JSACE 4/9

Air Permeability Tests of Masonry Structures

Received 2014/09/03

Accepted after revision 2014/11/10

Air Permeability Tests of Masonry Structures

Jolanta Šadauskienė, Karolis Banionis*, Valdas Paukštys

Institute of Architekture and Construction of Kaunas University of Technology
Tunelio st. 60, LT - 44405 Kaunas, Lithuania
Kaunas University of Technology, Faculty of Civil Engineering and Architecture
Studentu st. 48, LT-51367 Kaunas, Lithuania

*Corresponding author: **karolis.banionis@ktu.lt**

http://dx.doi.org/10.5755/j01.sace.9.4.7913

To date, the assurance of sufficient building's air tightness remains a problematic issue, because it is linked not only to the right technology solution selection and quality work, but also to the building envelope air permeability properties. Typically, when modelling building energy demand, it is considered that the building envelope is impermeable to air. Nevertheless, this claim is unjustified. Studies have shown that building materials are porous. However, there is no evidence how air permeability changes through the masonry construction, when it is heterogeneous. Therefore, this work is to determine the air permeability of the various types of masonry construction, also assessing the technological masonry aspects, determine the air permeability rate and evaluate the results obtained in the analysis by providing recommendations.

Keywords: Infiltration, Blower Door, Ventilation, Air Leakage, Energy.

Introduction

EU sustainable development approach focuses on efficient consumption of natural and energy resources. The latter is directly related to the construction and building maintenance sector. The increase potential of energy efficiency depends on the use of high-quality structural and insulating materials, which not only reduces heat loss, but also to ensure adequate sealing of the building (Pan, 2010), (Kalamees et al. 2010) (Sfakianakis et al. 2008), (Becker , 2010) (Kovanen et al. 2009) (Matrosov et al. 2007) (Feist et al. 2005) (Smeds and Wall, 2007) (Ambrosio et al. 2012).

To date, the assurance of sufficient building's air tightness remains a problematic issue, because it is linked not only to the right technology solution selection and quality work, but also to the building envelope air permeability properties. When evaluating the physical properties of building envelopes much attention is paid to the heat and humidity carry and the air transport has been completely ignored (Hens, 2007; Tariku et. Al. 2010). Typically, when modelling building energy demand, it is considered that the building envelope is impermeable to air. However, this claim is unfounded because the data shows that the building envelope can be permeable to air (Haupa et al. 1997, Santos and Mendes, 2009 Salahov et. Al., 2011 Sedmale et.al. 2009) and this can affect the partition temperature distribution and the total energy demand of the building. Studies have shown that building materials are porous, but this depends on the pore size and volume (Benazzouk et. Al. 2004, Hong et al. Al. 2012). Various materials such as separate masonry bricks, blocks or cubes were studied for air permeability (Bentz et al., 2000; Quenard et al. 1998 Kumaoka, 2000, Ohji and Fukushima, 2012 Studart et. Al. 2006), but a complex masonry design air permeability was not

Journal of Sustainable Architecture and Civil Engineering
Vol. 4 / No. 9 / 2014
pp. 74-82
DOI 10.5755/j01.sace.9.4.7913
© Kaunas University of Technology

sufficiently examined. There is no evidence how air permeability changes through heterogeneous masonry construction. Masonry and masonry joints material macrostructure can be different.

Furthermore, when examining the air permeability of the masonry structure it is important to assess the masonry joints installation technology (EN-998-2: A 2003 ST 121895674.06:2009). Modern masonry technologies can be only applied when installing horizontal masonry joints. Vertical non-installation of masonry joints can significantly increase air circulation and thus the total building heat loss.

Therefore, this work is to determine the air permeability of the various types of masonry construction, also assessing the technological masonry aspects, determine the leakage rate and evaluate the results obtained in the analysis by providing recommendations.

Methods

For the research, a variety of material fragments of masonry structures was selected, and then formed as specimens. There were 10 specimens for each type of construction. Masonry construction fragment was inserted into the different size wooden frame. The interface between the timber frame and masonry was sealed with a silicone core. Taking into account the recommendations of masonry constructions (ST 121895674.06:2009), vertical masonry joints were not installed to masonry structures of calcium silicate, expanded clay (ρ = 650 kg/m^3) and ceramic tiles. The technical characteristics of the test specimens can be found in Table 1.

Air permeability measurements of building partitions specimens were determined by the air bandwidth device „KS 3025/45 ASD SPS Touch“ **(Fig. 1)**.

During the measurement, the measuring chamber was supplied with air, causing the pressure difference between the camera's internal and external sides, which were separated by specimen. The experiment was designed to determine the amount of air leakage of the specimen, while changing the pressure from 10 to 100 Pa according to standard EN 13829 "Determination of air permeability of buildings". Air leakage rate per specimen area at the tests reference pressure difference was 50 Pa.

In order to determine the air permeability of 1 m^2 construction area, specimen air permeability VA was calculated using the following formula (1):

$$V_A = \frac{V_O}{S}; \tag{1}$$

where:

V_0 – air speed through the specimen in m^3/h;

S – area of the specimen, m^2.

Table 1

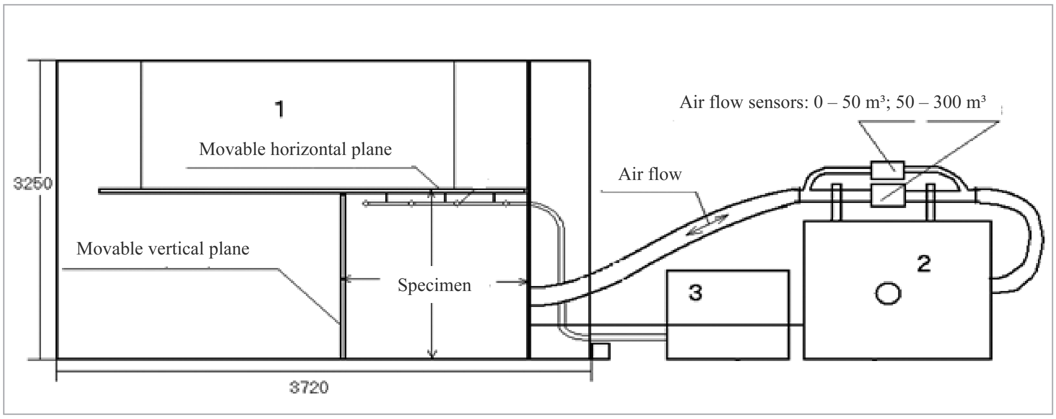
Technical characteristics of masonry structures specimens

Specimens No.	1	2	3	4	5	6	7	8
Material	Expanded clay	Expanded clay	Expanded clay	Silicate -concrete	Aerated concrete	Ceramic	Silicate -concrete	Ceramic
Density, kg/m^3	650	883	650	1210 ÷ 1400	575	850	1210 ÷ 1400	850
Area of specimen	0,604	0,576	0,604	0,410	0,668	0,752	0,410	0,752
Type of masonry joins	H	HV	HV	H	HV	H	HV	HV
Width of join, mm	~ 10	~ 10÷15	~ 10	~ 3	~ 3	~ 10÷15	~ 3	~ 10÷15

H- horizontal masonry joins; V - vertical masonry joins

Fig. 1

The scheme of air permeability determination device



One-factor ANOVA has been used in order to determine impact of the joints installation technologies on air permeability of masonry structures. Dependent variable is a masonry design air permeability V_A, which depends on the masonry joints installation factors: the installation of only the horizontal joint H and installing horizontal and vertical joints HV (Formula 2).

$$V_A = f(H, HV) \tag{2}$$

Thus, measurements were obtained for air permeability of masonry structures made from calcium silicate, expanded clay (ρ = 650 kg/m^3) and ceramic tiles with and without installed vertical masonry joints. For the purposes of one-factor ANOVA, the specimen means of the results obtained were compared with each other. All samples values had n = 10. Structured i-th specimen of the j-th observation $V_{A,ij}$ statistical model is quoted as follows (Formula 3)

$$V_{A,ij} = \bar{V}_{Ai} + e_{ij} = \bar{V}_A + \Delta\bar{V}_{Ai} + e_{ij}\ ; \tag{3}$$

where:

$V_{A,ij}$ – i-th masonry construction air permeability average;

e_{ij} – random error;

$\bar{V}_A$ – the total air permeability average of all tested type masonry constructions (total average);

$\Delta\bar{V}_{Ai}$ – the difference of i-th masonry construction air permeability average and total average.

In order to determine joint layout and filling influence on air permeability of the masonry structure, the following hypotheses were tested (Formula 4):

$$\begin{cases} H_0: \bar{V}_{A,1} = \bar{V}_{A,2} = \cdots = \bar{V}_k; \\ H_1 = \bar{V}_{A,i} \neq \bar{V}_{A,j} \end{cases} \tag{4}$$

The null hypothesis H_0 states that the vertical joints of masonry installation do not affect the air permeability of the masonry structure. H_1 hypothesis states that at least two specimen averages are different. The following formula is used to verify both assumptions (formula 5):

$$F = \frac{\sum_{i=1}^{k} n_i \left(V_{A,i} - \bar{V}_A\right)^2}{k-1} \cdot \frac{N-k}{\sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(V_{A,ij} - \bar{V}_{A,i}\right)^2} \tag{5}$$

where:

F – test statistic; N – statistical array.

The level of significance was $\alpha = 0.05$. This size is chosen so that the first type of error equal to α. The probability that the criterion of F statistics is not less than the observed realization t, expressed in p - value of $p = P\ (T \geq t)$, where H_0 is correct

The hypothesis H_0 is rejected if the p-value < α(H_1 is favoured, not all means are equal). Otherwise, H_0 is favoured (p-value $\geq \alpha$) .

In order to determine which of masonry structures air permeability specimen averages are significantly different, *"Bonferroni* correction post hoc" test was used, based on the so-called Q Stjudent distance statistic were applied. Averages $\bar{V}_{A,i}$ and $\bar{V}_{A,j}$ are statistically significantly different, according to 6, 7, 8 formulas:

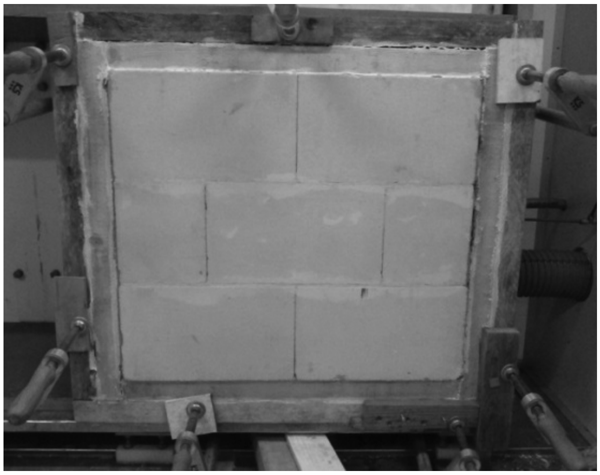


Fig. 2

The view of masonry structure specimen

$$\left|\bar{V}_{A,i} - \bar{V}_{A,j}\right| > TSD; \quad (6)$$

$$TSD = \sqrt{\frac{MSW}{n}} Q_\alpha(nk - k, k); \quad (7)$$

$$MSW = \frac{\sum_{i=1}^{k}\sum_{j=1}^{n_i}\left(V_{A,ij} - \bar{V}_i\right)^2}{N - k} \quad (8)$$

where:

TSD – "*Bonferroni* correction post hoc" test;

MSW – unbiased (inner) estimator of dispersion;

Q_a – the critical value of Q statistic's α level;

n - the size of the sample.

Results

In order to determine the amount of air flow through the fragments of masonry construction, air permeability test was carried out. Average air flow values are given in Table 2.

From the results shown in Table 2, it can be observed that the greatest air flow occurred in specimens made from expanded clay blocks (No. 1 and No. 3), at 50 Pa pressure difference an average air flow was 44.5 m^3/h and 56.9 m^3/h respectively. The density of the specimens was the same ρ = 650 kg/m^3, but the installation of masonry joints was different: specimen no. 1 had horizontal masonry joints installed, specimens no. 3 had both horizontal and vertical masonry joints installed. Masonry installation technology has resulted in different air flow performance. If vertical masonry joints are not installed, air flow through the wall structure increases.

Table 1

Average results of air flow through specimens

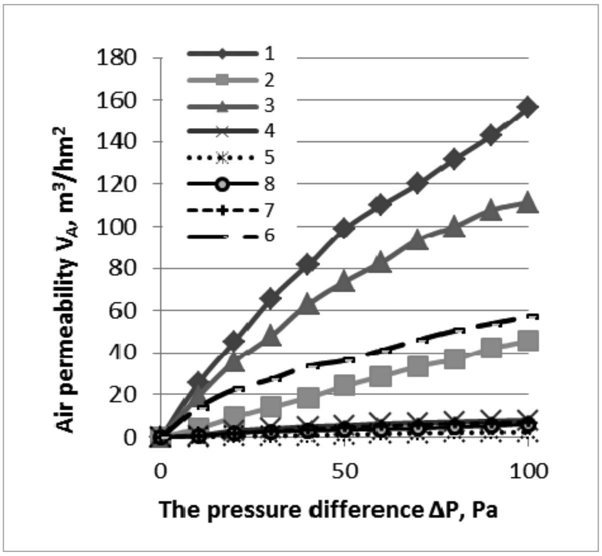
ΔP, Pa	Specimen No.							
	1	2	3	4	5	6	7	8
	Air flow V_{0t}, m^3/h							
10	14,7	2,4	11,7	0,4	0,1	10,5	0,4	0,5
20	26,1	5,5	21,6	1,3	0,3	17,0	1,2	1,5
30	37,9	8,1	29,0	1,7	0,5	20,6	1,7	2,0
40	47,0	10,7	38,1	2,1	0,6	25,2	2,1	2,3
50	56,9	13,9	44,5	2,3	0,8	27,3	2,3	2,6
60	62,6	16,5	50,0	2,6	1,0	31,0	2,6	2,9
70	67,8	19,3	56,5	2,8	1,3	34,7	2,8	3,1
80	76,0	21,2	58,9	3,0	1,4	38,1	3,0	3,7
90	82,3	24,3	65,1	3,1	1,5	40,5	3,1	4,0
101	90,1	26,3	67,3	3,7	1,6	43,1	3,7	4,7

Minimum air flow through the masonry construction is observed in those specimen made from aerated concrete blocks (No. 5), with an average air flow of 0.8 m³/h at 50 Pa pressure difference. These brick structures were sealed with mortar joints both vertically and horizontally.

Also measurements showed that the average air flow rate at 50 Pa pressure difference through the wall structure of calcium silicate blocks (specimen No. 4) is 2.3 m³/h, and the ceramic tiles stone (specimen No. 6) – 27.3 m³/h. These brick structures were equipped with only horizontal masonry joints.

Fig. 3

Air permeability measurement results of masonry structures specimens by changing pressure difference

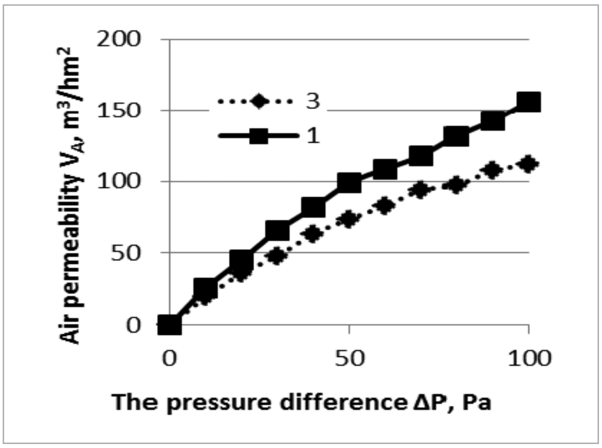


All measured masonry structures specimens' air permeability, changing the pressure difference, is shown in Figure 3.

The results in Figure 3 shows that least airtight specimens at a 50 Pa pressure difference were masonry structure of expanded clay blocks (no. 1, no. 2 and no. 3) with an air permeability of 98.7 m³/h·m², 24.1 m³/h ·m² and 73.6 m³/h· m². The most airtight specimens were of aerated concrete blocks (No.5, V_A = 1,2 m³/h·m²), silicate masonry blocks (No.7, V_A = 5,5 m³/h·m² and No.4, V_A = 4,6 m³/h·m²) and ceramic blocks (No.8, V_A = 3,5 m³/h·m²).

Fig. 4

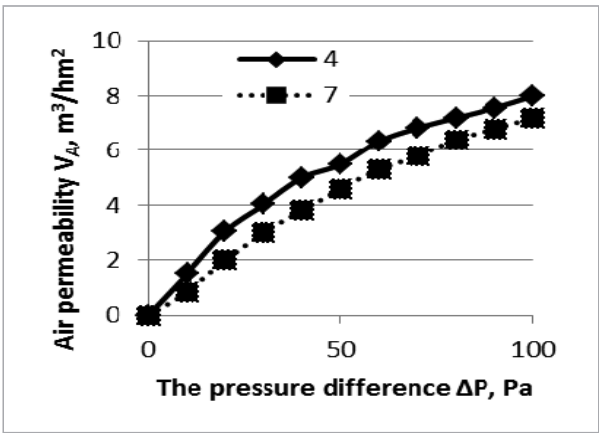
Air permeability measurement results of expanded clay masonry structure blocks (No. 1 and 3) by changing pressure difference and masonry joins technology



The analysis of masonry installation technologies on the specimen air permeability suggested that the air flow depends on the arrangement of the masonry joints and filling. Changing the pressure difference and changing the masonry joints technology, air permeability results through masonry specimens are presented in the figures 4, 5 and 6.

Fig. 5

Air permeability measurement results of silicate concrete masonry structure blocks (No. 4 and 7) by changing installation technology



Masonry specimens of expanded clay blocks had the same density ρ = 650 kg/m³, but the installation of masonry joints was different: specimen no. 1 had vertical masonry joints installed, specimen no. 3 had both horizontal and vertical masonry joints were installed. Masonry installation technology has led to different results. When vertical masonry joints are not installed, air tightness through the wall structure reduces. Specimen no. 1 air permeability at 50 Pa pressure difference was V_A = 98,7 m³/h·m², and specimen Nr. 3 - V_A = 73,6 m³/h·m². The estimated F-statistic p-value = 0.06 is greater than significance level of 0.05, so we reject the hypothesis of air permeability values mean equality. Parameter V_A averages are significantly different. In the masonry construction of expanded clay blocks, the installation of vertical joints affects the air permeability of construction.

Specimens of silicate masonry blocks joints installation differed: specimen no. 4 had vertical masonry joints installed; specimen no. 7 had both horizontal and vertical masonry joints installed.

Specimen no. 4 air permeability at 50 Pa pressure difference was 5.5 $m^3/h \cdot m^2$, and the specimen no. 7 - 4.6 $m^3/h \cdot m^2$. The estimated F-statistic p-value = 0.058 is greater than the significance level of 0.05, so we accept the hypothesis of the air permeability values mean equality. Parameter V_A mean differences were not significant. Masonry structure of calcium silicate blocks vertical joints installation does not affect the air permeability of the construction.

Masonry structure specimens of ceramic blocks had different installation joins: specimen No.6 had vertical installation joins and specimen No.8 had horizontal and vertical installation joins. At 50 Pa pressure difference air permeability of specimen No.6 was 36.2 $m^3/h \cdot m^2$ and No.8 - 3.5 $m^3/h \cdot m^2$.

The estimated F-statistic p-value = 0.00 is less than the significance level of 0.05, so the hypothesis of air permeability values mean equality reject. Parameter V_A averages are significantly different. In the masonry construction of ceramic tiles vertical joints installation affect the overall air permeability of construction.

"Bonferroni application of a post hoc" test (6, 7, 8 formulas) suggests that masonry structure of ceramic tiles V_A average is statistically significantly different from the other masonry structures air permeability values studied in this work. The estimated F-statistic p-value = 0.00 is less than the significance level of 0.05. The statistical assessment of air permeability dependency of masonry structures type is graphically displayed on the graph (Fig. 7).

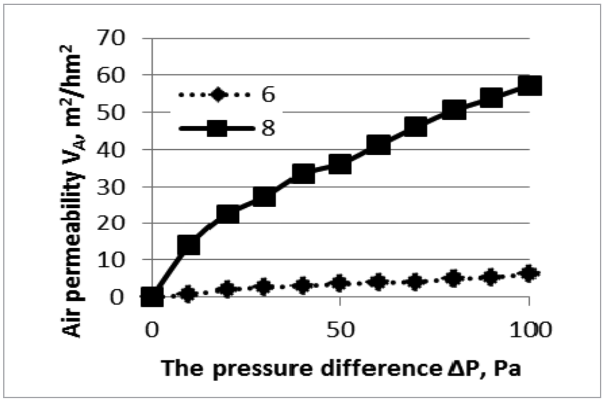


Fig. 6

Air permeability measurement results of ceramic masonry structure blocks (No. 6 and 8) by changing installation technology

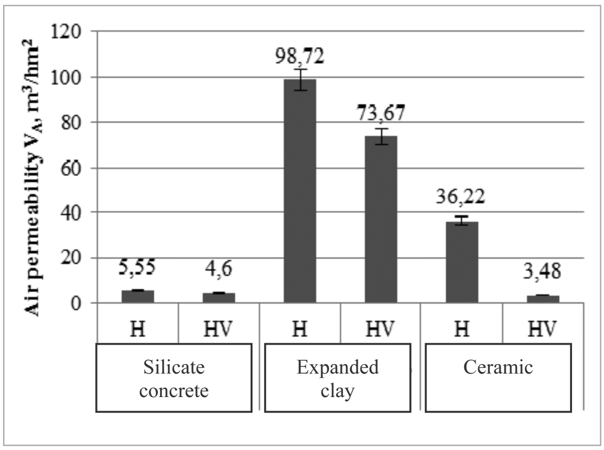


Fig. 7

The statistical assessment of air permeability dependency of masonry structures type at reference pressure difference 50 Pa

Discussion

The study of air permeability through various types of masonry construction suggests that the air tightness of the construction affects the material macrostructure. Macrostructure nature is characterized by small and large pore ratio, pore degree of openness and the capillary number connecting them.

Macrostructure is one of the key determinants that stipulates the cellular concrete properties. Porous concrete macrostructure is formed in its production (formation) process and fixated binder hydration. It is a fine-grained structure, although the predominant pore diameter of about 3 mm, but it is closed-cell system. Therefore, the porous concrete structure is tight enough for air flow at

V_A = 1.2 m^3 / h·m^2 at ΔP = 50 Pa.

In this paper studied ceramic tiles and calcium silicate blocks macrostructure is a fine-grained, with a porosity of 20% and 30% (Kumaoka, 2000). Evaluating from the air permeability aspect, the results show that the structure of the ceramic brick and calcium silicate blocks are sufficiently tight.

In summary, the above described masonry structures are sufficiently airtight, but the analysis of the resulting air permeability through masonry structures studied results show that there is air flow. This small air movement can be explained by the fact that the masonry structure is heterogeneous and the resulting micro-cracks within the concrete blocks and masonry joints installed, at a differential pressure, air movement conditions occur.

The analysis of air permeability through the masonry construction of expanded clay block values shows that in this case the air permeability value is the most different from the other air permeability values of masonry structures tested in this work . This was a result of coarse material structure of expanded clay blocks, which is characterized by open porosity and capillary system. This conclusion is further strengthened by the air permeability results obtained from different density expanded clay blocks: masonry construction of low density (ρ = 650 kg/m^3) expanded clay blocks air permeability at 50 Pa pressure difference was between V_A = 73.6 m^3/h·m^2; and masonry construction of higher density (ρ = 883 kg/m3) expanded clay blocks air permeability at 50 Pa pressure difference, V_A = 24.1 m^3/h·m^2. The same coarse-grained materials, but different densities of air permeability values varied about 3 times. This has resulted in pore diameter size, degree of openness and capillary number connecting them.

Masonry is a heterogeneous material and air permeability depends not only on the block macrostructure, but also on the masonry joints nature and technology. The analysis of the differences between the masonry structures, which have been equipped with only horizontal masonry joints, and masonry structures, which had both horizontal and vertical joints installed, showed that masonry structures, only with vertical masonry joints had air permeability resultshigher. Measurements showed that the masonry of the expanded clay blocks, installing vertical joints can reduce the air permeability about 3 times and the masonry of ceramic tiles - 10 times. Meanwhile, the masonry of silicate blocks vertical joints installation influence the design air permeability negligibly. This can be explained by the fact that during masonry, when putting blocks next to each other, small gaps are formed. The latter is a result from defects in the block and size variations, uneven rows of masonry, the block tie inaccuracy. Masonry construction rules (ST 121895674.06:2009) requires this type of exterior surface covered with plaster. However, the layer of plaster, exposed to various adverse climatic factors during the operation, loses its protective function and a masonry structure becomes permeable to air and inefficient from thermal point of view.

Conclusions

In this paper obtained masonry structures air permeability analysis of the results shows that building envelope air permeability depends on the masonry structure of the material and the installation of the masonry technology.

Building envelope air permeability measurements showed that the construction of the masonry expanded clay blocks (because of coarse macrostructure) were 70-90% more air permeable than other masonry structures investigated in this work. It is necessary to protect masonry structures from expanded clay blocks against adverse external climatic factors (wind, rain) by plastering the surfaces.

The analysis of masonry installation technologies on the specimen air permeability suggests that the air flow depends on the arrangement of the masonry joints and installation. The study found that for the masonry of the ceramic blocks, installation of horizontal and vertical joints can reduce the specimen air permeability 10 times comparing the structure only with vertical installation joins. Despite the masonry structures of ceramic tiles outer surface covered with plaster, it is recommended to install vertical and horizontal masonry joints.

Acknowledgment

Work is carried out in accordance with the Kaunas University of Technology Research interests "Buildings' Energy Performance and Heat Transfer in Buildings Research" program.

References

Ambrosio A., F., R.; Isola, D., M.; Ficco, G.; Tassini, F. 2012. Experimental analysis of air tightness in Mediterranen buildings using the fan pressurization method. *Building ant Environment,* 53, 16-25.

Becker, R. 2010. Air Leakage of Curtain Walls – Diagnostics and Remediation, *Journal of Building Physics*, 34(1), 57-75. http://dx.doi.org/10.1177/1744259109349665

Benazzouk, A.; Douzane, O.; Queneudec, M. 2004. Transport of fluids in cement-rubber composites, *Cement & Concrete Composites*, 26: 21-29. http://dx.doi.org/10.1016/S0958-9465(02)00119-1

Bentz, D., P.; Quenard, D., A.; Kunzel, H., M.; Baruchel, J.; Peyrin, F.; Martys, N. S.; Garboczi, E., J. 2000. Microstructure and transport properties of porous building materials. II: Three-dimensional X-ray tomographic studies, *Materials and Structures,* 33: 147-153. http://dx.doi.org/10.1007/BF02479408

Feist, W.; Schnieders, J.; Dorer, V.; Haas, A. 2005. Re-inventing air heating: Convenient and comfortable within the frame of the Passive House Concept, *Energy and Buildings*, 37, 1186-1203. http://dx.doi.org/10.1016/j.enbuild.2005.06.020

Haupl, P.; Grunewald, J.; Fechner, H. 1997. Coupled Heat Air and Moisture Transfer in Building Structures, *International Journal of Heat Mass Transfer*, 40: 1633-1642. http://dx.doi.org/10.1016/S0017-9310(96)00245-1

Hens, H. 2007. Heat, Air and Moisture, Fundamentals and Engineering Methods with Examples and Exercises, *Journal of Building Physics* 35: 192-209.

Hong, C.; Zhang X.; Han J.; Meng S.; Du S. 2012. Synthesis, Microstructure and Properties of High-Strength Porous Ceramics, *Ceramic Materials – Progress in Modern Ceramics*, Pro. Feng Shi (Ed.), ISBN: 978-953-51-0476-6, InTech, p.109-110.

Kalamees, T.; Kurnitski, J.; Jokisalo, J.; Eskola, L.; Jokiranta, K.; Vinba, J. 2010. Measured and simulated air pressure conditions in Finnish residential buildings, *Building Serv. Eng. Res. Technol.* 31(2), 177-190. http://dx.doi.org/10.1177/0143624410363655

Kovanen, K.A.; Laamanen, J.; Kauppinen, T.; Duanmu, L. 2009. Air tightness of New Residential Buildings in Finland, *6th International Symposium on Heating, Ventilating and Air Conditioning,* Vols I-III, Proceedings, p.p. 207-213.

Kumaoka, S., A., S. 2000 Porous ceramics provided with amorphous pore surfaces, *United States Patent No.US 6,420,292 B1*, p.16.

LST EN-998-2:2003 Specification for mortar for masonry - Part 2: Masonry mortar, Brussels. 36 p.

Matrosov, Y., A.; Chao, M.; Majersik, C. 2007. Increasing Thermal Performance and Energy Efficiency of Buildings in Russia: Problems and Solutions, *ASHRAE*. Available from Internet < http://www.cenef.ru/file/St-267e.pdf>.

Ohji, T.; Fukushima, M. 2012 Macro-porous ceramics: processing and properties, *International Materials Reviews*, 57(2): 115-131. http://dx.doi.org/10.1179/1743280411Y.0000000006

Pan, W. 2010. Relationships between air-tightness and its influencing factors of post-2006 vew-build dwellings in the UK, *Building and Environment*. 45, 2387-2399. http://dx.doi.org/10.1016/j.buildenv.2010.04.011

Quenard, D., A.; Xu, K.; Kunzel, H., M.; Bentz, D., P.; Martys, N. S. 1998. Microstructure and transport properties of porous building materials, *Materials and Structures,* 31(5): 317-324. http://dx.doi.org/10.1007/BF02480673

Salahov, A.; Tagirov, L.; Salahova, R.; Parfenov, V.; Ljadov, N. 2011. Characterization of building material pore and strength, 12: 25 -27 (in Russian).

Santos, G., H.; Mendes, N. 2009. Combined Heat, Air and Moisture (HAM) Transfer Model for Porous Building Materials, *Journal of Building Physics*, 32: 203-220. http://dx.doi.org/10.1177/1744259108098340

Sedmale, G.; Cimmers, A.; Sedmalis, U. 2009. Charasteristics of sillite clay and compositions for porous building ceramics production, *Chemine Technologija*, 2: 18-21.

Sfakianaki, A.; Pavlou, K., Santamouris, M. *et al.* 2008. Air tightness measurements of residential houses in Athens, Greece, *Building and Environment*. 43, 398-405. http://dx.doi.org/10.1016/j.buildenv.2007.01.006

Smeds, J; Wall, M. 2007. Enhanced energy conservation in houses through high performance design, *Energy and Buildings*, 39, 273-278. http://dx.doi.org/10.1016/j.enbuild.2006.07.003

ST 121895674.06:2009. Masonry works. Lithuanian Buildeers Association. Available from Internet < http://www.statybostaisykles.lt/node/322>.

Studart, A., R.; Gonzenbach, U., T.; Tervoort, E.; Gauckler, L., J. 2006. Processing Routes to Macroporous Ceramics: A Review, *Journal of the American Ceramic sočiety* 89(6): 1771-1789.

Tariku, F.; Kumaran, K.; Fazio, P. 2010. Transient model for coupled heat, air and moisture transfer through multilayered porous media. *International Journal of Heat and Mass Transfer* 53: 3035–3044. http://dx.doi.org/10.1016/j.ijheatmasstransfer.2010.03.024

About the authors

JOLANTA ŠADAUSKIENĖ

Researcher

Laboratory of Building Physics at the Institute of Architecture and Construction, KTU

Assoc. Professor

Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Department of Building Energy Systems

Main research area
The moisture state of the building constructions; physical-technical processes in building envelopes; heat loss in buildings

Address
Tunelio st. 60, LT-44405,
Kaunas, Lithuania.
Tel. +370 37 350779
E-mail: jolanta.sadauskiene@ktu.lt

KAROLIS BANIONIS

Researcher

Laboratory of Building Physics at the Institute of Architecture and Construction, KTU

Lector

Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Department of Building Energy Systems

Main research area
Energy efficiency and air permeability of buildings, heat transfer and thermal insulation, thermal impacts of solar radiation

Address
Tunelio st. 60, LT-44405,
Kaunas, Lithuania.
Tel. +370 37 350779
E-mail: karolis.banionis@ktu.lt

VALDAS PAUKŠTYS

Researcher

Laboratory of Building Physics at the Institute of Architecture and Construction, KTU

Assoc. Professor

Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Department of Building Energy Systems

Main research area
The moisture state of the building constructions; physical-technical processes and heat loss in building envelopes

Address
Studentų st. 48, LT-51367
Kaunas, Lithuania.
Tel. +370 37 300486
E-mail: valdas.paukstys@ktu.lt