Cent. Eur. For. J. 69 (2023) 126–131 sciendo DOI: 10.2478/forj-2022-0018
CENTRAL EUROPEAN Forestry Journal

ORIGINAL PAPER

Effect of larch wood extractive leaching on accelerated weathering aging durability of oil-based coatings

Ondřej Dvořák, Monika Sarvašová Kvietková*, Petr Horák, Kryštof Kubista, †Miloš Pánek, Irena Štěrbová

Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Kamýcká 129, CZ-16500 Praha 6 – Suchdol, Czech Republic

This paper as well as the entire special issue is dedicated to the memory of assoc. prof. Ing. Miloš Pánek, PhD., who significantly contributed to the development of science and research in the forestry and wood-processing industry. Through his teaching and publishing activities, he tirelessly passed on his knowledge to students and the wider scientific community. As a member of the "Central European Forestry Journal" editorial board, he significantly contributed to the improvement of this periodical. Thanks to his human and professional qualities, he was an example and an inspiration for us. Miloš, we will never forget you.

Abstract
Wood is a natural material and is subject to degradation due to weather, UV radiation, and humidity. Wood is composed of many components. The basic structural elements of wood include cellulose, hemicellulose, and lignin. Furthermore, these are accompanying substances, which also include extractive substances. Specifically, these substances, together with lignin, have a negative effect on its life thanks to their chemical reactions, which are initiated mainly by UV radiation (so-called photodegradation). This study evaluates the effect of controlled degradation of extractives and lignin on the surface of the wood before the application of the coating system and also on its overall service life. Samples of larch wood (*Larix decidua* Mill.) were exposed to exterior natural influences in Prague (Czech Republic) according to EN 927–3 (2020) for 10 and 20 weeks. Subsequently, the samples were sterilized in an autoclave, due to possible contamination of the surface with fungi. The specimens were then treated with two oil–coating systems (V–420 and V–429). Subsequently, they were exposed to artificial aging in a UV chamber according to EN 927–6 (2019). Testing occurred at predetermined time intervals of 0, 1, 3, and 6 weeks, roughly corresponding to 0, 2, 6, and 12 months outdoors. The evaluated factors were the change in color, gloss, and surface wettability. The results showed a slightly positive effect of surface washout lasting ten weeks before applying the coating system.

Key words: durability; finish; exterior; larch; leaching; wood components

Editor: Tomáš Gergeľ

1. Introduction

Wood is one of the most popular materials for both interior and exterior use (Sarvašová Kvietková et al. 2021). It is a natural material with a particular chemical structure, which is characterized by its biodegradation and aging under the action of abiotic and biotic factors (Matsuo et al. 2011; Tomášková et al. 2021). Abiotic factors most often include UV and VIS (visible radiation) radiation, rainwater, wind, temperature, and humidity changes, dust, and also their mutual combination (Cristea et al. 2010). An increase in resistance to these influences is therefore desirable, thereby prolonging the original appearance of the material, as well as its overall durability. According to the standard, the natural durability of wood can be divided into different grades (1–5) (EN 350 2019). It varies according to the type of wood, specifically depending on the anatomical structure, the content of extractive substances, tannins, and other accompanying substances that increase wood's natural resistance against biotic and abiotic pests (Reinprecht 2008). When wood is exposed to the exterior, however, these substances are washed away over time, and the wood begins to degrade from the point of view of physical and mechanical properties

*Corresponding author. Monika Sarvašová Kvietková, e-mail: kvietkova@fld.czu.cz
© 2022 Authors. This is an open access article under the CC BY 4.0 license.

visually and physically (Pánek et al. 2014). The visual characteristics include mainly the graying of the wood and the plastic texture. In terms of structure, lignin and polysaccharides in wood (hemicellulose, cellulose) are degraded (Myronycheva et al. 2018).

Lignin is chemically less stable than cellulose and has high light absorption (Gandelová et al. 2002). This is a crucial property that has implications for the durability of coating systems (Šimůnková et al. 2019). It mainly degrades by photolysis and photooxidation (Tolvaj et al. 1995). Under the influence of UV radiation, the proportion of carbonyl and carboxyl groups in lignin increases at the expense of hydroxyl and methoxyl groups (Feist et al. 1990; Xie et al. 2013). Decomposition products of lignin (organic acids, vanillin, syringaldehyde, and various higher molecular substances) are polar with water and are washed out of the wood (Pánek et al. 2016). Interesting findings also include the conclusion that visible light with a wavelength above 400 nm does not cause the darkening of lignin, as it does with UV radiation. Still, on the contrary, it's fading (Reinprecht 2008).

The hydrolysis of polysaccharides is also important from the point of view of the resistance of wood in the exterior. Hydrolysis would be minimal if it took place in pure water (Kim et al. 2020). On the exterior, however, there is water containing dust particles, microorganisms (for example, mold), and various types of emissions that change the PH of the water (Petrič 2013).

In general, wood that has a higher proportion of sapwood is less durable (Williams et al. 1996), and to increase the wood's durability and visual characteristics, it is advisable to treat the material with a coating system (Cristea et al. 2010), other methods include modification of the underlying wood species or coating system (Hill 2006; Özgenc et al. 2012).

The study is devoted to larch wood, characterized by relatively high natural durability. This wood species is popularly used in interior as well as exterior environments. A trend was noted for larch in the application to facades, windows, or terraces (Oberhofenerová et al. 2019). Larch wood is a facade material because it is aesthetic, can be built without surface treatment, and its properties are comparable to exotic woods. At the same time, the purchase price is significantly lower (Ugovšek et al. 2019). It is very resistant to damage by rot and insects, thanks to the specific composition of the resin contained in the wood. It is characterized by high acidity and a higher content of extractive substances, especially in the form of resins (Štěrbová et al. 2021). These accompanying components of the wood make it challenging to apply the coating and reduce its lifespan. After that, photodegradation in the form of graying occurs more quickly. This reaction to the action of UV and VIS radiation is considered in Western countries; some architects already work with a gray shade of wood in their studios (Karlsson et al. 2022).

2. Material and method

2.1. Wood samples, treatment and exposure

Larch heartwood samples (*Larix decidua,* Mill.) with dimensions of 378 × 78 × 20 mm (L × D × R) were prepared based on the EN 927-3 standard from the wood of Czech origin (Fig. 1, left).

The surfaces of samples (moisture ≈12%) were sanded with 120-grit sandpaper before treatment. The samples were exposed outdoors in racks placed at an angle of 45° to the south for 12 months. References from unexposed wood samples were also used. The samples were exposed for 10 and 20 weeks. Climatic conditions during exposure were: average daily temperature: 9.8 °C (extreme +26.9 °C, −10.1 °C); total precipitation 533 mm; average daily incident solar energy 12,226 kJ.m^{-2} (http://meteostanice.agrobiologie.cz). Subsequently, all samples were sterilized using a steam autoclave (MED 12, Biotrade Instruments, Prague) at a temperature of 125 °C to remove microorganisms (especially fungi) that could distort the research. Subsequently, the samples were dimensionally adjusted (150 × 38 × 20) (Fig. 1, right) so that they could be placed in the QUV accelerated weathering chamber (QUV/spray RP, Labimex, Praha) according to the standard ČSN EN 927–6 (2019). Before being inserted into the chamber, they were treated with two types of oil coating, V–420 and V–429. They were then put into the chamber. An exposure cycle of one week consists of a condensation period followed by a sub–cycle of water spray and UV–A 340 irradiation as in Table 1.

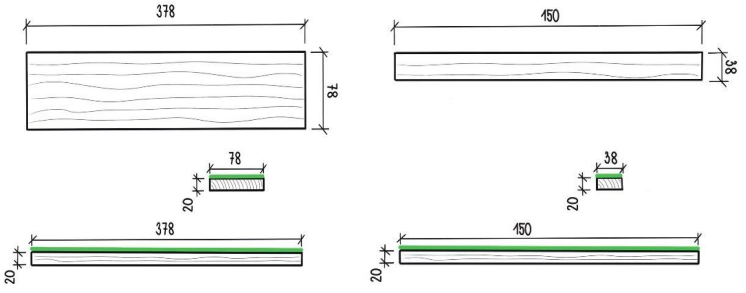


Fig. 1. A sample according to EN 927-3 (2020) is on the left and a sample according to EN 927-6 (2019) is on the right side; green line means a coating, dimensions in mm.

Table 1. Exposure cycles.

Step	Function	Temperature	Duration	Condition
1	Condensation	(45 ±3) °C	24 h	—
2	Subcycle step 3 + 4	—	144h consisting of 48 cycles of 3 h consisting of step 3 and 4	—
3	UV	(60 ±3) °C	2,5 h	Irradiance set point 0,89 W/(m² nm) at 340 nm
4	Spray	—	0,5 h	6 l/min to 7 l/min, UV off

The cycle lasts for 168 h (= 1 week). The cycle shall be repeated 6 times results in the total test exposure of 1,008 h (= 6 weeks). At the end of the 6-week exposure period was samples removed and condition at a temperature of (20 ±2) °C and a relative humidity of (65 ±5) %. Samples identification codes are in Table 2.

Table 2. Samples identification codes.

Name of sample	Type of paint	Time of leaching (before paint)
V 420 – 10w	V 420	10 weeks
V 420 – 20w	V 420	20 weeks
V 429 – 10w	V 429	10 weeks
V 429 – 20w	V 429	20 weeks
V bez	None (reference)	0 week

2.2. Changes in gloss, color, hydrophobicity

The color parameters L*a*b* (Tolvaj et al. 1995) of the test specimens were measured after 0, 1, 3 and 6 weeks of accelerated weathering (AW) using Spectrophotometer CM-600d (Konica Minolta, Osaka, Japan). For the observation of reflection, the specular component was included (SCI mode) at a 10° angle and d/8 geometry with an illumination standard of D65 (corresponding to daylight in 6,500 K). Eight measurements per sample were carried out for each weathering time. Color changes evaluations were done in CIE L*a*b* color space where:

L is lightness from 0 (black) to 100 (white),*
a is chromaticity coordinate + 60 (red) or – 60 (green),*
b is chromaticity coordinate + 60 (yellow) or – 60 (blue).*

The total color difference ΔE* (Tolvaj et al. 1995) was subsequently calculated from relative changes of color (ΔL*, Δa*, and Δb*) using equation [1]:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad [1]$$

Table 3. Table of color changes according to standard EN 927–3(2020).

0.2 > ΔE	invisible difference
0.2 < ΔE < 2	little difference
2 < ΔE < 3	color change visible with a high-quality filter
3 < ΔE < 6	color change visible with a medium-quality filter
6 < ΔE < 12	high color changes
ΔE > 12	different color

The gloss of the different coatings before and during weathering tests was measured based on EN ISO 2813 (2014) using glossmeter MG268-F2 (KSJ, Quanzhou, China). Four measurements at a 60° angle per sample after 0, 1, 3 and 6 weeks of AW were done to evaluate gloss changes.

The water contact angle on tangential surfaces of tested samples was measured using a goniometer Krüss DSA 30E (Krüss, Hamburg, Germany). The sessile drop method was used, five measurements per sample were performed before and after 0, 1, 3 and 6 weeks of AW with distilled water drops with a dosing volume of 5 µL.

Statistical analyses of data were performed in MS Excel and Statistica (StatSoft, Palo Alto, CA, USA) using mean values, whisker plots with mean values and 95% two-sided confidence intervals.

3. Results and discussion

From the results in Fig. 2, a decreasing tendency of the surface wettability values expressed by the contact angle of the liquid and the sample surface is evident. In monitoring this value, leaching did not have a statistically significant role. The surface treatment had a greater influence, with the surface-treated samples showing better results than the reference samples, which were not treated. Furthermore, it can be seen that the V 429 coating experienced a sharp drop in values after six weeks, which indicates its more significant degradation. This trend was noted in the works of Podgorski et al. (2011) and Oberhofnerová et al. (2019).

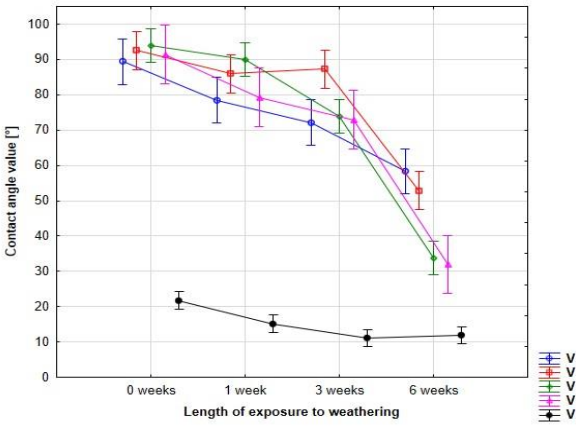


Fig. 2. Contact angle change development.

The values of light reflection, expressed by the change in gloss, correspond to the results of Štěrbová et al. (2021). The experiment focused on larch wood and confirmed that natural larch wood maintains a relatively constant matte surface on the exterior. For the surfaces treated with the paint, a statistically significant decrease was recorded without any evidence of the effect of premature aging of the surface (Fig. 3). For similar results in the degradation of the gloss value of larch wood had Oberhofnerová et al. (2017, 2019).

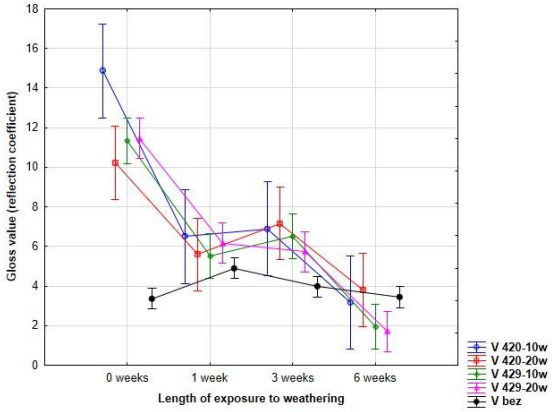


Fig. 3. Gloss change development.

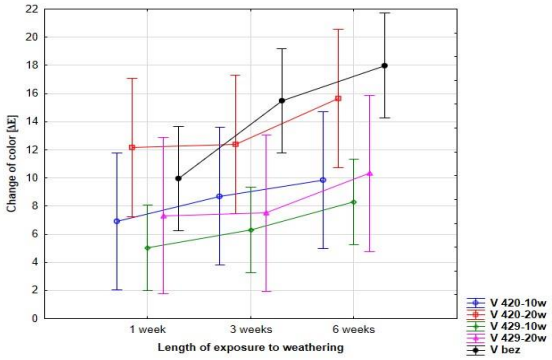


Fig. 4. Color change development.

On Fig. 4, we can see the dependence of surface aging before coating. Here, this method of surface modification showed the most favorable values. It can be read from the graph in Fig. 4 that if the surface was washed before painting after ten weeks of oak, the overall color changes were the least. After 20 weeks of leaching, samples showed lower values, while a positive modification trend was observed. The results are underlined by the fact that, despite the different results from the point of view of the chosen coating (V 420 × V 429), washing out for ten weeks always had better results. Based on the evaluation according to the EN 927 standard (Table 4), were the changes on samples "V bez" and "V 420 20 w" evaluated as „different color". High color changes were noted for the others. However, it cannot be said that a more excellent surface darkening caused this change; the changes were driven more by the coating, which is evidenced by Fig. 5.

In Fig. 6 and 7, we can see the trend of the parts of the color spectrum. Fig. 6 presents the development of the color change from red (+60), where you can see the trend of the color change from the original reddish, typical for larch, to green (−60). Fig. 7 shows the transition from yellow (+60) to blue (−60). These changes are typical for darkening the surfaces of typical graying, as described in the studies of Crewdson et al. (2009) and Evans et al. (2015).

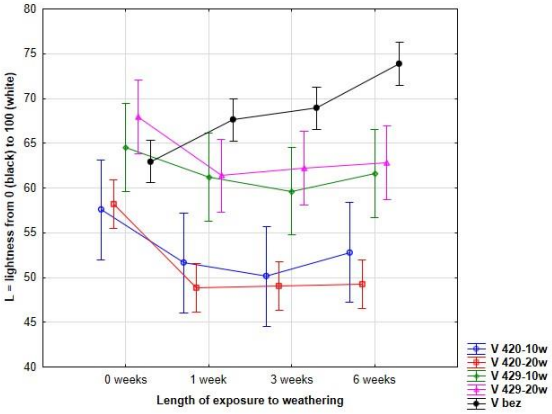


Fig. 5. Part of color spectrum, L – lightness.

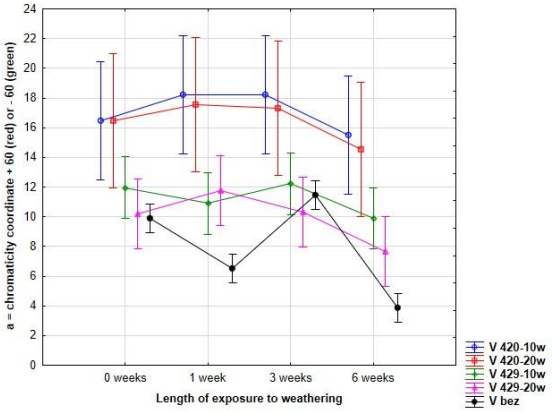


Fig. 6. Part of color spectrum "a".

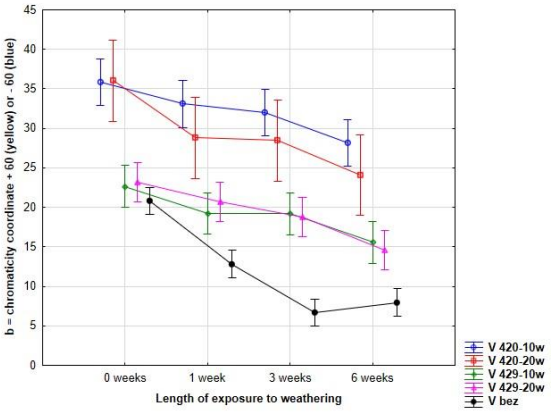


Fig. 7. Part of color spectrum "b".

4. Conclusion

The experiment proved the importance of leaching the surface of woody plants before surface treatment has potential for future studies. This research confirmed that if we remove from the surface of the wood substances that reduce the quality of the surface finish, for example, grease in the form of fats or resins, there will be a better cross-linking of the paint with the underlying wood. Thus,

the overall resistance of the color, or at least its parts, will increase. This intentional surface degradation must not last too long; 10 weeks can be considered a turning point. After 20 weeks of weathering, the effect decreases, or even the opposite effect occurs. This treatment could occur in special dryers where UV lamps would be placed, which would degrade the surface in a controlled manner. Depending on the wood, the service life of the coatings will be extended approx. by 15%.

Acknowledgements

Thanks to the Technology Agency of the Czech Republic for co-financing, specifically the project "TAČR TH02020873 – Increasing the resistance of coating systems on selected types of wood in exterior applications", which funded the research.

References

Cogulet, A., Blanchet, P., Landry, V., 2019: Evaluation of the impacts of four weathering methods on two acrylic paints: showcasing distinctions and particularities. Coatings, 9:121.

Cristea, M. V., Riedl, B., Blanchet, P., 2010: Enhancing the performance of exterior waterborne coatings for wood by inorganic nanosized UV absorbers. Progress in Organic Coatings, 69:432–441.

Crestini, C., D'Áuria, M., 1996: Photodegradation of lignin: the role of singlet oxygen. Journal of Photochemistry and Photobiology A: Chemistry, 101:69–73.

Crewdson, M. J. Ketola, W. D., 2009: Best practices in weathering: outdoor and accelerated testing compared. European Coatings Journal, 4:116–121, 116–121.

Evans, P. D., Haase, J. G., Shakri, A., Seman, B. M., Kiguchi, M., 2015: The search for durable exterior clear coatings for wood. Coatings, 5:830–864.

Feist, W. C., 1990: Outdoor wood weathering and protection (ed. Rowell, R. M.). Advanced in Chemistry Series No. 225. Washington, DC: American Chemical Society. Chapter 11:263–298.

Feist, W. C. 1988: Outdoor Wood Weathering and Protection. In: Rowell, R. M., Barbour, R. J. (eds.): Archaeological wood: properties, chemistry, and preservation. Advances in Chemistry Series 225. Proceedings of 196th meeting of the American Chemical Society, Los Angeles. Washington, DC: American Chemical Society, Chapter 11.

Gandelová, L., Šlezingerová, J., Horáček, P., 2002: Nauka o dřevě. Brno, Mendelova zemědělská a lesnická univerzita v Brně. ISBN 80-7157-577-1. (In Czech).

Gonzalez de Cademartori, P. H., Missio, A. L., Dufau Mattos, B., Gatto, D. A., 2015: Natural weathering performance of three fast-growing Eucalypt woods. Maderas. Ciencia y Tecnología, 17:799–808.

Hochmańska-Kaniewska, P., Janiszewska, D., Oleszek, T., 2022: Enhancement of the properties of acrylic wood coatings with the use of biopolymers. Progress in Organic Coatings, 162:106522.

Karlsson, O., Jones, D., Sandberg, D., 2022: Phenol-formaldehyde-resin treatment of Scots pine sapwood for the reduction of resin exudation through coatings. Wood Material Science & Engineering, p. 1–3.

Kim, I., Karlsson, O., Myronycheva, O., Jones, D., Sandberg, D., 2020: Methacrylic resin for protection of wood from discoloration by mould growth and weathering. BioResources, 15:7018–7033.

Matsuo, M., Yokoyama, M., Umemura, K., Sugiyama, J., Kawai, S., Gril, J. et al., 2011: Aging of wood: Analysis of color changes during natural aging and heat treatment.

Myronycheva, O., Sehlstedt-Persson, M., Karlsson, O. and Sandberg, D., 2018: Growth of Mold and Rot Fungi on Copper-impregnated Scots Pine Sapwood: Influence of Planing Depth and Inoculation Pattern. BioResources, 13:8787–8801.

Oberhofnerová, E., Pánek, M., García-Cimarras, A., 2017: The effect of natural weathering on untreated wood surface. Maderas. Ciencia y Technology, 19:173–184.

Oberhofnerová, E., Pánek, M., Podlena, M., Pavelek, M., Štěrbová, I., 2019: Color stabilization of Siberian and European larch wood using UVA, HALS, and nanoparticle pretreatments. Forests, 10:23.

Özgenc, O., Hiziroglu, S., Yildiz, U. C., 2012: Weathering properties of wood species treated with different coating applications. BioResources, 7:4875–4888.

Pánek, M., Reinprecht, L., 2014: Colour stability and surface defects of naturally aged wood treated with transparent paints for exterior constructions. Wood Research, 59:421–430.

Pánek, M., Reinprecht, L., 2016: Effect of the number of UV-protective coats on the color stability and surface-defects of painted black locust and Norway spruce woods subjected to natural weathering. BioResources, 11:4663–4676.

Petrič, M., 2013: Surface modification of wood. Reviews of Adhesion and Adhesives, 1:216–247.

Podgorski, L., Grüll, G., Georges, V., Truskaller, M., Bollmus, S., 2011: Coating performance on different types of modified wood: natural and artificial weathering results. Surface Coatings International 94:139–150.

Reinprecht, L., 2008: Ochrana dreva. Technical University in Zvolen, 453 p.

Sarvašová Kvietková, M., Gašparík, M., 2021: Surface irregularities of oak wood after transversal cutting with a circular saw. Wood Research, 66:1032–1045.

Šimůnková, K., Oberhofnerová, E., Reinprecht, L., Pánek, M., Podlena, M., Štěrbová, I., 2019: Durability of selected transparent and semi-transparent coatings on Siberian and European larch during artificial weathering. Coatings, 9:39.

Štěrbová, I., Oberhofnerová, E., Pánek, M., Dvořák, O. Pavelek, M., 2021: Influence of different exposition of larch wood facade models on their surface degradation processes. Central European Forestry Journal, 67:45–53.

Tolvaj, L., Faix, O., 1995: Artificial ageing of wood monitored by drift spectroscopy and CIE l*a*b* color measurements. 1. Effect of UV light. Holzforschung 49:397–404.

Tomášková, I., Pastierovič, F., Krejzková, A., Čepl, J., Hradecký, J., 2021: Norway spruce ecotypes distinguished by chlorophyll a fluorescence kinetics. Acta Physiologiae.

Williams, R.S ., Knaebe, M. T., Feist, W. C.,1996: Finishes for exterior wood. Madison: Forest Products Society.

Xie, Y., Fu, Q., Wang, Q., Xiao, Z., Militz, H., 2013: Effects of chemical modification on the mechanical properties of wood. European Journal of Wood and Wood Products, 71:401–416.

Other sources

EN ISO 2813, 2014: Paints and varnishes. Determination of gloss value at 20 degrees, 60 degrees and 85 degrees.

EN 350, 2019: Durability of wood and wood-based products – Testing and classification of the durability to biological agents of wood and wood-based material.

EN 927-6, 2019: Paints and varnishes. Coating materials and coating systems for exterior wood. Part 6: Exposure of wood coatings to artificial weathering using fluorescent UV lamps and water.

EN 927-3, 2020: Paints and varnishes. Coating materials and coating systems for exterior wood. Part 3: Natural weathering test.

http://meteostanice.agrobiologie.cz