Environment impact on the humidity change of beams from timber and glulam - experimental investigation

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Abstract. The paper relates to the humidity change in timber and glulam beams. Based on the literature moisture penetration into the wood phenomenon was briefly depict. The publication describes the carried out experiments: moisture measurement of glulam and timber beams in natural conditions. Results are presented in the form of graphs and photos on which cracks and warping of the samples is shown. Based on the literature and experimental results conclusions are drawn regarding the usage of glulam and timber beams in building industry.

1. Introduction
Timber structures are exposed to adverse impacts associated with the variability of the surrounding environment. Apart from biological and chemical factors, the influence of physical parameters of the environment such as relative humidity and air temperature are substantial. These parameters affect the physical and mechanical properties of wood, which successively leads to the creation of additional internal forces (in the form of stress) and affects the shape of beams or other timber elements. Additionally, the change in humidity causes shrinkage/swelling, which often results in numerous cracks in the whole mass of the solid. Therefore, the change of humidity is an important aspect which influences the stability and capacity of the structure as a whole load-bearing system. Nowadays, timber structures are usually made of solid wood (rafter framings or other small scale structures) or glued laminated timber (e.g. construction of the warehouse roofing). These structures works in various conditions subjected to the constant changes of the environment (practically from the first day after sawing the timber). The design standards (e.g. [1]) take into account the influence of humidity on the timber structure by assuming a serviceability class consistent with the average, annual, ambient humidity. However, those regulations do not take into account (explicitly) changes, that occur naturally at the initial stage of the construction production process.

Studies available in the literature which relate to humidity changes in timber, are overwhelmingly focused on the extreme service conditions of the structures, e.g. in the case of bridges or swimming pools [2] where humidity is constantly heightened. However, in order to provide practical knowledge for the designers, who design buildings placed in less aggressive environment, it is necessary to carry out simple tests of the timber and glulam behaviour under “standard usage” conditions. Also consideration of structure production cycle in tests is relevant. Question is: how timber or glulam beam behaves ”from wood sawing” (or delivery from stock for glulam) until material achieve equivalent humidity at the construction site.
2. Moisture penetration phenomenon in timber

Wood as an organic matter has hygroscopic properties, i.e. the ability to exchange humidity with the surrounding environment where absorbed water and water vapor are aggregated in liquefied form. Furthermore, it is possible to define three basic ways of damp storing [3]:

- free water - filling capillaries;
- hygroscopic water - filling submicroscope spaces in cell walls;
- constitutional water - built into the chemical structure of wood.

Depending on the prevailing external conditions, hygroscopic material derive or remit moisture to/from the environment - this phenomenon is called sorption. Hygroscopic equilibrium is a state of balance in which the number of water vapour particles adsorbed by wood is equal to the number of particles desorbed into the environment [4]. This is achieved with different moisture contents of the wood and depends on temperature and relative humidity of the environment (Table 1). Theory called BET (from Braunner, Emmett and Teller theory) is defining which type of wood sorption phenomena is dominant for particular ranges of relative air humidity:

- mononuclear sorption (in the 0-21 (%) range) - coating of capillaries walls with a "single" layer of water molecules;
- polymolecular sorption (in the 21-60 (%) range) - coating of capillaries with up to five layers of water molecules;
- capillary condensation (over 60 %) - the phenomenon of water condensation after disturbing the balance on the surface of the capillaries.

Hygroscopic equilibrium state is desired. Achieved balance between environment and timber, allows for the inhibition of erosive processes of structures (such as cracks and delamination). In addition, in order to limit the potential "capillary burst", it is worth to limit the movement of humidity at the air/wood surface zone to the phenomenon of mononuclear sorption.

### Table 1. Equivalent moisture content of timber [5].

| Relative air humidity (%) | 0   | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  | 45  | 50  | 55  | 60  | 65  | 70  | 75  | 80  | 85  | 90  | 95  | 100 |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| air temperature (°C)     |     |     |     |     |     |     |     |     |     | 5   | 10  | 15  | 20  | 25  | 30  | 35  | 40  | 45  | 50  | 55  | 60  |
| 25                       | 9.0 | 9.5 | 10  | 10.5| 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  | 16.5| 17  | 17.5| 18  | 18.5| 19  |
| 20                       | 8.5 | 9.0 | 9.5 | 10  | 10.5| 11  | 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  | 16.5| 17  | 17.5| 18  |
| 15                       | 8.0 | 8.5 | 9.0 | 9.5 | 10  | 10.5| 11  | 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  | 16.5| 17  | 17.5|
| 10                       | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10  | 10.5| 11  | 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  | 16.5| 17  |
| 5                        | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10  | 10.5| 11  | 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  | 16.5|
| 0                        | 6.5 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 10  | 10.5| 11  | 11.5| 12  | 12.5| 13  | 13.5| 14  | 14.5| 15  | 15.5| 16  |

In order to reduce erosion of wooden structures, glued laminated timber (“Glulam”) is being used increasingly. Wood, which is the main raw material used to create that composite, is dried under strictly defined conditions (in a closed environment of the dryer). That process allows to control the water
evaporation phenomena, which reduce defects of the timber caused by excessive or uneven dehydration. In addition, the multi-stage production process of glulam is based on mechanical and organoleptic sorting of the raw material, which eliminates discontinuities in the structure of the obtained material (so that during adsorption/desorption the glulam works freely, without local disturbances).

3. Experimental investigation

• Aim of the measurements

The aim of the investigation is to determine the magnitude and rate of changes in the moisture content of glulam (from the warehouse) and solid timber (raw) under normal use conditions.

• Measurement specimens

Six specimens (beams) were used for measurements:
- 3 beams from solid wood, pine, cross-sectional dimensions 10x20 +/-0,5 (cm), about 105 +/-2,5 (cm) length, raw (from own resources), initial moisture content not defined;
- 3 glulam beams, 10x20x100 +/-0,5 (cm), produced from spruce, („MUF” type glue), GL24h strength class, visual SI class, planed on four sides and chamfered along longer edges, humidity guaranteed by the manufacturer oscillates around 12,0 +/-2,0 (%);

![Figure 1. (a) View of the test stand. (b) Measuring device - „HIT3” hammer.](image)

- Measurements - stage I

Timber beams after the sawing, were transported to the laboratory in natural conditions (without any protection). Glulam beams were purchased in the warehouse in a protective foil, which was a barrier mainly for surface contamination (it was not a tight humid insulation).

All beams and their walls were numbered (I-III beams are from glulam, IV-VI beams are from solid timber). Each beam was roughly, mechanically cleaned and placed in the laboratory about 20 (cm) above the ground so that a small part of the beam's edge touches the support (lower surface has free access to air) (figure 1 a). The laboratory had a natural atmosphere which was not controlled. During the measurements, the air humidity fluctuate between 26-46 (%) and temperature between 20.1-24.0 (°C).

Measurements were taken every 7 days. The measuring hammer "HIT3" was used for measurements (figure 1b), calibrated in the „OUM” (District Office of Measures). Device specification:
- measuring range: 6-60 (%);
- measurement accuracy: +/- 1(%) (in the 6-15 (%) range), +/- 2(%) (in the 16-28 (%) range);
- about 10 (%) of the measured value (in the 16-28 (%) range);

• Measurements - stage II

The "HIT3" measuring hammer is equipped with needles which penetrate measured object into the depth of 5-7 (mm), through that the measurements in the first stage of the experiment can be considered as "superficial". In the second stage of research, the moisture content of the beams was measured according to section thickness (by destructive test).
After first stage of measurements, two selected beams (one from solid timber and one from glulam) were transported to the sawmill (which temporarily disturbed the ambient conditions). Then, on the stationary sawmill Pilous Forestor CTR 800, about 4-5 (mm) of the material was felled, without the use of coolant. After each cut, measurements with the usage of „HIT3” hammer were taken at 3 places of the beam: near the center and about 10-15 (cm) from ends of the specimen (figure 2). Ten cuts were made and each one reduced the width of the beam until the measurement was made at the symmetry surface of the original cross-section.

![Figure 2. Measuring points of further layers of the beam.](image)

4. Test results and data analysis
Moisture measurements were taken on each surface of the beam. Graphs below (figure 3 and figure 4) depict average values of moisture content level gained by beams, respectively by solid ones and from glulam.

![Figure 3. Average moisture content of glulam beams in each week of measurements.](image)

During the tests, the moisture content of the individual glulam beams was dropping almost evenly (figure 3). The deviation of the results from individual beams towards the average from all measurements in a given week is smaller than the accuracy of the measuring device. Thereby obtained results can be considered as reliable. The average weekly decrease in humidity is 0.42 (%).
Figure 4. Average moisture content of solid timber beams in each week of measurements.

Beams made from solid timber, at the beginning of the experiment can be characterized as „unstable” (figure 4). Initial, high humidity decline rapidly (by about 40 (%) on the first week of measurements). During first 2-3 weeks of the experiment, moisture content of the beams normalized with a clear downward tendency. Following weeks of testing showed a steady decrease in humidity, where the measurements of each specimen did not deviate from the average by more than the accuracy of the measuring device.

Figure 5. Average moisture content of solid and glulam beams.

On picture above (figure 5) we can see that the average moisture content of solid beams clearly drops down throughout the measurement period, stabilizing and approaching the average moisture content of glulam beams. Glulam beams behave more stable which can be caused by their earlier controlled drying in the production process. In the first phase of the measurements we can see that the average humidity of glulam beams increased slightly (by about 0.3 (%)) which may be caused by the inaccuracy of the measuring device (the accuracy of the hammer in the range of the prevailing environmental conditions is +/-1 (%)).

In order to carry out an organoleptic assessment of the behaviour of individual specimens, during the measurements photographic documentation was kept (figure 6 – figure 7).
Comparing elements 1-3 (figure 6 a and b), there is a noticeable lack of "warping" of glued laminated beams. Each one retained the original shape despite an average change of humidity by more than 5 (%). Comparing elements 4-6 (figure 6 a and b), a "warping" of solid wood beams is visible (it should be noted that just after sawing all beams had a cuboid geometry). On both types of beams, on narrow walls, no cracks are visible (except for superficial, shallow cracks on beam no. 4, which has been significantly distorted).

Comparing wider surfaces of the glulam beams before starting the measurements (figure 7 a) with the same surfaces after the measurements (figure 7 c), there have been no major changes in the samples – only local, superficial, micro cracks appeared. On the next pictures (figure 7 b and d) we can see timber beams surfaces. On the picture (figure 7 b) cracks which appeared before the start of the tests are visible, practically just after the wood was sawn (in less than 1 day) cracks have appeared. Cracks
in the middle part of the beams are conspicuous but shallow (less than 1 (cm)). At the ends of the elements, the cracks have a large opening (even 3 (mm)), but those are not propagated on the whole element. After moisture measurements, on solid beams additional cracks appeared (figure 7 d) (but only in the areas of attenuation of the beams - e.g. near knags). Existing cracks were elongated and their openness was slightly increased. In the middle parts of the solid beams, the cracks are superficial. At the ends of the beams, some of the scratches have a width of more than 4 (mm), but none of them causes complete delamination of the element. Sapstain appeared on beams number V and VI, which does not reduce the mechanical properties of the beams but affects the aesthetics and slows down the drying process of the element (especially at high humidity).

According to [6], we can distinguish six main directions cracks propagation (figure 9). The first letter gives the direction of the normal to the crack plane and the second letter indicates the direction of crack propagation. Because of the tension caused by water desorption (and the structure of the timber beams cutted out from the logs), during the experiment, most of the cracks propagate in “TL” direction, which is consistent with observations presented in other publications [6].

Figure 8. Graph of the average humidity level of solid and glulam beam towards to the subsequent measurement layers.

Figure 9. Six principal orientations of crack propagation in wood [6]

After the first stage of test, two beams were selected: one from solid wood and one from glulam. Then, the measurements were taken as described in in the chapter 3 of this paper. The graph (figure 8) shows the humidity of the beams as an average from 3 measurement points for each layer.

The diagram (figure 8) shows the change of humidity inside the specimens (from the outside-layer 1, to the inside of the beam - layer 11). The difference between the inner and outer part of the beam is about 2 (%) for a glulam beam and about 3.5 (%) for a solid beam. Both beams increase their moisture evenly towards to the central part of the measured specimen. The difference in humidity between the individual layers of solid and glulam beams is practically constant (apart from the two outer layers).
5. Summary and conclusions

On the basis of the obtained results, it can be concluded that:

- average humidity decrease of glulam beams over the entire measurement period was 0.42 (%/week);
- average humidity decrease of solid timber beams over the entire measurement period was 1.90 (%/week), and excluding the first part of the tests (the first 5 weeks of measurements) the decline was 0.48 (%/week);
- the rate of drying is important: solid timber beams attacked by sapstain dried out slowly in the initial stage of test and were not warped;
- glulam beams during humidity measurements behaved „more stable” than those from solid timber (decrease of humidity was steady and there were no cracks or warping);
- with a sufficiently long exposure time to weather conditions, the moisture content of glued laminated timber and solid timber beams is convergent;
- when cutting off subsequent measurement layers from timber and glulam beams, cracks caused by a change of humidity disappears (when cutting off a layer of about 10-15 (mm) thick, most cracks are already closed);
- most of the cracks caused by humidity decrease propagate in “TL” direction, which is consistent with observations presented in other papers;

Conducted research unambiguously indicate that the tested beams endeavor to equivalent humidity, which for an 26 (%) air humidity and temperature of about 20 (°C) is estimated at 5.0 (%) level. This value exceeds the range of measurement capabilities of conventional devices, so the tests were interrupted after 10 weeks (after that time, hammer "HIT3" was no longer able to make reliable measurements). Therefore, in order to perform measurements in the full range of the experiment it is necessary to use advanced measuring equipment or to perform destructive tests.

Studies have shown that glued laminated timber beams show much greater dimensional stability when the moisture content of the element changes. Additionally, the production process makes the glulam much more resistant to biological corrosion. Solid wood beams have warped at the initial stage of measurements (first week after sawing) where their moisture content dropped relatively quickly. It can be concluded that the care of solid, wooden elements in the first two weeks after sawing is crucial for their later suitability for construction purposes.

References

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