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# Monitoring success of remediation: Seven case studies of moisture and mold damaged buildings

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ABSTRACT

Based on seven case studies of buildings that underwent different degrees of moisture and mold damage remediation, we aimed to develop methodology for assessment of the success of the remediation process. Methods used in gauging the success included technical monitoring of performance of building structures and heating, ventilation and air conditioning (HVAC) systems, microbial monitoring of indoor air quality (IAQ), and health effects studies of building occupants. The assessment was based on measurable change in the situations before and after remediation. Based on technical monitoring, remediation was successful in three cases, with partial improvement noted in three cases, whereas no remediation was conducted in one case. Based on microbial monitoring, improvement was detected in one, partial improvement in two and no improvement in two cases, whereas no follow-up was conducted in two cases. Health effect studies (mainly self-reported health status) showed improvement in one case, partial improvement in two cases, and no improvement in two cases, whereas no follow-up was conducted in one case, and in one case, follow-up failed due to low response rate. The results illustrate that it is possible to monitor the effects of remediation using various metrics. However, in some cases, no improvement could be observed in IAQ or occupant health, even if the remediation was considered technically successful, i.e. the remediation was fully completed as recommended. This could be due to many reasons, including: 1) all damage may not have been addressed adequately; 2) IAQ or health may not have been perceived improved regardless of remediation; and/or 3) the methods used may not have been sensitive/specific enough to detect such improvement within the 6–12 months follow-up periods after completion of the remediation. There is a need to further develop tools for monitoring and assessment of the success of moisture damage remediation in buildings.



## 1. Introduction

Follow-up should be an essential part of every building repair process, but when this remediation involves moisture damage/dampness with possible mold contamination, it may become even more critical. Moisture and mold damage of buildings does not have a homogenous appearance but each building needs to be examined individually. Although there are uniform phenomena seen in the microbial contamination of the indoor environment and health effects of the occupants (Bornehag et al., 2001), the original causes of excess moisture and the possibilities to eliminate them vary. Thus, the mold remediation processes may be difficult to approach as a strictly scientific experimental set up. However, there may be important lessons to learn from individual, albeit varying cases of remediation.

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Assessing the success of remediation of moisture-damaged buildings can be done utilizing various methods. A technical approach, which focuses on the evaluation of existing damage, the degree to which the causes of damage are eliminated and damaged materials removed, and good quality of construction work, may be sufficient to manage the whole process. However, the process may become complicated when the damage has been linked with IAQ problems, and accompanied by health concerns among the building occupants. In such a case, the risk of exposure to indoor pollutants and risk posed to occupant health have to be taken into account in each step of the remediation. Based on seven individual case studies, this paper provides a summary of tools that can be useful in monitoring the success of the remediation measures.

## 2. Material and methods

Our cases studied included seven buildings that underwent varying degrees of moisture damage remediation and extensive follow-up programs. Background information on the buildings is presented in Table 1. First, the building conditions were inspected using applicable methods, based on which an initial assessment was made, and recommendations given for remediation of the damage, as summarized in Table 2. Methods used in the assessment are presented in Tables 3.1.1–3.3. The assessment of the effects of the remediation was based on the measurable change after the repairs. The change could be represented as improved structural or HVAC mechanical performance, microbial condition of the building, or health status of the building occupants.

The health questionnaire used was based on Örebro-questionnaire (MM40) and the Tuohilampi questionnaire (Andersson, 1998; Susitaival and Husman, 1996), and included 70 questions on irritation, respiratory and general symptoms, respiratory infections, acute and chronic respiratory diseases and allergic diseases. Additional questions were related to the symptoms work relatedness, and changes observed in between the repeated questionnaires. First, we inspected raw prevalence values of reported health symptoms and their work relatedness both before and after the remediation. The observed differences between frequency of reported health symptoms before and after remediation were tested using McNemar-test for paired observations with SPSS statistical package version 12.0.1. The associations were further modeled using GEE methodology, adjusting for age, gender, atopic predisposition, smoking, and having pets, with SAS statistical package version 8.2.

In the health clinic (1), as a result of a long dispute in decision-making regarding what should be done with the building, the building was evacuated per demand of occupational safety officials. No remediation was done and the

**Table 1 – Background information of the cases (information is not filled in if not known and/or considered irrelevant for the specific case)**

| a) Case;<br>b) Area of the building [m²]<br>c) Year of construction | d) Type of foundation;<br>e) Main frame material;<br>f) Type of roof;<br>g) Type of ventilation | h) Use, number of occupants;<br>i) Aim of the study |
|---|---|---|
| 1. a) Health clinic<br>b) 1300<br>c) 1985 | d) Slab on ground<br>e) Brick<br>f) Flat roof, bitumen roofing<br>g) Mechanical exhaust/partly mechanical support air | h) Psychiatric clinic, $n$=23<br>i) Detecting the causes of IAQ problems and giving recommendations for remediation and use of the building |
| 2. a) Laboratory/office building;<br>b) 800<br>c) 1968–1975/1995–1996 | d) Slab on ground<br>e) Light-weight concrete/brick<br>f) Ridge roof, bitumen roofing<br>g) No working ventilation | h) QC laboratory for hygiene products sold by a cosmetic company, $n$=60<br>i) Detecting the causes of IAQ problems and giving recommendations for remediation |
| 3. a) School building<br>b) 5600<br>c) 1966 | d) Slab on ground<br>e) Concrete/brick<br>f) Flat roof/bitumen roofing<br>g) Mechanical | h) Elementary school, $n$=25 (personnel), $n$=267 (students)<br>i) Detecting the causes of IAQ problems and giving recommendations for remediation |
| 4. a) University building<br>b) 40,000<br>c) 1981 | d) Crawl space<br>e) Concrete/brick<br>f) Flat roof, bitumen roofing<br>g) Mechanical exhaust/partly mechanical support air | h) Education and research, $n$=232<br>i) Detecting the causes of IAQ problems originating from a crawl space, recommendations and design of remediation |
| 5. a) Old age home;<br>b) 7500<br>c) 1981–82 | e) Concrete/brick<br>f) Ridge roof, bitumen/metal roofing<br>g) Mechanical | h) Old people care, $n$=41 (personnel), app. 100 bed sites for the elderly<br>i) Detecting the causes of IAQ problems related to leakage through roof and balcony structures and giving recommendations for remediation |
| 6. a) Hospital ward<br>b) 1000<br>c) 1980s | e) Concrete<br>f) Flat roof, bitumen roofing<br>g) Mechanical | h) Cancer patient treatment unit, $n$=40 (personnel)<br>i) Develop an approach to manage IAQ problems in hospital buildings, carry out a pilot remediation project |
| 7. a) Row-house complex<br>b) 51 two-five bdr (47–112 m²) apartments 2116 m² total<br>c) 1960s | d) Slab on ground<br>e) Concrete<br>f) Ridge roof, bitumen roofing<br>g) Mechanical exhaust | h) Residential, $n$=145<br>i) Detecting the causes of IAQ problems and giving advise for management and remediation |

**Table 2 – Initial observations or causes of dampness/moisture damage and microbial condition of the buildings and recommended remediation actions**

| Case | Observations or causes of dampness/moisture damage | Observations of microbial condition of the buildings | Recommended/ completed remediation actions |
|---|---|---|---|
| 1. Health clinic | – Damage in external walls and floors<br>– Imbalanced ventilation, air leakage through structures<br>– No vapor retarder in the upper-most floor structure | – Mold growth detected in bulk samples from damaged areas<br>– Microbial (and TVOC) concentrations in indoor air samples low compared to outdoor concentrations<br>– Indicator microbes detected from 5/9 indoor air samples | – Replacement of the damaged structures<br>– Balancing ventilation and sealing air leakages<br>– Installation of vapor retarder in the upper-most floor<br>– Improving ventilation |
| 2. Laboratory/ office building | – Poor ventilation (high air particle concentrations (>5,400,000 particles/m$^3$) observed as compared to levels normally found in office environments (Salonen et al., 2002))<br>– Air leakage through structures<br>– Local areas of moisture damage | – Indoor air concentrations of culturable microbes elevated (93–179 cfu/m$^3$) as compared to outdoor air levels (<3 cfu/m$^3$) in three rooms<br>–Indicator microbes present in the same rooms | – Sealing air leakages of the building envelope<br>– Improving insulation in the upper-most floor<br>– Remediation of local damage sites |
| 3. School building | – Poor ventilation, air leakage through structures<br>– Part of the windows in a poor repair<br>– Poor detailing of roofing/ wall joints<br>– Surface waters wetted walls and ground floor | – Elevated microbial concentrations (560–29,000 cfu/m$^3$) as compared to outdoor concentrations (170–350 cfu/m$^3$)<br>– Indicator microbes detected from 8/13 air samples | – Replacement of ventilation system and roofing<br>– Sealing air leakages through structures and openings, repair of windows<br>– Improving drainage system<br>– Remediation of wooden ground floor structures |
| 4. University building | – Debris in the crawl space, wet soil<br>– Air leakage from the crawl space through HVAC installations<br>– Other possible damage (e.g. related to external walls and sewage system) not included in this study | – Elevated concentrations and/or presence of indicator microbes in 8/11 air samples from the crawl space and the rooms above<br>– Samples from the soil cover of the crawl space revealed high concentrations of fungi | – Cleaning of the crawl space, renewal of soil covering<br>– Sealing air leakages through HVAC installations<br>– Improving ventilation/balancing air pressure of the crawl space |
| 5. Old age home | – Roof leakage through HVAC installations<br>– Poor detailing of eaves and drainage system<br>– Poor waterproofing of balconies<br>– Visible mold in the ceiling | – *Stachybotrys* sp. fungi cultivated from the damaged interior acoustic ceiling boards and from indoor air samples in locations nearby these sites<br>– Indicator microbes observed in 11/22 air samples | – Replacement of roofing and improving drainage system<br>– Remediation of balconies<br>– Replacement of damaged ceiling boards |
| 6. Hospital ward | – Signs of moisture/ mold damage in bathrooms | – Indicator microbes including *Stachybotrys* sp. fungi detected in air samples from bathrooms and the cavity space of their partition walls | – Remediation of bathrooms<br>– Developing a strategy to address mold remediation in the future |
| 7. Row-house complex | – Poor ventilation, air leakage through structures<br>– Poorly functioning drainage<br>– Elevated moisture contents in floors and walls | –Elevated concentrations and/or presence of indicator microbes observed in several apartments | – Improving ventilation and drainage<br>– Drying wet materials and improving moisture protection in bathrooms |

building was left out of use. However, this case is included in the overall assessment of the success of remediation process, as leaving buildings non-repaired and out of use could be considered an extreme way in dealing with a moisture-damaged building. In this case, since no remediation was done, no technical or microbial follow-up was conducted. We assessed the success of the process based on occupants' health questionnaire responses before and one year after relocation.

The laboratory/office building (2) provides an example of monitoring the effects of a comprehensive remediation (i.e. all dampness/moisture damage problems detected were repaired in a timely manner as recommended). In this case, microbial follow-up was conducted 17 months after the initial assessment (two months after the remediation had been completed). At the same time, the building was visually inspected, and the building occupants were interviewed for technical evaluation of the success of the remediation. The health questionnaire was repeated one year after the remediation was completed.

In the school building (3), although the remediation plans were inclusive of all repairs necessary, the repairs could not be implemented immediately due to budgetary constrains; as a result, repairs were extended over a 3-year time span, providing an example of a remediation conducted over a longer time period. Technical follow-up monitoring was conducted six months after completion of the remediation work, and microbial follow-up and health questionnaire was conducted annually during the three years course of remediation.

In the university building (4), the investigations and remediation were limited to address problems related to a large crawl space underneath the building. In addition to the remediation of the crawl space, the whole building went through a thorough cleaning, which was necessary because of

**Table 3.1.1 – Building investigation methods used in the initial assessment and in estimating effects of remediation**

| Method | Use in the cases 1–7 | Advantages | Limitations |
|---|---|---|---|
| Visual inspection methods, overall | | Non-destructive, easy to carry out | Subjective, hidden damage may be difficult to verify |
| – Walk-through | 1, 2, 3–7* | Essential information on visible damage | No information on damage that is not visible |
| – Check-lists | 1–6 | Systematical data collection | |
| – Occupant reports, questionnaires | 1–5*, 6, 7 | Information from occupants and their perceptions | May be difficult to interpret |
| Moisture measurements, overall | | Objective, normal levels usually known | Interpretation requires special expertise |
| – Surface moisture/ temperature detectors | 1, 2, 4–7 | Non-destructive | Indicative, instantaneous, interpretation often demanding |
| – Measuring moisture content from materials | 1, 2 | Almost non-destructive | Indicative other than for wood, instantaneous |
| – Measuring relative humidity (RH)/ temperature from structures | 1, 2, 3*, 4, 6, 7 | Accurate | Destructive (drill holes), instantaneous |
| – Measuring RH from bulk samples | 4, 7 | Accurate | Destructive, instantaneous |
| – Measuring RH/ temperature of air (long term/continuous) | 2, 4*, 7 | Long-term information on changes in conditions | Labor intensive data analyses |
| –Installing follow-up and alarm systems into the structures | 1, 6, 7* | Long-term information on structures' behavior | Calibrating equipment inside structures not possible |
| Structural openings/destructive methods, overall | | Possible to estimate the conditions of structures in-depth | Adverse aesthetic effects |
| –Optical devices | 3 | Possible to look inside structures through small openings | Observation difficult and local |
| –Hatches | 5, 6* | Non-destructive after installation | May cause air leaks |
| –Opening and dismantling structures | 1, 2, 3*, 5–7 | Reliable information about damage | Repair work often demanding |

Practical advantages/limitations observed when performing the field work.
* The method was also used in the follow-up phase.

cross contamination concerns. This case provides insights into effects of a localized remediation. Technical follow-up monitoring was conducted and the health questionnaire was repeated six months after completion of the remediation work. The microbial follow-up was conducted one year after the initial assessment.

In the old age home (5), the investigations and remediation only included roof and balcony ($n=40$) structures and related leakages. This case illustrates results from a large-scale remediation and follow-up program. However, it could be considered selective (and possibly incomprehensive), as the building (as a whole) was not systematically included in the assessment. Technical follow-up monitoring was conducted six months and the health questionnaire was repeated one year after completion of the remediation (only the personnel were included in the health effect monitoring). The microbial follow-up was conducted one year after the initial assessment.

The cases 6 and 7 are large building complexes that were in need of a strategy to address moisture and mold damage remediation. A pilot effort was conducted in one of the hospital (6) wards, which included remediation of a bathroom with severe mold contamination in partition wall structures. Technical follow-up was conducted primarily during the remediation (enhanced supervision of work conducted by representatives of building owner, contractor, occupants and research group members). In addition, continuous follow-up

**Table 3.1.2 – Methods to evaluate ventilation and air movement**

| Method | Use in the cases 1–7 | Advantages | Limitations |
|---|---|---|---|
| $CO_2$ concentration | 2, 7 | Relatively good surrogate of ventilation adequacy | Require long measurement period for reliable results |
| Pressure differences | 2, 4*, 7 | Indicative for air (and vapor) migration within building | Small differences difficult to detect, several factors (e.g. wind) may effect on results |
| Smoke | 2, 4*, 7* | Simple and easy to carry out | Local, instantaneous, can be irritating to occupants |
| Air flow measurements | 4, 7 | Accurate results on performance of ventilation | Interpretation requires special expertise, time consuming |
| Chemical markers/ tracer gas | 4* | Possible to locate even small air leaks | Requires special equipment and expertise |

Practical advantages/limitations observed when performing the field work.
* The method was also used in the follow-up phase.

**Table 3.2 – Methods to evaluate exposure to microbial pollutants**

| Method | Use in the cases 1–7 | Advantages | Limitations |
|---|---|---|---|
| Detecting microbial concentrations from air samples | | | |
| -Culturable fungi [a,b] | 1–7* | Well known, indicative | Selective, slow |
| -Total counts | 2–5* | Also non-culturables | Does not provide information on species |
| Detecting microbial concentrations from surface/bulk samples | | | Local, bulk samples also destructive |
| -Culturable fungi [b] | 1–7 | Well known, indicative | Selective, slow |
| -Direct microcopy | 1–7 | Also non-culturables | Indicative, does not provide information on species |
| Quantitative PCR [c] (polymerase chain reaction) | | Also non-culturables, species-specific, fast | Methods not well validated, normal levels not known, all methods not available for public, often expensive |
| Analytical methods to estimate microbial concentrations from air, surface, dust, or bulk samples – e.g. ergosterol, endotoxins, glucans, MVOC [c] – Mycotoxins [d] | 4 | Indicate biomass/ biological activity, microbial component or metabolite, typically fast | Methods not well validated, normal levels not known, all methods not available for public, often expensive |
| Parameters not specific for microbial exposure –VOCs, particulates, odors | 1*, 2, 4, 7 | Elevated concentrations indicate existing indoor air problem Normal/ recommended levels known | Unspecific |

Practical advantages/limitations observed when performing the field work/laboratory analyses.
* The method was also used in the follow-up phase.
[a] Collected using Andersen 6-stage impactor.
[b] Culturable fungi were determined using both 2% malt-extract agar (MEA), and dichloran-glycerol-18 agar (DG18); bacteria were cultivated on tryptone-yeast-glucose agar (TYG).
[c] Not employed in this study.
[d] Can not be measured directly from air.

was enabled by installation of temperature and humidity reading systems into the structures, and instructing building maintenance staff. Microbial follow-up was conducted one year after the initial assessment. Due to the limited extent of the remediation, health effect studies were included only in the initial assessment, but not in the follow-up phase.

In the row-house complex (7) remediation was completed in the most problematic apartments within one year after the initial assessment according to the remediation specifications developed for the building complex. Three years later, remediation was completed in all of the apartments. In this case, technical follow-up was conducted four years after the beginning of the remediation work (from six months to four years after completing remediation in each apartment). Microbial follow-up was not conducted during the course of this study due to lack of resources of the property owner. Information of occupant health after remediation was collected from spontaneous reporting of changes in perceived health.

In general, when possible, the microbial follow-up was conducted one year after the initial assessment and the health questionnaire was repeated one year after the remediation was completed. The remediation had been completed as a minimum of two months before the microbial follow-up.

**Table 3.3 – Methods to evaluate health effects**

| Method | Use in the cases 1–7 | Advantages | Limitations |
|---|---|---|---|
| Questionnaires /Symptom diary | 1–5*, 6, 7* 2*, 4*, 5*, 7 | Easy to carry out, relatively non-expensive, repeatable, sensitive | Non-specific outcomes, low response rate common, subjective |
| Interviews | 4* | Applicable for small population | Expensive, labor intensive |
| Clinical diagnosis /Lung function tests /Skin prick tests | 2, 4*, 7 | Objective, repeatable, correlate with symptoms, applicable for special groups (e.g. in occupational disease diagnostics) | Expensive, moderate specificity, low sensitivity |
| Biomarkers /Antibodies /Immunological responses | 2, 4, 6, 7 | Objective, repeatable, high sensitivity | Relatively expensive, are not widely available; for some parameters, non-specific |

Practical advantages/limitations observed when performing the field work.
* The method was also used in the follow-up phase.

## 3. Results and discussion

The findings of the case studies are summarized and quantitatively characterized herein, but due to limitations in the length, original data is not shown. A qualitative estimation of the success of the remediation in each case using different methods is presented in Table 4.

One year after the occupants of the health clinic (1) moved to another building, they reported significantly ($p<0.05$) less cough, eye symptoms, and fatigue related to work. Also, a significant decrease was observed in flu. With respect to other health symptoms, trends were generally decreasing, but the small number of observations limited the power of statistical analyses. Sudakin (1998) reported similar results five months after occupants of a water-damage building had been relocated. It is hypothesized that the reason for the improvement in the perceived health status could be related to the basic concept that the exposure to indoor air pollutants no longer existed in the new building. We concluded that the perceived health status of the evacuated building occupants improved after the relocation. However, the causes of moisture damage in the original problem building were left unresolved, and the building was not reoccupied. This endpoint could be considered discouraging, yet another case study reported by Jarvis and Morey (2001) suggests that vigorous remediation measures can prepare a formerly mold-contaminated structure for re-occupation by all persons (even those with hypersensitivity disease originating from building-related bioaerosol exposure).

In the laboratory/office building (2), the effects of the remediation could be observed in reduction of airborne microbial concentrations and also in particle concentrations, in which the differences between the concentrations before and after the repair were several orders of magnitude. The most obvious reason for this result was improved ventilation. Unfortunately, response rate to the health questionnaire in the post-remediation situation was so low that no conclusions could be drawn. It is speculated that in the post-remediation phase, occupants were less concerned about IAQ problems, and did not have same urgency or inclination to participate in the studies. We concluded that the remediation of the building was successful. However, it is quite impossible to say what was the cause (among the several possible causes) that had contributed most to the poor IAQ, and what was the most effective repair measure taken. This case study also highlighted that commitment of different parties (esp. building owners and occupants) is essential to determine the extent of success for follow-up study purposes. This observation is reinforced by the results of the health effect studies that were not of good quality due to low response rate.

In the school building (3), throughout the 3-year follow-up period, variation was observed in airborne microbial concentrations in different rooms, hence no conclusion could be drawn based on these results. Occupant health status remained similar or even deteriorated during the process. Based on technical monitoring (mainly using visual inspection methods), it was concluded that the remediation of this building was partially successful. However, it could be debated that extended duration of the remediation process could create additional stress among the occupants, and affect perceived health. Meklin et al. (2005) also reported difficulties in drawing conclusions after partial repairs of a school building. However, they reported decreases in both microbial concentrations and prevalence of symptoms after complete remediation.

In the university building (4), moisture conditions in the crawl space were measurably drier after the remediation, and also the air exchange between the crawl space and the other facilities had been eliminated, based on tracer gas measurements. Microbial concentrations decreased so that eventually they were lower than outdoor air concentrations. Similar decrease was not, however, observed in the occupied locations, and occupant health concerns did not dissipate: especially the

**Table 4 – Summary of the effects of remediation assessed based on different methods**

| Case | Building investigation methods | Microbial measurements | Health effect studies | Notes/ conclusions of the success of the remediation |
|---|---|---|---|---|
| 1. Health clinic | Follow-up not performed | Follow-up not performed | ++ | No remediation was carried out. Building evacuated, occupants' health symptoms ceased after moving to a new building. |
| 2. Laboratory/ office building | ++ | ++ | * | Remediation successful. |
| 3. School building | + | – | – | Remediation partially successful. |
| 4. University building | ++ | + | – | Local remediation work successful, problems in other parts of the building remained? Health problems continue. |
| 5. Old age home | ++ | + | + | Partial remediation work successful, no comprehensive information on the building condition. |
| 6. Hospital ward | + | + | Follow-up not performed | Pilot repair work successful. Protection of other facilities partially failed. Health problems continue. |
| 7. Row-house complex | + | Follow-up not performed | + | Remediation partially successful. Floor structures did not completely dry. Occupant reports on IAQ problems decreased. |

++ Improvement was detected using several parameters.
+ Partial improvement was detected.
– No improvement compared to the situation before remediation.
* Questionnaire response rate too low, work related symptoms continue.

symptoms' perceived association with work environment appeared to increase during the six months follow-up period. We concluded that the remediation of the crawl space was successful, but damage could still exist in other locations in this building. Remediation of a localized damage site may not solve perceived IAQ problems within the whole building.

In the old age home case (5), after remediation, water leakage through roof and balcony structures had stopped, and no more *Stachybotrys* spp. fungi was observed in the indoor air samples. However, low concentrations of other indicator microbes, i.e. microbes considered indicative to moisture damage in buildings (Samson et al., 1994), were still observed. Occupants reported significantly less nasal symptoms, hoarseness, sore throat, and eye symptoms. Symptoms association with work decreased significantly in facial eczema and cough. The prevalence of sinusitis was significantly decreased. We concluded that the partial remediation of the building was successful, but other damage could still exist in the building. A similar experience was reported by Ebbehoj et al. (2002): in a 2-phased approach, the initial remediation of a moisture-damaged building erased most visible signs of mold and resulted in decreased number of symptoms; after a second renovation, when the remediation of the building was considered complete, the occurrence of symptoms continued to decrease.

In the hospital building (6), microbial measurements indicated decreased concentrations of culturable fungi in the bathroom one week after the remediation was completed. However, at the same time, fungal species that had been present in the air samples collected from the bathroom before the remediation (that were not present in other parts of the hospital ward) were detected outside of the construction zone. It was discovered that there was possible air leakage through an airtight protection wall constructed in between the construction zone and other facilities. In addition, the negative pressure containment had been stopped while some of the demolished material was still in the construction zone. In the sampling regime carried out one year after the initial assessment, the concentrations of culturable fungi throughout the ward were low, and fungal species were similar to those detected in outdoor air samples. We concluded that the remediation of the bathroom was successful, but in future remediation work, more attention should be paid on containment to ensure the protection of the occupants, and to prevent dissemination of microbes and cross contamination of the facilities.

In the row-house complex (7), technical follow-up measurements indicated improved and more controlled ventilation. However, some of the floor structures still had elevated moisture contents. Occupant reports and complaints of poor IAQ had diminished. We concluded that the remediation had improved the condition of the apartments, but further microbial and health effect studies may be required for more definite conclusions.

### 3.1. *Discussion about the methods*

In this study, technical monitoring was phased starting from non-destructive methods and applying destructive methods (as in Table 3.1.1) as on need basis. After the remediation was completed information was collected mainly by occupant interviews, visual observations, and by using surface moisture detectors and air movement evaluating methods. Destructive methods were used if there were locations suspected to have new damage, or if the damage was suspected to be repaired unsatisfactory. It was concluded that collecting observational data on building condition and structures/components is the most applicable method for technical monitoring both during and after remediation. In addition, one should always emphasize the importance of continuous maintenance as the best follow-up practice to ensure the success of repair measures taken during the building life-span (Hiipakka and Buffington, 2000).

The issue of microbial monitoring is complicated from the follow-up point of view. For example, natural variation in the concentrations is large, and there is little information on so-called background levels and/or final clearance criteria after remediation (Gots et al., 2003; Quezada and Lange, 2004). One should aim to minimize the variation by carefully designing the sampling protocol, paying attention to timing and sampling locations. In our study, microbial monitoring in the post-remediation phase was conducted during the same season, collecting samples from same locations, as in the initial assessment. Additional post-remediation sampling campaign was conducted in winter, if the initial assessment was conducted summertime. The aim of this additional sampling was to verify the non-presence of indoor sources of microbes, when outdoor sources of microbes are negligible. The large number of samples required (e.g. Hyvärinen et al., 2001) and associated costs may limit the feasibility of using air samples as a success determinant. Another drawback of microbial sampling is that the building may need time to equilibrate after a remediation effort (Lignell et al., 2007). This may increase the length of a waiting period prior to sampling occurring, which is not desirable in most cases.

When estimating changes in occupant health using questionnaires, many factors, including sample size, response rate, and recall period, may impact on the accuracy of results (Andersson, 1998). In this study, questionnaires were delivered for all the occupants before, and 6–12 months after the remediation of each building were completed. Small samples size in cases 1 and 3, low response rate in case 2, and in case 5, the use of a different recall period from that what was used in the other cases, were factors that limited the overall conclusions that could be drawn from the results of the health questionnaires. In other studies, use of questionnaires and/or symptom diaries in collecting information on occupant self-reported symptoms has been considered a valid technique to estimate the health effects, especially when the same questionnaire form is used, and both pre- and post-remediation surveys are done in the same season of the year. In addition, analyses performed using repeated measurements and different recall periods have shown good or moderate agreement between repeated measurements (Haverinen-Shaughnessy et al., 2007). Local health care personnel, e.g. experts of the occupational health system could be used to improve the participation and response rate, especially with symptom diaries.

Clinical examinations and laboratory testing may include medical examinations, and pulmonary function and allergic reaction testing. Results from studies using these methods have been difficult to interpret (Immonen et al., 2000, 2001; Patovirta et al., 2004). This may be partly attributed to health outcomes often unspecific or difficult to measure. Other limitations include the high costs; these methods might be more useful for smaller specialized groups (i.e. people in high exposure environments) and for use in occupational health diagnostics. Occupants participating in our studies were sent to clinical examination and testing on an as-needed basis (no group-level analysis was made).

One important question related to health effect studies applies to the length of time needed for the symptoms to return back to "normal" levels. Rudblad et al. (2002, 2005) has investigated this aspect to some extent. Haverinen-Shaughnessy et al. (2004) provided information from a five-year follow-up period of school children. Based on these and a few other studies (e.g. Wilson et al., 2004), health effect studies may provide useful information for the assessment of remediation, for as long as the reference level is known, and the study population is large enough and motivated to participate in the studies.

### 3.2. Discussion about acceptable level of remediation

There are many open questions including issues of sufficient extension of the repair, effects of partial repairs, "normal" or "acceptable" levels of damage, concentrations of microbes, prevalence of symptoms etc. The general advice that was given to the building owners who wished to solve moisture related problems in buildings was to repair the damage, including both eliminating the original cause of moisture accumulation, and replacing damaged materials (Shaughnessy and Morey, 1999). However, these principles could not be strictly followed in every case. There was often a need to prioritize the repairs or seek for a compromise that may not have satisfied all the parties involved.

Many of these questions were related to expectations: someone may have estimated a remediation successful if it fulfilled the technical criteria, while someone else may have perceived it as a failure since the level of discomfort may not have been lessened. Thus, the success estimate of the remediation was partially dependent on the type of measure used or even the specific individual that the question was posed to. To overcome different expectations, there should be a consensus of the target levels set prior to the remediation, so that all the parties could be committed to them during the process.

Although scientists strive for more objective evidence on the effects of remediation, gathering the evidence presents challenges due to the complex nature of the issue. For example, exposure to specific agents is difficult to demonstrate, and uncontrollable variables in fieldwork are numerous. In addition, double-blinding and placebo-control components of study populations are difficult to include in the study designs (Kercsmar et al., 2006; Shoemaker and House, 2005). Current knowledge is therefore largely based on successful case studies. The results of the seven case studies reported herein were encouraging in terms of that positive effects of repairs could be measured using various methods.

## 4. Summary

Comprehensive and/or successful remediation of moisture/mold damaged buildings had positive effects on building environments and occupants. In cases where the remediation was only partial, or when it was unclear whether the work had been done properly, utilizing several different methods to evaluate the success was useful: different methods provided support and helped to gain sufficient information to draw more definite conclusions.

It was concluded that moisture/mold damage should be addressed in a timely manner: extended duration may lead to more damaged buildings and create additional stress among the occupants. Importance of commitment of different parties involved should be emphasized and the reference and target levels should be agreed upon prior to the remediation.

Careful design of the remediation includes solving the cause (s) of the damage, removing contaminated materials, reconstruction, and follow-up measures. Attention should be paid to protecting building occupants and facilities both inside and outside of the working zone, and even more importantly, if the occupants are vulnerable for suffering adverse effects related to microbiological contamination (such as sensitized or immunocompromised individuals). Pilot remediation (within a large building complex) may help in developing working remediation specifications and procedures, and to avoid severe pitfalls.

One of the final decisions to be made is related to reoccupancy of the remediated facilities. On a rare occasion, either total or partial re-occupancy of a building may not be achieved. Such outcome could become realistic, if the remediation costs would exceed the value of the building and/or total reconstruction. It is also possible that a small portion of occupants becomes sensitized to building contamination, and in such case sufficient level of cleanliness may not be achieved at a reasonable cost. Depending on the number of such occupants, appointing new working/living space may be the most feasible choice.

Finally, it is necessary to keep open mind towards problems that may have remained unsolved, and return back to monitor and re-evaluate the success of the remediation as necessary. More successful remediation, concrete results, and better documentation of the success may be expected if the follow-up measures are extended to cover the whole duration of the process (and further on, taken as a part of continuous maintenance practices of the buildings) rather than limited to the post-remediation monitoring. In the end, there is clearly a need for enhanced development of validated tools and protocols for assessment of the success of remediation process.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.scitotenv.2008.03.033.

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