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STUTTGART TECHNIK

ZAE BAYERN

Dynamic Simulation of VIP Moisture and Heat Transport

9th International Vacuum Insulation Symposium

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Structure

- Motivation
- Measurements of heat and moisture transport
- Description of heat and moisture transport
- Calculations of hygrothermal conditions in VIP
- Conclusion

Motivation

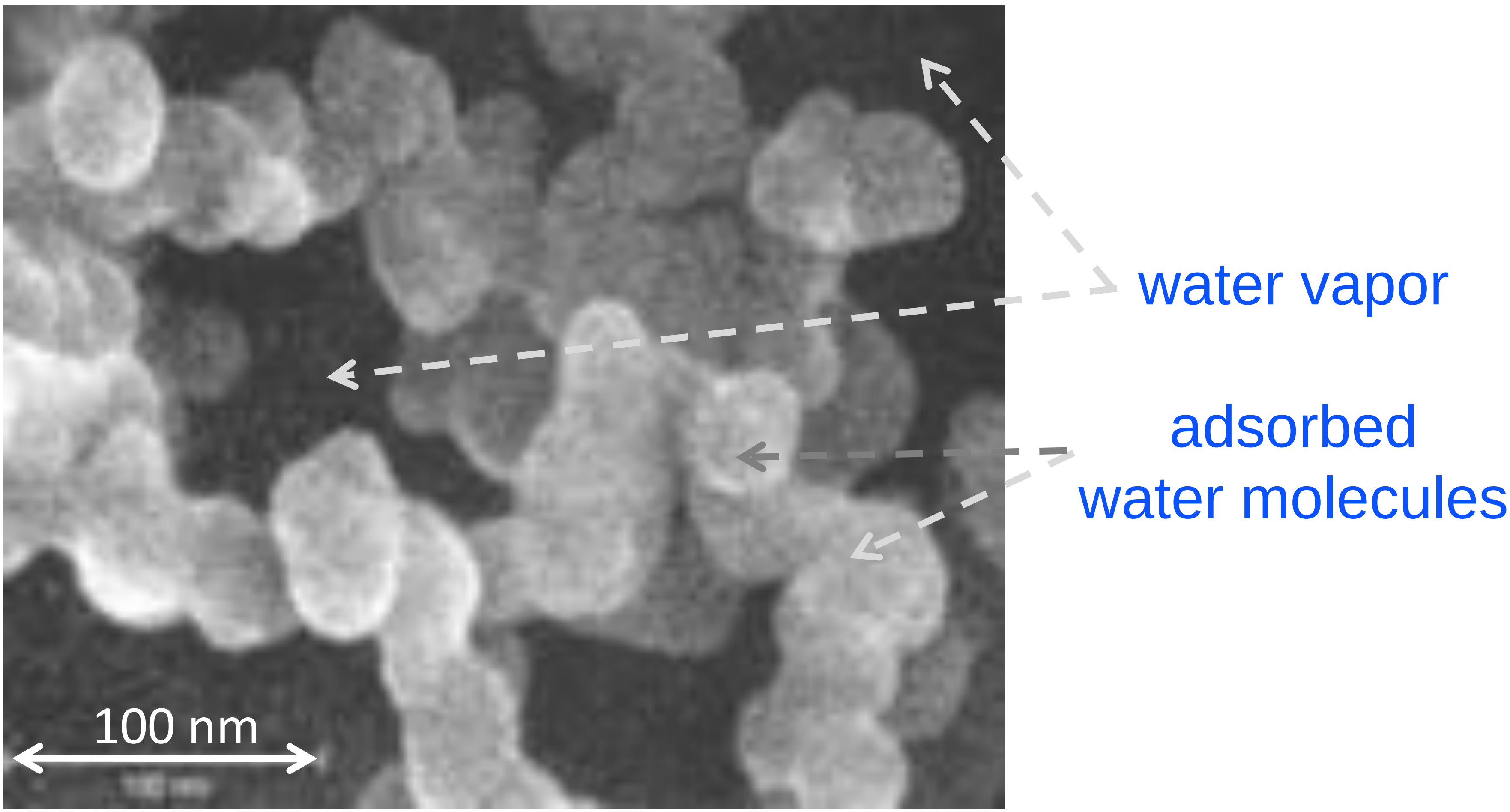
The increase in thermal conductivity is approximately proportional to the water content

0.5 mW/(mK) per 1 mass-% moisture content u

Schwab et al, ZAE Bayern, 2003
Beck et al, HFT Stuttgart, 2006

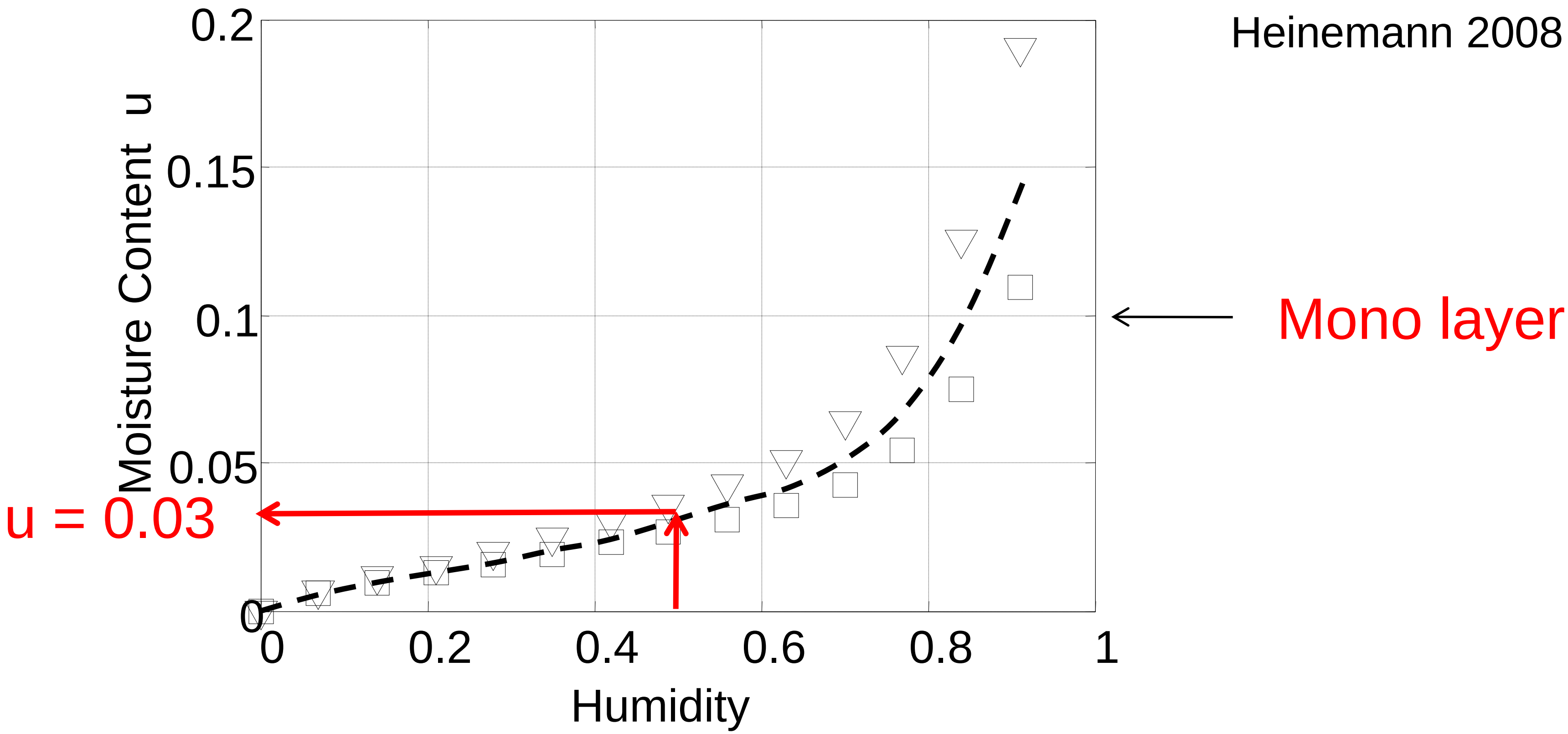
- How can this be explained?
- What happens within a moist VIP if the temperatures on the boundaries vary?

Microscopic structure of the silica kernel



Wacker Chemie

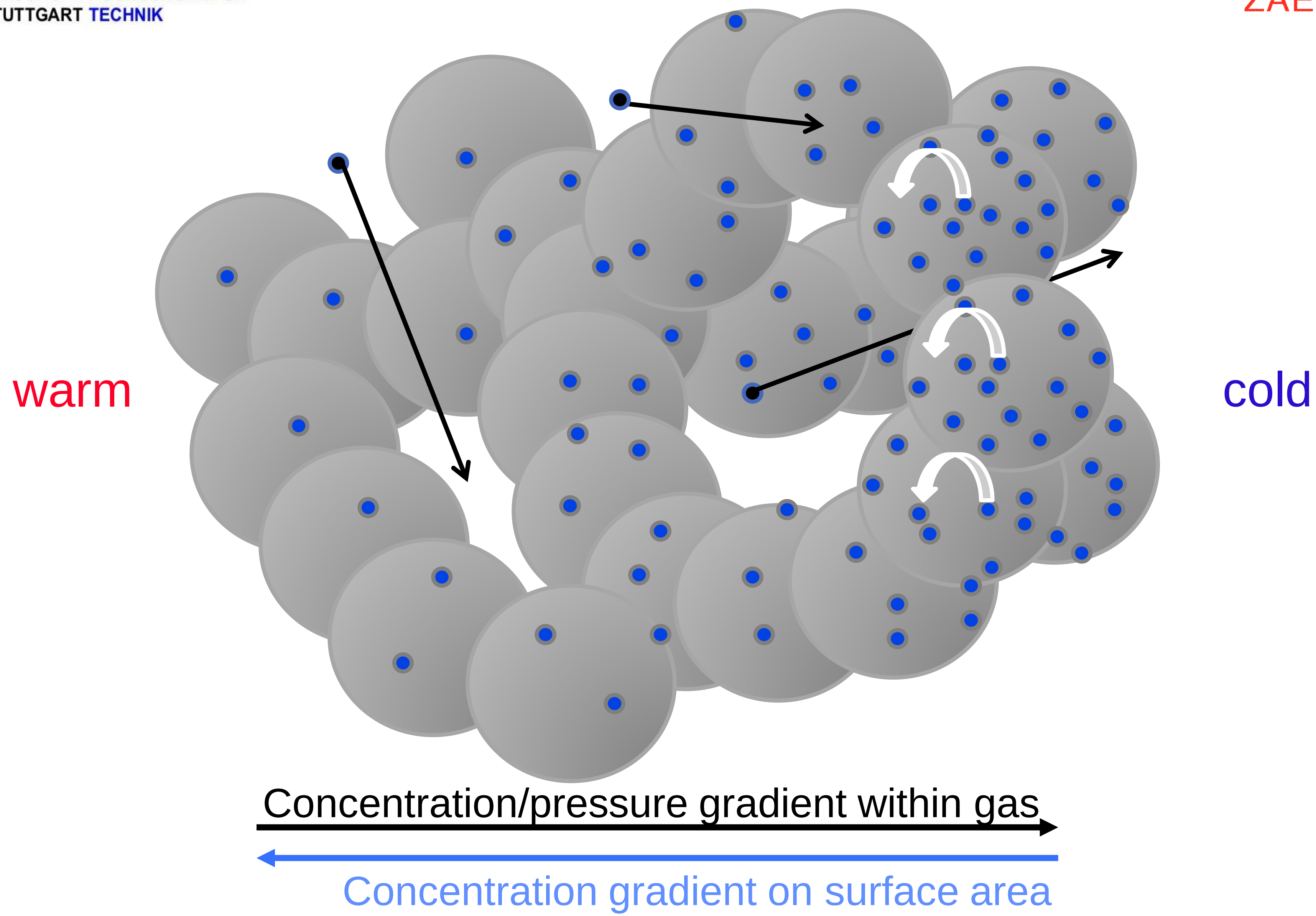
Sorption Isotherm



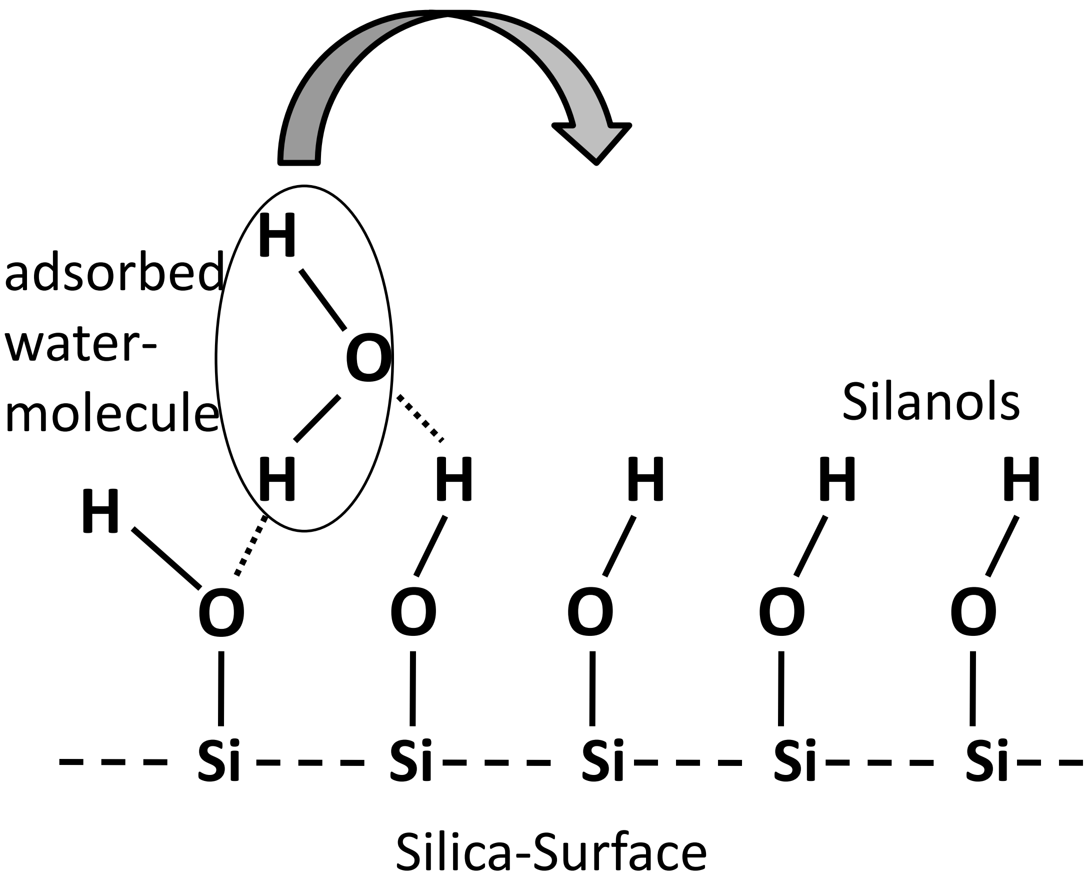
$$u = 0.03 \xrightarrow[\Phi = 0.53\ \text{nm}]{S = 300\ \text{m}^2/\text{g}} \Theta = 30\%\ \text{„surface coverage“}$$

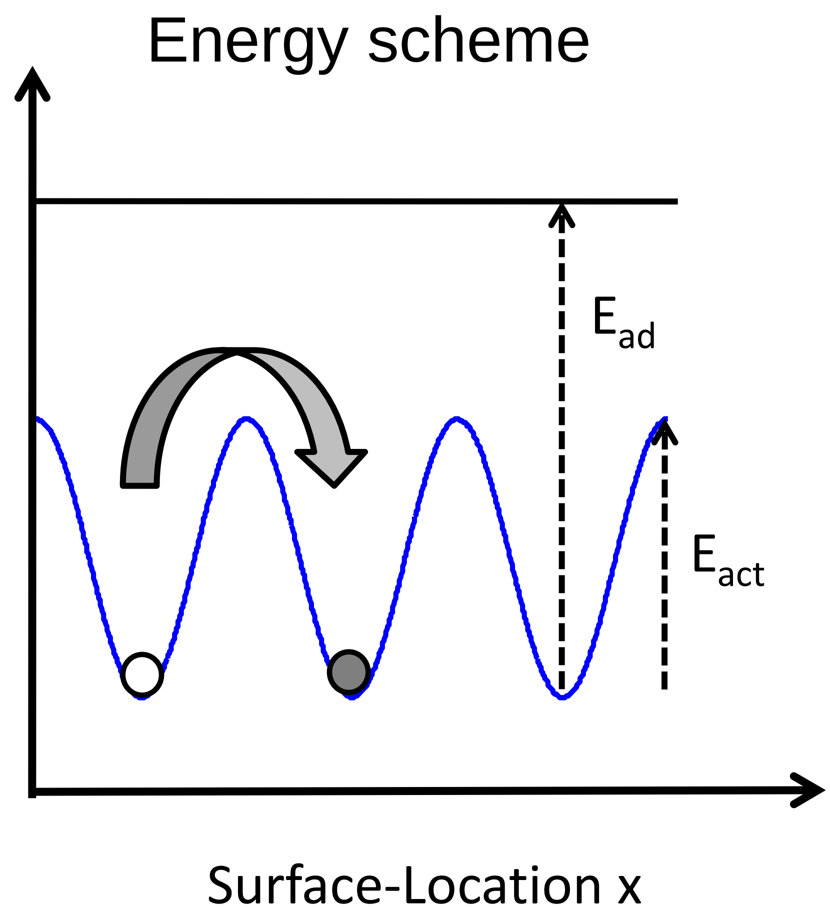
Clark 1985

Surface and bulk diffusion



Surface migration of adsorbed water molecules





E_{ad} = 50 kJ/mol

Heat and moisture transport

$$\varrho \frac{\partial u}{\partial t} = \frac{\partial}{\partial x}\left\{\frac{D_K}{RT}\frac{\partial p}{\partial x} + D_s \frac{\partial n_s}{\partial x}\right\} \qquad (1)$$

$$\varrho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left\{\lambda(p)\frac{\partial T}{\partial x} + E_{ad}\frac{D_K}{RT}\frac{\partial p}{\partial x}\right\} \qquad (2)$$

moisture (1)
and
heat (2)
transport

D_K : *molecular* diffusion coefficient

$D_s \sim \exp\left(-\frac{Eact}{RT}\right)$ *surface* diffusion coefficient

Dependence of λ on temperature for dry and moist VIP (u = 4.2 M-%)

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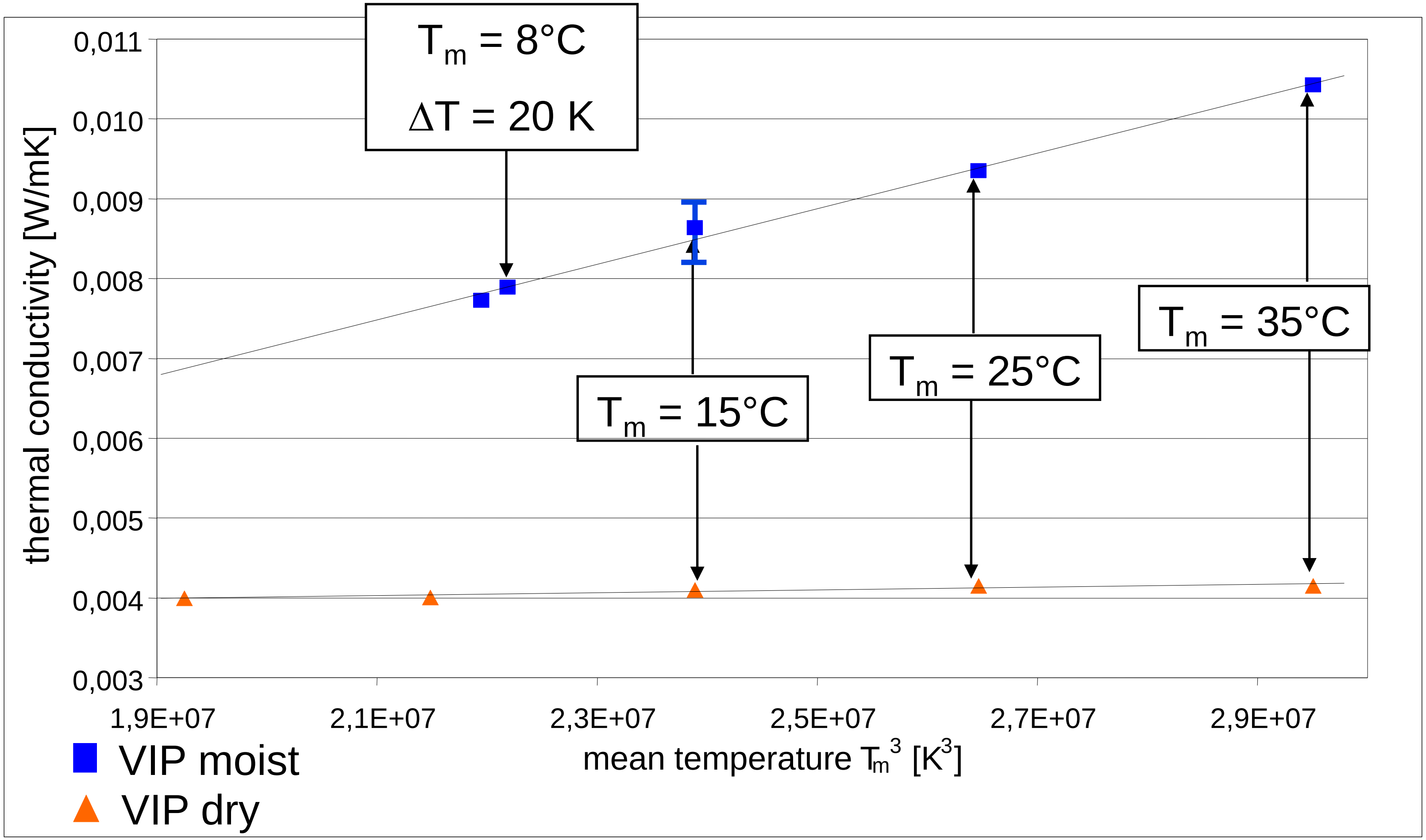
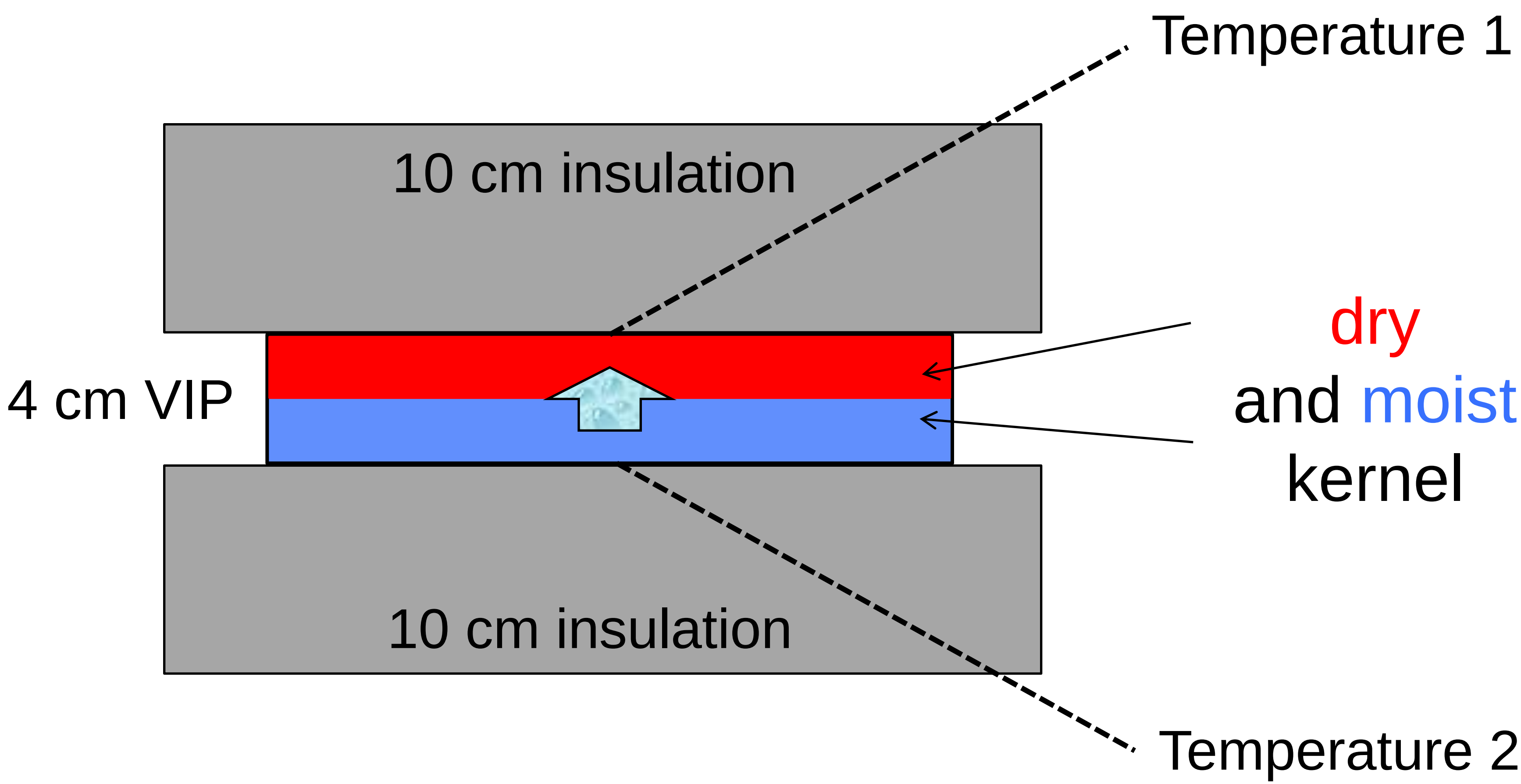


E_{act} = 20 kJ/mol

Beck 2007

Experimental Set-up to measure D_K



Temperatures due to de- and adsorption processes within the VIP

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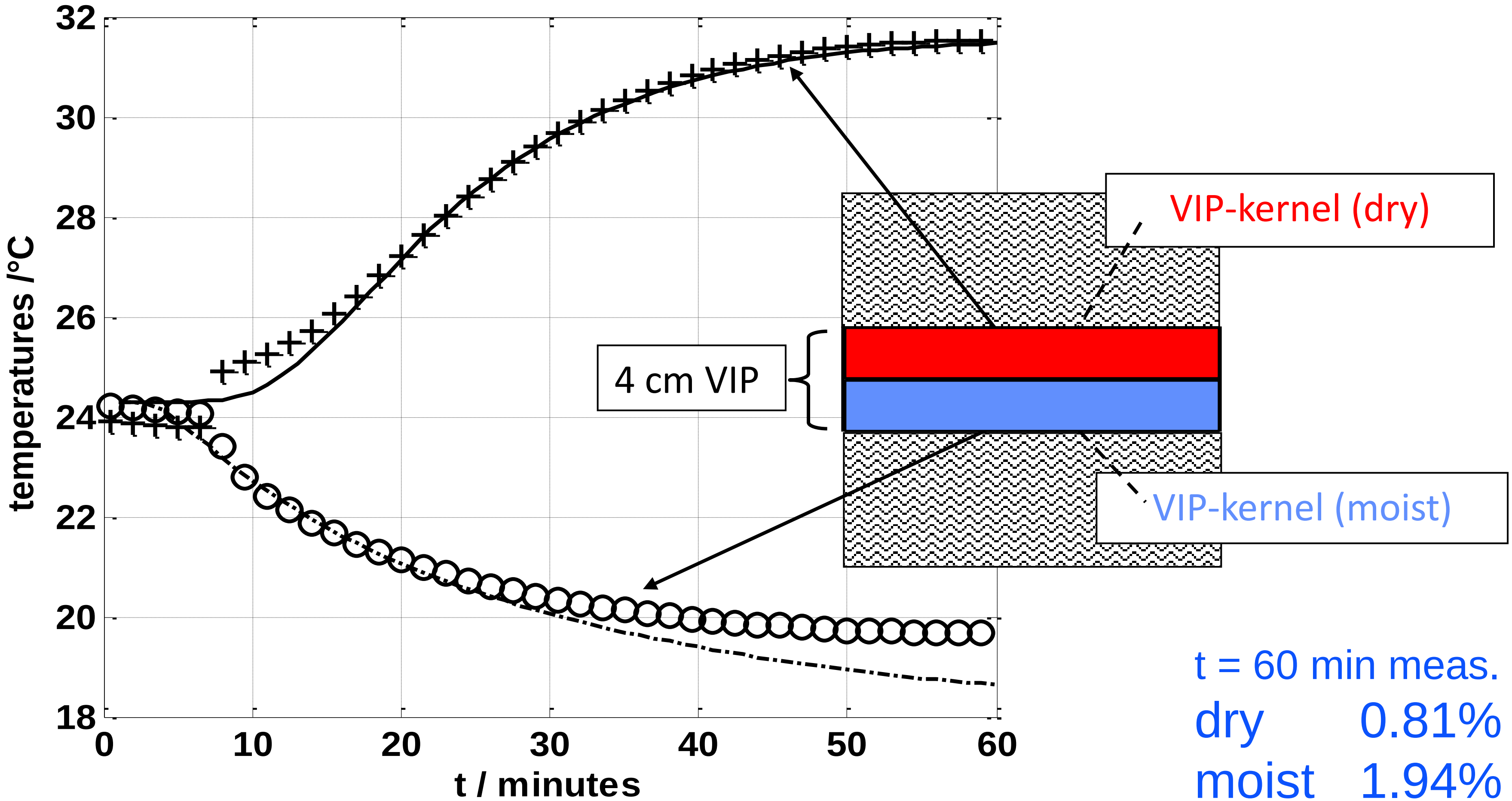

t = 60 min	meas.	calc.
dry	0.81%	0.7%
moist	1.94%	2.0%

$D_K = (1.6+/-0.2)*10^{-5}\ m^2/s \rightarrow d = 100\ nm$ „pore size“

Model predictions:
Thermal conductivity λ versus water content u

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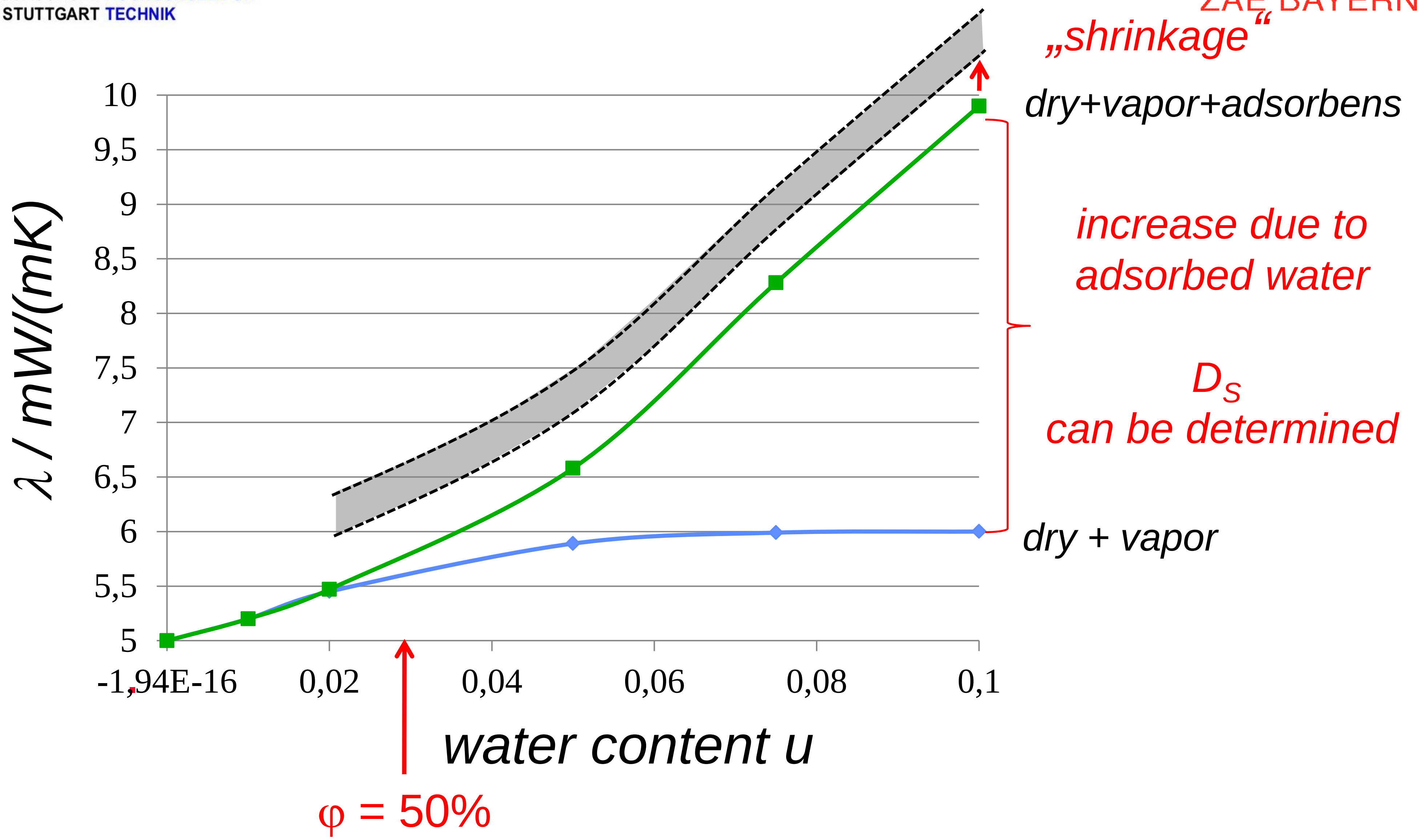
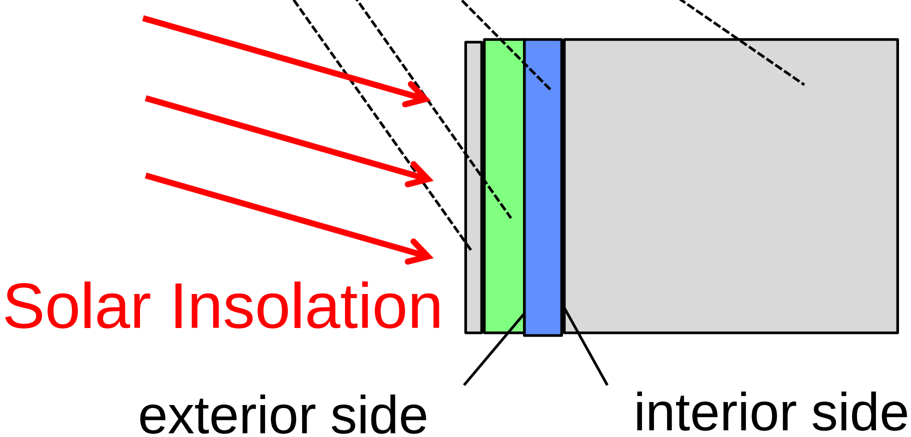


Hygrothermal conditions within VIP in different wall constructions

				Construction #1	Construction #2
Material	Heat capacity [kJ/(kg*K)]	Thermal conductivity [W/(m*K)]	Density [kg/m³]	Thickness of layer [m]	Thickness of layer [m]
Brick	1000	0.5	2000	0.30	0.30
VIP	700	Variable	200	0.02	0.02
Additional insulation	1000	0.04	30	0.00	0.02
Plaster	1000	0.8	1000	0.005	0.005



Solar absorption coefficient
a = 0.2 to 0.7

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Moisture migration due to temperature fluctuations (springtime)

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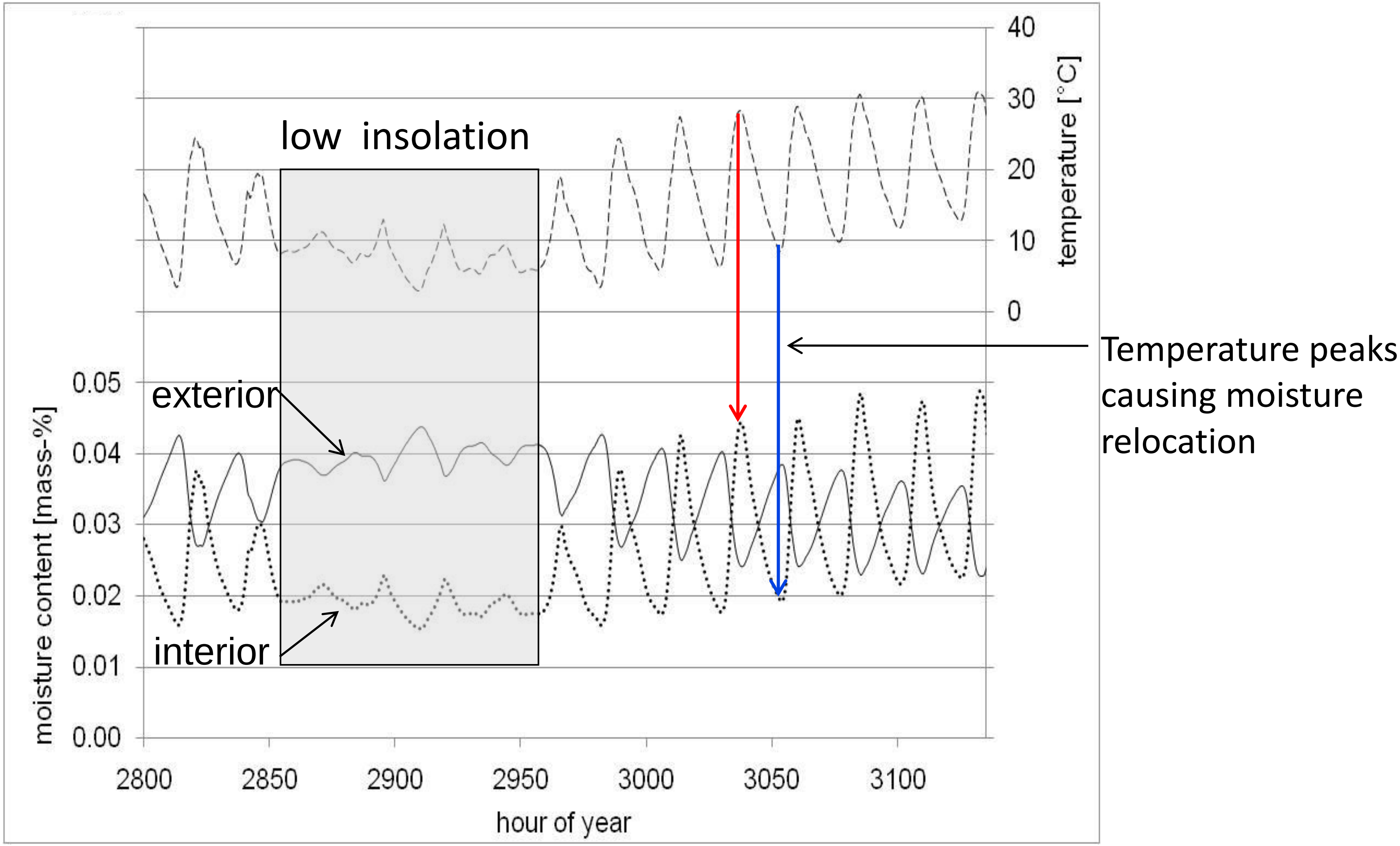

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Relative humidity versus temperature – without (left) and with insulation (right)

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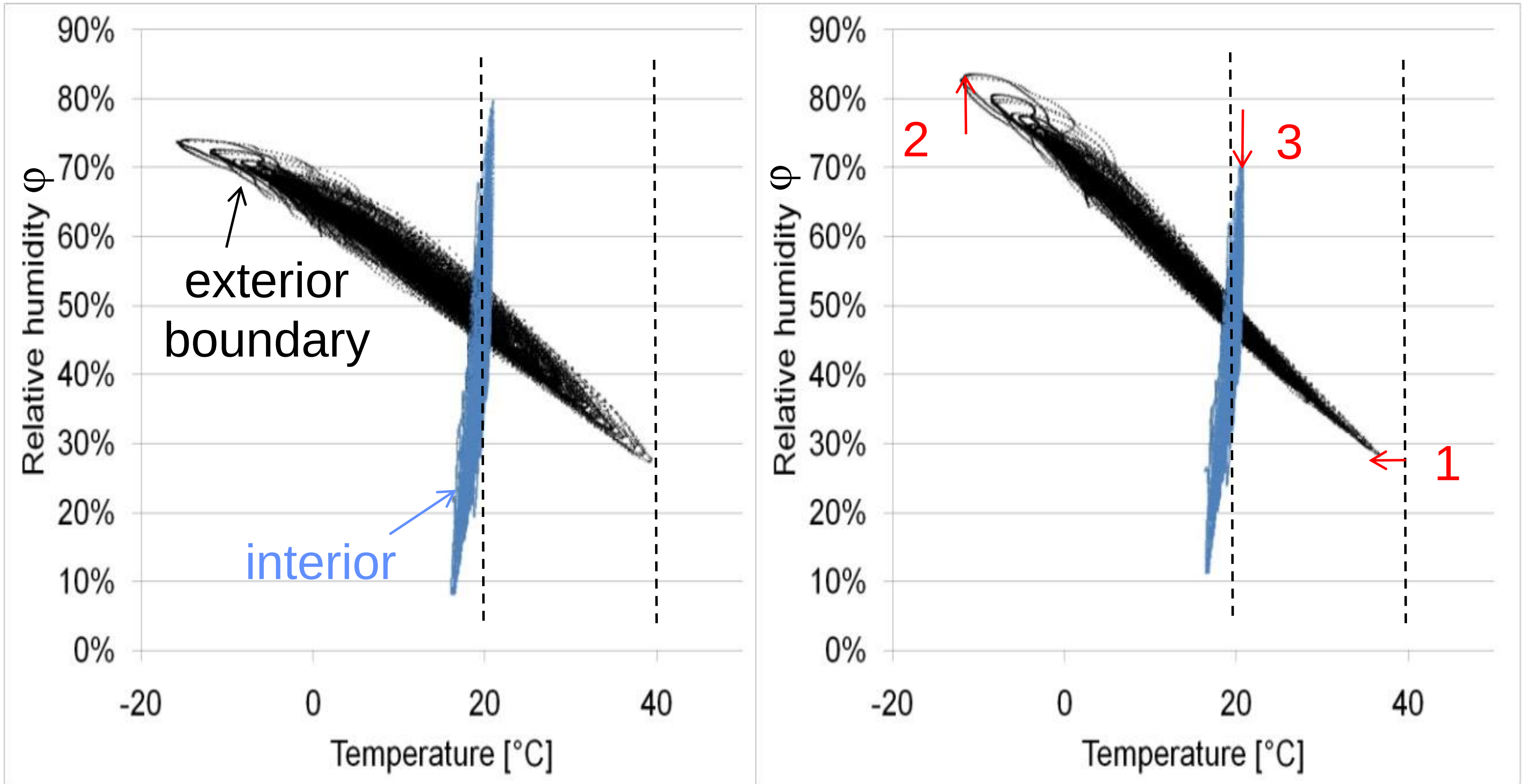
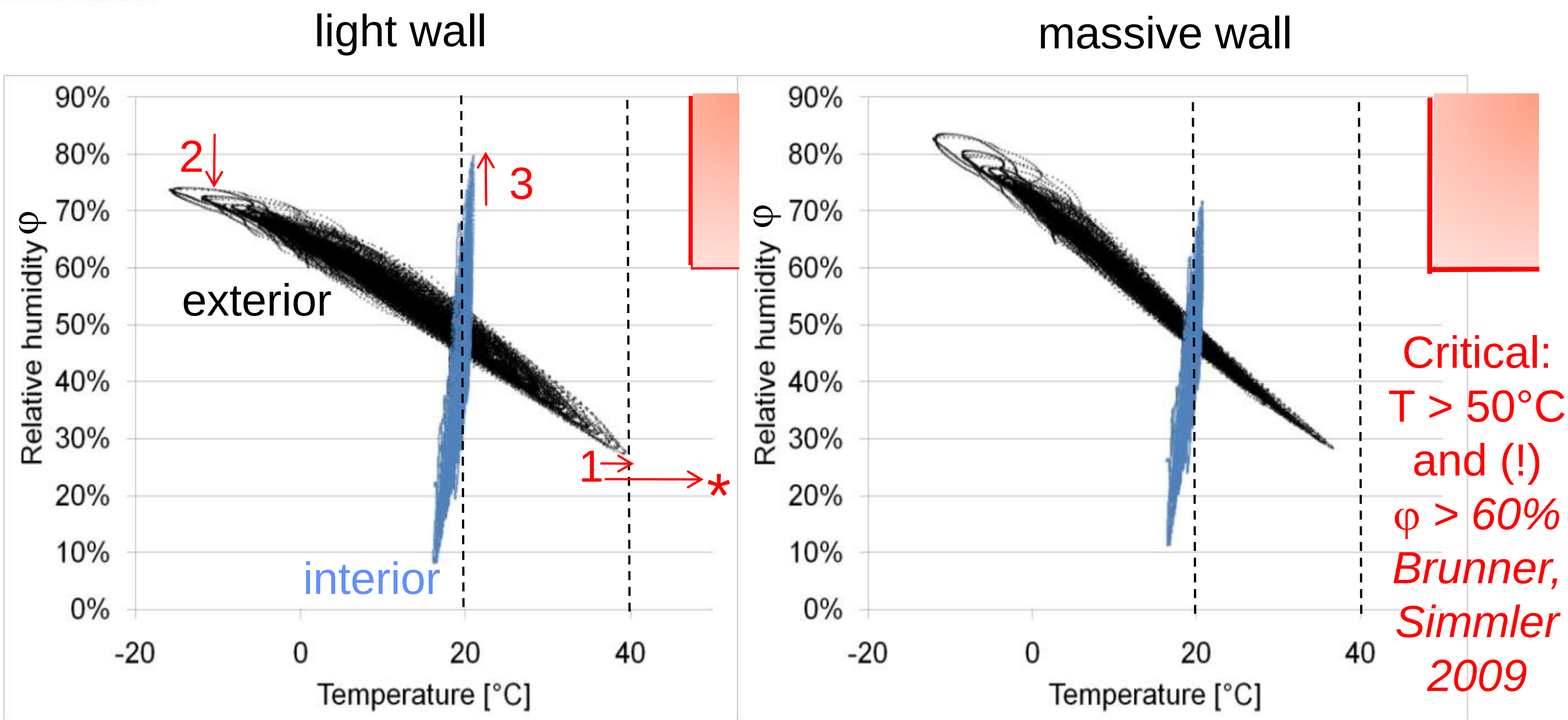
solar absorption coefficient a = 0.2



1) decrease of temperature
2) increase of humidity by about 10%
3) decrease of humidity by about 10%

Light wall – massive wall



1) increase of temperature
2) decrease of humdity by about 10%
3) increase of humidity by about 10%

* T_{max} = 50°C for a = 0.7

Summary

- A model was developed and tested to describe the heat and moisture transport within VIP
- The hygrothermal conditions within VIP were calculated quantitatively
- High temperatures (max. 50°C to 60°C; depending on solar absorption, orientation etc.) correspond to low humidity and vice versa
  - total increase of the thermal conductivity due to moisture: $\Delta\lambda \cong 1 - 2$ mW/(m K)
  - no aging of the laminates are expected

Thank you for your attention