A Comparison of Measured and Simulated Air Pressure Conditions of a Detached House in a Cold Climate

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Infiltration of buildings

- Depends on..
  - Air permeability of structures
  - Pressure conditions, that depends on:
    - Wind conditions
    - Stack effect
    - Ventilation system

Objective of the study

- To perform an evaluation of…
  - Pressure conditions predicted by a detailed multi-zone simulation model.
  - Simplified simulation of wind pressure

  …comparing experimental and numerical results
- To study…
  - Suitability of the model for detailed infiltration and energy analyses in the cold climate

Modeling object

- A prefabricated house:

- Timber frame construction
- Plastic air vapour barrier
- Mechanical supply and exhaust ventilation system

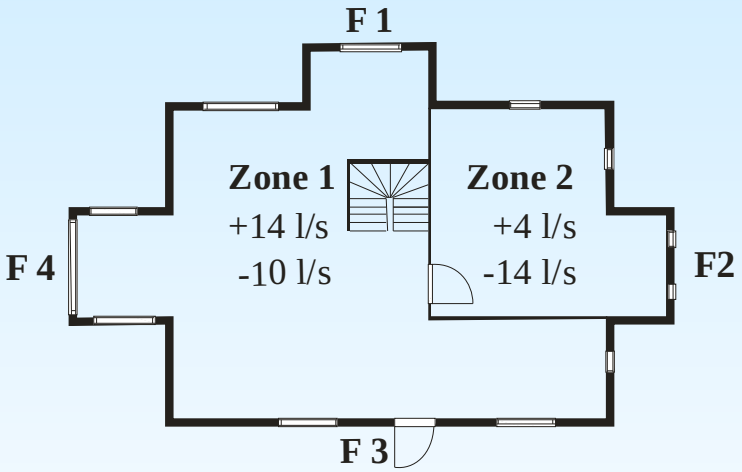
- Measured data for the model:
  - Ventilation air flow rates
  - Airtightness using pressurization test:

Resultant n_{50} = 3.9 ach

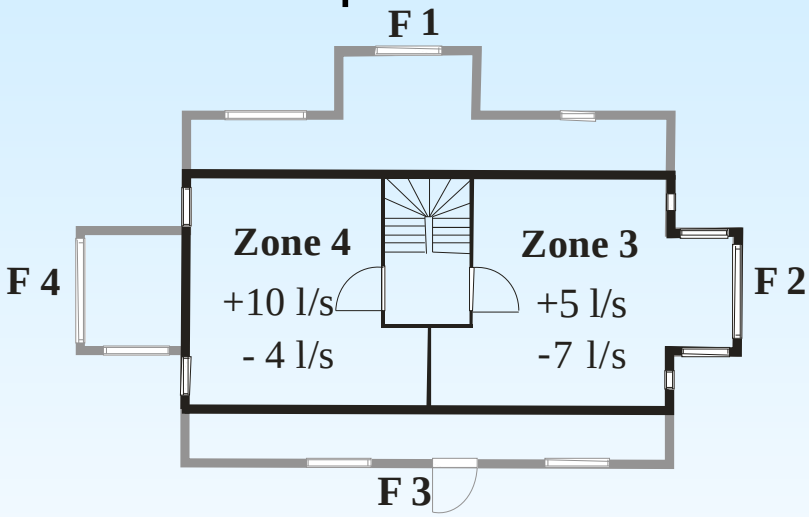
  - Leakage distribution over the envelope

Ventilation air flow rates

- The base floor



- The top floor

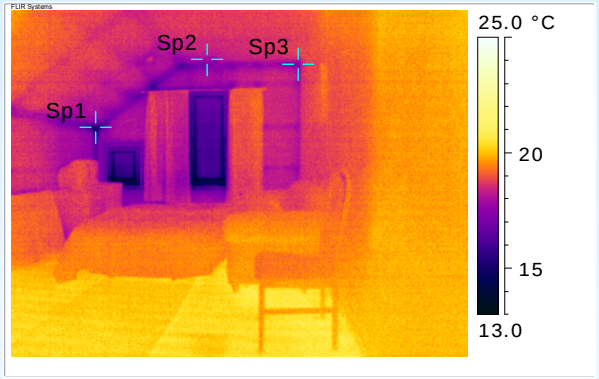


- Negatively pressurized system: Supply/extract = 0.94
- The ventilation air change rate: 0.4 ach

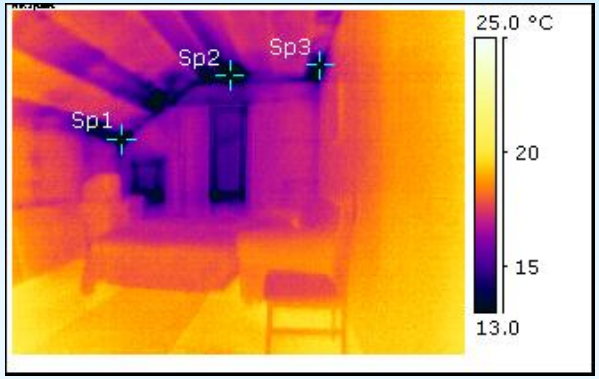
Leakage places and distribution

- Infrared photography inside the house in winter (ΔT=25°C):

$\Delta P \approx 0Pa$:



$\Delta P = -50Pa$:



- Relative temperature decrease: $\Delta T = \frac{T_{\Delta P \approx 0Pa} - T_{\Delta P \approx -50Pa}}{T_{in} - T_{out}} \times 100\%$

→ of the selected points:

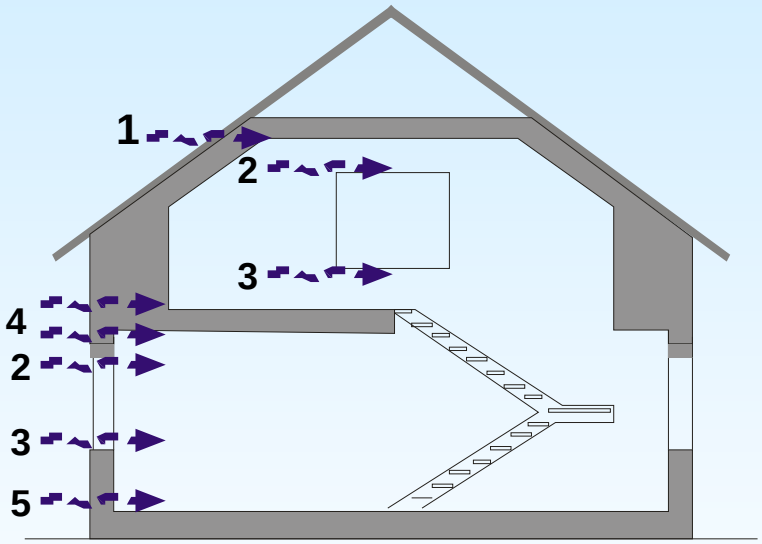
Point	Surface temperature, °C		Rel. temp. Decrease ΔT, %
	ΔP ≈ 0Pa	ΔP ≈ -50Pa	
Sp1	14.9	9.4	**22**
Sp2	17.8	8.5	**37**
Sp3	17.3	11.2	**24**

- The total number of leakage places: 56

Leakage distribution

- Typical places of the air leakage openings:

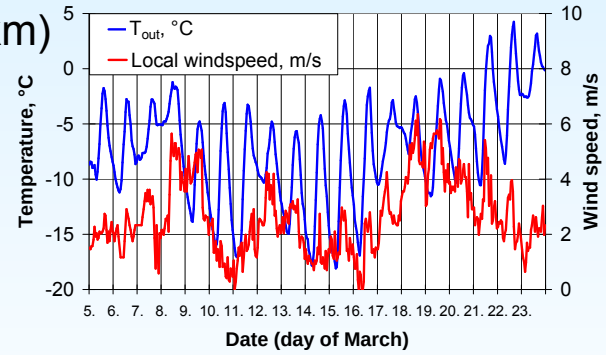
Category	
1	Junction of external wall and roof
2	Upper edge of window frame
3	Lower edge of window frame
4	Junction of external wall and intermediate floor
5	Junction of external wall and base floor.

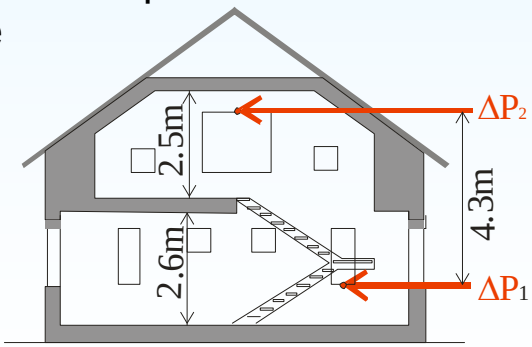


- Vertical leakage distribution:

3 weeks follow-up period

- In heating season between 3th – 24th of March
- Range of local outdoor temperatures: [-18, +4]°C, average -7°C
  - Measured next to the detached house
- Measured local wind data (speed, direction) not available
  - The data from the closest weather station (dist. 30km)
  - Local wind conditions: $U(h) = U_m \cdot k \cdot \left(\frac{h}{h_m}\right)^a$
- Data for the evaluation:
  - Indoor temperatures and pressure differences over the envelope

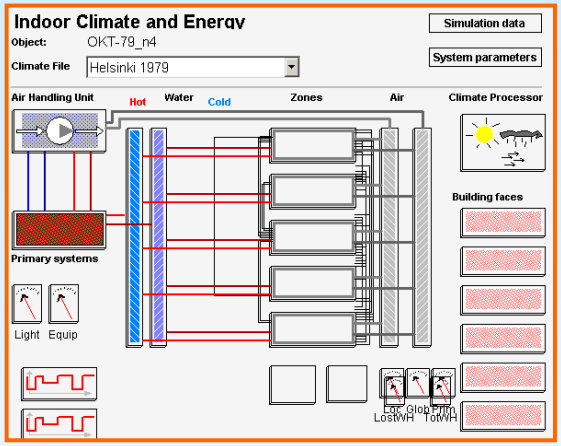


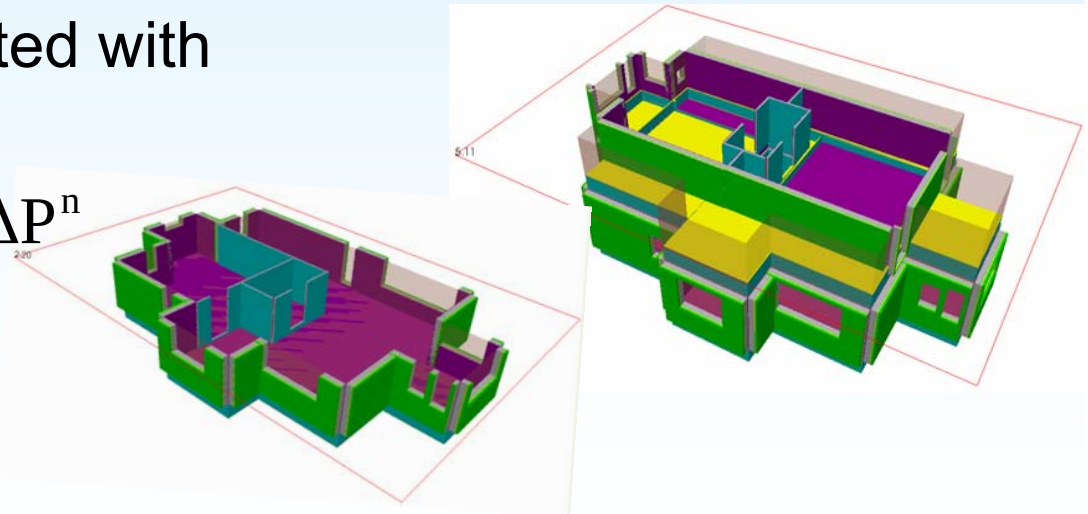


Pressure differences $\Delta P_{1,2}$

IDA-ICE simulation

- Dynamic whole building energy simulation tool
- Simultaneous simulation of heat transfer and air flows
- Multi-zone model where inter-zonal airflows simulated with nodal network model
- Crack-flows: $Q = C \cdot \Delta P^{n}$



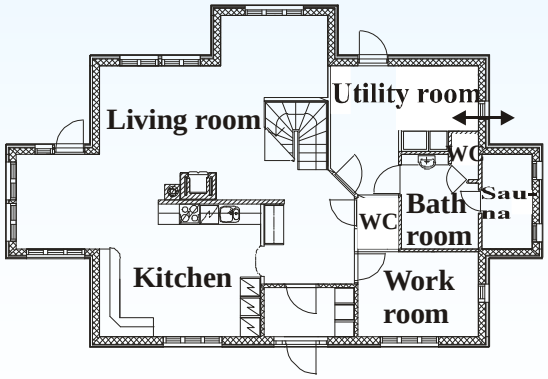


Simulation of wind pressure

- Wind pressure: $P_w = C_p \cdot \frac{1}{2} \rho_{out} \cdot U^2$
- Approximate wind pressure coefficients C_p published in Liddament (1986) were used:
- That are suitable for..
  - Rectangular (2:1) shaped buildings
  - Low-rise buildings up to 3 storeys
  - Located in sheltered wind conditions
- Floor plan of the studied house:

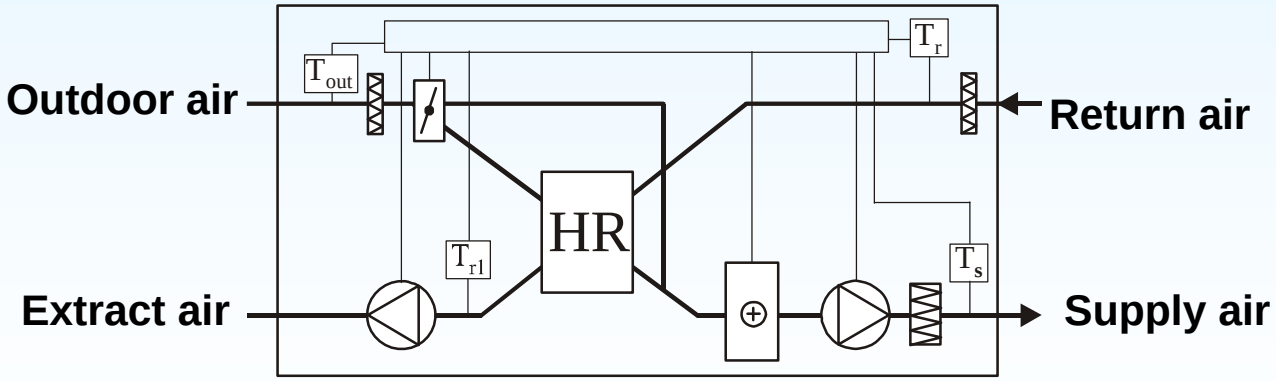
→ Are these coefficients suitable for this complicated building shape?

Wind Angle,°	Facade			
	F 1	F 2	F 3	F 4
0	0.06	-0.3	-0.3	-0.3
45	-0.12	0.15	-0.38	-0.32
90	-0.2	0.18	-0.2	-0.2
135	-0.38	0.15	-0.12	-0.32
180	-0.3	-0.3	0.06	-0.3
225	-0.38	-0.32	-0.12	0.15
270	-0.2	-0.2	-0.2	0.18
315	-0.12	-0.32	-0.38	0.15



Air handling unit

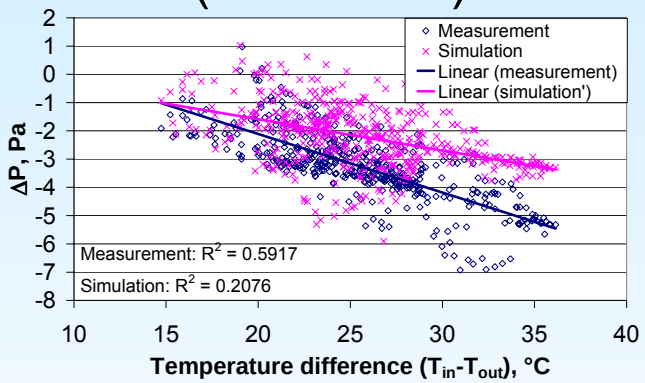
- Equipped with (air-to-air) heat recovery
- Defrost protection is needed in the cold climate
- Defrost protection methods for the plate heat exchanger:
  - On/off control of the supply fan (in the modeling object)
  - Bypass control
- Principle of air handling unit:

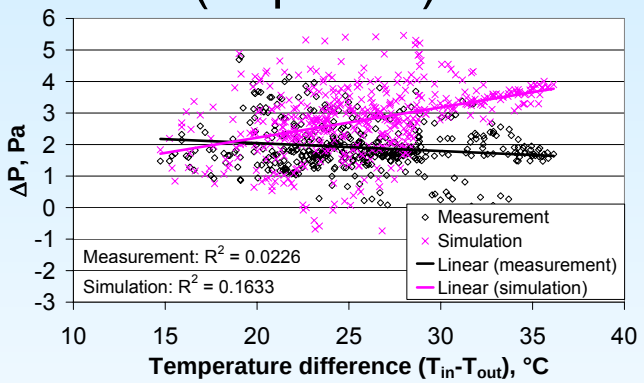


Evaluation of the model

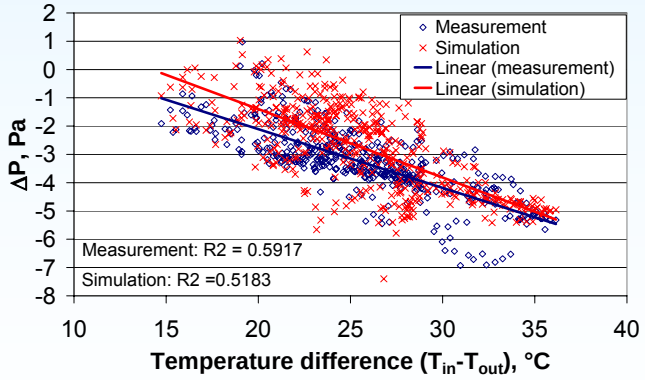
- **Measured and simulated pressure differences ΔP = f(ΔT):**

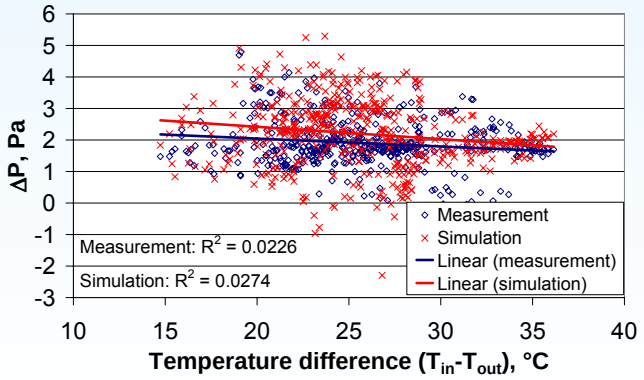
-Bypass control: (Base floor) (Top floor)





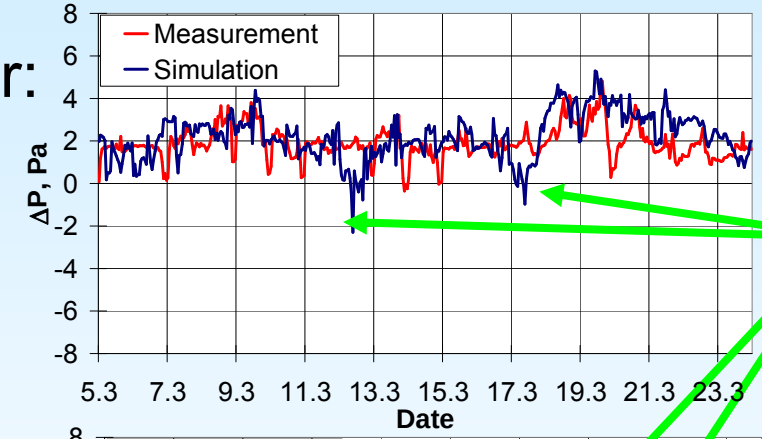
-On/off control





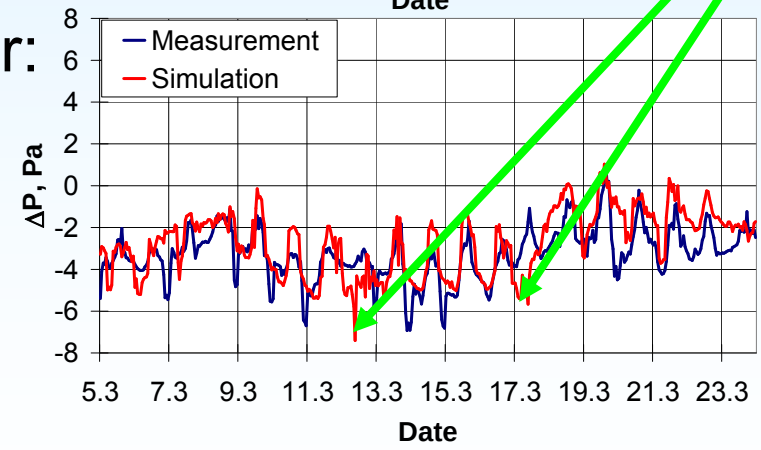
Evaluation of the model

- **Pressure difference ΔP = f(time) with (on/off control)**
  - Top floor:



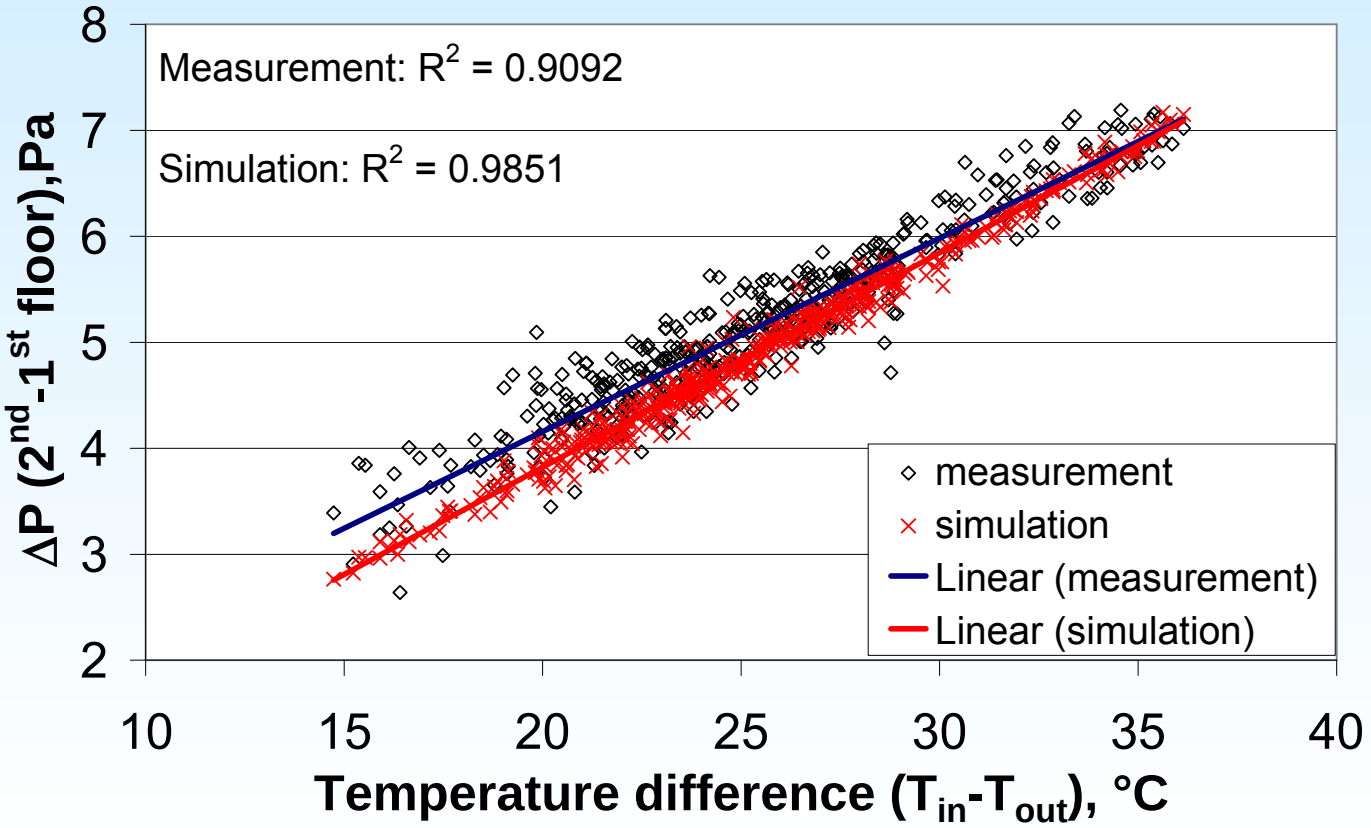
Some discrepancies

  - Base floor:



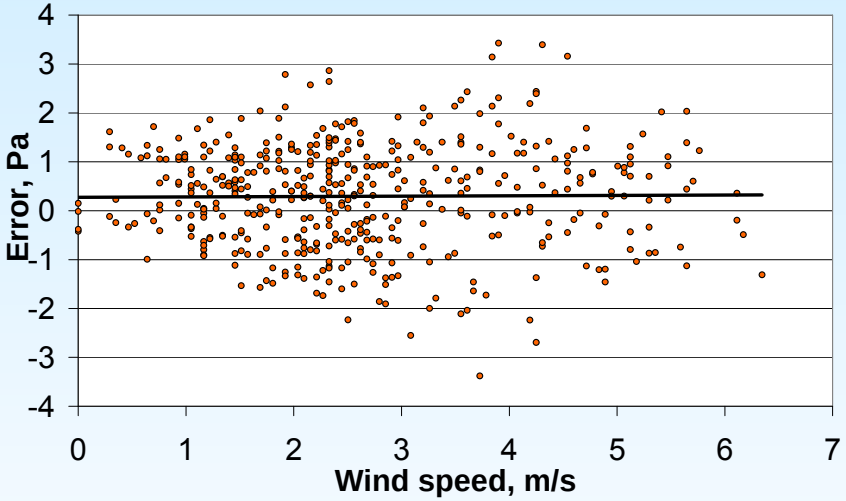
Evaluation of the model

- **Pressure difference: $\Delta P_{top} - \Delta P_{base} = f(\Delta T)$ with (on/off control)**

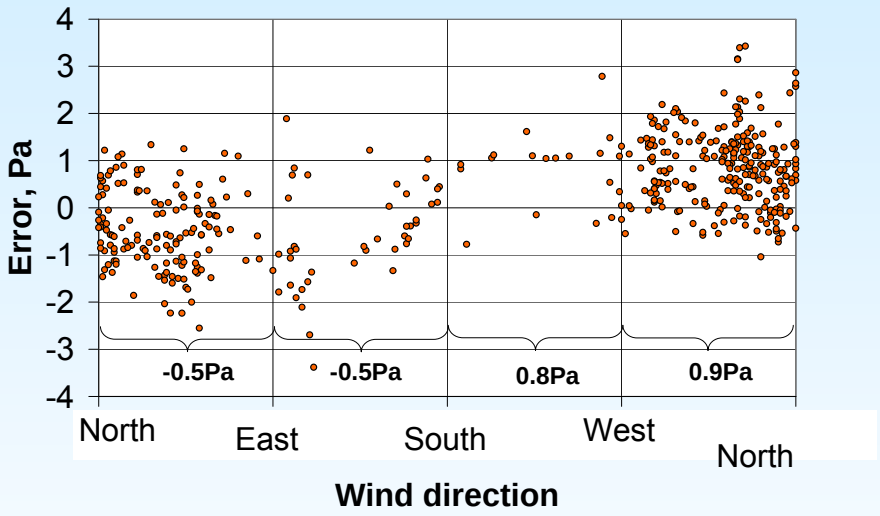


Simulation errors

- ΔP error vs. wind speed:



- ΔP error vs. wind direction:



- T_{indoor} and ΔP on average during 3-week test period:

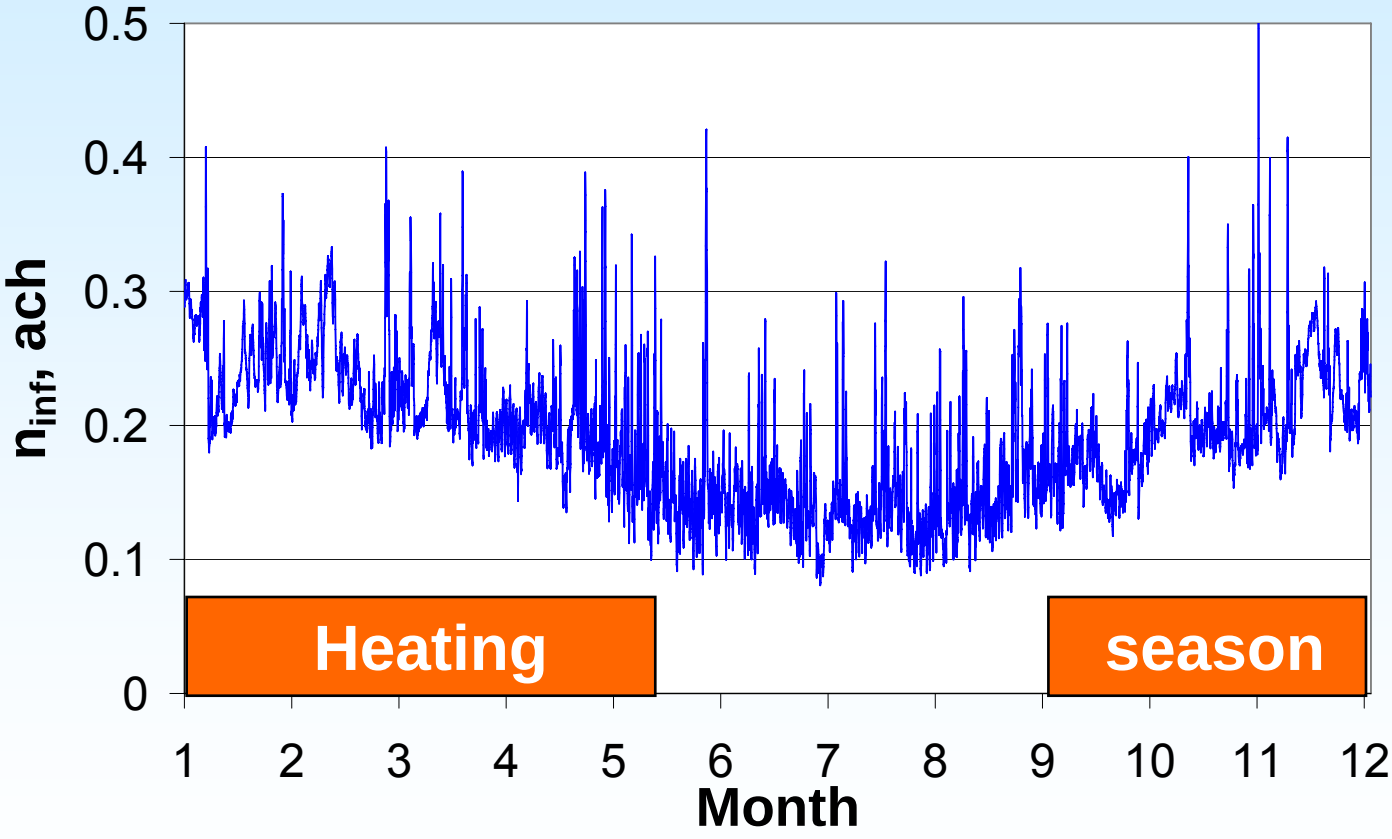
Method	Temperature, °C		Pressure difference, Pa	
	Floor			
	Base	Top	Base	Top
Measurement	19.7	17.0	-3.3	1.9
Simulation (on /off)	19.7	17.2	-2.7	2.2
Simulation (bypass)	19.8	17.2	-2.2	2.8

- **The max. average errors:**

Method	Temp, °C	ΔP, Pa
Simulation (on /off)	**0.2**	**0.6**
Simulation (bypass)	**0.2**	**1.1**

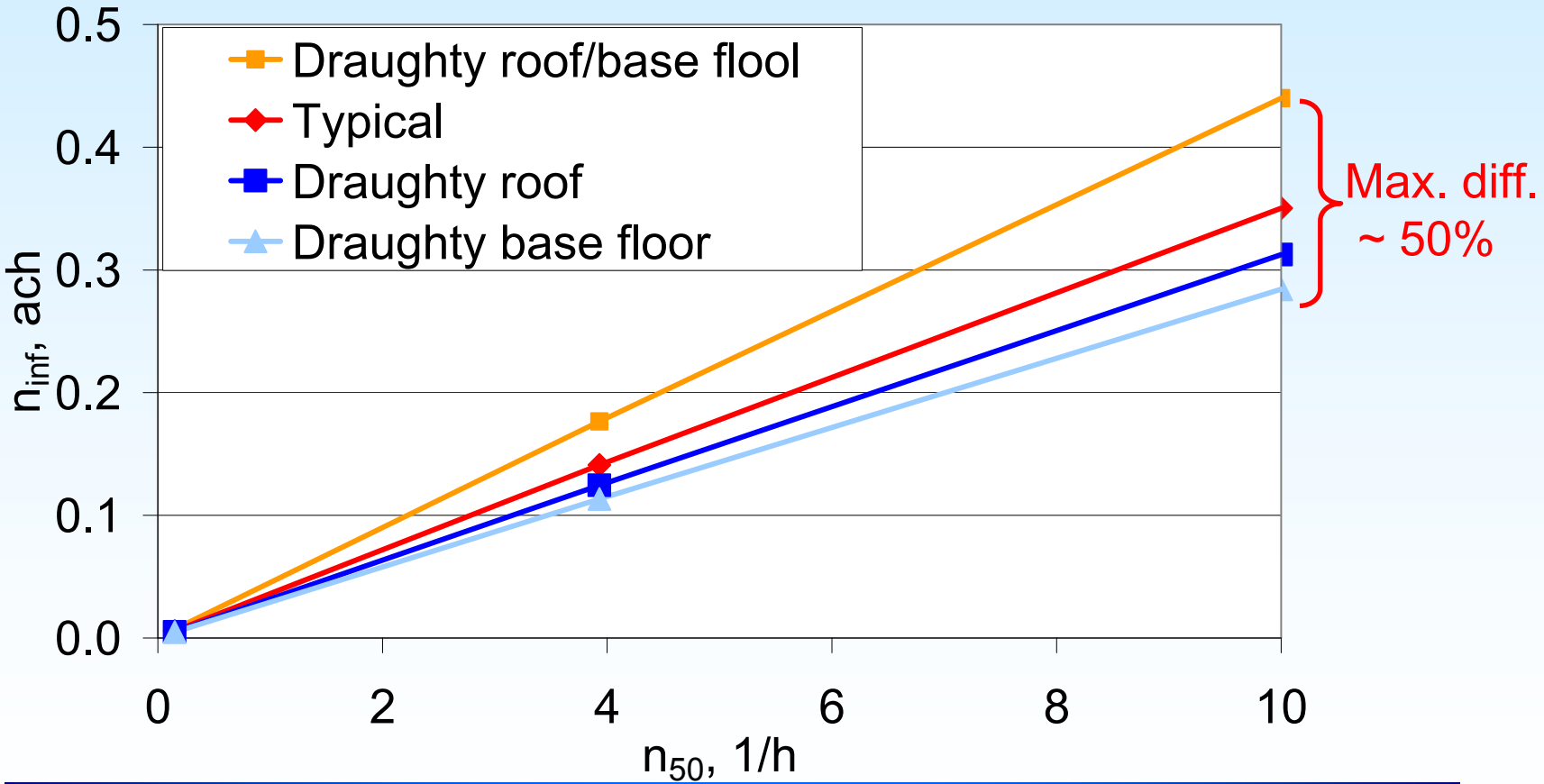
Application of the model

- Infiltration rate of the studied house:



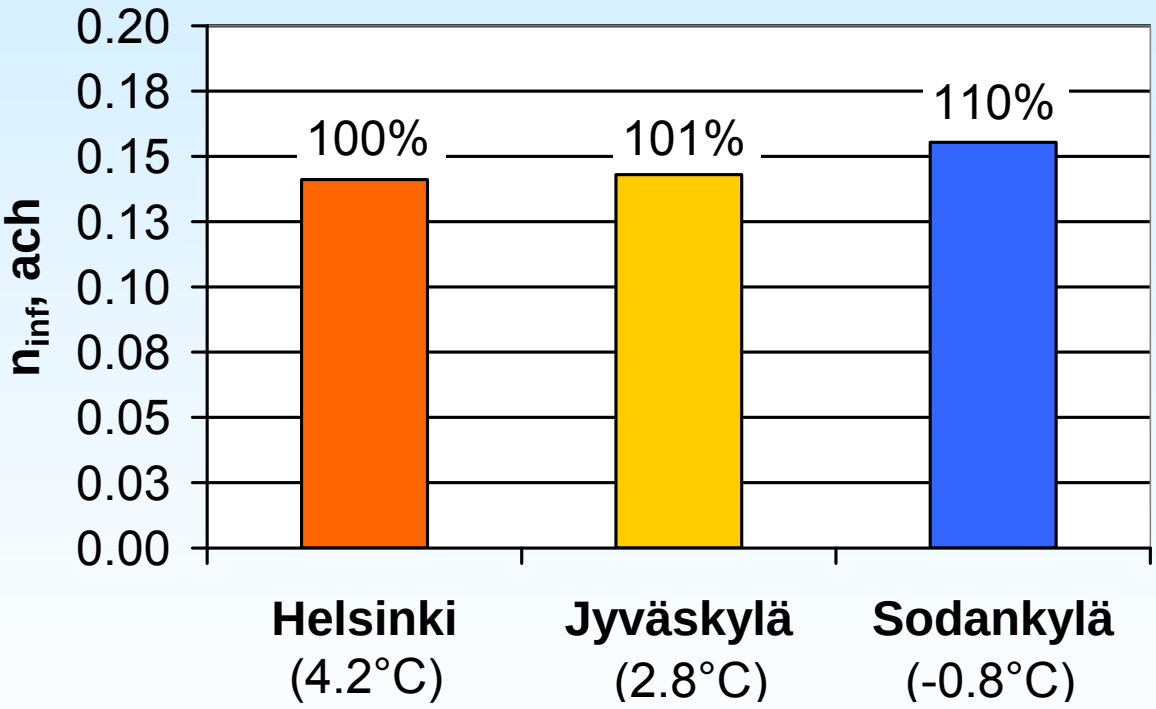
Application of the model

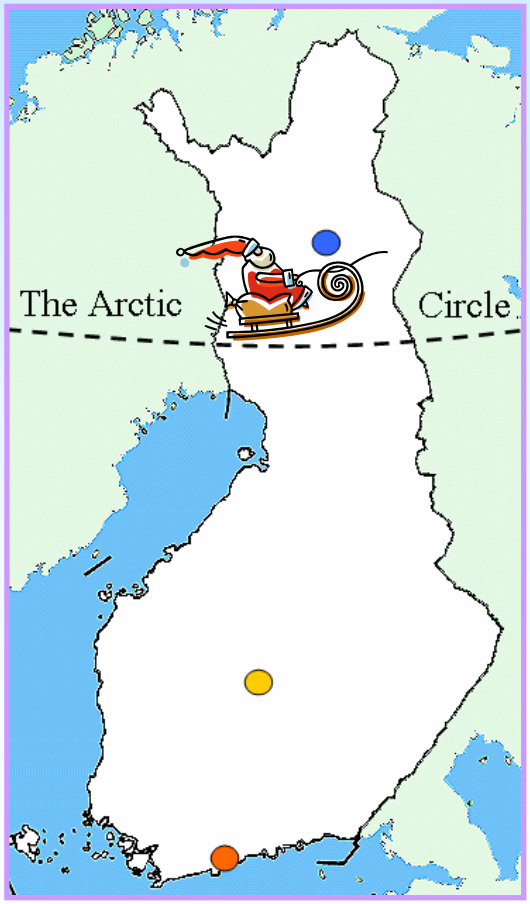
- Different leakage distributions:



Application of the model

- Climate conditions:





Summary

- Evaluation shows that this model predicts air pressure conditions of a detached house in sheltered wind conditions and cold climate realistically.
- The simulated air pressure conditions are reasonable, even if the modeling of wind-induced pressure conditions was greatly simplified.
- This multi-zone model can be used for infiltration and energy analyses.