Wood Sci Technol (2008) 42:663–677
DOI 10.1007/s00226-008-0190-9

ORIGINAL

Influence of wood moisture content and wood temperature on fungal decay in the field: observations in different micro-climates

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Received: 30 August 2007 / Published online: 3 April 2008

Abstract In this study, Scots pine sapwood (*Pinus sylvestris* L.) and Douglas fir heartwood (*Pseudotsuga menziesii* Franco) specimens were exposed in double layer field trials at four different exposure sites and under different exposure conditions (in total ten test sets). The material climate of wood in terms of wood moisture content (MC) and wood temperature was automatically monitored over a period of 6 years and compared with the progress of decay. The aim of this study was to highlight the interrelationship between microclimate, material climate, and decay as a basis for the establishment of dose-response functions to be used for service life prediction of wood and wood-based products. Differences in resulting decay dynamics between the test sites as well as between the different types of exposure were quantified and discussed with respect to corresponding microclimatic and material climatic conditions. The time between the beginning of exposure and the first occurrence of visible decay varied between the sites and influenced the total decay development. The fundamental importance of direct decay factors, such as MC and wood temperature, were underlined and basic requirements for establishing dose-response-functions to be used in service life prediction models were derived.

Introduction

Timber use in outdoor applications is compromised by biological degradation. The service life of timber constructions is influenced by numerous factors, both wood-inherent properties and environmental influences. Several field studies concerning wood durability revealed significant differences in service life of wood at different

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exposure sites (Edlund 1998; Leicester et al. 2005; Wakeling 2006; Augusta 2007). Site-specific climate can significantly influence decay and should therefore be considered for service life estimations. Different climate levels can be distinguished: The macroclimate (described by weather data of the site), the mesoclimate (described by influences that are caused by the environmental situation at the site, e.g. shading, windbreaks), and the microclimate (described by the situation at and within a construction). The key factors for fungal growth and decay are wood moisture content (MC) and wood temperature and their dynamics (Viitanen and Ritschkoff 1991; Viitanen 1997; Rydell et al. 2005), which together produce the "material climate" in the wood (Brischke et al. 2006). While the role of these factors is well known, the relationships between climate, wood conditions and subsequent decay remain poorly understood. The aim of this study was therefore to look for differences in material climate under various microclimatic conditions to provide a better understanding of the relationship between material climate and fungal decay. Automated recordings of wood MC and wood temperature were applied on double layer field trials at four different German test sites, each with different exposure situations (artificial shade, tropical greenhouse), and compared with the progress of decay as a basis for establishing dose-response functions to be used for service life prediction of wood.

Materials and methods

Field tests

Field test specimens of Scots pine sapwood (*Pinus sylvestris* L.) and Douglas fir heartwood (*Pseudotsuga menziesii* Franco) were monitored in terms of MC, wood temperature, and the progress of fungal decay for six years. The specimens ($500 \times 50 \times 25$ mm^3), according to EN 252 (1989), were exposed in double layer test rigs (Rapp and Augusta 2004) in the year 2000. The test rigs (Fig. 1) consisted of specimens placed horizontally in two layers and exposed above ground producing a decay risk corresponding to European Use Class 3 (EN 335 2006). The number and distribution of the specimens can be seen in Fig. 2. The specimens were supported at the cut ends by beams of CCB-impregnated pine sapwood, separated with bitumen foil from the preservative-treated supports. The whole test set-up formed a closed deck ($73 \times 65 \times 21$ cm^3) placed on paved ground or horticultural foil to prevent the growth of grass.

The double-layer trials in this study were part of a larger investigation (Brischke and Rapp 2005) on the influence of different factors causing decay. The test set-ups were exposed at 32 sites in Europe and the United States, which were selected for their defined climates (one test rig at each site/for each exposure). Climate data at all sites were available from adjacent official weather stations, where measurements of daily precipitation and daily average temperature were recorded.

The characteristic data for the four German sites at Hamburg, Reulbach, Freiburg, and Stuttgart that were used in this study are listed in Table 1. In addition, these four sites were provided with a second test set exposed in artificial shade. The "shade sets" were put in plywood boxes ($30 \times 90 \times 90$ cm^3) covered with fully

Fig. 1 *Left* Photograph showing the double-layer set-up with the upper layer shifted 25 mm horizontally to the lower layer. Specimens are separated with bitumen foil from CCB-impregnated support beams. *Right* Artificial shading by textile sheet of double layer test set

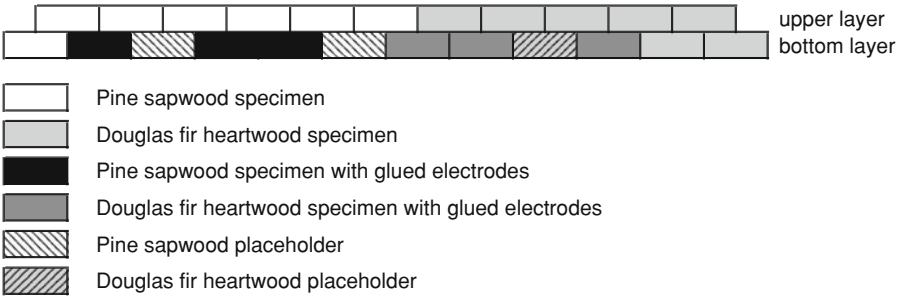

Fig. 2 Scheme of double layer test set up and distribution of specimens containing electrodes for MC measurements

water-permeable textile sheet, which transmitted only 10% of the incident sunlight (Fig. 1). Two additional sets at the Federal Research Centre for Forestry and Forest Products (BFH) in Hamburg were exposed in a tropical greenhouse during the winter (15 Oct–15 May), and the whole year (Table 1). The exposure in shade boxes and in the tropical greenhouse was carried out to bring about changes in microclimate and promote decay.

Decay assessment

The specimens were evaluated annually by rating the extent and distribution of decay according to EN 252 (1989) as: 0 (sound), 1 (slight attack), 2 (moderate attack), 3 (severe attack), or 4 (failure). The prevailing type of decay was identified for each species and exposure according to CEN/TS 15083-2 (2005).

Automated recordings of MC and wood temperature

The MC of three Scots pine sapwood and three Douglas fir heartwood samples in the bottom layer (Fig. 2) of each test set was measured and recorded daily. The measurement system applied in this study was described in an earlier publication (Brischke et al. 2007a) and can be summarized in brief as follows: Electrodes of

Table 1 Characteristic data for the field test sites

Test site	Test sets	Height above sea level (m)	Average temperature (°C)	Sum of precipitation (mm)
Hamburg	Hamburg sun/shade	35	10.6[a]	874[a]
	Greenhouse	35	21.6[d]	6,257[c]
	Greenhouse winter	35	18.6[d]	4,092[c, d]
Reulbach	Reulbach sun/shade	620	7.5[b]	820[a]
Stuttgart	Stuttgart sun/shade	459	9.9[b]	741[a]
Freiburg	Freiburg sun/shade	302	12.1[a]	911[a]

[a] Average of 2000–2005

[b] Average of 2001–2005

[c] Equivalent to a spraying of 120 l per week

[d] Average of 2000–2004

polyamide coated stainless steel cables were glued in holes, predrilled to a depth of 25 and 120 mm from the end grain. The end 5 mm of plastic coating was removed and put into conductive glue; the rest of the hole was filled with an isolating epoxy. The steel cables were connected to a small data logger (Materialfox Mini, Scanntronik Mugrauer GmbH, Zorneding, Germany), for recording the electrical resistance of the wood. Since electrical resistance measurements of wood below the freezing point produce anomalous values, days with a minimum temperature below 0°C were not considered. The data loggers were calibrated in a range between MC = 12 and 50% (Brischke et al. 2007a). Measurements above fiber saturation were found to become increasingly inaccurate, but still indicated a tendency within the calibration range.

The following temperature measurements were taken at the surface of the wood specimens using Thermofox Mini data logger (Scanntronik Mugrauer GmbH, Zorneding, Germany):

- Daily recording of average, minimum, and maximum temperatures below the bottom layer of each test set.
- Daily recording of average, minimum, and maximum temperatures between the layers at the Hamburg, Stuttgart, Freiburg and Reulbach test sites for sun-exposed pine sapwood and Douglas fir, and shade-exposed pine sapwood.
- 2-h-readings of wood temperature between the layers of the sun-exposed and the shade-exposed test set in Hamburg over a period of 11 months.

Results and discussion

Decay progress

In general, pine sapwood decayed faster than Douglas fir heartwood (Fig. 3a–e). However, decay of shaded Douglas fir in Stuttgart and Freiburg proceeded, after a

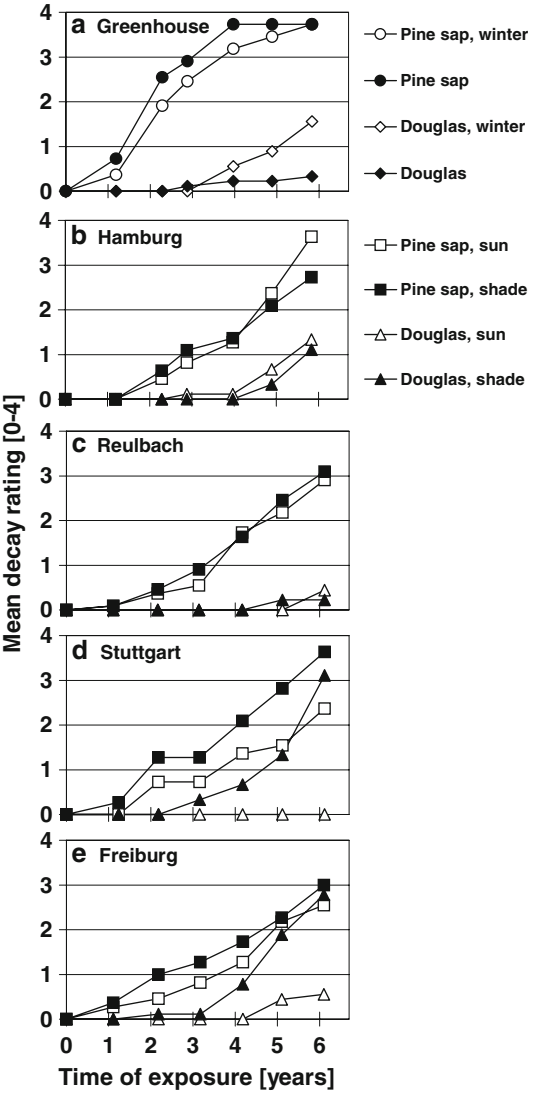

Fig. 3 Mean decay rating of pine sapwood and Douglas fir heartwood specimens exposed above ground in horizontal double layers. Exposure in a tropical greenhouse (**a**) in Hamburg for one test set during the whole year and for a second test set between 15 October and 16 May (winter). At the test sites Hamburg (**b**), Reulbach (**c**), Stuttgart (**d**), and Freiburg (**e**) the test sets were exposed in the sun and in the shade

time lag of 2–3 years, so fast, that it was more severely decayed than sun-exposed pine sapwood after 5–6 years (Fig. 3d, e). In Hamburg sun, Hamburg shade and Greenhouse winter, decay of Douglas fir proceeded comparatively slower. This may be explained by the dominating rot type at the different sites: brown rot was the predominant decay type on Douglas fir in Stuttgart and Freiburg, whereas in Hamburg and in the Greenhouse winter it was white rot. This comparatively higher decay progress by brown rot agrees with previous findings by Edlund (1998) and Augusta (2007).

The time required for slight attack to be detected, differed among test sites as well as between sun and shade exposures. Decay of pine sapwood was detected after one year of exposure in the Greenhouse and at the Stuttgart and Freiburg sites, but was not detected in Hamburg and Reulbach until the second year of exposure (Fig. 3a–e). Even more variation was found between time lags prior to decay for Douglas fir: 2 years in Stuttgart shade, but none detected after 6 years in Stuttgart sun (Fig. 3d). Thus, the sigmoid curves for decay, especially in above-ground exposures (Preston et al. 2000; Augusta et al. 2004; Brischke et al. 2007b), are mainly determined by the time lag at the beginning of exposure, and needs therefore to be regarded for the prediction of service lives. If it is possible to predict a time lag, then service life prediction becomes more accurate.

Fungal degradation of wood is complex, influenced not only by material-inherent properties of wood (endogenous factors), but also by abiotic and biotic environmental influences (exogenous factors) (Brischke et al. 2006). Therefore, also various reasons are conceivable for time lags between the beginning of exposure and detectable decay. Carey (2002a, b) isolated wood-destroying fungi from L-joint specimens after only 3–4 months, but the first visible signs of decay were not observed until three years of exposure. Thus, the onset of decay was somehow inhibited. Table 2 gives an overview of inhibitory effects on fungal activity, which potentially delay the start of fungal decay.

Once the initial inhibition was overcome, the rate of decay (cf. gradients in Fig. 3a–e) of pine sapwood was similar for different sites and partly also between shade and sun exposures. The greenhouse exposure was an exception; here decay was clearly accelerated compared to the other sites, which likely reflected the more favourable MC and temperature conditions. Compared to open exposure in Hamburg the decay ratings were up to five times higher in the greenhouse after 2.3 years of exposure. This coincides with the acceleration of decay progress between greenhouse/tropical conditions and central European outdoor exposure found in soil bed tests by Polman et al. (1991) and in Lap-joint-tests by Wong et al. (2004). As expected, the differences diminished with extended exposure due to the limited rating scale in EN 252 (1989).

Douglas fir tended to resist decay for far longer than pine sapwood, but once decay began, it proceeded more rapidly at some sites. However, since no decay of Douglas fir occurred after 6 years exposure at some sites, it is still too early for a final comparison.

The nominal differences in decay development between different test sites and different exposures can be derived from Table 3. In general, decay proceeded faster in the greenhouse (up to a factor of 2.4 for the time needed to reach a certain mean decay rating) and in the shade (up to a factor of 1.9) compared to the open field. Hereby, the influence of different test sites on the decay rate (up to a factor of 1.7) was similar to the influence of shade. However, with proceeding decay both differences diminished. This coincides with the findings of Augusta (2007) and Brischke et al. (2007b).

Table 2 Potential inhibitory effects on fungal activity that could delay the onset of decay

Causation	Mode of inhibition/effect	Described by
Competition	Competition between wood-destroying and non-wood-destroying organisms for nutrients or habitats	Rypáček (1966), Henningsson (1967), Rayner and Boddy (1988), Schmidt (2006)
Antagonism	Inhibition of wood-destroying organisms by non wood-destroying organisms, e.g. by production of toxic metabolites or mycoparasitism	Jacquiot (1968), Greaves (1970, 1972), Banerjee and Levy (1971), Behrendt et al. (1995), Schmidt and Müller (1996), Schmidt (2006)
Inhibitory extractives	Inhibition of fungal growth and decay by toxic extractives that can be inactivated by primary colonizers or leached from the wood substrate	Findlay (1966), Arndt and Willeitner (1969), Gref et al. (2001), Stirling and Morris (2006)
	Inhibition of spore germination by toxic extractives that can be inactivated by primary colonizers or leached from the wood substrate	Morton and French (1966), Schmidt and French (1979), Lee et al. (1992) Eberhardt et al. (1994), Augusta (2007)
Wood preservatives	Inhibition of fungal growth and decay. Detoxification of wood preservatives by primary colonizers or leaching	Detoxification: Choi et al. (2003), Wallace and Dickinson (2004) Leaching: Greaves (1977), Leicester et al. (2005)
Insufficient permeability	Increasing permeability by colonization of the substrate with blue stain fungi or bacteria	Dunleavy and McQuire (1970), Boutelje and Hägglund (1988), Fojutowski (2005)
Hydrophobicity	Mitigation of hydrophobic properties of refractory, coated, or oil/wax-impregnated wood by weathering (UV, leaching, bleeding)	Derbyshire and Carey (2001), Rapp et al. (2005), Stirling and Morris (2006)
Distance to infection sources	Differently high concentrations of fungal spores in the air	Vasiliauskas et al. (2005), Green et al. (2006), Kasprzyk and Worek (2006), Augusta (2007)
Contact to infection sources	Differently intensive contact to infection sources, e.g. mycelium[a]	Edlund (1998), Wakeling (2006), Augusta (2007)
Adverse moisture conditions	Mycelium growth may be limited due to low moisture content, whereas germination of spores is less affected by moisture	Morton and French (1966), Viitanen and Ritschkoff (1991), Viitanen (1997), Schmidt (2006)
UV light	Hindered spores germination due to lacking niches protected from degrading UV light; the formation of cracks can increase the protection of spores from UV	Panten et al. (1996), Schmidt (2006)

[a] Accelerating effect

Moisture conditions

As wood temperature and MC are important factors for fungal growth and wood decay (Viitanen 1997; Brischke et al. 2006), their values were determined and

Table 3 Time to reach a given mean decay rating according to EN 252 (1989) in horizontal double layers at various [exposures (– indicates] that the mean decay rating was not reached so far)

Wood species	Test site	Time to mean decay rating (years)			
		1	2	3	4
Pine sapwood	Greenhouse winter	1.6	2.4	3.7	–
	Greenhouse	1.4	2.0	3.0	–
	Hamburg sun	3.3	4.6	5.4	–
	Hamburg shade	2.7	4.8	–	–
	Reulbach sun	3.7	4.7	–	–
	Reulbach Shade	3.3	4.6	6.0	–
	Stuttgart sun	3.6	5.7	–	–
	Stuttgart shade	1.9	4.1	5.3	–
	Freiburg sun	3.6	4.9	–	–
	Freiburg shade	2.2	4.6	6.1	–
Douglas fir heartwood	Greenhouse winter	5.0	–	–	–
	Greenhouse	–	–	–	–
	Hamburg sun	5.4	–	–	–
	Hamburg shade	5.7	–	–	–
	Reulbach sun	–	–	–	–
	Reulbach shade	–	–	–	–
	Stuttgart sun	–	–	–	–
	Stuttgart shade	4.7	5.5	6.1	–
	Freiburg sun	–	–	–	–
	Freiburg shade	4.4	5.2	–	–

compared for the different test sites and exposures. Table 4 gives an overview of the number of wet days above certain MCs (MC = 20, 25, 30, 40, and 50%) and above 5°C wood temperature, which was considered as the lower temperature threshold for fungal activity.

Douglas fir heartwood was considerably drier than pine sapwood following all exposure periods. Therefore, the most distinctive differences between the sun and shade exposed test sets were found for the number of days above MC = 30% for Douglas fir and above MC = 40% for pine sapwood. While the number of wet days (MC > 40%) for pine was higher in the shade by a factor of 1.4 in Stuttgart, 1.5 in Hamburg and 1.7 in Reulbach, more wet days were found in the sun compared to the shade in Freiburg. The differences (days above MC = 30%) between sun and shade for Douglas fir were more pronounced compared to pine sapwood: i.e. factors between 1.6 and 2.2.

The differences between the test sites were slightly stronger for the sun exposure (factors up to 2.2 for pine sapwood, and up to 3.8 for Douglas fir) than for the shade exposure (factors up to 1.4 for pine sapwood, and up to 3.6 for Douglas fir). The exposure of pine sapwood in a tropical greenhouse led to higher numbers of wet days for both Greenhouse and Greenhouse winter compared to the other exposures and coincides with higher decay rates.

Table 4 Days with an average air temperature above 5°C and a moisture content above 20, 25, 30, 40, or 50% for the different test sites and exposures (based on a total exposure interval of 1,460 days)

Wood species	Test site	Days with MC >				
		20%	25%	30%	40%	50%
Pine sapwood	Greenhouse winter	1,449	1,446	1,412	1,003	500
	Greenhouse	1,452	1,391	1,299	963	363
	Hamburg sun	921	920	911	532	200
	Hamburg shade	933	921	908	900	543
	Reulbach sun	756	747	733	440	69
	Reulbach shade	788	788	778	666	19
	Stuttgart sun	846	822	791	576	83
	Stuttgart shade	906	894	879	780	160
	Freiburg sun	1,006	1,000	995	958	18
	Freiburg shade	998	995	980	878	207
Douglas fir heartwood	Greenhouse winter	1,218	988	352	63	0
	Greenhouse	1,257	689	17	0	0
	Hamburg sun	713	468	121	0	0
	Hamburg shade	806	625	252	2	0
	Reulbach sun	548	313	57	0	0
	Reulbach shade	707	492	123	0	0
	Stuttgart sun	637	486	216	0	0
	Stuttgart shade	871	759	436	0	0
	Freiburg sun	809	626	182	0	0
	Freiburg shade	939	781	291	0	0

The measuring intervals were 1 Jan 2001–30 Sept 2003 and 1 Oct 2004–31 Dec 2005. The time interval in between was excluded due to technical difficulties

Moisture content differences are shown for the test site in Stuttgart over a period of three years in Fig. 4. In general, the MC of pine sapwood, especially during summer, was higher compared to Douglas fir. Furthermore, the MC of both wood species was higher in the shade exposed sets, especially during summer (Fig. 4, mark 1), but also during winter (Fig. 4, mark 2). This coincides with the generally higher number of wet days in the shade exposed test sets compared to the sun exposed sets (cf. Table 4) and indicates a higher moisture induced risk for decay due to reduced incident irradiation and ventilation caused by the boxes, which reduced drying. The amplitudes of the moisture contents were higher for the sun exposed sets (Fig. 4, mark 3). This might also influence the conditions for fungal growth in the shaded sets, especially at the beginning of exposure.

Temperature conditions

The number of days above different temperatures and below 0°C is listed in Table 5. In general, the average temperature correlated well with the number of

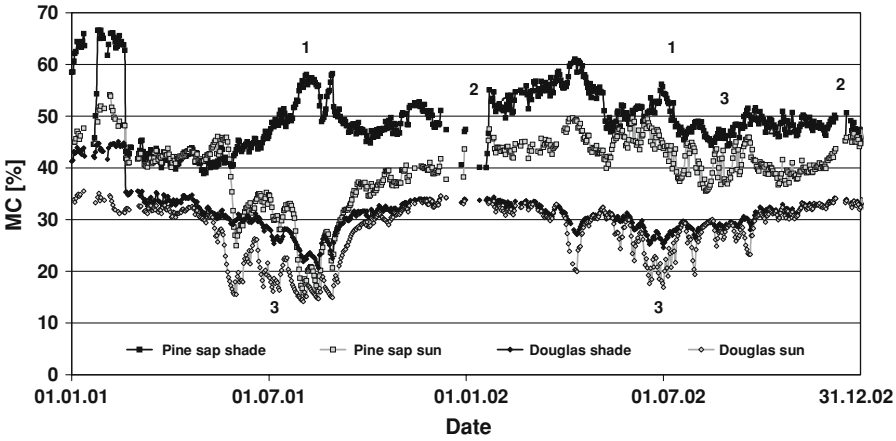

Fig. 4 Variation in moisture content (MC) of pine sapwood and Douglas fir heartwood specimens, sun-exposed and shade-exposed in double-layer test sets in Stuttgart; days with a minimum air temperature below 0°C were not considered (*Marks 1–3* indicate characteristics of the moisture course explained in the text)

days above/below certain temperatures, e.g. Reulbach, the test site with the lowest average temperature, showed the highest number of days below 0°C and the lowest number of days above 20°C. However, considering the shade exposed test sets, differences in the number of warm or cold days can be observed between test sites with nearly the same average temperature, e.g. between Freiburg shade (10.8°C) and Hamburg sun (10.4°C), a difference of 51 days below the freezing point (i.e. factor 1.4) was found. The comparison between sun and shade exposed sets revealed that nearly all shade exposed sets experienced less cold days ($\leq$0°C) and less very hot days (>25°C) than the sun exposed sets. Thus, the negative effect of extreme temperature days on fungal activity is mitigated in the shade. This coincides with higher decay activity in the shade sets at least at the beginning of exposure. However, there was no direct correlation between temperature extremes and the degree of decay suggesting a more complex dose–response relationship between wood temperature, MC and decay rate.

Interactions between MC and wood temperature in different exposures

The differences between sun and shade exposure on temperature is considered in detail in the following section. The results from 2-hourly readings of wood temperature are shown for the Hamburg test site (Fig. 5). Shade sets did not automatically have lower temperatures than sun-exposed sets (Fig. 5). Wood temperature in the sun-exposed set decreased to −8°C in December, while the temperature did not fall below 0°C in the shade (Fig. 5, mark 1). Temperature in the shade-exposed set did not fall below 0°C until it was colder and/or stayed cold for a longer period (Fig. 5, mark 2). Once the wood in the shade is frozen (MC > fiber saturation provided), then it stays frozen, whereby the temperature of the wood in

Table 5 Days with a temperature (measured directly below the bottom layer) above 25, 20, 15, 10, or 5°C or below 0°C for the different test sites and exposures (based on a total exposure interval of 1,460 days)

Test site	Average temperature (°C)	Days with					
		>25°C	>20°C	>15°C	>10°C	>5°C	≤0°C
Greenhouse winter	17.3	40	282	1,118	1,438	1,460	0
Greenhouse	18.4	55	483	1,185	1,451	1,460	0
Hamburg sun	10.4	32	191	476	743	1,006	139
Hamburg shade	10.2	13	179	470	726	972	117
Reulbach sun	8.2	12	121	408	779	1,119	344
Reulbach shade	8.2	8	130	425	739	1,104	314
Stuttgart sun	9.7	22	210	552	884	1,238	254
Stuttgart shade	9.1	2	135	500	822	1,178	234
Freiburg sun	11.7	110	351	677	1,007	1,371	172
Freiburg shade	10.8	57	261	607	977	1,313	190

The measuring intervals were 01 Jan 2001–30 Sept 2003 and 1 Oct 2004–31 Dec 2005. The time interval in between was excluded due to technical difficulties

the sun already exceeded 0°C (Fig. 5, mark 3). This can be understood when considering the course of temperatures in spring 2002 (Fig. 6).

Temperatures in the driest wood specimens (Douglas fir heartwood) were most often below 0°C (Fig. 6, mark 1). The temperature of the wetter pine sapwood specimens were below 0°C only once (Fig. 6, mark 2), when the air temperature was very low for one week. The wettest specimens were the shade-exposed pine

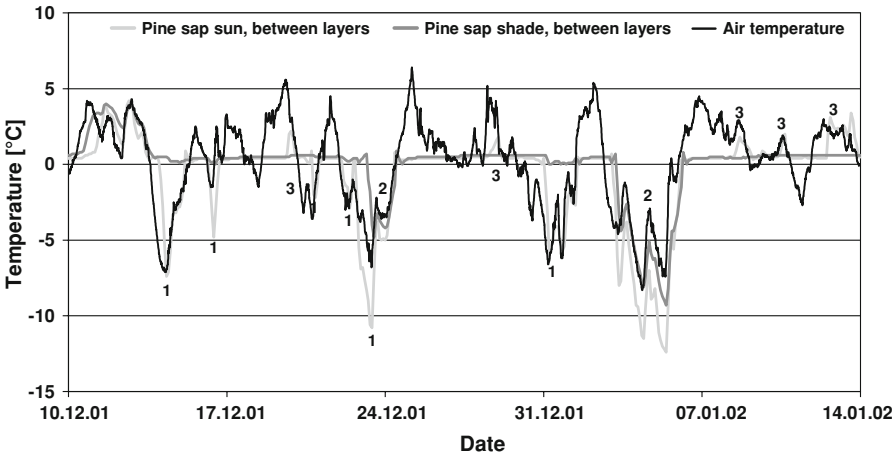

Fig. 5 Course of temperature between pine sapwood layers (sun-exposed: *light grey line*; shade-exposed: *dark grey line*) of double-layer test sets and corresponding air temperature (*black line*) in Hamburg between 10 December 2001and 14 January 2002 (*Marks 1–3* indicate characteristics of the temperature course explained in the text)

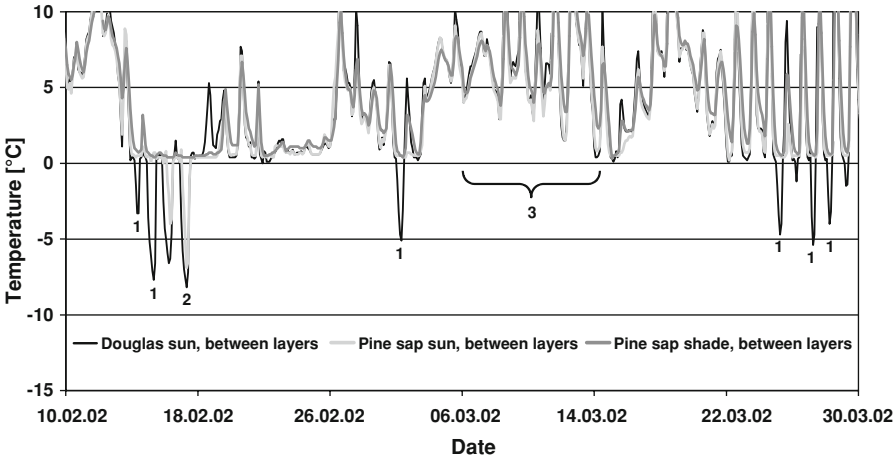

Fig. 6 Temperature variation between pine sapwood layers (sun-exposed: *light grey line*; shade-exposed: *dark grey line*), and sun-exposed Douglas fir layers (*black line*) of double-layer test sets in Hamburg between 10 February 2002 and 30 March 2002 (*Marks 1–3* indicate characteristic temperatures referred to in the text)

Table 6 Numerical evaluation of 2-hourly recorded temperature between the layers of double layer test sets in Hamburg between 30 Nov 2001 and 9 Oct 2002. Total number of readings was 3,760

Temperature between upper and bottom layer	Number of readings		
	Douglas fir	Pine sap	
	Hamburg sun	Hamburg sun	Hamburg shade
>35°C	122	79	4
>30°C	258	203	56
>25°C	421	366	246
<0°C	182	109	50
<−5°C	79	49	20
<−10°C	11	10	0

sapwood, which were never below 0°C during the whole spring of 2002 despite being exposed to many days of freezing temperatures. These differences can be explained by the thermal energy released while freezing, which kept the wood temperature up. Per kg water to freeze, 334 KJ are liberated, which prevent the wood from going below 0°C. Thus, the more water, that there is in the wood, the higher is its temperature, when the temperature falls below 0°C.

An additional effect occurs in cold, but not very cold nights during spring and autumn (e.g. Fig. 6, mark 3). Although the air temperature is well above the freezing point, the shade-exposed pine sapwood still showed the smallest drop of temperature during cold nights, because the textile cover sheet partly insulates the specimens.

The numerical results of nearly one year of 2-hourly recorded temperature between the layers of the double layer test sets in Hamburg (Table 6) can be summarized as follows: the temperature amplitudes in the shade are much smaller than in open, which means there are fewer extremes. The driest wood specimens showed the greatest amplitude referring to more hot days and more cold nights compared to specimens with higher moisture content. The shade is provided artificially by a membrane, which confers some insulation. In reality shade is not produced this way, but similar effects can be observed when shade is caused by trees, roofs or other buildings, e.g. under carports or courtyards.

Conclusion

Average weather data is insufficient for estimating decay hazard of an exposure site or exposure situation. As shown for exposure in artificial shade, the omission of extreme conditions, such as very low or very high temperatures, dampened amplitude of wood temperature and promoted fungal decay activity. It highlights the importance of direct decay influencing factors, such as MC and wood temperature for service life prediction.

It was shown, that the number of critical days (days above/below certain MC and temperature) seems to be a suitable measure to distinguish between differently severe exposure conditions. The integral of critical days in relation to corresponding decay assessments may therefore be useful to determine the dose, which impacts on a wooden component. However, the consideration of only one single parameter (in terms of critical days) will not lead to a useful correlation, as shown in this study. Thus, for a future set up of dose-response functions it is necessary to also consider potential interactions between moisture and temperature, which will be presented in a follow-up publication.

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