Influence of obstacle and surface emissivity on night-time cooling using mixing and displacement ventilation

– Experimental investigation –

Presented by : Michal Pomianowski
Jérôme Le Dréau
Rasmus Lund Jensen

Co-Authors: L. Karlsen, M. Litewnicki, L. Michaelsen, A. Møllerskov, H. Ødegaard, L. Svendsen, A. Marszal, F. Khalegi, G. Domarkas, J. Taminskas, K. Bandurski, K. Madsen, S. Gedsø, J. Nørgaard, O. Daniels, R. Justesen, M. Madsen, K. Mikkelsen, C. Topp

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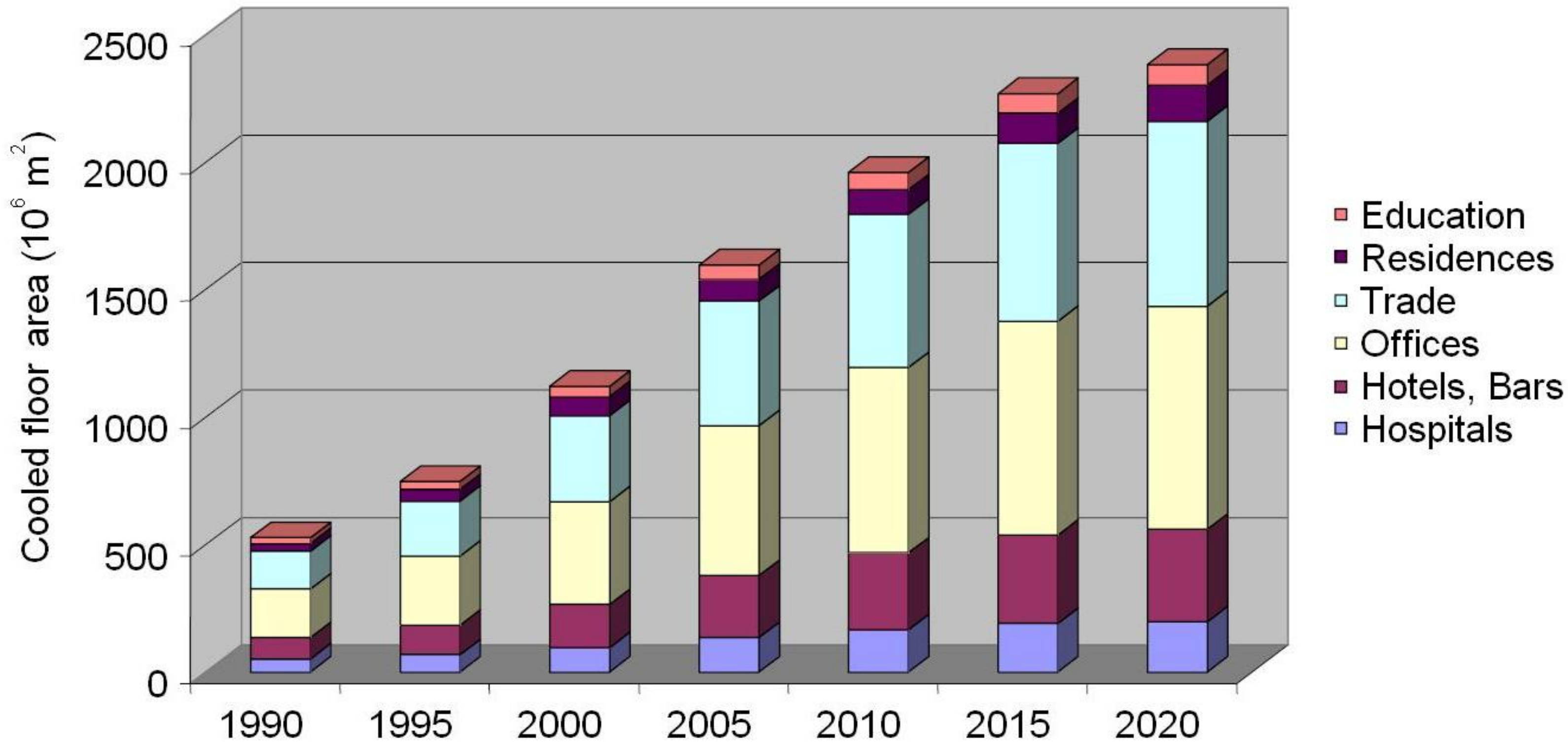
Cooled floor area in EU-15 countries



Source: EECCAC, 2003

Passive and low-energy cooling

Reduction of heat gains

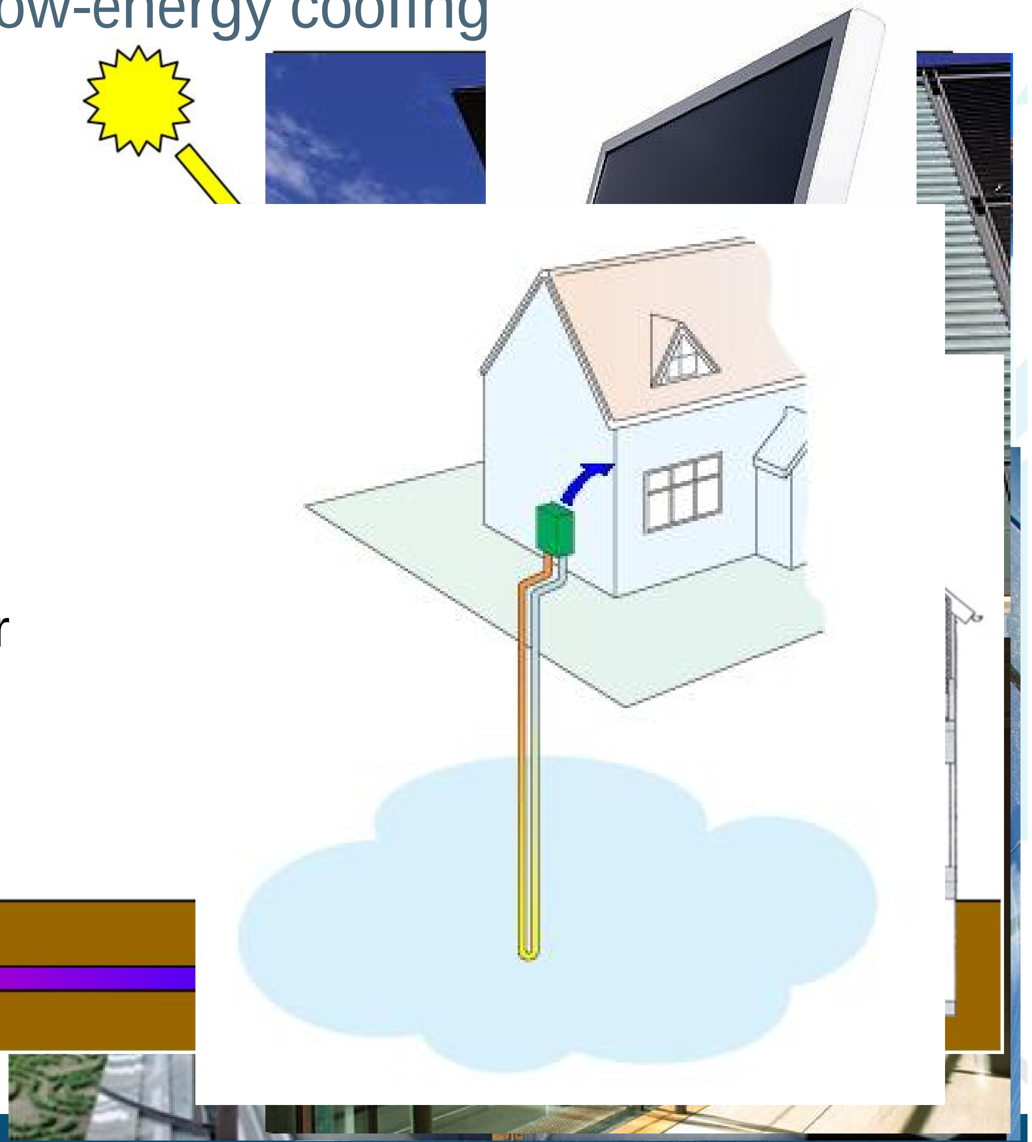
- Glazing ratio
- Solar shading
- Efficient office equipment
- Daylight utilisation

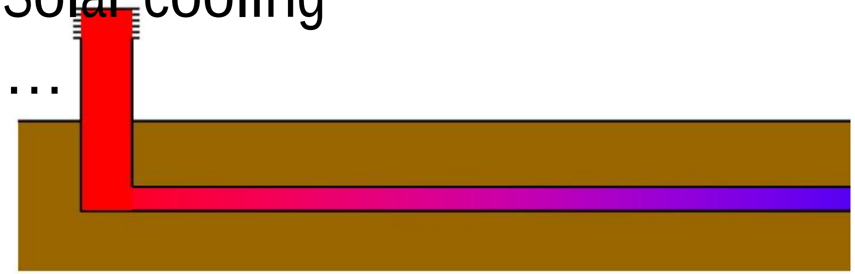
Natural heat sinks

- Night-time ventilation
- Earth-to-air heat exchanger
- Ground water

Solar cooling

…





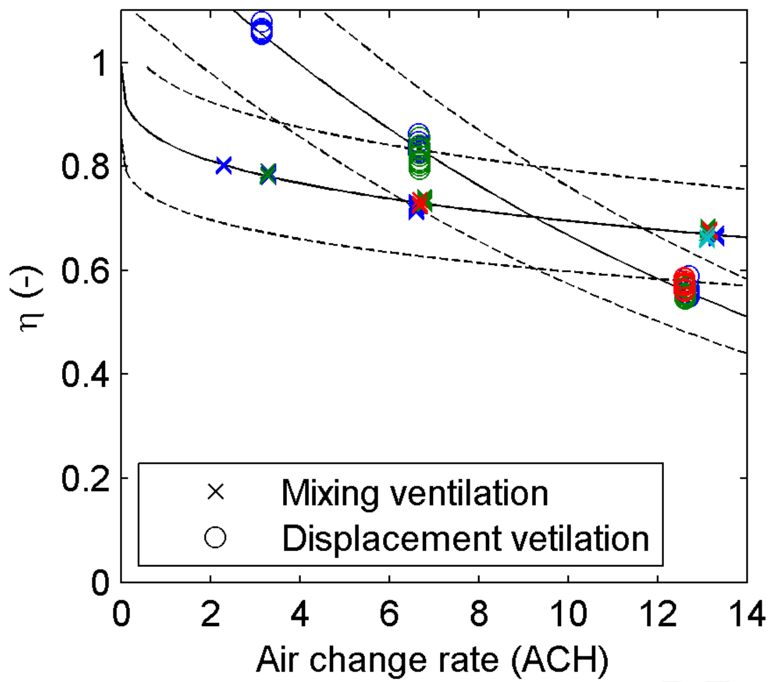
- Scope of the investigation:

Evaluate the potential of night cooling by night time ventilation

Measurement of the convective energy exchange and convective heat transfer coefficient

Effect of redistribution of energy between the surfaces due to radiation

Experiments conducted:
- o Changing the floor emissivity
- o Adding obstacles



Experimental set-up

- Test room at Aalborg University (DK):

Used by N. Artmann for his PhD entitled “Passive cooling of buildings by night-time ventilation”

Internal dimensions

2.64 m x 3.17 m (8.4 m²)

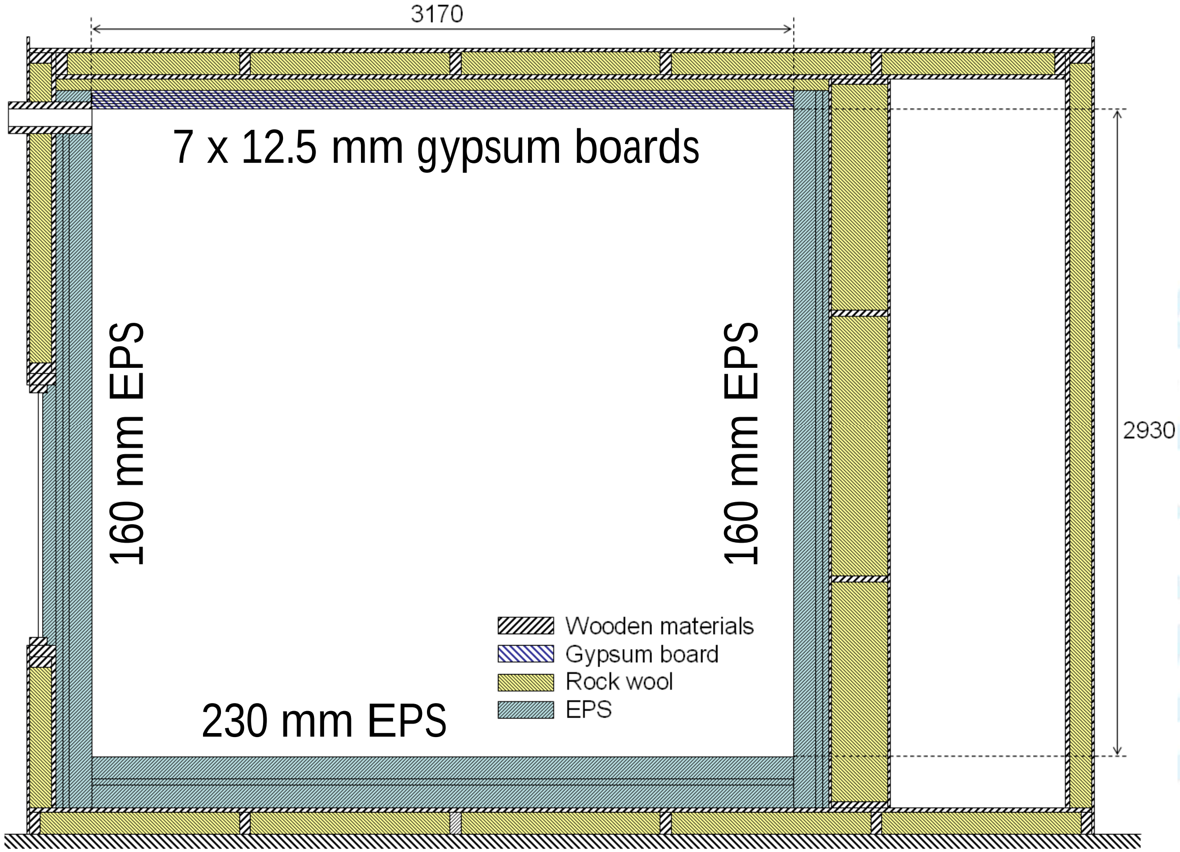
Height: 2.93 m

Volume

24.52 m^3

Night-time ventilation:

Influence of obstacle and surface emmisivity

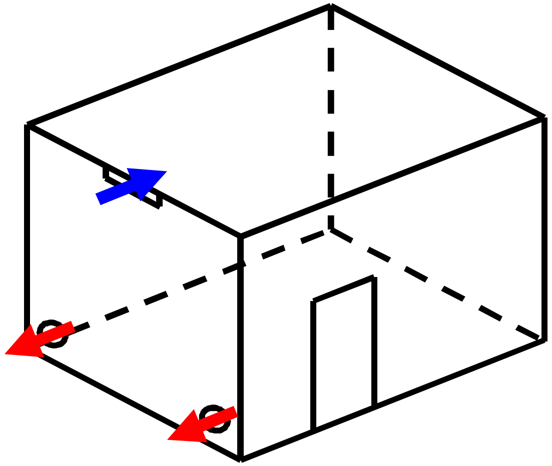


Test room:
cross section

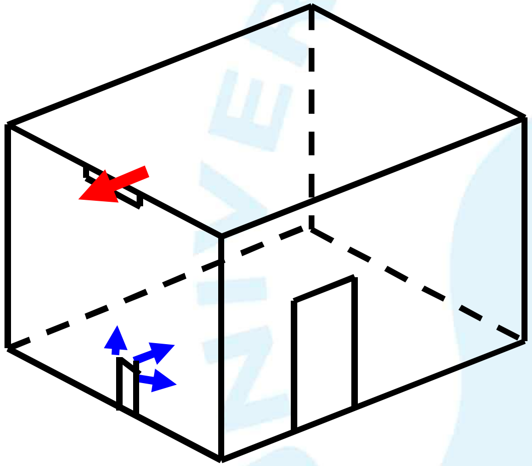
Material properties (λ, ϱ, ε, C_p) have been measured at EMPA.

- Air distribution principles:

Capacity of the system: air change rate going from 2.3 to 13.5 ACH



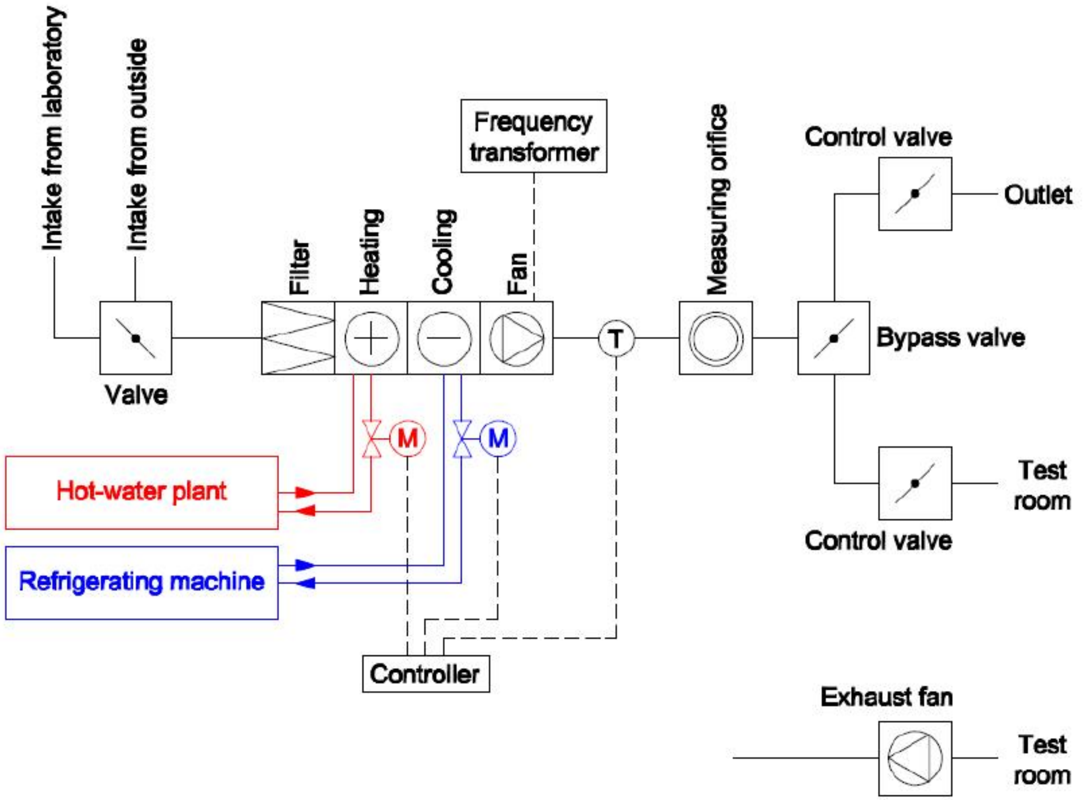
Mixing Ventilation



Displacement Ventilation

- Experiments:

- Homogeneous room temperature at the beginning of experiments
- Ventilation with cold air for 12 hours



- Temperature logged every 10 seconds

- Parameters varied

  Air distribution principle (mixing & displacement)

  Air change rate, *ACR*

  Initial temperature difference, ΔT_0

  Room layout (adding a table)

  Floor emissivity (adding a aluminium foil)

- Conduction:

Ceiling

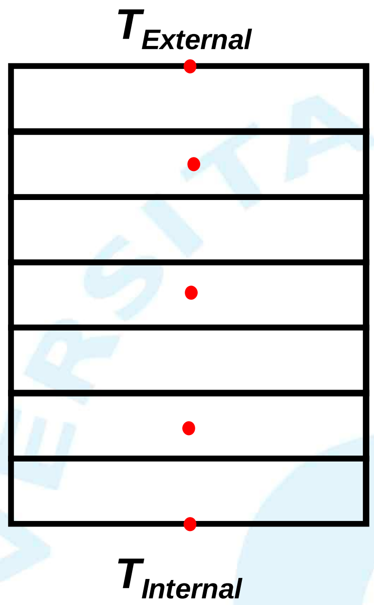
- Measured internal and external surface temperatures

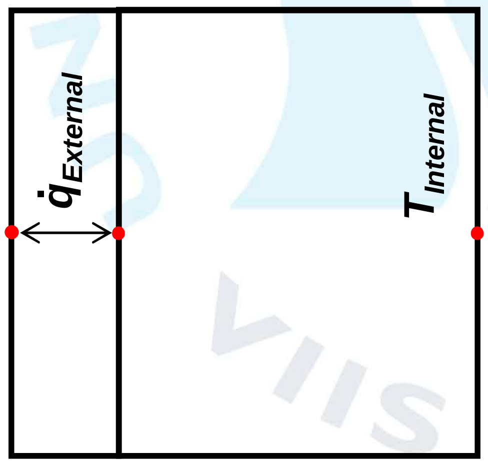
Walls and floor

- Measured internal surface temperatures and external heat flux

Calculation

- Boundary conditions to a transient 1-dimensional finite difference model
- Temperature gradient for each time step
- Conductive heat flux (moving average of 2.5 min)

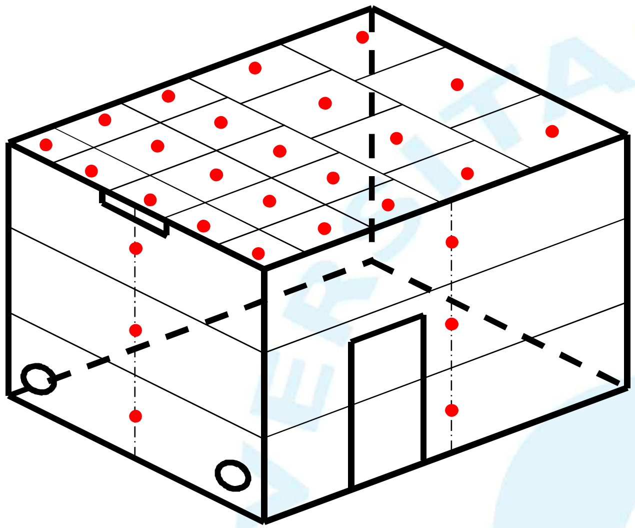




- Radiation:

22 sections at the ceiling
3 sections at walls and floor

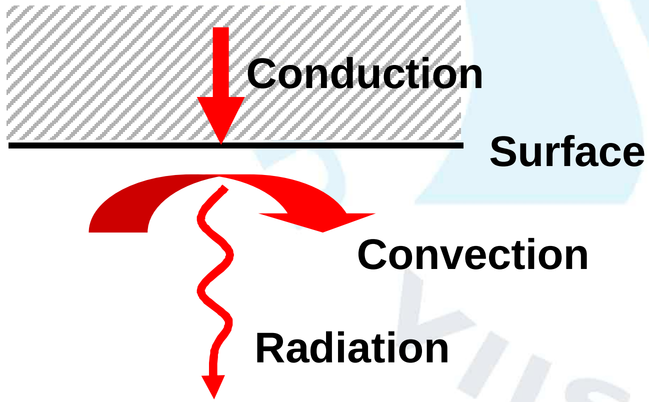
$$\dot{q}_{rad,\,i} = \sum_j \frac{\sigma \cdot \varepsilon_i \cdot \varepsilon_j \cdot F_{i,\,j}}{1-(1-\varepsilon_i)(1-\varepsilon_j)\cdot F_{i,\,j}\cdot F_{j,\,i}}\left(T_i^{\,4} - T_j^{\,4}\right)$$



- Convection:

Conservation of energy at the surface

$$\dot{q}_{conv,\,i} = \dot{q}_{cond,\,i} - \dot{q}_{rad,\,i}$$



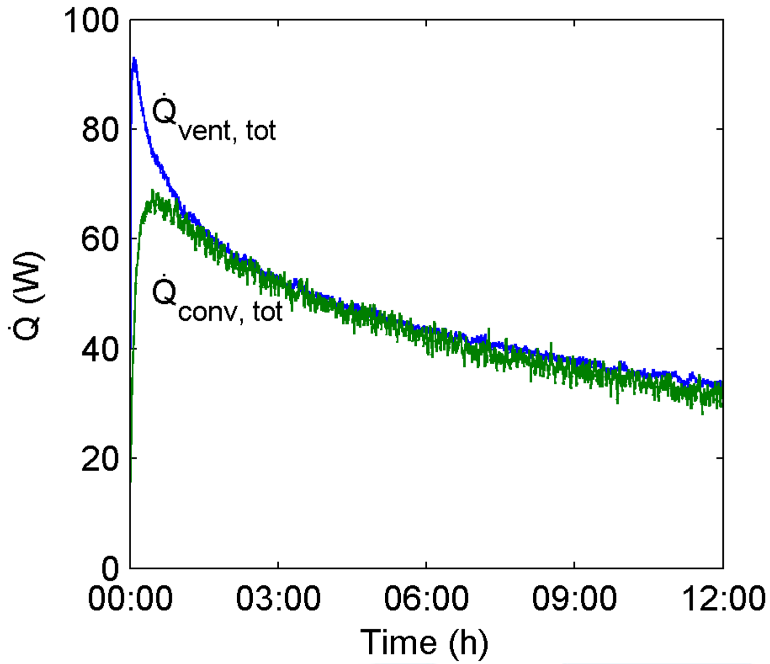
- Total heat discharged from the room:

Total convection at all surfaces

$$\dot{Q}_{conv,tot} = \sum_i A_i \cdot \dot{q}_{conv,i}$$

Ventilative heat flow

$$\dot{Q}_{vent,tot} = \dot{V} \cdot \rho \cdot c_p \cdot (T_{out} - T_{in})$$



- Uncertainty estimated:

$Q_{conv,tot}$: ± 16 %
$Q_{vent,tot}$: ± 12 %

Thermocouples (± 0.086 K), position, material properties, thickness…

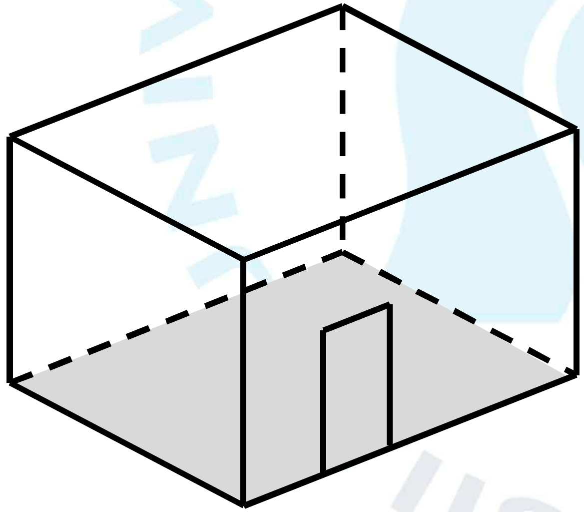
Influence of floor emissivity

- Set-up:

Initial flooring: EPS

↓

Aluminum-foil floor cover (ε=0.03)

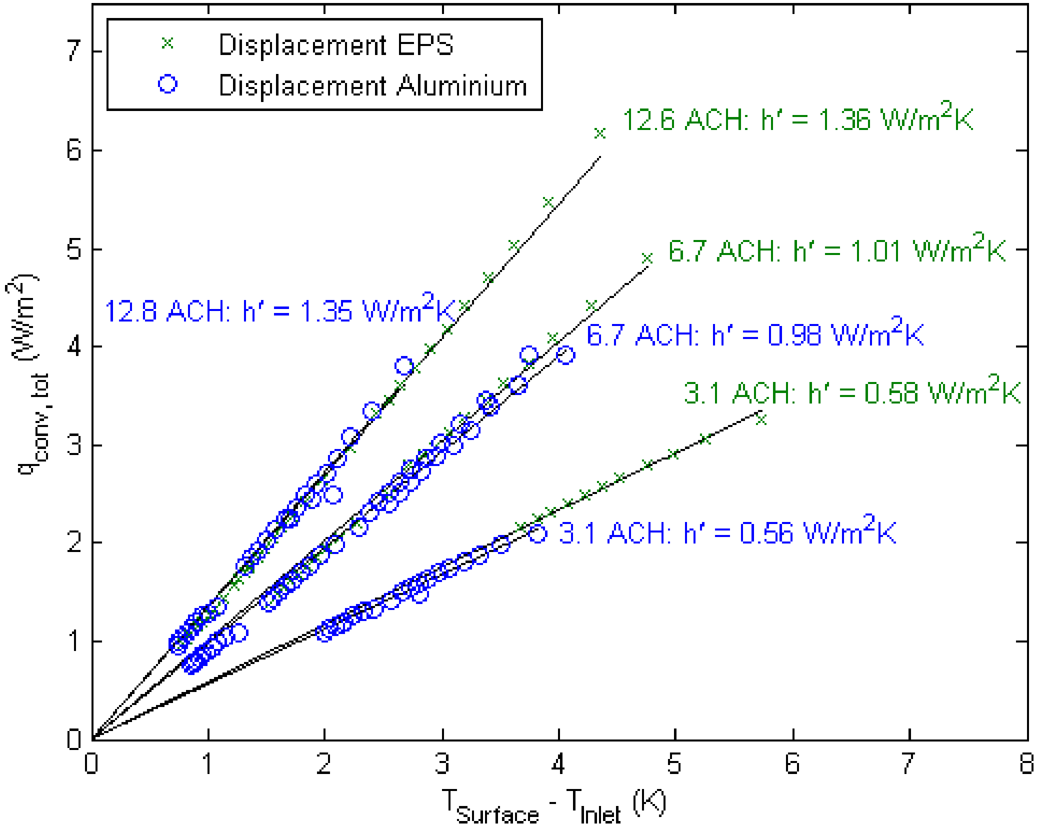


- Displacement ventilation:

9 new experiments

No	Type of flooring	ACR (ACH)	ΔT_0 (K)
1	EPS	3.1	10.1
2	EPS	6.7	5.8
3	EPS	6.7	11.3
4	EPS	12.6	3.6
5	EPS	12.6	6.0
6	EPS	12.7	12.7
11	Aluminium	3.1	5.0
12	Aluminium	3.1	6.7
13	Aluminium	6.7	2.8
14	Aluminium	6.7	5.2
15	Aluminium	6.6	8.9
16	Aluminium	6.7	9.6
17	Aluminium	13.1	3.1
18	Aluminium	13.2	5.9
19	Aluminium	12.8	7.6

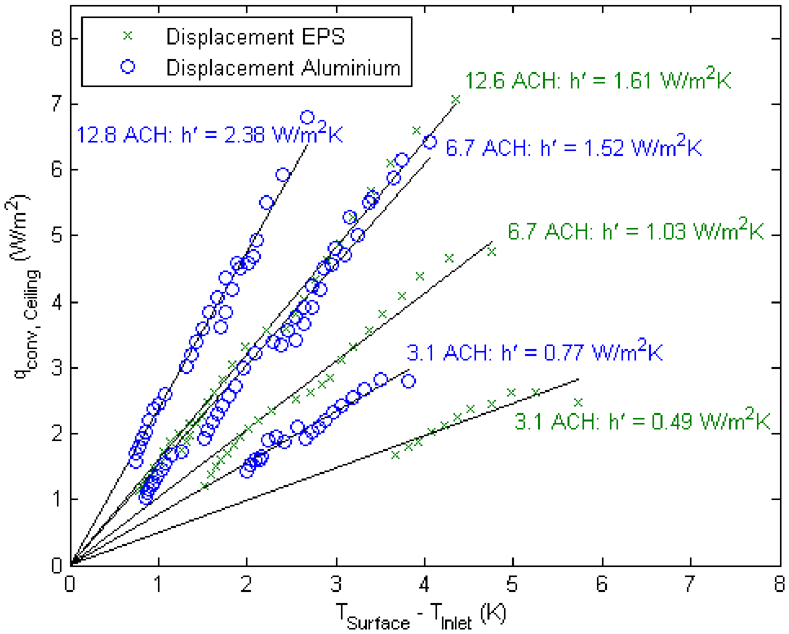
Mean convective heat flux from the room:

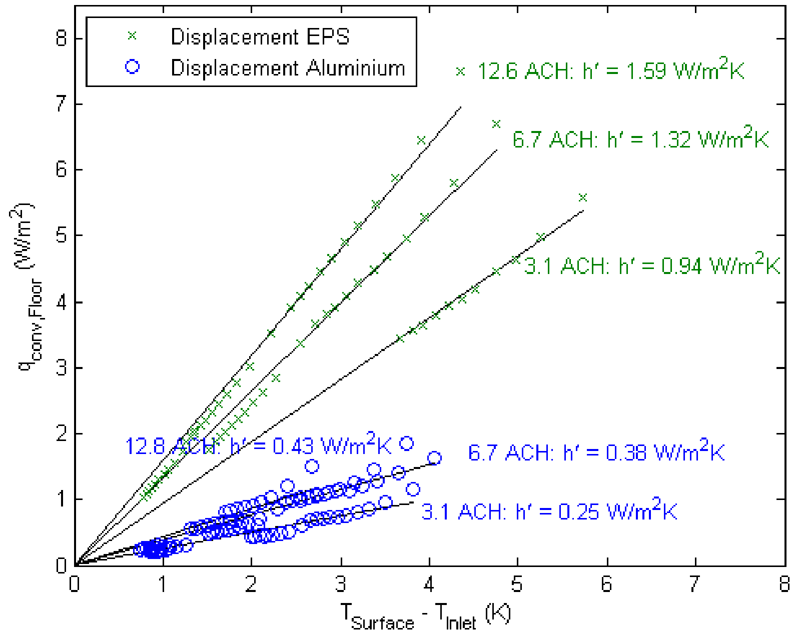


Average convective heat transfer coefficient:

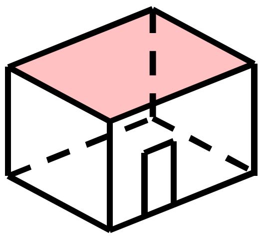
$$h' = \frac{q_{conv,tot}}{T_{surface} - T_{inlet}}$$

Mean convective heat flux from specific surfaces:

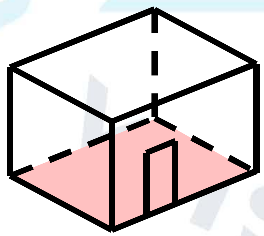




From ceiling

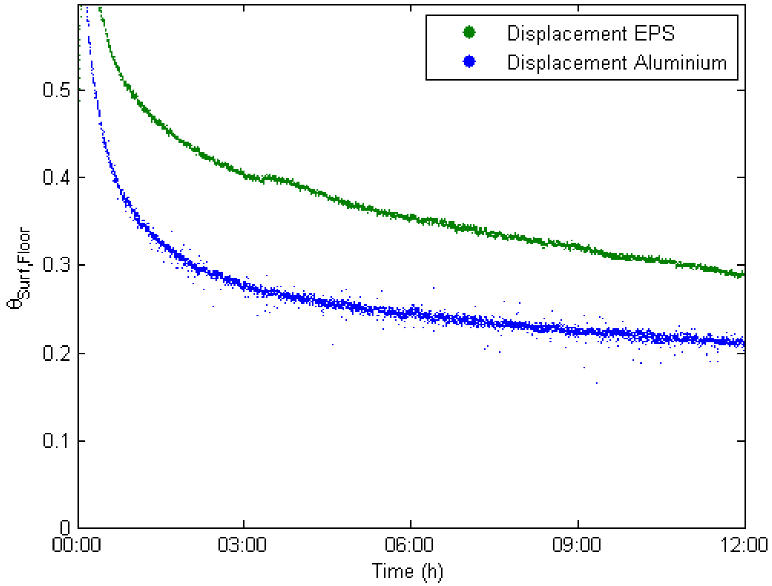


From floor

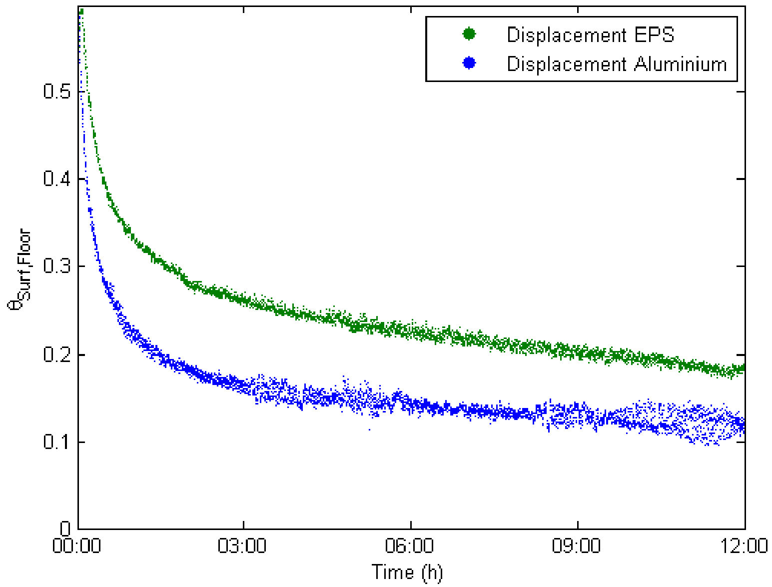


Surface temperature at the floor:

The dimensionless temperature is defined by: $$\theta = \frac{T - T_{inlet}}{\Delta T_0}$$



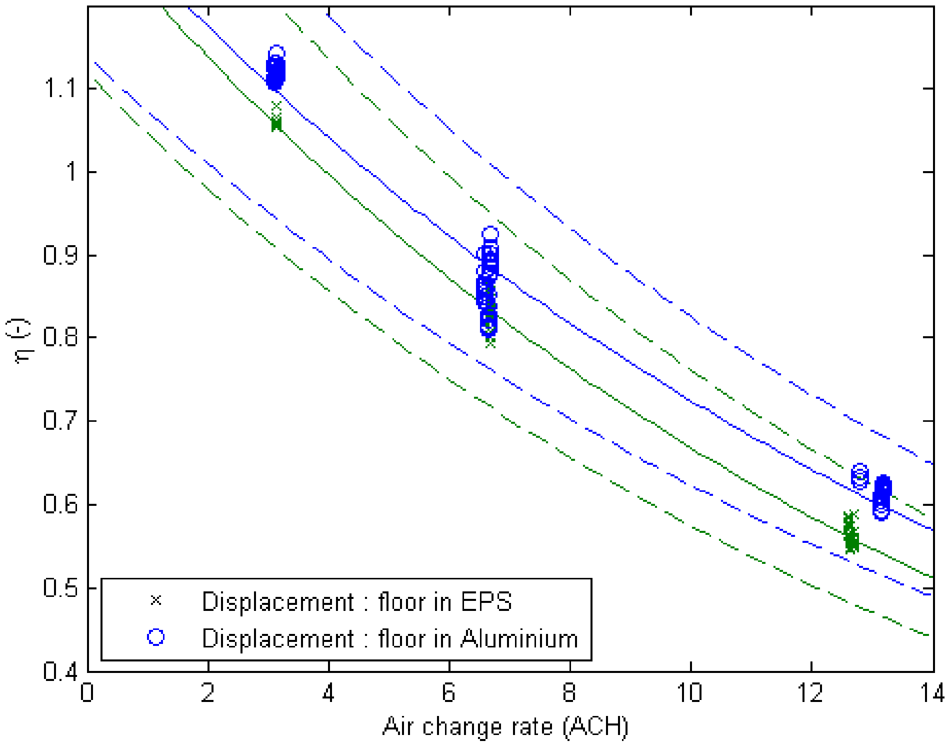
3.1 ACH



6.7 ACH

Temperature efficiency:

Feasible parameter for modelling night-time ventilation performance.



Temperature efficiency η:

$$\eta = \frac{T_{outlet} - T_{inlet}}{\bar{T}_{surface} - T_{inlet}}$$

Night-time ventilation:

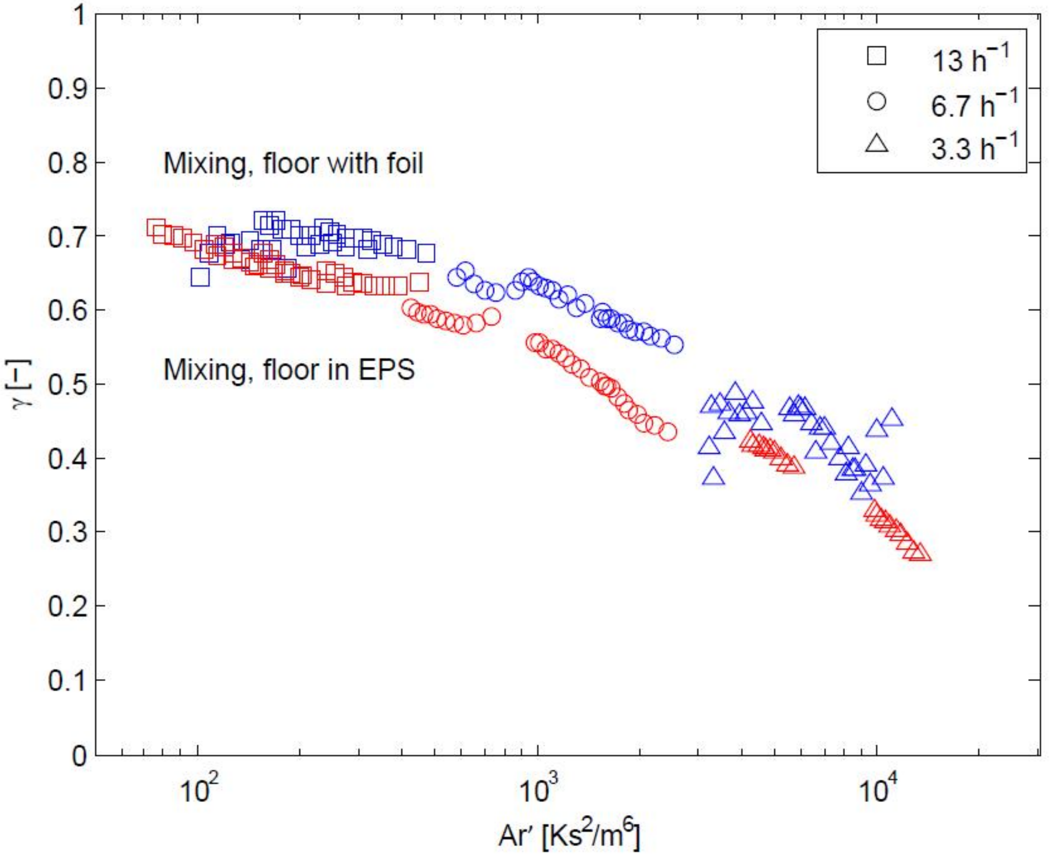
Influence of obstacle and surface emmisivity

- Mixing ventilation:

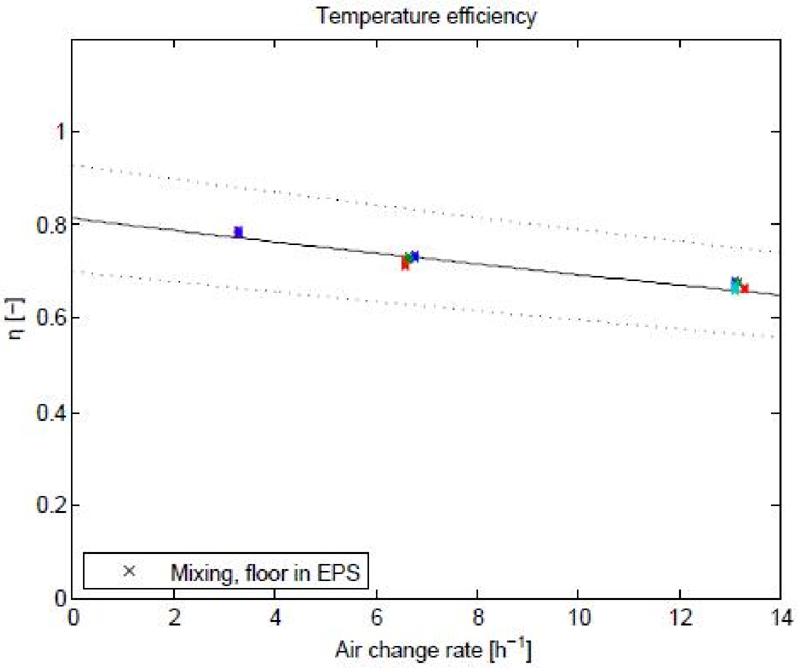
9 new experiments

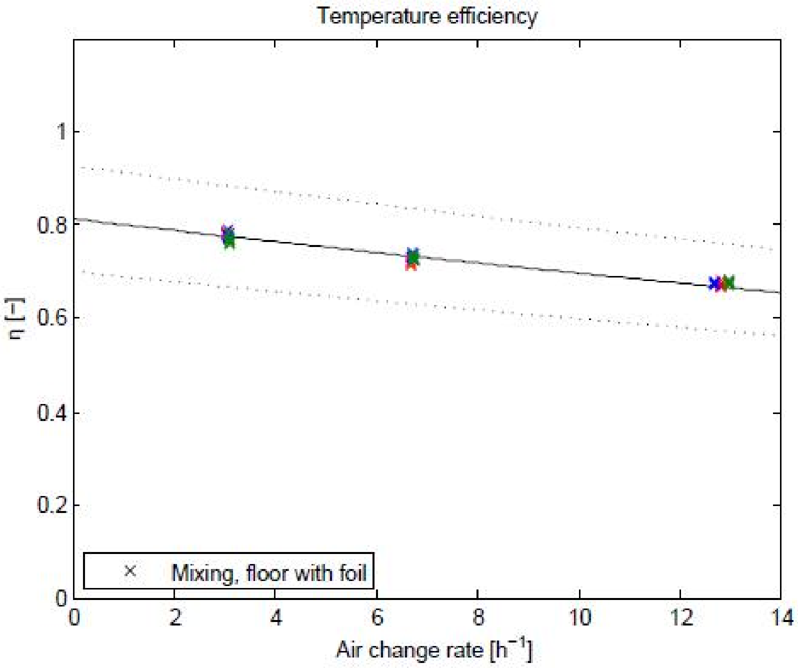
No	Type of flooring	ACR	$\Delta T_0 (K)$
1	EPS	3.3	4.3
2	EPS	3.3	10.2
3	EPS	6.7	2.9
4	EPS	6.8	6.1
5	EPS	6.6	8.9
6	EPS	13.1	2.9
7	EPS	13.2	4.0
8	EPS	13.1	5.3
9	EPS	13.3	9.2
4	Aluminium	3.3	2.0
3	Aluminium	3.3	5.0
9	Aluminium	3.3	8.0
6	Aluminium	6.7	2.9
2	Aluminium	6.7	6.0
8	Aluminium	6.7	10.2
1	Aluminium	13.0	2.9
7	Aluminium	13.0	5.3
5	Aluminium	13.0	8.0

Ratio of convection to total heat flow for the ceiling

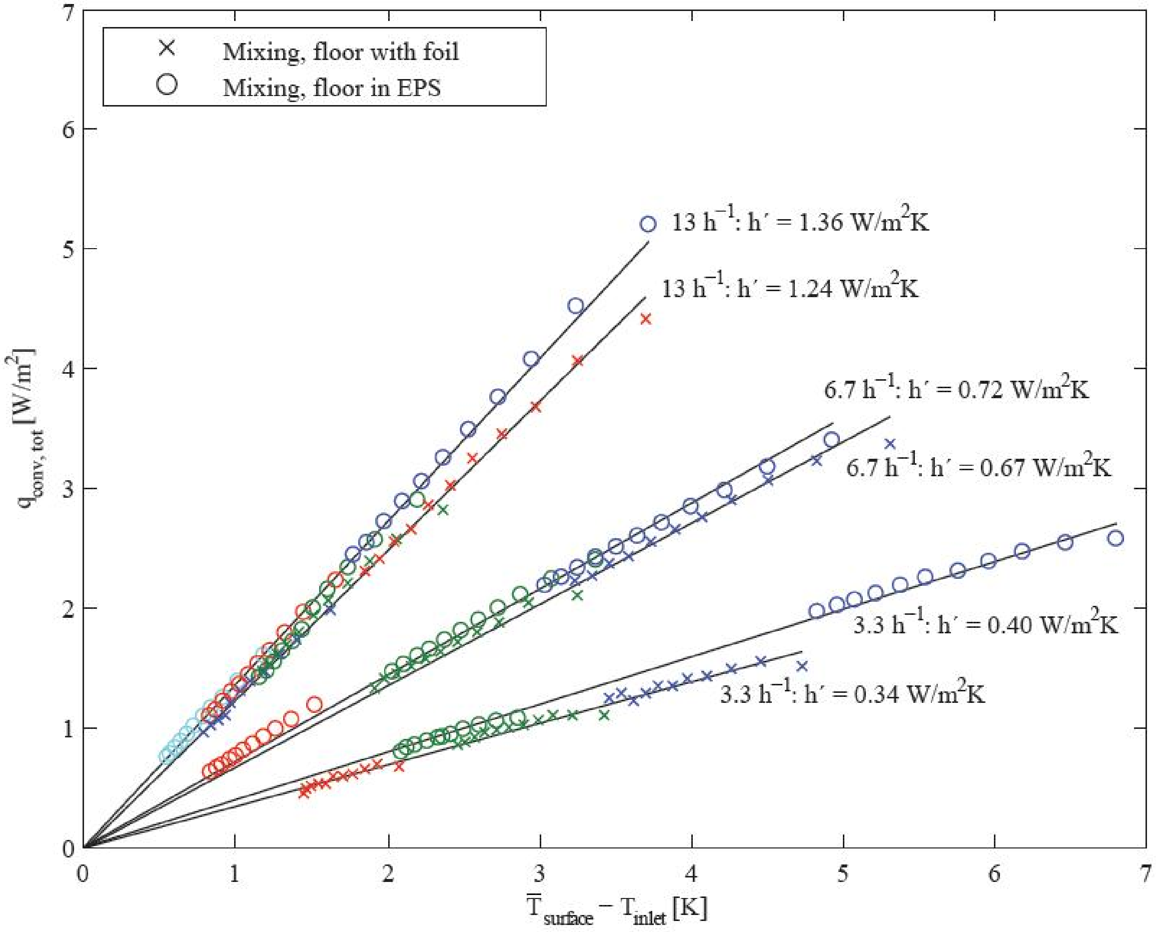


Temperature efficiency



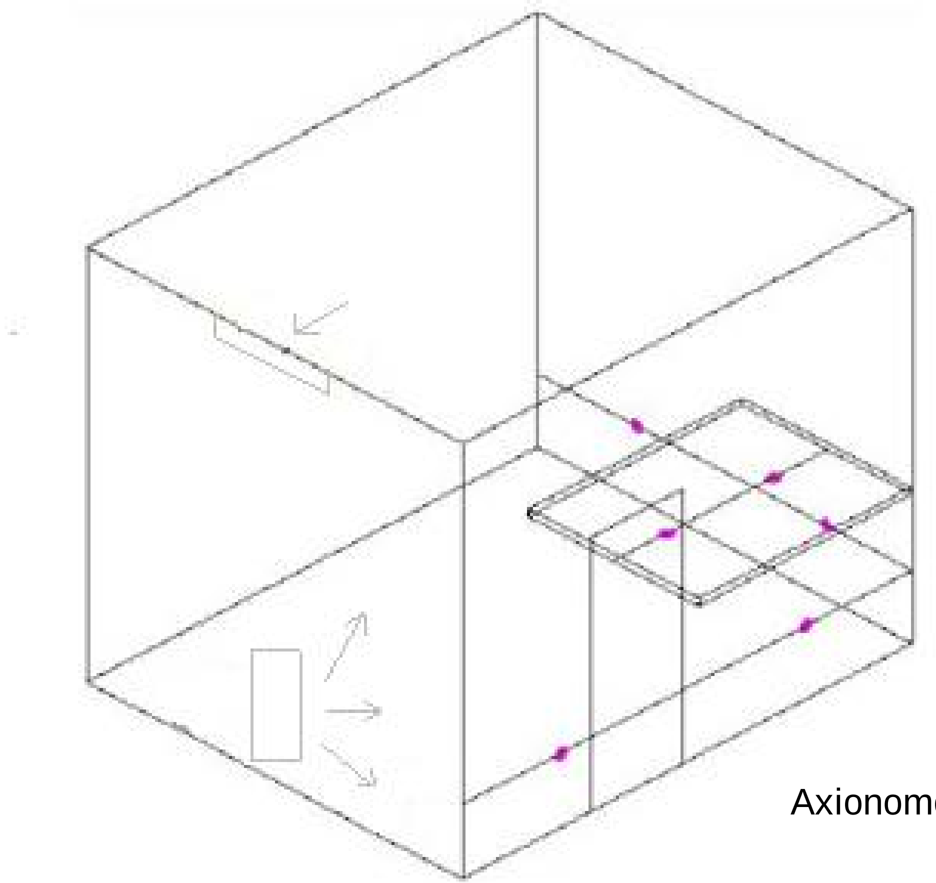


Mean Convective Heat Flux



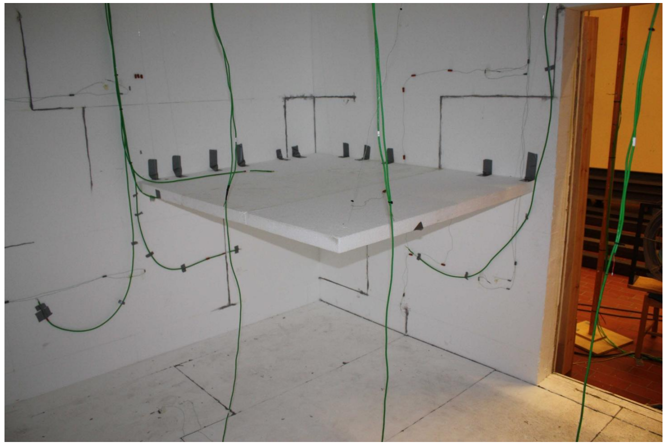
Influence of an internal obstacle

New set up with the internal obstacle: test room with the table



Axionometric view of the test room with the table

Overview of experiment with the table and displacement ventilation: Air Change Rate & ΔT



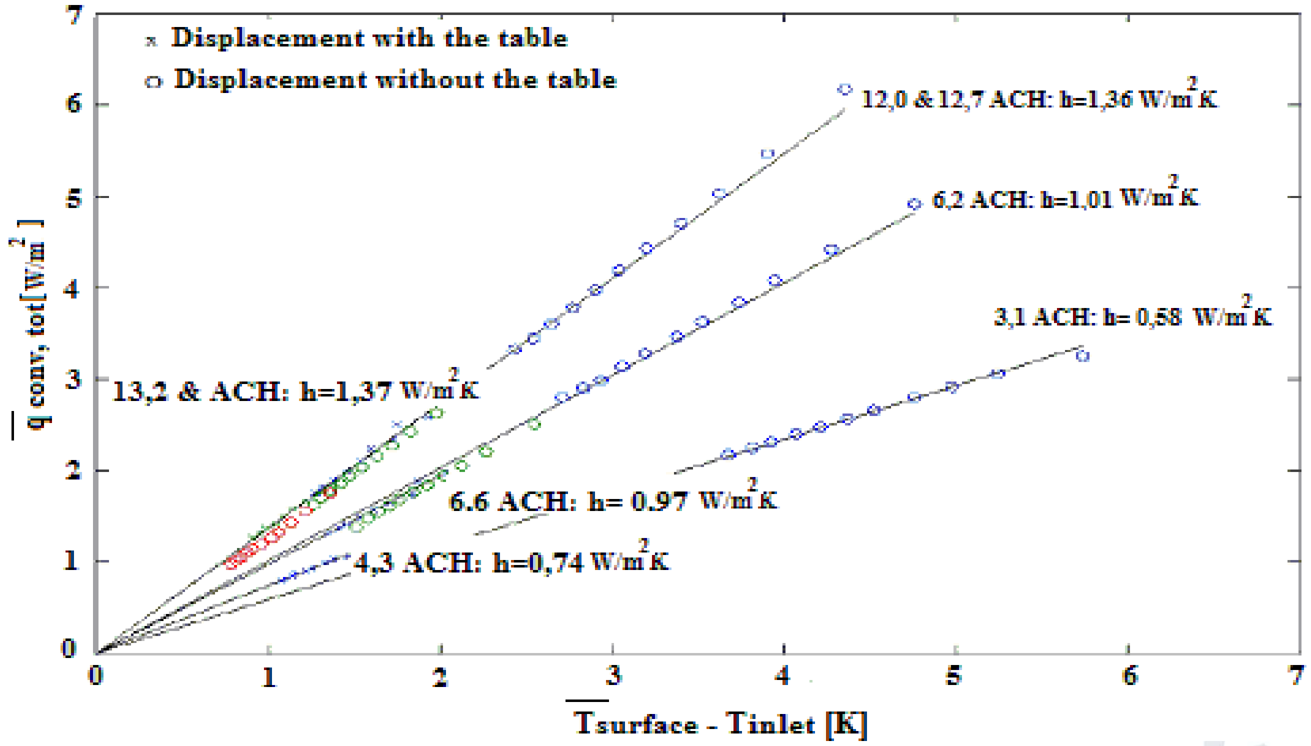
7 new experiments

No	Table	ACR (ACH)	ΔT_0 (K)
1	-	3.1	10.1
2	-	6.7	5.8
3	-	6.7	11.3
4	-	12.6	3.6
5	-	12.6	6.0
6	-	12.7	12.7
11	Yes	4.2	0.5
12	Yes	4.3	3.1
13	Yes	6.6	1.7
14	Yes	6.6	5.1
15	Yes	13.2	4.2
16	Yes	13.2	6.0
17	Yes	14	0.3

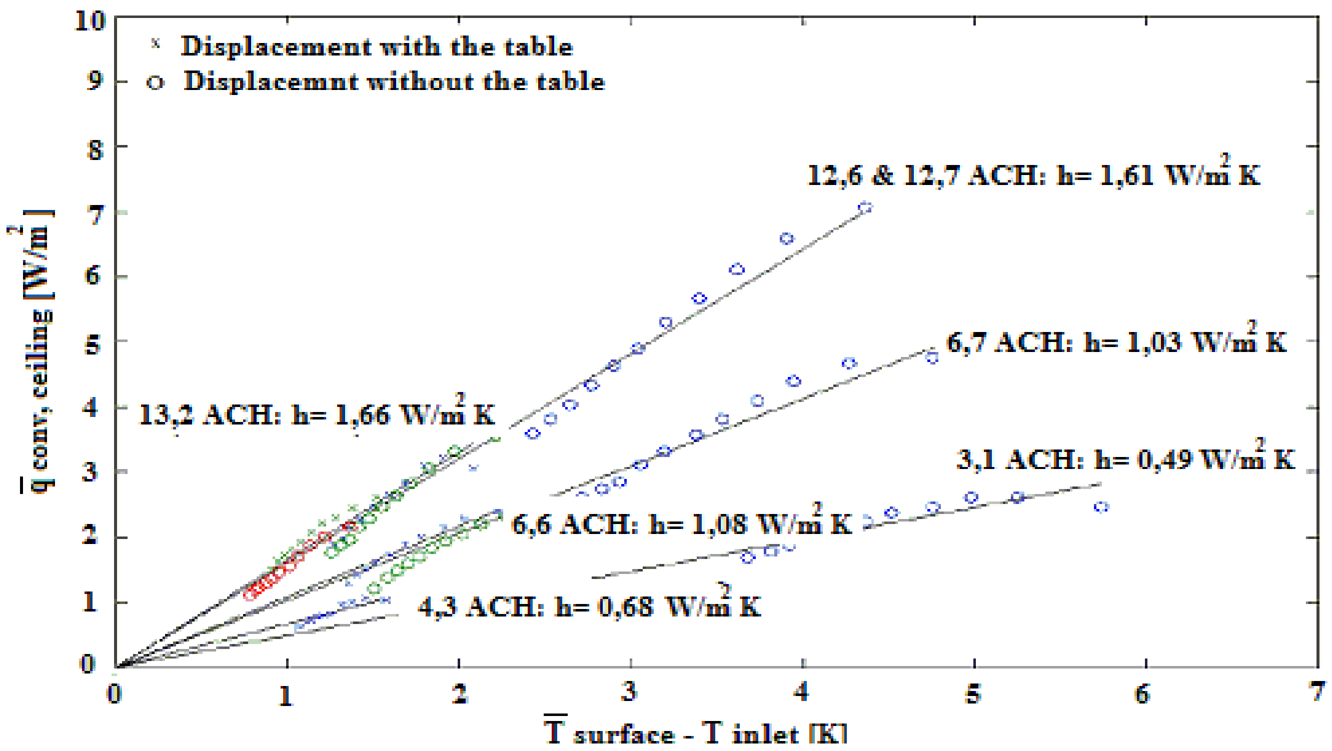
Night-time ventilation:

Influence of obstacle and surface emmisivity

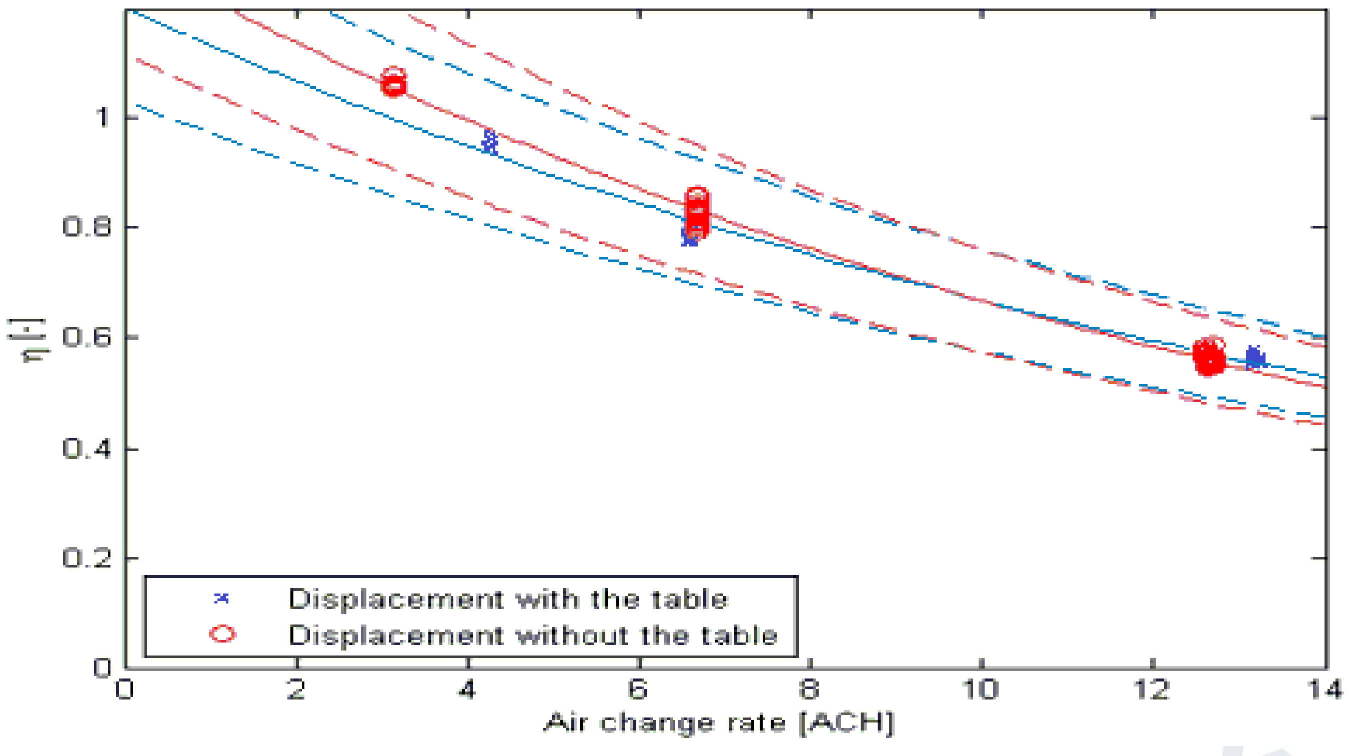
Results: Mean convective heat flux in the test chamber in function of temperature difference



Results: Mean convective heat flux at the ceiling of the test chamber in function of temperature difference



Results: Temperature efficiency in function of air change rate



Conclusions:

Influence of the floor emissisvity (Aluminium foil)

- Total convective heat transfer similar in both cases.
  Similar temperature efficiency.

- But some differences are visible in the case of displacement ventilation:
  - Surface temperature of the floor decreasing
  - Reorganisation of the convective heat transfer at the floor and at the ceiling

- In practice there is no influence of the extremly low emissivity of the floor cover on the efficiency of the night-time ventilation

Conclusions:

Set-up with table & displacement ventilation
vs set-up without table and displacement ventilation

- Based on obtained results it can be concluded that insertion of the table does not have significant influence on the heat distribution in the room
- Heat transfer due to convection and ratio of convective heat transfer to total heat transfer in the room remains the same for both set-ups and for various ACRs
- There can be observed insignificant changes in temperature efficiency

Thank you for your attention

Michal Pomianowski
Jérôme Le Dréau
Rasmus Lund Jensen

Results: Ratio of convective to tatal heat flow in function of Archimedes number