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Section 2 **Test methodology and assessment**

Service life prediction of wooden components – Part 2:

Impact of material, exposure and design details

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Service life prediction of wooden components – Part 2: Impact of material, exposure and design details

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ABSTRACT

Dose-response functions permit to estimate the moisture and temperature induced decay potential for any wooden building component and exposure, and thus the service life to be expected. In part 1 of this series dose-response functions were established as a result of double layer field trials carried out at 24 European test sites over up to eight years. Using them makes it no longer necessary to conduct field trials as long as decay actually occurs. They allow determining dose-time functions for a certain construction detail over shortened time periods (2-3 years).

Within this paper we present the test set up of different studies aiming on quantifying the impact of material, exposure and design details on the service life to be expected for wooden components. Therefore long-term moisture recordings were applied to different wooden commodities, e. g. fence posts, pickets, decking, and facades. Furthermore, the impact of orientation, distance to the ground, and driving rain load on facade panels was studied. Finally dose-time functions will be recorded for ten different wood species used in horizontal and vertical orientation. First results from the various studies including preliminary service life estimation for various components are also presented.

Keywords: Cladding, decking, facade, fence post, natural durability, orientation, shading

1. INTRODUCTION

Consolidated knowledge about the interrelationship between the intensity of fungal degradation over time and the numerous decay-influencing factors is needed to estimate the service life to be expected for wooden components in outdoor applications. In principal, there are three different sources providing information about decay processes. 1. Laboratory experiments, 2. Field trials, and 3. Surveys on structures in service (in-service performance). Laboratory tests allow setting up exactly defined conditions, e. g. in terms of moisture, temperature, and organisms involved. On the other hand it is difficult to mimic real life conditions in the lab, because many factors occurring in the field are not reproducible or are even unknown. Field tests are more time-consuming compared to lab tests, but closer to reality (Hedley 1993, Nilsson and Edlund 1995, Augusta 2007). While the test set up may be identical, the local climate conditions vary from one trial to the other in dependence of time and site. As a matter of course most realistic conditions appear on real buildings and building components. Surveys on such structures in service are therefore a very important data source (Ross Gobakken et al. 2008, Brischke and Rolf-Kiel 2009). However, in most cases they suffer from long exposure times until decay occurs or the lack of information about their history (initial protection measures, environmental conditions during exposure, and maintenance intervals).

The establishment of dose-response functions as described in part 1 of this series (Brischke and Rapp 2010) allows to overcome the drawback of long exposure times needed for field trials. Once the interrelationship between the most important decay influencing factors wood moisture content and wood temperature (dose) and fungal decay (response) is determined in long-time field experiments (dose-response functions), the impact of further decay factors may be quantified in terms of dose-time functions. To determine dose-time functions medium-term-recordings (2-3 years) of moisture content and temperature will be sufficient, because it is no longer necessary to await the onset of decay.

This study aims on quantifying the impact of material, exposure, and design detailing on the expected service life of wooden components. Therefore various field trials including automated moisture and temperature recordings were set up considering different wood species, typical outdoor commodities, vertical and horizontal exposure situations as well as differently oriented facades. The test set up and preliminary results will be presented.

2. DOSE-RESPONSE FUNCTIONS

This study approaches service life prediction of wooden components by using dose-response functions. Coming from results of long-term field trials a mathematical relationship was established between moisture and temperature induced dose and a response in terms of fungal decay. A detailed description of the experimental set up, the field test results and the modelling of dose-response functions are given in part 1 of this series.

Dose-time functions and resulting service life estimations are based on the following functions:

MC induced daily dose d_{MC}:

$$d_{MC} = 6.75 \bullet 10^{-10}\, MC^5 - 3.50 \bullet 10^{-7}\, MC^4 + 7.18 \bullet 10^{-5}\, MC^3 - 7.22 \bullet 10^{-3}\, MC^2 + 0.34MC - 4.98$$

; if MC ≥ 25% (1)

MC = daily moisture content

Temperature induced daily dose d_T:

$$d_T = 1.8 \bullet 10^{-6}\, T^4 + 9.57 \bullet 10^{-5}\, T^3 - 1.55 \bullet 10^{-3}\, T^2 + 4.17 \bullet 10^{-2}\, T$$

; if $T_{min} > -1°C$ and $T_{max} < 40°C$ (2)

T = daily average wood temperature

T_{min}= daily minimum temperature

T_{max}= daily maximum temperature

Daily dose d:

$$d = ((a \bullet d_T) + d_{MC}) / (a + 1)$$
$$; \text{if } d_T > 0 \text{ and } d_{MC} > 0 \qquad (3)$$

$a = 3.2$ (weighting factor of temperature induced daily dose component d_T)

Dose response function:

$$\text{Decay rating} = y = 4 \bullet \text{EXP} \bullet (-\text{EXP}(1.7716-(0.0032 \bullet D))) \qquad (4)$$

D = Total dose

The dose response function (4) was determined for Scots pine sapwood and Douglas fir heartwood and will further on be used for all wood species.

3. EXPERIMENTAL SET UP

3.1 Automated recordings of wood moisture content (MC) and wood temperature

The measurement system applied in this study was described in an earlier publication (Brischke et al. 2008a) and can be summarized in brief as follows: Electrodes of polyamide coated stainless steel cables were conductively glued in the specimens or wooden commodities respectively. The electrodes were connected to a small data logger (Materialfox Mini, Scanntronik Mugrauer GmbH, Zorneding, Germany), that recorded the electrical resistance of the wood. The data loggers were calibrated in a range between 12% and 50% MC (Brischke et al. 2008a). Measurements above fibre saturation were increasingly inaccurate, but still indicated a tendency within the calibration range. Minimum and maximum temperatures were recorded using Thermofox Mini data logger (Scanntronik Mugrauer GmbH, Zorneding, Germany) and used to calculate the average daily temperature. The logging intervals differed between the studies.

3.2 Combined facade and decking elements

To estimate the decay potential of different wood species under various exposure situations in terms of dose-time functions, combined facade and decking elements were built. Test boards of 500 x 100 x 20 mm³ were manufactured from the following wood species and exposed horizontally, vertically to the South, and vertically to the North (Figure 1):

- Norway spruce (*Picea abies* Karst.)
- Scots pine sapwood (*Pinus sylvestris* L.)
- Scots pine heartwood (*Pinus sylvestris* L.)
- European larch sapwood (*Larix decidua* L.)
- European larch heartwood (*Larix decidua* L.)
- Western Red Cedar (*Thuja plicata* Donn ex D.Don)
- English oak (*Quercus robur* L.)
- Beech (*Fagus sylvatica* L.)
- Black locust (*Robinia pseudoacacia* L.)

The facade was carried out as a board-on-board cladding, where the basic construction and the blind boards were made from Norway spruce. The end-grain of the vertically exposed boards was protected from rainwater by stainless steel sheets (Figure 2). For each wood species /

exposure combination n=3 boards were used and provided with one pair of moisture electrodes. Additionally, one temperature sensor was applied for each parameter combination. Moisture content of the facade was measured in cover boards exclusively; in the horizontally exposed boards measurements were taken centrally. Wood temperature and wood moisture content was recorded daily.

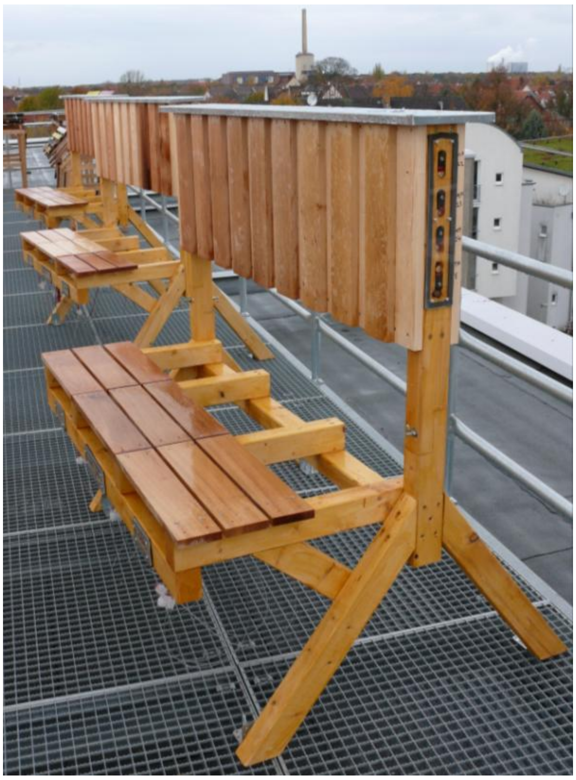

Figure 1: Combined facade and decking elements made from different wood species

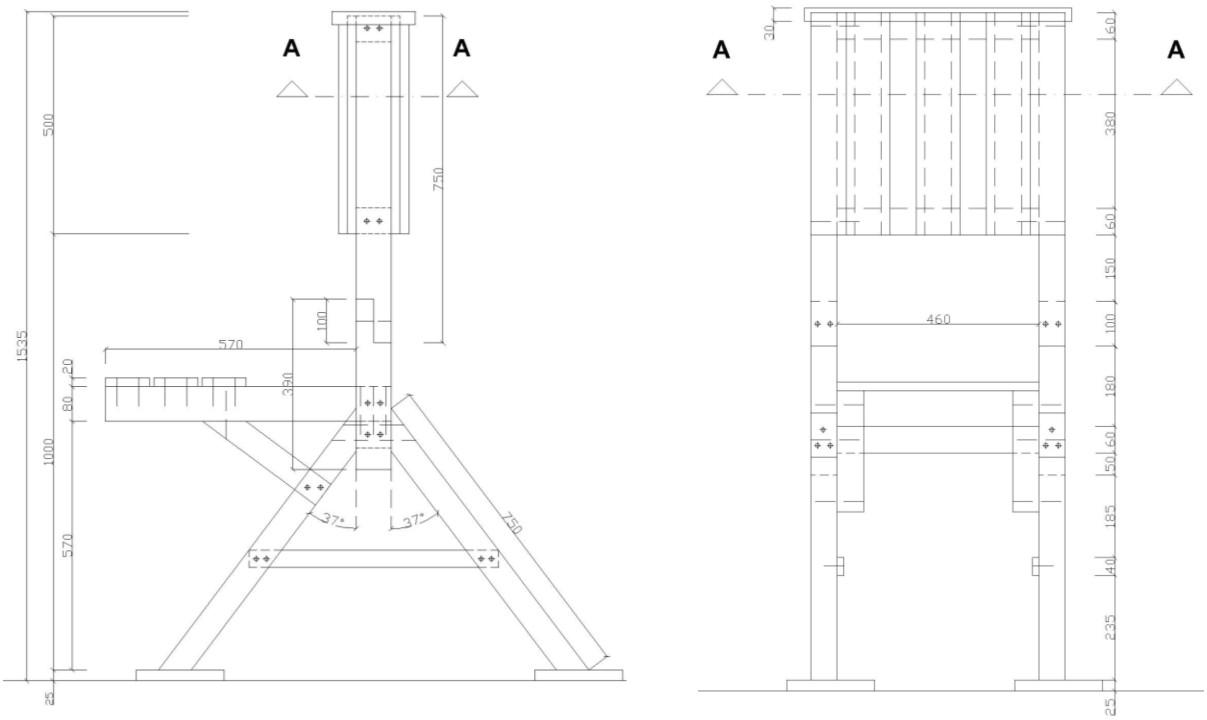

Figure 2: Sketches of combined facade and decking single element (dimensions in mm)

3.3 Wooden commodities

Dose-time functions were recorded on typical wooden commodities for outdoor use. Therefore long-term moisture and temperature recordings were carried out on fence posts, pickets and terrace decking. The assemblies were made from Scots pine sapwood, Norway spruce, and Douglas fir, afterwards instrumented and exposed on the IBW test site in Hannover-Herrenhausen (Figure 3 and Figure 4). The fence posts were buried directly in the ground; the decking elements were placed on pavers. The whole test field was covered with a water-permeable horticultural foil to protect the test devices from growth of grass and other plants.

Figure 3: Pine sapwood decking element instrumented with moisture and temperature logger

Figure 4: Instrumented fence and decking elements protected from grass growth by a horticultural foil

Measurement points were set at differently severe exposed positions on the assemblies (Figure 5 and Figure 6): On the fence posts close to the ground (M3), close to the picket (M2), and above the picket (M1); on the pickets close to the post (M4) and centred (M5); on the decking boards close to the support (M4-6) and centred (M7-9); and on the decking supports (M1-3). For each parameter combination n=3 moisture electrode pairs and an additional temperature sensor were installed. Wood temperature and wood moisture content were recorded daily.

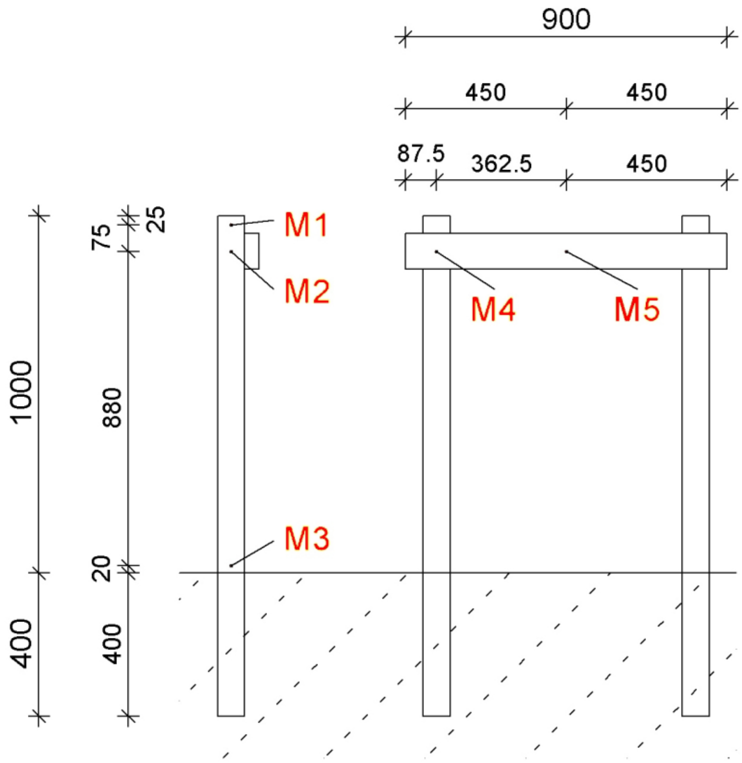

Figure 5: Position of measurement points M1 – M5 for daily wood moisture content recordings in the fence elements (dimensions in mm)

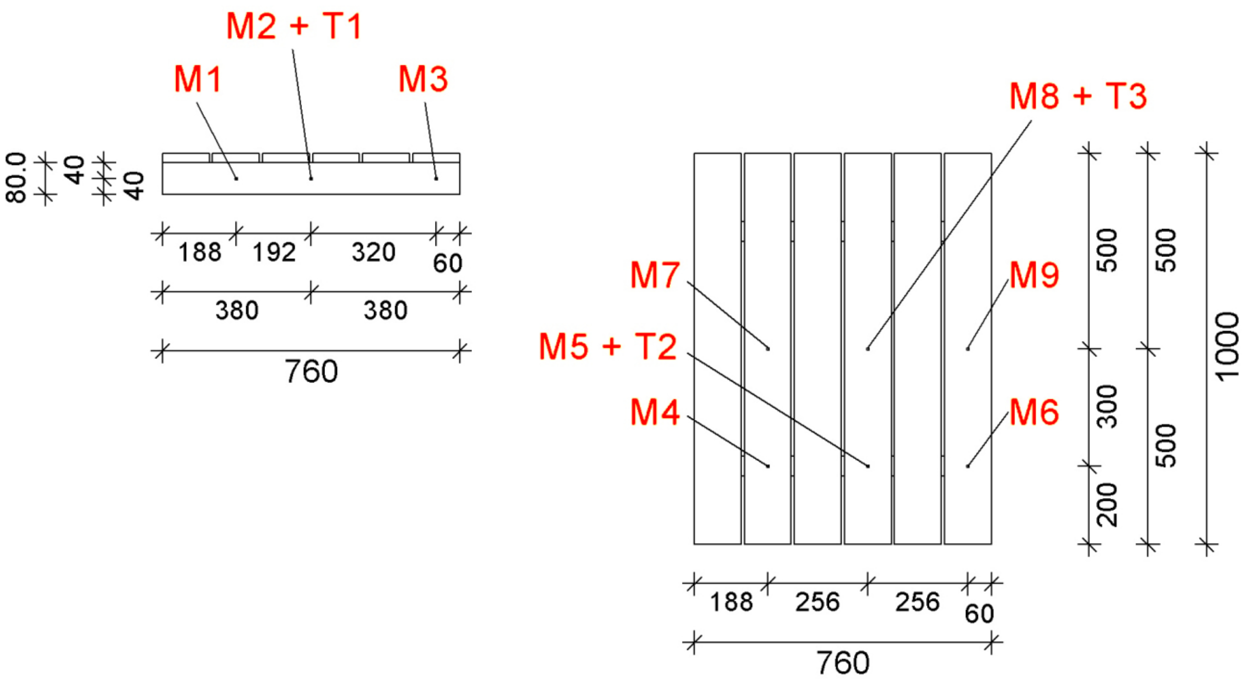

Figure 6: Position of measurement points M1 – M9 for daily wood moisture content and T1 – T3 wood temperature recordings in the decking elements (dimensions in mm)

3.4 Test house

The impact of wall orientation and of the distance to the ground on the moisture induced decay risk was studied on the claddings of a test house, which was built in Hannover-Herrenhausen in December 2008 (Figure 7). The house had a quadratic floor plan of 3 x 3 m² and a total height of 3.18 m. The four facades were exactly aligned to the cardinal points of the compass. The stud frame, which was made from Norway spruce, carried a board-on board cladding and a pyramidal broach roof. The roof overhang was minimized to a width of 7.5 cm including the gutter. Five test boards of Norway spruce, Scots pine sapwood and Douglas fir were mounted on each side of the building (Figure 8). The spaces in between were filled with so-called blind boards made from Norway spruce.

Figure 7: Test house in Hannover-Herrenhausen

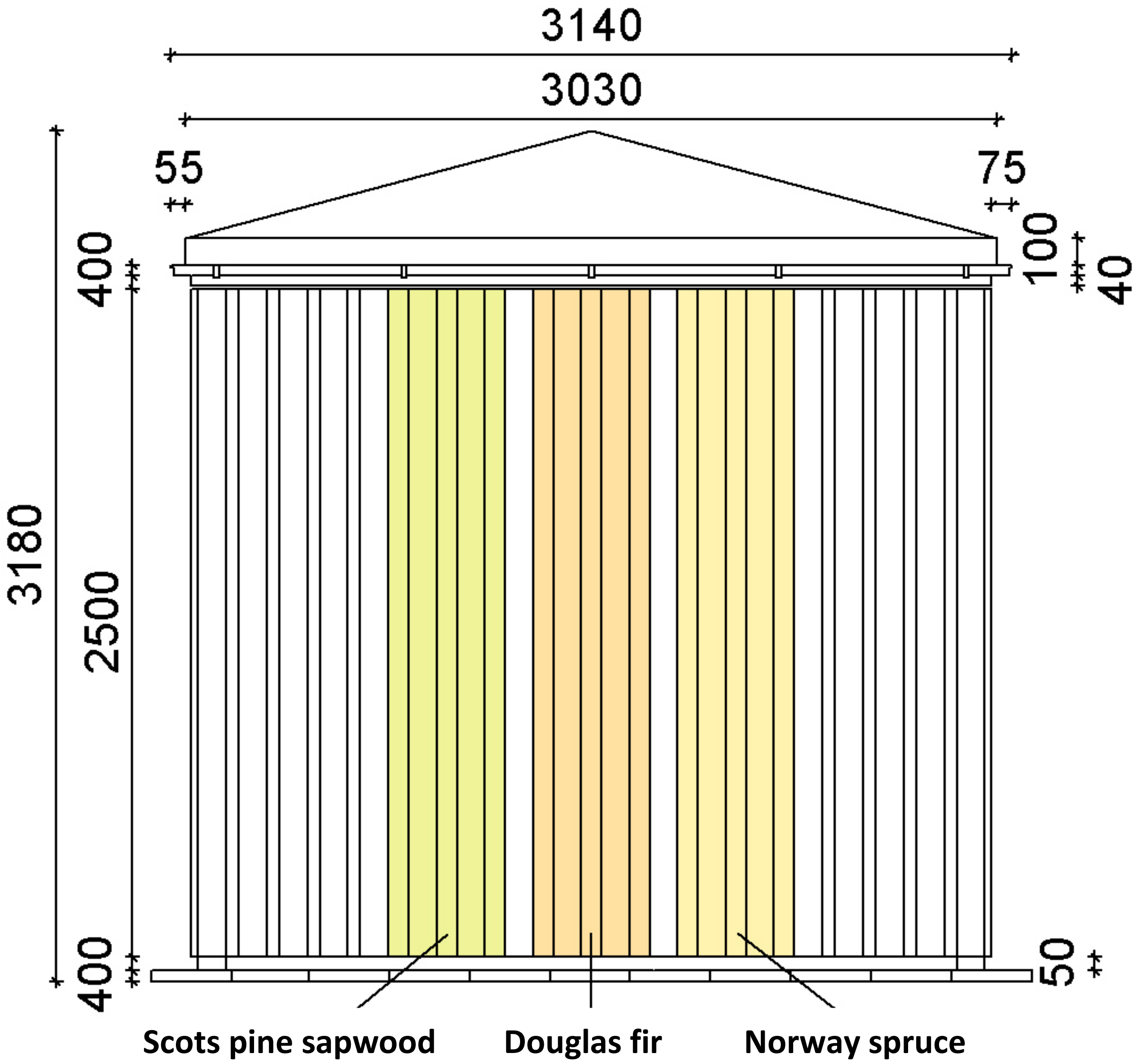

Figure 8: Position of test boards from different wood species in the board-on-board cladding of the test house (dimensions in mm)

For measuring the wood moisture content electrodes were installed at seven different heights: 5, 10, 20, 40, 80, 160, and 240 cm from the bottom end of the boards. Three measurement points per wood species, height and wall orientation were set, which means in total 252 pairs of electrodes. The electrodes were glued in from the back side of the cladding, two pairs in the central cover boards, and one pair in the central base board. In addition 84 temperature sensors were installed, one for each parameter combination. Temperature and wood moisture content were recorded every two hours.

Additionally, driving rain gauges were installed on each facade. Each driving rain event as well as the driving rain sum for each day was recorded automatically. Corresponding data on total precipitation, wind speed, and wind direction were taken from the Institute of Meteorology and Climatology, which is located 300 m from the test house.

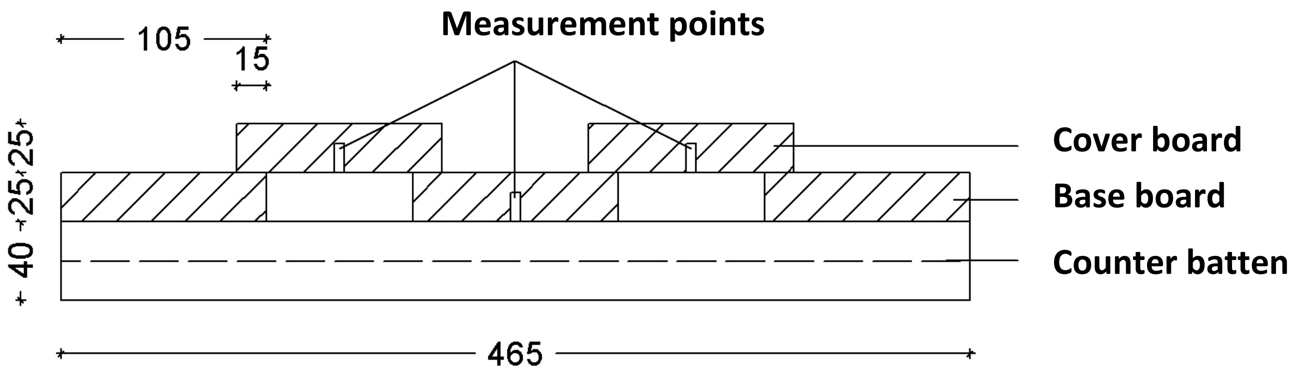

Figure 9: Position of measurement points in the board-on-board cladding of the test house (dimensions in mm)

3.4 Reference double layers

The dose-response functions as described in chapter 2 were determined in field trials with horizontal double layer test sets. Therefore reference double layers were also exposed in Hannover-Herrenhausen contemporaneously with and close to the other field tests devices. From each wood species 11 specimens were exposed. Moisture and temperature recording was carried out in accordance to Brischke and Rapp (2010).

4. PRELIMINARY RESULTS AND DISCUSSION

4.1 Wood species specific differences in horizontal orientation

First moisture recordings from the combined facade and decking elements showed differences between wood species already after the first four weeks of exposure (after that an unexpectedly long frost period followed). The MC courses for the decking elements are shown in Figure 10. Most significantly differences in the moisture load were found between Scots pine sapwood and all other wood species. In the very beginning of the trial differences between the other species were in a range of a few percent points only. However, bigger differences in moisture dynamics, which can have an important impact on wood durability (Hedley et al. 2004; Stirling et al. 2007), are expected to be more emphasized during the following spring season. For determination of dose-time functions for the various material-exposure combinations at least one full year of exposure needs to be awaited.

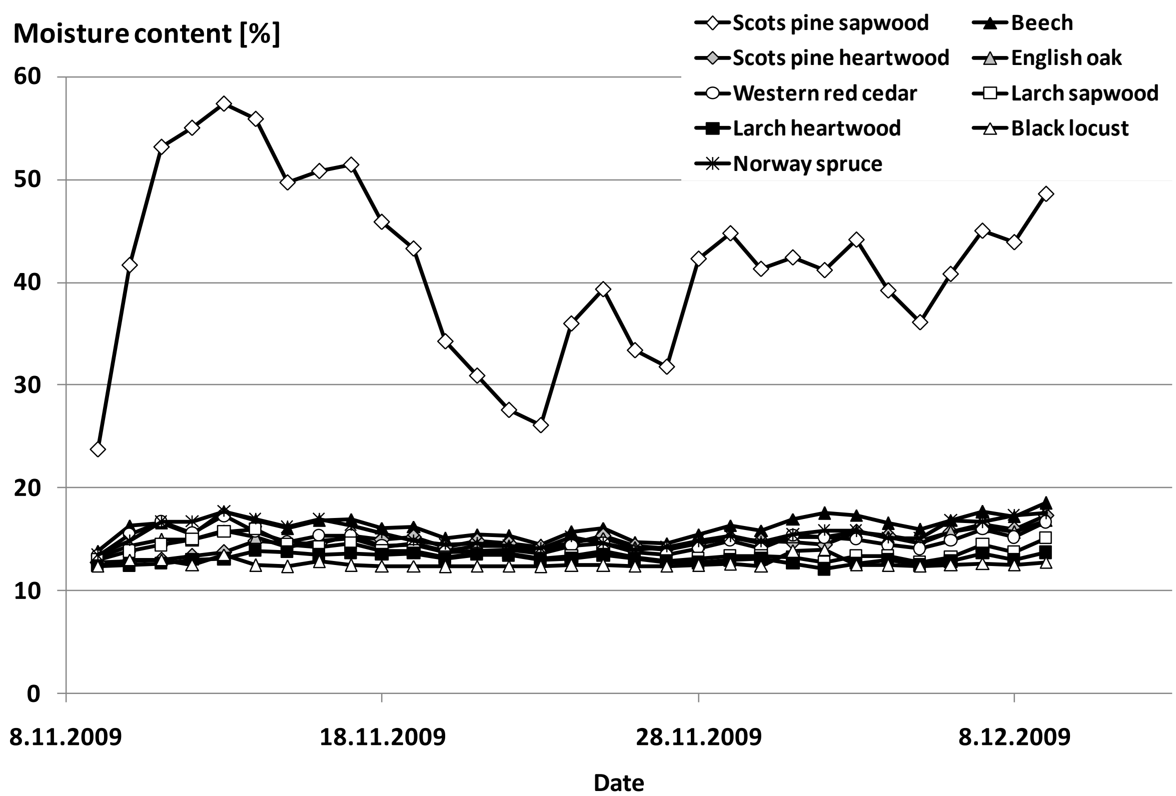

Figure 10: Course of wood moisture content in horizontally exposed boards (decking elements) made from different wood species during first 4 weeks of exposure

4.2 In and above ground exposure of wooden commodities

After one year of exposure (September 2008 till August 2009) the expected service life of the different wooden commodities was estimated. In

Table 1 and Table 2 the sum of the daily dose components d_{MC} and d_T as well as the sum of the total daily dose D are listed. The dose differed significantly between wood species, commodities, and differently severe exposed positions on the assemblies. Douglas fir featured least dose; pine sapwood - the most permeable species - had the highest dose. The dose differences between the wood species were more pronounced for those details, where re-drying of the assembly was allowed, e.g. the terrace board and picket centres. Furthermore the results clearly indicated the higher decay risk for those components, which suffered from hindered drying such as the contact face between picket and post or between terrace board and bearing.

So far the data show, that the experimental set ups are working as expected. Numeric calculation and quantification of decay risk will follow, when enough data for serious calculations have been collected.

Table 1: Sum of daily dose components d_{MC} and d_T and total daily dose D of different wooden decking assemblies determined for the exposure interval September 2008 till August 2009

Wood species	**Commodity**	**Σd_{MC}**	**Σd_T**	**$D = \Sigma d$**
Douglas fir	Terrace board centre	35.8	123.9	13.1
	Terrace board at contact face	96.9	117.8	23.3
	Bearing	51.9	140.1	23.0
Scots pine sapwood	Terrace board centre	198.7	123.8	82.1
	Terrace board at contact face	217.0	121.0	88.2
	Bearing	178.1	141.4	67.4
Norway spruce	Terrace board centre	114.8	129.1	43.1
	Terrace board at contact face	122.0	110.4	32.3
	Bearing	108.9	140.0	42.6

Table 2: Sum of daily dose components d_{MC} and d_T and total daily dose D_a of different wooden fence assemblies determined for the exposure interval September 2008 till August 2009

Wood species	**Commodity**	**Σd_{MC}**	**Σd_T**	**$D_a = \Sigma d$**
Douglas fir	Picket close to post	2.0	110.9	3.5
	Picket centred	0.2	115.5	0.5
	Post above picket	55.7	130.3	19.9
	Post close to picket	8.7	139.2	7.7
	Post close to ground	3.5	155.4	7.0
Scots pine sapwood	Picket close to post	134.4	110.7	56.1
	Picket centred	81.6	017.1	30.2
	Post above picket	136.5	128.9	48.0
	Post close to picket	96.7	141.9	36.5
	Post close to ground	142.9	152.2	104.0
Norway spruce	Picket close to post	2.0	108.8	13.1
	Picket centred	2.2	107.2	3.5
	Post above picket	69.3	128.9	21.0
	Post close to picket	51.7	139.8	22.7
	Post close to ground	88.6	145.1	67.9

For a first and very preliminary service life prediction of the assemblies a critical dose was determined according to the dose-response function in Figure 11. The following assumptions were made: A mean decay rating = 2, corresponding to moderate fungal decay, was set as limit state. Any decay rating above this limit state means that the serviceability is not longer given. According to Equation 4 a critical dose $D_{crit} = 670$ is needed to be summed up to reach the limit state. Finally in the following the expected service life was considered to be the quotient of the critical dose D_{crit} and the annual dose D_a for the first year of exposure.

For the decking elements service lives between 8 years (Scots pine sapwood) and 29 years (Douglas fir) were estimated (Table 3), which coincides with expectations from practice. The service life of well ventilated pickets was estimated to be much higher, 22 years for pine sapwood and even more for spruce and Douglas fir, whereby the expectation for Douglas fir (1340 years) seemed to be not plausible so far, but did well indicate the extremely low risk of fungal decay for this application.

An unexpectedly high dose was determined for the fence posts' upper ends, corresponding with predicted service lives between 14 and 34 years. Through setting the measurement points only 25 mm below the open and unprotected end grain of the posts, an easy water uptake as well as re-drying was allowed. However, with respect to the comparatively high moisture-induced dose (Table 2), in this case the moisture uptake seemed to have a dominating effect.

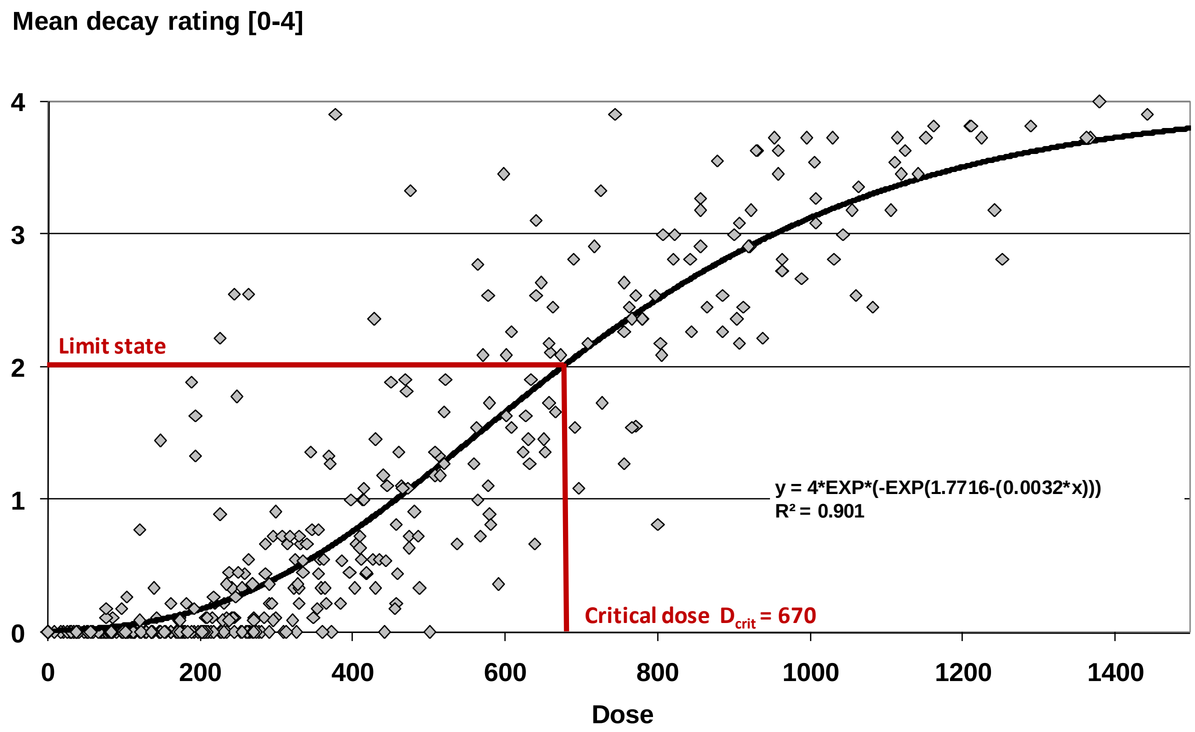

Figure 11: Determination of critical dose D_{crit} based on dose-response function for service life estimation of wooden components. Limit state: Mean decay rating = 2 (moderate decay).

Table 3: Preliminary estimation of service lives for different wooden fence and decking assemblies based on dose-response functions.

	Estimated service life [a]		
	Douglas fir	Scots pine sapwood	Norway spruce
Terrace board centre	51	8	16
Terrace board at contact face	29	8	21
Bearing	29	10	16
Picket close to post	191	12	51
Picket centred	1340	22	191
Post above picket	34	14	32
Post close to picket	87	18	30
Post close to ground	96	6	10

4.3 Facade orientation and distance to ground

Moisture and temperature data from the test house facades were analysed in analogy to the decking and fence assemblies. As expected, these invariably vertically exposed components showed less dose and thus longer service lives were predicted. The sum of total daily dose D_a and the corresponding service life estimations can be seen from Table 3. For many combinations of wood species, orientation and height above ground the service life to be expected was far above one century or even unlimited. At first view this seemed to be illegitimate, but was finally the result of no or at least very little measureable dose. Consequently, the results have to be interpreted as “snapshot” of the water-uptake behaviour at the present state. Ongoing weathering, staining, and decay will change that and lower the extremely high service life estimates. For future modelling the altering moisture behaviour might be extrapolated.

On the other hand, significant differences between the four test house walls were found. The West facade revealed the highest dosages for all wood species, leading to minimum service life estimations between 76 and 83 years. As South-west is the weather side in Hannover and solar irradiation is most intensive on the South side, it seems plausible that decay hazard is highest on the West facade. For the remaining three orientations no clear decay hazard ranking was indicated: Least severe exposure for Douglas fir was found in the North and East, for pine sapwood in the East and South, and for spruce on the North facade. In contrast, the impact of the distance to the ground on the decay potential became apparent in most cases: The highest dose was determined close to the ground (5-10 cm).

Table 4: Sum of total daily dose D_a of facades in dependence of orientation and height above ground determined for the exposure interval September 2008 till August 2009. In brackets: Corresponding preliminary estimation of service lives based on dose-response functions.

Wood species	Orientation	Height above ground [cm]						
		5	10	20	40	80	160	240
Douglas fir	North	0.00	0.00	0.00	0.12	0.00	0.00	0.00
		(∞)	(∞)	(∞)	(5583)	(∞)	(∞)	(∞)
	East	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		(∞)	(∞)	(∞)	(∞)	(∞)	(∞)	(∞)
	South	1.36	5.94	0.44	0.00	0.00	0.00	0.00
		(493)	(113)	(1523)	(∞)	(∞)	(∞)	(∞)
	West	4.84	6.71	5.33	8.09	7.76	6.90	6.70
		(138)	(100)	(126)	(83)	(98)	(97)	(99)
Scots pine sapwood	North	6.13	4.44	4.03	2.25	3.75	0.82	0.00
		(109)	(151)	(166)	(298)	(179)	(817)	(∞)
	East	0.00	0.93	0.00	0.15	0.17	0.00	0.00
		(∞)	(720)	(∞)	(4467)	(3941)	(∞)	(∞)
	South	0.00	0.00	0.00	0.00	0.00	0.35	3.02
		(∞)	(∞)	(∞)	(∞)	(∞)	(1914)	(222)
	West	5.30	8.87	5.90	5.48	6.05	4.65	4.55
		(126)	(76)	(114)	(122)	(111)	(144)	(147)
Norway spruce	North	1.38	0.73	0.00	0.41	1.51	0.43	0.00
		486	(918)	(∞)	(1634)	(444)	(1558)	(∞)
	East	2.88	4.20	5.58	4.44	0.47	0.89	0.00
		(233)	(160)	(120)	(151)	(1426)	(753)	(∞)
	South	7.47	1.72	0.69	0.00	0.00	0.00	0.00
		(90)	(390)	(971)	(∞)	(∞)	(∞)	(∞)
	West	8.77	8.88	7.90	5.20	6.45	1.32	1.32
		(76)	(76)	(85)	(129)	(104)	(508)	(508)

5. CONCLUSIONS

The impact of material and exposure conditions on the service life of wooden components as well as the effectiveness of different protective measures by design was found to be quantifiable through determination of dose-time functions. The impact is hereby indicated as service life number in years or alternatively as factor between two options.

After only one year of exposure, the results certainly need to be considered as preliminary. The annual dose D_a is most likely influenced by climatic variations between one year and the other. Therefore the annual dose should be calculated as mean average for at least three years. Reference years in terms of local climate should be identified. Furthermore one can expect that the moisture sorption behaviour of wood is influenced by weathering, e. g. through cracking, greying, and staining. Thus, the annual total dose may increase with exposure time.

For future studies further commodities and detailing need to be included in order to piece the puzzle together. On this matter a couple of studies were initiated to consider also the influence of roof overhangs, contact to ground and metal joints, covering, and coatings.

6. ACKNOWLEDGEMENTS

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