XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Wireless in situ measurements of moisture content and temperature in timber constructions

Karin Sandberg[1]
Anna Pousette [2]
Simon Dahlquist[3]

T12

ABSTRACT

The aim of this article is to report on experience from a continuous wireless in situ measuring system. Today more than 600 sensors have been installed in wooden structures (beams, posts) and buildings at several sites for various research projects in Sweden. In order to measure a large amount of data, a wireless monitoring system was chosen with gateway connected to a GSM modem that sends the information to an Internet-connected computer database from whence it is transferred to the users. A wireless system is a comparatively cheap system and is easy to install, since there is no need of wires. When the plans for continuous measurements started, this was a relatively untested system, and experience from large scale measurements was limited. The purpose of the measurements is to verify models for prediction of long-term durability of wooden structures and wooden buildings based on periods of surface wetting, on moisture conditions related to climatic loads, coatings, wood processing and design and from the position inside walls or floors. With wireless HygroTrac sensors, relative humidity can be measured in the range of 10% to 90% ±2.5%, temperature can be measured with an accuracy of ±0.5°C at 25°C and moisture content in the range of 8% to fiber saturation point (FSP) ±1%. After nearly two years of measuring with the wireless system, the following experience was gained: the sensors was easy to set up and build in, some problems with the operation of the devices and the need for restarts after power failures; the effective range from the gateway to the sensors needs to be depends on the individual building construction.

KEYWORDS

E Wireless sensors, Temperature, Moisture content, Relative humidity, In situ measurements

[1] SP Technical Research Institute of Sweden (SP Trätek), Skellefteå, SWEDEN, karin.sandberg@sp.se
[2] SP Technical Research Institute of Sweden (SP Trätek), Skellefteå, SWEDEN, anna.pousette@sp.se
[3] SP Technical Research Institute of Sweden (SP Trätek), Skellefteå, SWEDEN, simon.dahlquist@sp.se

1 INTRODUCTION

ervice-life assessments and life cycle costs are becoming gradually more important in the investment and planning of construction works. Durability is consequently essential for all outdoor structures where a long life is preferred to control costs. The ability of a construction to resist degradation depends on its materials and design, on maintenance and on the surrounding environment. For wooden structures in outdoor environments, such as bridge beams and columns, it is important for safety reasons to be able to determine when they can no longer carry the intended load and when actions are needed to repair damage. Decay reduces strength and is thus a factor to consider, but such other factors as cracks also influence service life. Large cracks can hold water and dirt that are favorable for the growth of microorganisms. A field test with beams and columns studies the effect of cracks and the prolongation of the life of structures [Pousette & Sandberg 2010].
There have been many attempts to make models to predict durability from different points of view. For instance, there are models based on laboratory tests to predict mould growth [Viitanen 1997a,] or decay [Viitanen 1997b]. Brischke & Rapp [2008] have a dose-response model based on fungal decay in field test sites above ground. To examine how geographic locations affect the construction, there are models that take climate data and exposure conditions into consideration as well [Isaksson *et al.* 2009, Viitanen *et al.* 2010, Häglund *et al.* 2010]. Van de Kuilen [2005] has made service-life predictions from existing structures. Foliente [2002] gives an overview of different approaches to durability design in wood construction and describes an Australian approach to developing an engineering tool as a method for durability design.

Woodbuild is the name of a research program in Sweden with the goal of developing engineering tools that can be used in the planning and design of timber structures with regard to service life. These tools will be based on computational models. The long-term durability of wooden structures depends mainly on moisture conditions in combination with temperature and exposure time. Climatic data and exposure conditions will be used as input in the models to calculate moisture content and risk of decay. The purpose of the in situ measurements is to verify such models for many different situations based on the duration of surface wetting, moisture conditions dependent on climatic loads, coatings, wood processing and design and the position inside walls or floors.
To verify models or provide a basis for assumptions, measurements on real test items may be necessary. In situ measurement tends to be difficult and expensive. For the purpose of making numerous measurements, a wireless system can be an alternative because it is cheap and the test objects can be transported with the probe inside, thus avoiding a tangle of wires. The disadvantages are that these systems have not been thoroughly tested on a large scale, nor is it certain how well the technologies withstand weather conditions and use. Today, more than 600 sensors have been installed in wooden structures (beams, posts) and buildings at several sites for different research projects in Sweden. In order to cover as many parameters as possible, there will be many measurements. In order to capture a large amount of data, a wireless system was chosen. To keep track of all the data, they are registered in a database. This is the first time this system has been used on this scale, which would have been impossible just a few years ago. But the developments of sensors together with access to GSM and internet have changed that. The aim of this article is to share experiences and solutions to difficulities that might arise during continuous measurement of moisture content (MC), relative humidity (RH) and temperature (T) with a wireless on-site measuring system.

2. MATERIAL AND METHODS

For continuous measurement of moisture content (MC,%), relative humidity (RH,%) and temperature (T,°C) in wood constructions, wireless sensors and the OmniSense Facility Monitoring System (FMS**)** [OmniSense 2010] were used. The sensors send measured values to a gateway connected to a broadband socket or GSM modem that sends the information further to an Internet-connected computer database. Through a website, data were transferred to a private database, and then measured data were compensated for wood species and temperature and transferred to the researchers or users.

2.1 Sensor

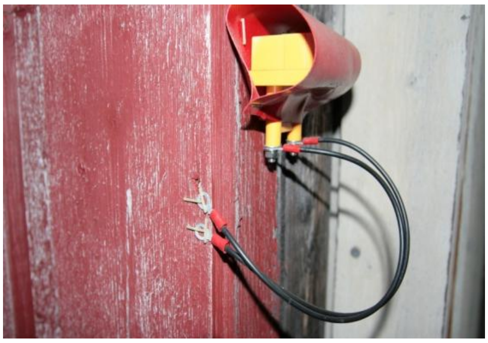
Protimeter HygroTrac sensors S-900-1 from General Electric [General Electric 2010] were used for registering MC, RH and T. The sensor dimensions are length 60 mm, width 30 mm and height 60 mm. The sensors have a lithium battery with 15 years' nominal battery life when reporting hourly. Transmission frequency was 868 MHz (EU). All sensors were delivered with a unique ID number for identification in the database.

The sensors measure relative humidity (RH) from 0% to 100% (noncondensing) with an accuracy of ±2.5% in the range of 10% to 90%. The range of temperature measurement is from -40°C to 85°C, with an accuracy of ±0.5°C at 25°C. In this case, the sensors have been controlled by OmniSense [OmniSense 2010] using an ESPEC LTU-112 humidity chamber and a General Eastern Optica chilled mirror reference. The sensors have been tested at 25°C and RH 50% and 85% to verify that they meet or exceed their specified accuracy of RH ±2.5%. The measurement range for moisture content was from 8% to fiber saturation point (FSP) with an accuracy of ±1%. The values are not correct for wood species, but are for temperature. Above FSP, there are values that showed some dissolution, but these have not been calibrated.

Measurements have been performed at the surface and at depths of 5 mm and 15 mm into the wood. To make it possible to measure the moisture content at different depths, the original screws were replaced with stainless steel nails (see Fig 1a). These nails were provided with shrink tubing as insulation to mimic the much more expensive gauge used with hand-held electrical moisture meters. The nails used were 35 mm long and had a diameter of 2.5 mm. The tip design was similar to the special measuring gauges and the tip had a depth of contact of 3 mm.

The sensors for surface moisture measurements have been equipped with ring terminals that have been attached to the surface with plastic clamps (see Fig.1b).

a)



b)

Figure 1. a) HygroTrac sensor nail b) Ring terminals that have been attached to the surface with plastic clamps.

2.2 Data transmission

In this work, each measurement point contained three values: T, RH, MC. The sensors were activated once an hour, and they sent data to a gateway FMS G-900-E from General Electric [General Electric 2010]. The distance between sensors and the data acquisition gateway was about 50 to 100 m. Fig. 2 shows the data distribution system used.

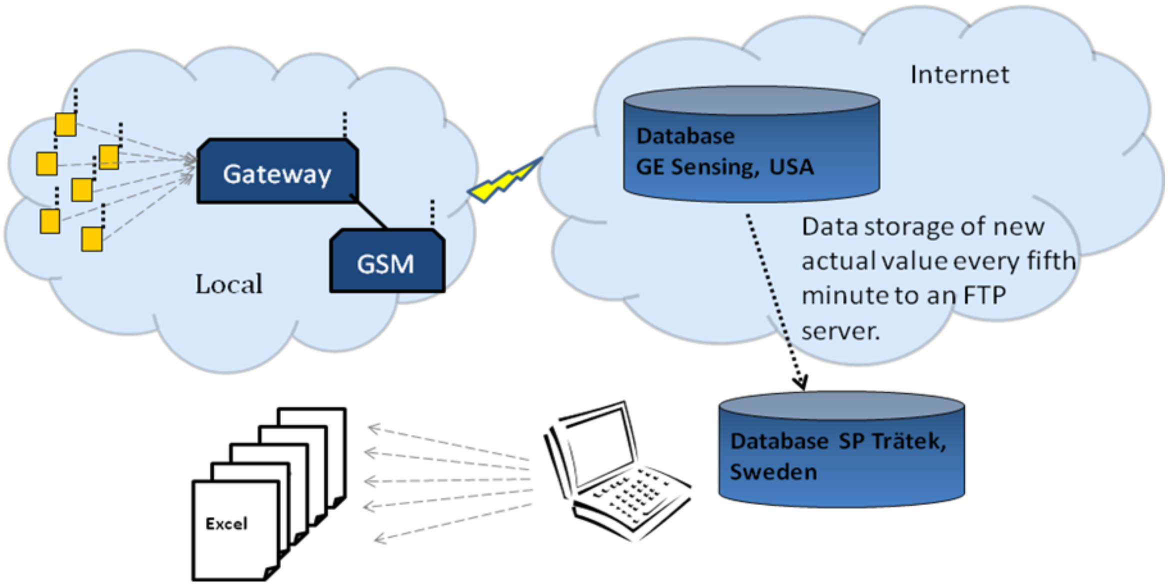


Figure 2. Data distribution schema. Data were transferred from wireless sensors to a gateway that collected and sent data to GE Sensing database through GSM. From the central database, data were sent to a local database where measured data were compensated for wood and temperature and sent via email to the user.

The data-acquisition gateway buffered data from the HygroTrac sensors and delivered measurements to a database provided by the manufacturer via local area network (LAN) when online. The LAN was connected to the Internet via Option GlobeSurfer X.1 Wi-Fi Cradle [Dustin 2010] using the 3G mobile connection standard. The sensors entered energy-saving mode between each transmission. Every 5 minutes, new measurements were exported as an xml file to an FTP server provided by SP. Data from these xml files were inserted into a private database specially developed by SP Trätek (SP Technical Research Institute of Sweden). In the SP Trätek database, additional parameters such as wood species, measurement depth, the four cardinal points, placement in wall, system of beams, floor, roof, *etc.*, were specified for each sensor. The sensors are searchable in the database due to these different parameters. Moreover, it is possible to attach drawings and photos to sensor data that show the orientation and location of the sensors.

When measured data were exported from the SP Trätek database to a user (researcher), each wood humidity value was compensated for wood species, *i.e.*, pine (*Pinus sylvestris*) and spruce (*Picea abies*) and for temperature according to Samuelsson [1990]. The values from surface moisture measurements were not compensated for wood species.

3. RESULTS AND DISUSSION

3.1 Assembly

The data transmission includes a chain of events as shown in Fig. 2. The wireless sensors offer great benefits during installation and make it possible to easily set up and follow the construction sets during manufacturing. Since there are no wires, the sensors can be built into and transported within the wall, and there is no need to have wires through the weatherproofing layer or the surface coat. **Fig.**

3a shows a sensor installed inside a wall at the factory on a wall stud under an opening for window. Fig. 3b shows installation of sensors on a roof joist at a building site.

Figure 3. a) Installation of a sensor inside wall b) Installation of two sensors in a roof.

Measurement in situ requires careful planning and flexibility. There are many factors to take into account: changes in planning schedules on the building site or at the house factory; accessibility people with the expertise to install the sensors; the place to put the sensor might be available only for a short time before it becomes closed in or the scaffold moved so that the location for installation of a sensor becomes impossible to reach; sensor installation might be forgotten due to misunderstanding or time pressure in the production; *etc*.

3.2 Sensors

A reference block for electric moisture meter was used to control the sensor reliability. The block consists of four resistors that correspond to the resistance of spruce at different MC. These are MC 10.8%, MC 16.1%, MC 19.8% and 25.9% MC. Fig 4 shows sensors measured resistances for each MC during three months.

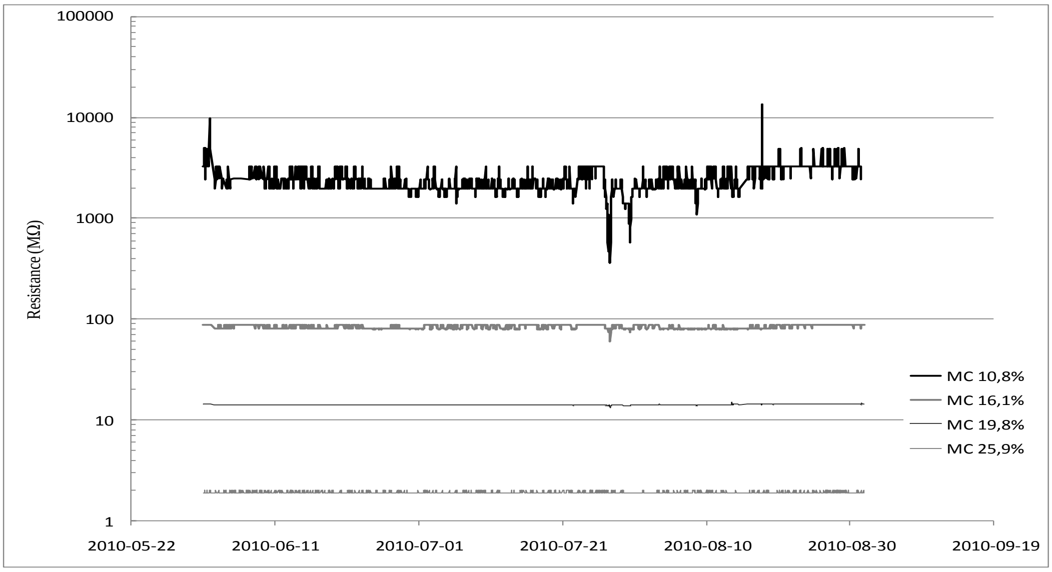


Figure 4. Resistance measured at reference block for spruce at MC 10.8%, 16.1%, 19.8% and 25.9%.

3.3 Loggers and antennas

After installation of the system, signals from some sensors were not picked up by the gateway, *i.e.*, the range was limited by certain building structures. The problem was solved by using more loggers and /or additional antennas. One must also consider where to place the gateway (practicability of location, availability of power, *etc*.) which may not always coincide with the optimal location to reach sensors. By replacing the original antenna to a splitter with two antennas, horizontal and vertical polarization of the signals from the sensors can be caught up in a better way. The variable polarization is due to the fact that the issue of antennas in the installation was not addressed in terms of final position in the design.

3.4 Reliability of service

As long as the gateways have power, they collect and store data from the sensors, but the collection of logged data is dependent on the GSM network and the Internet working. They are, unfortunately, not completely stable and may require visits to the site to reboot the system. Continuous follow-up of data collection will, however, minimize this. Usually data were retrieved once a month, which means that losses due to communication dropouts could be up to 4 weeks. When the Internet is not accessible, data cannot be retrieved, and the modem must be restarted manually on site. A timer, FailureGlobe Surfer, that restarts automatically once every 24 hour was used to minimize the need for visits to the location to manually restart the logger.
Power supply to the measuring system can be affected by thunderstorms, which can disrupt communications gateways, and data can be lost if the power goes off. At the building sites, when the houses were constructed, power failures were common. Also, disconnection of the logger due to builders' need for power outlets occurred, after which the logger might not be plugged in again. Battery failure of sensors might occur, especially for the ones installed on outdoor constructions exposured to large changes in temperature compared the ones installed within walls where the temperature changes are smaller. If the sensors are accessible, the battery can be replaced. Fig. 5a shows sensors that failed after cold and snowy weather. For installation on facades, beams, *etc.*, the yellow sensors were protected and hidden behind sheet metal or plastic covers painted in the same color as the specimen.

Figure 5. a) A beam with sensors after cold and snowy weather. b) Installation on a façade, sensor behind sheet metal painted in the same color as the wall.

3.5 Future work

Future work is to calibrate and verify the moisture measurements above FSP.

4. CONCLUSIONS

Wireless sensors can be used for measuring MC, RH and T in the field even when the number of measuring points is large. This technology has never been used to such a large extent before, and therefore new experiences were gained. This means that we have discovered flaws in the system and taken care of them. The positive aspects of this wireless system are:

• It is easier to set up many wireless sensors than it is to set up wired sensors.
• It is possible to build in sensors for measurements inside constructions (balcony, joist, beam, post, *etc*.) without any damages on weatherproofing layer and surface coat.
• Sensors can be installed inside walls during their construction at house-building factories and transported to the building site without any additional installation needed on site.
• Measurement at mobile constructions is possible.

Difficulties that may occur:

• Temporary data losses may occur (power down, wireless connection blocked, sensor-battery failure, lighting damage, *etc*.).
• Unsecure power supply at building sites.
• Equipment demands manual service on site.
• Hard outdoor climate puts higher demands on the equipment.

ACKNOWLEDGMENTS

This project is part of WoodBuild, a research program within the Sectoral R&D Program 2006-2012 for the Swedish forest-based industry. This Program is jointly funded by the government, industry and other stakeholders with interests related to the Swedish forest-based industry.

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