NSB2008

Nordic Symposium on Building Physics 2008

Proceedings of the 8th Symposium on Building Physics in the Nordic Countries

Volume 2

Tuesday, June 17

Copenhagen, June 16-18, 2008

Carsten Rode, editor

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Technical University of Denmark

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Society for Building Physics

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Contact Address

Nordic Symposium on Building Physics 2008
Department of Civil Engineering
Brovej, Building 118
Technical University of Denmark
DK-2800 Kgs. Lyngby, Denmark

Phone: +45 45 25 17 00
Fax: +45 45 88 32 82
E-mail: byg@byg.dtu.dk
Web: www.byg.dtu.dk
www.nsb2008.org

Reference to papers

Author. Title. Proceedings of the 8th Symposium on Building Physics in the Nordic Countries (C. Rode, editor) , Report R-189, Dept. of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark, 2008

DTU Byg Report R-189
ISBN 978-87-7877-265-7

Number of copies printed: 280
Printed by the Danish Society of Engineers, IDA
Copenhagen, Denmark, June, 2008

Humidity Migration and Condensation Risk in Autoclaved Aerated Concrete Walls

Anatolijs Borodiņecs, Dr.sc.ing;
Riga Technical university, Institute of Heat, Gas and Water Technology;
anatolijs.borodinecs@rtu.lv;

Andris Krelsins, Dr.hab. sc. ing. Prof.;
Riga Technical university, Institute of Heat, Gas and Water Technology;
kreslins@bf.rtu.lv;

Martins Vilnitis, M.sc.ing;
Riga Technical university, The Institute of Building Production;
martins.vilnitis@inbox.lv;

Juris Noviks, Dr.hab. sc. ing. Prof.;
Riga Technical university, The Institute of Building Production.

KEYWORDS: humidity migration, autoclaved aerated concrete

SUMMARY:
The paper is devoted to the analysis of problems of humidity migration in autoclaved aerated concrete walls. It presents the methods for monitoring of humidity migration processes. Especial attention is paid to the analysis of condensation risk on the surface between the autoclaved aerated concrete block and outdoor finishing. The paper gives theoretical calculation of condensation risk in autoclaved aerated concrete wall as well as presents the results of practical measurements. For the purpose of practical measurements, two experimental walls, on the northern and southern part of the building, were built in Tallinn imitating real living space. The analyzed walls had been constructed using autoclaved aerated concrete blocks 375 mm in thickness, volume weight ≤ 400 kg/m^3, glued together with a 2 mm thick layer of glue mortar. Starting from year 2005 the thermal measurements were carried out on the regular basis. The preliminary results of this experiment have shown that monitoring of humidity migration processes in autoclaved aerated concrete walls could be accurately done by cutting out test pieces and putting them on the scales. The influence of thermal qualities of autoclaved aerated concrete wall on the drying process of wall was also studied in the scope of this paper. As the result the dependences between heat conductivity coefficient and moisture content were developed.

1. Humidity evaporation process in autoclaved aerated concrete blocks

The main problem using autoclaved aerated concrete blocks in building construction is high initial moisture content of blocks. The average initial humidity of autoclaved aerated concrete blocks is up to 40% by weight. The optimal humidity of autoclaved aerated concrete blocks level is 4-6%. The evaporation process in newly constructed buildings in Latvian climatic conditions could be problematic due to the high outside air relative humidity. It is estimated that evaporation process could take up to 3 years long time period in order to reach optimal humidity level. The main parameters that could impact drying process are:

- surface finishing;
- outdoor and indoor air parameters;
- properties of additional heat insulation.

In the scope of this study 30 samples of autoclaved aerated concrete blocks were chosen in order to evaluate evaporation process. Analyzed samples were stored in non-heated warehouse. Two samples were artificially dried till optimal humidity level. The average weight of dry sample is 2.4 kg. The evaporation process in autoclaved aerated concrete samples is shown in Figure 1.

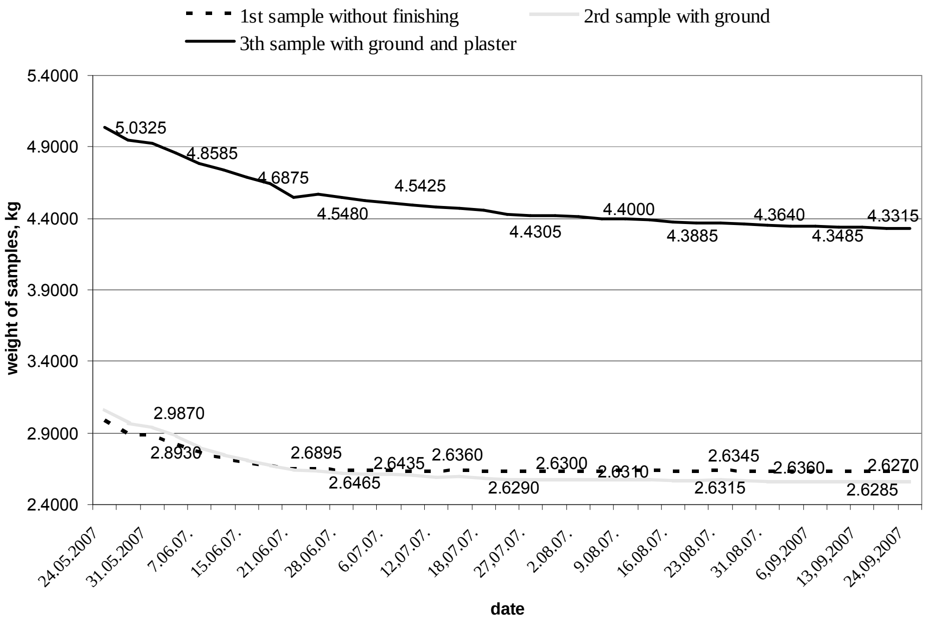

Fig.1. The3-dimensional evaporation process in autoclaved aerated concrete samples

As it could be seen from Figure 1, the most intensive evaporation process was taking place during the time period from May till July, when the average temperature was +14^{O}C. The initial weight of 1st sample was 2.987kg, of 2nd – 3.0605kg and 3rd – 5.0325kg. The average initial moisture content of analyzed samples was 29%. After three month evaporation process the humidity level of analyzed samples had reached for the 1st sample – 2.610kg (the moisture content – 8%) 2nd – 2.581kg (the moisture content – 7%) and 3rd – 4.252 kg. It could be concluded that the most intensive evaporation process in autoclaved aerated concrete samples takes place during firs two months after their production.

2. The moisture impact on thermal properties of autoclaved aerated concrete blocks

In order to find out the dependences between wall thermal conductivity coefficient and humidity level, the heat flow through two walls was measured. The analyzed walls were constructed in Tallin using the autoclaved aerated concrete blocks with depth 375mm and capacity mass ≤400 kg/m^3. The monitoring of surface temperature and outdoor and indoor air parameters was done as well. Regular measurements were done during the time period from 20.01.2005 till 14.05.2007. The measurements of humidity level in blocs were done by two different methods:

- practically measured moisture content, using special measuring equipment (special meters were placed inside the wall);
- practically measured moisture content done by cutting out small samples from the wall (EN 1353 method [2]).

The practical implementation of both methods has shown that special measuring equipment could be effectively used for the materials with humidity ration up to 10%, but for material with humidity ration higher than 10% it is recommended to use EN 1353 method.

The results of wall surface temperature measurements are shown in Figure.2. Since the temperature fluctuations of inner surface within a year are not observable, only southern and northern wall surface temperature difference is plotted.

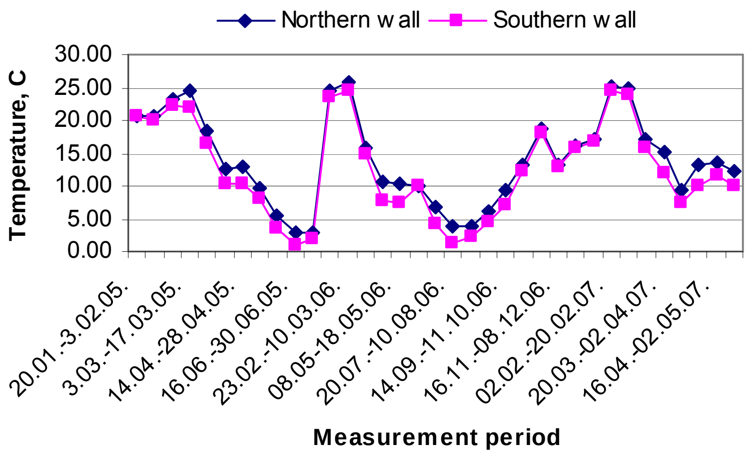

Fig.2. Temperature of external surface of wall

The value of heat transfer coefficient is determined by applying the data, acquired in the experiment, to the Equation 1.

$$U_k = \frac{Q}{t_i - t_e} \text{ W/(m}^2\text{K)} \qquad (1)$$

where:
Q – heat flow (W/m^2); τi – surface temperature of inner wall (^{0}C); τe – surface temperature of exterior wall (^{0}C).

Performed heat flow measurements are gathered and displayed in Figure 3. While analyzing the acquired experimental data, it could be calculated that heat flow through wall is directly related to the temperature of external surface of the wall. Temperature fluctuations during the experiment were insignificant, therefore we can deduce that sun activity notably affects the heat flow. As it was mentioned before, the temperature fluctuation of inner surface of the wall is not significant; therefore the wall's external surface temperature difference is largely affected by the solar radiation. It is due to the solar radiation that surface temperature of the external wall depends on and in its turn affects both the process of wall drying and total heat flow through aerocrete wall.

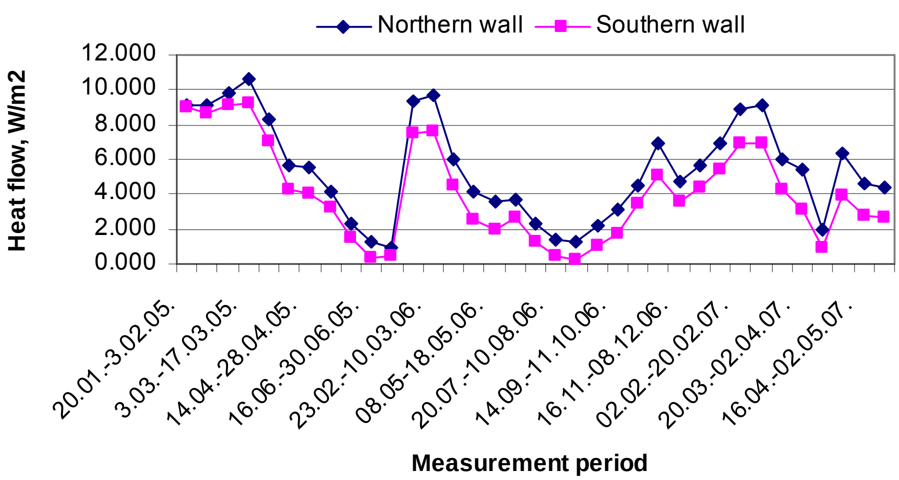

Fig.3. Heat flow through the wall

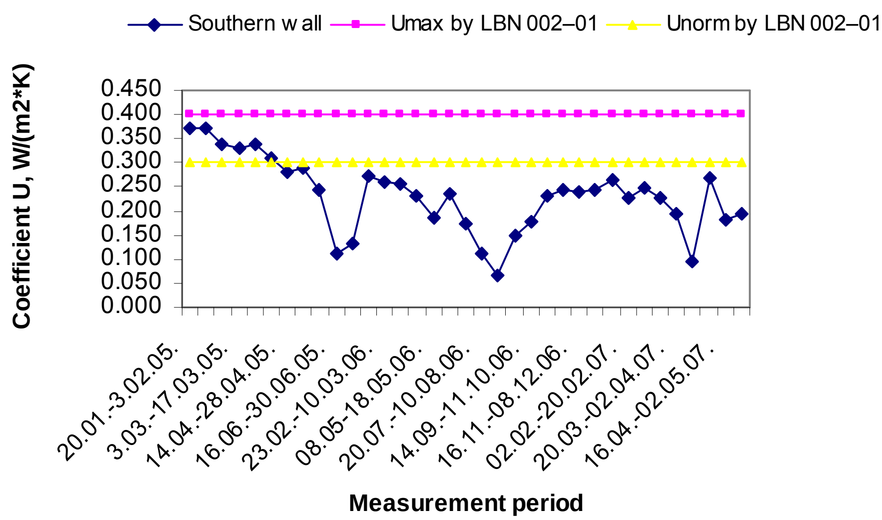

Fig.4 Apparent heat transfer coefficient of the wall

It could be seen from the Figure 4 that in the wintertime conditions the wall's, which is not yet dried and whose moisture is 24-14%, apparent heat transfer coefficient is equal to the Latvian building standard LBN 002 – 01 (1) requirements. According to Latvian building standard normative value of heat transfer coefficients for dwelling buildings is 0.25 W/(m^{2}K) and maximal value is 0.4 W/(m^{2}K). Calculation of the theoretical U value using Equation 2 has shown that heat transfer coefficient of aerated concrete wall with depth 375mm was 0.27 W/(m^{2}K).

$$U = \frac{1}{R_{si} + \frac{d}{l} + R_{Se}} \text{ W/(m}^2\text{K)} \qquad (2)$$

where: Rse – heat resistance of external surface, (m^{2}K) /W, Rse - heat resistance of internal surface,(m^{2}K) /W.

The difference between measured and calculated values can be explained with aerocrete's capacity to accumulate heat and material thermal inertia.

3. Analysis of condensation risk in autoclaved aerated concrete blocks

It is a well known fact that condensation of water vapour occurs when water vapour pressure exceeds saturated water vapour pressure. Usually the water vapour and saturated water vapour distribution is shown graphically. The saturated water vapour pressure depends only on the temperature distribution in the construction. In the wall's construction built from autoclaved aerated concrete blocks glued together without heat insulation these vapour pressure curves do not cross each other. But it should be taken into account that high condensation risk occurs on the surface between the autoclaved aerated concrete block and outdoor finishing in cases, when water vapour resistance factor of finishing is too high.

The theoretical evaluation of condensation risk was done on the example of the wall construction shown in Figure 5. In method traditionally used in Latvia water vapour pressure distribution is shown in the cross section of element drawn proportionally real element thickness d, m.

Water vapour distribution in element is found by Equation 3:

$$p_x = p_i - \frac{R_{tv}}{\sum R_{tv}} \left(p_i - p_e \right), \text{ Pa} \qquad (3)$$

where - p_i is water vapour pressure of the inside air, Pa; p_e is water vapour pressure of the outside air, Pa; R_{tv} is the sum of water vapour resistance of all previous layers, $m^2 \cdot h \cdot Pa/m$; ΣR_{tv} is total water vapour resistance of the element, $m^2 \cdot h \cdot Pa/m$.

Water vapour resistance of individual layer (4):

$$R_{tv} = \frac{d}{d}, \ m^2 \cdot h \cdot Pa/m \tag{4}$$

where - d is thickness of the layer, m; δ is vapour transfer coefficient (vapour permeability of the material), mg/m·h·Pa.

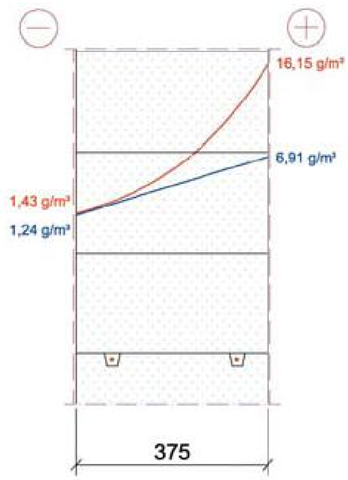

Fig.5. Cross section of element

The thermal conductivity coefficient of aerated concrete blocs with volume weight ≤400 kg/m^3 is 0.1W/(m*K) and vapour transfer coefficient 0.26 mg/m·h·Pa. The heat transfer coefficient of aerated concrete wall is equal to 0.27 W/(m^2K). The analysis of condensation risk in autoclaved aerated wall without extra insulation is shown in Table 1.

TABLE. 1: Vapour pressure distribution in aerated concrete wall without insulation

Nr	Layer	d, m	R_{tv}, $m^2 \cdot h \cdot Pa/m$	Inside temperature +20, outside (-20)			Inside temperature +20, outside (-10)		
				t ^OC	P_{sat}, Pa	p_x, Pa	t ^OC	P_{sat}, Pa	p_x, Pa
1	Indoor air			20	2336	1402	20	2336	1402
2	Indoor surface			18.7	2152	1402	19	2197	1402
3	Finishing	0.01	0.10	18.6	2137	1321	18.9	2186	1327
4	Aerated concrete	0.375	1.44	-19.5	108	153	-9.6	268	255
5	Finishing	0.01	0.10	-19.6	106	71	-9.70	266	181
6	Outdoor air			-20	102	71	-10	259	181

As it could be seen from the above mentioned table, vapour condensation occurs, when outside air temperature is -20^{O}C. Although the outside temperature below (-20) ^{O}C vapour condensation occurs for relatively short periods, in time the condensation will lead to the damage of external finishing. The additional calculations have shown that vapour condensation between the aerated concrete blocks and external finishing occurs, when outside air temperature is below -12^{O}C.

In order to find out the influence of additional outside insulation on vapour condensation risk in autoclaved aerated concrete walls, the calculations were done for the stone wool and expanded polystyrene materials (Table 2).

TABLE. 2: Vapour pressure distribution in aerated concrete wall with insulation (inside temperature +20 ^{O}C, outside temperature -20 ^{O}C)

Nr	Layer	d, m	Insulation: stone wool			Insulation: expanded polystyrene		
			R_{tv}, $m^2{\cdot}h{\cdot}Pa/m$	P_{sat}, Pa	p_x, Pa	R_{tv}, $m^2{\cdot}h{\cdot}Pa/m$	P_{sat}, Pa	p_x, Pa
1	Indoor air			2336	1402		2336	1402
2	Indoor surface			2196	1402		2196	1402
3	Finishing	0.01	0.10	2185	1324	0.10	2185	1348
4	Aerated concrete	0.375	1.44	264	204	1.44	264	572
5	Insulation	0.05	0.07	106	149	0.83	106	125
6	Finishing	0.01	0.10	105	71	0.10	105	71
7	Outdoor air			102	71		102	71

It could be seen from Table 2 that high condensation risk occurs between aerated concrete and expanded polystyrene heat insulation. Though use of stone wool prevents condensation on the surface between aerated concrete and insulation layer. In both cases the condensation risk occurs on the surface before external insulation.

4. Conclusions

1. The practical analysis has shown that the most intensive evaporation process in autoclaved aerated concrete samples takes place during first two months after their production. During this time moisture content reduces from 20% till 8%.
2. The practical measurements of moisture content in autoclaved aerated concrete blocks by two different methods have shown that special measuring equipment could be effectively used for the materials with humidity ration up to 10%, while for materials with humidity ration higher than 10% it is recommended to use EN 1353 method.
3. The results of measurement of heat flow through the autoclaved aerated concrete wall have shown that there are interdependence between the thermal conductivity coefficient, wall's external surface temperature and heat flow through aerocrete wall. In the wintertime conditions the aerocrete wall's, which is not yet dried and whose moisture decreased from 24% to 14%, coefficient U value corresponds to the standard LBN 002 – 01 requirements. Difference in the results of theoretical calculation of U value and experimental results could be explained by aerocrete's capacity to accumulate heat and material's thermal inertia.
4. Analysis of condensation risk in autoclaved aerated concrete blocks has shown that vapour condensation occurs, when outside air temperature is -20^{O}C. Although the outside temperature below (-20) ^{O}C occurs for relatively short periods, in time the condensation will lead to the damage of external finishing. The additional calculations have shown that vapour condensation between the aerated concrete blocks and external finishing occurs, when outside air temperature is below -12^{O}C.
5. In case when autoclaved aerated concrete blocks have additional external insulation, vapour condensation occurs between aerated concrete and expanded polystyrene heat insulation. Though use of stone wool heat insulation prevents condensation on the surface between aerated concrete and insulation layer. In both cases the condensation risk occurs on the surface before external insulation.

„This work has been partly supported by the European Social Fund within the National Programme „Support for the carrying out doctoral study programm's and post-doctoral researches" project „Support for the development of doctoral studies at Riga Technical University".

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