# Building Materials

## Lecture 5

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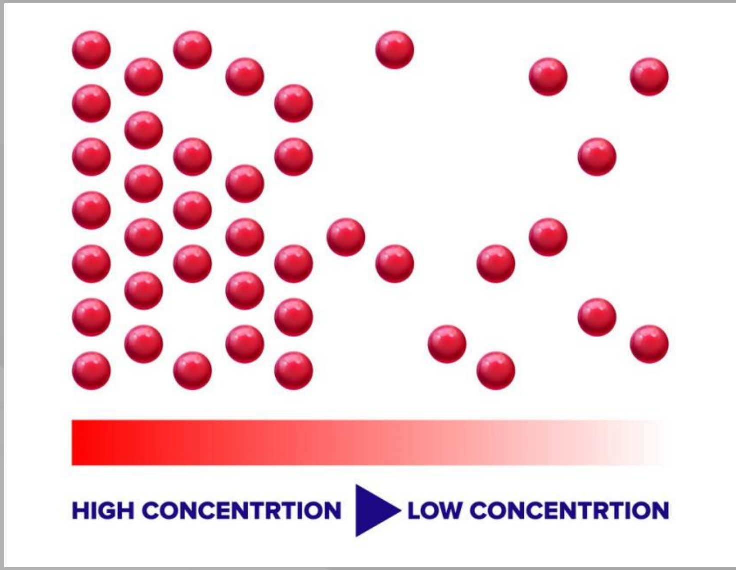
# Diffusion properties

# Diffusion

- **gases, vapor**
- spread of particles through random motion from regions of higher concentration to regions of lower concentration

- Important for:
  - vapor barriers
  - radon barriers
  - rehabilitation renders
  - paints
  - passive houses

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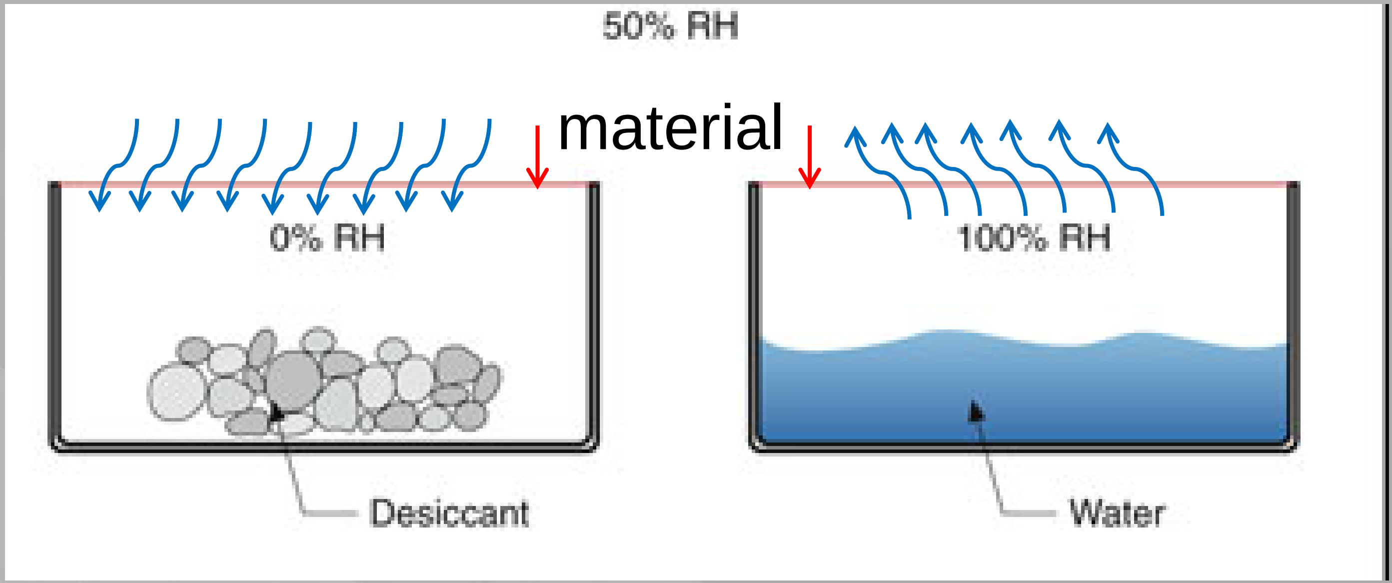
# Water vapor transport

**Important properties**:

- the water vapor diffusion coefficient **δ**
- the resistance to water vapor diffusion factor **μ**
- the water vapor diffusion equivalent air layer thickness $\mathbf{s_d}$

# Water vapor permeability test

- dry cup method
- wet cup method




- mass increase
- mass decrease

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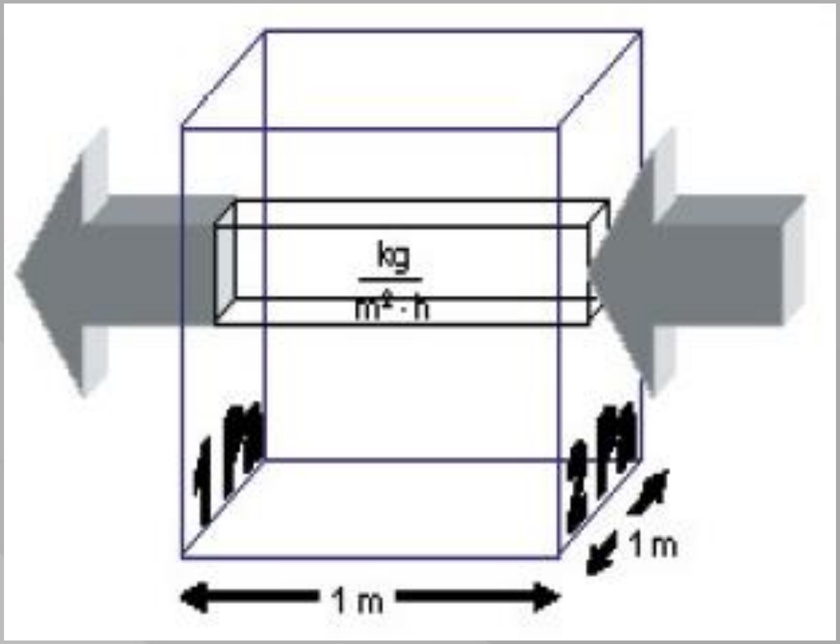
# Water vapor diffusion -
# - coefficient δ

- the amount of water vapor [kg] which diffuses through a layer of material which is 1 m thick and has an area of 1 m² at a partial water vapor pressure difference of 1 Pa in 1 hour

- units: **[kg/m.h.Pa]**

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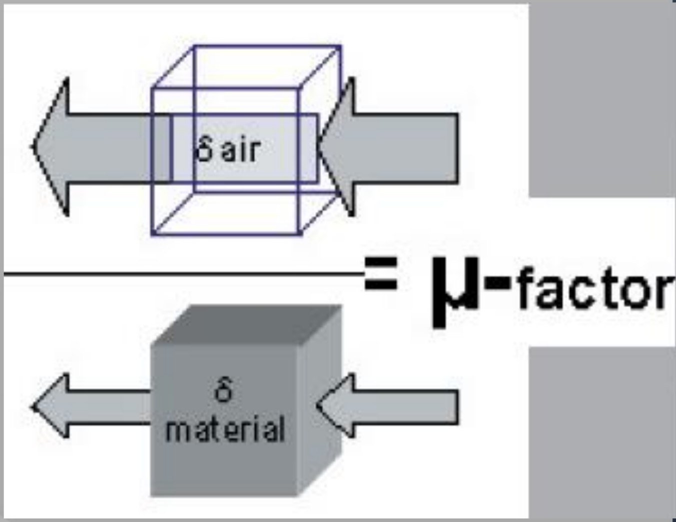
# Resistance to water vapor diffusion - factor μ

- **the ratio of the water vapor diffusion coefficient of the air $\delta_L$ to the value $\delta_{mat}$ of the material**

- a measure for the vapor tightness of a material
  (how many times greater the resistance to transmission of a layer of the material is compared to a static layer of air of the same thickness)



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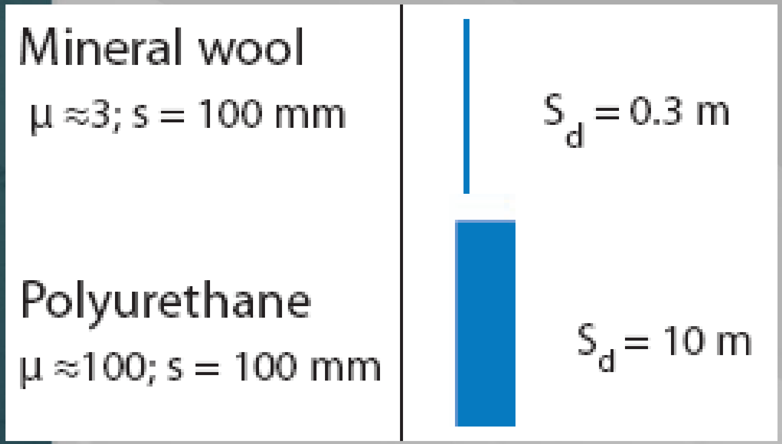
# μ -value of some materials

| Material | μ -value |
|---|---|
| Reinforced concrete | 90 |
| AAC (autoclaved aerated concrete ) | 6 |
| Masonry of full bricks | 7 |
| Steel (plate) | 600 000 |
| Window glass | 10 000 |
| Gypsum board | 12 |
| Gypsum fibre board | 10 -15 |
| Wooden fiber plates | 10 |
| Hydrophobic plywood | 60 - 100 |
| Mineral wool | 2 |
| OSB (oriented strand board) | 30 |
| EPS (expanded polystyrene) | 40 |
| XPS (extruded polystyrene foam) | 170 - 200 |

# Equivalent air layer thickness $S_d$

$$S_d = \mu \cdot s \ [\mathrm{m}]$$

- the thickness of a static layer of air in meters, which displays the same resistance to water vapor transmission as the building material in the thickness s with the resistance to water vapor transmission value μ




- Sd ≤ 0.5 m => **diffusion-open** materials
- 0.5 m < Sd => **diffusion-blocking** materials
- Sd ≥ 1500 m ≥ 1500 m => **diffusion-proof** materials

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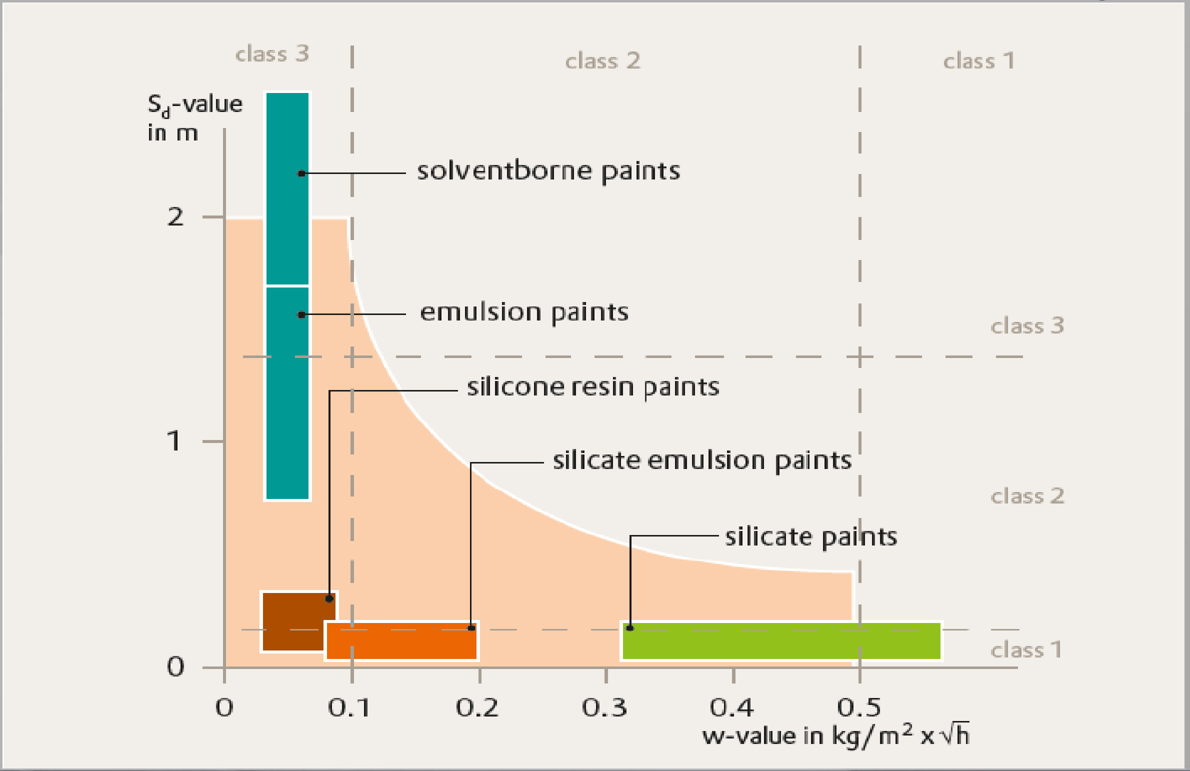
# Diffusion of coatings

Künzel's facade protection theory:

- protection and breathability of coating are influenced by water absorption capacity **w** and the water vapor permeability $\mathbf{S_d}$





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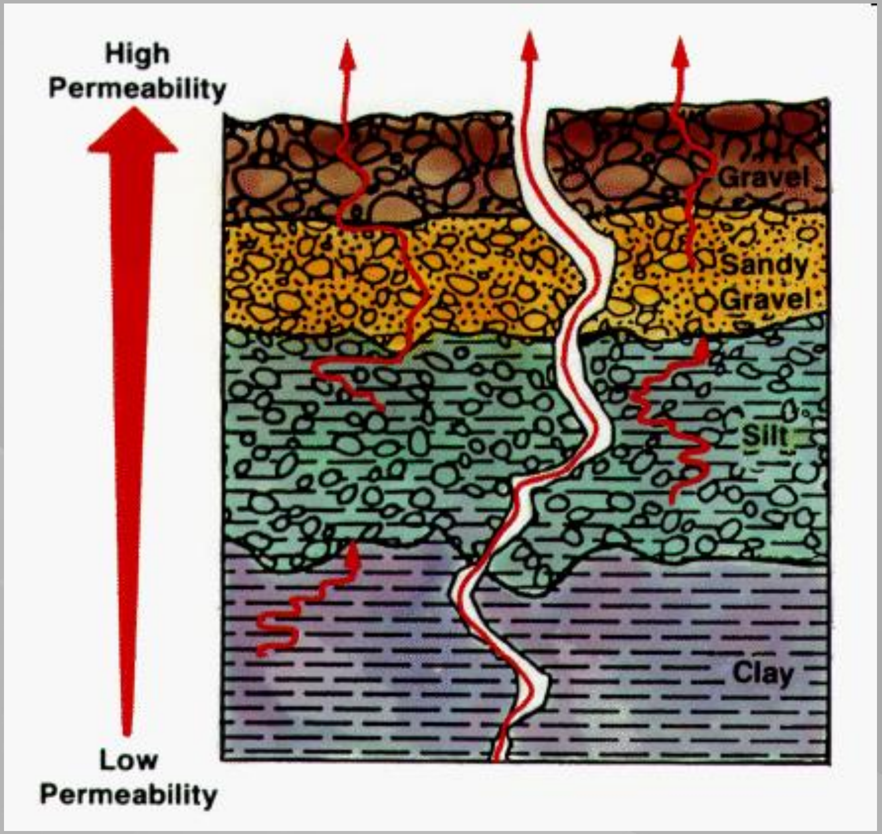
# Soil permeability

- ability of soil to transmit water and air
- important in the areas with radon risk



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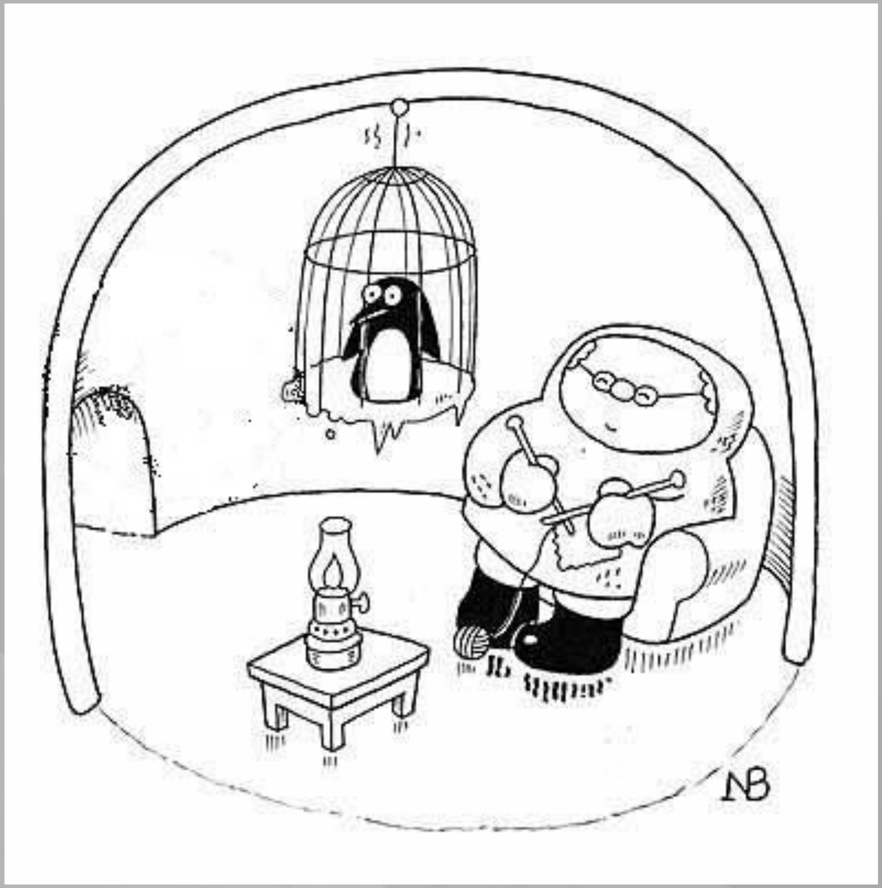
# Thermal properties



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# Interaction heat - material

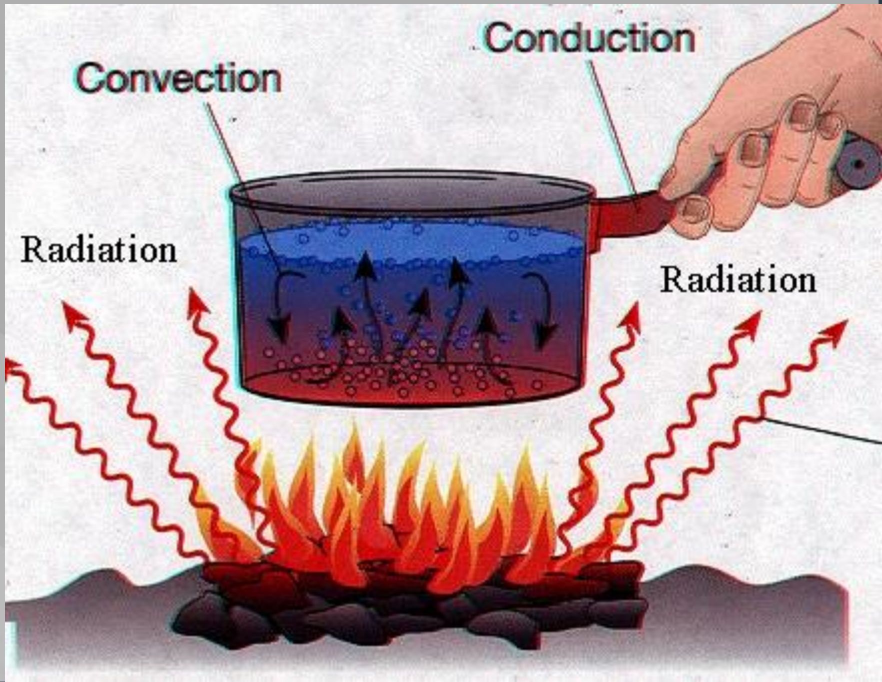
- If the surroundings of the material has different temperature than the material, the thermal energy is transferred

**Types of interaction:**

1. The properties of material influence the transmission of heat
2. Thermal energy influences the properties of material

# Heat transport

- **conduction – solids, gases, liquids**
  - the transfer of heat within a substance, molecule by molecule
- **convection - gases, liquids**
  - heat transfer by the mass movement of a fluid in the vertical direction
- **radiation – gases**
  - heat is transfered through wave energy

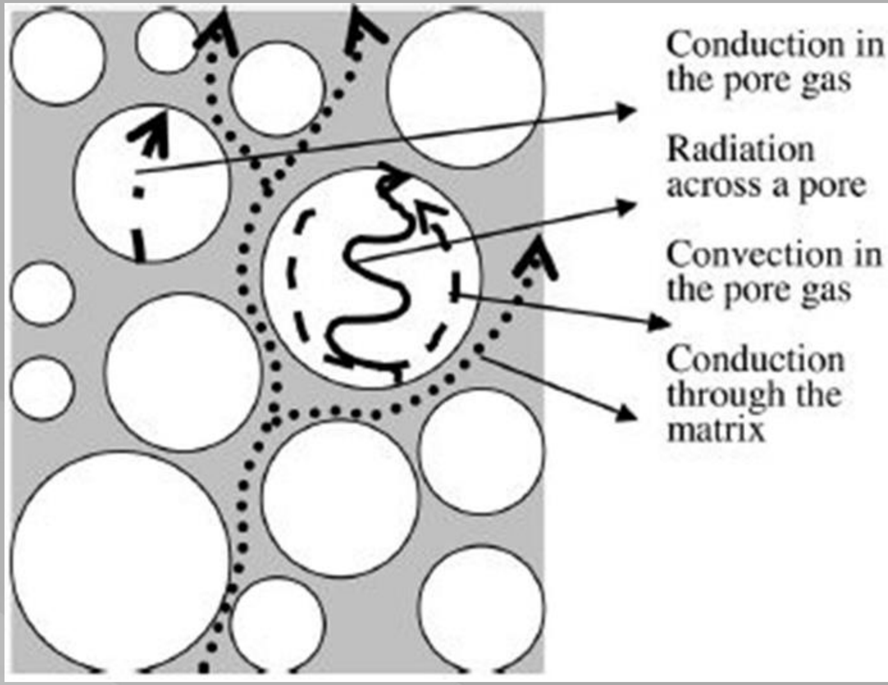


# Heat transport

- In the porous materials the heat is transferred by combination of all types of heat transport

Depends on:

- **porosity**
- **structure**
- **temperature**
- **material type**

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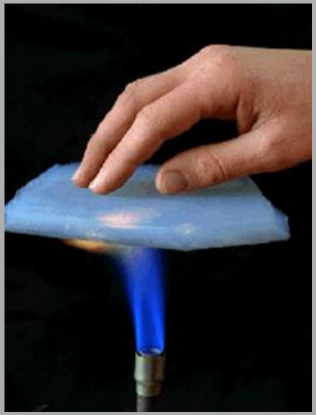
# Thermal conductivity

- a material's ability to conduct heat

- (coefficient of) **thermal conductivity** $\lambda$

# Thermal conductivity

- the quantity of heat transmitted, due to unit temperature gradient, in unit time under steady conditions in a direction normal to a surface
- λ (**K-value)**
- units SI: **[ W/m.K]**
  - imperial units: [Btu/hr.ft.F]
  - (1 Btu/hr.ft.F = 1.730735 W/m.K)
- **the lower λ, the better insulator**
  - (thermal insulating materials λ < 0,15 W/m.K)
- **range λ: $10^{-2}$ - $10^{2}$ W/m.K**



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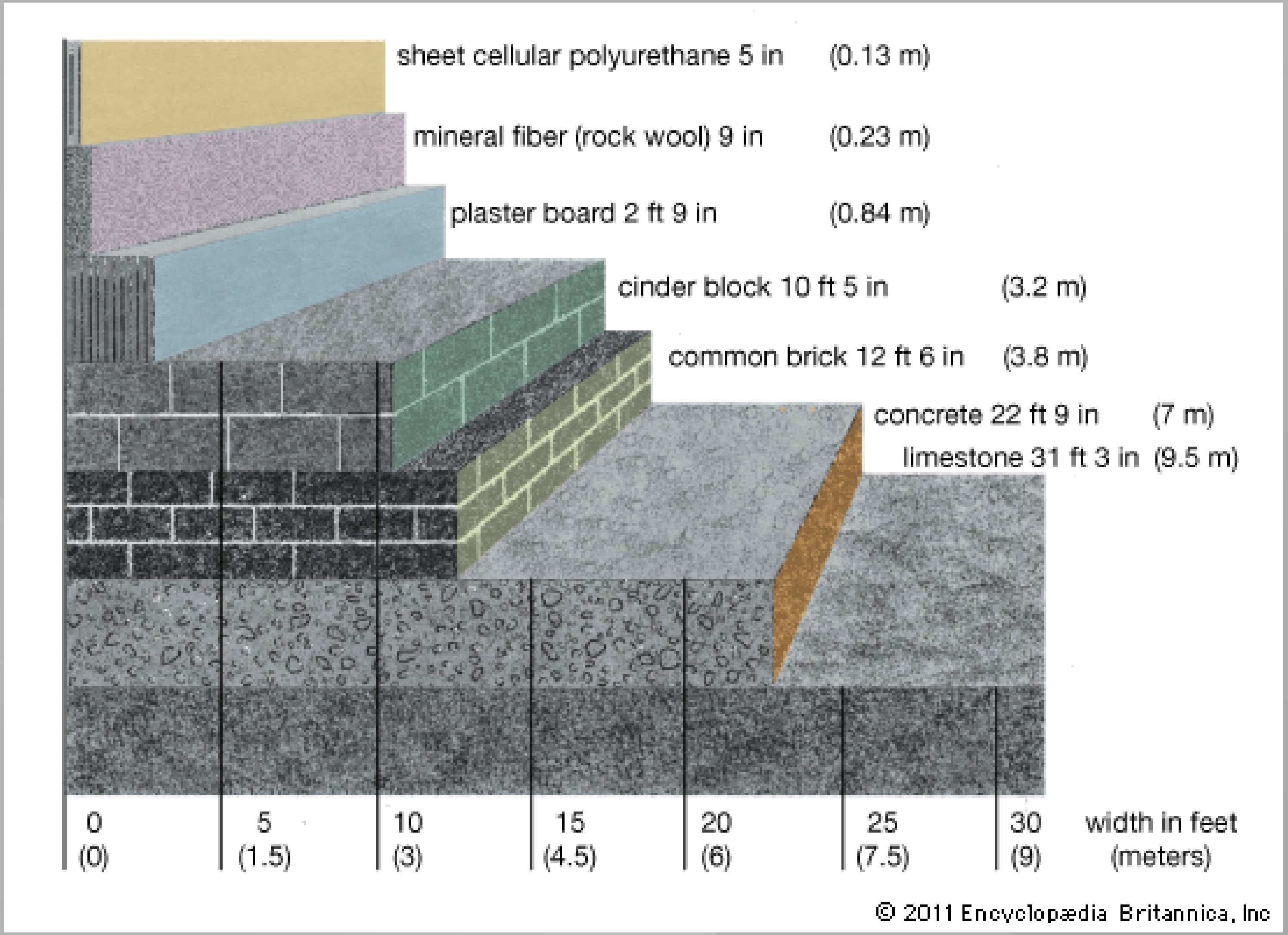
# Thermal conductivity - comparison



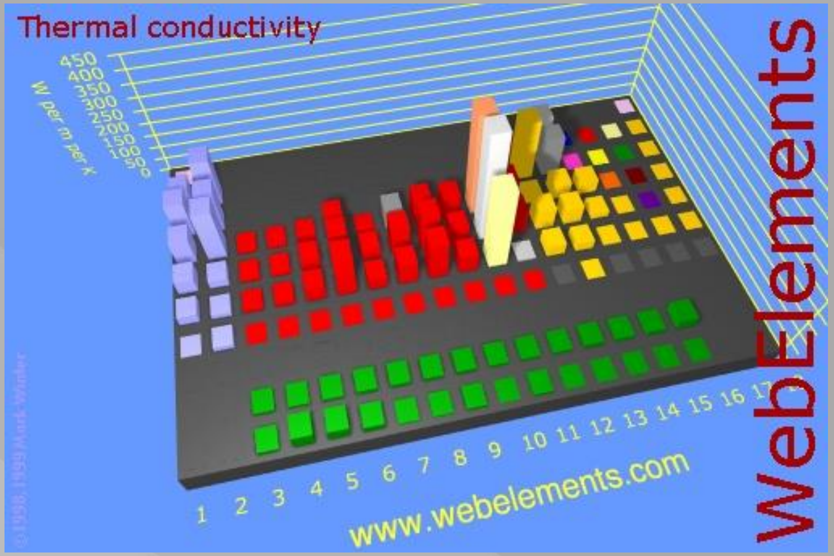
# Thermal conductivity
## Basic facts

- Organic materials are better insulators than inorganic m.
- Crystalline materials are better conductors than amorphous m.
- Materials with lower bulk density are usually better insulators.
- Metals are very good conductors.
- Anisotropic materials have different conductivity in different directions.

# Thermal conductivity

## Depends on:

- chemical composition
- structure
- porosity (bulk density)
- moisture
- temperature

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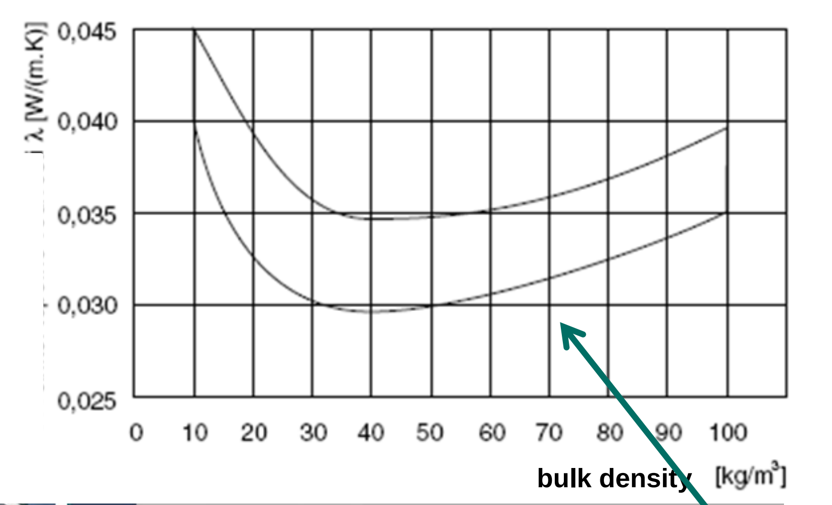
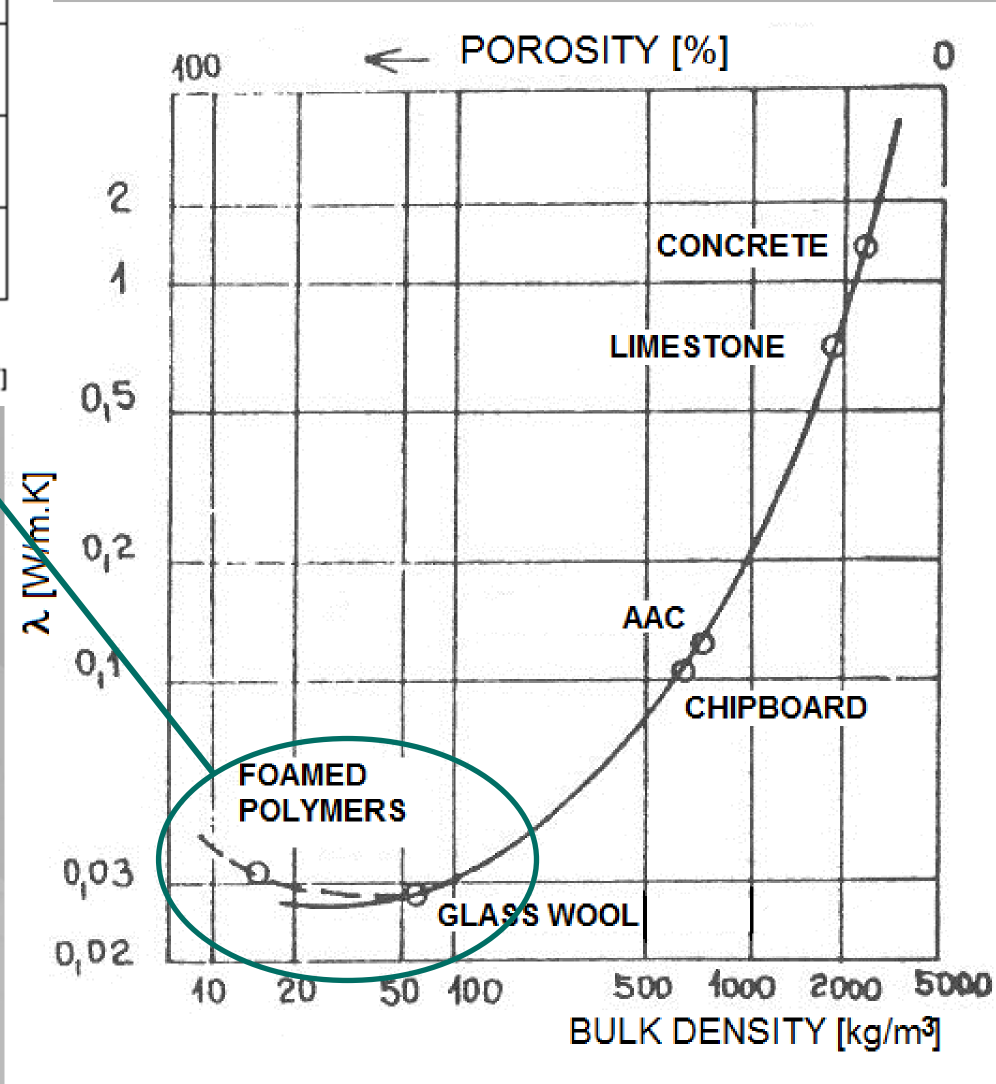
# Influence of porosity on thermal conductivity

- $\lambda_{AIR}$ = 0,025 W.m$^{-1}$.K$^{-1}$
- **the higher the amount of air in the material** (porosity), **the lower bulk density and thermal conductivity is**
- **size of pores is limited (best 0,1 – 1 mm)** (because of capillarity)

# Porosity x thermal conductivity




EPS





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# Influence of moisture on thermal conductivity

**$\lambda_{water}$ app. 25 x higher than $\lambda_{air}$**

- **moisture significantly reduces the thermal insulating ability of materials**
- **very small pores are liable to wetting (capillarity) – the best size of pores in insulating materials: 0,1 – 1 mm**

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# Moisture x thermal conductivity

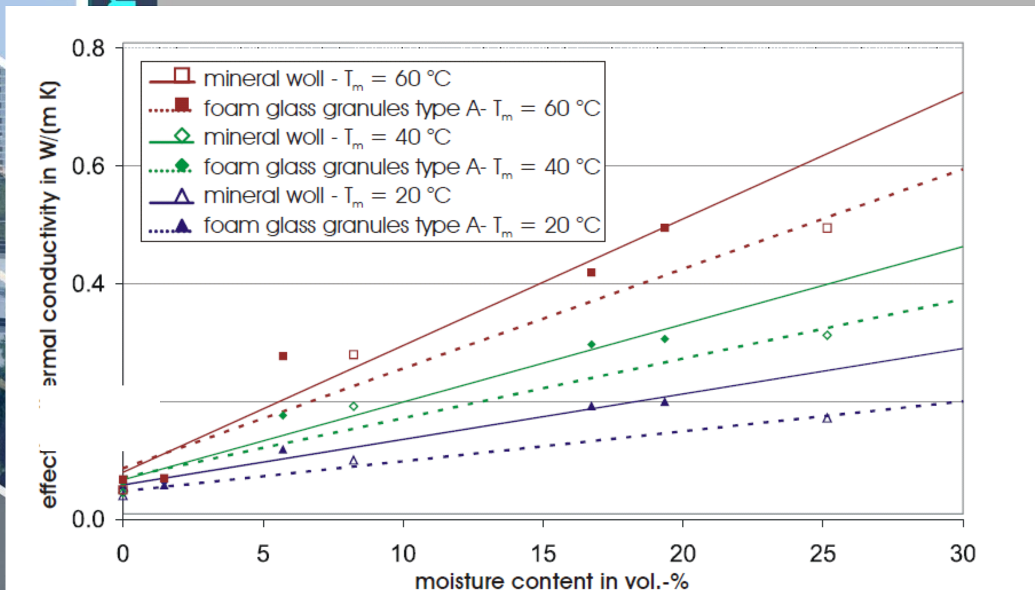
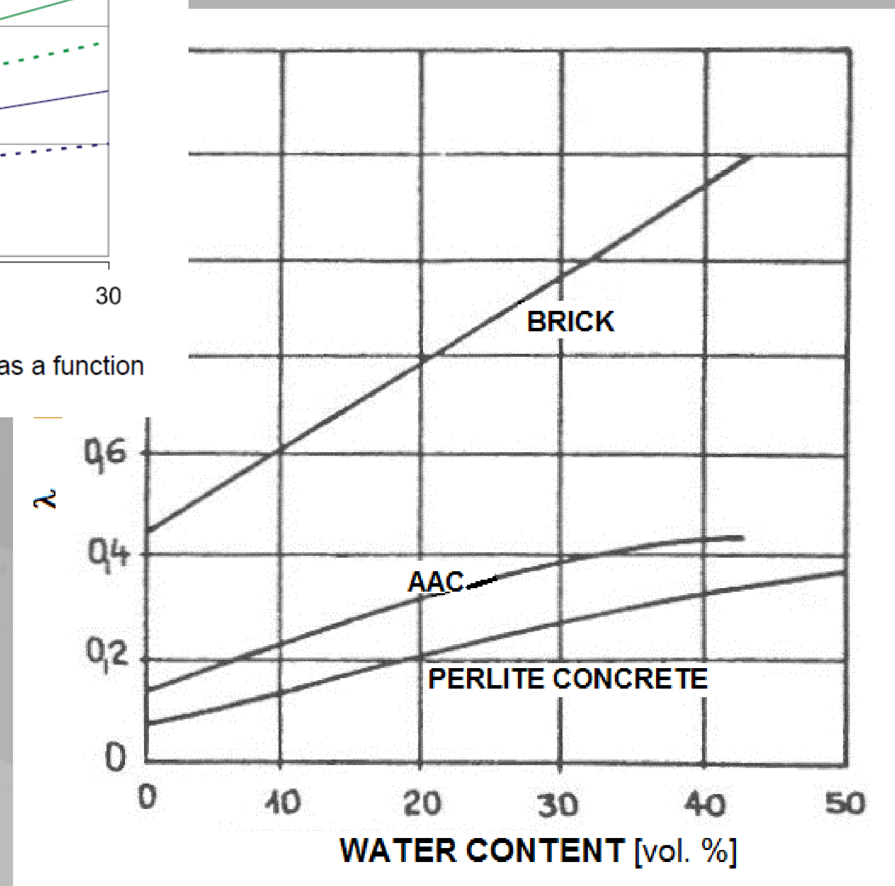



Figure 5: Thermal conductivity of mineral wool and foam glass granules as a function of the volume related moisture content and the temperature.

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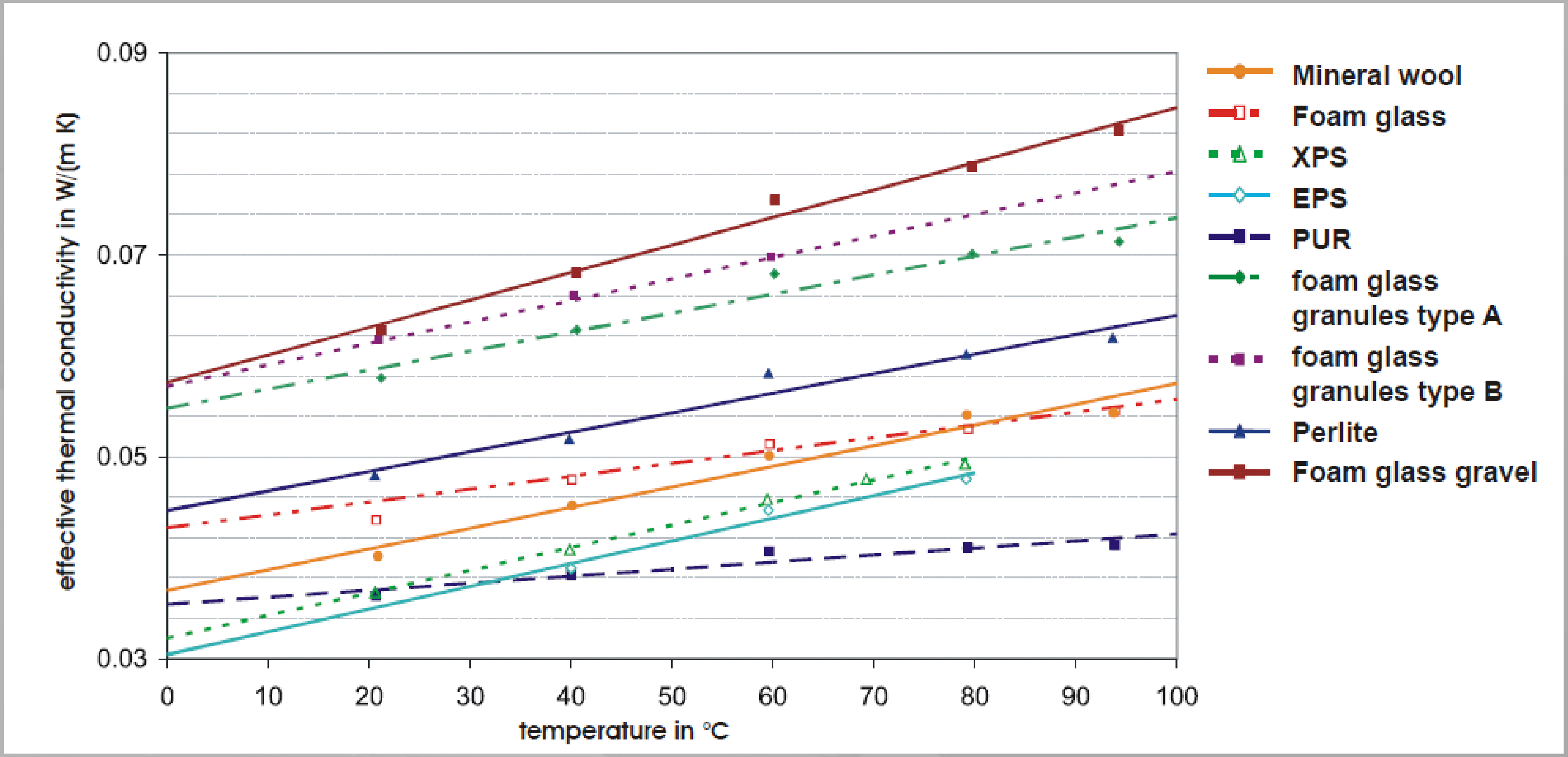
# Influence of temperature on thermal conductivity

- λ increases with rising temperature




$$\lambda_t = \lambda_0 + 0{,}0025t$$ (for t = 0 - 100°C)

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# Thermal insulating materials - overview

- **fibrous** **- mineral and glass fibers**

**- wood wool** (excelsior)

**- cellulose fibers**

**- recycled paper fibers**

**- straw** (bales, loose)

- **porous particles**

**- expanded clay aggregate**
**- expanded perlite**

**- ash**

**- cinders**

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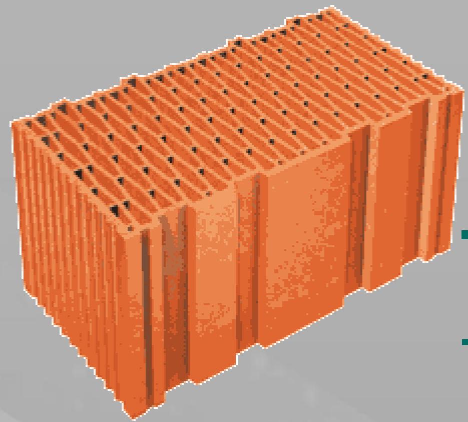
# Thermal insulating materials

- **shaped**
  - **lightweight concretes** (with lightweight aggregates, pervious c., aerated concretes)
  - **insulating brick blocks**
  - **diatomite**



- **foamed**
  - **foamed polymers (**PU,PS, phenolic foam)
  - **cellular glass**

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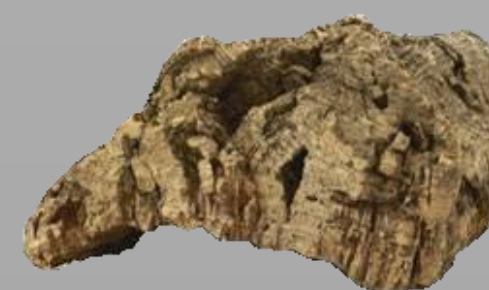
# Thermal insulating materials

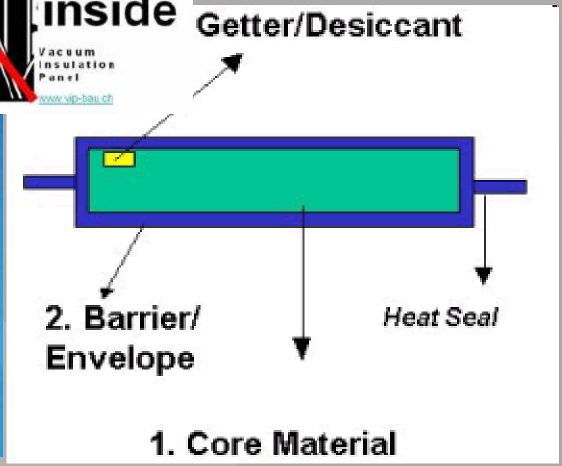
- **other**
  - **cork** (expanded)
  - **wood**
  - **wood-based materials** (fiber board, particle board)
  - **lamb wool**



# Best insulation?

- **vacuum**
- **„VIP“ = Vacuum Insulated Panel**
- a nearly gas-tight enclosure surrounding a rigid core, from which the air has been evacuated
- **λ = 0,004 – 0,008 W/m·K**



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# Thermal conductivity measuring

- **steady-state methods -** the temperature of the measured material does not change with time
- **transient** (non steady-state) **methods** - a measurement during the process of heating up

**Steady state** - a situation in which all variables are constant in spite of ongoing processes that strive to change them. For an entire system to be at steady state, i.e. for all state variables of a system to be constant, there must be a flow through the system

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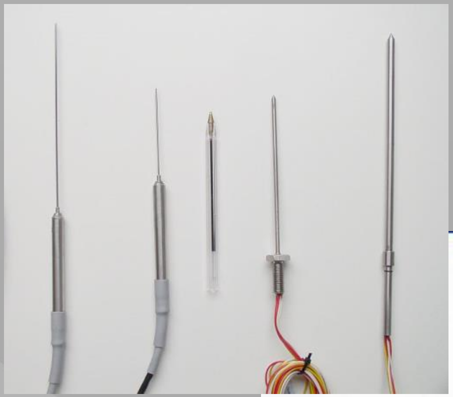
# Thermal conductivity measuring


## Steady-state methods:

- Guarded hot plate
- Divided bar
- Hot box

## Transient methods:

- Hot wire
- Plane source
- Needle probe
- Laser flash method



# Thermal conductivity measuring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# Thermal conductivity determination

- **Steady state method:**

$$\lambda = \frac{q \times d}{T_1 - T_2}$$

$$q = \frac{Q}{A}$$

**q**….. of heat passing through a unit area of the sample in unit time [W/m$^2$]

**d** …. average thickness of sample [m]

**$T_1$** .... temperature of warm side of the sample [K]

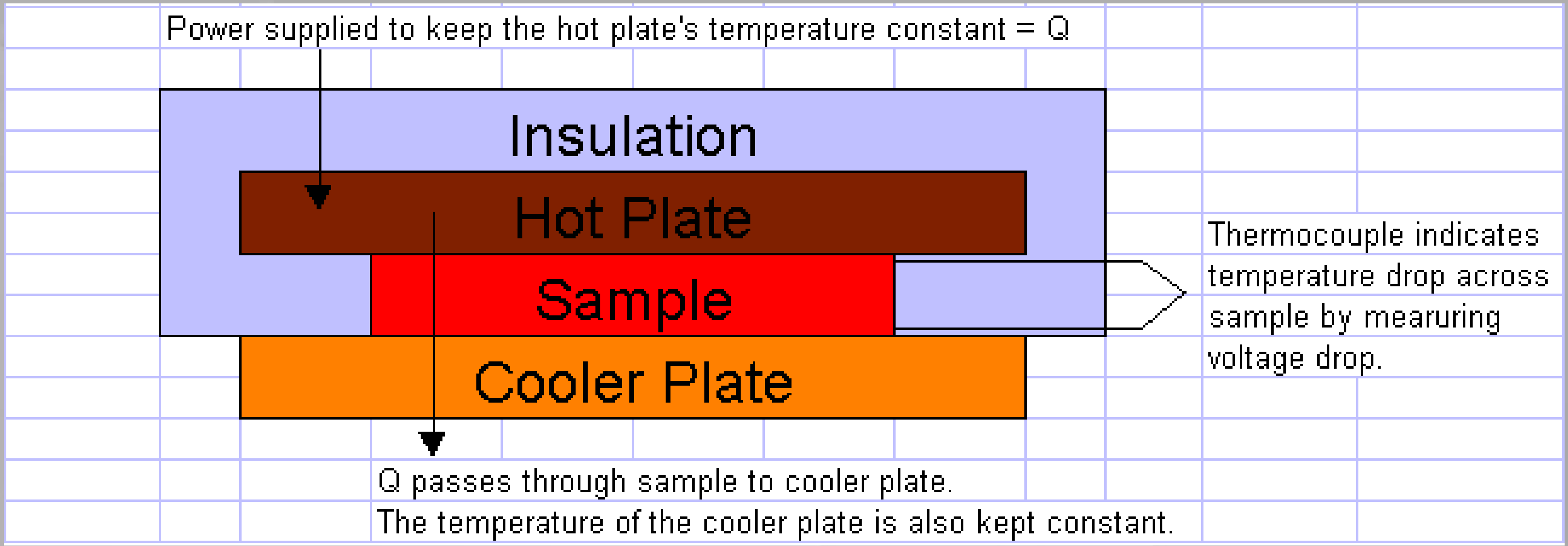
**$T_2$** … temperature of cold side of the sample [K]

**Q** .... quantity of heat passing through a base area of the sample [W]

**A** ..... base area of the sample [m$^2$]

# Guarded hot plate

- placing a solid sample of fixed dimension between two temperature-controlled plates
- one plate is heated while the other plate is cooled, and their temperatures are monitored until they are constant



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| Material | λ [$W.m^{-1}.K^{-1}$] |
|---|---|
| • Copper ………………………..... | ~370 |
| • Aluminium …………………….... | ~200 |
| • Carbon steel …………………. | ~50 |
| • Concrete ……………………..... | ~1,4 |
| • Glass …………………………. | ~0,75 |
| • Brick ……………………….. | ~0,7 |
| • Water (20° C, quiet)……….... | ~0,60 |
| • Wood ………………………....... | ~0,15 |
| • Mineral fibers …………………. | ~0,05 |
| • Polystyrene foamed …….. | ~0,035 |
| • Air (dry, quiet) ………………. | 0,025 |
| • Argon (quiet) ……………….... | ~0,015 |

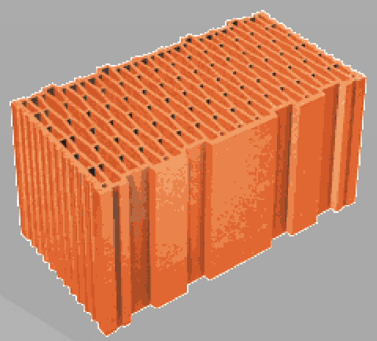
thermal insulations (Wood → Argon)

# Thermal resistance
# R-value

$$R = d / \lambda \; [(m^2 \cdot K) / W]$$

- directly proportional to the thickness of the material
- for construction, not material
- can be used for masonry blocks

$$R = 0{,}65 \; (m^2 \cdot K)/W$$



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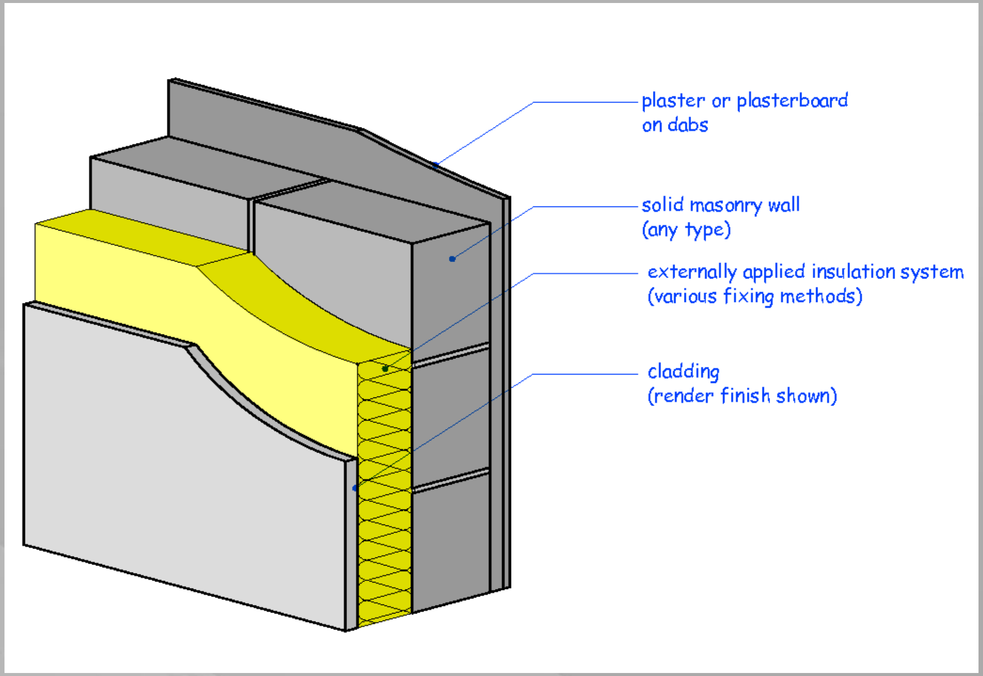
# Thermal resistance

- multi-layered construction : the R-values of the individual layers are summed



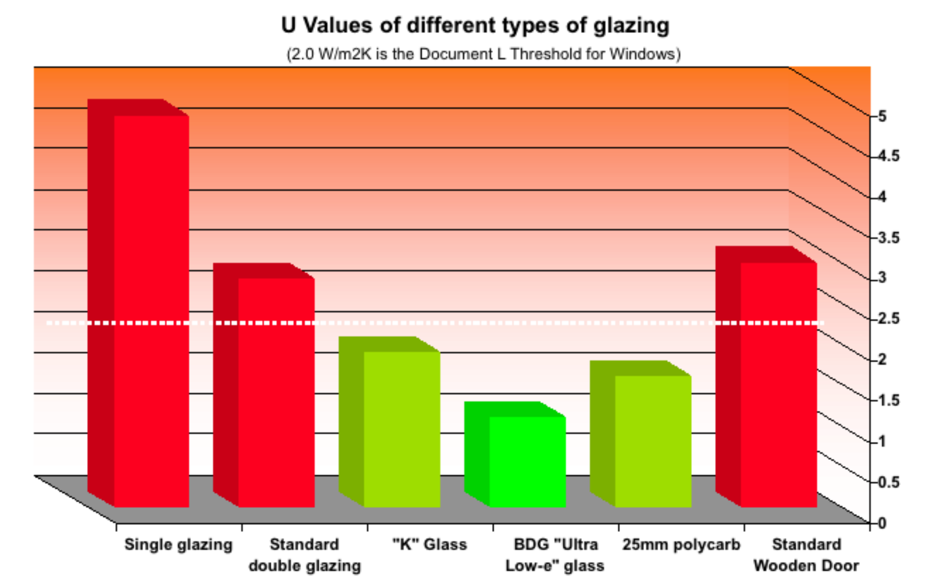

$$R_{total} = R_{outside\ air\ film} + R_{render} + R_{insulation} + R_{brick} + R_{plaster} + R_{inside\ air\ film}$$

# Thermal transmittance U-value

- the measure of the rate of heat loss through a material
- incorporates the thermal conductance of a structure along with heat transfer due to convection and radiation

**U-value = 1/R**

[ W / m$^2$·K ]

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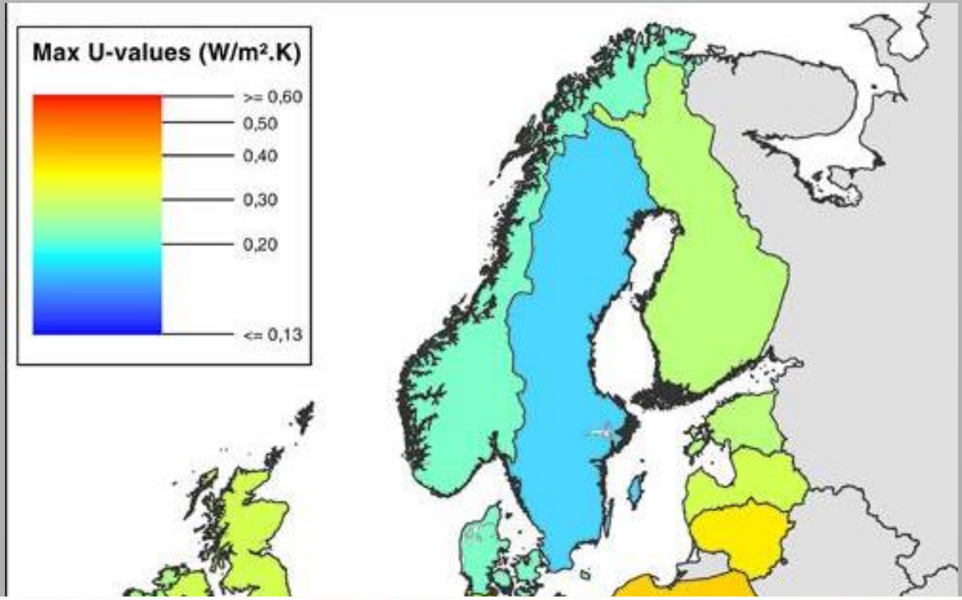
# U-value in Europe




| Rank | Country | Walls | Country | Roof | Country | Floor | Country | Windows |
|---|---|---|---|---|---|---|---|---|
| 1 | Sweden | 0.3 | Sweden | 0.2 | Sweden | 0.2 | Finland | 1.9 |
| 2 | Finland | 0.4 | Denmark | 0.3 | Denmark | 0.4 | Austria | 2.3 |
| 3 | Denmark | 0.5 | Finland | 0.3 | Finland | 0.4 | Denmark | 2.4 |
| 4 | Czech Republic | 0.8 | Czech Republic | 0.6 | Germany | 0.8 | Sweden | 2.5 |
| 5 | Austria | 0.9 | Austria | 0.6 | Czech Republic | 0.9 | Germany | 2.7 |
| 6 | Germany | 0.9 | Ireland | 0.7 | Belgium | 0.9 | Czech Republic | 2.7 |
| 7 | **UK** | 1.0 | Germany | 0.7 | France | 1.0 | France | 3.1 |
| 8 | Netherlands | 1.1 | **UK** | 1.1 | Ireland | 1.0 | Netherlands | 3.2 |
| 9 | France | 1.2 | Netherlands | 1.2 | Austria | 1.0 | Belgium | 3.8 |
| 10 | Ireland | 1.2 | France | 1.3 | **UK** | 1.2 | Ireland | 3.8 |
| 11 | Belgium | 1.5 | Belgium | 1.6 | Netherlands | 1.3 | **UK** | 3.9 |

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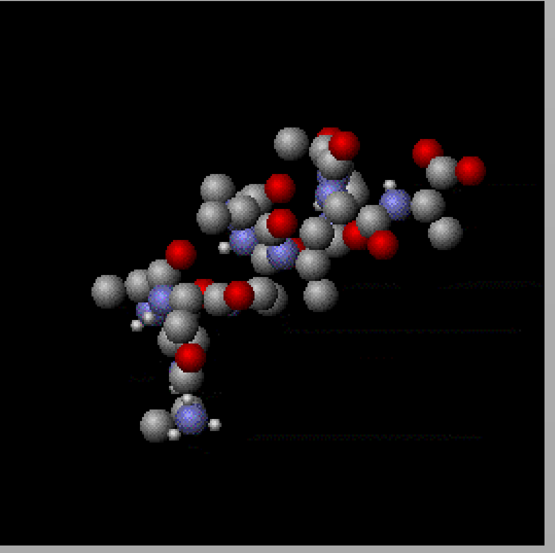
# Specific heat capacity c

**= specific heat**

- the amount of heat required to change 1 kg of substance's temperature by a 1 K
- units: **[$J.kg^{-1}.K^{-1}$]**



**Depends on:**

- **temperature**
- **moisture: $c = c_0 + 0{,}42\, w_m$**

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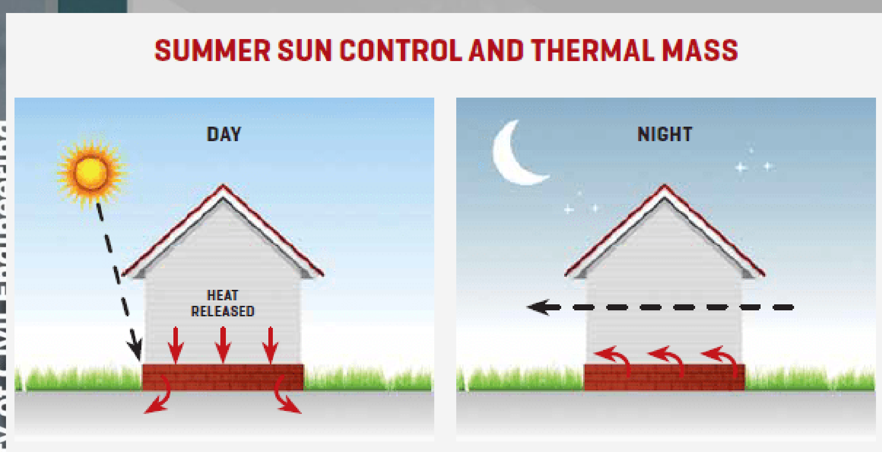
# Specific heat of some materials

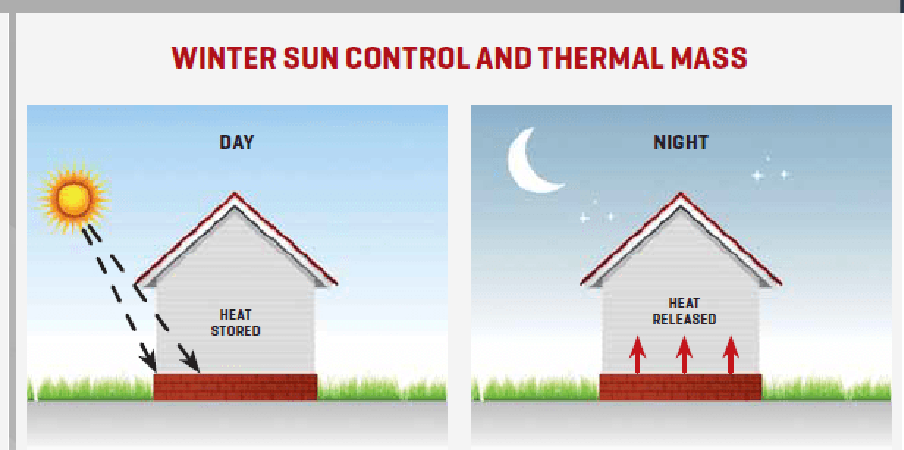
| Material | C [ kJ.kg$^{-1}$.K$^{-1}$] |
|---|---|
| asphalt | 0,92 |
| concrete | 0,88 |
| brick | 0,84 |
| glass | 0,84 |
| copper | 0,39 |
| granite | 0,79 |
| gypsum | 1,09 |
| water | 4,18 |
| wood ∥ to fibers | 0,42 |

# Heat accumulation

## Thermal mass of building

- absorbs thermal energy when the surroundings has higher temperature than the material and give thermal energy back when the surroundings are cooler



# Interior thermal control

## Phase - change materials (PCM)

- materials with very high latent heat storage capacities
- best melting point for building purposes about 25 °C
- heat is absorbed or released when the material changes from solid to liquid and vice versa

- **Materials**:
  - paraffin
  - fatty acids
  - salt hydrates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# Thermal effusivity

- determines the interfacial temperature when two semi-infinite objects at different temperatures touch

$$\mathbf{b} = \sqrt{\lambda . \mathbf{c} . \rho_v}$$

- units: **[ $W.s^{0,5}.m^{-2}.K^{-1}$ ]**
- the higher **b** is, the colder sensation gives the material

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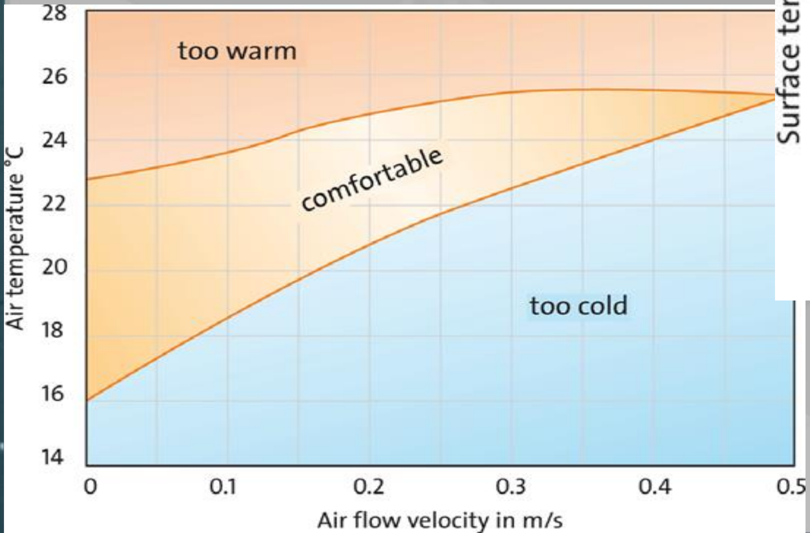
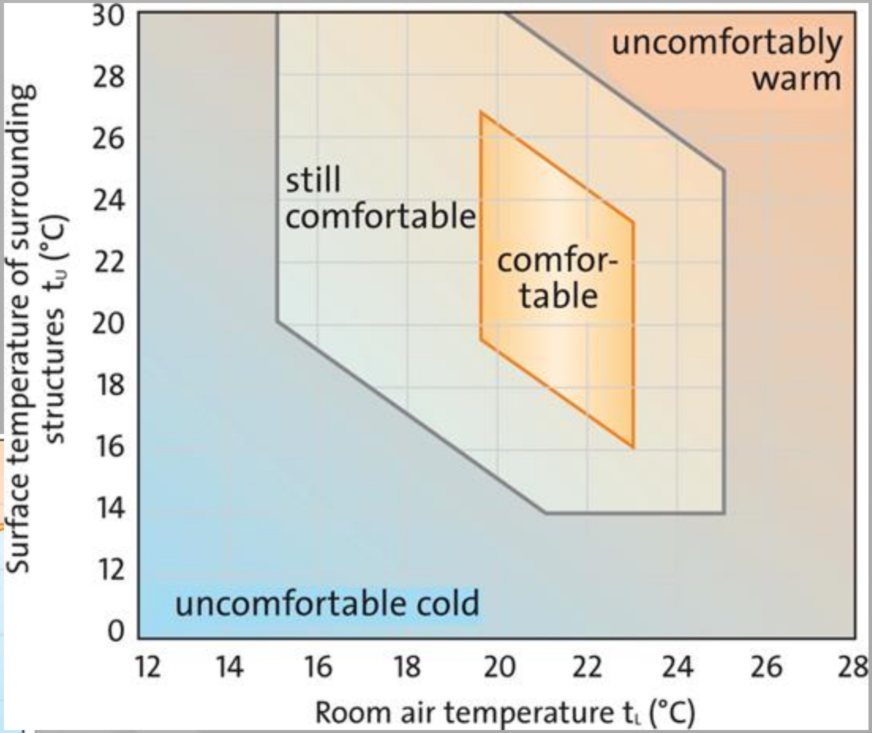
# Thermal comfort

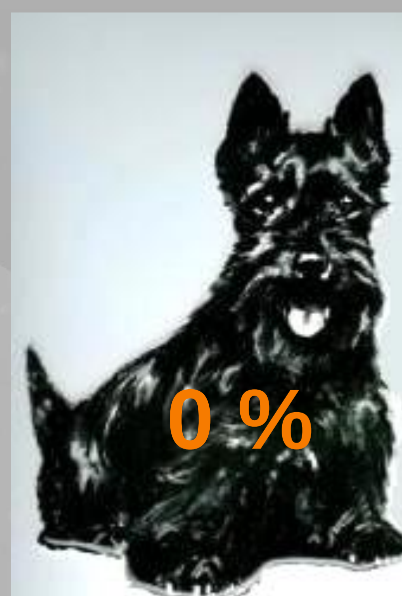
- **the condition of mind which expresses satisfaction with the thermal environment**
- affected by
  - – air temperature
  - – temp. of surrounding surfaces
  - – air flow velocity



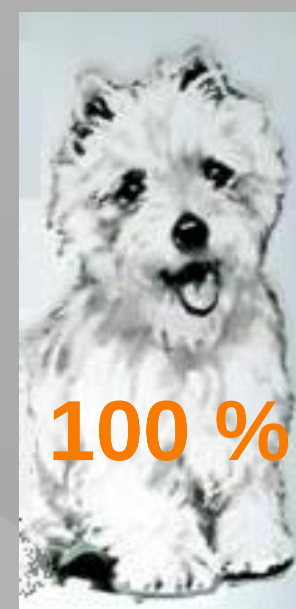



# Reflectivity

- the ability of a surface to reflect radiation
- light reflectivity - the percentage light reflected from a surface at a given wavelength.







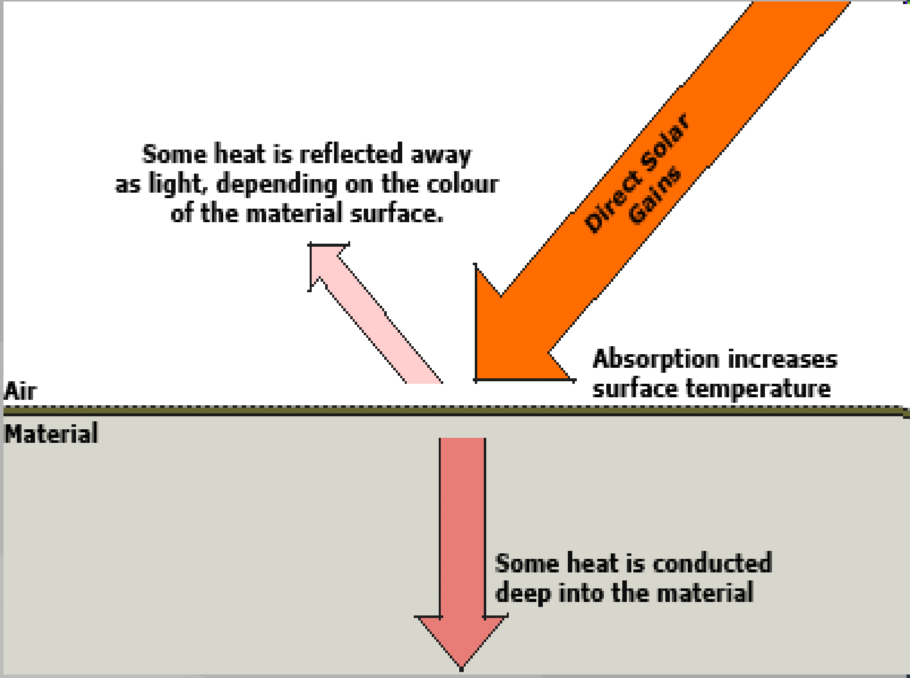
# Heat reflection and absorption

- **reflection** $\rho$
- **absorption** $\alpha$

$$\alpha + \rho = 1$$

## Heat reflectance:

$$\mathbf{R} = \frac{\alpha}{\textbf{incident heat}}$$




- black body **R =1**
- white **R = 0,5**

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# Solar absorptivity

Solar Absorptivity Chart for Selected Colours

| Code | Colour | Absorptivity |
|---|---|---|
| 6068 | Black | 0.94 |
| 6062 | Dark Brown | 0.91 |
| 6154 | Metro Brown | 0.89 |
| 6073 | Dark Green | 0.89 |
| 6072 | Charcoal | 0.89 |
| 6084 | Navy Blue | 0.87 |
| 6079 | Heron Blue | 0.85 |
| 6078 | Green | 0.84 |
| 6067 | Slate Blue | 0.8 |
| 6082 | Regent Grey | 0.75 |
| 6071 | Stone Grey | 0.6 |

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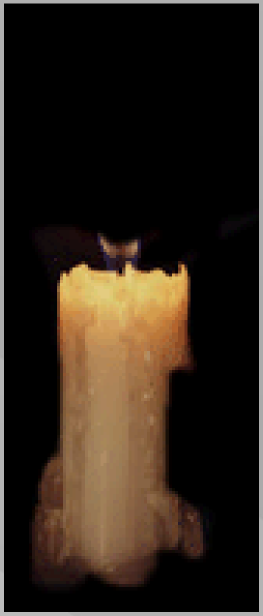
# Change of the materials by temperature





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# Thermal expansion

- **linear**

$$\Delta L = \alpha . L_0 . \Delta T$$

$\Delta$**L** ... dimension change (elongation) [m]

$\alpha$ .... **coefficient of thermal expansion [K$^{-1}$]**

**$L_0$** .... linear dimension (length) [m]

$\Delta$**T**.... temperature change [K]

# Thermal expansion

- **volumetric t. e.** $\gamma \cong 3\alpha$

**Values of $\alpha$ :**

common materials... $\alpha$ **= 6 – 16.10$^{-6}$ K$^{-1}$**

plastics .................. $\alpha$ **= 80 - 200.10$^{-6}$ K$^{-1}$**

$\alpha$ **concrete =** $\alpha$ **steel = 10 –12.10$^{-6}$ K$^{-1}$**

**Steel, concrete - 1m, temperature change 50 K:**

**$\Delta$L = (10.10$^{-6}$).1000.50 = 5. 10$^{-1}$ = 0,5 mm/1 m**

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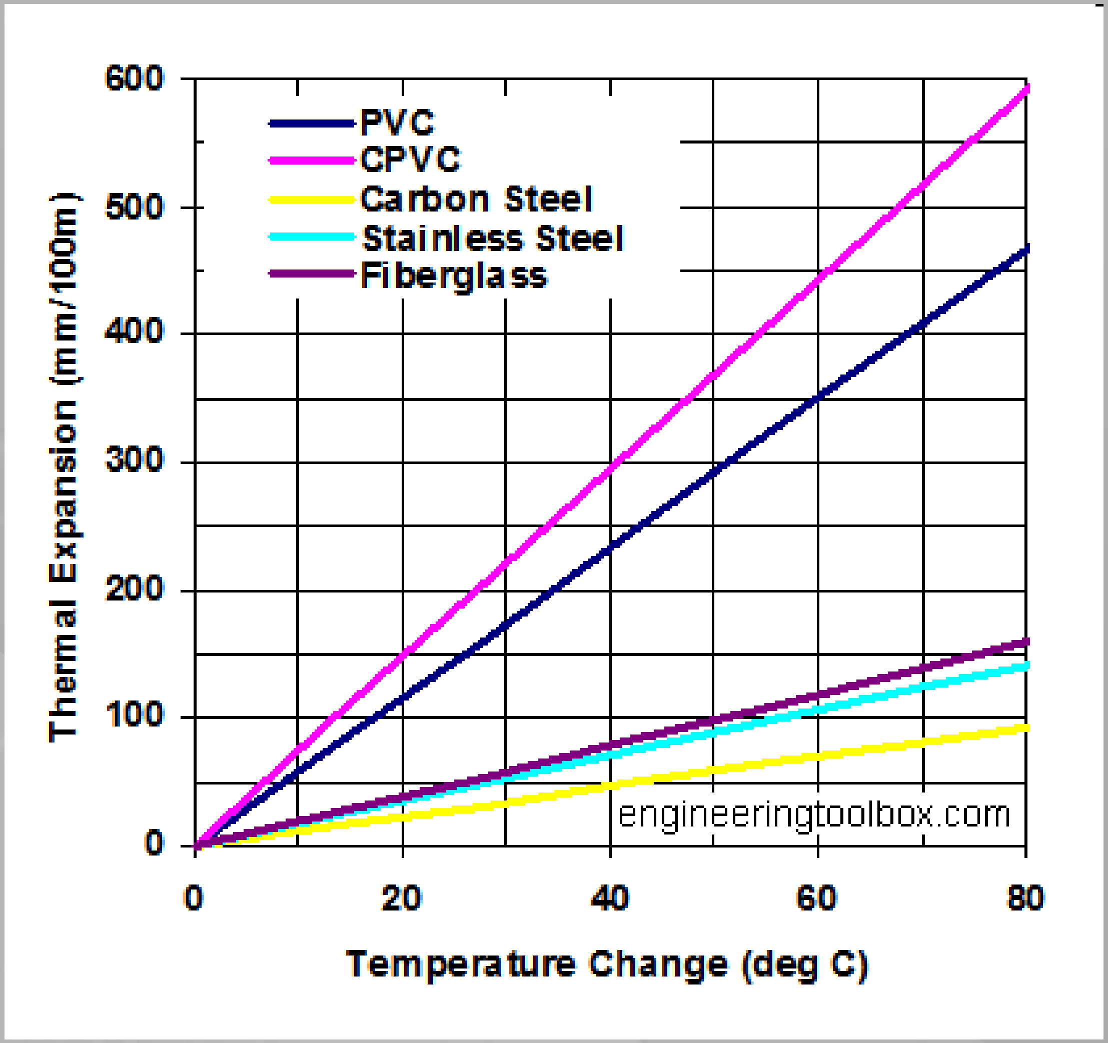
# Thermal expansion of different materials

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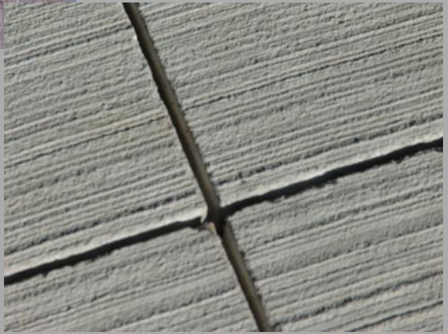
# Thermal expansion in buildings

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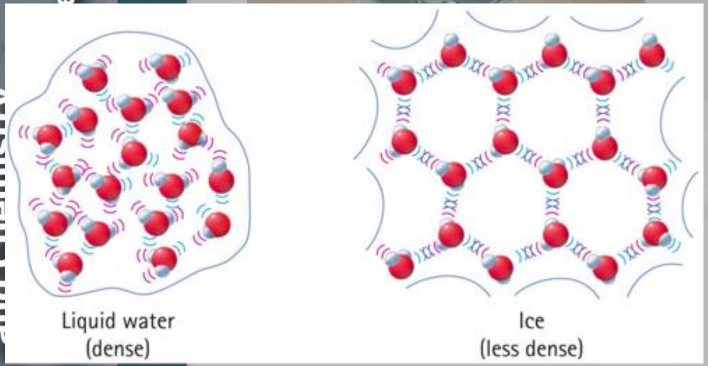
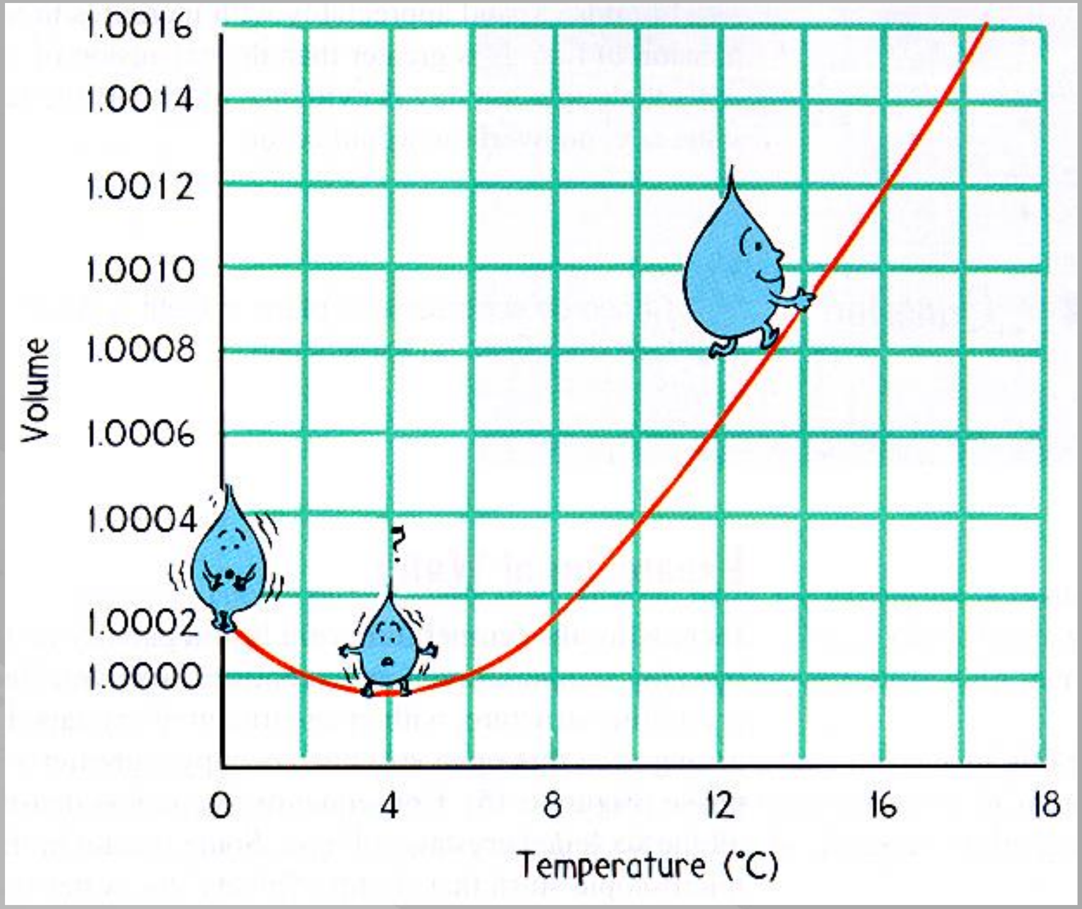
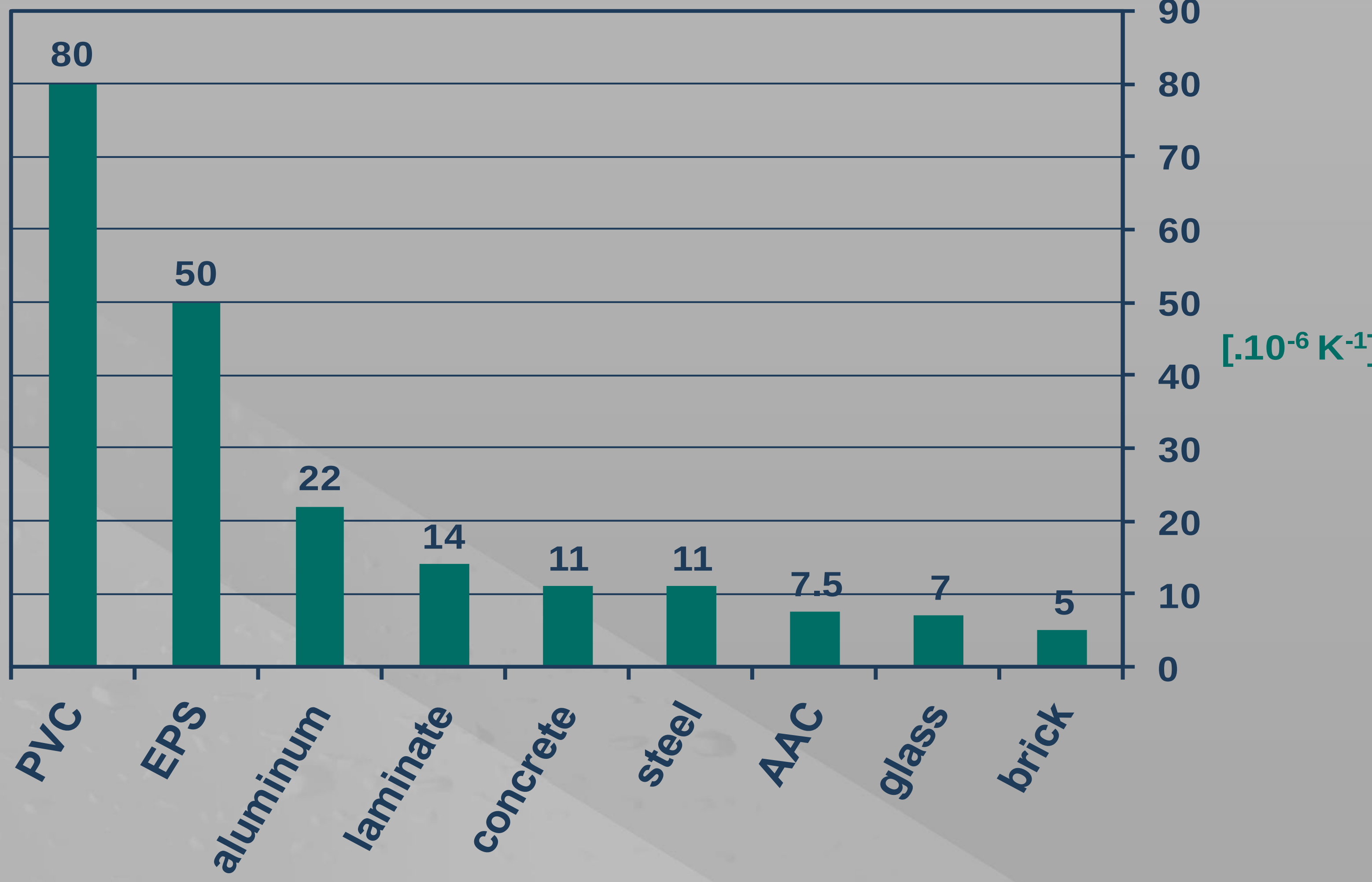
# Density anomaly of water

- from 0°C to 3,99°C the volume of the water decreases



# Coefficient of thermal expansion

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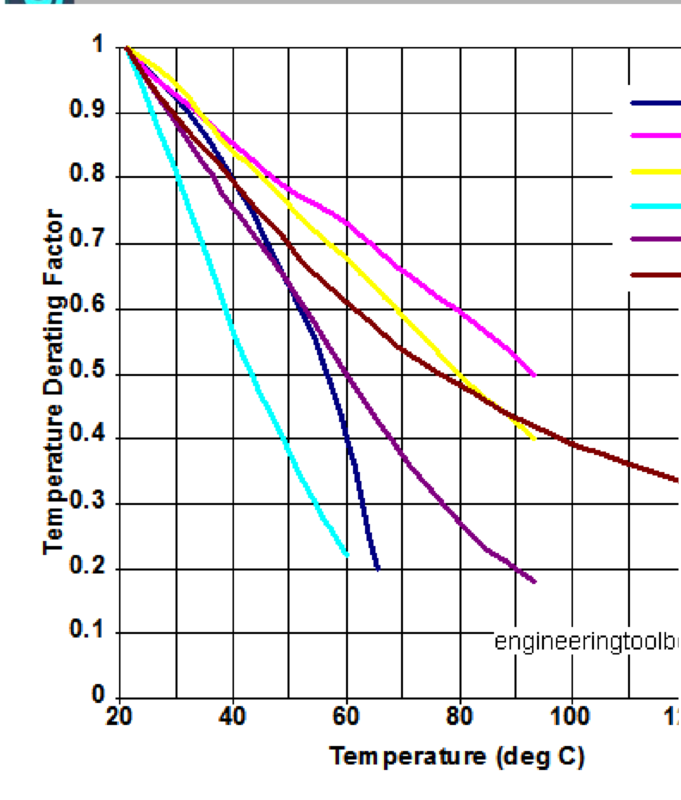
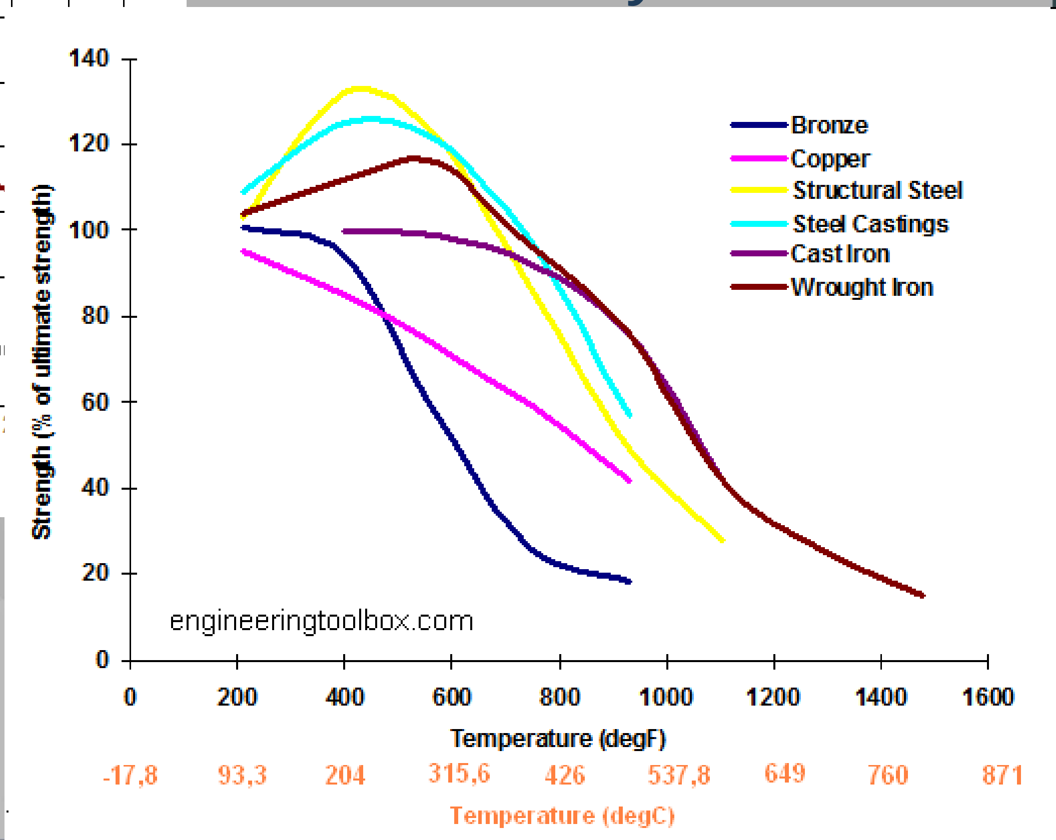
# Influence of heat on the mechanical properties

- the change of strength, modulus of elasticity

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# Fire resistance

- reaction of the materials and constructions to the fire



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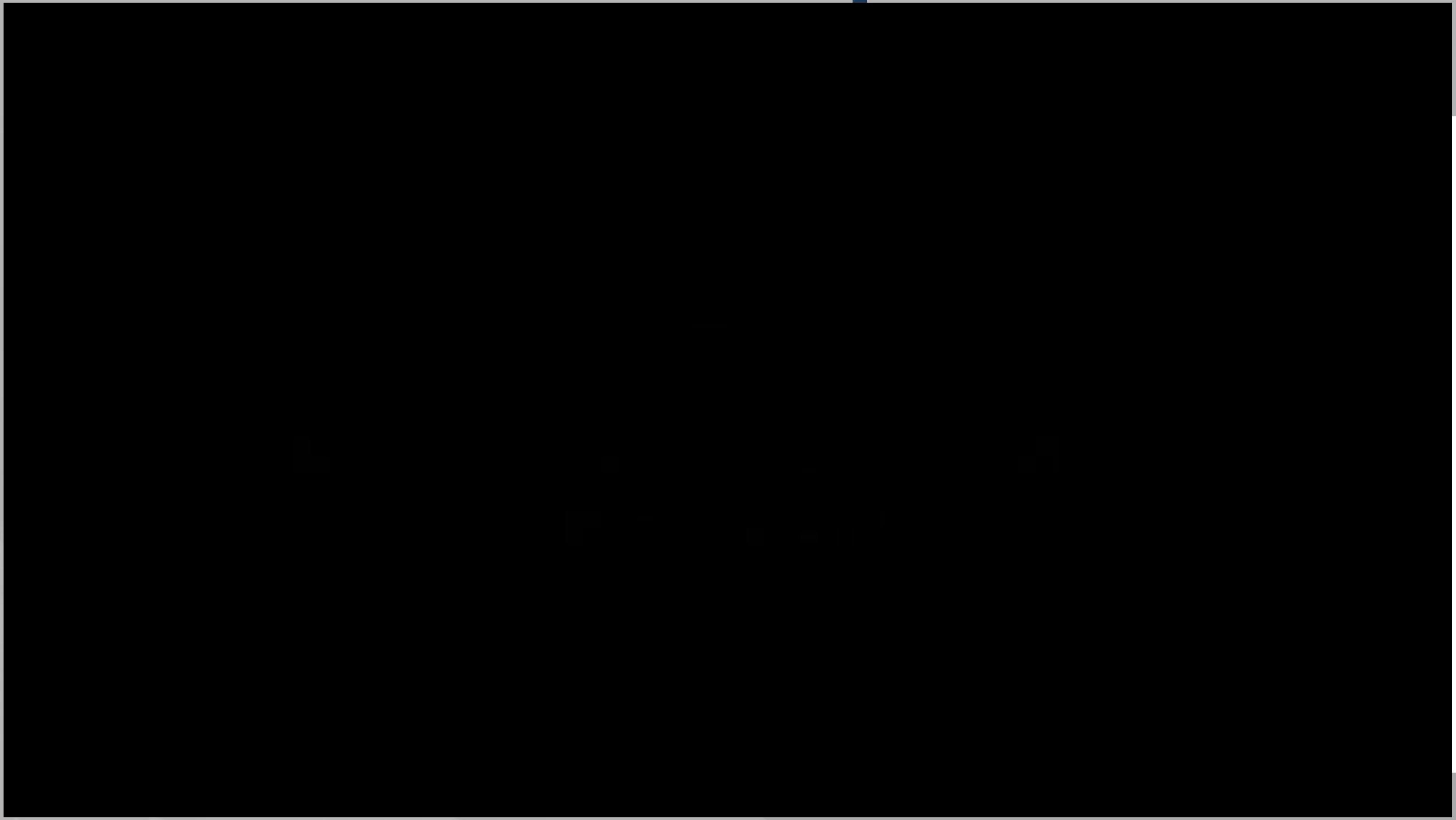
# Dangerous effects of fire

- **big heat**
- **deformation of materials** (loss of strength)
- **falling of burning droplets**
- **smoke**
- **toxic fumes**

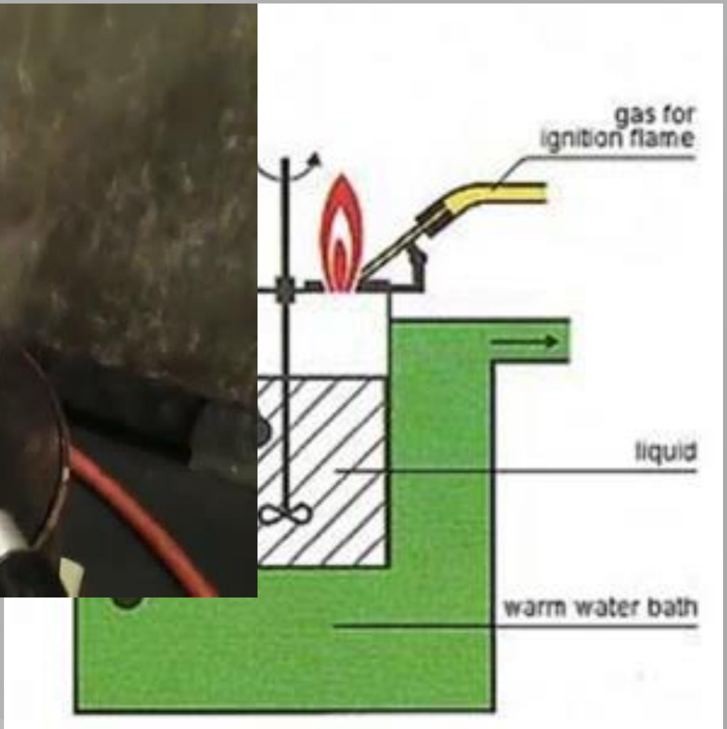
# Fire development



**Flashover** - a dramatic increase in the rate of heat release and smoke production (typically occurs when the combustion gases reach a temperature of around 600°C)

# Flash point

- the lowest temperature at which the vapor formed above a pool of a combustible liquid can be ignited in air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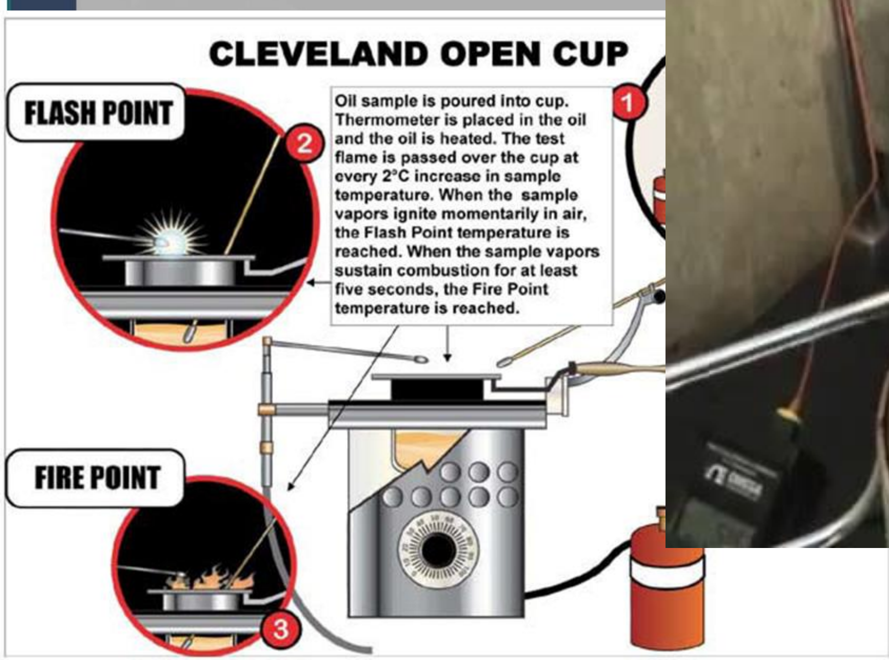
# Fire point

- the lowest temperature at which, on further heating beyond the flash point, the sample will support combustion for 5 seconds
- used for fuels




# Flammable and combustible liquids

- susceptibility to ignition

| Hazard classification for flammable liquids | | | |
|---|---|---|---|
| **Class** | **Flash point** | **Boiling point** | **Examples** |
| **I-A** | below 73°F (23°C) | below 100°F (38°C) | diethyl ether, pentane, ligroin, petroleum ether |
| **I-B** | below 73°F (23°C) | at or above 100°F (38°C) | acetone, benzene, cyclohexane, ethanol |
| **I-C** | 73-100°F (24-38°C) | ---- | p-xylene |
| **Hazard classification for combustible liquids** | | | |
| **II** | 101-140°F (39-60°C) | ---- | diesel fuel, motor oil, kerosene, cleaning solvents |
| **III-A** | 141-199°F (61-93°C) | ---- | paints (oil base), linseed oil, mineral oil |
| **III-B** | 200°F (93°C) or above | ---- | paints (oil base), neatsfoot oil |

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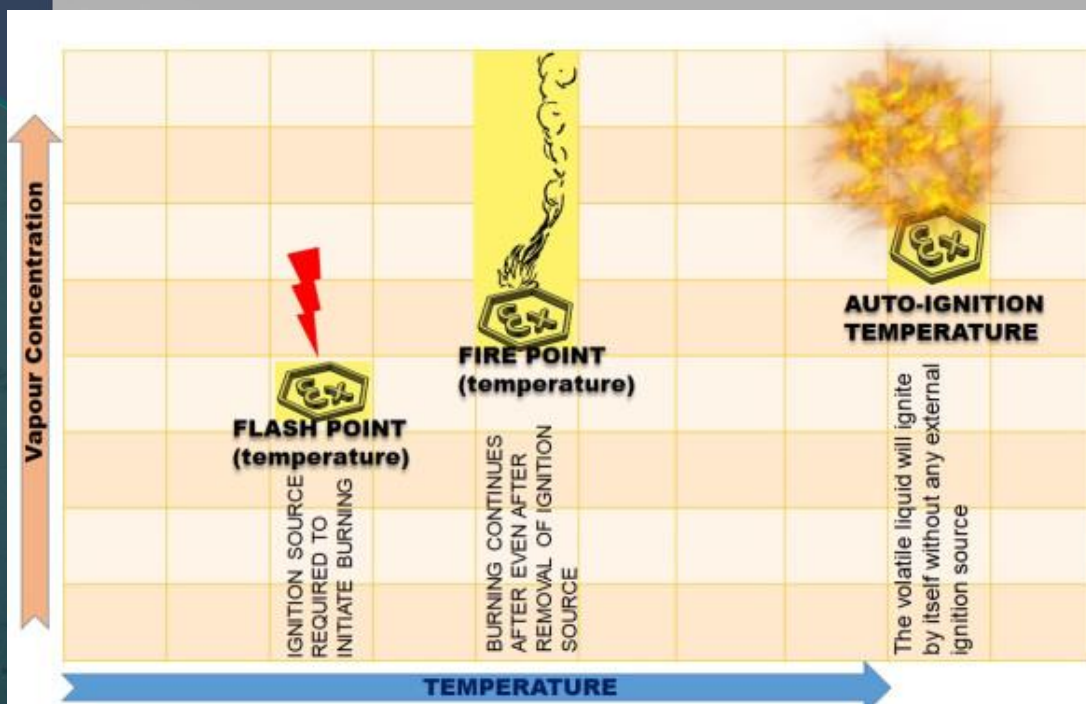
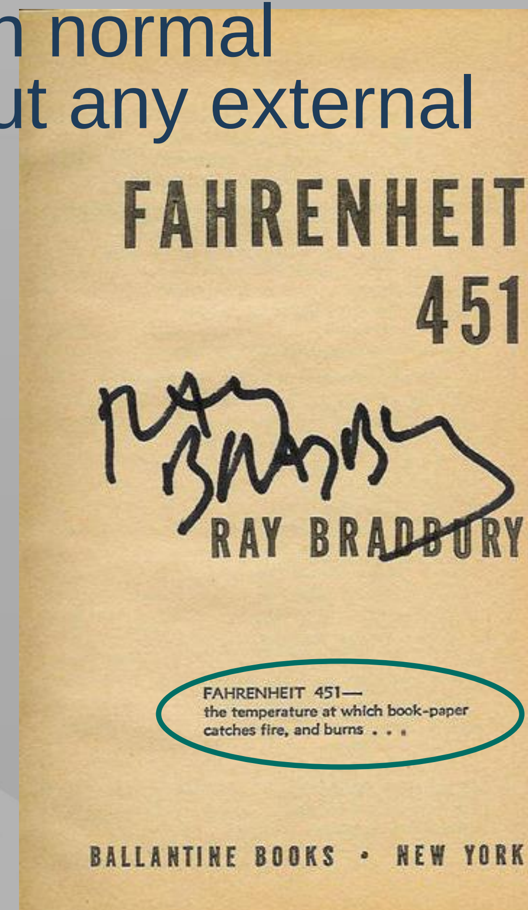
# Autoignition temperature (kindling point)

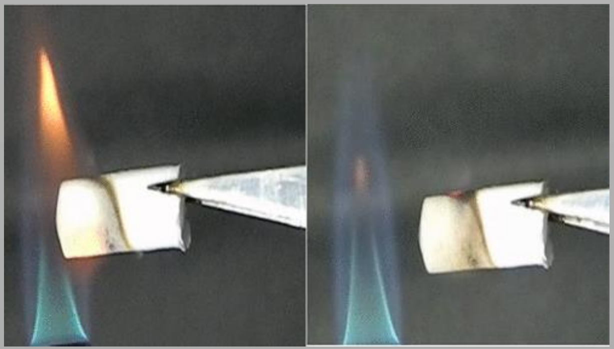
- the lowest temperature where a substance will auto-ignite and combust in normal atmospheric conditions without any external influences.

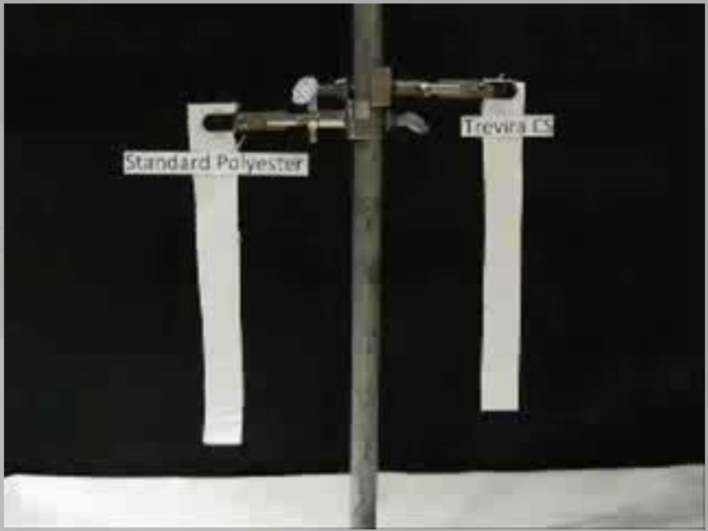


# Self- extinguishing materials

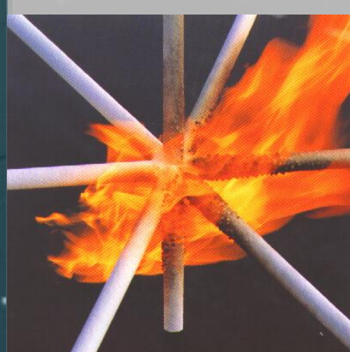
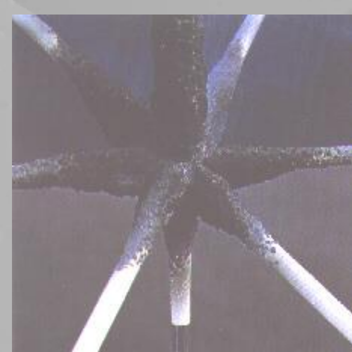
- the inability to support flame after the source of the flame is withdrawn
- some polymers (EPS, ..)





# Flame retardants

- **chemicals used in thermoplastics, thermosets, textiles and coatings that inhibit or resist the spread of fire**
  - a protective non-flammable layer around a combustible material
  - a chemical reaction releasing water vapors
  - layer of carbon char
  - intumescent layers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# Flammability (combustibility)

- how easily material will burn or ignite, causing fire or combustion
- older national standards

**Degree of combustibility** **(DIN 4102, BS 476):**

**A1** - 100 % noncombustible (concrete, brick)

**A2** - 98 % noncombustible (gypsum plaster)

**B1** - difficult to ignite (often self-extinguishing)

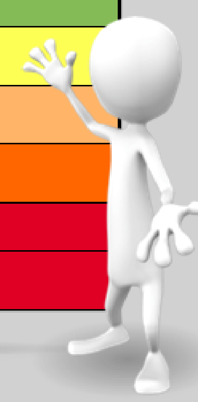
**B2** - normal combustibility (wood)

**B3** - easy to ignite (PU foam)

# Reaction to fire

- **EN 13501 –1** Fire classification of construction products and building elements
- determines whether a material fuels a fire
- 7 classes : **A1, A2, B, C, D, E, F**

| Euroclass | Contribution to fire |
|---|---|
| A1 | Non Combustible |
| A2 | Limited Combustible No Flashover |
| B | No Flashover |
| C | Flashover after 10 minutes |
| D | Flashover before 10 minutes |
| E | Flashover before 2 minutes |
| F | No Performance Determined |



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# Reaction to fire

| Class | Reaction to Fire | Flashover in the Room Corner reference test | Additional criteria tested for |
|---|---|---|---|
| **A1** | No contribution to a fire | No | None (*insignificant smoke release with no flaming droplets or particles expected*) |
| **A2** | No significant contribution to fire growth | No | Production of smoke & flaming droplets or particles |
| **B** | Very limited contribution to fire growth | No | Production of smoke & flaming droplets or particles |
| **C** | Limited contribution to flashover | Flashover after 10 min | Production of smoke & flaming droplets or particles |
| **D** | Contribution to flashover | Flashover between 2 to 10 min | Production of smoke & flaming droplets or particles |
| **E** | Significant contribution to flashover | Flashover before 2 min | Production of flaming droplets or particles (*Smoke release is expected to be substantial*) |
| **F** | Not tested or incapable of achieving Class E | No performance determined | |

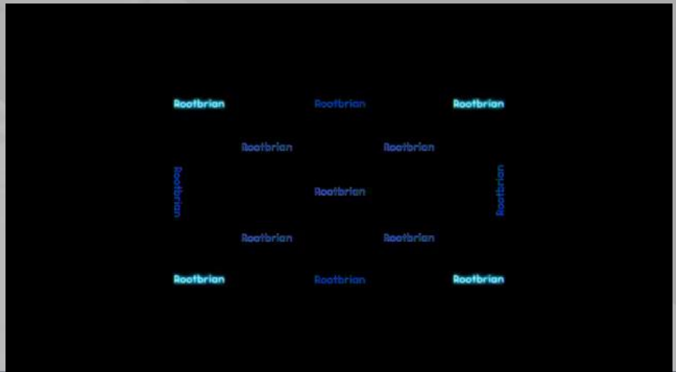
# Reaction to fire – additional classification

## Smoke:

- **s1** very limited amount of smoke developed
- **s2** limited amount of smoke developed
- **s3** no demands to the amount of smoke developed

## Burning droplets:

- **d0** no burning droplets or particles
- **d1** limited amount of burning droplets or particles
- **d2** no demand to the amount of burning droplets or particles



# Reaction to fire

## What does a classification look like?

The main part of a classification is its letter; A1, A2, B, C, D, E and F. A1 represents the highest level of performance. F represents the lowest level of "No performance determined".

There is a smoke classification, of s1, s2 and s3. s1 represents the highest level of performance. s3 represents the lowest level of performance.

$B_L$-s3,d0

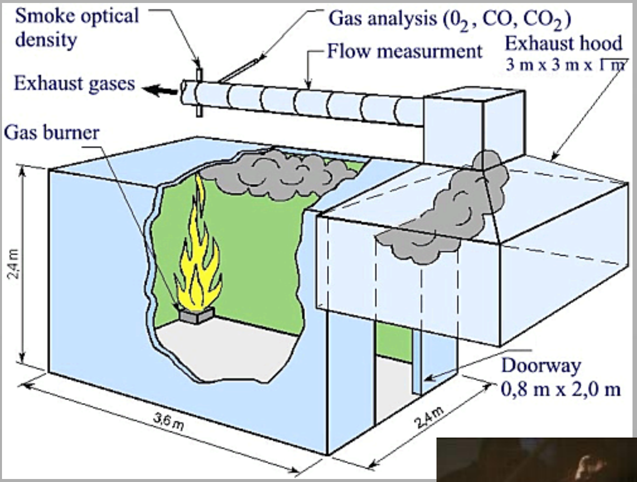
There may or may not be a subscript next to the letter. A subscript "fl" means the product has been classified for use as a flooring. A subscript "L" means the product has been classified for use as a linear pipe thermal insulation product. The absence of a subscript means the product is for use on walls or ceilings.

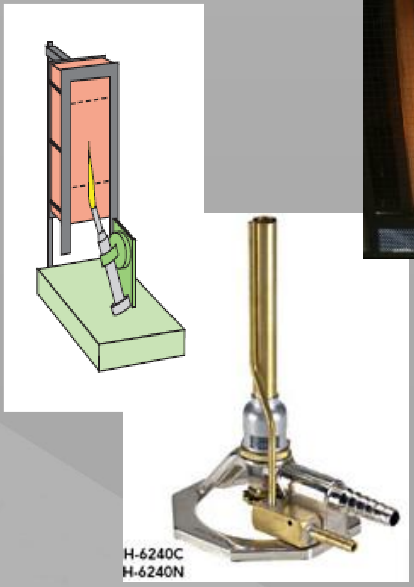
There is a classification for flaming droplets and particles during the tests, of d0 to d2. d0 represents the highest level of performance. d2 represents the lowest level of performance.

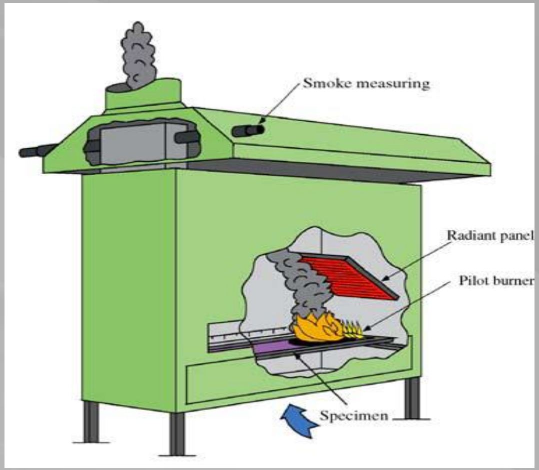
| | |
|---|---|
| Bioguard Plain | A2-s1, d0 |
| Bioguard Acoustic | A2-s1, d0 |

# Reaction to fire - tests

- **SBI test** – single burning item
- **small flame test**
  - flame spread within 20 - 60 s
- **RP test** – radiant panel
  - floorings



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# Class A1 without testing:

- Expanded clay
- Expanded perlite
- Expanded vermiculite
- Mineral wool
- Cellular glass
- Concrete
- Aggregate concrete (dense and lightweight mineral aggregates, excluding integral thermal insulation)
- Autoclaved aerated concrete units
- Fibre cement
- Cement
- Lime
- Blast furnace slag/pulverized fly ash (PFA)

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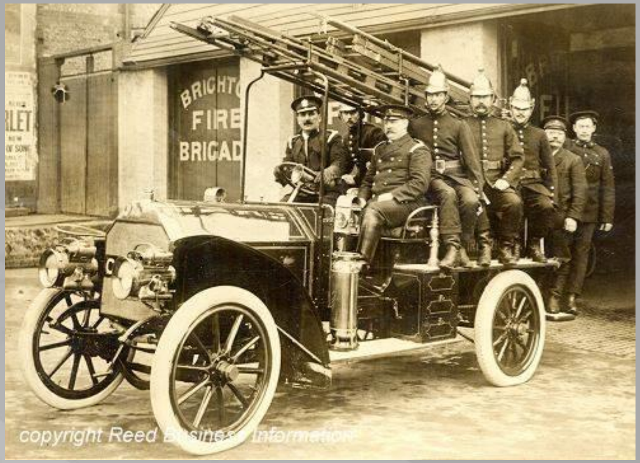
# Reaction to fire

| Class | Performance description | Fire scenario and heat attack | | Examples of products |
|---|---|---|---|---|
| **A1** | No contribution to fire | Fully developed fire in a room | At least 60 kW/m$^2$ | Products of natural stone, concrete, bricks, ceramic, glass, steel and many metallic products |
| **A2** | " | " | " | Products similar to those of class A1, including small amounts of organic compounds |
| **B** | Very limited contribution to fire | Single burning item in a room | 40 kW/m$^2$ on a limited area | Gypsum boards with different (thin) surface linings<br>Fire retardant wood products |
| **C** | Limited contribution to fire | " | " | Phenolic foam, gypsum boards with different surface linings (thicker than in class B) |
| **D** | Acceptable contribution to fire | " | " | Wood products with thickness ≥ about 10 mm and density ≥ about 400 kg/m$^3$ (depending on end use) |
| **E** | " | Small flame attack | Flame height of 20 mm | Low density fibreboard, plastic based insulation products |
| **F** | No performance requirements | – | – | Products not tested (no requirements) |

# Fire resistance

- **how well a building component** (for a stated period of time) **can hold back the fire and prevent it from penetrating from one room to another**
- **based on the time during which construction elements accomplish their function in case of an unstoppable, fully developed fire**

**Fire classification of construction, not material!**

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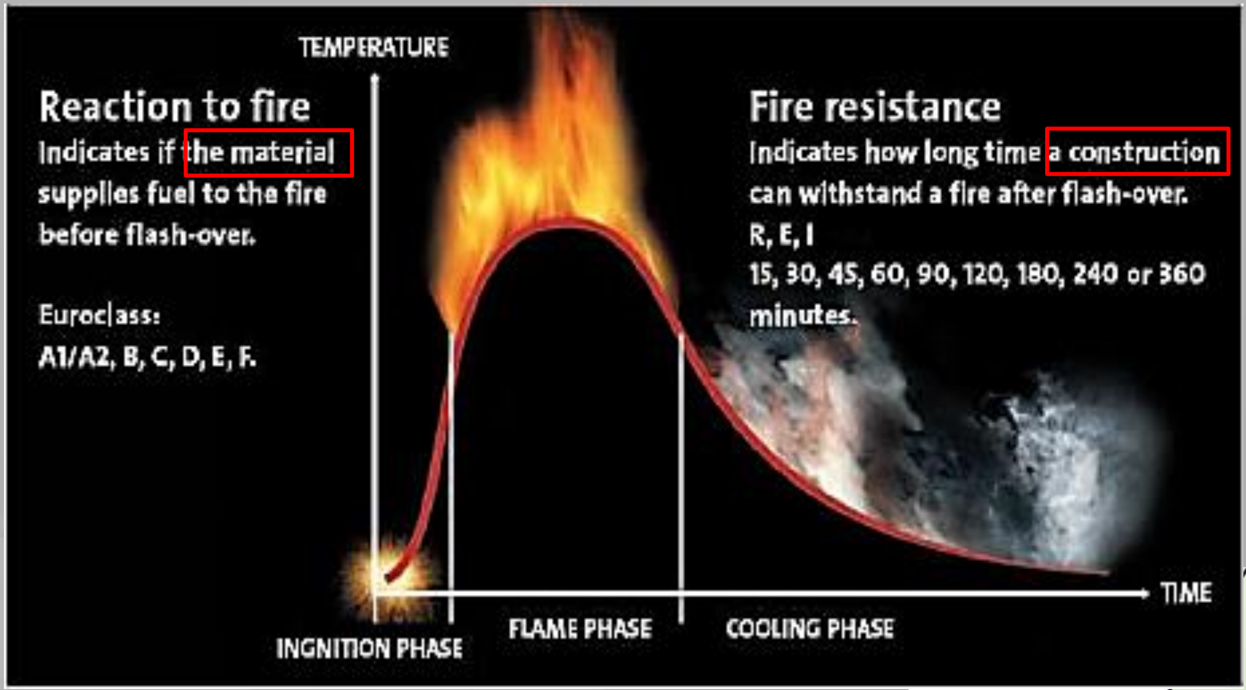
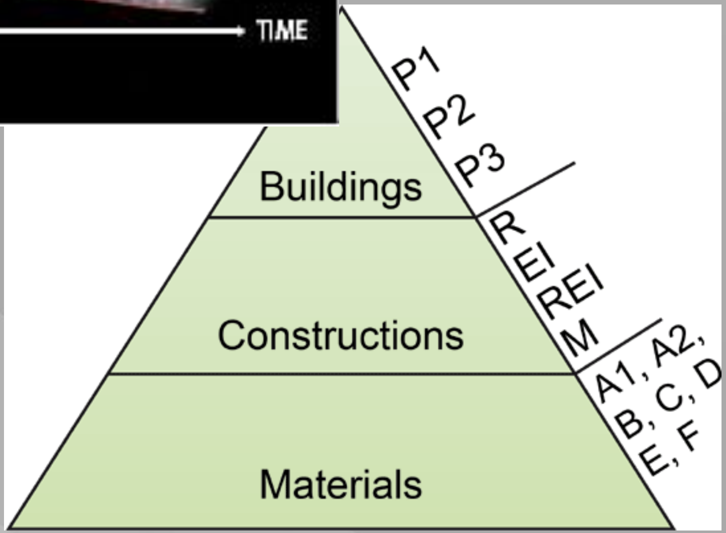
# Reaction to fire x Fire resistance



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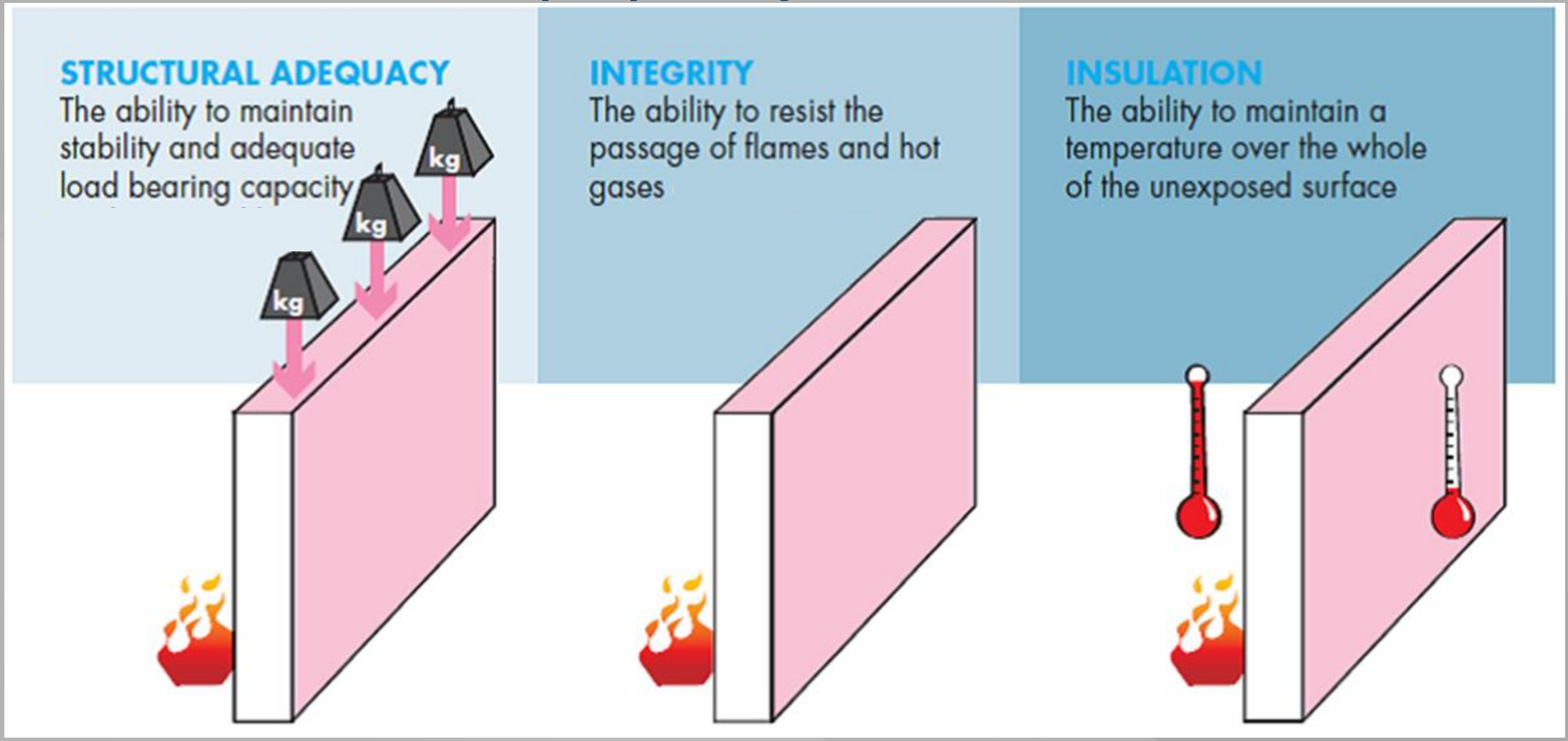
# Fire resistance criteria

- **R =** load bearing capacity
- **E =** integrity (capacity to remain intact)
- **I =** insulation (capacity to maintain a defined

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# Fire resistance criteria

- **R** - the structural element should not collapse or deflect beyond the permitted levels when subjected to the applied load
- **E -** the integrity of the room must be maintained. No breakthrough of flames is permitted.
- **I -** the temperature on the non-exposed side of the structural element must not rise more than 140° C above ambient as an average measurement and no more than 180° C at any one location.



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# Classification of building components

| Load bearing building components | |
|---|---|
| **REI** - time | the time span where all three criteria, load bearing capacity, integrity and insulation are fulfilled |
| **RE** - time | the time span where the two criteria, load bearing capacity and integrity, are fulfilled |
| **R** - time | the time span where the criteria load bearing capacity is fulfilled. |

| Non load bearing building components | |
|---|---|
| **EI** - time | time span where the two criteria, integrity and insulation, are fulfilled |
| **E** - time | the time span where the criteria integrity is fulfilled |

- **REI 120** – all three criteria must be fulfilled for 120 minutes

# Fire resistance of construction

- cement-bonded particleboard

| FIRE RESISTANCE [1] | THICKNESS OF TWO-SIDED COAT OF CETRIS® BOARDS (mm) | | | | | |
|---|---|---|---|---|---|---|
| | with air gap [2] | | | with mineral wool [3] | | |
| | COAT | GAP | COAT | COAT | INSULATION | COAT |
| EI 30 | 16 | - | 16 | | | |
| EI 45 | 10 + 10 | - | 10 + 10 | 12 | 60 | 12 |
| EI 60 | 12 + 12 | - | 12 + 12 | 16 | 60 | 16 |
| EI 90 | 18 + 16 | - | 18 + 16 | 12 + 12 | 60 | 12 + 12 |
| EI 120 | 18 + 12 + 12 | - | 18 + 12 + 12 | 16 + 16 | 60 | 16 + 16 |
| EI 180 | To be assessed | | | 18 + 12 + 12 | 60 | 18 + 12 + 12 |

Fire characteristics of load-bearing peripheral wall on wooden skeleton, height up to 3 m

| FIRE RESISTANCE [1] | CONSTRUCTION COMPOSITION | | | FIRE EXPOSURE |
|---|---|---|---|---|
| | Exterior coat | Mineral board [2] | Interior coat | |
| REI 60 D3 | CETRIS® 14 | 120 | Knauf® GKF 12.5 | External fire (exposed CETRIS® board) |
| REW 60 D3 [3] | | | | Internal fire (exposed KNAUF board) |

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# Other properties



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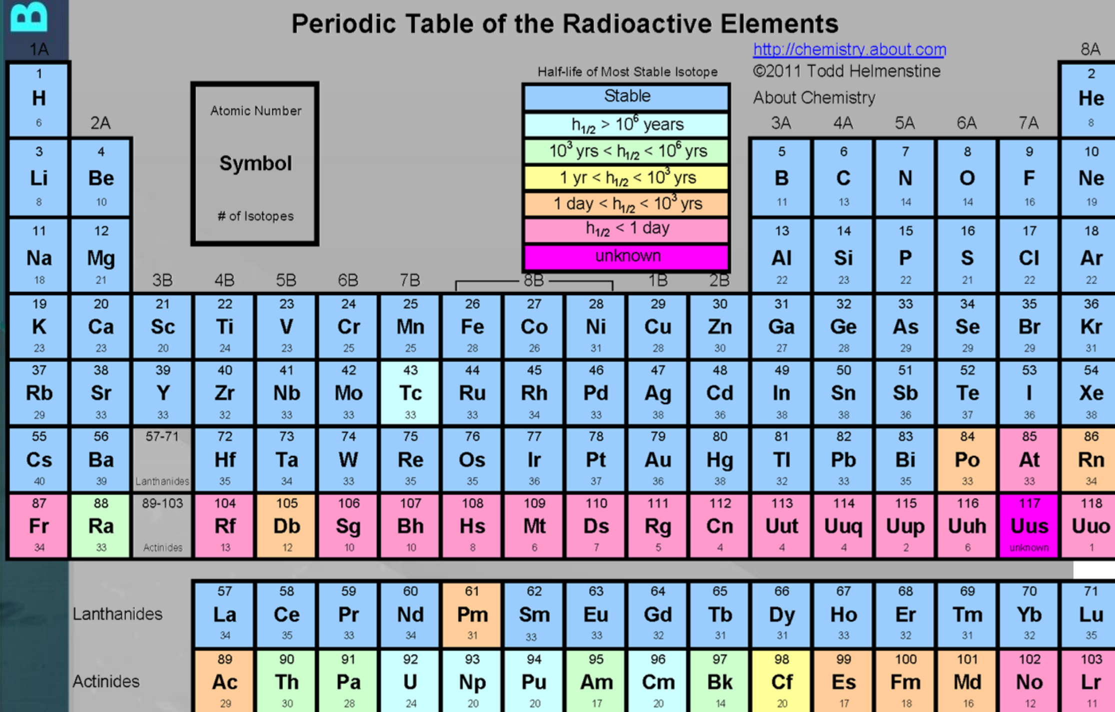
# Radioactivity

- natural radioactivity of materials



Periodic Table of the Radioactive Elements

http://chemistry.about.com
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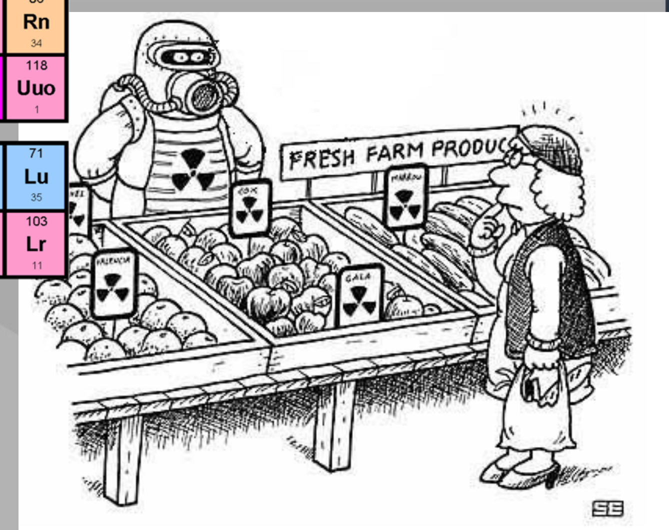
Half-life of Most Stable Isotope: Stable; $h_{1/2} > 10^6$ years; $10^3$ yrs < $h_{1/2}$ < $10^6$ yrs; 1 yr < $h_{1/2}$ < $10^3$ yrs; 1 day < $h_{1/2}$ < $10^3$ yrs; $h_{1/2}$ < 1 day; unknown

Key: Atomic Number / Symbol / # of Isotopes

| 1A | 2A | 3B | 4B | 5B | 6B | 7B | 8B | 8B | 8B | 1B | 2B | 3A | 4A | 5A | 6A | 7A | 8A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H 6 | | | | | | | | | | | | | | | | | 2 He 8 |
| 3 Li 8 | 4 Be 10 | | | | | | | | | | | 5 B 11 | 6 C 13 | 7 N 14 | 8 O 14 | 9 F 16 | 10 Ne 19 |
| 11 Na 18 | 12 Mg 21 | | | | | | | | | | | 13 Al 22 | 14 Si 23 | 15 P 22 | 16 S 21 | 17 Cl 22 | 18 Ar 22 |
| 19 K 23 | 20 Ca 23 | 21 Sc 20 | 22 Ti 24 | 23 V 23 | 24 Cr 25 | 25 Mn 25 | 26 Fe 28 | 27 Co 26 | 28 Ni 31 | 29 Cu 28 | 30 Zn 30 | 31 Ga 27 | 32 Ge 28 | 33 As 29 | 34 Se 29 | 35 Br 29 | 36 Kr 31 |
| 37 Rb 29 | 38 Sr 33 | 39 Y 33 | 40 Zr 32 | 41 Nb 33 | 42 Mo 33 | 43 Tc 33 | 44 Ru 33 | 45 Rh 34 | 46 Pd 33 | 47 Ag 38 | 48 Cd 36 | 49 In 38 | 50 Sn 38 | 51 Sb 36 | 52 Te 37 | 53 I 36 | 54 Xe 38 |
| 55 Cs 40 | 56 Ba 39 | 57-71 Lanthanides | 72 Hf 35 | 73 Ta 34 | 74 W 33 | 75 Re 35 | 76 Os 35 | 77 Ir 36 | 78 Pt 37 | 79 Au 36 | 80 Hg 38 | 81 Tl 32 | 82 Pb 33 | 83 Bi 35 | 84 Po 33 | 85 At 33 | 86 Rn 34 |
| 87 Fr 34 | 88 Ra 33 | 89-103 Actinides | 104 Rf 13 | 105 Db 12 | 106 Sg 10 | 107 Bh 10 | 108 Hs 8 | 109 Mt 6 | 110 Ds 7 | 111 Rg 5 | 112 Cn 4 | 113 Uut 4 | 114 Uuq 4 | 115 Uup 2 | 116 Uuh 6 | 117 Uus unknown | 118 Uuo 1 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lanthanides | 57 La 34 | 58 Ce 35 | 59 Pr 33 | 60 Nd 34 | 61 Pm 31 | 62 Sm 33 | 63 Eu 33 | 64 Gd 32 | 65 Tb 31 | 66 Dy 31 | 67 Ho 33 | 68 Er 32 | 69 Tm 31 | 70 Yb 32 | 71 Lu 35 |
| Actinides | 89 Ac 29 | 90 Th 30 | 91 Pa 28 | 92 U 24 | 93 Np 20 | 94 Pu 20 | 95 Am 17 | 96 Cm 20 | 97 Bk 14 | 98 Cf 20 | 99 Es 17 | 100 Fm 18 | 101 Md 16 | 102 No 12 | 103 Lr 11 |

- $^{40}K$, $^{226}Ra$, $^{228}Th$

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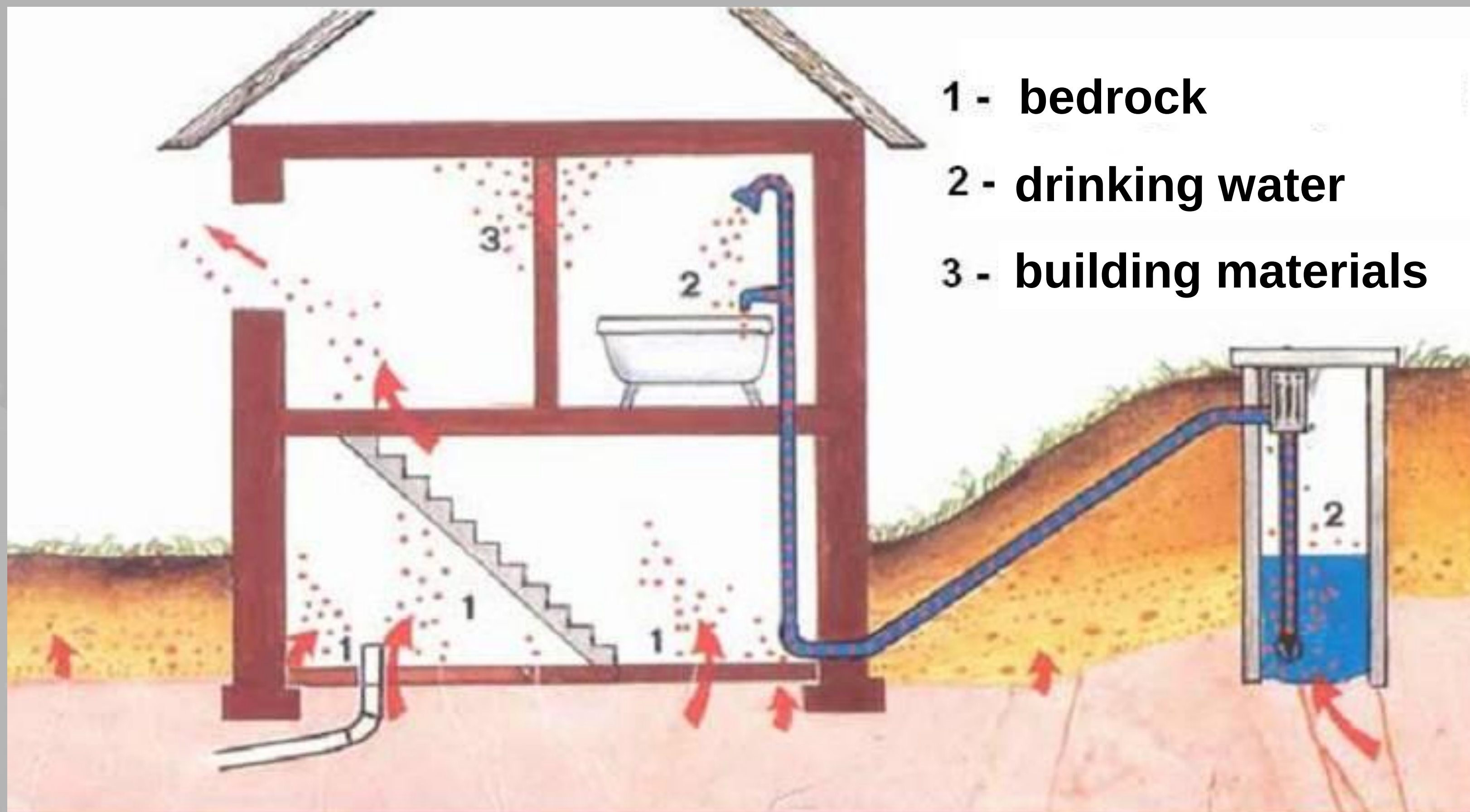
# Sources of radioactivity in the building



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# Radioactive materials

Radioactive could be (but not necessary!) e.g.:

- **aggregate from uranium ores**
- **blast–furnace slag**
- **cinder**
- **coal fly ash**
- **phosphogypsum**


Asbestos is not radioactive !

# Radioactivity of building materials

- **$^{226}Ra$ mass activity concentration** [Bq.kg$^{-1}$]
- **activity concentration index I** [unitless]

$$I = \frac{a_K}{3000} + \frac{a_{Ra}}{300} + \frac{a_{Th}}{200}$$

where $a_K$, $a_{Ra}$ , $a_{Th}$ are radium, thorium and potassium activity concentrations in material

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# Activity concentration

Activity concentration range (Bq/kg) of common building materials.

| Building material | $^{226}Ra$ [Bq/kg] | $^{232}Th$ [Bq/kg] | $^{40}K$ [Bq/kg] |
|---|---|---|---|
| Concrete | 18 - 67 | 3 - 43 | 16 - 1100 |
| Light weight concrete | 10 - 60 | 6 - 66 | 51 - 870 |
| Bricks | 7 - 140 | 8 - 127 | 227 - 1140 |
| Gypsum | 1 - 67 | 0.5 - 190 | 22 - 804 |
| Cement | 13 - 107 | 7 - 62 | 48 - 564 |

Activity concentration range (Bq/kg) of selected covering building materials.

| Building material | $^{226}Ra$ [Bq/kg] | $^{232}Th$ [Bq/kg] | $^{40}K$ [Bq/kg] |
|---|---|---|---|
| Ceramics | 25 - 193 | 29 - 66 | 320 - 1049 |
| Granite | ND - 160 | ND - 354 | 24 - 2355 |
| Tiles | 33 - 61 | 45 - 66 | 476 - 788 |
| Marble | 1 - 63 | 0.4 - 142 | 9 - 986 |

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# Radioactivity of building materials

- most countries with reference levels for radioactive elements in building materials apply activity indices or maximum permissible/recommended concentrations
- some countries - one reference level for $Ra^{226}$
- other countries – level for each $Ra^{226}$, $Th^{232}$ and $K^{40}$
- in most of the countries the levels are enforced, only in Norway are the reference levels advisory

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# Reference Levels for Radioactive Elements in Building Materials

**Czech Republic:**

- **enforced level**: **150-200 Bq/kg** - materials in buildings where people could stay more than 1000 h/year (depending on the type of material); 1000 Bq/kg for materials in other buildings.
- **advisory level**: **80-120 Bq/kg** in buildings where people normally stay more than 1000 h/year; 300-500 Bq/kg for materials in other buildings

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# Reference Levels for Radioactive Elements in Building Materials

| I | Type of building material | Example |
|---|---|---|
| **0,5** | materials used in bulk amount | bricks, cement, concrete, gypsum |
| **1** | raw materials | aggregates, stones, clay |
| **2** | materials used in „small“ amount | ceramic tiles |



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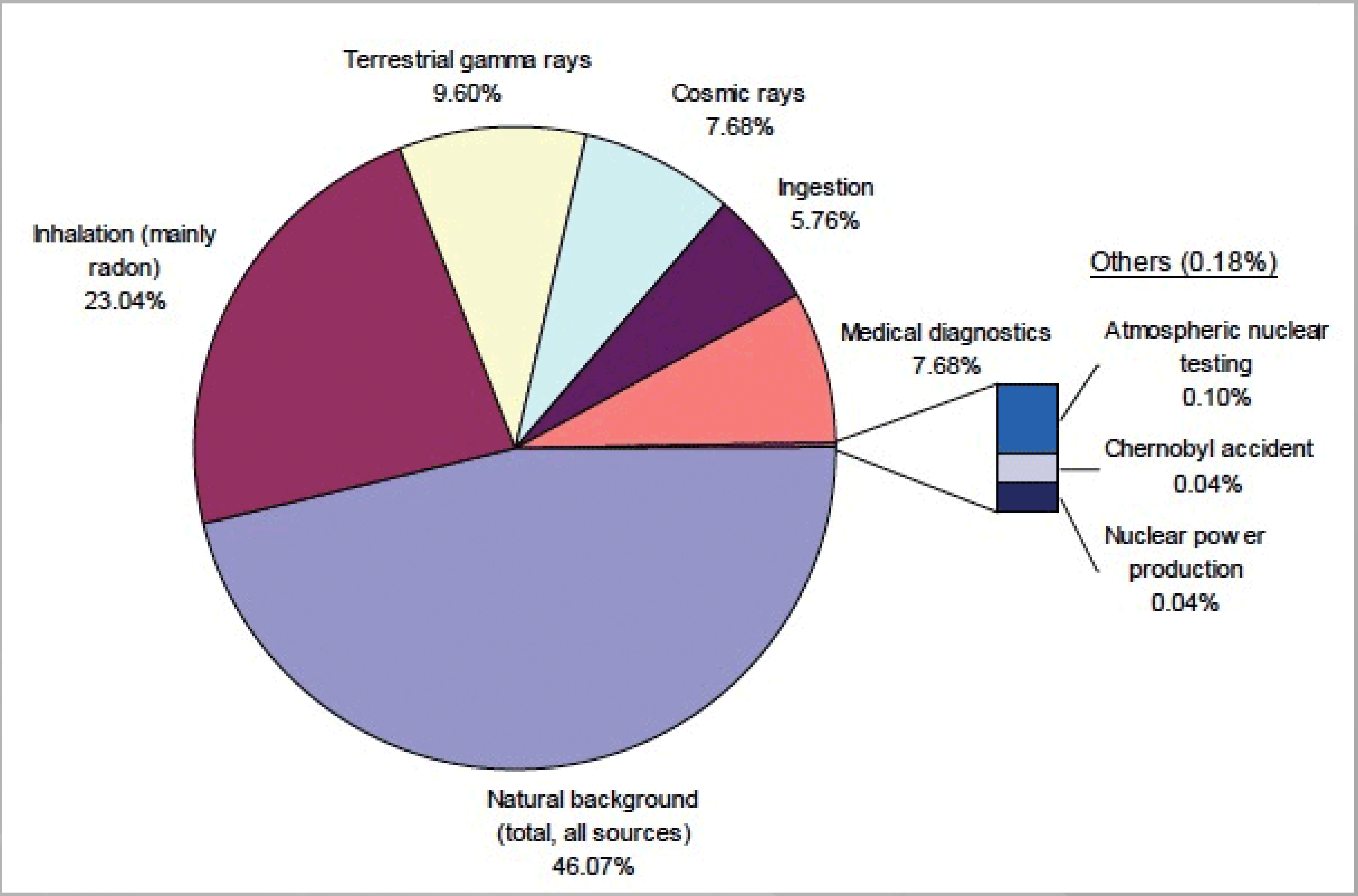
# Doses from radiation sources



# Radon

- colorless, odorless, tasteless gas
- radioactive product of decay uranium or thorium
- half-life 3,8 days → **radon daughters** (solids Po, Pb, Bi) stick to surfaces such as dust particles in the air
- if contaminated dust is inhaled, these particles can stick to the airways of the lung and increase the risk of developing lung cancer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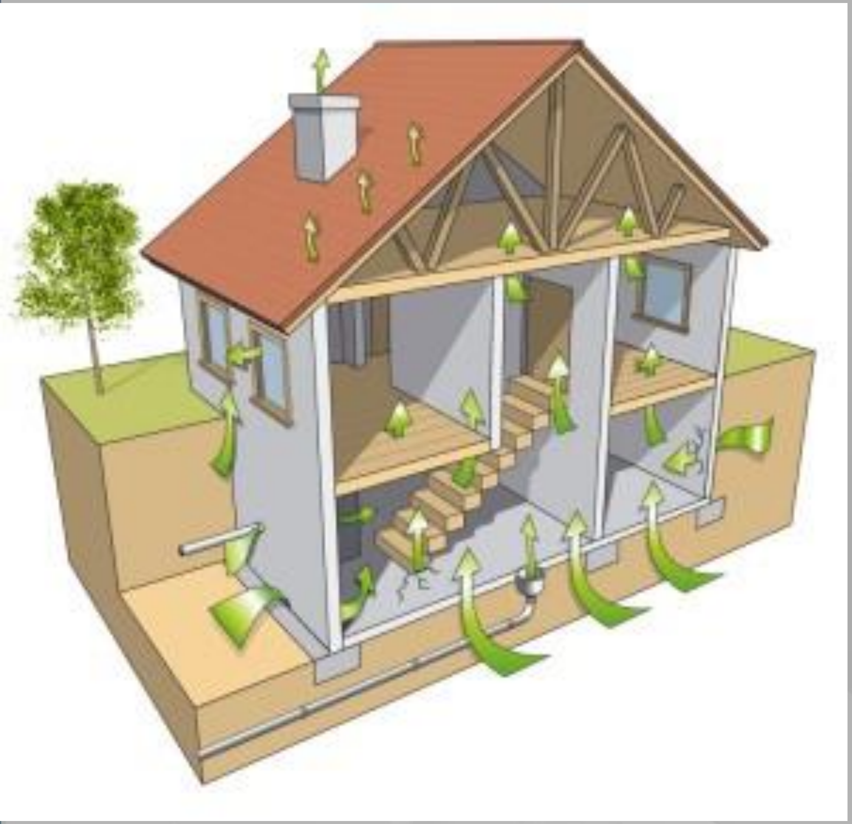
# Radon in houses



- Cracks in solid floors
- Construction joints
- Cracks in walls
- Gaps in suspended floors
- Gaps around service pipes
- Cavities inside walls
- The water supply

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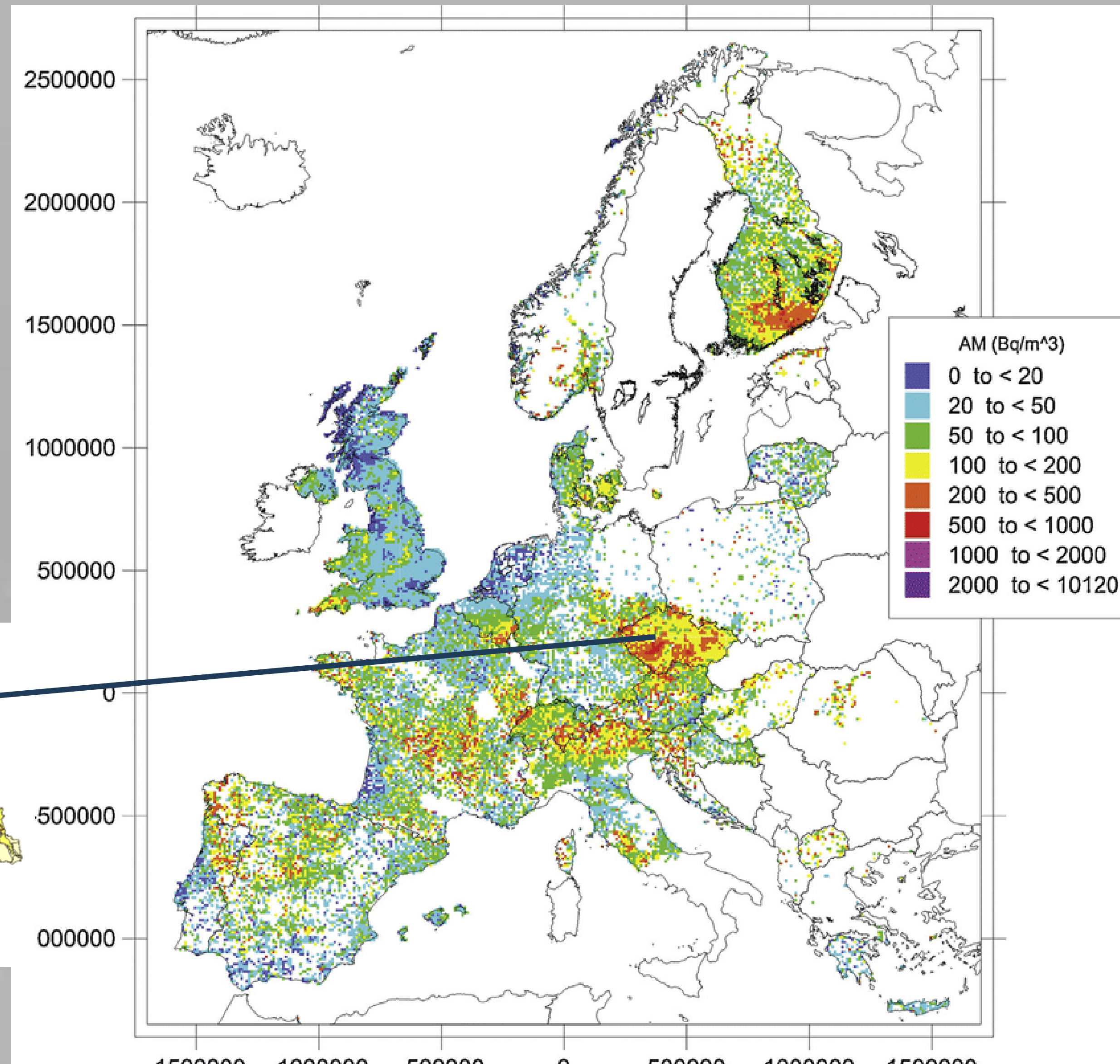
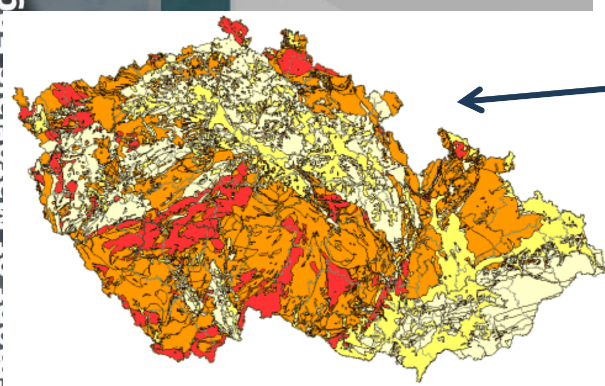
# Radon map

## Europe



## Czechia

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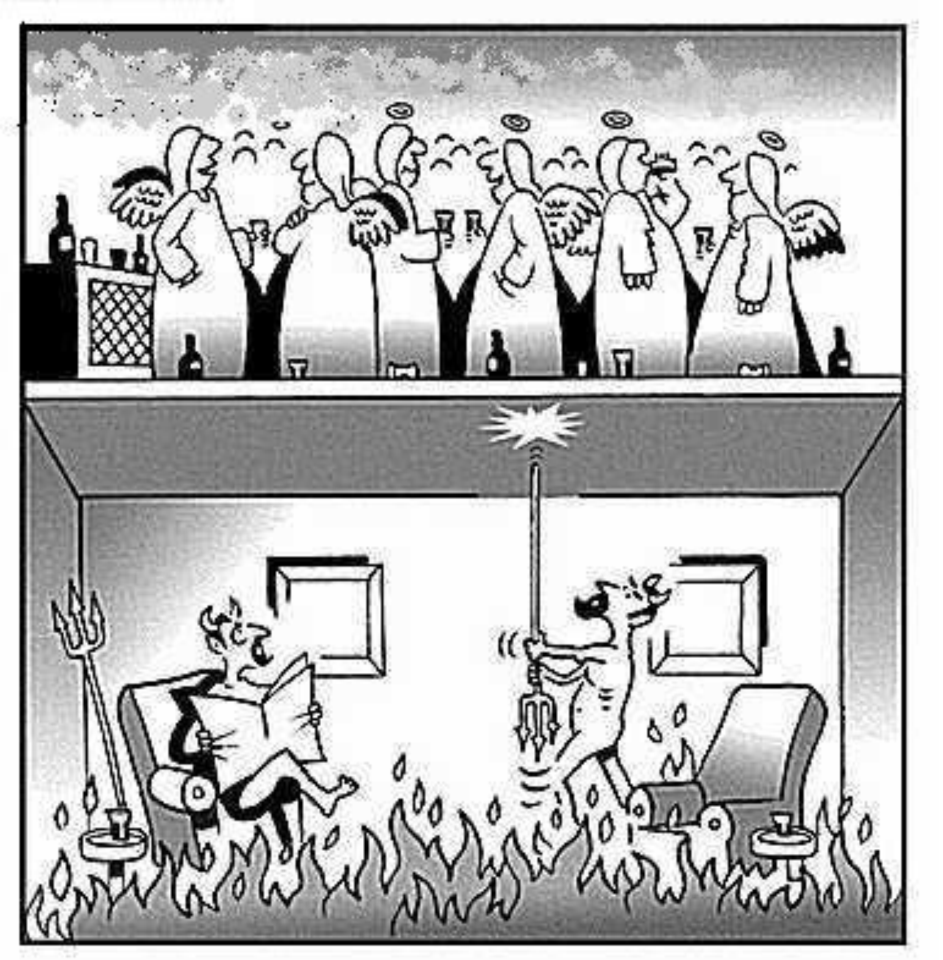
# Acoustic properties





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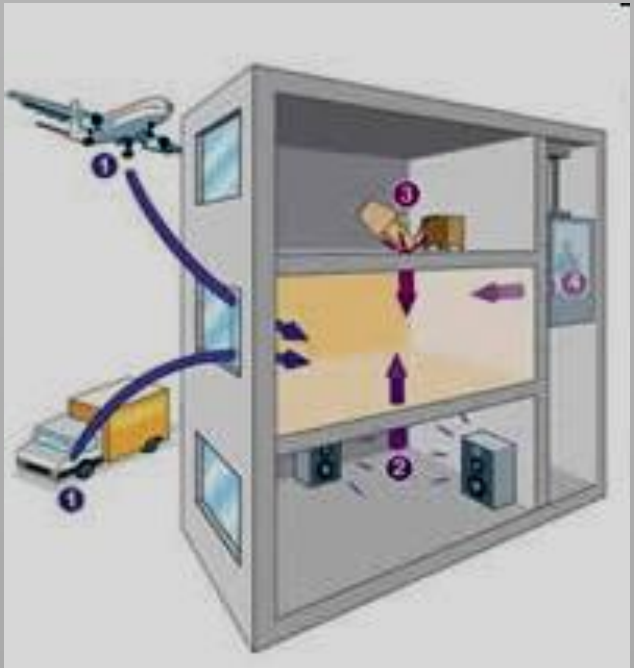
# Noise sources

- **Outside air-borne noises**: road, rail or air traffic
- **Inside air-borne noises**: conversations, hi-fi, TV...
- **Impact**: movement of people or furniture, falling objects...
- **Equipment noises**: lift, taps, mechanical ventilation, heating or air conditioning installation.



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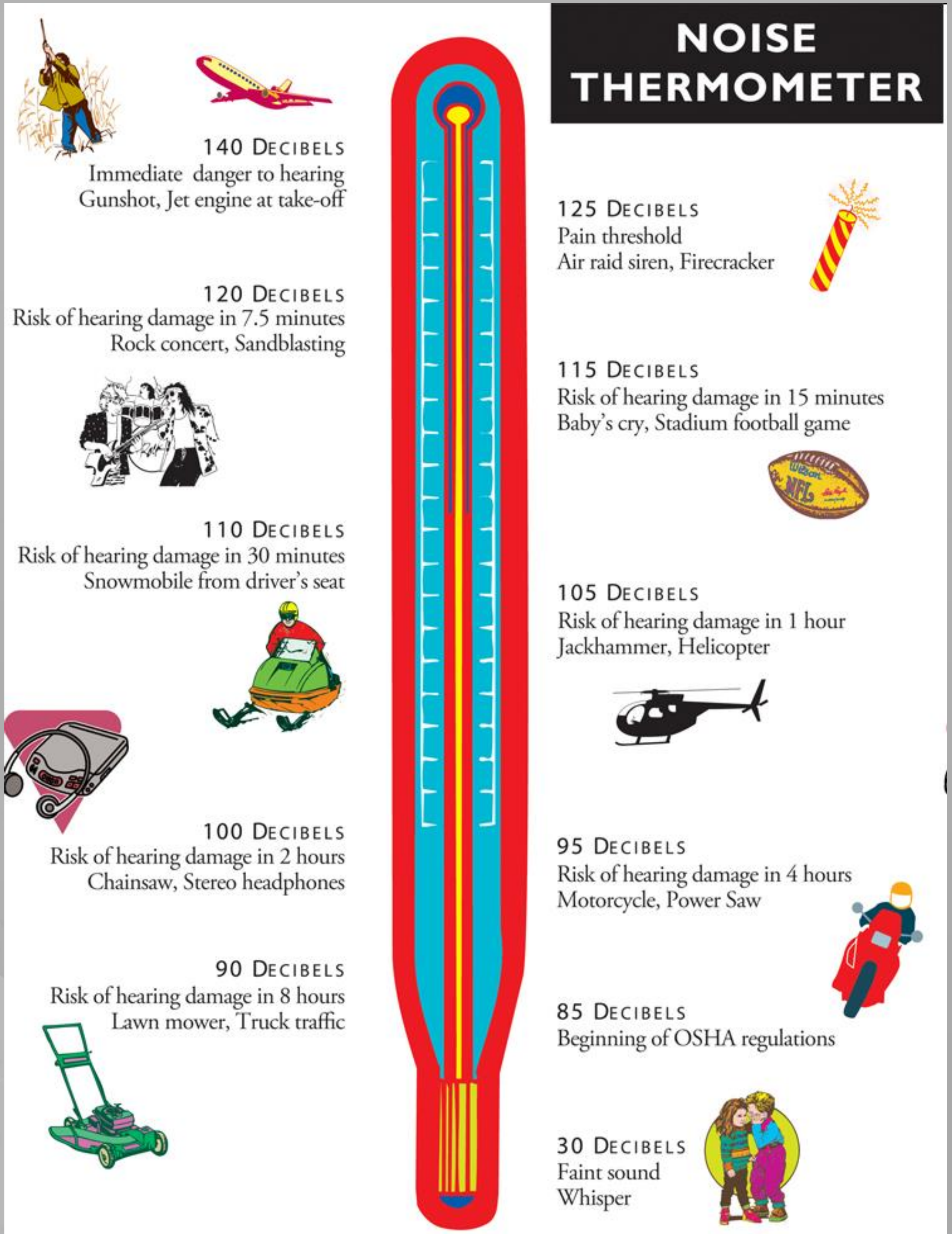
# Noise level

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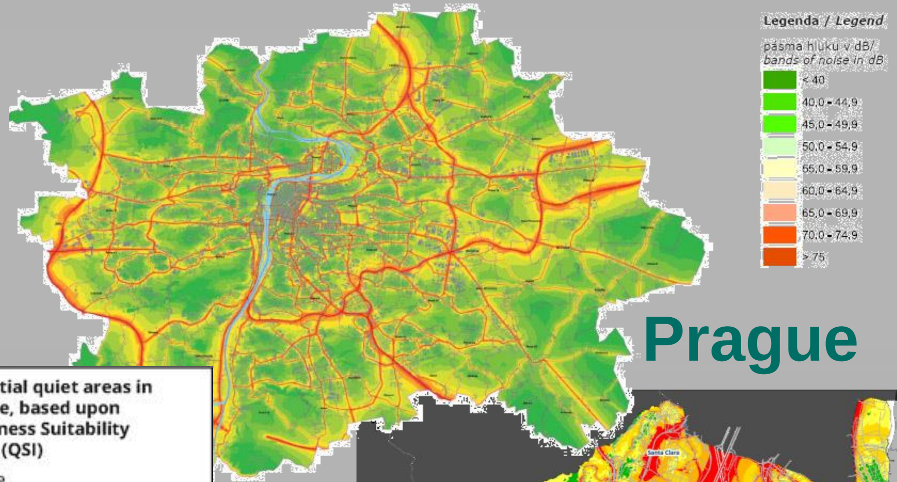
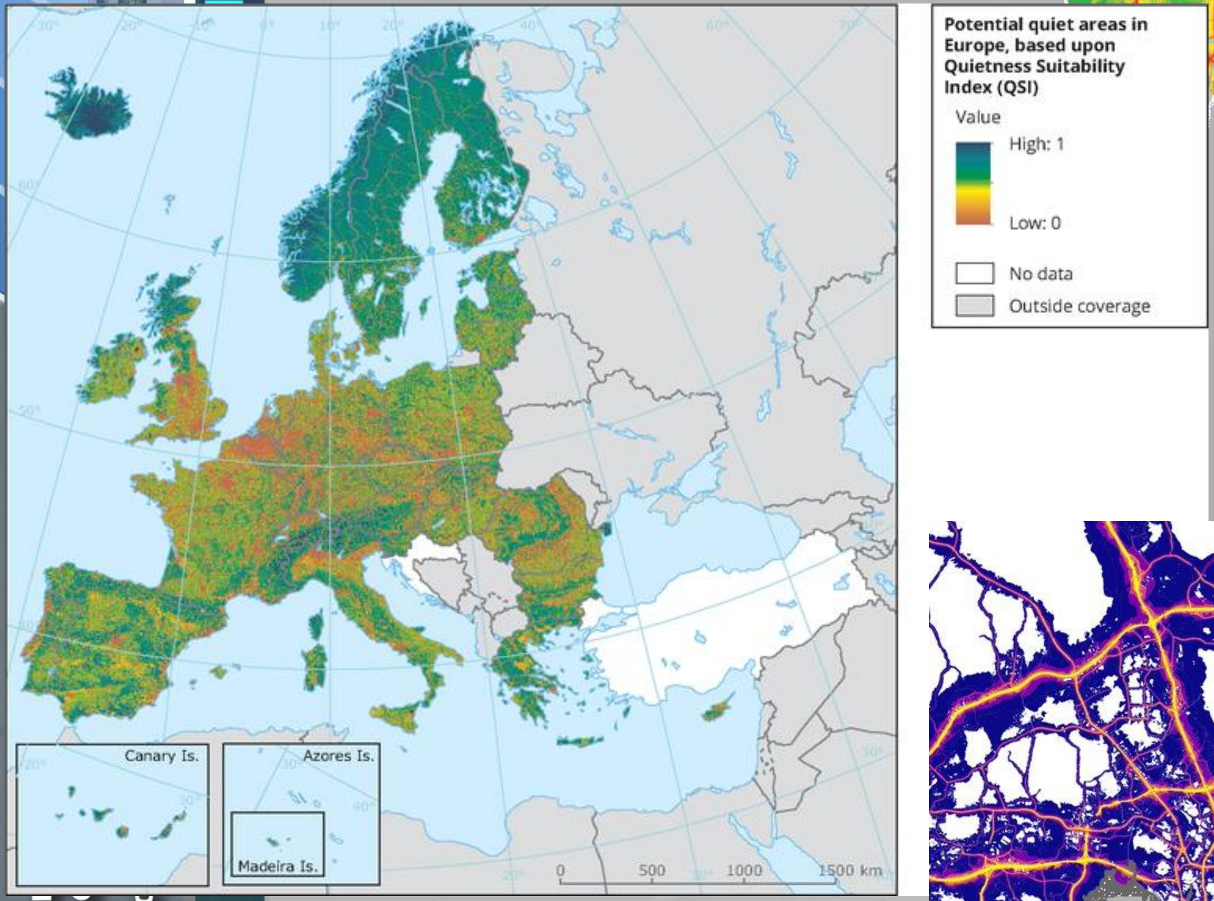
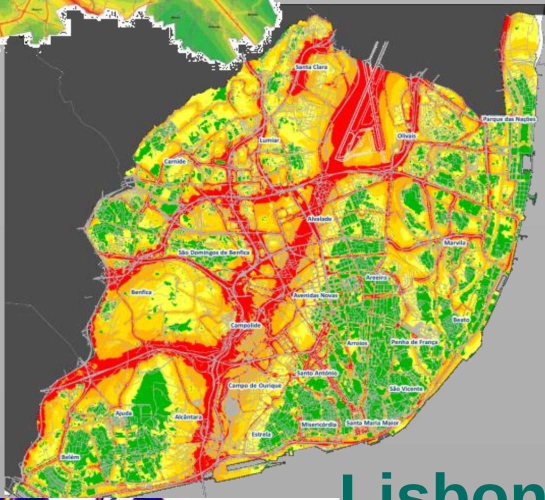
# Noise maps

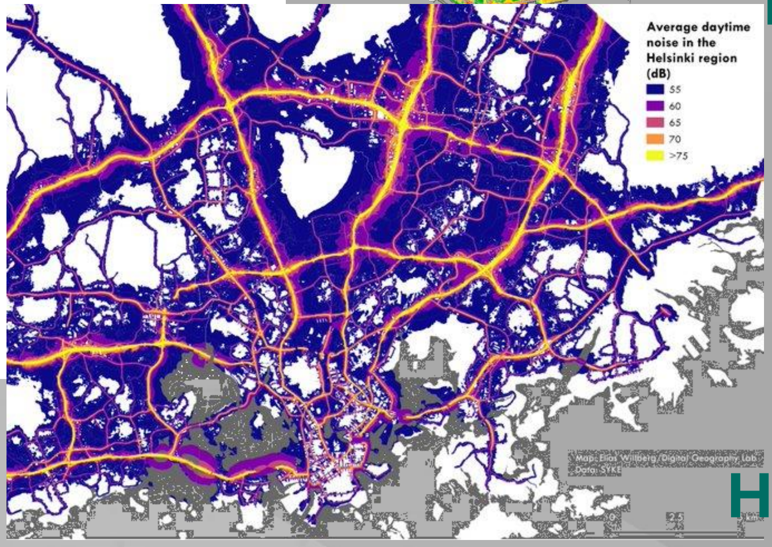



Prague



Lisbon

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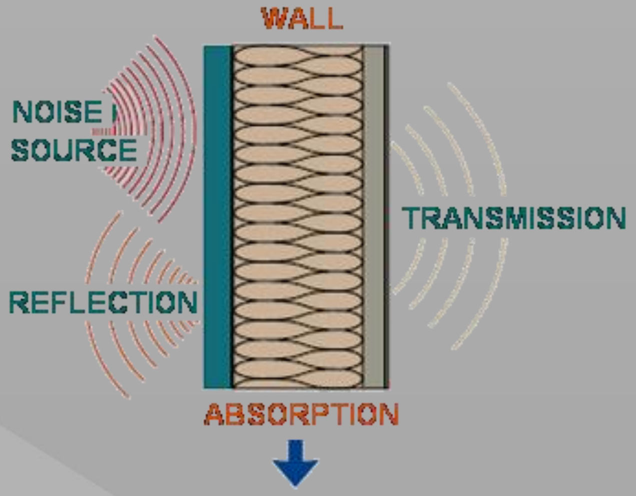
# Basic acoustic parameters

## Acoustic absorptivity

- **sound energy is reduced when sound waves pass through a medium or strike a surface** - the incident sound that strikes a material is not reflected back




## Reverberation

- **the collection of reflected sounds from the surfaces**

# Sound absorption coefficient

- how much of the sound is absorbed in the material

$$\alpha = \frac{I_a}{I_i}$$

$I_a$ ….. sound intensity absorbed [W/m$^2$]

$I_i$ …. incident sound intensity [W/m$^2$]

| Material | α |
|---|---|
| Plaster walls | 0.01 - 0.03 |
| Unpainted brickwork | 0.02 - 0.05 |
| Painted brickwork | 0.01 - 0.02 |
| 3 mm plywood panel | 0.01 - 0.02 |
| 6 mm cork sheet | 0.1 - 0.2 |
| Hardwood | 0.3 |
| 100 mm mineral wool | 0.65 |
| Persons, each | 2.0 - 5.0 |

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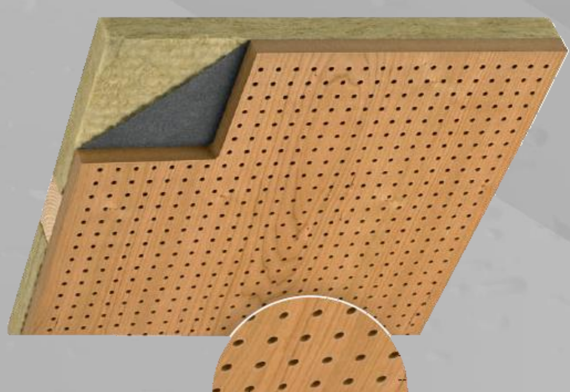
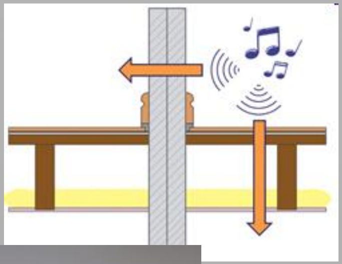
# Acoustic constructions

- against sound reflection – **materials with good sound absorptivity**
  – soft, pliable, porous materials
- against sound transmission – **sound insulating materials**
  - materials with high surface density



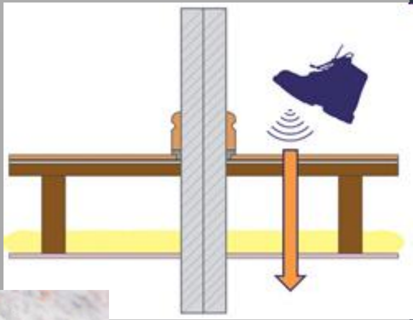
# Noise insulation

**Airborne noise** (voices, music)



- materials with high surface density (mass per unit area) - min 350 $kg.m^{-2}$

**Impact noise** (feet, moving furniture, dropped items)



- padding or cushioning - soft, sound absorbing materials (carpets, mineral wool)

# Acoustic comfort

- **good sound environment**
  - lower sound level
    - an acoustic ceiling with high absorption factor
  - reduced sound propagation
  - increased speech intelligibility
    - combination absorbers which enhance early reflections and minimize late reflections
  - appropriate reverberance
    - the room volume, the amount of absorbing material and the position of absorbers and reflectors



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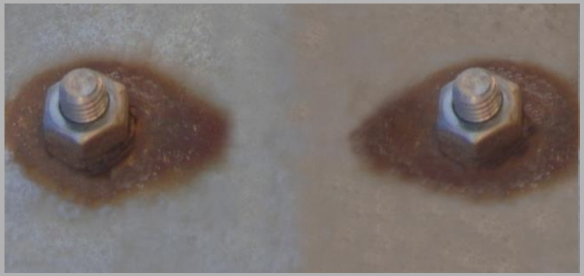
# Chemical properties

- **Chemical reactions in materials:**
  - **processing** (setting and hardening , foaming…)
  - **materials (in)compatibility**
  - **ageing**
  - **corrosion** (degradation) (inorganic materials, metals, biocorrosion…)

# Materials incompatibility

**Metals**:

- **galvanic corrosion** (dissimilar metal corrosion)
  - contact of two metals with different electrical potentials
- **aluminum** + **alkali** environment
- **copper** + **low pH** water, + **aggressive** soils
- **steel + gypsum**

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# Materials incompatibility

## Plastics:

- **EPS + solvents** (in the paints)
- **PVC + formaldehydes**
- **phenolic foam** (acid pH) + steel

| | ABS | ABS/PC | LCP | PA | PBT | PC | PC/PBT | PE | PEEK | PEI | PET | PMMA | POM | PP | PPO | PPS | PS | PVC | SAN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ABS | X | X | | | | | | | | | | X | | | | | O | O | O |
| ABS/PC | X | X | | | | X | O | | | | | O | | | | | | | |
| LCP | | | X | | | | | | | | | | | | | | | | |
| PA | | | | X | | | | | | | | | | | | | | | |
| PBT | | | | | X | | O | | | O | | | | | | | | | |
| PC | | X | | | | X | O | | | | | X | | | O | | | | |
| PC/PBT | | O | | | O | O | X | | | | | O | | | | | | | |
| PE | | | | | | | | X | | | | | | | | | | | |
| PEEK | | | | | | | | | X | | | | | | | | | | |
| PEI | | | | | O | | | | | X | | | | | | | | | |
| PET | | | | | | | | | | | X | | | | | | | | |
| PMMA | X | O | | | | X | O | | | | | X | | | | | | | O |
| POM | | | | | | | | | | | | | X | | | | | | |
| PP | | | | | | | | | | | | | | X | | | | | |
| PPO | | | | | | O | | | | | | | | | X | | X | | O |
| PPS | | | | | | | | | | | | | | | | X | | | |
| PS | O | | | | | | | | | | | | | | X | | X | | O |
| PVC | O | | | | | | | | | | | | | | | | | X | |
| SAN | O | | | | | | | | | | | O | | | O | | O | | X |

X COMPATIBLE   O OCCASIONALLY

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# Materials incompatibility

**Cement, concrete:**

- **cement + wood**
  - sugar content in the wood
- **concrete + glass fibers**
- **cement + some type of aggregates**
  - ASR - alkali-silica reaction

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# Corrosion

- the deterioration of a material due to interaction with its environment
- the disintegration of an engineered material into its constituent atoms due to chemical reactions with its surroundings
- **metals** – atmospheric corrosion
- **non-metal materials** -
  - ceramic
  - plastics
  - concrete
  - glass
  - biodegradation

# Corrosion of non-metal materials (degradation)

Ceramic

– refractory materials + wood combustion
– bricks + flue gases

Concrete

– decalcification (water without minerals)
– leaching
– sulphates
– bacteria

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# Biodegradation

**Caused by**:

- microorganism
- fungi
- insects
- birds
- plants
- rodents


Biodegradation is natural process!

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# Biodegradation - examples

- **wood + fungi** (dry rot - Merulius Lacrymans)
- **wood + insects** (old house borer - Hylotrupes Bajulus)
- **nitrifying bacteria** on the **asbestos-cement** roofs
- **sulphur oxidizing bacteria** on **concrete**

# Biodegradation - examples

- stone + lichen
- building + plants
- termites + thermal insulation

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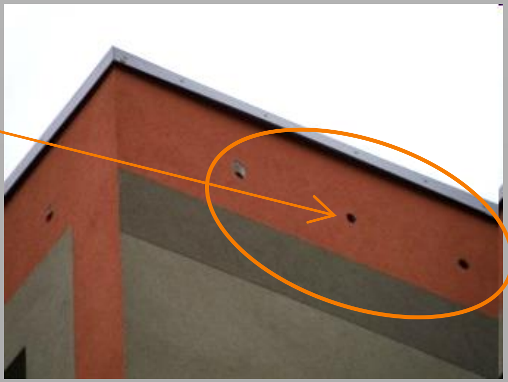
# Biodegradation - examples

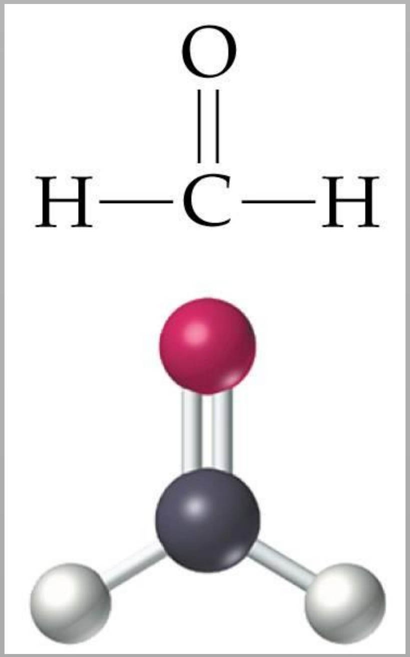
- insulated facade + woodpeckers



- rodents

# Hygienic properties

- pollutants in air (styrene, formaldehyde, plasticizers in PVC)
- contact with the skin (biocides, paints)
- respirable fibers (asbestos, glass)




The higher amount of pollutants can be caused by more accurate measuring methods, not in reality !



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# Environmental safety

- low energy consumption at production
- the renewable resources
- recycling possibility
- low liquidation costs

- PVC – bad recyclability, toxicity at incineration

# Durability of materials

- ability to be used over a desired period

Factors affecting durability:

- – **age**
- – **maintenance**
- – **high temperature**
- – **UV radiation**
- – **load**
- – **chemical attacks**
- – **weathering actions** (frost)

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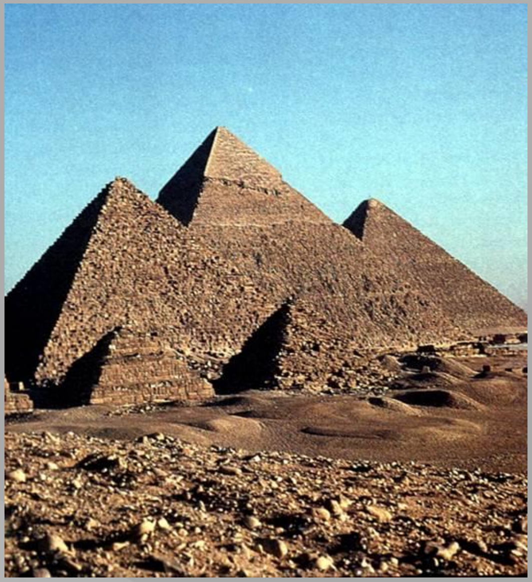
# Life span of buildings

- **40 – 100** years – industrial buildings
- **50 – 100** y. - residential buildings
- **70 – 500** y. – bridges and monuments
- special causes: **2 – 5 millennia** – nuclear waste disposals



# Durability of buildings and materials

| Life span of building | | Expected durability of building materials | | |
|---|---|---|---|---|
| | Yrs. | Easily replaceable | Replaceable with some effort | Unreplace-able |
| short | **10** | **10** | **10** | **10** |
| middle | **25** | **10** | **25** | **25** |
| normal | **50** | **10** | **25** | **50** |
| long | **100** | **10** | **25** | **100** |



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# Durability of some materials

## Roofing

- Ceramic tiles — 100 years
- Concrete tiles — 100 years
- Steel sheets — 50 years
- Asphalt shingle — less than 50 years

## Waterproof insulation

- asphalt felts — 15 years
- modified bitumen membranes — 100 years (exp.)
- rubber membrane — 70 years
- PVC membrane — 25 years

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