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ANALYSIS OF THE DIFFUSIONAL PROPERTIES OF PERIPHERAL WALLS OF WOODEN HOUSES DURING EMW RADIATION EXPOSURE

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ABSTRACT

The article discusses the changes in diffusion properties of wood and wood-based materials. These changes are caused by excessive moisture content within the materials and the consequent possible attack by wood-destroying pests. Wood-destroying pests in this case are represented by microscopic filamentous fungi (i.e. mould), which slightly changes and deteriorates both, the characteristics of wood and wood-based materials, and the environment humans live in. This paper discusses the theory and application of microwave radiation and the experimental optimization of radiation to sterilize these biotic factors. Furthermore, the article describes the experiments conducted at the Faculty of Civil Engineering, demonstrating the results of sterilization process with regards microscopic fungi that occur in building materials. By analysing the results of the research, the optimum intensity of microwave emitters and necessary lengths of irradiation times were determined.

KEYWORDS: Moisture content, EMW radiation, water vapour, diffusional properties, OSB.

INTRODUCTION

Diffusely-open building envelopes are designed in a way that they might allow the movement of water vapour at a molecular level towards the exterior of a building object. Therefore, in case of diffusely-open structures the materials of choice must be suited for envelopes and they must be correctly positioned within the composition. Timber framed wooden houses are special in comparison to masonries, etc., because the envelope of these kinds of buildings is light and is formed from multi-layered structures only. Thus a huge emphasis is put on their proper design and construction, which should restrict the appearance of defects into the future. The envelope, especially the peripheral vertical structures (i.e. peripheral walls) of timber framed wooden houses may be designed diffusely-open or closed ones, whereas in diffusely-open structures foils as water vapour barrier are replaced by water vapour retarders, since water vapour retarders do limit the penetration of water vapour into the structure. This layer is usually based upon large-format building materials, which simultaneously acts as sheathing and bracing over the timber frames as well.

By limiting the water vapour diffusion by water vapour retarders in the peripheral structures of wooden houses means a restrictions to diffusion (movement of water vapour produced by the gradient of partial vapour pressure) and to the flow of moisture (water vapour movement caused by convection) (Novotný et al. 2014).

MATERIAL AND METHODS

Retarders from OSB

In case of OSB it handles about one of the most widely used large-format wood-based material on wooden building. Within the structure as a whole it functions as a reinforcing, bracing element, while in case of air tightness and diffusely-open systems it fulfils the function of a vapour-proof layer. OSB is a thin, slab kind of element consisting of large wooden chips (from English "Oriented Strand Board"), which are stacked (chips are positioned one on another in the oriented layers) and then pressed together with a binder. The most commonly used binder resins include phenol-formaldehyde (PF), melamine-formaldehyde resin (MF), methylene di-phenyl di-isocyanate-polyurethane resin (MDI) or isocyanate (PMDI), all of which are waterproof. In Europe it is common to use a combination of binders for the production of OSB, for example: PMDI in the core and MF for the outermost layers.

Whereas OSB is a wood-based material, its mechanical and thermal properties depend on humidity. Although it is stated that OSB/3 and OSB/4 do have a sufficiently high resistance against UV radiation and moisture, a significant increase in the value of relative humidity of indoor air might still result in a degradation of built-in OSB's, as well in technical failures. A negative impact of elevated relative humidity onto OSB manufactured by EGGER is shown in Tab. 1. The data represent a degradation of OSB in a wall caused by failure in the sewerage system (Chang et al. 2015).

Tab. 1: Changes in diffusion resistance factor and absorption of moisture at different levels of relative humidity (Source: Technical Data Sheets from Egger).

Product	**μ value at air relative humidity (-)**				
	16 %	**26 %**	**53 %**	**73 %**	**88 %**
OSB Egger Eurostrand OSB/3	251	240	178	165	129
	Moisture sorption at 20°C and relative humidity (M %)				
	30 %	**50 %**	**65 %**	**80 %**	**95 %**
	5.8	7.5	9.0	13.8	26.2

Tab. 2: Parameters of OSB – diffusion resistance factor and equivalent diffusion thickness (Source: from technical sheets published by manufacturers of OSB).

Manufacturer	Thickness (m)	μ_{wet} (-)	μ_{dry} (-)	s_d (m)
Kronopol/Kronoply OSB 3	0.012	200	300	2.4 – 3.6
Kronospan OSB/3	0.015	100	200	1.5 – 3.0
Kronospan OSB/4	0.015	150	300	2.2 – 4.5
OSB Airstop ECO	0.015	400	500	6.0 – 7.5
OSB Reflex ECO	0.015	150	170	2.3 – 2.5
OSB Egger Eurostrand OSB/3	0.012	200	300	2.4 – 3.6
OSB Sterling 3	0.012	107	219	1.3 – 2.6
OSB according standard EN 13 986: 2004 (density 650 $kg.m^{-3}$)	-	30	50	-

Note: It handles about data published by manufacturers of OSB, therefore the authors of the article assume that the boundary conditions of "web bowl" and "dry bowl" tests to obtain the diffusion resistance factors are normative.

Most of the available wood-based products are insulators and have a very low thermal conductivity. Nonetheless their thermal conductivity values are highly dependent on humidity, therefore the drying of these materials and structures if built-in is a must. Drying of wood-based structures that got excessively wet due to negative external influences, failures of installations, etc. (for example: Failures of plumbing and HVAC, floods) can be dried in several ways:

- Conventionally without the application of any technical equipment. It is a long-term process when the desired values are often achieved after years.
- Using various dehumidifiers, mainly ones having a condenser coil. This procedure is suitable for drying of surfaces, mostly local moisture issues in structures. Capillary transport of molecules of water from a depth of aspirated material is hastened and the time required for drying is considerably reduced. It is a process lasting several weeks or months.
- Drying using heat equipment. Different hot air apparatus, heat radiators, thermal probes, and the like are representatives of this category. Every equipment of this type heats up the whole structure, including both wet and dry parts of it. They are easy to manipulate, and it is relatively simple to calculate the amount energy required by the drying process with respect to various materials.
- Using microwave technology (EMW radiation).

Drying by EMV radiation

The water molecules although having a bi-polar character are electrically neutral Therefore, in an electric field each and every water molecule is oriented by the polarity (positive to negative and negative to positive), especially if the polarity alternates. This is precisely the case of microwave radiation. The polarity of the electromagnetic field varies depending on the frequency F, where the frequency can be higher than 109 times per second (Novotný et al. 2014, Sobotka et al. 2014).

At high frequencies of radiation (i.e. oscillating vibration) and the subsequent change in orientation of molecules of loosely bound water produces heat. The thermal energy is produced by friction of molecules. This phenomenon is called as polar rotation or polar friction. In a simple manner it can be described as follows, the entry of microwaves into the structures causes a rapid change in the polarity of molecules of loosely bound water, causing their rapid movement in the material. Because of this movement the particles themselves collide into each other, hence produce thermal energy. This process results in a conversion of water from liquid state into gaseous form, and its subsequent evaporation from the structure (Novotný et al. 2014, Šuhajda et al. 2008).

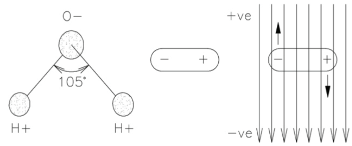

Fig. 1: Water molecule and its orientation in an electric field.

Advantages and disadvantages of EMW heating and radiation

The advantages of microwave radiation are:

- the so-called "Selective heating", i.e. by the radiation of multi-component structures only the materials absorbing microwave radiation are heated (i.e. materials containing loosely bound water);
- velocity of drying;
- lower energy and financial requirements in comparison with hot-air drying.

The only known disadvantage of microwave radiation application is:

- the possibility of local overheating due to inhomogeneity of the microwave field and the material itself (Novotný et al. 2014).

In terms of interaction of building material EMW radiation there are three possible outcomes. The material is either:

- transparent – radiation passes through the material without any reaction
- absorbing – radiation is converted to thermal energy
- reflecting – radiation is reflected back into the environment

For building practice the interaction of microwaves with water is the most important factor. The conversion of microwave energy into thermal energy, heat can be determined using the following relationship:

$$P=2.\pi.f.\varepsilon'.\varepsilon''.E^2 \qquad (1)$$

where: P - energy absorbed per unit volume (W.m^{-1}),
f - frequency microwave field (2450 MHz),
ε' - permittivity (F.m^{-1}),
ε'' - dielectric loss factor of the material,
E - electric field intensity inside the material (V.m^{-1}).

Diffusion properties test

The observations for the determination of diffusion properties of building materials was carried out according to standard "EN ISO 12572: 2001 - Hygrothermal performance of building materials and products - Determination of water vapour transmission properties", whereas the methodology described in this particular standard is suited for for both hygroscopic and non-hygroscopic (including plated ones as well) building materials. While measuring diffusion properties of buildings materials, temperature, humidity, homogeneity and porosity of the test sample, might influence the results at a huge rate. For wood-based materials diffusion properties also depend on the production procedure and choice of base materials (Sonderegger et al. 2009, 2012).

The essence behind tests of this type is to place the test samples on top of a cup with a sealed edge. Inside the bowls must be a kind of sorption medium – SILICAGEL in case of test cases described, the quantity of which is based on boundary conditions of the experiment. The entire test assembly was then placed into a climatic chamber, allowing total control over the relative humidity and temperature of air. With the differences in pressures inside and outside of the test assemblies water vapour moves through the tested samples. Subsequently the test assemblies were weighed at regular intervals according to ISO EN 12572: 2001.

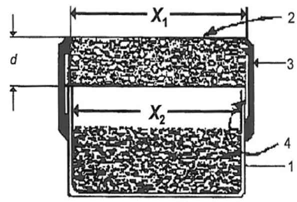

Fig. 2: Scheme of the test specimen.
(Explanations: 1. drying agent, 2. test sample, 3. sealant, 4. Sealing tape, X1/X2 Area of the a samples upper / lower plane, d. thickness of sample).

The experimental samples were prepared by cutting up two sets of OSB's obtained from two manufacturers, to ensure that the results might be comparable. The production numbers of OSB's were A2360, A2380 from the first of the producers and B2360, B2380 from the second. Six samples were tested from each production batch. Therefore, the experiments were provided on 24 samples. At the beginnings all of the samples were conditioned to constant weight. Then the test samples were sealed into a glass jar and were relocated into a climatic chamber. The relative humidity and temperature of air were set to: 60 % and 23°C for samples from productions batches A2360 and B2360, and 80 % / 23°C for samples coming from production batches with numbers The relative humidity and temperature values of indoor air do correspond to real life conditions in buildings. For example: 60 and 80 % of relative humidity can be measured in living spaces and bathrooms, respectively.

Slightly before the experiments described above took place, another set of samples (4 x 6 pcs, altogether 24 pcs) were tested for their moisture resistance capabilities in accordance with "EN 321: 2001 - Wood-based panels - Determination of moisture resistance cycling". The entire test had a total of three cycles, with each cycle having four parts. In the first part the samples were put into a water bath filled with fresh water for 70 hours. The pH value of the water was determined to have pH 7, and its temperature was 20°C. Then the test specimens were removed from the water bath and after the drip were placed into the climatic chamber set to -20°C. This freezing test lasted for 24 hours and was followed by the third part of the cycle, when the test samples are stored in an oven for 70 hours under a temperature load at 70°C. The final part of the cycle was about cooling of tested samples in a space with ambient temperature of 20°C. This process lasted for 4 hours (EN ISO 321: 2001).

This test was followed by a drying process incorporating EMW (microwave) radiation with a power level of 750 W lasting for 25 minutes. The irradiated samples were then subjected to diffusion test in the climatic chamber with a relative humidity of 60 % (samples A2360M and B2360M, where M stands for EMW irradiation).

For each set of sequential weighing of test sample the rate of mass change Δm_{12} was determined as:

$$\Delta m_{12} = \frac{m_2\text{-}m_1}{t_2\text{-}t_1} \tag{2}$$

where: Δm_{12} - weight change per time of each determination (kg.s^{-1});
m_1 - weight test setup time t_1, (kg);
m_2 - weight test setup time t_2, (kg);
t_1, t_2 - times consecutive weighing (s).

δ_a value was determined from average atmospheric pressure continuously throughout the duration of experiments from the Schirmer formula.

$$\delta_a = \frac{0.083\rho_0}{R_v \times T \times \rho}\left(\frac{T}{273}\right)^{1.81} \tag{3}$$

It is believed that the diffusion coefficient of conductivity of air and the material varies uniformly with changes in atmospheric pressure. Therefore, it can be assumed that diffusion resistance factor μ depends on atmospheric pressure. The formula below explains the determination of density of diffusion flux of water vapour.

$$g = \frac{\Delta\rho \times \delta_a}{\mu \times d} \tag{4}$$

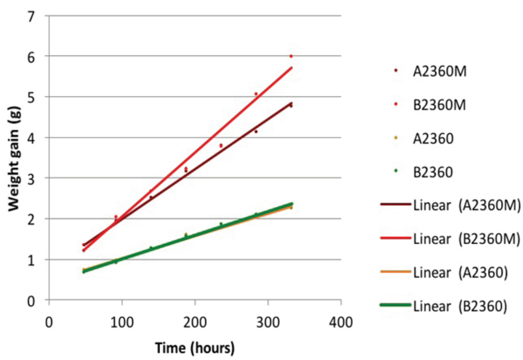

Fig. 3: Weight gain through time for different sample sets.

RESULTS AND DISCUSSION

Numerical model of timber framed peripheral wall

The computer simulations were provided in WUFI Pro software. WUFI Pro makes it possible to simulate heat and moisture propagation in building structures in a dynamic way. Throughout the simulation the properties of two timber framed peripheral wall structures were observed. These were:

- diffusely-open structure with a water vapour retarder layer out of OSB,
- and a diffusely-close structure with foil as a water vapour barrier.

Both compositions were dealt with in two stages, before and after exposure to EMW radiation.

As external boundary conditions, data from reference climate year in the Czech Republic were input into the simulations. The simulations were carried out for the OSB samples described earlier. In both cases various water vapour diffusion resistance factors were taken into consideration, which were decreasing due to exposure to EMW radiation. For comparison, the calculations included a reference OSB sample with value declared by the manufacturer.

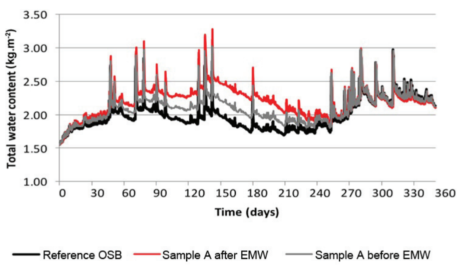

Fig. 4: Total water content in a diffusely-open timber framed wall structure throughout the year (Expl.: Sample A –A2360M, EMW – microwave radiation).

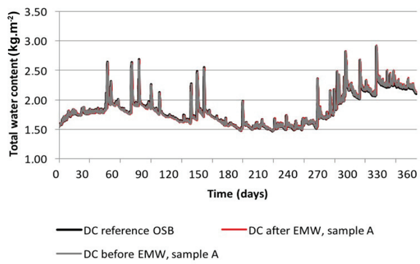

Fig. 5: Total water content in a diffusely-closed timber framed wall structure throughout the year (Expl.: Sample A –A2360M, EMW – microwave radiation).

Diffusion resistance factors μ (-) used throughout the simulations are listed in Tab. 3.

Tab. 3: OSB Diffusion resistance factors for numerical simulation.

	Diffusion resistance factor μ (-) before EMW radiation	**Diffusion resistance factor μ (-) after EMW radiation**	**Diffusion resistance factor μ (-) reference OSB**
A2360M	124	68	300
B2360M	140	82	300

Figs. 4, 5 shows that microwave radiation has a detrimental effect on the diffusion properties of OSB. Vapour diffusion resistance factor after exposure to radiation dropped to 30 % of the reference value (stated by the manufacturer). Simultaneously, from charts Figs. 4 and 5, it can be seen that due to impairment of diffusion resistance factor the total amount of water content in the diffusely-open structure increases. The peaks that occur in the critical months of the climatic reference year there may be an increase of almost 0.5 $kg.m^{-2}$.

CONCLUSIONS

Given the results of experiments it was found out that EMW radiation negatively influences the building physical characteristics of wood based materials and wood based structures.

Especially when the EMW radiation is used for drying of originally wet/moist elements. An exposition of these dried structures to high humidity sometimes later, it might come to a deterioration of their building physical parameters, including the diffusion resistance factor of each and every element within their compositions as well. This might bring about an increase of water content in the structure, and also in a higher probability of water condensation and mould growth risk. Whereas it handles about an issue which was not researched into depth yet, the evaluation of results and formulation of conclusions is kind of problematic because of the missing methodologies.

On the contrary, in the diffusely-closed composition the changes in diffusion properties does not effect the total amount of water content in the structure. It is caused by the fact that in case of the diffusely-closed structure the water-proof barrier is composed of a water vapour barrier foil. Hence the structure isn't threatened by humidity when the diffusion resistance of OSB drops. It turns out that they have a reinforcing effect. Nonetheless, once exposed to microwave radiation the mechanical properties of these materials should be verified as well, since they might be affected negatively by the EMV radiation.

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REFERENCES

1. Chang, S.J., Kim, S., 2015: Hygrothermal performance of exterior wall structures using a heat, air and moisture modelling. Energy Procedia 78: 3434-3439, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2015.12.328.
2. EN ISO 12572 – 2001: Hygrothermal performance of building materials and product – Determination of water vapour transmission properties.
3. EN ISO 321: 2001-2002: Wood-based panels - Determination of moisture resistance under cyclic test conditions.
4. Hukka, A., Viitanen, H.A., 1999: A mathematical model of mould growth on wooden material. Wood Science and Technology 33(6): 475-485.
5. Novotný, M., Šuhajda, K., Sobotka, J., Gintar, J., Šuhajdová, E., Mátl, M., 2014: Use of microwave radiation in building industry through application of wood element drying. Wood Research 59(3): 389-400, ISSN 1336-4561,
6. Sobotka, J., Novotný, M., Šuhajda, K., 2014: Masonry structures drying technology. In: contribution to the conference Rehabilitation and reconstruction of buildings 2014 conference proceedings (a series of lectures from conferences) CRRB - 16th International Conference on Rehabilitation and Reconstruction of Buildings, Scientific and Technical Society for redevelopment construction and maintenance of monuments - WTA CZ, BRNO, ISBN 978-80-02-02539-9.
7. Sonderegger, W., Niemz, P., 2009: Thermal conductivity and water vapour transmission properties of wood-based materials. European Journal of Wood and Wood Products 67(3): 313-321, Online ISSN 1436-736X.

8. Sonderegger, W., Niemz, P., 2012: Thermal and moisture flux in soft fibreboards. European Journal of Wood and Wood Products 70(1-3): 25-35, Online ISSN 1436-736X.
9. Šuhajda, K., Novotný, M., Škramlik, J., 2008: Monitoring of effectivity of microwave desiccation by means of rod plug-in antenna. The e-Journal of Nondestructive Testing, ISSN 1435-4934, Journal & Exhibition of non destructive Testing, Kirchwald, Germany. Pp 4-8.
10. Viitanen, H., Krus, M., Ojanen, T., Eitner, V., Zirkelbach, D., 2015: Mold risk classification based on comparative evaluation of two established growth models, Energy Procedia 78: 1425-1430, ISSN 1876-6102, http://dx.doi.org/10.1016/j.egypro.2015.11.165.

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