Short report for the research project:

Building Climate – Long-term measurements to determine the effect on the moisture gradient in timber structures

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Funded by:

Forschungsinitiative Zukunft Bau
Bundesamt für Bauwesen und Raumordnung
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This research project was funded by
Forschungsinitiative Zukunft Bau, Bundesamt für Bauwesen und Raumordnung.
(Reference number: Z6-10.08.18.7-07.19/II2-F20-07-29)
The responsibility for the content of this report lies with the authors.

Munich, 26 January 2012

1 Objective of the research project

The natural and renewable material wood is characterized by its pronounced hygroscopic nature. Even after processing, e.g. when used as construction material in buildings, changes in the ambient climatic conditions will result in changes of the timber moisture content (see Picture 1). This in turn leads to changes of virtually all physical and mechanical properties (e.g. strength properties) of wood. In standards for timber construction, this is accounted for by classifying the structural timber elements into one of three possible service classes according to the climatic conditions during the design service life.

An additional effect of changes of the wood moisture content is the associated shrinkage or swelling of the material. This is much more pronounced perpendicular to the grain than in grain direction. Since the absorption and release of moisture is realized through the surfaces, the outermost sections of the wood cross-sections will adapt to the climatic conditions at first. The resulting moisture gradient and the associated shrinkage or swelling will lead to internal stresses in the cross-section. These stresses will partly be reduced by relaxation processes but when the stresses exceed the very low tension perpendicular to grain strength of wood, the result will be a stress relief in form of cracks which can reduce the load-carrying capacity of structural timber elements.

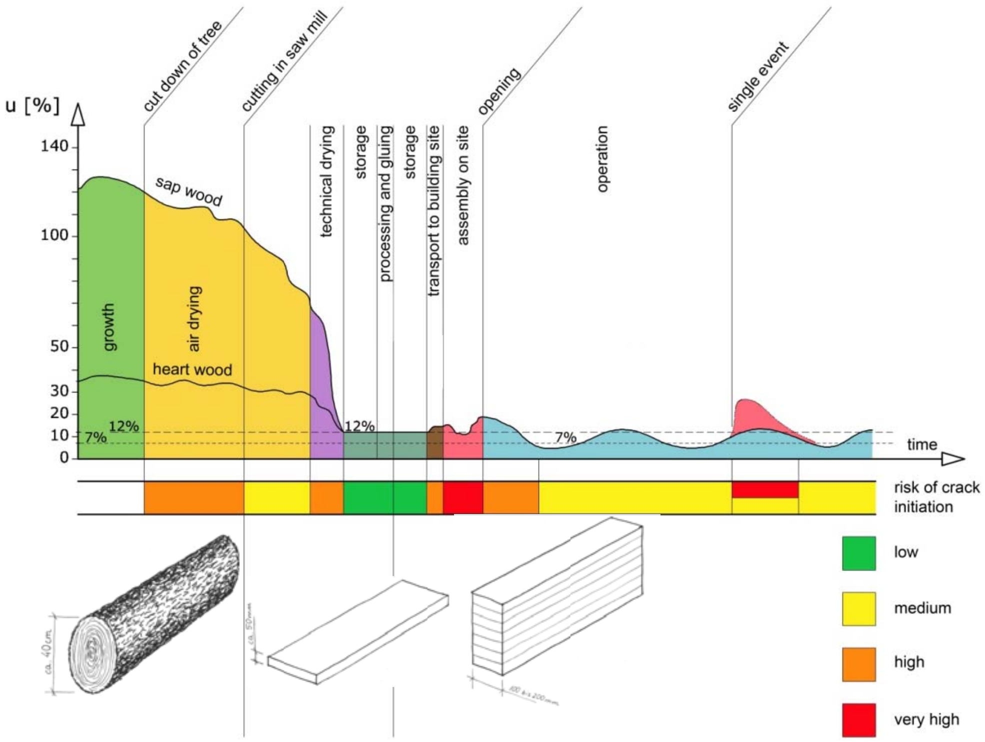

Figure 1: Sketch of a possible „moisture chain“, i.e. exposure to moisture and risk of cracking, from the tree to glulam elements in the building.

The evaluation of damaged large-span timber structures shows that the predominantly observed damage is pronounced cracking in the gluelines and lamellas of glued-laminated (glulam) timber elements. A significant proportion of these cracks is attributed to the seasonal and use-related climatic variations within large-scale buildings and the associated inhomogeneous shrinkage and swelling processes in the timber elements. This leads to the necessity to better determine and describe the climate-related stresses in large-span timber structures.

Through long-term measurements of climate data (temperature, relative humidity) and timber moisture content on large-span timber structures in buildings of typical construction type and use, data sets were generated which deliver information on the sequence and magnitude of seasonal variations. The measurement of moisture in different depths of the cross-section is of particular interest to draw conclusions on the size and speed of adjustment of the moisture distribution to changing climatic conditions. The moisture gradient has direct influence on the size of the internal stresses and possible damage potential. Similarly, the results provide a review and extension of the previous classification of buildings into use classes. They allow for a more precise indication of range of resulting equilibrium moisture content for the specific use, enabling the installation of timber elements with adjusted moisture content. The results of the research project also support the development of appropriate monitoring systems, which could be used in the form of early warning systems based on climate measurements.

2 Realisation of the research project

2.1 Untersuchte Nutzungen und Gebäudeauswahl

Within the research project, long-term measurements in a total of 21 halls with seven different types of use (see Table 1) were realized. When selecting the objects, attention was given to cover a wide range of types of timber constructions. In each hall, the data were collected at two different points of measurement in order to capture possibly varying climatic conditions (e.g. solar radiation or the influence of building appliances).

Table 1: Chosen types of use and number of objects in each use

Use	Number
Indoor swimming pool	3
Ice rink	4
Riding rink	3
Gymnasium	3
Production and Sales	2
Agriculture (livestock)	3
Warehouse	3
Total	21

2.2 Applied method of measurement

For the measurements of the timber moisture content the resistance measurement method was chosen, since this method constitutes the generally accepted state of the art. Moreover does this reliable and widely applied method allow for the non-destructive measurement of moisture gradients across the cross-section. The chosen method is based on measuring the electrical resistance or conductivity of wood. Since water has a much higher electrical conductivity than wood, meaning that its electrical resistance decreases with increasing moisture content, it is possible to deduct the present moisture content in one specific location. For the measurement of the distribution of moisture over the cross section, four pairs of teflon-insulated electrodes with varying length were used at each measuring point to enable the measurement of moisture content in clearly defined depths of the cross-section. The ram-in electrodes were connected to the moisture meter by custom-built shielded coaxial cables. The moisture meter developed in cooperation with the project partner enables the determination of moisture content at up to eight channels. The moisture measurements which were generated every hour at both points of measurement are subsequently transmitted to a data logger. The climate data are recorded via a second data logger in combination with a sensor unit for relative humidity and air temperature. In addition, the surface temperatures at the two points of measurement are recorded to allow for the temperature compensation of the moisture content (see Figure 2).

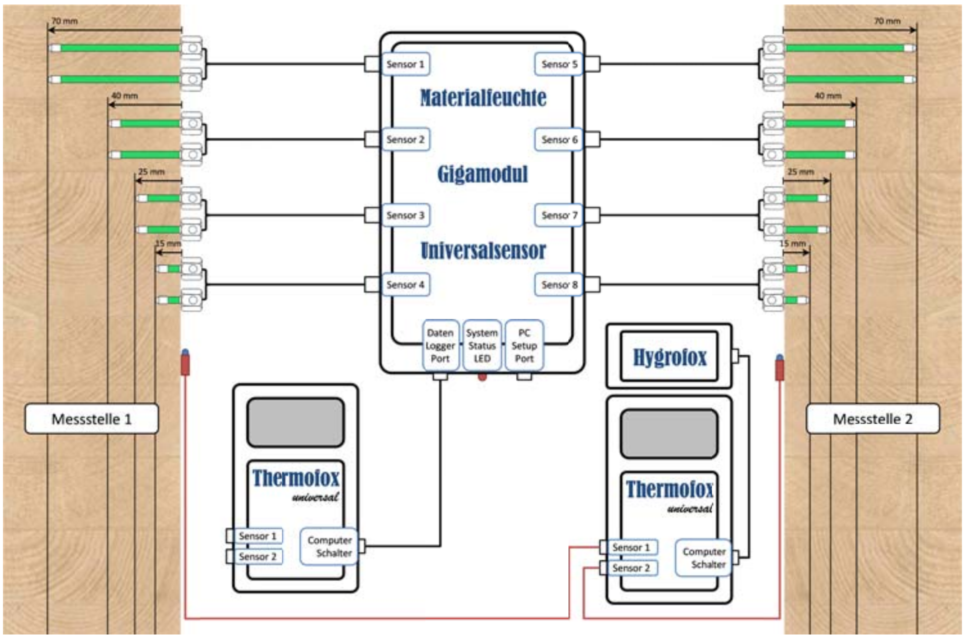

Figure 2: Systematic presentation of the measurement technique.

Before the installation of the measuring equipment in the buildings was carried out, the system was installed on test specimens of glued-laminated timber from spruce and exposed to very dry, very humid and varying climate conditions in the climate chambers of the materials testing laboratory at the TU München. The moisture contents were continuously measured with the measurement equipment and compared to the results of cyclic measurements with a calibrated reference moisture meter. There was neither a significant difference in the results of the two measurement systems, nor when using different types of electrodes. For further verification, two independent series of test specimens from spruce were stored under four different controlled climatic conditions (very dry to wet) until they reached constant weight before their moisture content was measured with the chosen moisture meter and two reference meters. By subsequent kiln-drying, the actual moisture content was determined. Good agreement was obtained for moisture contents between 12% and 18% and maximum deviations of 1.3% were realized for the dry specimen, whereby the chosen moisture meter tends to underestimate the actual moisture content at low ranges.

After installation of the measuring equipment in a total of 21 objects, the data stored in the data loggers were read out three times over the measurement period, whereby a functional check as well as a reference measurement with another moisture meter was carried out at the same time. To analyze the data, a program on the basis of Excel was developed which made it possible to read the large amounts of data at the end of the planned duration of measurement and to further process and graphically illustrate the data in different charts. When converting the measurements of electrical resistance from the raw data into timber moisture contents, a compensation of the effect of temperature was undertaken. For this, the actual material temperatures in the different depths were calculated from the measured surface temperatures, using the explicit Euler method. In addition, the equilibrium moisture content prevailing in the cross-section near the surface in dependence of the surrounding climate was determined by the theoretical model of Hailwood & Horrobin.

3 Summary of the results

The developed measuring system proved to be suitable to realize long-term measurements of timber moisture content and climatic conditions in buildings with timber structures. The use of teflon-insulated electrodes of different length allowed clear statements about the gradient of moisture in the cross sections. In addition, useful suggestions regarding the future application of this measuring system, e.g. for the monitoring of wood moisture and ambient climate could be derived. Within the evaluation period from 1 October 2010 to 30 September 2011, a total of over 2.2 million readings were collected and analyzed by means of a specially developed program. The data read from the data loggers were prepared as curves (time series) of relative humidity and temperature at the location of measurement over time, see Figure 3. The same type of representation was chosen for the measurements of timber moisture content in the four depths of the cross-section, see Figure 4. In addition, graphical representations over the cross section were derived for the timber moisture content. This type of representation allowed to create envelope curves of minimum and maximum timber moisture contents, see Figure 5, as well as envelope curves of minimum and maximum timber moisture gradient, see Figure 6. These results form the basis on which to draw conclusions about the magnitude of moisture induced stresses and hence the potential for crack initiation.

From the graphical representations, a damped and delayed adaptation of timber moisture content can be identified with increasing depth. A comparison of the results of the individual types of building use confirms the expected large range of possible climatic conditions in buildings with timber structures. Evaluated for all types of use, the average moisture contents lie between 4.4% and 17.1%. The moisture gradients are lower in insulated and air-conditioned buildings than in buildings with stronger influence of the naturally variing outdoor climate.

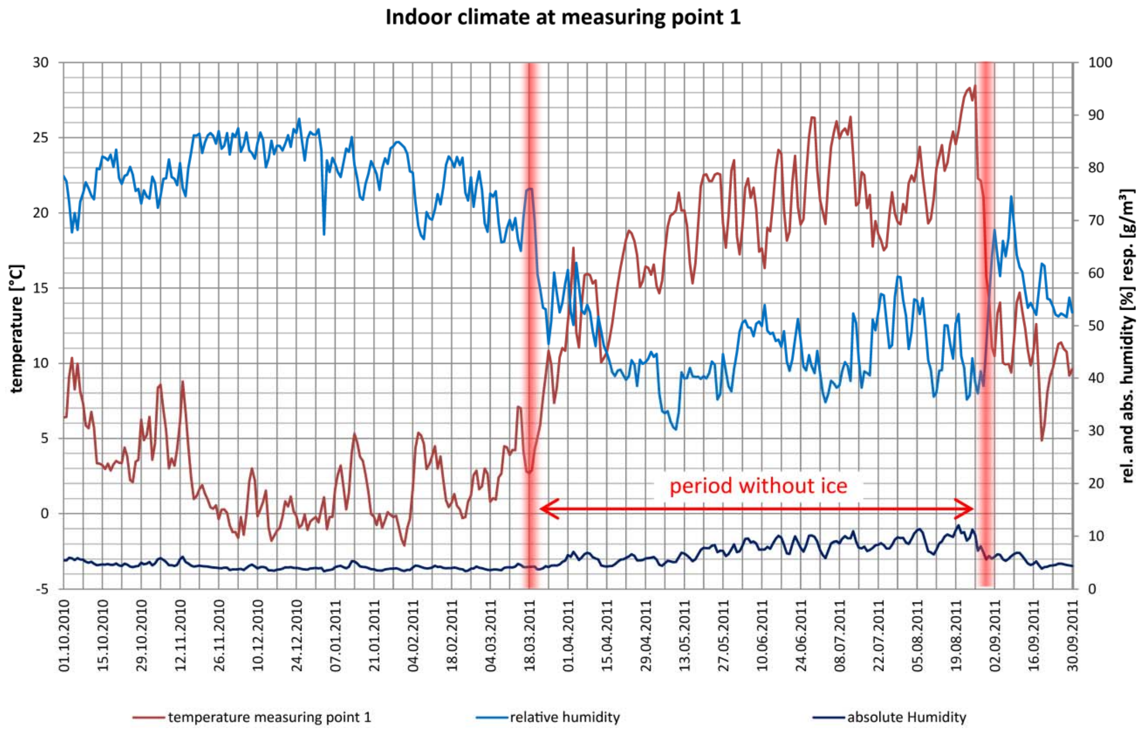

Figure 3: Variation of the relative and absolute humidity and the reference temperature over the measurement period, exemplary given for the ice rink in Buchloe.

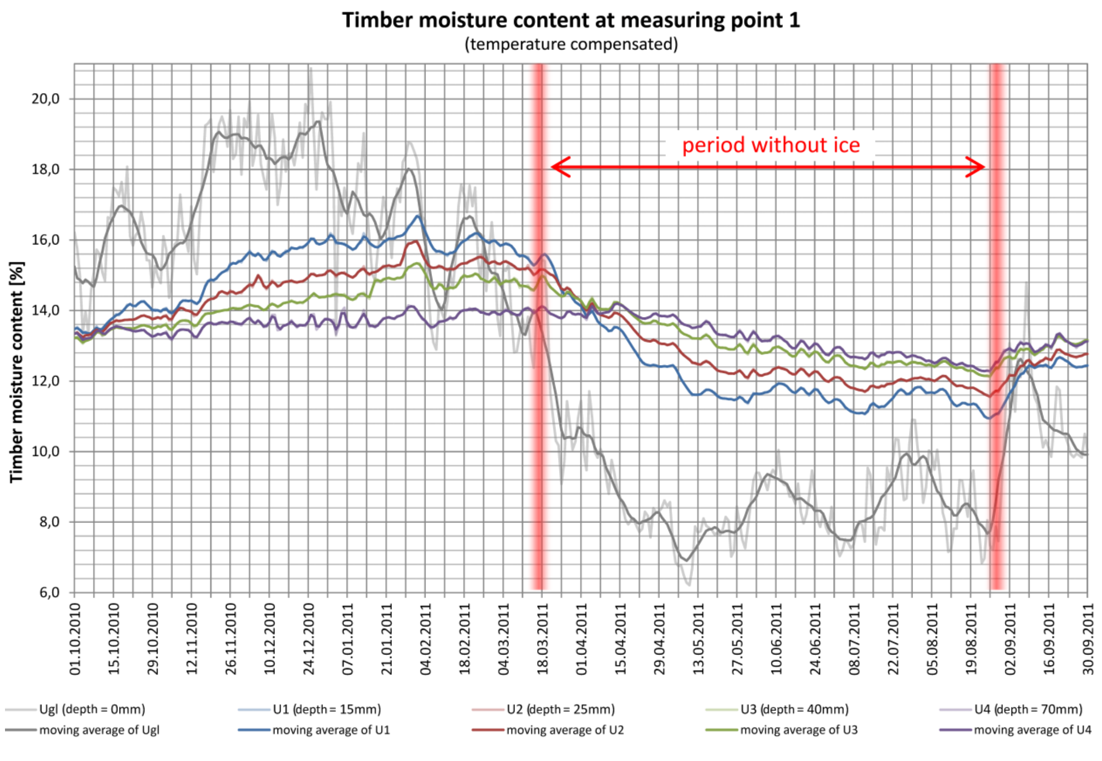

Figure 3: Variation of timber moisture content at different depths of the cross-section over the measurement period, exemplary given for the ice rink in Buchloe.

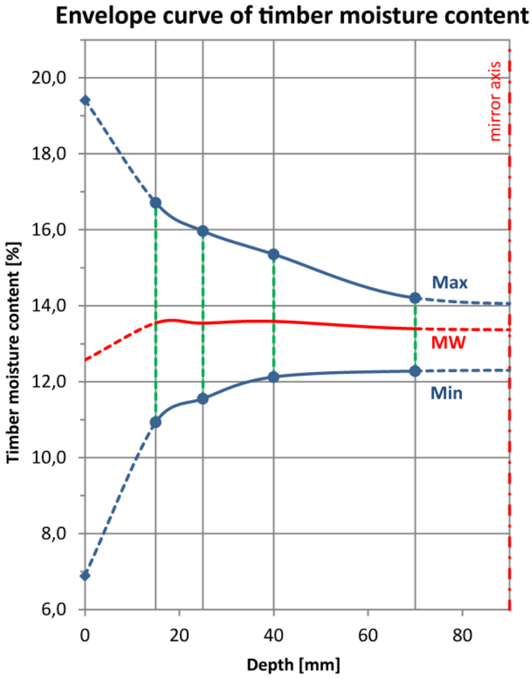

Figure 5: Envelope curve of the timber moisture content at different depths of the cross section, exemplary given for the ice rink in Buchloe.

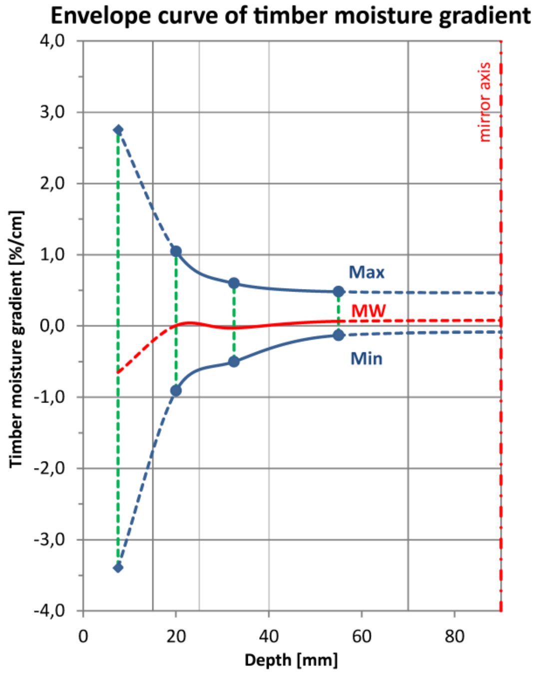

Figure 5: Envelope curve of the timber moisture gradient at different depths of the cross section, exemplary given for the ice rink in Buchloe.

For indoor swimming pools, very consistent climatic conditions were found which are uncritical with respect to the equilibrium timber moisture content of the structural elements. Transition zones to the outside air represent an exception due to the lowering of the temperature which results in high and more fluctuating moisture contents.

In gymnasiums, a constant climate was observed as well with relative humidity between 40% and 50%, which resulted in moisture contents between 8% and 10%. In areas exposed to direct sunlight, these values can be significantly lower. The most critical period with regard a potential crack initiation will in most cases be the first winter of operation of the gymnasium. During this period, heating systems should be adjusted to not reduce the relative humidity too fast and too strong. An artificial air humidification, e.g. in the form of evaporation ponds is another possibility to dampen the speed of drying of the structural timber elements. An alternative is a surface treatment, e.g. in the form of products which dampen the moisture absorption and release in the first years of operation of the building.

Production and sales facilities may, depending on the specific use, feature different climatic conditions. Therefore the climatic boundary conditions are to be determined individually for each object. Mostly these facilities will feature a constant and dry climate. For sales facilities, the comments given for gymnasiums are also valid.

The ambient climatic conditions in closed, non-air conditioned ice rinks are marked by a distinct change between winter and summer months (i.e. ice-free period). The timber moisture content in ice rinks is high and varies noticeably. By air-conditioning the buildings, this effect can be significantly dampened.

Comparable seasonal variations are found in riding rinks at high relative humidity (80% on average). During the winter months, the combination of cold air and the humidity introduced by the sprinklers, frequently results in condensation. In order to reduce this effect during the cold season should the sprinklers only be used when it is absolutely necessary for the equestrian sport. As in other types of use which are influenced by the outside air, higher moisture contents with stronger variations are found. Due to the seasonal nature of the variations, these result in noticeable but not in exceptionally high timber moisture gradients.

Similarly strong seasonal variations of climatic conditions were found for agricultural buildings with livestock. In the winter months, the interaction of the cold outside air and increased humidity in the building results in high moisture contents and partly in condensation.

The strongest seasonal variations in environmental conditions were found in warehouses. In the cold winter months, care should be taken that the goods do not introduce too much additional moisture into the building. Timber structures in areas exposed to direct sunlight (e.g. in window strips) should be given attention with respect to potential crack initiation due to rapid drying after a period of increased humidity. Protective covering in the form of panel materials seem to be another feasible measure.

In addition to the previously described, use-dependent climatic conditions and their influence on timber moisture content and the potential for crack initiation, do the results of the research project identify another important aspect. Temporary interventions, such as renovations or changes of use (temporary or permanent) can lead to major changes in climatic conditions, which are reflected in distinct changes in timber moisture content. Within this research project strong drying of timber elements (temporary conversion of an ice rink and renovation of an indoor swimming pool) as well as strong moistening of very dry timber elements (conversion of a former metal-processing production facility) was observed. This results in a major increase in potential for damage due to e.g. crack initiation in glued-laminated timber elements. Accordingly, care should be taken during such interventions to realize a decelerated change of ambient climate. The use of remedial measures (e.g. in form of evaporation basins or surface treatment) could also be a means to realize a dampened and controlled change of moisture content. Ideally, such interventions should be accompanied by expert personnel.

With the generation of - not yet existing – data sets of climatic conditions in buildings with large-span timber structures of typical types of use, a first basis was created to evaluate the impact of indoor climate on the moisture gradient in structural timber elements and the associated damage potential.