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Water vapour sorption of building materials – modelling of scanning curves

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Aim:

•To contribute to the database of the measured scanning curves

•To compare the capability of the chosen mathematical algorithms to describe the scanning curves. Considered models are able to predict the scanning curves from the given main hysteretic loop only, without requirement of experimental scanning curves data for their calibration.

Content:

- Description of measurements and measured materials
- Scanning curves modelling
- Comparison of the measured and predicted 1st scanning curves from 94, 85, 75 % RH
- Comparison of the measured and predicted desorption-adsorption loop
- Discussion
- Conclusions

Sorption measurements

Main adsorption, desorption isotherms, scanning curves

Standard gravimetric desiccator method
Temperature: 22.5 °C
Saturated salt solutions used: LiCl for 11.3%, $MgCl_2$ for 33%, $Mg(NO_3)_2$ for 53%, NaCl for 75%, KCl for 85%, KNO_3 for 94% and $CuSO_4$ for 98% RH

Materials

Material	Bulk density [kg/m^3]	Open porosity [-]	Capillary moisture content [m^3/m^3]
AAC Y	500	0.8	0.27
Brick P	1377	0.42	0.38

Bulk density was calculated from volume and mass of the dried out specimens (oven drying at 105°C).
Capillary moisture content was determined from a time-controlled capillary water uptake experiment
Open porosity was determined from water saturation test.

Scanning curves modelling: Mualem algorithm

A conceptual model of hysteresis has been suggested by Mualem (1974). It is based on Neel's similarity hypothesis and Everett's independent domain model. According to the Mualem model the moisture content during adsorption, after the relative humidity path $\varphi_{min} \rightarrow \varphi_1 \rightarrow \varphi_2 \ldots\ldots\ldots \rightarrow \varphi_N$ (i. e. after N/2 processes of adsorption and N/2 processes of desorption) is expressed by the relation:

$$u_m(\varphi) = u_{ads}(\varphi) + (u_{ads}(\varphi_{N-1}) - u_{ads}(\varphi)) \cdot \frac{u_{des}(\varphi_N) - u_{ads}(\varphi_N)}{u_{max} - u_{ads}(\varphi_N)} + \sum_{i=1}^{(N/2)-1} (u_{ads}(\varphi_{2i-1}) - u_{ads}(\varphi_{2i+1})) \cdot \frac{u_{des}(\varphi_{2i}) - u_{ads}(\varphi_{2i})}{u_{max} - u_{ads}(\varphi_{2i})}$$

Moisture content during desorption, after the relative humidity path $\varphi_{min} \rightarrow \varphi_1 \rightarrow \varphi_2 \ldots\ldots\ldots \rightarrow \varphi_N$ (i. e. after (N-1)/2 +1 processes of adsorption and (N-1)/2 processes of desorption) is given by the relation:

$$u_m(\varphi) = u_{ads}(\varphi) + (u_{ads}(\varphi_N) - u_{ads}(\varphi)) \cdot \frac{u_{des}(\varphi) - u_{ads}(\varphi)}{u_{max} - u_{ads}(\varphi)} + \sum_{i=1}^{(N-1)/2} (u_{ads}(\varphi_{2i-1}) - u_{ads}(\varphi_{2i+1})) \cdot \frac{u_{des}(\varphi_{2i}) - u_{ads}(\varphi_{2i})}{u_{max} - u_{ads}(\varphi_{2i})}$$

u_m = moisture content (kg/kg), φ = relative humidity (-) φ_{min}= starting relative humidity (-), $\varphi_{min} \approx 0$

u_{ads} = moisture content corresponding to main adsorption curve

u_{des} = moisture content corresponding to main desorption curve u_{max} = maximum moisture content

Scanning curves modelling: Slope algorithm

The empirical Slope method (Jaynes 1984) uses the main adsorption and desorption slopes for the scanning curves prediction. According to this algorithm the moisture content in time (N+1) is given by equation:

$$u_m(\varphi_{N+1}) = u_m(\varphi_N) + C \cdot (\varphi_{N+1} - \varphi_N)$$

for the process of adsorption:

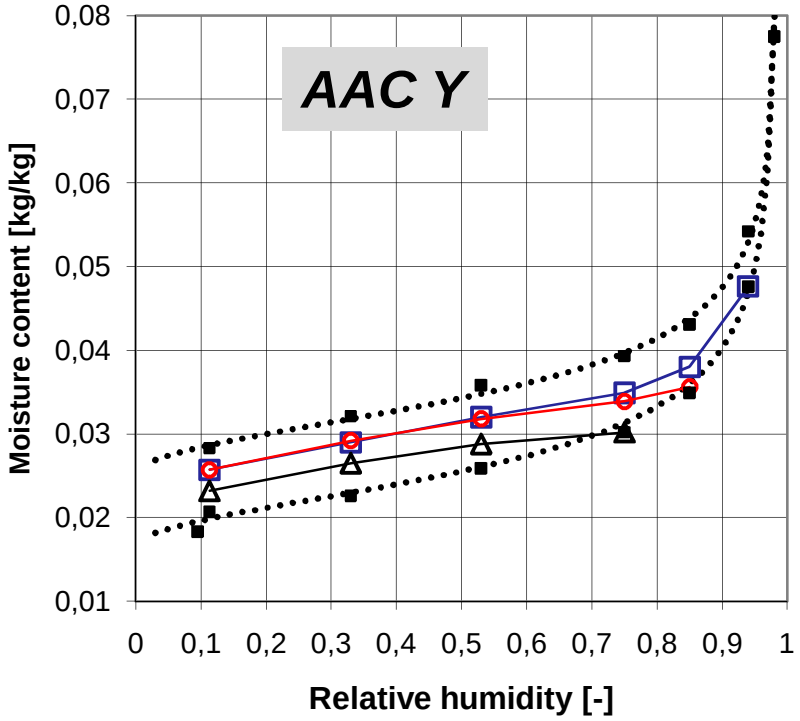
$$C = \frac{du_{ads}}{d\varphi} \cdot \frac{u_{des}(\varphi_{N+1}) - u_m(\varphi_{N+1})}{u_{des}(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})}$$

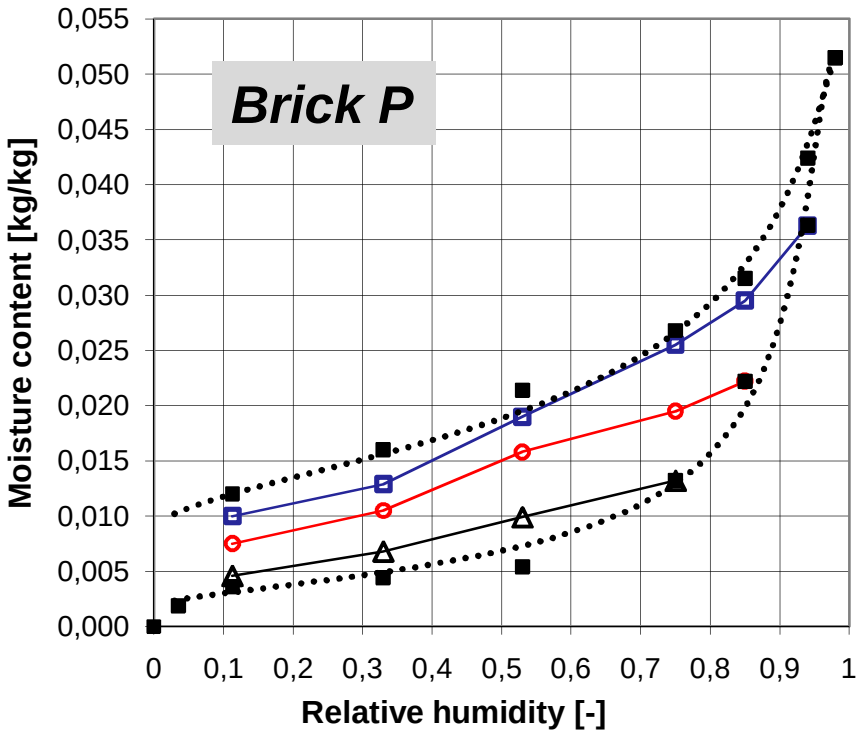
for the process of desorption:

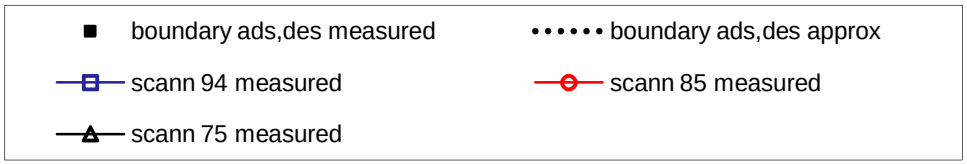
$$C = \frac{du_{des}}{d\varphi} \cdot \frac{u_m(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})}{u_{des}(\varphi_{N+1}) - u_{ads}(\varphi_{N+1})}$$

u_m = moisture content (kg/kg),
φ = relative humidity (-)
u_{ads} = moisture content corresponding to main adsorption curve
u_{des} = moisture content corresponding to main desorption curve

Measured scanning curves from 94%, 85% and 75%





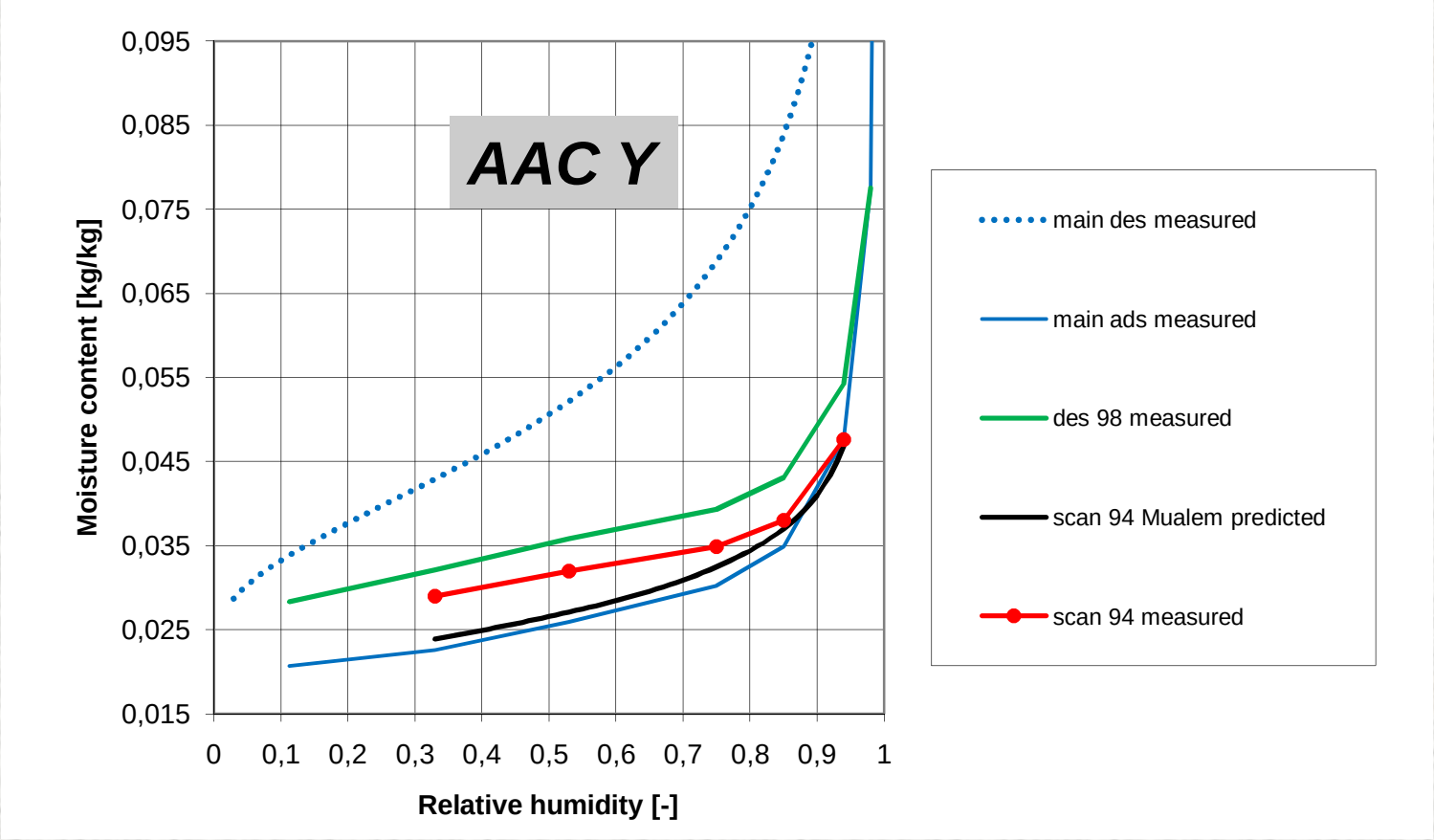


$$u_m(\varphi) = u_{\max} \cdot \left(1 - \left(\frac{\ln \varphi}{B}\right)^{n1}\right)^{-n2}$$

Material	Adsorption				Desorption from 98 %			
	u_{max} [kg/kg]	B	n2	n1	u_{max} [kg/kg]	B	n2	n1
AAC Y	0.08	0.004	0.2	1.12	0.08	0.0033	0.14286	1.12
Brick P	0.0515	0.037	0.35088	2.0	0.0515	0.06	0.33898	1.22

Measured and predicted scanning curves from 94%

Mualem algorithm, main hysteretic loop



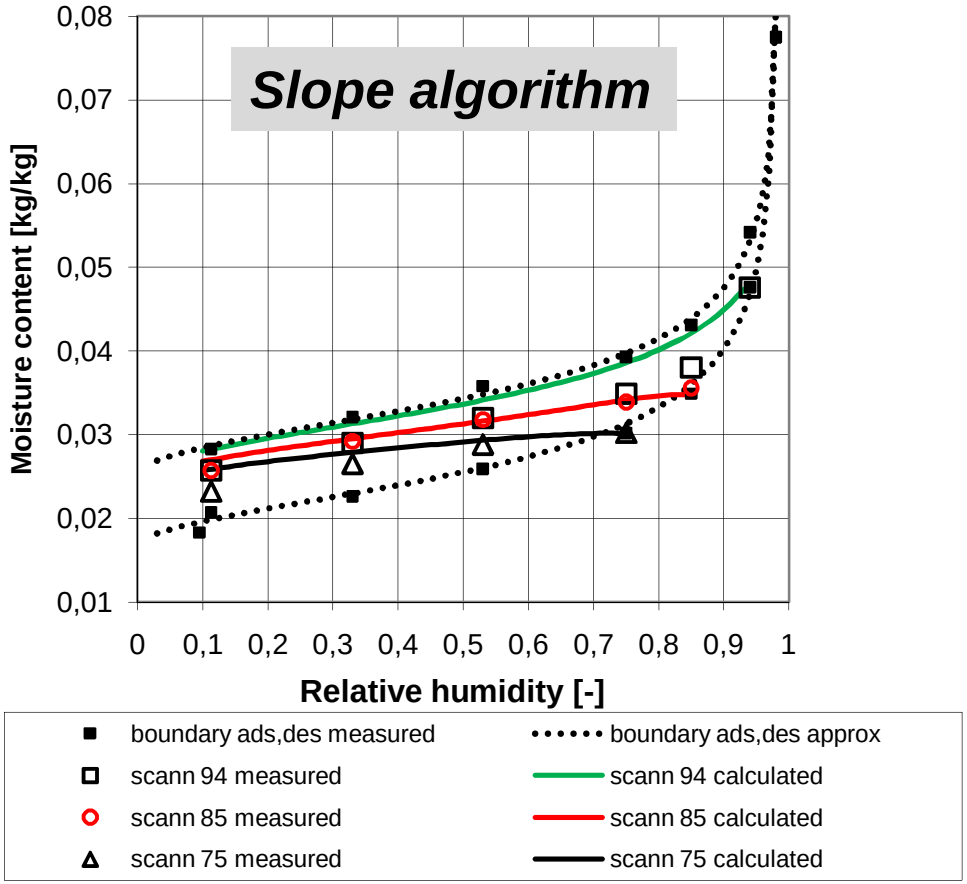
$$u_m(\varphi) = u_{\max} \cdot \left(1 - \left(\frac{\ln \varphi}{B}\right)^{n1}\right)^{-n2}$$

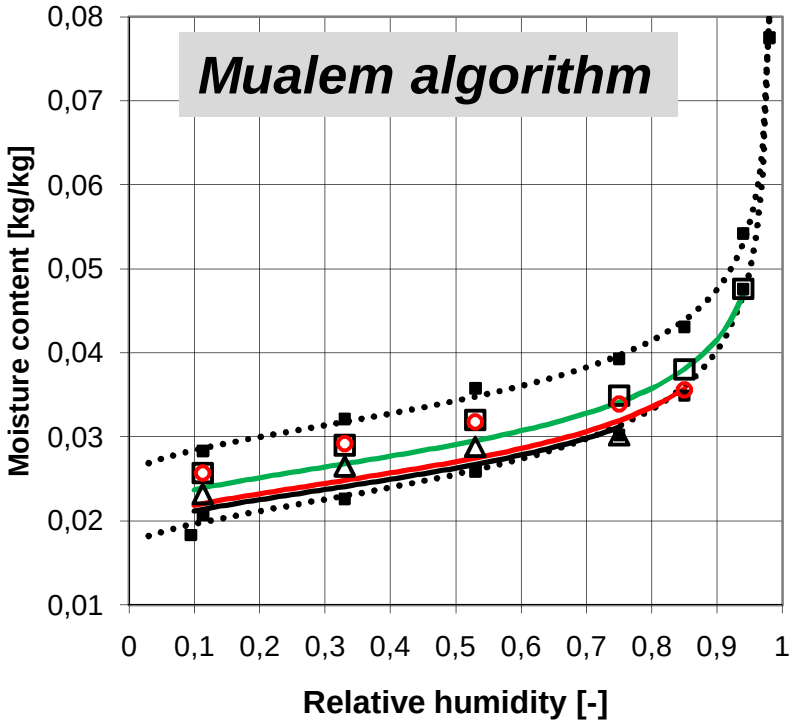
Adsorption				Desorption			
u_{max} [kg/kg]	B	n2	n1	u_{max} [kg/kg]	B	n2	n1
0.08	0.004	0.2	1.12	0.54	0.0033	0.14286	1.0

1st desorption scanning curves of AAC Y

Measured and predicted scanning curves from 94%, 85% and 75%

Partial hysteretic loop



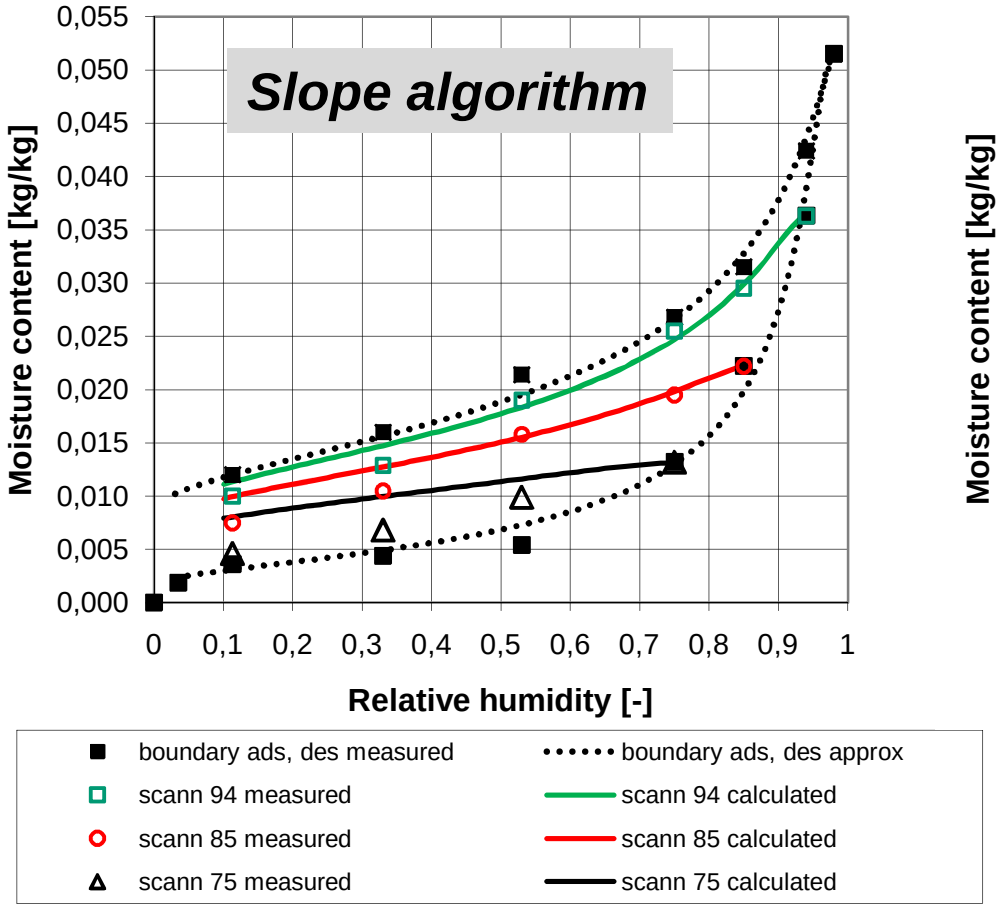


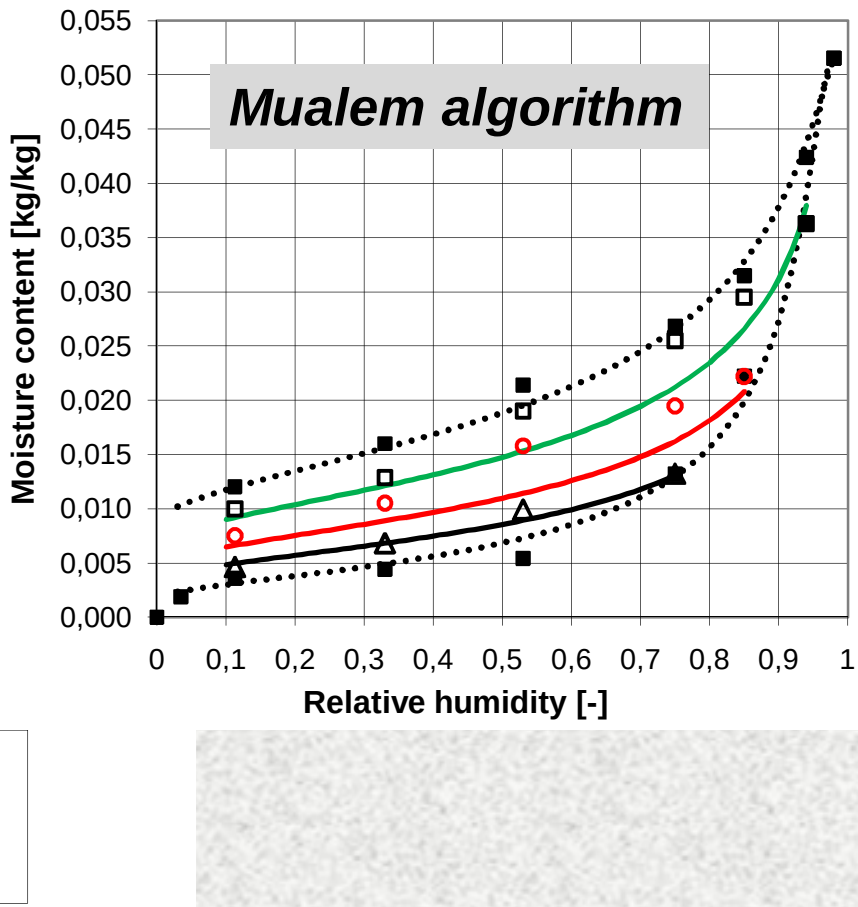
Method	Absolute value [kg/kg]			Relative value [%]		
	from 94%	from 85%	from 75%	from 94%	from 85%	from 75%
Slope	0.004	0.001	0.003	11 %	5 %	11 %
Mualem	0.003	0.004	0.002	8 %	15 %	9 %

1st desorption scanning curves of brick P

Measured and predicted scanning curves from 94%, 85% and 75%

Partial hysteretic loop



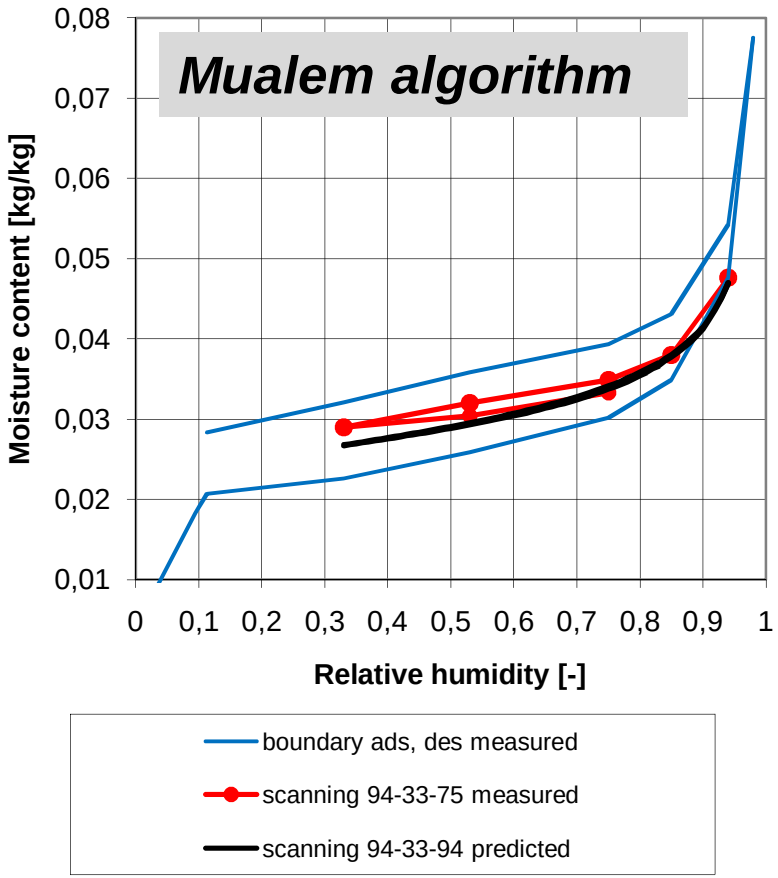


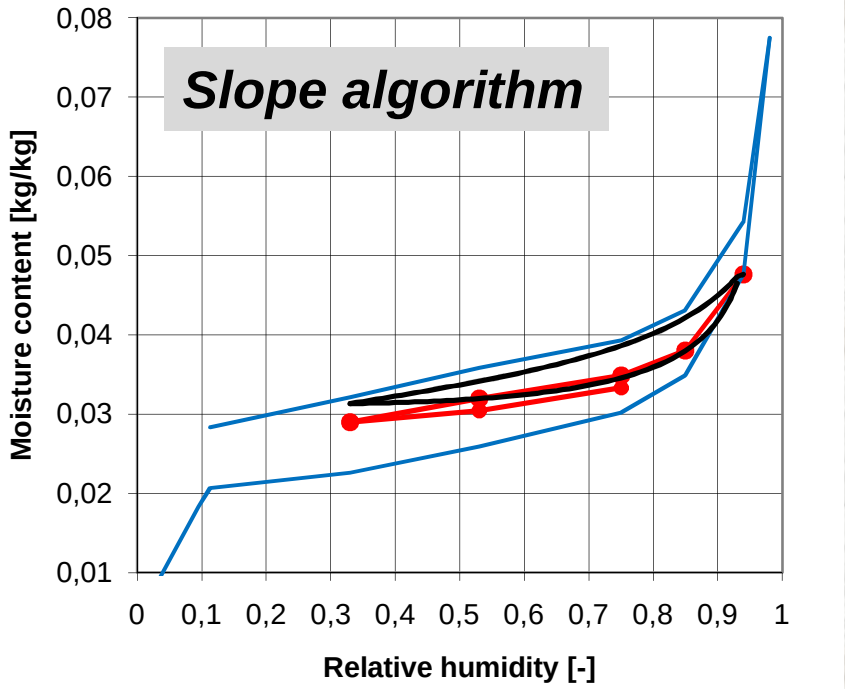
Method	Absolute value [kg/kg]			Relative value [%]		
	from 94%	from 85%	from 75%	from 94%	from 85%	from 75%
Slope	0.002	0.002	0.002	14 %	32 %	74 %
Mualem	0.004	0.004	0.001	17 %	26 %	7 %

1st desorption – adsorption loop of AAC Y

Measured and predicted curves

Partial hysteretic loop



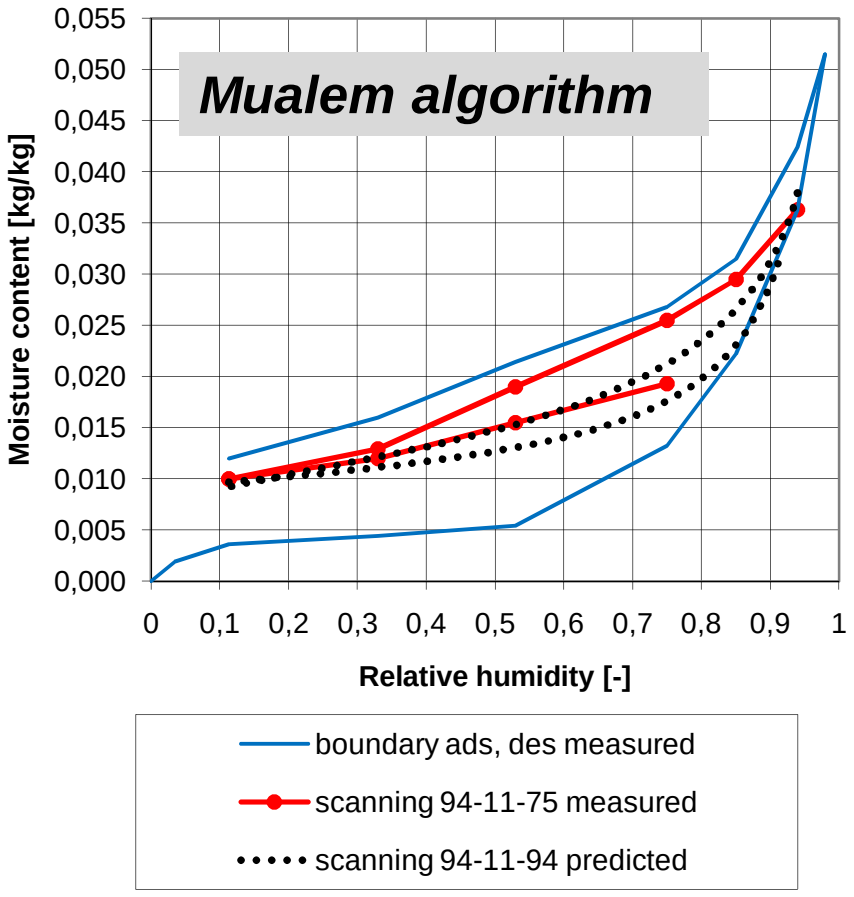


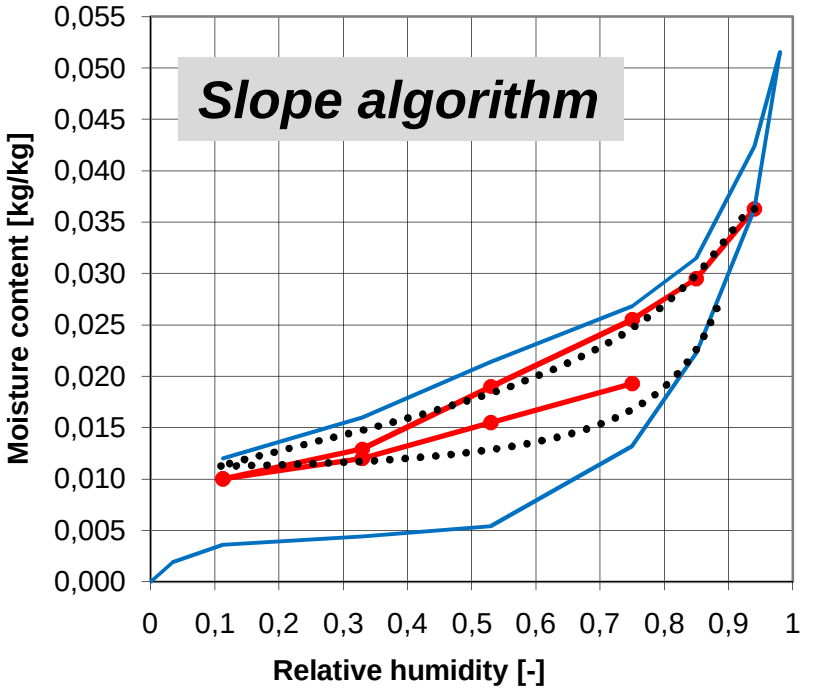
Maximum differences between the calculated and measured moisture content		
Method	Absolute value [kg/kg]	Relative value [%]
Slope	0.003	9 %
Mualem	0.002	7 %

1st desorption – adsorption loop of brick P

Measured and predicted curves

Partial hysteretic loop





Maximum differences between the calculated and measured moisture content		
Method	Absolute value [kg/kg]	Relative value [%]
Slope	0.002	17 %
Mualem	0.002	16 %

Conclusions

- The water vapour main adsorption, desorption, the 1st desorption scanning curves and 1st desorption – adsorption loops were measured for two building materials: autoclaved aerated concrete (AAC) and ceramic brick.

- A prediction of the scanning curves was done by Mualem algorithm and Slope algorithm. The advantage of these algorithms is that they are based on the knowledge of the main hysteretic loop only.

- The predicted results using the main hysteretic loop and the Mualem model were not satisfactory for AAC material.

- In case of using the partial hysteretic loop formed by the main adsorption curve and desorption isotherm from 98% RH, the coincidence of the measured and predicted scanning curves was acceptable. In this case both used algorithms have approximated the measured scanning curves with the similar degree of accuracy.

- For the more general conclusion regarding usability of the algorithms for an evaluation of the actual moisture capacity of building material under cyclic boundary conditions or for an implementation to hygro-thermal performance simulation tools, the further evaluation of their capability for series of alternating adsorption and desorption processes for another building materials should be done.