A novel technique for measuring moisture in constructions and application examples

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ABSTRACT
A new technique for measuring and monitoring moisture content in construction structures has been developed at the Applied Electronics Laboratory at Helsinki University of Technology. The technique uses low-cost passive sensors that can be assembled in contact with the structure under investigation during either construction or renovation. The sensors can be read with a separate reading device from outside the structure. 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 has been successfully tested at several construction sites.

INDEX TERMS
Concrete; Electromagnetic fields; Measurement technique; Moisture; Relative humidity

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 can be used to define 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 favourable 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 long-term monitoring of structural moisture in, for example, bathrooms. Possible leaks can then be observed before serious water damage occurs. The inhabitants of the building involved benefit from moisture measurements not only in regard to their health but also economically, since the value of their home is preserved.

Moisture that drifts into construction structures during construction or inhabitation provides, together with a favourable 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 (Haverinen, 2002). In addition, moisture also damages construction structures. Thus, controlling moisture is also important for maximizing the lifespan of buildings (Seppänen and Palonen, 1998).

At the moment, in the Nordic countries moisture content in construction 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

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damaged. Measuring moisture content with these methods always requires professional skill (Merikallio, 2002).

This article introduces a new non-invasive technique for measuring moisture within construction structures. The technique and instrumentation described have been developed in the Applied Electronics Laboratory at Helsinki University of Technology during the 2000–2003. The technique combines the advantages of the methods currently used, being simultaneously fast, reliable and affordable. The technique uses low-cost passive sensors that can be 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. This article also presents some applications in which the measurement concept has been tested.

TECHNOLOGY

The electrical basis of the measurement technique is capacitive coupling between passive sensors and a conductive material. The conductivity of the material 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.

Sensors

Several different sensors have been developed for implementing the technique. Electrically, they function similarly. However, the conductive material involved is different in each sensor type. The simplest sensor is referred to as the basic sensor. A more complex threshold sensor is also introduced.

The construction of the basic sensor is shown in **Figure 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 × 70 × 2 mm.

When the sensor is assembled in contact with a conductive material, the sensor couples capacitively with its surroundings. 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; thus, the resonance frequency and the quality factor increase.

Different building materials have different relationships between moisture content and conductivity. This problem has been solved by using standard filler, the electrical properties of which are known, in assembling the sensors. The filler, referred to as assembly filler, should be considered a crucial part of the basic sensor. 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 is referred to as the pre-cast basic sensor.

It is often necessary to know whether the relative humidity inside a material is above or below a certain threshold, e.g. whether concrete has dried beyond 85% relative humidity so that it can be covered with a smoothing compound. For this purpose, a threshold sensor has been developed. The threshold sensor consists of a basic sensor, a reacting layer, and a membrane that only water vapour can penetrate. The reactive layer of the threshold sensor consists of a compound of filler and salt. Since different salts tend to maintain different humidity levels, the choice of salt determines the relative humidity threshold. For example, an 85% threshold sensor can be accomplished by using potassium chloride (KCl). The conductivity of the compound changes dramatically at the threshold humidity. Thus, a large change in resonance frequency and quality factor can be registered.

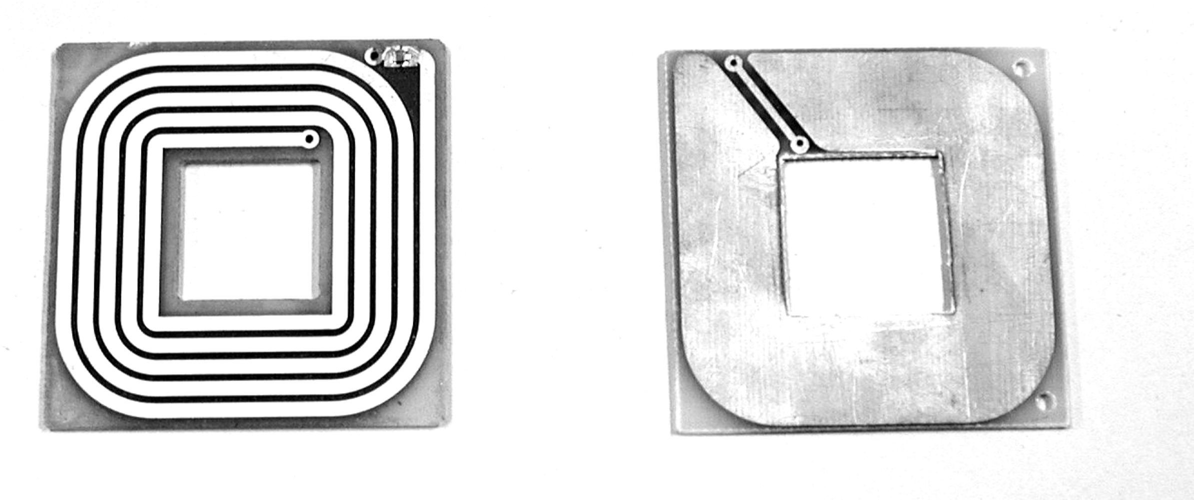

Figure 1 The construction of the basic sensor from both sides.

Current research aims to develop the sensor into a wide range relative humidity sensor that could be used in any material. 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.

Reading device

A handheld reading device prototype, shown in **Figure 2**, 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.

APPLICATION EXAMPLES

Bathrooms

The developed basic sensors have been tested in the bathrooms of apartment houses and prefabricated houses. The sensors are assembled into the walls and floor with the assembly filler before water insulation. The number of sensors needed for each bathroom is between six and ten, depending on its size and fixed furniture. **Figure 3** shows some typical assembly locations. Important locations are, for example, near the floor drain, in the walls in the vicinity of the shower, near penetrations and in a dry place for comparison. At the time of construction the sensors can be used to determine when the structures are dry enough for water insulation.

Later on the system can be used to investigate whether leaks or other moisture problems have occurred.

Figure 2 A photograph of the developed reading device prototype.

The measurement concept works if the sensors are assembled as specified. The sensors indicate the moisture content of the structures and they can be read with the reading device. The achievable accuracy seems to be around two percentage points of relative humidity. However, it is crucial that whoever assembles the sensors is motivated and documents the locations of the sensors accurately. The measurement concept only works if the sensors can be located and action is taken according to their readings. Some resistance to their adoption has been met since the surface moisture meters that are often used can be more easily used to get a suitable reading when behind schedule.

Drying of Concrete

Pre-cast basic sensors have been tested in concrete slabs. When the concrete is laid, the assembler presses the pre-cast sensors into the wet concrete at the monitoring depth of interest. The appropriate depth depends on whether the structure can dry in both directions or just up (Lumme, 2000). The sensors can be placed, for example, near floor drains. Then the sensors can be used later for monitoring possible leaks. The moisture content of the structure can be determined with the reading device. The achievable accuracy in this measurement seems to be one percentage point of relative humidity. The developed system can be used to supplement the work-intensive and time-consuming drill hole measurement method often used at the moment.

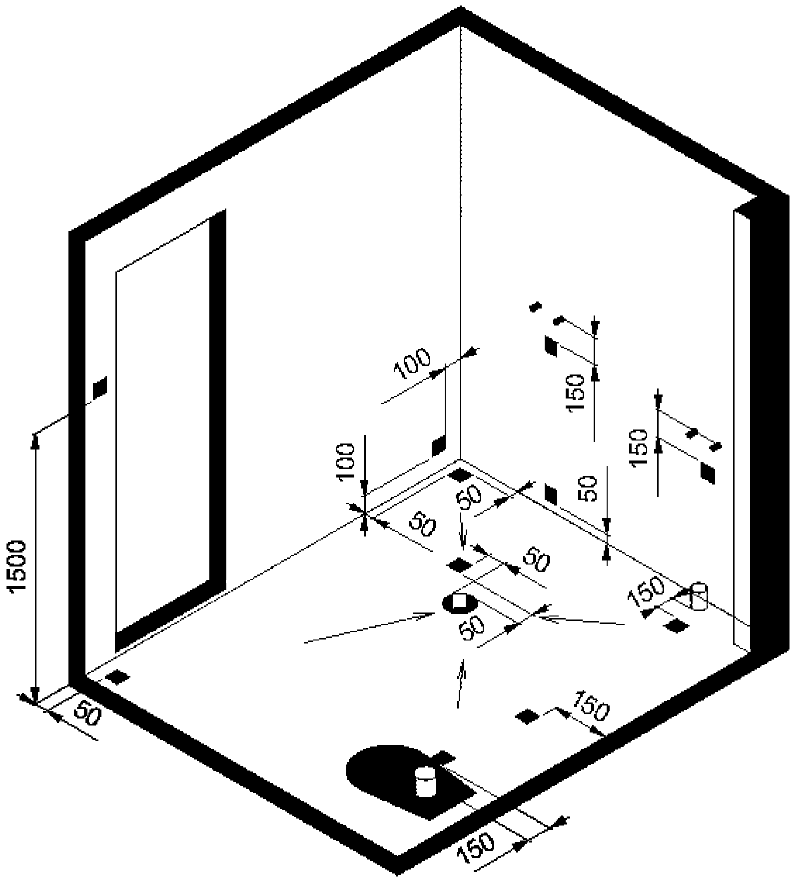

Figure 3 Possible assembly locations in a bathroom, distances shown in millimetres.

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.

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 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.

ACKNOWLEDGEMENTS

The authors would like to thank the National Technology Agency (Tekes), the Confederation of Finnish Construction Industries RT, the Federation of Finnish Insurance Companies, the Finnish Real Estate Federation, the City of Helsinki, and the Finnish companies Lohja Rudus Ltd., UPM-Kymmene Ltd., Koskisen Ltd., Optiroc Ltd., Saniroc Ltd., and Vigilan Ltd. for their financial support.

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