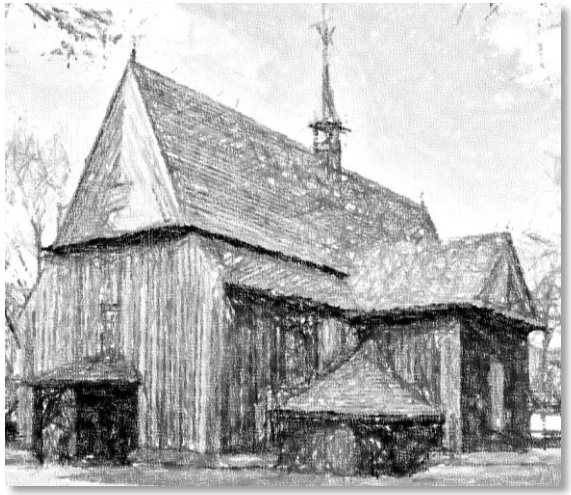
Particle sources and deposition in the indoor environment of historic churches

Marcin Strojecki

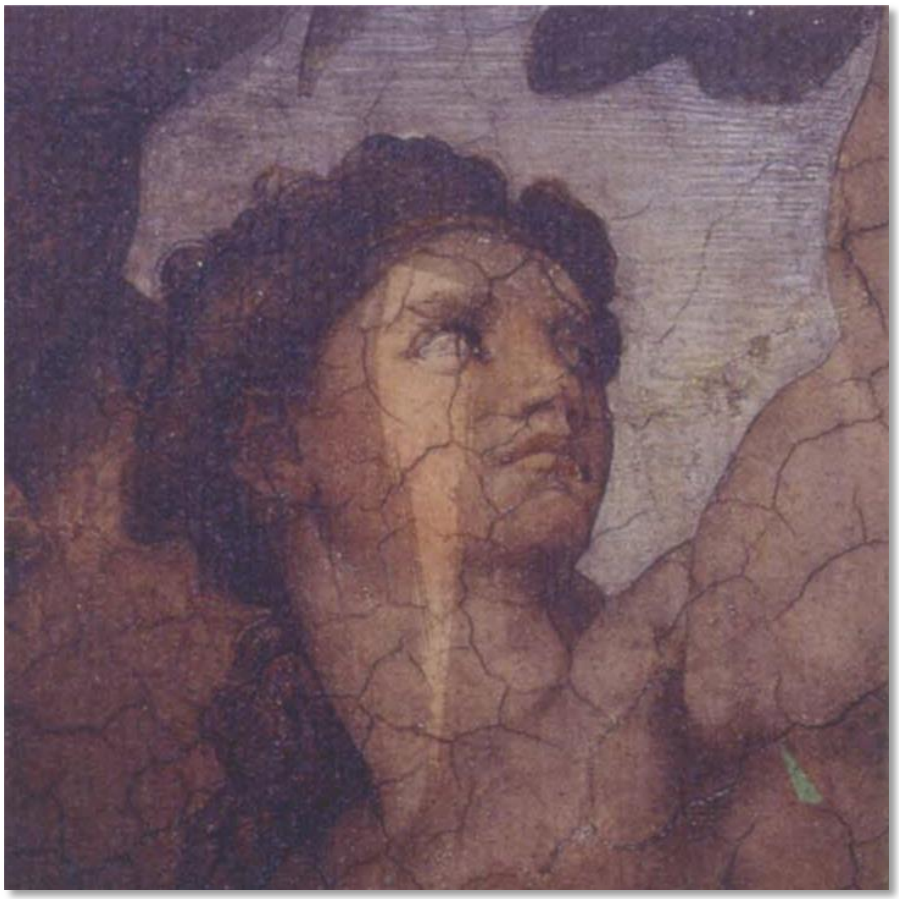


Our interest in the indoor environment of historic churches goes back to 2002…

The EC „Friendly Heating" project (2002-2005) studied the impact of heating systems on church environment

Soiling has been less researched…

- implications of burning candles and incense for human respiratory health
- short time monitoring associated with single liturgical activities



Methodology

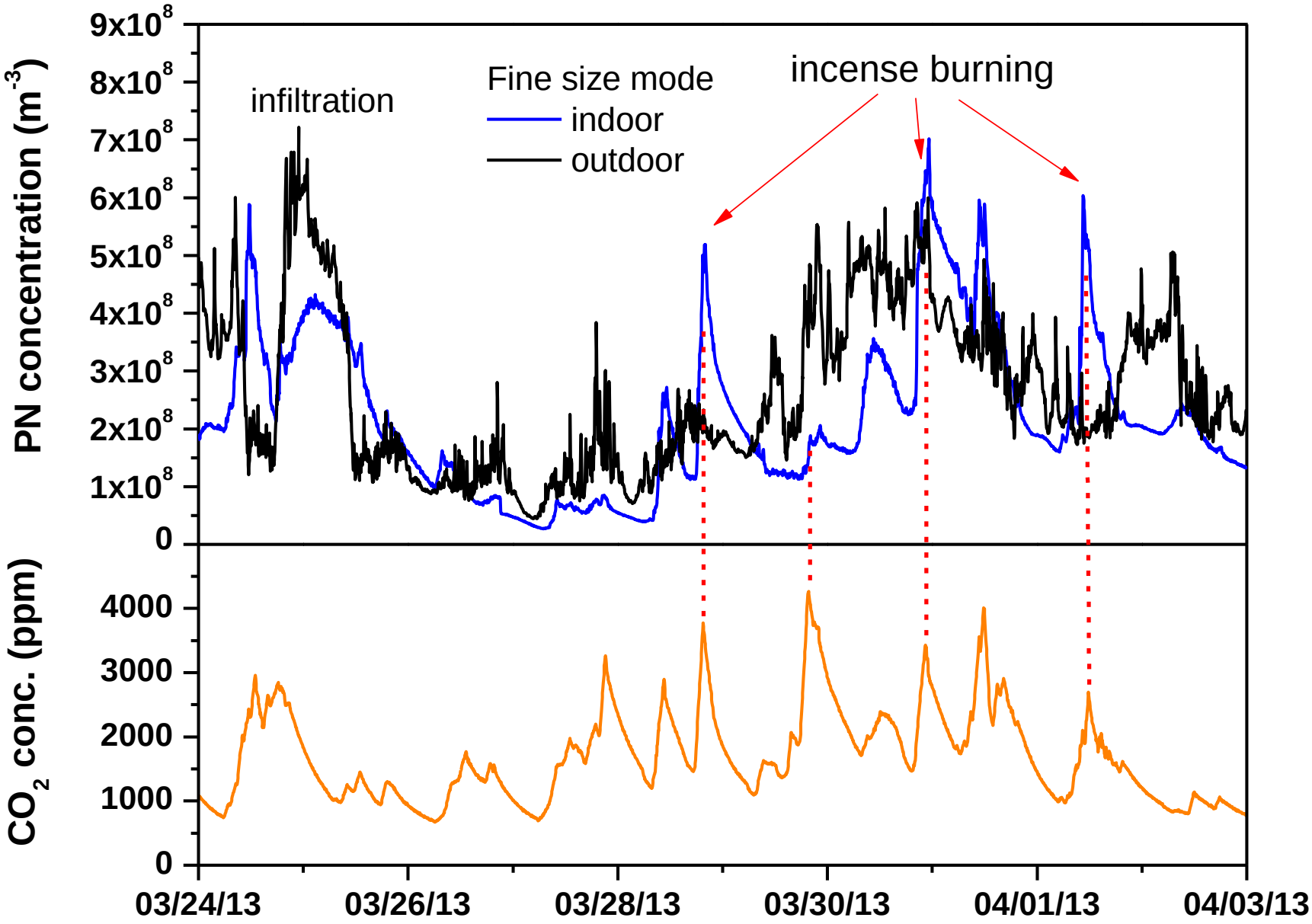
- 10 religious buildings – masonry and wooden constructions, located in urban and rural areas, various heating systems, various liturgies – Roman Catholic and Orthodox,
- set of dust sensors (Dylos DC1700) – particle number concentrations in two size modes

  0.3-1 µm – fine

  >1 µm – coarse
- monitoring of T, RH, CO_2
- continuous measurements for at least 10 months, records every 5 min.

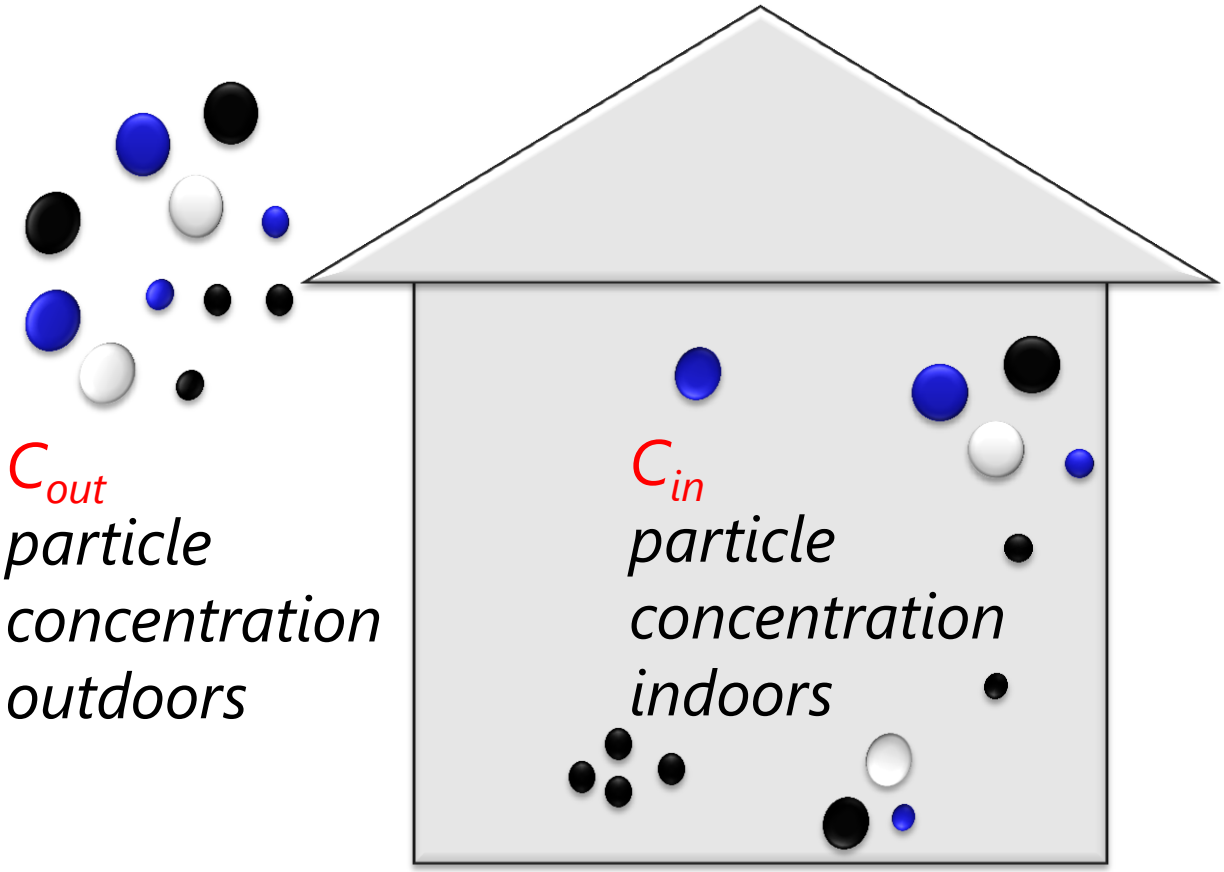
The monitoring system

Sample of the data



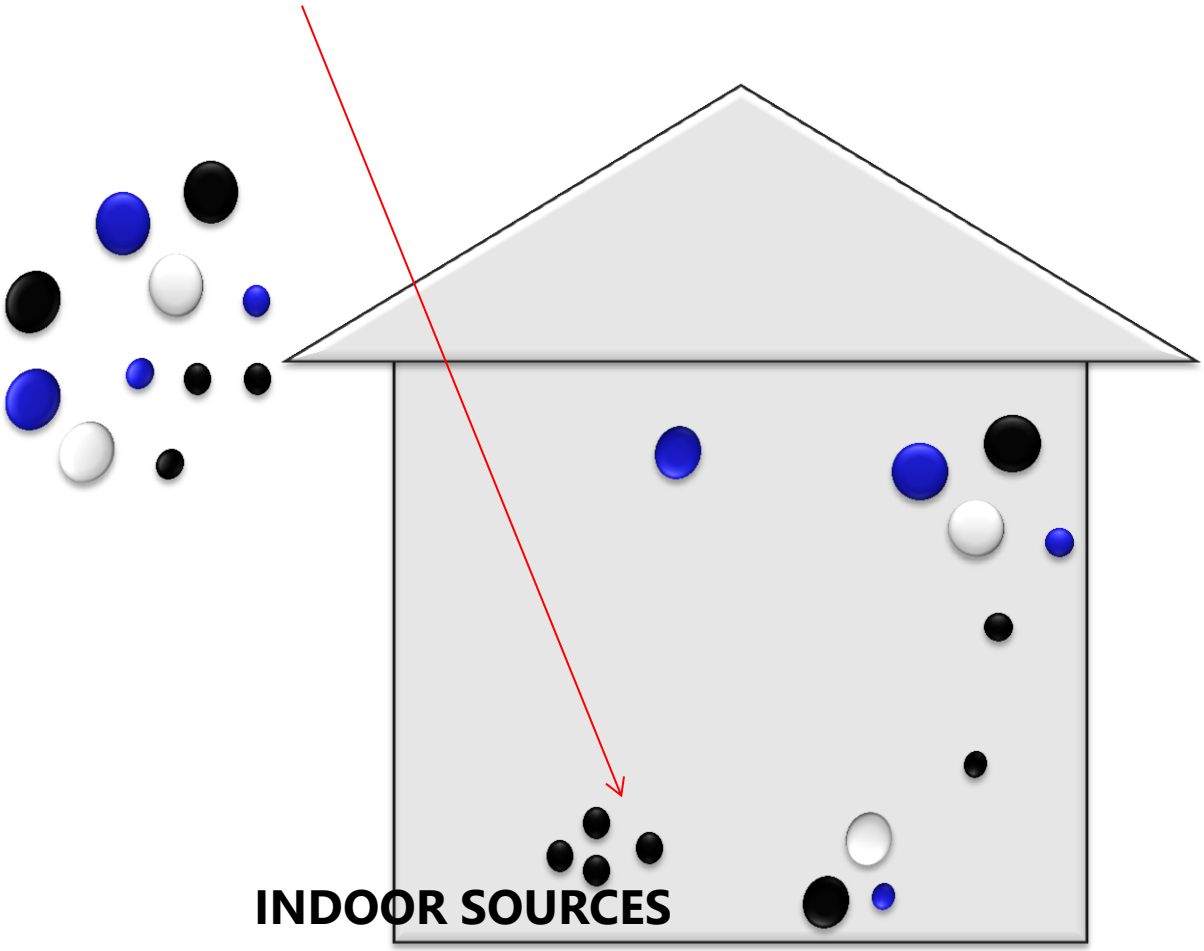
Mass conservation equation

$$dC_{in}/dt = S_i + C_{out} \cdot P \cdot AER - C_{in} \cdot AER - k \cdot C_{in}$$



Mass conservation equation

$$dC_{in}/dt = \boldsymbol{S_i} + C_{out} \cdot P \cdot AER - C_{in} \cdot AER - k \cdot C_{in}$$



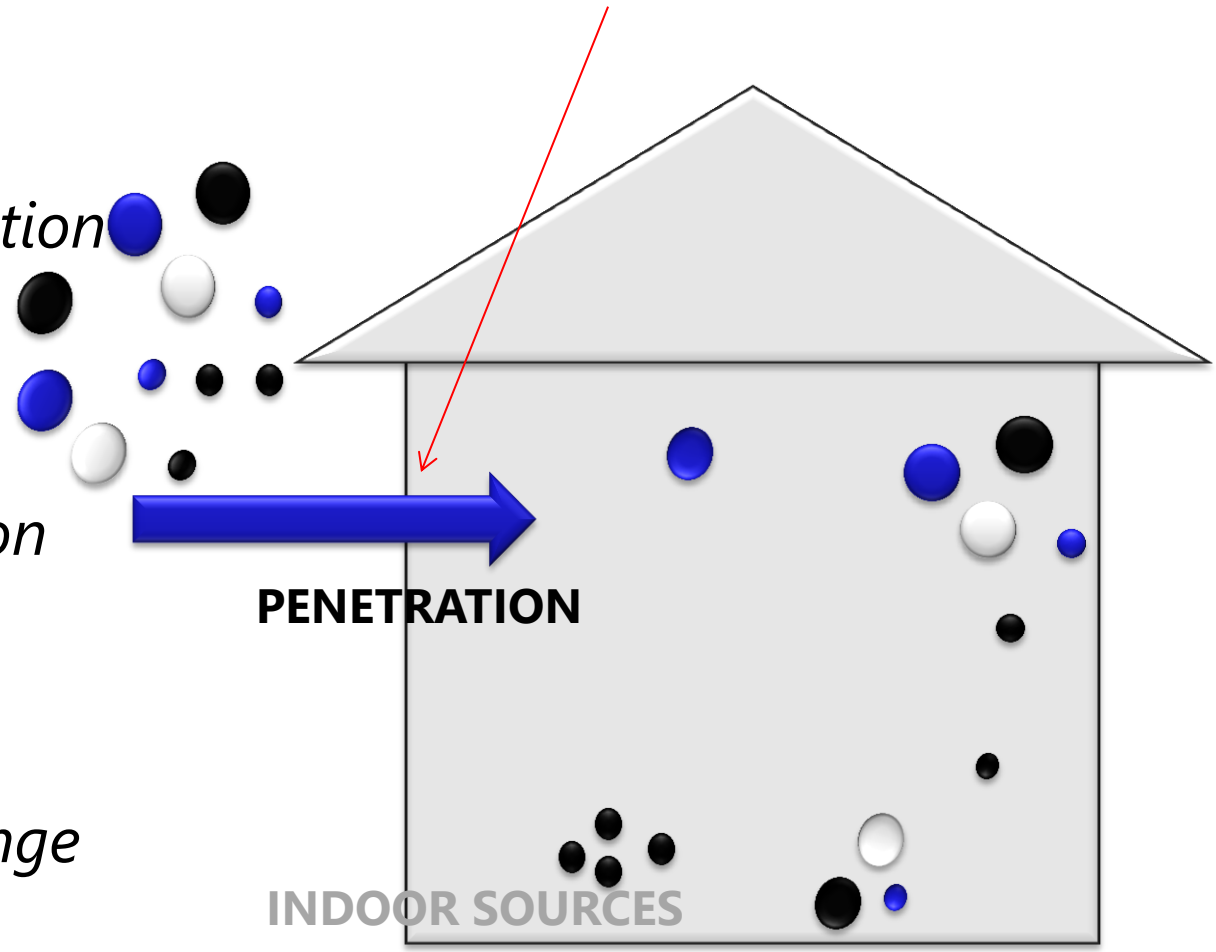
Mass conservation equation

$$dC_{in}/dt = S_i + \mathbf{C_{out}}\cdot\mathbf{P}\cdot\mathbf{AER} - C_{in}\cdot AER - k\cdot C_{in}$$

C_{out}
particle concentration outdoors

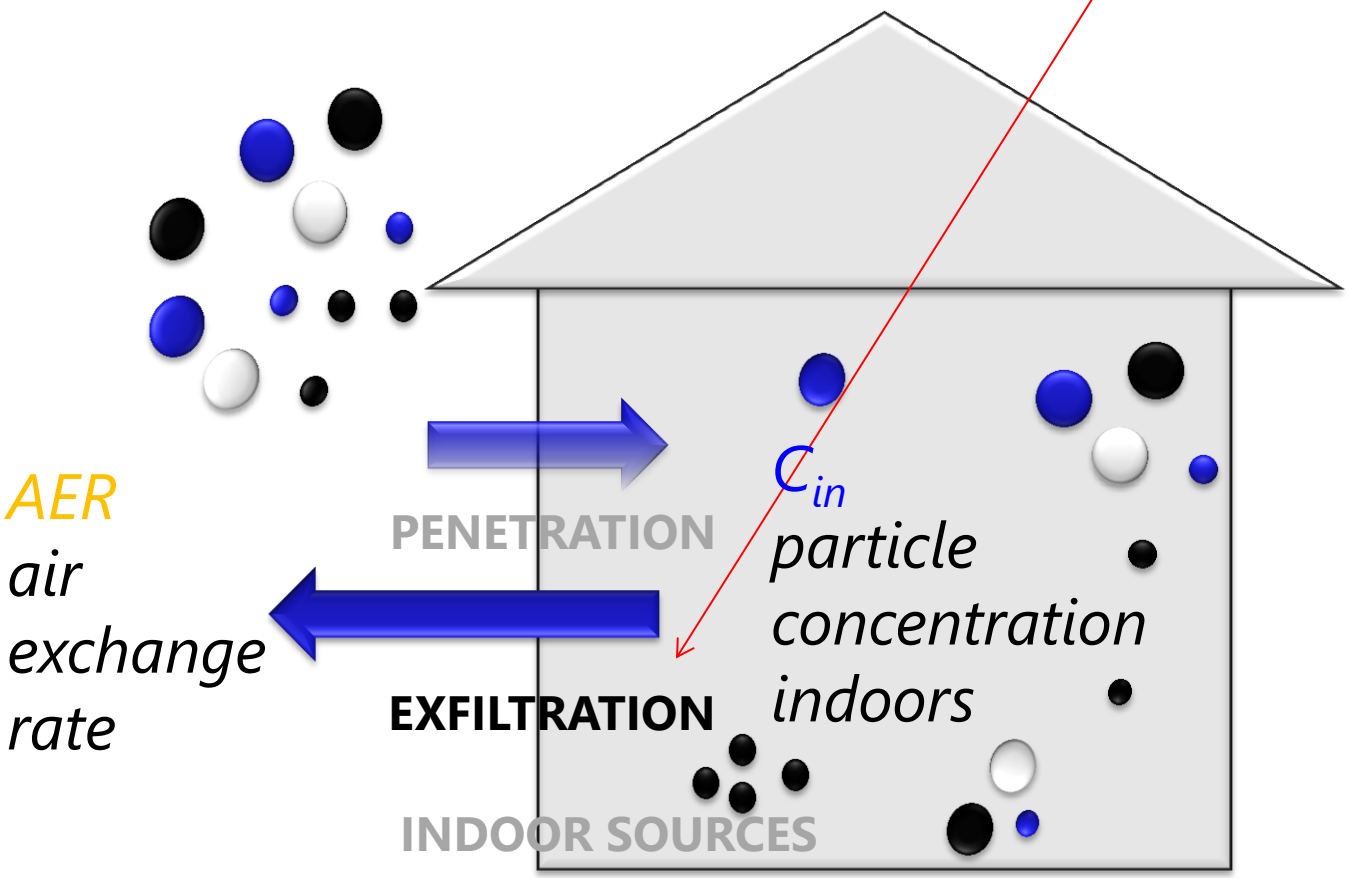
P
penetration factor

AER
air exchange rate



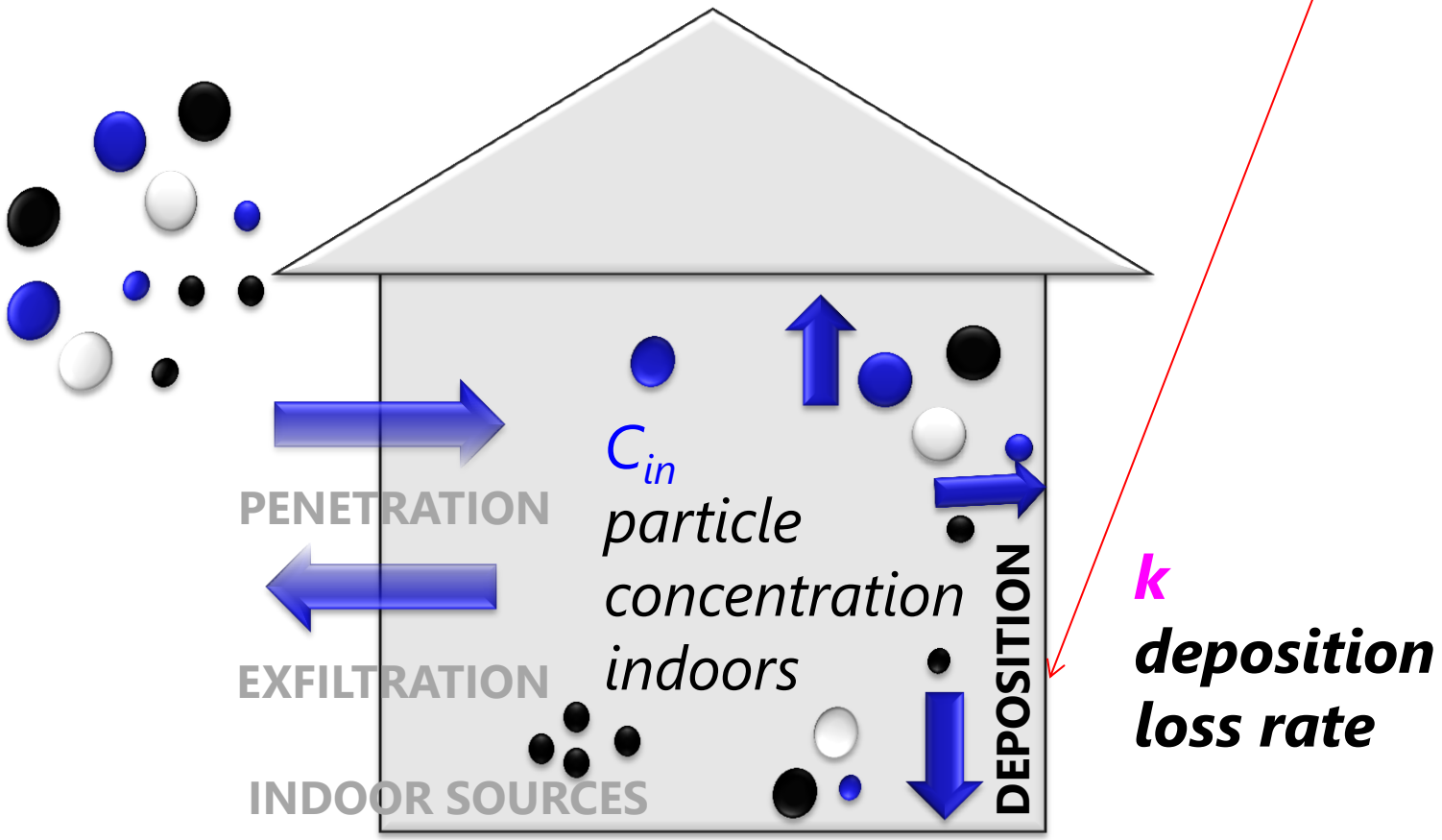
Mass conservation equation

$$dC_{in}/dt = S_i + C_{out} \cdot P \cdot AER - \mathbf{C_{in}} \cdot \mathbf{AER} - k \cdot C_{in}$$



Mass conservation equation

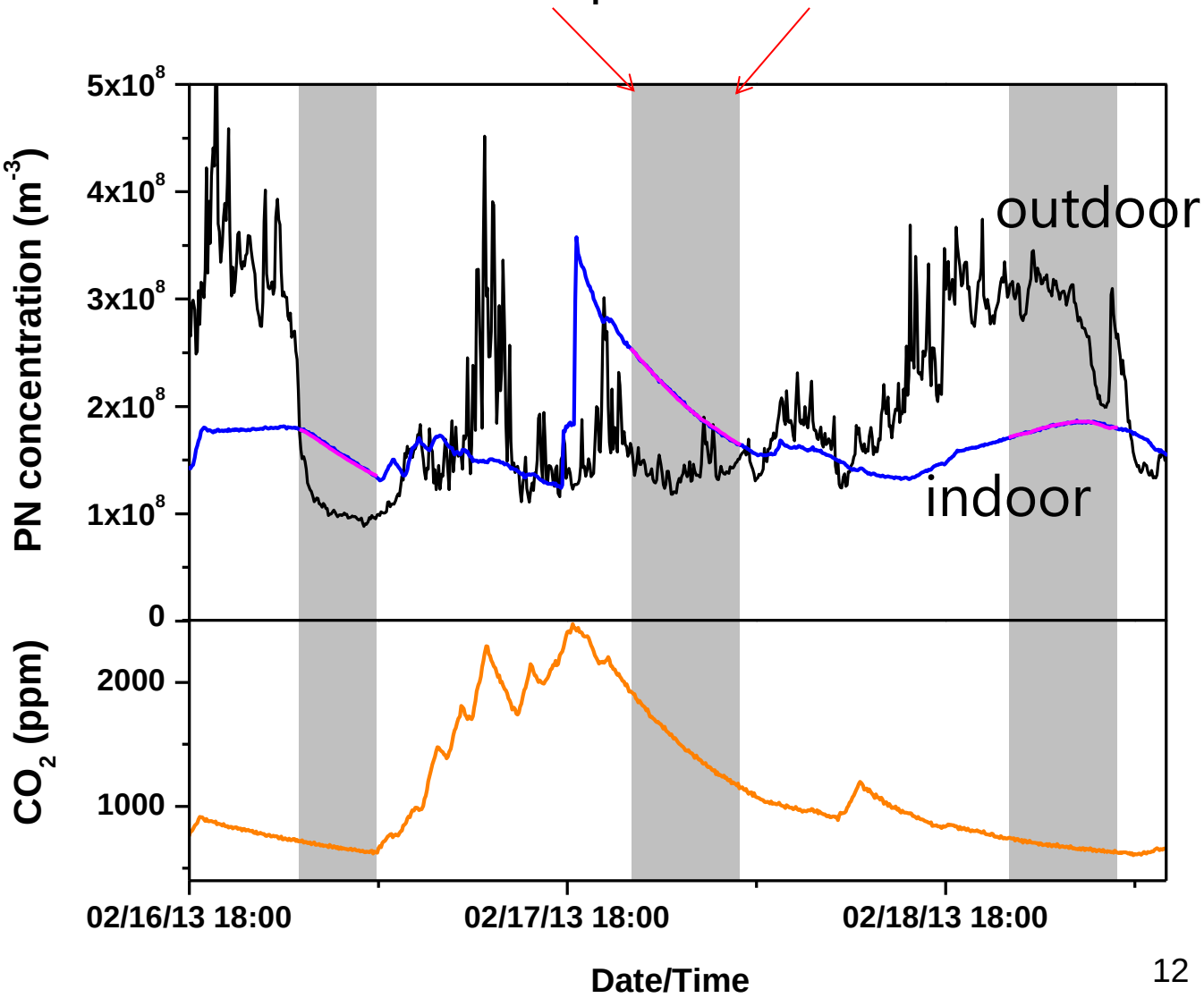
$$dC_{in}/dt = S_i + C_{out} \cdot P \cdot AER - C_{in} \cdot AER - \mathbf{k \cdot C_{in}}$$



Data analysis – indoor emission

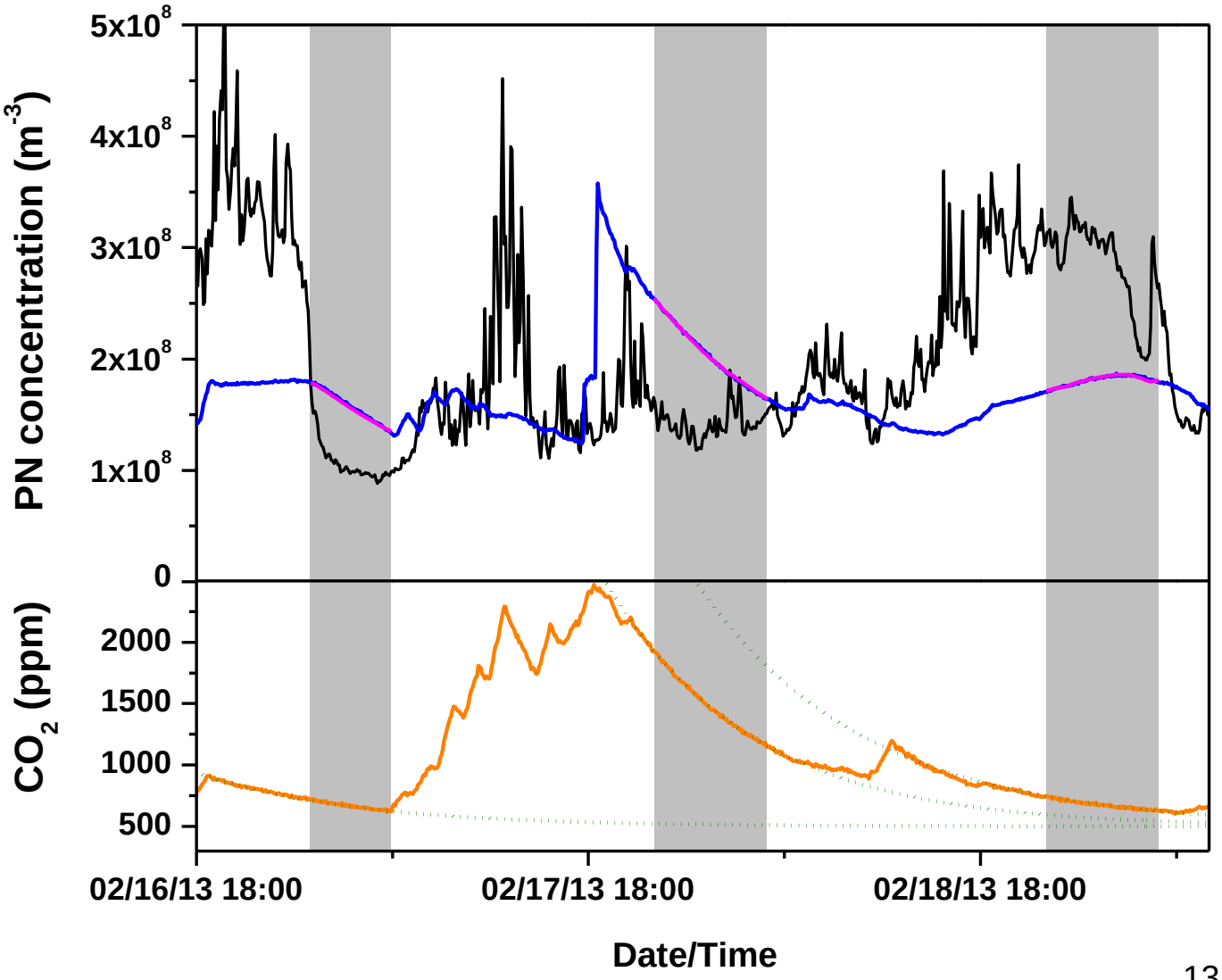
Church is closed between 10 pm and 6 am

Analysis is done for the non-source, mainly night-time periods.



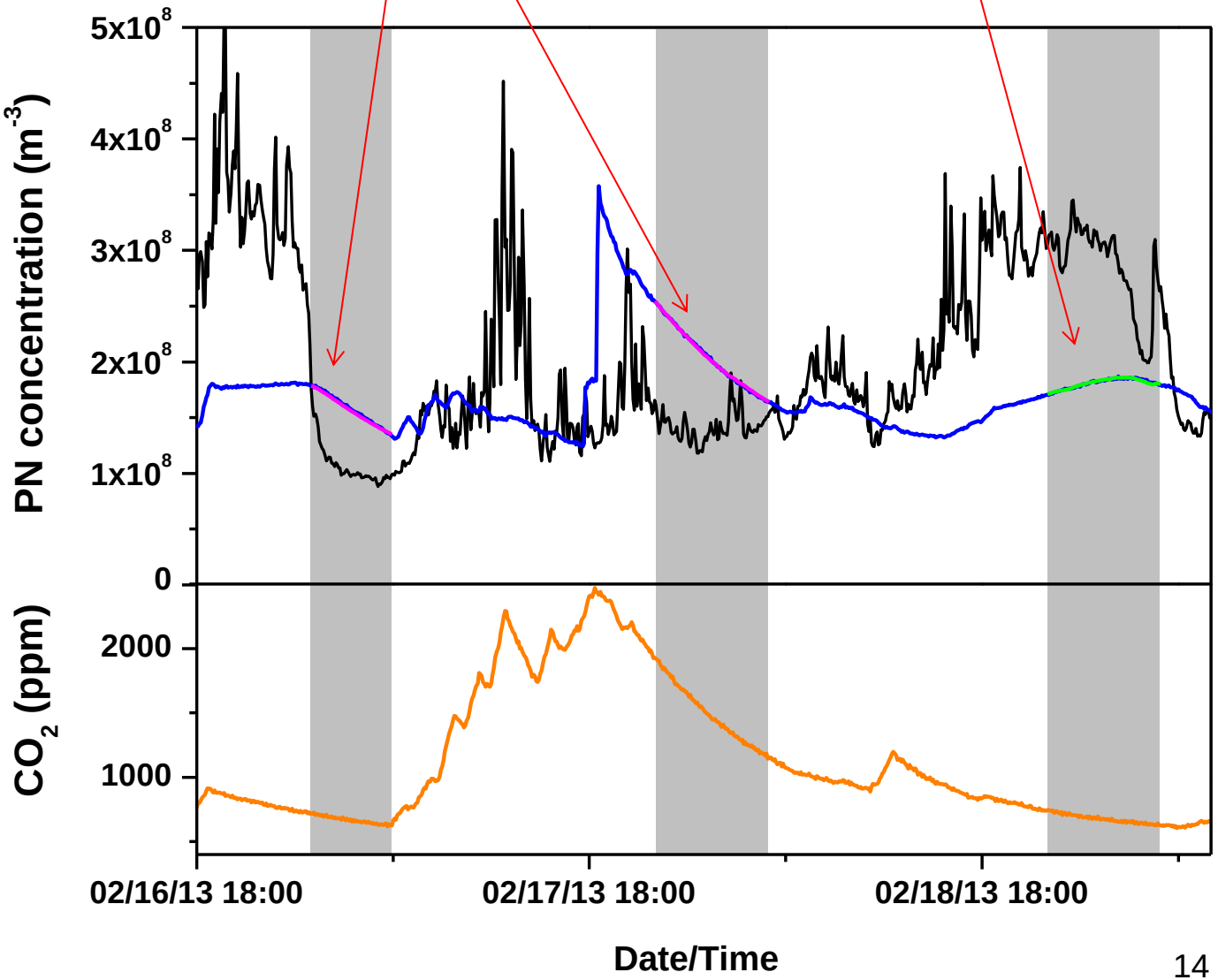
Data analysis – air exchange rate (*AER*)

Fitting exponential decay curve to the recorded concentration of indoor-generated CO_2.

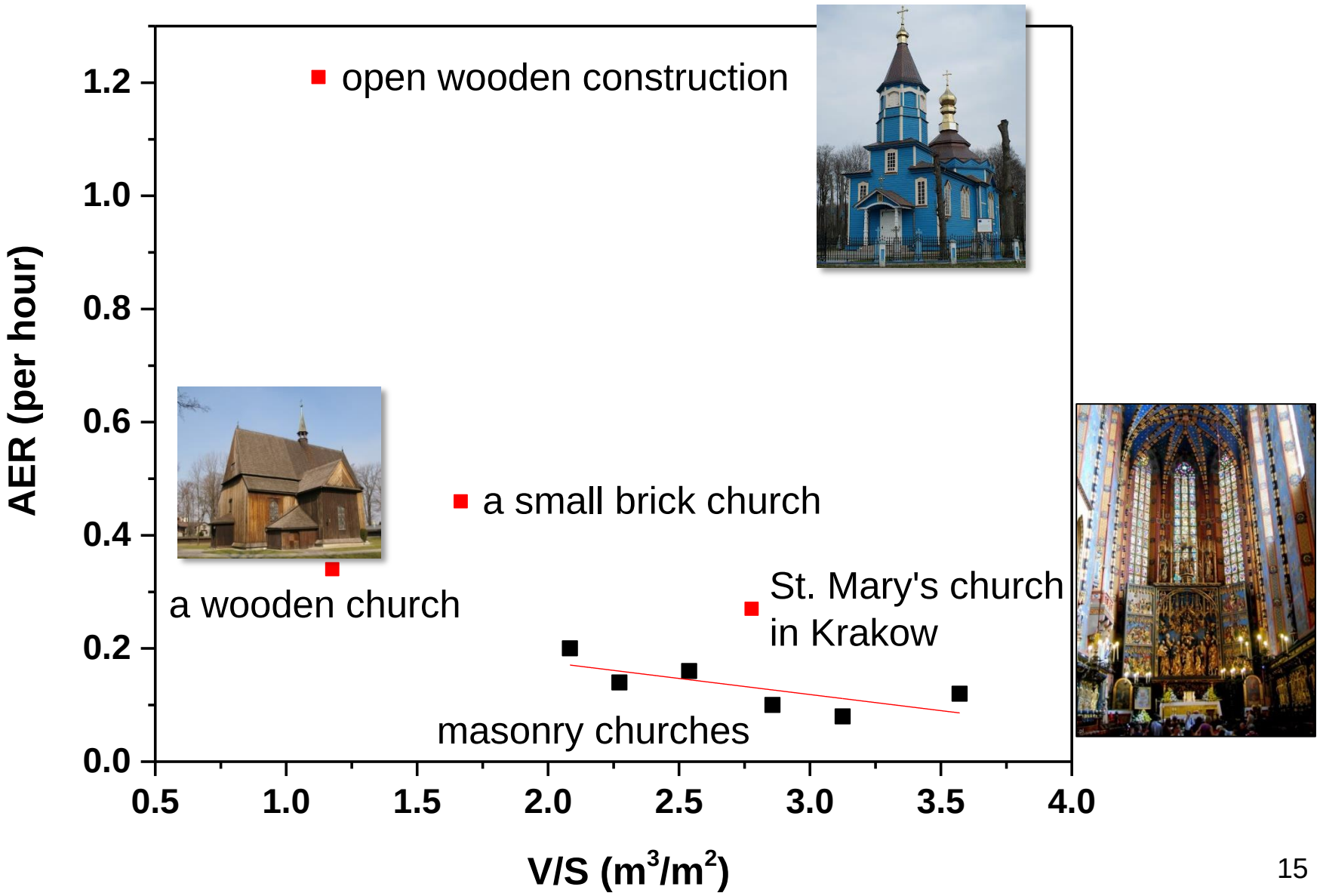


Data analysis – penetration factors and deposition loss rates

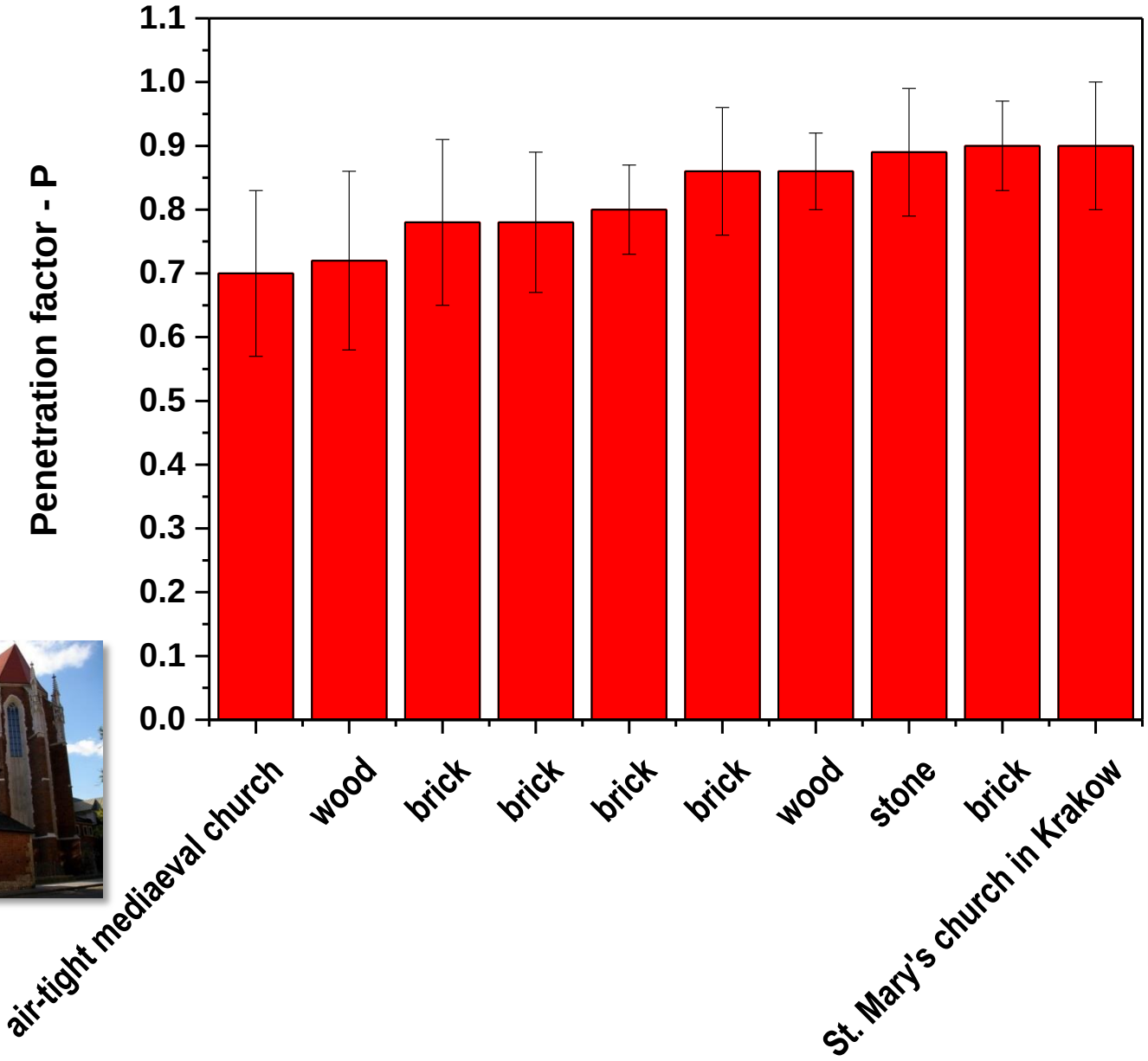
$$dC_{in}/dt = C_{out} \cdot P \cdot AER - C_{in}(AER + k)$$



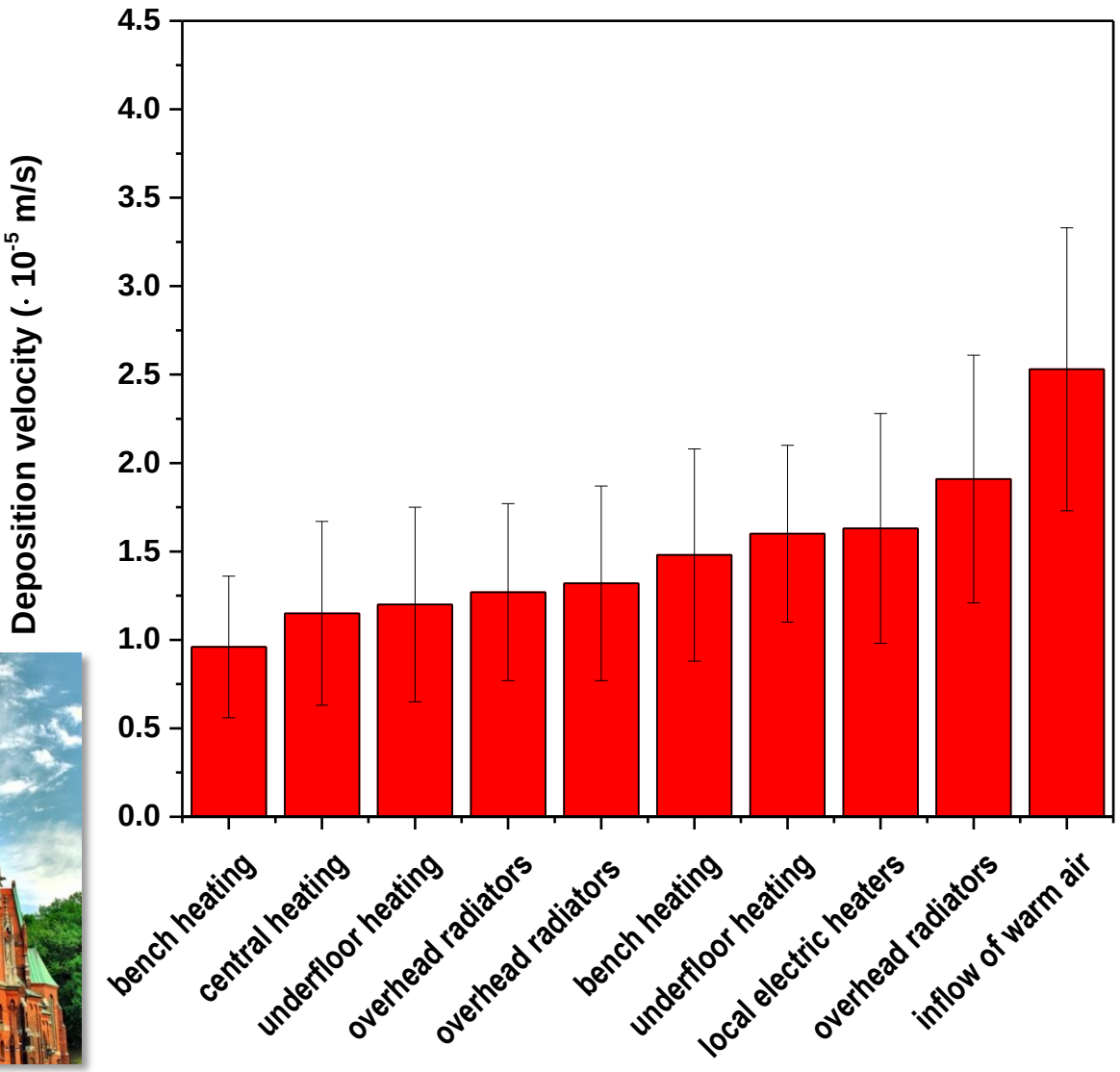
Results – air exchange rate due to the infiltration (closed church)



Results – penetration factors



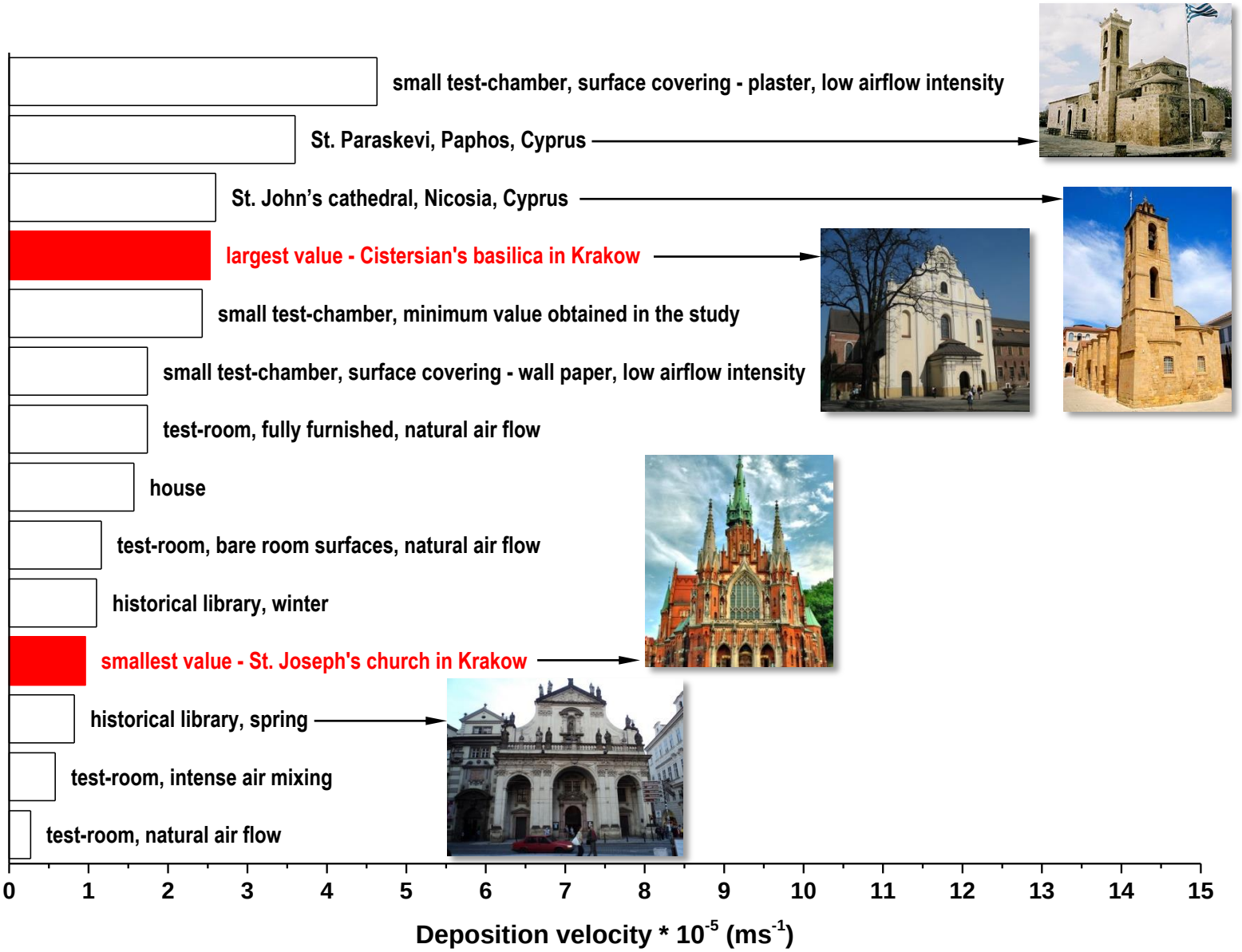
Results – deposition velocities are quite consistent between all churches



$v_d = V/S \cdot k$

$(m \cdot h^{-1})$

Deposition velocities - literature comparison

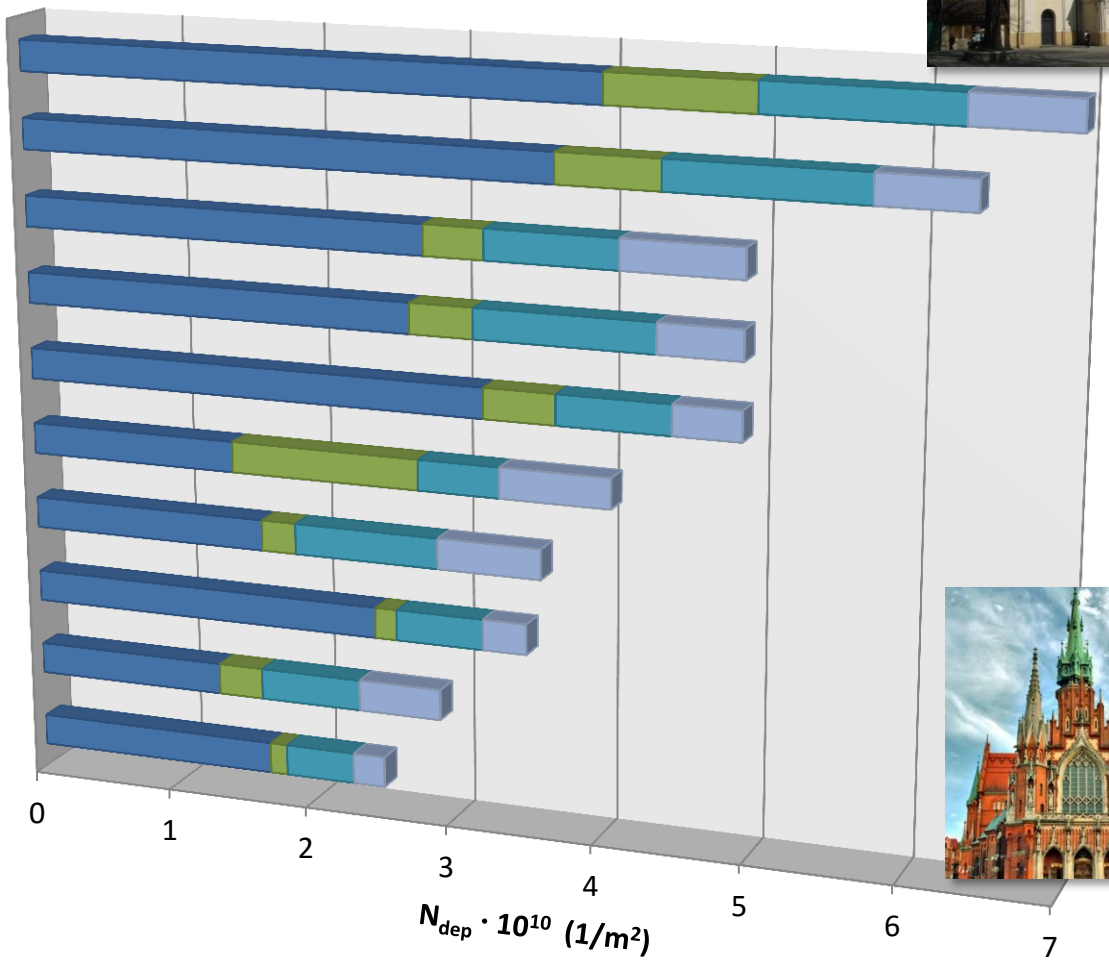


Deposition on 1 m^2 of indoor surface over 1 year

$$N_{dep} = v_d \cdot C_{in} \cdot t$$

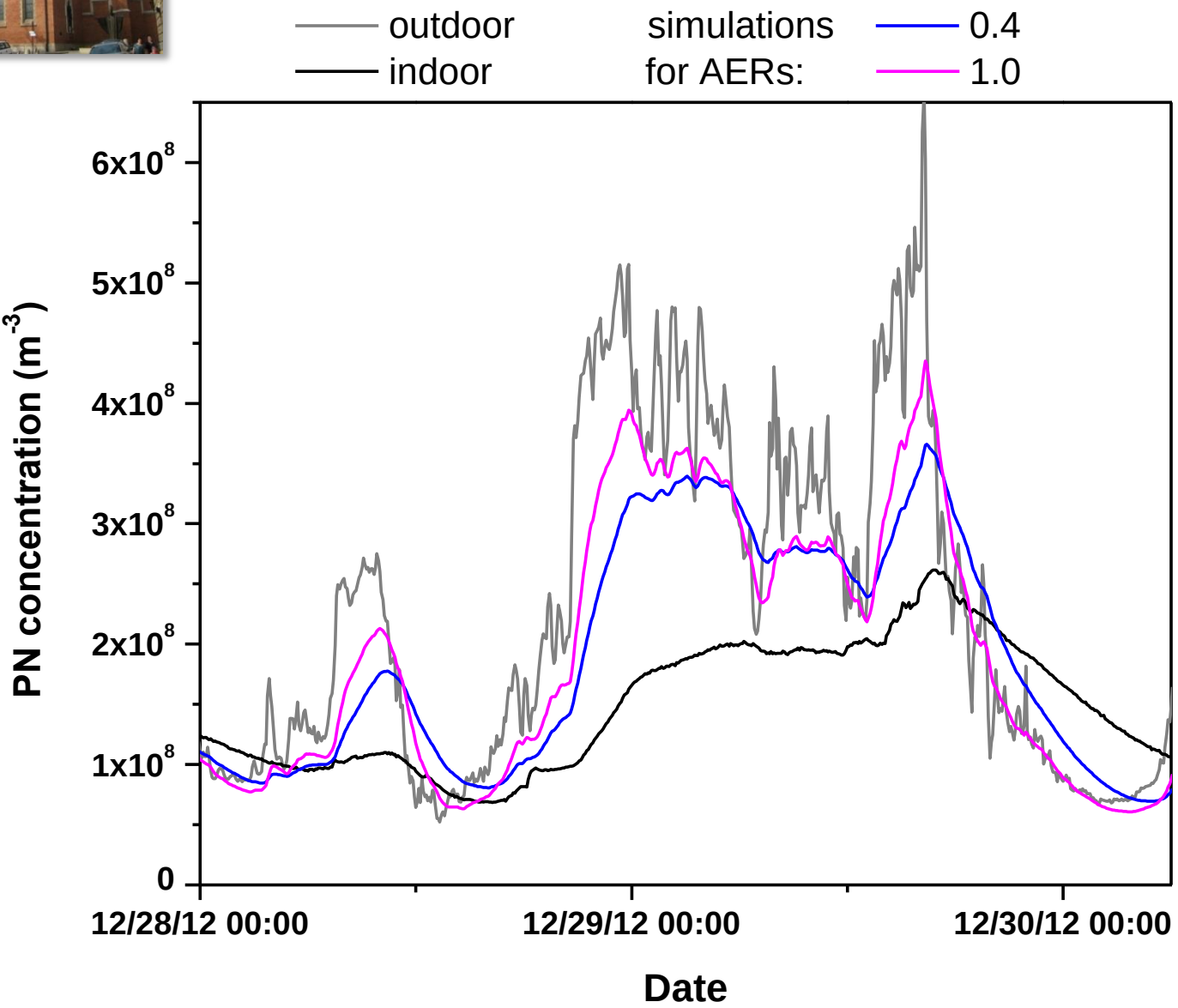
December-March
- infiltration from outside
- indoor sources

June-September
- infiltration from outside
- indoor sources

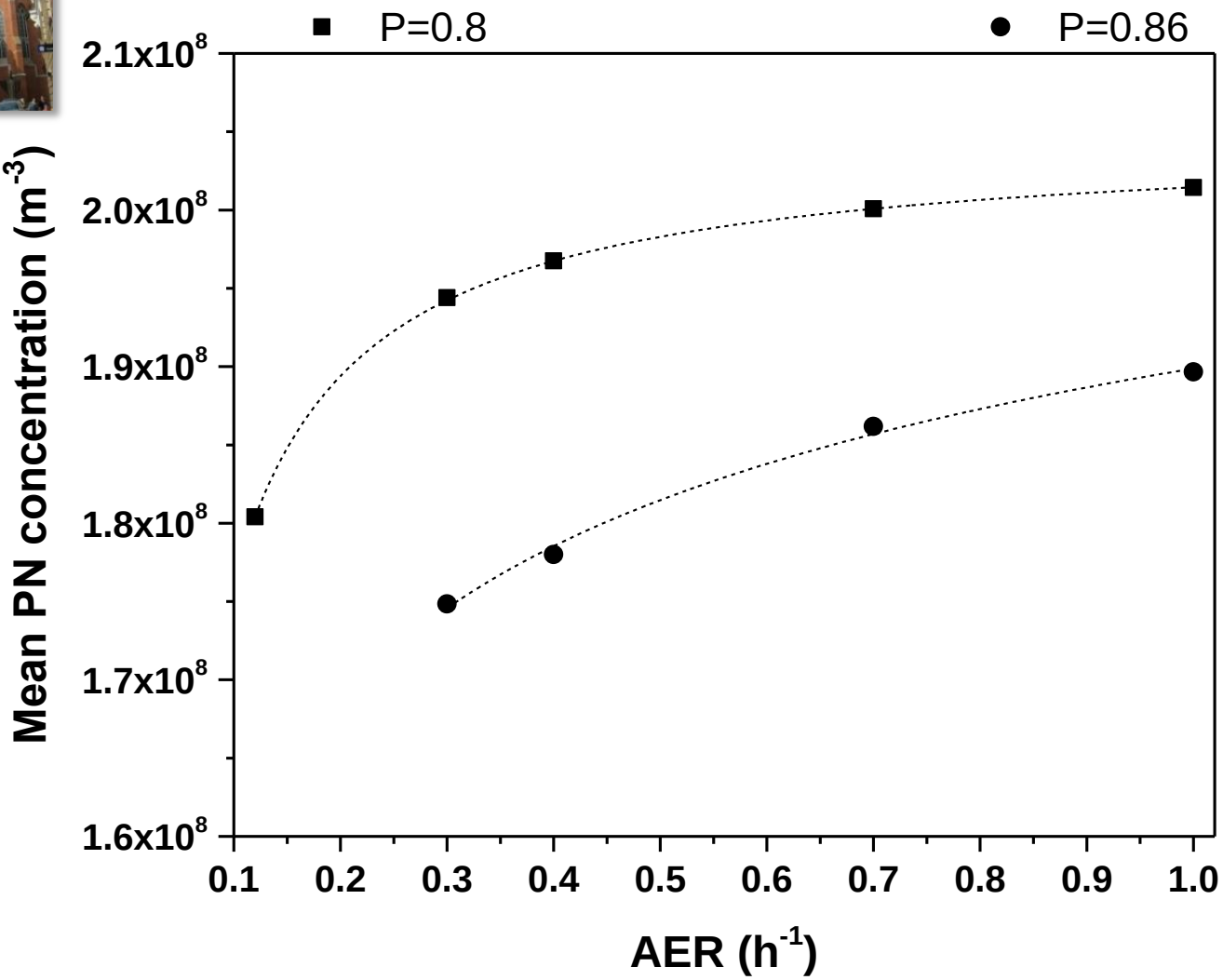


Generally, the deposition indoors is dominated by particles infiltrating from outside during the cold period.

Does air-tightness of the building shell reduce soiling?



Filtering capacity is more important than the air-tightness



Conclusions

The measurements covered at least 10 months which included considerable variability in outdoor particle concentrations and pattern of building use.

Robust values of physical parameters were obtained; values of the deposition velocities fall within the range determined for other historic buildings - churches and a library.

Conclusions

Deposition is predominantly the outcome of infiltration of the outdoor aerosol in winter.

The particle deposition velocity does not increase when various heating strategies and systems are used for low temperature of heating sources and small air flow velocities.

Soiling is primarily reduced due to particle filtering by building envelopes.

Acknowledgements

The team:

M. Strojecki, A. Mleczkowska, Ł. Bratasz*, R. Kozłowski

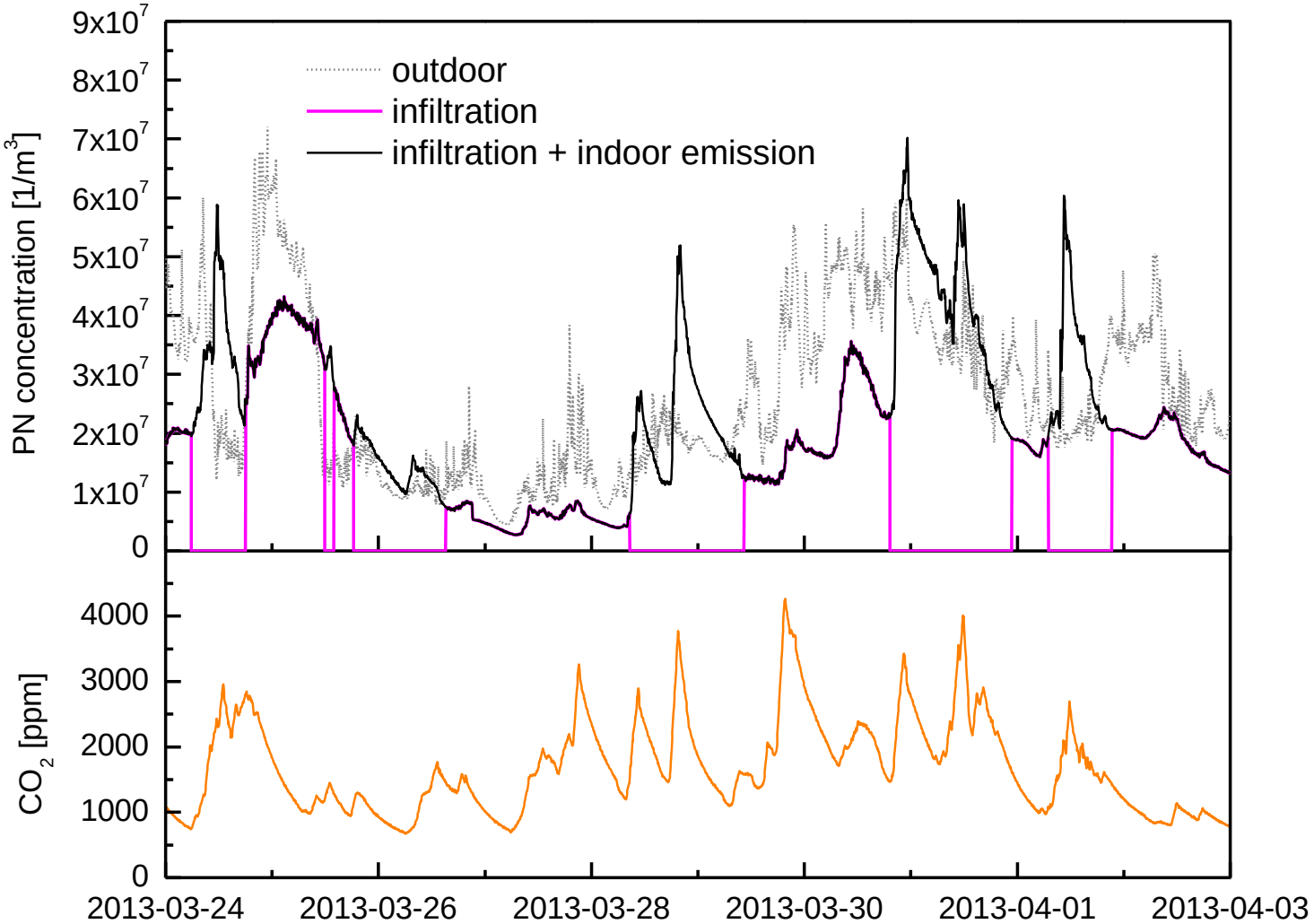
The Jerzy Haber Institute, Polish Academy of Sciences, Krakow, Poland

** now @ Institute for the Preservation of Cultural Heritage, Yale University, USA*

This research was supported by Grant 2011/01/D/HS2/02604

from the NATIONAL SCIENCE CENTRE POLAND

We can distinguish between indoor emission sources and infiltrating outdoor particles



Diurnal changes in AER

A **high *AER*** due to enhanced day ventilation and a **minimal *AER*** when the church was closed.