Universität Bremen

Fachbereich 4
Produktionstechnik
Maschinenbau &
Verfahrenstechnik

People 4 Production

Heat Happens: Thermodynamics in Daily Life

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Outline

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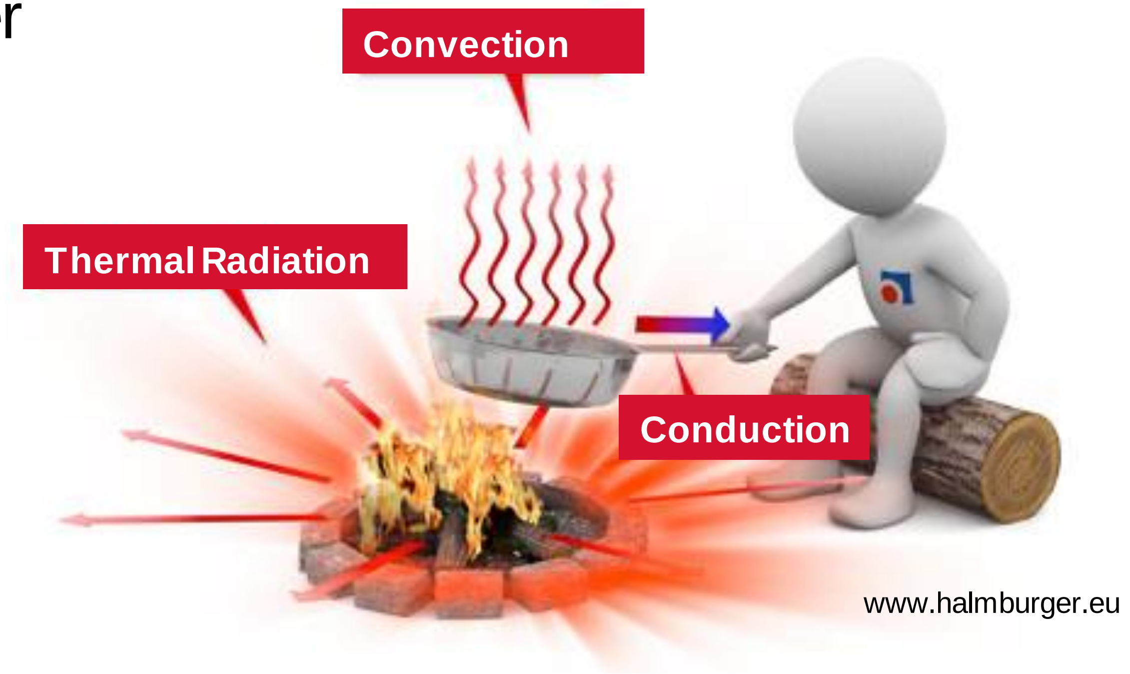
- ➢ Introduction to Overall Heat Transfer
- ➢ Analogy Between Thermal and Electrical Resistance
- ➢ Overall Heat Transfer



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Recap: The Three Mechanisms of Heat Transfer

Conduction

Energy transport by atomic/molecular interactions due to a temperature difference

Fourier's law of conduction:

One-dimensional:

$$\dot{q}_{\mathrm{x}} = -\lambda \frac{dT}{dx}$$

$$\dot{Q} = -\lambda\, A \frac{dT}{dx}$$

Convective Heat Transfer

In a flowing fluid, energy is transported by the macroscopic motion of the fluid; always accompanied by energy transport through conduction

Heat transfer between a solid wall and a flowing fluid:

$$\dot{q}_w = \alpha\,(T_w - T_\infty)$$

$$\dot{Q} = \alpha\, A\,(T_w - T_\infty)$$

Thermal Radiation

Energy transport by electromagnetic waves

Stefan-Boltzmann law:

For a black body:

$$\dot{q}_{\mathrm{b}} = \sigma\; T^4$$

For a grey body:

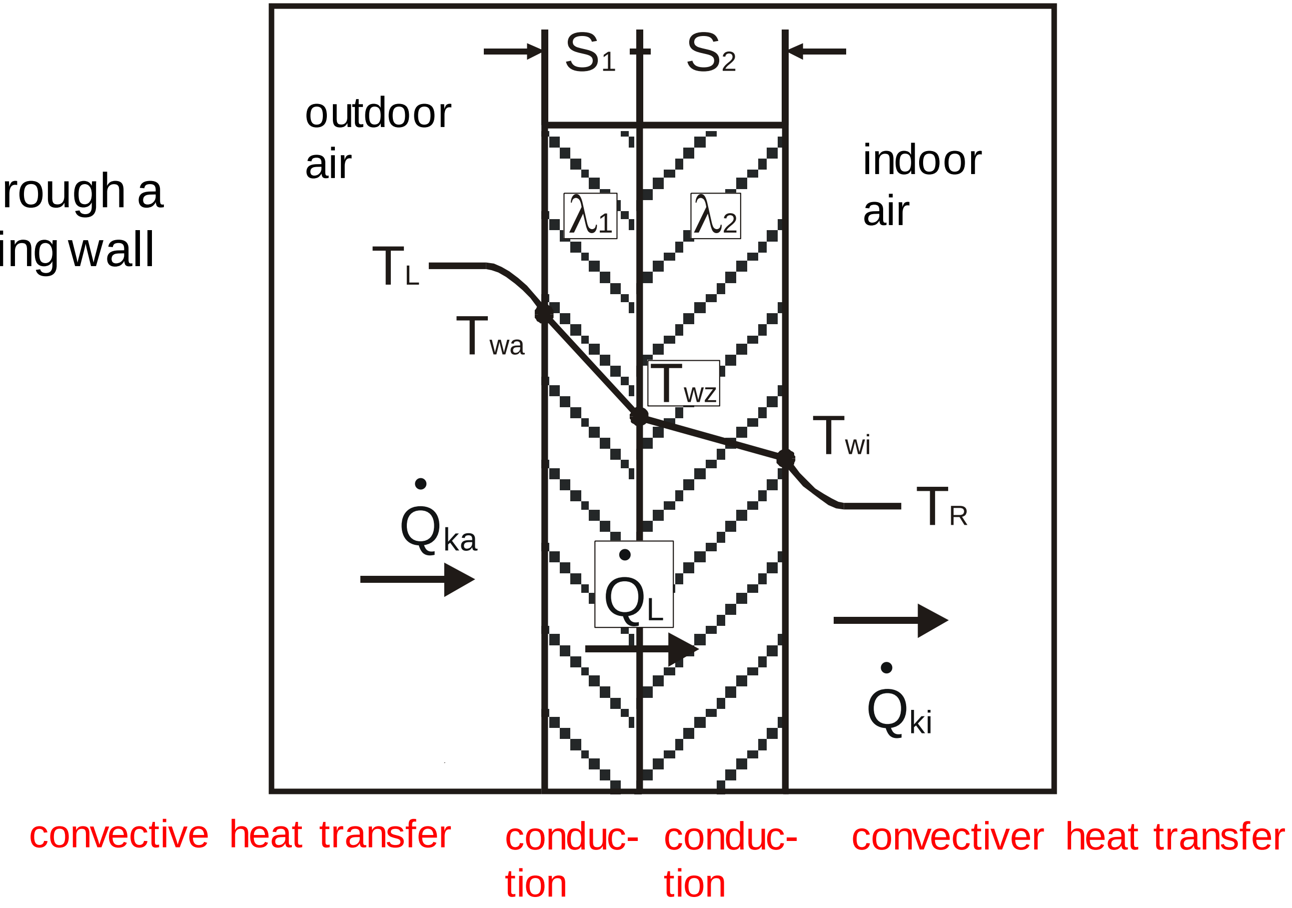
$$\dot{q} = \varepsilon\; \sigma\; T^4$$

Radiation exchange between two grey bodies with $T_1 > T_2$:

$$\dot{q} = \sigma\; F_{12}\,(T_1^4 - T_2^4)$$

Introduction to Overall Heat Transfer

Example:
Heat transfer through a multilayer building wall



→ Series combination of convective and conductive heat transfer processes:
overall heat transfer (*Wärmedurchgang*)

Heat Conduction and Convection

Heat conduction

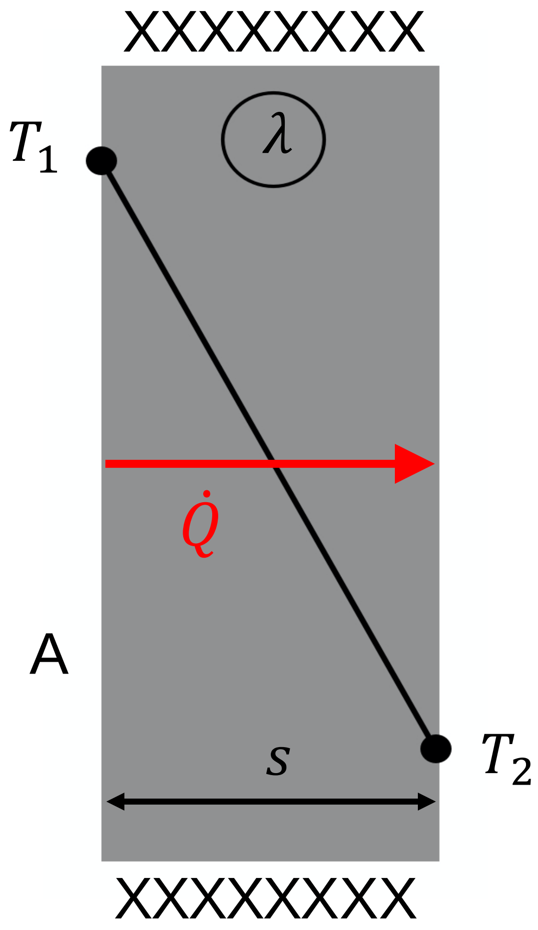
One-dimensional

$$\dot{q}_x = -\lambda \frac{dT}{dx}$$

$$\dot{q}_x = -\lambda \frac{(T_2 - T_1)}{s}$$

$$\dot{q}_x = \frac{\lambda}{s} (T_1 - T_2)$$

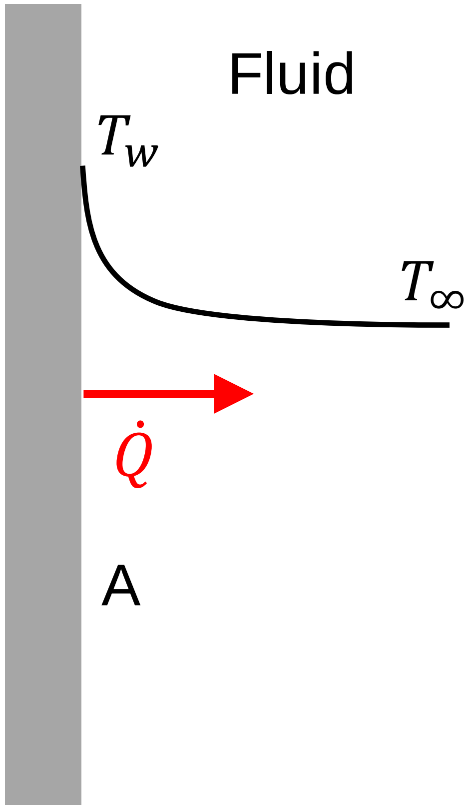
$$\dot{Q} = \frac{\lambda}{s} A (T_1 - T_2)$$



Heat convection

$$\dot{q}_w = \alpha (T_w - T_\infty)$$

$$\dot{Q} = \alpha A (T_w - T_\infty)$$



Analogy Between Thermal and Electrical Resistance

Heat conduction

$$\dot{Q} = \frac{\lambda A}{s}(T_1 - T_2) = \boxed{\frac{\lambda A}{s}} \Delta T$$

⟺

Electrical engineering

$$I = \boxed{\frac{1}{R}} U$$

$\dot{Q}$: heat flow rate (*Wärmestrom*) ⟺ I: electric current

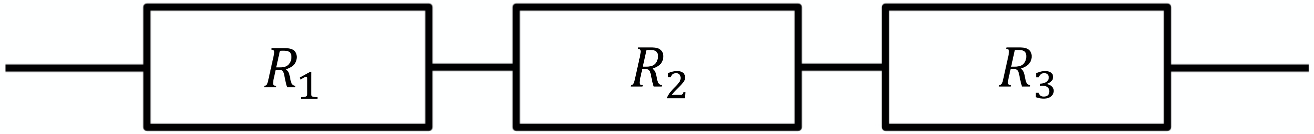
ΔT: temperature difference ⟺ U: voltage

$\frac{\lambda A}{s}$: reciprocal of thermal resistance ⟺ $\frac{1}{R}$: reciprocal of electrical resistance

→ **thermal resistance** $R_{\text{th}} = \frac{s}{\lambda A}$

Analogy Between Thermal and Electrical Resistance

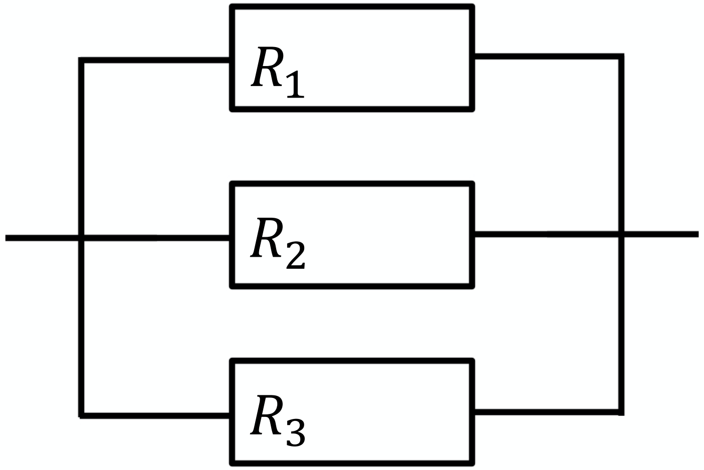
Resistances in Series



$$R_{\text{ges}} = R_1 + R_2 + R_3$$

Resistances in Parallel

$$\frac{1}{R_{\text{ges}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$



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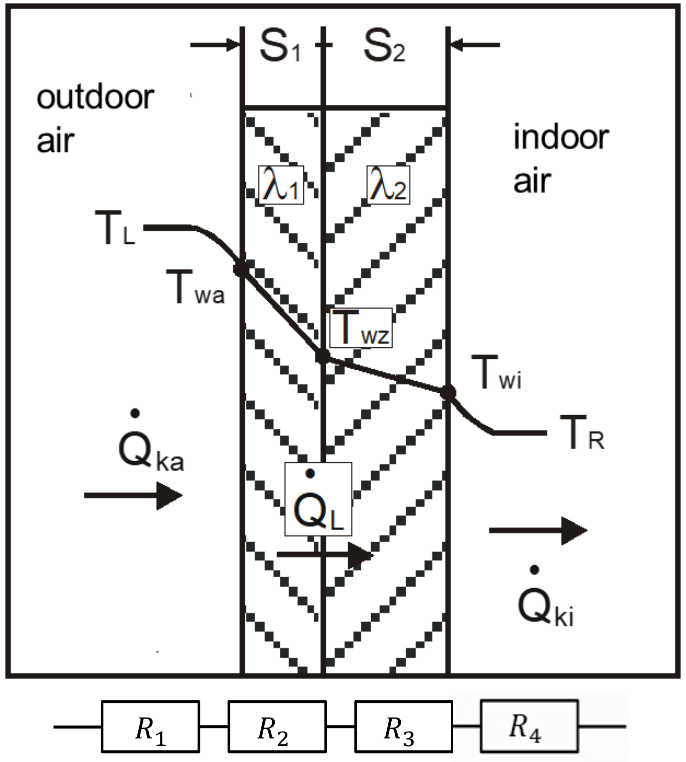
Overall Heat Transfer

Overall heat transfer (*Wärmedurchgang*):

$$\dot{Q} = \boxed{k\ A}\,(T_\mathrm{L} - T_\mathrm{R}) \quad \Leftrightarrow \quad I = \boxed{\frac{1}{R}}\,U$$

k : Overall heat transfer coefficient
(*Wärmedurchgangskoeffizient*)
Unit: [*k*] = W/(m² K)



Thermal resistances in series (*Reihenschaltung*):

$$R_\mathrm{th,ges} = R_{th,1} + R_{th,2} + R_{th,3} + R_{th,4}$$

$$\boxed{R_\mathrm{th,ges} = \frac{1}{k\ A} = R_\mathrm{th,1} + R_\mathrm{th,2} + R_\mathrm{th,3} + R_\mathrm{th,4} = \frac{1}{\alpha_a\ A_\mathrm{a}} + \frac{s_1}{\lambda_1\ A_\mathrm{m1}} + \frac{s_2}{\lambda_2\ A_\mathrm{m2}} + \frac{1}{\alpha_\mathrm{i}\ A_\mathrm{i}}}$$