Monitoring Relative Humidity and Temperature for Life-Time Assessment of Sandwich-Type Concrete Structures

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1 ABSTRACT

Moisture is a major factor in physical deterioration of concrete structures. Deterioration processes are typically caused by moisture movements and freezing. The continuous monitoring of temperature and relative humidity provides a good piece of information about the long-term performance of buildings.

The objective of the research is to improve the use of the ICT (Information and Communication Technology) in the real estate and construction sector. For that purpose a new thermal and moisture RHT-monitoring network system was developed. The thermal and moisture RHT-monitoring network system is useful for assessing the repaired sandwich-type building facades performance and giving knowledge about the physical functioning of building envelopes.

The laboratory work of the research focused on designing and testing the RHT-monitoring network system including the calibration of the temperature and relative humidity devices. The RHT-monitoring software for configuring the network system and data collecting was developed. The field measurements of three sandwich-type building facades that were repaired with different methods were carried out to monitor the temperature and relative humidity. The thermal and moisture condition were monitored at regular intervals of 15 minutes since the year 2004.

The results of relative humidity and temperature monitoring provide an opportunity to take a closer look at the hygrothermal performance of the wall assembly. The long-term moisture response indicator introduced and applied in the study is called the RHTT index derived from the relative humidity and temperature values measured over a period of time for any specific area of the wall cross-section. An important feature of the RHTT is that the increase of its numerical value indicates an increased severity of the hygrothermal response and thus a higher damage potential.

2 INTRODUCTION

Deterioration of concrete is one of the basic questions in the life time management of buildings and structures. Two of the most important factors in building deterioration subjected to outdoor conditions are moisture and temperature. Moisture is a major factor in physical deterioration processes that are typically caused by restrained moisture movements and freezing or they can be connected to chemical or biological attacks. Nowadays a severe climate may be a reason behind a chemical load on building. In addition, moisture will increase the heat flow through a structure and thus increase the consumption of heating energy. Huovinen et al. (1998)

Exposure classes for the concrete facade structures according to the BY 50 (2004) for different environmental conditions are shown in figure 1.
The continuous monitoring of temperature and relative humidity provides not only important information for life-time management of sandwich-type concrete structures but also introduces the possibilities of systematic condition monitoring in developing the predictive maintenance of power plant facilities.

3 RHT MONITORING NETWORK SYSTEM

One goal of the research was to develop a thermal and moisture monitoring method to understand the moisture and thermal performance of the repaired sandwich-type building facades. For that purpose, the RHT monitoring network system and RHT monitoring software were developed to gather and analyze large amounts of thermal and moisture data on repaired building facades.

3.1 RHT monitoring network system overview

The RHT monitoring network system was developed to monitor the thermal and moisture performance of repaired building facades. The RHT monitoring network system was built on Linet Light Network (Linet Oy Ltd., 2007). The RHT network system consists of a controller and nodes where relative humidity and temperature sensors are connected to. The controller provides configuration services and enables communication with the data acquisition system. The network system may contain up to 200 nodes connected to a twisted-pair CAT5 cable with a maximum total length of 1000 meters. A schematic diagram of the RHT monitoring network system is illustrated in figure 2.
3.2 RHT monitoring software

The RHT monitoring software communicates between the host computer and the RHT monitoring network system controller, collects relative humidity and temperature data, and processes the monitored data. The RHT monitoring software consists of four basic modules: a system configuration module, a Telnet simulation module, a RHT calculation and output module, and a data processing module. The flow chart of the RHT monitoring software modules is shown in figure 3.

![Flow chart of RHT communication software](image)

**Figure 3.** Flow chart of RHT communication software

4 MONITORING LOCATIONS AND INSTRUMENTATION

The monitoring of humidity and temperature using RHT-monitoring network system was carried out on sandwich-type building facades repaired with different methods. This paper focuses on two of the facades, one facade repaired by adding an external insulation (EPS) and a rendering coat as shown in figure 4. The other facade was repaired by adding an external mineral wool insulation and a rendering coat, shown in figure 5.

![Humidity and temperature sensors installation in northeast and southwest parts of the building facade repaired by adding an external insulation (EPS) and a rendering coat.](image)

**Figure 4.** Humidity and temperature sensors installation in northeast and southwest parts of the building facade repaired by adding an external insulation (EPS) and a rendering coat.
Figure 5. Humidity and temperature sensors installation in northeast and southwest parts of the building facade repaired by adding an external mineral wool insulation and a rendering coat.

A list of relative humidity and temperature sensors installed every repaired façade is shown in table 1. Relative humidity and temperature sensors were installed at points 1, 2, 3, 4 and 5, as shown in figures 4 and 5. There were also two relative humidity and temperature sensors outdoors.

Table 1. Humidity and temperature sensors used on the monitoring system.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Monitored parameters and location</th>
<th>Output data</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMP 44</td>
<td>Humidity and temperature sensor made by Vaisala Oy in Finland. (Accuracy of ±2 % to ±3 % RH)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>SHT15</td>
<td>Humidity and temperature sensor made by Sensirion in Switzerland. (Accuracy of ±2 % to ±4 % RH and ±0.3°C)</td>
<td>RH (%)</td>
</tr>
<tr>
<td>PT100</td>
<td>Platinum resistance thermometer. (Accuracy of ±0.3 °C at 0 °C)</td>
<td>T (°C)</td>
</tr>
</tbody>
</table>

5 RESULTS

5.1 Relative humidity and temperature of the repaired facades

The temperature and relative humidity under the external (EPS) insulation and the rendering coat of the repaired facade facing southwest are presented in figure 6. The temperature of the rendering coat varied between -24°C and +44°C. The temperature under the external EPS insulation did not decrease below 0°C. The relative humidity under the external insulation varied between 20% and 80% during the monitoring period.
The temperature and relative humidity under the external EPS insulation and under the rendering coat for the repaired facade are presented in Figure 6. The temperature in the rendering coat varied between -23°C and +35°C. The temperature under the extra mineral wool insulation dropped below 0°C during February 2006, and the minimum measured temperature was -4°C. The relative humidity of the rendering coat varied between 20% and 75% during the monitoring period.

The temperature and relative humidity under the extra mineral wool insulation and the rendering coat of the repaired facade facing northeast are presented in Figure 7. The temperature in the rendering coat varied between -23°C and +35°C. The temperature under the extra mineral wool insulation dropped below 0°C during February 2006, and the minimum measured temperature was -4°C. The relative humidity of the rendering coat varied between 30% and 92%. The relative humidity under the extra insulation varied between 20% and 75% during the monitoring period.

5.2 Effectiveness of the repairing methods

Figure 8 shows the drying of the original outer panel of the sandwich concrete facade after one and a half years of the installation of the external EPS insulation and the rendering coat. The relative humidity of the outer concrete panel, dropped from 97% to 67% in the facade facing the northeast and from 97% to 63% in the facade facing the southwest. The water vapour content of the outer concrete panel dropped from 24 g/m³ (northeast) and 29 g/m³ (southwest) to 4 and 6 g/m³ respectively between June 2005 and February 2007.

Figure 8. The relative humidity and water vapour content of the original outer sandwich concrete facade repaired by adding an external insulation (EPS) and a rendering coat.
Figure 9 shows the drying of the original outer panel of the sandwich concrete facade after one and a half years of the installation of the external mineral wool insulation (70 mm) and the rendering coat. The relative humidity of the outer concrete panel dropped from 88% to 67% in the facade facing southwest and from 64% to 54% in the facade facing northeast between June 2005 and February 2007. The water vapour content of the outer concrete panel dropped from 16 g/m³ (northeast) and 23 g/m³ (southwest) to 4 and 6 g/m³ respectively between June 2005 and February 2007.

As shown in figures 8 and 9, buildings facades gradually achieve moisture equilibrium by releasing moisture during the first and second years after repairing and their moisture content increases during the hot humid summer, and decreases during the cold dry winter.

5.3 Time-dependent relative humidity and temperature RHTT index

According to Mukhopadhyaya et al. (2005), the RHTT index is defined as the potential for any moisture damage when sustained high moisture levels and temperatures occur simultaneously for an extended period of time. Such conditions are favourable for the initiation of corrosion, swelling and expansion, efflorescence, subflorescence, and biological damage in the building envelope and its components. The RHTT index is defined in equations 1 – 6.

\[
RHTT_{(i)} = TOW_{(i)} \times RHT_{(i)}
\]

\[
TOW_{(i)} = \left( \frac{\sum_{h=1}^{k} t_{\text{counter}(i,h)}}{k} \right) / k
\]

\[
t_{\text{counter}(i,h)} = \begin{cases} 
1 & \text{if } T_{(i,h)} \geq 0 \text{°C and } RH_{(i,h)} \geq 80\% \\
0 & \text{else}
\end{cases}
\]

\[
RHT_{(i)} = \sum_{h=1}^{k} T_{\text{potential}(i,h)} \times RH_{\text{potential}(i,h)}
\]

\[
T_{\text{potential}(i,h)} = \begin{cases} 
(T_{(i,h)} - T_{\text{critical}}) & \text{if } T_{(i,h)} > T_{\text{critical}} \\
0 & \text{if } T_{(i,h)} \leq T_{\text{critical}}
\end{cases}
\]

\[
RH_{\text{potential}(i,h)} = \begin{cases} 
(RH_{(i,h)} - RH_{\text{critical}}) & \text{if } RH_{(i,h)} > RH_{\text{critical}} \\
0 & \text{if } RH_{(i,h)} \leq RH_{\text{critical}}
\end{cases}
\]

where:

- \(i\) is a spatial index for the considered part of the structure
- \(TOW_{(i)}\) is the calculated time of wetness within the considered part of the structure, (%)
- \(RHT_{(i)}\) is the calculated RHT index within the considered part of the structure
- \(t_{\text{counter}(i,h)}\) is the time of wetness, h
- \(T_{(i,h)}\) is the temperature of the considered part of the structure, °C
- \(RH_{(i,h)}\) is the relative humidity of the considered part of the structure, %
\( \text{RH}_{(i,h)} \) is the relative humidity of the considered part of the structure, \(^\%\)

\( T_{\text{potential}} \) is the potential temperature for moisture damage, \(^{\circ}\text{C}\)

\( \text{RH}_{\text{potential}} \) is the potential relative humidity for moisture damage, \(^{\%}\)

\( T_{\text{critical}} \) is the user-defined critical threshold value of temperature level above which moisture damage is more likely to occur, \(^{\circ}\text{C}\)

\( \text{RH}_{\text{critical}} \) is the user-defined critical threshold value of relative humidity level above which moisture damage is more likely to occur, \(^{\%}\)

\( k \) is the total sum of hours in a particular year, i.e. either 8760 or 8784 hours

The critical temperature and relative humidity vary depending on the nature of the construction material and the moisture damage involved. According to Viitanen (2003), biological deterioration of interior drywall due to mould growth may require temperature above +5\(^{\circ}\text{C}\) and relative humidity above 80\(^{\%}\).

The values of the RHTT index for the rendering coat and the original outer concrete panel of the facade repaired by adding an external insulation (EPS) and a rendering coat are shown in Table 2. The potential of mould growth on the rendering coat facing northeast was higher than that facing southwest. The highest mould growth potential due to thermal and moisture loading was in the rendering coat facing northeast in the first floor. The RHTT index of the original outer concrete panel did not increase after one year from repairing, which indicates the drying of the original facade.

**Table 2.** The values of the RHTT index for the facade repaired by adding an external insulation (EPS) and a rendering coat

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RHTT biological growth (( T &gt; 5^{\circ}\text{C} ) &amp; ( \text{RH} &gt; 80^{%}))</td>
<td>RHTT biological growth (( T &gt; 5^{\circ}\text{C} ) &amp; ( \text{RH} &gt; 80^{%}))</td>
<td></td>
</tr>
<tr>
<td>Rendering coat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North-east</td>
<td>1. floor</td>
<td>742</td>
<td>431</td>
</tr>
<tr>
<td></td>
<td>6. floor</td>
<td>448</td>
<td>340</td>
</tr>
<tr>
<td>South-west</td>
<td>1. floor</td>
<td>266</td>
<td>203</td>
</tr>
<tr>
<td></td>
<td>6. floor</td>
<td>422</td>
<td>225</td>
</tr>
<tr>
<td>Original outer concrete panel</td>
<td>1. floor</td>
<td>1438</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6. floor</td>
<td>264</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>South-west</td>
<td>1. floor</td>
<td>239</td>
</tr>
<tr>
<td></td>
<td>6. floor</td>
<td>1165</td>
<td>0</td>
</tr>
</tbody>
</table>
5.4 Freezing thawing index

The freezing thawing index (FT) is defined as the number of freezing or thawing oscillations when temperature oscillates around 0°C for those structures that are almost at the moisture saturation level, Mukhopadhyaya et al. (2005). According to Fagerlund (2001), the critical moisture saturation level for the potential of the frost damage of concrete is above 75%. The higher the number of cycles indicates the greater potential for frost damage. The freezing thawing index (FT) is defined in equations 7 – 8.

\[ FT_{(i)} = \sum_{h=1}^{k} FT_{\text{counter}(i,h)} \]  

\[ FT_{\text{counter}(i,h)} = \begin{cases} 1 & \text{if } (T_{(i,h)} \times T_{(i,h-1)}) < 0 \text{ and } RH_{(i,h)} \geq RH_{\text{critical}} \\ 0 & \text{else} \end{cases} \]  

where:
- \( i \) is a spatial index for the considered part of the structure
- \( \text{Counter}_{(i,h)} \) is a freezing or thawing oscillator when temperatures oscillate around 0°C
- \( T_{(i,h)} \) is the temperature within the considered part of the structure at a particular time step, °C
- \( RH_{(i,h)} \) is the relative humidity within the considered part of the structure at a particular time step, %
- \( RH_{\text{critical}} \) is the critical moisture saturation level in the envelope component, %
- \( k \) is the total sum of hours in a particular year, i.e. either 8760 or 8784 hours

The values of the FT index for the rendering coat and the original outer concrete panel of the facade repaired by adding an external insulation (EPS) and a rendering coat are shown in table 3. The FT indices were higher on the sixth floor facing southwest than on the sixth floor facing northeast, but lower on the first floor. The values of the FT index of the original outer concrete panel was zero right after repairing, which indicates that there was no risk for frost damage of concrete.

| Table 3. The values of the FT index for the facade repaired by adding an external insulation (EPS) and a rendering coat |
| --- | --- | --- | --- |
| **Repaired facade** | | | |
| **Rendering coat** | | | |
| North-east | | | |
| 1. floor | 116 | 68 | 184 |
| 6. floor | 78 | 77 | 155 |
| South-west | | | |
| 1. floor | 97 | 63 | 160 |
| 6. floor | 101 | 86 | 187 |
| **Original outer concrete panel** | | | |
| North-east | | | |
| 1. floor | 0 | 0 | 0 |
| 6. floor | 0 | 0 | 0 |
| South-west | | | |
| 1. floor | 0 | 0 | 0 |
| 6. floor | 0 | 0 | 0 |

6 CONCLUSION

The RHT monitoring network system is very useful for gathering a large amount of data about the thermal and moisture performance of repaired facades, which provides a better understanding of how the environment and the building interact and can complement visual inspections.

By measuring the temperature and relative humidity of building components, we can determine the potential for deterioration, wetting and drying patterns in building components, and changes in moisture content. Monitoring is especially useful when applied to the maintenance and repairing sector.
Documenting the performance of repaired buildings through monitoring can improve the understanding of repairing methods, repairing materials, and structural behaviour, which increase the durability and the service life cycle of the repaired structures.

This study uses a long-term moisture response indicator called the RHTT index derived from the relative humidity and temperature values over a period of time for any specific area of the wall cross-section. Although acceptable values for RHTT indices for various building materials are not available at this moment, the important feature of the RHTT index is that the higher RHTT index values indicate an increased severity of the hygrothermal response and higher damage potential.

The freezing thawing index (FT) is defined as the number of cycles when the temperature oscillates between the freezing and thawing point for the facade components that are almost at the moisture saturation level. The facades facing southwest have higher FT indices than the facades facing northeast. Increased freezing thawing index values indicate an increased severity of the frost action and a higher damage potential.

REFERENCES


