Study in the changes of the moisture content in wood

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Abstract. The presence of water in wooden elements is an important factor in the understanding of the evolution of this material used for a structure. This happens because wood has the ability to change its volume due to climate variations; it can shrink or it can double its size depending on the season. This can influence the mechanical properties of the wooden piece and introduce in the structure deformations and changes in sectional efforts that can be very dangerous. For this study, environmental conditions have been tampered with so that wood that has moisture content of 12% will intake or output water, in order to arrive at a moisture content of 8% respectively 16%. In this way, the moisture content of untreated Spruce (Picea abies) and Chestnut (Castanea Sativa) has been modified in a climatic chamber at certain conditions of temperature and relative humidity. The wooden pieces have been verified for their moisture content in an oven with a temperature of 105°C after a complete dry. The purpose of the study is to follow the behaviour of wooden pieces when found in other environments.

1. Introduction
The environment around us has been changing a lot and people have started concerning about the relationship between it and the buildings that they are constructing. This is one of the reasons why wood has become a substitute of the hard structures made of concrete or steel. Another reason might be the good properties that wood has and why not, the aesthetic look. The evolution of the wood building industry is the main purpose for the multitude of research programs and projects that try to optimize the performance of structures, the characteristics related to ecology and the energy performances [1].

One of the most important factors that intervene in the good development of wooden elements that are part of a structure is represented by the moisture content and its effects on wooden structures or more punctual on elements. Moisture content and its effects on wooden structures and elements is a domain that is becoming more and more studied around the world because the performance and strength of wood structures, especially the compression strength are very important due to the fact that under constant climatic conditions, the wood piece is subjected to cracking and this can affect the load carrying capacity [1].

Trees are mostly filled with water that represents the moisture content as the weight of water divided by the weight of dry wood substance. The moisture content found in green timber can be
between 30% and 250%. However, most of it has to be removed in order to increase the strength and rigidity of wood and also to protect it against natural biological damage. The process can only be done by using energy that can evaporate moisture from timber. One of the processes used for the evaporation of the water is drying which is very intensive and consumes up to 7-15% of the total industrial energy in developed countries [2].

The weight of wood depends on the moisture content. For example, a piece of recently cut piece of wood—green wood, can have a weight up to double its value than the one dried in the oven. However, there is a lot of information on wooden properties and not all of them use the same standards or testing procedures and so there can be a variety of values. The standard value is taken for a moisture content of 12% found when the wooden piece arrives at an equilibrium moisture content with the exterior air at a temperature of 20 °C and a relative humidity of 65%. Depositing wood in different areas with a lower value of the relative humidity will result in a lower density of the wooden piece [2].

As it was mentioned above, moisture content is a very important factor in the evolution of the wooden material through time because as Eurocode 5 highlights it can “affect the strength and stiffness properties of timber and wood based elements and shall be taken into account in the design for mechanical resistance and serviceability” [3]. That is why the effects of moisture content and the changes they can make on the wooden elements have to be taken into account.

Researches have been conducted with experiments on different states of water presence in wood exposed to conditions established beforehand in a controlled environment chamber. The results of the tests have been considered relevant in order to analyse the influence of moisture content on the behaviour of wood. Wood degradation was determined each time some differences appeared in the weighed mass of the wooden samples. The process implies that specimens have to arrive at a constant mass for the environment conditions of 95% and 25°C when they have to be weighed before being put in an oven at 103°C and dried completely before being weighed again. The results of the study have revealed a lot of differences between the different states of water presence in wood and moreover the moment when degradation is installed [4].

Other researchers have made some tests on wooden pieces submitted to a certain climatic environment pre-established in a climatic chamber. After that, they studied the hygroscopicity of wood at the level of changes that take place between the level of water in the exterior and in the interior of wood. They reduced the moisture content in the climatic chamber and in the end they compared the fibre saturation points. Some samples have been subjected to different treatments such as: steaming process and longitudinal compression treatment where a reduction of the initial length with 20% appeared. The conclusions of the study show that through the steaming process, the equilibrium moisture content is reduced with 3,7% and the compression causes a difference of 1% from the wooden samples. In the end, the authors affirm that “wood shrinks and swells less in variable environmental conditions” [5].

The study “in Wood Dryer Chamber”, presents data on the moisture content of wood considered a porous material, hygroscopic, that absorbs the moisture content from air up until it arrives at an equilibrium with the environment. This is why mechanical properties vary according to temperature and humidity. Wood has its own moisture content that can vary from 50 to 120% and takes into account the wood specie and if it is green or not. On one side, the freshly cut wood in normal climate conditions (from a temperate area) can be dried up until a moisture content of 18%. On the other side, for the connections, the ideal moisture content is of 10-15% [6].

2. Moisture contents facts
As it was said before, the environmental conditions are an important factor in the evolution of the mechanical properties of wooden elements. This is because wood is a hygroscopic material that has the ability to take in water or dispose it in the environment in order to arrive at a certain equilibrium with it. The water can be absorbed by wood, creating a swelling, because of the high temperatures and relative humidity or it can be desorbed if the environment is dry. Different phenomenon of
modifications that appear on wood when environmental conditions are affecting wooden elements are presented in the figure below.

**Figure 1.** Swelling of wood and other phenomenon that appear when water in contact with wood for a certain amount of time (source: Fredericksburg Wood Restoration).

These constant modifications that appear in the structure of wood can influence its mechanical properties and can be dangerous for the integrity of the future structure in which they will be implemented. A multitude of modification factors can appear in the structure or wood such as: changes in the volume, damages (cracks, wood decay) or conducive environment for moulds, microbes, modification in strength.

In some of the wooden elements used for the current study, changes have occurred in their exterior such as cracks. These can be seen in the pictures below, taken after their introduction in the climatic chamber and kept at the environment considered for the experiment.

**Figure 2.** Changes on the wooden surfaces of elements modified in the climatic chamber.

Wood shrinks when losing moisture from its interior and swells when gaining moisture. This happens mostly in the tangential direction, followed by the radial direction (almost half) and finally in the longitudinal direction of the fibres [7]. If moisture content increases, strength and elasticity values are lowered. However, if the variations of moisture content are found above the fibre saturation point, there will be no effect on mechanical properties; this happens because the variations are depending on the free water found in the wooden cells [8]. Some of the percentage changes that appear in the mechanical properties of wood for 1% change in moisture content can be seen in Table 1.

**Table 1.** Approximate changes in the mechanical properties of wood for a 1% of change in moisture content [9].

| Properties                               | Change (%) |
|------------------------------------------|------------|
| Compression strength parallel to fibre direction | 5          |
| Compression strength perpendicular to fibre direction | 5          |
| Bending strength parallel to fibre direction | 4          |
| Tension strength parallel to fibre direction | 2.5        |
| Tension strength perpendicular to fibre direction | 2          |
| Shear strength parallel to fibre direction   | 3          |
| Modulus of elasticity parallel to fibre direction | 1.5        |

When implementing wood in a structure, the material has a high humidity (maximum 20%) and if there is no other possibility of being dried on site, construction conditions will be adopted, protective measures and details in the making that permit the ventilation of wooden elements without inducing in
the resistance structure dangerous deformations or growth in the sectional efforts. In this case, it is more preferable the usage of joints that are not influenced by humidity variations (jointed joints, with rods or metal connections) and that are easy accessible for adjustment and control [10]. However, the material is still affected by the environment when the conditions change so these variations have to be taken into consideration to an average moisture content of the area in which the structure will be implemented in order to minimize the changes that can appear.

The standard reference moisture content is corresponding to an environment that has a temperature of 20°C and 65% relative humidity for wood elements. If the wood is not found in these standard conditions, its mechanical characteristics can still be calculated by following the standard EN 384-Structural timber-Determination of characteristic values of mechanical properties and density [11].

The standard mentioned above gives an idea on how to calculate the strength of timber elements that are different from their designated values. EN 384 [11] specifies that the characteristic values that have to be determined for elements that do not find themselves in the standard values are: bending, mean modulus of elasticity parallel to grain and density. The other values can be found in the standard EN338 tables.

For wooden elements that are not found in the reference conditions but have a moisture content between 10% and 18% the next regulations have to be followed:
   a) For bending and tension strength: no adjustment;
   b) For compression parallel to grain strength: 3% change for every percentage point difference in moisture content;
   c) For modulus of elasticity: 2% change for every percentage point difference in moisture content;
   d) For compression parallel to grain strength and modulus of elasticity: the adjustments are carried out so that the properties increase if the data are adjusted from a higher moisture content, and vice versa [11].

3. The principles of the calculation and the experiments

In order to have some real data on how temperature and relative humidity influence the moisture content of wood, experiments have been conducted in a climatic chamber (FITOCLIMA 1000EC45) in order to provide a dry and a humid environment for two series of tests of pieces of wood.

In the climatic chamber temperatures and humidity can have different values that follow surrounding environments depending on climate: low or high temperatures or in which the humidity intervenes in the modification of structural elements that are part of a construction. In this manner, the climatic chamber is ideal for testing material performances, for example their heat resistance, in dry or cold environments. The dimensions of a climatic chamber vary depending on the samples that are analysed. The temperatures can have values from -70°C to 150°C and the humidity from 10% to 98%. These values are different depending on the characteristics of each climatic chamber however, in any case, the temperature and humidity have to be monitored throughout the process.

For this experimental campaign temperature has a linear value of 20°C for the two types of environments considered and only the relative humidity RH decreases or increases so that the wooden pieces arrive at the desired moisture content of 8% and 16%.

The standard ISO 13061-1 2014 [12] used for the determination of the moisture content defines it as “the amount of water contained in the wood, usually expressed as a percentage of the mass of moisture in wood expressed as a percentage of its oven-dry mass”. The moisture content is believed to be one of the most important elements that intervene in the properties of wood in a physical and mechanical level.

For this experiment, the samples of wood used are made of Chestnut (Castanea sativa) and Spruce (Picea abies) and their dimensions are mostly: 16,8x8,9x7 (cm) and 16,8x5,9x7 (cm). The pieces of wood have a standard moisture content of 12%. To ensure that these facts are right, a sample has been put in an oven at the temperature of 105 °C and dried to a constant mass. The initial mass of the sample
piece has been 434.73g and after 2 measurements, the mass has reached an equilibrium state of 385g. After the calculations, the moisture content in the piece of wood is approximately 12%.

The main principle of the experimental campaign is determining the moisture content by weighing the piece of wood before and after drying it in the oven when its mass has reached a constant value. When calculating moisture content, the interest is given on the mass loss as a percentage of the mass of the test piece after drying [12]. The wooden samples have been individually weighed before being introduced in the climatic chamber and after the process has ended.

Regarding the moisture content, this has been calculated for each wooden specie because after the process of drying, the piece does not present any more water in its interior so it cannot be used anymore for the desired experiments and at the necessary moisture content for the calculation. Also, when the samples have been weighed in the exterior of the climatic chamber, these have been exposed to the exterior for a certain amount of time, very short so that there is no possibility to change its characteristics (level of humidity) following the new environment and for making the following calculation more exact. The formulas used for the determination of the moisture content in the piece of wood are taken from the standard ISO 13061-1 2014 [12].

\[
mc = \frac{m_1 - m_2}{m_2} \times 100
\]

where:
- \(mc\) = moisture content in %;
- \(m_1\) = the initial mass of the test piece before drying [g];
- \(m_2\) = the oven-dry mass of the test piece [g].

![Figure 3](image-url)

**Figure 3.** The set–up of the climatic chamber where the samples have been introduced.

The figure above presents the climatic chamber in which the wooden samples have been introduced in order to change their moisture content: images from the exterior and the interior where the wooden pieces are placed on two levels but also superimposed and separated with a differentiator for air to circulate between them. The climatic conditions that are found in the climatic chamber, relative humidity and temperature have to be monitored. This has to be done so that the function of the chamber is fulfilled for an exact study: to maintain a certain environment for a particular equilibrium of the moisture content. For this to happen, a certain stability between the relative humidity and the temperature is necessary in order to maintain the equilibrium of moisture content [13].

However, for the current study, the purpose is to use pieces of wood of different moisture contents in order to see how the mechanical properties differ in this matter. For the initial experiments, the wooden pieces are desired to have a moisture content of 8%. For this, pieces of wood have been introduced in a climatic chamber, where the temperature is 10°C and the relative humidity of the air
RH=40%. This, according to the hygroscopic equilibrium curves of wood depending on the environment [14] situates the moisture content of wood in the desired conditions. With these curves, the researchers can see on their own the environmental conditions in terms of temperature and humidity that change the characteristics of the wooden pieces. Figure 4 presents the hygroscopic curves used for the determination of temperature and relative humidity in relation with moisture content of wooden elements taken from two sources. The values from the curves are further on used for the climatic chamber in order to change the moisture content of the elements.

![Hygroscopic curves](image)

**Figure 4.** Hygroscopic curves for the wooden material that depend on the environment (source: a) NP005/2013 [15], b) (Wallner, 2012) [14].

### 4. Experimental campaign

For this study there are used 2 species of wood: Spruce and Chestnut in two sizes (16,8x8,9x7 and 16,8x5,9x7 dimensions in cm) presented in the figure below. For the first step of the experiment each element is kept in the climatic chamber at a constant temperature of 20℃ and a relative humidity of 29% so that the moisture content of the wood arrives at a value of 8-8,5% for the wooden pieces considered in the study. These values are taken from tables in the standards. The wooden densities are calculated before and after the changing of the moisture content, after the exposure at the new environmental conditions and after complete dry of the samples for the validation of the new humidity.

![Sample of wood](image)

**Figure 5.** Sample of wood used in the study: (a) Chestnut, (b) Spruce and (c) weighing process.

Table 2 presents the initial mass and density of the two species of wood used in the current study and the mass loss that intervenes in the process when the pieces of wood are introduced in the climatic chamber together with the new density. It can be clearly seen that there is a mass difference from the initial state, before being introduced in the climatic chamber and when the pieces have lost water.
These differences show that the species of wood are important; the mass loss of Chestnut is higher than the mass of Spruce and the size of the specimens is also important.

**Table 2.** The results of the initial mass and density of the wooden pieces before being introduced in the climatic chamber, the mass difference and density after the moisture content arrives at 8%.

| Wood specie | Initial mass [g] | Mass loss [g] | Initial ρ | ρ for mc=8% |
|-------------|------------------|---------------|-----------|-------------|
| Chestnut    |                  |               |           |             |
| Piece 1    | 606,45           | 25,31         | 642,23    | 647,85      |
| Piece 2    | 358,30           | 13,00         | 495,25    | 406,88      |
| Spruce     |                  |               |           |             |
| Piece 1    | 521,86           | 10,72         | 408,16    | 533,69      |
| Piece 2    | 305,54           | 4,14          | 455,94    | 391,94      |

*a* sample of dimensions 16,8x8,9x7 cm  
*b* sample of dimensions 16,8x5,9x7 cm  
ρ wood density in [kg/m³]

For these experiments 21 wooden big pieces (16,8x8,9x7) have been used and 42 small (16,8x5,9x7) wooden pieces that have been introduced in the climatic chamber. Following the curves of the hygroscopic equilibrium that depend on the environmental conditions in order to arrive at a moisture content of 8%, for the values for temperature and relative humidity T=20°C și RH= 40% it has been noticed that after 18 days, the mass loss was not enough for this time duration (from 2;2,24 for the small pieces of Chestnut and Spruce and 6,73;12,68 for the big pieces). This is why RH has been changed to 29% (from 4,25; 5,44 for the small pieces of Chestnut and Spruce and 7,26; 10,72 for the big pieces). This shows that after changing the value of humidity, the mass loss has arrived quicker and the wooden pieces have arrived at the desired moisture content.

![Figure 6](image-url)  
(a)  
(b)

**Figure 6.** Gradual mass loss in time in the climatic chamber from the initial mass until the value for 8% moisture content (a) for the big pieces (16,8x8,9x7) and (b) for the small ones (16,8x5,9x7).

From the figure above it can be observed that the samples of Chestnut (represented in a darker colour) that have a heavier weight and the samples of Spruce (represented in a lighted colour) the mass loss is directly proportional with the element’s mass. This highlights that the modification of the quantity of the interior water of wooden elements depends also on their specie. From the experiments it can also be seen that the Chestnut samples do not arrive in the same time as the Spruce samples at the moisture content needed, the difference between them being of 0,5%. However, both wood species have been kept and modified in the climatic chamber in the same time period.

In the same time, **Figure 7** shows the evolution of moisture content in % related to the increase in relative humidity in %.
When the samples have arrived at the desired moisture content of 8%, the wooden pieces have been used further on in other experiments. In order to verify the correct values of the moisture content, a wooden piece has been introduced in an oven at a temperature of 105°C. Its weight has been measured before being introduced in the oven and after 48 hours the moisture content has been calculated. The verification supports the arrival of the wooden piece at 8% moisture content after being calculated following equation (1).

The graphic presented in Figure 8 represents the mass loss of the wooden pieces that have been introduced in a climatic chamber. The mass loss is represented in [g] in the necessary time for which the wooden pieces arrive at a moisture content of 8% from the initial state for the two shapes of samples. The first line represents Chestnut and the second one Spruce, Chestnut being heavier. Figure (a) is presented for the big wooden pieces (16,8x8,9x7) and (b) for the small pieces (16,8x5,9x7).

For the next step of the experiments, the same number of samples have been introduced in the climatic chamber at a temperature T=20°C and a relative humidity RH=80% so that the moisture content of the wooden pieces arrives at 16%. The new moisture content has been verified in the same manner as the previous one and after that other types of tests have been conducted.
Table 3 presents the initial mass and density of the two species of wooden used in the current study and the mass gained while the pieces of wood are introduced in the climatic chamber together with the new density. The environmental conditions that are required in the climatic chamber so that the pieces arrive at the moisture content desired of 16% are: T=20°C, RH=80%. The values for the temperature and the relative humidity are taken from standards. It can be clearly seen that there is a mass difference from the initial state, before being introduced in the climatic chamber and when the pieces have accumulated water. These differences also show that the species of wood are important and also the size of the specimens; the mass loss of Chestnut is higher than the mass of Spruce.

**Table 3.** The results of the initial mass and density of the wooden pieces before being introduced in the climatic chamber, the mass difference and density after its moisture content arrives to 16%

| Wood specie | Initial mass [g] | Mass loss [g] | Initial ρ | ρ for mc=16% |
|-------------|------------------|---------------|-----------|-------------|
| Chestnut    |                  |               |           |             |
| Piece 1a    | 661,91           | 6,09          | 642,23    | 644,47      |
| Piece 2b    | 365,88           | 3,12          | 495,25    | 438,55      |
| Spruce      |                  |               |           |             |
| Piece 1a    | 457,17           | 4,33          | 408,16    | 588,55      |
| Piece 2b    | 330,54           | 3,46          | 455,94    | 400,35      |

*a* sample of dimensions 16,8x8,9x7 cm  
*b* sample of dimensions 16,8x5,9x7 cm  
ρ wood density in [kg/m^3]

**Figure 9.** Gradual mass loss in time in the climatic chamber at the environment conditions established from the initial mass until the value of 16% moisture content; Chestnut is represented with the dark colour and Spruce with the lighter one.

In order to arrive at a moisture content of 16% the wooden pieces containing an initial value of moisture content of 12% have to take water. As it can be seen on the graphic, the water quantities are not very high as in the case of 8%. Figure 9 (a) presents the big wooden pieces (16,8x8,9x7) and (b) the small pieces (16,8x5,9x7).
Figure 10. Mass loss in [g] and in time from the initial state until the modification of the moisture content to 16%. Chestnut is represented with the dark colour and Spruce with the lighter one.

The graphic from Figure 10 presents the mass loss of the wooden pieces that have been introduced in a climatic chamber from the initial state until the modification of the moisture content. The mass loss is represented in [g] in the necessary time for which the wooden pieces arrive at a moisture content of 16%. The first line represents Chestnut and the second one Spruce, Chestnut being heavier.

Figure 11. Detailed representation of mass loss for a Chestnut sample for a moisture content of (a) 8% and the intake of water for a moisture content of (b) 16%.

The detailed graph presented above in Figure 11 shows the evolution in terms of mass changes that occurs in a wooden sample of Chestnut of (16.8x8.9x7) when the environment has two different characteristics. Figure 11 (a) follows the mass loss of the sample from 12% to 8% moisture content in time until the piece arrives at the equilibrium moisture content when it cannot receive nor give water. (b) follows the intake of water of the same type of wooden pieces from 12% to 16% moisture content.

5. Conclusions
The study presents an experimental campaign made on two different species of wood Chestnut and Spruce. The results show how these species respond in time in a climatic chamber at certain
environmental conditions where with the variation of temperature and humidity, following the standards they change their interior moisture content.

Wood has this ability to change after its environment and it can absorb water or lose it, depending on the climatic conditions. These studies have shown that by changing the environment for wood kept at a constant moisture content of 12% the mechanical characteristics of the samples change. This can be dangerous for the structure in which the elements are used because new efforts can appear, they can change their shape by retaining or disposing water and the wooden pieces do not respond in the same manner for which they have been calculated.

In the current study, the differences between the moisture contents for the wooden pieces used are not that big, however, changes intervene in their structure and these modifications should be taken into considerations. Moreover, for wooden pieces that are found in environments that periodically change their climate conditions, a study of their modifications due to the presence of water in the wooden elements is necessary.

When talking about the mass loss it is clearly that Chestnut loses water much more easily than Spruce even though its mass is higher (14.60g difference for the big samples and 8.86g for the small samples compared with Spruce). In the process of water intake the differences are not that big between the two species (less than 2 g for the big samples). The results between the two wood species depend on the moisture content but also on the type of wood, the species (hardwood or softwood) and the physical and mechanical properties that they have.

The article shows that changes in the moisture content of wooden elements influence their volume, density, mechanical properties and exterior features such as cracks (as in this case), or facilitate a perfect environment for moulds and biological attacks. This is why, when introduced in structures, these modifications can influence the integrity of the wooden pieces and in the end the integrity of the entire structure.

References

[1] Alpo R-M 2001 Effects of climate and climate variations on strength Timber Engineering 2000-course (Lund)
[2] Baronas R, Ivanauskas F, Juodeikiene I and Kajalavicius A 2001 Modelling of Moisture Movement on Wood during Outdoor Storage Nonlinear Analysis: Modelling and Control v.6 No. 2, 3-14
[3] EN 1995-1-1 Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings (European Committee for standardization Brussels)
[4] Lenth C and Kamke F 2001 Equilibrium moisture content of wood in high-temperature pressurized environments Wood and Fiber Science 33(1) pp. 104-118
[5] Bader M and Nemeth R Sciences 2017 Hygroscopicity of Longitudinally Compressed Wood Acta Silv. Lign. Hung pp 135–144
[6] Siikamaki R MA 2003 Performance of HMP247 proven in Humidity Measurement Test in Wood Dryer Chamber (Swedish Institute for Wood Technology Research Tratek)
[7] Carll C and Wiedenhoeft A 2009 Moisture-Related Properties of Wood and the Effects of Moisture on Wood and Wood Products Moisture control in buildings: the key factor in mold preventions ed 2nd West Conshohocken chapter 4 pp 54-79
[8] Leonardo da Vinci Project 2008 Handbook 2- Design of timber structures according to EC Educational Materials for Designing and Testing of Timber Structures TEMTIS
[9] Borgström E 2016 Design of timber structures Structural aspects of timber construction vol 1 Edition 2 Swedish Forest Industries Federation
[10] Ilharcio T, Paupério E, Guedes J and Costa A 2010 Sustainable interventions: Rehabilitation of old timber structures with traditional materials, SB10mad Sustainable building conference (Madrid)
[11] EN 384:2004 Structural timber-Determination of characteristic values of mechanical properties and density (Brussels)
[12] ISO 13061-1:2014 Physical and mechanical properties of wood -- Test methods for small clear wood specimens - Part 1: Determination of moisture content for physical and mechanical tests
[13] Peștișanu C 1979 Construcții, ed Didactică și pedagogică (București)
[14] Wallner B 2012 Versuchstechnische Evaluierung feuchteinduzierter Kräfte in Brettschichtholz verursacht durch das Einbringen von Schraubstangen (Institut für Holzbau und Holztechnologie Technische Universität Graz)
[15] NP 005-96 Normativ privind proiectarea construcțiilor din lemn (București)