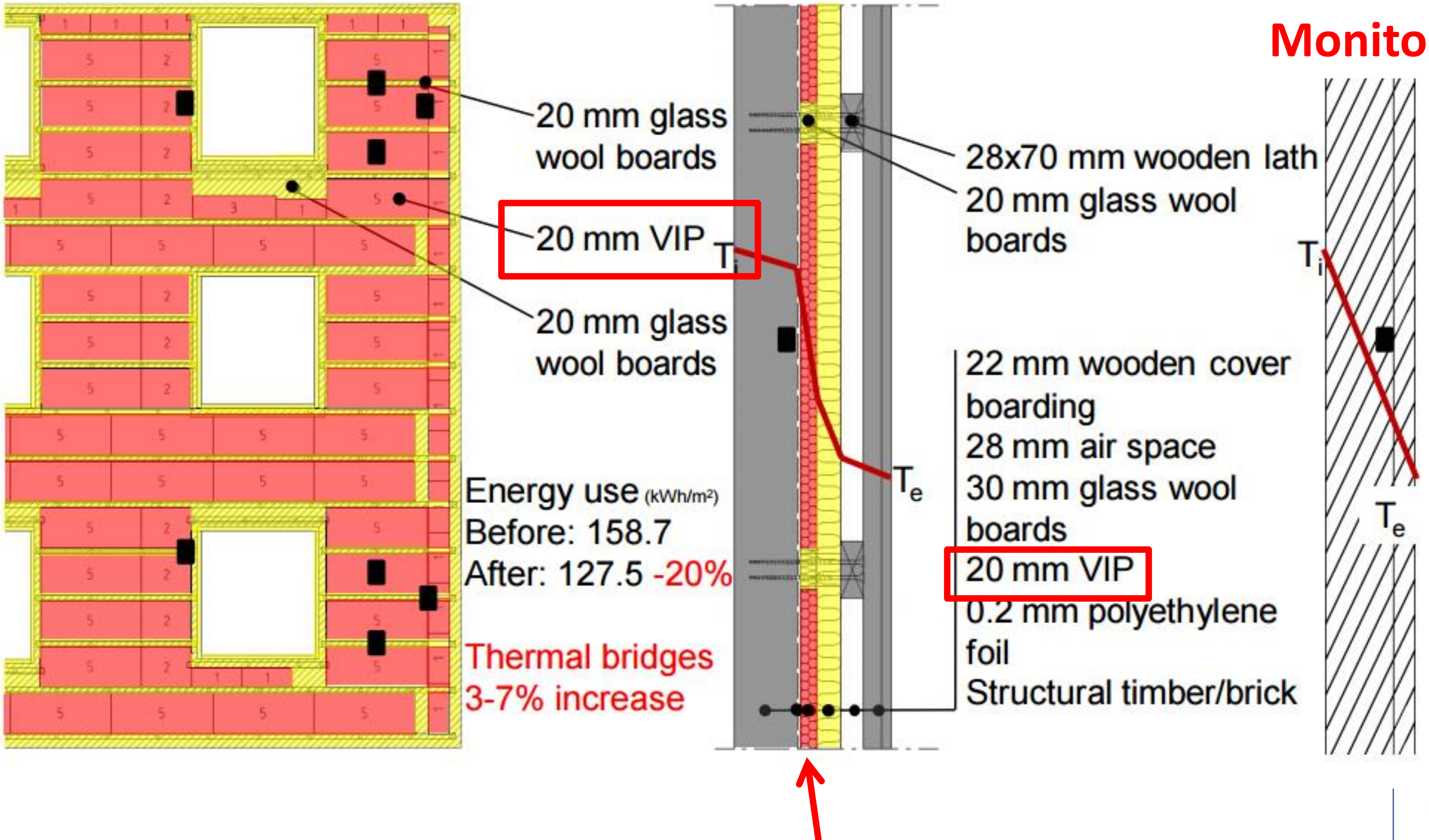
SUBTASK III
Case studies

Monitoring



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AMSTEIN + WALTHERT

Renovation in Switzerland with ASPEN aerogel mat

1. evening of the subsurface with mortar

2. adhesive mortar layer

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3. each insulation layer has to be applied in a **still moist** adhesive mortar layer

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AMSTEIN + WALTHERT

4. application of the plaster base-mesh

5. mechanical fixing with plastic anchors

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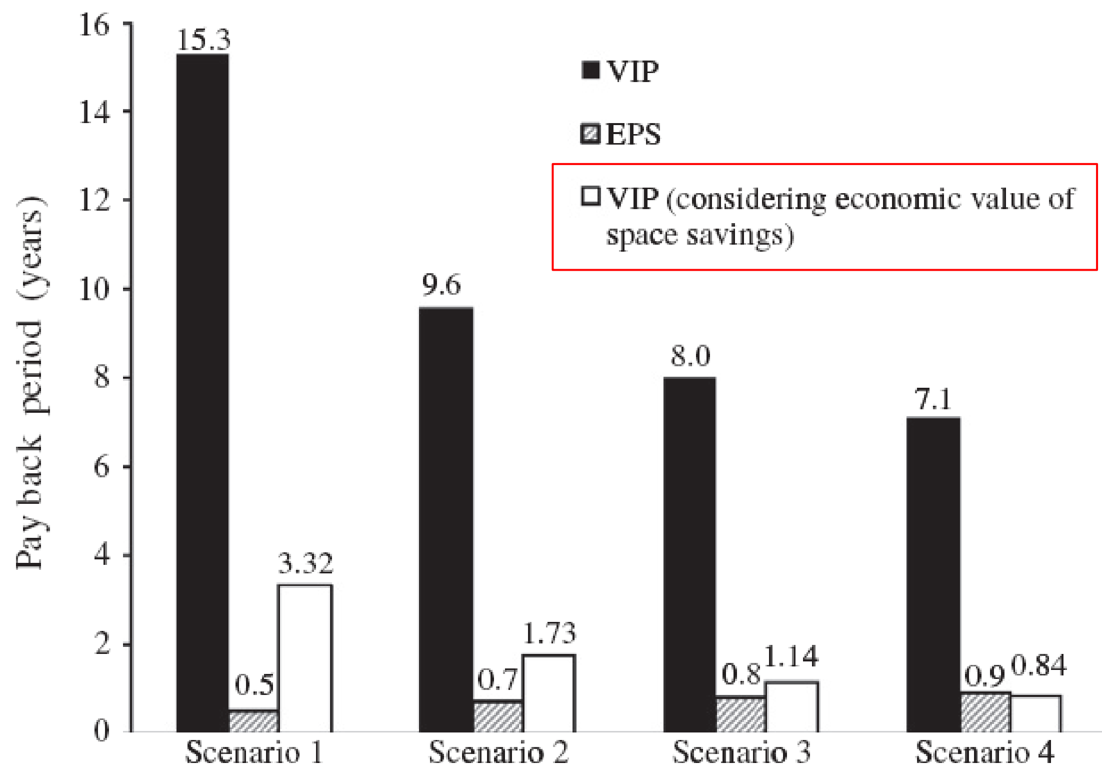
Payback period of VIP and EPS different scenarios of insulation for buildings.

Insulation scenarios and main parameters used in payback period calculation.

		Parameters	Value
Scenario 1		Average building *U*-value	0.40 ($W m^{-2} K^{-1}$)
	(VIP)	Thickness	10 mm
		Cost	£70 m^{-2}
	(EPS)	Thickness	48.3 mm
		Cost	£2.40 m^{-2}
Scenario 2		Average building *U*-value	0.31 ($W m^{-2} K^{-1}$)
	(VIP)	Thickness	25 mm
		Cost	£80 m^{-2}
	(EPS)	Thickness	113 mm
		Cost	£6.19 m^{-2}
Scenario 3		Average building *U*-value	0.27 ($W m^{-2} K^{-1}$)
	(VIP)	Thickness	40 mm
		Cost	£80 m^{-2}
	(EPS)	Thickness	180 mm
		Cost	£8.38 m^{-2}
Scenario 4		Average *U*-value	0.24 ($W m^{-2} K^{-1}$)
	(VIP)	Thickness	60 mm
		Cost	£80 m^{-2}
	(EPS)	Thickness	256 mm
		Cost	£10.78 m^{-2}
Other parameters		Fuel	Natural gas
		Emission conversion factor	0.20
		HDD	1931 °C day
		C_f	£0.40 m^{-3}
		H_v	39.5×10^6 ($J m^{-3}$)
		η	0.9
		N	25
		i	10%



Source : Vacuum Insulation Panels (VIPs) for building construction industry – A review of the contemporary developments and future directions
M. Alam ⇑, H. Singh, M.C. Limbachiya - Applied Energy 88 (2011) 3592–3602

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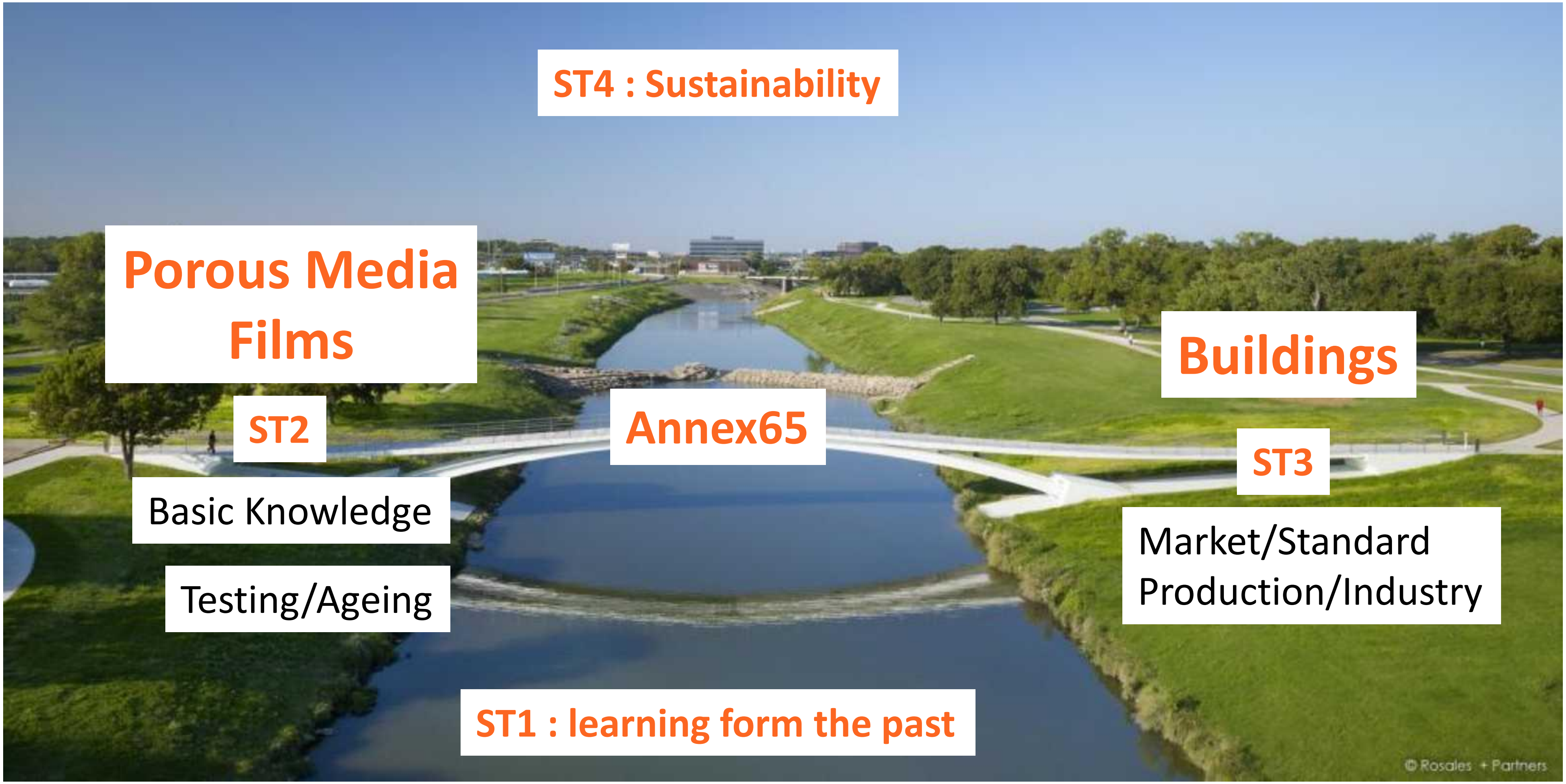
Annex65 : a bridge between science & market



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http://aasarchitecture.com/2013/03/phyllis-j-tilley-memorial-bridge-by-rosales-partners-architects.html

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SIM : Super Insulating Materials ?

Advanced Porous Materials APM	Gas Filled Panel GFP	Vacuum Insulation Panel VIP
		

$$\lambda_g = \cdot \frac{\lambda_{g0}}{1 + C \cdot \frac{T}{\delta \cdot P}}$$

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Objective of the Annex 65

The aim of Annex 65 is to develop the necessary knowledge, tools and networks to improve the confidence of end-users regarding super-insulating materials and to foster a wider public acceptance in the future.

By providing

- Reliable data (properties & durability)
- Secure implementation techniques
- Sustainability Analysis

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Scope

Two main types of SIM :

- Vacuum Insulation Panel
- Advanced-Porous Materials, such as Aerogel

State of the Art

Learning from the past (ST1)

Three scientific & technical issues:

Performance & Durability - (ST2)

Design & Installation (ST3)

Sustainability (LCA, LCC, EE) – (ST4)

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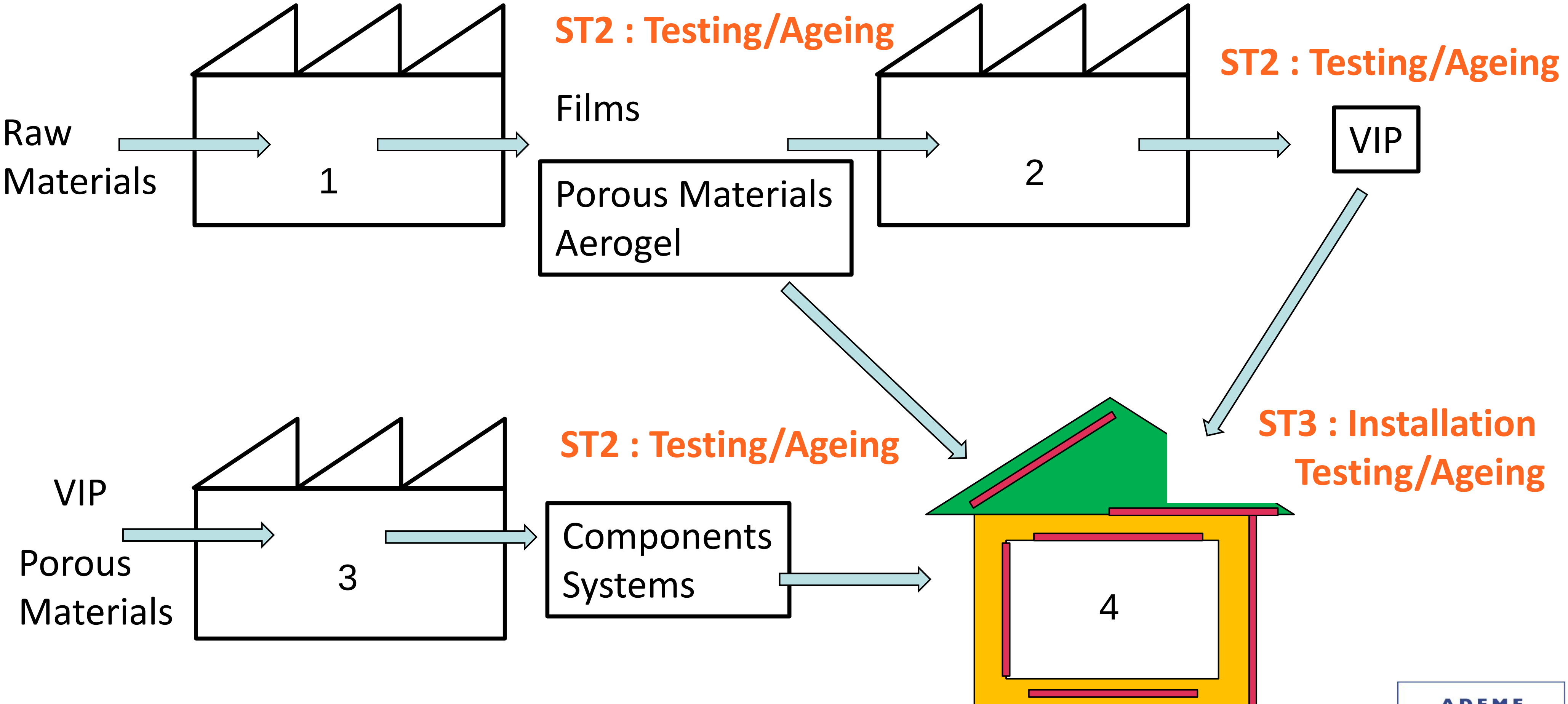
Annex65 & SIM value chain

ST1 : learning from the past



ST4 : Sustainability

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Four SubTasks

SUBTASK 1: State of the Art - Materials & Components - Case Studies

SubTask Leader: ZAE Bayern – Ulrich Heinemann

SUBTASK 2: Characterization of materials & components - Lab Scale

SubTask Leader: FIW Munich – Andreas Holm / Christoph Sprengard

SUBTASK 3: Practical Applications – Retrofitting

Subtask Leader: Chalmers Univ. Bijan Adl Zarrabi

SUBBASK 4: Sustainability (LCC, LCA, EE)

Subtask Leader : Chalmers Univ. Holger Wallbaum

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Deliverables/Target Audience

Ref.	Deliverables	Related subtask	Target Audience
D1	State of the Art and Case Studies	ST1	Supply Chain
D2	Scientific Information for Standardization Bodies (Hygro-Thermo-Mechanical Properties & Ageing)	ST2	CEN, ISO, EOTA, UEATc, Testing laboratories Materials Manufacturers
D3	Guidelines for Design, Installation & Inspection Special focus on Retrofitting	ST3	Designers, Engineers, Contractors, Builders
D4	Report on Sustainability Aspect (LCC, LCA, EE)	ST4	Supply Chain

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Participants ~50 - Countries : 17

Belgium: Recticel, Dow Corning,
China: Nanjing University of Aeronautics and Astronautics (NUAA), Siltherm, Creek
France: EDF, Mines-Paristech, INSA Lyon, Univ. Lorraine, Saint-Gobain ,Toray, ArcelorMittal, REXOR, Enersens, CSTB,
Germany: ZAE Bayern, Fraunhofer IVV, va-Q-tec, FIW Munich, Evonik, DLR , Metra-Group, Porextherm, Cabot, Aspen-Aerogel
Italy: Politecnico di Milano, Politecnico di Torino, Univ. Perugia, Stress Scarl
Norway: SINTEF
Spain: Tecnalia,
United Kingdom: Kingspan,
South Korea : Kongju National University, OCI
Sweden : Chalmers University, KTH
Israel : Hanita Coatings (observer)
Japan : Annex65 Japanese Support Committee (10 members)
Turkey : Arcelik
Greece : National Technical University of Athens (NTUA)
Switzerland : EMPA
Canada : Ryerson University/Toronto, Univ. of Victoria
Denmark : Rockwool

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KEY ISSUES

TECHNICAL SOLUTIONS

- PRODUCT PERFORMANCE
  DURABILITY & LIFE CYCLE
- INDUSTRIALISATION
  vs STOCK REFURBISHMENT
- INTEGRABILITY
  CRAFTMEN UPGRADE
- INDUSTRIALIST INVESTMENT
  Vs WOOL & FOAMS

PUBLIC POLICIES REQUIREMENTS

SAFETY - FIRE

HEALTH – COV, NANO PARTICLES

ENERGIE – ENERGY SAVING RATIO

ENVIRONMENT - SUSTAINABILITY

ECONOMY – LAND COST, PRICE

SOCIAL -

IT INFORMATION – RFID

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CONCLUSION

TECHNICAL SOLUTIONS ARE ABOUT TO EXIST

PARTIAL PUBLIC POLICIES SATISFACTION

STILL R&D NEEDS TO OVERCOME KEY ISSUES

MATURE MARKET FOR CONVENTIONNAL INSULATING MATERIALS

ENERGY REGULATIONS PRESSURE IN EU – US – ASIA

PRODUCTION CAPACITY OVERSIZE & MONOPOLE

TOWARDS A CHEMISTERY PLAYER BREAKTHROUGH?