Heat Transfer

Natural Convection in enclosed spaces

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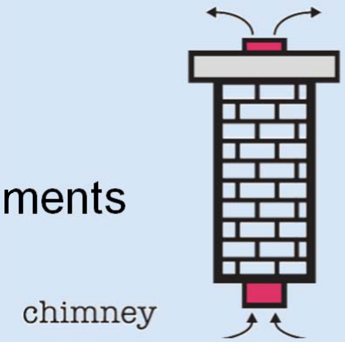
Learning Goals

- Natural Convection in enclosed spaces
  - ➢ Understanding of the influence of heated and cooled surfaces in enclosed spaces.
  - ➢ Decision-making competence for vertical and horizontal arrangements
  - ➢ Gain an overview of different applications



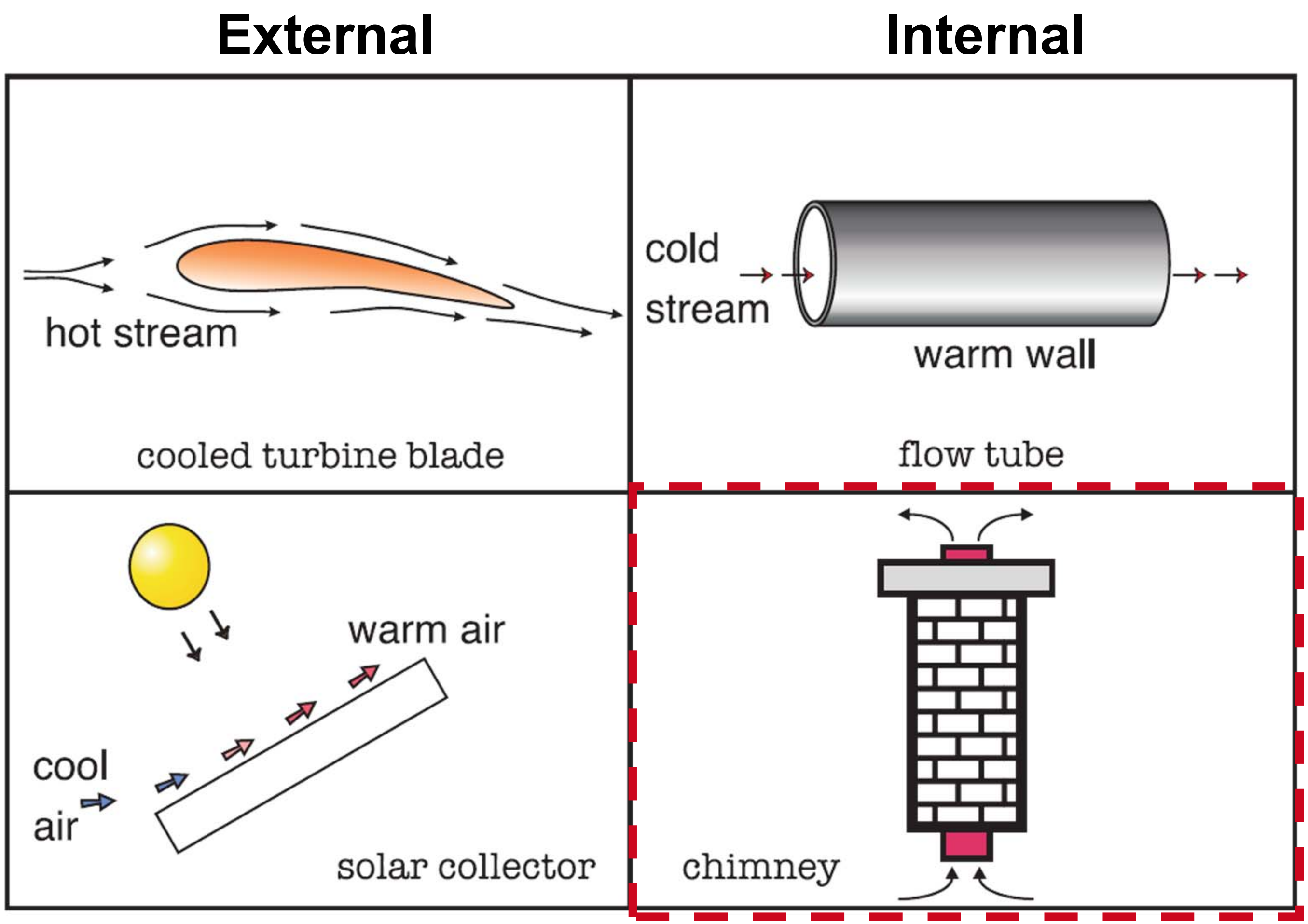
Classifications according to flow regime

Forced Convection

- Driven by externally generated movement of the fluid/object

Free Convection

- Inherently driven due to heat transfer (density differences)

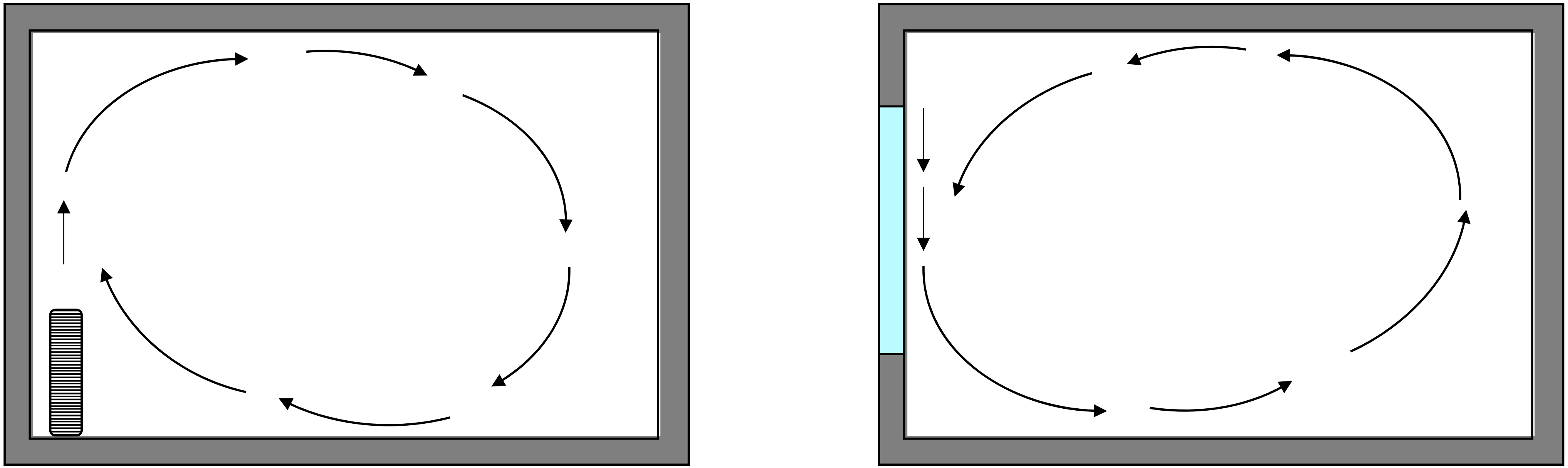


Natural Convection in enclosed spaces

The distance s between the heated and the cooled surface is used as the characteristic length L, the heated and cooled wall temperatures are used as the driving temperatures

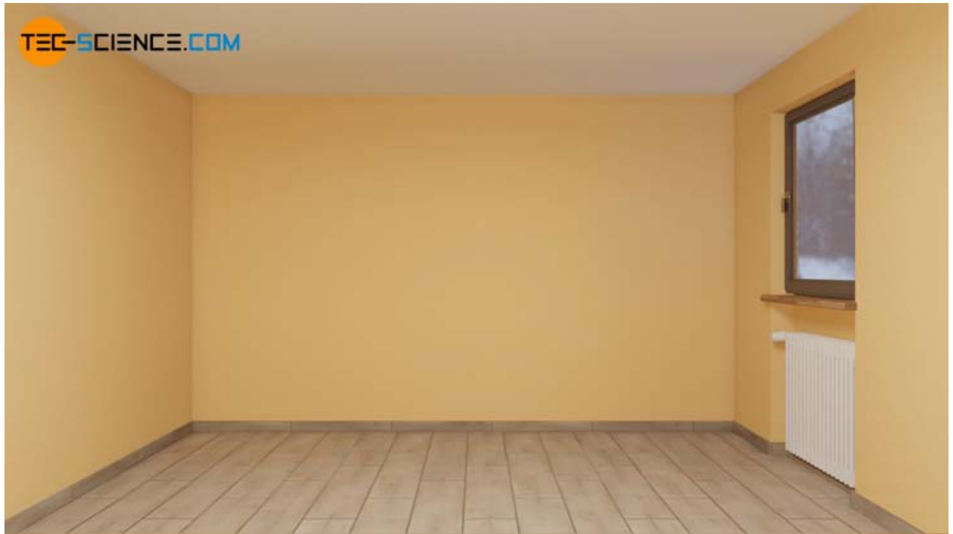
Lift flow through radiators

Cold air drop at the window



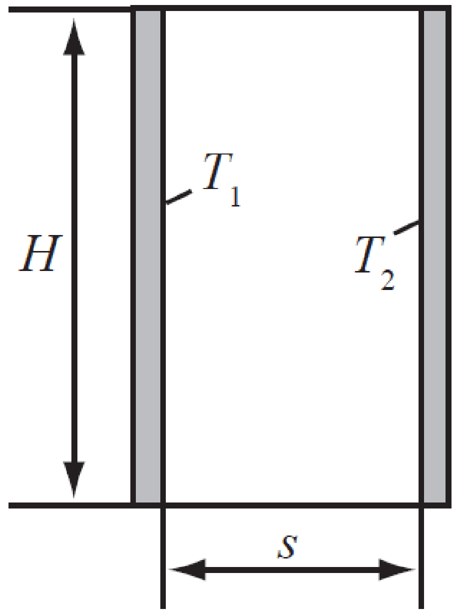
How is the heat transferred?

Natural Convection in Room



Source: www.tec-science.com/de/thermodynamik-waermelehre/waerme/warme-und-thermodynamisches-gleichgewicht/
www.tec-science.com/de/thermodynamik-waermelehre/waerme/warum-befinden-sich-heizkorper-meist-unter-einem-fenster/

Fluid layers between isothermal, vertical walls with a height/distance ratio $3{,}1 < \frac{H}{s} < 42{,}2$ according to Bayley et al. (1972)



For $\mathrm{Gr_s} < 2 \cdot 10^3$ (**heat conduction only**) $\overline{\mathrm{Nu_s}} = 1$

For the **laminar** range $2 \cdot 10^3 < \mathrm{Gr_s} < 2 \cdot 10^4$

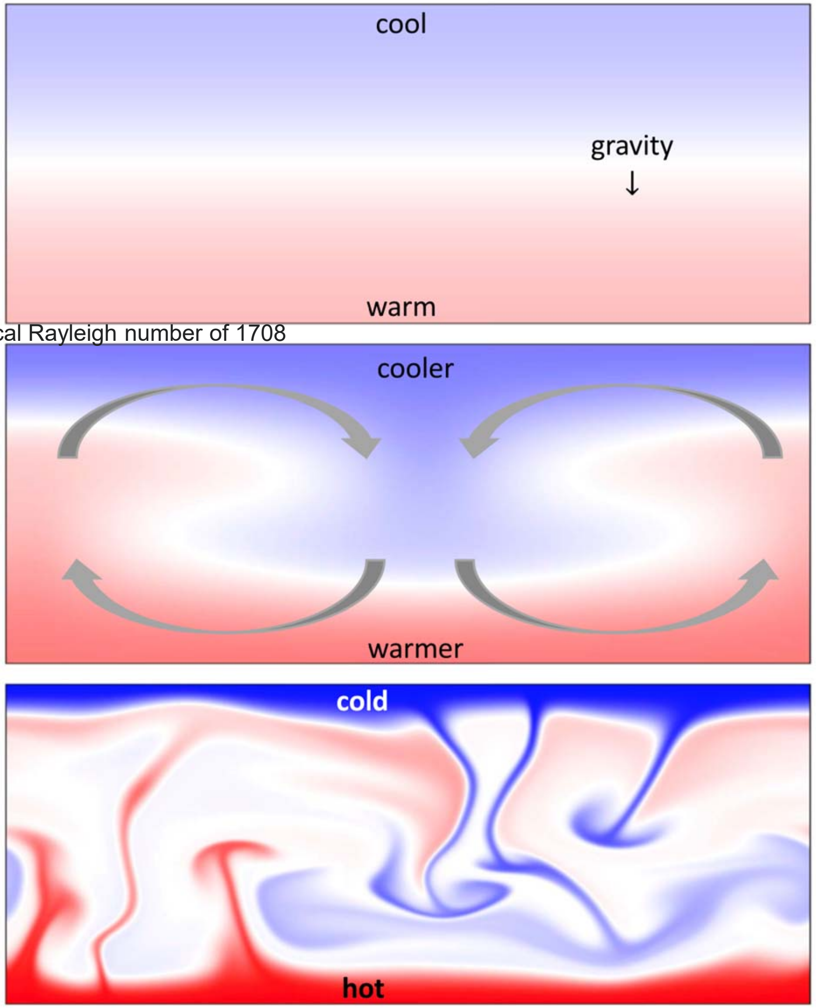
$$\overline{\mathrm{Nu_s}} = 0{,}20 \left(\frac{H}{s}\right)^{-\frac{1}{9}} (\mathrm{Gr_s Pr})^{\frac{1}{4}} \qquad \text{(HTC.25)}$$

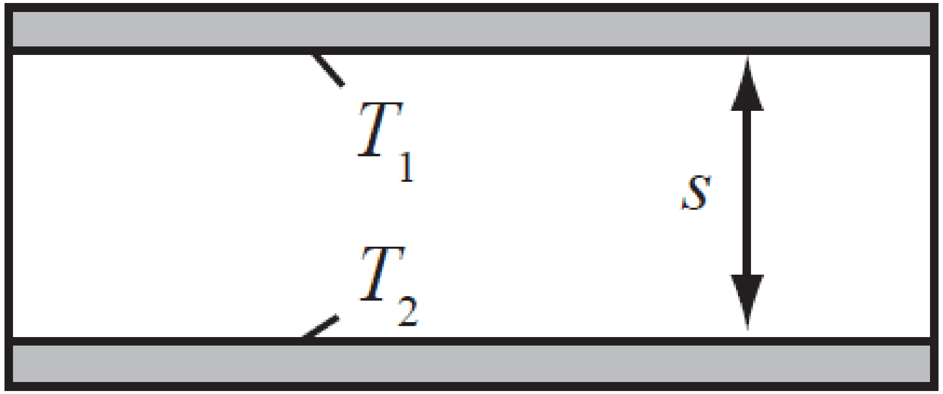
For the **turbulent** range $2 \cdot 10^5 < \mathrm{Gr_s} < 10^7$

$$\overline{\mathrm{Nu_s}} = 0{,}071 \left(\frac{H}{s}\right)^{-\frac{1}{9}} (\mathrm{Gr_s Pr})^{\frac{1}{3}} \qquad \text{(HTC.26)}$$

$Gr_s Pr = Ra_s$ $\qquad$ $Ra = \text{Rayleigh Number}$

Fluid layers between isothermal, horizontal surfaces (Rayleigh-Benard)





Turning up the heat in turbulent thermal convection
C.R.Doering, PNAS 2020, 117 (18) 961-9673
Available online.

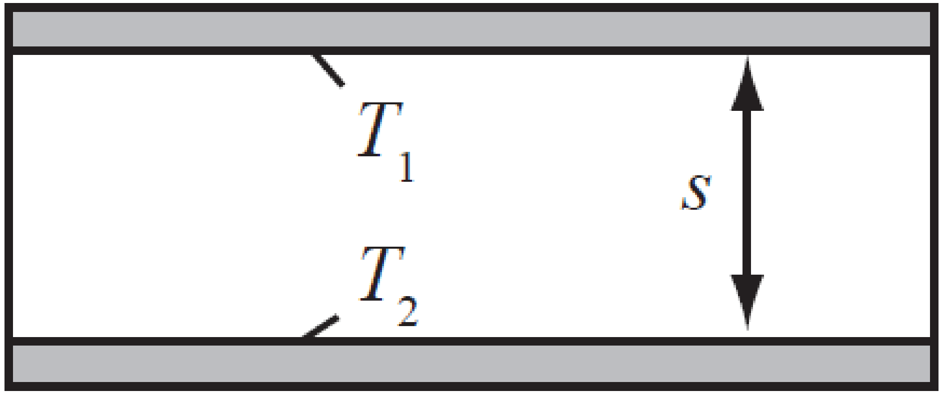
Fig. 1. Snapshots of the temperature field in 2D Rayleigh–Bénard convection simulations. (*Top*) For suitably weak temperature drops Δ*T* the fluid remains at rest and heat transfers via conduction. (*Middle*) Sufficiently large Δ*T* destabilizes the conduction state and coherent convection rolls actively increase the heat flux. (*Bottom*) Convective turbulence sets in at larger Δ*T*.

Rayleigh Benard Turbulent

Source: turbulenceteam youtube. “Rayleigh Benard Convection in 2 dimensions (numerical simulation)

Fluid layers between isothermal, horizontal surfaces, heating from below according to Holman (1976)

If heating is from above, a stable stratification forms. The heat is transferred purely by heat conduction.



Heating from below:

For $\mathrm{Gr_s} < 2 \cdot 10^3$ (**heat conduction only**) $\overline{Nu_s} = 1$

For the **laminar** range $10^4 < \mathrm{Gr_s} < 3{,}2 \cdot 10^5$

$$\overline{\mathrm{Nu_s}} = 0{,}21\,(\mathrm{Gr_s Pr})^{\frac{1}{4}} \tag{HTC.27}$$

For the **turbulent** range $3{,}2 \cdot 10^5 < \mathrm{Gr_s} < 10^7$

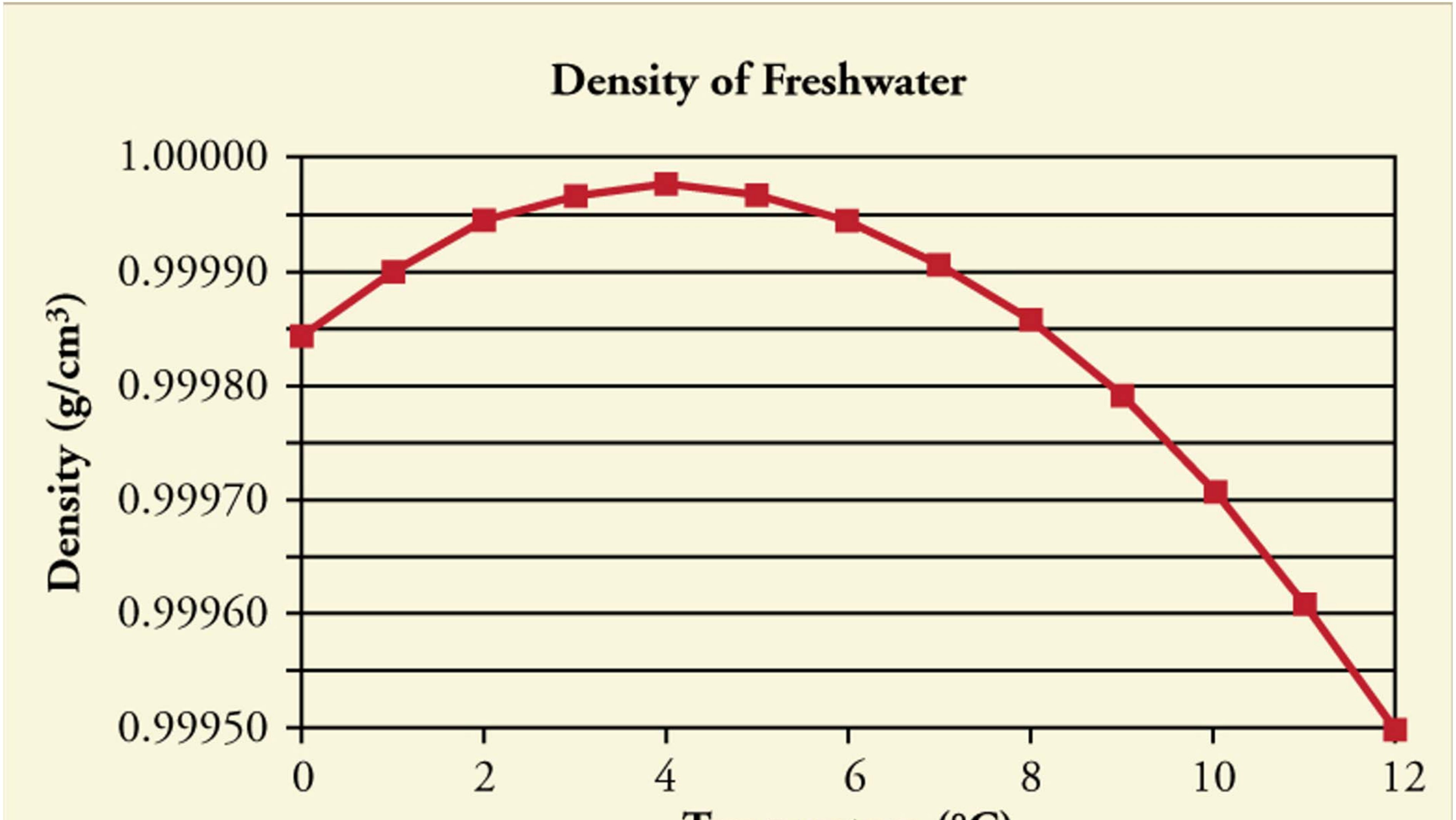
$$\overline{\mathrm{Nu_s}} = 0{,}075\,(\mathrm{Gr_s Pr})^{\frac{1}{3}} \tag{HTC.28}$$

Comprehension Questions

Why is heat generally transferred between two horizontal surfaces in a fluid layer only by conduction when the upper plate is heated?

Which exception exists to the rule stated in the question above?

Water between 4 degrees and 0 degrees !



Source:lumenlearning.com physics