



HVAC Load Calculation

Thermal Transmittance

march 2025



Program

- Non-homogeneous structures
- Equivalent resistive networks
- Resistance calculation
- Equivalent transmittance calculation
- example

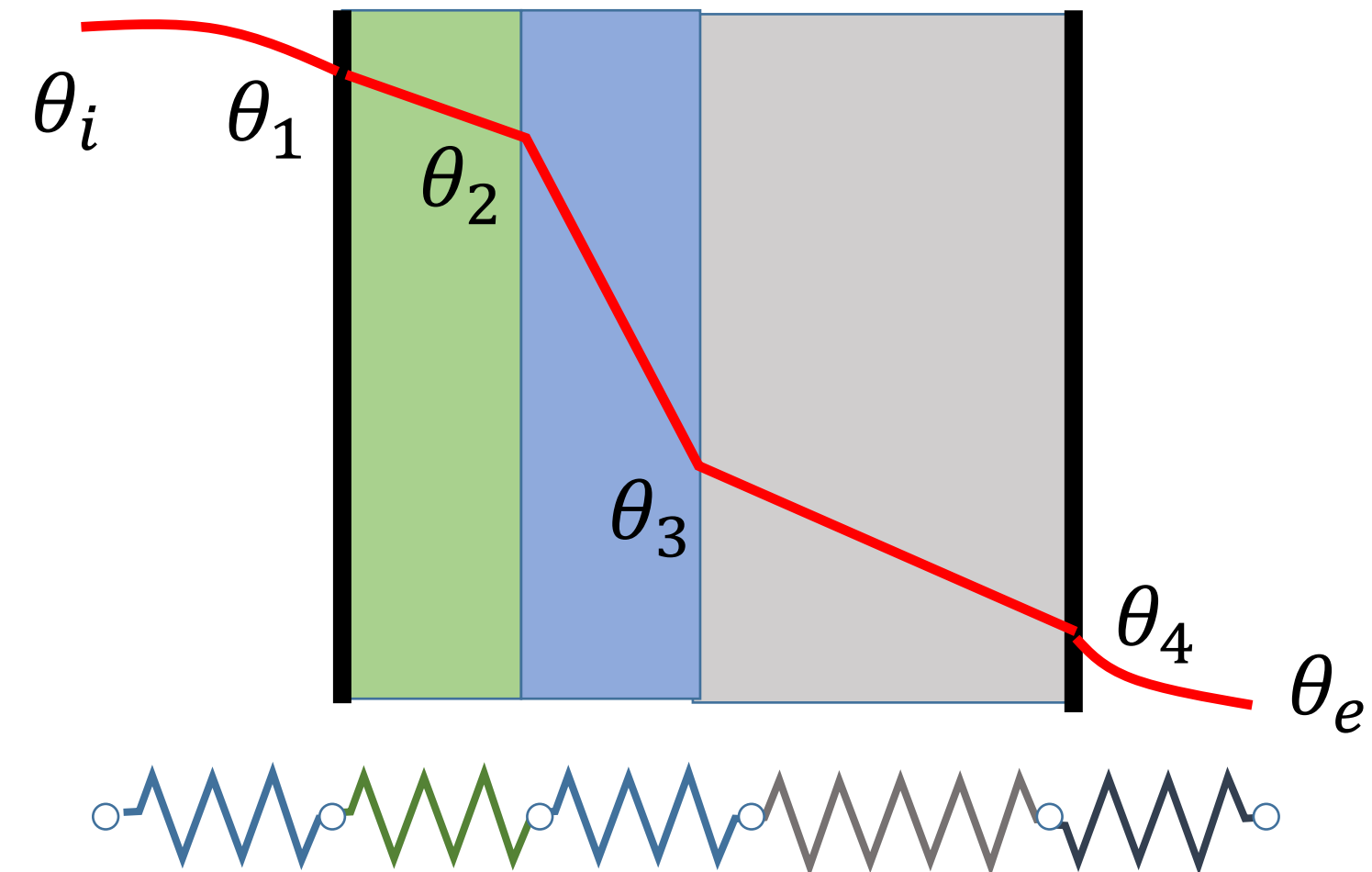
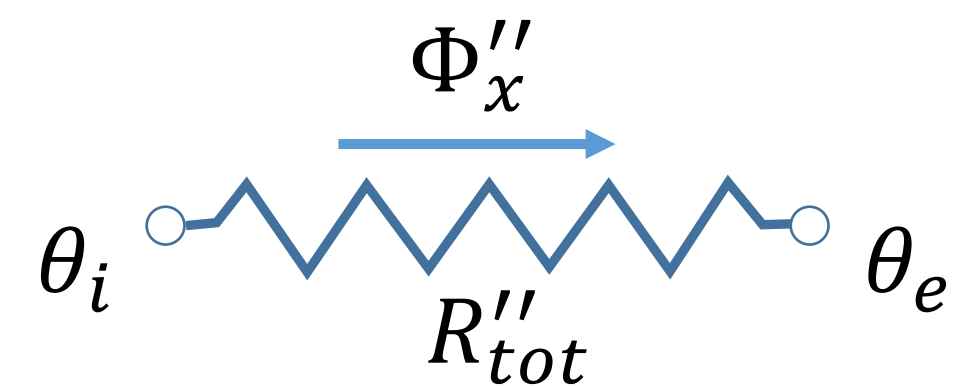
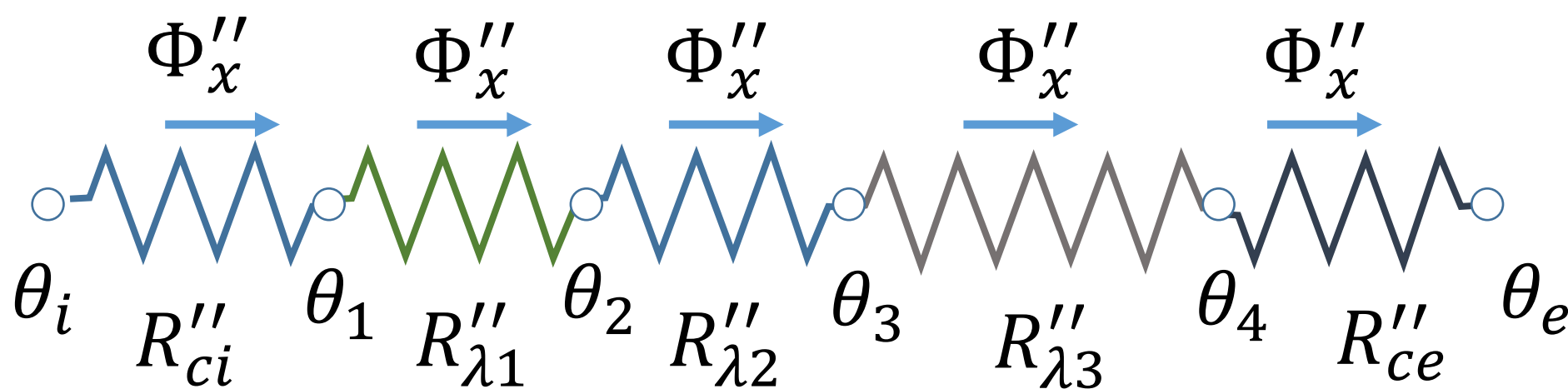




Electrical Net equivalence, composite wall

- Multilayered wall
- Solve the problem with equivalent net

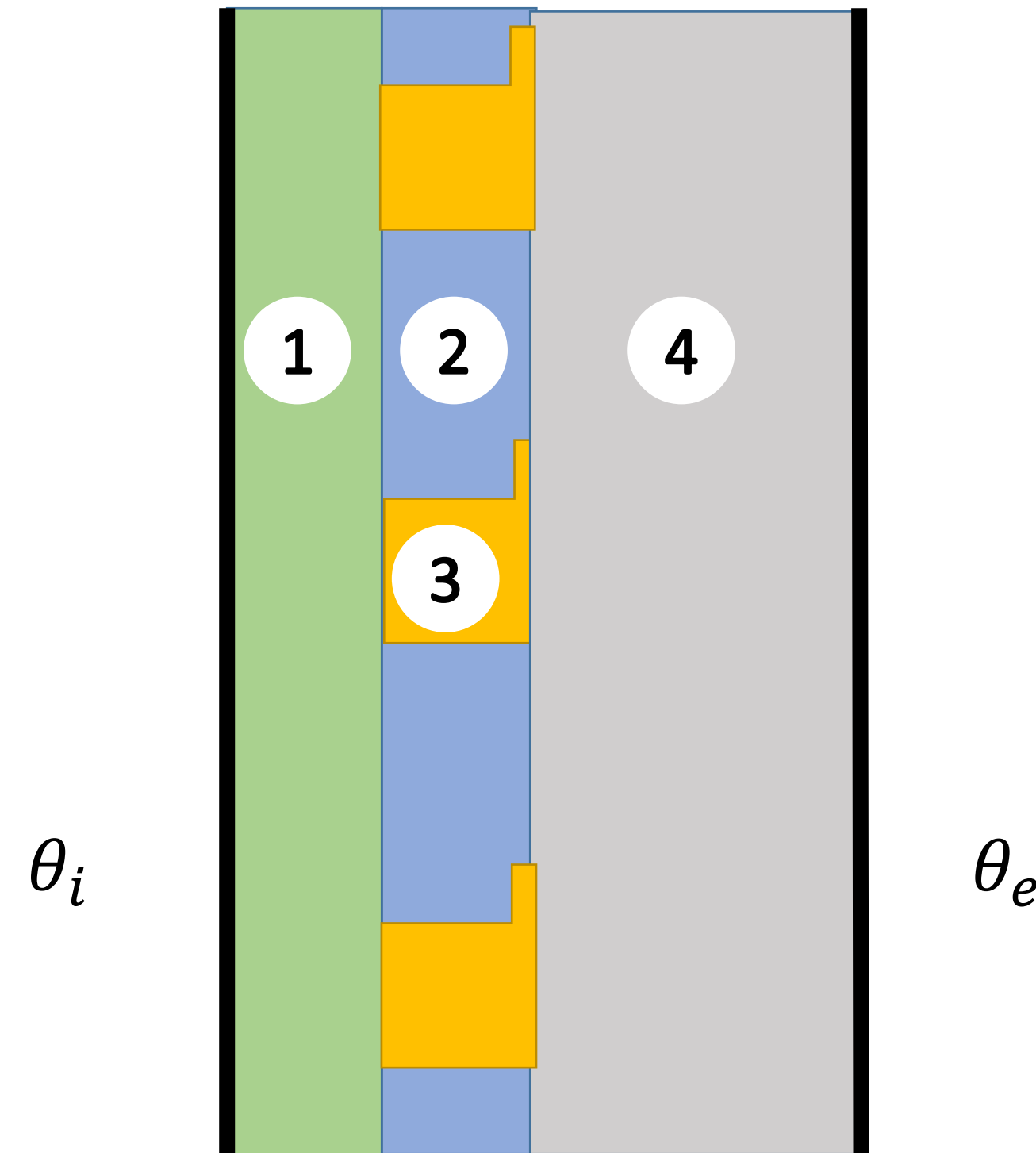
$$\Phi''_x = \frac{\theta_i - \theta_e}{R''_{tot}}$$
$$R''_{tot} = R_{ci} + \sum_j R_{\lambda,j} + R_{ce}$$





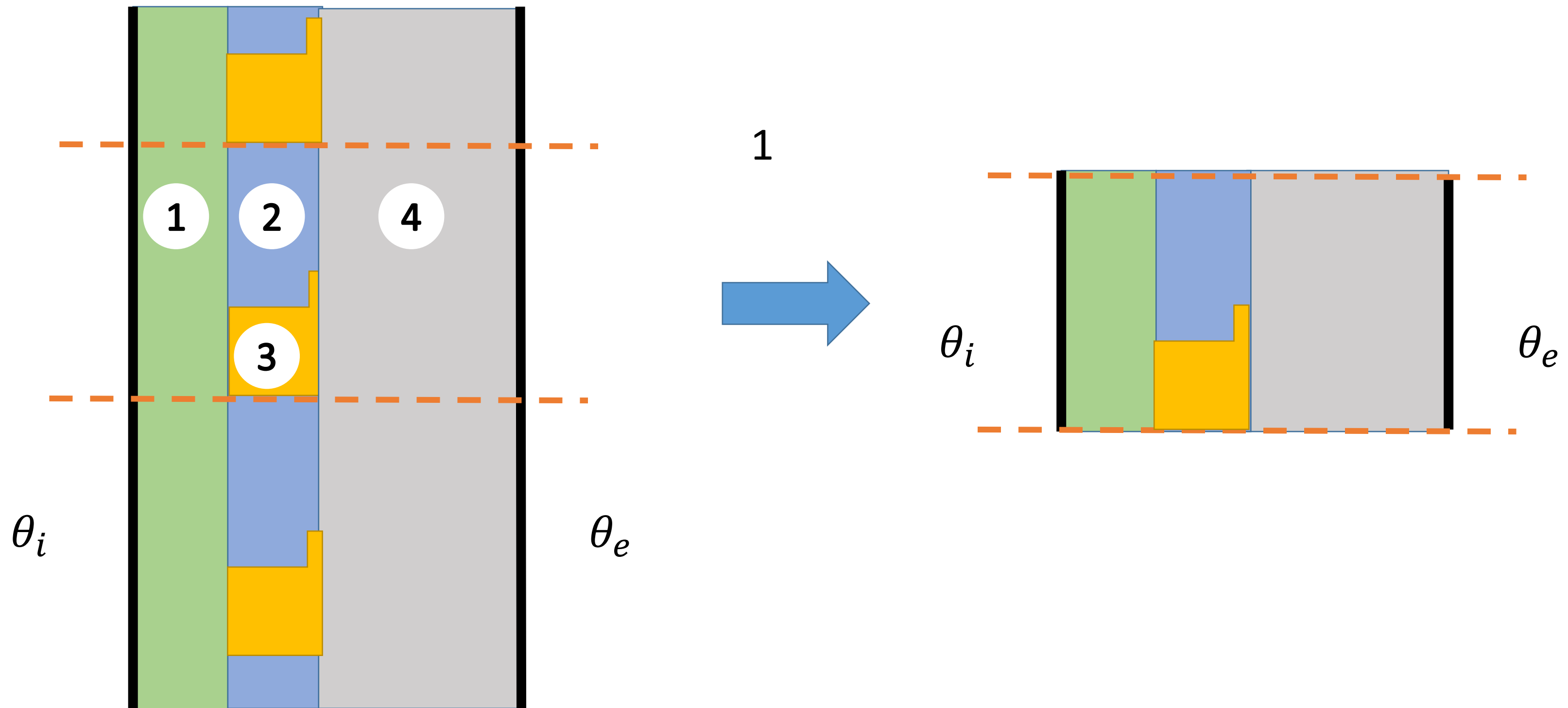
How to deal with uneven walls?

- Typical case with uneven material
- Different materials
- Very common in buildings
- For example: internal insulation systems



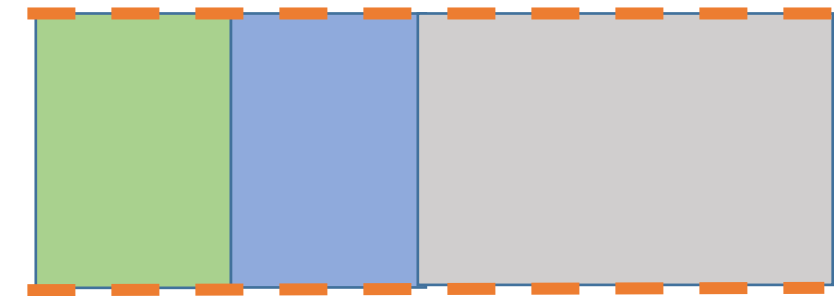
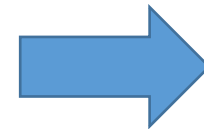
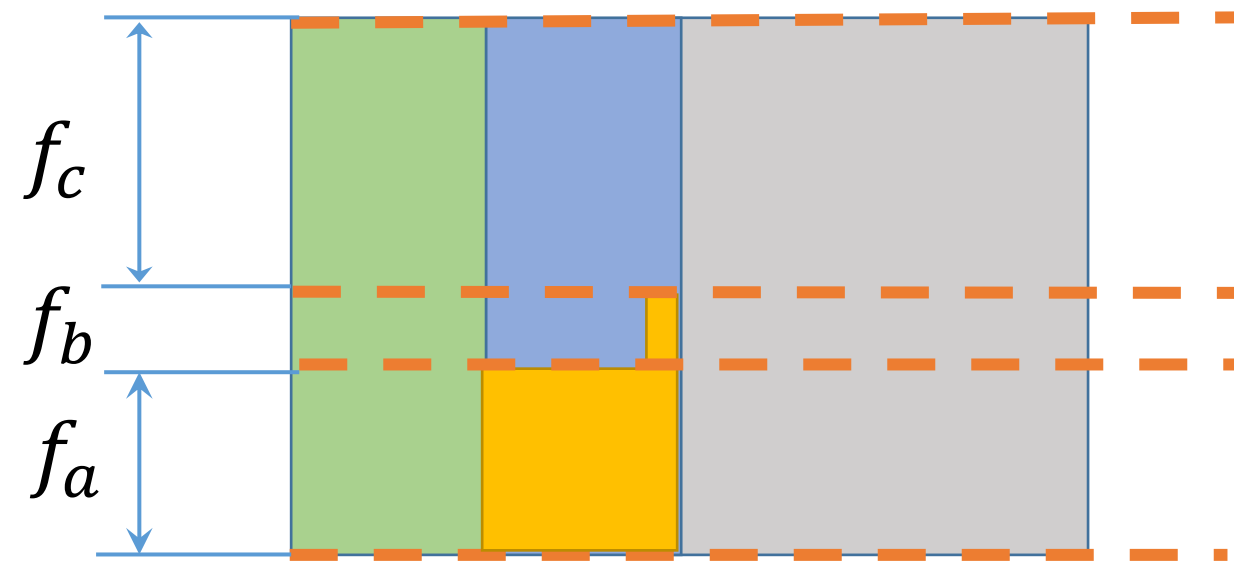


Periodic geometry



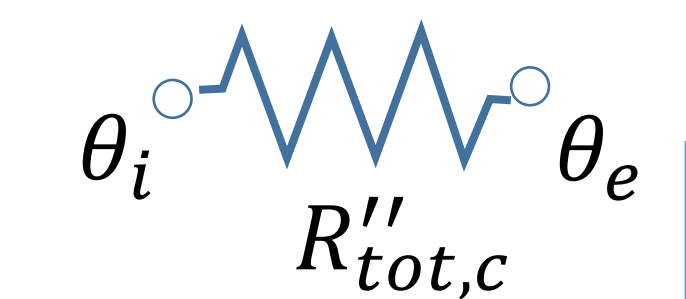
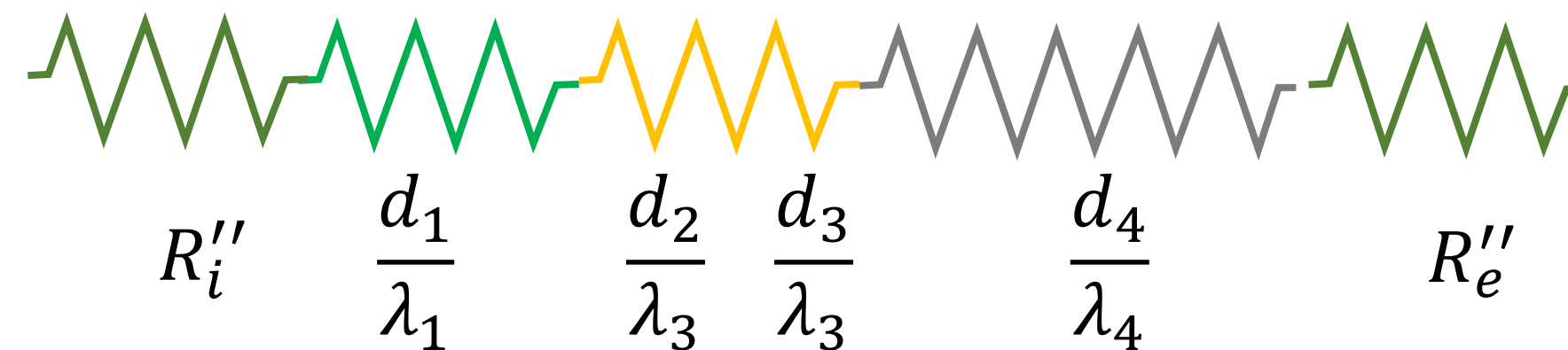
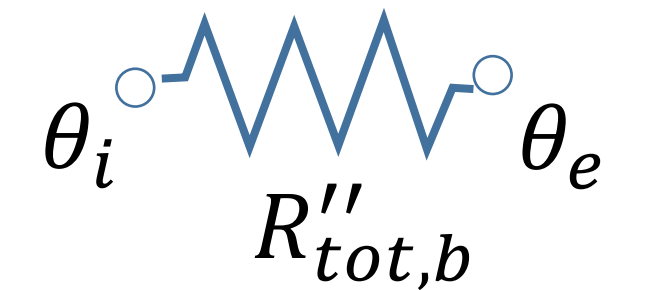
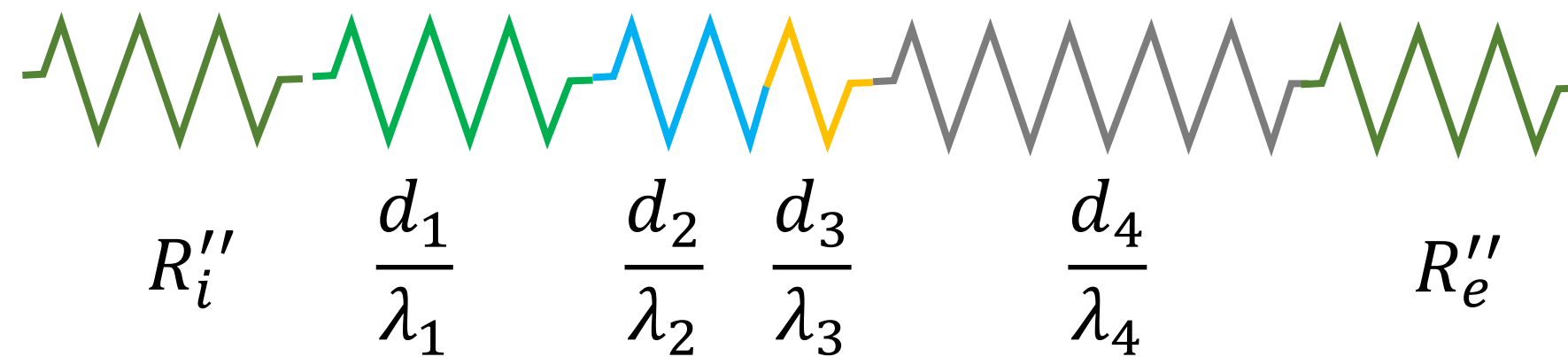
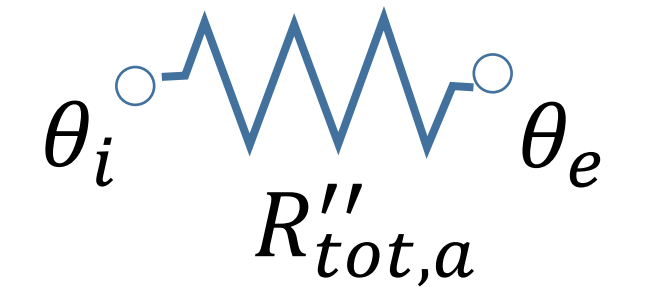
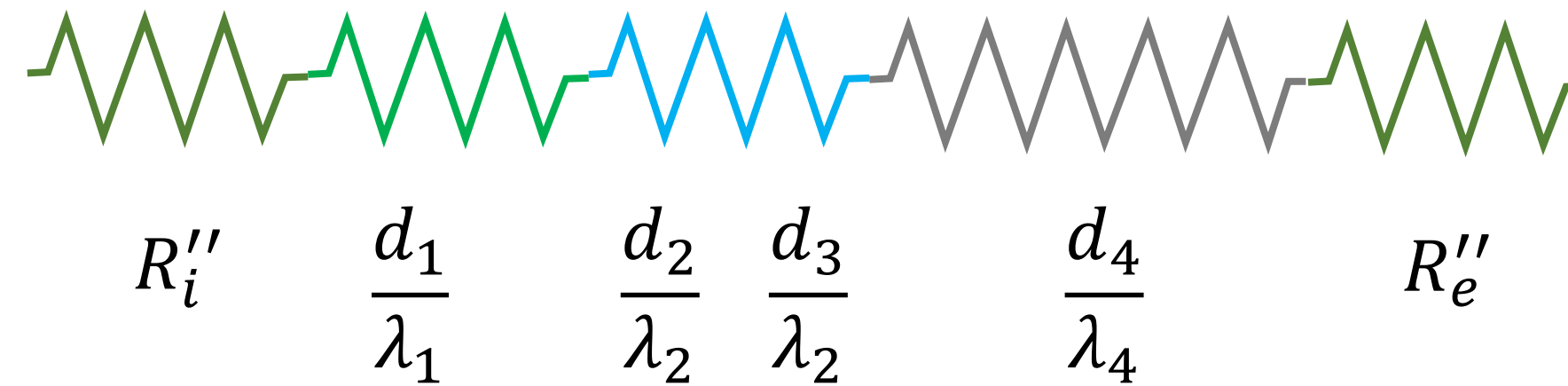
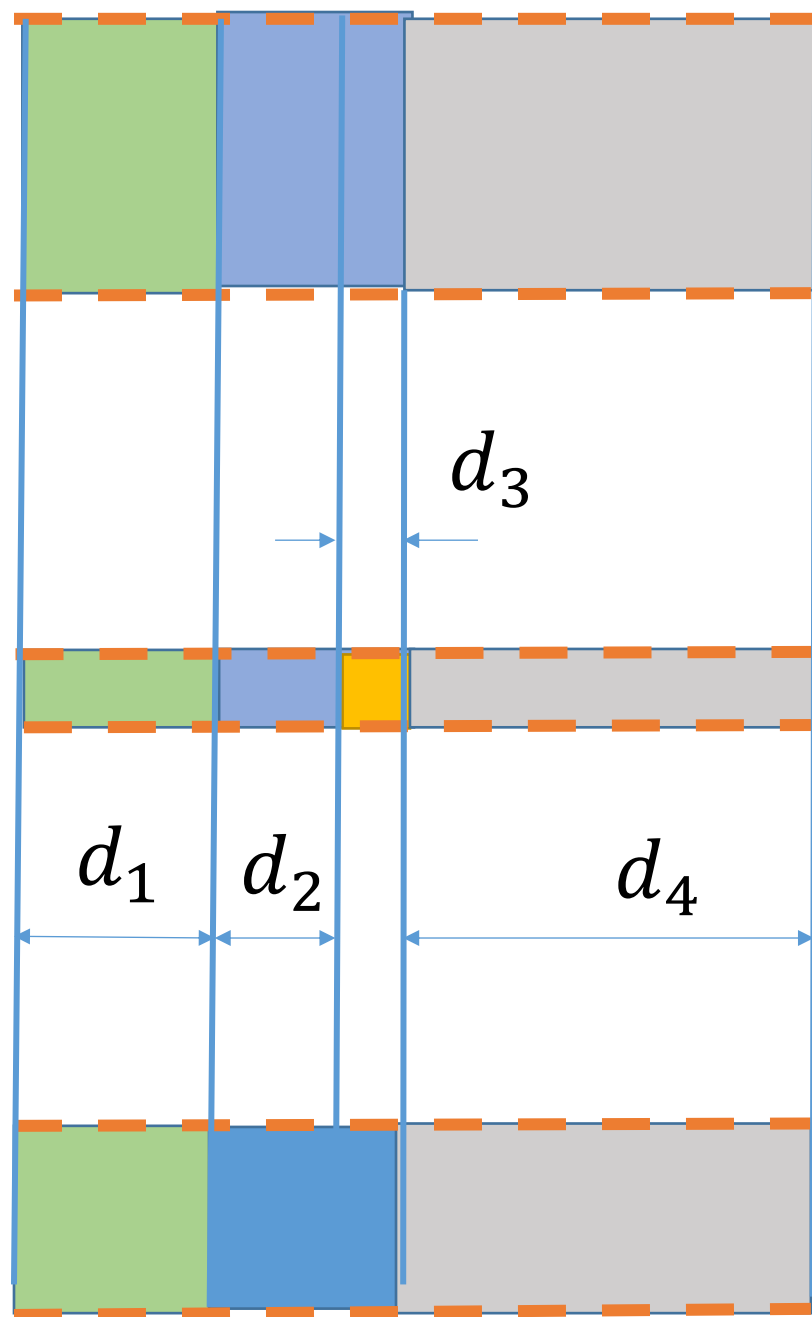


Higher limit of thermal resistance





Uneven structures





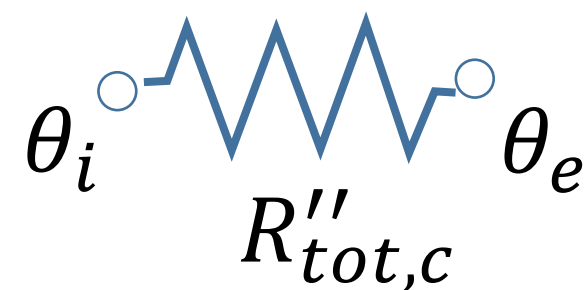
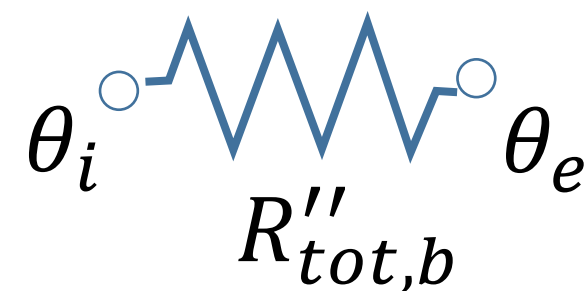
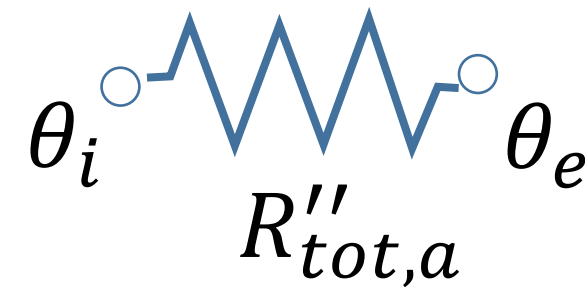
Higher limit of thermal resistance

$$R''_{tot,a} = \frac{1}{h_i} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_2} + \frac{d_4}{\lambda_4} + \frac{1}{h_e}$$

$$R''_{tot,b} = \frac{1}{h_i} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} + \frac{1}{h_e}$$

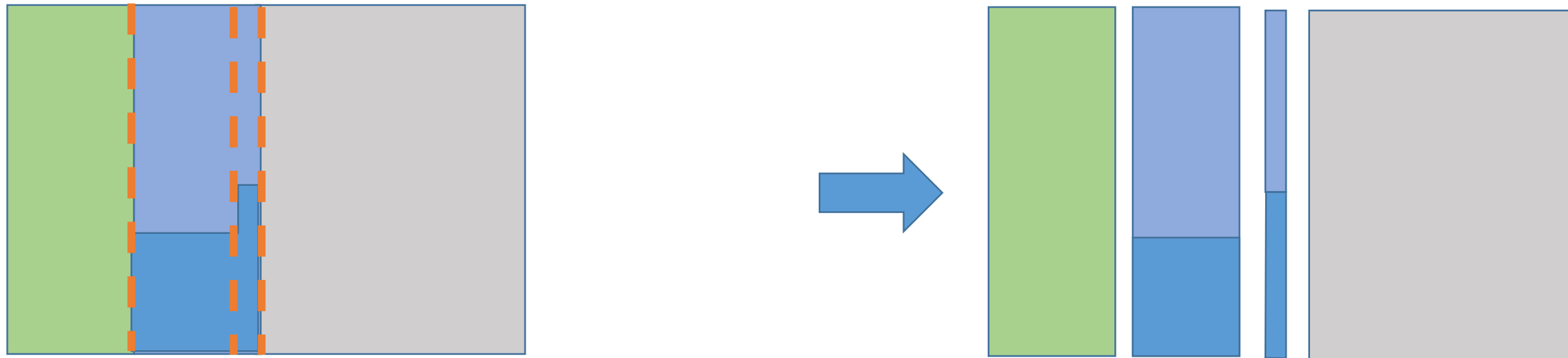
$$R''_{tot,c} = \frac{1}{h_i} + \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_3} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} + \frac{1}{h_e}$$

$$\frac{1}{R''_{tot,sup}} = \frac{f_a}{R''_{tot,a}} + \frac{f_b}{R''_{tot,b}} + \frac{f_c}{R''_{tot,c}}$$



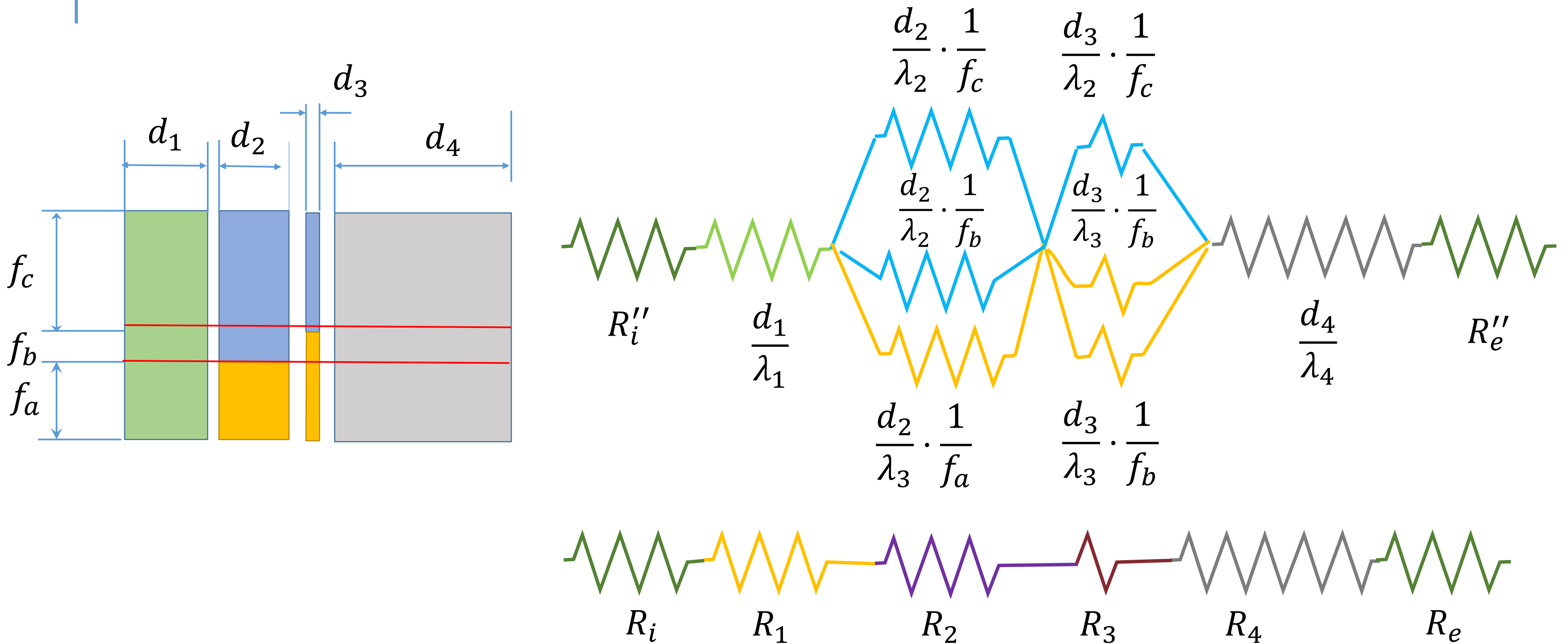


Lower limit of thermal resistance





Lower limit





Lower limit

$$R_1 = \left(\frac{1}{d_1/\lambda_1} \right)^{-1}$$

$$R_2 = \left(\frac{f_c}{d_2/\lambda_2} + \frac{f_b}{d_2/\lambda_2} + \frac{f_a}{d_2/\lambda_3} \right)^{-1}$$

$$R_3 = \left(\frac{f_c}{d_3/\lambda_2} + \frac{f_b}{d_3/\lambda_3} + \frac{f_a}{d_3/\lambda_3} \right)^{-1}$$

$$R_4 = \left(\frac{1}{d_4/\lambda_4} \right)^{-1}$$

$$R_{tot,inf} = R_i + R_1 + R_2 + R_3 + R_4 + R_e$$

$$R_{tot,} = \frac{R_{tot,inf} + R_{tot,sup}}{2}$$

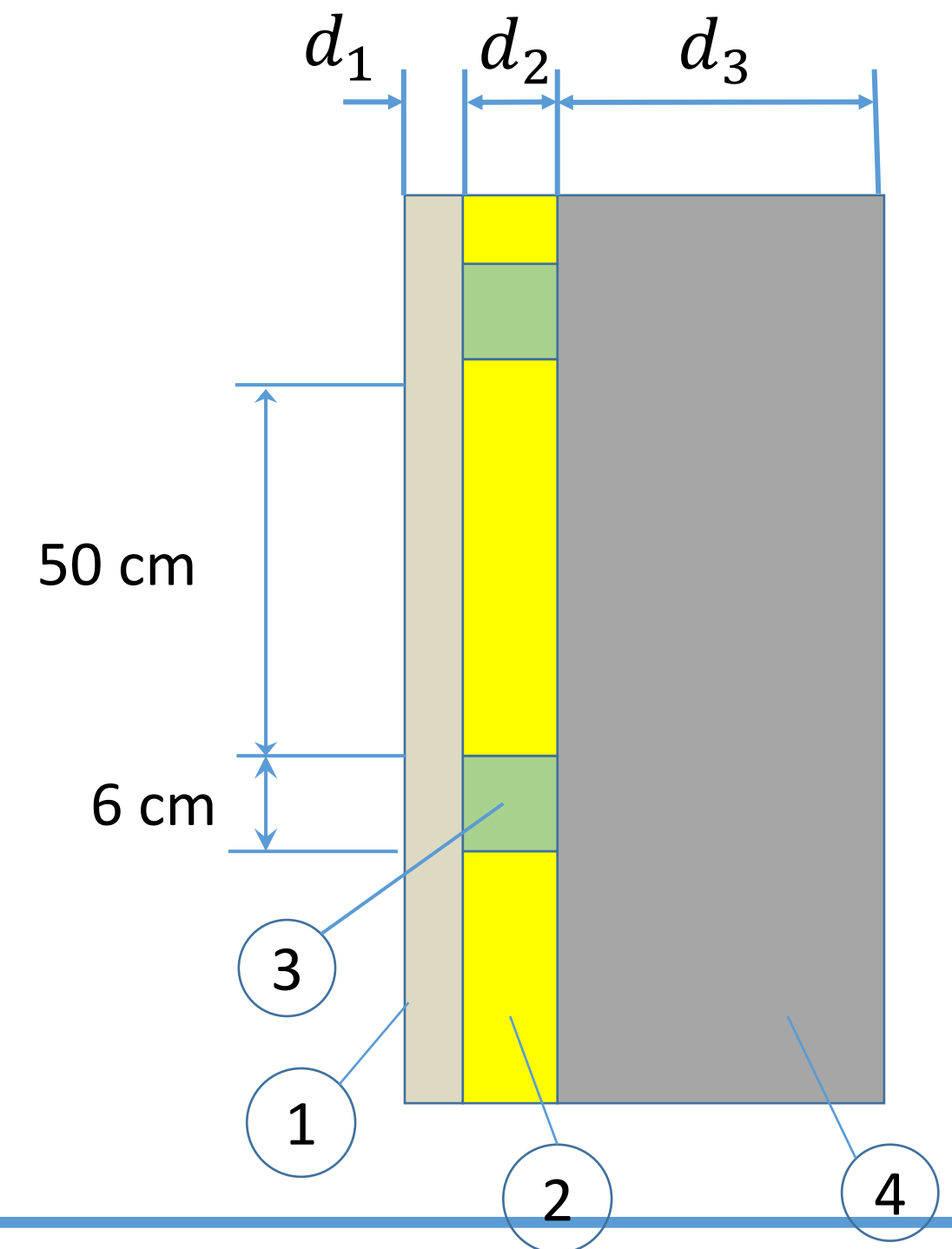


Problem

$$d_1 = 0,0125 \text{ m}; d_2 = 0,03 \text{ m}; d_3 = 0,32 \text{ m}$$

$$\lambda_1 = 0,2, \lambda_2 = 0,032, \lambda_3 = 0,12, \lambda_4 = 0,8 \frac{\text{W}}{\text{m} \cdot \text{K}}$$

Compute the transmittance





Air gaps

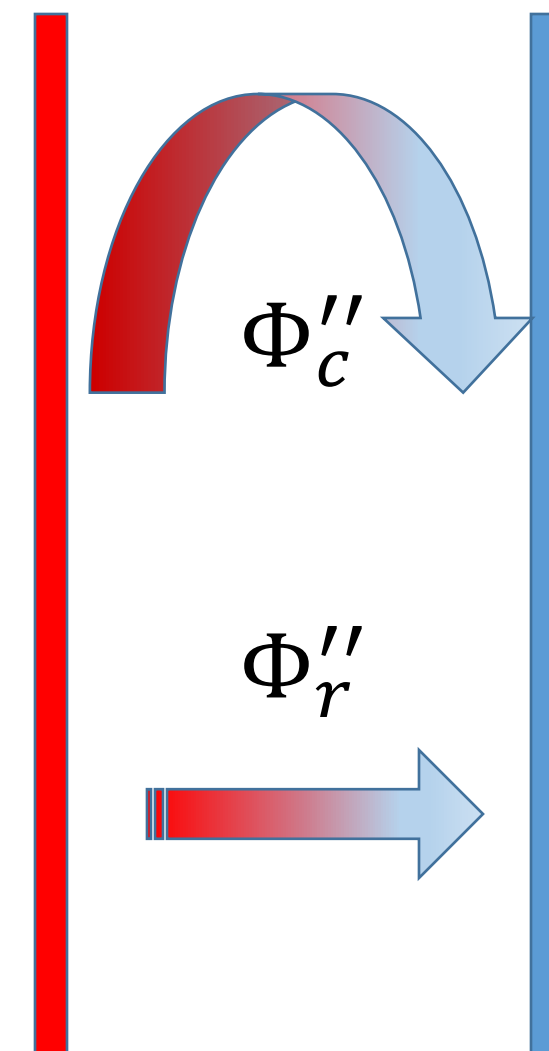
- In building structures, both closed and open cavities are very common
- Closed cavities
- Hollow-box walls
- Internal and external thermal insulation
- Double or triple glazing (with other gases)
- Open cavities
- Attics
- Ventilated insulation





Calcolo della trasmittanza

- Heat exchange occurs by convection and radiation
- Convection exchange is linear
- Radiation exchange is non-linear
- Radiation exchange is linearizable



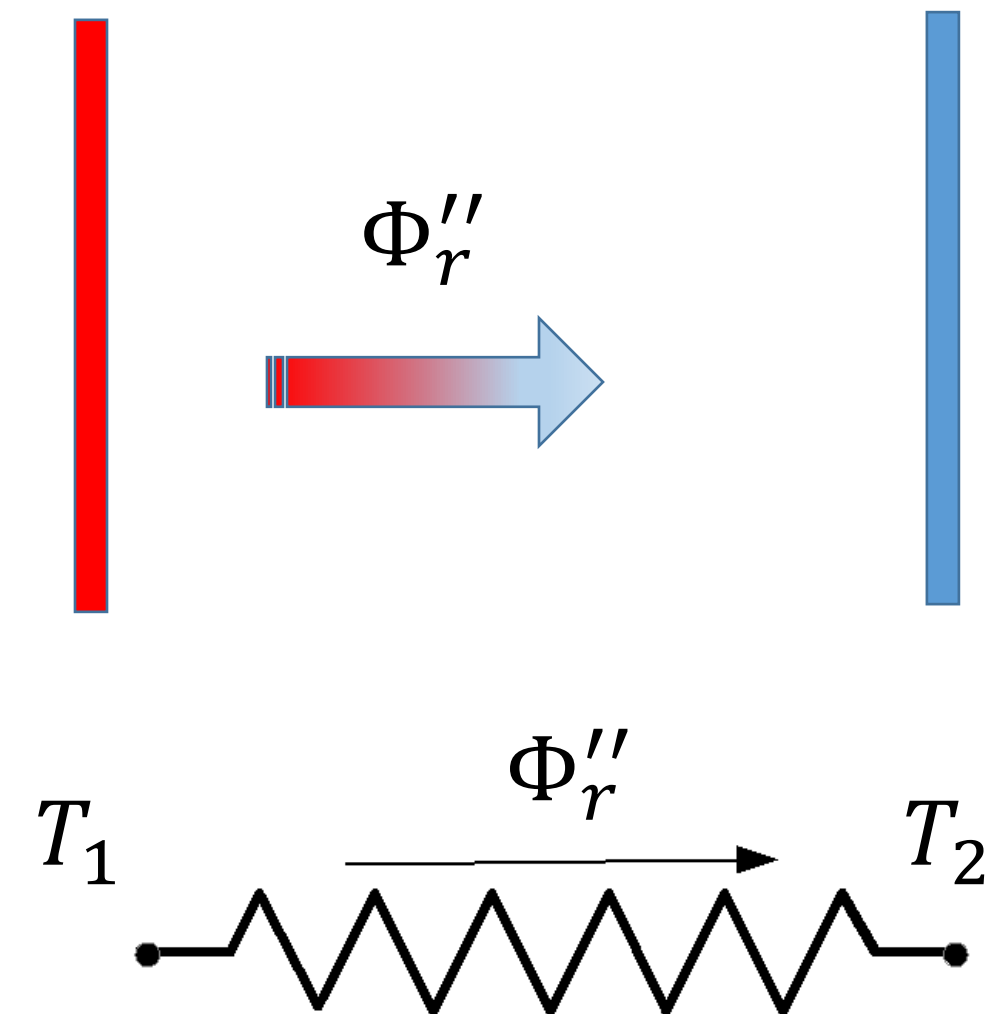


Radiant heat exchange

- Simple geometry parallel walls
- Specific heat transfer

$$\Phi_r'' = \sigma_0 \cdot \frac{(T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

- Heat exchanged depends on the emissivities of the walls

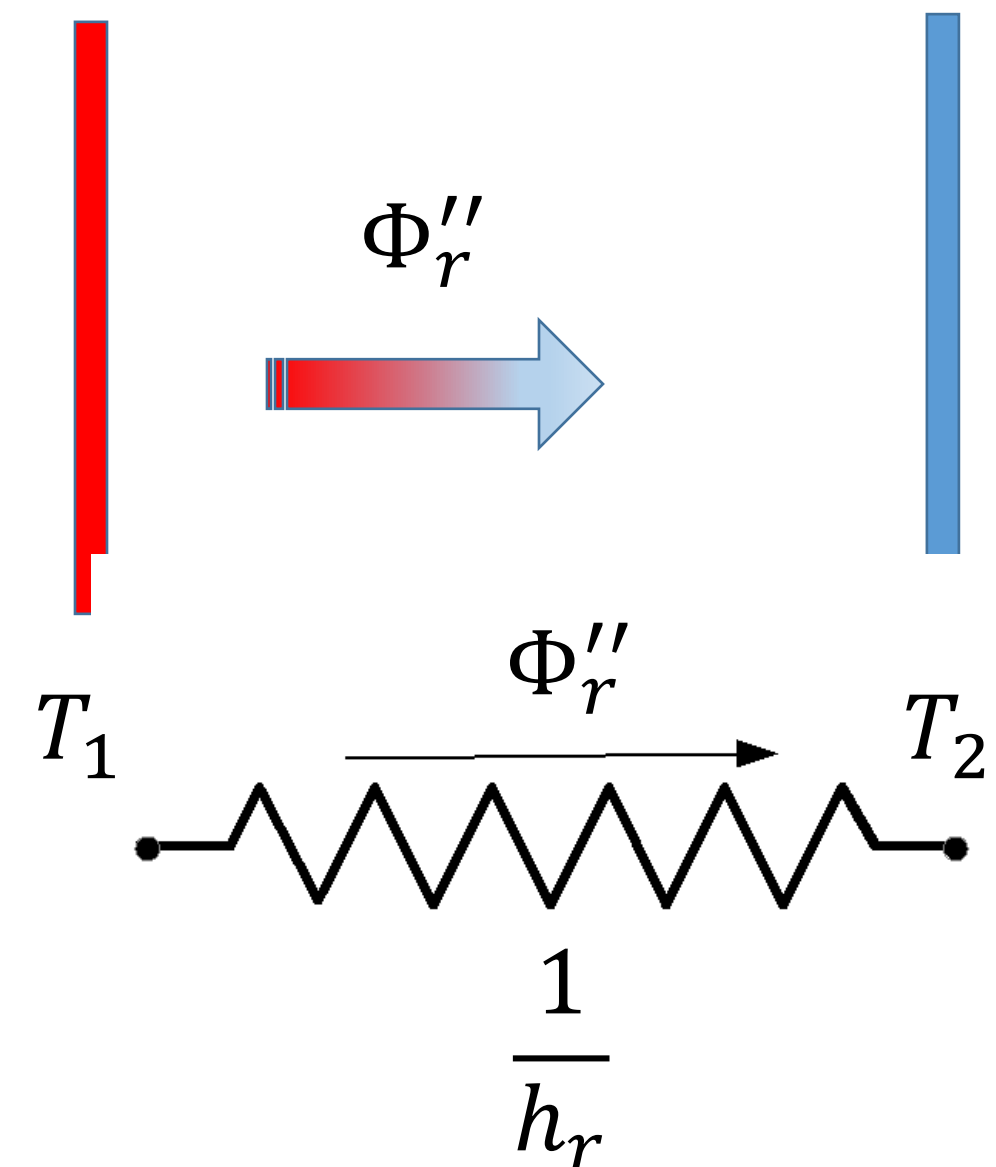




Linearizzazione dello scambio radiativo

- The nonlinear term is given by the difference of temperatures at the fourth power
- Temperatures are expressed in [K]
- The difference of temperatures is small
$$(T_1^4 - T_2^4) = (T_1^2 + T_2^2) \cdot (T_1^2 - T_2^2) =$$
$$= (T_1^2 + T_2^2) \cdot (T_1 + T_2) \cdot (T_1 - T_2)$$
$$\cong 2 \cdot T_m^2 \cdot 2 \cdot T_m \cdot (\theta_1 - \theta_2) = 4 \cdot T_m^3 \cdot (\theta_1 - \theta_2)$$

$$T_m = \frac{T_1 + T_2}{2} \text{ [K]}$$





Radiation heat transfer linearization

$$\phi_r'' = \sigma_0 \cdot 4 \cdot T_m^3 \cdot \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \cdot (\theta_1 - \theta_2)$$

$$\phi_r'' = h_r \cdot (\theta_1 - \theta_2)$$

$$\Phi_r'' = \frac{\theta_1 - \theta_2}{R_r''}$$

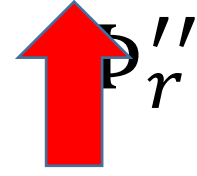
$\varepsilon_1, \varepsilon_2$



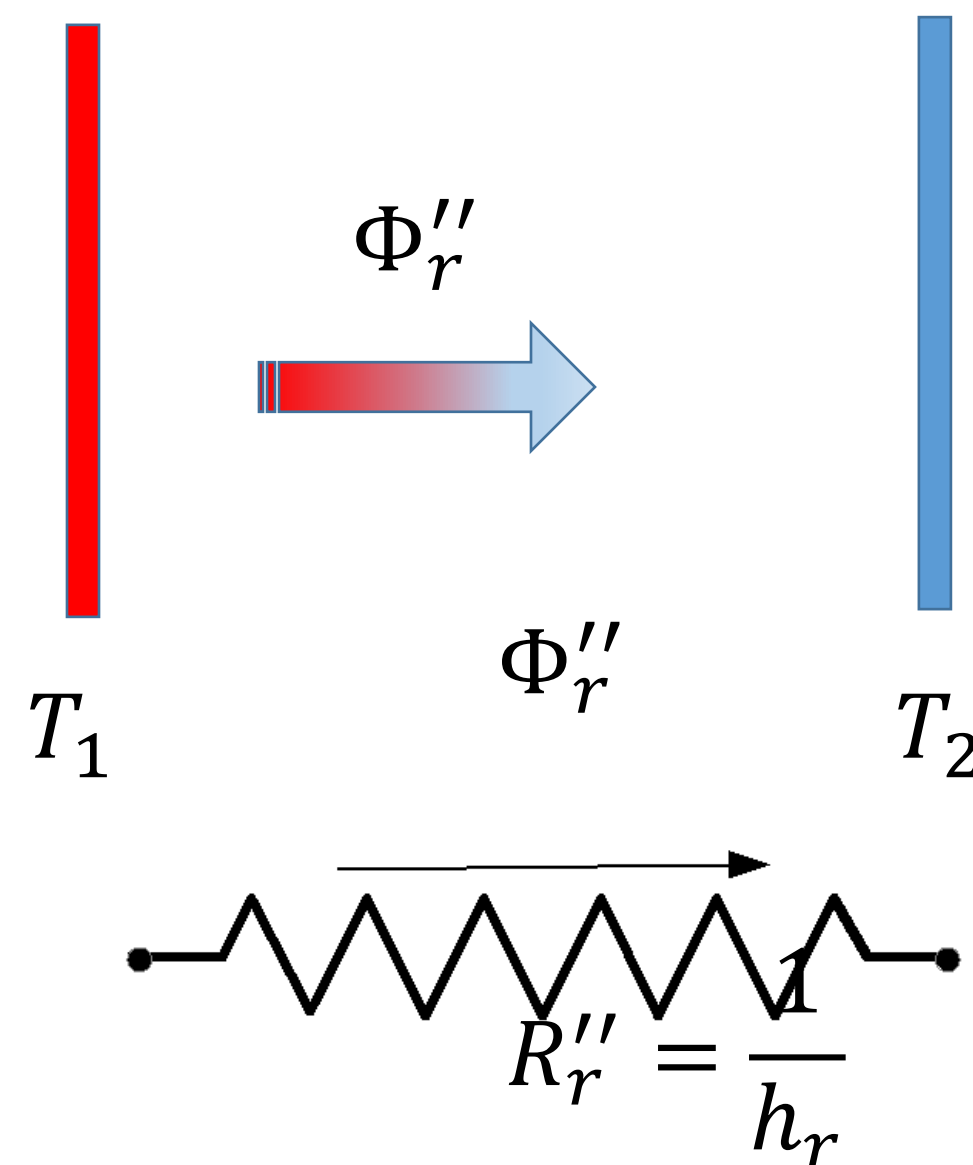
h_r



R_r''



Φ_r''



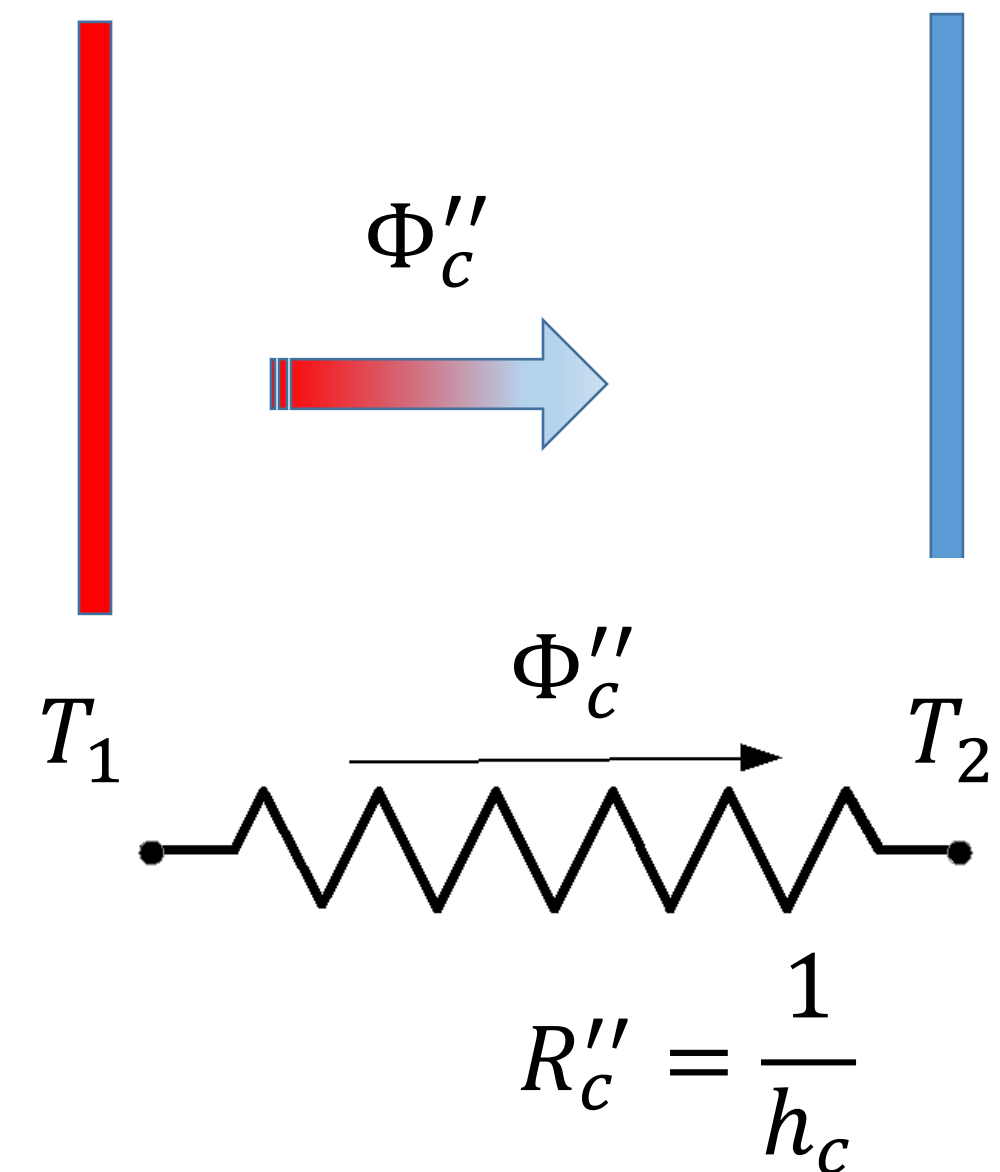


Coupled heat transfer

- Convective coefficient is obtained from tables UNI EN ISO 6946

$\Delta T \leq 5 K$	
Direction	$h_a [W/(m^2 \cdot K)]$
horizontal	1,25
upwards	1,95
downwards	$0,12 \cdot d^{-0,44}$

$\Delta T > 5 K$	
Direction	$h_a [W/(m^2 \cdot K)]$
horizontal	$0,73 \cdot \Delta T^{\frac{1}{3}}$
upwards	$1,14 \cdot \Delta T^{\frac{1}{3}}$
downwards	$0,09 \cdot \Delta T^{0,187} \cdot d^{-0,44}$





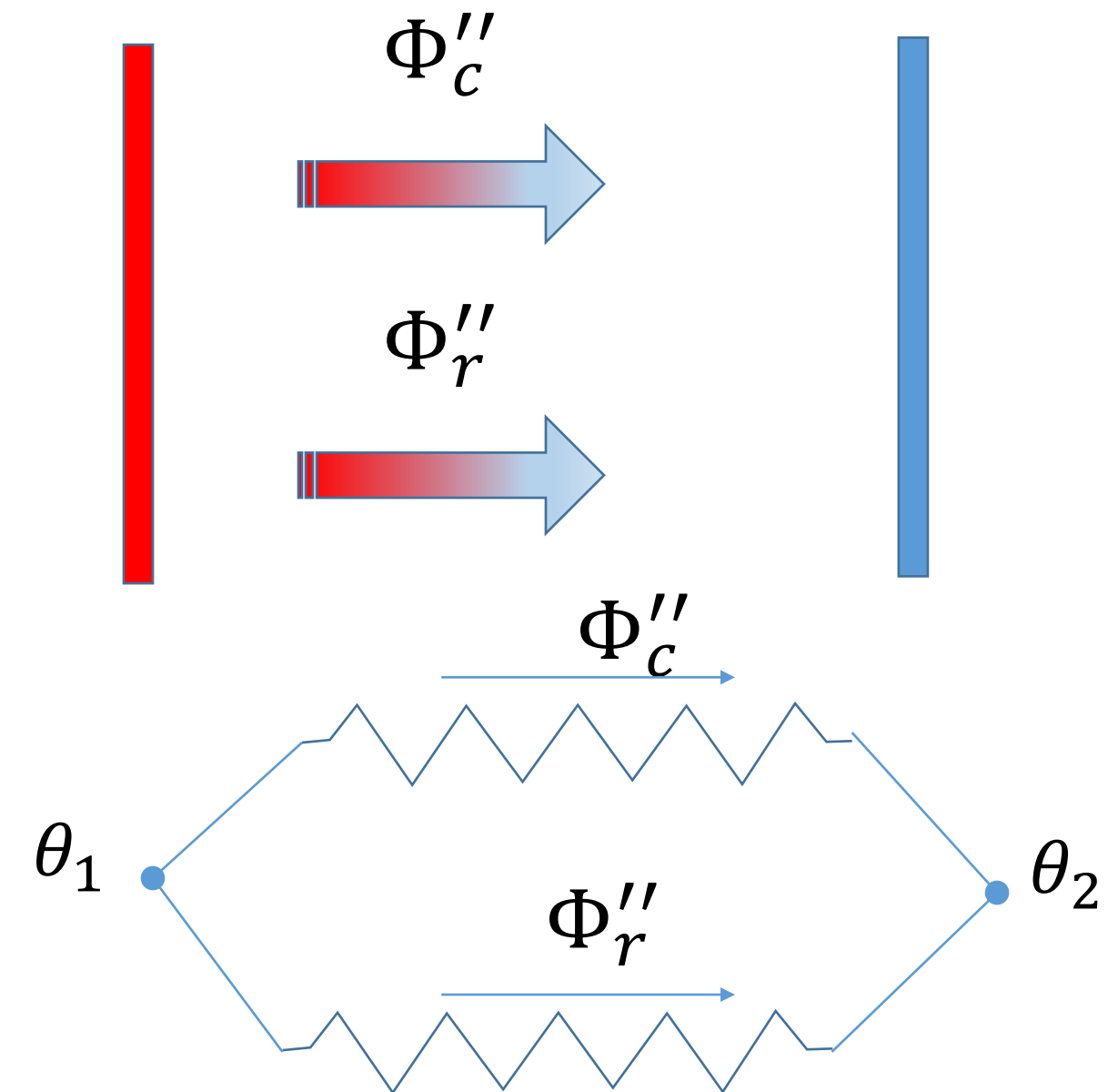
Convective and radiative heat transfer

- Consider both heat exchange

$$\Phi_g'' = (h_a + h_r) \cdot (\theta_1 - \theta_2)$$

$$\phi_g'' = \frac{(\theta_1 - \theta_2)}{R_g}$$

$$R_g = \frac{1}{h_a + h_r}$$





Example

- $\theta_1 = 19\text{ }^{\circ}\text{C}$
- $\theta_2 = 15\text{ }^{\circ}\text{C}$
- $T_m = 290,15\text{ K}$
- $\varepsilon_1 = 0,9$

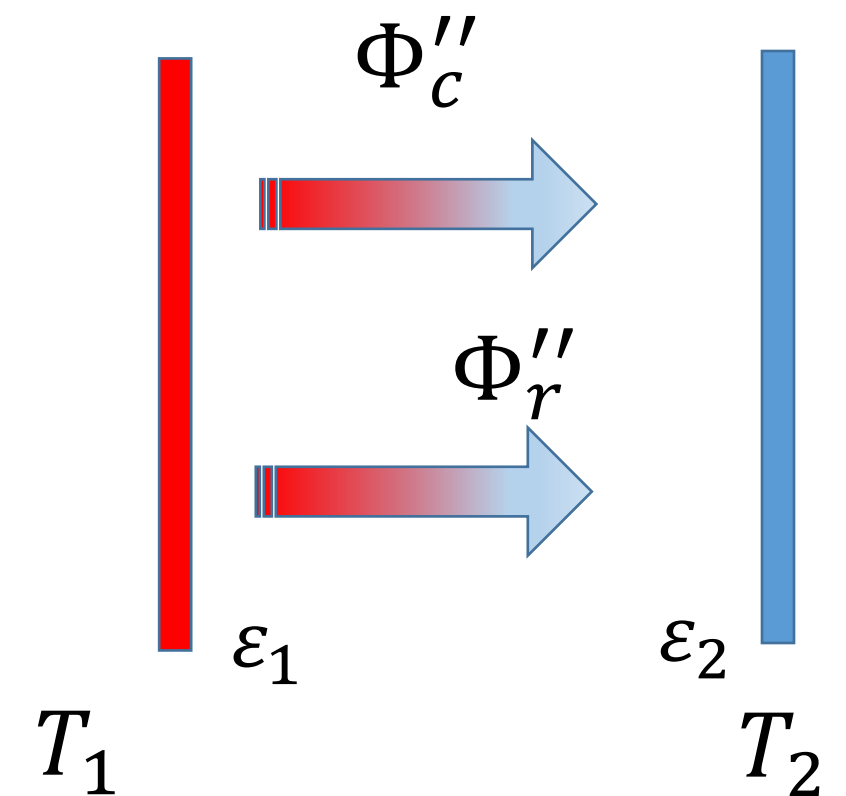
- $\varepsilon_2 = 0,95$

- $h_c = 1,25\text{ W}/(\text{m}^2 \cdot \text{K})$
- $h_r = 4,76\text{ W}/(\text{m}^2 \cdot \text{K})$
- $h = h_c + h_r = 6,01\text{ W}/(\text{m}^2 \cdot \text{K})$
- $\Phi = h \cdot (E_{n1} - E_{n2}) = 24,04\text{ W}/\text{m}^2$

- $\theta_1 = 19\text{ }^{\circ}\text{C}$
- $\theta_2 = 15\text{ }^{\circ}\text{C}$
- $T_m = 290,15\text{ K}$
- $\varepsilon_1 = 0,9$

- $\varepsilon_2 = 0,1$

- $h_c = 1,25\text{ W}/(\text{m}^2 \cdot \text{K})$
- $h_r = 0,548\text{ W}/(\text{m}^2 \cdot \text{K})$
- $h = h_c + h_r = 1,797\text{ W}/(\text{m}^2 \cdot \text{K})$
- $\Phi = h \cdot (E_{n1} - E_{n2}) = 7,19\text{ W}/\text{m}^2$





Convection heat transfer in enclosures

- Old Italian standard UNI 10345 reported formulas for computing the heat transfer in enclosures

$$h_g = Nu \cdot \frac{\lambda}{s}$$

s gap thickness

λ gas conductivity

$$Nu = a \cdot (Gr \cdot Pr)^b$$

Vertical surfaces:

$$a=0.035, \quad b=0.38$$

Horizontal surfaces

$$a=0.16, \quad b=0.28$$

Inclined surfaces

$$a=0.10, \quad b=0.31$$



Non dimensional parameters

$$Gr = \frac{\rho^2 \cdot s^3 \cdot 9.81 \cdot \Delta T}{T_m \cdot \mu^2}$$

$$Pr = \frac{c \cdot \mu}{\lambda}$$



Gas properties

Prospetto III — Proprietà termofisiche dei gas usati nelle intercapedini

Gas	Temperatura di riferimento °C	Massa volumica kg/m ³	Viscosità dinamica* · 10 ⁵ kg/(ms)	Conducibilità termica** · 10 ² W/(mK)	Capacità termica massica kJ/(kgK)
Aria	– 10	1,326	1,661	2,336	1,008
	0	1,277	1,711	2,416	
	10	1,232	1,761	2,496	
	20	1,189	1,811	2,576	
Argon	– 10	1,829	2,038	1,584	0,519
	0	1,762	2,101	1,634	
	10	1,699	2,164	1,684	
	20	1,640	2,228	1,734	
SF	– 10	6,844	1,383	1,119	0,614
	0	6,602	1,421	1,197	
	10	6,360	1,459	1,275	
	20	6,118	1,497	1,354	
Krypton	– 10	3,832	2,020	0,842	0,245
	0	3,690	2,340	0,870	
	10	3,560	2,670	0,900	
	20	3,430	2,500	0,926	

* Dividere i valori per 10⁵.

** Dividere i valori per 10².