BEEP **Training Programme for Building Designers**

DECEMBER 2016

Thermal Insulation of buildings

Claude-Alain Roulet

Climatic architecture

- We spend most of our time indoors
- Buildings should be comfortable
- According to P. Lavigne, a French architect:

The free floating building
(that is without any HVAC system running)
should be **at least as comfortable** as
the outdoor environment.

The building envelope

Protection from:

- rain and wind
- cold, heat, and sun
- noise

Controls the

- natural ventilation
- daylighting

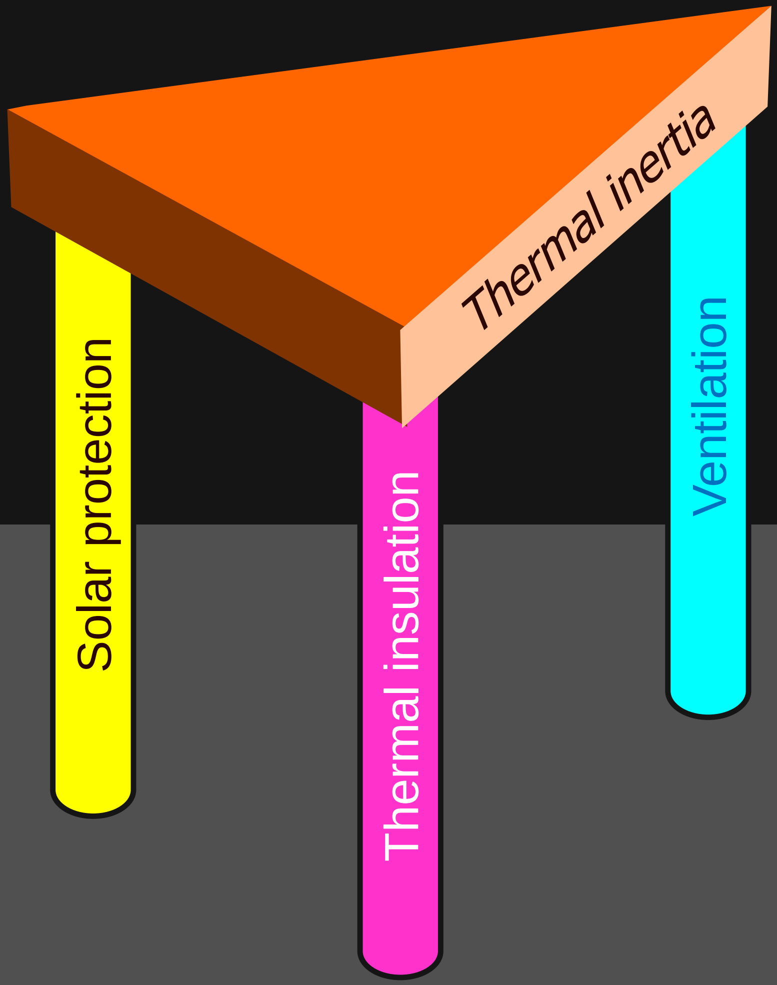
The building envelope is..

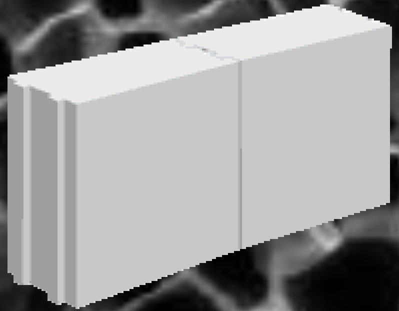
First a **protection**,

….then an **expression**.

Bldg 9B, DLF Cyber city, Gurgaon, India. Firstgreen Ltd consultants.

Thermal comfort





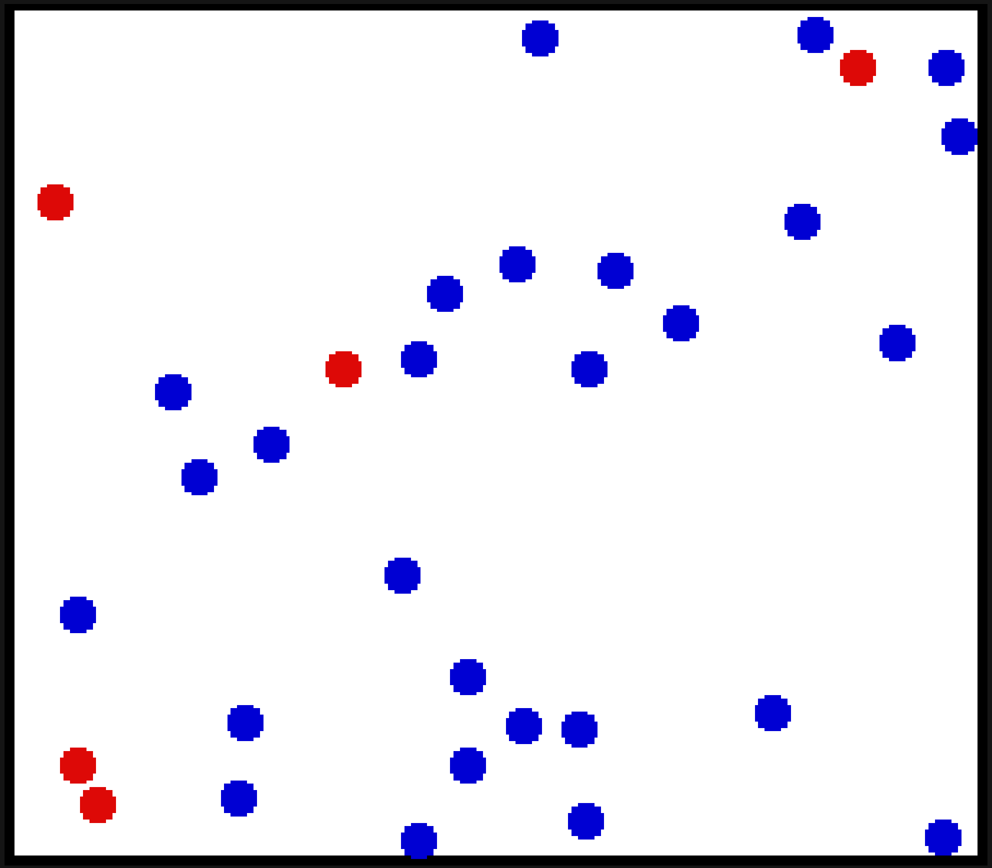
Thermal insulation materials

Thermal insulation material

- A material that restricts the transfer of heat.
- In buildings, material that restricts the heat transfer better than structure materials

Heat

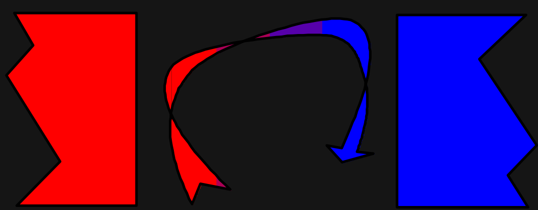
- Heat rises the temperature of matter



Heat transfer modes

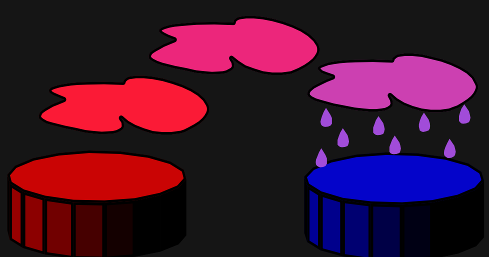
Heat = random vibration of atoms/molecules

- **Conduction**: direct transfer of the thermal movements from atom to atom or molecule to molecule



- **Convection**: transport of heat in moving warm fluids

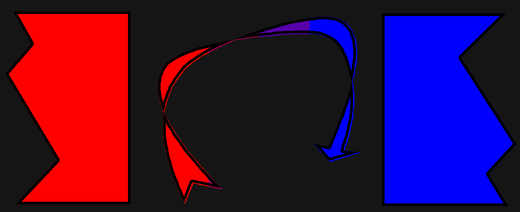
- **Radiation**: agitated, charged atoms or molecules emit electromagnetic radiation, which in turn agitate quieter charged atoms or molecules



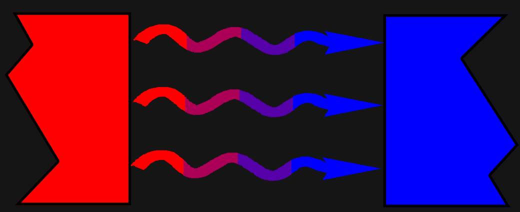
- **Evaporation- condensation:** the heat needed to evaporate a liquid is recovered where this vapour condenses.

To reduce heat transfer:

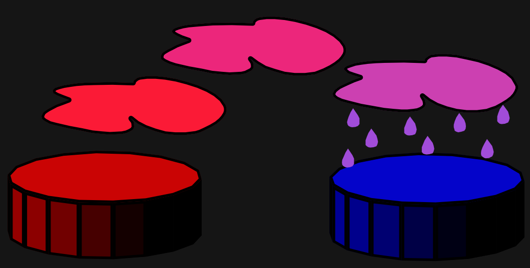
- Reduce the amount of matter to reduce **conduction**



- Lock or suppress any fluid to avoid **convection**



- Using opaque or even reflecting materials to reduce **radiation**



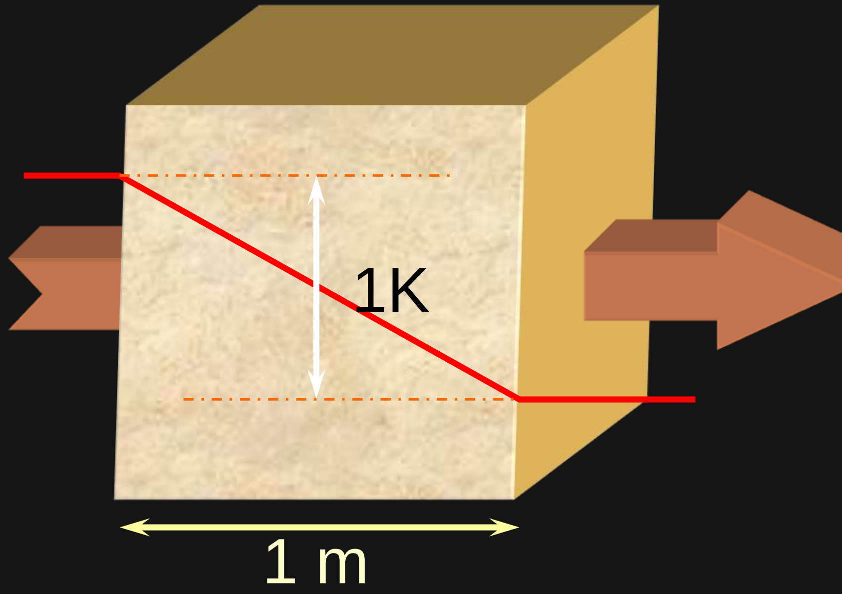
- Keep the product dry to avoid **evaporation-condensation**

The main thermal insulating material in buildings is

Locked air

- Air is a poor thermal conductor
- Air is locked in foam bubbles or between fibres
- Bubbles walls and fibres are themselves opaque to thermal radiation.

Thermal conductivity κ



Amount of heat transferred in
1 second, through
1 m² of an homogeneous layer
1 metre thick, under a temperature difference of
1 degree.

SI unit watt per meter-Kelvin (W/[m·K])

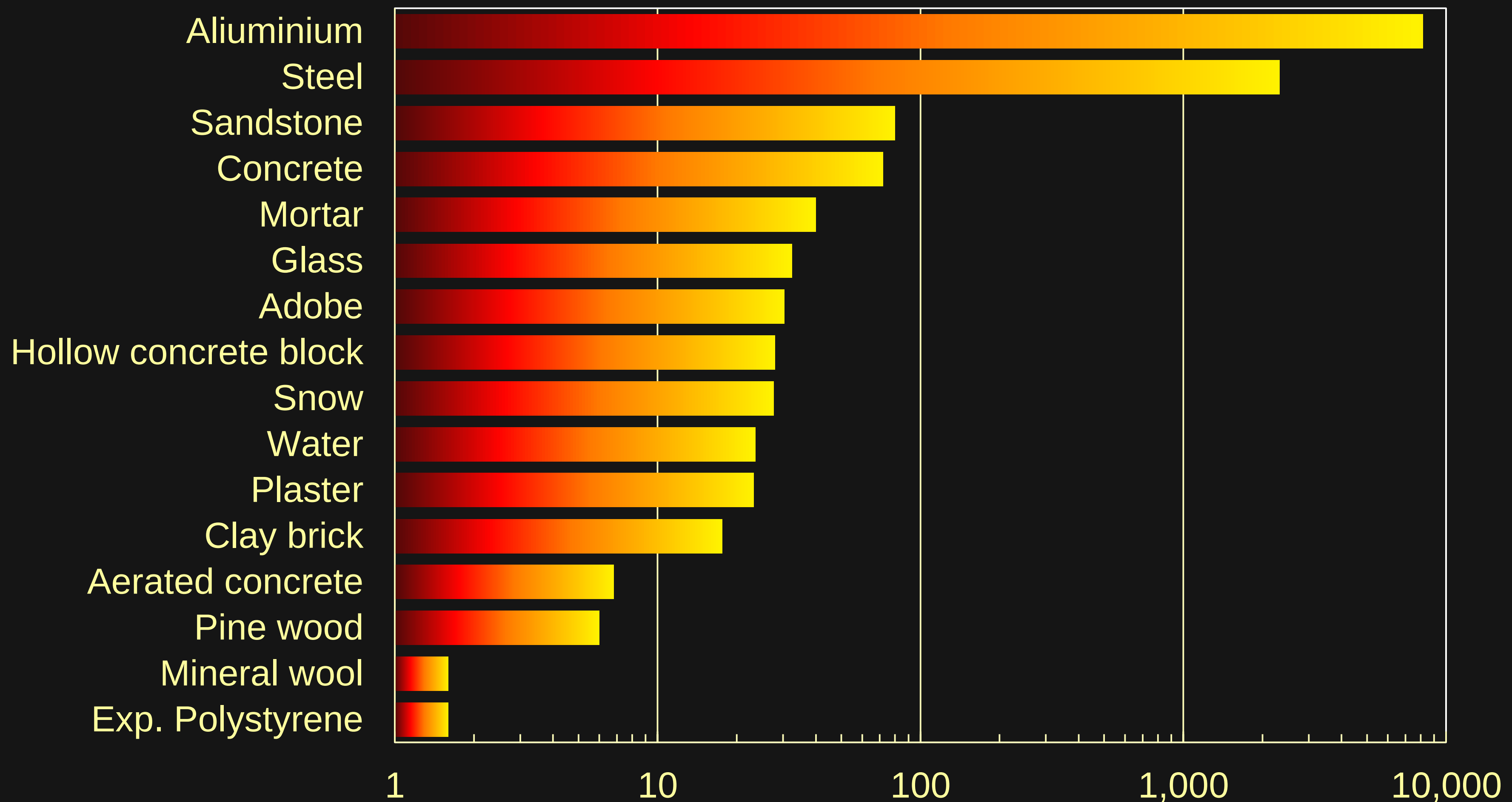
also mW/(m·K)

UK and US Btu·in/(sq ft·°F)

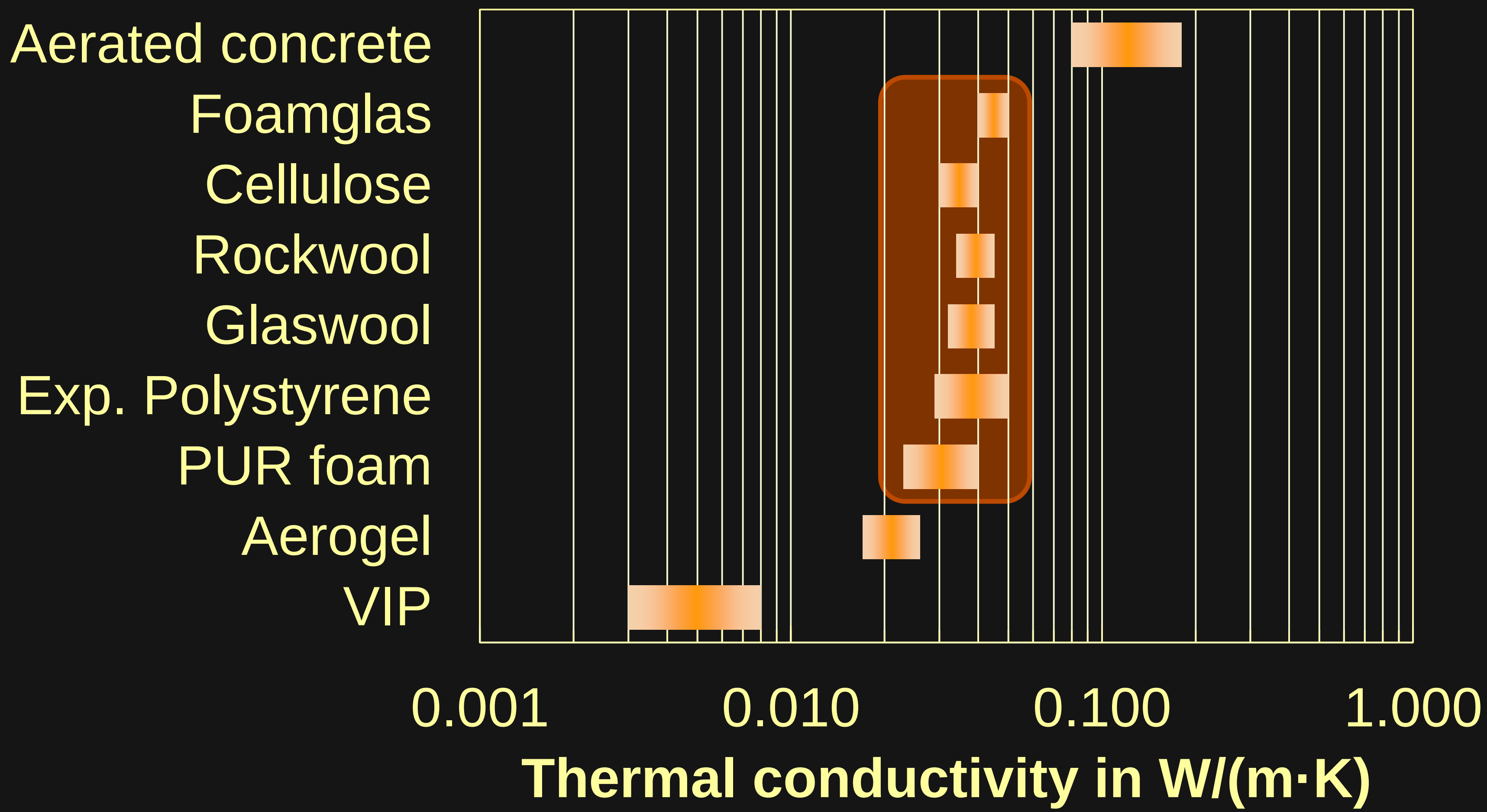
1 Btu·in/(sq ft·°F) = 0.1442278889 W/(m·K)

1 W/(m·K) = 6.9811179 ≈ 7 Btu·in/(sq ft·°F)

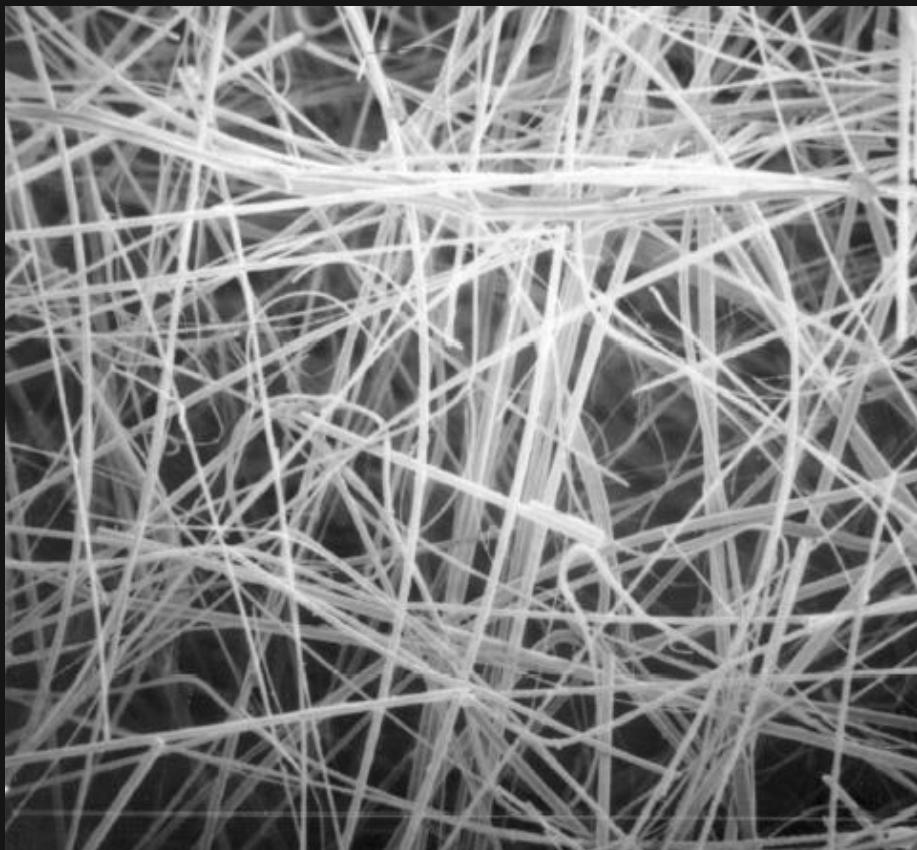
Relative thermal conductivities
Air = 1



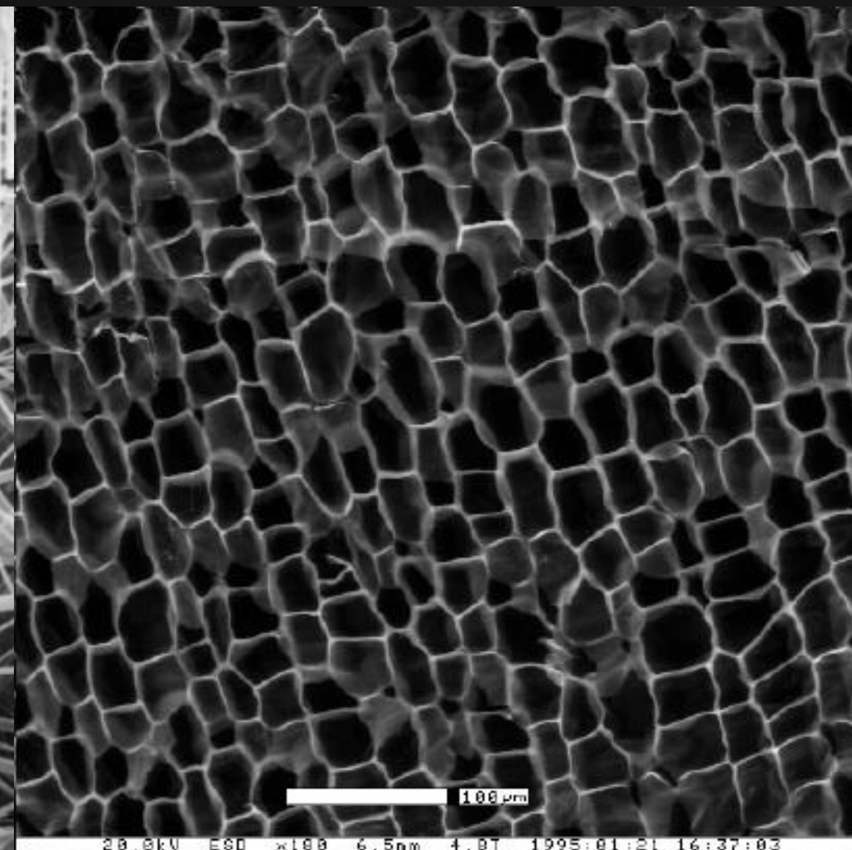
Thremal conductivities



Locking the air



Between fibres

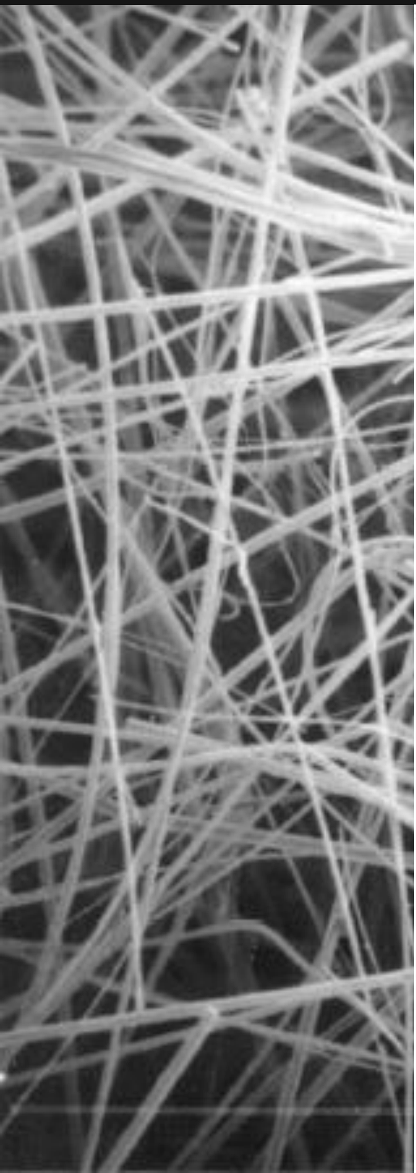


Within cells

Mineral fibres

- Fibres made out of melted glass, ceramic or rock, manufactured by centrifugation spinning.
- Fiberglass from recycled glass
- Rock wool from artificial lava or basalt
- Pure silica and aluminosilicates for high temperatures
- Coated with a resin or needled to make mats and plates

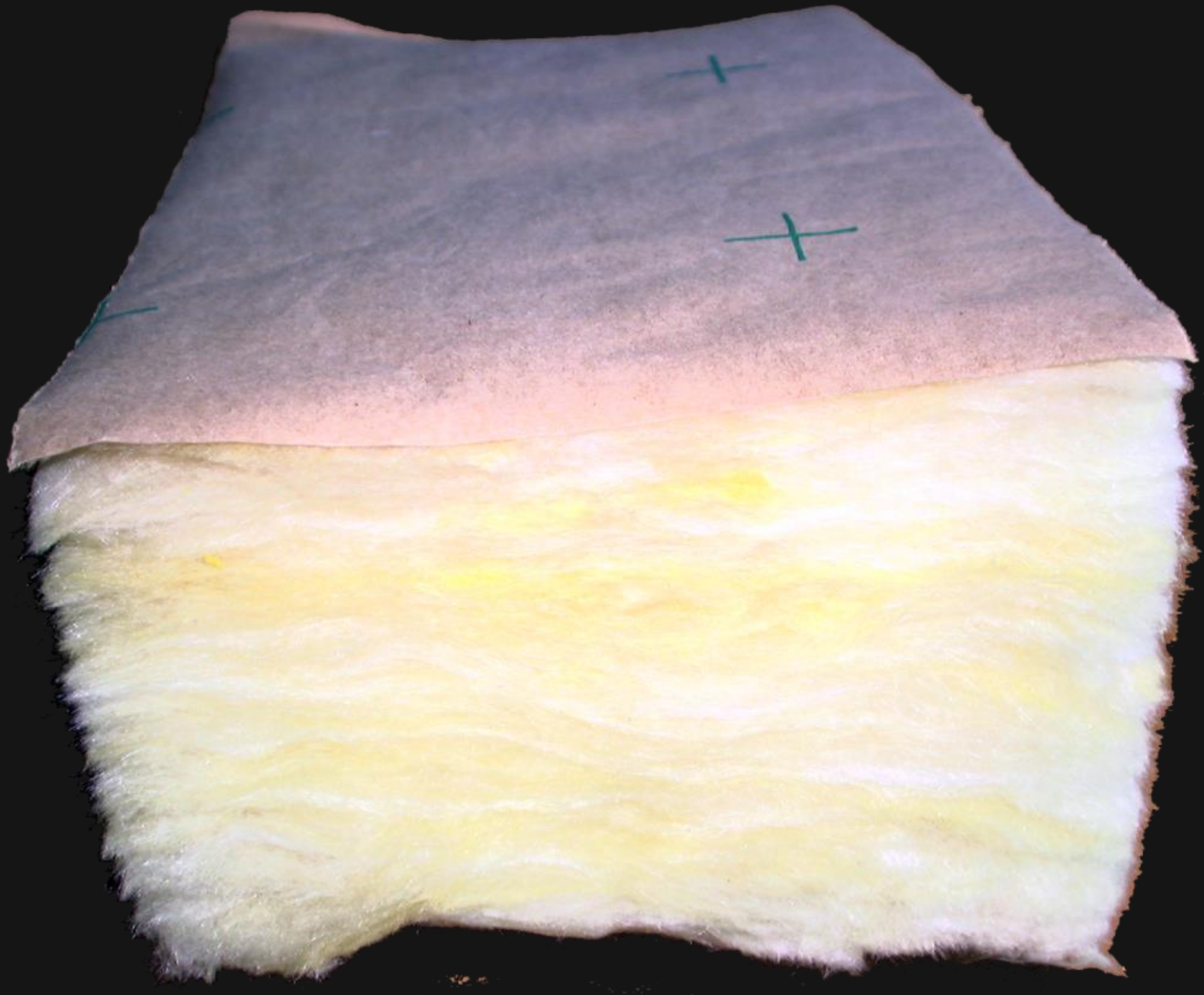
Examples of mineral fibres



Properties of mineral fibres

- Excellent resistance to fire
- Good thermal insulation
- Sound absorption qualities.
- High durability
- Resistant to rot, mould and vermin
- Permeable to air and water vapour
- Absorb water by immersion but drip and dry easily.

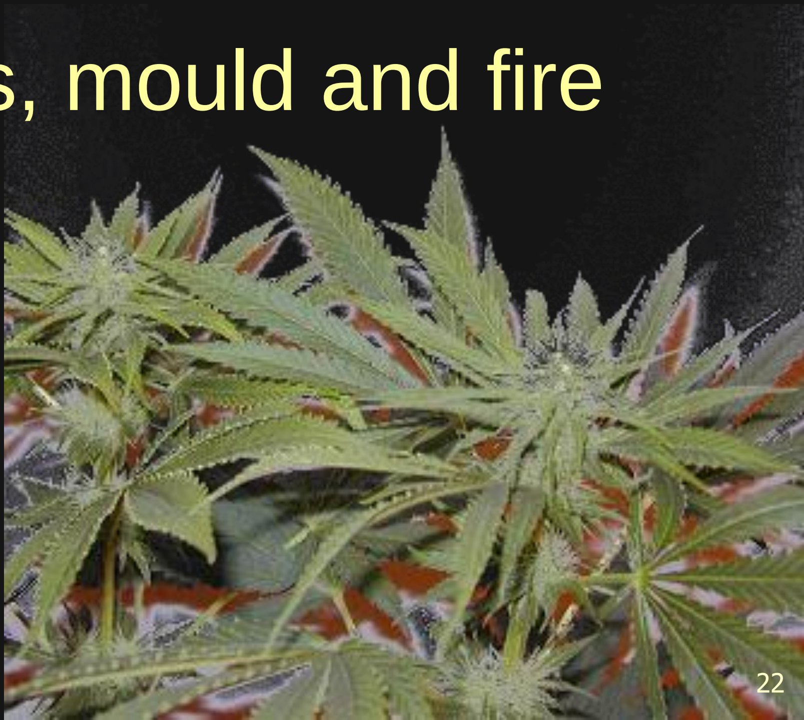
Lightweight glass fibres mat



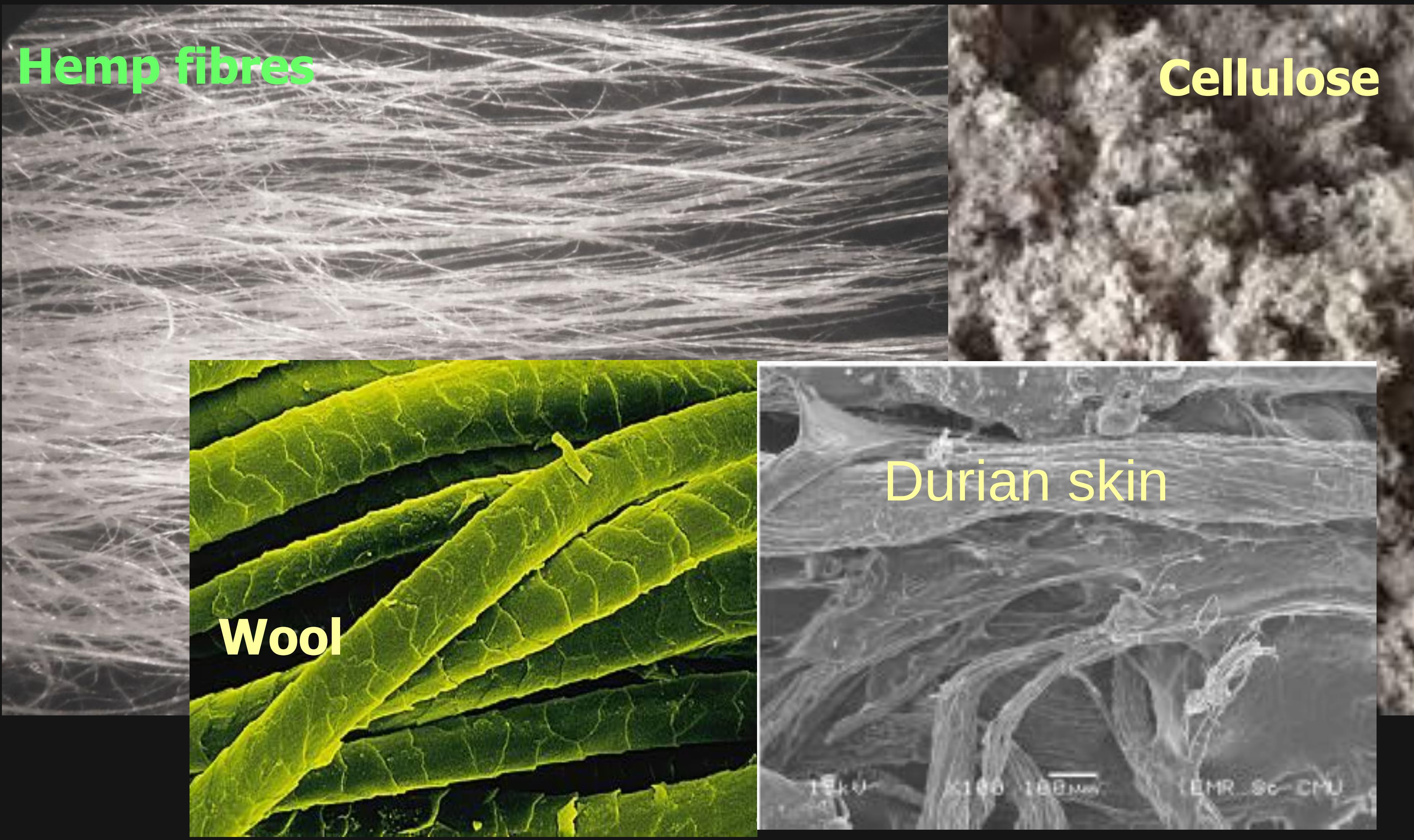
Dense mineral fibres plates

Organic fibres

- Wool, cotton, cellulose, straw, fibres from hemp plant, rice hulls, coco nut or durian
- Marginal market, growing
- Sensitive to moisture, pests, mould and fire
- Absorbs water

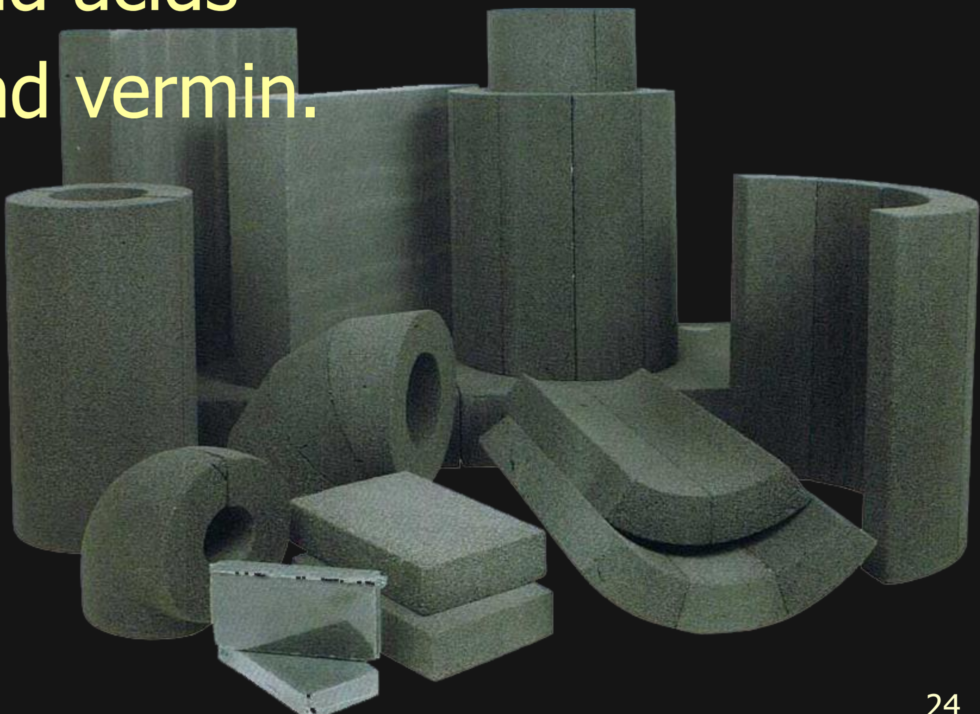


Organic fibres

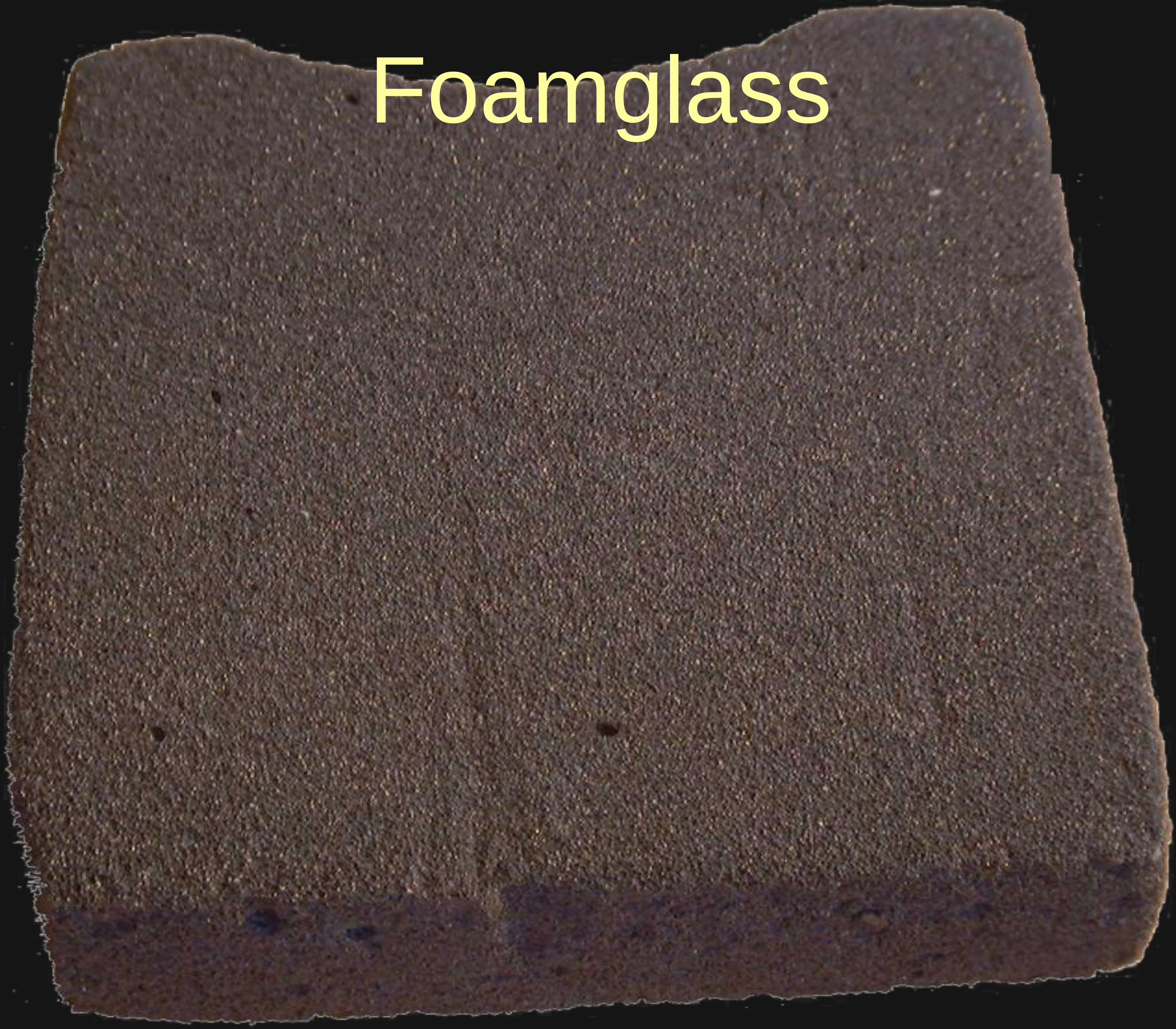


Mineral foams: glass foam

- Good resistance to compression but fragile
- Totally tight to water and water vapour
- Fireproof, service up to 450°C
- Resistant to solvents and acids
- Resists to rot, mould and vermin.
- Expensive



Foamglass



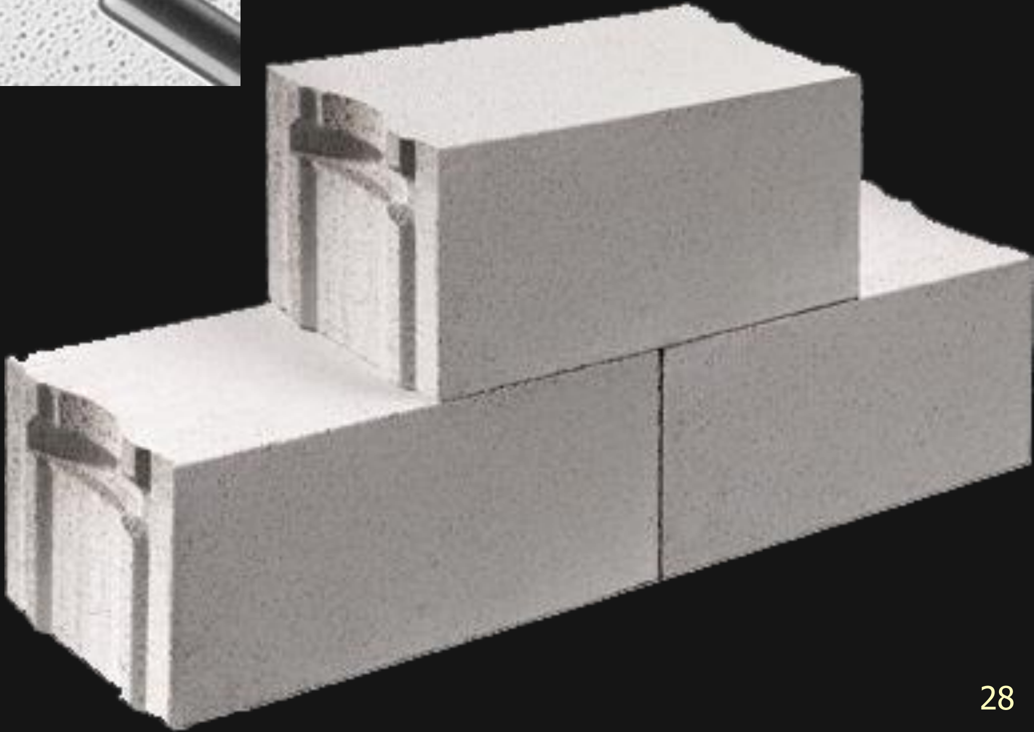
Perlite

Autoclaved aerated concrete

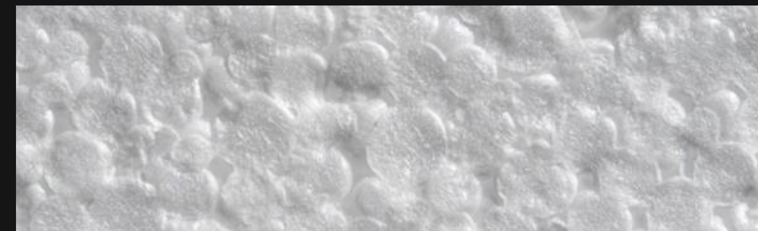
(AAC), also known as autoclaved cellular concrete (ACC), autoclaved lightweight concrete (ALC)

- Cement mortar with aluminium powder, autoclaved
- Poor thermal insulation (0.16 < κ <0.21)
- Fair mechanical strength
- Lightweight building components, roofs, walls
- Absorbs water and is very sensitive to frost when wet

Autoclaved aerated concrete



Organic foams



Expanded polystyrene EPS
- General use
- Poor resistance to water
- Mechanical strength sufficient in most cases
- Cheap

Extruded polystyrene XPS
- Inverted roofs
- Underground, drained insulation
- Fair resistance to weather and water
- Good mechanical strength
- More expensive than EPS

Polystyrene foam resist to mould and rot, but can be destroyed by rodents or insects.

It does not resist to solvents and temperatures exceeding 80 °

Organic foams

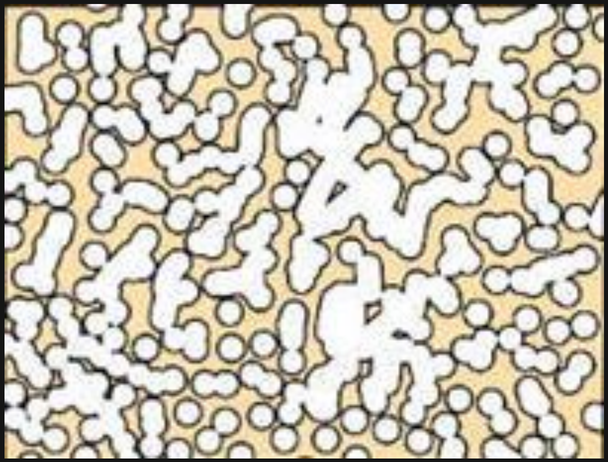
Polyurethane, polyisocyanurate

- Good mechanical strength
- Low κ
- No resistance to weather and UV and sunlight
- On site spraying or injection possible

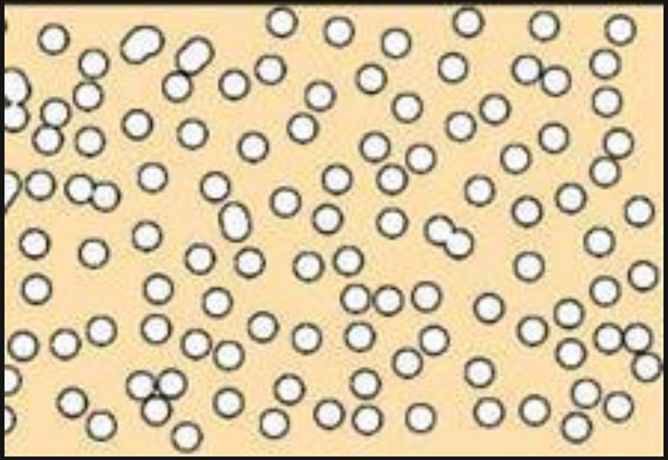
Urea-formaldehyde

- On site injectable foam
- No resistance to water but resists rotting
- No mechanical strength
- Gives off formaldehyde when hardening

Open and closed cells



Open cell foam



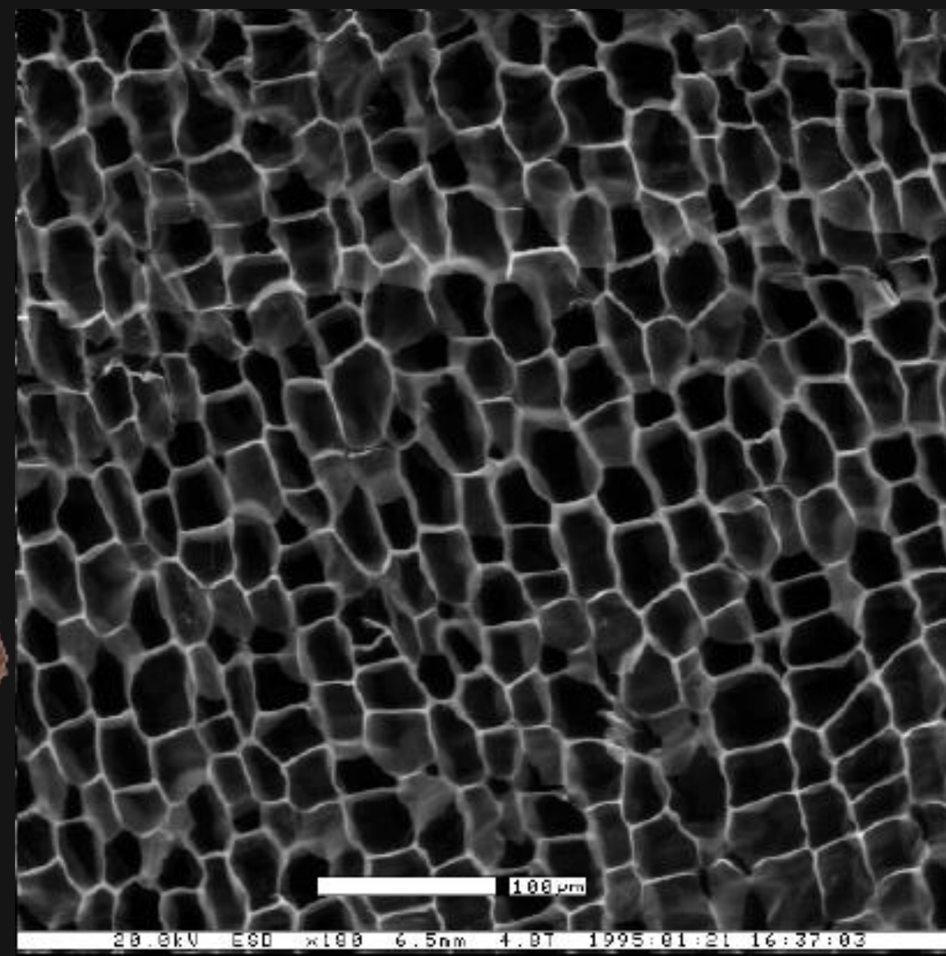
Closed cell foam

Woody materials

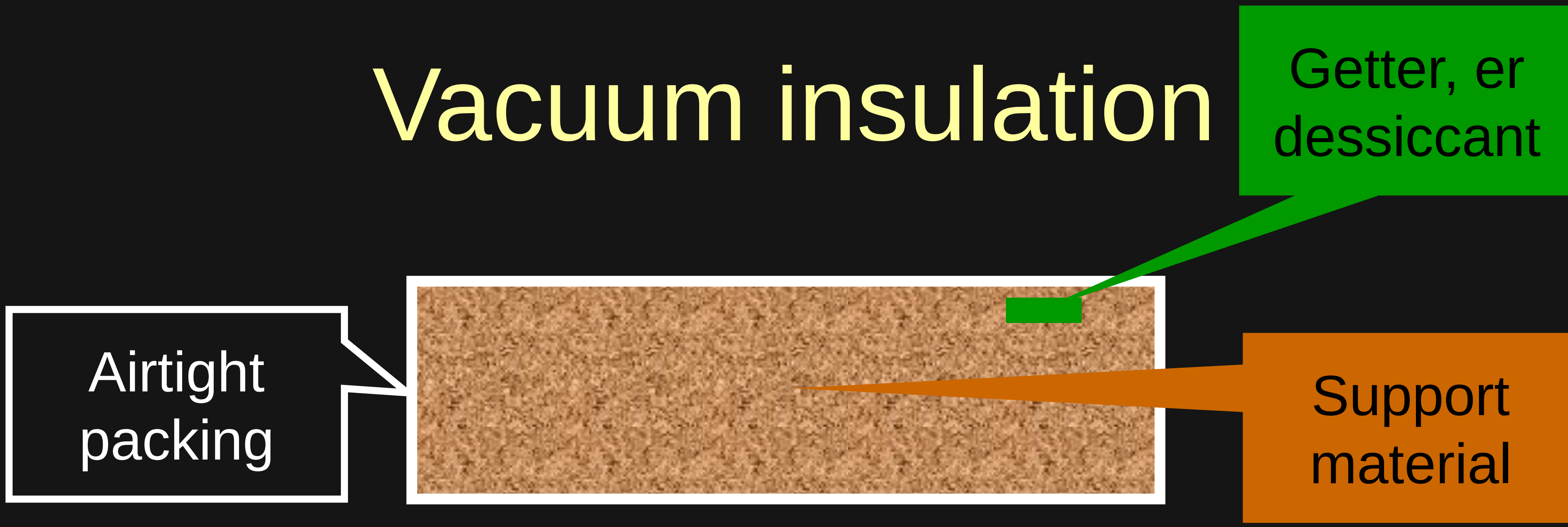
Wood fibre and straw

Cork

- Good mechanical strength
- May rot when wet for long
- Fair resistance to fire

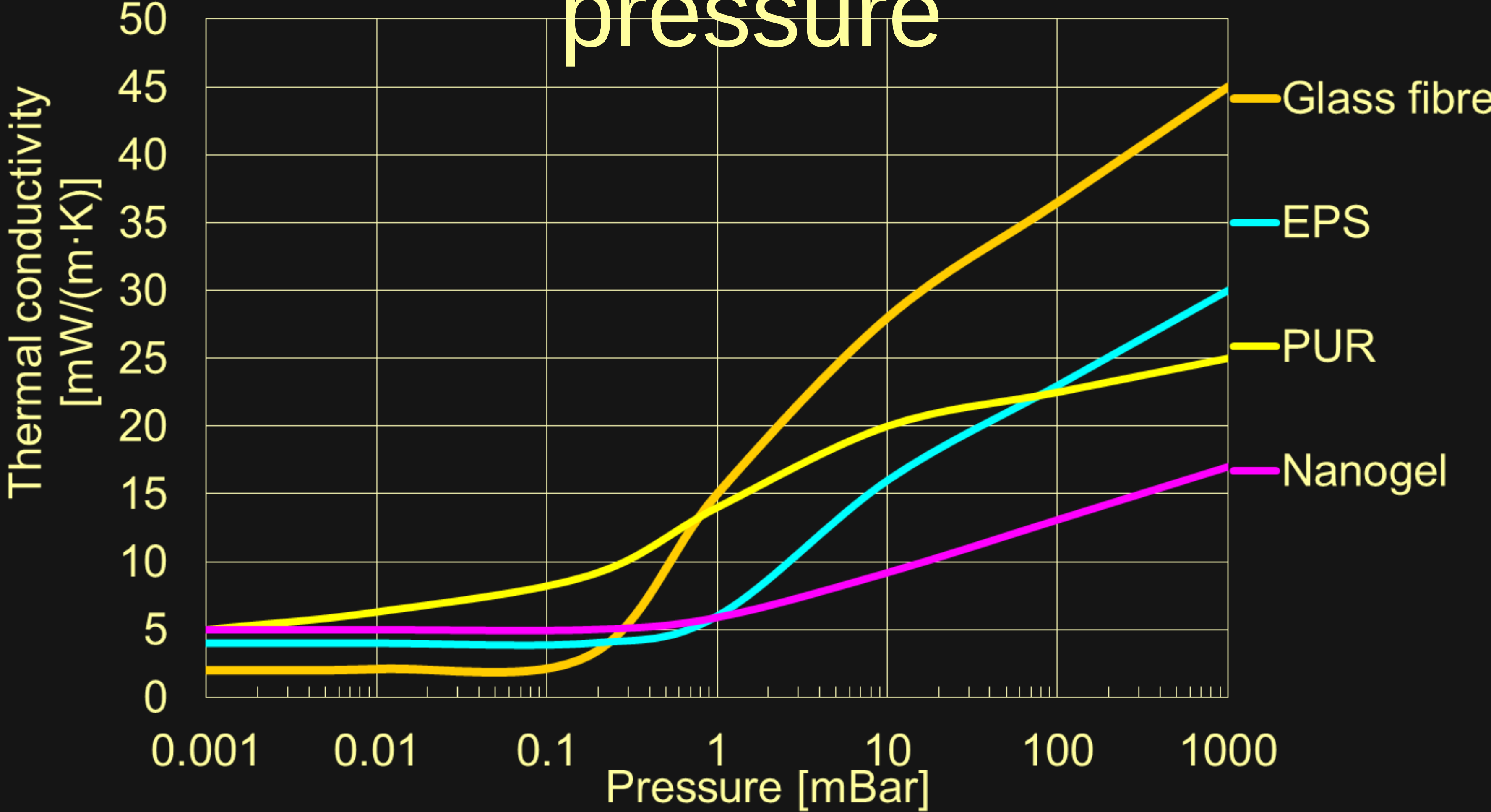


Vacuum insulation



- Resists to atmospheric pressure (10 t/m^2)
- Avoids air to fill the voids in the support material
- Keeps a good vacuum despite degassing

Thermal conductivity and pressure

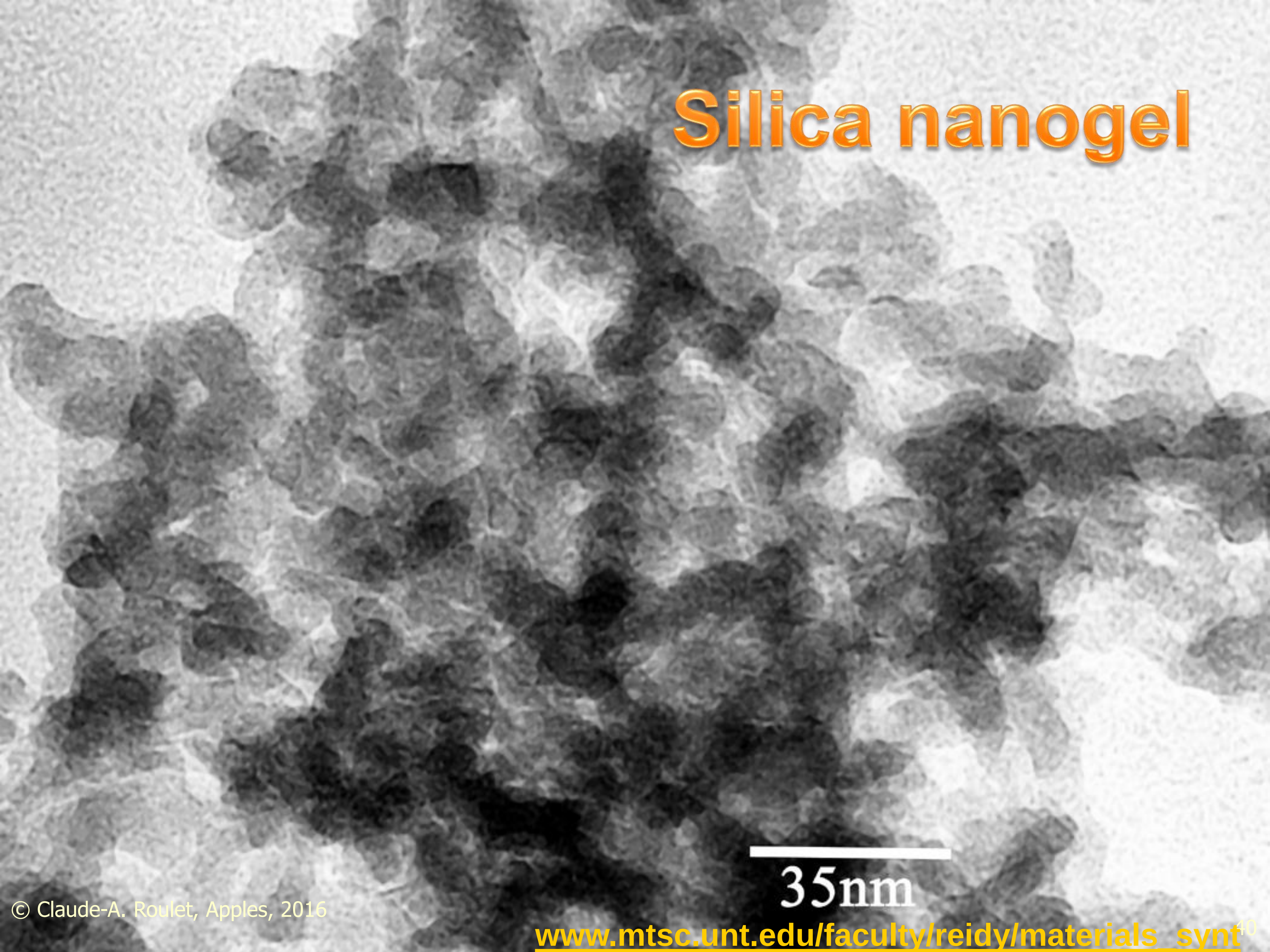


Vacuum insulation

Silica nanogel

- Silica aerogels are produced by extracting the liquid component of a silica gel through drying at a high temperature and pressure
- Produces a foam which pores are so small that the molecules of air hit much more often the walls than other molecules.
- $\kappa < 0{,}017$ W/(m·K) à 1 bar
  $\kappa < 0{,}005$ W/(m·K) à 0,1 mbar

Silica nanogel



www.mtsc.unt.edu/faculty/reidy/materials_synt

Silica nanogel

http://www.boingboing.net/200602061740.jpg

Nanogel products

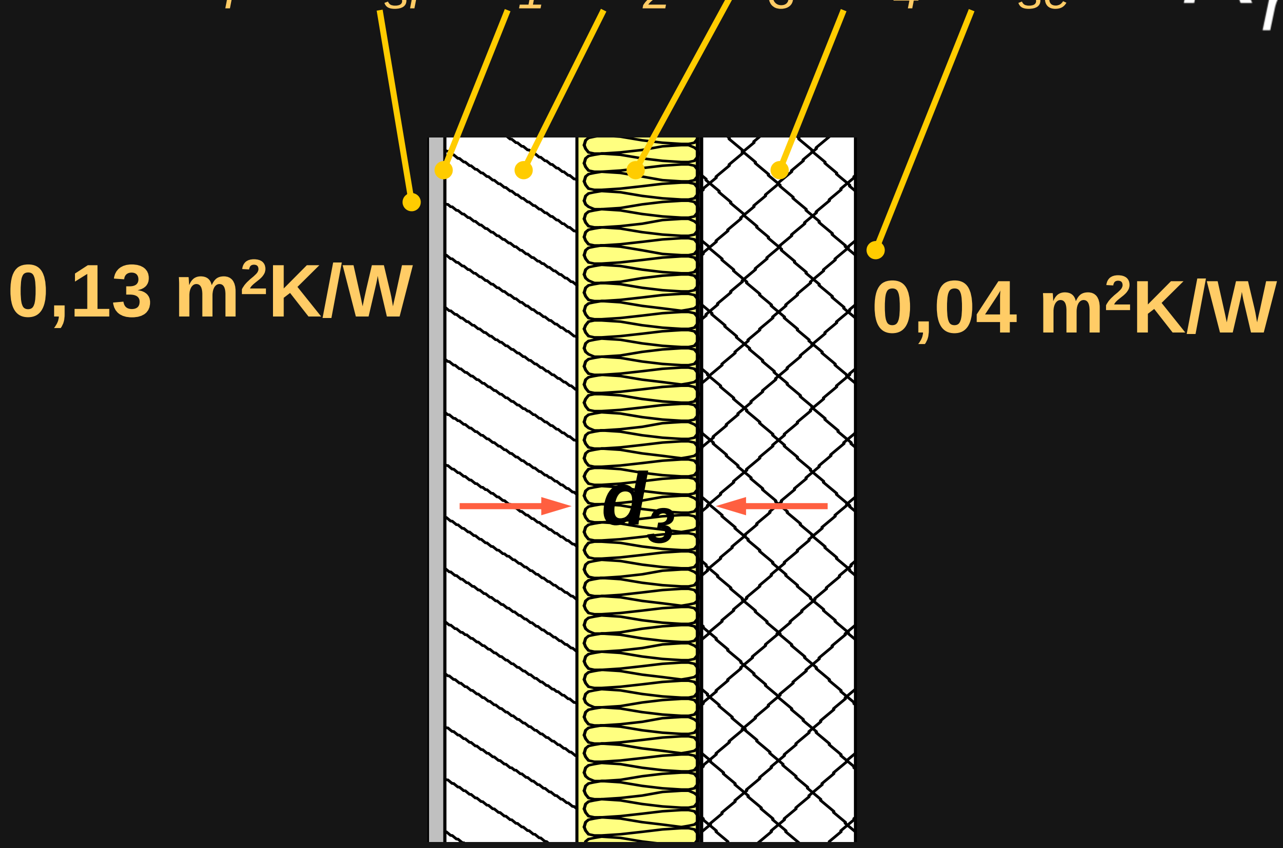
Heavy gases

- Thermal conductivity of locked gases decreases with the molecular mass
- Ar, Kr, Xe, CO_2, Freons, SF_6 are used in:
  - Incandescent lamps
  - Double and triple glass panes
  - Some foams (e.g. PUR)

Thermal resistance of a component

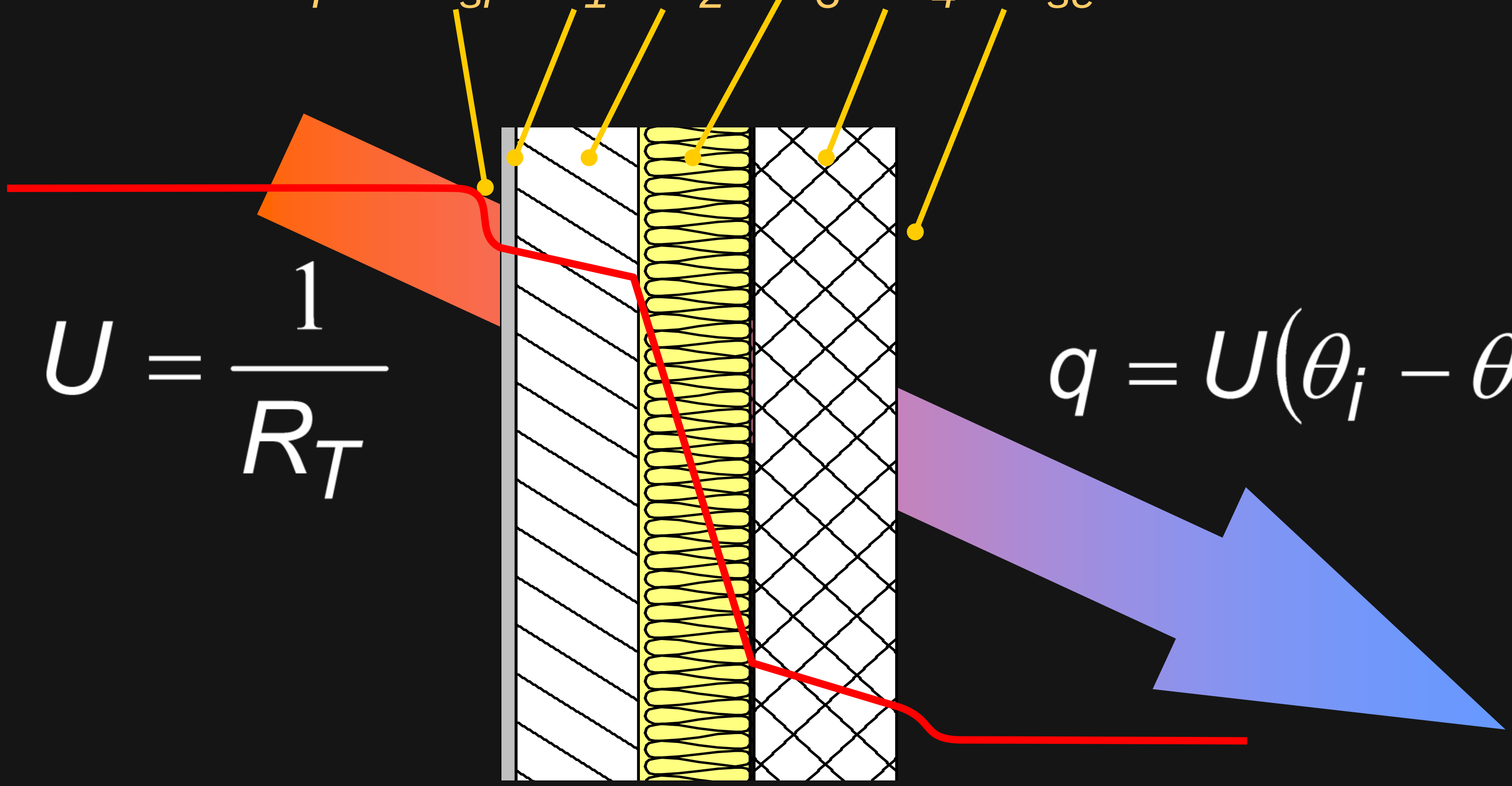
$$R_T = R_{si} + R_1 + R_2 + R_3 + R_4 + R_{se}$$

$$R_n = \frac{d_n}{\kappa_n}$$



Heat transfer coefficient

$$R_T = R_{si}+R_1+R_2+R_3+R_4+R_{se}$$

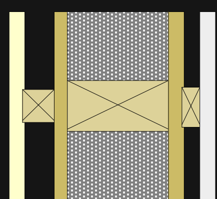


$$U = \frac{1}{R_T}$$

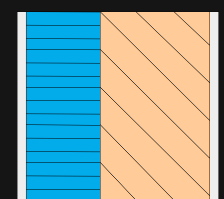
$$q = U\left(\theta_i - \theta_e\right)$$

Minimum thickness for U ≤ 0.40 W/m^{2}K

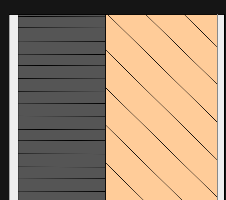
min. 20 cm
Thermal, porosified brick



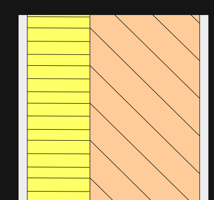
10 cm
Cellulose



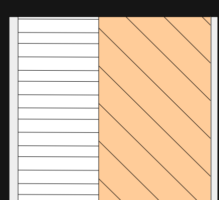
7.5 cm
XPS



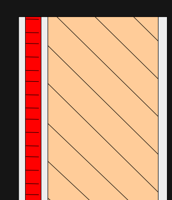
9 cm
Foam glas



6 cm
PUR



8 cm
EPS



1 cm
Vacuum fibre glas

Properties specific to use

Characteristics	Use
10% compression strength	Roof and floor materials that should stand some compression
Traction rupture strength	EIFS (External Insulation and Finishing Systems) materials
Dimensional stability	Insulation materials used on flat roofs
Resistance to heat	Insulation materials under bituminous roofing

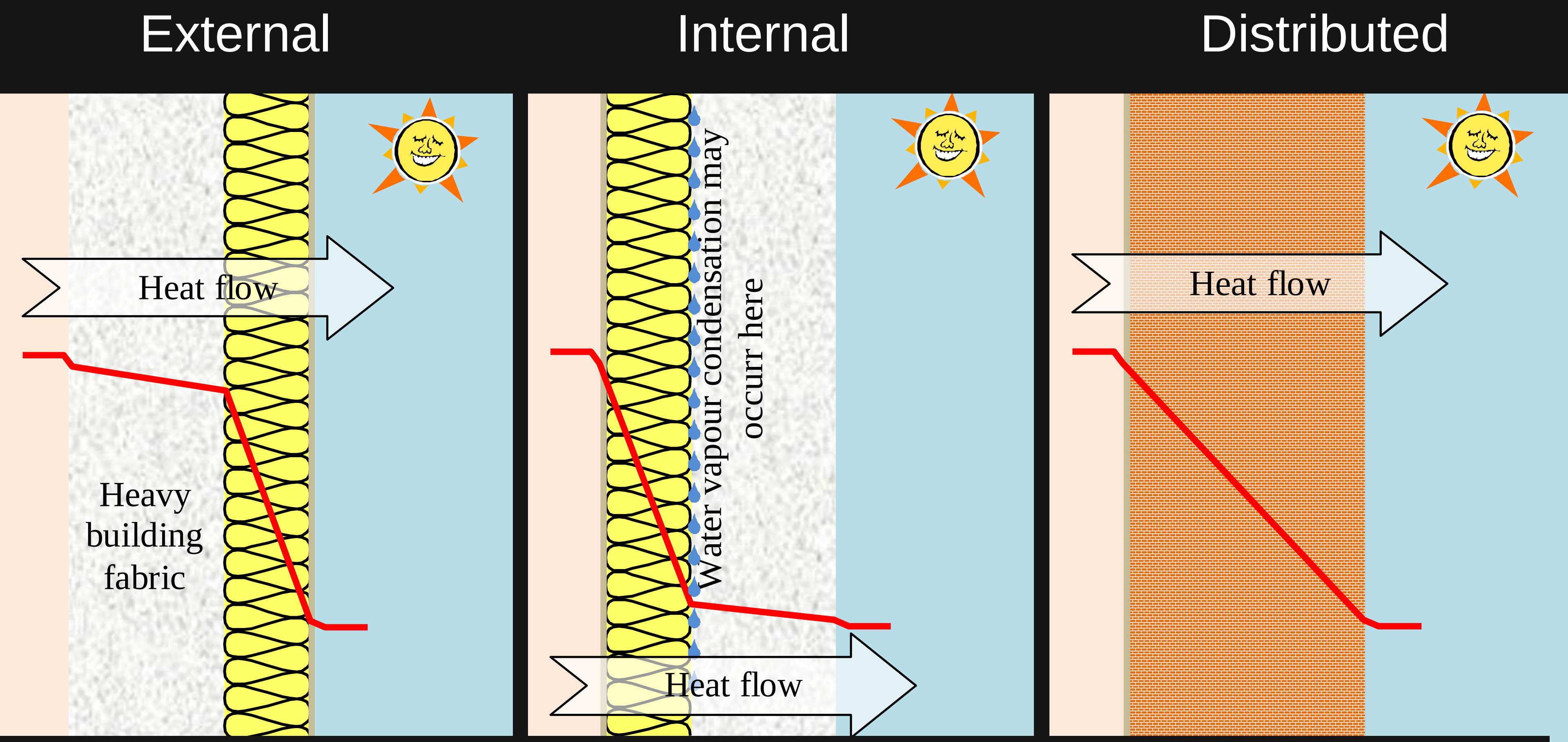
Properties specific to use

Water absorption by - immersion - floating	Materials exposed to water e.g. for inverted roofs or ground insulation
Water adsorption in a thermal gradient	Extruded polystyrene used on inverted roofs
Permeability to water vapour	Materials installed in elements that present a risk of water vapour condensation

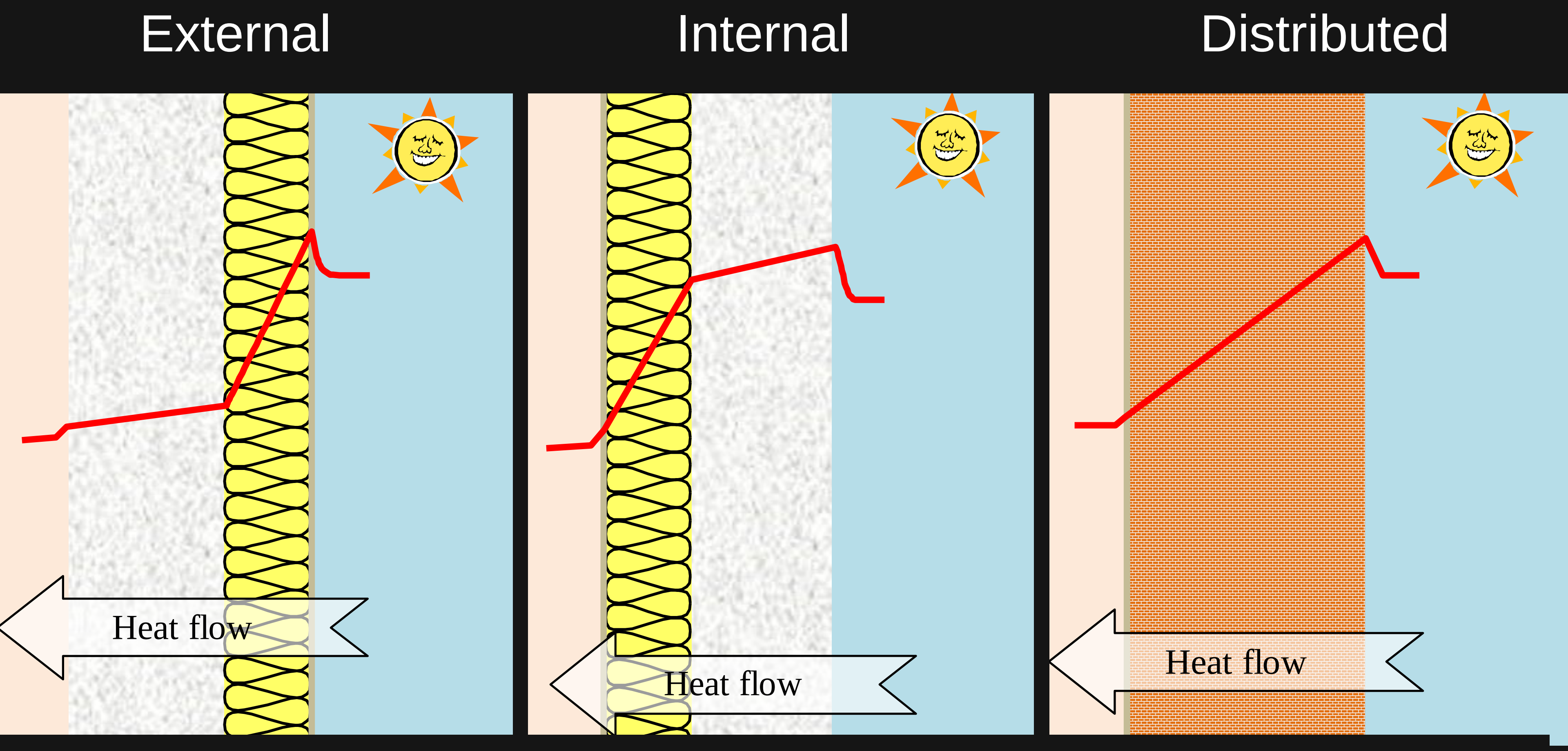
Caracteristics of insulating materials	Insulating power	Density	Fire résistance	Water vapour diffusion	Resistance to water	Compression strength	Traction strength	Heat resistance	Absorption of vibrations	Absorption of aerial noise	Cost at given insulation	Grey energy
Light mineral wool	+	- -	++	- -	0	- -	- -	+		++	$	- -
Dense mineral wool	++	+	++	- -	0	0	-	++	++	+	$	0
Hemp fiber	0	- -	0	- -	- -	0	- -	0		++	$	- -
Wood fibers	0	++	0	- -	- -	+	- -	+	+	++	$$	-
Wood straw -cement	-	++	+	- -	- -	+	0	+	0	+	$$	-
Cellulose flakes	+	- -	0	- -	- -	- -	-	0		++	$	- -
Cork	+	++	+	+	-	+	0	++	+	-	$$	- -
Glass foam	+	+	++	++	++	++	++	++	- -	-	$$$	0
Cellular concrete	- -	++	++	-	-	++	+	++	- -	-	$$$	0
PUR	++	-	0	-	0	+	+	++	-	- -	$	++
EPS	+	- -	+	+	0	+	+	0	-	- -	$$$	-
Graphited EPS	++	- -	+	+	0	+	+	0	-	- -	$	-
XPS	++	0	+	++	+	+	++	0	-	- -	$	+
Silica aerogel	+++	- -	+	- -	++	- -	-	+	++	- -	$$$$	+++

Applications

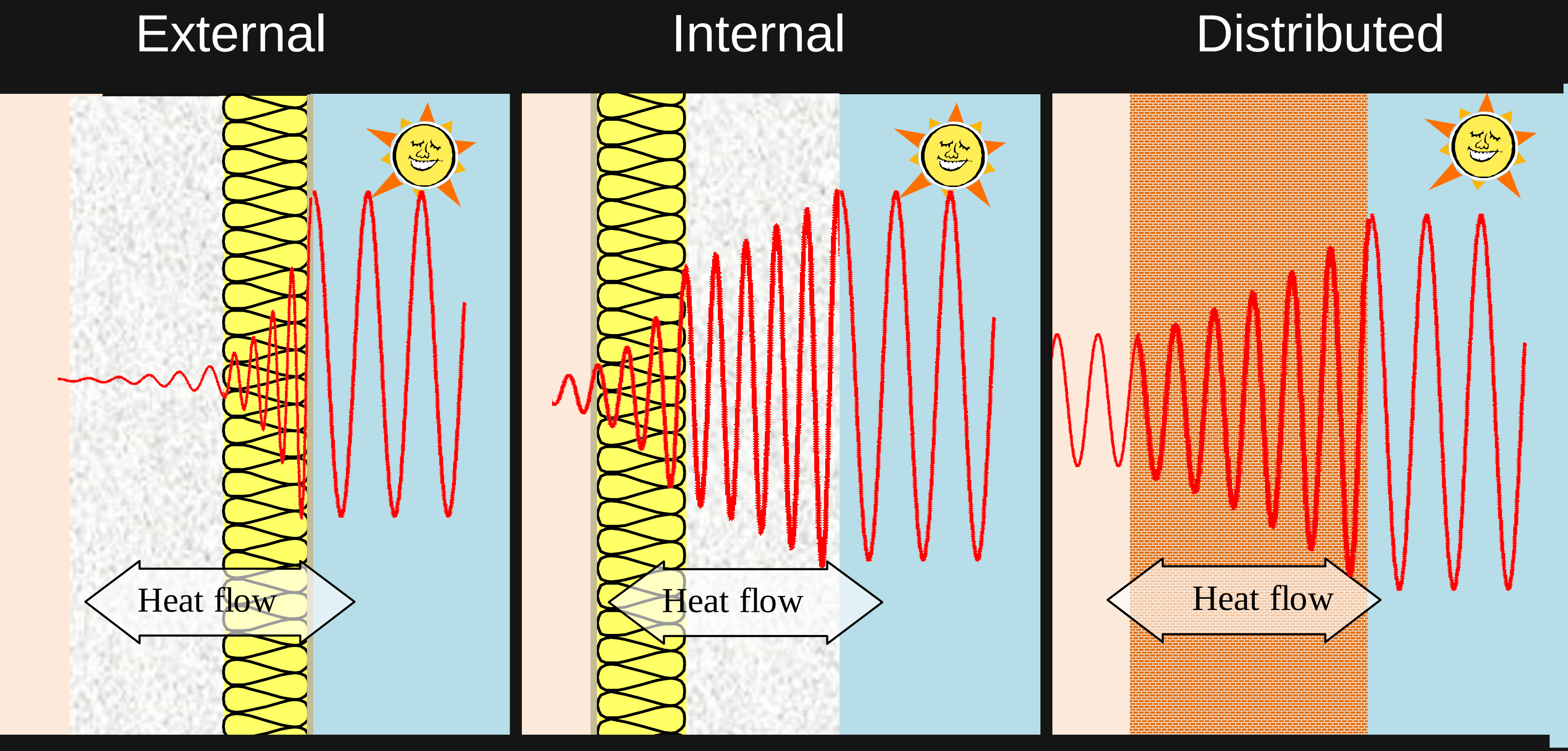
Internal or external thermal insulation? Steady state, cold climate



Internal or external thermal insulation? Steady state, hot, sunny climate



Internal or external thermal insulation? Variable outdoor temperature



External insulation

Advantages

- increases the time constant;
- stabilizes the temperature;
- store excess heat or recover stored heat;
- suppresses most thermal bridges;
- in cold climates, completely suppress the risk of water vapour condensation inside the building element.

Inconveniences

- application from outside;
- increases the time required to change the internal temperature.
- In air-conditioned buildings located in warm and humid climate, may increase the risk of water vapour condensation inside the building element

Internal insulation

Advantages

- application from inside;
- decreases the time required to change the internal temperature;
- In air-conditioned buildings located in warm and humid climate, decreases the risk of water vapour condensation inside the building element.

Inconveniences

- thermal bridges
- in heated buildings located in cold climate, may increase the risk of water vapour condensation inside the building element;
- decreases the time constant of the building;
- building structure exposed to external variations

Distributed insulation

Advantages

- simple construction: a single material is used;
- regular distribution of the temperature in the wall;
- relatively high internal thermal inertia
- no condensation problem if permeable finishing.

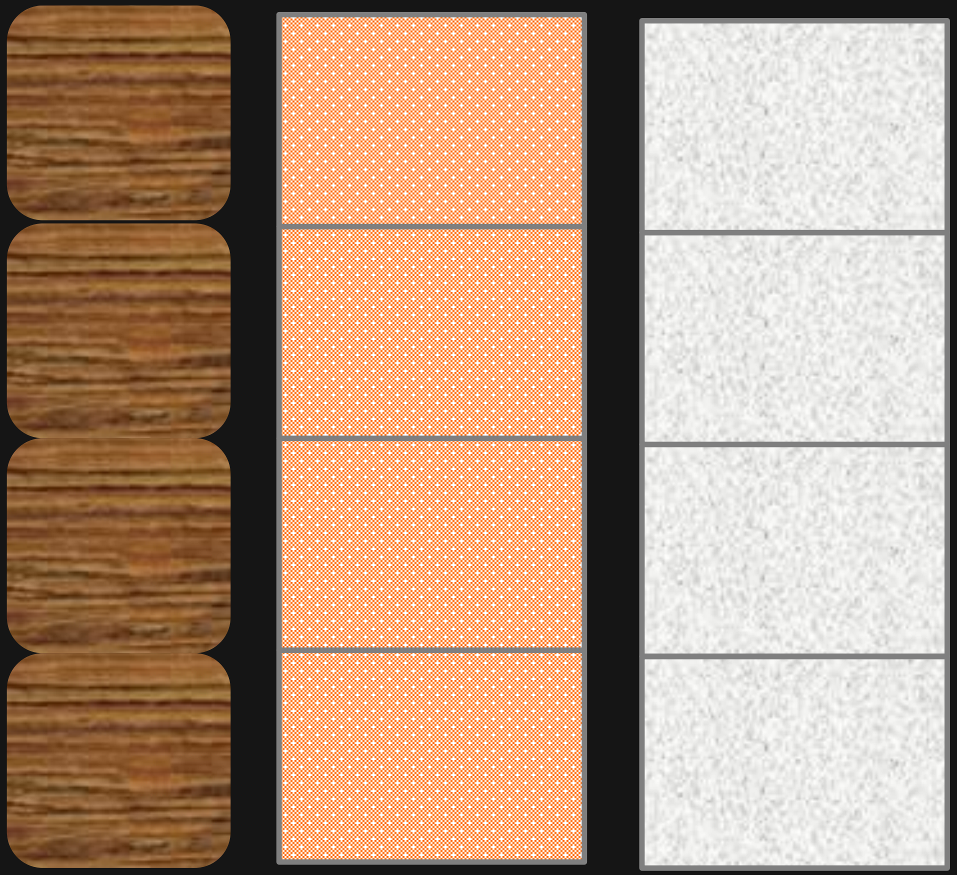
Inconveniences

- limited insulation, or
- very thick components.
- building structure exposed to external variations

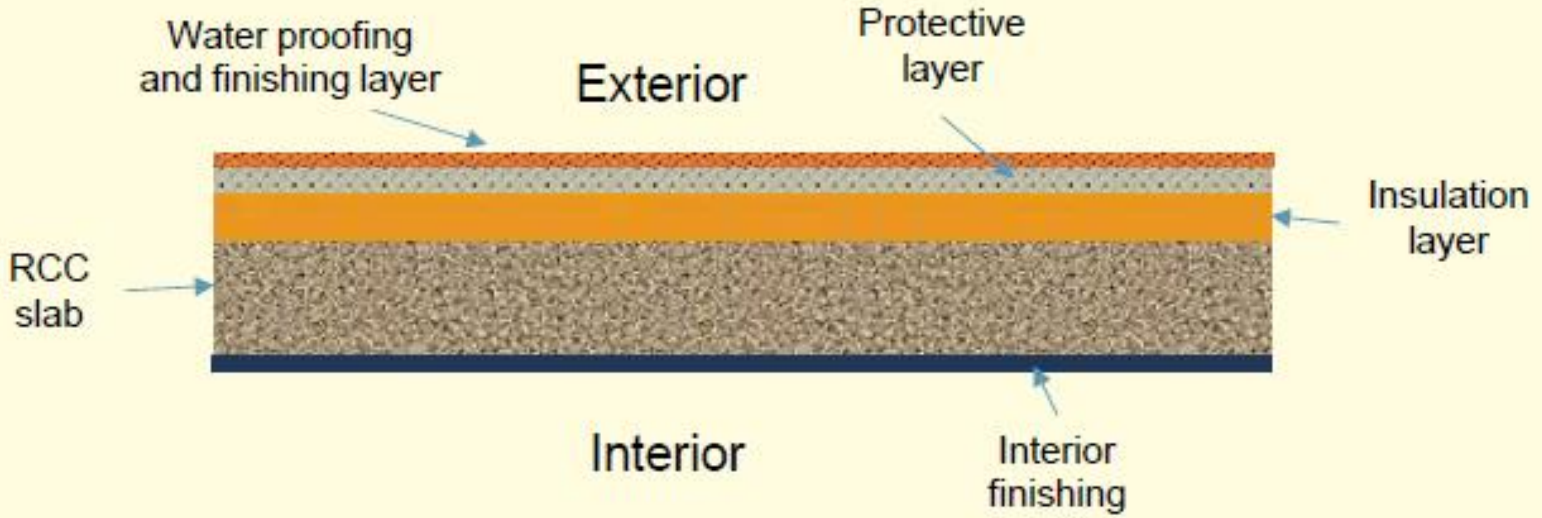
Thermal insulation in the building envelope

Homogeneous walls

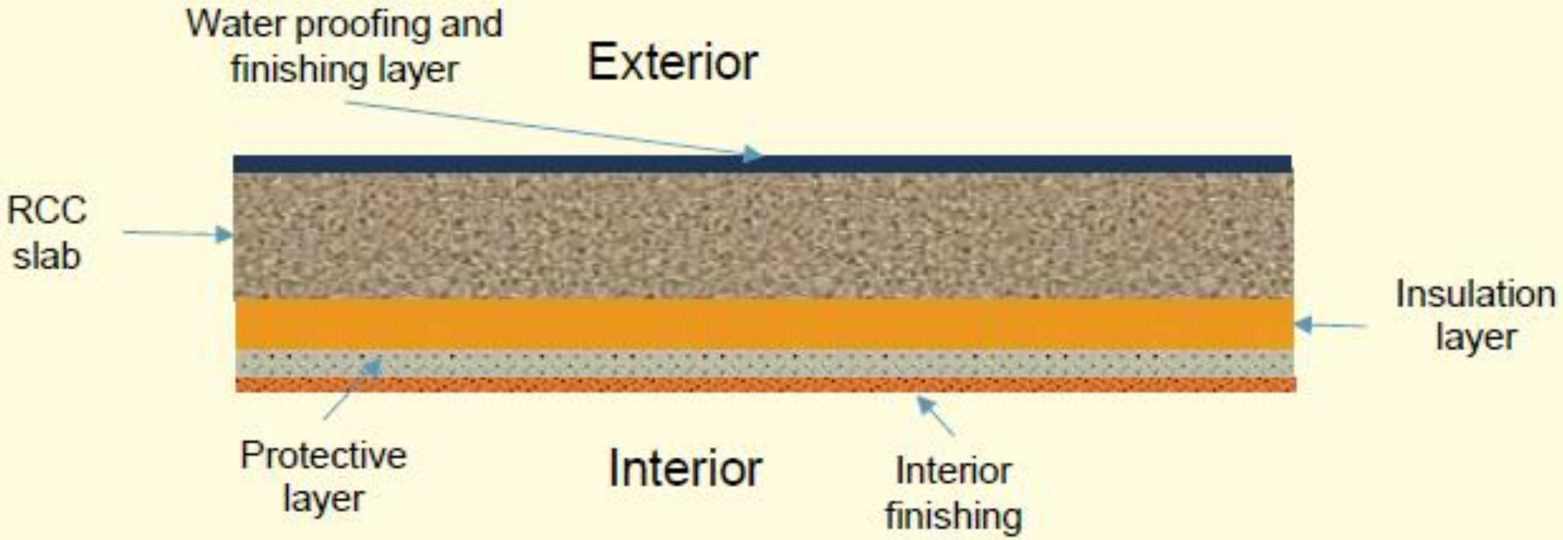
- massive wood
- porosified clay brick,
- aerated concrete
- compressed straw
- adobe



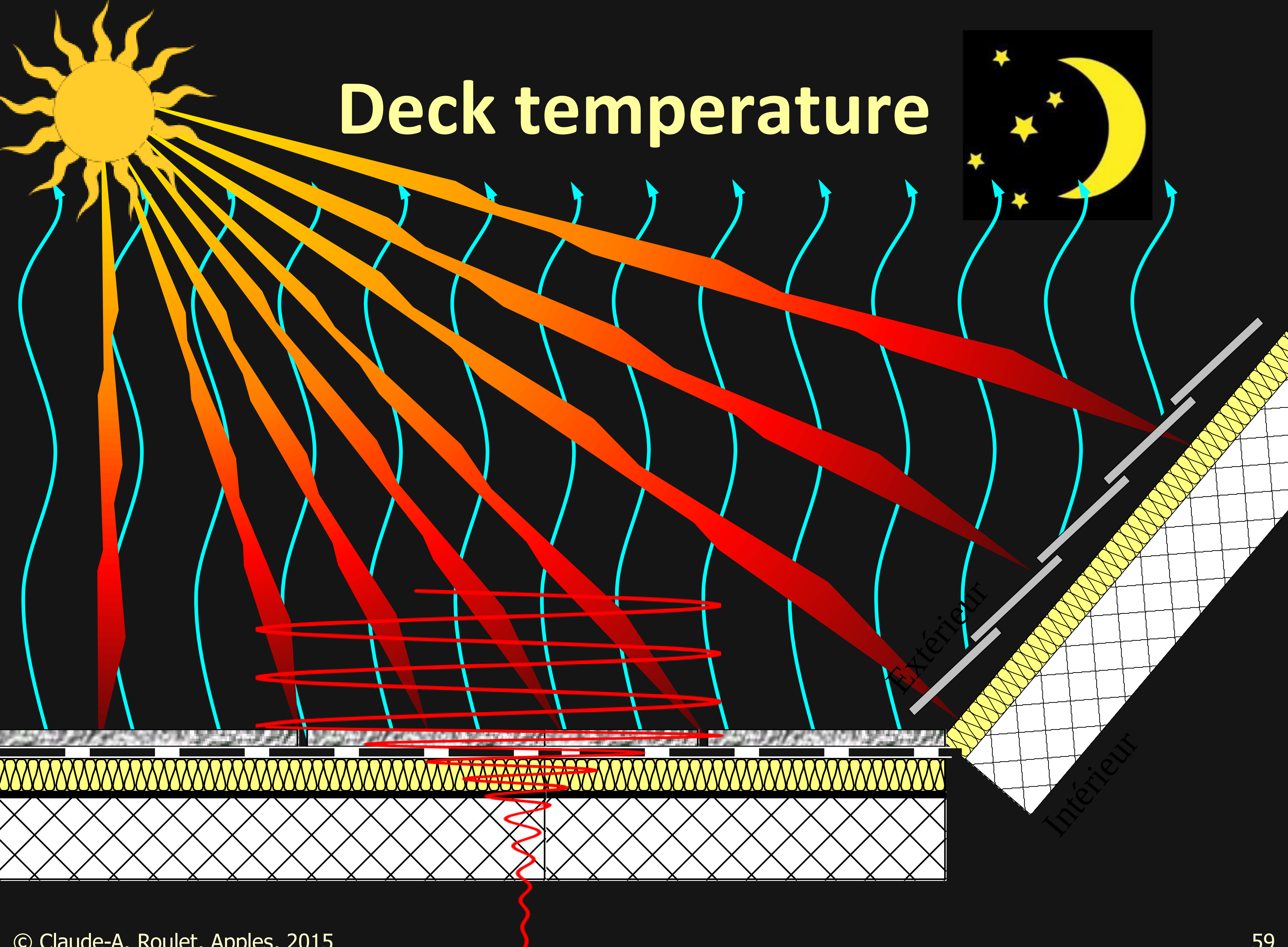
Roof with Over-deck Insulation



Roof with Under-deck Insulation

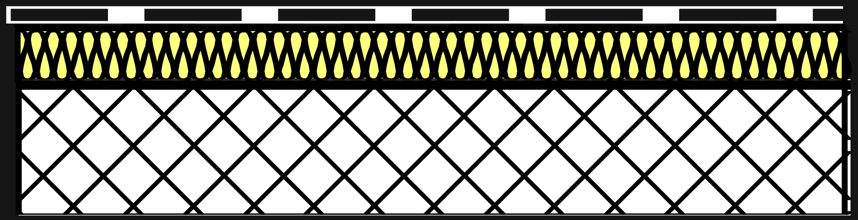


Deck temperature

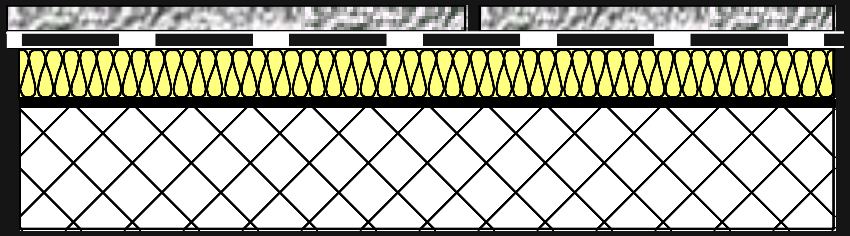


Roof over-deck

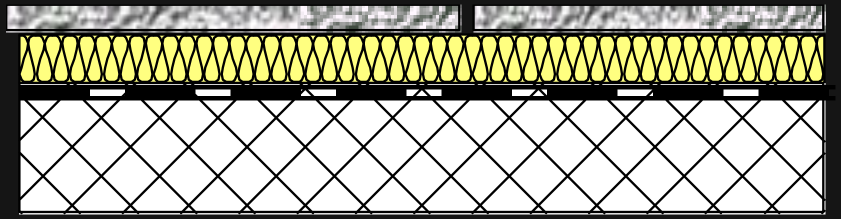
Without protection



With protection



Inverted roof

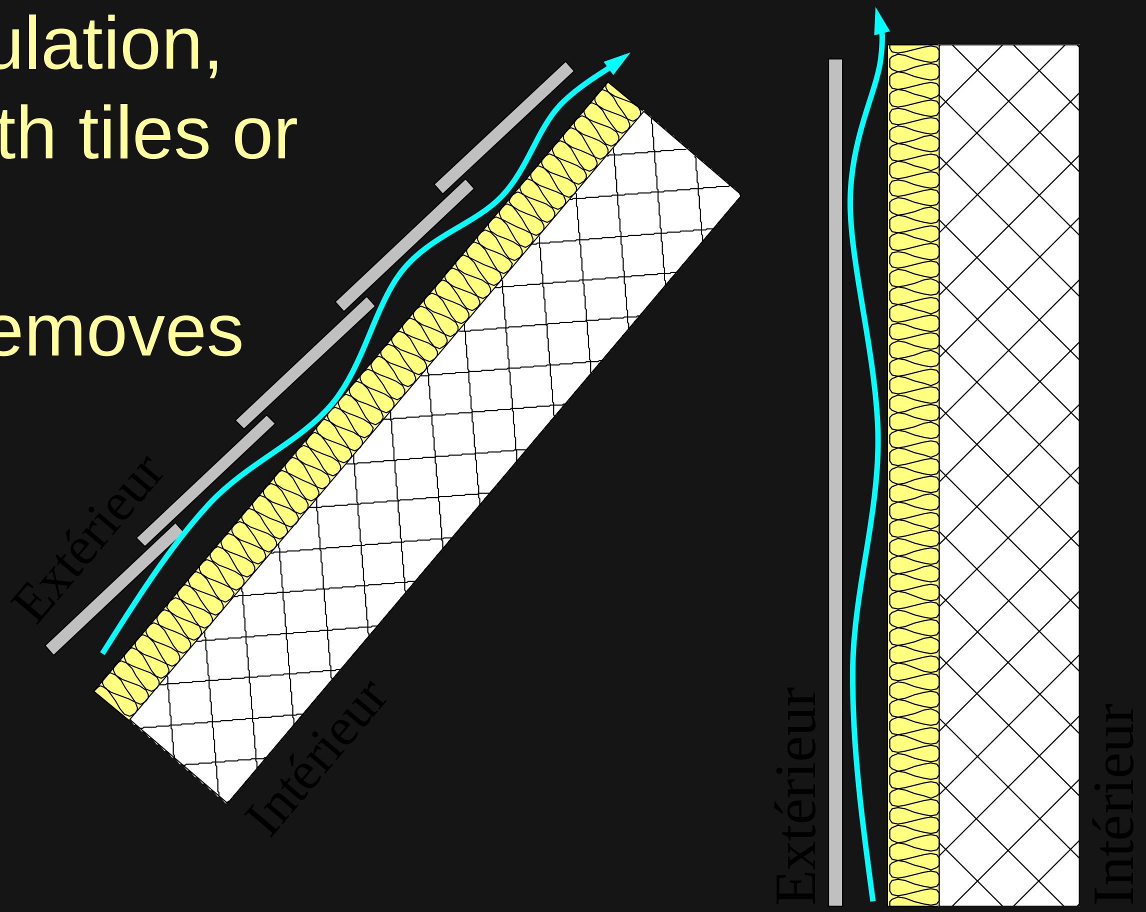


Green roofs

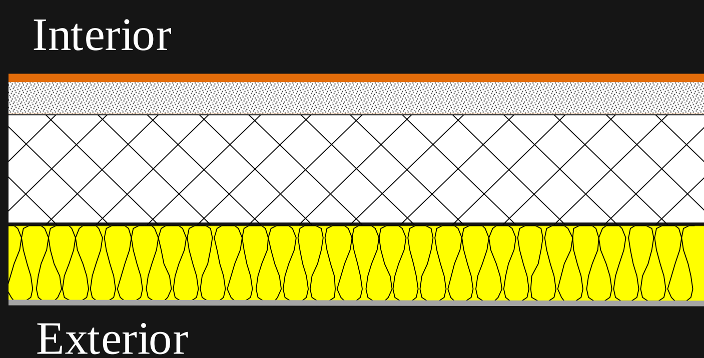
Ventilated walls and roofs

External insulation, protected with tiles or cladding

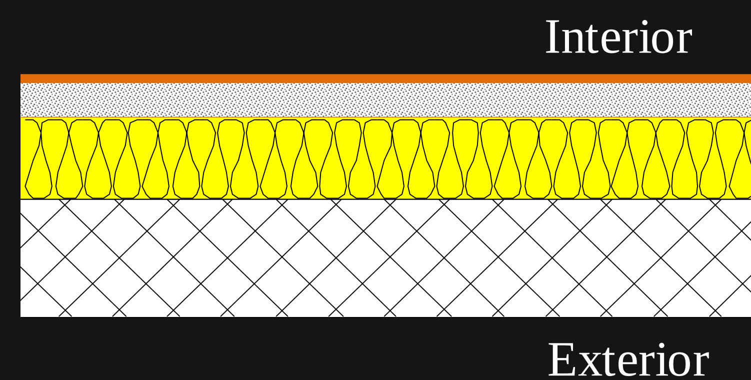
Ventilation removes moisture



Floor slabs

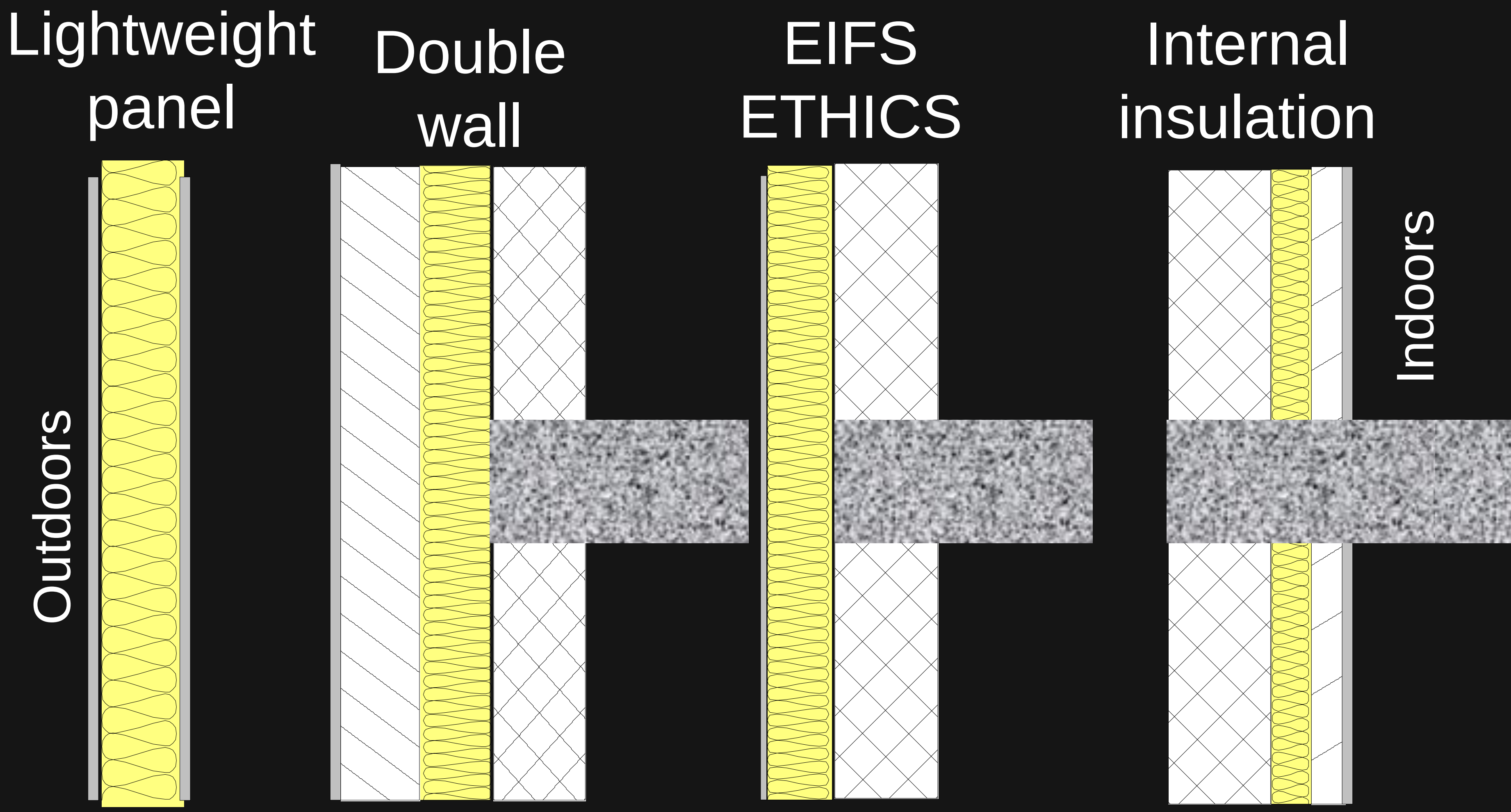


External insulation

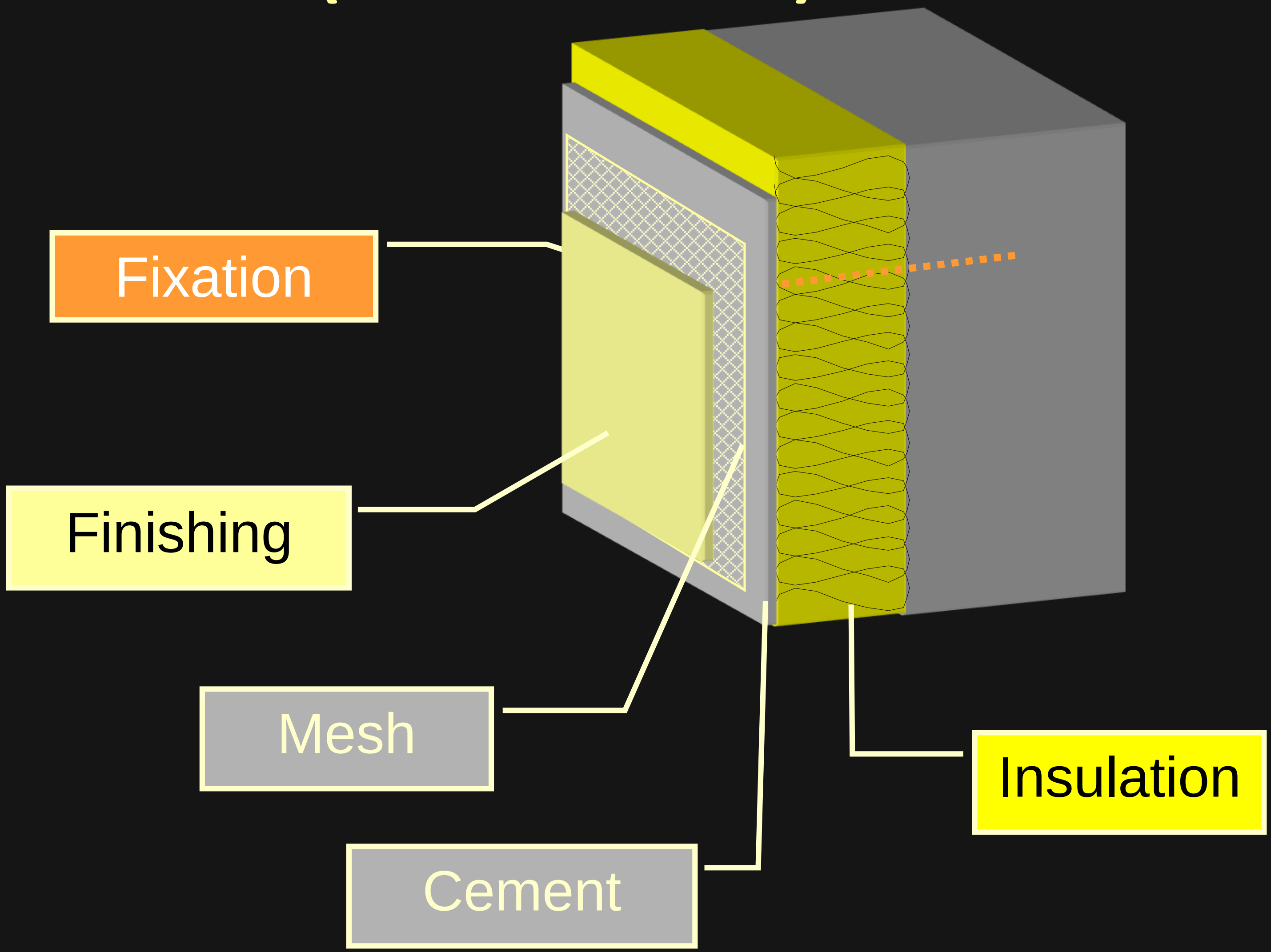


Internal insulation

Insulation of walls



External Insulation and Finishing Systems (EIFS or ETICS)



EIFS-ETHICS

Advantages

External insulation

- No thermal bridge
- High thermal innertia
- Good protection of the structure
- No internal condensation.

Cautions

- Use only proven systems
- DIY is dangerous
- Poor shock resistance.

Applications of PUR foam

Applications Material	Homogeneous walls	Common flat roof	Inverted roof	Ventilated insulation	Between walls	Injected	Floors	Prefabricated panels	EIFS	Fire protection	Acoustic absorption	Isolation to shock noise
Light mineral fibre	×	×	×	☺	☺	☺	×	×	×	😐	😐	×
Dense mineral fibre	×	☺	×	😐	😐		☺		😐	☺	☺	☺
Organic fibres	×	×	×	☺	☺		×	×	×	×	☺	
Wood	☺		×				☺	☺	×	☹		
Wood fibres	×	×	×	😐	😐		😐	☺	×	×	☺	☺
Cellulose fibres	×	×	×	☺	☺	☺			×	×	☺	
Cork	×	☺	×	☺	😐	😐	☺	☺	×	😐	😐	☺
Glass foam	×	☺	×	😐	😐	☺	☺	😐	😐		×	×
Aerated concrete	☺	☹	×	😐	😐		☺	😐		☺	×	×
PUR, PIR	×	☺	×	😐	😐	☺	☺	☺	😐	×		☹
PS expanded	×	☹	×	☺	☺	☺	☺	☺	☺	×	☹	😐
PS extruded	×	☺	☺	😐	😐		☺	☺	😐	×	☹	😐
Urea Formaldehyde	×	×	×			☺	×	×	×	×	×	×

Conclusions

- Buildings are first built to provide comfort
- Passive ways should be used first
- Thermal insulation is essential in most climates
- There is no poor insulation material, but there may be bad uses or poor applications

THNAK YOU!