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Section 2 **Test methodology and assessment**

COST FP 1303 Cooperative Performance Test – Results after two years outdoor exposure

Lesar B.[1 *], Humar M.[1], Brischke, C.[2], Meyer-Veltrup L.[2], Jones D.[3abc], Thaler N.[1], Abascal , J.M.[4], Alfredsen, G.[5], Brunnhuber, B.[6], Grodås, E.[5], Irle, M.[7], Kers, J.[8], Klamer, M.[9], Mahnert, K.-C.[10], Melcher, E.[11], Palanti, S.[12], Noël, M.[13], Suttie, E.[14], Pfabigan, N.[6], Touza, M.[15]

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ABSTRACT

COST Action FP 1303 'Performance of Bio-Based Building Materials' started in October 2013 and an ambitious program was set up for four years. Among this a collaborative field test was planned. The idea of the cooperative performance test was to distribute a fairly simple test set up to as many places in Europe as possible in order to collect performance data reflecting the full range of climatic exposure conditions within the COST zone. Performance tables were exposed on 15th September 2014 at 27 different locations around Europe. A folding table with boards consisting of three different materials (i.e. Norway spruce, English oak and thermally modified spruce) was shipped as ready-to-use test object. Significant colour changes and growth of blue staining fungi were found after two years of outdoor exposure. Also first signs of decay occurred on Norway spruce samples exposed in Hamburg, Germany.

Keywords: wood, performance, English oak, Norway spruce, thermally modified wood, moisture content, degradation

1. INTRODUCTION

Importance of wood and bio-building materials is increasing in the recent decades in most parts of Europe. With higher demand of wood and wooden products also the need for forecasting the service life of wood exposed outdoor increased, not at least because it is required from different regulations. One of the most important is the European Construction Products Regulation as well as by warranty providers and end users (Kutnik et al., 2014). Life expectancy of wood and wood-based products used in buildings is related to a number of factors (Brischke et al., 2006) such as wood properties, quality of manufacturing, building design, interactions with other materials, preservative impregnation or surface treatment as well as material climate and local climate (Gobakken and Høibø, 2011). It is important to distinguish between functional service life and aesthetical service life.

Functional service life is strongly related to durability. Durability can be defined as the capacity of a structure to give a required performance during an intended service period under the influence of degradation mechanisms. For determination of performance based service life different parameters are needed (macro and micro climate, design, surface treatment, material performance…) as for instance described by Thelandersson et al., (2011). On the other hand, for the aesthetic service life mostly surface properties are important (colour changes as a result of weathering, formation of cracks, growth of mould and staining fungi, Gobakken and Høibø, (2011). The development of performance-based design methods for durability requires that models are available to predict performance in a quantitative and probabilistic format. The availability and accessibility of performance data is a basic prerequisite for both, modelling and performance classification, but is still limited. Therefore, a Cooperative Performance Test in the frame of the COST Action FP 1303 'Performance of Bio-Based Building Materials' was set up.

In this performance test 50 simple test set-ups (tables) were exposed on 27 different locations around Europe. Decay, discoloration, development of mould and other staining fungi, corrosion, formation of cracks, and moisture performance (optional) were regularly evaluated. Humar and co-workers (2015) presented the set up and measurement details of the trial.

The aim of this paper was to elucidate the results after two years of outdoor exposure and the influence of different climates around Europe on the performance of the exposed materials Norway spruce, Oak, and thermally modified Norway spruce.

2. EXPERIMENTAL

All details about the COST FP 1303 Cooperative performance test were presented at IRG 46 by Humar et al. (2015).

Performance tables were exposed on September 15th, 2014, at 27 different locations around Europe. Folding tables with boards made from Norway spruce (NS, *Picea abies* Karst.), English oak (O, *Quercus robur* L.) and thermally modified Norway spruce (TM) were shipped as ready-to-use test objects. Assessment data were analysed for the first two years of exposure. The following parameters were evaluated: fungal decay, discolouration, development of mould and other staining fungi, corrosion of fasteners, formation of cracks, moisture performance (only in case of table version A) (Humar et al., 2014, 2015).

At some locations different versions of the tables were exposed. In this paper the focus were on tables with and without electrical moisture data logger (Set version A and B). Tables including further wood-base materials are only partial addressed in this paper. After two years we collected data from 15 different locations in Europe (Table 1).

Table 1: List of partners, which contribute data for 2 years observations.

Partner	Abbreviation	City	Country
Holzforschung Austria	WIE	Wien	Austria
Danish Technological Institute	DTI	Taastrup	Denmark
Tallinn University of Technology	TAL	Tallinn	Estonia
Groupe ESB École supérieure du bois	NTE	Nantes	France
Thünen-Institut für Holzforschung	HAM	Hamburg	Germany
Leibniz Universität Hannover, Institut für Berufswissenschaften im Bauwesen (ibw)	HAN	Hannover	Germany
CNR IVALSA	ITA	Florence	Italy
Norwegian Forest and Landscape Institute	ÅS	Ås	Norway
Norwegian Institute of Wood technology	OSL	Oslo	Norway
University of Ljubljana, Biotechnical Faculty	ULJ	Ljubljana	Slovenia
Silvaprodukt d.o.o.	SIL	Ig	Slovenia
Área de Innovación y Tecnología, Centro de Innovación y Servicios Tecnológicos de la Madera	SCI	San Cibrao das Viñas	Spain
Tecnalia R&I	TEC	Azpeitia - Gipuzkoa	Spain
Berner Fachhochschule - Architektur, Holz und Bau	BIE	Biel-Bienne	Switzerland
Building Research Establishment (BRE)	BRE	Garston	UK

For easy evaluation of surface disfigurement due to fungal growth, the following criteria adapted from EN 152 (2011) were used (Table 2). We add 5th category X, for rating of the specimens where distinguish between staining and weathering was not possible. Therefore the upper and lower surface of the test specimens was examined visually for the presence of mould and staining fungi.

Table 2: Fungal disfigurement rating scale

Rating	Classification	Definition
0	no disfigurement	No surface disfigurement can be detected visually on the surface.
1	Slight disfigurement	The surface exhibits only a few individual small colonies none larger than 1.5 mm in width and 4 mm in length.
2	Moderate disfigurement	The surface is colonized up to a maximum of one third of the total area.
3	Severe disfigurement	More than one third of the surface area is colonised.
x	Grey surface	Distinguish between staining and weathering was not possible

3. RESULTS AND DISCUSSION

3.1 Colour changes and surface disfigurement

The colour stability of the materials was examined by means of the total colour distance ΔE according to the CIE L*a*b* colour measurement system. Colour changes were most prominent at all locations during the first months of exposure. The colour changes between individual measurements were the highest between measurements after 6 and 12 months of exposure. Such results were expected. The first six months of exposure were during autumn and winter, while the second six months were during spring and summer with higher sun radiation at all exposure sites. It is well known that weathering of wood is influenced predominantly by sun radiation and rain (Altgen and Miltz, 2015). Photochemical degradation is manifested by an initial colour change followed by loss of gloss, roughening and checking. The change of wood colour is ascribed to the UV light component of sunlight. UV light acts in combination with moisture, temperature, environmental pollutants and oxidative agents such as oxygen and/or ozone to depolymerise lignin and cellulose in the wood cell wall (Chang, 1982; Hon and Feist, 1992; Williams, 2005). Our data clearly showed, that samples became grey in the first year; afterwards colour changes were less significant. Comparison between exposure sites showed that the colour changes in the beginning of the experiment were lower in the northern countries. However, colour changes between sites became more uniform with increasing exposure time. Apart from the table exposed at Tallinn University, ΔE for all materials were much higher compared to sites located more in the south.

At all exposure sites, the most prominent colour changes were determined on Norway spruce specimens. For example; after first week of exposure, ΔE between 9.6 (Oslo) and 17.2 (Ljubljana) were calculated. In addition, 24 months of exposure of Norway spruce wood resulted in ΔE between 32.2 (Biel) and 63.7 (Tallinn) (Table 3). The second most prominent colour changes were observed on thermally modified spruce and the lowest on the oak wood specimens. Results are in line with our expectations. Before exposure the spruce specimens were bright, TM Spruce samples were dark brown and light brown. After two years of exposure the colour of all specimens (NS, O and TM) looked very similar, i.e. greyish.

Colour changes were also influenced by growth of disfigurement fungi (blue stain fungi and moulds). Results of the evolution of the growth of staining fungi can be resolved from table 3. Rating of fungal disfigurement coincided well with colour changes at the respective locations.

Already after one year of exposure it was hard to detect discoloration fungi on the upper side of the tables, because of greying of the samples.

During the first months of exposure, the highest rating of stain was reported for Norway spruce specimens, followed by oak and TM Norway spruce specimens at all sites. However, after one year, at the majority of locations, staining was reported on TM spruce as well. Based on the reports, the majority of discolorations were assigned to blue stain fungi.

On the bottom side of the exposed specimens discoloration was less prominent and remained constant during exposure. However, at some locations discoloration significantly increased with exposure time (Table 4). After 24 months, the highest rating was reported for TM Norway spruce specimens in Ås, Biel, and San Cibrao das Viñas. At other locations most notable developed on the bottom side of the Norway spruce specimens. Appearance of mould fungi was not reported. In contrary, on Scots pine sapwood samples exposed in Ljubljana, severely growth of mould fungi was found (Figure 1).

Figure 1: Growth of blue stain and mould fungi on Scots pine sapwood samples exposed in Ljubljana.

Table 3: Colour difference (ΔE) of Norway spruce (NS), English oak (O) and thermally modified spruce (TM) during exposure at different locations across Europe.

Location	Mate-rial	Weeks of exposure									Months of exposure		
		1	2	3	4	8	12	16	20	24	12	18	24
ULJ	NS	17.2	9.6	10.7	10.6	12.9	18.9	19.3	-	21.2	36.0	37.9	39.3
	O	29.9	8.1	5.9	6.2	11.3	17	18.9	-	18.1	28.8	29.1	28.8
	TM	12.3	20.1	20.6	19.8	10.4	10.4	13.4	-	14.6	15.8	15.8	17.2
SIL	NS	16.9	22.9	11.1	11.1	11.0	15.2	-	15.9	32.1	33.5	37.2	45.6
	O	2.5	3.0	13.6	14.2	15.3	9.6	-	18.4	16.8	15.7	15.5	13.8
	TM	17.5	7.2	5.2	3.4	11.1	16.9	-	16.1	23.1	19.9	23.0	25.8
HAN	NS	13.5	13.7	14.8	13.6	15.3	18.6	19.9	21.6	25.5	35.8	35.9	39.9
	O	4.9	3.3	3.3	1.8	8.6	12.2	15.9	17.3	18.4	27.4	26.0	23.9
	TM	4.4	3.9	8.1	9.9	13.9	14.8	14.6	15.5	15.5	19.0	19.5	18.6
AS	NS	9.7	9.2	7.3	7.1	9.2	26.4	-	15.2	15.2	29.6	29.5	32.5
	O	4.6	4.6	5	5.7	7.8	29.1	-	13.5	13.3	23.7	21.1	24.3
	TM	7.2	10	11.8	12.8	15.6	11.9	-	14.7	14.9	17.8	17.9	16.1
WIE	NS	-	-	6.1	11	24	23.7	22.3	24.9	25.1	34.1	34.5	34.5
	O	-	-	3	4.6	14.2	20.1	22.0	22.1	23.7	22.6	22.2	24.4
	TM	-	-	7.5	10.8	10	11.6	13.7	14.3	14.4	18.1	17.7	16.4
BIE	NS	11.6	13.1	13.5	15.3	23.8	26.7	28.4	28.0	28.1	33.3	-	32.2
	O	4.3	5.6	4.5	3.7	14.4	19.3	20.5	18.5	20.3	23.5	-	25.6
	TM	5.4	7.6	8.5	9.4	12	13.3	14.6	15.6	16.6	17.5	-	17.8
OSL	NS	9.6	11.9	12	10.3	18.7	15.2	25.4	-	15.5	33.0	84.6	35.8
	O	17.1	5.2	2.6	2.1	15.9	9.5	25.2	-	12.7	26.1	68.1	24.5
	TM	20.2	5.9	5.7	8.1	6.1	7.7	13.3	-	12.6	19.3	48.5	19.5
ITA	NS	13.5	16.2	19.4	14.3	14.8	22.9	24.5	-	-	-	-	38.4
	O	4.1	6.7	4.3	1.1	6.7	18.7	19.1	-	-	-	-	27.6
	TM	5.9	5.5	8.9	9.8	12.8	8.5	12.2	-	-	-	-	15.9
NTE	NS	9.7	14.8	16.7	12.9	12.5	16.4	24.7	49.5	37.0	86.6	40.7	38.9
	O	9.1	8.8	18.6	6	6.2	12.2	18.8	27.5	27.2	69.3	27.3	25.6
	TM	2.2	6.3	3	7.6	12	17.3	20.0	17.2	20.8	50.7	20.9	19.2
HAM	NS	12.6	12.4	12.3	10.9	19.7	13	14.2	15.5	16.9	35.3	34.6	37.4
	O	7.7	5.8	4.8	3.1	23.9	16.3	18.6	19.5	20.4	30.6	28.0	26.8
	TM	1.2	2.8	3.7	9.6	10.3	10.3	11.9	12.7	13.4	19.4	19.2	18.9
TAL	NS	10.1	13.6	12.6	12.1	22.2	19.4	-	47.7	48.0	44.8	60.3	63.7
	O	4.4	2.1	1.8	3.7	13.3	18.5	-	44.3	45.6	37.0	49.0	50.3
	TM	6.1	6.7	8.8	11.3	7.0	11.5	-	31.6	32.1	23.3	38.9	38.9
SCI	NS	13.8	14.2	10.2	12.1	21.7	-	28.4	-	-	39.3	-	-
	O	7.0	5.7	3.3	3.1	15.9	-	23.1	-	-	34.0	-	-
	TM	4.9	7.5	9.5	9.6	12.1	-	15.0	-	-	17.6	-	-
TEC	NS	13.6	16.3	13.9	12.8	18.0	24.1	35.0	27.5	34.0	37.2	34.8	-
	O	6.1	5.0	1.1	3.0	10.2	17.7	5.0	21.9	11.4	27.1	22.5	-
	TM	5.6	6.2	9.2	11.0	12.9	16.1	8.0	14.5	4.3	16.9	16.1	-
BRE	NS	16.9	13.0	12.2	17.3	27.8	30.3	24.7	22.1	28.9	32.7	33.4	37.3
	O	9.9	8.3	9.1	6.6	7.1	10.6	6.2	18.2	17.7	16.5	16.7	16.7
	TM	7.6	7.5	6.2	4.1	10.7	16.0	10.5	12.5	18.3	23.3	23.0	24.2

Table 4: Fungal disfigurement of the upper surface of Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) samples exposed at different locations across Europe. Rating scheme is resolved from Table 3 (Humar et al., 2015)

		Weeks of exposure							**Months of exposure**		
	Mate-	**0**	**4**	**8**	**12**	**16**	**20**	**24**	**12**	**18**	**24**
Location	**rial**	**Average rating of fungal disfigurement**									
	NS	0.0	2.0	3.0	3.0	-	-	3.0	x	x	x
ULJ	O	0.0	1.0	3.0	3.0	-	-	3.0	0.0	x	x
	TM	0.0	0.0	0.3	0.0	-	-	0.0	1.3	2.3	x
	NS	0.0	1.0	3.0	3.0	0.0	-	3.0	3.0	x	x
SIL	O	0.0	0.3	1.7	2.7	2.7	-	2.7	2.7	x	x
	TM	0.0	0.0	0.3	0.3	0.0	-	0.7	0.3	1.7	x
	NS	0.0	0.0	1.0	2.0	3.0	3.0	3.0	0.0	0.0	0.0
HAN	O	0.0	0.7	0.7	1.3	1.3	1.3	1.0	1.0	1.0	1.0
	TM	0.0	0.0	0.0	0.3	0.3	1.0	1.0	1.0	1.0	1.0
	NS	0.0	1.0	1.3	2.3	2.3	3.0	3.0	3.0	3.0	3.0
AS	O	0.0	1.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
	NS	0.0	1.3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
WIE	O	0.0	2.3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.0	1.0	1.3	1.7	1.7	2.0	3.0	3.0	3.0
	NS	0.0	2.7	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
BIE	O	0.0	1.0	1.3	2.3	2.3	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.3	1.3	2.3	2.3	2.3	3.0	3.0	3.0	3.0
	NS	0.0	1.0	1.0	2.0	2.0	0.0	2.0	0.7	0.0	0.0
OSL	O	0.0	1.0	2.0	2.0	2.3	0.0	2.0	2.0	1.7	1.3
	TM	0.0	0.3	0.7	1.0	1.0	0.0	0.7	0.7	0.3	0.3
	NS	0.0	0.0	1.0	1.0	1.0	-	-	-	-	-
ITA	O	0.0	0.0	1.0	1.0	1.0	-	-	-	-	-
	TM	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-
	NS	0.0	1.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
HAM	O	0.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	x*	0.3	1.0	1.0	x	x	x
	NS	0.0	1.0	1.0	2.0	2.0	2.0	3.0	2.0	0.0	2.3
TAL	O	0.0	1.0	1.0	2.0	2.0	2.0	3.0	2.0	0.0	2.0
	TM	0.0	0.0	0.0	0.0	0.0	0.3	1.0	1.0	0.0	0.3
	NS	0.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
SCI	O	0.0	1.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0
	NS	0.0	0.0	1.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0
DTI	O	0.0	0.0	0.0	1.0	1.0	1.0	2.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	0.0	1.0	1.0	2.0	3.0	3.0	3.0

X-mean grey surface

Table 5: Fungal disfigurement of the bottom surface of Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) samples exposed at different locations across Europe. Rating scheme is resolved from Table 3 (Humar et al., 2015)

		Weeks of exposure							Months of exposure		
	Mate-	0	4	8	12	16	20	24	12	18	24
Location	**rial**	Average fungal disfigurement rating									
	NS	0.0	0.0	1.7	1.7	0.0	0.0	1.3	0.0	1.3	2.0
ULJ	O	0.0	0.0	2.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0
	TM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0
	NS	0.0	0.0	0.0	0.0	-	0.0	0.0	0.3	1.0	0.3
SIL	O	0.0	0.0	0.3	2.0	-	0.0	2.0	1.0	1.0	0.3
	TM	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	1.0	0.0
	NS	0.0	0.0	0.0	1.0	2.0	2.0	2.0	0.0	0.3	0.3
HAN	O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0
	TM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
	NS	0.0	0.0	0.3	1.0	1.0	2.0	2.0	2.0	2.0	2.0
AS	O	0.0	0.0	0.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	1.0	1.0	1.0	2.0	3.0	3.0	3.0
	NS	0.0	0.0	1.0	1.3	2.3	2.3	2.3	2.3	2.3	2.7
WIE	O	0.0	0.0	1.0	2.0	2.3	2.7	3.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	0.3	1.3	1.3	1.3	2.3	2.7	3.0
	NS	0.0	1.0	1.0	1.3	1.3	1.3	2.0	2.3	2.7	3.0
BIE	O	0.0	0.0	1.0	1.0	1.0	2.0	2.7	3.0	3.0	3.0
	TM	0.0	0.3	0.3	1.0	1.3	1.3	1.3	2.3	3.0	3.0
	NS	0.0	0.0	0.0	0.0	0.3	0.0	0.7	1.0	0.0	0.0
OSL	O	0.0	0.0	1.0	1.0	1.0	0.0	1.3	2.3	2.0	1.7
	TM	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.7	0.7
	NS	0.0	0.0	0.0	1.0	1.0	-	-	-	-	-
ITA	O	0.0	0.0	0.0	1.0	1.0	-	-	-	-	-
	TM	0.0	0.0	0.0	0.0	0.0	-	-	-	-	-
	NS	0.0	0.0	1.0	1.7	2.0	2.0	2.0	2.3	3.0	3.0
HAM	O	0.0	0.0	1.0	2.3	3.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	0.0	0.0	0.7	0.7	1.7	2.0	2.0
	NS	0.0	1.0	1.0	2.0	2.0	2.0	2.0	2.3	0.0	2.3
TAL	O	0.0	1.0	1.0	2.0	2.0	2.0	3.0	3.0	0.0	2.3
	TM	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.7	0.0	0.3
	NS	0.0	0.0	1.0	2.3	2.7	3.0	3.0	3.0	3.0	3.0
SCI	O	0.0	0.0	0.0	2.7	2.0	3.0	3.0	3.0	3.0	3.0
	TM	0.0	0.0	0.0	0.3	0.3	1.0	2.0	2.0	3.0	3.0
	NS	0.0	0.0	0.0	1.0	2.0	2.0	2.0	2.0	2.0	2.0
DTI	O	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0
	TM	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0

3.2 Cracks

The assessment of cracks turned out to be the most challenging task of the evaluation. Cracks were evaluated every three months. During evaluation the number of cracks, the total crack length and the crack width were recorded (Humar at al., 2015). From table 5, it can be resolved that the number and length of cracks increased with exposure time. On oak samples exposed in Hamburg and Biel for 24 months, there were so many cracks, that it was almost impossible to count them. At other locations specimens showed less cracks.

It was observed that the orientation of annual rings in the individual specimens had a more prominent effect on number, length and width of cracks than the wood species. Most of the cracks were found on specimens with annual rings approximately parallel to the exposed specimen surface. Besides orientation the formation of cracks was influenced by moisture content of the specimens. We found, that the duration between the last rain event and the crack assessment had a considerable influence on the crack formation. For instance, considerable differences were observed between morning and afternoon evaluations. Therefore, we concluded, that for more precise cracking evaluation of wood, more definite instructions will be needed.

Table 6: Formation of cracks on Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) specimens at different locations across Europe. 1st part

		Months of exposure																				
		3			**6**			**9**			**12**			**15**			**18**			**24**		
Location	**Mate-rial**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**
ULJ	NS	0.0	0.0	1.5	258.7	2.7	0.2	-	-	-	445.3	5.3	0.5	445.3	5.3	0.5	445.3	5.3	0.5	596.7	7.7	0.7
	O	0.0	0.0	2.3	0.0	0.0	0.0	-	-	-	72.7	5.7	0.1	72.7	5.7	0.1	72.7	5.7	0.1	103.3	3.3	0.1
	TM	0.0	0.0	0.8	290.7	3.0	0.1	-	-	-	334.3	4.3	0.3	334.3	4.3	0.3	334.3	4.3	0.3	502.7	6.0	0.3
SIL	NS	11.7	3.0	1.5	-	-	-	-	-	-	174.0	3.3	0.3	174.0	3.3	0.3	174.0	3.3	0.3	181.7	3.7	0.3
	O	25.0	5.7	2.3	-	-	-	-	-	-	27.7	2.7	0.1	27.7	2.7	0.1	27.7	2.7	0.1	181.0	8.0	0.2
	TM	3.0	1.3	0.8	-	-	-	-	-	-	122.7	2.0	0.0	122.7	2.0	0.0	122.7	2.0	0.0	247.7	4.0	0.2
HAN	NS	0.0	0.0	0.0	0.0	0.0	0.0	2.5	1.5	0.2	2.5	1.0	0.2	6.4	2.3	0.1	7.4	2.7	0.2	10.7	4.0	0.3
	O	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.0	0.1	2.7	2.0	0.2	4.0	2.0	0.1	10.0	4.0	0.2	55.8	15.0	0.3
	TM	0.0	0.0	0.0	0.0	0.0	0.0	2.1	1.3	0.1	2.6	1.5	0.2	5.2	2.2	0.1	8.7	3.3	0.2	33.3	9.5	0.3
AS	NS	0.0	0.0	0.0	0.3	0.0	0.2	2.5	2.7	0.5	9.0	1.7	0.2	12.3	3.3	0.3	21.9	7.7	0.5	20.8	5.0	0.5
	O	0.0	0.0	0.0	0.7	0.0	0.0	22.9	4.0	0.3	29.0	6.3	0.5	58.2	8.3	0.7	60.9	8.7	0.7	51.5	9.0	0.7
	TM	0.0	0.0	0.0	0.0	0.0	0.0	35.5	5.3	0.5	26.2	3.7	0.3	29.7	4.7	0.3	55.8	7.0	0.5	66.2	6.7	0.5
WIE	NS	11.7	3.0	1.5	11.2	13.0	0.1	-	-	-	56.3	21.0	0.4	56.1	21.0	0.4	-	-	-	101.5	32.3	0.4
	O	3.0	1.3	0.8	0.2	0.3	0.1	0.9	1.0	0.3	1.8	1.3	0.3	2.3	1.3	0.3	-	-	-	4.2	3.3	0.3
	TM	25.0	5.7	2.3	35.6	6.7	0.2	-	-	-	63.3	12.0	0.3	60.9	12.0	0.3	-	-	-	87.7	16.0	0.3
BIE	NS	0.0	0.0	0.0	0.0	0.0	0.0	56.4	2.3	0.3	100.6	3.0	0.3	118.7	3.7	0.3	138.2	3.7	0.4	-	>50	-
	O	0.0	0.0	0.0	0.0	0.0	0.0	139.0	4.0	0.1	171.6	4.3	0.2	254.3	5.7	0.3	-	-	-	-	>50	-
	TM	163.1	1.7	0.1	221.7	2.3	0.2	377.3	4.3	0.3	422.3	4.3	0.3	484.0	4.7	0.3	503.9	4.7	0.5	558.0	6.3	0.2

Table 5: continued…

Table 5: Formation of cracks on Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) specimens at different locations across Europe. 2nd part

		Months of exposure																				
		3			**6**			**9**			**12**			**15**			**18**			**24**		
Location	**Mate-rial**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**	**Total crack length**	**Av. No. of cracks**	**Mean crack width**
OSL	NS	1.1	0.7	0.1	2.4	3.0	0.1	6.1	4.0	0.1	6.6	3.7	0.1	8.1	5.0	0.1	9.6	5.7	0.1	13.6	8.7	0.2
	O	1.9	1.7	0.0	3.2	1.7	0.1	4.8	2.0	0.0	6.9	2.3	0.0	7.0	2.3	0.0	7.5	2.7	0.1	7.3	3.3	0.9
	TM	3.1	1.3	0.2	5.4	3.3	0.1	8.0	4.3	0.1	8.2	3.3	0.2	10.5	4.0	0.1	12.9	4.7	0.1	21.7	5.7	0.2
	NS	19.9	1.6	4.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20.7	3.7	0.2
ITA	O	0.0	0.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	39.8	8.3	0.9
	TM	0.0	1.0	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	24.5	1.7	0.2
	NS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.7	1.0	0.1	1.0	1.0	0.1
HAM	O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		>50	0.2	18.5	6.0	0.2
	TM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6.2	2.0	0.3	6.3	2.0	0.1
	NS	0.0	0.0	0.0		0.0		4.1	3.3	0.4	8.1	3.0	0.4	16.0	7.0	0.3	-	-	-	29.3	7.0	0.4
TAL	O	0.0	0.0	0.0		0.0		21.8	8.7	0.2	22.5	9.0	0.2	12.6	9.0	0.3	-	-	-	32.7	9.0	0.4
	TM	0.0	0.0		9.8	5.3	0.3	4.2	2.7	0.1	14.6	3.7	0.1	11.8	3.3	0.1	-	-	-	12.6	1.3	0.3
	NS	4.5	1.3	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.6	1.7	0.7
SCI	O	3.7	1.0	2.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.7	3.0	0.7
	TM	3.0	1.0	0.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8.0	3.0	0.5
	NS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.3	0.1	0.8	0.3	0.1	12.0	1.7	0.2
TEC	O	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.3	0.2	1.8	1.3	0.2	9.0	1.3	0.2
	TM	0.0	0.0	0.0	0.0	0.0	0.0	18.0	1.3	0.3	21.7	2.3	0.4	27.3	3.0	0.5	27.3	3.0	0.5	28.7	3.3	0.5

3.3 Decay

First decay was observed after 24 months of exposure on Norway spruce and Fir samples exposed in Hamburg. Fruiting bodies of *Dacrymyces* spp. (Figure 2) were found close to surface cracks. Moisture content around crack was higher for longer time what influence on suitable conditions for fungal growth.

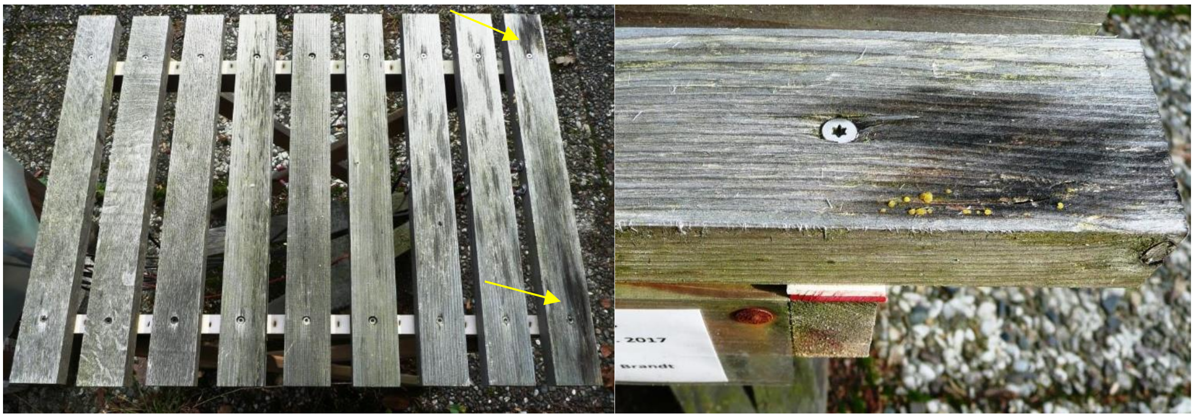

Figure 2: Top view of table with first fruiting bodies of Dacrymyces spp. on Norway spruce (left). Infection is associated to cracks (right)

3.4 Time of wetness (ToW)

Moisture content was measured on table version A only. These tables were exposed only at some locations, namely in Hannover, Hamburg, Azpeitia – Gipuzkoa, Ås, Florence, and Ljubljana. The number of measurements was between 77 and 1462. Such high differences were due to technical problems with measurement equipment at same locations (Table 6).

The highest median moisture content (MC) was determined in Hannover (24.8 %), Hamburg (26.1 %), Azpeitia – Gipuzkoa (27.8 %) and Ås (42.5 %) on TM samples. In Ljubljana and Florence the highest median MC was determined on Norway spruce samples. At all locations the lowest median MC was determined on Oak samples. The highest MC in Norway spruce specimens was reported in Ljubljana (28.5 %), and the highest median MC was in Oak and TM specimens in Ås.

The time of wetness (ToW) was expressed as number of days per year with a MC > 20 % and a temperature above 20 °C. These conditions are considered to be favourable for fungal growth and decay. ToW of Norway spruce was highest in Ljubljana (45 days), followed by Azpeitia – Gipuzkoa (30 days) and Ås (30 days). On the other hand, the ToW of TM spruce and oak wood was the highest in Azpeitia – Gipuzkoa (38 and 27 days). The lowest ToW was reported for Hamburg. This might stand in contrast to the observation of fruiting bodies on the Norway spruce specimens in Hamburg. However, after only two years of exposure it is still too early for a final interpretation. Furthermore, the fungal genus *Dacrymyces* which had been identified in Hamburg is frequently reported to require comparatively little moisture (Huckfeldt and Rehbein 2011) Finally, the resistance based moisture content measurements had been conducted in the central part of the specimens, while the decay reported in Hamburg developed in cracks rather remote from the measuring points.

In Hamburg parallel gravimetric MC were determined on table version B. At the beginning moisture was determined every week and later once per month. From figure 3 it can be seen that during the whole period Norway spruce specimens had the highest MC followed by oak samples and the lowest MC was determined in thermally modified spruce specimens. In addition, it can be clearly seen, that MC of the specimens varied during the year. In Norway spruce specimens MC varied between 12 % during the summer months and 35 % during the winter months.

Table 7: Moisture content (MC) of Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) oat different locations across Europe.

	Material	**HAN**	**HAM**	**TEC**	**AS**	**ITA**	**ULJ**
No. of measurements	Norway spruce	1208	1066	77	364	137	1462
Mean (%)		21.4	22.4	27.2	27.1	20.9	28.0
Median (%)		19.3	20.8	22.5	24.3	17.2	28.5
MIN (%)		9.4	9.1	11.1	17.1	11.1	5.8
MAX (%)		90.5	63.2	75.4	71.8	102.4	54.2
MC > 20 %		535	556	46	317	43	1226
MC > 30 %		159	179	23	91	11	660
MC > 20 % and T < 20 °C		52	36	6	30	8	181
No. of days per year MC >20 % and T > 20 °C		16	12	30	30	21	45
No. of measurements	Thermally modified Spruce (TM)	794	1066	80	365	202	1462
Mean (%)		25.9	27.3	29.7	42.0	17.7	22.3
Median (%)		24.8	26.1	27.8	42.5	13.8	21.3
MIN (%)		3.5	7.4	3.6	16.8	3.7	10.8
MAX (%)		65.3	57.1	67.8	73.3	73.6	48.4
MC > 20 %		484	710	49	349	69	1029
MC > 30 %		281	423	37	300	41	159
MC > 20 % and T < 20 °C		40	63	8	33	15	140
No. of days per year MC >20 % and T > 20 °C		18	22	38	33	27	35
No. of measurements	Oak	792	1066	81	365	202	1462
Mean (%)		17.0	16.0	23.6	25.2	12.8	16.5
Median (%)		15.9	14.9	21.6	25.5	11.2	16.4
MIN (%)		6.8	7.1	10.3	11.0	4.1	5.3
MAX (%)		38.7	32.4	75.2	40.9	30.3	35.0
MC > 20 %		235	200	42	248	19	445
MC > 30 %		30	3	21	105	2	25
MC > 20 % and T < 20 °C		13	8	6	20	2	21
No. of days per year MC >20 % and T > 20 °C		6	3	27	20	3	5

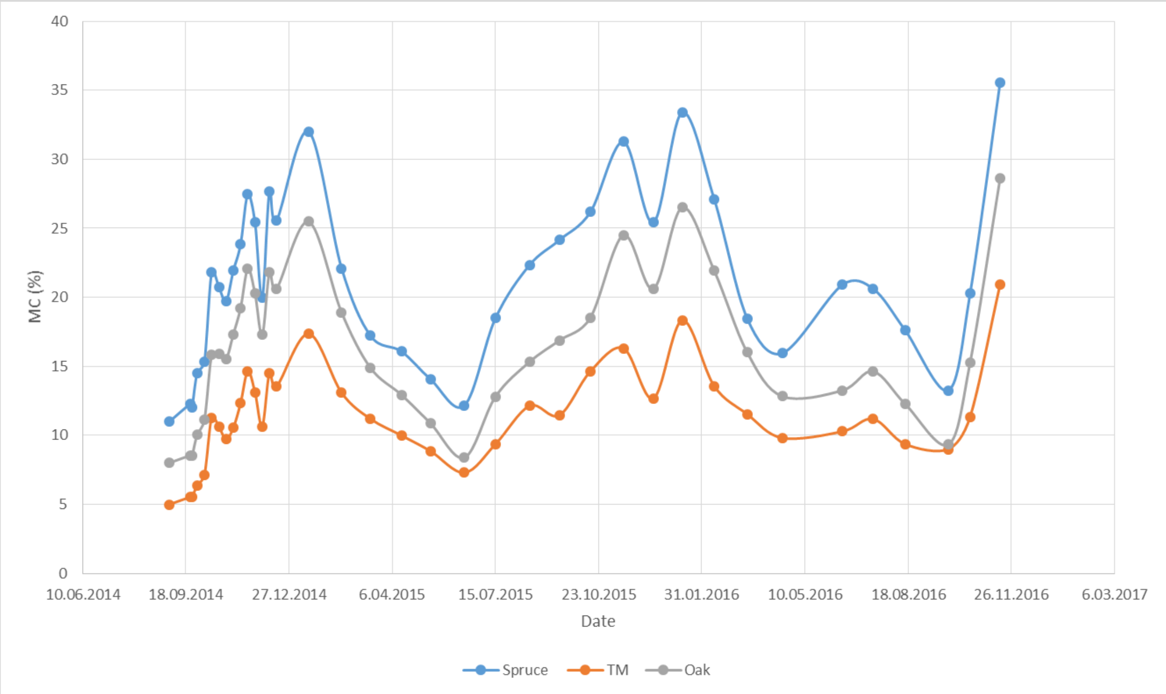

Figure 3: Gravimetrically determined average moisture content of Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) in table version B exposed in Hamburg.

3.5 Corrosion of the fasteners

Corrosion of the fasteners is important from two points of view, i. e. the discoloration of wood around the corroded fasteners and secondly, the loss of mechanical strength of the fasteners. In this study we examined the corrosion of stainless steel and galvanized screws. Evaluations were performed every six months.

Stainless steel fasteners were without any signs of corrosion after two years of outdoor exposure at all of the locations. On the other hand, galvanized screws corrode already after the first six months of exposure. The most prominent corrosion became evident on screws in contact with oak wood (average corrosion rating between 0 in Hannover and 3.7 in Biel (Table 8). Corrosion increased with time. After 24 months, at most of the locations rating 4 was reported, which means that more than 95 % of the surface was corroded. Less prominent corrosion was observed in Hannover, Oslo and Hamburg, only. Corrosiveness of oak wood is assigned to low pH and tannins and to the most important external factor, the water uptake (Melcher et al. 2016).

Second most corrosive wood used in our research was thermally modified wood. Corrosion rating of the fasteners in contact with TM wood after 24 months of exposure ranged between 1 and 4. Hence, between 5 and 95 % of the surface were corroded. Thermally treated wood stimulates corrosion of metals because of the degradation products remaining in wood after modification process (Esteves and Pereira, 2009).

On Norway spruce specimens corrosion was found only on the bottom side of galvanized screws, which were fixed in copper based impregnated parts of the tables. Surface of screws were corroded maximum up to 50 %. Tables were made from spruce wood pressure impregnated with copper-amine based wood preservative. It is well known that copper based wood preservatives cause corrosion of galvanized screws (Richardson, 1997).

Table 8: Corrosion of fasteners in contact with Norway spruce (NS). English oak (O) and thermally modified Norway spruce (TM) specimens at different locations across Europe. Rating scheme is resolved from Table 4 (Humar et al., 2015)

		Months of exposure			
		6	**12**	**18**	**24**
Location	**Material**	**Mean corrosion rating**			
ULJ	NS	2.0	2.0	2.0	2.0
	O	3.0	4.0	4.0	4.0
	TM	2.0	2.3	2.3	2.3
SIL	NS	1.7	1.7	2.0	1.7
	O	1.7	3.7	4.0	4.0
	TM	1.3	2.3	2.3	2.7
HAN	NS	0.0	1.0	1.0	1.0
	O	0.0	0.0	1.0	1.0
	TM	0.0	0.0	1.0	1.0
AS	NS	0.0	2.0	2.0	2.0
	O	0.0	3.0	4.0	4.0
	TM	0.0	2.0	3.0	3.0
WIE	NS	2.0	2.0	2.0	2.0
	O	2.3	3.3	4.0	4.0
	TM	1.7	2.0	2.3	3.0
BIE	NS	2.0	2.3	2.3	3.0
	O	3.7	4.0	4.0	4.0
	TM	2.3	3.0	3.0	3.0
OSL	NS	0.0	0.0	0.0	0.0
	O	1.0	2.0	2.0	2.0
	TM	0.0	0.0	0.5	1.0
HAM	NS	2.0	2.0	2.0	2.0
	O	2.0	2.0	2.0	2.0
	TM	3.0	3.0	3.0	3.0
TAL	NS	2.0	3.0	3.0	3.0
	O	3.0	4.0	4.0	4.0
	TM	2.0	3.0	3.0	3.0
SCI	NS	-	-	-	1.0
	O	-	-	-	4.0
	TM	-	-	-	2.0
TEC	NS	0.0	0.0	0.0	0.7
	O	3.0	3.0	3.0	4.0
	TM	0.0	0.0	2.0	4.0

4. CONCLUSIONS

After two years of exposure, data from 15 locations in Europe were collected. Colour changes were most prominent at all locations during the first months of exposure. Specimens became grey during the first year, afterwards colour changes were minor. After two years of exposure it was hard to detect discoloration fungi on the upper side of the tables, because of greying of the samples. On bottom side discoloration was much less prominent and stayed constant during exposure. After two years of exposure, first signs of decay and first fruit bodies were found on Norway spruce wood samples exposed in Hamburg. At other locations and on other materials no decay was detected, yet. The most challenging task during assessment was the evaluation of cracks. Exposed samples had different orientation of the tree rings, and hence rather big differences were found even between samples of the same material. On average English oak specimens showed more and smaller cracks, while Norway spruce and thermally modified specimens had longer cracks.

No corrosion was found on stainless steel screws after two years on all materials and at all locations. In contrast, galvanized screws corroded in English oak specimens and partly in thermally modified spruce specimens. On screws in contact to Norway spruce specimens, corrosion was found only on the bottom side of galvanized screws, which were fixed in copper treated parts of the tables.

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