Moisture and frost risks for different external walls of test houses under Latvian climate conditions

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KEYWORDS: *multi-layered wall, moisture risks, frost risks*

SUMMARY:
The aim of the current paper is to analyse the moisture and frost risks for different building solutions of external walls. Calculations of heat and moisture transfer through the wall have been done in a long term. It is shown that in case of an external wall consisting only of aerated clay blocks, a significant part is exposed to frost risks. Usage of 5 cm insulation material layer outside does not protect the wall perfectly. Moisture risks for external walls mainly consisting of wooden materials and insulation layer are high even when a vapour barrier is used. Measurements show a good agreement with calculations and any differences can be explained, therefore the results obtained by numerical simulations are reliable.

1. Introduction

The moisture and frost risks in the building components continue to be a highly topical problem. Sedlbauer (2001, pp. 215) gives a generalized isopleths' system for spore germination to predict moisture risks in building constructions. Nowadays these curves are used as a standard according to (German institute for standardisation, 2001). After Sedlbauer (2001) the models for estimating of mould growth risks in different building materials are developed and widely researched. Hazardous classes were defined with the aim to differentiate the mould fungi according to the health dangers in (Sedlbauer & Krus & Breuer, 2003). In (Isaksson & Thelandersson & Extrand-Tobin & Johansson, 2010) the model for predicting onset of mould growth with reasonable reliability is developed. In (Viitanen, 2011) results on mould growth in different materials were shown and existing models on the risk of mould growth development were evaluated. Countless papers about frost damages in different building materials have been published. Comprehensive study about frost damages in concrete is given in (Fagerlund, G. 1995). Relations between the concrete composition, and the frost resistance, are presented and discussed.

Since the critical conditions for mould growth as well as frost risks in different building materials have been widely researched in the laboratory conditions, it is interesting to analyse the moisture risks in real building structures in the real climatic conditions. Although the investigation of moisture risks in building constructions has been implemented recently , e.g. (Mlakar, J. & Strancar, J. 2013), the experiments that compare different building structures with similar conditions (orientation, size, room volume, placement of windows and door, loft, floor, roof, etc) are rarely found. Moreover, this type of analysis for the conditions of Latvian climate has not been available hitherto.

The main aim of this paper is to analyse the moisture and frost risks in case of different building structures of external walls for Latvian climatic conditions.

2. Short description of multi-layered external walls

The current section provides a brief description of external walls of five test stands built in Riga, Latvia.

A detailed description of parameters of some of the external walls is also given in (EEM, 2011; Ozolins, A. & Jakovics, A. 2013; Ozolins, A. & Jakovics, A. & Ratnieks, J. & Gendelis, S. 2012; Ozolins, A. & Jakovics, A. & Ratnieks, J. 2013). The project homepage (EEM, 2011) provides a comprehensive gallery of test stand images.

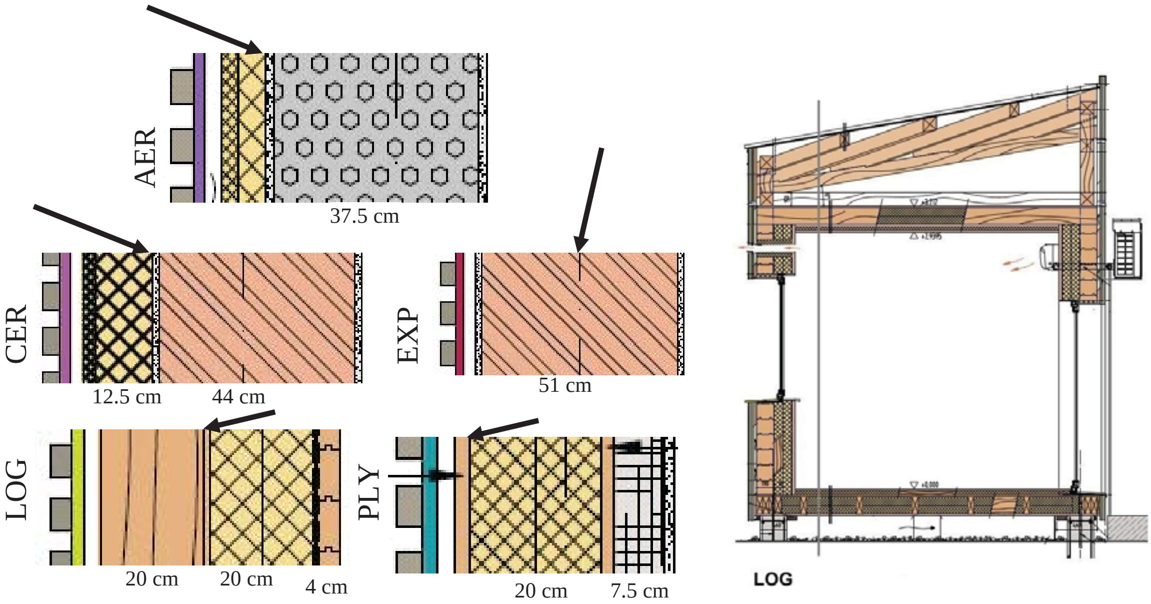


FIG 1. Cross-sections of 5 different external walls. On the right: cross-section of one test house. Arrows indicate temperature and relative humidity sensor placement

TABLE 1. Parameters of building construction walls

AER house	CER house	EXP house	LOG house	PLY house
Material, thermal conductivity λ (W/mK), diffusion resistance factor μ, thickness d (cm)				
Exterior				
Wind protection slab, 0.034, 1, 3	Wind protection slab, 0.034, 1, 3	Lime plaster, 0.7, 7, 1.5	Wooden log, 0.13, 130, 20	Plywood, 0.17, 700, 2
Elasticity stone wool, 0.036, 1, 2	Elasticity stone wool, 0.043, 1, 12.5	Aerated clay bricks with insulation fillings, 0.095, 8, 51	Elasticity stone wool, 0.044, 1, 20	Elasticity stone wool, 0.041, 1, 20
Lime plaster, 0.7, 7, 1.5	Lime plaster, 0.7, 7, 1.5			Plywood, 0.17, 700, 2
Aerated concrete, 0.072, 4, 37.5	Aerated clay bricks, 0.175, 7, 44		Decorative wooden log, 0.13, 130, 4	Fibrolite, 0.068, 2, 7.5
Lime plaster, 0.7, 7, 1.5	Lime plaster, 0.7, 7, 1.5	Lime plaster, 0.7, 7, 1.5		Lime plaster, 0.7, 7, 1.5
Interior				

In Fig. 1 a cross section of each external wall is shown. In Table 1, the multi-layered external walls of each test house are characterized. Ventilated facade is used to protect the walls from the wind and the rain.

Summary, critical conditions for mould growth are on PLY house in the interlayer between the stone wool and the plywood outside and on the LOG house in the interlayer between the outside wooden logs and stone wool. EXP house is the only case where the insulation material is not applied on the external wall. In this case frost risks could be observed because of aerated clay bricks placed outside with no insulation protection. Moisture risks could not be observed on the AER house. However, long drying period of initial moisture at the aerated concrete is expected in this case. It could be predicted that frost and moisture risks may not be observed in case of the CER house. It can be noted that aerated clay bricks consist from the macroscopic cavities.

3. Measurement conditions

Test stands of houses were built in December 2012. The experimental results have been obtained from April, 2013.

3.1 Placement of sensors

Placement of sensors for measurement of relative humidity and temperature are shown in Fig. 1. Arrows indicate the exact placement. For test stands of PLY and LOG, the sensors have been placed in the critical places where the highest moisture risks are predicted. For the test stands of AER and CER the chosen places indicate the highest frost risks on the external wall. For the test stands of EXP, the sensor is placed on the porous domain. One sensor for each of the test stands is also placed by the door jamb. These sensors can also help to estimate the moisture level in each test stand because of their placement near the construction wall.

3.2 Outdoor and indoor climate conditions

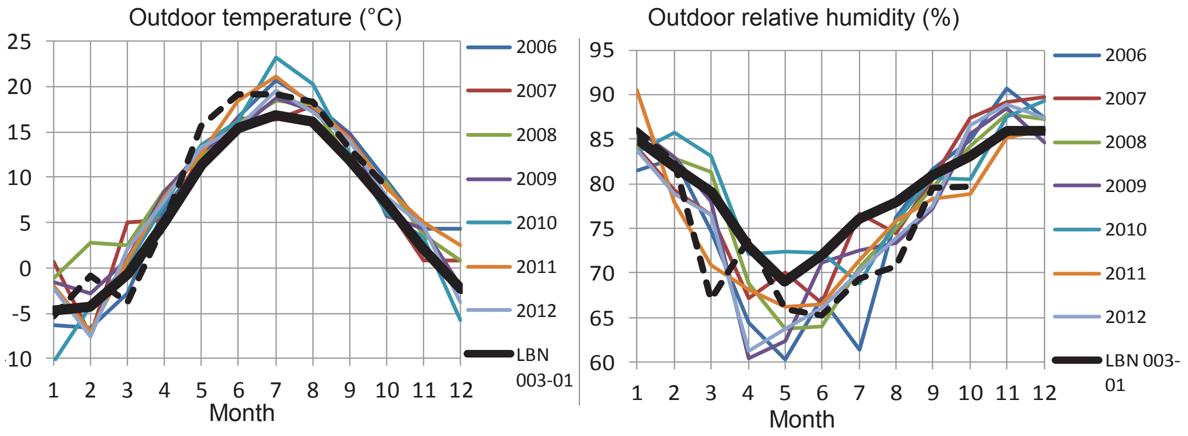


FIG 2. Monthly average outdoor climate conditions in Riga, Latvia. Thicker line denotes the conditions prescribed by the Latvian construction standard

Fig. 2 demonstrates the monthly average outdoor temperature and relative humidity during a period of 7 years. Latvian standard (Latvian Construction Standard, 2001) is also included. According to the illustration, some differences are observed for each year, e.g. colder winters, warmer summers in comparison to those provided for in (Latvian Construction Standard, 2001). Especially significant differences between Latvian construction standard and the real climate conditions are observed in spring and in summer when relative humidity is lower.

4. Results and discussions

In the current section the analysis of results obtained both from measurements and calculations is provided. The software WUFI has been used for the calculations of heat and moisture transfer through building components. In (Kunzel, 1995) the model assumptions are explained in details.

4.1 Moisture risks in a long term

The moisture analysis for external walls of wooden constructions PLY and LOG in a long term will be addressed. A similar analysis was implemented in (Ozolins & Jakovics, 2013). However, the data of outdoor climate is not averaged in the current work. Instead, the calculation has been done throughout a period of 7 years, therefore it is taken into account that some years from this perspective are better (moisture risks are lower) and some years encourage higher moisture risks in a building construction. Indoor climate conditions are defined according to (European Standard, 2007). In (Ozolins & Jakovics & Ratnieks, 2013) it has been shown that measurements are well fitted with the numerical model. It means that the results obtained from simulations in a long term are reliable.

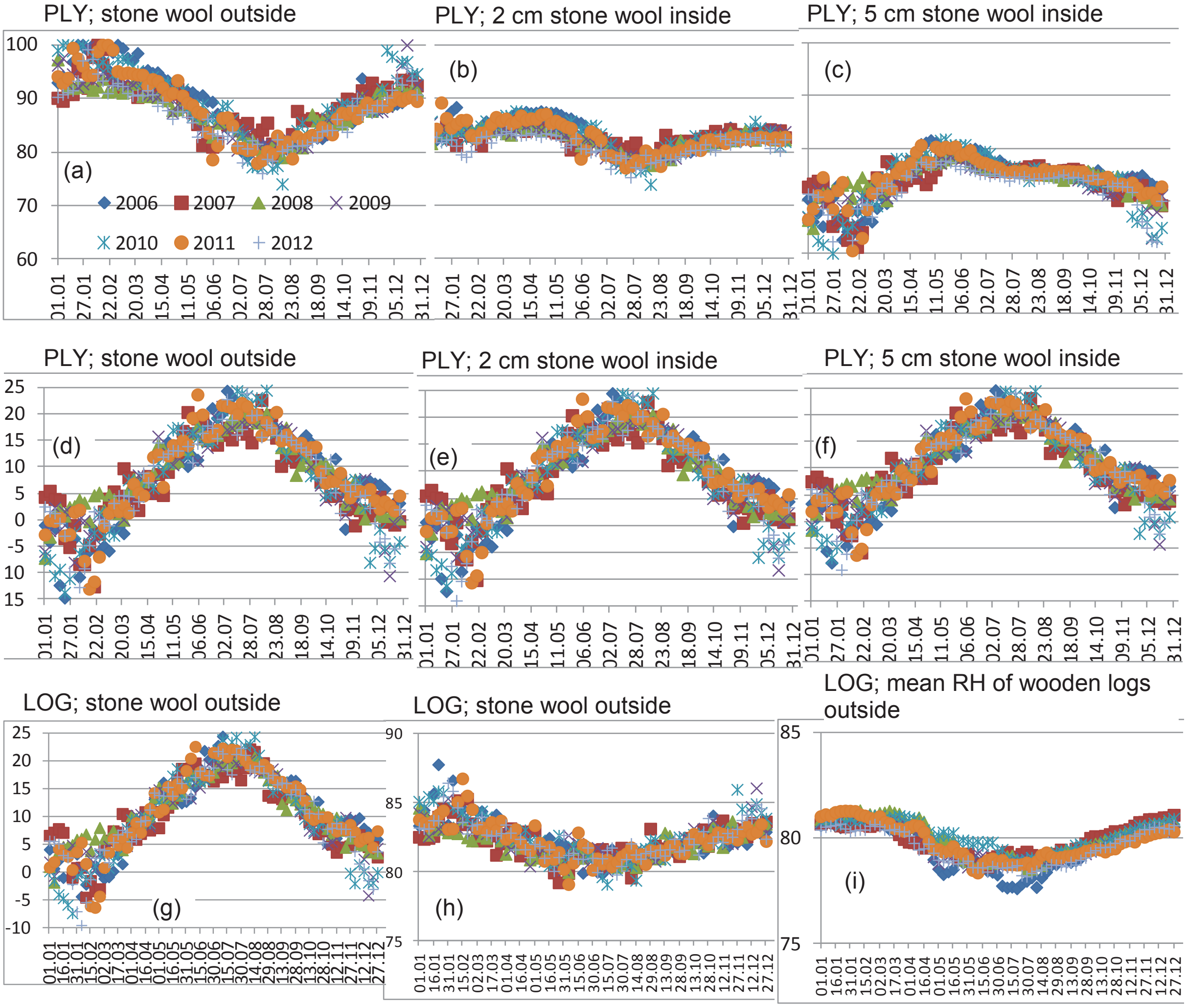


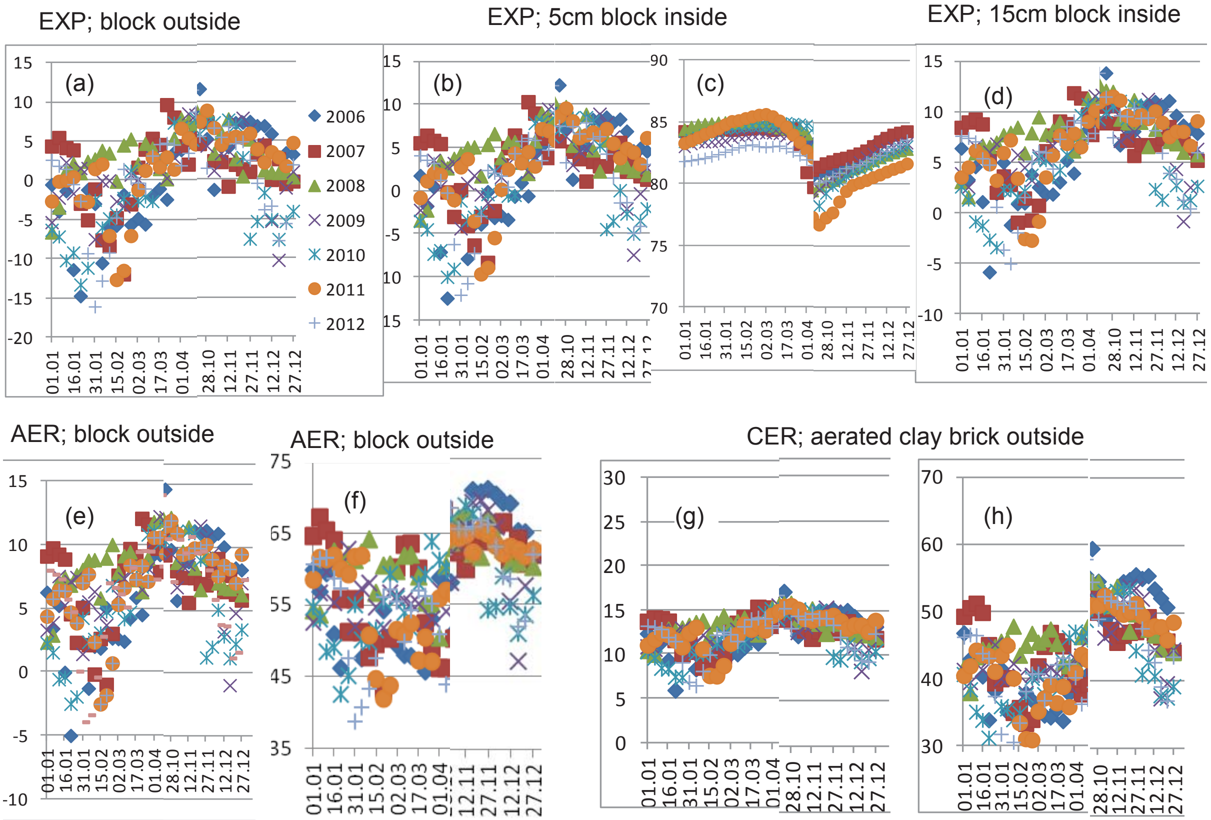
FIG 3. Test stands of LOG and PLY. (a), (b), (c), (h), (i) Relative humidity [%] and (d), (e), (f), (g) temperature [°C] in different places of external walls. Markers describe average 5 day period

Experiments show that even condensation can be observed in case of the external wall of PLY (Fig. 3a). The solution can be to drill small holes on the external plywood plates with the aim to ensure a better ventilation of the layer consisting of mineral wool. Another alternative could be to replace the external plywood with a low vapour barrier. As it is shown in Fig. 3b, c, the relative humidity is significantly lower just only some centimetres deeper in the stone wool layer in the direction from exterior towards inside. For the test stand of LOG the relative humidity in a critical place is significantly lower and the maximal φ varies between 82-87% in a longer term (Fig. 3h). Mean φ of wooden logs outside is almost identical for each year within the time period of 2006-2012 (Fig. 3i). The relative humidity fluctuates from 77-82% therefore moisture risks are low for outside layer consisting of wooden logs.

Temperature significantly rises in spring (Fig. 3d,e,f,h) therefore mould growth risks are higher in spring because vapour is diffusing significantly slower through the building’s construction. Lower limiting humidity level according to (German institute for standardisation, 2001) can be overreached for a longer time period therefore mould growth risks can also be observed for the external wall of LOG despite the usage of vapour barrier. Since the method (German institute for standardisation, 2001) is only applicable for interior surfaces, lower limiting humidity level is not useful for the critical place of the external wall of PLY.

4.2 Frost risks in a long term

In the current subsection the frost risks will be analysed for houses AER, CER and EXP, where aerated concrete and clay bricks are used: material can be damaged due to the low outdoor temperature. Especially high frost risks are for external wall of EXP due to no usage of insulation material on the outside. Since the frost risks are not high for wooden materials, houses LOG and PLY are not inspected in the current subsection.


EXP; block outside

EXP; 5cm block inside

EXP; 15cm block inside

AER; block outside

AER; block outside

CER; aerated clay brick outside

FIG 4. Test stands of AER, CER and EXP. (a), (b), (d), (e), (f), (g) Temperature [°C] and (c), (h) relative humidity [%] in different places of external walls. Markers describe average of 5 day period

As it is shown at the top of Fig. 4, not only the outer side of a block (Fig. 4a) but also the section 5 cm deeper in a block (Fig. 4b) is exposed to the frost risk. The situation can be quite different in each year, e.g. the duration of $T_{5cm}<0$ is estimated as 3 months (winter 2009-2010) or only a short time period (winter, 2007-2008). However, an overall situation shows that $T_{5cm}<0$ could often be in case in the winter. φ_{5cm} is estimated approximately between 80 % and 85 % in the winter and the differences between the years are insignificant (Fig. 4c). Since the rain is not taken into account than the water content can forming in the block. Therefore it can be concluded that the total water content can be high enough to encourage moisture damages. During several periods in a winter, the temperature can decrease below 0 °C even in the section up to15 cm deep within the block (Fig. 4d). However, in this case the situation would not be critical because of a low predicted water content in that section.

5 cm and 15 cm thickness of insulation materials have been used for the walls of AER and CER, respectively, therefore frost risks are insignificant in a long term (Fig. 4e, f, g, h). Only a short time period could be critical for the wall of AER (Fig 4e). For CER the situation is safe (Fig. 4g).

4.3 Short overview about measurements at the initial time period

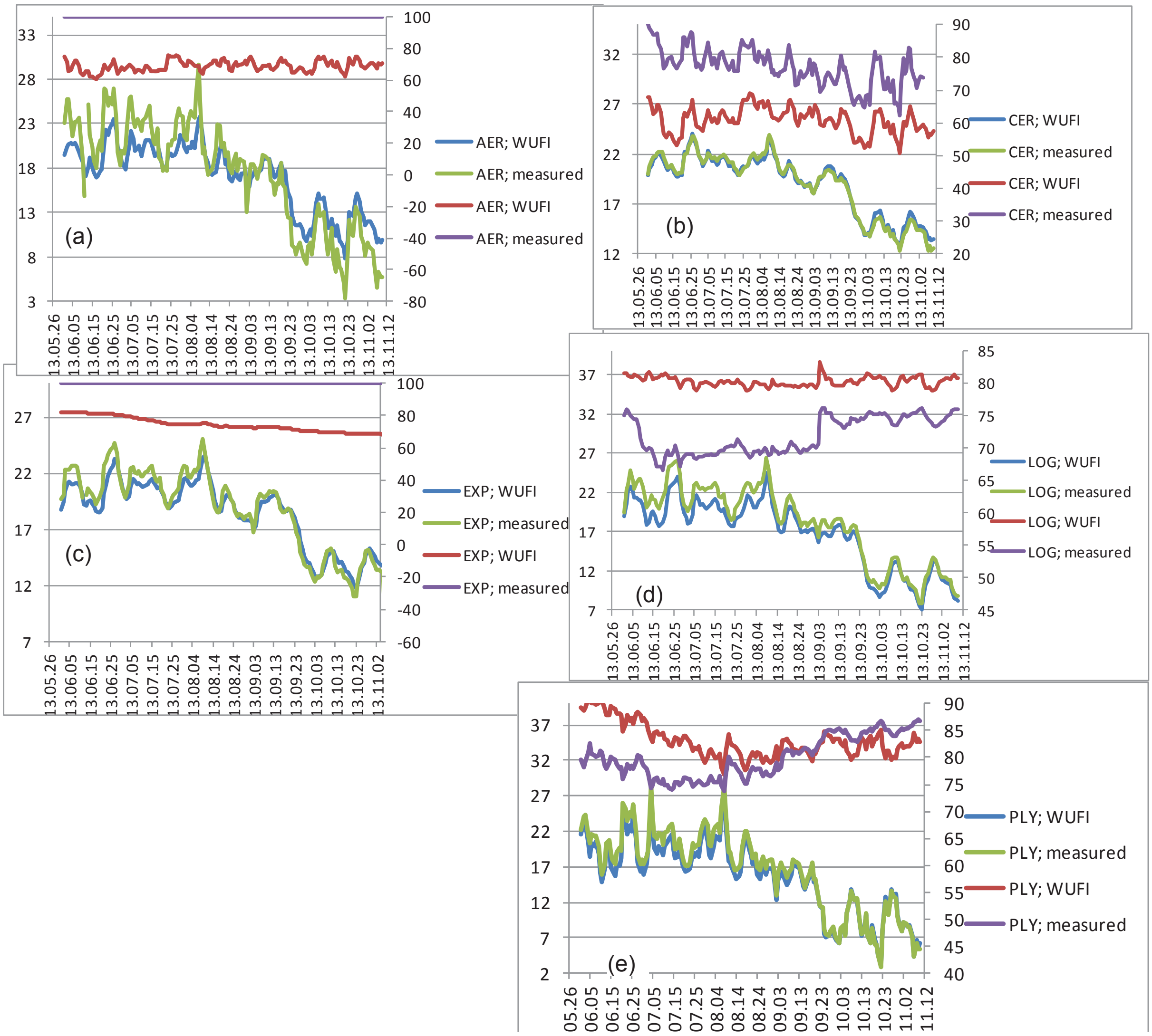


FIG 5. Dynamics of relative humidity and temperature in a specific place of building construction: measurements versus calculations. Specific place for each external wall is shown in Fig. 1, black arrows. Daily average values are used

In the current subsection we will focus on the experimental results at the initial period of test stands' monitoring. These results are compared with the WUFI calculations. The calculation has commenced in December 2012, and it is taken that the initial moisture of external walls equals with 80 % and the time step of 1 hour is chosen. However, initial moisture for each building material can differ significantly.

The real situation shows that high moisture on the wall is observed for external walls of EXP and AER (see Fig. 5a, c). Sensors on the walls show that φ=100 % in the middle of EXP block and on the external side of aerated concrete. Calculated temperatures are almost identical to the real temperatures for test stands of CER, EXP, LOG, PLY (Fig. 5b, c, d, e). Significant differences are observed for the external wall of AER (Fig. 5a). It is explained with a high initial moisture and therefore significantly higher thermal conductivity for the aerated concrete and for insulation materials. From this assumption it follows that the temperature near the external side of aerated concrete is more dependent on T_{out}. However, all temperature curves (see Fig. 5) show that the WUFI model works well for estimating frost risks in a long term, as described in the previous subsection.

The dynamic of measured relative humidity significantly differs from the relative humidity calculated for all test stands. Measurements for AER and EXP (Fig. 5a, c) show 100 % due to the initial moisture. The sensor on the external side of CER block (Fig. 5b) shows a significantly higher relative humidity than the results from calculations. However, fluctuations are similar, therefore with the choice of higher initial moisture in WUFI it will be possible to obtain a good agreement with measurements. The situation is opposite for the LOG (Fig. 5d) and real initial moisture has been lower in this case. Only for the test stand of PLY the differences are not simply explained (Fig. 5e). Currently the only explanation could be different material properties of plywood.

Sensors placed in the door jambs confirm that a high moisture is observed for the AER and EXP at the initial time period despite the same dynamics of a temperature for each case (see Fig. 6).

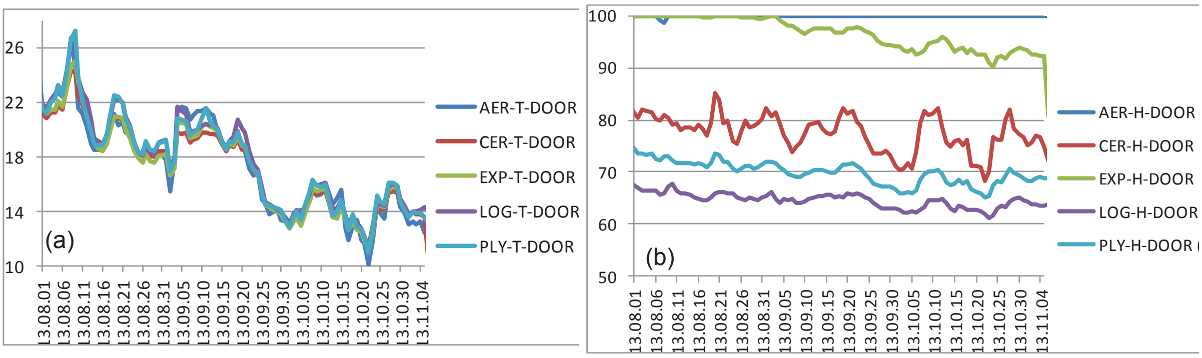


FIG 6. (a) Temperature near the door jamb; (b) Relative humidity near the door jamb

5. Conclusions

Measurements and detailed analysis that have been implemented from several aspects show that the best solution of 5 real external walls inspected in the current work could be the multi-layered wall consisting from aerated clay bricks and insulation materials placed outside of a wall. Moisture and frost risks are not observed in that case either through numerical calculations or measurements. Constructions mainly consisting of wooden materials and insulation materials have been exposed to moisture risks, and further measurements in test houses are recommended to observe, whether the experimental results will confirm the calculations in a long term.

The external wall which consists only of aerated clay bricks with the insulation filling is strongly prone to frost risks. Even in the section 15 cm deep in a block, the temperature below 0 °C could be observed. In case of the test house consisting of aerated concrete and insulation material outside, the frost risks could also be observed. It is planned to implement the analysis to estimate whether real frost damages will be observed for these two test houses.

6. Acknowledgements

The current work was supported by the European Regional Development Fund in Latvia within the project No. 2011/0003/2DP/2.1.1.1.0/10/APIA/VIAA/041.

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