Moisture damage in residential buildings as a function of engineer and occupant observations

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ABSTRACT

Visual inspection performed by trained building inspectors, and interviewer-administered questionnaires collected from building occupants, have been used to evaluate the presence of moisture and mould damage in buildings. The aims of this study are to find out if moisture damage classification is independent of the observing inspector, and if the classification is different from that made by the occupants. Fifteen houses were inspected based on a standardized checklist by two civil engineers with similar training and work experience. Interviewer-administered questionnaires were collected from the occupants prior to the inspection. The data collected by the inspectors included measurements of temperature and relative humidity (RH), and estimation of number of damage sites and extent (size) of damage in the residences; occurrence and severity of moisture damage in eleven locations; visible mould growth and perceived odours. The questionnaire included same questions related to the occurrence and severity of moisture damage in different locations and visible mould growth and odours. The results suggest that the agreement between two inspectors is better than the agreement between the inspector's and occupants reporting, and that agreement on readily measurable or observable items is better than on items requiring subjective estimation. This is a pilot study: a larger sample size is needed to reach a definitive conclusion.

INDEX TERMS

Moisture damage; Mould; Visual inspection; Questionnaire

INTRODUCTION

Epidemiological studies have linked the presence of moisture damage and microbial growth in buildings to health symptoms of the occupants living in these buildings (Bornehag *et al.*, 2001). Methods commonly used to estimate the exposure caused by moisture damage include the use of questionnaires and visual inspection of buildings (Dales *et al.*, 1991; Haverinen *et al.*, 1999). Both methods aim to collect information on the occurrence and characteristics of moisture problems in a relatively straightforward manner without performing in-depth measurements or sampling protocols that are often destructive, time-consuming and expensive. The use of objective and accurate methods is critical in epidemiological studies and also in practical building investigations

Although on-site building investigations are considered to be more objective and accurate than occupants' reports on moisture damage, the method is still vulnerable to subjectivity of estimation between different investigators. However, there are only few studies in the literature comparing on-site building investigations and occupant reports on moisture damage, and no studies assessing the variation in between different inspectors. The aim of this study is

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to assess the accuracy of non-destructive building investigation methods by comparing observations reported by two different building inspectors and building occupants.

MATERIAL AND METHODS

A sample of 15 houses was visually investigated by two civil engineers with similar training and work experience. The time between the investigations was 2–4 weeks. Objective measurements: temperatures and relative humidity (RH) levels, both indoors and outdoors were performed at the time of inspection. The investigators estimated the total number of damage sites within the homes, and the overall extent (size) of damage in square metres. They sought out and identified signs of moisture damage in specific locations within the homes such as walls, roofs, floors, windows, ventilation and plumbing systems, and classified the severity of each damage incident according to the scale of a pre-designed checklist. Surface moisture recorders were used to identify moist areas. Other items relevant to moisture damage were observed visible mould growth and perceived odours. Both investigators have several years of experience in using the checklist and the investigation protocol.

Prior to the investigation, the occupants of the buildings filled in an interviewer-administered questionnaire. The questionnaire included same questions on signs of moisture damage that were later on observed by the inspectors, i.e. occurrence and severity of moisture damage in different locations, visible mould growth and odours.

The data was coded and analyzed with the SPSS program (SPSS Inc., 1988). When studying the variability of observer categorical ratings, observed agreement and kappa were used. When studying the variability of observer continuous or discrete measurements, depending on the distribution of the data, *t*-test or Wilcoxon Rank Sum tests were used. The independence of observer in assessing the severity of damage in specific locations was assessed using contingency tables and chi-square test. The differences were considered statistically significant with $\alpha = 0.05$.

RESULTS

The results from the objective measurements on environmental conditions conducted by the two inspectors were significantly different from each other only for outdoor air temperature, which can be explained by the instantaneous nature of these measurements, and the 2–4 weeks time-span that occurred between the inspections (Table 1). There were no statistical differences between the two inspectors on the estimates of the number of damage sites and extent of the damage in homes.

Table 1 Objective measurements of environmental conditions and estimated number of damage sites and size of damage recorded by the two inspectors

	N, mean, median		*p*
	INS1	INS2	
Temperature			
Indoors	15, 22.8, 22.6	15, 23.0, 23.0	0.716[a]
Outdoors	15, 0.2, –0.5	8, 7.2, 6.0	0.019[a]
Relative humidity			
Indoors	15, 31.4, 31.0	15, 32.5, 32.0	0.685[a]
Outdoors	15, 73.2, 78.0	8, 70.9, 76.0	0.743[a]
Extent of damage (m^2)	14, 1.0, 0.1	15, 0.7, 0.2	0.693[b]
Number of damage sites	15, 1.7, 1.0	15, 2.5, 2.0	0.164[b]

INS1 = inspector 1; INS2 = inspector 2; Experimental unit = residence.
[a]Based on *t*-test; [b]Based on Wilcoxon Rank Sum Test.

The prevalence, proportion of agreement and κ values for estimation of categorical variables made by the two inspectors and the occupants are shown in Table 2. The proportion of agreement between inspectors was 0.8 ($\kappa = 0.4$) for overall moisture damage observations reported, and varied between 0.7 and 1.0 for moisture damage observations in different locations, visible mould observations and perceived odours. The proportion of agreement between the occupants and the two inspectors' reports of overall moisture damage observations was 0.5 and 0.3, with κ values of 0.2 and –0.1, respectively. The proportion of agreement between the occupants and the two inspectors observations of moisture damage in different locations, and visible mould observations and odours was 0.5–1.0 (averages 0.8 with average κ values of 0.14 and 0.27, respectively); being smaller than the corresponding agreement between inspectors (average 0.85 with $\kappa = 0.6$).

To test if estimating severity of damage in the 11 specific locations within each subject residence, as in Table 2, is independent of the inspector we used contingency tables. Four severity categories were used, category 0 representing no damage observed, and categories 1–3 the more severe categories (Nevalainen *et al.*, 1998). The null hypothesis of independence between observations by the inspectors was rejected for three degrees of freedom (df = 3) with chi square critical being 7.8 and the chi-square observed being 13.6. However, the conclusion was not definitive because of limitations of sample size in several cells of the contingency tables. Therefore, the null hypothesis was also tested by combining all the categories 1–3, and the observed chi square value 4.4 was still higher than the critical value 3.8 (df = 1). We concluded that assessing the severity of moisture damage is not independent of the inspector.

Table 2 Prevalence, proportion of agreement and kappa-values for the observations made by the two inspectors and the occupants

	N (%)			p_0, κ		
	INS1	INS2	OCC	INS1 vs. INS2	INS1 vs. OCC	INS2 vs. OCC
Observed moisture damage	10 (83)	13(87)	5(33)	0.8, 0.4	0.5, 0.2	0.3, -0.1
Damage observed in						
1. Uppermost floor	2 (14)	1 (7)	1 (7)	0.9, 0.9	0.8, 0.6	1.0, 1.0
2. Upper floor, ceiling	2 (14)	2 (13)	0 (–)	1.0, 1.0	1.0, –	1.0, –
3. Windows	7 (50)	6 (43)	2 (13)	0.9, 0.8	0.6, –0.3	0.7, 0.4
4. External wall	3 (21)	4 (27)	3 (20)	0.9, 0.8	0.6, –0.3	0.6, 0.1
5. Partition wall	4 (29)	7 (47)	2 (13)	0.8, 0.6	0.7, 0.2	0.7, 0.3
6. Upper floor, floor	1 (7)	5 (33)	4 (27)	0.8, 0.7	0.7, 0.3	0.5, 0.1
7. Ground floor	4 (29)	7 (47)	3 (20)	0.8, 0.7	0.6, 0.3	0.6, 0.3
8. HVAC system	0 (–)	0 (–)	0 (–)	1.0, –	1.0, –	1.0, –
9. Plumbing system	1 (33)	2 (13)	4 (27)	0.9, 0.6	0.6, –0.1	0.8, 0.2
10. Equipment/furniture	1 (7)	2 (13)	1 (7)	0.7, –	0.9, –0.1	0.9, 0.6
11. Other/unknown	2 (14)	3 (20)	2 (13)	0.8, 0.3	0.9, 0.4	0.7, –0.2
Visible mould	2 (14)	5 (33)	0 (–)	0.8, 0.5	0.9, –	0.7, –
Mould odour	2 (14)	0	2 (13)	0.9, –	0.9, 0.6	0.9, –
Other odours	1 (7)	3 (20)	1 (7)	0.7, –0.12	0.9, –0.1	0.7, –0.1

INS1 = inspector 1; INS2 = inspector 2; OCC = occupants; Experimental unit = damage site in the item 2 or the residence in the items 1, 3–11; p_0 = proportion of agreement.

DISCUSSION

The capability of indirect methods, such as non-destructive investigation of buildings, to discern the level of risk of exposure is limited. However, the development of indirect methods can be supported since the collected information can help in assessing the relationships between the source, the exposures, and the responses. It has been estimated that the main advantage of indirect approaches is that they can be used to calculate, rapidly and inexpensively, estimates of exposure over a wide range of exposure scenarios. Conversely, direct exposure assessment approaches involve the deployment of a large number of exposure monitors, and different scenarios must be investigated by collecting additional data (Klepeis, 1999). The validity and reliability of indirect methods is a concern that should be addressed.

Information gathered by occupants is subjective. Validity and reliability of the results gathered from questionnaires are affected by several survey factors such as sample size, response rate, recall period, and factors related to the design of the questionnaire. Apart from objective measurements, self-reports are complex, requiring observation, interpretation, judgment as to the degree of severity, and finally verbal expression (Dales *et al.*, 1997). Conversely, the use of questionnaires is a relatively cost-effective method in collecting information of occupant perceived indoor air quality, especially if the sample size is large. In addition, the use of questionnaire responses collected from the occupants themselves provides first hand information, and the occupants' perceptions are also of importance when assessing the condition of the building. On the other hand, trained building inspectors are experienced to observe and evaluate their observations, and they are also more objective than the occupants who have a personal relationship with the building. Especially in many case studies conducted in problem buildings, both of occupants' and inspector's observations are combined in order to obtain comprehensive estimates. The advantages gathered by using this approach would not, however, totally exclude the subjectivity of indirect methods.

Few studies have analyzed differences between occupant reported and investigator verified moisture and mould observations in dwellings. Douwes *et al.* (1999) suggested that occupants' reports are more reliable in estimating 'dampness' than investigators' reports. Bornehag *et al.* (2001) also concluded that whereas in most studies occupants had reported more 'dampness' than investigators had, it was due to the longer time perspective of the occupants, as opposed to the 'snapshot' of the investigators. A conflicting study by Williamson *et al.* (1997) reported occupants having a tendency to underestimate 'dampness'. Nevalainen *et al.* (1998) also reached the same conclusion, suggesting the explanation to be a result of a trained eye of the inspectors together with their knowledge of what represent critical problems.

Our analyses included objective measurements of environmental conditions, variables related to moisture damage observations in different locations in homes, their estimated extent and severity, and other building and moisture damage related characteristics with potential impact on indoor air quality and exposures to indoor air pollutants. The objective measurements made in a cross sectional study design are prone to continuously changing RH and temperature, and the only conclusion that can be drawn based on these measurements is that the differences in the results gathered clearly reflect changes in environmental conditions. The estimation of overall damage status, number of damage sites and extent of damage was made independently of the inspectors. The estimation of visible mould growth, odours, and the severity of damage in different locations was more prone to subjective estimation of the inspectors. However, the difference between corresponding inspector and occupant observations was higher on average than the one between the two inspectors.

Although the small sample size used in this pilot study limits the possibility to arrive at a definitive conclusion, we suggest that to achieve more accurate information, studies related to moisture damage in buildings should rely on data collected by independent inspectors rather than occupant reporting. Moreover, we suggest that the inspectors should focus on estimating items that are readily observed rather than items that require subjective, qualitative or quantitative estimation, because such observations are independent of the observing engineer.

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