OCCURRENCE AND CHARACTERISTICS OF MOISTURE DAMAGE IN SCHOOL BUILDINGS

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ABSTRACT
A total of 30 school units, including 41 school buildings, were technically investigated according to a standardized protocol by trained surveyors, and moisture damage status of each building was assessed. Based on the assessment, the buildings were classified into two categories: 31 index buildings had notable moisture damage observations, whereas 10 reference buildings had not. This classification was used in order to evaluate the effect of different building characteristics, such as age of the building, predominant building materials, and type of structural assemblies, on the occurrence of moisture damage. Moisture damage characteristics, such as location of damage, damaged structure type, and presence of mold/mold odor, were analyzed in order to assess their distribution and inter relationships. With these analyses we seek further insights of such building- and moisture damage characteristics that may be significant for causes and effects of indoor air pollution related to excessive moisture in school buildings.

INDEX TERMS
Building characteristics, Damp, Mold, Visual investigation

INTRODUCTION
Indoor air quality of school buildings may be a significant factor for children's health, as children spend a considerable amount of time in school environments on daily basis. Excessive moisture in buildings can lead to microbial growth in building constructions and harmful emissions into indoor air (Samson et al. 1994). Few case studies published so far have indicated health consequences associated with moisture problems in schools (Haverinen et al. 1999, Savilahti et al. 2000, Sigsgaard et al. 1999). This study was made as a part of exposure assessment in a study program made in order to find links between moisture damage and microbial growth in school buildings, and respiratory heath of the students (Meklin et al. accepted for publication).

MATERIAL AND METHODS
The material consisted of 30 school units, including 41 buildings. The building characteristics of interest are listed in Table 1. According to the main frame material, the buildings were distinctly distributed into buildings with concrete/brick frame (n=18) and wooden frame (n=23). The buildings were built between 1896-1994, the wooden frame buildings being slightly older (1896 –1985) than the concrete/brick frame buildings (1923 – 1994). The wooden frame buildings were also smaller (mean size 380 m^2) than the concrete/brick frame buildings (mean size 3612 m^2).

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Table 1. Building characteristics of interest.

Main frame material	Roof covering material
Age of the building	Existence of eaves
Size of the building	Ventilation system
Number of storeys above ground level	Perceived adequacy of ventilation
Number of storeys below ground level	Repair situation
Floor structure	When the previous repair was made
Facade material	Extension of the repair
Types of windows	Existence of school kitchen
Roof shape	Moisture damage reported by occupants

The investigation was made by a trained civil engineer, who sought out and identified signs of moisture damage in locations within the schools such as walls, roofs, floors, windows, ventilation and plumbing systems. Signs of water leaks, as well as condensation on cold surfaces, detached interior coverings, blistered painted walls, detached interior surfaces or wallboards were registered as well as any other signs that could be interpreted as moisture damage. No structural components were dismantled. A checklist was used to standardize the results, and surface moisture recorders were used to identify moist areas. Moisture damage characteristics of interest are listed in Table 2.

Table 2. Moisture damage characteristics of interest.

Location of damage in a building	Estimated severity of damage
Damaged structure type	Repair situation of damage
Area of damage	Moisture level detected
Estimated duration of damage	Perceived mold odor
Reason of the damage	

Based on the investigation, the buildings were classified into two categories based on the amount, area, and severity of the damage (Nevalainen et al. 1998) in relation to the size of the building. A total of 10 buildings were denoted as reference buildings, having no major moisture damage observed, whereas 31 school buildings were denoted as index buildings having notable moisture damage patterns. Further on, the index buildings were divided into two groups based on their main frame material: buildings with wooden frame (n=16) and buildings with concrete/brick frame (n=15). Both of these classifications of buildings were used in order to analyze the effect of building characteristics on the damage status of the buildings. Moisture damage observations were analyzed in order to establish associations between different moisture damage characteristics. Statistical analyses were done with SPSS – program (SPSS Inc. 1988) using χ^2-test for categorical variables.

RESULTS AND DISCUSSION

Distribution of the index buildings was different from the reference buildings in floor structure, main frame material, façade material, ventilation system and repair history (Table 3). The observed difference in the prevalence was greater than 10%, but none of the associations reached the level of statistical significance ($p<0.05$).

Considering the group of index buildings, buildings with wooden frame differed from buildings with concrete/brick frame statistically significantly in floor structure (more ground floors in the concrete/brick frame buildings), façade material (strongly correlated with the frame) roof covering material (more bitumen roof covering in the concrete/brick frame buildings) and

ventilation system. These results are presented in Table 3. In addition, mold odor was more frequently perceived in the concrete/brick frame buildings (p=0.033).

Table 3. Distribution of some building characteristics in the reference and index buildings, and in the wooden frame and concrete/brick frame buildings.

	Reference schools Total n(%)	Index schools		
		Total n (%)	Concrete / brick frame n (%)	Wooden frame n (%)
Number of school buildings	10 (100)	31 (100)	15 (100)	16 (100)
Floor structure				[b]
ground floor	7 (70)	18 (58)[a]	10 (67)	8 (50)
crawl space, ventilated	3 (30)	13 (42)[a]	3 (20)	10 (62)
crawl space, ventilated	0	3 (9)	3 (20)	0
Roof covering material				[b]
bitumen	2 (20)	7 (23)	6 (40)	1 (6)
metal	5 (50)	16 (52)	7 (47)	9 (56)
brick	3 (30)	8 (26)	2 (13)	6 (38)
Façade material				[b]
wood	7 (67)	15 (48)[a]	0	15 (94)
brick	1 (11)	11 (36)[a]	10 (67)	1 (6)
plaster	2 (22)	5(16)	5 (33)	0
Ventilation system				[b]
natural	2 (20)	11 (35)[a]	3 (20)	8 (50)
mechanical exhaust	5 (50)	12 (39)[a]	4 (27)	8 (50)
mechanical intake and exhaust	3 (30)	8 (26)	8 (53)	0
Last time renovated				
0 – 5 years ago	2 (22)	16 (52)[a]	8 (53)	8 (50)
6 – 10 years ago	4 (40)	6 (19)[a]	1 (7)	5 (31)
11 – 20 years ago	1 (10)	4 (13)	2 (13)	2 (12)
over 20 years ago	0	1 (3)	0	1 (6)
not repaired	3 (30)	4 (13)[a]	4 (27)	0

[a] greater than 10% difference compared to reference buildings; [b] statistically significant ($p < 0.05$) difference compared to the concrete / brick frame buildings

A total of 1205 moisture damage observations were recorded, 1087 of which were in the index buildings. Most of the damage was less than 4 m^2 of size. In the index category, there were 930 damage observations in the buildings with concrete/brick frame and 157 in the buildings with wooden frame. However, the amount of damage / building size [m^2] was 1.27 fold in the wooden framed buildings compared to the concrete/brick frame buildings.

Out of all damage sites 23% were located in classrooms, 20% in wet rooms (i.e. bathrooms and toilets), 12% in corridors, and 6% in kitchens. By structure type, 27% of damage was found from floor structures, 19% from partition walls, 17% from external walls, 15% from upper floors, and 8% from upper-most floors. In concrete/brick frame buildings most of the damage (28%) was observed in floor structures, whereas in wooden frame buildings most of the damage (30%) was found from external walls. The most common reason for damage was technical aging of materials, concerning a total of 325 (27%) damage observations. Other common reasons were

related to moisture sources outside of buildings (e.g. surface water or rising water), 270 (22%) damage observations, and water leaks, 159 (13%) damage observations.

CONCLUSION AND IMPLICATIONS

There was no clear association between any particular building characteristics and damage status of the school buildings. Important building characteristics related to their moisture damage status may include frame material, ventilation system and repair history of buildings as well as floor structure and type of roofing. Wooden frame buildings differ from concrete/brick frame buildings by several means, which may indirectly affect on the moisture damage status. The most common reason for moisture damage was technical aging of materials. This implies that attention should be paid on appropriate maintenance and repair of school buildings.

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