# Need to repair moisture- and mould damage in different structures in finnish public buildings

**NEED TO REPAIR MOISTURE- AND MOULD DAMAGE IN DIFFERENT STRUCTURES IN FINNISH PUBLIC BUILDINGS**

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**ABSTRACT**

Moisture- and mould damage and resulting impurities are related to complex indoor air quality problems. This study focuses on the need to repair moisture- and mould damage in different structures. The research material consists of 168 Finnish public buildings. Based on research material, the highest need for repair is in timber-framed ground floor with crawl-in space, slab-on-ground structures, external walls in concrete-framed buildings and walls in contact with soil. A need to repair these structures exists in 56-85% of the examined buildings. The study reveals that buildings are multi-problematic: on average 3.1 main category structures were damaged in every studied building.

KEYWORDS:

Moisture damage, mould damage, moisture performance assessment, condition investigation, indoor air, refurbishment

## 1 INTRODUCTION

Moisture- and mould damage in different structures and possible resultant indoor air quality (IAQ) problems in public buildings have been a hot topic in various media and publications. To summarize, these issues are common for example in Nordic countries (Bornehag et al. 2001), North America (Mudarri and Fisk 2007) and the rest of Europe (Bornehag et al. 2004). Furthermore, it is estimated nationally that these problems are suffered by up to 26% of Finnish municipal buildings (Reijula et al. 2012). Repairing this damage and solving indoor air quality problems are important due to the possible negative health effects of indoor air impurities (Bornehag et al. 2001).

Even though moisture- and mould damage are common in Finnish public buildings, it is not clearly demonstrated in which structures the need for repair is concentrated. Knowing this is important, when future refurbishment actions and needs are under examination.

The statistical data from this study can utilised for this purpose, when examining the need for repair in larger building groups, for example in public buildings in a city or town. However, previous studies (Kero 2011, Marttila et al. 2015a, Marttila et al. 2015b, Annila et al. 2017) have pointed out that comprehensive moisture performance assessment had to perform before renovation of individual old buildings - renovation cannot be based on the statistical data from similar buildings. This is mainly a consequence of the fact that every building is individual and damage varied greatly between the buildings (Annila et al. 2017).

The aim of this research is to point out the need for the repair of moisture- and mould damage in different structures in Finnish public buildings. The research is based on data from 168 public buildings. Moisture- and mould damage is only one possible reason for indoor air quality problems, but this study focuses on this damage only, and other indoor air impurities and possible health issues are out of scope.

## 2 LITERATURE REVIEW

### 2.1 Extent of moisture- and mould damage

The extent and consequences of moisture- and mould damage have been studied in multiple scientific studies and national reports. However, the results of the studies are not comparable with each other, because research methods and objectives, and other factors, such as building types, vary. Moreover, the definition of moisture- and mould damage also varies and there is no consensus for this definition. Table 1 summarises a couple of studies related to the extent of moisture or mould damage. As can be noticed from the table, moisture- and mould damage or signs of such damage are common issues in many different countries, irrespective of the purpose of the building or other above-mentioned factors, as the results of these studies point out. The share of moisture or mould-damaged building could be high: up to 80% (Nevalainen et al. 1998).

Table 1. Extent of moisture- and mould damage in a couple of scientific studies

| **Reference** | **Extent of moisture- and mould damage**<br>• research material<br>• result |
|---|---|
| Lawton et al. (1998) | • 59 homes in Canada<br>• The share of moisture damaged structures was between 0-77%. |
| Nevalainen et al. (1998) | • 450 houses in Finland.<br>• Trained civil engineers detected current or previous moisture faults in over 80% of buildings. |
| Howden-Chapman et al. (2005) | • 613 households in New Zealand<br>• 35% of occupants from these houses reported visible mould in one or more of their rooms |
| Haas et al. (2007) | • 66 households in Austria<br>• In on-site inspections, visible mould growth was found in 56% of the apartments. |
| Salonen et al. (2007) | • 77 office buildings in Finland<br>• Experienced construction engineers found dampness or visible mould damage in 44% of buildings. |
| Holme et al. (2008) | • 205 homes in Norway<br>• Professional inspectors detected one or more visible indicators of a moisture problem in 50% of the buildings. |
| Haverinen-Shaughnessy et al. (2012) | • 59 school buildings in Finland, 85 in Spain and 92 in the Netherlands.<br>• Signs of damp or mould were detected in 24% of Finnish schools, 47% of Spanish schools and 43% of Dutch schools. |

Although moisture- and mould damage are common in building stock, the damage is usually isolated and divided into multiple structures and different spaces inside one building (Haverinen et al. 2001, Haas et al. 2007, Holme et al. 2008, Haverinen-Shaughnessy et al. 2008, Haverinen-Shaughnessy et al. 2012).

Furthermore, a recent study (Annila et al. 2017) indicates that the share of moisture- and mould damaged structures is on average 2.4-16.3%, which means that on average moisture- and mould damage is isolated rather than widespread.

### 2.2 Location of moisture- and mould damage

The location of moisture- and mould damage has been examined in a couple of studies, for example Partanen et al. (1995), Lawton et al. (1998), Haverinen et al. (2001), Pirinen (2006) and Holme et al. (2008). However, the location has not been the main research questions in these studies, which is why these studies are not directly comparable with each other. Furthermore, two key factors, definition of moisture- and mould damage and classification of structures are different in these studies.

Haverinen et al. (2001) have pointed out that most damaged structures were external walls and partition walls. The share of buildings where moisture- and mould damage appears on these structures was 29% and 27% respectively. It is, however, unclear whether they examined in their study house that had suffered multiple damage.

In his dissertation, Pirinen (2006) also studied the location of damage in residential houses. The most common damage was in ground floors (damage found from 35% of examined buildings), structures of bathrooms (33%) and walls with soil contact (26%). However, the study does not specify the location of damage in bathrooms. Damage may be located, for example, in partition walls, ground floors, external walls or walls in soil contact, depending on location of bathroom. The location of damage varied between different decades in the 20$^{th}$ century, which indicates that construction period and type of structure may have an influence on moisture- and mould damage.

The numerous moisture-related problems detected in Finnish slab-on-ground structures have already been known for a couple decades (Partanen et al. 1995), which is why for example Leivo and Rantala (2005), and Rantala and Leivo (2008) have focused on moisture problems on ground floors in their studies.

The Association of Finnish Local and Regional Authorities published its '*Reasons for and number of cases of moisture- and mould damage in municipal buildings'* survey in 2006 (Ruokojoki 2006). The survey based on questionnaires rather than on technical inspections. According to the answers, the most commonly damaged structures were roofs and ground floors. The share of these structures of all damaged structures was 33% and 30% respectively.

International studies may be even less comparable to this study or other Finnish studies, due to differences in building techniques and climate conditions. However, the results and findings are a quite similar. Windows, basement walls and on-grade floors were the most moisture-damaged structures in study by Lawton et al. (1998). The share of damaged structures was 77%, 34% and 36% respectively. Holme et al. (2008) point out that indications of a visible moisture problem are more common in basements than in bathrooms or living spaces.

### 2.3 Sensitivity of building materials to moisture- and mould damage

Buildings materials have a variable capacity to resist moisture stress before mould growth occurs. The sensitivity of building materials to microbial growth can be assessed by various mould growth models. They can be used to calculate the time needed for mould growth under given temperature and humidity conditions. They can also determine the minimum moisture requirement for microbial growth to start. Mould growth models have been compared, for example, by Vereecken and Roels (2012). Table 2 presents the Finnish mould growth model, where building materials are divided into four sensitivity classes (Ojanen et al. 2010, Viitanen et al. 2010). Organic materials, such as wood-based products, are more sensitive to mould growth than, for example, mineral wool or concrete.

Table 2. Mould growth sensitivity classes (Ojanen et al. 2010 & Viitanen et al. 2010).

| Sensitivity Class | Materials |
|---|---|
| Very sensitive | Sawn spruce and pine, planed pine, pine sapwood |
| Sensitive | Planed spruce, glued wooden boards, PUR with paper surface, gypsum boards, paper-based products |

| | |
|---|---|
| Medium resistant | Carbonated concrete, aerated and cellular concrete, glass wool, polyester wool, cement-based products |
| Resistant | PUR with polished surface, glass, metals, alkali new concrete |

Johansson et al. (2012) have presented critical moisture levels for different materials. For example, the critical limit for pine is 75–80% RH and for cement-based boards 90–95% RH. These are the materials of Johansson et al. (2012) based on an earlier publication (Johansson et al. 2005), which have been used in many studies since the original one. Sedlbauer (2002) has also presented corresponding substrate categories for building materials. Material classification in these mould growth models (Sedlbauer 2002 and Johansson et al. 2005) are quite similar to those presented in Table 2.

However, none of these above-mentioned mould growth models can be classified as traditional and much-used building materials, as they based on today’s building materials. Moss, straw, peat and sawdust are examples for traditional organic materials, which were used in some buildings in Finland until the 1960s (Neuvonen 2006). It is probable that these materials belong to the most sensitive class.

# 3 MATERIALS AND METHODS

## 3.1 RESEARCH MATERIAL

The research data consists of moisture performance assessments reports, and the data has been gathered from a total from 168 Finnish public buildings. These assessments were initially separate fee-based services for municipalities and many companies have performed them. However, the procedures of moisture performance assessments settled into their present form in the early 2000s in Finland, which allows the comparison between the assessments. The collection of the research data started in 2014 in conjunction with the doctoral thesis of Annila, and continued during the earlier *‘Assessment of state-supported mould remediation projects, follow-up research’* study (Marttila et al. 2015a & 2015b) and ongoing *‘COMBI – Comprehensive development of nearly zero-energy municipal service buildings’* project (Vinha et al. 2015).

Original assessments were performed between 1997 and 2015. The original reason for moisture performance assessment has usually been mentioned in reports, but that reason is not always clear. Indoor air quality problems and the determination of the need for repair were mentioned together in 45.2% of assessments. These two reasons appeared also separately: indoor air quality problems in 25.0% and determination of need for repair in 20.2% of cases. In 9.5% of assessments the original reason was not mentioned, but there is suggestion that these two reasons together or separately were the original reason.

The assessments have been thorough, which means that the microbial condition of every structure and indoor space was examined during the assessments. In addition, other possible indoor air impurities and factors, such as VOC-emissions and the efficiency of HVAC, were in the scope on these assessments. If original assessment was not comprehensive, it was rejected as research material. This study, however, focused only moisture- and mould damage in structures, with other possible indoor air quality problems out of scope. Moreover, the possible health effects of damage or other impurities are also ignored.

During the study, it has been impossible to supplement the earlier assessments or to carry out new field studies. The possible limitations and possibilities of research material have been taken into consideration in the posing of research questions.

Data relating to moisture- and mould damage has been collected from moisture performance assessment reports and entered into a moisture- and mould damage database. The database contains all basic facts about the examined buildings, such as year of construction, building materials, number of floors and types of structure. In addition, more detailed information from every individual case of damage has also been entered into the database. This includes for example the location, extent and severity of damage, and the detection method used during the original field study.

The purpose of the examined buildings varies: 115 are school buildings, 29 kindergartens and 24 something else, mainly different kinds of health service buildings. The studied buildings were built between 1840 and 1998. Table 3 presents how the examined buildings were divided into different age groups. The table also presents the number of buildings, average year of construction and standard deviation of age in these six age groups. Finnish buildings stock is relatively young, which is why a similar age classification is often used when Finnish building stock is the subject of study (Vainio et al. 2006).

Table 3. Age groups and constructions periods of research material.

| Age group | Before 1950 | 1950-1959 | 1960-1969 | 1970-1979 | 1980-1989 | After 1990 |
|---|---|---|---|---|---|---|
| Number of buildings | 27 | 33 | 29 | 36 | 35 | 8 |
| Group average construction year | 1915 | 1954 | 1964 | 1974 | 1986 | 1995 |
| Standard deviation of age | 23.7 | 3.0 | 3.0 | 2.9 | 3.1 | 2.7 |

Table 4 catalogues the main structures and materials in the buildings under examination. This table also illustrates changes in Finnish building techniques and how materials used have changed over the decades.

Structures developed during 20th century. In Finland the main changes were a transition from timber buildings to masonry structures at the beginning of the century and a further transition to concrete buildings (Neuvonen 2006) in the middle of century. These changes are illustrated in Table 4. Other significant changes are:

- in intermediate floors: the transition from structures with organic filler material to massive in situ concrete slabs or elements structures during the 1960s, 1970s and 1980s
- in structures with soil contact: replacement of internal thermal insulation with external thermal insulation during 1960s and 1970s

Thermal insulation materials and energy regulations also developed during 20$^{th}$ century.

Table 4. Structures and main materials of the buildings

| Age group | Number of buildings | Type of roof | Share of buildings with wall in contact with soil | Supporting vertical frame | Supporting material of intermediate floor | Structure of base floor |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Before 1950 | 27 | ridge roof 100% | 67% | masonry 48%<br>log 44%<br>combination 4%<br>timber framing 4% | concrete 52%<br>timber 26% | ground slab 63%<br>timber structure with crawl space 48%<br>concrete structure with crawl space 7% |
| 1950-1959 | 33 | ridge roof 100% | 97% | masonry 61%<br>concrete 21%<br>timber framing 6%<br>log 6%<br>combination 6% | concrete 91%<br>timber 3% | ground slab 97%<br>concrete structure with crawl space 15%<br>timber structure with crawl space 6% |
| 1960-1969 | 29 | ridge roof 55%<br>flat roof 45% | 76% | concrete 72%<br>timber framing 21%<br>masonry 7% | concrete 79% | ground slab 86%<br>concrete structure with crawl space 31%<br>timber structure with crawl space 3% |
| 1970-1979 | 36 | ridge roof 36%<br>flat roof 64% | 50% | concrete 64%<br>timber framing 25%<br>combination 8%<br>masonry 3% | concrete 56%<br>timber 3% | ground slab 94%<br>concrete structure with crawl space 25%<br>timber structure with crawl space 8% |
| 1980-1989 | 35 | ridge roof 77%<br>flat roof 23% | 43% | timber framing 46%<br>concrete 37%<br>masonry 14%<br>combination 3% | concrete 40%<br>timber 6% | ground slab 89%<br>concrete structure with crawl space 23%<br>timber structure with crawl space 6% |
| After 1990 | 8 | ridge roof 88%<br>flat roof 13% | 38% | concrete 63%<br>combination 25%<br>timber framing 13% | concrete 63% | ground slab 100%<br>concrete structure with crawl space 13% |

## 3.2 RESEARCH METHODS

### 3.2.1 Need for repair

In this study, a need for repair exists when at least one of the following criteria is found in the examined structure:

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, a little 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 (2% malt extract agar) agar, DG18 (dischloran 18% glycerol agar) or TYG (tryptone glucose yeast) agar.

Basically, a need for repair exists when the structure is moisture- or mould-damaged according to these criteria. Similar criteria were also used in previous studies (Annila et al. 2014, 2015A, 2015 B, 2016, 2017), which are also in the moisture- and mould damage database of Tampere University of Technology (TUT).

### 3.2.2 Classification of structures

Structures have been divided into seven main categories and more precisely into 14 subcategories as presented in Table 5. External walls, which are partly or fully below the ground, have been classified into subcategory walls with soil contact. Furthermore, the classification of external walls is based on the type of vertical load-bearing material. Roof structures are classified based on main structure type. Basement floors can be slab-on-ground structures or ground floors with crawl space (attic floor structure). Some of the buildings have both of these structures, in which case the buildings have been included in both the two main categories. The total number of main category structures is seven.

Table 5. Classification of structures used

| Main category | Subcategory |
|---|---|
| 1 Roof | Ridge roof<br>Flat roof |
| 2 Slab-on-ground | Slab-on-ground |
| 3 Ground floors with crawl space (attic floor structures) | Wooden ground floor with crawl space<br>Concrete ground floor with crawl space |
| 4 External walls | External wall in concrete building<br>External wall in timber frame building<br>External wall in log building<br>External wall in masonry building<br>External wall in mixed frame building |
| 5 Wall in soil contact | Wall in soil contact |
| 6 Intermediate floor | Concrete intermediate floor<br>Wooden intermediate floor |
| 7 Partition wall | Partition wall |

## 4 RESULTS

### 4.1 Number of damaged structures

The results indicate that the buildings examined had suffered multiple damage, meaning that the need to repair moisture- and mould damage was found in many different structures, as presented in Figure 1. According to the structural classification, damage was found in all seven different main category structures, as presented in Table 5. Figure 1 also illustrates the average number of main category structures and share of damaged structures in different age groups.

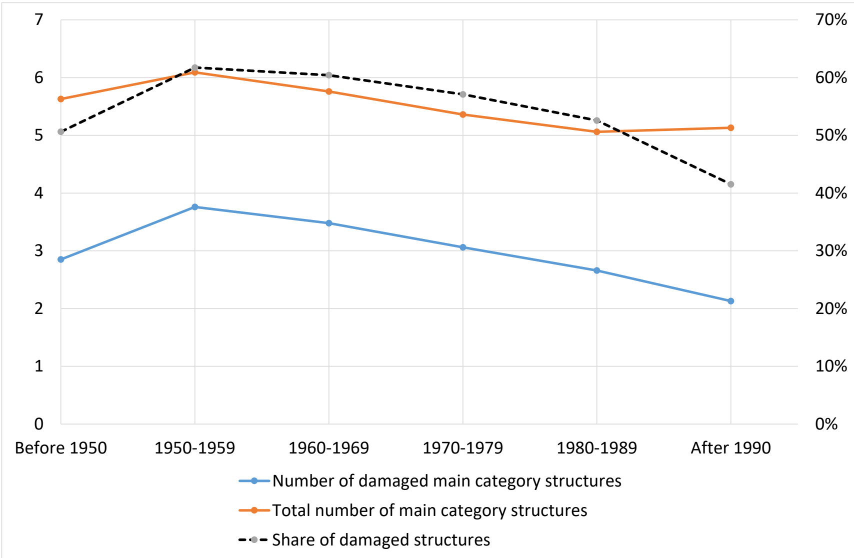


Figure 1. Number of damaged structures and total number of structures.

The number of damaged main category structures in the entire body of research was 3.1 damaged structures per building. The value is highest in buildings from the 1950s, with on average 3.8 different structures being moisture- or mould-damaged. The share of damaged structures was 62% of the total number of structures in these buildings. After the 1950s, the trend of number of damaged structures and trend of total number of structures decreases. Moreover, when the share of damaged structures of the total number of structures is evaluated, the trend also decreases in buildings built after the 1950s. It seems that newer buildings are simpler than older buildings and one reason for this is that newer buildings are more often built without a basement. They are also more rectangular in shape and simpler in terms of architecture. Basically this means massive single-material structures or at least fewer different materials. Figure 1 clearly demonstrates that in newer buildings the need for repair of moisture- and mould damage is rarer than in older buildings.

Buildings built before 1950 are a little bit simpler than newer buildings in terms of total number of main category structures. This group is also more heterogeneous than other age groups considering the age of building, as presented in Table 3. It is also probable that most damaged buildings from this oldest group are not in use anymore.  In summary, these factors probably explain the deviation from the trend of the other age group.

## 4.2 Need for repair

The need for moisture- and mould-damage repairs was also within scope. The result of this part of the analysis is shown in Table 6. If the structure existed in less than five buildings, it was marked with symbol '-'. The total number of buildings with a combined vertical supporting frame was less than five in every age group, which is why external walls from these buildings have been excluded from Table 6. The need for repair has been calculated from those buildings where the structure exists: for example, in the 1970s in 36% of buildings (13/36 buildings), the main roof type was a ridge roof as presented in Table 4. The need for repair exists in 23% of these buildings, which means that in 3/13 buildings there was moisture- and mould damage in the ridge roof. It is important to note that the following percentages of need for repairs represent only the research material. The need for repair of the entire building stock cannot be directly concluded from these values, because the research material represents only damaged buildings, not the entire building stock.

Table 6. Need for repair of different structures. The unit is per cent.

| | Roofs | | External walls | | | | | Intermediate floors | | | | Ground floor with crawl space | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ridge roof | Flat roof | Wall in soil contact | Concrete building | Masonry building | Timber framing building | Log building | Concrete | Timber | Partition wall | Slab-on-ground | Concrete | Timber |
| Before 1950 | 41 | - | 61 | - | 31 | - | 50 | 57 | 43 | 30 | 77 | - | 85 |
| 1950-1959 | 39 | - | 63 | 86 | 60 | - | - | 57 | - | 64 | 84 | 40 | - |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1960-1969 | 19 | 31 | 55 | 62 | - | 50 | - | 57 | - | 72 | 96 | 56 | - |
| 1970-1979 | 23 | 48 | 56 | 83 | - | 44 | - | 60 | - | 50 | 74 | 33 | - |
| 1980-1989 | 37 | 13 | 47 | 85 | 20 | 69 | - | 43 | - | 37 | 84 | 50 | - |
| After 1989 | 14 | - | - | 20 | - | - | - | 20 | - | 63 | 75 | - | - |
| Average | 29 | 30 | 56 | 67 | 37 | 54 | 50 | 49 | 43 | 53 | 82 | 45 | 85 |

An average need for repair of many structures is more than 50%, which means that it is more probable that these structures need moisture- and mould damage repair than that they do not. The need for repair is highest in a timber-framed ground floor with crawl space (85%), slab-on-ground structures (82%), external walls in concrete buildings (67%) and walls in soil contact (56%). The need for repair of partition walls (53%) and intermediate floor (49%), especially those built before the 1980s is high (57-60%). Until the 1970s, organic filling materials inside the enclosures of concrete intermediate floors were normal. After the 1970s, there was a shift massive concrete slabs and elements, which is probably the reason the decreased need for repair in concrete intermediate floors. The need for repair is lowest in ridge roofs (29%), flat roofs (30%) and external walls in masonry buildings (37%).

## 5 DISCUSSION

The results and observations from this study are quite similar to previous studies (Partanen et al. 1995, Lawton et al. 1998, Haverinen et al. 2001, Pirinen 2006, Ruokojoki 2006 and Holme et al. 2008). Moisture- and mould damage are common in structures with soil contact, in basements or spaces in ground floors. Moreover, the need for repair of intermediate floor and partition walls is also high. The need for repair of partition walls is also partly connected to basement and moisture capillary movements of these walls. The reasons for moisture- and mould damage were out of scope, but it is probable that, in internal structures (partition walls and intermediate floors), damaging is at least partly related to bathrooms and other water points inside the building. This also reflects results from a previous study (Pirinen 2006), which points out that moisture- and mould damage is related to bathroom structure or other spaces where water is used.

It would be better if the classification of some structures could be done in more detailed. External walls are a good example from this: in concrete-framed buildings beneath a window, there may be a masonry façade and, above, a wooden façade. Afterwards, it is sometimes impossible to determine the exact location of damage from reports of moisture performance assessments; is it in the wooden, concrete or masonry façade? This is why classification has been done based on the vertical load-bearing frame. The effect of façade material on damage to external walls need further studies, but it seems that moisture- and mould damage are more infrequent in simpler than in multiform façades.

Earlier studies (Pirinen 2006, Holme et al. 2008) have pointed out that, in terms of moisture- and mould damage, buildings could suffer multiple damage. However, it was surprising that the number of damaged structures was so high in the study: on average 3.1 main category structures were damaged in the entire research material. Also, in the newest buildings built after 1990, there were 2.1 damaged structures on average. Based on this finding, it is probable that the comprehensive refurbishment of a single structure is not enough to solve all moisture- and mould problems, which further highlights the need for comprehensive examination of building and not only single structures.

It has also been seen that the age of a building affects the amount of moisture- and mould damage issues. Problems with moisture are more common in older buildings (Holme et al. 2008, Haverinen-Shaughnessy et al. 2012). In this regard, the results of this study are similar.

The development of structures in Finland is described in research material section and Table 4. Changes have happened over long periods and the changes were not implemented in every building at the same time. That is why it is difficult to determine how the changes have influenced the need for repair of moisture- and mould damage. From the results, the most identifiable change is in need for repair of concrete intermediate floors: the need for repair decreases significantly from group '*1970-1979*' to group '*after 1989'* as presented in Table 6.

Almost without exception, in every Finnish building and structure there are materials which are classified as most sensitive materials in different mould growth models (Ojanen et al. 2010, Vinha et al. 2013, Johansson et al. 2005, Seldlbauer 2002). Examples of these materials are organic coatings, wooden parts and traditional organic thermal insulation materials, such as sawdust. This means that continuous moisture stress will probable lead to damage even in concrete or masonry structures and, as results indicate, moisture- and mould damage occurred in every structure type.

The trend of the number of moisture- and mould-damaged structures is almost linear, if we ignore the oldest building group *'before 1950'* and draw linear regression into Figure 1. As mentioned before, the group *'before 1950'* is quite a heterogeneous group of buildings and it is probable that the most damaged buildings are not in use anymore. This may be why this group differs from other groups as presented in Figure 1. The direction of the trend is as supposed: the need for repair is greater in older buildings, also in terms of moisture and mould damage.

According to the linear regression, it takes 25.6 years for a new structure to deteriorate sufficiently to need repair of moisture- and mould damage. The linear regression does not cross the x-axis when the building age is 0 years old, which means that, even in new buildings, 1.5 structures may need some level of moisture- and mould repair action. Further, it is known that even new buildings have problems with moisture, which may be a consequence of, for example, construction errors, insufficient weather protection or moisture control during a construction phase. These kinds of problems can be read about every week in newspapers.

Mould growth models give some estimates of how long it takes before mould growth appears in certain materials or structures under certain hygrothermal conditions. Furthermore, service life periods for materials and structures regularly used in Finland (RT 18-10922) have been estimated. These Finnish estimates are based mainly on practical experiences of building stock and not on scientific service life models, and they are not estimates from a perspective of moisture- and mould damage, which may shorten service life. This topic was not included the research questions, so research was not performed from this perspective and the research material may not be the best for this kind of analysis. After all, according to the results and above-mentioned linear regression, the number of moisture- and mould-damaged structures can be estimated with the formulae:

$$N_{mmd} = 1.5 + y / 25.6 \pm E_{80\%}$$

$$E_{80\%} = y / 57.0 + 0.9$$

In which $N_{mmd}$ means the number of moisture- and mould-damaged structures, $E_{80\%}$ is the error term, and y means the age of the building in years. Error term represents the range that includes 80% of the research material. The number of moisture- and mould-damaged structures, for example in a 45-year-old building is 3.2 ± 1.7 (range is 1.5…4.9 damaged structure). This topic and formula, however, need further studies before validation and wide use. This does, however, seem to mirror practical experiences from the field.

The originally research question was, where does moisture- and mould-damage start. However, as the results show, the buildings were more damaged than expected. The average number of damaged structures varied between 2.1-3.8 main category structures per building. Afterwards, from reports of moisture performance assessment, it was impossible to determine which structure suffered damage first. In the sample of 168 buildings, there were only a few buildings where the need for repair appeared only in one structure. It cannot be determined which structures were probably damaged first. The sample was too small to analyse that.

The age distribution of the research material is quite similar to the age distribution of Finnish municipal building stock, when similar types of building have been taken into account. It can be considered that the research material is representative of Finnish public buildings, but only those that are damaged. Also, all widely used Finnish structures were represented in the study.

## 6 CONCLUSIONS

The study reveals that public buildings are multi-problematic, when municipalities have to react to indoor air quality complaints, or refurbishment projects starts for other reasons. On the basis of analysis of 168

Finnish public building moisture performance assessments, the average number of moisture- and mould-damaged structures was 3.1. Damage occurred in every structure type, irrespective of the age of building or load-bearing frame material, and the share of damaged structures varied between 13% and 96%. The need for repair was highest in timber-framed ground floors with crawl space (85%), slab-on-ground structures (82%), external walls in concrete buildings (67%) and walls in soil contact (56%). The need for repair was lowest in ridge roofs (29%), flat roofs (30%) and external walls in masonry buildings (37%).

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