Prof. Mario Misale

Master Degree in Innovative Technologies in Energy Efficient Buildings for Russian & Armenian Universities and Stakeholders

HEAT TRANSFER

Co-funded by the Erasmus+ Programme of the European Union

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University of Genoa, Italy
About Genoa

Genoa, capital of Liguria, faces the homonymous gulf in the Mediterranean Sea, between the coast and the surrounding mountains. The city, famous for its natural port since the Sixth Century B.C., enjoyed a period of great splendour as a Republic during the middle Ages. Because of its participation to the crusades, Genoa managed to conquer a marine and commercial supremacy on the entire Mediterranean, which lasted until 1400.
As evidence of its history, Genoa boasts many magnificent and luxurious palaces, which justify the name of 'Superba' given to the city.

Already in the 13th century in Genoa there were Colleges. College of Law existed before 1307. The foundation of College of Medicine was probably in 1353. In 1536 Ansaldo Grimaldi left a legacy for the establishment of four other University chairs: of Canon Law, Civil Law, Moral Philosophy, and Mathematics.

Polytechnic School of the University of Genoa

The Polytechnic School (before Engineering Faculty) has a long history and cultural tradition. It was founded in 1870 as the Royal Naval School of Superior Studies and is today one of the most active in Italy.

Polytechnic School – 5 Departments

•DIBRIS
•DICCA
•**DIME - Department of Mechanical, Energy, Management and Transportation Engineering**
•DITEN
•DSA

Prof. Mario MISALE (Full professor, since 2004)

Received his degree in mechanical engineering at University of Genoa, Italy, in 1981, than he was development engineer at Italian Advanced Nuclear Reactors.

Education teaching: Applied physics, Heat transfer, Thermo-Fluid-Dynamic. Since 2012 he is vice-coordinator of Mechanical Engineering Courses.

Author and co-author of more than 100 scientific publications focused on heat transfer, fluid flow in single-phase and two-phase, thermophysical properties of materials.

He is the Editor in Chief – (Europe) (2016) of the “**Journal of Fundamentals of Renewable Energy and Applications”**
He is member of the Editorial Board of the “**JP Journal of Heat and Mass Transfer**”, and the **“Open Journal of Fluid Dynamics *(OJFD*)**”.

He collaborates with Rensselaer Polytechnic Institute (RPI, Troy, NY), Edinburgh University (UK), Universidade Federal de Santa Caterina (Brazil), University of Liverpool (UK)

Heat Transfer

The heat is that form of thermal energy that propagates through the boundary of the system.

Objective of HEAT TRANFER is the study of thermal phenomena and the calculation of the heat flows.

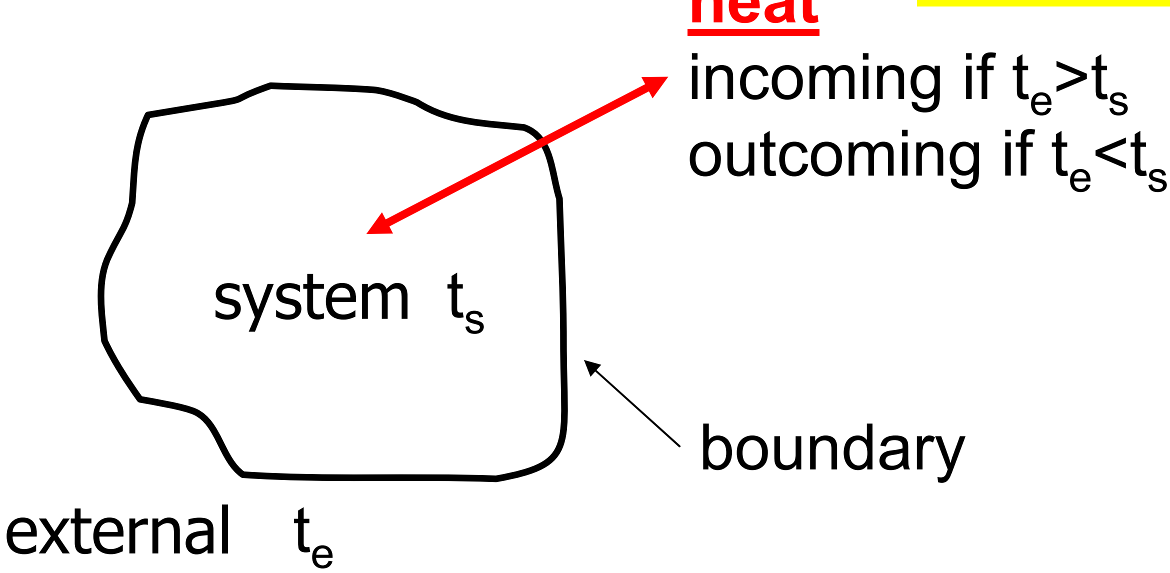
According to the first law of thermodynamics (neglecting the work) can be obtained

$$dq - \cancel{dL} = du \quad \longleftarrow \left[\frac{J}{kg}\right]$$

$$\longleftarrow [J]$$

$$q = \frac{d\dot{q}}{d\tau} = \frac{d\dot{U}}{d\tau}$$

q ⇨ heat flux ⇨ $\left[\frac{J}{s}\right] = [W]$



Heat Transfer Mechanisms

Heat Conduction ⇨ energy transfer that occurs by interaction of the particles of a substance with a greater energy with those adjacent to lower energy (only energy transport).

Heat Convection ⇨ energy transfer between a solid surface and the adjacent fluid in relative movement (transport of energy + mass transport).

Thermal Radiation ⇨ energy emitted by a solid wall in the form of electromagnetic waves (temperature) (energy transport does not require the presence of a medium).

All of the heat transfer mechanisms require the existence of a TEMPERATURE DIFFERENCE between hot and cold zones

Δ**T**→ Temperature difference **is the cause**

q→ Heat flux **is the effect**

Heat Conduction

The thermal conduction in solid is due to vibrations of the molecules in the crystal lattice and the energy transport by free electrons, whereas in liquids and gases is due to collisions between molecules during their random motion.

$$q = \frac{d\dot{q}}{d\tau} = -k \cdot A \cdot \frac{\partial T}{\partial n}$$

⇦ Fourier's Law

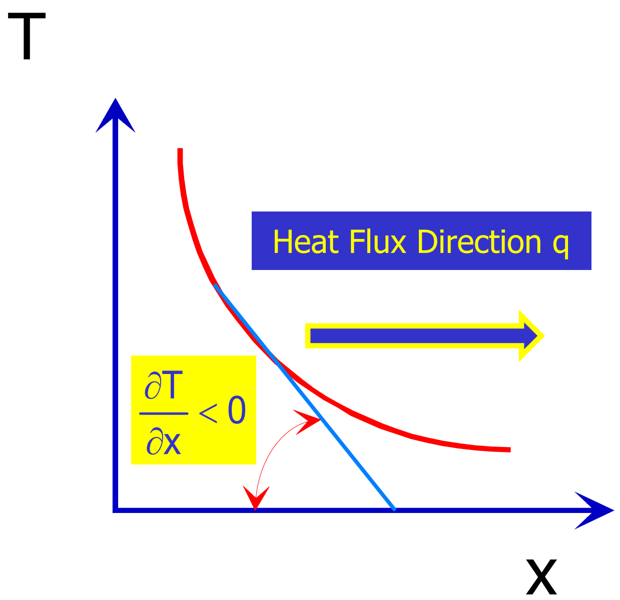
$q \Rightarrow$ heat flux $\rightarrow$ [W]

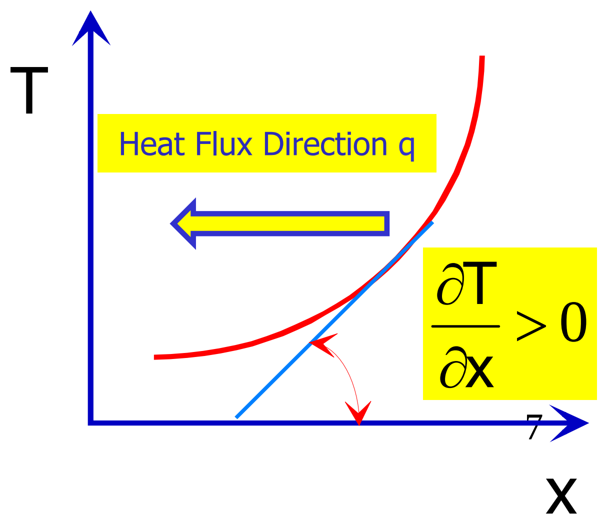
$k \Rightarrow$ thermal conductivity $\rightarrow \left[\frac{W}{m \cdot K}\right]$

$A \Rightarrow$ heat transfer surface $\rightarrow$ (m^2)

$\frac{\partial T}{\partial n} \Rightarrow$ thermal gradient in normal direction $\rightarrow \left[\frac{K}{m}\right]$

Why is there the minus?
because the heat flux is considered positive if its direction is the same of the x axis.



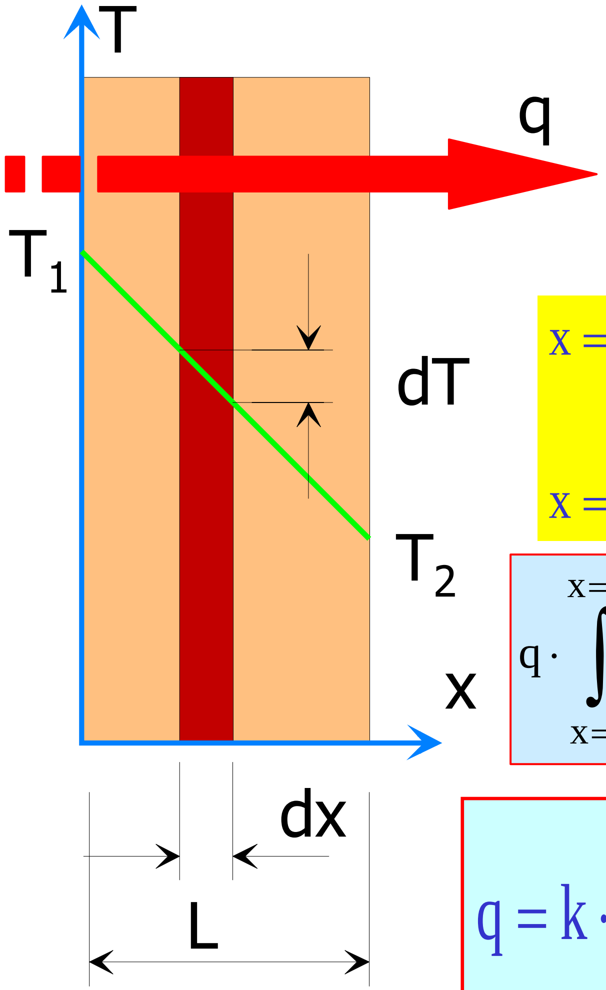


Thermal Conductivity, W/(mK)

Diamond	2300	Solid
Silver	429	
Copper	401	
Aluminium	237	
Stainlees steel (AISI 304)	15	
Bricks	0.5-0.6	
Cement	1.1-1.6	
Fiberglass	0.04	
Water (300 K)	0.61	Liquid
R12 (refrigerant) (20 °C)	0.073	
Air (300 K)	0.0261	Gas
carbon dioxide CO_2 (300 K)	0.0166	
Aerogel	**0.013-0.014**	

Solid+Gas=Aerogel

One Dimensional Steady Heat Conduction in Plane Wall



$$q = -k \cdot A \cdot \frac{dT}{dx}$$

$$x = 0 \rightarrow T = T_1$$

$$x = L \rightarrow T = T_2$$

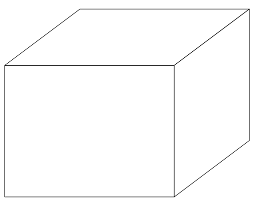
Boundary conditions

$$q \cdot \int_{x=0}^{x=L} dx = -k \cdot A \int_{T=T_1}^{T=T_2} dT$$

k=constant and homogeneous and isotropic material

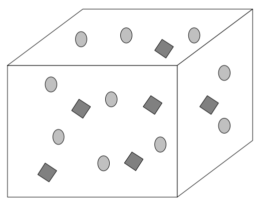
$$q = k \cdot A \cdot \frac{T_1 - T_2}{L}$$

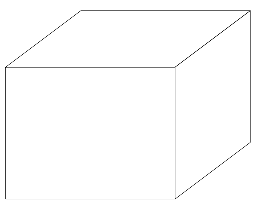
$$q = \frac{T_1 - T_2}{\frac{L}{k \cdot A}}$$



⬅homogeneous material

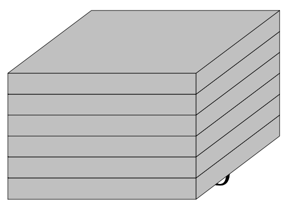
Non-homogeneous material➡



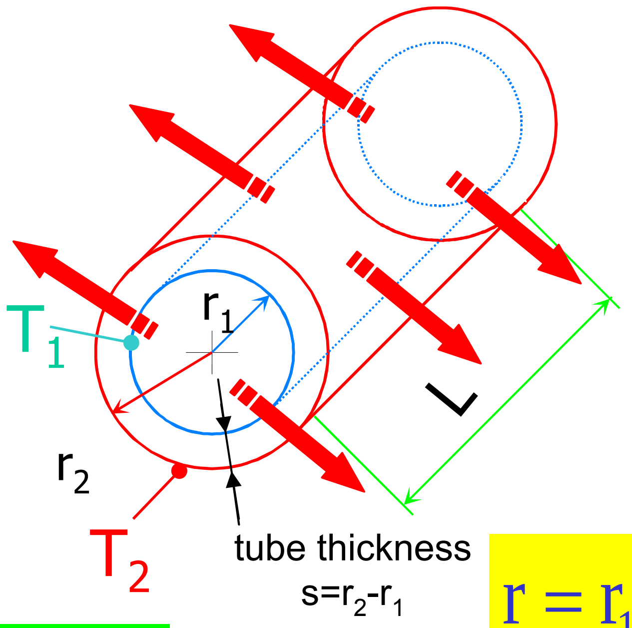


⬅isoltropic material

Non-isotropic material➡



One Dimensional Steady Heat Conduction in Cylindrical Wall



$$q = -k \cdot A \cdot \frac{dT}{dr}$$

$$r = r_1 \rightarrow T = T_1$$

$$r = r_2 \rightarrow T = T_2$$

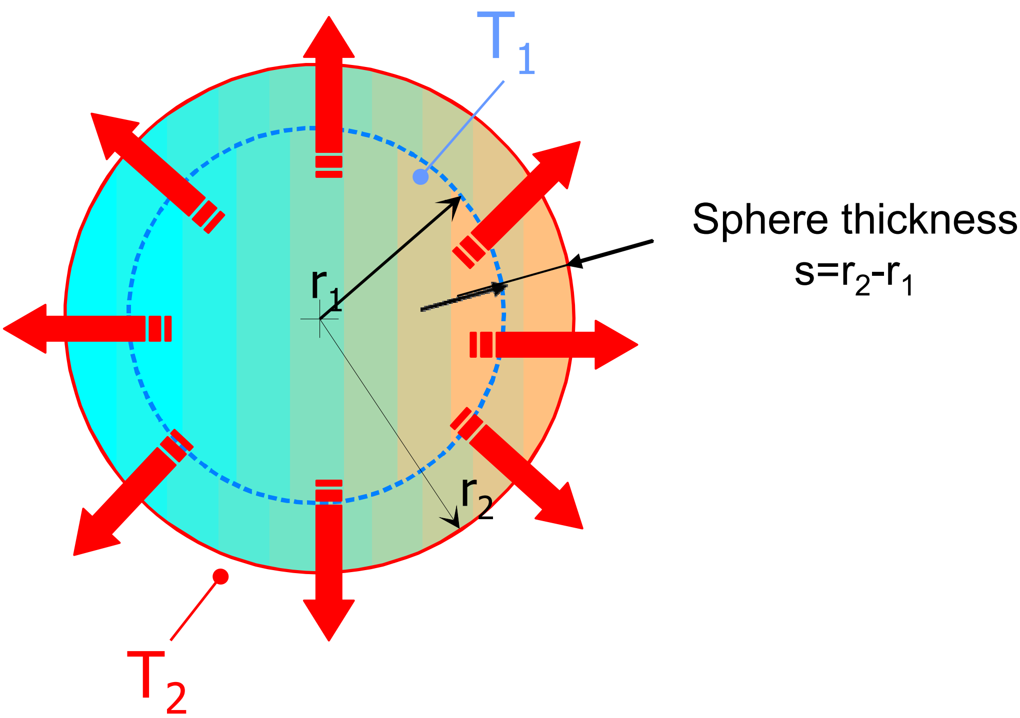
$$A = 2 \cdot \pi \cdot r \cdot L$$

$$q \cdot \int_{r=r_1}^{r=r_2} \frac{dr}{r} = -k \cdot 2 \cdot \pi \cdot L \int_{T=T_1}^{T=T_2} dT$$

$$q = 2 \cdot \pi \cdot L \cdot k \frac{T_1 - T_2}{\ln(r_2/r_1)}$$

$$q = \frac{T_1 - T_2}{\dfrac{\ln(r_2/r_1)}{2 \cdot \pi \cdot L \cdot k}}$$

One Dimensional Steady Heat Conduction in Spherical Wall



$$q = -k \cdot A \cdot \frac{dT}{dr}$$

$$r = r_1 \rightarrow T = T_1$$

$$r = r_2 \rightarrow T = T_2$$

$$A = 4 \cdot \pi \cdot r^2$$

$$q \cdot \int_{r=r_1}^{r=r_2} \frac{dr}{r^2} = -k \cdot 4 \cdot \pi \int_{T=T_1}^{T=T_2} dT$$

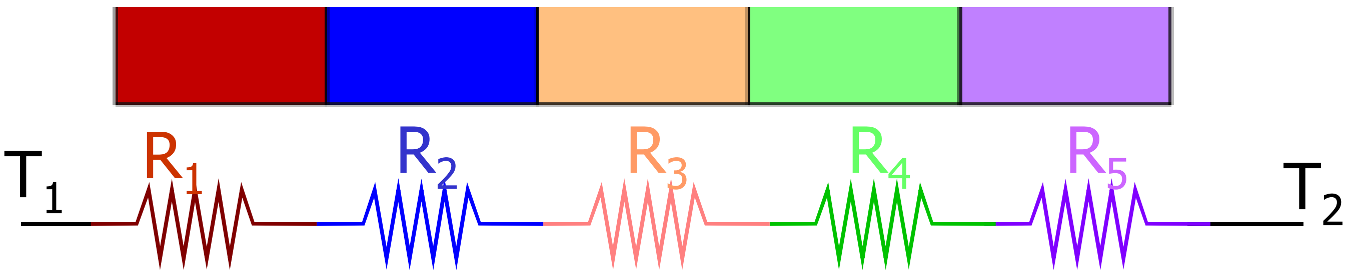
$$q = 4 \cdot \pi \cdot r_1 \cdot r_2 \cdot k \frac{T_1 - T_2}{r_2 - r_1}$$

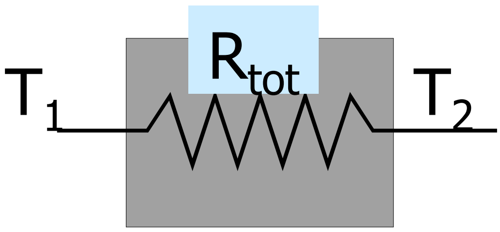
$$q = \frac{T_1 - T_2}{\dfrac{r_2 - r_1}{4 \cdot \pi \cdot r_1 \cdot r_2 \cdot k}}$$

Series thermal resistance

In general, <u>the thermal resistance</u> (R) is the proportionality factor between the cause (ΔT) and the effect (q)

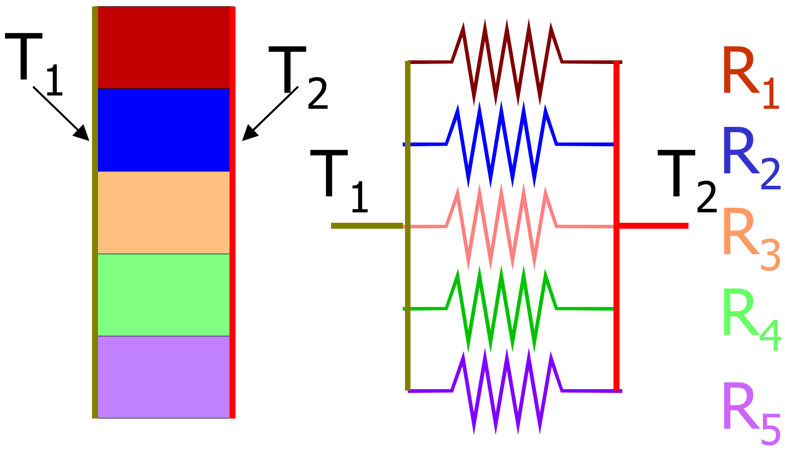
In this thermal resistance network (**Series**) the **heat flux** (current) remains **<u>constant</u>**, whereas the **temperature difference** (voltage difference) **<u>changes for each thermal resistance</u>**.



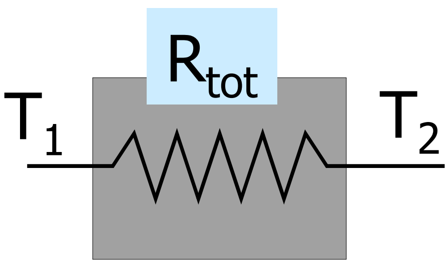


$$R_{tot} = \sum_{i=1}^{n} R_i$$

Parallel thermal resistances



In this thermal resistance network (**Parallel**) the **temperature difference** (voltage difference) remains **<u>constant</u>**, whereas the **heat flux** (current) **<u>changes for each thermal resistance</u>**.

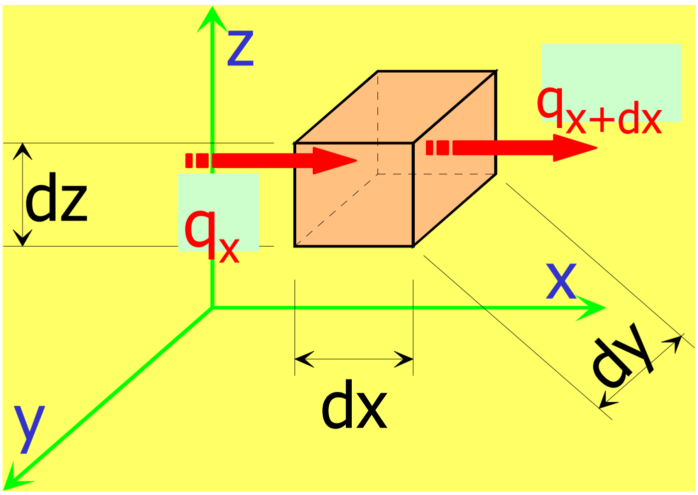


$$\frac{1}{R_{tot}} = \sum_{j=1}^{m} \frac{1}{R_j}$$

Generalised Heat Conduction Equation

Consider a very small element characterised by dimensions (dx, dy, dx), moreover in theis volume is present a heat source . On the basis of the First Law of Thermodynamics. In this case the thermal system is not in steady-state condition, hence the temperature depens by the three geometrical coordinates and time.

The final equation is called ''Generalise Heat Conduction Equation''



$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{k}=\frac{1}{a}\frac{\partial T}{\partial \tau}$$

Where a is the thermal diffusivity $a=\frac{k}{\rho \cdot c_p} \rightarrow \left(\frac{m^2}{s}\right)$

Particular forms of the Generalised Heat Conduction Equation

$$\dot{q} = 0 \quad \Rightarrow \quad a \cdot \nabla^2 T = \frac{\partial T}{\partial \tau}$$ Fourier's Law

$$\frac{\partial T}{\partial \tau} = 0 \quad \Rightarrow \quad \nabla^2 T + \frac{\dot{q}}{k} = 0$$ Poisson's Law

$$\frac{\partial T}{\partial \tau} = 0 \; ; \; \dot{q} = 0 \quad \Rightarrow \quad \nabla^2 T = 0$$ Laplace's Law

Thermophisical properties of some materials

k= thermal conductivity
ρ=density
c=specific heat
a=thermal diffisivity

	k [W/mK]	ρ [kg/m^3]	c [J/kgK]	a [m^2/s]
Diamant	2300	3500	510	1.29E-03
Silver	429	10500	235	1.74E-04
Copper	401	8900	385	1.17E-04
Aluminium	237	2700	902	9.73E-05
Stainless Steel	15	7900	477	3.98E-06
Brick	0.6	1600	600	6.25E-07
Concrite	1.6	1900	880	9.57E-07
Fiberglass	0.04	30	670	1.99E-06
Asbestos (dry)	0.05	135	1000	3.70E-07
Asbestosin (slabs)	0.9	1900	820	5.78E-07
AeroGel	**0.013**	**125(+)-3(*)**	**1000**	(+) - (*)

(+) → $1.04 \cdot 10^{-7}$

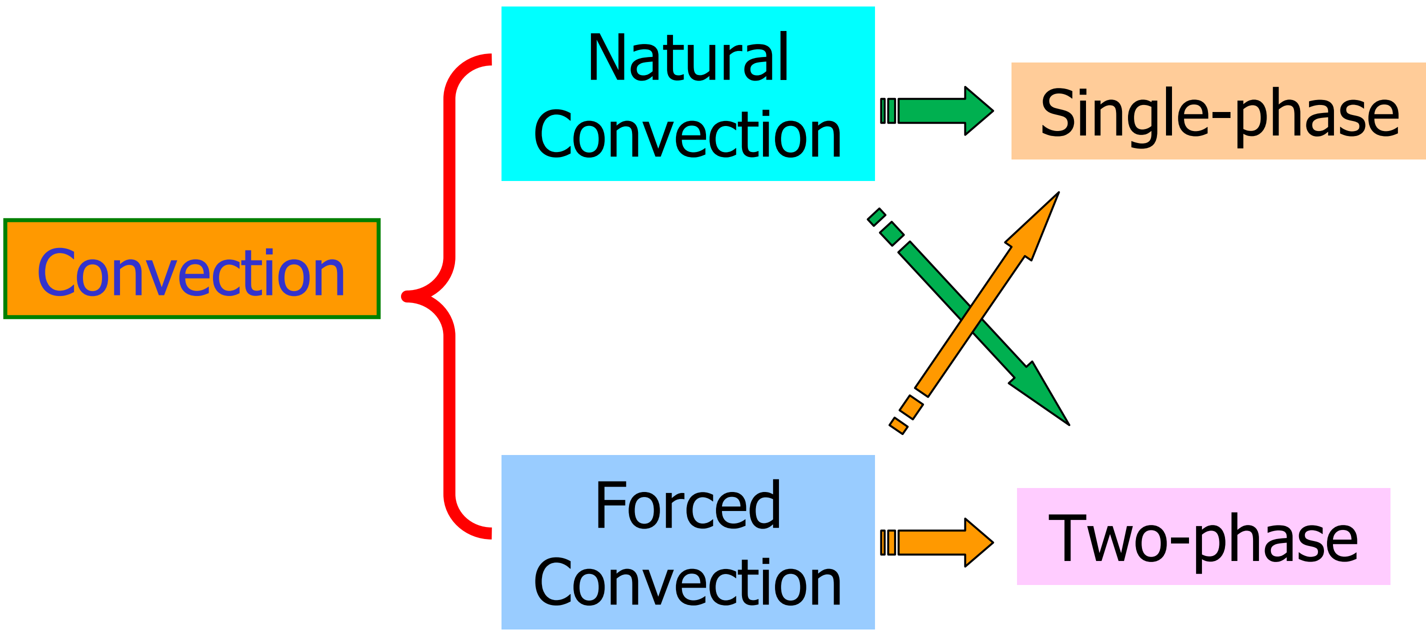
(*) → $4.33 \cdot 10^{-6}$

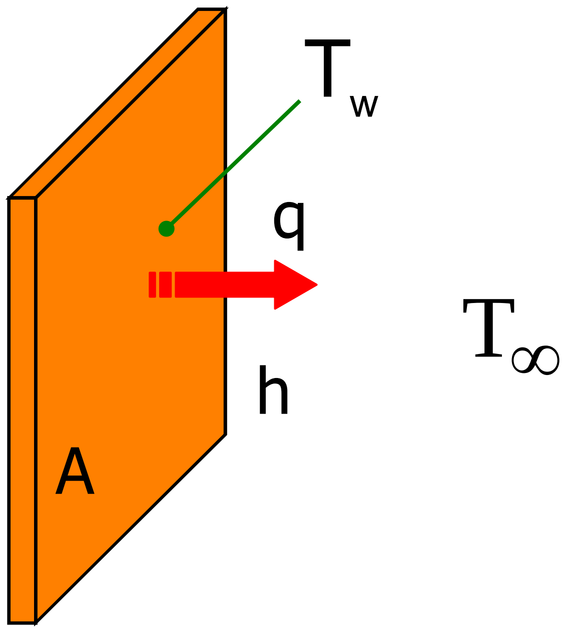
(+) density of the solid
(*) apparent density solid+gel

Thermal Convection

Conduction and **convection** are similar: heat transfer mechanisms **require** the presence of a **material medium** and at the same time needs the presence of **fluid and/or surface motions**.

If the fluid motion is caused by an external cause (pump, fan) it is in the presence of **forced convection.** In **natural convection** the fluid motion is caused by local temperature gradients that generate local density gradients, in the presence of a force field (gravity). The fluid motion follows the Archimedes' law.





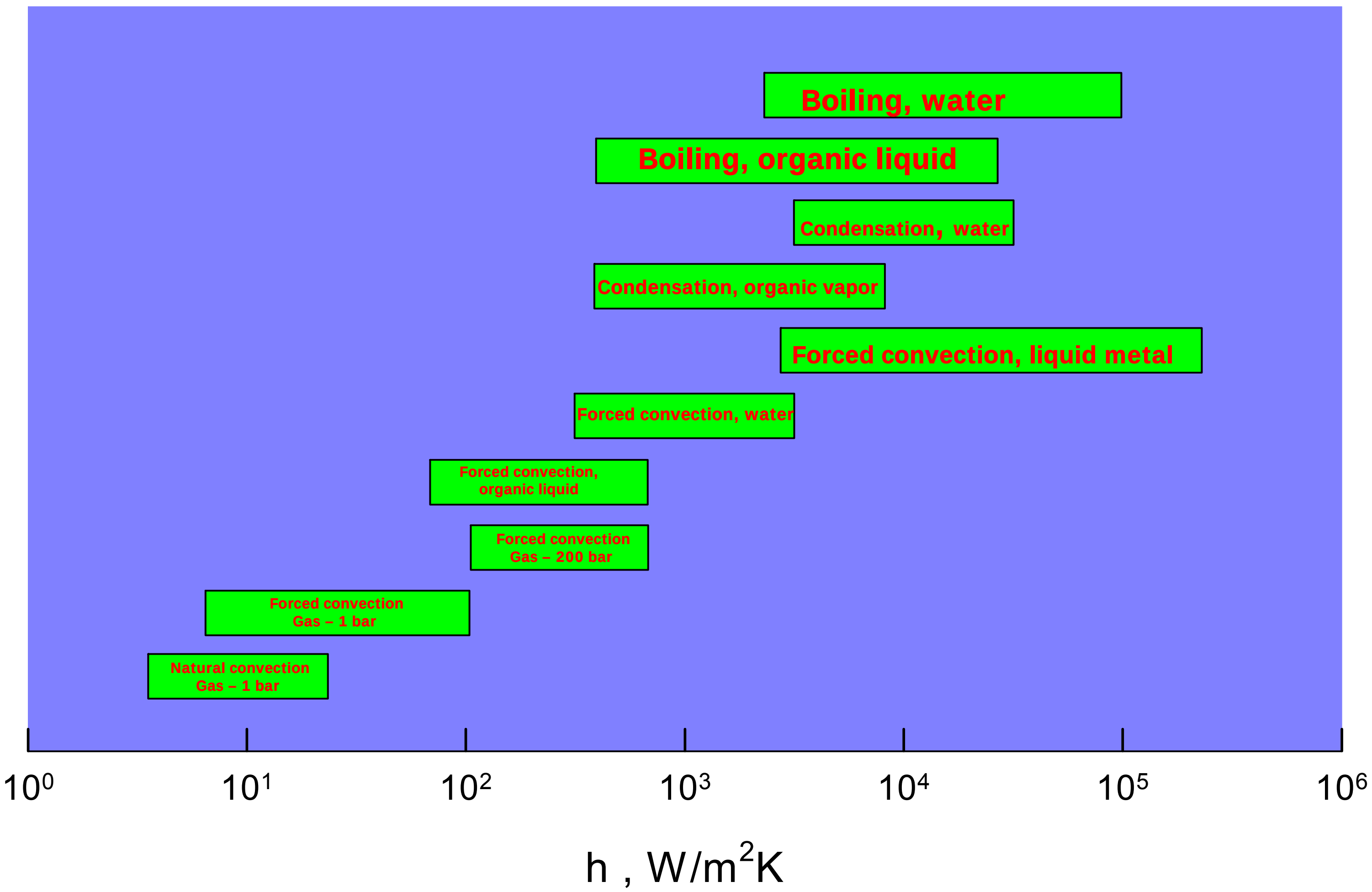
Newton's Law

$$q = h \cdot A \cdot (T_w - T_\infty)$$

$$q = \frac{T_p - T_\infty}{\frac{1}{h \cdot A}}$$

T_w is the surface temperature [K, °C]
T_∞ is the fluid temperature [K, °C]
A is the surface area [m^2]

h is the heat transfer coefficient → $\frac{W}{m^2 \cdot K}$

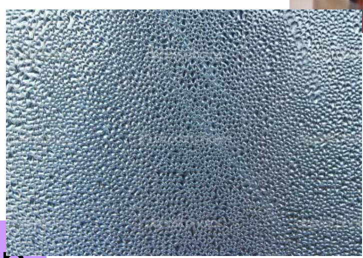


Theraml convection with phase-change

Liquid → Vapour

Evaporation: occurs at the *liquid–vapor interface* when the vapor pressure is less than the saturation pressure of the liquid at a given temperature.

Boiling: occurs at the *solid–liquid interface* when a liquid is brought into contact with a surface maintained at a temperature sufficiently above the saturation temperature of the liquid



Vapour → Liquid

Drops condensation

Film condensation

In the case of building the condensation can be very dangerous.

Evaluation of heat transfer coefficientDimensinless numbers

$$Nu = \frac{h \cdot L}{k}$$

Nusselt

$$\mathbf{Pr} = \frac{\nu \cdot c'}{k}$$

Prandtl

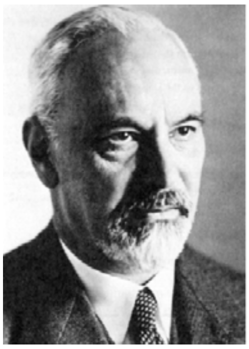
$$\mathbf{Re} = \frac{w \cdot L}{\nu}$$

Reynolds

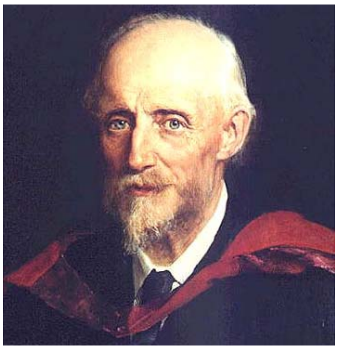
$$Gr = \frac{\beta g \cdot L^3 \cdot \Delta T}{\nu^2}$$

Grashof

Ernest Kraft Wiehelm Nusselt (1882-1957)



Ludwing Prandtl (1875-1953)



Osborne Reynolds (1842-1912)

Franz Grashof (1826-1893)

Nu=f(Re, Pr) ⇨ Forced Convection

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.33}$$

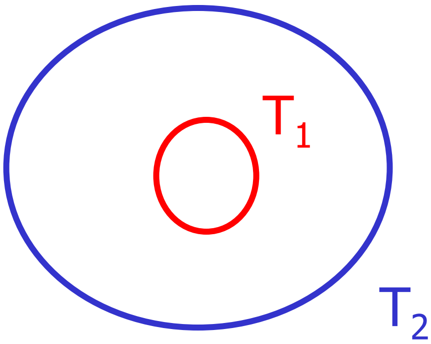
Nu=f(Gr, Pr) ⇨ Natural Convection

$$Nu = 0.59 \cdot (Gr \cdot Pr)^{0.25}$$

h=heat transfer coefficient [W/(m²K)]
L=reference lenght [m]
k=thermal conductivity [W/(mK)]
ν=dinamic viscosity [m²/s]
c'=ρ·c [W/(m³K)]
c=specific heat [J/(kgK)]
w=fluid velocity [m/s]
g=gravity acceleration [m/s²]
ΔT=temperature difference (wall-fluid) [K]
β=volume expansion coefficient [1/K]

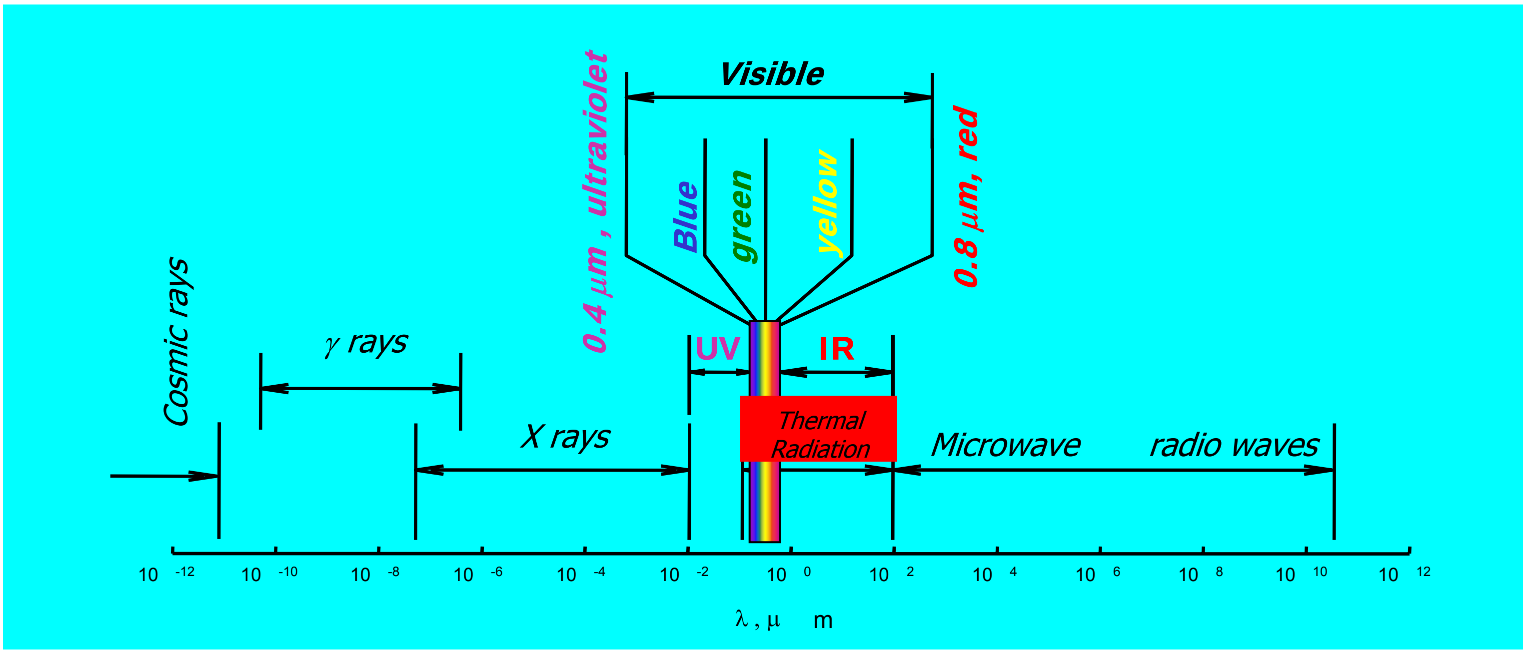
Thermal Radiation

A body at a surface temperature of T_1 place inside a cavity in which it was made the vacuum, it will be cooled or heated depending on the temperature of the cavity T_2 when $T_2 < T_1$ or $T_2 > T_1$, respectively. The heat exchange mechanism by which heat is transmitted from a hotter surface to a cooler surface (2^{nd} Law of Thermodynamic) without the AID of medium, it is said THERMAL RADIATION



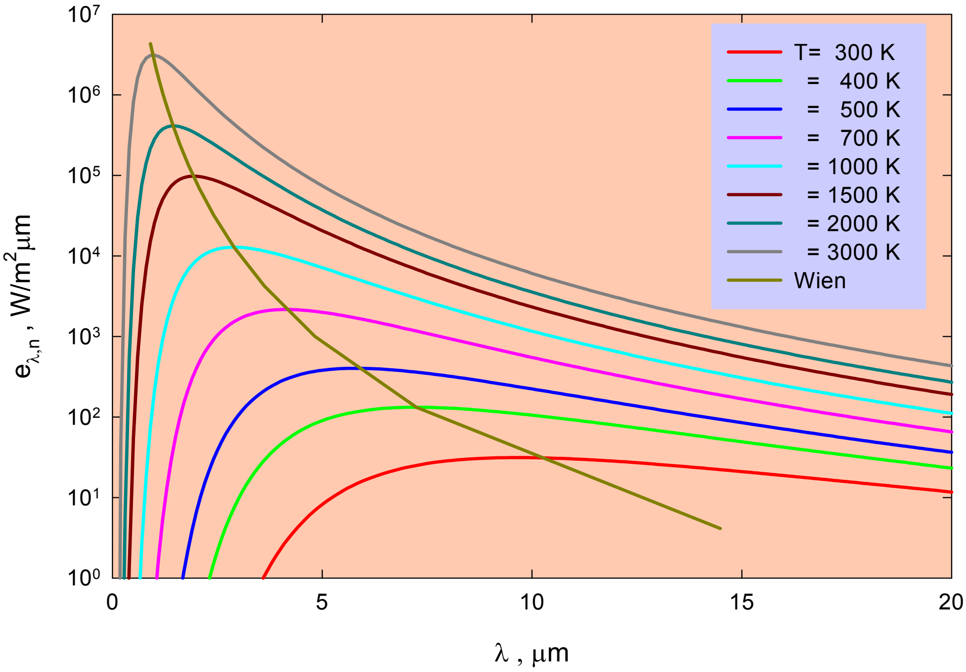
The emitted energy, in the form of electromagnetic waves, depends on the TEMPERATURE ABSOLUTE of the surface and from the surface NATURE

Spectrum of electromagnetic waves



$0.1 \leq$ thermal radiation wavelenght ≤ 100 μm
$0.4 \leq$ visible radiation wavelenght ≤ 0.8 μm

Spectral blackbody emissive power Planck's Law



$$e_{\lambda,n} = \frac{C_1}{\lambda^5 \cdot (e^{C_2/\lambda \cdot T} - 1)}$$

$$C_1 = 3.743 \cdot 10^8 \left[\frac{W \cdot \mu m^4}{m^2}\right]$$

$$C_2 = 1.439 \cdot 10^4 \ [\mu m \cdot K]$$

$$E_n = \int_0^\infty e_{\lambda,n}(\lambda, T) \cdot d\lambda = \sigma \cdot T^4 \left[\frac{W}{m^2}\right]$$

$$\sigma = 5.67 \cdot 10^{-8} \left[\frac{W}{m^2 \cdot K^4}\right]$$

Stefan's Law

$e_{\lambda,n}$ =<u>spectral</u> blackbody emissive power
E_n =<u>total</u> blackbody emissive power

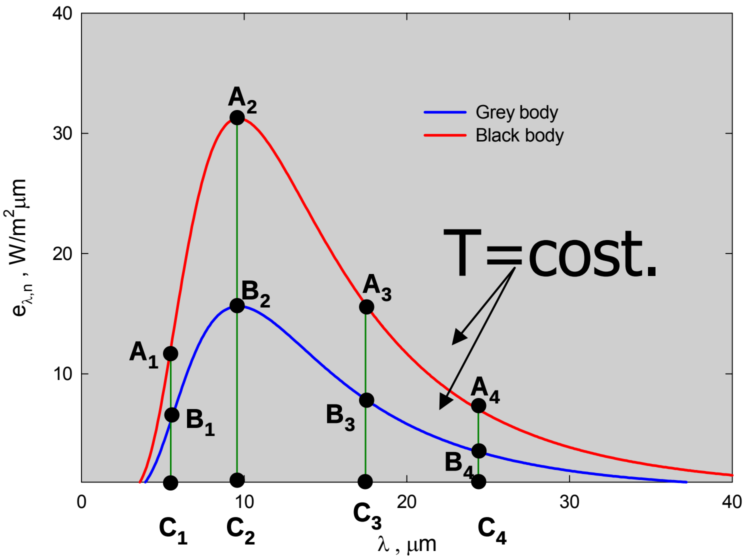
The amount of radiation energy emitted from a surface at a given wavelength depends on:
the material of the body and the condition of its surface,
the absolute surface temperature.
The blackbody is a model that is characterized by the maximum amount of radiation that can be emitted by a surface at a given temperature.
At a specified temperature and wavelength, no surface can emit more energy than a blackbody.

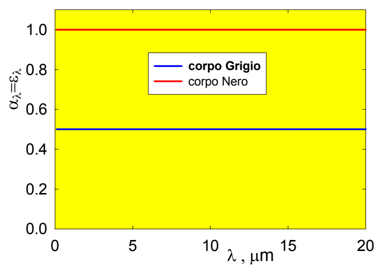
The wavelength at which the peak of $e_{\lambda,n}$ occurs is given by <u>Wien's displacement law</u>

$$\lambda_{max} \cdot T = 2898 \ \ [\mu m \cdot K]$$

Spectral **gray body** emissive power

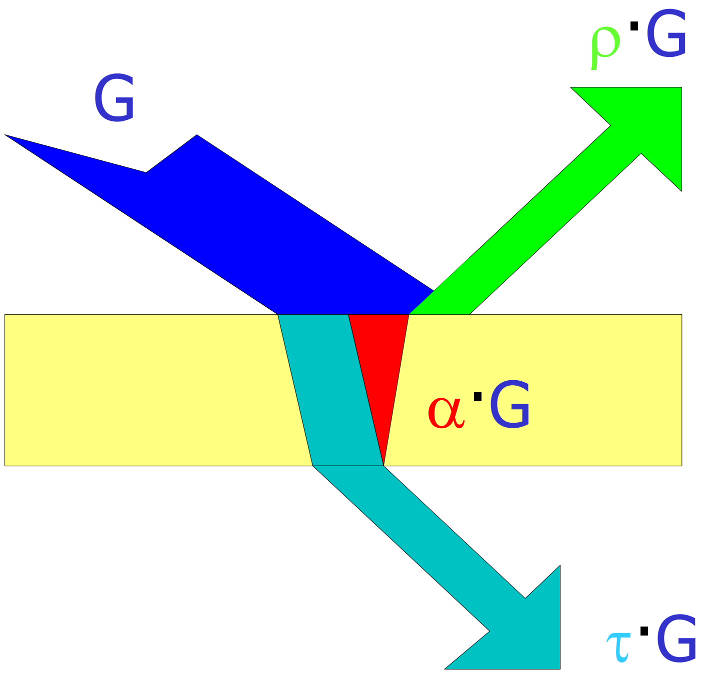
$$\frac{\overline{B_1C_1}}{\overline{A_1C_1}} = \frac{\overline{B_2C_2}}{\overline{A_2C_2}} = \frac{\overline{B_3C_3}}{\overline{A_3C_3}} = \frac{\overline{B_4C_4}}{\overline{A_4C_4}} = 0.5$$





$$E = \varepsilon \cdot \int_0^\infty e_{\lambda,n} \cdot d\lambda = \varepsilon \cdot \sigma \cdot T^4$$

Radiative properties of materials

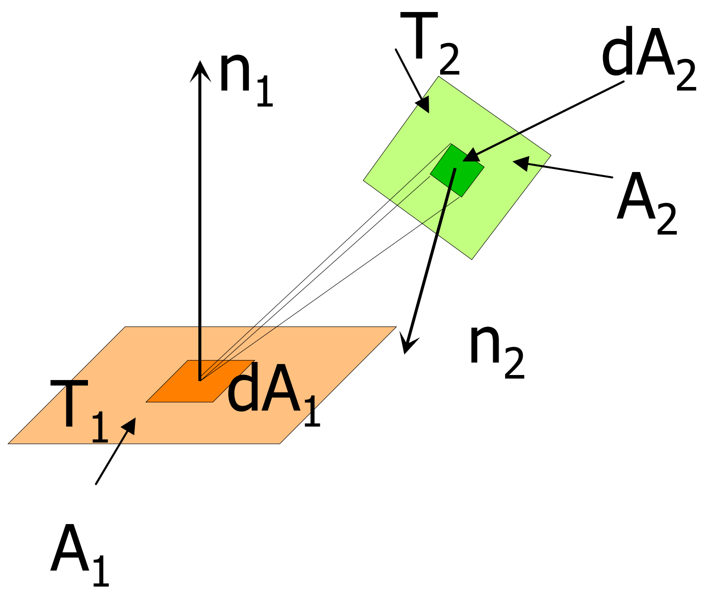


$$G = \rho \cdot G + \alpha \cdot G + \tau \cdot G$$

$$1 = \rho + \alpha + \tau$$

$\rho \rightarrow$ Reflectivity
$\alpha \rightarrow$ Absorptivity
$\tau \rightarrow$ Transmissivity

Radiation Heat Transfer between "black bodies"
View Factor



Radiation heat transfer between black surfaces depends on the orientation of the surfaces relative to each other as well as their surface temperatures.

View factor ($F_{i,j}$) is defined to account for the effects of orientation on radiation heat transfer between two surfaces.
View factor is a purely geometric quantity and is independent of the surface properties and temperature.

$$q_{1\to 2} = E_{n1} \cdot A_1 \cdot F_{1-2}$$

$$q_{2\to 1} = E_{n2} \cdot A_2 \cdot F_{2-1}$$

$F_{i,j}$ is the amonunt of the radiation energy emittes by surface "i" and intercepted by the surface "j"

$$q_{1,2} = q_{1\to 2} - q_{2\to 1} = E_{n1} \cdot A_1 \cdot F_{1-2} - E_{n2} \cdot A_2 \cdot F_{2-1}$$

$$\text{if } T_1 = T_2 \Rightarrow q_{1,2} = 0 \Rightarrow A_1 \cdot F_{1-2} = A_2 \cdot F_{2-1}$$

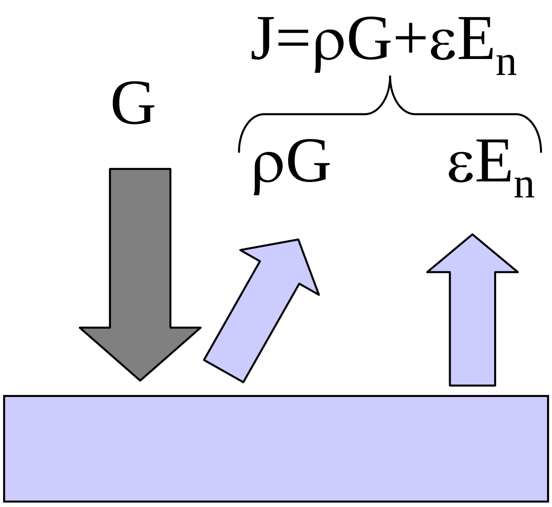
reprocity relation

$$q_{1,2} = A_1 \cdot F_{1-2} \cdot (E_{n1} - E_{n2}) = A_2 \cdot F_{2-1} \cdot (E_{n1} - E_{n2})$$

$$q_{1,2} = A_1 \cdot F_{1-2} \cdot \sigma(T_1^4 - T_2^4) = A_2 \cdot F_{2-1} \cdot \sigma(T_1^4 - T_2^4)$$

Radiation Heat Transfer between “gray bodies”

In the case of gray body we must consider that the surface is characterized by the following relationship $\alpha+\rho+\tau=1$. This formula for a opaque surface simplifies as $\alpha+\rho=1$ being $\tau=0$.
Consider a gray surface on which radiation affects a G and assume that $\alpha=\varepsilon$.



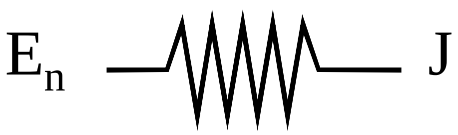
The total energy J that leaves the surface will be the sum of the contributions relating to both the reflected component ρG and that emitted component εE_n. With J will indicate the radiosity, whose expression is:

$J= \rho\ G+\varepsilon E_n$

The net flow which leaves the surface per unit area will be:

$$q''=\frac{q}{A}=J-G=$$

$$=\frac{E_n-J}{\frac{1-\varepsilon}{\varepsilon}}\Rightarrow q=\frac{E_n-J}{\frac{1-\varepsilon}{A\varepsilon}}$$



$$\frac{1-\varepsilon}{A\varepsilon}$$

The denominator represents a <u>surface thermal resistance</u>

The report previously obtained refers to the energy balance of the i-th surface. In case of more heat exchange surfaces that you have to put in the various reports radiosity. Assuming, for simplicity, two gray surfaces a and b which exchange heat by radiation, the net heat transfer will be assessable involving the view factors

$$q_{a\rightarrow b}=A_aF_{ab}J_a \qquad ; \qquad q_{b\rightarrow a}=A_bF_{ba}J_b$$

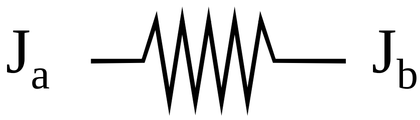
The net heat flow will be:

$$q_{ab} = A_a F_{ab}(J_a - J_b) = A_b F_{ba}(J_a - J_b)$$

More simply, you can write:

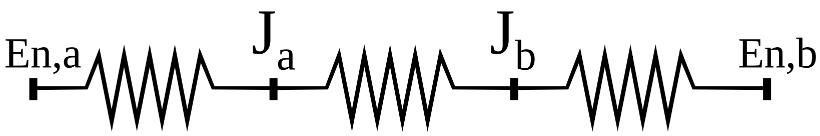
$$q_{ab} = A_a F_{ab}(J_a - J_b) = \frac{J_a - J_b}{\frac{1}{A_a F_{ab}}} = \frac{J_a - J_b}{R_{ab}}$$

Where R_{ab} is a thermal resistance between the two radiosities J_a and J_b.



$$R_{ab} = \frac{1}{A_a F_{ab}}$$

This final relationship allows to evaluate the heat exchange q_{ab} between gray surfaces, and it takes into account both the surface thermal resistance and the geometric thermal resistance.



$$\frac{1-\varepsilon_a}{A_a \varepsilon_a} \qquad \frac{1}{A_a F_{ab}} \qquad \frac{1-\varepsilon_b}{A_b \varepsilon_b}$$

$$q_{ab} = \frac{\sigma(T_a^4 - T_b^4)}{\frac{1-\varepsilon_a}{A_a \varepsilon_a} + \frac{1}{A_a F_{ab}} + \frac{1-\varepsilon_b}{A_b \varepsilon_b}}$$

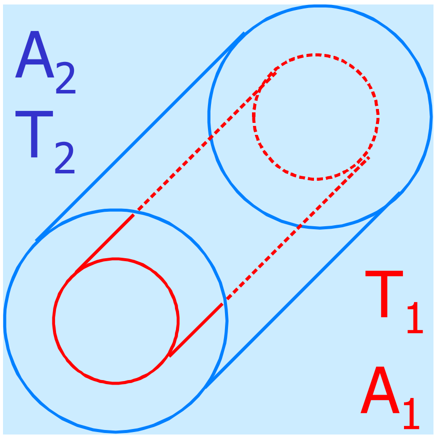
Examples of radiation heat exchange between gray surfaces

Plain surfaces

$A_1=A_2$; $F_{1,2}=F_{2,1}=1$

$$q''=\frac{\sigma\cdot(T_1^4-T_2^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}$$

Concentric cylinders



$F_{1,2}=1$

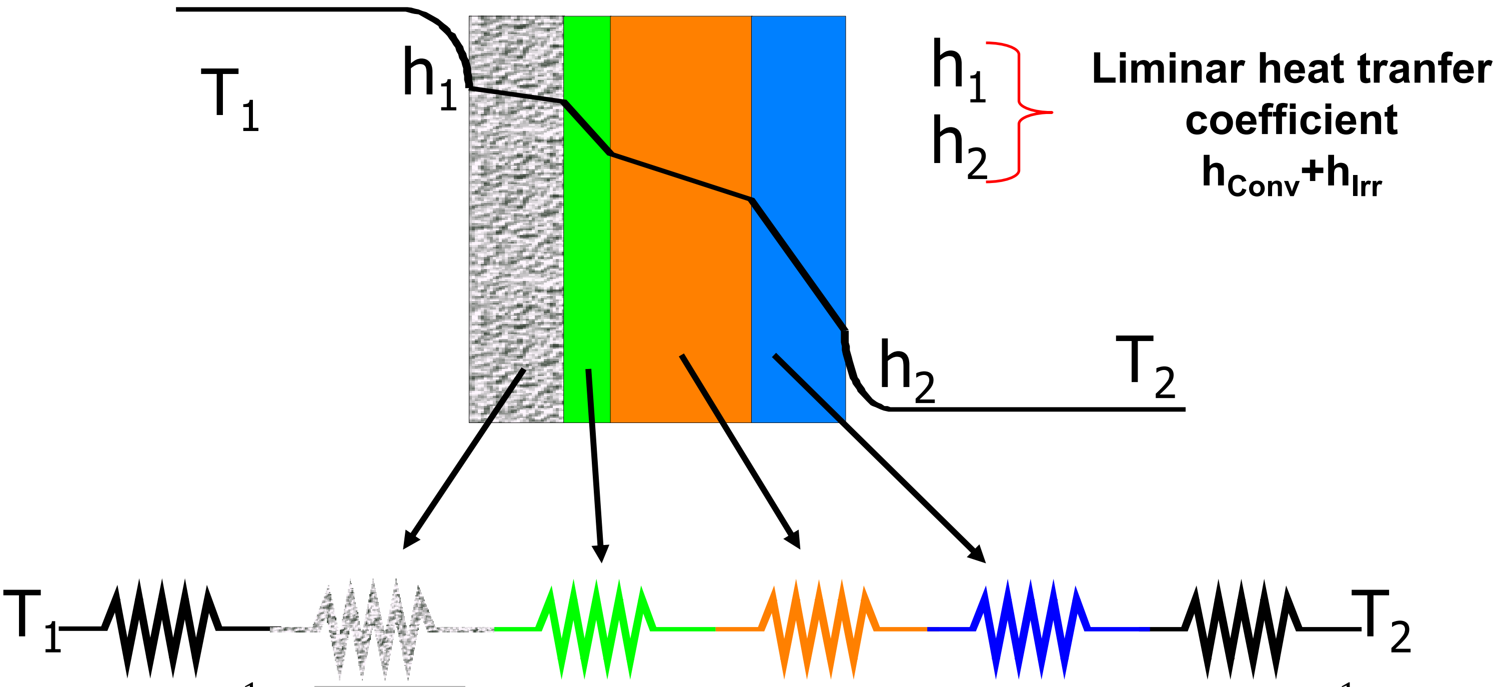
$$q=\frac{\sigma\cdot(T_1^4-T_2^4)}{\frac{1}{\varepsilon_1\cdot A_1}+\frac{1}{\varepsilon_2\cdot A_2}-\frac{1}{A_2}}=\frac{\sigma\cdot A_1\cdot(T_1^4-T_2^4)}{\frac{1}{\varepsilon_1}+\frac{A_1}{A2}\left(\frac{1}{\varepsilon_2}-1\right)}$$

Heat Transfer coefficient by radiation

$$q''=\frac{\sigma\cdot(T_1^4-T_2^4)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}=\frac{\sigma\cdot(T_1^2+T_2^2)\cdot(T_1+T_2)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}\cdot(T_1-T_2)=h_i\cdot(T_1-T_2)=\frac{T_1-T_2}{\frac{1}{h_i}}$$

$$q=\frac{\sigma\cdot(T_1^4-T_2^4)}{\frac{1}{\varepsilon_1}+\frac{A_1}{A2}\left(\frac{1}{\varepsilon_2}-1\right)}=\frac{\sigma\cdot(T_1^2+T_2^2)\cdot(T_1+T_2)}{\frac{1}{\varepsilon_1}+\frac{A_1}{A2}\left(\frac{1}{\varepsilon_2}-1\right)}\cdot A_1\cdot(T_1-T_2)=h_i\cdot A_1\cdot(T_1-T_2)=\frac{T_1-T_2}{\frac{1}{h_i\cdot A_1}}$$

Overall heat transfer coefficient



$(R_{Conv+Irr})_1 = \frac{1}{h_1}$ $(R_{Cond})_1 = \frac{L_1}{k_1}$ $(R_{Cond})_2 = \frac{L_2}{k_2}$ $(R_{Cond})_3 = \frac{L_3}{k_3}$ $(R_{Cond})_4 = \frac{L_4}{k_4}$ $(R_{Conv+Irr})_2 = \frac{1}{h_2}$

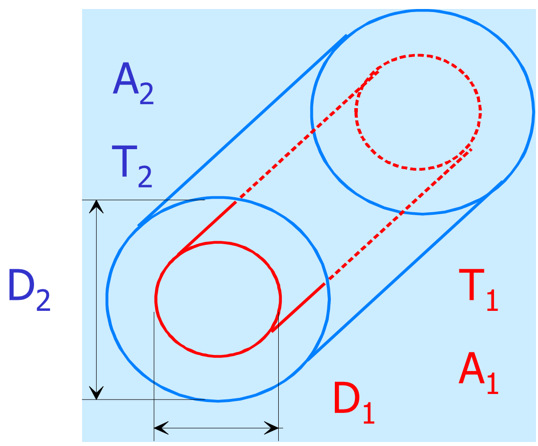
Plane geometry

$$K = \frac{1}{R_{tot}} = \frac{1}{\frac{1}{h_1} + \sum_{i=1}^{n} \frac{L_i}{k_i} + \frac{1}{h_2}}$$

Overall heat transfer coefficient

$$K \Rightarrow \left[\frac{W}{m^2 \cdot K}\right]$$

Cylindrical geometry



$$q = K_1 \cdot A_1 \cdot (T_1 - T_2) = K_2 \cdot A_2 \cdot (T_1 - T_2)$$

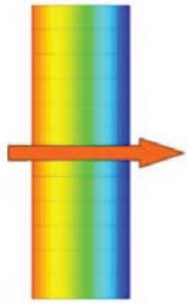
$$K_1 = \frac{1}{\frac{D_1}{h_2 \cdot D_2} + \frac{D_1}{2 \cdot k} \cdot \ln(\frac{D_2}{D_1}) + \frac{1}{h_1}}$$

$$K_2 = \frac{1}{\frac{1}{h_2} + \frac{D_2}{2 \cdot k} \cdot \ln(\frac{D_2}{D_1}) + \frac{D_2}{h_1 \cdot D_1}}$$

Thermal bridge

In the heat transfer by conduction a major hypothesis is to have a one-dimensional model as well as consider the homogeneous and isotropic materials.

However the **building envelope** is never perfectly homogeneous and has discontinuities, both geometric (eg. corner) ad different materials. Therefore the hypothesis on the one-dimensional flow is no longer satisfied. These geometric and / or structural configurations, which produce such deviations, **are known as thermal bridges**



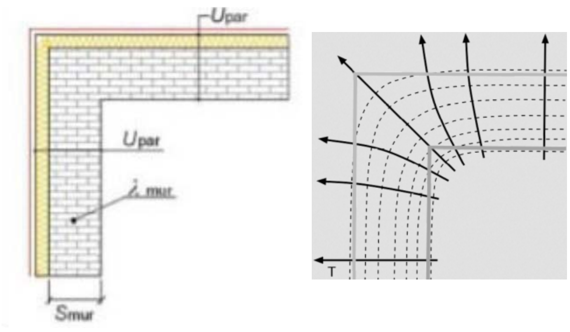
Thermal bridge classification

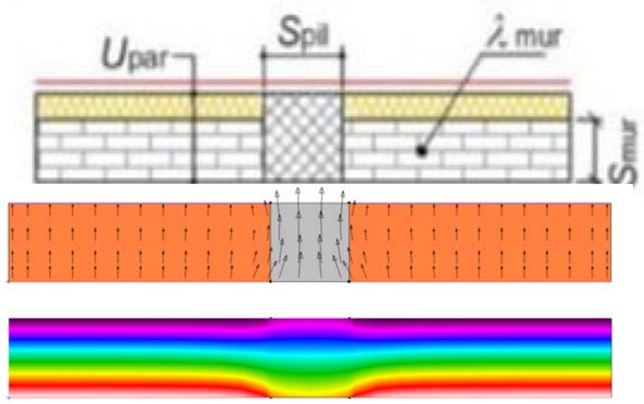
Thermal bridges can be of three types:

•shaped thermal bridges, where the diversion of the heat flow is due solely to the part geometry;

•structure of thermal bridges, where the thermal flux deviation is due to the presence of a constructive element of a different material; thermal

•bridges of a mixed type, the heat flux deviation is due to the presence of both thermal bridges listed previously.



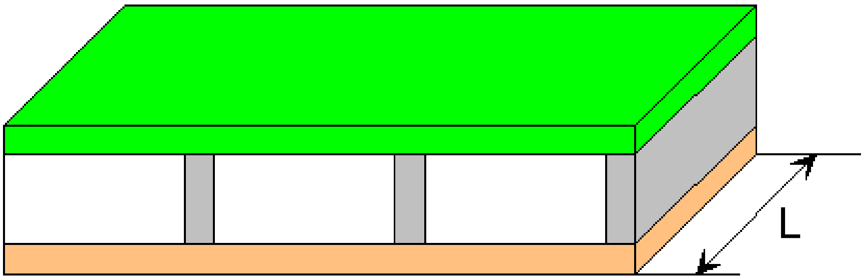


shaped thermal bridges

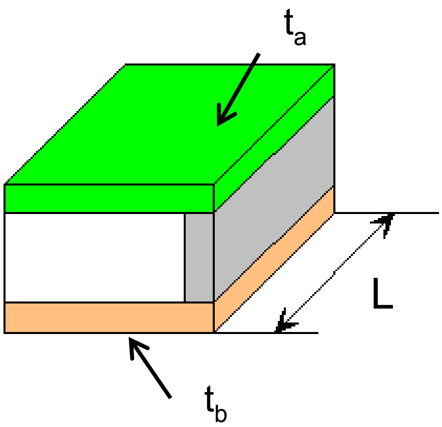
structure of thermal bridges

Example of thermal bridge

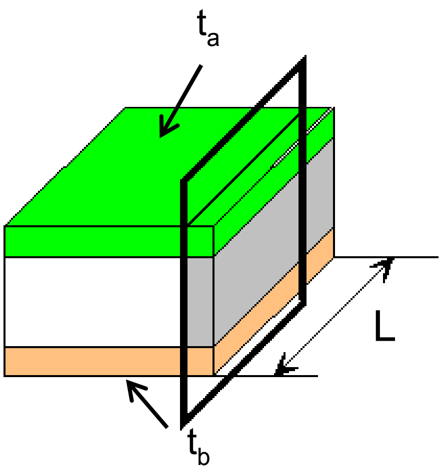
In the figure is shown schematically a floor. It consists of repetitive elements. Each color means a different thermal conductivity.

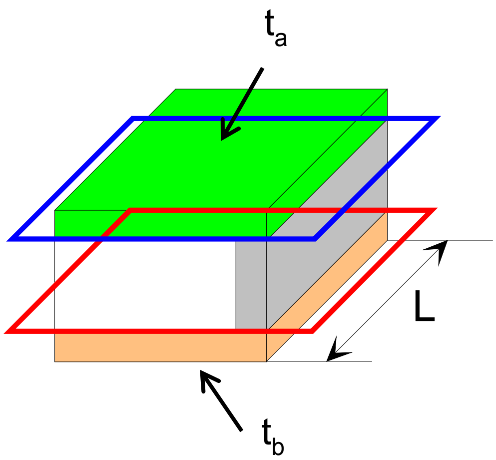


To analyze this floor you can select the single repetitive element



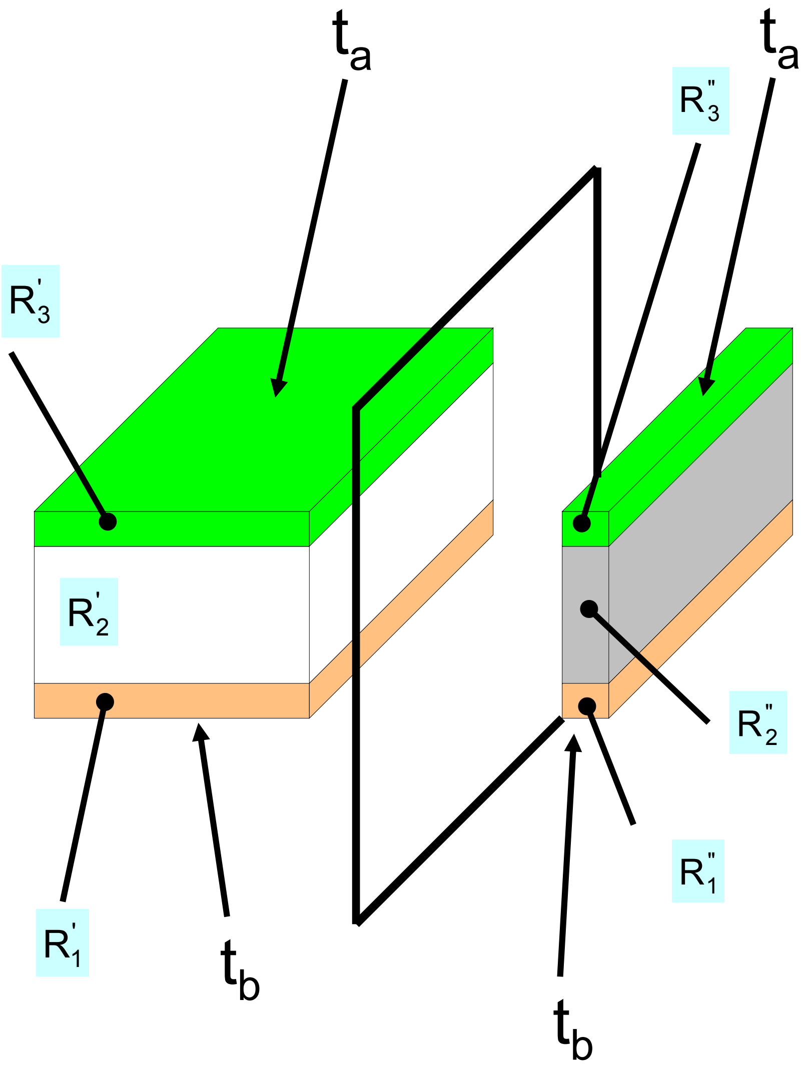
The single element can be designed in different ways, in term of thermal resistances, this for the fact that each element is characterized by a different thermal conductivity.

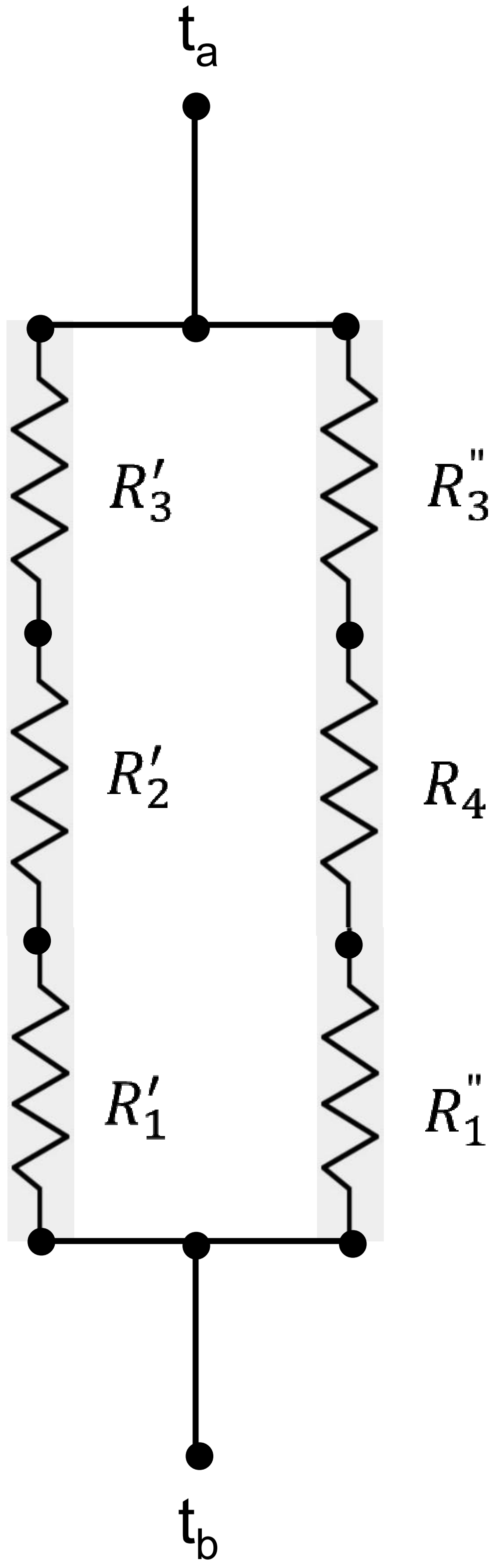




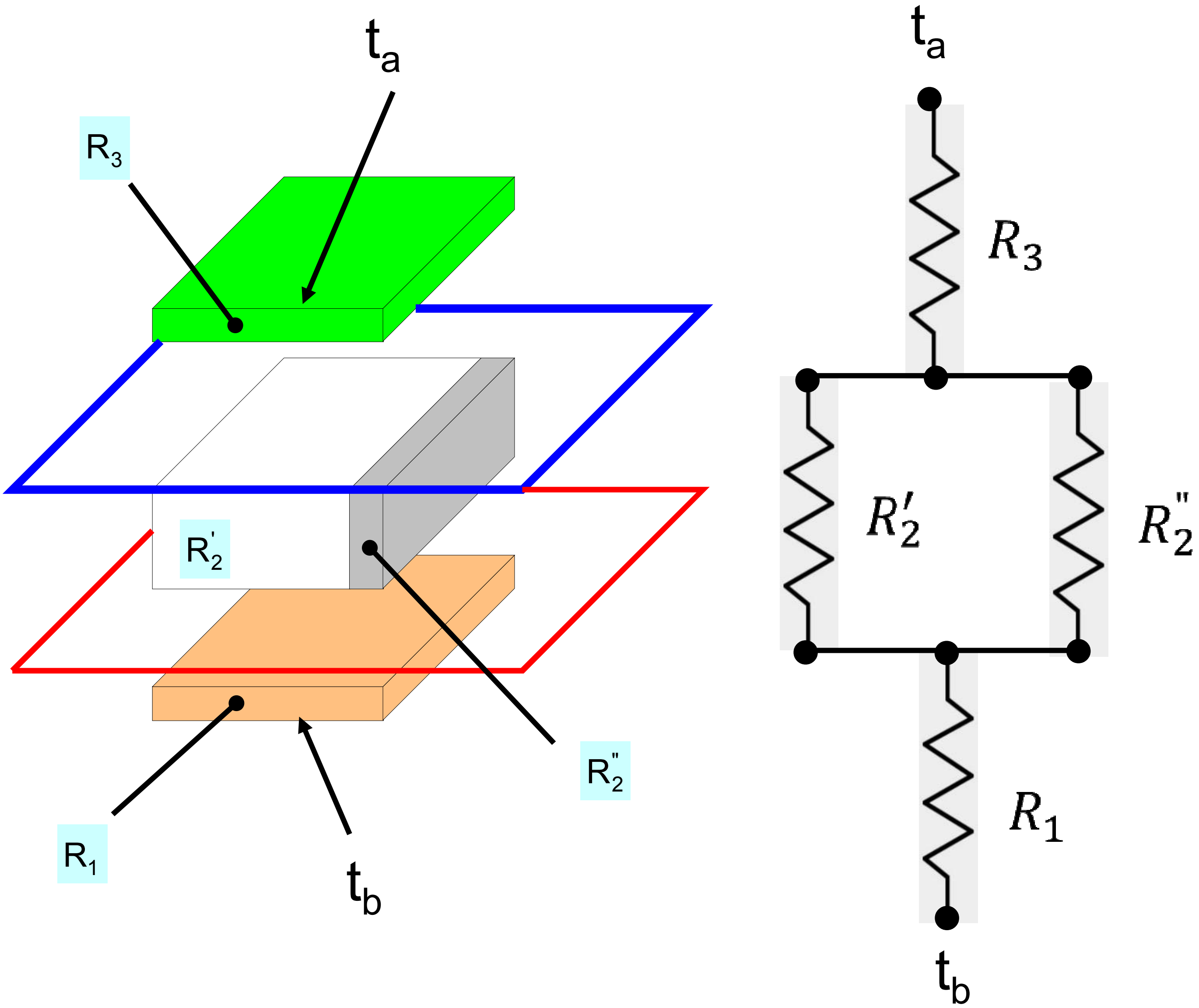
Scheme A **Scheme B**

Scheme A





Scheme B



Notes

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