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Section 2 Test methodology and assessment

Introduction of the COST FP 1303 Cooperative Performance Test

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ABSTRACT

COST Action FP 1303 "Performance of bio-based building materials" successfully started in October 2013 and an ambitious program was set up for the four year programme. COST Actions provide an excellent opportunity for collaborative research, e.g. in the frame of Round Robin tests.

The idea of this respective 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 range of climatic exposure conditions. Furthermore we wanted to consider performance in its manifold meaning, i.e. optical, aesthetical, moisture and functional performance and durability. In contrast to traditional Round Robin tests aiming on comparative evaluation and validation of results from different test laboratories, this initiative aims on collecting performance data under climatically different exposure conditions. Therefore it was required to provide weather data from the respective test sites to allow establishing relationships between climate conditions and the following measured, which shall be evaluated regularly: decay, discolouration, development of mould and other staining fungi, corrosion, formation of cracks and moisture performance (if data logging device is included). Further details about the test and the first outcomes are presented in this paper.

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

1. INTRODUCTION

There is an increasing need for consideration of performance classification for wood and other bio-based building materials, as evidenced by the European Construction Products Regulation, as well as by warranty providers and end user demands for information. In the frame of several European research projects this issue has been addressed and emphasized by CEN /TC 38 in recent years (Kutnik *et al.* 2014).

The development of performance-based design methods for durability requires that models are available to predict performance in a quantitative and probabilistic format. During the last decade great progress has been made, in that the wood sector caught up with other competing areas such as the steel, concrete, and polymer sector. The relationship between durability determined in laboratory or field tests and the performance under in-service conditions needs to be quantified in statistical terms and the resulting prediction models need verification and adaptation according to performance in real life (Brischke and Thelandersson 2014). The availability and accessibility of performance data is a basic prerequisite for both modelling and performance classification, but is still limited. Therefore a joint initiative has been set up between participating groups within COST Action FP1303 "Performance of bio-based building materials".

This COST action started in October 2013 and an ambitious program was set up for the four year programme. Among this a collaborative field test was planned. As we learned from earlier Actions it is valuable to start with such cooperative activities as early as possible in the life of an Action. This allows harvesting results within the run-time of the Action and helps to initiate discussions during workshops and meetings.

A Cooperative Performance Test has been organized in the frame of this COST Action as decided during the first workshop in Paris in January 2014. The idea 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 range of climatic exposure conditions. Furthermore, the test aimed on considering performance in its manifold meaning, *i. e.* optical, aesthetical, moisture and functional performance and durability. In contrast to traditional Round Robin tests aiming on comparative evaluation and validation of results from different test laboratories, this initiative aimed on collecting performance data under climatically different exposure conditions. Therefore it was required to provide weather data from the respective test sites to allow establishing relationships between climate conditions and the following parameters, which were evaluated regularly:

- Fungal decay
- Discolouration
- Development of mould and other staining fungi
- Corrosion
- Formation of cracks
- Moisture performance (optional)

The results expected from this cooperative performance test shall contribute to a better understanding of performance aspects of bio-based materials in the building sector under the influence of geographical and climatic differences. Furthermore, it shall enable the participants to estimate their own location in terms of exposure severity and performance to be expected.

2. EXPERIMENTAL

2.1 Principle set up

A folding table with boards made from three different materials, *i.e.* Norway spruce, English oak and thermally modified Norway spruce (
Table 1) served as easy shippable and ready-to-use test object (Fig. 1). The boards were fixed with partly stainless and partly ordinary steel screws. The table was available in three different versions:

- <u>Version A:</u> Performance table with the three materials mounted; including data logging device for recording temperature and wood MC (8 channels)
- <u>Version B:</u> Performance table with 3 materials mounted, no data logger
- <u>Version C:</u> Performance table, blank rig for testing extra materials according to personal/regional preferences (delivered only in addition to version A or/and B)

Table 1. Obligatory wood species used for the performance test.

Wood species	Botanical name	Oven dry density [g/cm³]
Norway spruce	*Picea abies*	0.465
English oak	*Quercus* sp.	0.708
Thermally modified Norway spruce	*Picea abies*	0.435

Fig. 1. Performance folding table.

2.2 Exposure conditions

The test sites for exposure of the performance table had to meet the following requirements:

- Typical free exposure (avoiding canopies and vicinity to buildings and other shading elements)
- Standard test site (if available) to allow for further comparison with your running tests
- Safety (against vandalism, thievery, storm, and other catastrophes, which might occur at the site)
- Fixation with the ground, *e.g.* with steel angles.
- Steel box with data loggers positioned below the table or on a nearby holder. Leakage should be prevented.

2.3 Documentation

2.3.1 Documentation of exposure site

The following information of the respective exposure site was collected:

- Geographical position (GPS coordinates)
- Height above sea level
- Photographs showing the performance table and the surrounding showing the four compass directions

2.3.2 Documentation of exposure conditions

For interpretation of the results detailed information about the respective exposure conditions were required. In particular the weather parameters corresponding to the exposure period were requested as follows:

- Precipitation
- Average air temperature
- Minimum and maximum air temperature
- Average relative humidity

If available also the following parameters were considered valuable:

- Wind speed
- Wind direction
- Global irradiance

In order to obtain these data the closest weather station, which might be an official, private or even own station was used.

2.3.1 Documentation of results

All results and all other relevant data were requested in an Excel sheet template that has been delivered with the performance table. Results and documentation reports are requested regularly.

2.4 Assessment and evaluation

2.4.1 Fungal decay

The specimens were inspected once a year regarding the onset and progress of fungal decay. Therefore the screws were loosened and the specimens removed from the rig to allow inspection from all sides. Decay was assessed by visual inspection combined with a pick-test using a pointed knife. The knife should be pricked into the specimens and pulled out again to inspect the surface strength as well as the fracture depth and splinter characteristics for the rating pursuant to EN 252 (2012). The rating scheme according to EN 252 (2012) is shown in

Table 2.

Table 2. Decay rating scale according to EN 252 (2012)

Rating	Classification	Definition
0	No attack	No change perceptible by the means at the disposal of the inspector in the field. If only a change of colour is observed, it shall be rated 0.
1	Slight attack	Perceptible changes, but very limited in their intensity and their position or distribution: changes which only reveal themselves externally by superficial degradation, softening of the wood being the most common symptom.
2	Moderate attack	Clear changes: softening of the wood to a depth of at least 2 mm over a wide surface (covering at least 10 square centimetres) or by softening to a depth of at least 5 mm over a limited surface area (covering less than 1 square centimetre).
3	Severe attack	Severe changes: marked decay in the wood to a depth of at least 3 mm over a wider surface (covering at least 25 square centimetres) or by softening to a depth of at least 10 mm over a more limited surface area.
4	Failure	Impact failure of the stake in the field.

Additionally, on the basis of visible characteristics the type of decay should be identified. Information how to distinguish the main decay types (brown rot, white rot, soft rot and tunnelling bacteria) can be found in CEN/TS 15083-2 (2005) – Annex D. Typical examples of the main decay types are shown in Fig. 2 and Fig. 3.

Fig. 2: Left: Beech. Failure after 0.5 years exposure. Visual inspection showed typical signs of white rot: whitish discoloration, long-fibred splinter, fibred fracture. Right: Southern yellow pine. Failure after 0.5 years exposure. Visual inspection showed typical signs of brown rot: brownish discoloration, brittle/cubical splinter, cross-checking texture

Fig. 3: European ash. Failure after 0.5 years exposure. Visual inspection showed typical signs of soft rot: shell-shaped splinter, attack on the outer wood shell, clean fracture.

2.4.2 Discoloration

*CIE L*a*b* colour measurements - colorimeter*

Colour measurements were recorded at three points on the upper surface of each specimen with a colorimeter. The measuring points were marked on each specimen through cross lines. The positions were centrally between the long sides of the specimens and 30 mm from the end-grain and in the middle of the specimen as shown in Fig. 4.

Fig. 4. Positions for measuring L*a*b* colour values.

The measurements were taken in L*a*b coordinates, as established by the Commision Internationale de Enluminure (CIE) in 1976, where $L*$ determines the lightness, $a*$ and $b*$ determine the chromatic coordinates on the green-red and blue-yellow axis, respectively. First measurements were performed at University Ljubljana before shipment of the specimens. Second measurement to determine initial values were performed immediately upon the delivery of the table (= before exposure and storage in the lab). The measurements were conducted every week during the first four weeks of exposure, every 4 weeks during the first six months, and later on twice a year. Measurements were determined on the dry surface, at least 2 hours after the last rainfall. In case that there was snow or ice on the table, measurements were postponed. To determine colour changes over time the distance in colour space ΔE was determined according to Equation 1:

Equation 1: Distance in colour space ΔE

$$\Delta E = \sqrt{(\Delta L^{*})^2 + (\Delta a^{*})^2 + (\Delta b^{*})^2}$$

; ΔE = *distance in color space [-]*

; $L*$ = *lightness [-]*

; $a*$ = *chromatic coordinate of the red-green axis [ ]*

; $b*$ = *chromatic coordinate of the yellow-blue axis [ ]*

2.4.3 Surface disfigurement due to mould and staining fungi

For easy evaluation of surface disfigurement due to fungal growth the following criteria adapted from EN 152 (2011) were used (Table 3). Therefore the upper and lower surface of the test specimens was examined visually for the presence of mould and staining fungi.

Table 3. 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.

2.4.4 Corrosion

Corrosion was assessed according to the adopted procedure described by Jermer and Andersson (2005). Each fastener was washed in ethanol and weighed before being fixed in the wood sample. There were two types of fasteners used, galvanized and stainless steel screws.

Intermediate assessments

In parallel with the visual assessment of fungal decay the fasteners were inspected regarding corrosion. All fasteners on the upper surface were removed and inspected visually according to the rating scheme presented in Table 4.

Table 4. Assessment of corrosion attack (Jermer and Andersson 2005)

Rating	Description	Definition
0	No attack	
1	Insignificant attack	<5 % of surface attacked
2	Slight attack	5-50 % of surface attacked
3	Serious attack	50-95 % of surface attacked
4	Completely attacked	>95 % of surface attacked

Final evaluation

After 3 years of exposure, fasteners will be replaced with new ones. The old ones will be analysed according to the following procedure. The metal loss is calculated and expressed as metal loss (%) and as depth of corrosion (mm). In order to determine the metal loss and depth of corrosion the corrosion products had to be eliminated. Thus the fasteners will be pickled, cleaned and then weighed. Pickling and cleaning will be performed as follows:

1.) 5 min pickling in Clark’s solution: Concentrated hydrochloric acid with an additive of 20 g/l antimony oxide and 20 g/l stannic chloride
2.) 2 min cleaning in hot water
3.) 10 s rinsing in hot running water
4.) Drying with a clean paper tissue
5.) Dipping for 30 s in 96 % ethanol
6.) Drying with a clean paper tissue
7.) Storage for at least one hour in a desiccator. To equalize the temperature, storage shall be done in the same room as the weighing

Equation 2: Metal loss due to corrosion [%]

$$MeL = \frac{(m_{initial} - m_{pickled})}{m_{initial}} \times 100\ [\%]$$

; MeL= metal loss [%]

; $m_{initial}$ = initial mass of screws [g]

; $m_{pickled}$ = mass after pickling [g]

Equation 3: Corrosion depth [mm]

$$d_{corrosion} = \frac{1}{2} \times (\emptyset_{initial} - \emptyset_{pickled})[mm]$$

; $d_{corrosion}$= depth of corrosion [mm]

; $ø_{initial}$ = initial diameter [mm]

; $ø_{pickled}$ = diameter after pickling [mm]

2.4.5 Crack formation

The formation of cracks on the upper surface of the specimens was determined using the following three measures:

- Total crack length (total length of cracks with length of more than 5 mm)
- Number of cracks (longer than 5 mm)
- Mean maximum crack width

The length of cracks can be easily determined using a ruler. For measuring the crack width a crack measuring gauge (Fig. 5) was used. The maximum width of each single crack (longer than 5 mm) was recorded to determine the mean maximum crack width. The sides and the lower surface of the specimens will not be considered. Specimens were inspected regarding the formation of cracks before exposure (initial state) and then every 3 months.

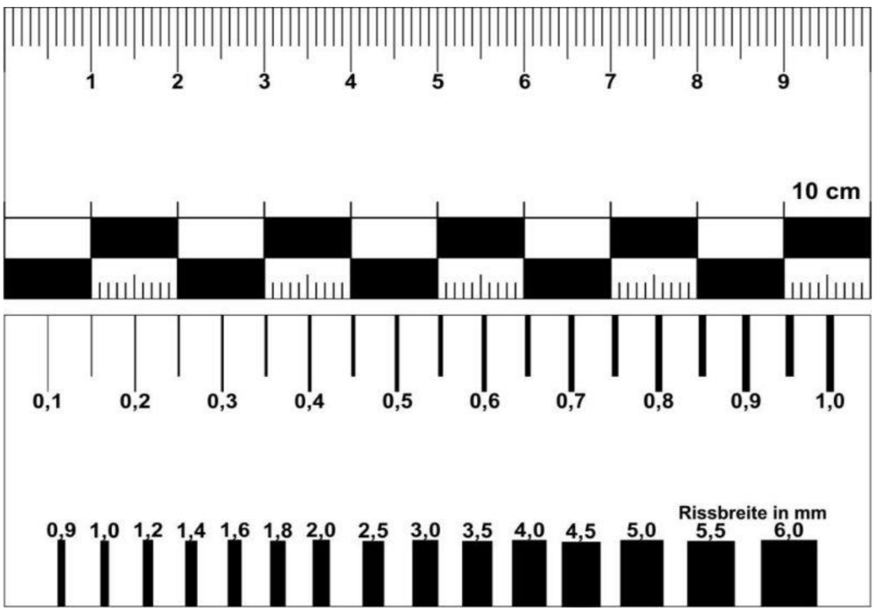

Fig. 5. Crack measuring gauge.

2.4.6 Moisture content and temperature (optional)

Version A of the performance table was equipped with moisture content sensors, a Thermofox datalogger and a connected gigamodule (Scanntronik Mugrauer GmbH, Zorneding, Germany) for electrical resistance measurements and recordings. Data loggers were connected with the test specimens. Electrodes were fixed to the wood with insulated fasteners as shown in Fig. 6. Therefore, the moisture content was recorded only in the central part of the specimen

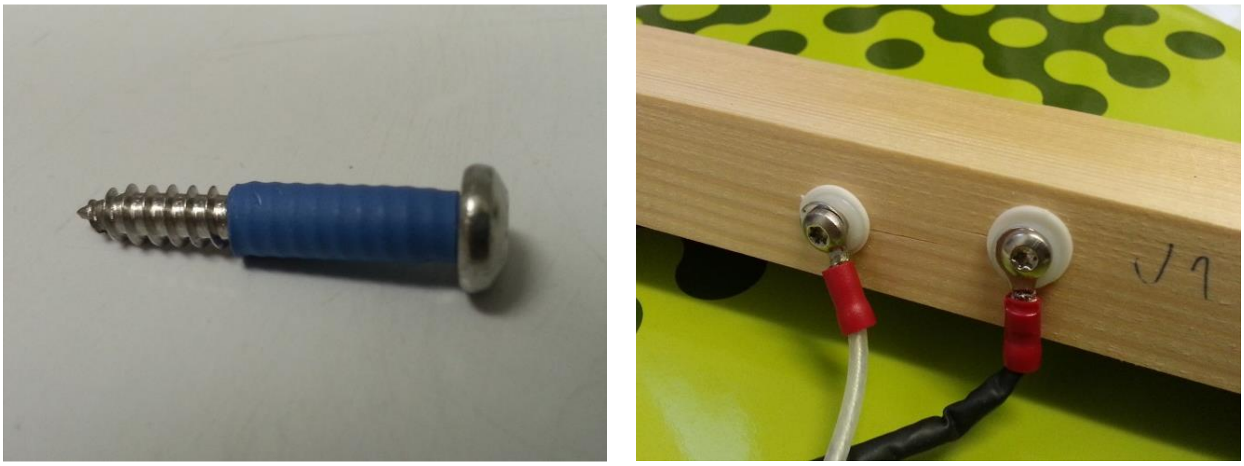

Fig. 6. Isolated fasteners (left) used for fixing electrodes on wood specimens (right).

There were eight electrodes mounted to the wood; first three in the Norway spruce, second three in thermally modified spruce, and the last two in English oak. Temperature was measured and recorded in the least dense (thermally modified Norway spruce) and the densest material only (English oak).

2.5 Measurement intervals - summary

The schedule for measurements and assessment given in Table 5 was followed:

Table 5. Assessment schedule for performance tests.

Test/Assessment	Period	Interval
Fungal decay	full	every 6 months
Mould / stain	first 6 months	every 4 weeks
	from month 7 on	every 6 months
Crack formation	full	every 3 months
Colour measurements	first 4 weeks	every week
	first 6 months	every 4 weeks
	from months 7 on	every 6 months
Corrosion visual	full	every 6 months
Corrosion final	after 3 years	-
MC recordings (read out of data logger)	full	every 3 months

3. FIRST OUTCOMES AND DISCUSSION

3.1 Location of the COST FP 1303 performance test tables

In total, 28 research institutions and industrial partners are participating, wherefore the performance tables were wide spread through Europe (Fig. 7, Table 6). Therefore, 17 tables of version A (equipped with moisture logging sensors), 14 tables of version B (without moisture logging sensors) and 16 tables of version C (blank rig) were manufactured.

Fig. 7. Distribution of partners within the COST FP 1303 Cooperative Performance Test.

The performance tables were exposed September 2014. A detailed guideline for all assessments was prepared together with Excel forms to enable easy comparison of the results. Data from the test will be available to the public, most likely through the IRG-WP Durability database at a later stage.

Table 6. List of partners.

Partner	Abbreviation	City	Country
Holzforschung Austria	HFA	Wien	Austria
UGent - Woodlab	UGE	Gent	Belgium
Danish Technological Institute	DTI	Taastrup	Denmark
Tallinn University of Technology	TAL	Tallinn	Estonia
Estonian University of Life Sciences, Institute of Forestry and Rural Engineering, Departement of Rural Building	TAR	Tartu	Estonia
Groupe ESB École supérieure du bois	NTE	Nantes	France
Thünen-Institut für Holzforschung	HAM	Hamburg	Germany
MPA Eberswalde, Materialprüfanstalt Brandenburg GmbH	MPA	Eberswalde	Germany
BASF Wolman GmbH	SIN	Sinzheim	Germany
Gutachtenbüro Rapp	ARA	Hannover	Germany
Leibniz Universität Hannover, Institut für Berufswissenschaften im Bauwesen (ibw)	HAN	Hannover	Germany
Robert Ott - Sachverständiger für Holzschutz und Holzschäden	OTT	Gammertingen	Germany
TU München, Holzforschung München	MUN	München	Germany
CNR IVALSA	ITA	Florence	Italy
Norwegian Forest and Landscape Institute	ÅS	Ås	Norway
Norwegian Institute of Wood technology	OSL	Oslo	Norway
Poznań University of Life Sciences Institute of Chemical Wood Technology	POL	Poznań	Poland
LNEC	LIS	Lisbon	Portugal
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	SCV	San Cibrao das Viñas	Spain
Tecnalia R&I	TEC	Azpeitia - Gipuzkoa	Spain
SP Technical Research Institute of Sweden	BOR	Borås	Sweden
SP Technical Research Institute of Sweden	OSQ	Stockholm,	Sweden
Lund University, Division of Structural Engineering	LUN	Lund	Sweden
Berner Fachhochschule - Architektur, Holz und Bau	BIE	Biel-Bienne	Switzerland
Building Research Establishment (BRE)	BRE	Garston	UK
Bangor University, BioComposites Centre	BNG	Bangor	UK

3.2 Decay and corrosion of fasteners

Preliminary results, reported in this paper, were obtained after 12 weeks of exposure only. As expected, fungal decay did not occur after such a short exposure period. Fungal decay as well as the corrosion of the fasteners will be reported after one year of exposure.

3.3 Colour changes

Colour is one of the most frequently used indicators for monitoring of the changes due to the weathering. Colour reflects the changes of chemical structure of wood main components. One of the most important weaknesses of the colour is the fact, that colour changes appear due to various abiotic (UV, weathering, *etc*.) and biotic (staining fungi, degrading fungi, algae, *etc*.) factors.

As can be seen from Table 7, the first colour changes appeared during the first week of exposure. Colour changes appeared on all wood species tested. Intensity of colour and colour changes depends on the actual weather conditions. However, determination of colour was not possible on all the proposed terms, because colour measurements should be performed on dry specimens only.

Table 7: Colour changes of Norway spruce (NS), English oak (O) and thermally modified spruce (TM) during exposure on different locations across Europe.

Location	Wood species	Period of exposure (weeks)																				
		0			1			2			3			4			8			12		
		CIE *L*a*b** color value																				
		L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b
ULJ	NS	82.7	5.0	20.6	76.2	9.0	36.0	78.3	6.9	28.9	76.6	7.7	29.0	75.1	7.8	27.4	70.0	6.2	20.0	64.4	6.9	16.7
	O	61.6	7.4	21.0	32.5	10.4	15.4	53.7	6.7	19.5	56.1	6.6	19.3	56.1	6.5	18.4	55.2	4.1	12.3	48.6	2.9	11.0
	TM	45.6	8.1	16.6	45.7	13.2	27.9	63.3	7.7	26.1	64.1	7.5	25.8	63.9	7.1	24.2	55.0	3.6	15.9	50.9	4.1	8.6
SIL	NS	84.3	4.2	19.6	78.3	7.8	34.9	68.0	10.2	34.4	78.8	7.5	28.6	76.9	7.5	27.2	73.9	7.2	17.8			
	O	46.0	8.9	17.5	43.6	8.1	18.0	45.0	8.8	20.3	59.4	6.4	18.6	59.9	6.1	17.2	58.8	5.0	10.0			
	TM	62.4	7.3	20.6	46.8	12.6	26.4	61.2	9.2	27.5	65.9	7.4	24.5	65.2	6.8	22.4	55.0	4.1	13.0			
HAN	NS	82.3	4.3	21.6	74.8	8.1	32.1	72.6	8.0	30.5	71.6	9.3	30.6	71.2	8.8	27.8	67.5	7.2	19.2	64.6	6.4	16.5
	O	63.9	7.8	21.4	63.0	7.9	26.2	63.7	7.3	24.7	63.6	7.6	24.7	64.5	6.3	20.6	60.5	3.8	14.6	58.0	2.8	12.0
	TM	42.1	9.9	19.1	46.0	8.5	20.5	45.1	7.4	19.2	49.9	8.1	18.6	51.3	7.6	16.4	52.3	5.2	10.9	51.3	4.4	8.9
DTI	NS	78.5	0.8	30.7																55.3	7.3	34.9
	O	63.0	6.0	25.5																40.0	5.0	17.7
	TM	44.6	2.7	25.1																32.1	4.4	21.3
BOR	NS	83.7	4.5	22.8	68.6	2.3	24.0	66.6	3.2	22.6	53.2	5.5	22.4	56.6	3.0	17.5						
	O	65.9	7.9	22.2	57.7	3.2	19.3	56.5	2.6	17.8	33.7	4.7	11.9	47.4	0.0	11.8						
	TM	43.8	9.1	18.4	41.7	2.3	24.0	44.0	2.2	11.3	28.1	4.8	8.1	43.7	1.3	9.2						
OSQ	NS	83.6	4.6	21.7				76.5	6.9	30.7	75.7	8.4	31.1	74.5	8.3	28.3				62.1	6.9	21.2
	O	63.6	7.7	22.1				65.0	7.3	25.5	64.8	7.4	24.9	64.1	6.6	21.9				54.1	2.6	13.6
	TM	42.1	9.7	18.1				49.8	7.7	20.1	50.6	8.0	19.3	51.7	7.5	17.0				48.7	5.1	11.3
AS	NS	80.4	4.0	21.9	76.2	7.0	30.0	75.8	7.3	29.0	75.7	7.1	26.5	75.7	7.3	25.9	72.1	6.4	18.9	57.6	10.0	33.7
	O	62.5	7.7	21.6	64.5	8.0	25.8	65.9	7.5	24.7	67.4	6.7	21.6	68.0	6.5	20.7	63.2	3.8	14.9	33.7	7.6	17.4
	TM	43.3	8.0	17.0	50.0	7.0	19.3	53.1	6.8	18.4	54.9	6.6	17.5	56.0	6.4	16.7	57.8	5.4	12.0	31.7	10.8	15.7
HFA	NS	79.9	6.1	22.9							74.1	5.6	21.2	69.9	9.7	25.8	57.2	5.8	15.4	58.4	5.2	13.0
	O	64.0	7.9	23.1							60.9	8.1	23.4	59.8	7.3	21.3	54.2	4.0	13.6	48.9	4.5	10.3
	TM	44.4	10.7	19.5							51.9	9.6	19.7	55.1	9.2	19.4	50.0	6.6	12.3	49.1	5.5	10.2
BIE	NS	81.3	4.6	22.1	74.9	8.1	31.1	72.2	8.5	30.6	69.9	8.7	28.0	66.4	7.5	23.3	58.6	5.5	15.3	56.3	4.8	12.9
	O	63.1	8.0	21.8	63.7	8.1	26.1	62.8	8.2	27.4	63.5	8.0	26.4	60.2	6.6	23.7	51.4	3.7	14.6	47.4	2.8	11.9
	TM	42.8	9.7	19.7	47.9	8.3	20.1	50.2	8.2	20.2	51.2	8.6	19.2	51.6	7.8	17.2	49.8	5.1	11.2	48.8	4.3	9.2
OSL	NS	81.2	4.6	23.2	74.8	6.8	29.9	74.7	7.9	32.6	74.1	8.9	31.8	73.9	8.7	29.0	67.4	10.1	34.5	66.7	8.8	24.7
	O	63.8	8.8	22.3	46.9	7.3	20.5	64.2	9.2	27.5	63.7	9.4	24.9	65.0	8.1	23.8	50.0	12.1	29.6	56.6	5.2	17.3
	TM	43.1	9.5	20.2	62.5	8.9	25.6	48.5	7.8	21.8	48.7	8.7	20.9	51.0	7.6	19.6	38.6	11.8	23.6	47.9	6.8	14.8
BNG	NS				76.6	7.0	31.7	76.4	7.9	31.5	75.5	9.2	33.3	76.9	7.8	27.0	70.6	9.4	32.8	72.9	6.8	18.4
	O				58.5	10.1	28.8	63.1	8.8	28.8	60.5	8.5	24.2	65.4	8.1	25.0	52.4	11.7	29.9	64.0	5.7	16.6
	TM				50.3	8.1	21.4	53.9	8.4	21.9	52.2	8.7	20.1	57.6	7.4	18.4	46.7	11.5	25.0	61.5	5.1	10.5
ITA	NS	82.2	4.6	23.2	74.0	8.7	33.1	72.9	9.7	35.4	72.2	9.7	39.0	70.4	10.2	28.9	68.0	8.3	21.5	61.1	5.7	14.5
	O	61.8	8.5	22.7	59.9	8.8	26.2	60.8	9.6	29.2	62.8	8.8	26.9	61.5	7.7	22.0	58.6	5.4	17.6	48.4	2.6	11.0
	TM	42.4	9.8	18.6	48.0	8.1	19.4	43.0	11.0	23.9	50.9	8.7	20.8	52.1	8.1	17.6	53.8	6.5	13.9	44.9	5.7	11.6

Table 7 cont'd: Colour changes of Norway spruce (NS), English oak (O) and thermally modified spruce (TM) during exposure on different locations across Europe.

Location	Wood species	Period of exposure (weeks)																				
		0			1			2			3			4			8			12		
		CIE *L*a*b** color value																				
		L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b	L	a	b
NTE	NS	82.7	3.2	25.5	77.3	4.5	33.5	74.5	5.3	37.7	72.2	6.1	38.2	74.7	5.9	35.3	71.7	7.3	20.9	69.3	3.6	15.9
	O	64.5	5.3	24.8	59.9	6.0	32.6	61.4	5.8	33.0	48.8	8.7	34.2	62.7	5.6	30.5	63.4	5.3	18.6	62.0	1.9	13.3
	TM	45.0	6.5	22.4	44.2	5.6	24.3	48.8	5.4	27.3	46.5	5.7	24.9	51.4	5.5	26.5	54.6	6.4	15.2	57.2	2.7	10.7
HAM	NS	81.4	3.6	21.0	76.8	5.3	32.6	75.0	5.9	31.4	74.4	6.2	30.7	74.2	6.3	28.8	64.5	7.6	30.5	68.7	5.3	18.9
	O	64.7	6.2	22.1	62.8	7.2	29.4	62.5	6.8	27.4	63.3	6.5	26.7	62.3	5.8	24.1	41.3	5.7	17.3	51.1	2.6	13.8
	TM	47.3	7.1	21.3	48.1	6.8	20.4	49.7	6.8	19.8	49.8	7.0	18.6	41.4	6.6	13.8	49.8	4.7	11.5	49.8	4.7	11.5
SCV	NS	80.7	3.9	21.4	74.3	6.8	33.2	73.5	7.7	33.1	73.4	6.7	28.0	70.1	7.0	26.3	60.5	3.4	13.5			
	O	63.3	7.1	22.1	62.5	7.6	29.0	63.5	7.5	27.8	64.6	6.4	25.0	60.8	5.4	22.9	52.2	2.0	11.9			
	TM	42.6	8.5	17.9	47.0	7.1	19.6	49.7	7.6	20.2	51.9	6.6	18.5	52.0	6.7	17.4	49.6	2.3	10.3			

After 12 weeks of exposure, the most prominent average difference appeared on Norway spruce wood (ΔE = 20.3), followed by English oak (ΔE = 16.9) and thermally modified spruce (ΔE = 12.4). The highest colour difference was determined at oak wood exposed in Ås (ΔE = 29.1) and the lowest at thermally modified spruce in Oslo (ΔE = 7.7). As already mentioned, fungal disfigurement could be one of the possible reasons for disfigurement. As there was considerable portion of the surface discoloured due moulding. However, there is not very tight correlation determined between fungal surface disfigurement and colour changes (Table 7, Table 8 and Table 9).

Table 8: Colour difference (ΔE) of Norway spruce (NS), English oak (O) and thermally modified spruce (TM) during exposure on different locations across Europe.

Location	**Wood species**	**Weeks of exposure**					
		1	**2**	**3**	**4**	**8**	**12**
ULJ	NS	17.2	9.6	10.7	10.6	12.9	18.9
	O	29.9	8.1	5.9	6.2	11.3	17.0
	TM	12.3	20.1	20.6	19.8	10.4	10.4
SIL	NS	16.9	22.9	11.1	11.1	11.0	11.0
	O	2.5	3.0	13.6	14.2	15.3	15.3
	TM	17.5	7.2	5.2	3.4	11.1	11.1
HAN	NS	13.5	13.7	14.8	13.6	15.3	18.6
	O	4.9	3.3	3.3	1.8	8.6	12.2
	TM	4.4	3.9	8.1	9.9	13.9	14.8
DTI	NS						24.5
	O						24.3
	TM						13.1
BOR	NS	15.2	17.2	30.5	27.6		27.6
	O	9.9	11.7	34.0	22.6		22.6
	TM	9.0	9.8	19.2	12.1		12.1
OSQ	NS		11.6	12.9	11.9		21.7
	O		3.7	3.1	1.2		13.8
	TM		8.2	8.7	9.9		10.6
AS	NS	9.7	9.2	7.3	7.1	9.2	26.4
	O	4.6	4.6	5.0	5.7	7.8	29.1
	TM	7.2	10.0	11.8	12.8	15.6	11.9
HFA	NS			6.1	11.0	24.0	23.7
	O			3.0	4.6	14.2	20.1
	TM			7.5	10.8	10.0	11.6
BIE	NS	11.6	13.1	13.5	15.3	23.8	26.7
	O	4.3	5.6	4.5	3.7	14.4	19.3
	TM	5.4	7.6	8.5	9.4	12.0	13.3
OSL	NS	9.6	11.9	12.0	10.3	18.7	15.2
	O	17.1	5.2	2.6	2.1	15.9	9.5
	TM	20.2	5.9	5.7	8.1	6.1	7.7
BNG	NS	10.7	11.0	13.3	7.4	15.9	10.2
	O	8.0	7.1	2.8	4.8	12.9	6.1
	TM	5.3	8.8	6.8	12.3	6.4	18.7
ITA	NS	13.5	16.2	19.4	14.3	14.8	22.9
	O	4.1	6.7	4.3	1.1	6.7	18.7
	TM	5.9	5.5	8.9	9.8	12.8	8.5
NTE	NS	9.7	14.8	16.7	12.9	12.5	16.4
	O	9.1	8.8	18.6	6.0	6.2	12.2
	TM	2.2	6.3	3.0	7.6	12.0	17.3
HAM	NS	12.6	12.4	12.3	10.9	19.7	13.0
	O	7.7	5.8	4.8	3.1	23.9	16.3
	TM	1.2	2.8	3.7	9.6	10.3	10.3
SCV	NS	13,8	14,2	10,2	12,1	21,7	
	O	7,0	5,7	3,3	3,1	15,9	
	TM	4,9	7,5	9,5	9,6	12,1	

3.4 Surface disfigurement

Aesthetic perception of wood considerably influences the service life of the wood (Gobakken and Høibø 2011, Grüll et al. 2011, Englund 2013, Brischke and Kaudewitz 2015). Wooden furniture used outside is frequently replaced due to the change of its visual appearance. One of the most important factors contributing to the visual appearance is fungal disfigurement caused by staining and moulding fungi.

Table 9. Fungal surface disfigurement on the Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) on different locations across Europe. Rating scheme is resolved from Table 3.

Location	Weeks of exposure	Wood species		
		NS	O	TM
		Fungal disfigurement rating on the upper side		
ULJ	4	2	1	0
	8	3	3	0
	12	3	3	0
SIL	4	1	0	0
	8	3	2	0
	12	3	2	0
HAN	4	0	1	0
	8	1	1	0
	12	2	1	0
DTI	4	0	0	0
	8	1	0	0
	12	2	1	0
BOR	4	2	1	0
	8	1	0	0
	12			
OSQ	4	2	1	0
	8			
	12	3	3	1
MUN	4	2	2	1
	8	3	3	2
	12			
ÅS	4	1	1	1
	8	1	2	1
	12	2	2	2
HFA	4	1	2	0
	8	3	3	0
	12	3	3	0
BIE	4	3	1	1
	8	3	1	2
	12	3	2	2
OSL	4	1	1	0
	8	1	2	1
	12	2	2	1
BNG	4	1	1	0
	8	1	2	0
	12	2	2	0
ITA	4	1	1	0
	8	1	1	0
	12	1	1	0
HAM	4	1	2	0
	8	3	3	0
	12	3	3	0
SCV	4	0	1	2
	8	0	1	2
	12	0	1	2

Similarly as reported for colour changes, the most prominent disfigurement appeared on Norway spruce (1.8), followed by oak (1.6). It seemed that thermally modified spruce was either least susceptible for fungal disfigurement (0.4) or the fungal disfigurement was the least visible on the dark surface. In the respective period, the most prominent staining appeared in Stockholm (OSQ, 2.3) and Biel (BIE, 2.3). In contrast, only little disfigurement was determined in Florence (ITA, 0.7), Hannover (HAN, 1.0) and Taastrup DTI, 1.0).

3.5 Cracks

Formation of cracks strongly depends on moisture oscillation (*e.g*. Sandberg 1999, Sandberg and Söderström 2006). However, cracks become more apparent in dry conditions, therefore we expect that cracks will become more visible in dry periods of the year. However, cracks are important from the aesthetic point of view, but the cracks on the other hand plays key role in the moisture and consequent fungal performance (Meierhofer and Sell 1979, Austigard *et al*. 2014, Brischke and Melcher 2015). Cracks are trap for water and fungal spores and may therefore serve as staring points for fungal degradation.

Table 10. Total crack length, number of cracks and mean crack width on Norway spruce (NS), English oak (O) and thermally modified Norway spruce (TM) at different locations across Europe after 3 months of exposure.

Location	**Value**	**Wood species**		
		NS	**O**	**TM**
ULJ	Total crack length	0	0	0
	# cracks	0	0	0
	Mean crack width	1.5	2.3	0.8
SIL	Total crack length	11.7	25.0	3.0
	# cracks	3.0	5.7	1.3
	Mean crack width	1.5	2.3	0.8
HAN	Total crack length	0	0	0
	# cracks	0	0	0
	Mean crack width	0	0	0
DTI	Total crack length	0	0	0
	# cracks	0	0	0
	Mean crack width	0	0	0
BOR	Total crack length	0	0	0
	# cracks	0	0	0
	Mean crack width	0	0	0
OSQ	Total crack length	11.7	25.0	3.0
	# cracks	3.0	5.7	1.3
	Mean crack width	1.5	2.3	0.8
ÅS	Total crack length	0	0	0
	# cracks	0	0	0
	Mean crack width	0	0	0
HFA	Total crack length	11.7	25.0	3.0
	# cracks	3.0	5.7	1.3
	Mean crack width	1.5	2.3	0.8
BIE	Total crack length	0	0	163.1
	# cracks	0	0	1.7
	Mean crack width	0	0	0.1
OSL	Total crack length	11.7	25.0	3.0
	# cracks	3.0	5.7	1.3
	Mean crack width	1.5	2.3	0.8
BNG	Total crack length	0	2.3	0
	# cracks	0	0.7	0
	Mean crack width	0	0.1	0
ITA	Total crack length	19.9	0	0
	# cracks	1.6	0	1.0
	Mean crack width	4.2	0	0
NTE	Total crack length	0	12.3	0
	# cracks	0	1.0	0
	Mean crack width	0	0.1	0.3
HAM	Total crack length	0.3	5.5	1.7
	# cracks	0.3	4.3	1.3
	Mean crack width	0.2	0.1	0.1
SCV	Total crack length	12	25	3
	# cracks	1.3	1	1
	Mean crack width	1.0	2.3	0.8

Monitoring of cracks is rather challenging. Cracks are predominately visible, when wood is dry. This might explain, why for instance no cracks were reported from Hannover, Taastrup, Borås and Ås. In most of the locations, the highest number of cracks was reported for thermally modified wood; however these cracks were rather small. We believe that there will be more cracks formed after the summer with longer dry periods.

3.5 Moisture content

MC monitoring results are expected not before 6 months of exposure and will be reported later on.

4. CONCLUSIONS

In the frame of the COST FP 1303 Cooperative Performance Test 28 institutions and industry partners teamed up to generate performance data of wood and wood-based materials under consideration of environmental factors such as organisms, solar radiation, and other climate parameters. During the remaining running time of the action and beyond it is expected to collect data from in total 28 test locations for reported wood species and for the wood species of national importance. Data shall be used to further establish relationships between the various examined performance criteria and geographical and climate related parameter.

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