Lifetime moisture monitoring system for buildings

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Summary

A new technique for measuring and monitoring moisture content in construction structures has been developed. The technique uses low-cost sensors that are assembled in contact with the structure under investigation during construction or renovation. The sensors can then be read wirelessly from outside the structure with a separate reading device. The most significant advantage, compared to the techniques currently used, is that moisture content can be measured accurately at the depth of interest without damaging the structure. The technique can be used to monitor structural moisture during construction as well as during the whole lifetime of the building. The technique provides a new tool for evaluating construction quality and long-term monitoring the condition of buildings. The measurement system has been successfully tested in actual building environments.

Keywords: Measurement technique, moisture content, relative humidity, concrete

1. Introduction

Moisture in construction structures is assessed at different stages of the life cycle of a building. At the time of construction, moisture content measurements are often used to determine when a structure is dry enough to be covered with layers of other materials. If they are covered at too early a stage, the covering materials may be damaged and a favorable growth environment for microbes may arise. On the other hand, too long a waiting period increases building costs. Another important field of application for moisture content measurements is evaluating the condition of a building. This is typically done when a potential purchaser of an apartment or a house wishes to conduct a condition survey or when moisture damage is suspected to have occurred. However, previously it has not been feasible to monitor structural moisture routinely in order to perceive possible leaks before more serious damage occurs.

Moisture that drifts into construction structures during construction or inhabitation provides, together with a favorable temperature, suitable conditions for microbe growth. Both microbes and wet building materials release volatile organic chemicals (VOCs) into the indoor air. The association of structural moisture with different health symptoms has been investigated in several studies [1]. In addition, moisture also damages construction structures. Thus, controlling moisture is also important for maximizing the life span of buildings [2].

At the moment, in the Nordic countries moisture content in structures is assessed either with surface moisture meters or relative humidity meters. Surface moisture meters function by measuring the electrical properties of the material near the surface of the structure. They are usually fast, but the measurement result only applies to the surface of the structure to an unspecified depth. Relative humidity measurement systems function by measuring the relative humidity and the temperature of the air inside the structure. Relative humidity measurements are considered reliable, but the measurement procedure may take several days, since the probe must reach equilibrium with the humidity of its environment. In addition, a hole must be made to insert the probe into the structure. Thus, the structure is damaged. Measuring moisture content with these methods always requires professional skill. [3]

This article introduces a novel non-invasive technique for measuring moisture and describes how the technique can be used for routine lifetime monitoring of moisture in buildings. The technique and instrumentation described have been developed in the Applied Electronics Laboratory at Helsinki University of Technology during the years 2000 - 2003. The monitoring procedures have been developed together with the companies and associations that participated in the research project, all of them somehow connected to the construction industry.

2. Technology

The developed measurement technique combines the advantages of the methods currently used, being simultaneously fast, reliable, and affordable. The technique uses low-cost sensors that are assembled inside or on construction structures during either construction or renovation. Only the moisture in the structure of interest and at the desired depth affects the sensor. A separate reading device can then be used to read the moisture content wirelessly from outside the structure whenever desired.

The electrical basis of the measurement technique is capacitive coupling between passive sensors and a conductive material. The conductivity of many materials changes as a function of moisture content. The resulting changes in the electrical properties of the sensor can then be sensed inductively from outside the structure with a reading device. However, different building materials have different relationships between moisture content and conductivity. Using standard filler, the electrical properties of which are known, in assembling the sensors has solved this problem. The filler, referred to as assembly filler, should be considered a crucial part of the sensor.

A measurement accuracy of 2 percentage points of relative humidity has been acquired. Due to their robust and simple structure, individual sensors need not be calibrated when the assembly filler is used. In production, measuring samples of the sensors is adequate to control their quality. The reading device can be calibrated by measuring calibration sensors, i.e. electrical resonant circuits that represent the sensors in different moisture levels. A more detailed description of the technique and instrumentation can be found in another publication [4].

2.1 Sensors

Fig. 1. Pre-cast basic sensor, basic sensor and reading device

Several different sensor types have been developed for implementing the technique. The moisture content sensors measure either the amount of free water in a structure or the relative humidity of the air in the pores of the structure material. Electrically, all sensor types function similarly. However, the conductive material involved is different in each sensor type. The simplest and most affordable sensor is referred to as the basic sensor. This article concentrates on the functionality and usage of basic sensors.

The basic sensor is shown in the lower left corner of Fig. 1. The sensor consists of a printed circuit board with a copper coil on one side and a copper shield on the other. A capacitor is connected in parallel with the coil in order to set the sensor to an appropriate operating frequency. The sensor is laminated with a polyethylene layer.

The dimensions of the basic sensor are 70 x 70 x 2 mm. Due to its geometry, the sensor slightly effects the moisture movements in the structure. However, the effects are insignificant, since the involved time constants are fairly large. As an option, the sensor can be cast into a 10 mm-thick layer of assembly filler before it is assembled into the structure. This version of the basic sensor, shown in the upper left corner of Fig. 1, is referred to as the pre-cast basic sensor.

When the sensor is assembled in contact with a conductive material, the sensor couples capacitively with its surroundings, through the laminate. When the conductivity of the building material increases with moisture, the electrical characteristics of the sensor circuit are affected. The electrical resonance frequency of the sensor decreases and losses in the conductive material diminish the quality factor of the resonance. Correspondingly, when the material dries, conductivity decreases, and thus the resonance frequency and the quality factor increase.

Current research aims to develop the sensor into a wide range relative humidity sensor that could be used in any material without using special assembly filler. The sensor is also to be equipped with a means of measuring temperature and a system for identifying sensors and for storing a small measurement history into each sensor. The necessary technology has already been developed. A sensor with these properties is currently tested in a laboratory environment.

2.2 Reading device

A handheld reading device prototype, shown on the right in Fig. 1, has been developed. The main purpose of the device is locating and reading the sensors from outside the structure. The wireless connection between the reading device and the sensors is carried out with inductive coupling. Thus, the reading device creates a magnetic field with a varying frequency. From the frequency response of the sensor, the device determines the resonance frequency and quality factor of the sensor. On the basis of these measures and pre-calculated conversion tables, the device calculates the relative humidity of the structure of interest and displays it to the user. The measurement can be made in a few seconds.

The reading device also includes a search routine that makes it easier to locate the sensors. The device shows a bar indicating the strength of the inductive coupling. The location where the coupling is the strongest is the location nearest to the sensor. However, the approximate location must be known in advance. Otherwise, the search may take frustratingly long. In addition to these measurement functions, the reading device can be used as a systematic documenting tool. The measurement results can be saved into the memory of the device and later uploaded to a PC.

3. Application case

Fig. 2. Construction site in February 2003

As an example of utilizing the system in a new construction, the sensors have been used to monitor moisture in a 250 m^2 6-room 2-story low-energy house shown in Fig. 2. The house is constructed by Koskisen Oy Herrala Talot and it is one of the exhibition houses of the Heinola dwelling fair 2004 (Suomen asuntomessut) in Heinola, Finland. The developed monitoring system is assembled as a pilot assembly to test its functionality in actual circumstances.

In this site, moisture content is monitored in two stages. At the first stage, during construction, the drying of the concrete base floor and intermediate floor slabs is monitored in order to determine when they are dry enough to be covered with other materials. At the second stage, the moisture technical behavior of the most critical structures of the building, mainly the bathroom, is assessed throughout the life of the building.

3.1 Drying of concrete

The drying of the base floor concrete slab is measured with both pre-cast and basic sensors. The pre-cast sensors were assembled at the time of laying the concrete by pressing the sensors into the wet concrete at the depth of interest, in this case between 4 and 5 cm. Four sensors were assembled to this depth. In addition to this, two pre-cast sensors and five basic sensors were assembled to a depth of approximately 1 cm to be used in both monitoring stages.

The drying of the intermediate floor concrete slab is monitored with four pre-cast sensors. The concrete was cast on composite floor sheets, so the slab only dries in one direction. The sensors have been placed at approximately 2 cm depths in different rooms. One of them was pressed into the wet concrete, the other three were tied to the iron reinforcement, as shown in Fig. 3, prior to laying the concrete.

All of the sensors can be measured with a reading device in a couple of minutes. The acquired moisture content of the slab at different depths can now be used to evaluate when it may be water insulated or covered with parquet. Afterwards, the sensors can be used to monitor the development of the moisture content inside the structure.

Fig. 3. Pre-cast sensor before casting intermediate floor slab

3.2 Long-term monitoring

The second stage of measuring moisture content in the site is long-term monitoring. It is done in order to find signs of possible leaks and increasing moisture content before actual moisture damage occurs. The sensors are assembled into the walls and floor to the most critical locations by using the assembly filler. In this site, a total of 15 sensors are used for long-term monitoring, 13 of them are located in the bathroom and sauna area shown in Fig. 4. The bathroom has two showers on one separating shower wall. The wall on the left of the shower wall is an exterior wall and the wall on the right is a separating wall. The monitoring is concentrated near the showers and the two floor drains. The monitoring is partly done using the sensors already used for monitoring the drying of the base floor. The long-term monitoring sensors on the floor were assembled to the following locations

1. Next to the bathroom floor drains, with a 50 mm distance from each drain (2 sensors)
2. In the corner of the shower wall and the exterior wall on the left, with a 50 mm distance from both walls
3. In the middle of the exterior wall on the left, with a 50 mm distance from the wall

4. Next to the sauna floor drain, with a 50 mm distance from the drain
5. Other floor drains in the base floor, with a 50 mm distance from each drain (2 sensors)

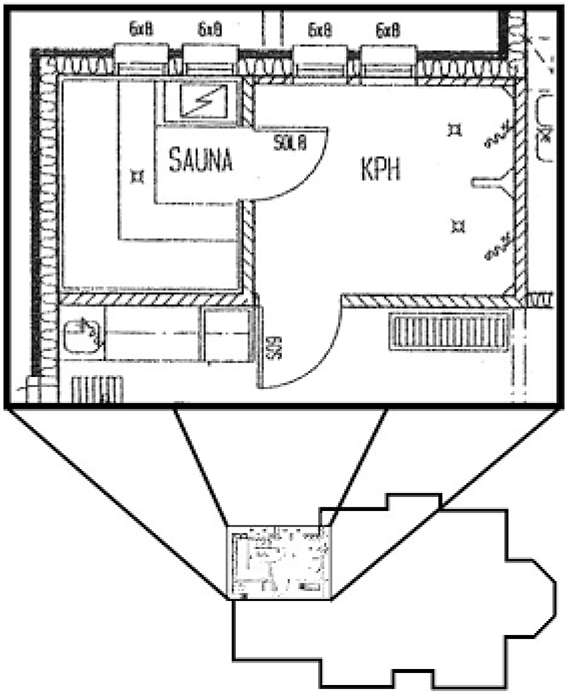

Fig. 4. Floor plan of the bathroom and sauna

In addition to these floor sensors, eight sensors were assembled to the bathroom walls. They were placed to the following locations

1. Directly below the shower mixers, with a 150 mm distance from each mixer (2 sensors)
2. On the lower edge of the shower wall, with a 50 mm distance from the floor, between the showers
3. On the lower edge of both walls adjacent to the shower, with a 100 mm distance from the floor, and 1000 mm from the corners (2 sensors)
4. To the corners of the shower wall and the adjacent walls, with a 100 mm distance from the floor and from the corner (2 sensors)
5. A reference sensor on a dry wall near the doorway

Fig. 5. Assembling a basic sensor

The basic sensors both in the walls and the floor are assembled, as shown in Fig. 5, with the assembly filler before water insulation. Thus, they indicate the moisture content of the wall behind the insulation, and moisture that is caused by normal use of the bathroom does not affect the sensors.

At the moment, the sensors have been read twice with approximately a one-month interval. After the owner of the building has moved in, he can continue the monitoring process by reading the sensors for example once a month. All the sensors can be read in a few minutes and if needed, the results can be uploaded to a computer.

4. Conclusions

A new technique for measuring moisture in constructions has been developed. As an advantage over the techniques currently used, moisture content in structures can be measured fast and without damaging the structure but still accurately and at the depth of interest. The sensors are assembled during construction or renovation and can be read wirelessly with a separate reading device. According to field observations, the assembly and measurement procedures are easy and fast.

If widely adopted for use, the developed technique and instrumentation could be used to diminish the exposure of people to health risks that are related to moisture in construction structures. The health risks do not just concern a few people - it is an issue of political economy. Builders would also benefit, since many construction events could be timed more accurately and thus time would not be wasted in unnecessary waiting. In addition, the technique could be used as a tool to evaluate construction quality and the condition of buildings. This would lead to more durable buildings.

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