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# Monitoring non-structural performance of exterior masonry walls

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**Abstract**

The theme of the 2001 annual conference of the Association for Preservation Technology was appropriately titled *The Test of Time*. One of the main issues discussed was the lack of documentation on the long-term performance of structures and buildings which have been restored and repaired.

Both simple and comprehensive monitoring schemes are an excellent means of determining long-term performance in service. This especially applies to repairs and masonry preservation projects. In essence every masonry preservation project is a learning experience. Documenting the performance of repairs through monitoring can go a long way in improving our understanding of masonry materials and structural behaviour.

This paper addresses issues involved in monitoring performance especially durability with the emphasis on heat, air and moisture issues in exterior masonry walls of older buildings.

## 1. Introduction

One of the main issues discussed at the 2001 annual conference of the Association for Preservation Technology was the lack of documentation on the long-term performance of structures and buildings which have been restored and repaired. Lack of documentation on performance is also addressed by Blockley (1) who asked "why construction is one of the few industries where in-service measurement is seen as a weakness and not a strength? …we are not as good at learning from projects and from the way our structures behave in use as we should be". This paper addresses issues involved in monitoring performance especially durability with the emphasis on heat, air and moisture issues in exterior masonry walls of older buildings.

The Canadian Standards Associations guideline on durability of buildings states the service life of any component or assembly is affected by environmental conditions, installation and maintenance (2). Monitoring of environmental conditions is therefore important, as well as keeping a record of the materials used, installation practices and any subsequent maintenance (3, 4). The information obtained can greatly help with the diagnosis of causes of deterioration should they occur and thereby improve future interventions and repairs. A global approach to the building or building element is needed to see how building components interact with each other and with the environment. A general approach, including a flow chart, for assessing the condition and performance of building envelope systems and components is given in SEI/ASCE standard 30-00 (5).

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Monitoring can have several objectives:

- improve the understanding of the behaviour of buildings and their components and a check on theoretical predictions.
- provide data to improve accelerated laboratory durability tests.
- as part of a maintenance program, act as an early warning system to ensure safety and provide for timely renovation or repairs (preventative maintenance program). Timely repairs reduce long-term maintenance costs.
- provide data for improved control of interior environmental conditions.
- establish priorities to manage and reduce risk whenever insufficient funding is available to carry out repairs.
- assess the impact on the building envelope of interventions, repairs, change in use or occupancy (operating conditions, addition of insulation to an formerly un-insulated wall, renovation, etc.) which could improve the effectiveness of the design of future interventions.

A monitoring program set up to assess long term durability must first consider possible performance and deterioration mechanisms. Durability is affected by the environment, material characteristics, design, construction, and maintenance. All these should be documented. Monitoring will primarily concentrate on the interior and exterior environment and its effect on the masonry.

Moisture, with or without contaminants, is the most important environmental agent causing premature deterioration of building components and assemblies especially in colder climates where freeze-thaw action is a major cause of damage. Temperature has an important secondary influence. The level of moisture is affected by the weather, orientation of the masonry facade, design of building details (especially water shedding and water barrier details), and maintenance (e.g. repair of gutters and cracks).

The accumulation of moisture within masonry can affect its durability in several ways. They include:

- frost damage which depends on factors such as water content, freeze-thaw cycles, cooling rate, and salts.
- salt crystallisation within and on the surface of the masonry; sulphate attack on mortar.
- leaching of binders from the mortar. Rain has a natural acidity which can be increased by pollutants such as sulphur dioxide.
- biological effects caused by moss & climbing plants. Micro-organisms can create hygroscopic surface deposits, retard drying and affect porosity of the masonry surface. This can lead to staining and accelerated weathering with increased risk of frost damage and sulphate attack.

Long-term material changes can also play a role (e.g. carbonation of the mortar). In addition other components within the wall may affect durability, for example, corrosion of metal components. Temperature cycles on their own can also cause deterioration by causing gradual widening of cracks which cannot close because of debris collected within the crack while it was fully open (cracks can allow increased water ingress). Structural movement can also cause damage. Feilden (6) and Franke et al (7) give more detail on failure mechanisms. Feilden also gives examples of the results of monitoring.

Apart from deterioration mechanisms, performance characteristics of interest are water leakage, dampness, heat transmission through the exterior building envelope including thermal bridges, and air infiltration and exfiltration.

Based on the above issues, items worth monitoring include rain fall, acidity of the rain, wind direction and speed during rainfall, outdoor and indoor air temperature & relative humidity, wetting patterns on the surface of the wall including performance of water shedding details, changes in level and distribution of moisture within the masonry, differential air pressure across the exterior wall, heat flow through the wall, and the temperature distribution across the wall.

## 2. Monitoring options

Having developed clear objectives, there are varying levels of monitoring that are possible. They can range from simple visual inspections at regular intervals to continuous long or short term monitoring that may include many sensors. Monitoring is usually non-destructive but it may include minor destructive tests or procedures (for example installing sensors within a wall).

### 2.1 Periodic monitoring

Visual observations at regular intervals can provide a large benefit compared to the little time it takes. A checklist, together with a still or video camera, and possibly binoculars, are all that is needed. Items to look for are deterioration (e.g. cracking, bowing, spalling, staining, efflorescence), and wetting caused by rain, surface runoff, dampness or condensation (wetter locations have a higher risk of damage). Mould or moss growth on building surfaces are also an indication of high moisture levels.

Visual observations can be supplemented by simple measurements of crack widths, surface profile at selected locations, surface moisture content, hardness of pointing mortar, and the analysis of any observed salts to determine their likely source. More elaborate measurements can also be made. These include photogrammetry and laser scanning to obtain detailed surface profiles, and infra-red thermography to obtain an indication of the distribution of moisture and locations where there is air leakage or a thermal bridge. These latter more expensive techniques have the advantage of being able to scan large areas.

### 2.2 Continuous monitoring

Continuous monitoring can complement visual inspections. Simple, unobtrusive, self contained data logging devices are available that will measure air temperature, relative humidity and air pressure. This can be expanded to datalogging systems monitoring many sensors. Sensors are available to measure temperature of building components, movement at repaired cracks, air pressure differences (to determine potential air infiltration or exfiltration), heat flow (to obtain thermal resistance), wetting and drying patterns in building components, and changes in moisture content.

Continuous monitoring provides a much better understanding of how the environment and the building interact. On the other hand it costs more (although equipment costs are reducing as well as becoming more reliable), and requires adequate allocation of time to analyse the data. If the monitoring is to be long term, adequate consideration must also be given to the durability of the instrumentation and the fixings, as well as the need for periodic calibration.

The data produced can be overwhelming, therefore clear objectives should be defined, software developed to analyse and check the data automatically, and procedures developed for storing and retrieving the data. Modern software is available which will allow instant viewing of the sensor location and its output superimposed on a plan of the building or component (Fig 1). The sensor output can also be integrated into an existing building automation system for the heating, cooling and ventilating equipment. They can then also be used to improve the interior climatic conditions (Garrecht). Analysis and interpretation of the data can be greatly aided with the help of numerical modelling programs. Long term monitoring generally lasts at least one or two years to cover a range of climatic conditions, but the actual length will depend on the objectives. Many years may be required to determine long-term performance of repair materials.

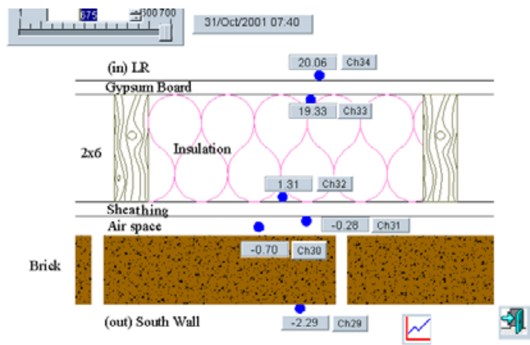


**Figure 1** Real time data presentation from computer screen
(Brick veneer attached to an insulated wood frame wall of a house)

## 3. Techniques for assessing and measuring

### 3.1 Moisture measurements

The objective is to determine the source, location and amount of moisture and changes with time.

For larger monitoring schemes a small weather station can be installed to measure air temperature, relative humidity, rainfall, rain acidity, wind direction and speed, barometric pressure, and solar radiation.

Wetting and drying patterns on the surface of the masonry can be assessed by moisture sensors including portable resistance meters, electrode pins inserted in the masonry (Fig 2), capacitance meters, wetness sensors such as Sereda (8) and Wetcorr (9), and rain gauges attached to the masonry facade. Photography and video can also be used to record surface wetting patterns during or following rain or snow melt. Infrared thermography during the colder months can identify moisture accumulation due condensation from air leakage and vapour diffusion, and absorption of rain, snow-melt water and groundwater.

The likelihood of air flow through leakage openings in a wall can be assessed by air pressure differences across the wall or component in the wall system, thermography, or smoke pencil. Thermographic images (Fig. 3) superimposed on video images make them much easier to interpret (10).

Condensation potential can be assessed by calculating the air dew-point temperature and comparing it to the masonry surface temperatures. Air leaking through the wall may contribute to both wetting by condensation or to drying depending on the dew-point of the air and the temperature of the surfaces along which it passes.

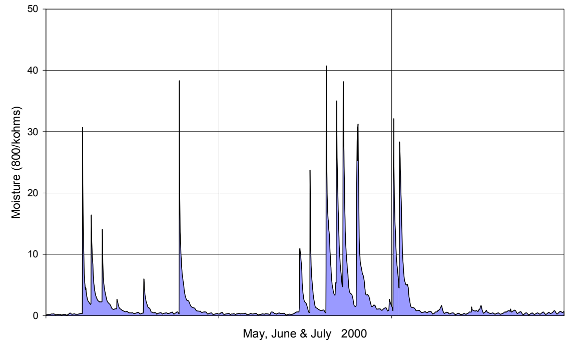


**Figure 2** Measuring rain wetting of the surface of a masonry wall (resistance across stainless steel pins inserted in a mortar joint)


**Figure 3** Thermographic scan superimposed on a video image. Arrows show points where air exfiltration is occurring (building pressurized for this test)

Moisture content of the masonry itself is difficult to assess non-destructively. Resistance moisture sensors have been used to give a qualitative assessment (changes in moisture level) but difficult to obtain quantitative values although this is improving (11). Other approximate means include the use of relative humidity/temperature probes inserted in the material (their size is decreasing (12)), capacitance gauges, and use of small moisture resistance blocks made from the same material as the masonry. Microwave techniques are also being evaluated (13). Microwave technique works on a similar principle to the capacitance technique, but at a much higher frequency. The microwave method is claimed to give much better accuracy (13) because the high frequency makes it less susceptible to impurities in the masonry such as salt. Other methods under consideration are time domain reflectometry and ground penetrating radar (Groot, Maierhofer). Moisture content can also be assessed by removing small samples from the wall (minor destructive technique). One example is the drill method (14).

### 3.2 Temperature measurements

Temperature for continuous monitoring is usually measured with type-T thermocouples or RTDs. Figure 4 shows the number of freeze-thaw cycles measured at four orientations using thermocouples. For handheld measurements, digital probes based are available including an infrared non-contact gauge. Thermal resistance can be determined with heat flux transducers combined with temperature sensors at different depths within the wall (15). The heat flux transducers can also indirectly be used to assess changes in moisture content within the wall through changes in thermal resistance, which decreases with increasing moisture content.

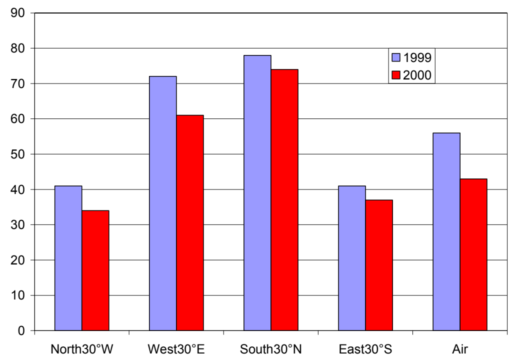


**Figure 4** Effect of orientation on the annual number of freeze-thaw cycles
Surface of masonry buttresses

### 3.3 Surface conditions

- Surface erosion/spalling can be monitored using photography, photogrammetry (3) and laser scanning (Fig 5), and at selected locations using a profile gauge.
- Cracks can be measured manually (e.g. vernier gauge, Demec gauge, see ref 16) or electronically (e.g. LVDTs; see Fig 6).
- Staining is best recorded photographically. At the same time samples are taken to determine the salt type.
- The condition of the mortar can also be assessed by measuring its hardness. For flat surfaces such as brickwork a pendulum hammer can be used (17). Minor-destructive techniques also available such as the pin penetration test or drill penetrometer (18, Liberatore et al, Tiano).

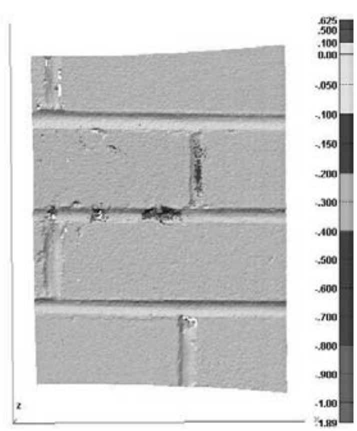

**Figure 5** Laser scan of brickwork panel showing difference between two scans
(darker areas show where mortar was chipped out between scans)

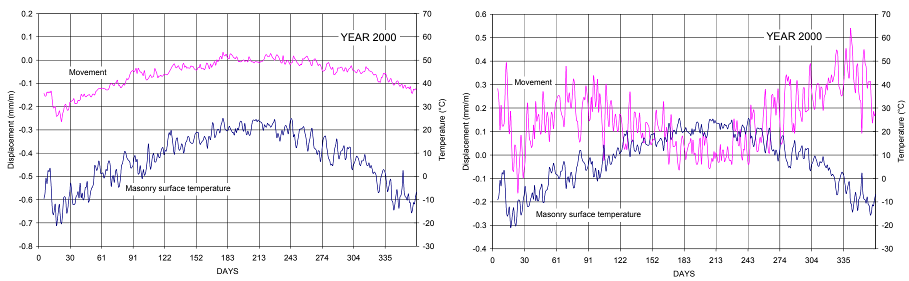


**Figure 6** Displacement sensor across repaired cracks
In the right figure, cracking has occurred again. The lower curve is masonry surface temperature; the upper curve is movement

**3.4 Installation of sensors & data-logging equipment**
Instrumentation should, where possible, be simple, economical, reliable, easily maintained, and easily interpreted without the need of an expert. The main considerations in selecting the instrumentation system are accuracy, stability, and durability. The system should withstand or be protected from the ambient environment, be stable, and capable of maintaining accuracy over time. The drift should be as little as possible in order to reduce the cost of re-calibration checks. Sensors and their fixings should not cause damage indirectly to the masonry (e.g. staining, corrosion causing cracking). Protection against electrical transients (surges) should be provided by grounding and surge protectors (transients may also occur along sensor cables). Protection against damage from possible lightning strikes should also be considered for taller structures and higher locations (6, 19). Other considerations in selecting the instrumentation system include minimum visual intrusion, easily removable for calibration if needed, battery backup in case of power failure, remote access by modem, protective enclosures for dataloggers and the use of more than one datalogger to reduce the length of wiring to sensors.

## 4. Concluding remarks

Monitoring equipment is becoming more reliable, easier to use and more economical. Therefore there is more incentive to conduct continuous monitoring in addition to periodic monitoring. But even if only simple visual monitoring is conducted this already provides good information on long-term performance in service. Monitoring is especially useful when applied to repairs and restoration projects. In essence every masonry preservation project is a learning experience. Documenting the performance of repairs through monitoring can go a long way in improving our understanding of masonry materials and structural behaviour. Furthermore, the results from monitoring can apply to numerous other masonry structures with similar construction characteristics. In our search for increased performance and durability, and a longer life cycle from our buildings and structures, can we afford not to monitor and not to learn in a more scientific and systematic way from our site experience?

## 5. Acknowledgements

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## 6. References

Author's names in brackets in the text refer to papers contained in the proceedings.

1. Blockley D. I. ‘Thinking outside of the box with Phil's eight new maxims’. *The Structural Engineer*. **79** (20) (2001) 22-29.
2. Canadian Standards Association. ‘Guideline on durability in buildings’. S478-95. (1995).
3. Moore J. F. A., editor. 1992. ‘Monitoring of building structures’. (Blackie / Van Nostrand Reinhold, 1992)
4. Maurenbrecher A.H.P., Said M.N.A., Ibrahim K. & Cornick S.M., ‘Monitoring the performance of masonry building envelopes’. Proceedings 12th Int Brick/Block Masonry Conference. **2** (2000) 1221-1233.
5. American Society of Civil Engineers. ‘Guideline for condition assessment of the building envelope’. Standard SEI/ASCE 30-00. (2000).
6. Feilden B. M. ‘Conservation of historic buildings’. (Butterworth-Heinemann Ltd. 1994).
7. Franke L., Schumann I. et al. ‘Damage Atlas, Classification and analyses of damage patterns found in brick masonry’. (Fraunhofer IRB Verlag., 1998)
8. Hechler J. J., Boulanger J., Noël D., Dufresne R. & Pinon C. ‘A study of large sets of ASTM G84 time-of-wetness sensors’. ASTM STP 1000, Symposium on corrosion testing and evaluation. American Society for Testing and Materials. (1990) 260-278.
9. Norberg P. ‘Microclimate measurements in the built environment’. Centre for Built Environment, KTH, Box 88, SE-801 02 Gävle, Sweden. (1998).
10. Colantonio, A., ‘Thermal performance patterns on solid masonry exterior walls of historic buildings’, J. Thermal Insul. and Bldg. Envs. **21**, (Oct 1997) 185-201
11. Kus H. & Norberg P. ‘Monitoring of moisture in rendered autoclaved aerated concrete wall by nail electrodes’. Proceedings Int Conf on Bldg Envelope Systems & Technologies. Vol 1. Ottawa. (2001). 237-242
12. Cunnigham, M.J. ‘Development and performance of a small relative humidity sensor for indoor mircoclimate measurements’. Building and Environment **34** (1999), 349-352.
13. Dill M.J. ‘A Review of testing for moisture in building elements’. CIRIA Report No. CIRIA-C538, Westminster, London SW1P 3AU, UK, (2000).
14. RILEM. ‘MS-D.10 Measurement of moisture content by drilling’. Materials & Structures. **30**, (1997) 323-328.
15. Brown, W.C. & Schuyler, G.D. ‘In situ measurements of frame wall thermal resistance’, ASHRAE Transactions, **88** (Part 1), 667-676.
16. Building Research Establishment. ‘Simple measuring and monitoring of movement in low-rise building, Part 1: cracks’. BRE Digest 343. (1989)
17. RILEM. ‘MS-D.7 Determination of pointing hardness by pendulum hammer.’ Materials & Structures. **30** (1997) 323-328.
18. De Vekey R.C. & Sassu M. ‘Comparison of non-destructive in-situ mechanical tests on masonry mortars: the PNT-G method and the Helix method’. Proceedings 11$^{th}$ Int Brick/Masonry Conf, China. (1997) 376-384.
19. Building Research Establishment. ‘Protecting buildings against lightning’. BRE Digest 428. (1998)