Practical Experiences from Several Moisture Performance Assessments

Petri J. Annila, Jukka Lahdensivu, Jommi Suonketo and Matti Pentti

Abstract This study analysed the moisture performance assessment reports of 76 buildings: 56 schools, nine healthcare buildings, three daycare centres and five office buildings. The researchers' practical experiences from moisture performance assessments were also made use of in the study. The aim of this study was to determine the methods used to detect moisture and mould damage in the building stock. The results of the study show that most moisture and mould damage is detected by a surface moisture indicator (Annila et al. in Proceedings of the 1st international symposium on building pathology, pp 115–122, 2015a). That is an important finding since these indicators enable easy measuring of large sections of structures and targeting of more detailed inspections, moisture measurements and material samplings based on mapping with them.

Keywords Indoor air quality · Moisture · Mould · Sick building syndrome · Condition assessment

1 Introduction

The indoor air quality (IAQ) problems of the building stock are caused by many factors including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), particular matter (PM), high indoor temperature and relative humidity, low

P.J. Annila (✉) · J. Lahdensivu · J. Suonketo · M. Pentti
Department of Civil Engineering, Tampere University of Technology,
P.O. Box 600, 33101 Tampere, Finland
e-mail: petri.annila@tut.fi

J. Lahdensivu
e-mail: jukka.lahdensivu@tut.fi

J. Suonketo
e-mail: Jommi.suonketo@tut.fi

M. Pentti
e-mail: matti.pentti@tut.fi

J.M.P.Q. Delgado (ed.), *Recent Developments in Building Diagnosis Techniques*,
Building Pathology and Rehabilitation 5, DOI 10.1007/978-981-10-0466-7_1

ventilation rate, mould, bacteria, volatile organic compounds (VOC), chemicals, dust, cigarette smoke, pet allergens, radon, asbestos and formaldehyde (HCHO). The most significant factor varies by region and year of construction (Weschler 2009). In the Nordic countries and in North America, indoor air problems are often related to moisture and mould damage in structures and buildings (Bornehag et al. 2001, 2004; Hyvärinen 2002; Mudarri and Fisk 2007).

A recent study (Annila et al. 2015a) established the methods used in Finland to detect moisture and mould damage in buildings and structures. The research material consisted of moisture performance assessment reports on 76 buildings. Moreover, experiences from practical moisture performance assessments were used to find new targets of development. The study was conducted as part of wider research aimed at developing operating procedures and methods for earlier detection of moisture and mould damage. The methods can help prevent moisture and mould damage and ensuing IAQ problems and negative health impacts.

2 Literature Review

2.1 Moisture Performance Assessment in Finland

Awareness of moisture and mould damage in the building stock and its impact on IAQ and the health of users increased in the 80s. Subsequently, the subject area was researched a lot and the methods presently used in Finnish moisture performance assessment became established in the 90s. They are partly described, for instance, in Haverinen-Shaughnessy et al. (2008) and Asikainen (2008). An updated guide for moisture performance assessment is currently being prepared as part of the moisture and mould programme of the Ministry of the Environment in Finland.

In Finland, research on moisture and mould damage is referred to either as moisture performance assessment or IAQ research. In practice, their contents are nearly identical, but their aims are different. Moisture performance assessment determines the current condition of structures, any possible damage in them, and their future repair needs. Indoor air research focuses on IAQ and possible impurities in the air. High quality indoor air research, however, also establishes the moisture and mould damage to structures which makes its content practically identical to that of a moisture performance assessment.

Moisture performance assessments generally consist of the four main phases described in Fig. 1 (Annila et al. 2015a): analysis of background and input data, field study, necessary laboratory tests, and analysis and conclusions.

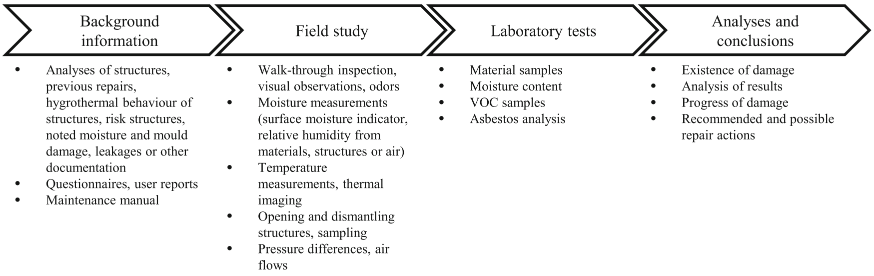

Fig. 1 Four main phases of moisture performance assessment and their main content (Annila et al. 2015a)

2.2 *Initiation of Moisture and Mould Damage*

Moisture and mould damage and the ensuing indoor air problems and repair need are described in Fig. 2. Damage to structures is initiated by moisture stress. There is wide variation between moisture sources and levels of moisture stress. When moisture stress is sufficiently high and lasts long enough, the capacity of a material subject to moisture stress may be exceeded leading to moisture damage. Depending on the material's properties and prevailing conditions, the moisture in a structure may further lead to mould damage. The moisture stress and time required for mould growth can be estimated by different mould growth models (Vereecken and Roels 2012; Ojanen et al. 2010; Vinha et al. 2013; Johansson et al. 2005, 2012; Sedlbauer 2002).

Depending on the prevailing conditions, the material layers of a structure, air flows and location of mould damage, impurities may spread from a damaged area into indoor air leading to an indoor air problem and possible health symptoms in users. Due to the complexity of the phenomena, the links between concentrations of indoor air impurities and health symptoms have not been determined, but the correlation between them is clear (Bornehag et al. 2001, 2004).

Usually, only health symptoms of users lead to moisture performance assessments or indoor air studies that determine the repair need of a building.

The period between the various phases is typically very long. Asikainen (2008) estimated that repairs are typically undertaken 2–5 years after the occurrence of health symptoms. Even after repairs, it takes 6–12 months for indoor air conditions to stabilise (Haverinen-Shaughnessy et al. 2008). Thus, depending on the occupancy of the building, the users can be exposed to impurities for quite long periods even after IAQ problems or moisture and mould damage have been identified.

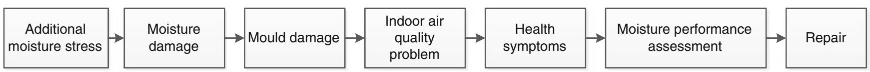

Fig. 2 Development of moisture and mould damage and related repair need

Consequently, there is a clear need for more effective procedures that enable faster identification of moisture and mould damage.

2.3 Extent of Moisture and Mould Damage in Buildings

The extent of moisture and mould damage in the building stock has been the subject of many studies, for instance, in Canada (Lawton et al. 1998), Finland (Nevalainen et al. 1998), Sweden (Smedje et al. 1997), Austria (Haas et al. 2007) and Norway (Holme et al. 2008). The results have also been published in scientific journals. Zock et al. (2002) studied the link between moisture and mould damage and asthma in 18 countries, in Europe and elsewhere. Undoubtedly many national studies, whose results have not been presented in English-language scientific journals, have also been conducted. Several studies made in Finland have also been aimed at decision makers, not scientific circles. A comprehensive summary of these Finnish studies was prepared in 2012 (Reijula et al. 2012). An abstract of it is available in English.

Reijula et al. (2012) summarised the major moisture and mould damage occurring in the Finnish building stock as follows: *We estimate that the prevalence of significant damp and mould damage is 7–10 % of the floor area in small and row houses, 6–9 % in multi-storey apartment block, 12–18 % in schools and kindergartens, 20–26 % in care institutions and 2, 5–5 % in offices.*

Although the extent of moisture and mould damage has been examined in several studies, their results are not mutually comparable since the research methods and definitions of moisture and mould damage have varied. Many studies have investigated the extent of moisture and mould damage through questionnaires directed at users (Lawton et al. 1998; Nevalainen et al. 1998; Haas et al. 2007; Holme et al. 2008; Zock et al. 2002). Questionnaires have been complemented for instance by visual observations made by professionals (Lawton et al. 1998; Nevalainen et al. 1998; Haas et al. 2007; Holme et al. 2008), measurements (Lawton et al. 1998) and indoor air samples (Lawton et al. 1998; Haas et al. 2007; Holme et al. 2008). Comparison of these research methods to the thorough Finnish moisture performance assessment of Fig. 1 makes the difference between the methods apparent.

Studies have shown that a significant part (Partanen et al. 1995), up to one-third (Pirinen 2006), of moisture and mould damage may be hidden, that is, not detectable on the surface of structures despite being examined by an expert. Thus, studies of moisture and mould damage to the building stock based on user surveys and partial measurements are not accurate. It is possible that some damage has gone unnoticed which may accentuate the significance of observable damage in such studies where hidden damage may be totally ignored (Asikainen 2008). Yet, visual observations and user reports on moisture and mould damage play a major role in damage identification and moisture performance assessment (Leivo et al. 1998).

Due to the variance in research methods and questions, the picture of the present state of the building stock and its moisture and mould damage is inaccurate. Lawton et al. (1998) stated in the 90s that information about the condition of a building is the most important factor when planning its repair. The same observation was made in connection with a study on the moisture and mould damage repair projects of Finnish municipalities (Kero 2011). Inadequate moisture performance assessments have led to many failed repair projects (Kero 2011).

A recent study (Annila et al. 2015b) showed that Finnish buildings suffering from indoor air problems often have multiple problems, that is, moisture and mould damage in several structures. In the study the structures were divided into six groups: base floors, roof assembly, intermediate floors, external walls, walls in soil contact and partitions. All examined buildings did not have intermediate floors and walls in soil contact. 68 % of the examined buildings had moisture and mould damage in at least three different structural elements such as the base floor, the roof assembly and an external wall. It was also discovered that individual damaged spots were quite small in area (Annila et al. 2015b).

Thorough moisture performance assessments are necessary to avoid failed repairs (Lawton et al. 1998; Kero 2011; Marttila 2014). Most important from the viewpoint of successful repairs is to know all existing damage despite it being spread across several structures (Annila et al. 2015b) and partly hidden (Partanen et al. 1995; Pirinen 2006). For this reason, more effective identification of moisture and mould damage and development of moisture performance assessment are still topical research areas.

2.4 Definition of Moisture and Mould Damage

For the purposes of this study (Annila et al. 2015a), any damage that meets at least one of the following criteria was considered moisture and mould damage (Annila et al. 2015b):

- I Mould damage visible to the naked eye without magnification.
- II Unrepaired, active water leakage detrimental to the structure or building material that it wets.
- III A structure or building material found to be moist, extremely moist or wet by a surface moisture detector based on a five-step assessment scale: dry, slightly moist, moist, extremely moist and wet.
- IV Relative humidity of the structure exceeds 80 % in a drill-hole measurement.
- V A material sample shows active microbial (fungal or bacterial) growth. The fungal and bacterial colonies are determined by dilution plating on MEA agar and TYG agar.

Criterion I

The occurrence of moisture and mould damage has been examined in several scientific studies based on sensory observations (e.g. Lawton et al. 1998; Nevalainen et al. 1998; Smedje et al. 1997; Haas et al. 2007; Holme et al. 2008; Zock et al. 2002). In a summary of the Finnish building stock (Reijula et al. 2012), many of the original studies are also based, at least partly, on visual observations of damage in buildings. That research method was considered scientific enough for the purposes of these studies.

The observations of TUT researchers about moisture performance assessments support the assumption that moisture and mould damage can be so clearly visible to the naked eye on the surface of a structure or through an inspection opening without a magnifying glass or microscope that establishment of damage requires no more detailed studies. Figure 3 shows an example of clearly visible mould damage on a chipboard wall. Verbally described observations in moisture performance reports are often illustrated by photos which also allow the reader to see what the target of observation looked like during field study.

Olfactory observations by a condition investigator were not used as a criterion of moisture and mould damage in this study because the existence of a strong mould odour in a space does not necessarily indicate reliably which structure in the said space is damaged. Air flows and leaks can carry odours from other spaces.

Criterion II

Water leaks, which may occur both in pipes and structures, have been made into a separate criterion among visual observations. These leaks have not necessarily led to moisture or mould damage by the time of the moisture performance assessment, but an unrepaired leak is highly likely to damage structures and materials. Thus, repair of observed leaks is as important as that of observed existing moisture and mould damage. Figure 4 shows an example of a leaky roof assembly.

Criterion III

Nevalainen et al. (1998) used surface moisture measurements in their study on moisture and mould damage. The mapping made in TUT moisture performance assessments using a surface moisture indicator was the basis of dividing structures into five classes: dry, slightly moist, moist, extremely moist and wet. Similar classification is used in Finland quite generally. In many moisture performance

Fig. 3 Example of visually observed mould damage to a chipboard structure

Fig. 4 Example of leak in a roof assembly detected during a moisture performance assessment

assessment reports analysed for the study, the results of surface moisture measurements had been complemented with more accurate moisture measurements of structures, which allows comparison of the results of surface moisture measurements and more accurate moisture measurements. The combination of the observations of TUT researchers and performed measurements constitute a reliable method properly used for determining the moisture content of structures although surface moisture measurements do not yield an accurate numerical value.

Criterion IV

The moisture and mould damage in structures and the building materials they contain can be modelled by different mould growth models. Vereecken and Roels (2012) have compared the different models that allow estimating the conditions and speed at which structures develop mould damage. Table 1 shows the mould growth sensitivity classes of the VTT-TUT mould growth model often used in Finnish studies (Ojanen et al. 2010, 2011; Vinha et al. 2013).

Johansson et al. (2005, 2012) have suggested critical moisture contents for various materials at which mould growth is possible. The sensitivity of materials to mould growth based on those critical contents is similar to that of the classification of Table 1. For instance, Johansson et al. (2012) determined that the critical moisture content of pine is 75–80 % RH and that of cement-based boards 90–95 %

Table 1 Mould growth sensitivity classes (Ojanen et al. 2010, 2011; Vinha et al. 2013)

Sensitivity class	Materials
Very sensitive	Sawn spruce and pine, planed pine, pine sapwood
Sensitive	Planed spruce, gluelam board, paper-coated PUR, gypsum boards, paper-based products
Medium resistant	Carbonated concrete, aerated and cellular concrete, glass wool, polyester wool, cement-based products
Resistant	Polished PUR, glass, metals, fresh alkali concrete

RH. Their material is based on an earlier publication used in several studies after the original one (Johansson et al. 2005). Sedlbauer (2002) also presented similar substrate categories for building materials.

Based on a summary of the mould growth models (Ojanen et al. 2010, 2011; Vinha et al. 2013; Johansson et al. 2005, 2012; Sedlbauer 2002), mould growth in the most sensitive materials, such as organic building materials, is possible at about 80 % RH at normal temperature of the structures.

A survey of the typical structures found in the Finnish building stock shows that the structures themselves or their component materials fall into the two most sensitive classes of Table 1. Therefore, the critical value of 80 % RH was used in this study to assess Finnish structures.

Criterion V
Material samples detached from building materials can be used with the direct culture or diluted culture method to determine whether there is microbial (fungal or bacterial) growth in the sample. The fungal and bacterial colonies were determined by dilution plating on MEA agar (20.0 g of malt extract, 20.0 g of saccharose, 1.0 g of peptone, 20.0 g of agar, and 0.1 g of chloramphenicol in 1 l of deionized water) and TYG agar (5.0 g of tryptone, 2.5 g of yeast extract, 1.0 g of glucose, 15.0 g of agar, and 0.5 g of cycloheximide in 1 l, of deionized water). The colonies were counted on day 7 (fungal) and day 10 (bacterial) after incubation. The fungal genera were identified microscopically. Furthermore, bacteria were classified as actinomycetes and other bacteria. This is a customary material sample analysis method in Finland (Pessi et al. 2002).

3 Research Materials and Methods

3.1 Research Material

Researchers at TUT Department of Civil Engineering have performed moisture performance assessments of 76 municipality-owned buildings: 59 schools, nine healthcare buildings, three daycare centres and five office buildings. The originally independent studies were later summarised in various ways. Users of all examined buildings have had different health symptoms and other negative sensations of poor IAQ. In the case of 49 buildings, the date of completion of the plan for the moisture performance assessment, the field study and reporting could be determined.

The studied buildings represent well the age distribution of the Finnish building stock. The oldest individual buildings had been built in the 1800s while the majority had been completed in the 50s, 60s and 70s—the period when school construction was especially brisk in Finland. The age distribution of the research material is shown in Fig. 5. The research material included all conventional structures, building materials and building systems used in Finland.

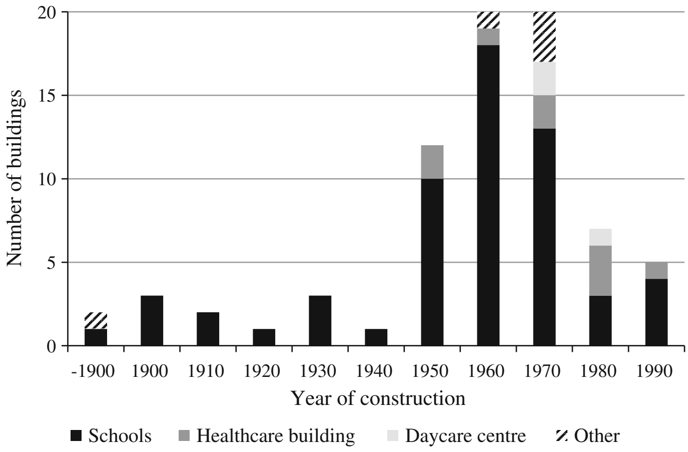

Fig. 5 Age distribution of examined buildings (Annila et al. 2015a)

3.2 Research Method

The 76 buildings of the study were originally examined as individual units. However, the content of the moisture performance assessments had been the same with all buildings (as shown in Fig. 1). At the outset of the study, the content of the moisture performance assessment reports on the 76 buildings, especially as concerns moisture and mould damage, was transferred to a database. All observed moisture and mould damage mentioned in the reports including related basic data, such as structure, material and used research methods, was entered. Basic data of each building such as year of construction, material of bearing frame, occupancy, location, time of assessment, number of storeys, roof type and foundation method were also recorded.

A total of 1784 observations suggesting moisture and mould damage had been made about the studied buildings. After their recording, observations were classified into two groups: "0 = undamaged" and "1 = damaged" based on the below definition of acute moisture and mould damage. An observation was classified as acute moisture and/or mould damage (class 1 = damaged) if it met at least one of the following criteria (Annila et al. 2015b):

I Mould damage visible to the naked eye without magnification.
II Unrepaired, active water leakage detrimental to the structure or building material that it wets.
III A structure or building material found to be moist, extremely moist or wet by a surface moisture detector based on a five-step assessment scale: dry, slightly moist, moist, extremely moist and wet.

Table 2 Basic structure of the database and four examples

Example	Visual observation	Active leakage	Surface moisture detector	Relative humidity	Mould growth	Class: undamaged or damaged
1	Discolouration		Dry			0
2	Paint peeling off		Moist	86.3 % RH		1
3	Discolouration		Extremely moist		Actinomycetes	1
4	Visible damage	Yes				1

IV Relative humidity of the structure exceeds 80 % in a drill-hole measurement.
V A material sample shows active microbial (fungal or bacterial) growth. The fungal and bacterial colonies were determined by dilution plating on MEA agar and TYG agar.

Table 2 shows examples of entries in the database. They are related to observations and measurements made in the buildings to detect moisture and mould damage in structures.

The examples in Table 2 may correspond, e.g., to observations like the following.

1. The wall surfacing material had discolouration that was dry according to the surface moisture indicator. The discolouration was the result of normal soiling of the structure.
2. The coat of paint on the wall in soil contact was peeling off. Drill-hole measurements on the concrete structure indicated a moisture content of 86.3 % RH.
3. Moisture stains were visible in the ceiling and the structure was extremely moist according to the surface moisture indicator. A material sample from the roof assembly showed strong growth of actinomycetes.
4. The partition had visually observable damage around a leaking tap water pipe.

Of the above described observations and those presented in Table 2, nos. 2, 3 and 4 have been classified as damage in accordance with the used acute moisture and mould damage definition.

3.3 Scope of the Study

The study was limited to moisture and mould damage occurring in structures. A similar approach was followed also in the original moisture performance assessments. They examined what types of damage occur in structures and their repair need.

Moisture and mould damage has been found to have a negative impact on the health of users (Bornehag et al. 2001, 2004). The 76 moisture performance assessment reports used as research material did not, however, focus on the health symptoms experienced by users, which is why this study also excludes them. The original moisture performance assessment reports also dealt with ventilation and shortcomings and observations related to its performance. Yet, this study excludes building systems.

The scope of the study is based on the following hypothesis: When all moisture and mould damage in structures is repaired, the building cannot cause any health symptoms or indoor air problems related to moisture and mould damage to structures.

4 Results

4.1 Length of Moisture Performance Assessment Process

Different mould growth models (Vereecken and Roels 2012; Ojanen et al. 2010; Vinha et al. 2013; Johansson et al. 2005, 2012; Sedlbauer 2002) can be used to estimate the time required for mould damage to occur. Generally it is weeks, even months, depending on the level of moisture stress and the sensitivity of a material to mould growth.

Presently, there is not sufficient research data on how quickly and what types of mould damage spread impurities into indoor air which may cause health symptoms in users. The spreading is influenced by many factors such as pressure ratios, location of damage, materials of structure and air flows. Moreover, people react differently to spreading impurities. TUT has conducted user surveys and interviewed building users in connection with moisture performance assessments. According to users, health problems have generally continued for quite long before investigation of the cause of symptoms and the building's condition has started.

The analysed moisture performance assessment reports have been used to determine the time between (1) the start of planning the research and the first day of field study, (2) the start of field study and reporting, and (3) the start of planning the study and reporting.

The length of the first period indicates the slowness of municipal decision-making processes although the users experience health symptoms related to a building. The length of the second period indicates the time taken by a moisture performance assessment. The third criterion represents the length of the overall process, being the sum of the two previous ones. Figure 6 shows the length distribution of these three periods for the 49 buildings for which the data in question could be determined.

In the case of 31 (63.3 %) buildings, the moisture performance assessment was launched within 2 months of submission of tender. The moisture performance assessment proper including reporting may take several months: according to the study material, the shortest time it took to write the report was 1–2 months after the field study. A total of five (10.2 %) condition assessments were completed that

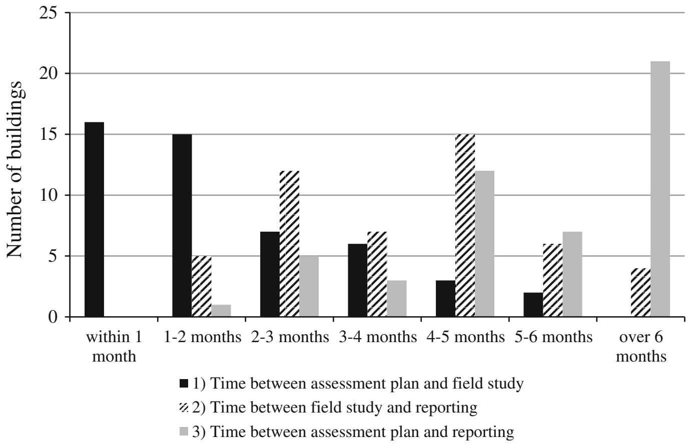

Fig. 6 Lengths of different phases of moisture performance assessments in research data

quickly. The period between the planning and reporting of the assessment was over six months in the case of 21 buildings (42.9 %).

Asikainen (2008) found that it can take 2–5 years between the occurrence of health symptoms and the completion of repairs. In addition, Haverinen-Shaughnessy et al. (2008) found that it takes 6–12 months after repairs for the impurity content to stabilise.

Due to the slowness of the processes, the exposure times to indoor air impurities caused by moisture and mould damage are long. Therefore, there is a clear need to develop moisture and mould damage detection methods so that damage can be observed more effectively before health symptoms appear.

4.2 Detection Methods

Based on the used criteria, a total of 920 observations on acute moisture and mould damage were made in the examined 76 buildings. The number of detected damage was great since the moisture performance assessments examined the extent of damage to determine the extent of required repairs. Thus, for instance, the base floor may have been investigated from different spaces whereby several observations about moisture and mould damage in an individual structural element of a building may have been made.

Figure 7 shows the distribution of observed moisture and mould damage in examined buildings by structures.

Figure 8 shows the methods used to detect the 920 moisture and mould damage in question. Part of the damage was detected by several methods, for example, surface moisture measurement and material samples. A single method was used to

Fig. 7 Locations of moisture and mould damage by structures

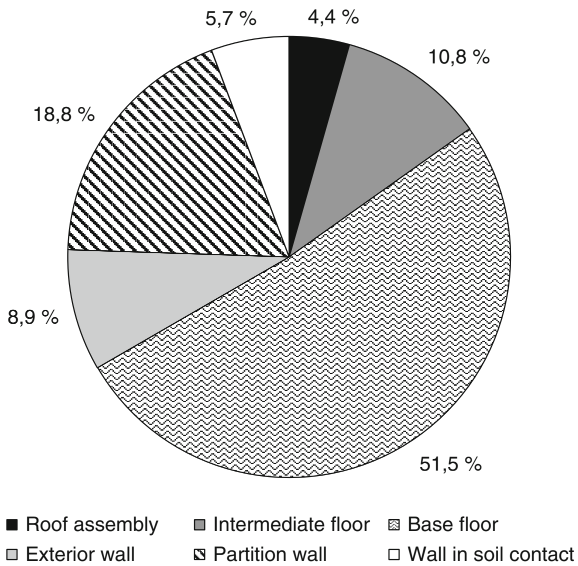

Fig. 8 Methods used to detect moisture and mould damage

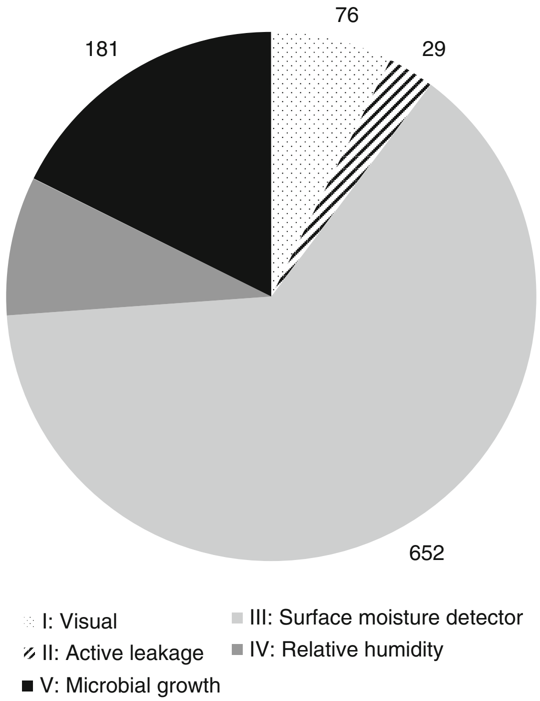

Table 3 Methods used to detect moisture and mould damage

Detection method	Number of detections	Share of all detections (%)	Confirmed measurements or observations (%)
I Visual: clear damage	76	7.4	47.4
II Visual: active leakage	29	2.8	13.8
III Surface moisture detector	652	63.6	12.1
IV Relative humidity	87	8.5	34.5
V Material sample test	181	17.7	30.4

detect 821 (89.2 %) damage while two or more methods were used for the other 99 (10.8 %).

The number of confirmed measurements and observations (99 damage) is small. This is due to the fact that measurements at one spot are rarely made by several methods. For example, if damage is suspected in the base floor, the moisture content of the structure can be measured from a different spot than the material sample taken. If both methods indicate damage in the base floor, the base floor of the space in question has two damaged areas according to the calculation method, the existence of neither having been confirmed by the other. When the base floor is examined as a unit, more confirming measurements are made, but at different points of the structure.

Table 3 shows the number and share of detections by different methods as well as how often measurements and observations have been confirmed by another method. According to Table 3, moisture and mould damage was detected 652 times with a surface moisture indicator. Some other method was used to confirm 12.1 % of these measurements.

Visually observed clear mould damage, RH measurements and material samples have most often been confirmed by other methods: in 47.4, 34.5 and 30.4 % of the cases, respectively. The used confirmation method has often been surface moisture measurement.

Table 3 shows that surface moisture measurements (63.6 %) are clearly the most used method for detecting moisture and mould damage. The second most popular method is material samples (17.7 %)—the large difference between their use is due to the fact that surface moisture measurements yield a value that indicates the moisture content of a structure quickly and cost-effectively.

A total of 589 sensory observations by condition investigators had been recorded in the assessment reports on the 76 buildings involved in the study. Of these observations 258 (43.8 %) were linked to 920 detected moisture and mould damage. Moisture and mould damage could be detected by a single sensory observation in 105 instances. It is highly likely that considerably more sensory observations

Table 4 Methods used to detect moisture and mould damage in different structures

Detection method	Roof assembly (%)	Intermediate floor (%)	Base floor (%)	Exterior wall (%)	Partition wall (%)	Wall in soil contact (%)	Average (%)
I Visual: clear damage	13.3	7.5	5.7	8.8	11.5	3.5	8.4
II Visual: active leakage	13.3	0.9	2.1	0.0	0.5	1.8	3.1
III Surface moisture detector	13.3	65.4	67.9	48.4	68.8	77.2	56.8
IV Relative humidity	11.1	9.3	11.8	3.3	2.1	5.3	7.2
V Material sample test	48.9	16.8	12.4	39.6	17.2	12.3	24.5

were made in connection with field studies. If sensory observations were found to be unconnected to moisture and mould damage, they have not necessarily been entered in the moisture performance assessment report. Moreover, the sensory observation may not have been recorded either if a structure had been subjected to moisture measurements or material sample tests. Yet, the significance of an investigator's sensory observations is high.

Table 4 shows the method used to detect damage in different structures. The shown deviation between moisture and mould damage detection methods for different structures is wide.

5 Discussion

5.1 Length of Moisture Performance Assessment Process

The time from the beginning of moisture stress and the occurrence of moisture and mould damage is long in Finland. The process may take several years as found in earlier studies (Asikainen 2008). The observations of this study and that by Haverinen-Shaughnessy et al. (2008) support the view of the long duration of the process phases. In the case of the 76 moisture performance assessments included in this study, the date of completion of the condition assessment plan, the field study and the report could be established. In 21 (42.9 %) cases, the interval between the completion of the moisture performance assessment plan and reporting was over six months, 358 days at the longest.

All phases of the process need to be developed in order that repair of moisture and mould damage becomes faster and exposure of users to indoor air impurities due to moisture and mould damage becomes shorter. Moisture performance assessments also need to be developed and studied further and the best phase for launching assessments determined. Presently, they often start only after a building's users start to show health symptoms. Yet, we should be able to act before these health symptoms occur. Early detection of moisture and mould damage and management of moisture risks require more effective methods and approaches.

The study showed that moisture performance assessments take a long time: based on the research material the period between completion of the assessment plan and the report was on average 183 days. Of that, the completion of the assessment plan and the field study took 63 days, on average, while the remaining 120 days were spent completing the report and analyses after field study.

The shortest time required for the actual moisture performance assessment process (from field study to reporting) is about one month, since the analysis of material samples generally takes at least two weeks. In the case of five buildings (10.2 % of research material), the moisture performance assessment report was finished in 1–2 months after the field study. However, the longest time required was over six months (in 4 of 49 cases). The length of the moisture performance assessment process is probably due to the fact that the results of material sample tests are not known during field study but have to be waited for. That may lead to a situation where further samples from a building are needed, which naturally doubles the time needed to complete the report.

5.2 Moisture and Mould Damage Detection Methods

Based on the research results, the sensory observations of the condition investigator and surface moisture measurements play a significant role in the detection of moisture and mould damage. That is also suggested by the fact that many studies on the damage suffered by the building stock have searched for moisture and mould damage especially by sensory observations (e.g. Lawton et al. 1998; Nevalainen et al. 1998; Smedje et al. 1997; Haas et al. 2007; Holme et al. 2008; Zock et al. 2002). An expert opinion and surface moisture measurements can indeed establish quickly and cost-effectively the repair need of buildings. It is not a novel finding since Lappalainen et al. (2001) have shown that the order of importance of school building repairs can be set based on sensory observations and surface moisture measurements.

However, an expert's observations reflect only the conditions at isolated spots of a building. The regular users of a building make observations over the long term. Leivo et al. (1998) recognised that users play an important role in the detection of moisture and mould damage. The significance of users has also been noted in studies on the damage suffered by the building stock and their impact (Zock et al. 2002; Howden-Chapman et al. 2005). The subject requires further study in order for us to know how well building users without expertise in moisture and mould damage and IAQ problems can detect related damage and risks compared to an expert.

Based on the results of this study, 73.9 % of detected moisture and mould damage could be detected from the surface of structures as clear mould damage (Detection method I), a water leak (II) or by surface moisture measurements (III). As previously stated, visual observations have probably been made in connection with moisture measurements (IV) and material sample tests (V), which were not necessarily always recorded in moisture performance assessment reports, or that by themselves were not sufficiently clear indicators of the existence of damage.

Partanen et al. (1995) found that a significant portion of the moisture and mould damage in the Finnish building stock is hidden. Pirinen (2006) estimated that one-third of all moisture and mould damage is hidden. The results of this study support the results and observations of those two earlier studies since about a quarter of the damage could not be detected from the surface of structures but required using destructive methods.

The moisture and mould damage of different structures were detected by very different methods as Table 3 indicates. This can probably be largely explained by the differences between structures. For example, a concrete slab with a moist soffit that is part of the base floor probably also has a moist top due to its capillarity, whereby its moistness can be detected by a surface moisture detector. On the other hand, the thermal insulation of a roof assembly is generally external to the air/vapour barrier which may prevent detecting damage from the surface of the structure. That may require, for instance, a mould sample from the thermal insulation of the roof assembly.

In the study 73.9 % of all damage was detected on the surface of structures (Detection methods I-III). Yet, it is important to note (Table 3) that only 39.9 % of the damage in roof assembly could be detected from the surface of structures. The share was highest at 82.5 % in walls in soil contact. Further study on detection methods suitable for different structures is needed.

The scope of the study was limited based on the hypothesis that if a building has no moisture and mould damage, related health symptoms and indoor air problems cannot occur there. Excessive repairs are not generally economically feasible, or even profitable. Thus, we should have criteria for the kinds of moisture and mould damage that should be repaired to avoid the occurrence of health symptoms. Repair of the smallest and slightest damage is not necessarily needed. Currently, we do not know what impurity-content level in relation to moisture and mould damage causes health symptoms for groups or individual users. This has been recognised earlier (Bornehag et al. 2001, 2004), but the research problem remains unsolved and further medical research is needed.

6 Conclusions

This study determined on the basis of moisture performance assessment reports on 76 buildings the methods used to detect moisture and mould damage in Finland. It also sought targets of development related to moisture performance assessments based on these condition assessment reports and the practical experiences of researchers who have conducted moisture performance assessments.

According to the study, 73.9 % of moisture and mould damage can be detected on the surface of structures by sensory observations or surface moisture measurements. However, the share can be significantly smaller depending on the assessed structure: in roof assembly 39.9 % of the damage could be detected on the surface of a structure.

The study found that the mere time taken by a moisture performance assessment is long: the period between the completion of the assessment plan and the report was, on average, 183 days. Moisture and mould damage processes are long also in other respects and can take several years. All phases certainly have areas that can be improved so that the processes and the exposure of users to the impurities caused by moisture and mould damage can be shortened. The moisture performance assessment process also requires development.

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