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Section 2 **Test methodology and assessment**

Moisture performance based wood durability testing

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Moisture performance based wood durability testing

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ABSTRACT

In the frame of a scientific cooperation within the Swedish research program 'WoodBuild' comparative field and laboratory durability studies have been carried out by the Technical Research Institute of Sweden SP and Leibniz University Hannover. One objective was to improve test methods as well as evaluation systems in order to facilitate the use of (field) testing for service life prediction. Therefore field trials containing long-term moisture and temperature recordings were set up to verify the suitability of different test methods for estimating the durability of wood under different exposure conditions.

In this paper the test set up as well as preliminary results of the comparative studies on moisture performance of different materials in standardized and non-standardized field tests are presented. The field trials include graveyard, double layer, sandwich as well as lap-joint tests, which were performed with natural durable, modified and preservative treated timber. To consider the aspect that different climate conditions affect wood degrading processes the tests were carried out at three different test sites: Borås (Sweden), Hilo (Hawaii, USA) and Hannover (Germany). In addition, different laboratory decay and moisture uptake tests were conducted on samples matched to the field specimens.

Preliminary results of the continuous moisture content (MC) measurements pointed on differences in moisture load between test methods, materials, and test sites. A more detailed understanding of the respective moisture regime can be expected when using different above ground test methods. Compared to traditional durability field testing the moisture performance based testing allows for reducing exposure intervals and more use-class related assessment. Due to this it seems worthwhile to quantify further test methods related to their severity and consequently to different exposure situations. The results for the different modified and preservative treated timber products pointed on the need for determination of material-dependent critical MC.

Keywords: double layer test, lap-joint test, moisture monitoring, sandwich test

1. INTRODUCTION

Wood shows numerous advantages compared to other building materials. However, some factors delimitate its use in different exposure conditions. The wood moisture content (MC) and temperature advance or constrain the conditions for decay fungi. Different physiological studies on wood destroying fungi (Schmidt 2006, Huckfeldt and Schmidt 2006, Viitanen 1991) showed the considerable impact of MC and temperature for fungal decay. Besides the material inherent resistance a constant wetting and temperatures between 20 to 30°C (Carll and Highley 1999, Boddy 1983) promote the risk of infestation which can finally cause a decrease in structural stability. Consequently, long-term moisture and temperature recordings on field tests seem reasonable to quantify the impact of both parameters on different wood-based materials and wooden components in different outdoor exposure situations.

Decay on timber exposed in the ground (UC 4) is predominantly affected by temperature and the fungal flora present at the respective test site. Constant wetting of the wood is usually assured (e.g. Wakeling 2006, Augusta 2007, Brischke *et al*. 2011). In contrast, testing the durability of timber above ground (UC 2 and 3) requires consideration of more factors. In particular the respective moisture regime needs to be considered carefully depending on the exposure situation. A wide range of moisture loads can be expected for details such as decking, claddings, or sheltered constructions. Consequently, different test methods referring to the different exposure situations are needed, but not available in any case.

More than 60 different above ground test methods have been reported in literature (e.g. De Groot 1982, Fougerousse 1976, Råberg *et al.* 2005, Fredriksson 2010, Brischke *et al.* 2012), but less than 10 of them are standardized today. Most of these test methods were mainly conducted to compare different wood species, modifications or treatments (Fredriksson 2010). However, since the moisture and temperature load in the different test set ups is usually not determined, no reliable information is available about the ability of different test set ups to reflect different exposure situations. Furthermore, the effectiveness of different acceleration measures like water trapping, artificial shading and modified bearings, e.g. in form of feeder boards, is not fully understood. The high variation of non-standardized test methods which are applied under diverse conditions (different researchers, different sites and partly with different accelerations) makes it more difficult to get comparable results which are indispensable for service life prediction (Brischke *et al.* 2011).

To proof the suitability of existing standardized and non-standardized test methods for estimating the durability of wood under different exposure conditions comparative field studies were carried out containing long-term moisture and temperature recordings. Due to the fact that use class related testing can lead to an enormous extension of test durations for less severe conditions like in UC 3.1 and UC 2 the applicability of MC recordings to serve as a time-saving alternative to long-term field tests was considered and will be discussed.

The overall objective of this comparative study – as part of the research program ‘WoodBuild’ - was to investigate different field and laboratory test methods with respect to the following:

- Applicability to all relevant wood and wood-based materials
- Securing realistic levels of severity in terms of moisture loads
- Relationship between test material, test method, and test site
- Assess moisture performance to reduce test durations to acceptable levels
- Identify suitable elements and tools for a comprehensive test methodology

This paper gives an overview of the complete experimental set up of the 'WoodBuild' durability trials as well as preliminary results related to the moisture performance of various wood based materials in different test set ups.

2. EXPERIMENTAL SET UP

2.1 Wood materials

The test set up covered four different field test methods using 40 different wood based materials. In total 2249 specimens were exposed at the three test sites (*cf.* chapter 2.4). Natural durable timbers, preservative treated as well as chemically and thermally modified timbers were included. The test specimens for the tests conducted in Hannover were made from the following wood materials (Table 1 to Table 3)

Table 1: Native timber for field trials in Hannover
(DL= Double layer test, LJ= Lap joint test, SW= Sandwich test, GY= Graveyard test)

Material	**Botanical name**	**DL**	**LJ**	**SW**	**GY**
Scots pine sapwood	*Pinus sylvestris* L.	x	x	x	x
Scots pine heartwood	*Pinus sylvestris* L.	x	x	x	x
Scots pine resinous	*Pinus sylvestris* L.	x		x	x
Southern yellow pine sapwood	*Pinus* spp.	x		x	x
Radiata pine sapwood	*Pinus radiata* D. Don.	x	x	x	x
Norway spruce	*Picea abies* Karst.	x	x	x	x
Douglas fir heartwood	*Pseudotsuga menziesii* Franco	x	x	x	x
Douglas fir sapwood	*Pseudotsuga menziesii* Franco	x	x	x	x
Beech	*Fagus sylvatica* L.	x	x	x	x
English oak	*Quercus robur* L.	x	x	x	x
European ash	*Fraxinus excelsior* L.	x	x	x	x
Black locust	*Robinia pseudoacacia* L.	x	x	x	x

Table 2: Modified timber for field trials in Hannover
(DL= Double layer test, LJ= Lap joint test, SW= Sandwich test, GY= Graveyard test)

Material	**DL**	**LJ**	**SW**	**GY**
Furfurylated Southern yellow pine	x	x		x
Furfurylated Scots pine	x		x	x
Furfurylated Maple	x			
Furfurylated Radiata	x		x	x
Furfurylated Beech	x		x	x
Acetylated Southern yellow pine	x		x	x
Acetylated Radiata pine	x	x	x	x
Thermally modified Scots pine	x	x		
Oil-heat treated Norway spruce	x	x	x	x
Oil-heat treated European ash	x	x	x	x

Table 3: Preservative treated timber for field trials in Hannover, all materials made from Scots pine sapwood (DL= Double layer test, LJ= Lap joint test, SW= Sandwich test, GY= Graveyard test)

Material	DL	LJ	SW	GY
CCA 2 kg/m³	x		x	x
CCA 4 kg/m³	x	x	x	x
CCA 9 kg/m³				x
ACQ	x		x	x
ACQ Micronized copper	x		x	x
Metal-free	x		x	x

2.2 Test set up

2.2.1 Graveyard test

The graveyard test was carried out according to EN 252 (1990). The stakes (25 mm x 50 mm x 500 mm) were buried half to their length (Figure 1). The stakes were put in rows with a distance of approximately 300 mm and the different materials were installed alternately. All specimens were free of cracks, decay and other obvious defects.

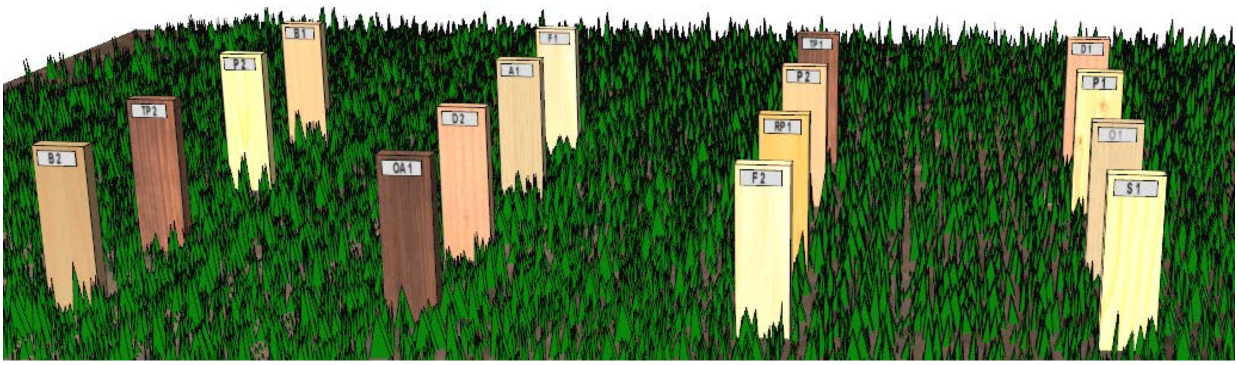

Figure 1: Graveyard test

2.2.2 Double layer test

Double layer tests were carried out according to Augusta (2007). Within the double layer test eleven replicates of each test material (25 mm x 50 mm x 500 mm) were exposed horizontally and 25 cm above ground in supports made from aluminum L-profiles (Figure 2). The upper layers were displaced laterally by 25 mm to the bottom layers. The different wood materials were separated by polyethylene spacers. All specimens were free of cracks, decay and other obvious defects.

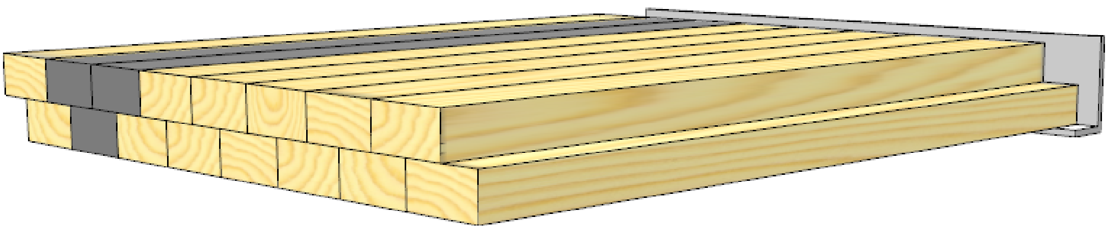

Figure 2: Double layer test (PE spacers in black)

2.2.3 Lap-joint test

In accordance with CEN/TS 12037 (2003) Lap-joint specimens (38 mm x 85 mm x 180 mm) (Figure 3) were exposed horizontally in supports made from aluminum L-profiles on test rigs 1 m above ground in Hannover and Borås (Figure 4). The specimens in Hilo were exposed 0.5 m above ground. The end-grains of the specimens were sealed with a polyurethane sealant (SIKAFLEX 298). The two segments of one specimen were fastened together with stainless steel clamps. All specimens were free of cracks, decay and other obvious defects.

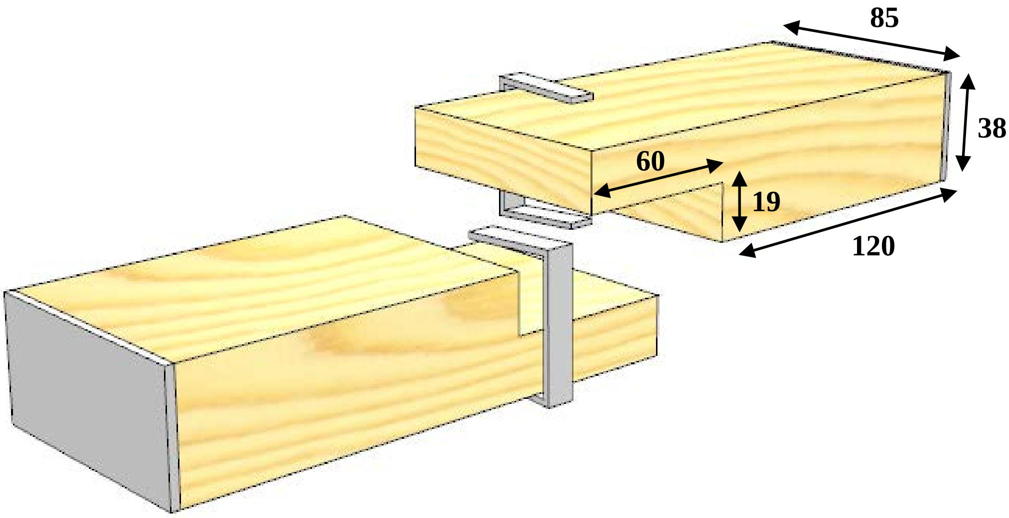

Figure 3: Exploded view of lap joint specimen, all dimensions in millimeter

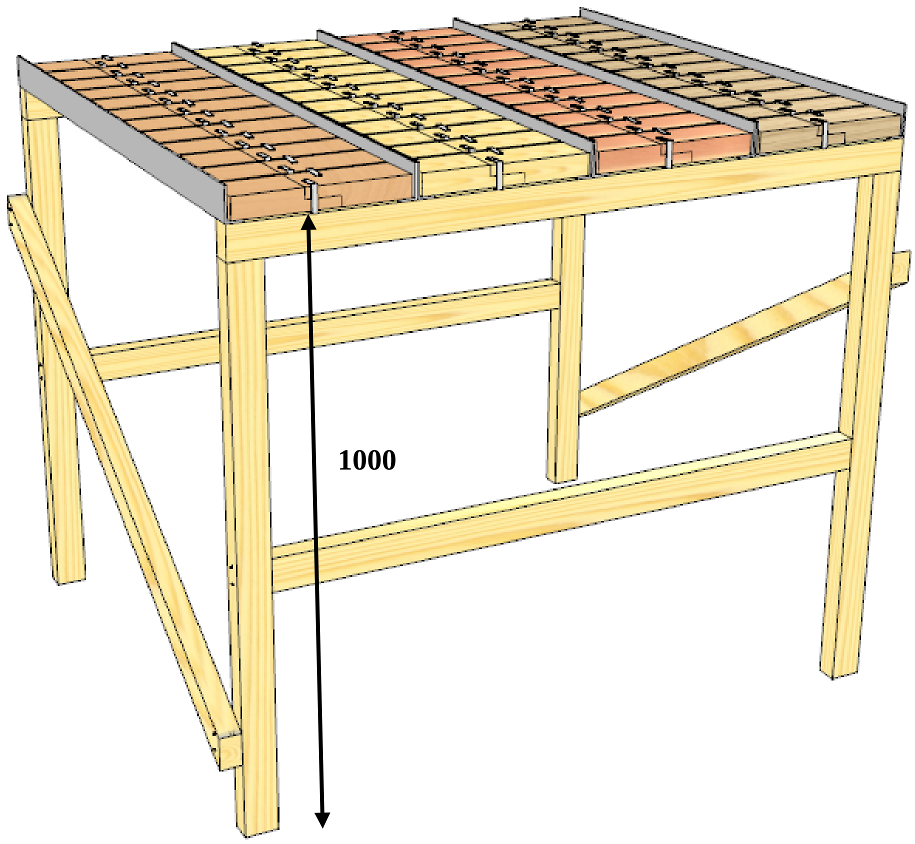

Figure 4: Lap joint test rig in Hannover and Borås, all dimensions in millimeter

2.2.4 Sandwich test

Sandwich tests were carried out according to Zahora (2008). One bottom segment (25 mm x 100 mm x 200 mm) and two top segments (25 mm x 49 mm x 200 mm) were fastened together with stainless steel clamps (Figure 5) and exposed horizontally in supports made from aluminum L-profiles on test rigs 1 m above ground in Hannover (Figure 6). Specimens in Borås were exposed 0.3 m above ground and 0.5 m in Hilo. The top layers were rounded on the edges (r=5 mm). All specimens were free of cracks, decay and other obvious defects.

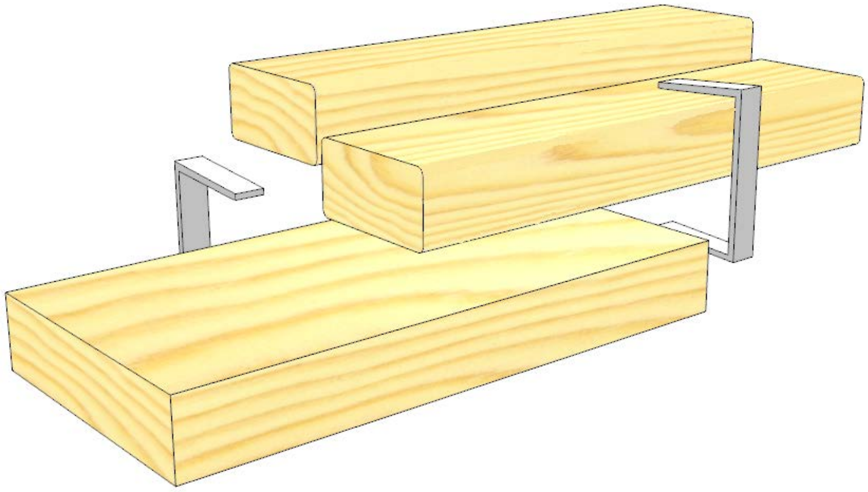

Figure 5: Exploded view of sandwich specimen

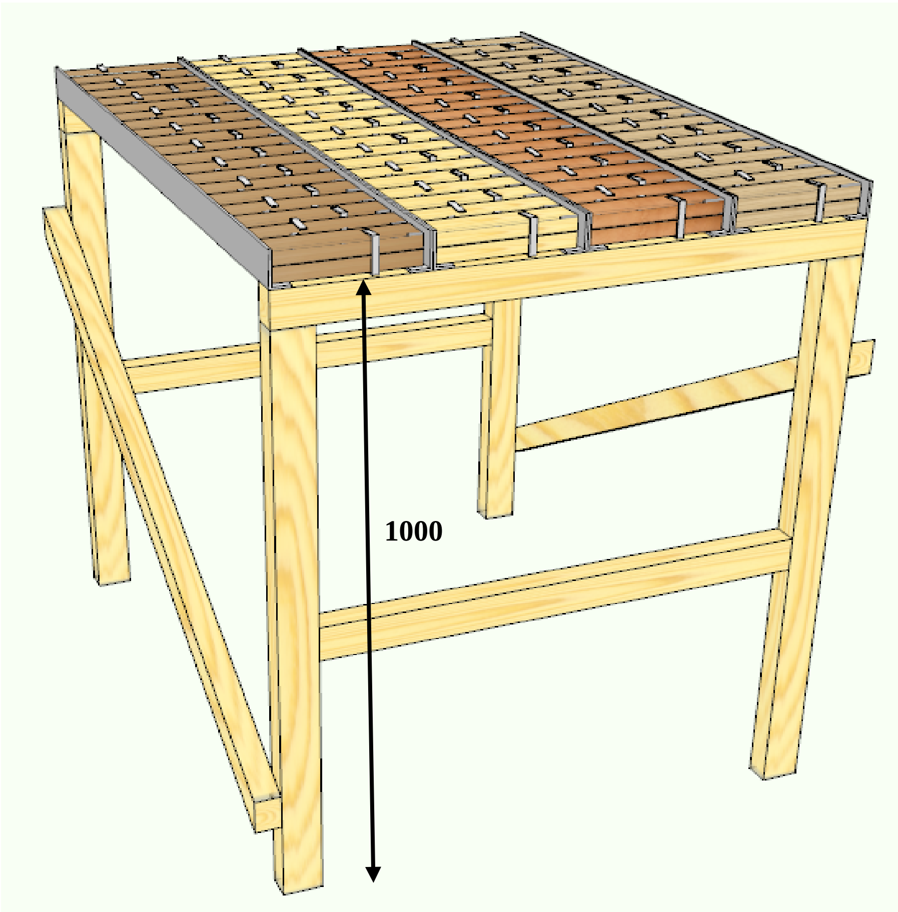

Figure 6: Sandwich test rig in Hannover, all dimensions in millimeter

2.3 Decay assessment

Decay was assessed every six months using the ‘Pick-Test’ and evaluated according to EN 252 (1990) (Table 4) and AWPA-E7 (2009) (Table 5).

Table 4: Rating scale according to EN 252 (1990)

Rating	Description	Definition
0	Sound	No evidence of decay, discoloration, softening or weakening caused by microorganisms.
1	Slight attack	Limited evidence of decay, no significant softening or weakening up to 1 mm depth.
2	Moderate attack	Significant evidence of decay, with areas of decay (softened or weakened wood) from 2 to 3 mm depth.
3	Severe attack	Strong evidence of decay, extensive softening and weakening, typical fungal decay at large areas from 3 to 5 mm depth or more.
4	Failure	Sample breaks after a bending test.

Table 5: Rating scale according to AWPA-E7 (2009)

Rating	Description	Definition
10	Sound	No sign or evidence of decay, wood softening or discoloration caused by microorganism attack.
9.5	Trace-suspect	Some areas of discoloration and/or softening associated with superficial microorganism attack.
9	Slight attack	Decay and wood softening is present. Up to 3% of the cross sectional area is affected.
8	Moderate attack	Similar to 9 but more extensive attack with 3-10% of cross sectional area affected.
7	Moderate/severe attack	Sample has between 10-30% of cross sectional area decayed.
6	Severe Attack	Sample has between 30-50% of cross sectional area decayed.
4	Very severe attack	Sample has between 50-75% of cross sectional area decayed.
0	Failure	Sample has functionally failed.

2.4 Test sites

The tests described in chapter 2.2 were carried out at the following three test sites.

Hannover, Germany (roof)

Coordinates: 52.392823 ° N, 9.696368 ° E

Elevation: 54 m (ground level) + 16 m

Mean temperature: 9.2 °C

Rainfall sum: 642 mm

Climate: Temperate oceanic

Tests: Lap joint, sandwich, double layer

Hannover, Germany (ground)

Coordinates: 52.395067 ° N, 9.701913 ° E

Elevation: 54 m

Tests: Graveyard

Borås, Sweden

Coordinates: 57.714895 ° N, 12.887354 ° E

Elevation: 177 m

Mean temperature: 6.1 °C

Rainfall sum: 950 mm

Climate: Temperate continental

Tests: Sandwich, lap joint, double layer

Figure 7: Test sites

Borås, Sweden

Tests: Graveyard

Hilo, Hawaii

Coordinates: 19.400545 °N, -154.927034 ° E

Elevation: 44 m

Mean temperature: 23.3 °C

Rainfall sum: 3277 mm

Climate zone: Equatorial

Tests: Sandwich, lap joint, double layer

Hilo, Hawaii

Tests: Graveyard

Figure 7 cont´d: Test sites

2.5 Moisture content and temperature measurements

2.5.1 Measurement devices

The moisture and temperature recording was performed with data logging devices "Materialfox Mini" and "Thermofox Mini" (Scanntronik Mugrauer GmbH, Zorneding, Germany, Figure 8). Each data logger was equipped with three ports. Resistance characteristic curves were determined for each material by investigating the relationship between the gravimetric moisture content and the electric moisture content at different temperatures (Lampen 2012). The data logger were calibrated in a range between 15 and 50 % wood MC (equivalent reduced EMC of modified timber) and between 4 and 36 °C.

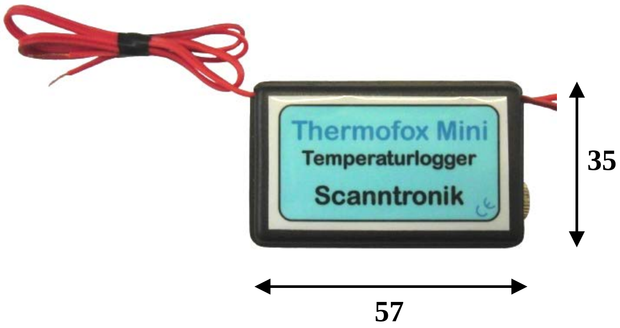

Figure 8: Data logging device ‚Thermofox Mini', all dimensions in millimeter

2.5.2 Electrodes

The electrodes were made from polyamide coated stainless steel cables with a core diameter of 1 mm. The electrodes were glued into predrilled holes of 4 mm diameter with an epoxy resin. The bottom part of the holes was filled with 0,1 ml of an epoxy-graphite mixture to provide conductivity. The first 5 mm of the plastic coating of the electrode was removed before putting it into the glue. After 24 h hardening the remaining was filled up with an isolating epoxy resin. After hardening the electrodes were connected to the data logger.

2.5.3 Measuring points

In all tests wood moisture and temperature were determined on three of ten replicates per material in Hannover. For comparison MC measurements were conducted also on Scots pine sapwood and Scots pine heartwood in Borås and Hilo. The measuring points were installed at the bottom side of the specimens and located in the centre (Figure 9). At the segmented sandwich specimens the electrodes were installed in the bottom segment. The distance between the centers of the two measuring points was 30 mm parallel and 6 mm orthogonal to the grain. The electrodes were installed to half of the depth of each specimen.

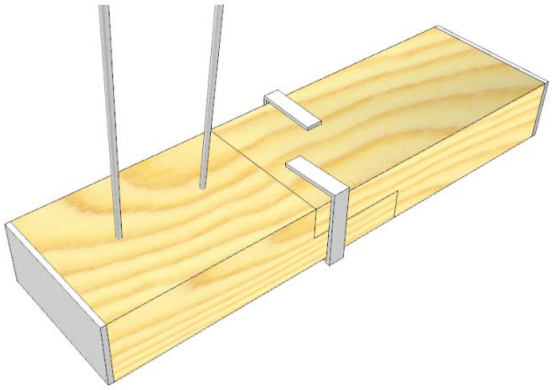

Figure 9: Lap joint specimen (upside down) with electrodes installed at the bottom side

2.6 Additional laboratory tests

In addition to the various field tests, matched samples of all tested materials were used for different laboratory tests – moisture uptake tests as well as decay tests against different wood-destroying fungi and in unsterile soil. The results of the laboratory tests will be presented at a later stage.

2.6.1 Moisture uptake tests

To determine liquid water uptake one set of specimens was submerged in deionized water for 24 h. The ratios between specimen surface and specimen volume was identical with the double layer specimen, but the dimensions were scaled down to one fifth (5 x 10 x 100 mm). A second set of specimens was exposed to 20 °C/100 % RH for 24 h to determine the moisture uptake in water saturated atmosphere. Therefore the specimens were placed in a closed but ventilated small-scale climate chamber over deionized water. Both sets were oven dried before. After weighing the moist specimens again the moisture uptake was determined.

2.6.2 Decay tests

Besides moisture performance and durability under field conditions, the resistance of all materials was assessed in the lab. Therefore ‘mini-block’ tests (Bravery and Dickinson 1978) against *Trametes versicolor, Coniophora puteana* and *Poria placenta* will be conducted on two sets of samples (5 x 10 x 30 mm). One half of the samples was leached according to EN 84 (1997), the other half was pre-weathered naturally in Hannover-Herrenhausen for a period of six months.

Furthermore, another set of specimens was applied to decay tests against soft-rotting fungi according to CEN/TS 15083-2 (2005).

3. RESULTS AND DISCUSSION

3.1 Graveyard test

The decay assessment after 0.5 years exposure did not allow any clear conclusions to be drawn yet. However, high decay activity in Borås and Hannover has been indicated. Soft, white and brown rot have been found in different samples.

3.2 Native hardwoods

Figure 10 to Figure 12 show the moisture course of the first six month of exposure for all native hardwoods exposed in the different tests. Differences between the wood species are clearly indicated. Moisture contents above 25 % were found for beech and oak whereby the highest peaks were recorded in the sandwich tests. English oak showed unexpectedly high moisture contents in sandwich and lap joint tests. The moisture contents determined for European ash and black locust were uncritical over the whole period.

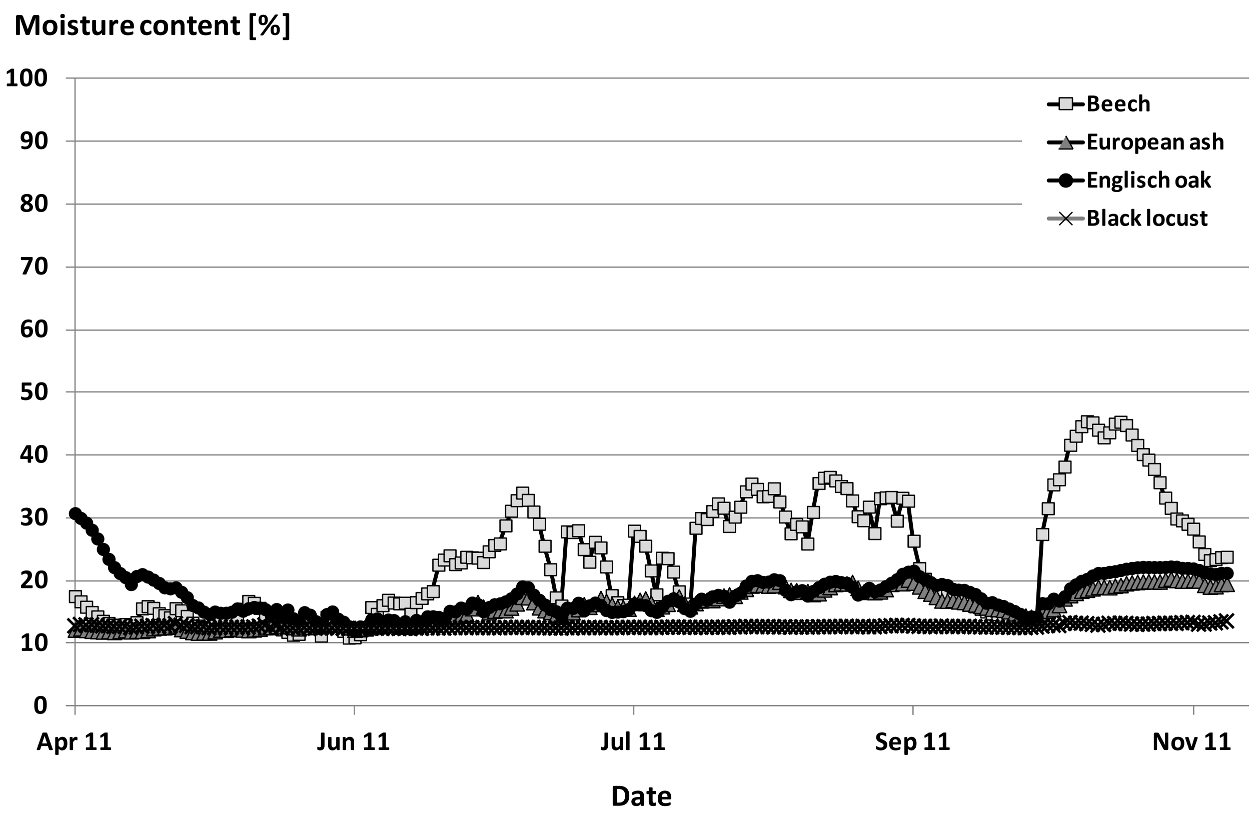

Figure 10: Moisture course of native hardwoods exposed in double layer tests in Hannover

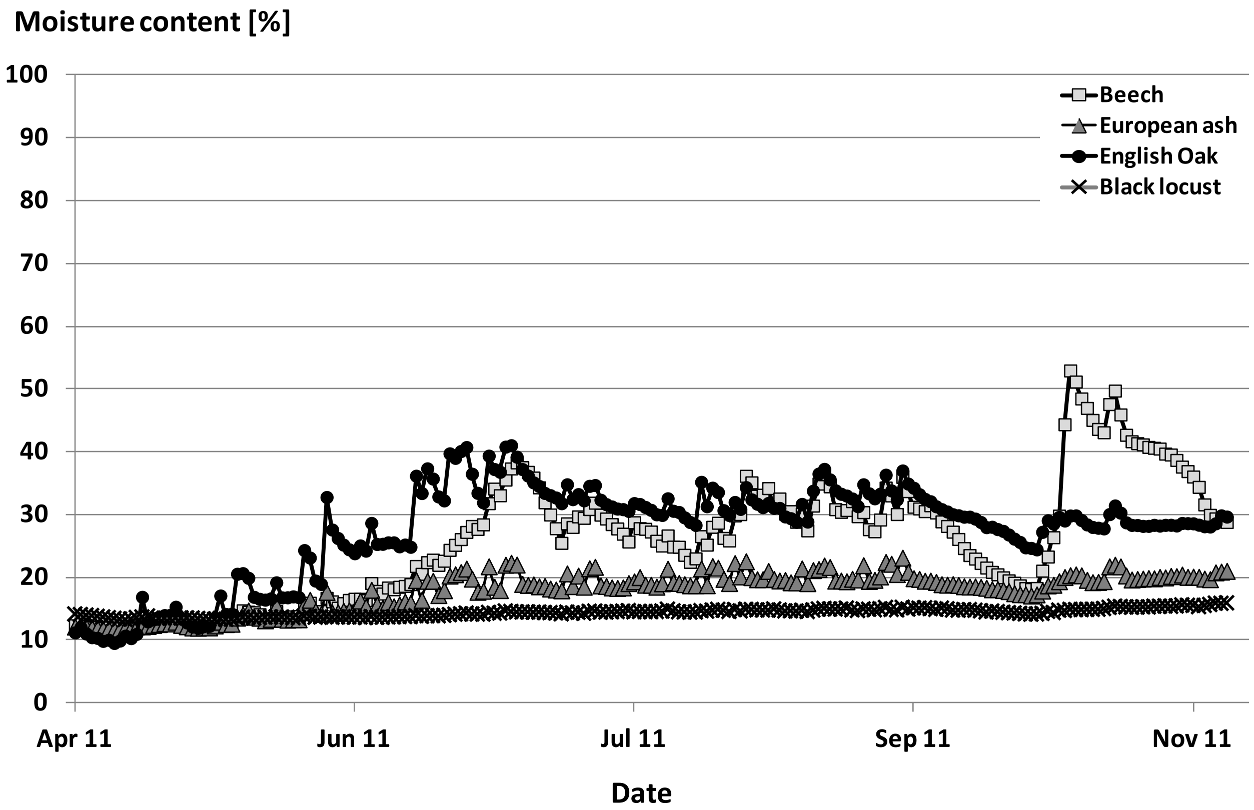

Figure 11: Moisture course of native hardwoods exposed in lap joint tests in Hannover

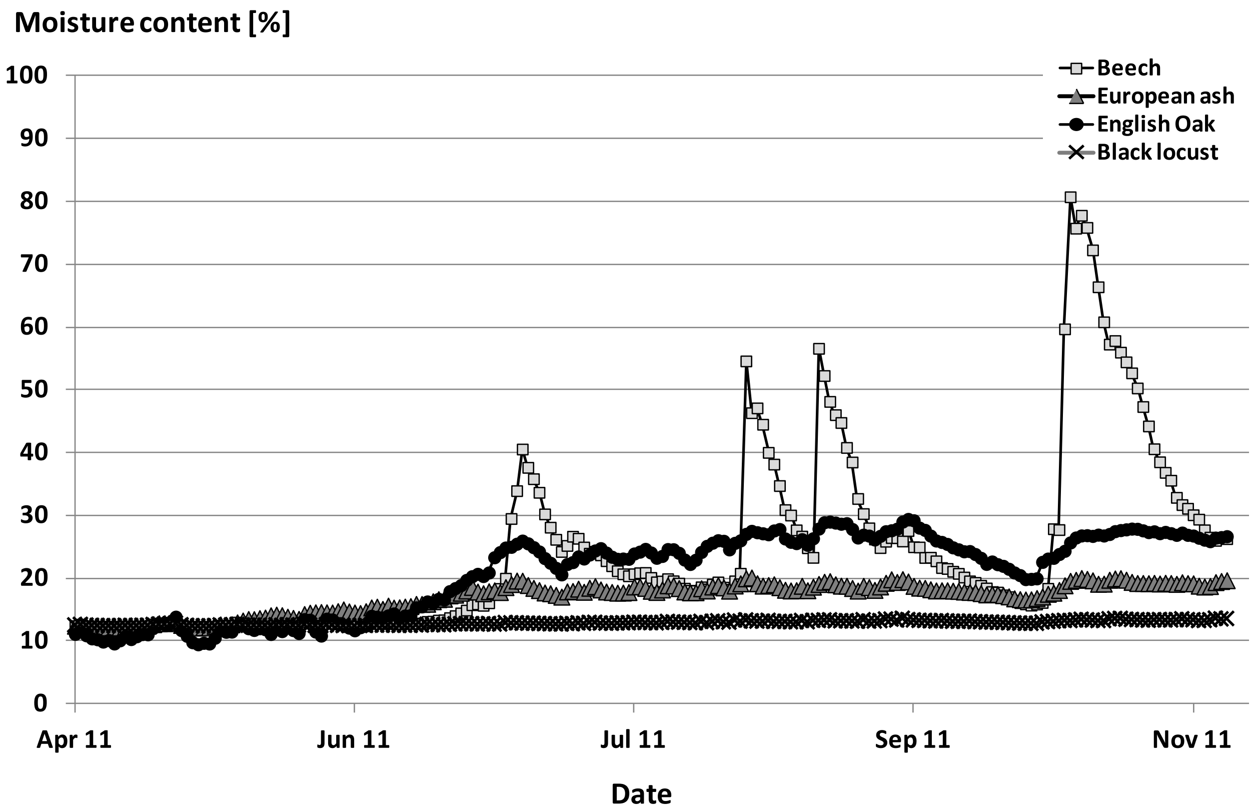

Figure 12: Moisture course of native hardwoods exposed in sandwich tests in Hannover

3.3 Native softwoods

Differences between wood species became apparent in all three tests (Figure 13 to Figure 15). However, the range between the moisture courses was least distinct in the double layer tests. As expected the different pine sapwoods showed the highest MC over the whole period.

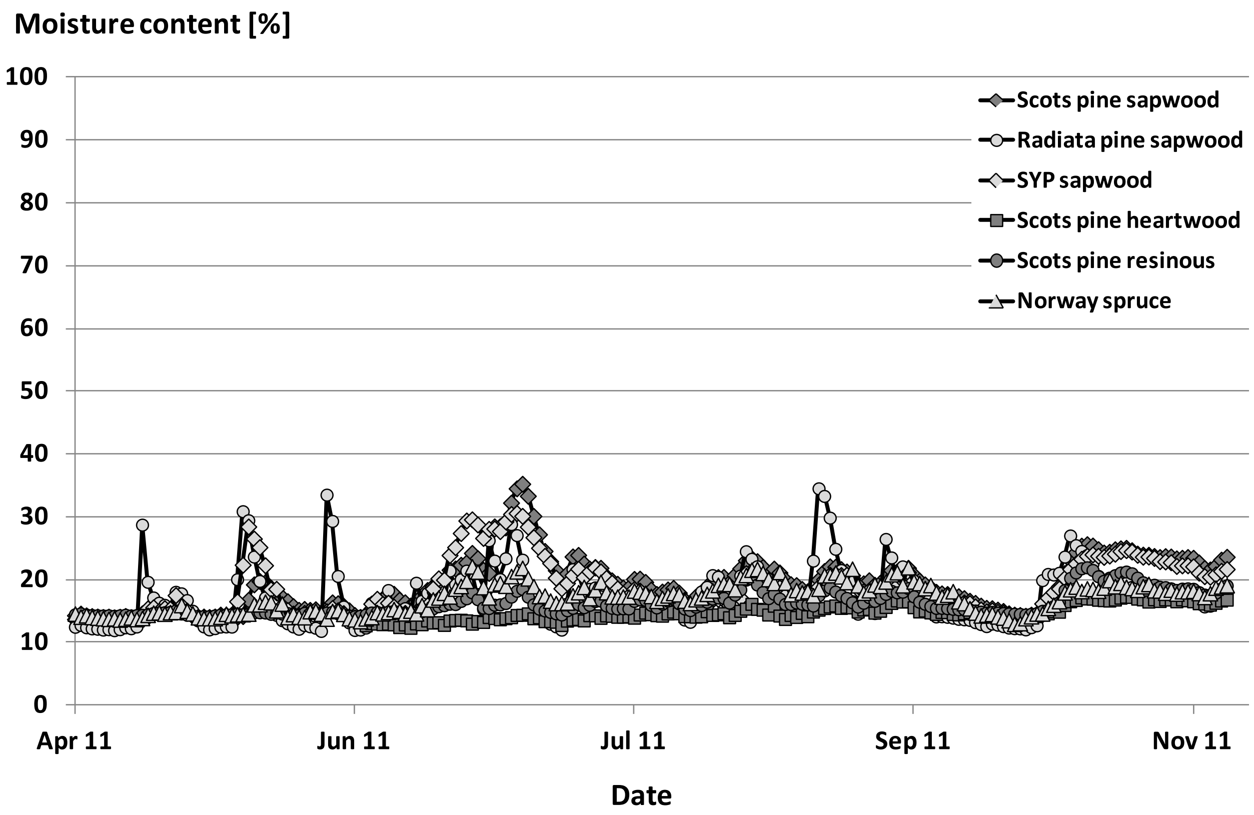

Figure 13: Moisture course of native softwoods exposed in double layer tests in Hannover

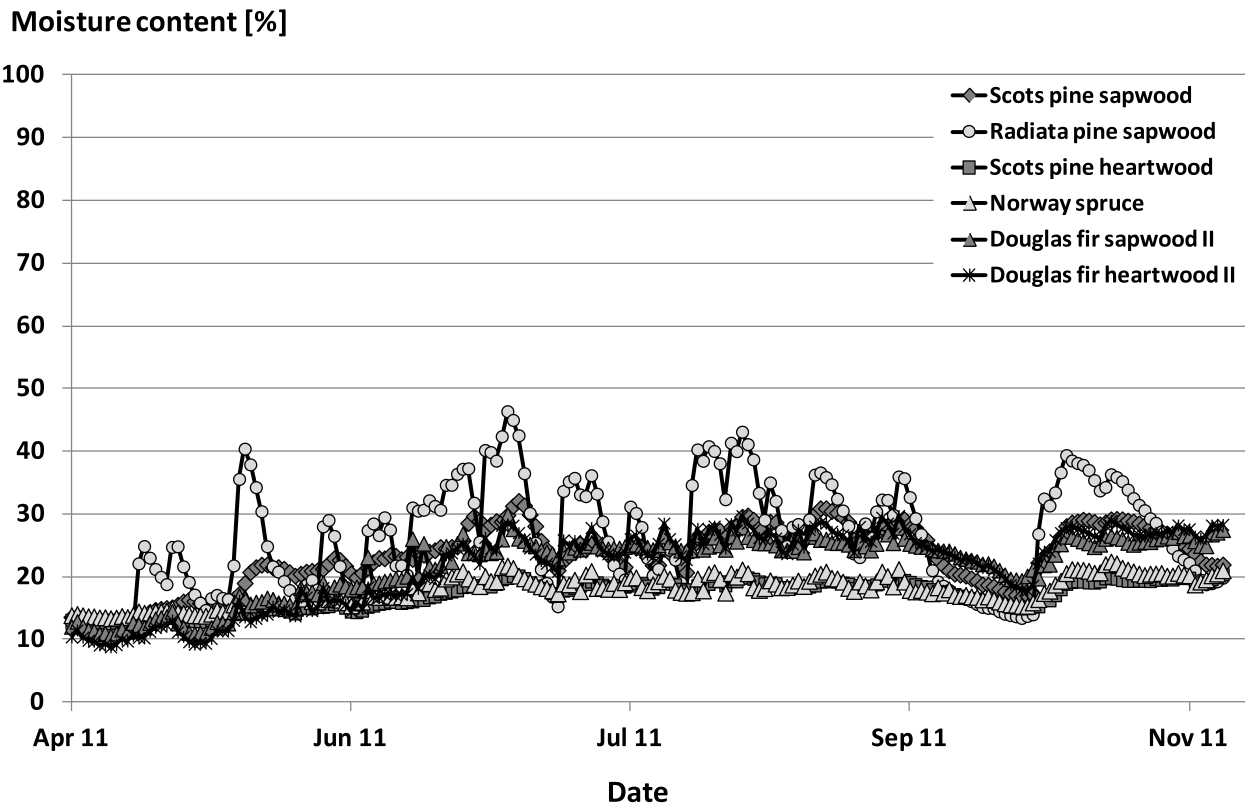

Figure 14: Moisture course of native softwoods exposed in lap joint tests in Hannover

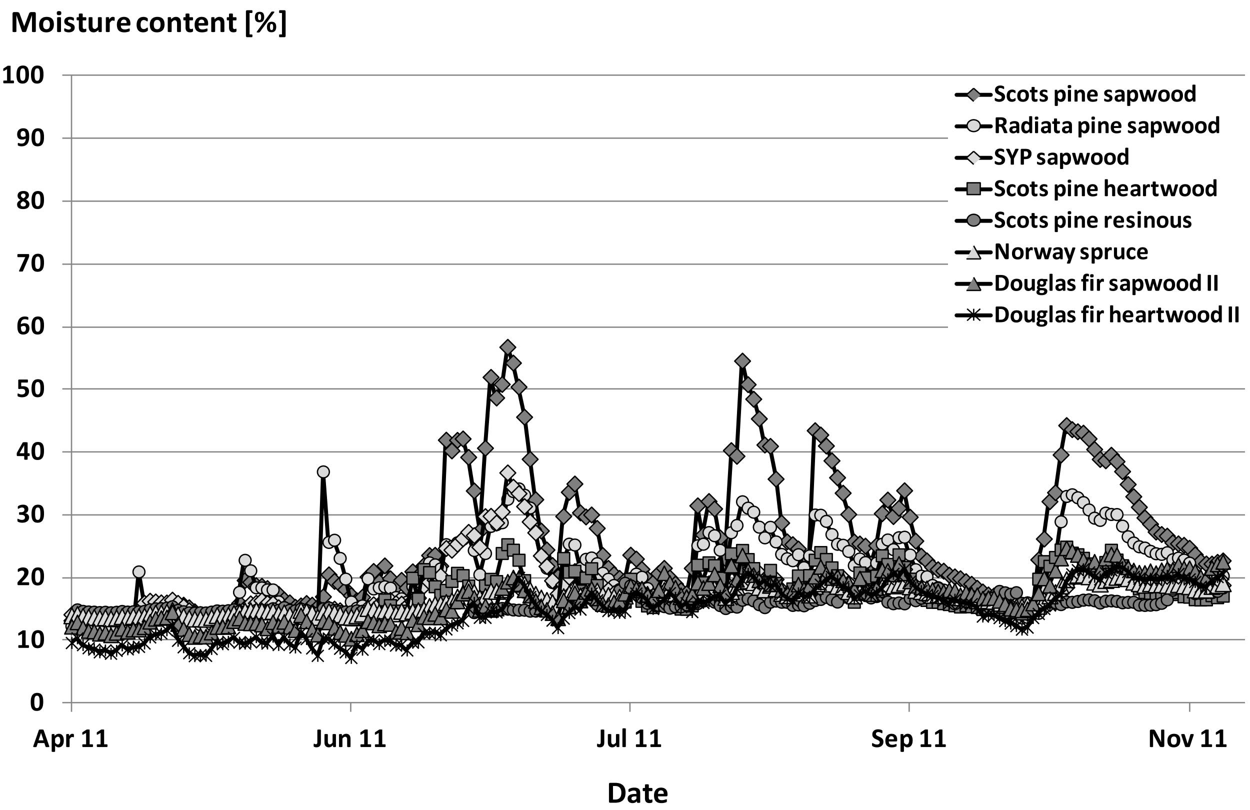

Figure 15: Moisture course of native softwoods exposed in sandwich tests in Hannover

3.4 Modified timber

Apart from acetylated southern yellow pine (SYP) all modified materials showed low MC (Figure 16 to Figure 18). However, the fact that the modification processes decrease the equilibrium moisture content (EMC) (Tjeerdsma *et al.* 1998, Larsson and Simonson 1994, Esteves *et al.* 2011) needs to be considered for estimation of the resulting decay risk (see chapter 3.6, Table 7). Based on the calculated EMC (*cf.* Table 7) acetylated and furfurylated SYP as well as thermally modified Scots pine reached critical MC for longer periods.

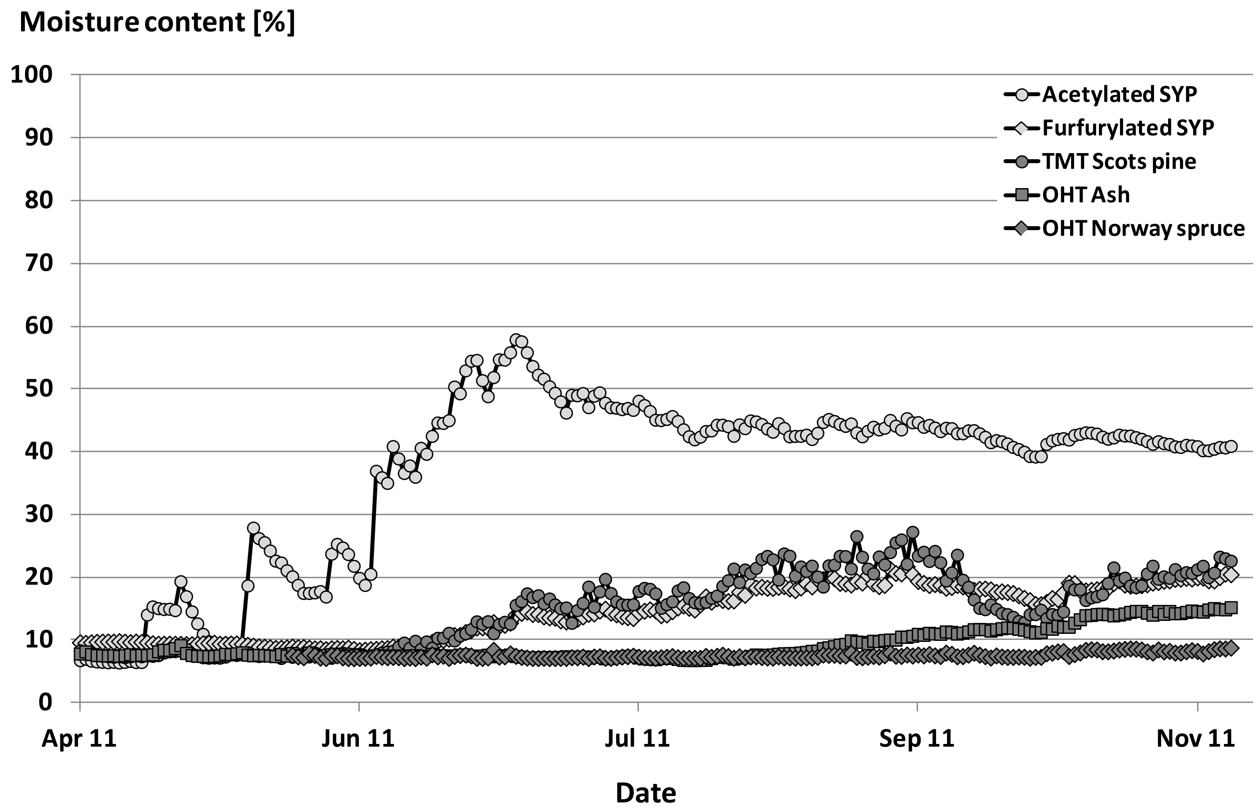

Figure 16: Moisture course of modified timber exposed in double layer tests in Hannover

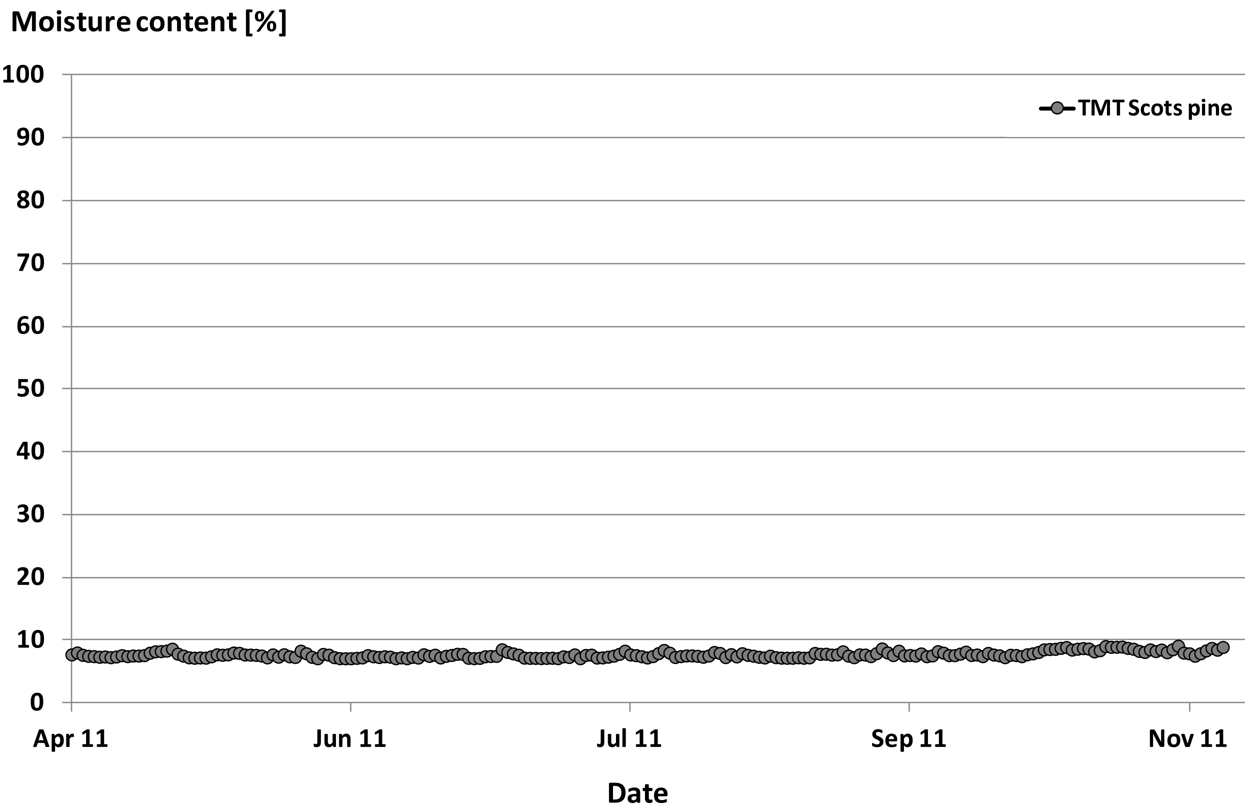

Figure 17: Moisture course of modified timber exposed in lap joint tests in Hannover

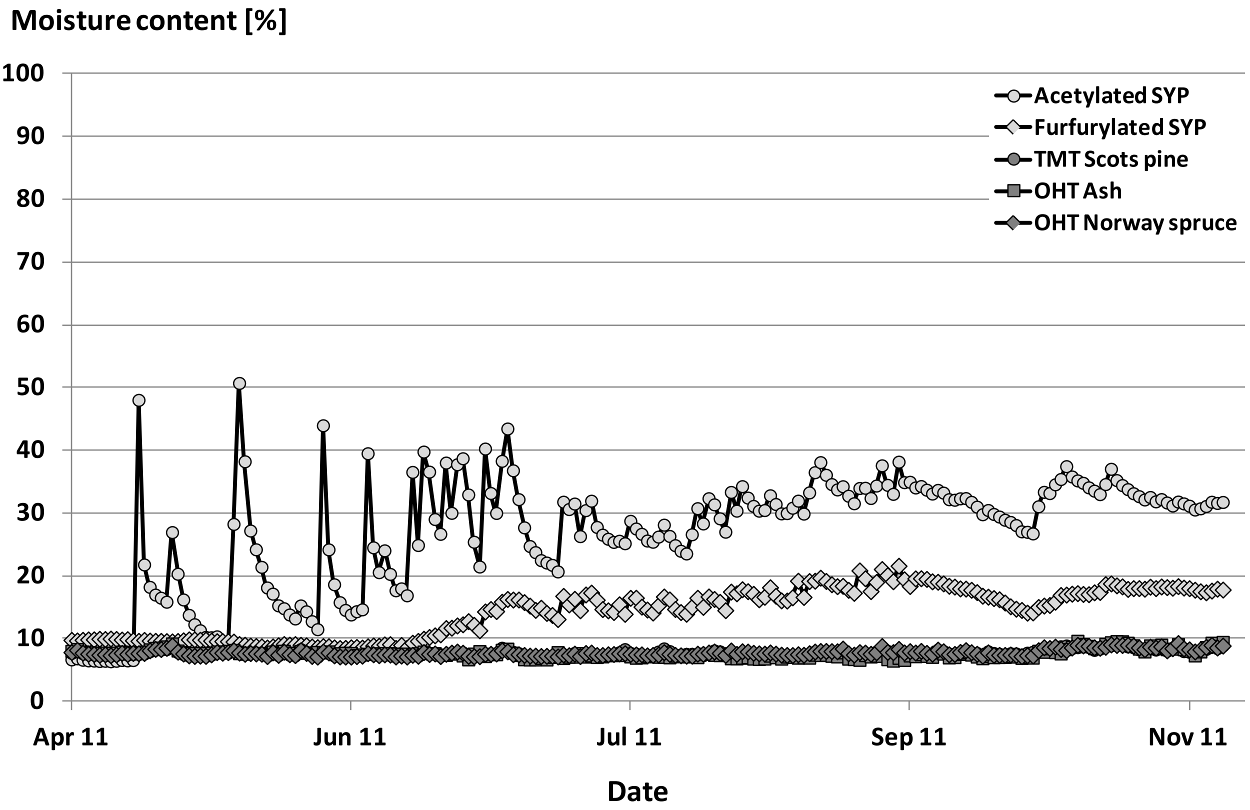

Figure 18: Moisture course of modified timber exposed in sandwich tests in Hannover

3.5 Preservative treated timber

The preservative treated timber showed considerable high MC compared to untreated Scots pine sapwood (Figure 19 to Figure 21). Which might be explained by effects of different ingredients (active or not) of the preservatives. Due to this it is indispensable to conduct laboratory investigations on the impact of increased sorption (e.g. through salt impregnation) in addition to tests on their toxic effectiveness.

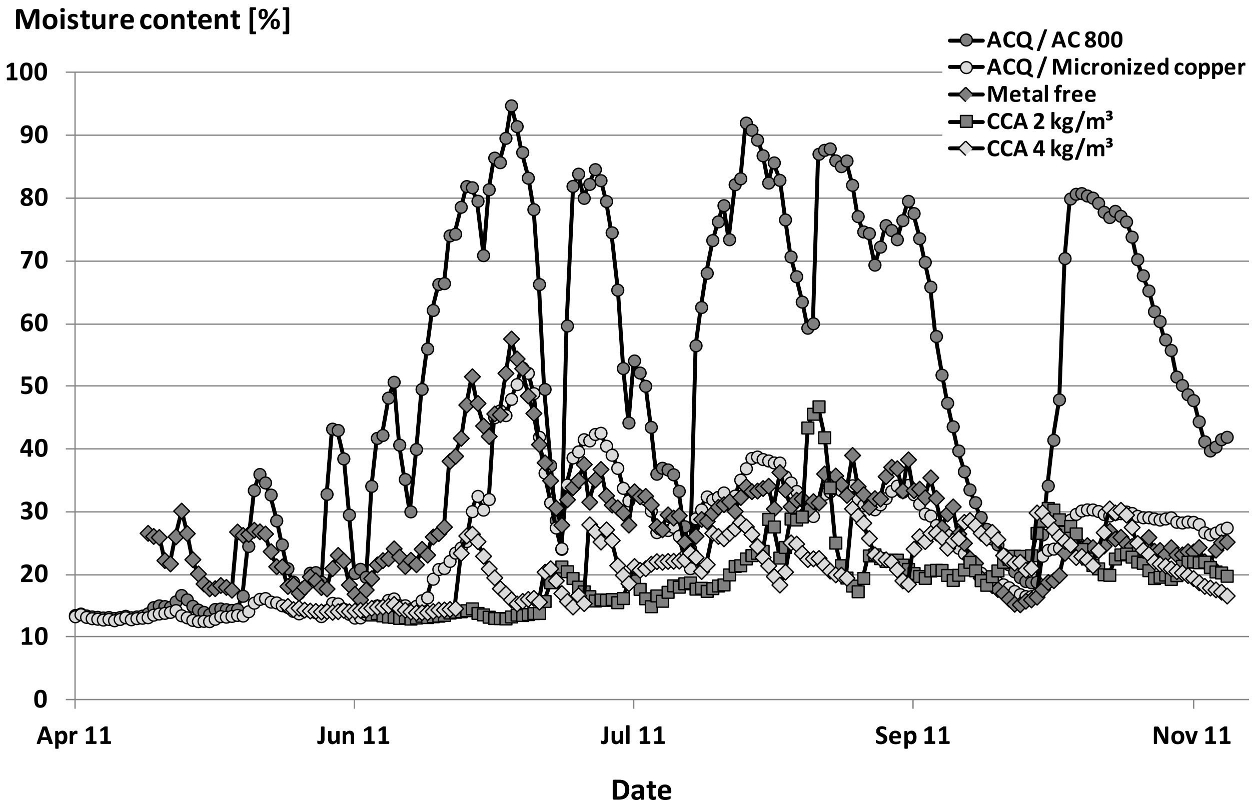

Figure 19: Moisture course of preservative treated timber exposed in double layer tests in Hannover

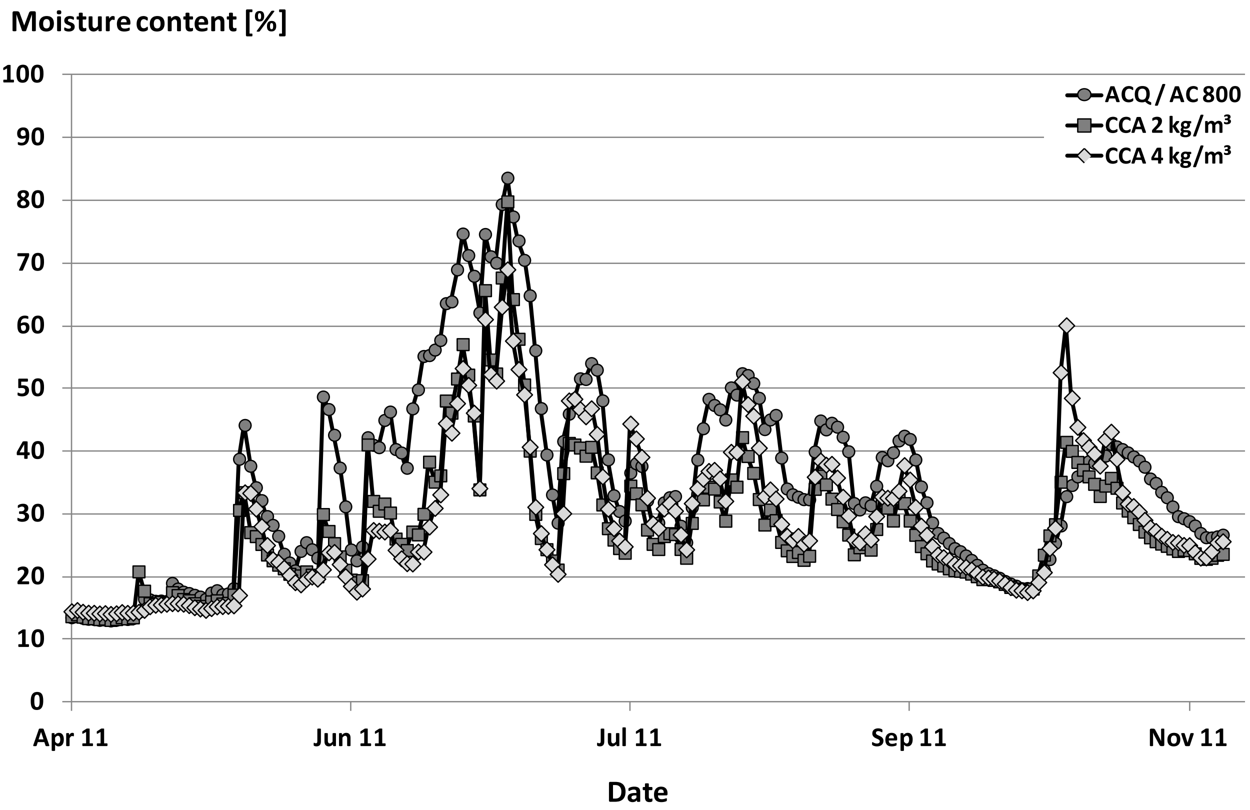

Figure 20: Moisture course of preservative treated timber exposed in lap joint tests in Hannover

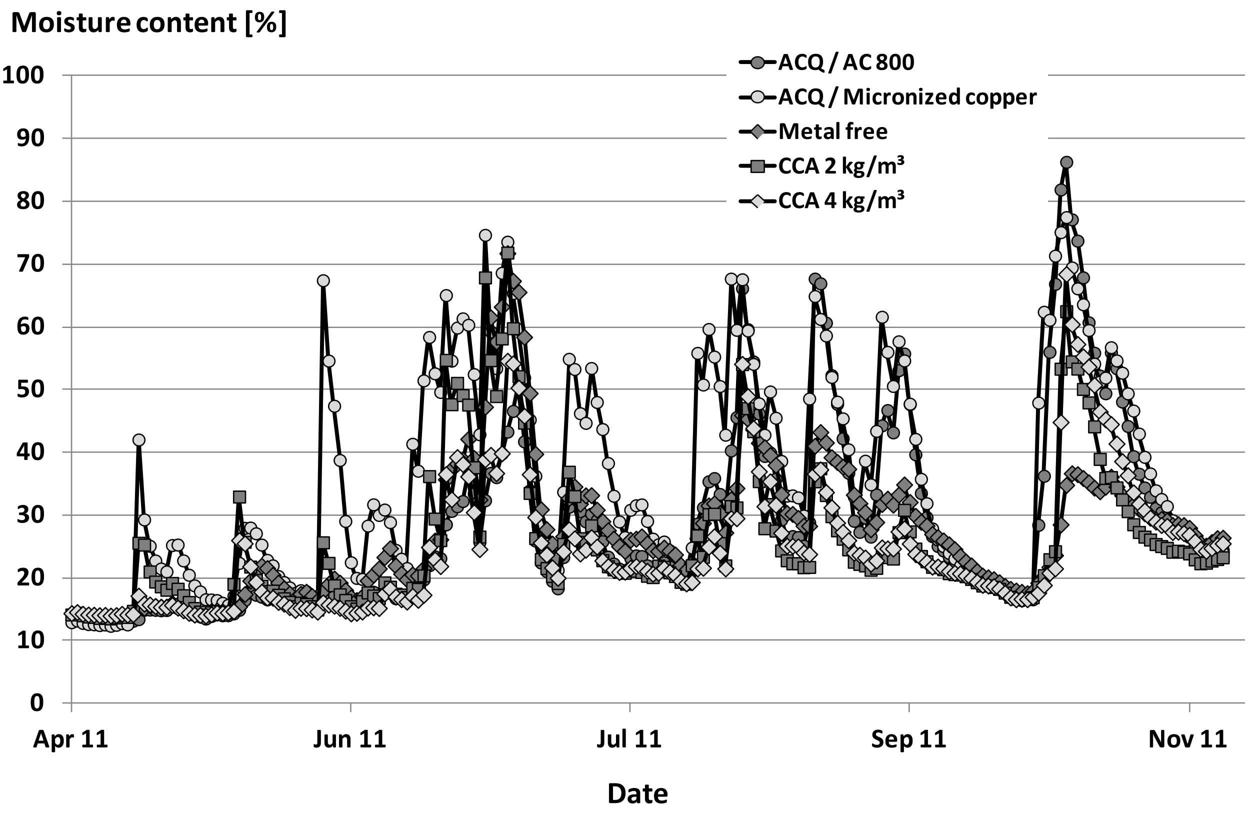

Figure 21: Moisture course of preservative treated timber exposed in sandwich tests in Hannover

3.6 Exposure-dependent moisture performance

The MC measurements resulted in material-dependent differences. For comparison the number of wet days has been calculated for the different tests exposed in Hannover (Table 6). For most materials the highest number of wet days was found in lap joint and sandwich tests. The surprisingly low moisture load in the double layer tests might be explained by the exposure of the rigs on top of a roof (16 m above ground) where higher wind loads provoke re-drying.

Table 6: Number of days above 25 % moisture content (MC) (total number of days= 208)

Material	Number of wet days (>25% MC)		
	Double layer	Sandwich	Lap joint
Scots pine sapwood	13	86	82
Scots pine heartwood	0	1	0
Scots pine resinous	0	0	-
SYP sapwood	19	14	-
Radiata pine sapwood	14	56	111
Norway spruce	0	0	0
Douglas fir heartwood	-	0	85
Douglas fir sapwood	-	0	71
Beech	88	72	118
English oak	7	75	154
European ash	0	0	0
Black locust	0	0	0
CCA 2 kg/m³	32	72	111
CCA 4 kg/m³	73	73	121
ACQ / AC 800	154	97	150
ACQ Micronized copper	115	137	-
Metal-free	116	113	-
SYP Acetylated	158	143	-
SYP Furfurylated	0	0	-
Scots pine TMT	4	0	24
European ash OHT	16	0	-
Norway spruce OHT	0	0	-

Table 7 shows the number of days above critical MC for the modified timber exposed in Hannover. The critical MC was calculated according to the determined reduction of EMC. All materials reached a considerably higher number of days above critical MC. However, since these values are calculated only limited conclusions on how critical the MC for the differently modified timber really is can be made. Hence it seems necessary to determine physiological threshold values for wood decay fungi with respect to modified timber.

Table 7: Number of days above critical Moisture content ($MC_{Critical}$) calculated for the modified timber (total number of days=208)

Material	EMC reduction	$MC_{Critical}$	Number of wet days (>$MC_{Critical}$)		
	[%]	[%]	Double layer	Sandwich	Lap joint
SYP Acetylated	61,0	**15,3**	180	177	-
SYP Furfurylated	35,1	**8,8**	188	193	-
Scots pine TMT	31,5	**7,9**	163	64	165
European ash OHT	45,7	**11,4**	31	0	-
Norway spruce OHT	55,1	**13,8**	0	0	-

3.7 Test site-dependent moisture performance

Figure 22 to Figure 24 show the moisture course of approximately four months of exposure for Scots pine heartwood and Scots pine sapwood exposed in the three tests in Hannover and Borås. Moisture performance differed significantly between test sites, but depended strongly on the test method. While the double layer tests showed a clear difference in moisture performance of the two materials between Borås and Hannover, no clear differentiation was determined for the lap joint and sandwich tests. Possible reasons for the reduced moisture content in the double layer tests in Hannover could be found in the test conditions. The test rigs in Hannover were exposed 16 m above ground level on a roof test site with lattice structured flooring. Due to this the constant circulation could accelerate re-drying. Furthermore most of the test rigs in Borås were exposed under trees (*cf.* Figure 7). The shade and additionally leaves could therefore decelerate drying (Brischke and Rapp 2007, Augusta 2007). This would suggest that the test conditions are decisive for the resulting moisture performance rather than the test method itself.

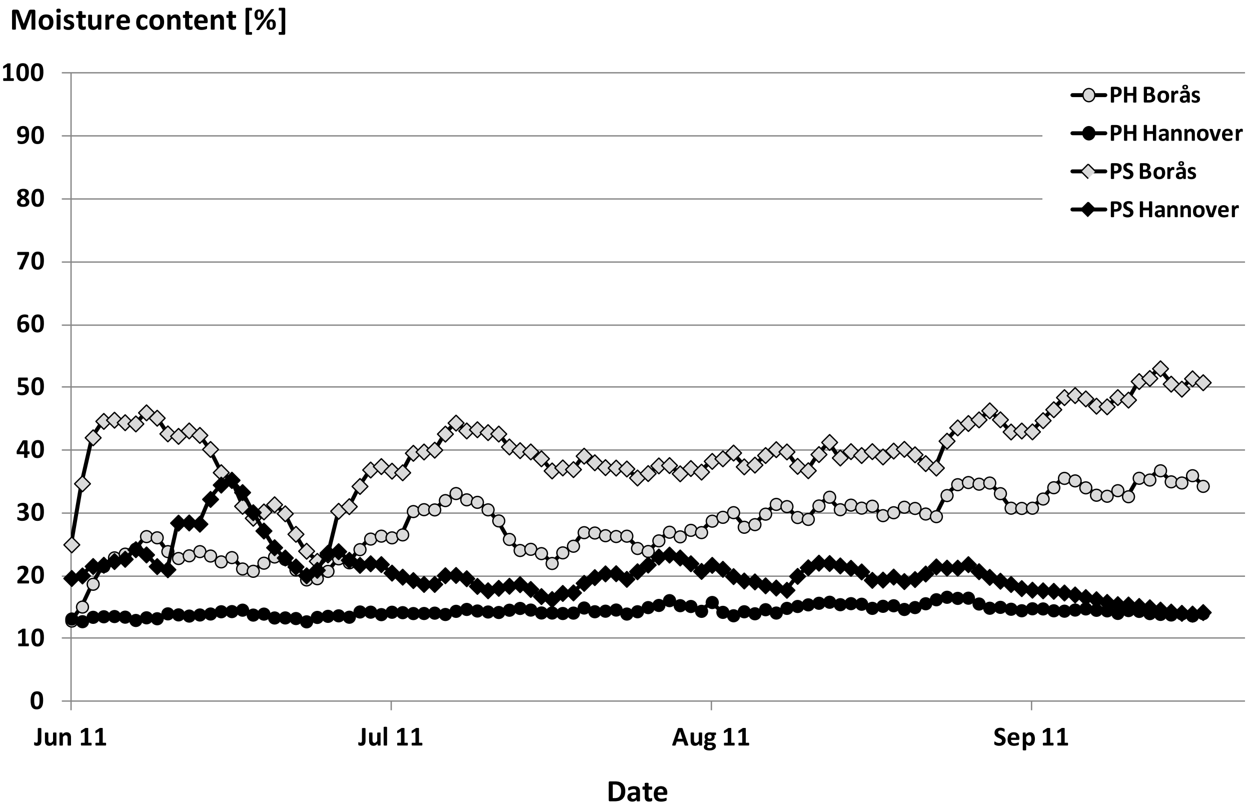

Figure 22: Moisture course of Scots pine heartwood (PH) and Scots pine sapwood (PS) exposed in Borås and Hannover in double layer tests

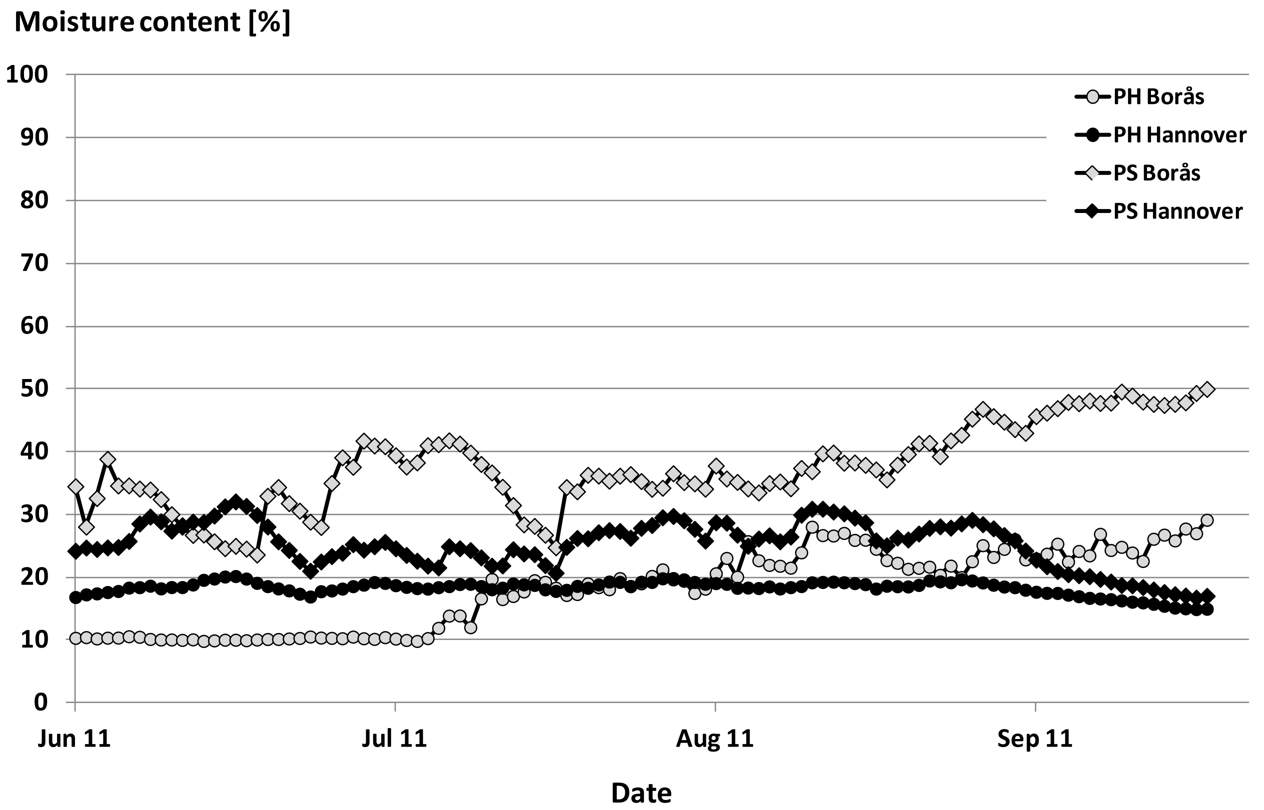

Figure 23: Moisture course of Scots pine heartwood (PH) and Scots pine sapwood (PS) exposed in Borås and Hannover in lap joint tests

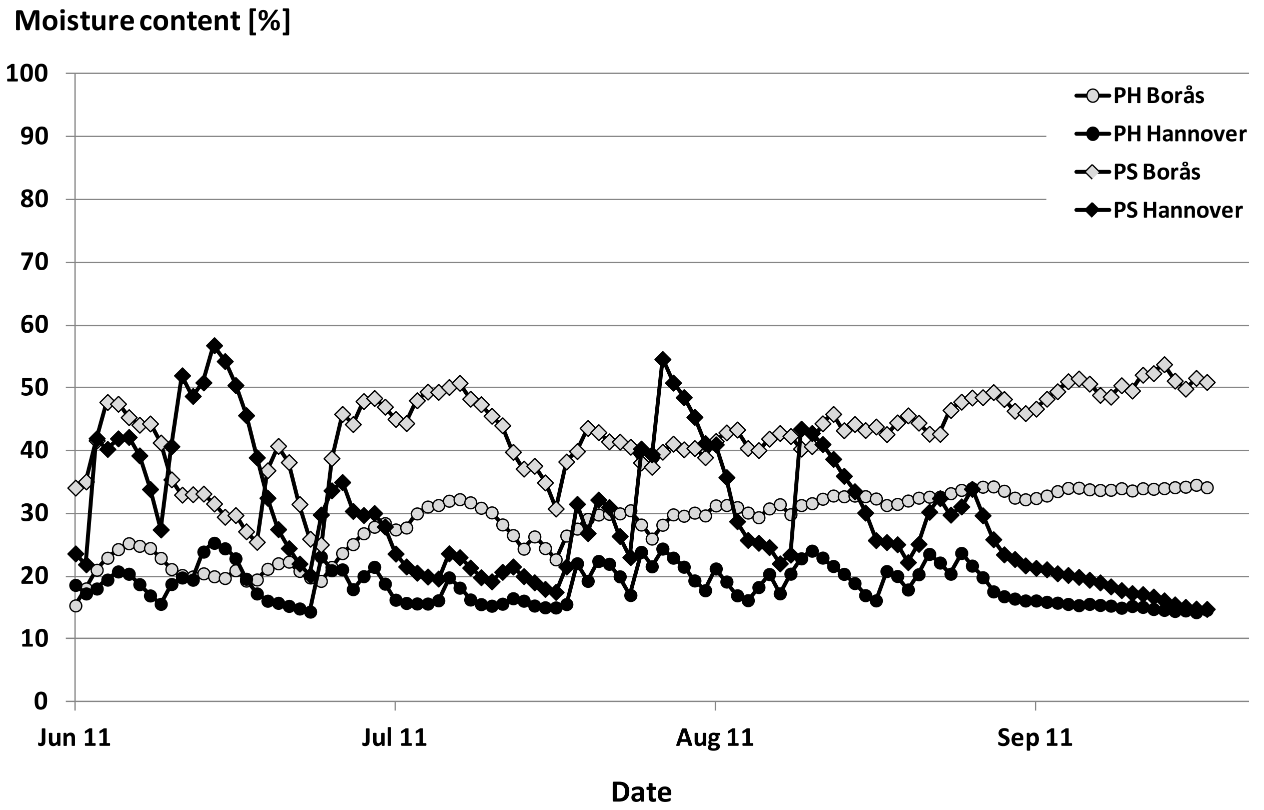

Figure 24: Moisture course of Scots pine heartwood (PH) and Scots pine sapwood (PS) exposed in Borås and Hannover in sandwich tests

4. CONCLUSIONS

The MC measurement system was found to be applicable for all tested wood based materials submitted to the three above ground test methods and plausible data was provided. The influence of different cell wall modifications and preservative treatments on the moisture performance was found to be detectable. However, to assess these results it is indispensable to conduct additional laboratory decay studies on the influence of toxic ingredients and different modifications on the moisture performance and consequently conducive conditions for fungal growth. Information about the critical MC for these materials is still lacking.

The impact of test sites, which was shown in this study to be existent, can be superposed by microclimatic effects. The results showed that small deviations (shelter, leaves, air circulation) can have an enormous impact. Therefore climate and its influence on decay needs to be determined under conditions, which are as similar as possible, otherwise ‘microclimate acceleration measures’ have to be considered.

Since the preliminary results presented in this paper have shown differences in moisture performance between the three different test methods, it seems worthwhile to conduct MC recordings to a wider range of above ground durability tests. MC measurements could therefore serve as an instrument to quantify these methods related to differently severe above ground situations and finally approach a comprehensive test methodology. Therefore it is intended to bring out 27 different above ground test methods containing long term moisture recordings on the test site in Hannover, Germany in April 2012. The test set up will contain established tests (L-joint test, decking test, ground proximity test, ...) as well as some new alternative test methods.

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