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DIFFUSION OF WATER VAPOUR, MONITORING AND RISK ANALYSIS OF WOODEN WALLS

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ABSTRACT

This paper presents an experimental study of 4 different building structures of used to construct modern timber houses. These structures are monitored on the Experimental Timber Framed House - EXDR since 2012. Since the EXDR is located outdoors, the materials and structures are exposed to actual real life climatic conditions (i.e. weather change rate and solar gains) and are monitored under real-time. As for the indoor conditions, those can be controlled in full scale. It is possible to change the indoor air temperature, humidity production and air exchange rate.

The main aim of this experimental project is to use the measured data in the development of a new improved model for mould risks prediction. The data are collected by a data logger developed under DIY framework from two prototyping platforms, the Arduino and the Raspberry Pi.

This peculiar paper presents how water vapour affects existing structures created with the application of a vapour barrier from PE based foils or oriented strand boards (OSB). An analysis of mould growth risks model and its comparison to measured mould growth risks is also presented.

KEYWORDS: Humidity, mould, water vapour, monitoring, wooden walls.

INTRODUCTION

Wood is one of the oldest materials available which mankind has learned to transform into useful elements. Humanity began to make building objects, i.e. homes from wood, then to produce tools necessary for them to make for living and also as a energy source in the end. In comparison to commonly used building materials like ceramic bricks, concrete and steel, wood is a renewable raw material. Wood has minimal demand for energy and the processing of trees to wood to lumber produces almost zero amount of waste.

Wooden houses of today unfortunately do have almost nothing in common with the historical structural solutions of structural systems and constructions of huts and other types of buildings. The advancements in the fields of civil engineering, like materials and structural engineering, building physics, sustainable development and many more, have contributed to the deployment of wood in the form of timber for the production of family residences. Howbeit, wooden structural elements are also used in the construction processes of single and multi-storey administrative buildings. Thus, it can be stated that timber structures are now becoming a viable alternative to the predominant materials of architecture.

Due to the technical development of modern wooden structures their popularity among general public rises at a rapid rate. Therefore it is important to solve the deficiencies that do accompany these types of structures. Such deficiencies might be caused by improper utilization of structural wooden elements, i.e. timber, throughout the construction works or by insufficient design of the wooden elements with respect to building physics. The issues in the field of building physics may be connected to building acoustics and hydrothermal conditions.

The main objective of the research team of the Brno University of Technology is to describe the behaviour of modern timber envelopes with a focus on humidity and temperature, whereas under certain conditions, combinations of heat and humidity

the risk of mould growth may be bigger. Moreover, it might influence the reliability and durability of the resulting construction, too. This mould existence can cause several defects of wooden structures which are hard to remove (Novotný et al. 2013).

MATERIAL AND METHODS

An experimental two storey timber framed house was designed and later erected by the research team of the Institute of Building Structure of the Faculty of Civil Engineering, Brno University of Technology to research the behaviour of wooden structures with respect to changing outdoor and indoor boundary conditions. This experimental timber framed house (EXDR) is located in Brno, Czech Republic. The building object has two identical rooms on each floor (four identical rooms altogether) suited for experimental activities to take place, and has halls (these may be referred to as corridors too) for technical background. The external dimensions of the building object in plan are 6.9 x 7.1 m whereas its height is equal to 7.3 m. The glazed elements (windows) do have a South-West cardinal orientation to increase solar heat gains. The total area of the house is 101.5 m^2, albeit the area suited for experiments is 48 m^2. The air volume of experimental section is 132 m^3. The construction processes of the EXDR were finished by the end of 2012. The scheme and photographs of the building are shown on Fig. 1. The air tightness of the building was a subject to Blower Door measurement at a pressure difference of 50 Pa between indoors and outdoors. The air change rate of the whole experimental

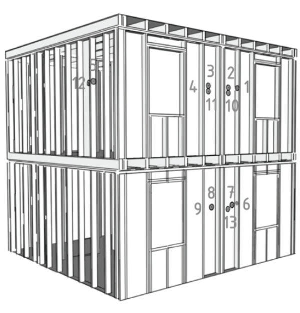

Fig. 1: Experimental house construction scheme.

Fig. 2: Experimental house photography.

house is n_{50} = 1.2 h^{-1}, on the other hand the airtightness of the rooms separately was set to n_{50} = 0.8 h^{-1}. The possibility of full scale testing and simulation of real life usage condition is enabled by equipment like air humidifiers, CO_2 generators, waste and human heat generators and general HVAC equipment, located indoors.

Material solution sub-element structure

As noted above the experimental activities, measurements were carried out on the experimental house EXDR1. For the monitoring of hydrothermal processes each and every of the 4 main rooms were equipped with different external walls. Since wood is and inhomogeneous anisotropic material, the position of the probes in each of the elements was chosen on the basis of basic visual verification. It was aimed to place the probes at locations where no knots were visible on the surface of the lumber, since the density of a knot is higher than that of the rest of the cross-section and causes the water to evaporate from the material within a longer time interval.

The probes were primarily fitted to the supporting columns in both the diffusely closed and diffusely open alternatives of building envelope. Location of the investigated profile was in the middle of the field, since this place is the most moist. As an additional component for monitoring of moisture the OSB boards were chosen. In case of the diffusely closed structural solutions the OSB boards do serve as a cladding and also as a bracing structure at the exact same time. In comparison to the diffusely open structures the diffusely closed ones do have an additional layer, a layer of water vapour barrier. For this reason the location of the probe is closer to the interior. In its principles the locations of probes is identical to that of columns. Because the envelopes of houses are composed of different structural elements (the inhomogeneous), the locations must be selected with care to mechanical and thermal properties and the probes must be placed properly to each of the sub-elements.

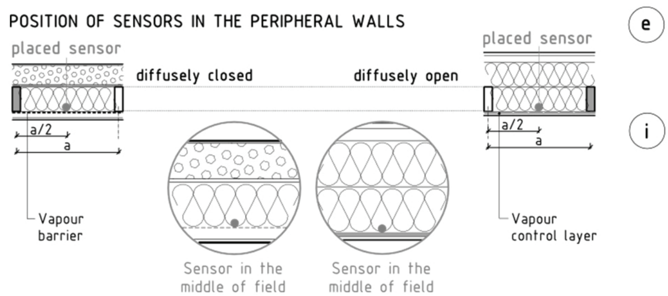

Fig. 3: Installation of probes for the determination of temperature and relative humidity in the wood the wall was constructed from.

The probes were anchored to the 50 m x 150 mm columns at the centre of the profile, or at a depth of 25 mm and at a height of 1800 mm above the floor (probe No. 1, 4, 6, 9). Other probes were placed into the middle of OSB boards with a thickness of 12 mm, or at a depth of 6 mm, and 1800 mm above the floor (probe No. 2, 3, 7, 8). This was done in two rooms on the 1st floor and 2nd floor respectively that are separated one from another structurally to avoid an interaction between monitored values.

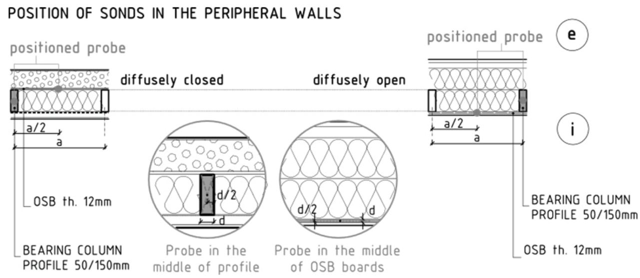

Fig. 4: Installation of sensors for the determination of temperature and relative humidity in the in the air near the vapour barrier.

For the monitoring process all of the experimental rooms were fitted with a different composition of wooden wall. These were set up and named after the water vapour barrier solution used, namely:

Tab. 1: Structure of exterior wall with general PE foil vapour barrier.

External wall – common PE foil				
Material from interior	d (mm)	μ (-)	s_d (m)	λ ($W.m^{-1}.K^{-1}$)
Gypsum board	12.5	8	0.10	0.22
Air cavity	40.0	0.25	0.01	0.222
Water vapour barrier with alumina film	0.25	200 000	50.00	0.35
Lumber 50x150 mm	150.0	157	23.55	0.18
Mineral fibre board posts	150.0	2	0.30	0.041
Oriented strand board	12.0	300	3.60	0.13
EPS 70 F, glued by PUR	100.0	30	3.00	0.039
Glue and mastic ETICS	4.0	35	0.14	0.8
External plaster/colour on silicon base	3.0	50	0.15	0.86

Tab. 2: Structure of exterior wall with general PE foil vapour barrier with al layer.

External wall - PE foil with alumina layer				
Material from interior	d (mm)	μ (-)	s_d (m)	λ ($W.m^{-1}.K^{-1}$)
Gypsum board	12.5	8	0.10	0.22
Air cavity	40.0	0.25	0.01	0.222
Reflexive water vapour barrier with alumina film on the top	0.27	1100000	300.00	0.39
Lumber 50x150 mm	150.0	157	23.55	0.18
Mineral fibre board posts	150.0	2	0.30	0.041
Oriented strand board	12.0	300	3.60	0.13
EPS 70 F, glued by PUR	100.0	30	3.00	0.039
Glue and mastic ETICS	4.0	35	0.14	0.8
External plaster/colour on silicon base	3.0	50	0.15	0.86

Tab. 3: Structure of exterior wall with vapour barrier made of OSB board with two layer latex paint.

External wall - Latex paint OSB				
Material from interior	d (mm)	μ (-)	s_d (m)	λ ($W.m^{-1}.K^{-1}$)
Gypsum board	12 5	8	0.10	0.22
Latex coating	0 14	2 070	0.29	0.21
Oriented strand board	12 0	300	3.60	0.13
Lumber 50x150 mm	150 0	157	23.55	0.18
Mineral fibre board posts	150 0	1	0.15	0.039
MVD Mineral fibre board for exterior including lathing	150 0	1	0.15	0.041
Contact diffuse foil	0.5	40.00	0.02	0.39
Ventilated air cavity	60. 0	-	-	-
Wooden coating of facade	20.0	-	-	-

Tab. 4: Structure of exterior wall with natural OSB board vapour barrier.

External wall - Natural OSB				
Material from interior	d (mm)	μ (-)	s_d (m)	λ ($W.m^{-1}.K^{-1}$)
Gypsum board	12.5	8	0.10	0.22
Oriented strand board	12.0	300	3.60	0.13
Lumber 50x150 mm	150.0	157	23.55	0.18
Rock fibre thermal insulation	150.0	1	0.15	0.039
Rock fibre thermal insulation for facade	150.0	1	0.15	0.041
Contact diffuse foil	0.5	40.00	0.02	0.39
Ventilated air cavity	60.0	-	-	-
Wooden coating of facade	20.0	-	-	-

Building remote sensors technology

The main point of the research is to conduct real time, real life measurements to obtain temperature and relative humidity values on the surfaces of the structures described earlier, and also inside the external walls. The experimental timber framed house EXDR1 presented in this paper is assessed with the help of 50 sensors, which scan temperature and relative humidity values. 20 of these are monitoring the situation inside the wooden structural elements (timber columns and OSB's), 16 do measure ambient properties of indoor air and 14 are scanning temperature and relative humidity behind the vapour barrier in the wooden wall. They were installed in the house while it was under construction, so the structure was not damaged due the installation of sensors. The sensors for measuring temperature are 2-wire digital (2-wire refers to serial or I2C communication protocols. The sensors used are of I2C type) temperature and relative humidity meters – the Honeywell HIH-6031 which do have an accuracy up to 1.0°C and possibility to operate in the temperature range of -55 to +125°C. With respect to humidity measurements their range varies from 0-100 % and do have an accuracy of 4.5 % (the numbers are specified by manufacturer for the whole range of measurements). With preprocessing correction the accuracy of measurements in the range of 10 to 25°C is approximately 3 % of relative humidity and 0.6°C. The sensors work are operated by BRESET system based on Arduino and Raspberry Pi prototyping units, the so called ArduPi technology. Since the sensors are digital it is possible to read both temperature and RH values in real time (Bečkovský and Vajkay 2014). For observations inside the wood elements the ELBEZ system with anti-corrosive sensors for wood driers are used. The contacts and poles are fixed by screws.

RESULTS

Through the monitoring process of structures (also during 2013), structures which were properly designed and constructed, the changes in their compositions did not affect their hydrothermal behaviour. The major factor that influences the humidity of wooden elements is the actual moisture entering the structure from the exterior since the water vapour barrier functions well. Since the quantity of obtained data is quite large the results represented in the paper are an interpretation of a two-day period when the normal boundary conditions were met for residential buildings in the country.

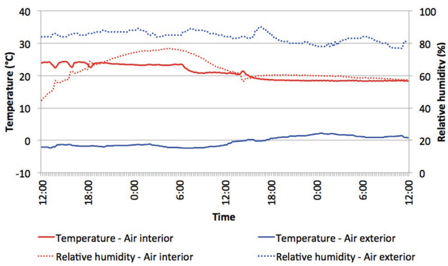

Fig. 5: Typical two-day review of boundary conditions.

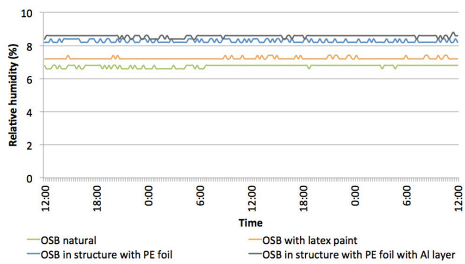

Fig. 6: Typical two-day review of humidity in the middle of OSB boards.

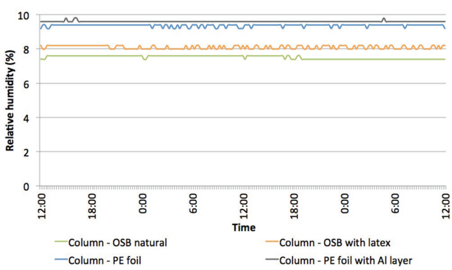

Fig. 7: Typical two-day review of humidity in the middle of timber columns.

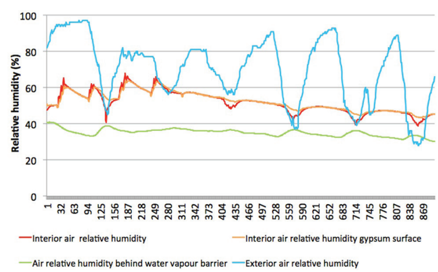

Fig. 8: Relative humidity of internal air at different positions.

The differences (Figs. 6 and 7) can be influenced by accuracy of the sensors. The only significant differences which were clearly recognizable can be connected to relative humidity of air inside. Its value was dependent on the position where the measurements were taken. In the next Fig. 8 the relative humidity levels are show in the middle of the room, near the surface of gypsum boards and behind the water vapour barrier. Because of the peaks the time scale is equal to one week.

Relative humidity of air behind the water vapour barrier reflects more or less the conditions acting in the exterior. This is however made possible, if the structure functions as it should on the basis of a superb design and provided construction works. Otherwise the chances of higher humidity a mould growth are going to be bigger. An aim of a new research topic is to monitor and describe the phase shift between humidity oscillations.

DISCUSSION

The measured data were used to assess the risk of humidity and mould growth (Viitanen and Ojanen 2007, Fedorik and Illikainen 2013). The completed data were used to analyse a mould growth risk in the defined points of the external wall. Two factors are included in the analysis. These are the temperature and the relative humidity. Fig. 9 shows the limiting isoplots for building materials while each of the point do represents a certain hydrothermal condition.

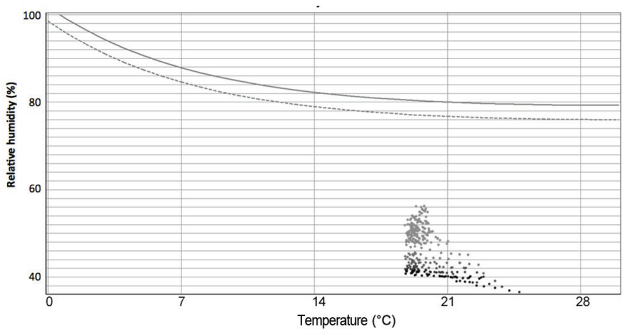

Fig. 9: Courses of limiting isoplots for building materials and the dots representing the hydrothermal conditions on an internal surface.

The main aim was to monitor four external walls of wooden houses, focusing on the comparison of diffusion open and closed construction. Due to the quality of construction, details and parameters of each material were not differences between structures in no way essential.

CONCLUSIONS

The design of the experimental timber framed house was subjected to experimental and numerical analysis of mould growth risk, with a full scale measurement on going since the end of 2012. The debate on whether the diffusion retarders should be used in the compositions of structures is still current and intensive. Nonetheless the only possibility to arrive at clearly definable conclusions was to do some measurements and analyse the obtained data. As is mentioned above, with a proper implementation of structural elements the risk of mould growth decreases. The verified data were used to analyse the risk of mould growth based on the theory published by Viitanen and Ojanen (2007). The risk of mould growth was verified on the basis of a years worth of reference data in the location of observed points. It was found out that relative humidity and temperature did not show a risk of mould growth during the period. Only wooden elements exposed to external climatic conditions were subjected to such a risk, though only in a small degree, and quite independently of the type of structure in terms of permeability to water vapour.

Further work should lead to an analysis of long-term monitoring of structures and parameters of risk. These experiments are considered as full scale experiments and also for testing in small climatic chamber for larger quantities of samples, whereas they can copy real climatic conditions.

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