Enhanced U-value of a wall structure using interior sensor driven forced or natural convection

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Research programme

strong research environments – Formas- a five years programme start 2011

homes for tomorrow

- **Active multifunctional building envelopes**
- Concrete composites with energy storage potential
- Indoor water systems
- Perceptions of homes – light and structures

Top down

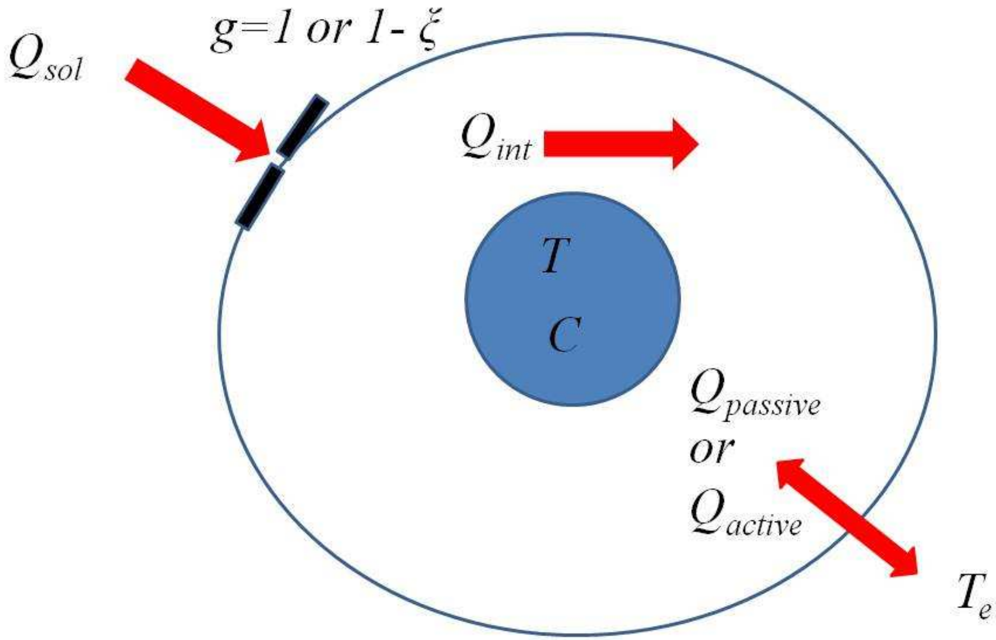
a) **Building as a system.** Requirements due to performance criteria. Potential of novel systems and their limitations.

b) **Building component.** Requirements for satisfying system demands. Potential of novel components and their limitations.

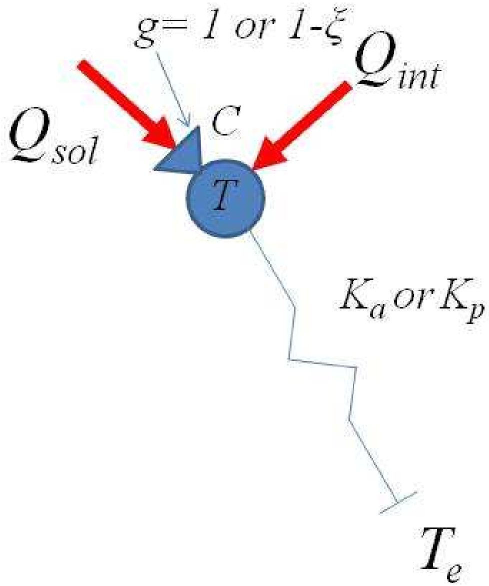
c) **Building material.** Requirements for satisfying component demands. Potential of novel materials and their limitations.

Bottom up

At system level: controlling solar gains, ventilation and heat transmission: Examples - Effects on ventilated spaces



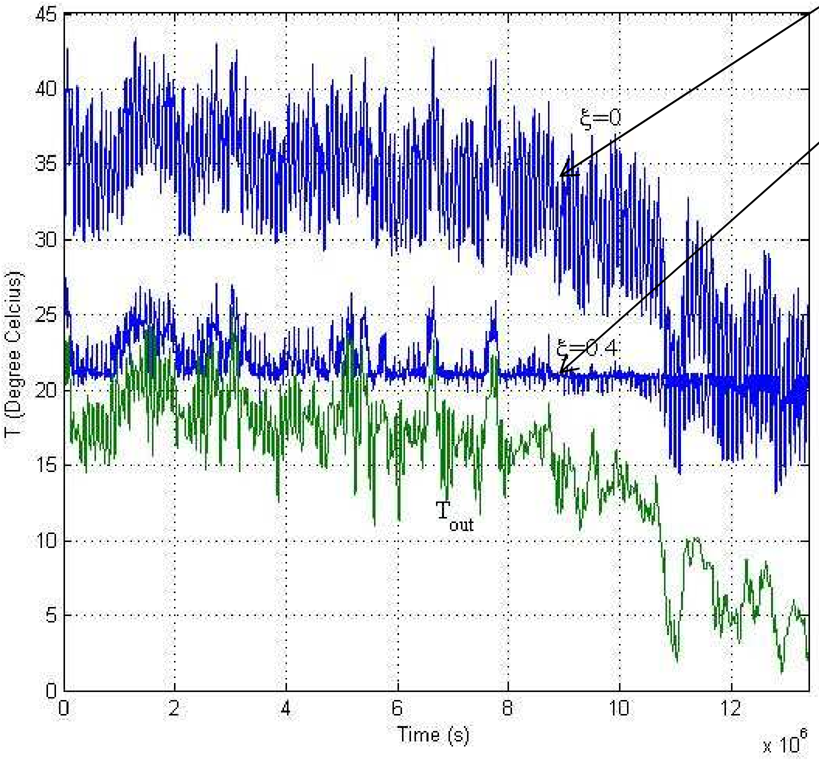
Network representation

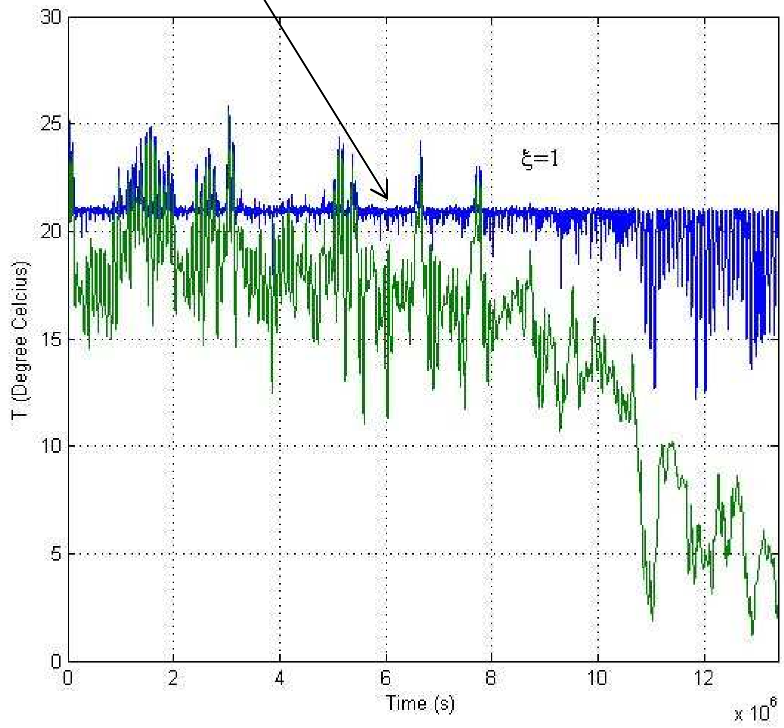


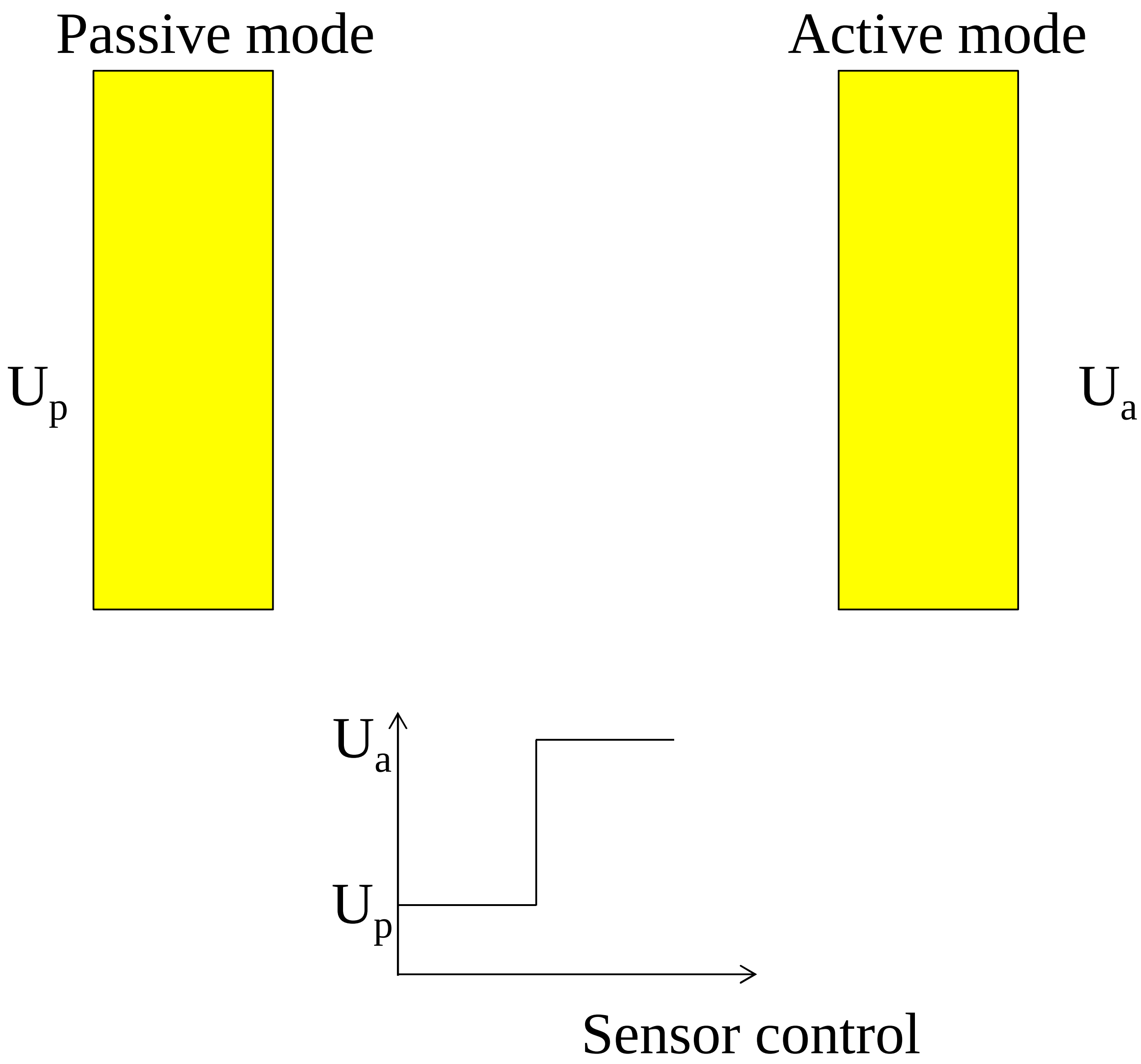
ξ =0, passive
ξ =1, fully active

Indoor temperature during half a year: Changing the degree of activity (ξ)

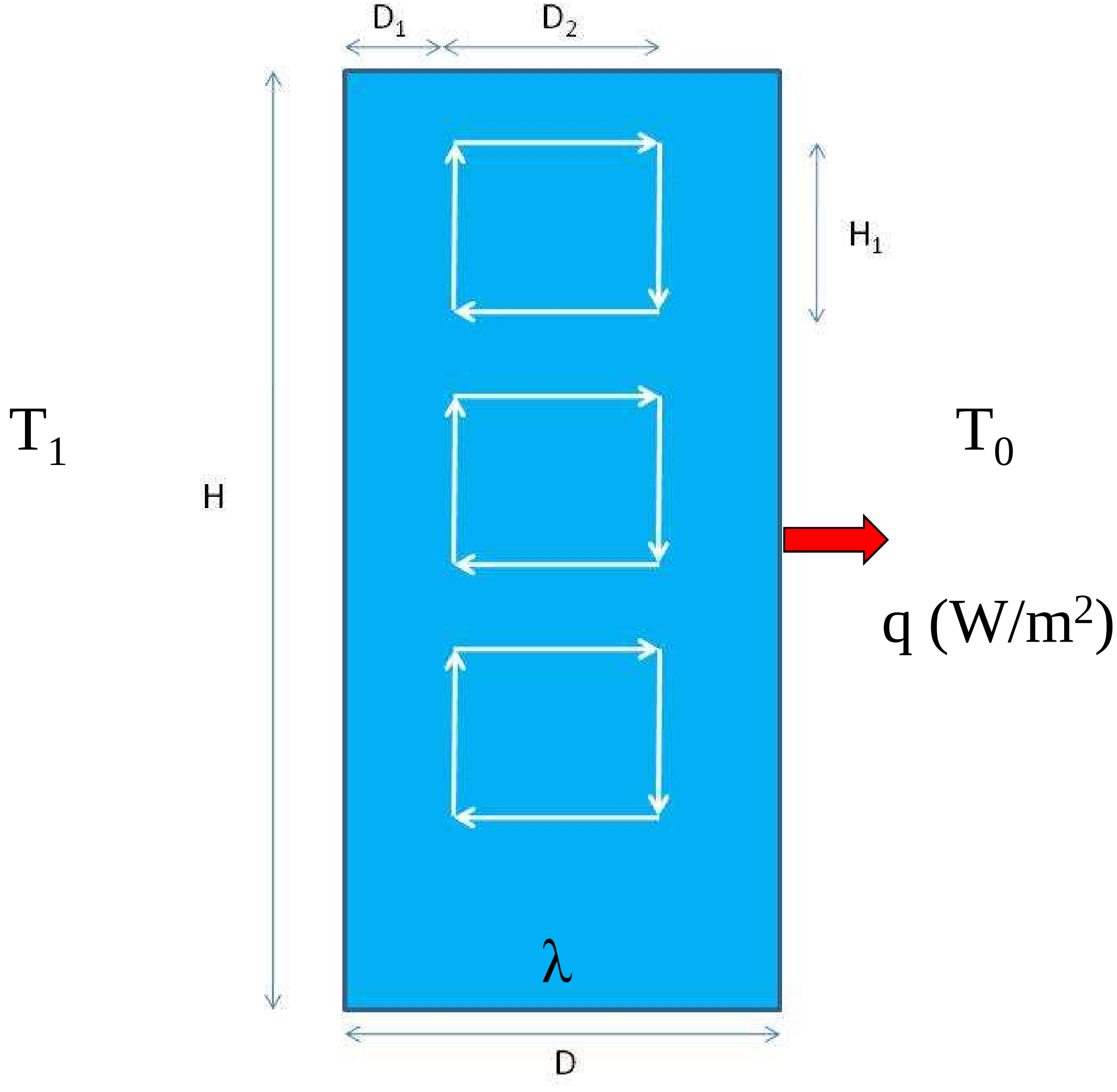
ξ= 0 0.4   1.0






Passive mode
Active mode
U_p
U_a
U_a
U_p
Sensor control

Idea: Airflow loops/channels – sensor controlled valves
Airflow driven by small fans or by natural convection



Forced convection – Steady state

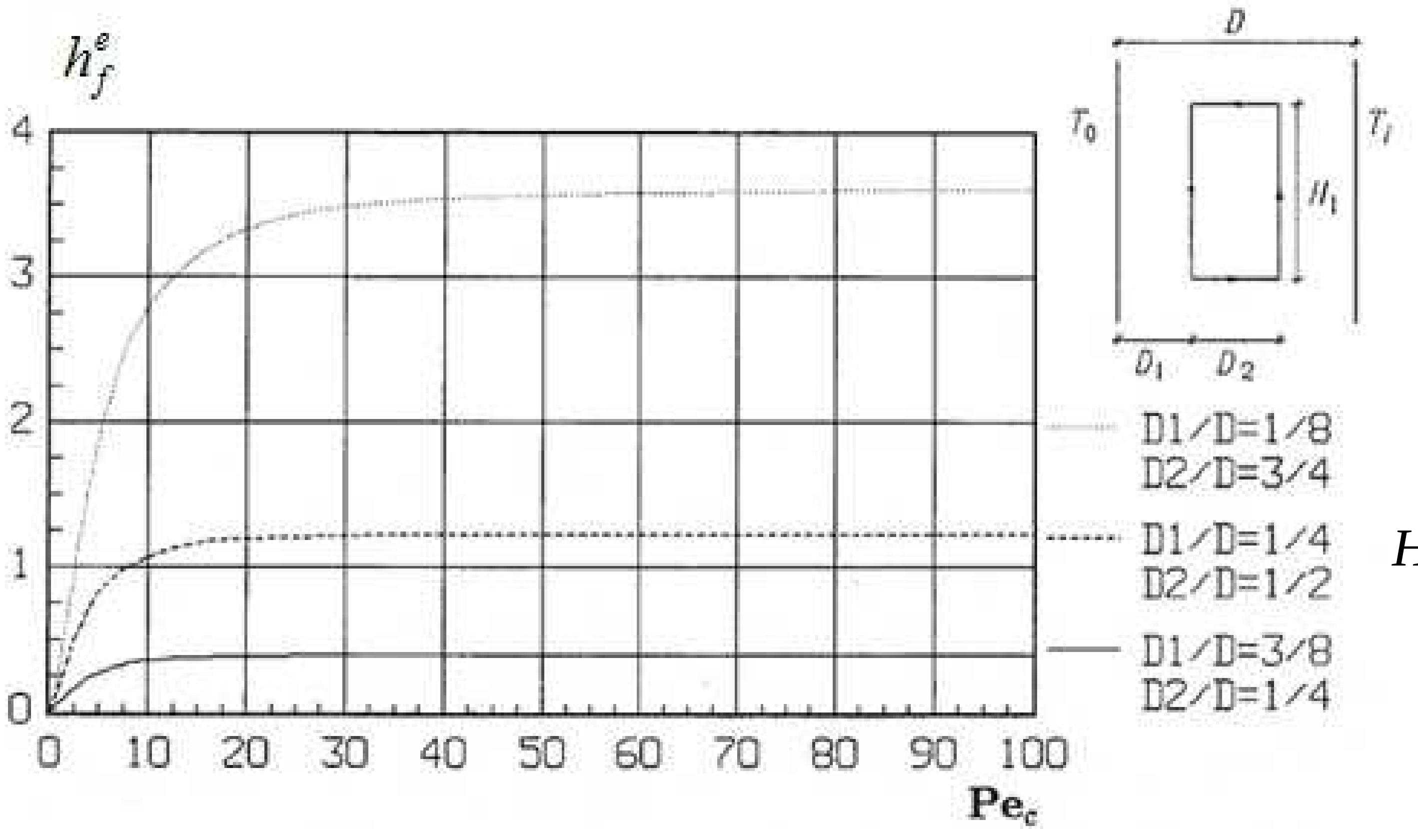
$$U = U_0 + \Delta U$$

$$\Delta U = \frac{\lambda}{H} \cdot h_f^e \left(\mathbf{Pe}_{\mathbf{c}}, \frac{D_1}{D}, \frac{D_2}{D}, \frac{H_1}{D}\right)$$

$$\mathbf{Pe}_{\mathbf{c}} = \frac{q_a \rho_a c_a}{\lambda}$$

q_a: Airflow rate
$\rho_a c_a$: Volumetric heat capacity of air

Simplifications: Homogeneous insulated walls, no surface resistances



$H_1/D=1$

q_a (m^3/ms)	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}
Pe_c (-)	0.0032	0.032	0.32	3.2	32
h_f^e (-)	0.013	0.13	1.3	3.5	3.75
ΔU (W/m^2K)	0.0026	0.026	0.26	0.7	0.75
U (W/m^2K)	0.203	0.226	0.458	0.9	0.95

Enhanced U-value with a factor of approximately 4!

Natural convection – Steady state

$$\Delta U = \frac{\lambda}{H_1} \cdot h_n^e(\mathrm{R}a_\mathrm{c}, \frac{D_1}{D}, \frac{D_2}{D}, \frac{H_1}{D})$$

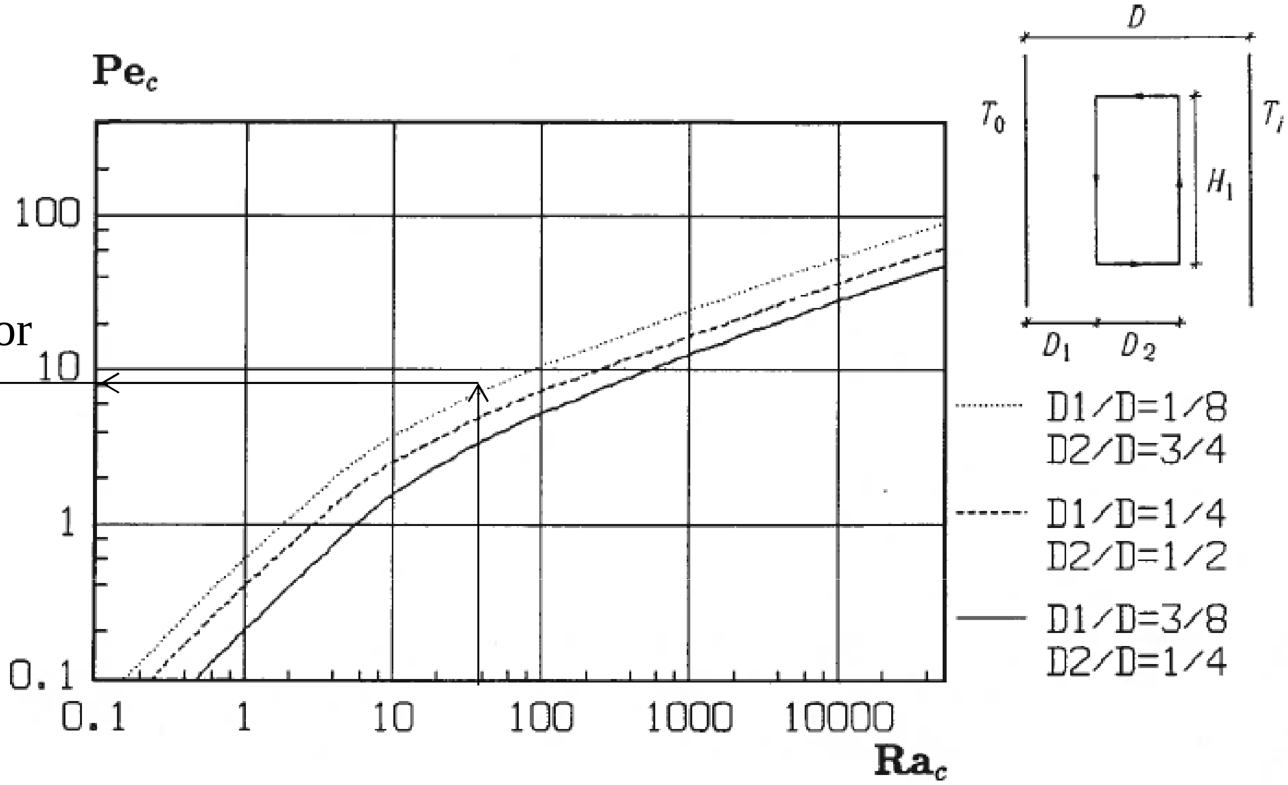
$$\mathbf{Pe_c} = f(\mathbf{Ra_c})$$

$$\mathbf{Ra_c} = \frac{g\beta\rho_a H_1 (T_1 - T_0)}{R_{fc}} \cdot \frac{\rho_a c_a}{\lambda}$$

R_{fc}: Airflow resistance in channel
β: Volume expansion of air coeff.

ERRATA: HEADING IS WRONG, PAGE 807 IN PROCEEDINGS
CORRECT IS:
4. STEADY-STATE HEAT TRANSFER USING INTERIOR <u>NATURAL</u> CONVECTION

Pe_c gives heat loss factor according to previous figure!



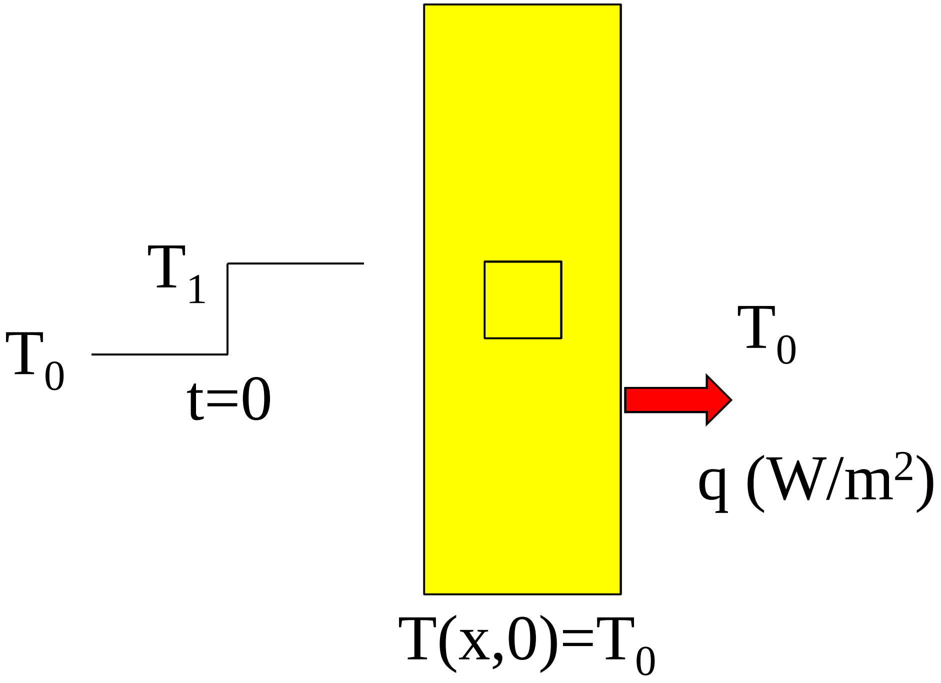
H_1/D=1

b: Air gap width

b (mm)	1	2	5	10	20
R_{fc} (hPa/ (m^3/ms))	2140	351	38.5	8.2	1.8
Ra_c (-)	0.024	0.15	1.3	6.4	28
Pe_c (-)	<0.1	0.1	1.1	3	6
q_a (μm^3/ms)	<3.2	3.2	35	96	190
h_n^e (-)	<0.04	0.04	0.44	1.5	2.2
ΔU (W/m^2K)	<0.008	0.008	0.09	0.30	0.44
U (W/m^2K)	<0.21	0.21	0.29	0.50	0.64

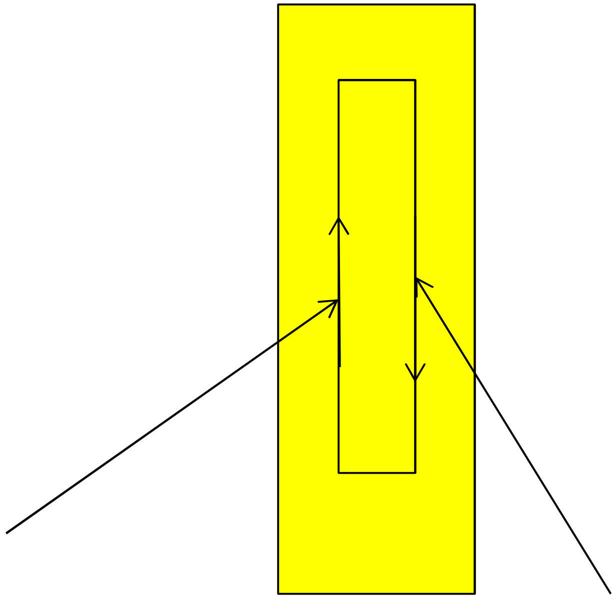
b = 20 mm gives up to three times higher U-value ←

Thermal inertia – Forced convection/Step response



$$q(t) = \frac{\lambda(T_1 - T_0)}{D} \cdot h_f\left(\frac{\sqrt{at}}{D}, \mathbf{Pe_c}, \frac{D_1}{D}, \frac{D_2}{D}, \frac{H_1}{D}\right)$$

Numerical technique – Forced convection

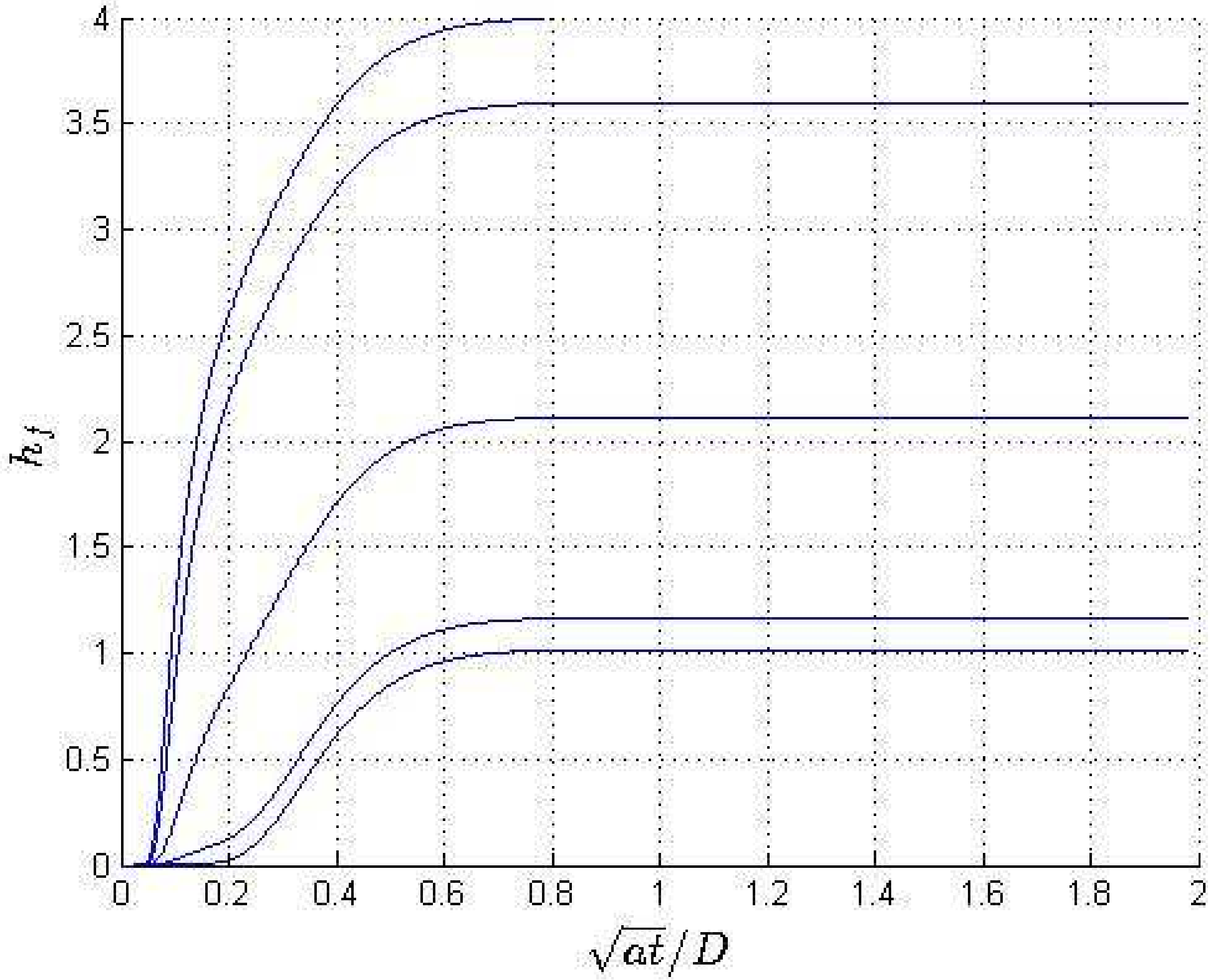


1D-FDM simulation
Using internal heat sources

Heat is taken up
by air -
representing a heat sink
-q_c

Heat is released
by air –
representing a heat source
q_c

$$q_c(t) = \frac{q_a \cdot \rho_a c_{pa}}{H_1} \cdot \left(T(D_1,t) - T(D_1 + D_2,t)\right)$$



Peclet number
0.0032(lower curve), 0.032, …32(upper curve)
D_1/D=1/8, D_2/D=3/4 and H_1/D=1

Steady-state is reached approx. at $\sqrt{at} = 0.5 \cdot D$

a: thermal diffusivity

Higher Peclet number – faster response!
Reaching half the terminal value is four times faster!

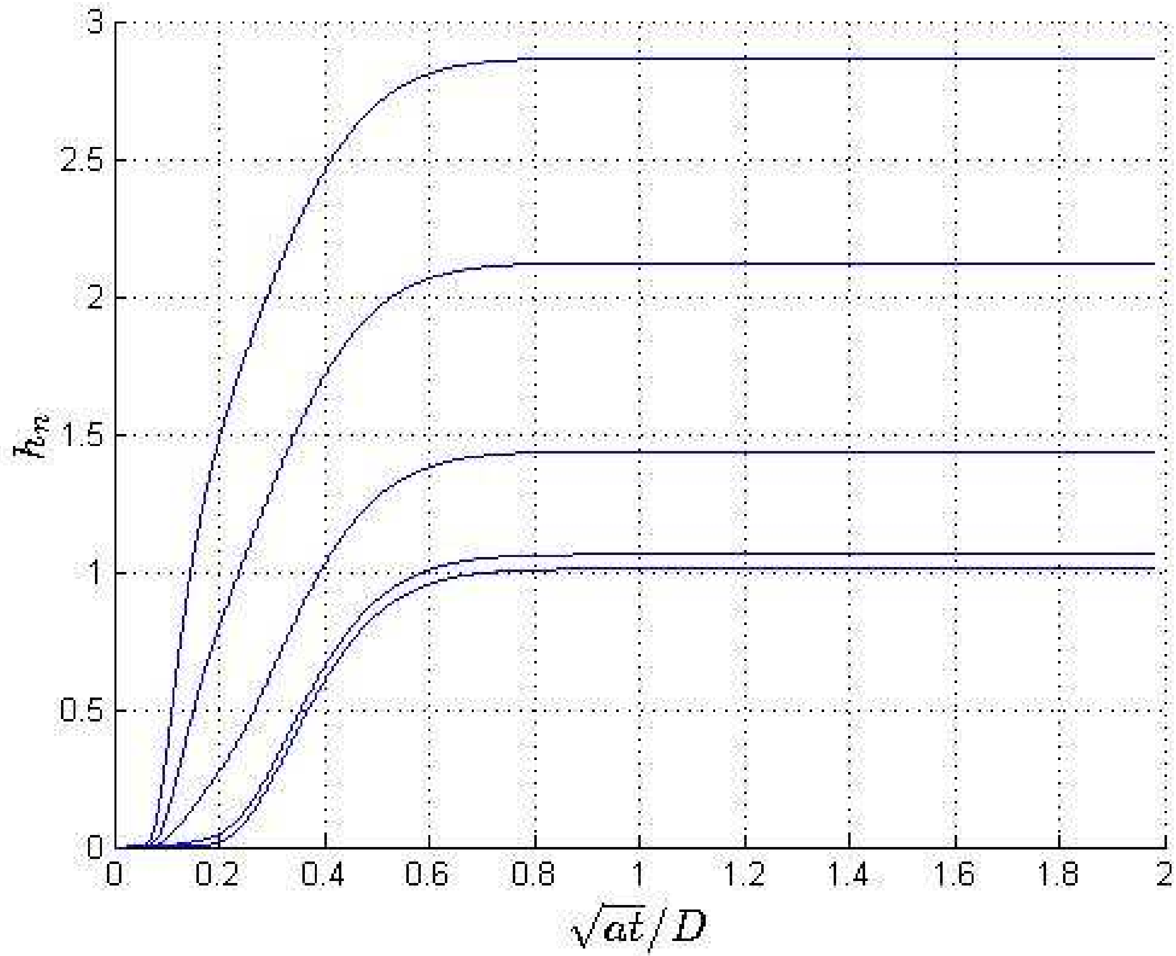
Error in terminal value: 1.5-19%

Numerical results – Natural convection

$$q(t) = \frac{\lambda(T_1 - T_0)}{D} \cdot h_n\left(\frac{\sqrt{at}}{D}, \mathbf{Ra_c}, \frac{D_1}{D}, \frac{D_2}{D}, \frac{H_1}{D}\right)$$

Heat source in numerical simulation:

$$q_c(t) = \mathbf{Ra_c} \cdot \frac{\lambda}{H_1(T_1 - T_0)} \left(T(D_1, t) - T(D_1 + D_2, t)\right)^2$$



Different Rayleigh numbers (top curve) 28,10, 5,2,0 (bottom): D_1/D=1/8, D_2/D=3/4 and H_1/D=1

Error in terminal value: 5-12%

Conclusions

- Using a interior air flow loop, the U-value can be controlled both using forced and natural convection.
- In the examples, the U-value increased between three to around four times.
- Time response can be speeded up, and the example show around a factor of four.
- This paper also shows how to simplify the dynamical modeling of walls with air flow loops inside. By using the one-dimensional model demonstrated the thermal feature of a room component of a building and a whole building can be modeled quite accurately.

Thank you for your attention.

Everything should be made as simple as possible, but not simpler..
Albert Einstein