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## **MOISTURE MEASURING OF BUILDING MATERIALS**

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Tässä työssä on tutkittu erilaisia tapoja mitata betonin ja puun kosteutta. Työssä on testattu erilaisia kosteusmittausmenetelmiä aluksi betonin sijasta hiekalla. Myöhemmässä vaiheessa erilaiset anturivaihtoehdot sekä niihin liittyvät kytkennät on testattu myös betonissa ja puussa.

Työssä esitellään erilaisten kosteuden mittaustapojen toimintaperiaatteet ja kytkentäkaaviot. Lisäksi työssä esitellään betoni ja puu rakennusmateriaaleina sekä kosteuden siirtyminen betonissa ja puussa. Kosteuden siirtymisellä tarkoitetaan materiaalin kuivumista ja kostumista.

Työn lopputuloksena on löydetty muutamia erilaisia tapoja mitata betonin ja puun kosteutta. Lisäksi on saatu mittaustuloksia kosteusmittauksista erilaisia mittausten menetelmiä käytettäessä sekä kehitettiin prototyyppilaitte puun ja betonin kosteusmittaukseen.

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Asiasanat:

*Kosteuden mittaaminen, Betoni, Puu*

## ABSTRACT

Oulu University of Applied Sciences  
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The aim of this Master's thesis was to research different methods to measure the moisture of concrete and wood. In this work different moisture measurement methods were at first tested with sand instead of concrete. Later, different sensor alternatives and measurement circuits were tested in concrete and wood.

In this thesis the principle of different moisture measurement methods and circuits are presented. Additionally, concrete and wood are presented as a building material. Also, it is described how moisture moves in concrete and wood. The moisture moving in this case means becoming dry and moist.

As the results of this thesis some moisture measurement methods were found for the concrete and the wood. In addition, the results of different moisture measurements methods were achieved and a prototype circuit for moisture measurements were developed.

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Keywords:

*Moisture measuring, Concrete, Wood*

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## ABBREVIATIONS

$\hat{o}$	Ohm is the unit of resistance
C	Capacitance $C = r * o * A / d$
F	Farad is the unit of capacitance
$g/m^3$	Grams per cubic meter
Hz	Hertz is the unit of frequency
$kg/m^3$	Kilograms per cubic meter
$l/m^3$	Liters per cubic meter
Moisture Content	The moisture content (MC) expresses what is the weight of water relative to dry weight of object.
Resistance	The resistance announce the ability to resist the current
RFID	The RFID (Radio frequency Identification) is a short range radio technique, which consists of a tag and a receiver. A passive tag gets operating power from the receiver's signal.

# 1 INTRODUCTION

This Master's thesis has been made for the Oulu University of Applied Sciences. In Pirakko project the moisture of detached house building elements are researched. The moisture measurements are made during the building process and after that. The measurements are continuously made for example at every hour. The moisture needs to be measured inside concrete and wood elements. The measurement results will be sent to a mobile phone. For example the relative humidity (RH) needs to be less than 80% before a surface on concrete can be coated.

The aim of this Master's thesis project has to research the different electric circuits and methods of the moisture measuring. The topic included also studying measurement methods, analysing results and comparing our results to the results of commercial products. The basis of the moisture content measurements was the resistance measuring and capacitance measuring from the material. The measurement circuit needed to design to the concrete and the wood materials. When results were ready, then I needed to design the prototype for the Pirakko project. The measurement sensor had to be placed inside the concrete during the molding phase. After that the measurement of concrete was made. Then the concrete was dried and the measurement was made again, and so on.

I started to familiarize the topic by studying moisture measurement methods, units and electric circuits. This topic was very interesting and important, because the information volume of this kind of measurement was small. The Pirakko project needed this kind of information and measurement method in their project.



## 2 CONCRETE

The concrete is strong, long life and energy saving material. The concrete is massive and so it saves energy during it using. The concrete is recyclable material. Smashed concrete rubbish can be used as ballast and gravel layer of roads, where features of smashed concrete can be utilized. The concrete rubbish and process water can be used again in the concrete mill. There is not dissolved harmful compositions or discharges from the concrete. (Betoni, date of retrieval 9.11.2012)

The concrete is most popular building material in the world. The concrete is used in buildings, bridges, dykes and other infra structures. The concrete is strong and strength material and it needs not a lot of service. The concrete buildings spend energy during a life cycle. The concrete has good soundproof and fire safety. Raw materials of concrete are cement, water and sand (stone matter). The cement is manufactured mainly from chalkstone, which is one most used stone sort on the world. The concrete is very cost-effective building material. (Betoni, date of retrieval 9.11.2012)

The concrete is used 5 billion tons in every year. The concrete is used in trunk structure of buildings about 40% and façade about 15%. The concrete element can be implemented strength and economy façade conclusions. Building blocks and flagstones fit very good to independent building, because those are easy to move. Manufacturers offer a lot different concrete sorts for summer and winter building. (Betoni, date of retrieval 9.11.2012)

The infra buildings are different dikes, tunnels and bridges. The concrete fits very good to those, because it endures moisture, different weather, high temperatures and mechanical consumptions. The concrete endures stress from the ground better than other materials. (Betoni, date of retrieval 9.11.2012)

### 3 WOOD

Wood is a strong and light building material. It is stronger than any other building material according to its own weight. The heat insulation capacity of wood is about 400 times better than that of steel, 1,500 times better than aluminum and 12 times better than concrete. That is why humidity does not condense to the surface of wood and wood is comfortable in both cold and warm temperature. Wood expands only 1/3 compared to steel or concrete. The wood engorges to some extent, when it gets moist. As building materials, pine and spruce are dried, when moisture content is 15-25 %. Wood is a natural material and it can be returned to nature without damage. (Hyvä tietää puusta, date of retrieval 9.11.2012)

The pine and spruce sawn timber are sorted to quality classes A1-A4, B, C and D. A<sub>1</sub> class is the best and D<sub>4</sub> is the weakest quality class. Spruce is used to outdoor cladding because it becomes moist worse than pine. In a wood store miscellaneous qualities and sizes of wood building material are sold. (Hyvä tietää puusta, date of retrieval 9.11.2012)

The wood building material can be usually stored to outdoors but it must be covered from the sunshine, rain and ground moisture. The moisture can cause mildew and decay. Wood gets moist from concrete if it is in contact with it. Dry wood must always be used for building. (Hyvä tietää puusta, date of retrieval 9.11.2012)

## **4 HUMIDITY**

The humidity range in the open air in different seasons is large. In the summer the water vapour content can be even  $14 \text{ g/m}^3$  and in the winter less than  $1 \text{ g/m}^3$ . The humidity inside comes partly from outside. The humidity also comes from building process. The water vapour content indoors is about 1 . 4  $\text{g/m}^3$  bigger than outdoors. (Pärnänen 2011, 7)

The moisture of concrete fabric moves typically via the water vapour or liquid water. The water vapour moves with a diffusion or convection. The liquid water moves in a concrete fabric with the capillary and pressure effect of ventilation. The moisture of wood fabric moves the same way via the water vapor or liquid water. The wood becomes moist and dry fast from cut surface. (Pärnänen 2011, 7) (Kokko 1999, 26)

### **4.1 Relative humidity**

The relative humidity (RH) is a relationship of the water vapour pressure and the saturation vapour pressure in some temperature. It tells the percent of absolute moisture from the saturation moisture of current temperature. Dew point temperature is a temperature where air should cool down so that the saturation state will be reached. (Pärnänen 2011, 7)

### **4.2 Absolute moisture**

The absolute moisture is a relationship of the water vapour mass and the total volume of air. It is announced by water per kilograms. The unit is also used as grams of water per a cubic meter ( $\text{g/m}^3$ ). The upper limit of absolute moisture (saturation moisture) expresses how much water vapour can be in the air in every temperature. Warm air can include more water vapour than cold air. If there is evaporated water over saturation moisture in the air, then the water

vapour starts to condense into drops. The same happens, when air cools down and saturation moisture becomes lower. (Pärnänen 2011, 8)

### **4.3 Moisture in concrete**

The water in a concrete manufacturing is partly engaged chemically. A big part of engaging happens at the beginning of a strength progress. Even though concrete is engaged chemically to its final strength, it can be very moist. The drying will happen, when the physically engaged water evaporates from the concrete. The drying takes a long time when the relative humidity of concrete pores is the same as the relative humidity of the surrounding air. (Pärnänen 2011, 7)

When the concrete is molded, the relative humidity of its pores is 100% in the long time. The normal concrete (K-30õ 40) includes about 180 l/m<sup>3</sup> water in the manufacturing process. The concrete becomes dry fastest from the surface. The humidity, temperature and motion of the surrounding air affect the drying of concrete. There are three phases in drying concrete:

- 1) After the molding process, the drying happens via evaporation from the surface. The moisture inside is a capillary area. From there water moves to the surface via absorption.
- 2) The surface of concrete aspires to the same moisture that the surrounding air. During that, the evaporation limit moves deeper to concrete structure. Water moves capillary to the evaporation limit. Drying get slower when evaporation limit moves to deeper to concrete structure.
- 3) The concrete becomes dry deeper in places where water moves by water vapour in pores. Coating slows down the drying of concrete. In some cases when the coating is tight, the drying might be fully ended.

(Halsas 2007, 5-6)

#### 4.4 Moisture in wood

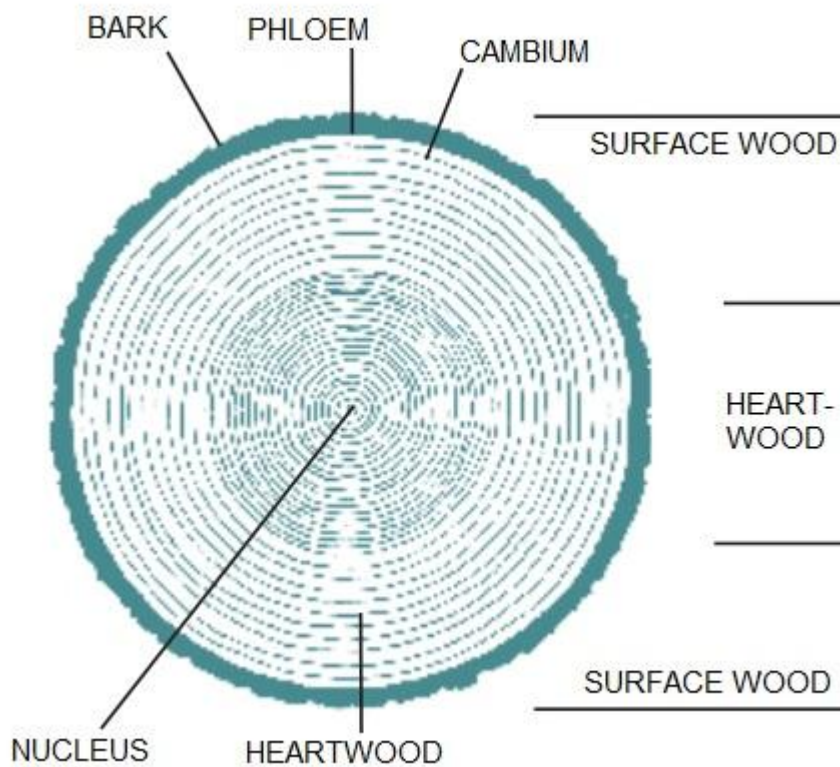
A specific strength of wood is good, even excellent. A cellular structure gives thermal insulation features for wood. The moisture features of the wood are positive and negative when wood is used. The wood can deliver and take moisture from the air, but this has been exploited pretty slightly in the moisture physics of structure. (Kokko 1999, 25)

The moisture is the most important thing for wood preservation. A tissue of wood surface has consisted during the growth by transporting water. Later, it changes to a heartwood and it does not transport water. Alive and just cut wood is wet and moisture of surface wood changes depending on wood, part of trunk and time of year. Usually, the moisture is 120-180%, that means about 500-800 l/m<sup>3</sup> water when the density of wood is 460kg/m<sup>3</sup>. The density of wood affects to the maximum moisture content of wood. It means that more water fits into thick wood than a cellular wood. The transporting of water happens in parts of surface wood. (Kokko 1999, 25)

The heartwood is usually notably dryer than the surface wood. The moisture content is on average 35-60%. The heartwood of pine differs from the surface wood also in composition. The heartwood of pine has accumulated different compounds. They are the reasons for the smaller moisture content, smaller permeability, and better rotten congestion of the heartwood. The wood cell structure of a spruce is different than that of a pine. The voids of spruce close very tight when it becomes dry. Because of that, the heartwood of spruce stays dryer. The quality and share of heartwood vary depending on wood, age and growth speed. (Kokko 1999, 26)

When wood becomes dry, water first exits from a cell lumen and after that from a cell wall. This is called the saturation point of wood cells. Then the moisture of pine and spruce is 30-35%. When wood becomes dry, water also exits from the cell walls and then the dimensions of wood change. The moisture can move in wood via capillary water or diffusion water vapour. The dimensions of wood increase or decrease, because the moisture content changes. (Kokko 1999, 26)

The moisture of wood follows the humidity of the surrounding air. The wood becomes moist best in a direct water contact when water is absorbed capillary into wood. The moisture does not damage wood but it undermines the strength of wood and thermal insulation. The changing moisture can also cause peeling off and transformation. The surface finishing prevents the moisture to get into the wood structures. (Kokko 1999, 26)



PICTURE 1. Structure of wood (Hyvä tietää puusta, date of retrieval 9.11.2012)

## **5 OFTEN USED MOISTURE MEASURING METHODS**

The moisture measuring of the structure has been developed by different measuring methods. They can be distributed to surface measuring and methods, as there is a need to break the structure somehow. These methods are a sample and a bore method. (Halsas 2007, 8)

### **5.1 Surface measurement**

The surface measurement gives an estimate from structure moisture, but not the real moisture of structure. The surface moisture is easy to measure with an electric moisture meter but the measurement method is noise exposed. Air bells, pipes and stainless structures in the concrete can cause noise to the measurement. (Halsas 2007, 9-10)

The measurement results of different surface moisture meters can differ from each other. The meters can report different values. The dispersion with the different surface moisture meters is large. The topography of concrete can also effect to the measurement result also. (Halsas 2007, 11)

### **5.2 Sample method**

A weighing drying method is a method which is based on samples. In this case the moisture of material is defined by a weight percent. In this method an oven is used to dry the material. The sample is weighted at times and dried again in the oven. The sample is dried totally dry and finally it reaches its real dry weight. After that the moisture content percent can be calculated. (Halsas 2007, 8)

In a calcium carbide method the moisture reacts with a calcium carbide and the pressure rising in a measurement container. The pressure is compared to table figures. An issue is that the figures of different concrete types are not available. (Halsas 2007, 8)

### **5.3 Bore method**

The measuring of a bore method is measured from a bore, which is drilled to the concrete structure. The moisture sensor is set to the bore and a plug to the meter, so that the temperature and relative humidity can be read. The drilling needs to be accomplished so, that it does not damage any heating cable or water pipe. The measurement result is presented by a relative humidity (RH). (Halsas 2007, 9)

The relative humidity measurement is recommended to be made at least three days after the drilling. The bore method is used to find out if it is possible to coat concrete. It is also used to check a moisture damage in old structures. (Halsas 2007, 9)



## **6 ELECTRIC MOISTURE SENSORS**

An electric moisture measurement method gives a moisture content estimate of a fabric fast and accurately. The most used moisture meters are typically resistive or capacitive (dielectric) meters. The knowledge of the usual temperature is needed when the measurement is done. (Swafford 2011, 12)

### **6.1 Resistive moisture sensor**

The resistive moisture meter usually uses pin type electrodes that measure the resistance between each other. Typically a polymer or a suitable salt in the element is used when its resistance is measured. The accuracy of the resistive sensor is about 3% RH. The advantages of resistive sensor are cheap price and small size. The disadvantages of resistive sensors are accuracy, sensitivity and dependence on temperature. (Ilvonen 2011, 6)

### **6.2 Resistive moisture meter circuit**

The material has a certain resistance that depends on moisture. The voltage divider is a basic linear circuit which divides the voltage between material and a reference resistor. In here (figure 1.)  $R_{ref}$  is the reference resistor and  $R_{material}$  is the resistance between the electrodes which are in the material. An operation amplifier operates like a buffer that gives the voltage of  $R_{material}$  from its output. (Swafford 2011, 15-16)

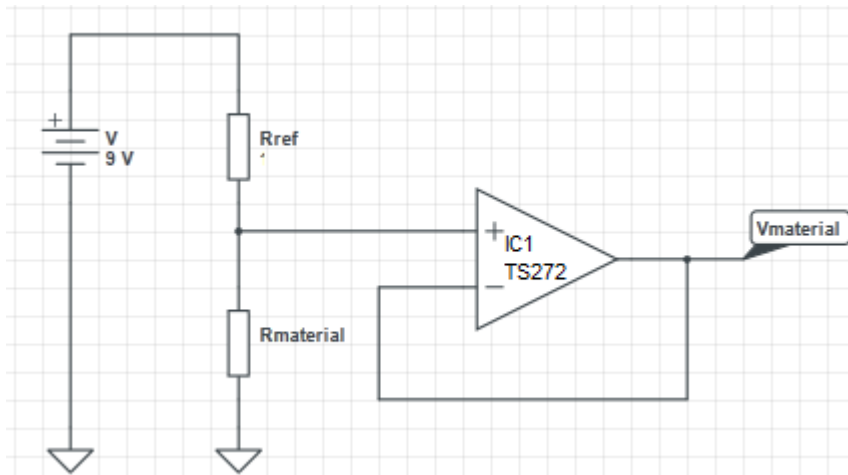


FIGURE 1. Resistive moisture meter circuit

The input voltage  $V$  (9V) and current affects through the  $R_{ref}$  and  $R_{material}$ . The current is same through both resistances, the voltage is divided to resistances which follow the Ohms law. (Swafford 2011, 16)

FORMULA 1. Formula for voltage division

$$V_{material} = V * \frac{R_{material}}{R_{ref} + R_{material}}$$

When the moisture of the material is high, the material conducts very well. Then the resistance of the material is small and  $V_{material}$  low. When the moisture of the material is low, the material conducts badly. Then the resistance of the material is large and  $V_{material}$  is large.

### 6.3 Capacitive moisture sensor

The capacitive moisture sensor consists of two plates which are near each other and between them is an insulator. The relative permittivity of the intermediate plates and their capacitance depend on the moisture of dielectric. The capacitance of a sensor changes very linearly according to the relative humidity. Typically 1% change in the relative humidity responds to 0.2 . 0.5 pF change in the capacitance. The advantages of capacitive sensor are cheap price, small size and large temperature area. (Ilvonen 2011, 5)

## 6.4 Capacitive moisture meter circuit

A basic capacitor consists of two conductors separated by a non-conducting or dielectric material. The capacitor equation is given below. (Swafford 2011, 17)

*FORMULA 2. Formula for Capacitance*

$$C = \epsilon_r * \epsilon_0 * \frac{A}{d}$$

Where

A = area of the one conductor,

d = distance between the two conductors,

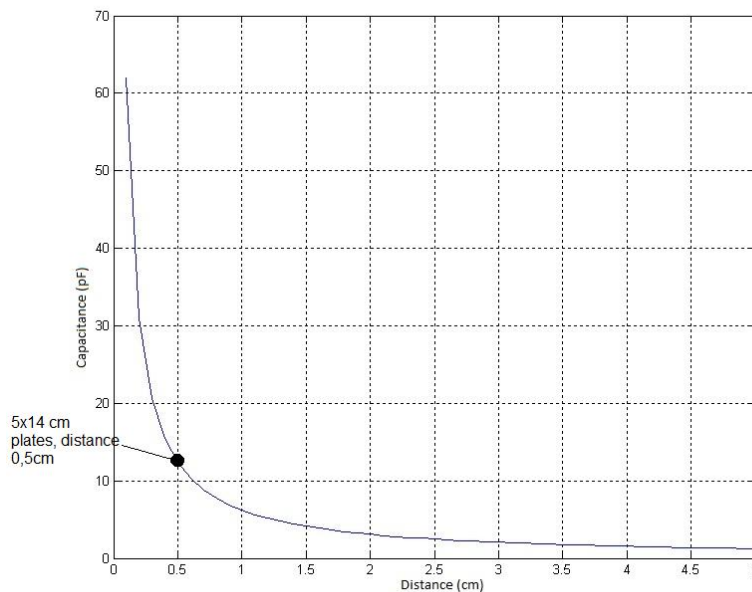
r = relative permittivity of the material,

$\epsilon_0$  = electric constant ( $8.854 \times 10^{-12} \text{ Fm}^{-1}$ ).

Example:

Capacitance between 5x14 cm metal plates, distance 5 mm

$$8.854 * 10^{-12} \text{ Fm}^{-1} * \frac{0.05\text{m} * 0.14\text{m}}{0.005\text{m}} = 12\text{pF}$$



*FIGURE 2. Theoretical capacitance between two 5x14 cm air isolated plates*

The sensor consists of two conductive pads. They are side by side and the insulating material is between those pads. When the moisture of the insulating material changes, then the dielectric constant changes between the pads, too. For example, the capacitance between two plates is about 12pF. The capacitance between real plates was measured with a Fluke PM6304 meter and the capacitance was approximately the same. (Swafford 2011, 17)

The circuit (figure 3.) works like an inverting amplifier, where input voltage is a sine wave signal. Input impedance is the moisture sensor and feedback impedance is a known capacitor. As the moisture of the material changes, then the capacitance of the sensor changes, too. Input impedance changes, amplification changes and  $V_f$  of circuit changes.

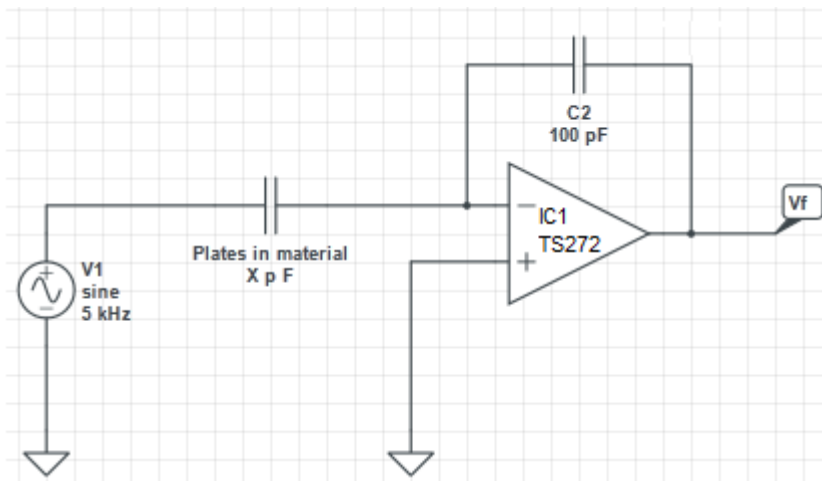


FIGURE 3. Capacitive moisture meter circuit

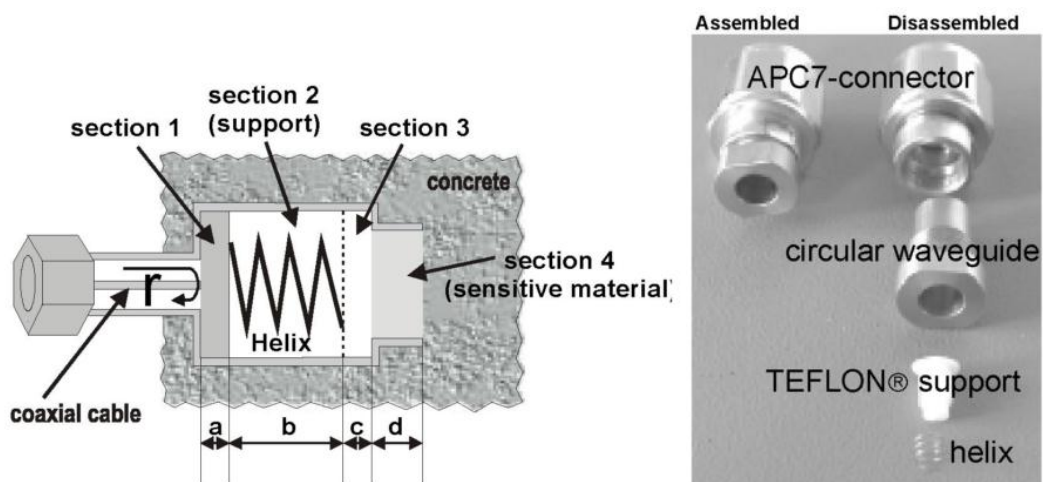
## 7 OTHER MOISTURE SENSORS

In this chapter some other moisture measurement sensors are presented. There are some new innovative concrete moisture sensors found in the internet. In this chapter a resonant moisture sensor and a Sensible Solution company's TwinTag moisture sensor are introduced.

### 7.1 Resonant moisture sensor

The resonant moisture sensor is based on a circular waveguide which is filled with a sensitive material. A wire helix is mounted at the defined position within the circular waveguide. The waveguide is connected to a standard coaxial cable that allows an operation at any frequency within a broad band. The second end is left open so there is a contact with the surrounding material. (Jannsen 2001, 1-2, date of retrieval 1.12.2012)

The resonance frequency of a sensor changes when the moisture changes. For example in this case the resonance frequency for 0% relative humidity is 2,28GHz. The resonance frequency decreases with the increasing moisture. (Jannsen 2001, 1-2, date of retrieval 1.12.2012)



PICTURE 2. Resonant moisture sensor (Jannsen B., date of retrieval 1.12.2012)

## 7.2 RFID moisture sensors

There are moisture sensors in the market, which are developed with RFID. One interesting product is TwinTag, which a Swedish company Sensible Solutions has developed. It works so that two RFID tags are incorporated into one TwinTag sticker. The first tag is an antenna, which is sensitive to moisture. The second tag has a non-sensitive antenna. The sensitive tag absorbs moisture and the input impedance of the antenna changes. (Sensible solutions, date of retrieval 28.11.2012)

The moisture is read from the tags with a reader device. The system works with a passive RFID technology, so sensors do not need batteries. The sensors get power from a radio signal of a reader device and the tags have a very long operational lifetime. The reading distance is about 0.5 meters, depending on the material between the sticker and the reader. (Sensible solutions, Moisture indicator by Sensible Solutions, date of retrieval 28.11.2012)



*PICTURE 3. Sensible solutions moisture tags and reader (Sensible solutions, date of retrieval 28.11.2012)*

## **8 MOISTURE MEASUREMENT TESTS**

The moisture measurement tests were started with wood and sand. The resistive and capacitive measurements were done for both materials. The moisture with real moisture meters was measured from the wood and concrete later. Then the resistance between electrodes was measured. The electrodes were in the concrete and wood. With this test it was found the approximate resistance range.

### **8.1 Resistive measurement tests**

The resistive test was made for the wood and the sand. The moisture was measured with real moisture meters from the wood and the concrete. With this test it was found approximate resistance range.

#### **8.1.1 Resistive measurement for wood**

In this test a piece of wood with two nails was immersed in the water and left there for about 20 hours. Dry wood become moist, when it was immersed in the water. When it was taken off from the water, it was moist and there was some resistance between the nails. The wood started to become dry and the resistance between nails increased. The figure 4 presents the resistance of drying wood. Drying was happened in a room temperature. The resistance is presented in  $M\Omega$  and time in minutes.



PICTURE 4. Two pins in a piece of wood

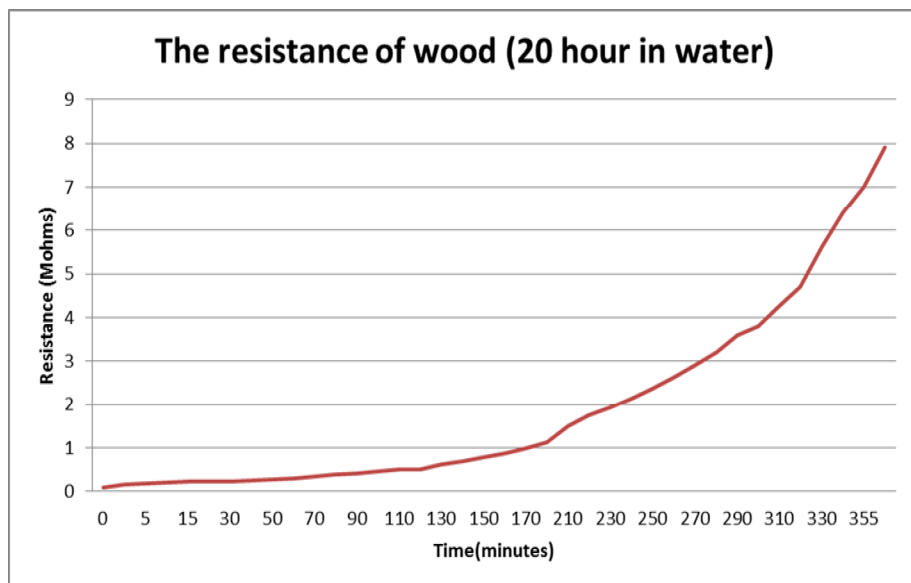


FIGURE 4. The resistance between nails which are in drying wood

### 8.1.2 Resistive measurement for sand

The moist sand was in a container. Two nails and metal plates were put about 2 cm away from each other. Dry sand started to become moist, when it was outdoors in the moist open air. When the sand was brought indoors and put into a covered container the moisture became steady. Some time ago the cover was removed and the nails and metal plates were put into the sand. The sand was moist and there was some resistance between the nails and plates. The sand started to become dry and the resistance between the nails and plates increased. The figure 5 presents resistance of drying sand. Drying happened in



a room temperature. The resistance is presented in mega Ohms and time in minutes.



PICTURE 5. Measurement setup

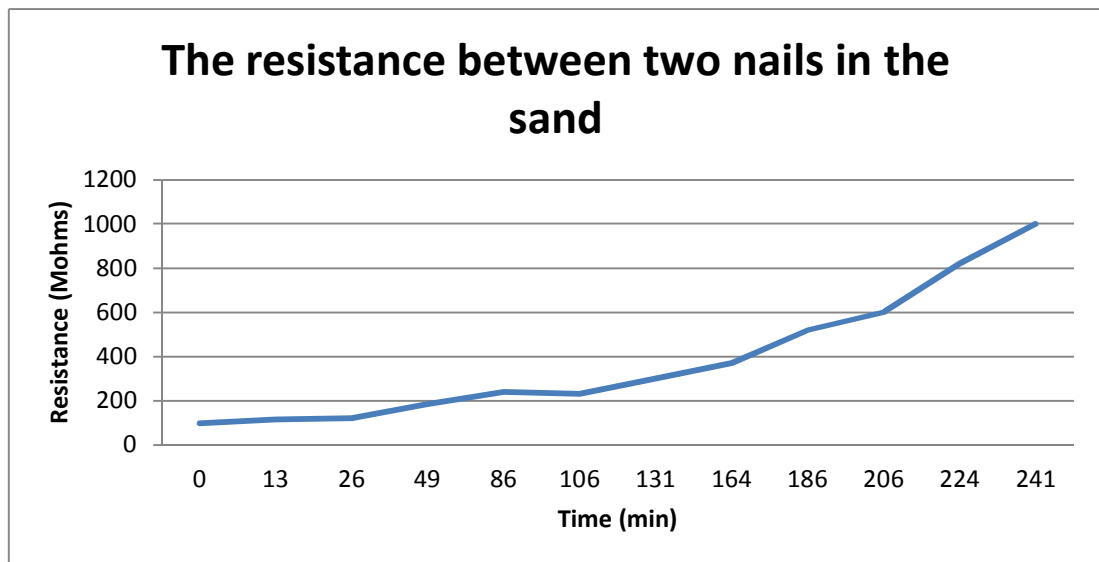


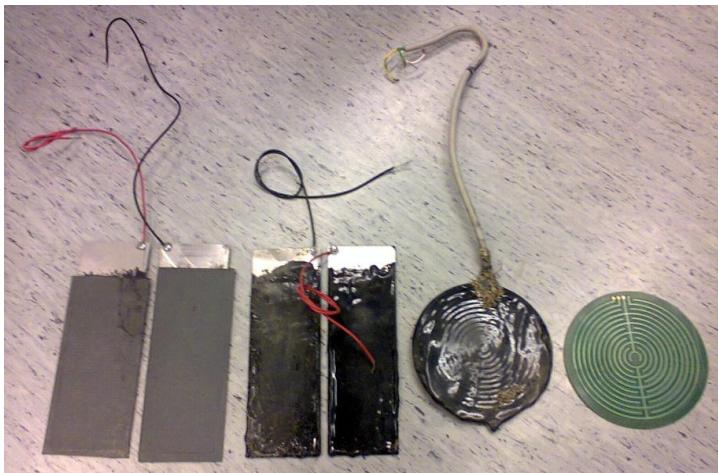
FIGURE 5. The resistance between nails which are in drying sand

The resistive measurement was made for a very moist sand, too. The nails and plates were put into a container same way like before. The start resistance value between the nails was 130k $\Omega$  and between the plates 90k $\Omega$ .

## 8.2 Capacitive measurement tests

In capacitive measurement tests two different sensors were used. The sensors used were two metal plates and a sensor that had been manufactured from a

printed circuit board. The circuit board sensor model was found in the Internet. The capacitive sensors must be coated by a dielectric material. Different coating materials with a capacitive measurement were tested. The used coating materials were an electronic lac, a thin gum mat and a flexible conveyor belt repair material. The tests were started with the electronic lac, but then it had to be changed to better solutions because the electric lac did not endure in the concrete.



*PICTURE 6. Sensors with different coatings*

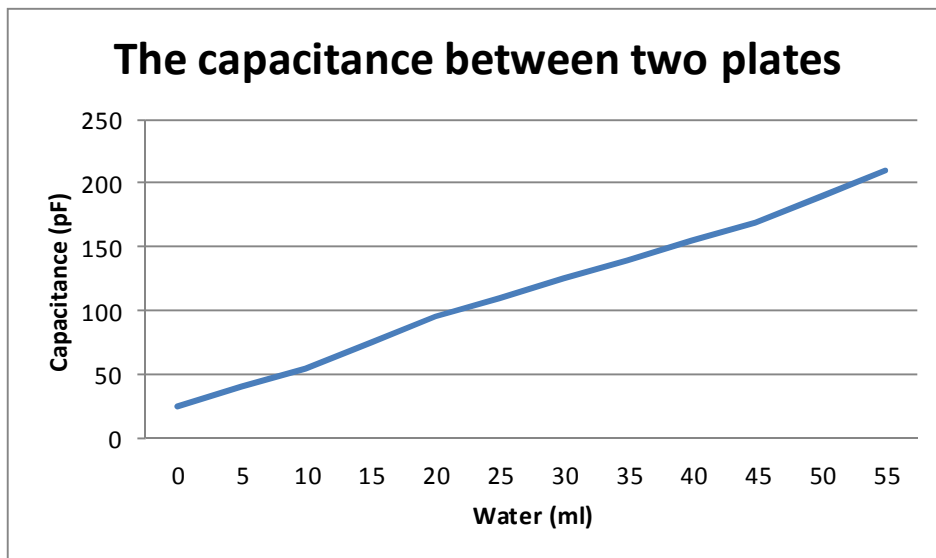
### **8.2.1 Two metal plates**

In first case two metal plates were used as a moisture sensor (picture 7.). The plates operate like a capacitor, the capacitance of which changes when the moisture changes between them. At the beginning sand was almost dry, then the moisture started to increase.



*PICTURE 7. Measuring setup*

A transition of capacitance was measured with a Fluke PM6304 meter. The measurements were accomplished for two plates with a thin gum mat coating (figure 6.) and plates with a flexible conveyor belt repair material. The sensors were placed into the dry sand then the sand was moistened and measured.

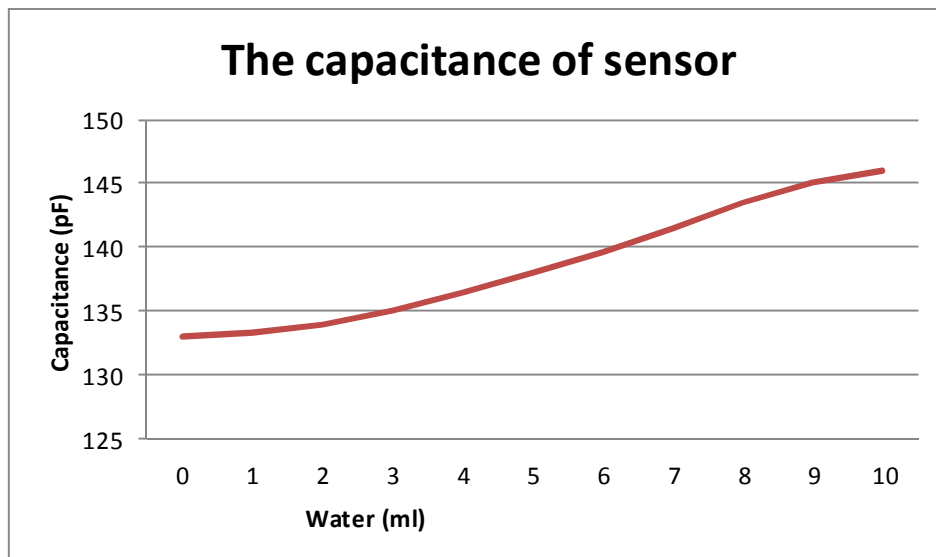


*FIGURE 6. The capacitance between two plates with a thin gum mat coating*

### 8.2.2 Printed circuit board sensor

In the second case it was used a moisture sensor, which was made from a circuit board with the conveyor belt repair material coating. In this test the dry sand was put on the sensor and then the sand were moistened and measured.

The transition of capacitance between the plates was very much bigger than with the circuit board sensor. So in this case the two plate sensors seemed to operate better than circuit board sensor.



*FIGURE 7. The capacitance of the circuit board sensor with a conveyor belt repair material coating*

### 8.3 Moisture and resistance

Those tests were created in order to know the resistance range of moisture measuring for wood and concrete. The moisture was measured with a real moisture meter and then the resistance was measured with two electrodes in the material.

### **8.3.1 Moisture and resistance in the wood**

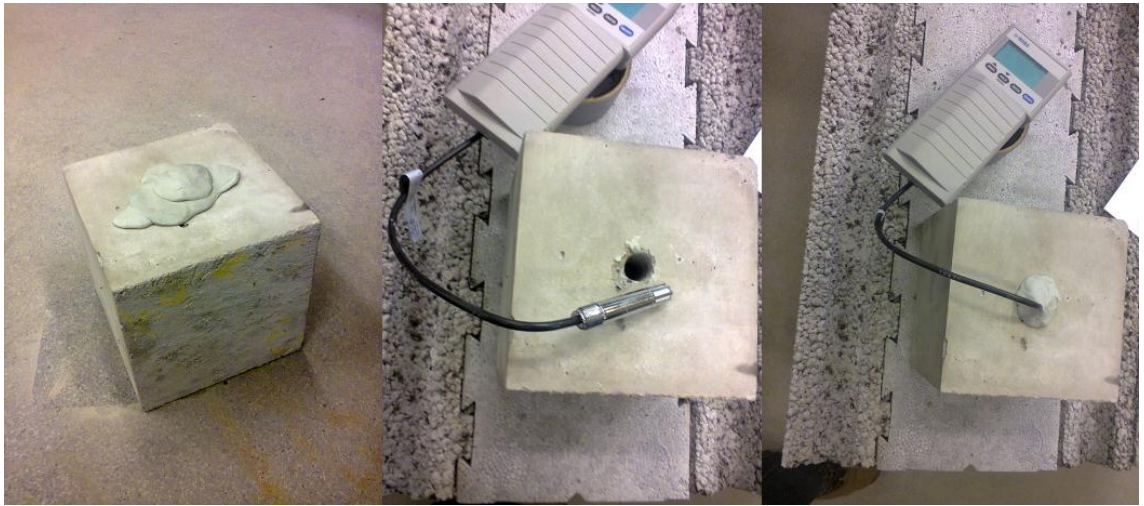
In this test a 2x4 inch plank was used. It is used in building worksites. The moisture was measured with a Gann RTU600 meter and a ram-in electrode M18 sensor. The measured value was 23,4 . 25,6 %. The resistance measuring was made between two nails, which are in wood at 2cm distance. The measured resistance was 396kô .

### **8.3.2 Moisture and resistance in the concrete**

In this test a molded concrete object was used. The moisture was measured with a Vaisala HMI41 meter and a Vaisala HMP44 sensor. A bore method was used as a measuring method. The measured value was RH 73,8%. The resistance measuring was made between two screws, which are in concrete at 2cm distance. The measured resistance was about 20kô .

### **8.3.3 Measuring with bore method**

The measuring with the bore method is made so, that a bore is drilled to the concrete. After that the bore needs to be cleaned and tamped. The moisture needs to become steady in the bore, so it is necessary to wait for 3-5 days. Then the moisture can be measured with the moisture meter. A sensor is put to the bore and tamped to the bore tight. After three hours the meter shows the confident moisture (relative humidity) value.



*PICTURE 8. Moisture measuring from concrete with a bore method*

## 9 MEASUREMENTS FOR WOOD AND CONCRETE

The measurements for wood and concrete were made, where the resistance and the capacitance of them were measured. The wood and the concrete objects were measured with real moisture meters and their weights were monitored, too. With those measurements the resistance and capacitance values for the every moisture content were found.

### 9.1 The commercial moisture meters and sensors

The Rotronic HygroPalm23 is a moisture meter, with which different moisture sensors can be used. In the concrete measurements it was used the bore sensor, which measures the relative humidity (RH) from the bore.

The Tramex CMEX2 is a moisture meter, which is used with different building materials for example with concrete and wood. The moisture measuring from the concrete is accomplished so that the meter is placed on the concrete surface. The moisture measuring from wood is possible with a Tramex HA21SP52 pin sensor. The pins are nailed to wood and the meter gives a moisture figure. This meter works with a resistive method.

The Gann Hydromette RTU 600 is a moisture meter, with which different moisture sensors can be connected. In this work the meter was used for measuring the moisture of wood. For the wood measuring it was used a Ram-in electrode M 18 sensor (picture 9.), which works same way that Tramex HA21SP52.



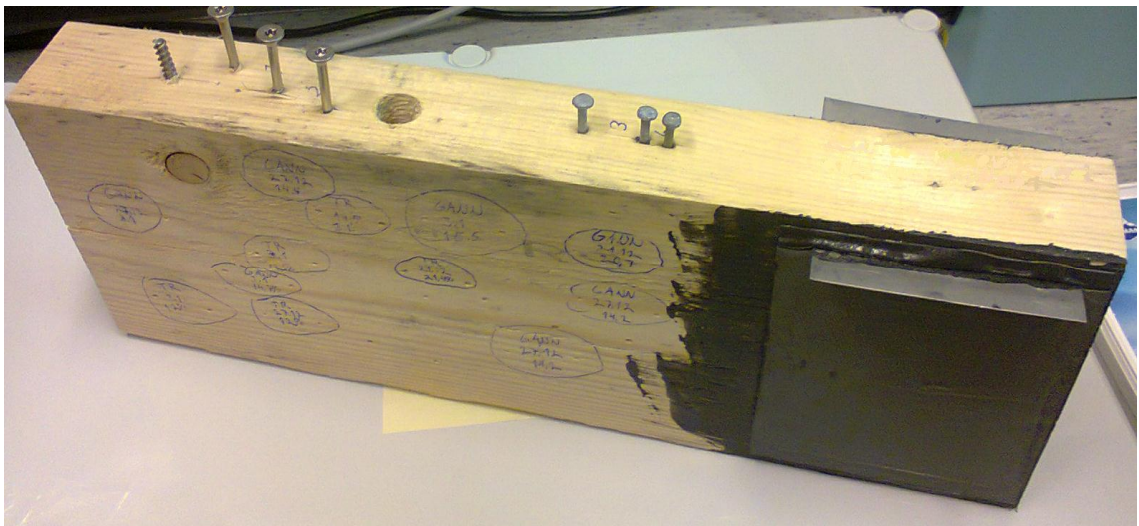
*PICTURE 9. The Ram-in electrode M 18 pin sensor (GANN . Moisture Measurement. Ramm-Elektrode M18. date of retrieval 11.2.2013)*

## 9.2 Measurements for wood

For the wood measuring it was used a plank, which was two inch in width. To the plank were fixed two metal plates with the glue and the plates were isolated with a thin gum mat. The plates measure the capacitance between them and their dimensions were about 8x12cm. The capacitance will change, when the moisture content changes. (picture 10.)

For resistance measurements the two nails and the two screws were set in the wood. The screws and the nails were screwed and nailed about 6cm deep. The screws and the nails measure the resistance between them. The resistance will be changed, when the moisture content will be changed. (picture 10.)

The plank was also measured with pin moisture meters and the weight was monitored during the measurements. Finally, the plank was dried absolutely dry, and then its dry weight was received.



*PICTURE 10. The wood moisture measuring test object*

At the beginning the moisture of the plank was raised by watering it. The moisture was apportioned in a constricted locker after watering. Then the measuring and the drying were started, until the wanted moisture was reached.



### 9.2.1 Results of wood measurements

The figure 8 presents the resistance between the screws, when the moisture content changes in the wood object. The resistance was measured between two screw pairs. Both diagrams are very near each other and so the results are very good and reliable.

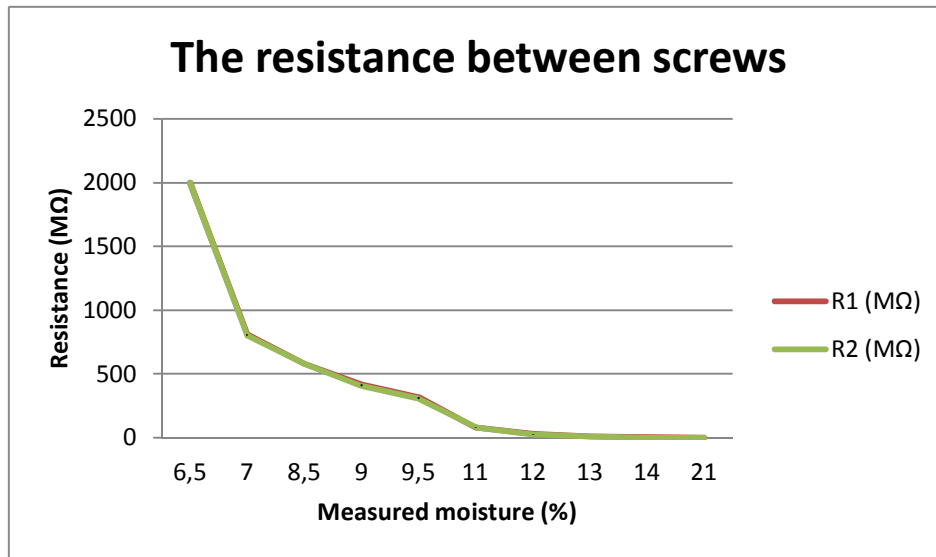


FIGURE 8. Resistance between screws

The figure 9 presents the capacitance between the plates, when the moisture content changes in the wood object. The capacitance was only measured between one plate pair and the capacitance values were very small, when the moisture content was less than 15%.

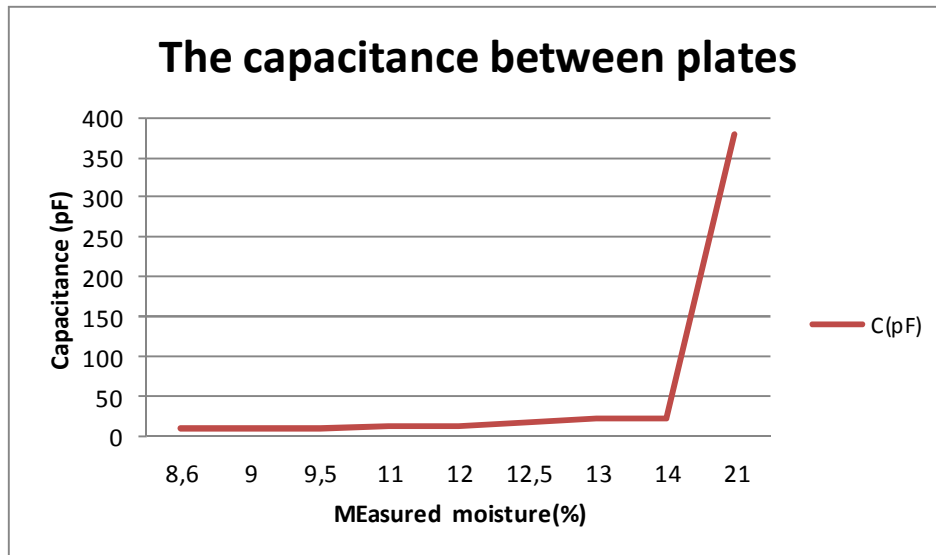


FIGURE 9. The capacitance between plates

### 9.3 Measurements for concrete

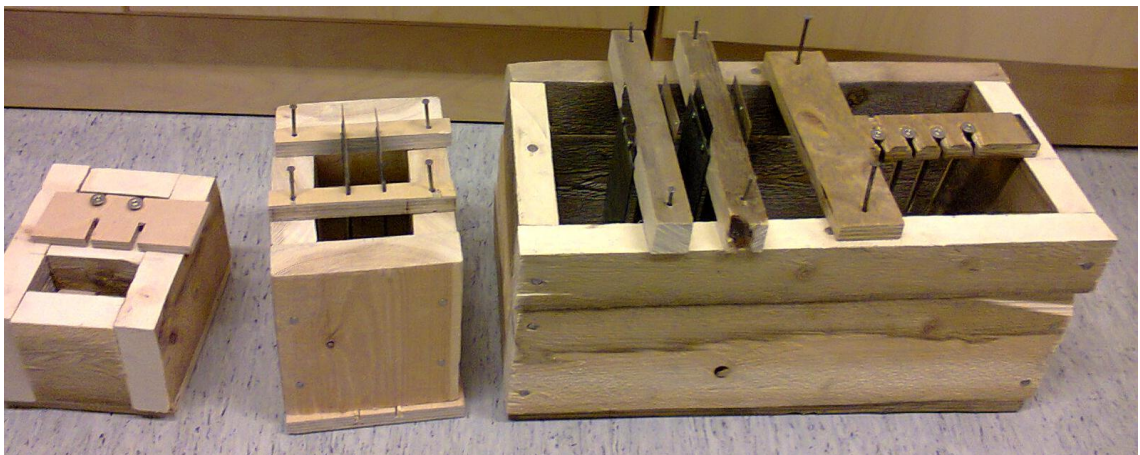
The concrete object was molded for the concrete measuring, where two metal plates with the gum mat coating were placed in the mold. The metal plates capacitance was measured in the same way as from the wood. The plates were between 2cm distance in concrete mold and the dimensions were about 5x11cm.

For resistance measurements the two screws were put in the mold. The screws were placed about 6cm deep and the resistance between them was measured. The resistance will change, when the moisture content changes.

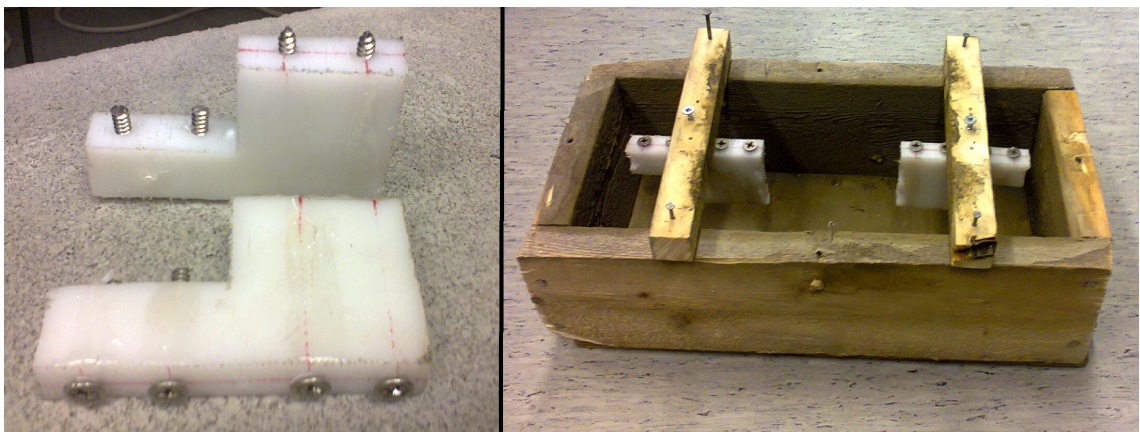
To the concrete was also drilled a hole for the bore sensor for the relative humidity (RH) measurement. The concrete object was weighed every time when measurements were done. The concrete object was dried absolutely dry at the end. Then its dry weight was received.

### 9.3.1 Concrete test object molding

The concrete objects were molded to casts, which were self-made from wood. The metal plates and the screws were in a holder, which kept them in place. The concrete was molded to one bigger cast, where many sensors were set. Also, the concrete was molded to smaller casts which are the final sensors. (picture 11.) In another test mold it was used screws, which were screwed to plastic object. Those screws measured the resistance from 2cm and 5cm deep. (picture 12.)



PICTURE 11. The molding casts



PICTURE 12. Another resistive screw sensor and the molding cast

The sensors needed to be weighed with a scale, before they were put to the concrete mold. When the test object was weighed, then the sensor weight

needed to subtract from the weighed result. The weight of a screw was 4g/piece and the weight of metal plate was about 48g/piece. (picture 13.)



*PICTURE 13. The sensor weighing*

The concrete molding was made by the Vetonit S-100 dry concrete. The molding needed to be accomplished so, that there is no air cavities in the mold. (picture 14.)



*PICTURE 14. The concrete molding*

The casts were demolished next day after the molding. The measurements started immediately after that. Below there are the sensors and test concrete objects. (picture 15.)



*PICTURE 15. The test concrete objects and the sensors*

### **9.3.2 Results of concrete measurements**

The figure 10 presents the resistance between the screws, when the relative humidity changes in the concrete object. The resistance was measured between from four screws pairs. The diagrams R1 and R4 show the measured resistance from 2cm deep and the diagrams R2 and R3 show the measured resistance from 5 cm deep. It is seen in the figure 10, that concrete dry faster near the surface.

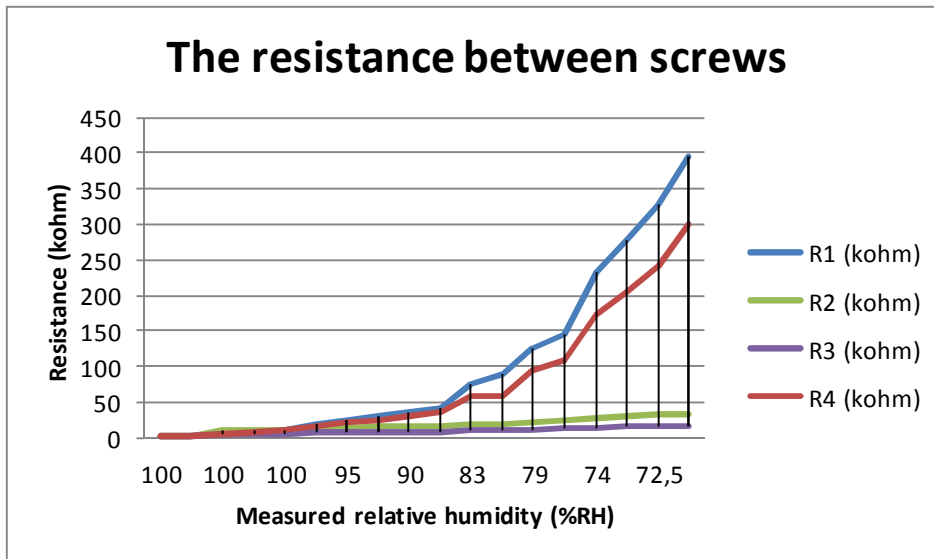


FIGURE 10. The resistance between screws

The figure 11 presents capacitance between plates, when relative humidity changes in the concrete object. The capacitance was measured between from three plate pair and diagrams of capacitance follows a same shape.

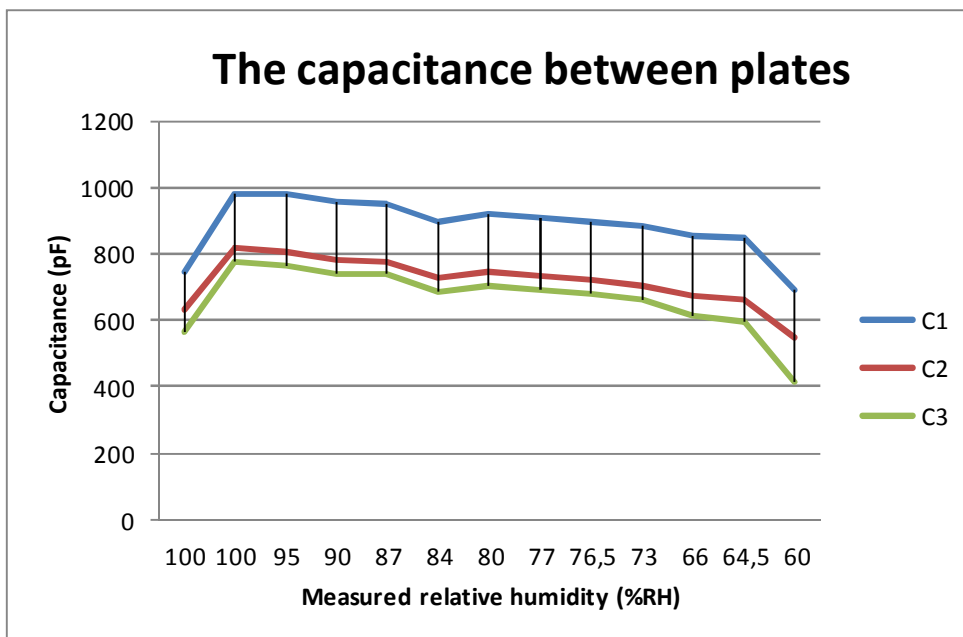


FIGURE 11. The capacitance between plates

## **10 CONCLUSION**

The aim of this thesis was to research different moisture measuring methods and design a prototype device for moisture measurement. In this thesis were utilised the learnt things from measurement technology and electronics. The thesis included things of mechanics and building technology, too.

This thesis work was started in October 2012. At the beginning the features of concrete, wood and different methods of moisture measuring were familiarized. Next the measurement methods with sand and wood were tested. Finally, the tests for drying wood and concrete were accomplished. In the tests, official reference meters and the monitored weight of objects were used.

As a result, the methods to measure moisture of the wood and the concrete were achieved. The aim of the thesis was reached. The designed sensors are cheap to manufacture and they are sufficiently accurate. The sensors can be placed to any concrete structure for example to the floor or even to the bridge. In addition, some other methods to measure moisture of concrete were found. Those methods were also presented in this work.

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PICTURE 2. Janssen B & Jacob A. A miniaturized resonant moisture sensor.  
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PICTURE 3. Sensible solutions. Moisture indicator by Sensible Solutions. date  
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