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Monitoring the "material climate" of wood to predict the potential for decay: Results from in situ measurements on buildings

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Abstract

Moisture has an important influence on fungal decay and therefore on the service life of wooden building components. The applicability of a long-term moisture recording system with glued electrodes was investigated on two different building objects: a cladding with different roof overhangs in Taastrup, Denmark, and a pedestrian timber bridge in Essing, Germany. Results after 2–4 years of in situ measurements are presented in this paper.

The measurement system was found to be applicable and provided plausible data on both objects. For measurements on the Essing bridge, the measurement system was modified by means of using electrodes containing wooden substitute dowels to avoid the gluing at site under adverse circumstances.

Moisture differences depending on the roof overhang and the distance to ground were identified and quantified within the cladding in Taastrup. Differently severe moisture conditions were observed for different building components of the Essing bridge, as well as weakening points of the construction in terms of moisture accumulation. Besides valuable information about variable moisture conditions within the examined objects, the use of automated moisture recordings provides an early warning system against increased decay hazards.

Keywords: Cladding; Decay factor; Long-term moisture recording; Roof overhang; Substitute dowel; Timber bridge

1. Introduction

The "material climate" of wood, mainly determined by wood moisture content (MC), wood temperature, and their dynamics, has an essential influence on fungal decay and therefore on the service life of wooden building components [1]. To determine the "material climate" of wood, an automated system for long-term MC measurements with glued electrodes was developed and described in a previous paper [2]. This study deals with two different applications of the measuring system and provides results from a field study and measurements on a building in service.

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The service life of wooden claddings, which are a typical application of timber in the wide-ranging European hazard class 3 [3], is influenced by a number of different factors. Moisture and temperature conditions of a cladding depend on the microclimate by means of orientation, shading, or distance to the ground as well as on the design level by means of roof overhangs or ventilation [4 9]. Therefore, in a first study the measurement system was applied on a wooden cladding to examine its moisture conditions in dependence of different roof overhangs.

Different approaches to predict the service life of wooden components do already exist [10,11], but a reliable database concerning wood durability in different exposures is still fragmentary [12]. The evaluation of in-service performance is the most realistic way to obtain data compared to field studies and laboratory tests. In situ measurements on

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Abstract

Moisture has an important influence on fungal decay and therefore on the service life of wooden building components. The applicability of a long-term moisture recording system with glued electrodes was investigated on two different building objects: A cladding with different roof overhangs in Taastrup, Denmark, and a pedestrian timber bridge in Essing, Germany. Results after 2-4 years of in-situ measurements are presented in this paper.

The measurement system was found to be applicable and provided plausible data on both objects. For measurements on the Essing bridge the measurement system was modified by means of using electrodes containing wooden substitute dowels to avoid the gluing at site under adverse circumstances.

Moisture differences depending on the roof overhang and the distance to ground were identified and quantified within the cladding in Taastrup. Differently severe moisture conditions were observed for different building components of the Essing bridge, as well as weakening points of the construction in terms of moisture accumulation. Besides valuable information about variable moisture

conditions within the examined objects, the use of automated moisture recordings provides an early warning system against increased decay hazards.

Keywords: Cladding, decay factor, long-term moisture recording, roof overhang, substitute dowel, timber bridge.

7.3.1 Introduction

The "material climate" of wood, mainly determined by wood moisture content (MC), wood temperature, and their dynamics, has an essential influence on fungal decay and therefore on the service life of wooden building components [1]. To determine the "material climate" of wood an automated system for long-term MC measurements with glued electrodes was developed and described in a previous paper [2]. This study deals with two different applications of the measuring system and provides results from a field study and measurements on a building in service.

The service life of wooden claddings, which are a typical application of timber in the wide-ranging European hazard class 3 [3], is influenced by a number of different factors. Moisture and temperature conditions of a cladding depend on the micro climate by means of orientation, shading, or distance to the ground as well as on the design level by means of roof overhangs or ventilation [4-9]. Therefore, in a first study the measurement system was applied on a wooden cladding to examine its moisture conditions in dependence of different roof overhangs.

Different approaches to predict the service life of wooden components do already exist [10,11], but a reliable data base concerning wood durability in different exposures is still fragmentary [12]. The evaluation of in-service performance is the most realistic way to obtain data compared to field studies and laboratory tests. In-situ measurements on buildings in service may therefore contribute to a better estimation of decay hazards and were applied in a second study: Moisture measurements on a pedestrian timber bridge, on which brown rot decay was detected before, were carried out. Here the use of preservative treated wooden substitute dowels was required due to the fact that gluing of electrodes was impossible on-site. The major aims were to identify differences in the moisture regime between different building components on the one hand, and to investigate the suitability of the measurement system for its use as an early warning system against decay hazards on the other hand.

7.3.2 Materials and methods

Object 1: Cladding in Taastrup, Denmark

The objective of this study was to examine the influence of a roof overhang on the moisture conditions within a cladding. Therefore moisture measurements were conducted on a cladding (15 m long, 2.5 m high) with three different roof overhangs (12 cm, 62 cm, 112 cm) on the test site of the Danish Technological Institute (DTI) in Taastrup, Denmark (Table 7.3-1, Figure 7.3-1). The cladding was made from unmachined Norway spruce (*Picea abies* Karst.) boards of 1170x105x25 mm³, faced to the north, and carried out as a vertical, rear ventilated board-on-board cladding (Figure 7.3-2). The cladding was split into an upper and a bottom part, each with a height of 117 cm, separated from each other by a horizontal board, acting as a small roof overhang of 4.5 cm width. The distance between the boards of the bottom cladding and the ground was 15 cm.

Table 7.3-1. Characteristic data of sites.

Site	Geographic coordinates		Elevation	Average air temperature	Sum of precipitation
	Latitude	Longitude	[m]	[°C]	[mm]
Taastrup	55°38'49''N	12°17'50''E	14	8.6[a)]	636[a)]
Essing	48°56'18''N	11°46'51''E	362	8.5[b)]	637[b)]

[a)]based on data from meteorological station in Copenhagen.
[b)]based on data from meteorological station in Regensburg.

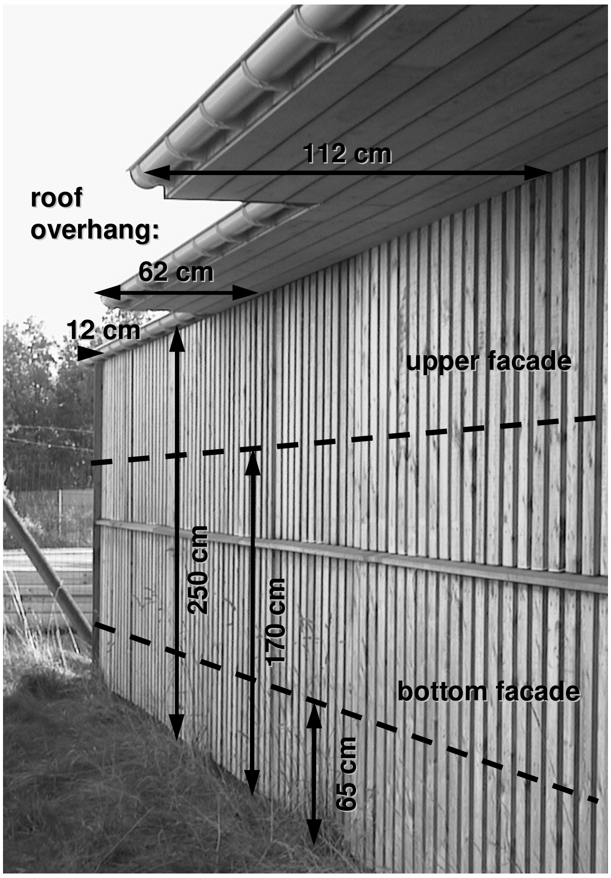

Figure 7.3-1. Board-on-board cladding with different roof overhangs in Taastrup, Denmark. Dashed lines mark the heights of measurement points on the upper and bottom parts of the façade.

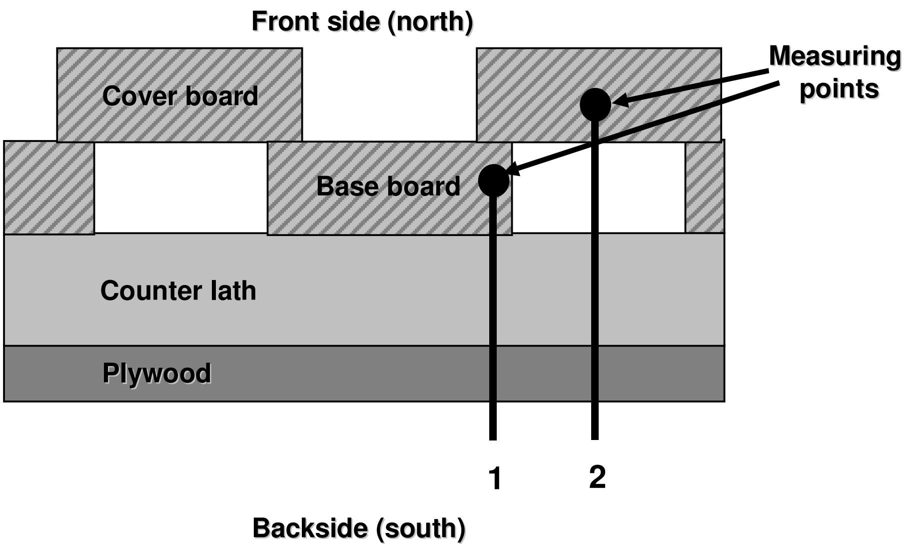

Figure 7.3-2. Cross cut through the cladding and schematic arrangement of the measurement points. Measuring point 1 installed in the overlapping zone of a base board; measuring point 2 installed centrally in a cover board.

Electrodes for MC measurements were glued in from the back of the cladding at two different heights, 65 cm and 170 cm. The installation of the electrodes is described in detail in the previous paper. In total 18 pairs of electrodes were installed, three for each roof overhang/height combination and connected to "Materialfox Mini" data logger (Scanntronik Mugrauer GmbH, Zorneding, Germany) with three channels (Figure 7.3-2).

Object 2: Pedestrian timber bridge in Essing, Germany

General aspects

The pedestrian bridge in Essing, Bavaria, is a self-supporting timber bridge of 190 m total length and crosses the Main-Danube canal (Table 7.3-1, Figure 7.3-3). Apart from the wooden pedestrian planking, the whole construction was made from Norway spruce gluelam, which was brush treated with an oil-borne preservative and a water-repellent after completion. The bridge was built in 1987, a first damage on the main trusses caused by brown-rot fungi was detected in 1997, and the bridge was sanified afterwards. After a second damage by wood-destroying fungi, which occurred behind nail plates at the bottom of the construction in 2003, moisture monitoring devices were installed at different components of the bridge.

Figure 7.3-3. Self-supporting pedestrian timber bridge in Essing, made from Norway spruce gluelam: ① Bottom nail plates, ② region above bottom nail plates for installation of measuring points remote from the nail plates, ③ upper nail plates, ④ main trusses covered with plywood.

The objective of this study was to install devices for long-term moisture recordings on selected wooden components of the bridge, and to correlate the obtained MC data with occurring damages by wood-destroying fungi. In addition, devices for measuring and recording temperature, relative humidity and rainfall were installed on the bridge. Hereby the automated recordings should provide an early warning system as well as information on the influence of MC, wood temperature, and some climate factors on the onset of decay on buildings, especially next to water.

The installation of electrodes on the Essing bridge revealed two major problems:

1. Some electrodes needed to be glued in from the underside of the beams, which meant to fill in the glue upside down.

2. Some measurement sites showed already decay before installation, or the onset of decay could be expected soon, respectively.

Therefore the suitability of preservative treated and electrodes-containing substitute dowels for MC measurements was examined in a preliminary study to avoid the installation of electrodes in the field on the one hand, and a to avoid direct contact between decayed wood and the electrodes on the other hand.

Suitability of substitute dowels for moisture measurements

To examine the applicability of preservative treated wood for substitute dowels, the influence of different organic wood preservatives on the electric conductivity of wood was examined. Axially matched specimens of 50x2.5x50 mm^3 (long. x tan. x rad.) were vacuum-pressure impregnated (15 min/20 mbar abs.; 15 min/9 bar abs.) with three different organic wood preservatives (Table 7.3-2). After impregnation and drying, two grooves (1.5 mm deep, 3 mm wide) with a distance of 30 mm from each other were cut into the specimens. The grooves ran parallel to the grain for one half of the specimens, and orthogonal to the grain for the other half. Stainless steel cables (Ø 1.5 mm) were glued into the grooves with a graphite-containing conductive epoxy resin. MC measurements were carried out with a moisture meter type GANN Hydromette RTU 600 after storage at 30℃ in a drying oven for 90 h, at 20℃/65%RH for 9 d, and at 20℃/98%RH for 9 d.

Table 7.3-2. Organic wood preservative formulations examined with respect to their influence on electric conductivity.

ID	Wood preservative	Concentration of active ingredients
P1	Koranol Holzbau DV, Obermeier GmbH & Co KG, Germany	1.50% propiconacole 0.06% cyfluthrine 0.23% IPBC
P2	special formulation, Obermeier GmbH & Co KG, Germany	1.50% propiconacole 1.50% tebuconazole
P3	Wolvac L0-F, Dr. Wolman GmbH, Germany	0.80% propiconacole 0.01% farox

The suitability of wooden dowels with glued electrodes for MC measurements was examined by comparative gravimetric (MC_{grav}) and electric measurements (MC_{res}). Therefore 24 pine sapwood dowels (Ø 13 mm, 60 mm long) were prepared. One half was provided with electrodes as follows (Table 7.3-6): Two holes (Ø 2 mm) with a depth of 15 mm and 60 mm and a distance of 5 mm to each other were drilled in axial direction into the dowels. In analogy to the method described in the previous paper, two stainless steel cables were glued in the holes with a graphite-containing conductive glue. The drilling holes were sealed with an isolating epoxy resin (Figure 7.3-4). Thus, the electrical resistance was measured over a distance of 30 mm in axial direction with an offset of 5 mm orthogonal to the grain.

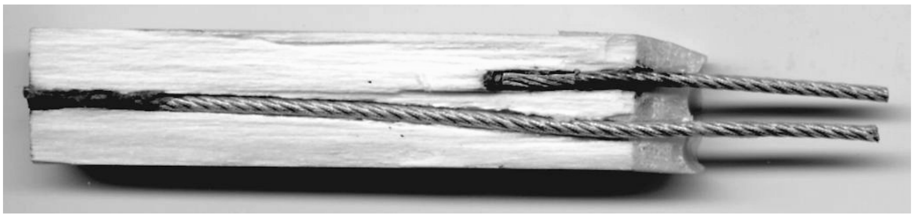

Figure 7.3-4. Longitudinal cut through a substitute dowel made from Scots pine sapwood, impregnated with tebuconacole in white spirit, containing a pair of glued electrodes.

To simulate the influence of natural weathering on the connection between electrode, conductive glue, and wood, one half of the dowels was stressed artificially by a water vacuum-pressure impregnation (15 min/20 mbar abs.; 15 min/9 bar abs.) followed by drying at 60℃ in a drying oven for 24 h. MC measurements were carried out with a moisture meter type GANN Hydromette RTU 600 on specimens with electrodes, and gravimetrically on specimens without electrodes after storage at 20℃/65%RH for 4 d, and at 20℃/98%RH for 22 d. All pre-treatments of wooden dowels can be seen from Table 7.3-6.

Installation of measurement devices

In total, 64 wooden substitute dowels were installed on the Essing bridge in May 2004. The measurement points were selected with respect to differences between weather side and non-weather side, and to the influence of nail plates in different heights of the construction (Figure 7.3-3, marks ①, ②, and ③). These plates act as a connection between single gluelam beams in the piers of the bridge. In addition, dowels were installed in the main trusses of the bridge, where firstly decay was observed in 1997, but which were afterwards protected from rain water by plywood covers (Figure 7.3-3, mark ④). Here, the efficacy of this protective measure should be verified.

For MC recording "Materialfox Mini" data logger were applied, each connected to 2 or 3 substitute dowels. In addition to the MC measurements, daily relative humidity and air temperature were recorded at four different sites on the bridge using "Hygrofox Mini" data logger. All data logger were provided by Scanntronik Mugrauer GmbH, Zorneding, Germany. During a yearly inspection all data were collected from the logger and the timber around the measuring points was assessed visually with respect to the onset of decay.

7.3.3 Results and discussion

Object 1: Cladding in Taastrup, Denmark – Roof overhang effects on moisture conditions

The system applied for measuring the MC within different parts of the cladding provided plausible values over the whole period of examination (Figure 7.3-5). The MC ranged between 15 and 30% over the year. MCs above 25%, which can become critical for the onset of fungal decay [13], were found between November and March. However, the risk of fungal decay during those months was limited, because of coinciding low temperatures.

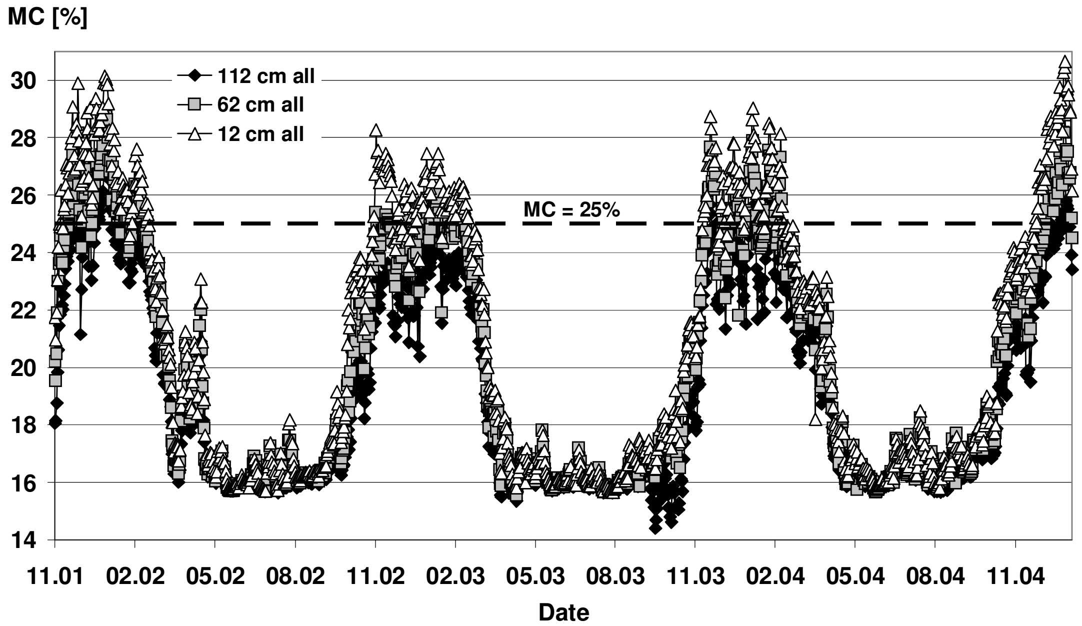

Figure 7.3-5. Moisture course in boards of the upper facade for different roof overhangs.

The number of wet days differed significantly between different measuring points of the cladding. Therefore the number of days above certain MCs (MC=20, 23, 25, 27, and 30%) over the whole measuring period is listed in Table 7.3-3 and Table 7.3-4. The most distinctive differences between the measuring points were found for the number of days above MC=25%. Significantly less wet days of the upper facade compared to the bottom facade were found to depend strongly on the roof overhang (Table 7.3-3). With increasing roof overhang the difference between upper and bottom facade was stronger pronounced so that the upper facade with 112 cm roofing showed only 56 days above MC=25% compared to 252 days on the bottom facade. In general, the differences in the number of wet days between 112 cm and 62 cm roof overhang were more pronounced compared to differences between 62 cm and 12 cm.

Table 7.3-3. Days with a moisture content above 20, 23, 25, 27, and 30% for different roof overhangs in the upper and bottom part of the cladding (based on a total exposure interval of 1145 days).

		Days with MC >				
Roof overhang	Facade	20%	23%	25%	27%	30%
112 cm	upper	456	263	56	2	0
	bottom	608	447	252	34	0
62 cm	upper	526	373	194	30	0
	bottom	557	416	286	81	0
12 cm	upper	550	425	304	119	5
	bottom	555	444	299	103	3

Table 7.3-4. Days with a moisture content above 20, 23, 25, 27, and 30% for base and cover boards in the upper and bottom part of the cladding (based on a total exposure interval of 1145 days).

		Days with MC >				
Facade	Board type	20%	23%	25%	27%	30%
upper	base boards	516	362	165	22	0
	cover boards	517	367	182	35	0
bottom	base boards	559	409	253	47	0
	cover boards	567	429	289	81	0

Possible reasons for MC differences between differently oriented facades were mentioned by Nore *et al.* [8]: Besides the stronger influence of wind-driven rain on west walls compared to east walls, solar radiation and wind play an important role for drying processes. As the facade, examined in this study, was faced to north, the influence of direct solar radiation as well as the influence of wind-driven rain are very limited.

The number of wet days was also significantly lower for the base (e.g. 165 days above MC=25% in the upper facade) compared to the cover boards (182 days) of the cladding (Table 7.3-4), although the electrodes in the base boards were installed, where they were overlapped by the cover boards and hindered drying could be expected (*cf.* measuring point 1 in Figure 7.3-2).

Object 2: Pedestrian timber bridge in Essing, Germany

Suitability of substitute dowels for moisture measurements

Significant differences in MC, measured parallel to the grain, were found between P2 and P3, and between P2 and untreated pine sapwood after conditioning in 20℃/65%RH (Table 7.3-5). No significant influence of the preservative impregnation on the electric resistance of pine sapwood was observed for P1 and P3, neither for measurements parallel, nor orthogonal to the grain. Further on P3 was used for impregnation of wooden dowels.

Table 7.3-5. Electrically measured moisture content (MC) of untreated and differently preservative treated pine sapwood specimens parallel and orthogonal to the grain after conditioning in different climates (P1 = Koranol Holzbau DV, P2 = special formulation, P3 = Wolvac L0-F). Standard deviation in brackets.

Conditioning	Treatment	MC [%]	
		parallel to grain	orthogonal to grain
30℃/drying oven, 72 h	untreated	6.0 (1.0)	4.5 (0.1)
	P1	6.3 (0.4)	4.2 (0.3)
	P2	5.2 (1.9)	5.2 (0.8)
	P3	5.2 (0.4)	4.7 (1.0)
20℃/65%RH, 9 d	untreated	9.4 (0.2)	7.7 (0.2)
	P1	9.0 (0.4)	7.3 (0.3)
	P2	8.7 (0.2)	7.6 (0.2)
	P3	9.1 (0.1)	7.4 (0.2)
20℃/98%RH, 9 d	untreated	20.4 (1.0)	19.9 (0.4)
	P1	20.5 (0.7)	19.4 (0.2)
	P2	19.6 (0.2)	20.0 (0.2)
	P3	20.3 (0.7)	19.7 (0.2)

The comparative measurements on wooden dowels revealed only slight differences between gravimetrically (MC_{grav}) and electrically (MC_{res}) determined MC values (Table 7.3-6). After conditioning at 20℃/65%RH the MC_{grav} was approx. 1%-point lower compared to the MC_{res}, after conditioning in 20℃/98%RH MC_{res} was slightly lower than MCgrav. Furthermore, neither a significant influence of the wood preservative, nor of the artificial pre-stress was observed. Thus, the differences between both measurement systems seemed to be negligibly small and the use of wooden substitute dowels suitable for in-situ MC measurements.

Table 7.3-6. ID, treatment, and moisture content (MC) of pine sapwood dowels, partly with installed electrodes for electrical measurements (E), partly pre-stressed (S), and partly treated with an organic wood preservative (T) after different conditioning regimes (n=3 for each combination).

ID	Impregnation with Wolvac L0-F	Glued electrodes	Artificially stressed	MC [%][a]	
				after 4 d in 20℃/65%RH	after 22 d in 20℃/98%RH
U	no	yes	no	11.7 (0.1)	21.6 (0.0)
UE	no	yes	yes	12.4 (0.3)	20.8 (0.3)
US	yes	yes	no	11.7 (0.0)	21.6 (0.0)
UES	yes	yes	yes	12.6 (0.2)	20.2 (0.1)
T	no	no	no	11.6 (0.3)	21.6 (0.5)
TE	no	no	yes	12.9 (0.3)	21.3 (0.7)
TS	yes	no	no	11.6 (0.2)	21.3 (0.7)
TES	yes	no	yes	11.9 (0.3)	19.7 (0.2)

[a]MC of dowels without electrodes was determined gravimetrically.

Moisture courses in selected building components

The long-term moisture recordings on the Essing bridge provided plausible values over the whole measuring period of two years. The main findings are displayed in Figure 7.3-6, showing exemplarily the moisture courses of selected building components in comparison, and can be summarized as follows:

- Higher MCs were found on the weather side of the bridge compared to the non-weather side at all times. This is shown in Figure 7.3-6a for two measurement sites on the same pier. On the weather side the MC increased up to 50% during winter, whereas the MC on the non-weather side stayed below 30%.
- The MC close to the bottom nail plates was significantly higher as remote from (directly above) the plates for most of the examined piers (Figure 7.3-6b). This coincides with severe decay in eight different beams, which was unexceptionally found close to bottom nail plates.
- The risk of moisture accumulation close to the upper nail plates was found to be significantly lower compared to the bottom nail plates (Figure 7.3-6c). However, the MC close to some upper nail plates on the weather side was equal to that close to the corresponding bottom nail plates, but never higher.
- The MC in areas with decay (here: brown rot decay) was drastically increased, and as decay was found only behind nail plates, the wood did not dry out again (Figure 7.3-6d).

- The plywood sheets, which cover the main trusses of the bridge, were found to be an effective protective measure; the MC in the trusses never exceeded 25% (Figure 7.3-6e).
- Differences in relative humidity and air temperature between different parts of the bridge (close to/ apart from the water) were negligibly small.

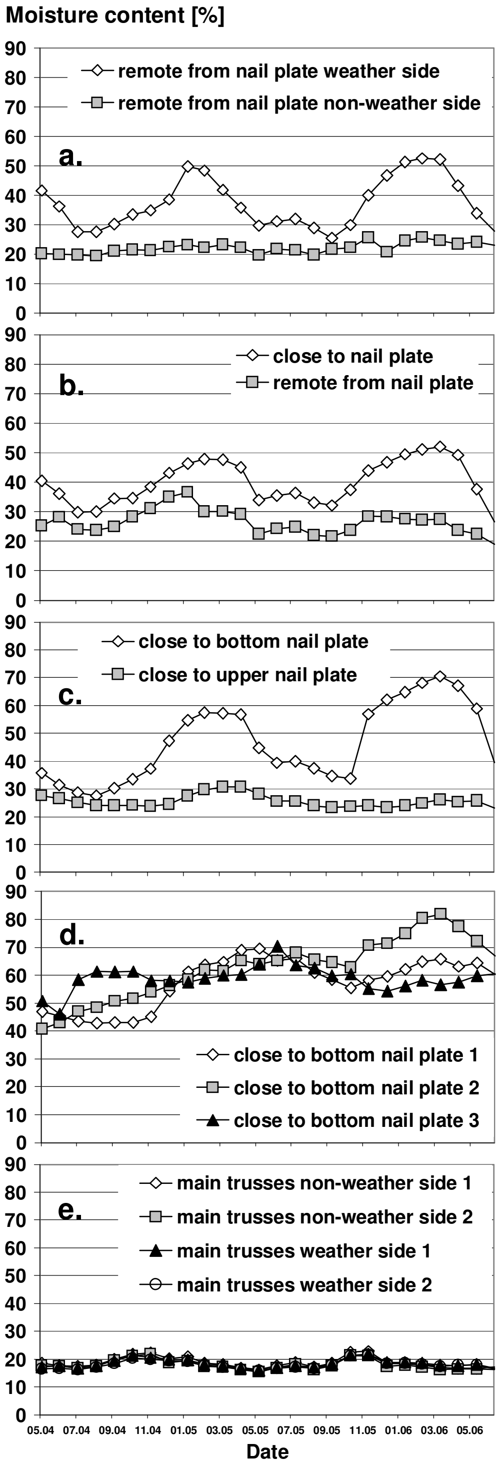

Figure 7.3-6. Examples of monthly mean moisture content courses in comparison between selected distinctive building components of the Essing bridge. (a) Course of MC in piers on the weather and the non-weather side, remote from nail plates, (b) Course of MC in a pier close to and remote from a nail plate, (c) Course of MC close to a bottom and an upper nail plate, (d) Courses of MC in three piers of the weather side close to bottom nail plates, already showing decay, (e) Courses of MC for four measuring points on the plywood covered main trusses on the weather and the non-weather side.

The results after two years showed the suitability of the measurement system, especially in combination with preservative treated substitute dowels, for long-term moisture monitoring on buildings in service. Differently severe decay hazards in terms of MC, e.g. between the weather side and the non-weather side of the bridge, were detected and quantified. The use of the measurement system as an early warning system for the onset of decay in the bridge piers seems to be dispensable as the MC values are here extremely high in general. However, in case of the main trusses, where effective protective measures were applied, the detection of irregularly high moisture as a precondition for fungal decay is possible. In combination with an alarm device, leakages or otherwise caused irregular moisture accumulations can be detected at an early stage before the onset of decay. To minimize the number of measurement and alarm devices the electrode pairs can be connected parallel with only one data logger. As soon as the MC at only one measurement point exceeds a certain limit, the alarm will be set off. Such MC based warning systems can be of high benefit for the conservation of wooden constructions as well as for monitoring of ancient or recent buildings.

Some building codes allow to avoid chemical wood preservation for load-bearing components in interior dry applications, provided that a potentially occurring damage by insects is detectable at an early stage (e.g. so called hazard class 0, [14]). If this idea is transferred to moisture/fungal hazards, the new tool could be used to detect a hazard also at an early stage and help to avoid biocides in buildings and environment.

7.3.4 Conclusions

The MC measurement system was applicable in both studies and provided plausible data. The modification of the system by means of preservative treated wooden substitute dowels allowed also measurements in decayed wood and on buildings, where an in-situ installation of glued electrodes was impossible. The objectives of the different studies were fulfilled. Firstly, the MC measurements on the wooden cladding revealed differences in the number of wet days between different roof overhangs and between selected parts of the wall. For implementation of the moisture data in a prediction model, a more comprehensive approach, considering also the influence of wall orientation, external shading, and splash water at ground level will be helpful and is therefore in progress.

Secondly, the moisture courses from the Essing bridge partly revealed extremely different decay potentials between the building components, such as between weather and non-weather side. It was clearly shown, that the bridge is insufficiently protected by design in general. The nail plates, especially at the bottom part of the construction, were figured out as weak points in detail.

The moisture monitoring method proved to be suitable for the detection of critical moisture conditions by means of a possible fungal infestation as shown for the main trusses. However, in case of the generally extreme high moisture induced risk of fungal decay of the support structure, the application of an early warning system becomes redundant. Nevertheless, such warning systems may allow the renunciation of wood preservatives in certain applications within European hazard class 1 and 2, and the establishment of a hazard class 0 regarding fungal decay appears as an option.

7.3.5 Acknowledgements

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7.3.6 References

[1] Brischke C, Rapp AO, Bayerbach R. Decay influencing factors: A basis for service life prediction of wood and wood-based products. Wood Material Science and Engineering 2007;1(3&4):91-107.

[2] Brischke C, Rapp AO, Bayerbach R. Measurement system for long-term recording of wood moisture content with internal conductively glued electrodes. Building and Environment 2007. Submitted for publication.

[3] EN 335-1, Hazard classes of wood and wood-based products against biological attack. Classification of hazard classes. European Committee for Standardization 1992.

[4] Böttcher P. Zum Verhalten unterschiedlich feuchtedurchlässiger Anstriche auf einigen einheimischen Holzarten bei natürlicher Bewitterung. Holz als Roh- und Werkstoff 1975;33:116-20.

[5] Willeitner H, Schwab E. Holz – Außenverwendung im Hochbau. Stuttgart: Alexander Koch GmbH; 1981.

[6] Trübswetter T. Gefährdung bewitterter Bauteile. In: Tagungsband zur 22. Holzschutztagung der DGfH, Bad Kissingen, Germany, October, 17th-18th 2000.

[7] Pöhlmann R. Untersuchungen zur Bewitterungsbeanspruchung an einem Objekt in ökologischer Holzbauweise. Diploma thesis, University of Hamburg, Germany, 2001.

[8] Nore K, Thue JV, Time B, Rognvik E. Ventilated wooden cladding – a field investigation. 7th Nordic Building Physics Symposium, Reykjavik, Iceland, June 13th-15th 2005.

[9] Sahal N, Lacasse MA. Water entry function of a hardboard siding-clad wood stud wall. Building and Environment 2005;40:1479-91.

[10] Leicester RH, Wang C-H, Nguyen MN, Thornton JD, Johnson G, Gardner D, Foliente GC, MacKenzie C. An engineering model for the decay of timber in ground contact. Document No. IRG/WP 03-20260. International Research Group on Wood Protection, Stockholm, Sweden, 2003.

[11] Leicester RH, Wang C-H, Nguyen MN, Foliente GC. Engineering models for biological attack on timber structures. In: Proceedings of the 10th Conference on Durability of Building Materials and Components, TT4-217, Lyon, France, 2005.

[12] Brischke C, Rapp AO. Relation between lab tests, field tests, and in-service performance and their contribution to SLP. In: Proceedings of COST E37 Workshop, 19th-21st June 2005, Oslo, Norway.

[13] Schmidt O. Wood and tree fungi. Biology, Damage, Protection, and Use. Berlin: Springer-Verlag; 2006.

[14] DIN 68800-3, Holzschutz im Hochbau. Vorbeugender chemischer Holzschutz. Deutsches Institut für Normung 1990.