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Extent of moisture and mould damage in structures of public buildings

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ABSTRACT

The study concentrated on the extent of moisture and mould damage in different structures in 25 public buildings in Finland. Users of all the buildings had health symptoms suspected to be the result of moisture and mould damage, which is why moisture performance assessments had been performed. The assessment reports on each building were available as research material. The reports indicated that the examined buildings suffered from multiple moisture and mould problems in several different structures. On average, however, a relatively small proportion of the total number of structures had suffered damage. On the basis of the research material, damage was most extensive in walls in soil contact (16.3%) and base floor structures (12.5%). The lowest damage rates were found in partition walls (2.4%), external walls (2.6%) and intermediate floors (2.5%). The results of the study underline the importance of thorough moisture performance assessments to ensure that all point-sized moisture and mould damage is detected.

1. Introduction

Indoor air problems are common around the world but their causes vary by region. Many indoor air problems can cause diverse health symptoms to building users. Since the causes are many, and the health symptoms vary, we are dealing with a rather complex set of problems. In Finland, indoor air problems are in many cases related to moisture, and moisture and mould damage in structures. They have been shown to cause health symptoms in users even though the reasons are not clear [1,2]. Moisture and mould damage are also common in other countries [3–7].

The aim of this study is to determine the extent of moisture and mould damage in different structures of 25 Finnish public buildings. The users of all these buildings had reported health symptoms of varying intensity linking them to poor indoor air quality, which is why thorough moisture performance assessments had been conducted to determine the moisture and microbial condition of structures.

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2. Literature review

2.1. Extent of moisture and mould damage

The extent of moisture and mould damage has been examined in many international studies. It can also be assumed that such studies have taken place on the national level, but the results have not been presented in scientific publications of international scientific circulation. The Finnish Parliamentary Audit Committee has made a summary of the extent of moisture and mould damage in Finnish buildings [8]. The summary is based partly on scientific publications and partly on national Finnish-language surveys.

According to the publication of the Parliamentary Audit Committee, moisture and mould damage are found in 2.5–26% of the Finnish building stock. The proportion of damaged buildings varies by building type and is largest in public buildings: moisture and mould damage is found in 12–18% of schools and day-care centres and in 20–26% of health care facilities. Up to 11% of Finns live in houses with moisture and mould damage, and 6–10% of Finland's national wealth is subject to substantial moisture and mould damage. Moreover, 5.6–7.5% of the total annual value of building construction consists of repairing existing damage [8].

However, moisture and mould damage problems are not limited only to Finland. Scientific studies have found moisture and mould damage or signs of it in 19–80% of buildings in various countries [3–7]. It should, however, be noted that the research methods, target buildings, and definition of moisture and mould damage varied between the studies. Thus, the results are not mutually comparable. Nevertheless, it can be concluded that, irrespective of the definition, moisture and mould damage and signs of its presence are rather common internationally.

2.2. Moisture performance assessments

Moisture performance assessments are used to chart moisture and mould damage in buildings, which is one of the most common causes of indoor air problems in Finnish buildings [8]. Moisture performance assessments are sometimes also called indoor air quality (IAQ) studies in Finland. A thorough moisture performance assessment based on the practice established in Finland already in the 1990′s comprises four stages [9]:

Analysis of input data,

1) Field studies,
2) Laboratory tests,
3) Analysis and summary.

In the analysis of input data, the structures of a building, their previous repairs, as well as defects, problems and damage observed by users are charted. The analysis of input data is needed to assess the presence of moisture and mould damage as well as its location and the probability of its occurrence. The analysis guides the design of the content of the field study [9].

The field study includes measuring the building’s temperatures, moisture levels, pressure differences, air flows, and taking of material samples. It often also includes comprehensive moisture mapping with a surface moisture detector. Material samples are also often taken in field studies for subsequent laboratory analysis with other possible samples. Material samples are used in moisture performance assessments mainly when there is uncertainty about mould growth. Therefore, samples are not usually taken from areas of clear moisture and mould damage but from points where mould growth is possible but not established [9].

At the last stage of the moisture performance assessment, the results are analysed and summarised. The summary includes recommended measures for eliminating the detected moisture and mould damage and possible alternatives for them [9].

2.3. Definition of moisture and mould damage

In this study acute moisture and mould damage refers to damage that meets at least one of the following criteria [10]:

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

3. Material and methods

3.1. Research material

Tampere University of Technology (TUT) has carried out comprehensive moisture performance assessments of numerous buildings in the 2000′s. These assessments were originally performed separately and were not part of a single scientific study. However, all of the moisture performance assessments followed standard methods widely used in Finland [9]. That made subsequent scientific comparison and analysis of separate assessments possible in this study. It has not been possible to supplement the contents of original assessments or mend any possible deficiencies. That has affected the formulation of suitable research questions for the study.

A total of 25 public buildings were chosen randomly for this study. They were assessed between 2003 and 2010 in separate for-fee studies. Seventeen of the studied buildings were schools (building codes S1–S17 in results), four were day-care centres (K18–K21) and two health care facilities (H22–H23). Two buildings (O24–25) were classified under 'other occupancy': one was an assembly hall and the other a parish centre.

At the time of the moisture performance assessments, the age of the buildings varied from 10 to 114 years. The average construction year was 1956 and standard deviation 32.2 years. Some of the buildings had been built in several stages, which is why such buildings are divided into groups based on year of construction. That allows establishing the age of each detected damaged structure. The material of the load-bearing vertical frame was concrete in 9 schools, wood in 9 schools and masonry in 7 schools while the average number of floors was 1.9, 1.3 and 3.3, respectively. The research material represents well the Finnish building stock owned by municipalities.

The structures of these buildings were divided into 6 groups: roofing decks, external walls, intermediate floors, partition walls, walls in soil contact, and base floors. Base floors include both ground slabs and base floors with a crawl space. Walls partly in contact with soil were considered walls in soil contact.

Users of all buildings had felt health symptoms of varying degree due to indoor air quality problems as well as other negative sensations related to indoor air. These feelings had resulted in complaints which led to the decision that a comprehensive moisture performance assessment must be performed to determine the possible existence of indoor air quality problems. This study focuses on moisture and mould damage in structures.

A report was written on each study which presented all observations on the extent and location of moisture damage made during the assessment. Other indoor air impurities were also considered in the assessments but this study concentrates only on the extent of moisture and mould damage in structures. This is due the fact that if there is no moisture or mould damage in a building, any existing indoor air quality problems cannot be caused by it.

3.2. Research method

The extent of moisture and mould damage detected in the comprehensive moisture performance assessments is indicated in the floor plans of buildings. On the basis of the scale of the floor plans, the total amounts of each structural element were measured from floor plans with a ruler: metres of wall (m) in the case of vertical structures, and areas of horizontal structures (m^2). The total number of the spaces of a building was also calculated. The corresponding extent of damage detected in moisture performance assessments was also calculated for different structures. If the damage was located in an intermediate floor or partition wall structure, it was considered to pertain to the spaces on both sides of the structure, since it may have affected indoor air quality on both sides.

Part of the damage was detected by single point measurement methods such as relative humidity measurements and material samples. Their extent was set to 1 m^2 in horizontal structures or 1 m in vertical structures, unless the extent of the damage in question was presented in more detail. Windows and doors were included in the total numbers of wall structures.

4. Results

A total of 357 instances of acute moisture and mould damage meeting the used definition were found in the assessed buildings. That means, on average, 14.3 instances in each of the 25 buildings.

Most damage was found in base floors (57%) while clearly less was observed in other structures: 16% in partition walls, 9% in intermediate floors, 8% in walls in soil contact, 7% in external walls and 3% in roofs.

The study revealed that buildings are usually beset by multiple problems, that is, moisture and mould damage is found in several structures. Based on the classification of the study, a maximum of six different structures can suffer from such damage. In the assessed buildings, it had affected, on average, 2.92 structures. Damage was found in more than half (56%) of the total number of structures of each building. Furthermore, the many separate damaged areas of different structures mean that moisture and mould damage exists in 32.8% of indoor spaces, on average.

The results indicate wide variation in the number of damage instances between buildings. All but 3 buildings had at least 1 structure with no moisture and mould damage. The 5, 10 and 20% fractiles were calculated from the distribution of damage for each structure. The distributions plotted on the basis of these fractiles are shown in Fig. 1. For instance, in 23 buildings (92% of the buildings of the research material) less than 5% of the area of the roof was damaged. In 24 buildings (96%) less than 10% of the area of the roofing deck was damaged.

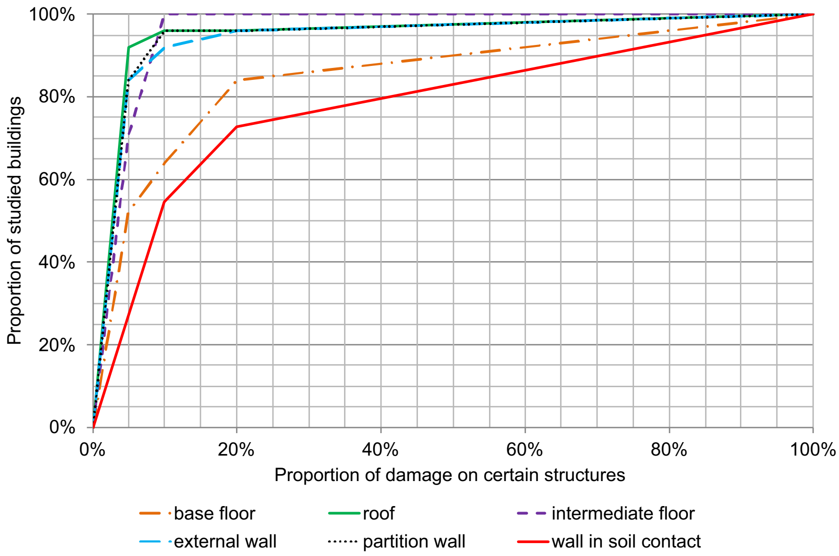

Fig. 1. Distributions of damage between structures.

Table 1 shows the average proportion of each structure having suffered damage. In addition, it shows the highest degree of damage and standard deviation. The lowest degree of damage of all structures was 0%, which is why it is not shown in Table 1. As shown the average proportion of damaged structures (mean value) is relatively small with all structures while their standard deviations are remarkable which underlines the differences between various buildings.

5. Discussion

The study reveals that the moisture or mould damage from which the studied buildings suffered had multiple sources. Thus, even extensive repairs on a single structure are unlikely to eliminate all problems. As to the extent of damage, Table 1 shows that, on average, damage affects a relatively small portion of structures, sometimes less than 5%. However, in individual buildings, damage to a single structural component may be very extensive, especially in the case of walls in soil contact, base floors, and roofing decks as shown in Table 1. The values indicate high variations between damaged buildings.

It is probable that the basic features of buildings like materials and structures, HVAC, and age have a significant effect on the occurrence of moisture and mould damage. Yet, previous studies [11,12] have indicated that even though buildings have similar basic features they are individual entities. Thus, it is probable that the moisture and mould damage suffered by similar buildings also varies a lot. The analysis of the influence of basic properties would require a much bigger sample of damaged buildings than this study has.

Moreover, one main finding of previous studies [11–13] is that municipalities have deficiencies in the management of their buildings such as omitting to perform adequate maintenance and timely repairs. The failure to keep record of measures undertaken is also a clear shortcoming. Later analysis of the effects of maintenance and occupants is difficult afterwards when measures undertaken are not known.

The research material indicates that it is hard to determine the main factor causing moisture and mould damage in each case. The damage can be the result of a combination of factors such as poor hygrothermal behaviour of a structure, mistakes made during the construction phase, shortcomings in maintenance, ageing of materials, or something exceptional like pipe leaks [3,6,14,15]. The causes of damage were beyond the scope of this study and further studies and measures are needed to eliminate or mitigate them in the future.

The distribution of damage across 2.92 structures, on average, is reflected in the large average share of damaged spaces (32.8%). Thus, wide-spread damage distributed across several structures may cause extensive indoor air quality problems in the affected building. However, many things such as air leakage in structures, pressure differences across structures and ventilation determine how impurities spread into indoor air and how occupants react to them. This study focuses only on the

Table 1
Proportion of moisture- and mould-damaged structures.

	Wall in soil contact	Base floor	Roof	External wall	Intermediate floor	Partition wall
Mean value	16.3%	12.5%	4.5%	2.6%	2.5%	2.4%
Maximum value	75.3%	81.7%	100.0%	27.3%	9.3%	22.2%
Standard deviation	21.7%	18.6%	20.0%	6.1%	3.4%	4.9%

extent of moisture and mould damage, not its impact on indoor air or occupants' health, which still needs to be studied and analysed further based on the research data.

The repair of moisture and mould damage has been considered important due to the increased risk for negative health effects from it [1,2]. The success of repairs is still uncertain partly due to the lack of a commonly accepted tool or criteria for its assessment: repairs may appear successful based on one indicator and a failure based on another [16].

Inadequate input data on the condition of the building have been identified as one factor behind failed moisture and mould damage repairs [12]. In practice, that means inadequate or erroneous moisture performance assessment. The results of this study further underline the importance of thorough moisture performance assessments, even though some damage has already been detected. Thorough assessments are only an alternative to detecting all point-sized damage across different structures.

It is important to note that the degrees of damage presented in this study cannot be used directly to determine the required extent of repairs. In the Finnish building stock, moisture and mould damage often occurs in at-risk structures [13]. A feature shared by them is poor hygrothermal performance. In practice, this usually means that their drying capacity is too low in relation to the mould susceptibility of the materials. Consequently, wetting of a structure often unavoidably leads to moisture and mould damage. Even in at-risk structures damage may occur only in a small area, but it may nevertheless be sensible to repair the entire structure at once. Other imminent renovation needs and possible changes in occupancy of premises should also be taken into account when determining the extent of the area to be repaired.

6. Conclusions

The research material comprised reports of thorough moisture performance assessments of 25 public buildings. The study focused only on the extent of moisture and mould damage in different structures even though other indoor air quality (IAQ) problems and impurities may have beset the examined buildings. Any possible health concerns due to detected damage and other impurities were also excluded.

The study's main findings on 25 moisture- and mould-damaged Finnish public buildings were:

- Buildings with moisture and mould damage are multi-problematic. On average, 2.92 building structures were found to be moisture- and mould-damaged in the performed assessments.
- The moisture- and mould-damaged proportion of all structures is, however, fairly small and damage seems to be point-sized rather than widespread. The proportion of damaged structures was, on average, 2.4–16.3% depending on the structure.
- The remarkable standard deviation of the damaged area indicates that every building should be examined separately to ensure that all moisture and mould damage will be detected.

The results of the study underline the importance of thorough moisture performance assessments in the identification of all moisture and mould damage of different structures.

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