## 7.4 Publikation IV: Influence of wood moisture content and wood temperature on fungal decay in the field - Observations in different micro-climates

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**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 10 test sets). The material climate of wood in terms of wood moisture content (MC) and wood temperature was automatically monitored over a period of six 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. Differently long time lags between the beginning of exposure and the first occurrence of visible decay seemed to have an impact on 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.

## 7.4.1 Introduction

Timber use in outdoor applications is compromised by means of 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 exposure sites (Edlund 1998; Leicester et al. 2005; Wakeling 2006a; Augusta 2007). Site-specific climate can have an essential influence on 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 provoked 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 combine to 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 after differences in material climate under various microclimatic conditions to provide a better understanding of the relationship between climate and fungal decay. Automated recordings of wood moisture content 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.

## 7.4.2 Material and methods

### Field tests

Field test specimens from 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 (500x50x25 mm$^3$), according to EN 252 (1989), were exposed in double layer test rigs (Rapp and Augusta 2004) in 2000. The test rigs (Figure 7.4-1) consisted of specimens placed horizontally in two layers and exposed above ground producing a decay risk corresponding to European Hazard Class 3 (EN 335, 2006). The number and distribution of the specimens can be seen from Figure 7.4-2. 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 (73x65x21 cm$^3$) placed on paved ground or horticultural foil to avoid the growth of grass.



**Figure 7.4-1. 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.**
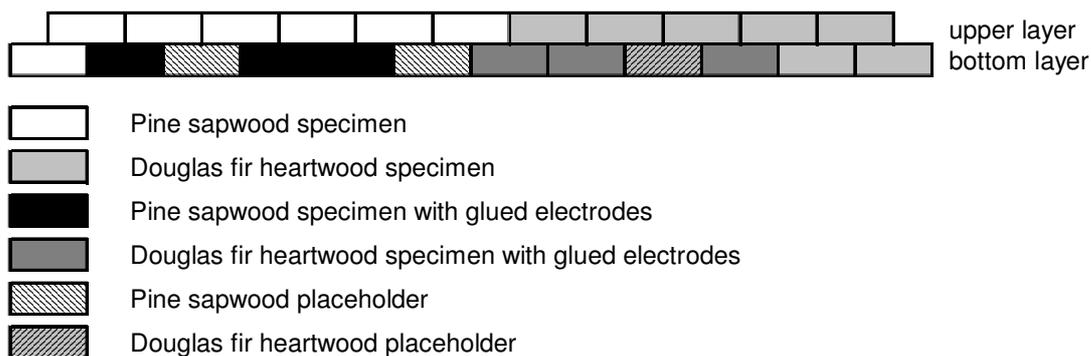


**Figure 7.4-2. Scheme of double layer test set up and distribution of specimens containing electrodes for MC measurements.**

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 average temperature were recorded.

The characteristic data for the four German sites at Hamburg, Reulbach, Freiburg, and Stuttgart, that were considered in this study, are listed in Table 7.4-1. In addition, these four sites were provided with a second test set exposed in artificial shade. The "shade sets" were put in plywood boxes (30x90x90 cm³) covered with fully water-permeable textile sheets, which were transmitting only 10% of the sunlight (Figure 7.4-1). 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 (Oct 15$^{th}$ – May 15$^{th}$), and the whole year (Table 7.4-1). The exposure in shade boxes and in the tropical greenhouse was carried out to provoke changes in terms of the microclimate and to promote the conditions for decay.

**Table 7.4-1. Characteristic data of 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 [1] | 874 [1] |
| | Greenhouse | 35 | 21.6 [4] | 6257 [3] |
| | Greenhouse winter | 35 | 18.6 [4] | 4092 [3] [4] |
| Reulbach | Reulbach sun/shade | 620 | 7.5 [2] | 820 [1] |
| Stuttgart | Stuttgart sun/shade | 459 | 9.9 [2] | 741 [1] |
| Freiburg | Freiburg sun/shade | 302 | 12.1 [1] | 911 [1] |

[1] average of 2000-2005
[2] average of 2001-2005
[3] equivalent to a spraying of 120 l per week
[4] average of 2000-2004

**Decay assessment**

The specimens were evaluated yearly 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 EN 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 (Figure 7.4-2) of each test set was measured and recorded

once a day. 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 polyamide coated stainless steel cables were glued in holes predrilled to a depth of 25 mm. The end 5 mm of plastic coating was removed and put into a 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 logger were calibrated in a range between MC=12% and MC=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 conducted directly on the wood specimens using Thermofox Mini data logger (Scanntronik Mugrauer GmbH, Zorneding, Germany):

- Daily recording of average, minimum, and maximum temperature below the bottom layer of each test set
- Daily recording of average, minimum, and maximum temperature 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.

## 7.4.3 Results and discussion

**Decay progress**

Pine sapwood decayed faster than Douglas fir heartwood in general (Figure 7.4-3a-e). However, decay of shaded Douglas fir in Stuttgart and Freiburg proceeded, after a time lag of 2 to 3 years, so fast, that it was more severely

decayed than sun-exposed pine sapwood after 5 to 6 years (Figure 7.4-3d, e). In Hamburg sun, Hamburg shade and Greenhouse winter decay on Douglas fir proceeded comparatively more slowly. 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, where in Hamburg and in Greenhouse winter it was white rot. This comparatively higher decay progress by brown rot agrees with previous findings by Edlund (1998) and Augusta (2007).

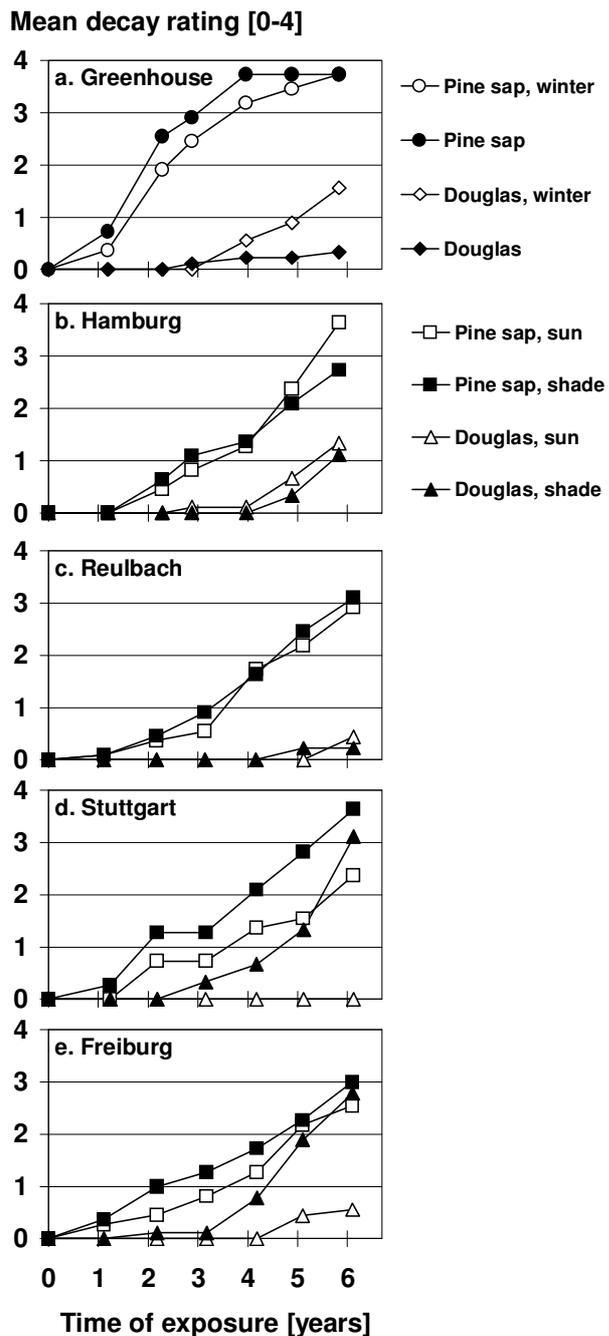**Mean decay rating [0-4]**



**Time of exposure [years]**

**Figure 7.4-3. 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 ran for one test set during the whole year and for a second test set between October 15th and May 16th (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.**

The time lags, where nearly no decay occurred, differed among test sites as well as between sun and shade exposures. Decay on pine sapwood started immediately in the first 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 (Figure 7.4-3a-e). Even more variation was found between time lags for Douglas fir: two years in Stuttgart shade, but six years in Stuttgart sun (Figure 7.4-3d). Thus, the sigmoid courses of 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.

Fungal degradation of wood is a very complex process, which is 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 the appearance of time lags between the beginning of exposure and detectable decay. Carey (2002a, b) isolated wood-destroying fungi from L-joint specimens after only 3 to 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 7.4-2 gives an overview of inhibitory effects on fungal activity, which potentially cause the delayed start of fungal decay.

**Table 7.4-2. Potential inhibitory effects on fungal activity that could delayed the onset of decay.**

| Causation | Mode of inhibition/Effect | e.g. 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 (1967); 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 (e.g. toxic) extractives that can be inactivated by primary colonizers or leached out from the wood substrate | Findlay (1966); Arndt and Willeitner (1969); Gref et al. (2001); Stirling and Morris (2006) |
| | Inhibition of spore germination by (e.g. toxic) extractives that can be inactivated by primary colonizers or leached out 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[1] | 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) |

[1] accelerating effect

Once the initial inhibition was overcome, the rate of decay (cf. gradients in Figure 7.4-3a-e) of pine sapwood was similar between the different test 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 moisture 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 proceeding exposure time due to the limited rating scale after EN 252 (1989).

Douglas fir tended to resist initiation of decay for far longer than pine sapwood, but once decay began, it generally proceeded more rapidly. However, due to very little decay of Douglas fir after six 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 the time needed to reach a certain mean decay rating (Table 7.4-3). In general, decay proceeded faster in the greenhouse (up to a factor of 2.4) 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 7.4-3. Time to reach a given mean decay rating after CEN (1989) in horizontal double layers at various exposures.**

| Wood species | Test site | Time to mean decay rating [y] | | | |
|---|---|---|---|---|---|
| | | 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 | - | - |

## Moisture conditions

As wood temperature and MC count to the key factors for fungal growth and wood decay (Viitanen 1997, Brischke et al. 2006), their quantity was determined and compared for the different test sites and exposures in the following. Table 7.4-4 gives an overview about the number of wet days above certain MCs (MC=20, 25, 30, 40, and 50%) and above 5°C wood temperature, which can be seen as the lower limitation for fungal activity.

**Table 7.4-4. 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 1460 days\*).**

| Wood species | Test site | Days with MC > | | | | |
|---|---|---|---|---|---|---|
| | | 20% | 25% | 30% | 40% | 50% |
| Pine sapwood | Greenhouse winter | 1449 | 1446 | 1412 | 1003 | 500 |
| | Greenhouse | 1452 | 1391 | 1299 | 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 | 1006 | 1000 | 995 | 958 | 18 |
| | Freiburg shade | 998 | 995 | 980 | 878 | 207 |
| Douglas fir heartwood | Greenhouse winter | 1218 | 988 | 352 | 63 | 0 |
| | Greenhouse | 1257 | 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 01.01.2001-30.09.2003 and 01.10.2004-31.12.2005. The time interval in between was excluded due to technical difficulties.

Douglas fir heartwood was considerably dryer than pine sapwood at nearly all times of exposure. 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. As 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 stronger 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

extremely higher numbers of wet days for both Greenhouse and Greenhouse winter compared to the other exposures and coincides with remarkable higher decay rates.

Moisture courses are exemplarily shown for the test site in Stuttgart over a period of three years in Figure 7.4-4. 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 (Figure 7.4-4, mark 1), but also during winter (Figure 7.4-4, 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 7.4-4) and indicates a higher moisture induced risk for decay due to reduced sunlight irradiation and hindered ventilation caused by the boxes. The amplitudes of the moisture course were higher for the sun exposed sets (Figure 7.4-4, mark 3). This might also have positively affected the conditions for fungal growth in the shade exposed sets, especially in the beginning of exposure.
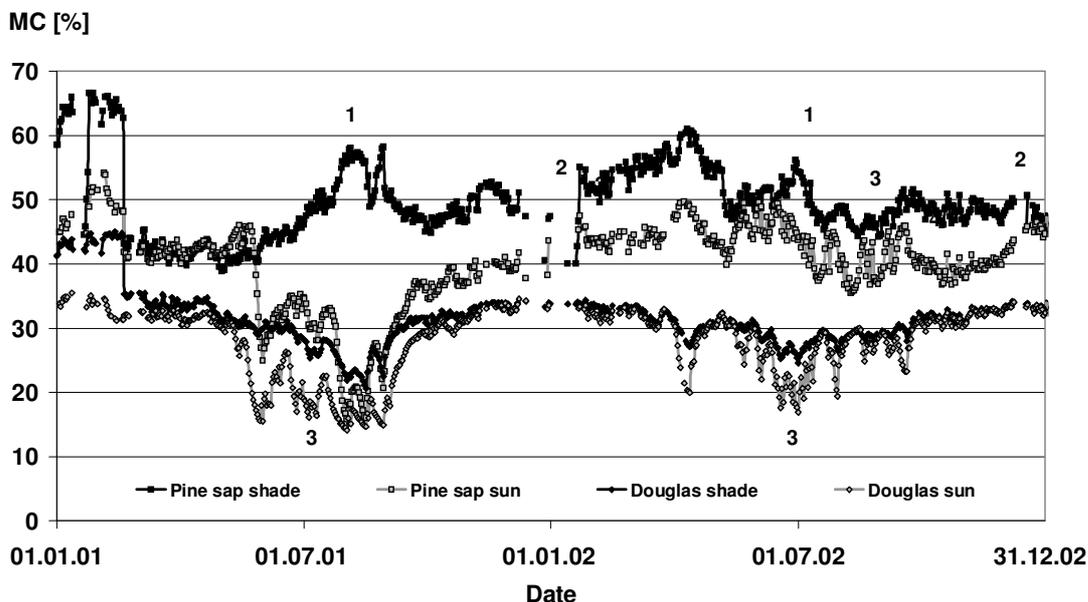


**Figure 7.4-4. Courses of moisture content (MC) of pine sapwood and Douglas fir heartwood specimens, sun-exposed and shade-exposed in double-layer test sets in Stuttgart; days with a minimum air temperature below 0°C were not considered (Marks 1 to 3 indicate characteristics of the moisture course explained in the text).**

**Temperature conditions**

The number of days above different temperatures and below the freezing point respectively are listed in Table 7.4-5. In general, the average temperature correlated well with the number of 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, when considering also 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 (≤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.

**Table 7.4-5. 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 1460 days\*).**

| Test site | Average temperature | Days with | | | | | |
|---|---|---|---|---|---|---|---|
| | [°C] | > 25°C | > 20°C | > 15°C | > 10°C | > 5°C | < 0°C |
| Greenhouse winter | 17.3 | 40 | 282 | 1118 | 1438 | 1460 | 0 |
| Greenhouse | 18.4 | 55 | 483 | 1185 | 1451 | 1460 | 0 |
| Hamburg sun | 10.4 | 32 | 191 | 476 | 743 | 1006 | 139 |
| Hamburg shade | 10.2 | 13 | 179 | 470 | 726 | 972 | 117 |
| Reulbach sun | 8.2 | 12 | 121 | 408 | 779 | 1119 | 344 |
| Reulbach shade | 8.2 | 8 | 130 | 425 | 739 | 1104 | 314 |
| Stuttgart sun | 9.7 | 22 | 210 | 552 | 884 | 1238 | 254 |
| Stuttgart shade | 9.1 | 2 | 135 | 500 | 822 | 1178 | 234 |
| Freiburg sun | 11.7 | 110 | 351 | 677 | 1007 | 1371 | 172 |
| Freiburg shade | 10.8 | 57 | 261 | 607 | 977 | 1313 | 190 |

\*the measuring intervals were 01.01.2001-30.09.2003 and 01.10.2004-31.12.2005. The time interval in between was excluded due to technical difficulties.

**Interactions between MC and wood temperature in different exposures**

The differences between sun and shade exposure with respect to temperature conditions will be considered more detailed in the following. Therefore the results from 2-hourly readings of wood temperature are shown as an example for the Hamburg test site (Figure 7.4-5). Shade sets did not automatically have lower temperatures than sun-exposed sets (Figure 7.4-5). Wood temperature in the sun-exposed set declined to –8 °C in the start of the winter, while the temperature did not fall below 0 °C in the shade (Figure 7.4-5, mark 1). Temperature in the shade-exposed set did not decline below 0 °C until it was colder or/and stayed cold for a longer period (Figure 7.4-5, mark 2). If once the wood in the shade is frozen (MC > fiber saturation provided), then it stays, whereby the temperature of the wood in the sun already exceeded 0 °C (Figure 7.4-5, mark 3). This can be understood when considering the course of temperatures in spring 2002 (Figure 7.4-6).
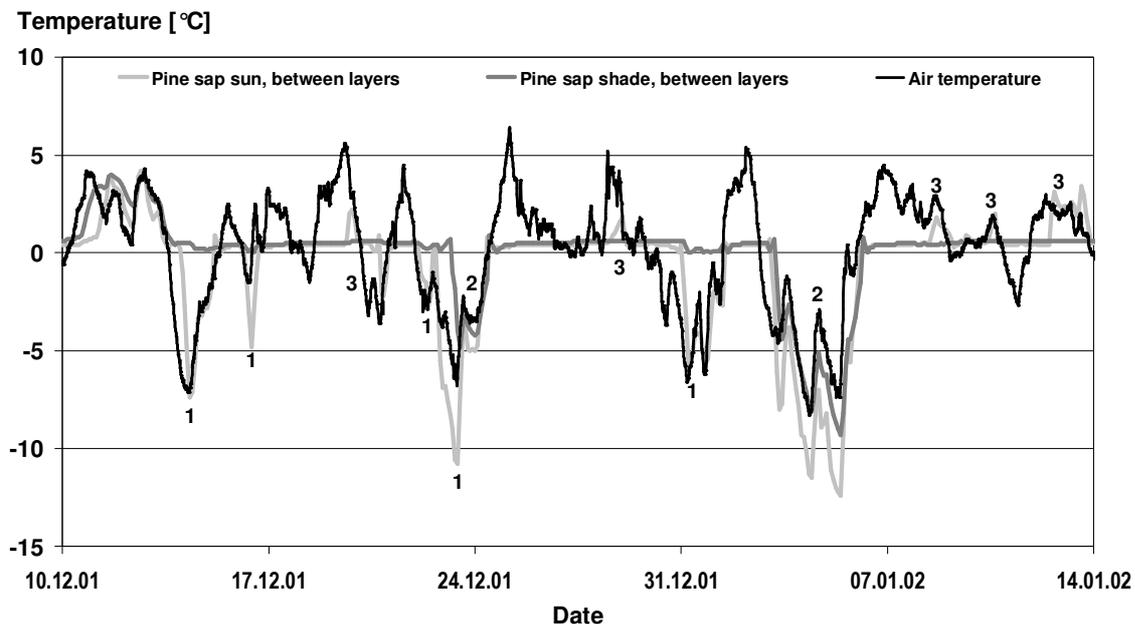


**Figure 7.4-5. Course of temperature between pine sapwood layers (sun-exposed: light grey line; shade-exposed: dark grey line) of double-layer test sets and corresponding air temperature (black line) in Hamburg in winter 2001 (Marks 1 to 3 indicate characteristics of the temperature course explained in the text).**
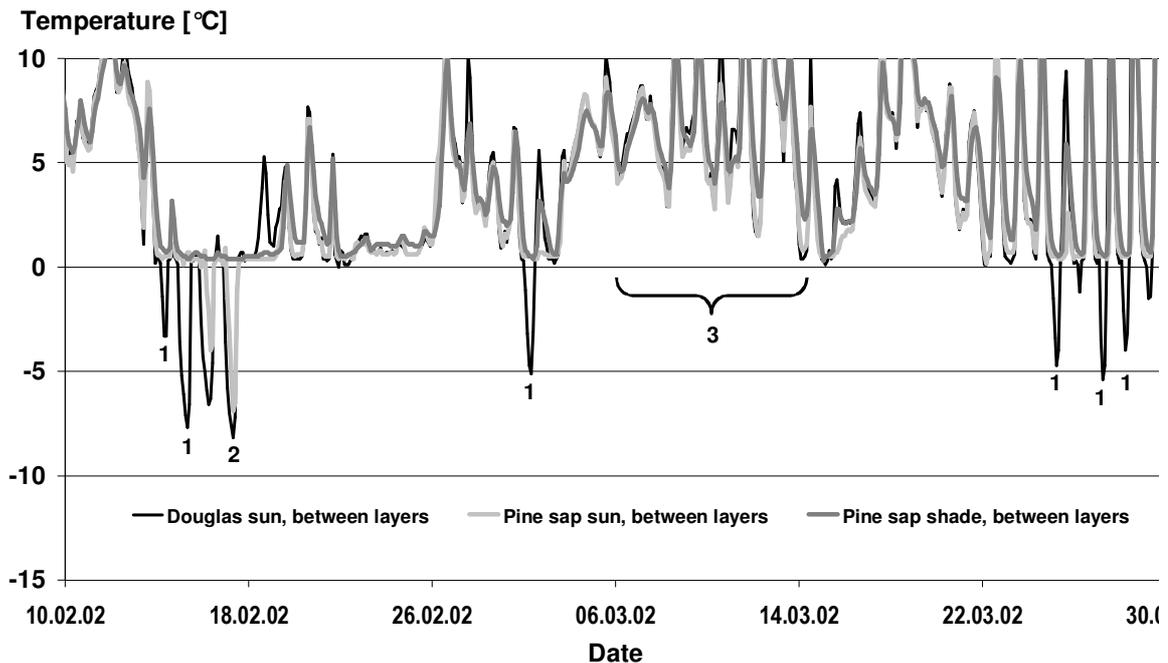
**Figure 7.4-6. Course of temperature between pine sapwood layers (sun-exposed: light grey line; shade-exposed: dark grey line), and sun-exposed Douglas fir layers (black line) of double-layer test sets in Hamburg in spring 2002 (Marks 1 to 3 indicate characteristics of the temperature course explained in the text).**

Temperatures in the driest wood specimens (Douglas fir heartwood) were below 0 °C most often (Figure 7.4-6, mark 1). The temperature of the wetter pine sapwood specimens were below 0 °C only once (Figure 7.4-6, mark 2), when the air temperature was very low for one week. The wettest specimens were the shade-exposed pine 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 and 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 is in the wood, the higher is its temperature.

An additional effect occurs in cold, but not very cold nights during spring and autumn (e.g. Figure 7.4-6, 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 kept the falling cold air away from 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 7.4-4) can

be summarized as follows: the temperature amplitudes in the shade are much smaller than under open sky, which means the occurrence of less extremes in terms of less hot days and less cold nights. The driest wood specimens showed the tallest amplitudes referring to more hot days and more cold nights compared to specimens with higher moisture content.

**Table 7.4-6. Numerical evaluation of 2-hourly recorded temperature between the layers of double layer test sets in Hamburg between 30.11.2001 and 09.10.2002. Total number of readings was 3760.**

| 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 |

## 7.4.4 Conclusions

It became obvious, that dealing with average weather data only is insufficient for estimating the decay hazard of a certain exposure site, or exposure situation, respectively. As shown for exposure in artificial shade, the omission of extreme conditions, such as very low or very high temperatures, led to a dampened amplitude of wood temperature and had presumably a positive effect on fungal activity. This underlines the essential meaning of direct decay influencing factors, such as MC and wood temperature, to be considered for service life prediction of wood.

Furthermore, 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 consider also potential interactions

between moisture and temperature, which will be presented in a follow-up publication.

## 7.4.5 References

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