A BASIC GUIDE TO

THE SCIENCE OF INSULATION

PREPARED BY

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The case for energy efficiency in buildings.

WHY DO WE NEED INSULATION?

Although sound insulation is also desirable in a comfortable building (specially in noisy environments, such as a city), it is probably heat insulation the most critical variable for a house.

Heat insulation is a matter of **energy efficiency.** A properly insulated building will retain heat and cool much better, saving energy and money.

Energy savings could also dramatically reduce the carbon footprint of a house, in terms of energy consumed to make it livable during cold or heat climatic conditions.

These savings are of utmost importance in a world facing a climate crisis due to carbon emissions.

What is the carbon footprint of a house?

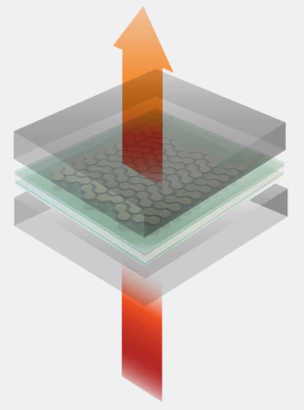
It is the total amount of greenhouse gases produced to build a house and create the right conditions for the dwellers to live in, usually expressed in equivalent tons of carbon dioxide (CO2).

Understanding thermal efficiency in buildings.

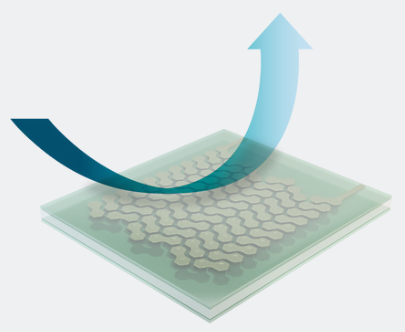
HOW DOES INSULATION WORK?

Heat Insulation is about blocking the heat flux (or heat transfer) between the inside and outside of a building. Therefore, to understand thermal insulation we should understand how thermal performance works.

Heat is a form of energy. It can be transferred in three different ways: **conduction, convection and radiation.** Each of them needs a temperature difference, and the result is that the heat is transferred from the potential with higher temperature to the one with lower temperature.
However, only conduction and convection are relevant to understand insulation.



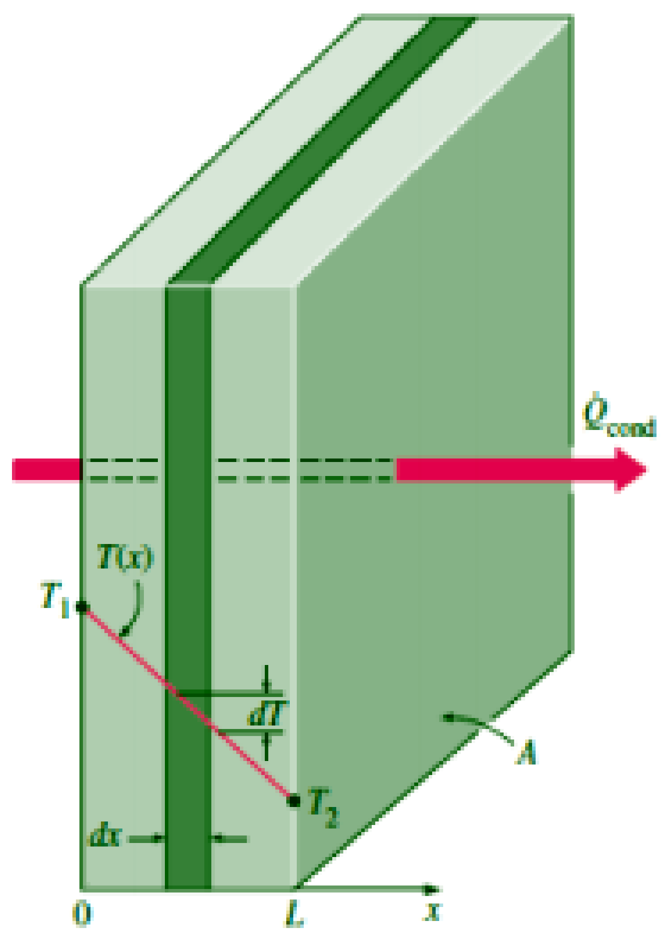
Conduction can take place in solids, liquids and gases. The velocity of heat conduction through the system depends on the geometrical configuration of it, thickness and material it is made of and the temperature difference between its ends or limits.



Convection heat transfer is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.
Convection heat transfer depends on the fluid properties such as dynamic viscosity, thermal conductivity, density, specific heat and fluid velocity, as well as the geometry and the roughness of the solid surface.

How does conduction work?

CALCULATING HEAT CONDUCTION THROUGH A WALL



Under steady conditions, temperature distribution in a plane wall (Yunus A Çengel 2004) (1)

The heat conduction through a wall is proportional to the temperature difference through it and the area of heat transfer, but inversely proportional to the thickness of the wall.

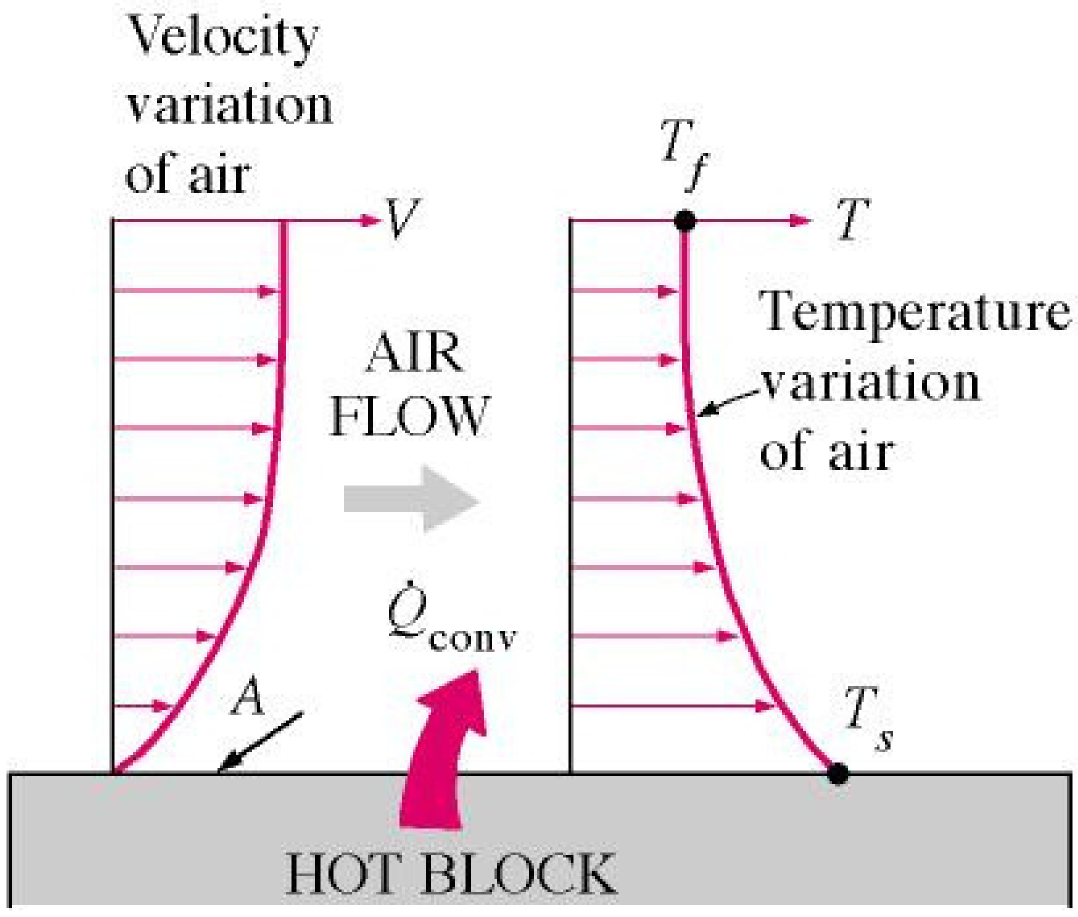
The process is explained by the **Fourier's law of heat conduction**, where

$$\dot{Q}_{cond} = -k \cdot A \frac{dT}{dx} = -k \cdot A \frac{T_1 - T_2}{L} \quad (W)$$

Where:
$Qcond$: heat transfer trough the wall (J/s=W).
k: thermal conductivity (W/(m·K)).
A: transversal area of heat transfer (m2).
L: wall thickness (m).
T: temperature difference (K).

How does convection work? Basic equation.

CALCULATING CONVECTION



Convection is considered the most complex mechanism of heat transfer. It can be expressed by **Newton’s law of cooling:**

$$\dot{Q}_{conv} = hA_s(T_s - T_f)(w)$$

Where:

Q̇conv: heat transfer (W).
h: convection heat transfer coefficient (W/m2·ºC).
As: heat transfer surface area (m2).
Ts: temperature of the surface (ºC).
Tf: temperature of the fluid surrounding the surface (ºC).

It is important to draw attention to the convection heat transfer coefficient, which is the value of heat transferred between a solid surface and a fluid.

It is difficult to determine the convection heat transfer coefficient because convection depends on the multiple variables mentioned before. Moreover, it also changes through the fluid. As a solution we can take the average value. For more info, go to the next page.

(1) Yunus A Çengel 2004: Heat transfer: a practical approach, New York, McGraw-Hill 2nd ed

How does convection work?Further considerations.

CALCULATING CONVECTION

The convection heat transfer coefficient is influenced by the type of flow, laminar or turbulent.

Laminar:

$$Nu = \frac{h \cdot L_c}{k} = 0{,}664 \cdot Re^{0{,}5} \cdot Pr^{1/3} \qquad Re_L < 5 \cdot 10^5$$

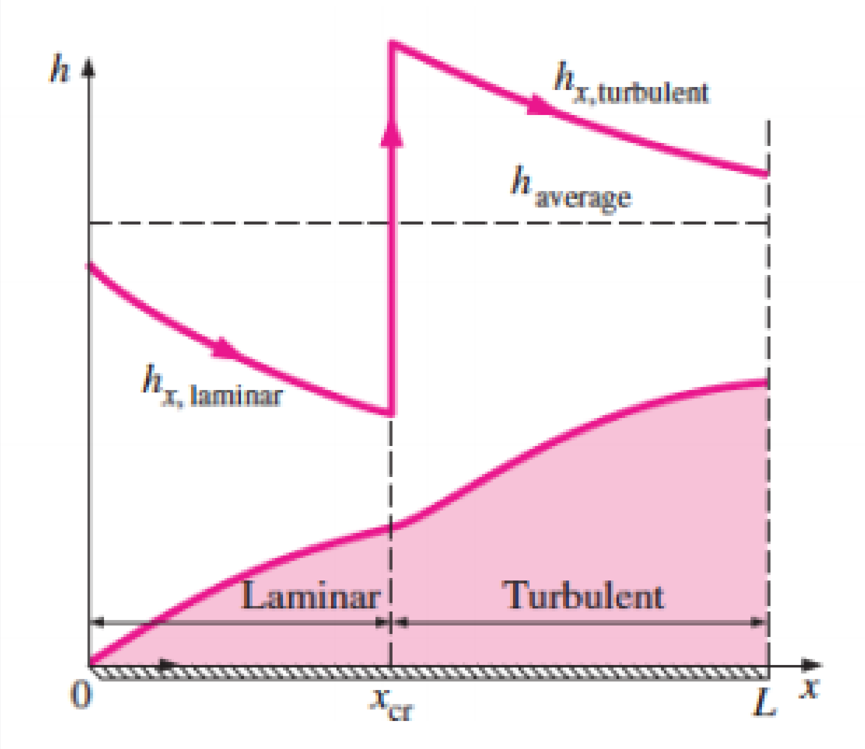
Turbulent:

$$Nu = \frac{h \cdot L_c}{k} = 0{,}037 \cdot Re^{0{,}8} \cdot Pr^{1/3} \qquad 0{,}6 \leq Pr \leq 60$$

$$5 \cdot 10^5 \leq Re_L \leq 10^7$$

Where:
Nu: Nussel number.
Pr: Prandlt number.
Re: Reynolds number.
Lc: characteristic length (m)
h: convection heat transfer coefficient in laminar flow (W/(m2·K)).

The convection heat transfer coefficient is influenced by the Reynolds number, which determines the type of the flow. In this figure we represent the average heat transfer coefficient for a plate with laminar and turbulent flow (*Yunus A Çengel, 2004*) (1). It shows how it changes through the fluid flow.



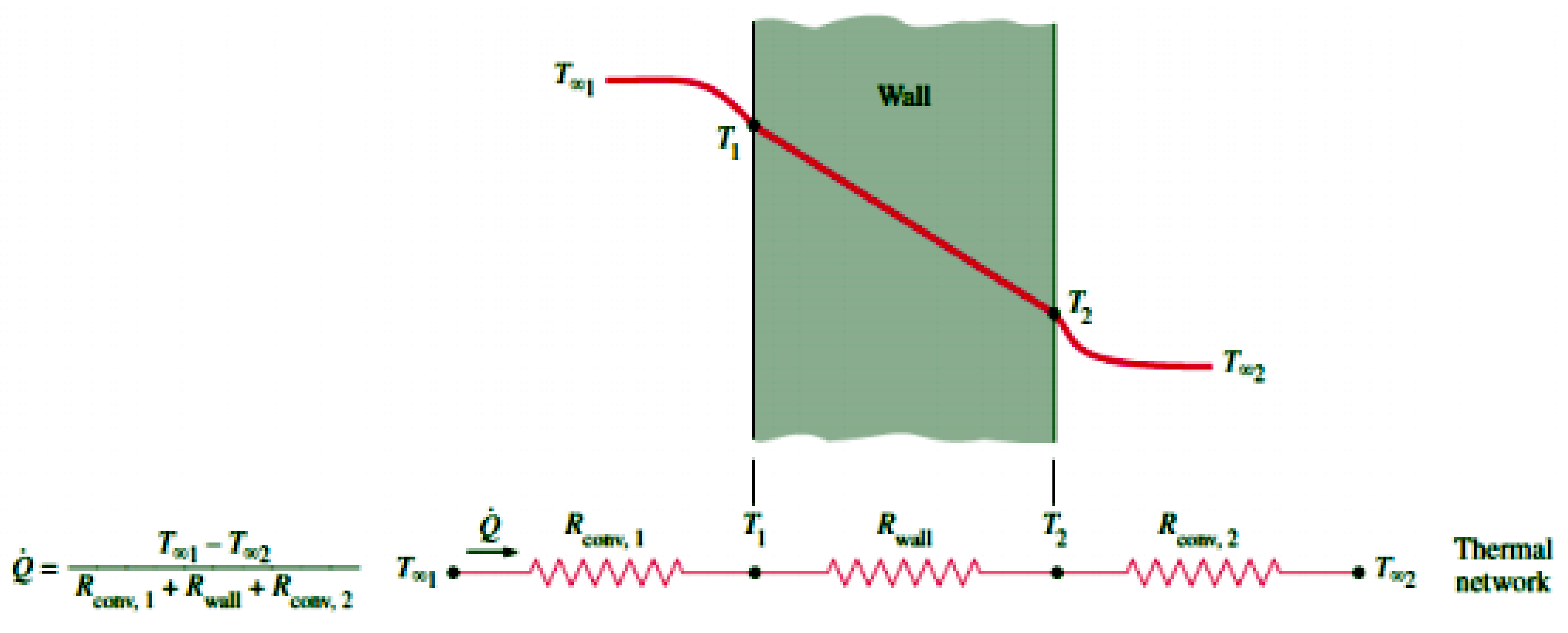
Where:
hx,laminar: convection heat transfer coefficient in laminar flow (W/(m2·K)).
hx,turbulent: convection heat transfer coefficient in turbulent flow (W/(m2·K)).
haverage: mean convection heat transfer (W/(m2·K)).

The maximal convection heat transfer coefficient value is at the transition between turbulent and laminar flow.

(1) Yunus A Çengel 2004: Heat transfer: a practical approach, New York, McGraw-Hill 2nd ed

Combining conduction and convection calculations.

CALCULATING HEAT TRANSFER THROUGH A WALL



Thermal resistance network for a heat transfer through a plane wall subjected to convection on both sides. (Yunus A Çengel 2004) (1)

Calculating heat conduction through a wall

The formula for calculting heat conduction through a wall is: $\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}}$ (W)

Where:

$$R_{total} = R_{conv,1} + R_{wall} + R_{conv,2} = \frac{1}{h_1 A} + \frac{L}{kA} + \frac{1}{h_2 A} \quad \left(\frac{K}{W}\right)$$

where:

$\dot{Q}$: total heat transferred (W).
T∞1:temperature outside the wall (ºC).
T∞2:temperature inside the wall (ºC).
h1/2: convection heat transfer coefficient outside (1) and inside (2) the wall (W/m2·K).
k: conduction heat transfer coefficient of the wall (W/m·K).
L: thickness of the wall (m).
A: total transversal area (m2).

The **specific heat flow (q)** is the total heat flow $\dot{Q}$ divided by the area A:

$$q = \frac{\dot{Q}}{A} \quad \left(\frac{W}{m^2}\right)$$

(1) Yunus A Çengel 2004: Heat transfer: a practical approach, New York, McGraw-Hill 2nd ed

Main values for insulation measurement.

U-VALUE AND R-VALUE

U-value

The U-Value is the thermal transmittance of any material. If we go back to the formula explained previously, it would be:

$$U = \frac{q}{(T_{\infty 1} - T_{\infty 2})} \quad \left(\frac{W}{m^2 \cdot K}\right)$$

With the U-Value we can also calculate the heat flow through the wall, which is proportional to the thermal transmittance and the temperature difference between both sides:

$$\dot{Q} = \mathrm{UA}(\mathrm{T}_{\infty 1} - \mathrm{T}_{\infty 2})$$

R-value

The R value is the thermal resistance of any material. It is the quantity determined by the temperature difference, at steady state, between two defined surfaces of a material or construction that induces a unit heat flow through a unit area. Equation is as follows:

$$R = \frac{T_{\infty 1} - T_{\infty 2}}{q} \quad \left(\frac{m^2 \cdot k}{W}\right)$$

Mathematically, both the U- and the R-value describe the thermal performance of a building element. Both values are reciprocal. **The lower the U-value, the higher the R value and the better the thermal performance of the assessed element.**

It might be easier to understand that an R-value of $R1$ = 8 is better than an R-value of $R2$ = 4 instead of dealing with the corresponding U-values, which are below one: $U1$ = 0.125 and $U2$ = 0.25.
One should always be aware of the composition of the stated R- or U-value as they sometimes indicate only one component of the element.

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