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Water Vapour Permeability of Clay Bricks

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Abstract

The water vapour permeability of clay bricks has been experimentally measured in order to draw a representative outline of the industrial products without pore-forming additives. The correlations among the water vapour permeability and the main compositional and microstructural parameters of both bricks and clay bodies have been investigated. A statistical model was set up in order to predict with reasonable precision and reliability the water vapour permeability on the basis of the open porosity, bulk density, mean pore size and pore specific surface values of bricks, and the finer particle size of clay bodies.

Keywords: Water vapour permeability, clay bricks, microstructure.

Introduction

The knowledge of the thermo-hygrometric performance of building materials is fundamental to avoid the formation of superficial moisture due to environmental and/or construction factors (e.g. humidity absorption from air, capillary rise) as well as to assess the extent of condensation phenomena.

The appraisal of the ability of clay bricks to waste in operating conditions the moisture absorbed for superficial condensation or capillarity requires the knowledge of a series of physical parameters, i.e. hygroscopic capacity, diffusion resistance and water vapour permeability. Both the hygroscopic capacity and the diffusion resistance are necessary to describe the absorption process of water vapour in non steady state. In steady conditions, indeed, the water vapour permeability is the single variable necessary to correlate the density of vapour flow to the pressure gradient in any time and in any point of a system [1].

Notwithstanding the interest of this subject, just few studies in the literature dealt with the thermo-hygrometric properties of clay bricks, but practically no data on water vapour permeability have been published. As a matter of fact, the available results concern measurements of the equilibrium moisture content of ordinary [2] and lightweight bricks [3]. These investigations pointed out some significant correlations between the moisture content on the one hand, and the pore specific surface [2], the bulk density, the total porosity and the mean pore size on the other hand [3]. In general, the larger the porosity and/or the pore size, the larger the amount of humidity absorbed by the brick.

This study is aimed at the experimental determination of the water vapour permeability of clay bricks, in order to draw a picture representative of the industrial products without pore-forming additives. Moreover, any relationship between the water vapour permeability and the microstructural properties of the ceramic material will be investigated.

Experimental

Thirteen clays were selected in order to get a wide range of chemical and mineralogical compositions (Table I) and particle size distributions (Fig. 1).
A particular attention was paid during the preparation of samples for the permeability measurements in order to achieve materials fully comparable to the industrial products. For this purpose, in every brickwork a 30 x 30 x 30 cm^3 clay block was taken from the extruder after removal of the head die. Then 2 cm thick slabs were cut off and circular specimens (10 cm diameter) were obtained using circular punches.
Drying and firing of samples were carried out in the same brickwork, taking care to adopt for each product the firing temperature of the corresponding industrial kiln (Table II).
The water vapour permeability was determined according to the Italian standard [4] using three specimens for each clay body with an analytical error below 2%.
The composition of clays was determined as follows: chemistry by XRF spectrometry on powder pellets, mineralogy by CuKα X-ray powder diffraction, and particle size distribution by photosedimentation [5].
The microstructural characterization of bricks was performed by mercury intrusion porosimetry with measurement of open porosity (OP), bulk density (B), mean pore size (MPS) and pore size selection (PSL). The impervious (IP) and total porosity (TP) were calculated on the basis of specific weight values measured by the ASTM C 329 method [6]. The pore specific surface (PSS) was analysed according to ASTM C1069 standard [7].

Results and Discussion

The water vapour permeability (δ) of clay bricks is in the $3 \div 13 \cdot 10^{-12}$ $kg \cdot m^{-1} s^{-1} Pa^{-1}$ range. Most data are between 5.5 and 8.5 $kg \cdot m^{-1} s^{-1} Pa^{-1}$; samples A and S exhibit lower values, as samples CA, MO and X present a larger permeability (Table III).
A statistical factor analysis was undertaken considering the δ values and the microstructural variables of bricks as well as the main mineralogical and particle size parameters of clay bodies (Fig. 2). The extraction of the principal components highlighted:
i) a positive correlation of the water vapour permeability with the open porosity and the mean pore size and
ii) a negative correlation of δ with the bulk density, the pore specific surface, and the clay fraction of the body,
iii) a doubtful correlation of δ with the pore size selection, the mineralogical composition and the sandy fraction of clays.
In effect, the water vapour permeability exhibits an almost linear increase at increasing porosity for most bricks (Fig. 3). Samples CA, MO and X, however, are clearly more permeable than that expected from their porosity values.
As far as the positive correlation between δ and the mean pore size (Fig. 4), the main exception is represented by sample S, which was fired at the higher temperature and consequently developed low porosity and relatively large pore size.
On the other hand, the water vapour permeability presents a strong negative correlation with the finer fraction of the clay body (Fig. 5). This relationship allows to explain the anomalous δ values of samples CA, MO and X, which were prepared with the coarser grained clays. The correlations between water vapour permeability and the bulk density, the pore specific surface and the pore size selection are represented in Fig. 6, 7 and 8, respectively.
Coupling the most significant variables, the highest values of δ are expected to occur when porosity is over 30% and mean pore size larger than 1 µm (Fig. 9) or when the clay

fraction of the body is below 45%, independently by bulk density, which appears to play an appreciable role just in fine-grained bodies (Fig. 10).
The development of a simple previsional model of the water vapour permeability was attempted by a stepwise multiple regression analysis. The permeability was taken as dependent variable, while the porosimetric parameters (OP, B, MPS, PSS) and the clay particle size were considered as independent variables.
The best prediction of δ values was possible on the basis of open porosity, bulk density, mean pore size, pore specific surface, and clay fraction data (Table IV). This regression procedure gave a high multiple correlation coefficient (R=0.95) with a low probability level (p=0.006) and residual scores in the $\pm 1.5 \cdot 10^{-12}$ $kg \cdot m^{-1} s^{-1} Pa^{-1}$ range (Fig. 11). There is a predominant statistical weight (larger β factors) of open porosity and bulk density in the prediction of the water vapour permeability, with minor contribution by MPS, PSS and clay particle size.
This statement basically confirms the conclusions of the previous studies on the equilibrium moisture content of clay bricks [2, 3] with moreover the interesting role of the fine fraction of the clay body, which seems to affect significantly the microstructure of the fired brick.

Conclusions

The water vapour permeability was experimentally determined on clay bricks manufactured with a wide range of raw material compositions.
The values obtained are in the $3 \div 13 \cdot 10^{-12}$ $kg \cdot m^{-1} s^{-1} Pa^{-1}$ range and depend to a large extent on the microstructure of the ceramic material, particularly volume, size and tortuosity of pores.
A tentative predictional model was set up with an empirical approach. It is able to predict with reasonable precision and reliability the water vapour permeability on the basis of the values of open porosity, bulk density, mean pore size, and pore specific surface of bricks, and the amount of fine particles in the clay body.

Acknowledgements

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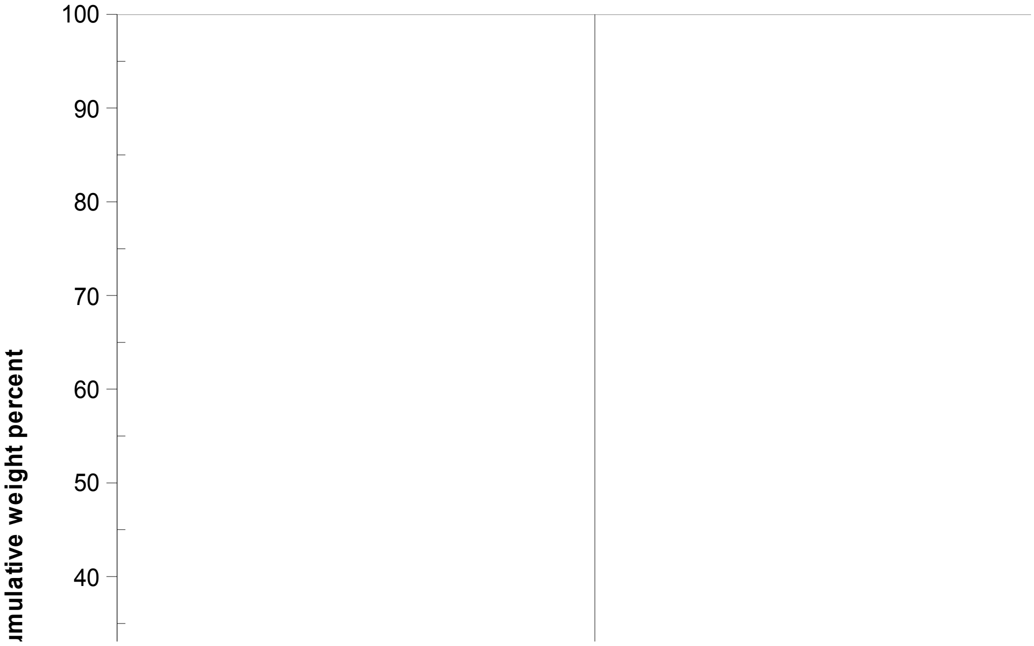


Fig. 1. Particle size distribution of clays.

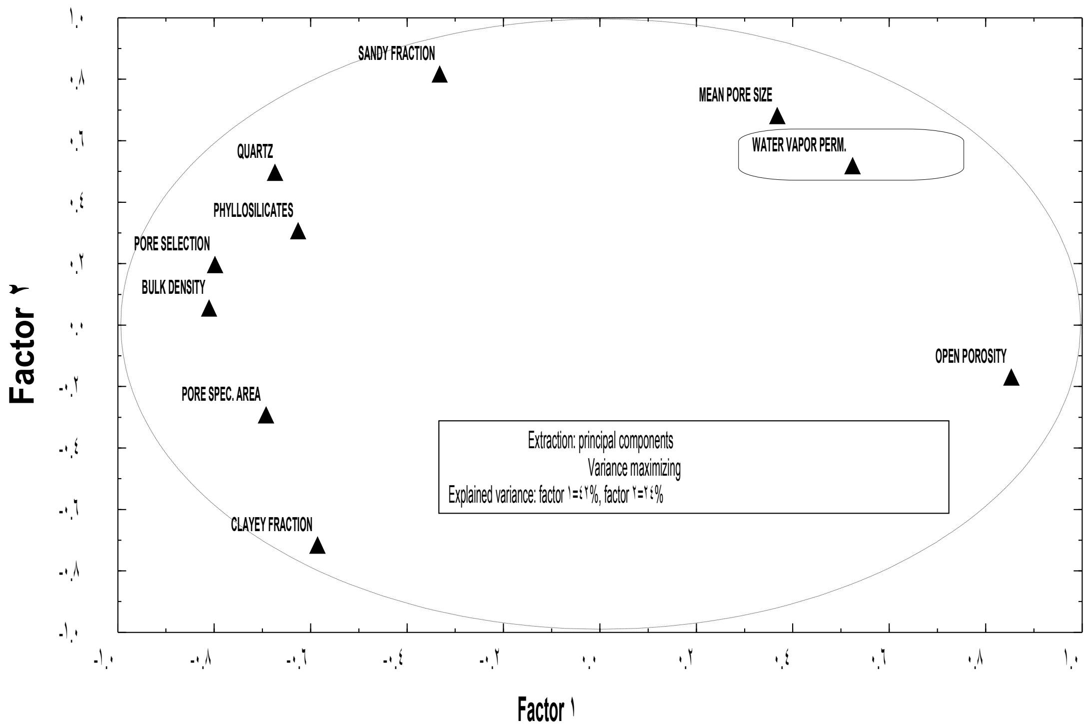


Fig. 2. Analysis of the main components performed considering: water vapour permeability, microstructural variables of bricks, mineralogy and particle size of clay bodies.

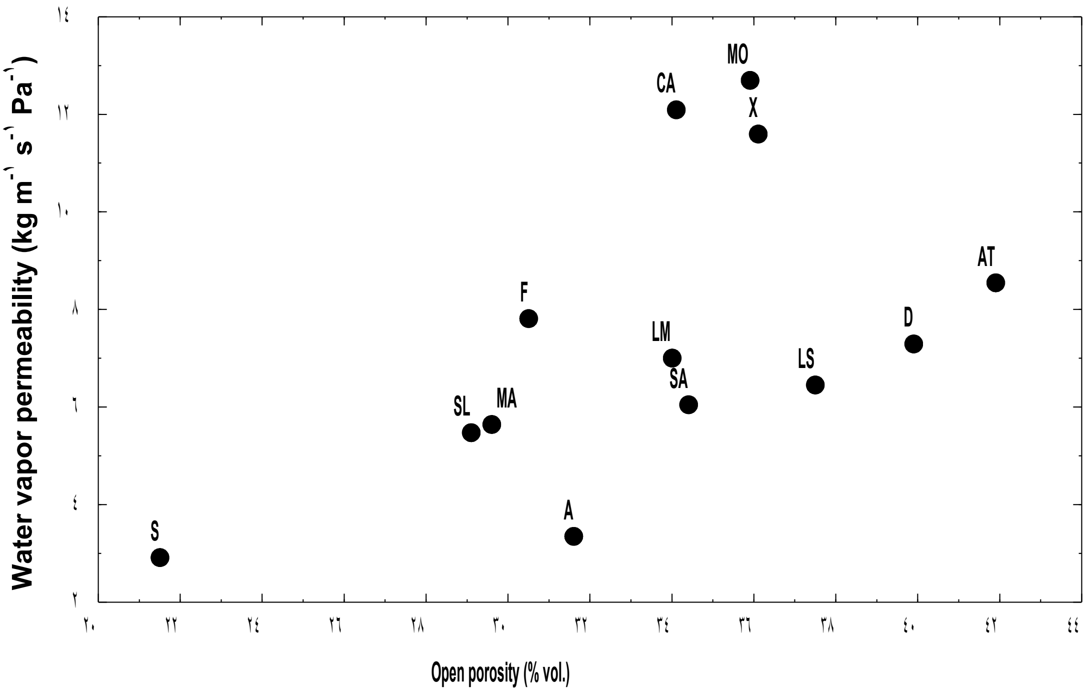
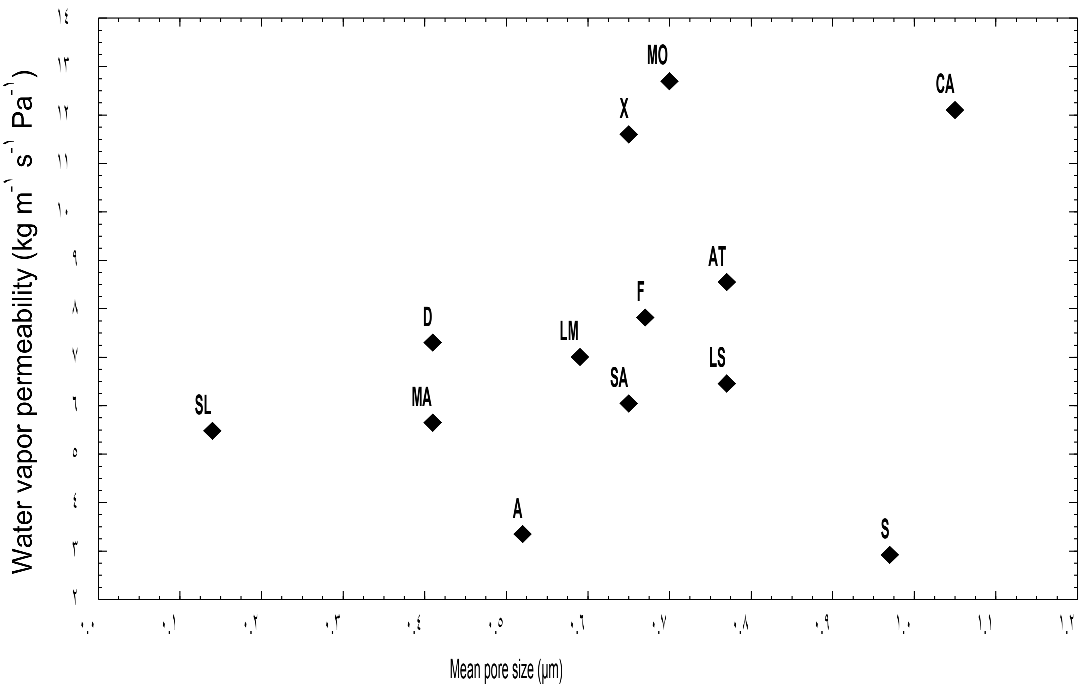


Fig. 3.

Correlation between the water vapour permeability and the open porosity of bricks.

Fig. 4.



Correlation between the water vapour permeability and the mean pore size of bricks.

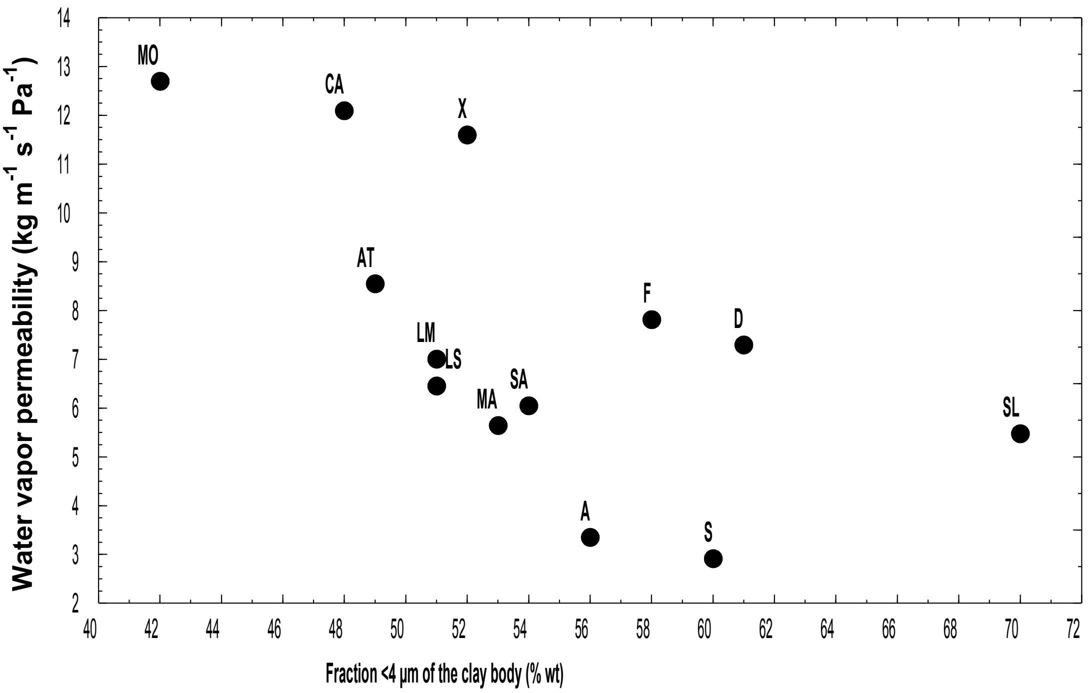


Fig. 5. Correlation between the water vapour permeability and the clay fraction of bodies.

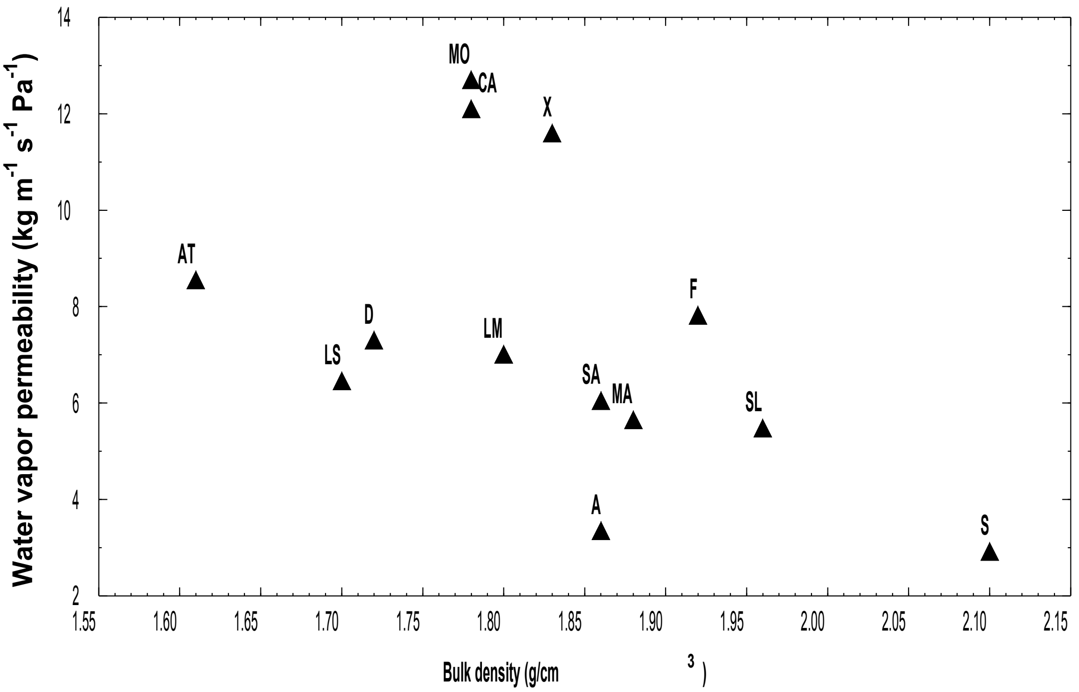


Fig. 6. Correlation between the water vapour permeability and the bulk density of bricks.

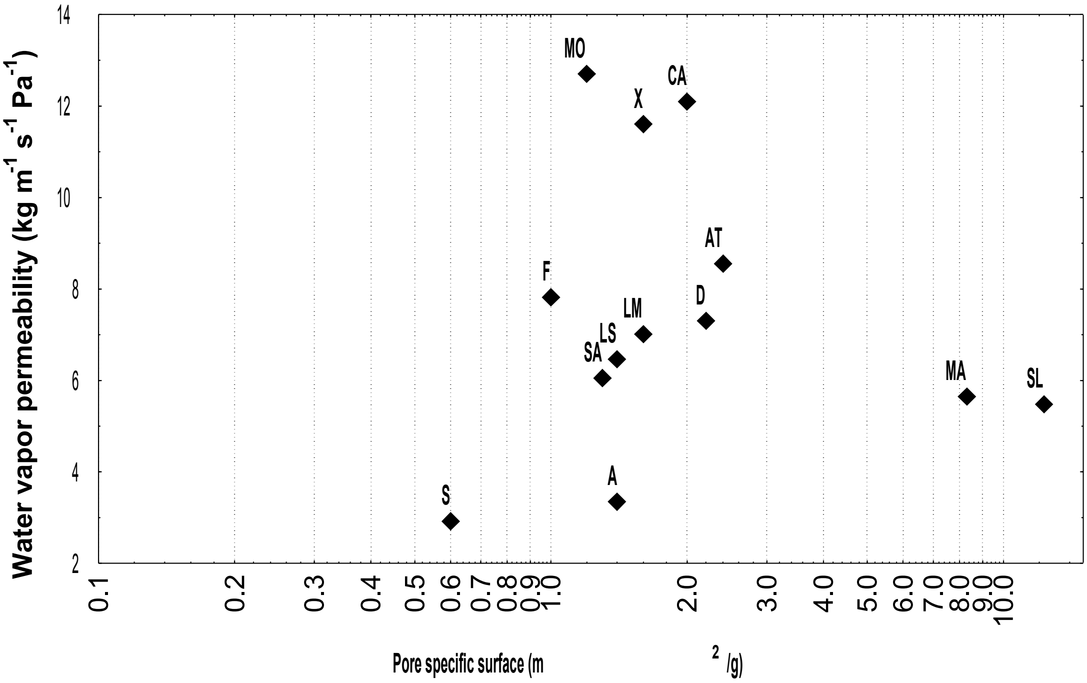
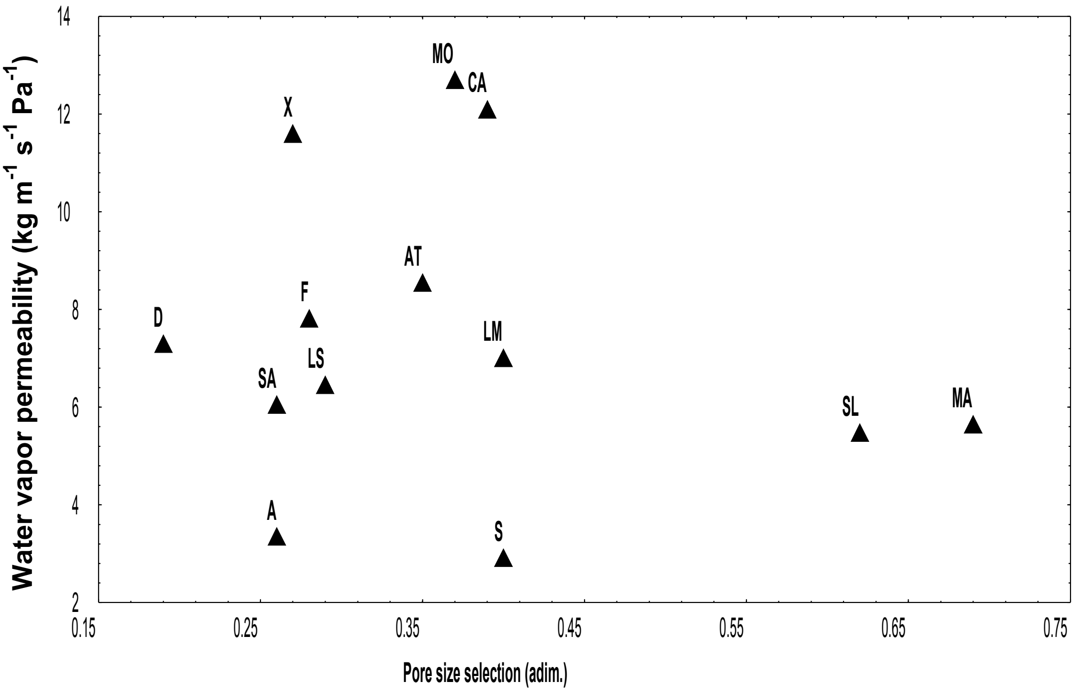


Fig. 7. Correlation between the water vapour permeability and the specific pore surface of bricks.

Fig. 8.



Correlation between the water vapour permeability and the pore size selection of bricks.

Figure 8

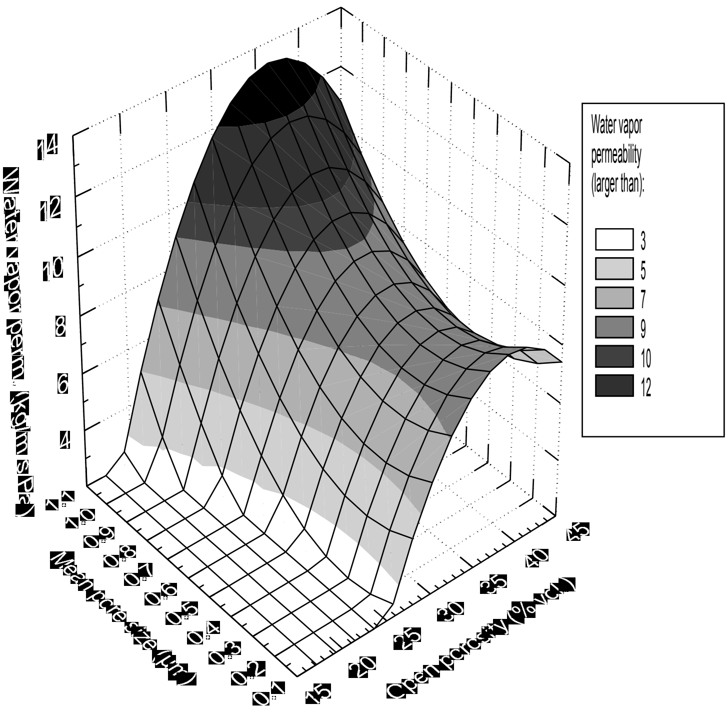


Fig 9. Surface plot of water vapour permeability, open porosity and mean pore size of bricks.

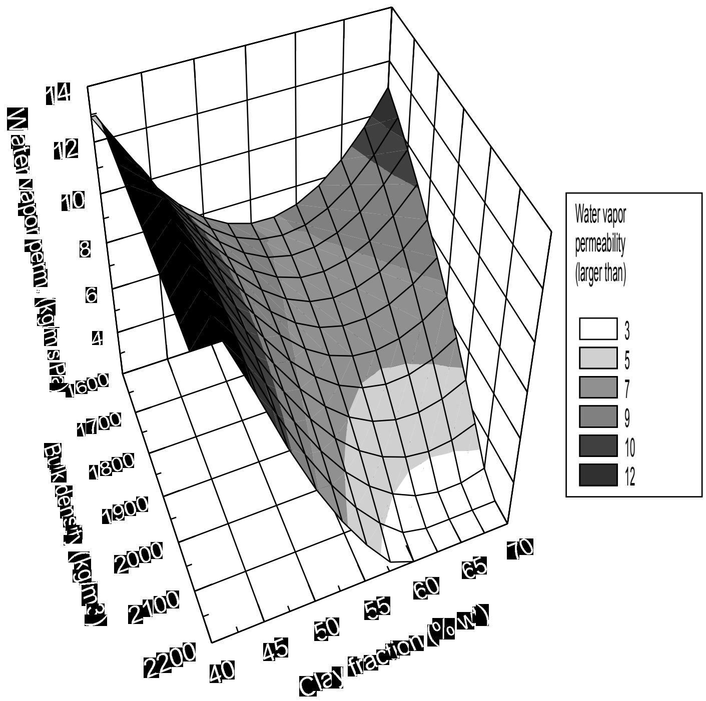


Fig. 10. Surface plot of water vapour permeability, bulk density and clay fraction of bricks.

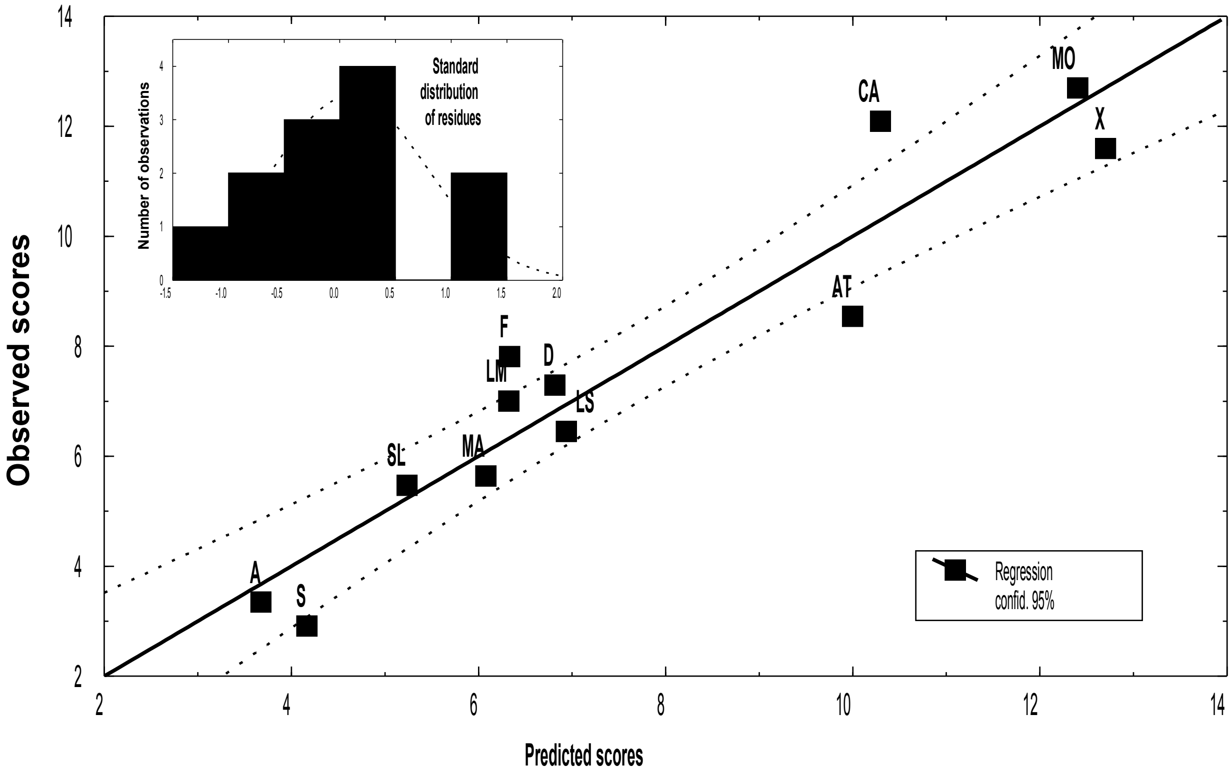


Fig. 11. Predicted versus observed values of water vapour permeability, with standard distribution residues, achieved with the multiple regression analysis.

Table I
Chemical and mineralogical composition of clays

% wt	A	AT	CA	D	F	LM	LS	MA	MO	S	SA	SL
SiO_2	50.24	50.12	54.55	41.95	55.84	53.05	45.47	64.63	52.58	63.14	49.03	58.88
TiO_2	0.64	0.70	0.89	0.59	0.66	0.74	0.64	0.66	0.74	0.71	0.58	1.02
Al_2O_3	12.56	14.78	17.01	10.54	14.27	14.06	11.38	16.10	13.09	16.32	11.62	21.24
Fe_2O_3	4.71	5.56	6.39	4.00	5.77	5.14	4.23	5.25	5.51	6.02	4.30	7.46
MnO	0.10	0.10	0.16	0.08	0.15	0.09	0.08	0.11	0.13	0.15	0.11	0.15
MgO	2.73	3.86	2.87	3.06	3.73	2.42	2.59	1.26	2.28	3.28	2.44	0.75
CaO	11.62	7.45	3.83	17.95	5.70	8.74	16.13	1.60	9.28	0.54	13.36	0.19
Na_2O	1.20	1.18	0.84	0.95	1.12	1.07	1.04	0.70	0.87	1.08	1.12	0.54
K_2O	2.26	2.86	3.44	2.10	2.35	2.47	2.28	2.25	2.33	2.62	2.07	3.57
P_2O_5	0.16	0.15	0.19	0.17	0.17	0.17	0.20	0.06	0.12	0.13	0.16	0.07
L.o.I.	13.53	13.24	9.84	18.58	9.90	11.77	16.46	7.37	12.30	6.05	15.13	6.06
Organic matter	0.9	2.6	0.5	1.2	1.2	0.7	1.7	1.9	1.9	1.7	0.9	<0.1
Illite	22	28	33	20	12	25	22	16	22	27	21	19
Kaolinite	4	tr.	4	2	11	4	3	18	3	6	3	31
Chlorite	4	6	3	4	14	9	4	6	8	12	5	-
Smectite	tr.	10	tr.	tr.	2	tr.	tr.	tr.	8	tr.	tr.	-
Quartz	29	24	30	24	29	29	26	39	29	36	29	27
Feldspars	10	8	10	8	17	9	9	11	6	12	10	14
Calcite	17	8	tr.	27	10	16	25	3	17	-	21	-

Dolomite	8	10	10	9	tr.	tr.	7	tr.	tr.	-	5	-
Fe oxides	4	5	6	3	4	4	4	4	4	4	3	7
Accessories	2	1	4	3	1	4	-	3	3	3	3	2

tr. = traces. - = absent.

Table II
Working conditions of the clays sampled

Clay	Drying shrinkage (cm m^{-1})	Pressure of extrusion (bar)	Firing temperature (°C)
A	6.0	16	910
AT	3.5	18	910
CA	4.5	18	910
D	>7.5	21	910
F	4.5	n.d.	960
LM	6.0	19	910
LS	5.5	20	910
MA	6.5	n.d.	910
MO	4.5	13	960
S	6.5	17	960
SA	6.0	18	910
SL	6.5	21	910
X	6.0	20	910

n.d. = *not determined*

Table III
Water vapor permeability and porosimetric characteristics of clay bricks

Brick	Water vapor permeability $kg \cdot m^{-1} s^{-1} Pa^{-1}$	Open porosity % vol.	Closed porosity % vol.	Total porosity % vol.	Bulk density $kg\ m^{-3}$	Mean pore diameter µm	Pore size selection adim.	Spec surfa m^2 g
A	$3.35 \cdot 10^{-12}$	31.6	6.6	31.8	1860	0.52	0.26	
AT	$8.55 \cdot 10^{-12}$	41.9	3.6	42.6	1610	0.77	0.35	
CA	$12.1 \cdot 10^{-12}$	34.1	1.6	34.9	1780	1.05	0.39	
D	$7.30 \cdot 10^{-12}$	39.9	7.8	40.5	1720	0.41	0.19	
F	$7.82 \cdot 10^{-12}$	30.5	2.8	27.3	1920	0.67	0.28	
LM	$7.01 \cdot 10^{-12}$	34.0	5.0	32.9	1800	0.59	0.40	
LS	$6.46 \cdot 10^{-12}$	37.5	5.9	39.4	1700	0.77	0.29	
MA	$5.65 \cdot 10^{-12}$	29.6	0.0	30.5	1880	0.41	0.69	
MO	$12.70 \cdot 10^{-12}$	35.9	0.2	36.5	1780	0.70	0.37	
S	$2.92 \cdot 10^{-12}$	34.4	0.0	18.8	1860	0.97	0.40	
SA	$6.05 \cdot 10^{-12}$	29.1	7.3	34.5	1960	0.65	0.26	
SL	$5.48 \cdot 10^{-12}$	21.5	0.0	28.9	2100	0.14	0.62	[illegible]
X	$11.60 \cdot 10^{-12}$	36.1	1.9	36.7	1830	0.65	0.27	

Table IV
Results of the stepwise multiple regression analysis. For each selected independent variable are listed: standardized (β) and non standardized coefficients (B) with corresponding standard errors and probability level (p).

Multiple correlation coefficients	R = 0.950	R^2 = 0.903	
Probability level	0.006		
Number of samples	n = 12		
Independent variables	β	***B***	
Intercept	-	-165.14 ± 32.22	< 0
Open porosity	3.03 ± 0.59	1.77 ± 0.35	< 0
Bulk density	2.83 ± 0.62	70.10 ± 15.32	< 0
Mean pore size	0.70 ± 0.24	7.95 ± 2.74	0
Pore Specific Surface	0.85 ± 0.24	0.77 ± 0.22	0
Clay fraction (<4 μm)	-0.92 ± 0.20	-0.41 ± 0.09	< 0