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RISKS OF CONDENSATE FORMATION AND MOULD GROWTH IN BUILDINGS UNDER LATVIAN CLIMATE CONDITIONS

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The paper considers the impact of Latvian climate on various building constructions. The humidity effect is estimated for three different constructions. The risks of condensate formation in a multi-layer wall are analyzed for transient outdoor conditions. The risks of mould growth are discussed in detail taking into account the building material's properties and the temperature/seasonal dependence of humidity. The effect of a vapour barrier is analyzed from several aspects. The theoretical analysis is performed on the basis of real test stands built in Riga.

Keywords: *moisture, temperature, multi-layer wall, mould growth.*

1. INTRODUCTION

At the present time, a highly topical problem is that of reducing the energy consumption for heating and cooling in buildings due to ever increasing energy prices. Moreover, Directive 2010/31/EU of the European Parliament aims at promoting the energy performance of buildings and building units [1]. By 31 December 2020, all new buildings are to become the "nearly-zero energy consumption" ones. Therefore, the sustainability analysis is required for different building solutions. One of the factors that may have a negative influence on the buildings' sustainability is moisture. The wall's U-value can significantly increase due to the water content in a building's construction, and consequently, its energy consumption could also increase. The condensate formed in such a construction can cause a serious damage. Also, the mould growing under high moisture has a negative influence on the building's sustainability and human health. The critical conditions regarding the mould growth are analysed in [2-5]. An important requirement for the design of components in a building's envelope is to limit the risks of this phenomenon.

Therefore, the theoretical and experimental analysis of buildings' sustainability is recommended, taking into account the climatic conditions of Latvia. The current paper is focused on the theoretical analysis. At the same time, this analysis is firmly based on real experiments that were run in the winter of 2012-2013.

For the first time in Riga (Latvia) five test stands have been built for the research purposes (see Fig. 1), with the purpose to verify the energy efficiency and sustainability of the solutions developed for construction of external walls from local raw materials (ceramic blocks, foam concrete, wood, plywood, fibrolite, granules, sawdust plates, etc.) taking into account the Latvian climate conditions. The test stands are equipped with a full system for monitoring, collection and storage of data. On the south wall of such a stand the windows are made in order to analyse the influence of solar radiation on the energy consumption for heating and cooling and on the indoor thermal comfort conditions (more information and results are available in [6]).

Fig 1. Polygon of test stands. Above: in the front – test stand of wooden logs; to the left – test stand of aerated concrete; at the back – test stand of plywood panels. Below: the completed test stands.

Similar (in a sense) polygon investigations were carried out at the Technical University of Tampere in Finland (*Vinha J., 2007*). However, the stands in Tampere were designed for different purposes; besides, they are smaller, without windows, and based on other design solutions.

A polygon with test stands meant for comparing the efficiency of phase change materials has been built at the Lleida Technical University (Spain). The relevant research is aimed to create the least energy consumption solution for the air conditioning systems in hot climate conditions (significantly differing from the Latvian ones). Besides, the design of stands in Lleida does not account for the solar energy which enters through a window. Thereby, these investigations are not duplicated, which substantiates the scientific and practical value of the current research as appropriate for the Latvian climate conditions.

In [7], similar building solutions (with using mostly local raw materials) are reported; these were mainly focused on stationary cases and the outside temperature variation within 24-h periodicity. In the mentioned work, the characteristics of theoretically simulated constructions are as close as possible to those of the real test stands reviewed in this paper.

Overall, the main goal of the current work is to estimate the risk of condensate formation and mould growth for different building solutions with similar U-values under real Latvian climatic conditions in the long term using a polygon of test stands.

2. DESCRIPTION OF THE ANALYSED BUILDING CONSTRUCTIONS

The building construction walls are described by the parameters tabulated below.

Table 1.

Parameters of building construction walls

Test stands	Thickness	Thermal conductivity	Specific heat capacity	Density	Water vapour diffusion resistance factor
	m	W/(m·K)	J/(kg·K)	kg/m^3	
Stand of plywood Outside Ventilated facade					
Plywood	0.02	0.17	1500	500	700
Mineral wool	0.2	0.036	850	40	1
Plywood	0.02	0.17	1500	500	700
Fibrolite	0.075	0.068	2100	360	2
Lime plaster	0.015	0.7	840	1600	7
U-value ≈ 0.14 W/(m^{2}K)					
Stand of wooden logs Ventilated facade					
Wooden logs	0.2	0.13	2100	600	130
Mineral wool	0.2	0.036	850	40	1
Wooden log	0.04	0.13	2100	600	130
U-value 0.13-0.14 W/(m^{2}K)					
Stand of wooden logs: inverse solution Ventilated facade					
Wooden logs	0.02	0.13	2000	600	132
Mineral wool	0.2	0.036	850	40	1
Wooden logs	0.22	0.13	2000	600	132
U-value ≈0.13-0.14 W/(m^{2}K)					

Cont.

Stand of aerated concrete					
Ventilated facade					
Wind protection slab	0.03	0.034	850	70	1
Mineral wool	0.05	0.036	850	40	1
Lime plaster	0.015	0.7	840	1600	7
Aerated concrete	0.375	0.072	850	300	4
Lime plaster	0.015	0.7	840	1600	7
U-value ≈0.14 W/(m^{2}K)					

Four building constructions with multi-layer walls have been analysed. The layers are listed in the outdoor-indoor direction. The data on materials were obtained from *WUFI* software used in the simulations of the coupled heat and moisture transfer in building elements; some data were provided by the manufacturers [8-9]. The U-values with thermal "boundary layers" of air are approximately estimated for wet conditions taking into account the thermal conductivity change due to moisture. The outdoors/indoors convective heat transfer coefficient is assumed to be constant (7.8 W/(m^{2}K)) due to the ventilated facade.

In the test stand made of wooden logs, behind the mineral wool on the side closer to its interior there is a vapour barrier (μ=10000). In the test stand of plywood such a barrier was not used; however, to analyse the effect of a vapour barrier it was added behind the mineral wool also in this case.

In the test stand of wooden logs the insulation material is incorporated into the wall; the inverse construction is also inspected for comparison: the insulation material is mainly outside (with only a thin wooden layer as the outside decoration).

The roof, floor, windows and doors of all test stands are similar. The present paper is focused on the analysis of the heat and moisture transfer through external walls.

3. DATA ON THE LATVIAN WEATHER CONDITIONS

To analyse the risks of condensate formation and mould growth in multi-layered walls in a longer period the annual cycle was taken (*Fig. 2*). The meteorological data were borrowed from [10], with an hour's time step for the relative humidity and temperature. A four-year span (2009-2012) was chosen, and the temperature was taken on the hourly basis (the data were mostly averaged). The purpose of choosing this time span was to avoid weather anomalies that could arise in one year for a short time. The weather data are not fully averaged: variations in the weather conditions during a time of few days were also taken into account.

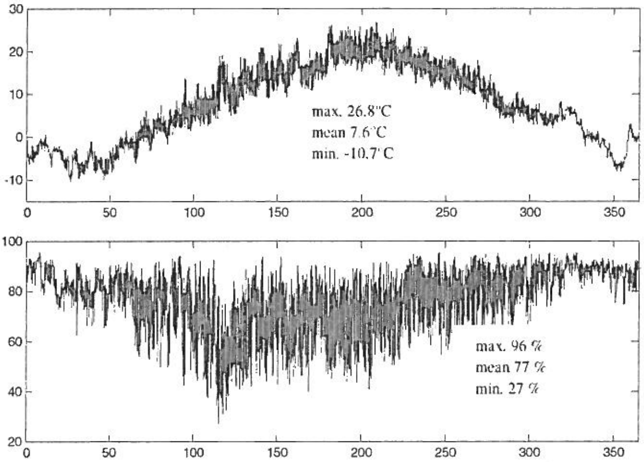

Fig. 2. Annual cycle of temperature and relative humidity in the Latvian climatic conditions

The data on the wind speed and direction as well as on the solar influence (see, e.g. [10]) were not used in the simulations, because the walls of test stands are protected by the ventilated facade (see Fig. 1). It is assumed that the temperature and relative humidity of the ventilated air layer are the same as those outdoors. The heat exchange coefficient is the same as that for the interior air.

4. SIMULATION METHODS

For calculation of the simultaneous heat and moisture transport in one-dimensional multi-layered building components the commercial software *WUFI®pro* was used. In the heat transport calculations this software takes into account the thermal conduction, movement of enthalpy flows through moisture with phase change and short-wave solar radiation. Convective heat transport by air flows in the constructions is disregarded, since it is usually difficult to quantify. The vapour transport mechanisms included in *WUFI®pro* are vapour diffusion and liquid phase diffusion. Convective vapour transport by air flows is also ignored. The liquid transport mechanisms taken into account are the capillary conduction and the surface diffusion. Seepage flows via gravitation, hydraulic flows caused by pressure differences as well as electro-kinetic and osmotic effects have not been included. *WUFI®pro* takes into account the hourly outdoor climate values.

The 1D mathematical model was also implemented in the programming environment *MATLAB*, see [7]. The results were compared with those obtained using *WUFI®pro*; both the approaches have not shown significant differences in typical cases.

5. RESULTS AND DISCUSSION

Our results were obtained under the assumption that the indoor temperature and the relative humidity are +20°C and 50%, respectively. The outdoor temperature and the relative humidity are changing on the annual cycle (see Fig. 2).

The results presented in Fig. 3 were obtained for one year – the 6th year after five years from the initiation of calculations, so some building materials could have become wetter. For the constructions under consideration the maximum/minimum relative humidity and the relative humidity in winter were calculated (in simulation it was assumed that the average winter lasts from December 1 to February 28). At analysing the mould growth an important factor is the duration of relative humidity in some places of the construction. Figure 3 also demonstrates the probability density distribution for humidity.

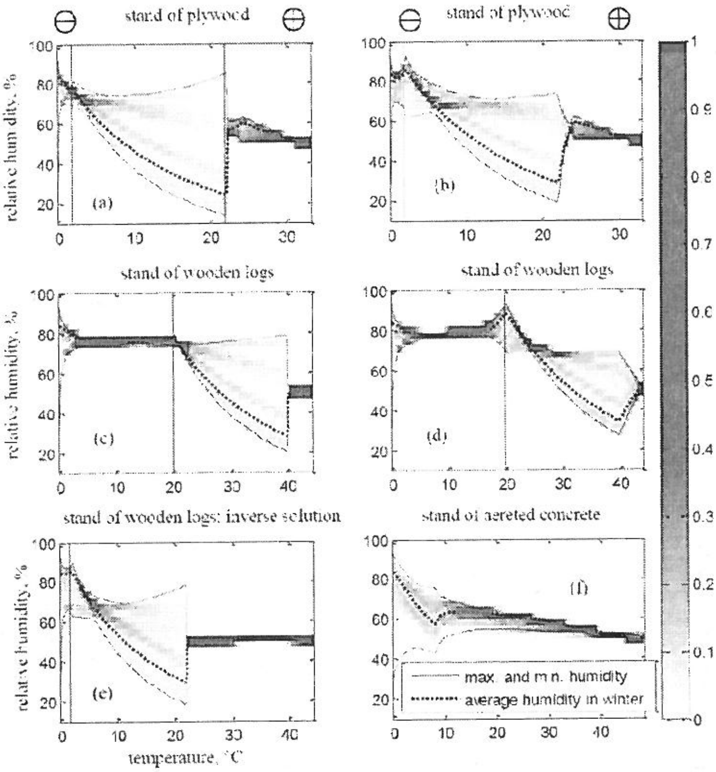

Fig. 3. The relative humidity curves and probability density distribution (annual cycle) for three different test stands. Colour in the region corresponding to colour bar value 0.2 denotes the respective part of the year when the relative humidity is indicated in the grid element. The vertical dashed lines show the critical places for the stands: (a), (b) plywood; (c), (d) wooden logs; (e) inverse wooden logs; (f) aerated concrete: (a), (c), (e) – vapour barrier is added behind the mineral wool toward the interior.

In Fig. 3, symbol ⊖ denotes the external side of a building wall, and ⊕ – its internal side. Figure 3*b* shows that the test stand of plywood without the vapour barrier is under high risk of condensate formation. The vapour barrier effectively neutralises this risk in the interlayer adjacent to the external layer; however, the risk of condensate formation is higher in the interlayer between the mineral wool and the plywood inside (see Fig. 3*a*). This is explained by the summer vapour coming in the direction from the outside to the inside. Figure 3*a* also shows that the vapour barrier effect can be somewhat ambiguous. Moreover, it is expected that the relative humidity inside would exceed 50% in summer if the cooling systems are not used; therefore, the maximum relative humidity could be higher in a real situation.

Comparison of Fig. 3*c* and 3*d* shows that the vapour barrier effectively neutralises the risk of condensate in the test stand of wooden logs; however, the risk of mould growth remains. The inverse solution (see Fig. 3*e*) seems to be preferable, although rains could drastically change the situation with risks of condensate in this case, so the use of a ventilated facade behind the external layer of wooden logs is here strongly recommended.

In the case of the aerated concrete test stand, the highest relative humidity is on the wind protection slab outside (Fig. 3*f*). However, in this place the lowest temperature prevails; therefore, the risk of mould growth is relatively low.

In winter, the condensate risks are usually higher (Fig. 3, dotted lines). On the other hand, the temperature is then lower, so the conditions for mycelium growth and spore germination are less favourable. This is the main motivation for a detailed analysis of moisture in building elements, since the mould growth depends not only on the relative humidity but also on the temperature.

The relative humidity *vs*. temperature in a building's wall is shown in detail in Fig. 4.

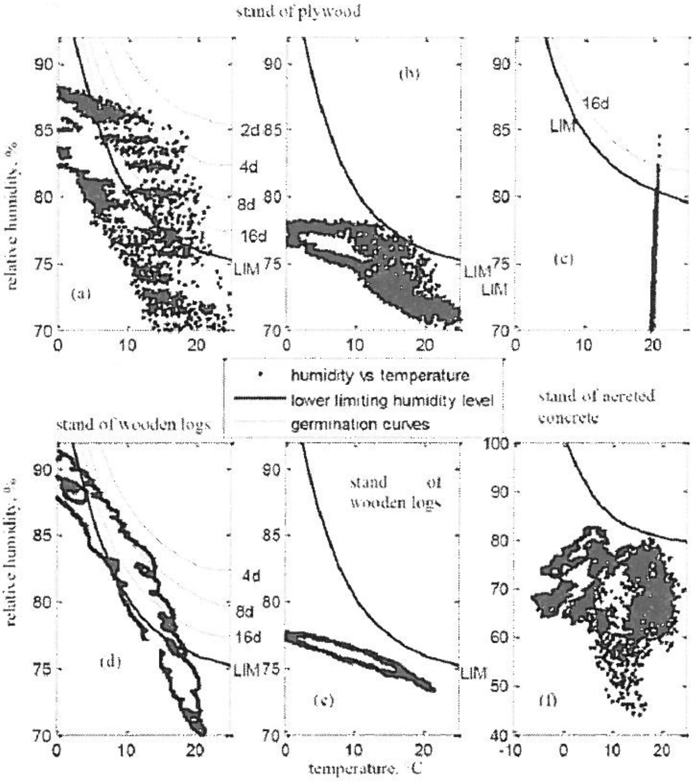

Fig. 4. Relative humidity *vs*. temperature in a building's wall for the test stands of: (a), (b), (c) plywood; (d), (e) wooden logs; (f) aerated concrete. External plywood adjacent to mineral wool with: (a) no vapour barrier (Fig. 3b, vertical dashed line); (b) vapour barrier (Fig. 3a, vertical dashed line). External wooden logs adjacent to mineral wool with: (d) no vapour barrier (Fig. 3d, vertical dashed line); (e) vapour barrier (Fig. 3c, vertical dashed line). (c) Mineral wool adjacent to plywood layer in direction towards interior (Fig. 3a, vertical dashed line). (f) Wind protection slab adjacent to mineral wool layer.

Ciphers with letter *d* in Fig. 4*a,c* indicate the mould germination time in days, i.e., correspond to the generalized isopleth system for spore germination. The lower limiting humidity level (LIM) shows the critical conditions for mould growth (a thicker solid line, taken from [3], p.583). Below the LIM there is no biological activity. It is taken into account that LIM differs in the cases of biodegradable substrates (plywood, wooden logs) and porous materials (mineral wool). Dotted marks show the humidity *vs.* temperature on the annual cycle at a 3-h time step.

Figure 4 demonstrates that a vapour barrier significantly helps to decrease the risks of mould growth (Fig. 4*b* against Fig. 4*a,* Fig. 4*d* against Fig. 4*e*). On the other hand, these risks can increase in the insulation material (Fig. 4*c*), although to a lesser extent: the total time for humidity to reach or exceed the limiting level is only 70 h. Nevertheless, the risk of mould growth could increase in summer if a stronger vapour barrier is used.

Figure 5 provides a detailed illustration for analysing the mould growth risks and allows taking into account the season and the time span.

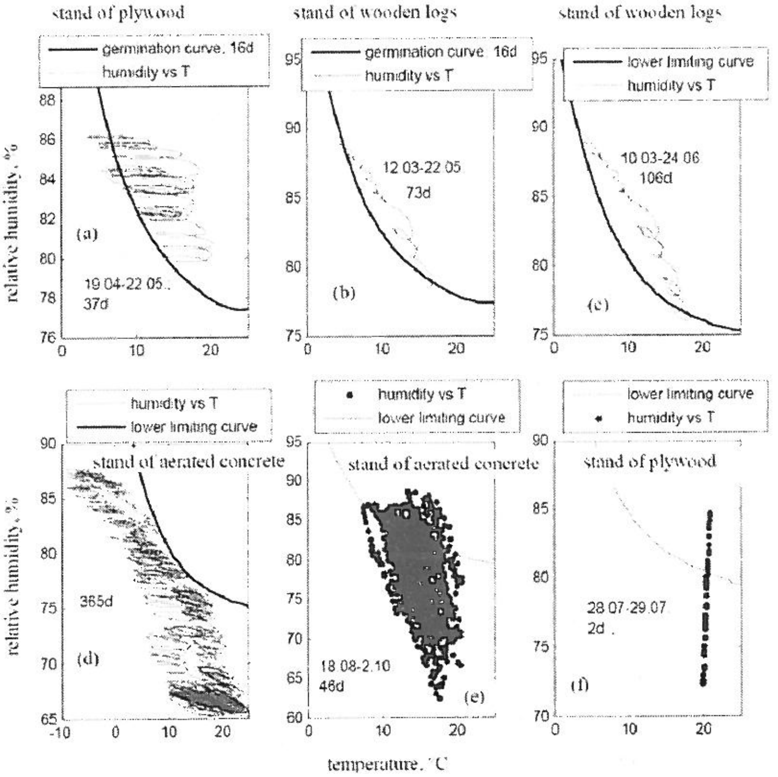

Fig. 5. Humidity *vs.* temperature for the test stands of: (a), (f) plywood; (b), (c) wooden logs; (d), (e) aerated concrete. (a) External plywood adjacent to mineral wool (Fig. 3b, vertical dashed line). (b), (c) Wooden logs adjacent to mineral wool (Fig. 3d, vertical dashed line). Wind protection slab: (d) adjacent to mineral wool; (e) slab near the boundary. (f) Mineral wool adjacent to plywood (Fig. 3a, vertical dashed line)

For the test stand of plywood and wooden logs the risk of mould growth is high from March to June (Fig. 5*a,b,c*). This can be observed because the relative humidity is high during winter due to a high outdoor relative humidity (in a particular place chosen for the review in the test stand). However, the temperature significantly rises in spring while vapour is diffusing significantly slower through the building's construction. This process is especially slow in the case of wooden logs' test stand (Fig. 5*b,c*) due to a high resistance to water vapour diffusion characteristic of wooden logs (see Table 1). The risks of mould growth are insignificant for the test stand of aerated concrete (Fig. *5d,e*). This can be explained by high vapour permeability for insulation materials and aerated concrete, which allows the vapour to diffuse relatively quickly through insulation materials; therefore, the relative humidity is higher only in the winter time, when the risks of mould growth are smaller due to low outdoor temperatures.

6. CONCLUSIONS

The current work demonstrates that moisture can have a significant negative influence on particular buildings' constructions, e.g. those made of wooden materials. The mould growth risk depends not only on the relative humidity but also on the temperature. The construction of wooden logs is particularly prone to such risk due to the relatively low permeability for water vapour.

The vapour barrier can effectively decrease the risk of condensate formation and mould growth. However, the role of such a vapour barrier is ambiguous since it can potentially heighten the risk of mould growth in the insulation material (in the direction towards the interior in summer time). However, in the observed cases this risk was insignificant.

The next step of the present analysis is comparison of the experimental results for similar constructions with the results of corresponding theoretical calculations. Currently, experiments of the type are going on in the test stands. A particularly interesting challenge would be analysis of the moisture influence and drying time in the initial time span – 1 to 2 years since the time when the building units had just been built.

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KONDENSĀTA UN SĒNĪŠU AUGŠANAS RISKI DAŽĀDĀS BŪVKONSTRUKCIJĀS LATVIJAS KLIMATISKAJOS APSTĀKĻOS

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Kopsavilkums

Darbā apskatīti kondensāta rašanās riski dažās tipiskās būvkonstrukcijās reālos Latvijas klimatiskajos apstākļos. Šādu konstrukciju izpēte uzsākta Rīgā izveidotajos testēšanas stendos. Papildus apskatīti kondensāta rašanās riski, kā arī veikta detalizēta sēnīšu augšanas risku analīze, ņemot vērā ne tikai relatīvo mitrumu konstrukcijā, bet arī temperatūru un dienu skaitu, kad ir labvēlīgi apstākļi sēnīšu augšanai. Parādīts, ka situācija būvkonstrukcijās vasaras un ziemas periodos būtiski atšķiras, kā arī tas, ka prettvaiku plēves izmantošana dažos gadījumos efektīvi samazina kondensāta un sēnīšu augšanas riskus būvkonstrukcijās.

13.05.2013.