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THE EFFECT OF TEMPERATURE/MOISTURE CONDITIONS IN CLADDING OF WOOD-BASED BUILDINGS ON THEIR RELIABILITY AND SERVICE LIFE

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ABSTRACT

The service life and reliability of buildings and constructions of wood and of wood-based materials are substantially influenced by the moisture content in these materials. One of the natural properties of wood and wood-based materials is their soaking capacity or hygroscopicity. The wood in wooden frame cladding changes its moisture content depending on temperature and moisture conditions of the environment it is built into. The equilibrium moisture content has a decisive influence on the below-mentioned basic requirements placed on building constructions. Common heat-technical assessment can thus be considered as not fully sufficient as to discover these influences on the reliability and service life of wood-based constructions and buildings.

This article contains the results of wood moisture content measurements taken in wooden cladding samples placed between air-conditioned chambers. The measured values are subsequently compared to the values calculated using our newly proposed method based on construction moisture balance according to the ČSN 730540 standard.

KEYWORDS: Wood moisture content, temperature and environment humidity, reliability, service life.

INTRODUCTION

The equilibrium moisture content of wood built into the cladding influences certain basic requirements cited in the annex 1NV No. 163/2002 Coll. as amended by NV No. 312/2005 Coll. respectively, No. 190/2005 Coll., subsequently amended. With today's trend towards increasing heat-insulation parameters of cladding intended to reduce the energy consumption needed for heating, it is important to take into account that building construction is, at the same time, also to comply in a reliable way with other basic requirements. An increase in heat-insulation properties of those constructions should therefore be conducted with respect to these requirements. When increasing one of the properties relating to the basic requirements, a reduction in the functional reliability of constructions and buildings regarding the basic requirements must not occur. The adequate service life or durability of wooden construction and buildings must be ensured. (ETAG 007 Guideline for European Technical Certification, see art. 4.7.1 – Wooden Frame Building Assemblies.) From the point of view of durability, the design of a wooden frame building structure must ensure that the materials and parts wear during their expected service life would not significantly influence the behavior of the entire assembly with regard to compliance with basic requirements 1 – 6.

The design and production of reliable wooden framing requires above all a good knowledge of wood as a construction material that means, primarily the knowledge of its properties depending on an environment it is built in. These can often have an absolutely decisive influence on complying with the basic following requirements placed on buildings:

Basic requirement 1 - Mechanical resistance and stability

According to the classification of a construction element into one of the utilization classes and also according to the class of load duration, the strength properties of the material are modified by a modification coefficient k_{mod}, which lowers the strength of wood in the function of its rising equilibrium moisture content. (see Tab. F. 1 in ČSN 73 1702 standard). In this case the impact of moisture content will not be as important as it would be in the case of assessment of the construction according to its limiting state of usability, when the time-dependent creeping deformations must be taken into account. Here, the initial deformation must be multiplied by the coefficient $(1+k_{def})$ where k_{def} is a coefficient related to the wood moisture content (Tab. 2 of the standard).

The wood moisture has therefore a demonstrably important influence on basic requirement 1.

Basic requirement 3 – Hygiene, health and environment protection

The construction must be designed and built in such a way so that it wouldn't pose a threat to hygiene and health of its dwellers, mainly due to (among others):

Occurrence of moisture in parts of the construction or on the interior surfaces of the building.

The moisture content in wood has a demonstrably important influence on the basic requirement 3 and also on the durability and service life of the construction.

Basic requirement 6 – Energy saving and protection of heat

A building and its heating, cooling and ventilation equipment must be designed and built in such a way so that the service energy consumption would be low with regard to the climatic conditions of the place and the requirements of its users.

Because the moisture content in wood significantly influences heat conductivity of wood it has therefore a demonstrably important influence on basic requirement 6.

Contemporary method of construction assessment according to the ČSN 73 0540 standard

Obligation to assess the construction from the point of view of vapor condensation and moisture propagation in constructions is set by the ČSN 73 0540-2 art. 6. 1. The condensation inside the construction is not admitted for a construction where the condensed vapor inside it could pose a threat to its required function: $M_{c,a} = 0$

For a construction where the condensed vapor does not pose a threat to its function, there is a limitation requirement of the annual volume of water vapor condensed inside the construction that must comply with the following condition: $M_{c,a} \leq M_{c,N}$

The decision on whether the vapor condensation inside a construction does or does not pose a threat to its required function is left to the designer. The corresponding ČSN standard doesn't contain any further detailed procedures for his qualified decision.

MATERIAL AND METHODS

Suggestion for method of evaluating the requirement 1

We are building on the premise that the thermal insulation made of mineral fiber can be considered a system composed of air capsules separated by fiber structure. While the fiber structure significantly restricts the transport of water vapor by convection, the transport of water vapor by diffusion does occur in an amount proportional to the diffusion resistance of the material. Each element of the wooden framework is then, within each layer of fiber thermal insulation, exposed to a different environment with a different calculated layer temperature and calculated partial pressure of water vapor in the given layer.

Wood is a hygroscopic material capable of changing its moisture content in relation to the temperature and moisture content of the surrounding environment. The moisture content in wood stabilized at given environment conditions (relative humidity and temperature of air) is called equilibrium moisture content of wood (EMCW). The achieved state is than called state of moisture equilibrium (SME). With each change in relative humidity and temperature of air, the equilibrium moisture content of wood also changes. If the moisture content of wood is lower than SME the wood adsorbs water in the form of water vapors from surrounding environment until it reaches the state of moisture equilibrium. If the moisture content in wood is higher than SME, the process inverts and the wood begins to lose water which we call desorption. This process of change of wood moisture content as a function of the relative humidity and temperature of air is reversible but doesn't follow the same curve. At the same relative humidity and temperature of air, the moisture content is higher during desorption than during adsorption by 2.5–3.5 %, at a span of air relative humidity RH 30 % – 90 %. (Gandelová et al. 2002). This can lead us to the assumption that the measured values of equilibrium moisture content of the wooden framework inside the cladding would oscillate in comparison to the calculated values within the span of approx. ± 1.5 %.

To interpret requirement 1 (art. 6.1 a 6.2 in ČSN 730540–2 standard) first at the interfaces between the layers of the cladding, or in other places where the wooden framework or wood-based construction boards are built into the cladding, we set, by calculation according to the ČSN 73 0540 standard considering one-dimensional conduction of heat and moisture, the temperatures and partial pressures of water vapor and saturated water vapor. From those values we calculate the relative humidity of air in the surrounding environment in a given place. Out of the temperature and relative humidity of the surrounding environment we can then derive the supposed wood moisture content in the given zone of the construction using for example Tchulicky's nomogram. From the span of such calculated values of wood moisture equilibrium in the cladding, we can reliably categorize the assessed construction into a relevant utilization class (Havířová 2006, Havířová and Kubů 2005a, Havířová and Kubů 2005b, Havířová and Kubů 2006). We can also reliably specify the thermal conductivity of wood in the framework. If it is possible to reliably categorize the corresponding construction of cladding into the utilization class 1 or 2 according to the ČSN 73 1702 standard and prove that the equilibrium moisture content would, in the whole of the respective zone, comply with the value $w_m \leq 20$ %, it is possible to consider requirement 1 see art. 6.1 a 6.2 in ČSN 730540 standard as accomplished.

Measuring the equilibrium moisture content in real wooden frameworks of outer cladding

The measurement of equilibrium moisture content in diffusion-open cladding constructions was carried out in air conditioned chambers of the accredited test laboratory of the Center of Building Engineering in Prague.

The central intertie of the sample (dimensions 2100 x 2500 mm) was first equipped with wood moisture sensors with temperature compensation WS-16T that were then connected via shielded cables to the Elbez MS3+ data hub.

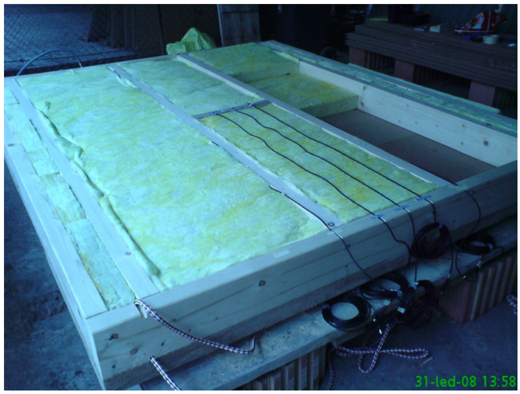

Fig. 1: Test sample of cladding with built-in wood moisture content sensors.

Fig. 2: Test sample placed in the air-conditioned chambers of CSI a.s. Prague.

The measurements were taken at two types of diffusion-open constructions of cladding. The composition and distribution of sensors see Figs. 3 and 4.

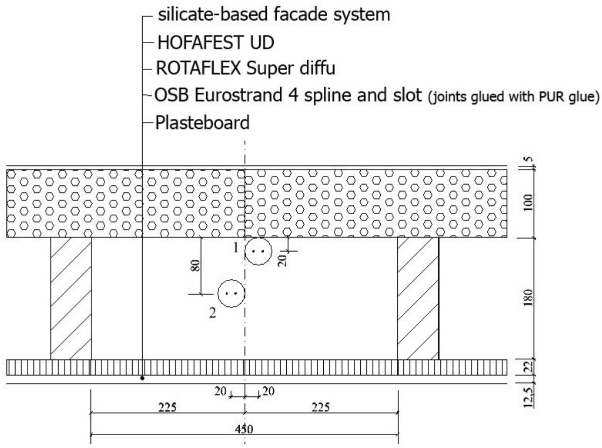

Fig. 3: Sample of a Diffuwall® system cladding, characteristic sector with the distribution of sensors (mm).

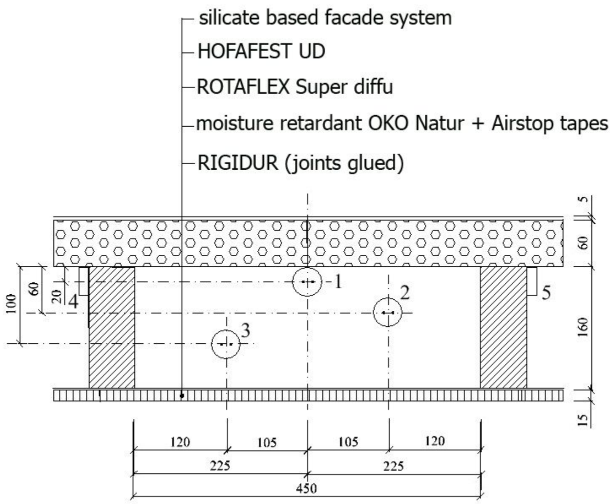

Fig. 4: Sample of a Rigips – diffuwall cladding, characteristic sector with the distribution of sensors (mm).

RESULTS AND DISCUSSION

The test samples were exposed during a period of 14 days to the temperature conditions typical for the habitable rooms in winter. Marginal conditions of measurement including the measured values see Tabs. 1 and 2.

Tab. 1: Marginal conditions and measured equilibrium moisture contents of wood in the Diffuwall® system.

Interval: from 2nd January 2007 12:26:27 till 23rd January 2007 8:07:50

Channel	Minimum	Maximum	Average	Decisive variation	No. of samples
Ch. 1 Moist. W [%]	4.8	10.6	6.1	1.8	456
Ch. 2 Moist. W [%]	6.0	15.6	7.4	1.9	456
Ch. 12 T_in [°C]	18.4	21.2	20.2	0.5	456
Ch. 13 RH_in [%]	24.9	73.8	49.8	12.7	456
Ch. 14 T_out [°C]	15.6-	30.2	-9.5	12.8	456
Ch. 15 RH_out [%]	21.2	70.6	47.1	9.1	456

Tab. 2: Marginal conditions and measured equilibrium moisture contents of wood in the Rigips-diffuwall system.

Interval: from18th February 2008 13:00:22 till 7th March 2008 9:06:50

Channel	Minimum	Maximum	Average	Decisive variation	No. of samples
Ch. 1 Moist.W [%]	7.6	12.1	7.8	0.3	336
Ch. 2 Moist.w [%]	6.6	11.4	7.2	0.4	336
Ch. 3 Moist.W [%]	6.0	11.0	6.8	0.5	336
Ch. 4 Moist.w [%]	4.6	11.4	5.2	0.4	336
Ch. 5 Moist.w [%]	4.5	10.6	4.8	0.3	336
Ch. 12 T_in [°C]	19.5	21.0	20.6	0.1	336
Ch. 13 RH_in [%]	15.4	87.4	67.1	4.4	336
Ch. 14 T_out [°C]	15.1-	22.9	-14.5	3.0	336
Ch. 15 RH_out [%]	14.9	59.5	44.6	2.5	336

From the measured values of equilibrium moisture content of wood in wooden framework, it is evident that at both of these diffusion-open constructions, the equilibrium moisture content of softwood of 20 % was not exceeded even under very unfavorable conditions.

Subsequently, we are going to compare the measured values of wood moisture content with the values set according to the proposed way of assessment of wooden frameworks in view of criterion 1. For this purpose, intervals of approx. from 36 to 48 h were selected out of the whole set of measured values, capable of being considered as a quasi-stabilized state of moisture equilibrium of the wooden construction. The values measured in the end of such quasi-stabilized state were then used for the calculation of temperatures and partial pressures development in the construction according the method of the ČSN 730540 standard see Figs. 5, 6, and Tabs. 3, 4. With the test-sample of Rigips-diffuwall, the sensors 4 and 5 were situated in the so-called compensation zone. The values measured by these sensors were eliminated from further evaluation.

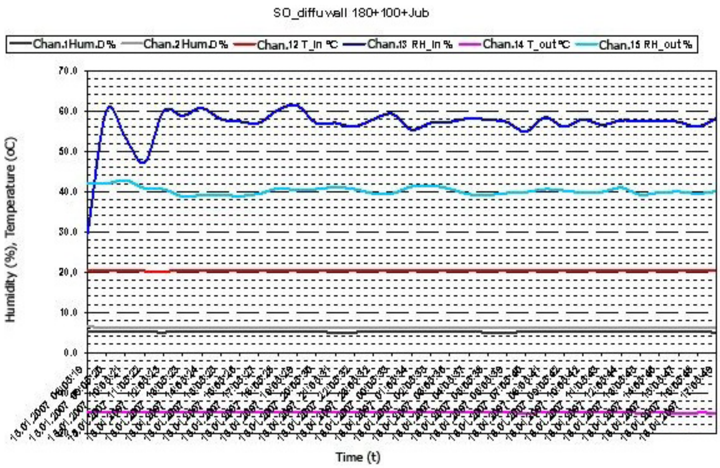

Fig.5: Diffuwall® – development of temperature and humidity – quasi stabilized state.

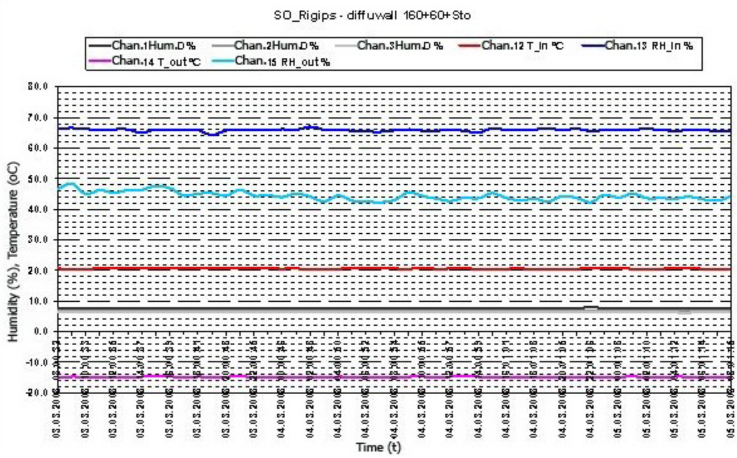

Fig. 6: Rigips-diffuwall – development of temperature and humidity – quasi stabilized state.

Tab. 3: Diffuwall 180+100+Jub_ measured values – quasi stabilized state.

Date and time	Channel 1 moist. D	Channel 2 moist. D	Channel 12 T_in	Channel 13 RH_in	Channel 14 T out	Channel 15 RH_out
	%	%	°C	%	°C	%
16.01.2007 17:05:49	5.0	6.2	**20.3**	**58.1**	**-15.0**	**40.1**

Tab. 4: Rigips-diffuwall 160+60+Sto_measured values – quasi stabilized state.

Date and time	Channel 1 moist. D	Channel 2 moist. D	Channel 3 moist. D	Channel 12 T_in	Channel 13 RH_in	Channel 14 T_out	Channel 15 RH_out
	%	%	%	°C	%	°C	%
05.03.2008 08:01:15	7.9	6.9	6.3	20.6	65.4	- 14.7	44.3

Subsequently, the course of partial pressures of water vapor and temperatures inside the construction were calculated for these values of temperatures and relative humidities of interior and exterior air according to the method in the ČSN 73 0540 standard. To such calculated values, the corresponding equilibrium moisture contents of wood were then assigned; see nomogram of equilibrium moisture content of N.N. Tchulicky (Perelygin 1965).

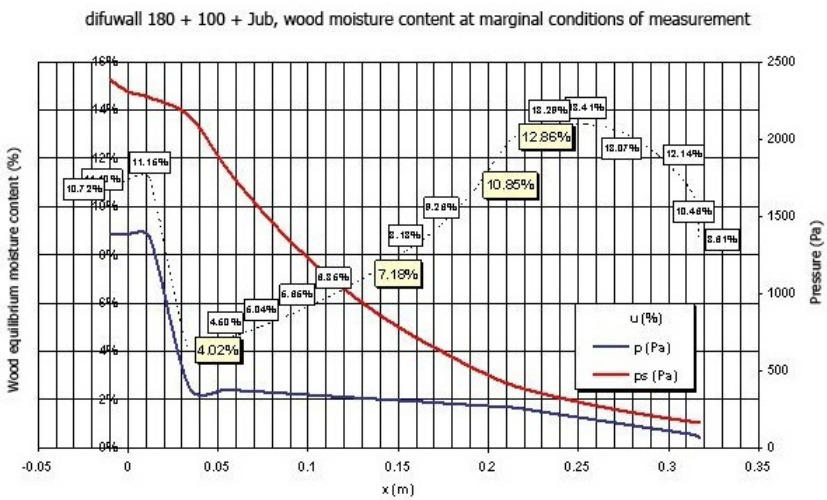

Fig. 7: Equilibrium moisture content of wood determined from the course of partial pressures of water vapor and temperatures at marginal conditions in the air-conditioned chambers.

Highlighted values of wood moisture content correspond to the inner and outer side of the wooden framework and to the distribution of sensors inside the test sample. Sensor 2 placed in 80 mm distance form the exterior side of wooden framework measured the wood moisture content of 6.2 %. The wood moisture content value calculated from the relative humidity of air and temperature in the given place is 7.2 %. Approximately in the middle of the wood framework section, the difference between measured and calculated value reaches 1 %. From the point of view of the equilibrium moisture content, the calculated value is on the safe side. Sensor 1 measured approximately half the value of the wood moisture content compared to the calculated one. It is necessary to take into account that the sensors, including their cables, are placed into the cladding sample weighing approximately 250-300 kg during its production. During the subsequent handling, transport and situating of the sample into the test-chamber, a failure of sensor or of its connection may occur. Its repair or replacement is not possible without the destruction of the entire sample. The values measured by the sensor 1 were therefore excluded from further evaluation.

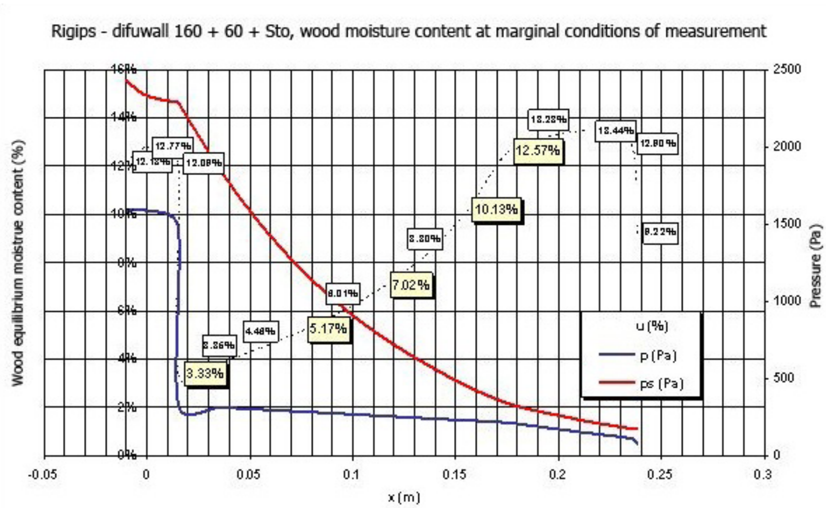

Fig. 8: Equilibrium moisture content of wood determined from the course of partial pressures of water vapor and temperatures at marginal conditions in the air-conditioned chambers.

Sensor 2 placed in 60 mm distance form the exterior side of wooden framework measured the wood moisture content of 6.9 %. The wood moisture content value calculated from the relative humidity of air and temperature in a given place is 7.02 %. Approximately in the middle of the wood framework section, the difference between measured and calculated value is negligible. Sensor 1 measured the moisture content of 7.9 %. The moisture determined by calculation is 10.1 % Sensor 3 measured the moisture content in a quasi stabilized state of 6.3 %. The moisture content determined by calculation for this interface is 5.2 %. Once again, the measured and calculated values are those from the approximate center of the wood frame section. Lower moisture gradient across the framing section seems to correspond to the re-distribution of the moisture within the wood.

For the assessment of the cladding structures according to requirement 1 see art. 6.1 a 6.2 in ČSN 730540 standard it is necessary to re-calculate the course of temperatures, partial pressures of water vapor and corresponding equilibrium moisture contents to the marginal conditions of interior and exterior environment according to the mentioned standard see Figs. 9,10.

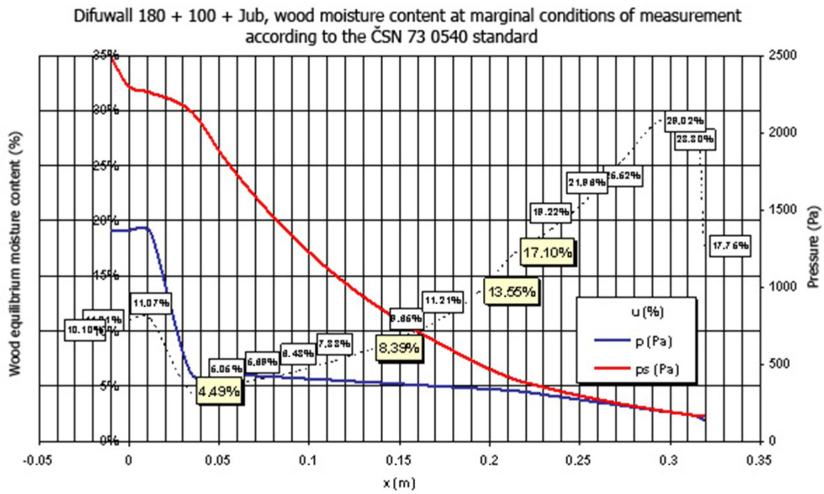

Fig. 9: Equilibrium moisture content of wood determined from the course of partial pressures of water vapor and temperatures at marginal conditions according to the ČSN 73 0540 standard.

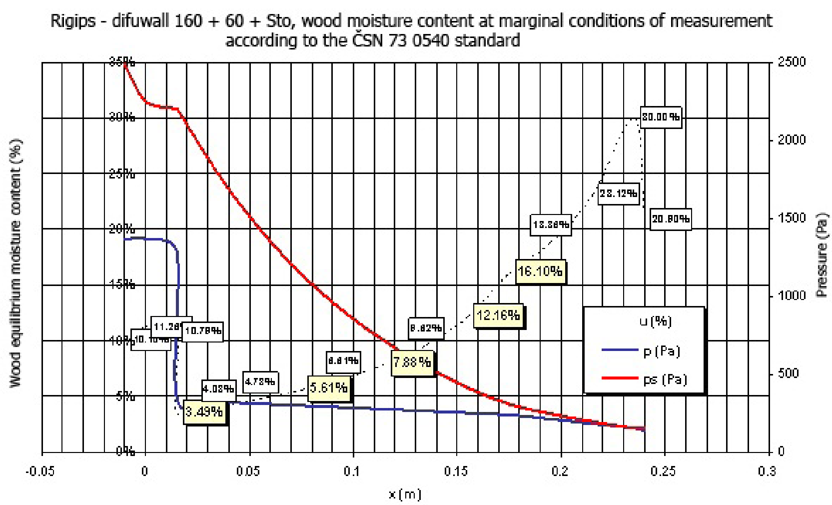

Fig. 10: Equilibrium moisture content of wood determined from the course of partial pressures of water vapor and temperatures under marginal conditions according to the ČSN 73 0540 standard.

The calculated values of equilibrium moisture contents in wooden framework under marginal measurement conditions correspond with sufficient accuracy to the equilibrium moisture contents measured in wooden framework placed in the air-conditioned chamber. The course of partial pressures of water vapor at marginal conditions of temperature and relative humidity, mainly in exterior environment, doesn't entirely correspond to the marginal conditions of real exterior environment. Although the air-conditioned chamber simulating the exterior environment during winter is able to keep the air temperature at te -15°C. It is impossible to reach higher relative humidity at this temperature than approx. 45 %, due to the limited available space of the chamber. Otherwise the vapor condensates on the stainless steel surface of the chamber. In order to reliably evaluate the requirement 1 (6.1 a 6.2 v ČSN 730540) we have to set the design calculation conditions equal to the aforementioned standard by the means of calculation of equilibrium moisture contents in wood built into the construction. Such calculated values let us state that at the diffuwall cladding construction, the maximum mass moisture content of wood during winter does not rise above 17 % while at the Rigips-diffuwall cladding construction, the maximum mass moisture content of wooden framework stays below approx. 16 %. This evaluation is valid for thermal zone with exterior air temperature of - 15°C.

CONCLUSION

The aim of the measurements and calculation assessments carried out was to check whether it is possible to verify the supposed equilibrium moisture content of wood within this construction out of the heat-technical assessment of the construction in question and evaluation of moisture content balance according to current technical standard. At diffusion-open constructions, where no vapor condensation is taking place within the zone of wooden framework, we are able to state that, based on comparison of measured equilibrium moisture content values of wooden framework of the cladding and the values of equilibrium moisture content set using the calculated course of temperatures and partial pressures within the constructions, they can be reliably placed into the Utilization class 2 according to ČSN 73 1702 standard or EUROCODE 5. With the view of the average equilibrium moisture content value of wooden framework profiles, we could consider also placing them into the Utilization class 1, according to the above mentioned technical standards.

ACKNOWLEDGMENTS

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