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Review Article

Dampness in Buildings and Health

Nordic Interdisciplinary Review of the Scientific Evidence on Associations between Exposure to "Dampness" in Buildings and Health Effects (NORDDAMP)

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Abstract Several epidemiological investigations concerning indoor environments have indicated that "dampness" in buildings is associated to health effects such as respiratory symptoms, asthma and allergy. The aim of the present interdisciplinary review is to evaluate this association as shown in the epidemiological literature. A literature search identified 590 peer-reviewed articles of which 61 have been the foundation for this review. The review shows that "dampness" in buildings appears to increase the risk for health effects in the airways, such as cough, wheeze and asthma. Relative risks are in the range of OR 1.4–2.2. There also seems to be an association between "dampness" and other symptoms such as tiredness, headache and airways infections. It is concluded that the evidence for a causal association between "dampness" and health effects is strong. However, the mechanisms are unknown. Several definitions of dampness have been used in the studies, but all seems to be associated with health problems. Sensitisation to mites may be one but obviously not the only mechanism. Even if the mechanisms are unknown, there is sufficient evidence to take preventive measures against dampness in buildings.

Key words Review; Dampness; Exposure; Health effects; Allergy; Asthma.

Practical Implications
"Dampness" in buildings appears to increase the risk for a number of health effects such as cough, wheeze, asthma, airways infections, tiredness, and headache. However, with the exception of mite-exposure, it is not known which humidity related agents in indoor air that are responsible for the health effects. Both chemical and microbiological exposures are suspected. Thus, even if it is a great challenge to science to explain the associations, the practical advice is "avoid dampness in buildings". This means that there is not enough scientific knowledge today to do health relevant evaluations of dampness related exposures indoors.

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Introduction

Several epidemiological studies have reported an association between "damp" buildings and health problems such as asthma and other respiratory symptoms. Furthermore, some studies suggest that living in "damp homes" is a risk factor for sensitisation and development of allergy (Commission on Environmental Health, 1996; Sundell and Kjellman, 1994). However "dampness" is a rather vague concept, with variable definitions, and specific chemical or biological factor that can explain the association needs to be identified. Some issues that need to be evaluated are:

- Which health effects are associated with "damp" buildings?
- Are the associations between "dampness" and health due to bias?
- Which agents, due to "dampness" is health relevant?
- Is there a health relevant definition of a "damp" building?

The objective is to evaluate the association between

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"dampness" in buildings and health. The work was performed by an interdisciplinary group of Nordic researchers.

Material and Methods

In the light of experience of earlier consensus work (Andersson et al., 1997, Ahlbom et al., 1998), a planning seminar was first held in order to agree on the composition of the group of researchers and on guidelines for the work. Nordic scientists with great experience in evaluating scientific literature, and with expert knowledge in, some of the areas involved, were invited. The invited scientists had documented expert knowledge in at least one of the following disciplines: occupational medicine, building hygiene, HVAC technology, building physics, microbiology, allergy, and epidemiology.

A literature search in MEDLINE (articles published prior to July 1998) was carried out. The search profile was:

Exposures: "Dampness, humidity, mould growth, microorganisms".

Health effects: "Hypersensitivity, respiratory tract disease, asthma, cough, wheeze, bronchial disease, bronchial hypersensitivity, lung diseases, otorhinolaryngological diseases, nose diseases, conjunctival diseases, conjunctivitis, dermatitis, eczema, skin diseases, eczamatous".

Environment: "Houses, dwellings, schools, offices, daycare centers, non-industrial environments".

The literature search identified 590 articles; 477 articles were excluded as they were reviews, case studies, studies of occupational exposure, or studies on mites. Mite studies were excluded, as there exist good reviews in this area. Consequently, 113 studies have been scrutinised by the review group.

During the review seminar all articles were distributed to the participants. A "reporter" presented each article with comments from an "assessor", after which the article was discussed and evaluated on the basis of the following criteria:

– Are exposure and health effects charted and described in a relevant manner, with respect to e.g. time of exposure (e.g. infancy, childhood years, actual exposure)?
– Is the selection of the investigated persons satisfactory?
– Is the statistical analysis including control of "confounders" and effect modification satisfactory?

Of the 113 reviewed studies 52 articles were excluded in the review work because they were judged as "non-informative" or "inconclusive", table 6. The term "non-informative" indicates that the article lacks essential information concerning exposure or health effects or that the analysis did not consider possible confounding from other factors. The term "inconclusive" indicates that data processing or reporting makes it impossible to draw conclusions concerning the relationship between exposure to "dampness" and health effects. It should be pointed out that many of the excluded studies have had other purposes than investigating associations between "dampness" and health. Consequently, 61 studies have been the foundation for the review.

When articles were discussed, anyone who was author or co author of an article concerned left the room. The group agreed on the position taken regarding each article, concerning both the relevance of the article to the issues at hand, and the conclusions that can be drawn from the article. A proposal was then made for a joint consensus statement concerning all scrutinised articles. At final seminars a smaller number of important articles were again discussed, and the consensus statement was then adopted.

Results

Moisture in buildings can be in the form of water vapour or as free water. Measurements of relative humidity (RH) gives information of the water vapour content in the air and/or in the building material. There are mainly four sources for "dampness" and moisture in buildings:

1. Leakage of rain and snow into the building construction or moisture from the ground, i.e. *outdoor sources.*
2. Moisture from humans and indoor activities, e.g. cocking, bathing, human expiration, humidifiers, etc, i.e. *indoor sources.*
3. Moisture within building materials and constructions from the erection time due to that materials have not been protected against rain and snow, or due to insufficient time for drying out, e.g. humidity in concrete floors, i.e. *building sources.*
4. Water leakage from e.g. pipes, flooding and other types of *accidents.*

A distinction should be made between moisture in the building structure and humidity in indoor air. Moisture in the building structure can affect building materials leading to microbiological and chemical processes, with e.g. emission of odorous and irritant substances and/or allergens. Relative humidity in indoor air may cause condensation on cold indoor surfaces or condensation in the construction, also resulting in microbial growth and chemical processes. Increased humidity may also increase the risk of house dust mite infestation.

Numerous "dampness" indicators have been used in the reviewed articles, e.g. "*Visible mould*", "*Damp stains*", "*Condensation on window panes and/or walls*", "*Flooding*", "*Water damage*", "*Smell/odour*", indicating different "dampness" sources. The indicators are related to different problems in the building. "Visible mould" and "condensation" are indications of a high relative humidity in indoor air in combination with cold surfaces. "damp stains and spots", "damp water damage", "bad smell and odour" and "flooding" are often indications of moisture in the construction. In

Table 1 Reviewed studies divided into one or more of 4 categories depending on different kinds of data on dampness and health effects. Dampness have been characterised by questionnaires, inspections by professional staff, humidity measurements and/or by humidity related exposures indoors. Health effects have been investigated by questionnaires and/or by clinical examinations

	Health Effects							
	Self-reported symptoms				Clinical examinations (signs and tests)			
	Author(s)	Positive associations²	No associations	Study design¹	Author(s)	Positive associations²	No associations	Study design¹
Dampness								
Self-reported dampness	See text and Table 2 (infants 0–6 years) (6 studies) and Table 3 on cross-sectional studies on children 6–16 years (26 studies), Table 4 including case-control studies on children 6–16 years (8 studies) and Table 5 on adults (11 studies), in total 51 studies. The main findings are positive associations between self-reported dampness at home and at workplaces and self-reported allergy- and asthma symptoms (i.e. asthma, wheeze, and cough).				Brunekreef et al., 1989	X(ns)	X	CS, 3655, Ch
					Brunekreef, 1992a	X(ns)	X	CS, 3460, Ch
					Cuijpers et al., 1995	X(ns)	X	CS, 470, Ch
					Dijkstra et al., 1990		X	CS, 634, Ch
					Hyndman et al., 1990	X(ns)		CC, 30/30, A
					Iversen and Dahl, 1990	X*		326 asthmatic patients
					Iversen and Dahl, 1995		X	677 asthmatic patients
					Lindfors et al., 1995	X*		CC, 193/318, Ch
					Nafstad et al., 1998	X*		CC, 251/251, Ch
					Norbäck et al., 1995		X	CC, 41/47, A
					Norrman et al., 1994	X*		CS, 1112, Ch
					Rönmark et al., 1998		X	CS, 3431, A
					Verhoeff et al., 1995	X*	X	CC, 259/257, Ch
					Williamson et al., 1997	X*		CC, 102/196, A/Ch
Observed dampness by inspectors	Hyndman et al., 1990	X*		CC, 30/30, A	Mohamed et al., 1995	X*		CC, 77/77, Ch
	Martin et al., 1987	X*	X	CS, 358, A/Ch	Nafstad et al., 1998	X*		CC, 251/251, Ch
	Mohamed et al., 1995	X*		CC, 77/77, Ch	Verhoeff et al., 1995	X*	X	CC, 259/257, Ch
	Nafstad et al., 1998	X*		CC, 251/251, Ch	Williamson et al., 1997	X*	X	CC, 102/196, A/Ch
	Platt et al., 1989	X*		CS, 1169, Ch				
	Smedje et al., 1997		X	CS, 762, Ch				
	Verhoeff et al., 1995	X(ns)		CC, 259/257, Ch				
Humidity measurements	Björnsson et al., 1995	X*		CC, 41/47, A	Strachan and Sanders, 1989		X	CS, 778, Ch
	Hyndman et al., 1990	X*		CC, 30/30, A				
	Smedje et al., 1997	X*		CS, 762, Ch				
	Strachan and Sanders 1989		X	CS, 778, Ch				
Humidity related exposure measurements indoors	Björnsson et al., 1995	X*	X	CC, 41/47, A	Björnsson et al., 1995	X*	X	CC, 41/47, A
	Dales et al. 1997	X*		CS, 403, A	Strachan et al., 1990	X(ns)		CC, 11/23/29/25, Ch
	Huang and Kimbrough, 1997	X*		CC, 25/19, Ch	Dotterud et al., 1995b	X*		CC, 19/19, Ch
	Hyndman et al., 1990		X	CC, 30/30, A	Dotterud et al., 1996		X	CC, 19/19, Ch
	Li et al., 1997b	X*		CS, 264, A	Williamson et al., 1997	X*		CC, 102/196, A/Ch
	Li et al., 1997d		X	CC, 46/20/26, Ch				
	Platt et al., 1989	X*		CS, 1169, Ch				
	Smedje et al., 1997	X*		CS, 762, Ch				
	Strachan et al., 1990	X*		CC, 11/23/29/25, Ch				
	Verhoeff et al., 1994	X*	X	CC, 31/29, Ch				
	Waegemaekers et al., 1989	X*		CS, 56, Ch				
	Wickman et al., 1992	X*		CC, 61/57/57, Ch				

¹⁾ CS=Cross-Sectional, CC=Case-Control, Number of humans in the study, A=Adults, Ch=Children. ²⁾X=positive associations between different kinds indications for dampness and health effects, *=significant associations ($P<0.05$), (ns)=non significant association

Table 2 Studies including infants (0–6 years) on symptoms vs. dampness at home

Author(s)	No. of humans	Age and Country	Result
Infante-Rivard, 1993	457/457	3–4 years, Canada	Use of humidifier was associated to asthma (OR 1.89 (CI:1.30–2.74))
Jaakkola et al., 1993	2568	1–6 years, Finland	Any self-reported dampness exposure at home was significantly associated with persistent cough (AOR 2.17 (CI:1.39–3.39)), persistent phlegm (AOR 2.20 (CI:1.27–3.82)), persistent wheezing (AOR 2.62 (CI:1.39–4.39)), weekly nasal congestion (AOR 1.94 (CI:1.15–4.98)). Current asthma was not associated with dampness
Kerr, 1981	269	0–5 months, Polynesian	The incidence of lower respiratory symptoms in five months old infants was 42%. The prevalence of damp house/flat was 36.8 % among non-wheezy infants, 56.5% among mild wheezy infants and 59.6% among infants with severe wheeze
Lindfors et al., 1995	193/318	1–4 years, Sweden	Windowpane condensation tended to be most frequent in homes with children sensitised to cat and/or dog (OR 1.9 (CI:0.9–4.3))
Nafstad et al., 1998	251/251	0–2 years, Norway	Reported dampness (AOR 2.5 (CI:1.1–5.5)) and observed dampness (AOR 3.8 (CI:2.0–7.2)) risk factors for bronchial obstruction
Tariq et al., 1996	981	4 years, UK	6% of the children were sensitised to moulds (Alternaria, Cladisporium). Reported dampness at home was not associated to sensitisation to moulds.

Table 3 Cross-sectional studies including children 6–16 years on self-reported symptoms (asthma, cough, wheeze) vs. self-reported dampness/mould in their homes. Associations are expressed as odds ratios. In the table "damp" means condensation on windowpane, damp spots, flooding etc, "mould" visible mould, mould odour etc, and "index" is a summary measure used by the authors

Author(s)	No. of Humans	Asthma			Cough			Wheeze		
		damp	mould	index	damp	mould	index	damp	mould	index
Andrae et al., 1988	2793			1,10			1,90			
Austin and Russel, 1997	1537				1,62	1,78				
Brunekreef, 1992a	985	1,70	1,12		1,97	3,06		1,46	1,37	
Brunekreef, 1992a	2475	1,30	1,53		1,57	2,05		1,52	1,90	
Brunekreef et al., 1989	4625		1,27	1,42		2,12	2,16		1,79	1,23
Bråbäck et al., 1995.	2594						1,41			1,47
Cuijpers et al., 1995 (boys)	222				3,01			0,56		
Cuipers et al., 1995 (girls)	248				1,41			1,48		
Dales et al., 1994	770			1,42			1,57			1,49
Dales et al., 1991a	13495	1,58	1,40	1,45	1,91	1,61	1,89	1,74	1,42	1,58
Dekker et al., 1991	10819			1,46						1,61
Dijkstra et al., 1990	775		1,56	1,16		3,62	0,57		1,54	1,13
Forsberg et al., 1997	15962			1,20			1,60			
Kelly et al., 1996	3746						1,56			1,24
Li et al. 1996a	1340		1,12	1,18		1,87	1,43		1,20	1,11
Maier et al., 1997	925		1,30	1,40					1,20	1,10
Norrman et al., 1994	1112		1,54							
Norrman et al., 1998	990		3,00							
Rönmark et al., 1998	3431			1,90						
Spengler et al., 1994	12842		1,50	1,31						
Strachan, 1988	873				2,81	1,75		2,23	3,81	
Strachan and Elton, 1986	165							2,70	3,90	
Strachan and Sanders, 1989	775							3,10	3,10	
Strachan et al., 1990	1000								3,70	
Timonen et al., 1995	2542			2,50			2,40			
Waegemakers et al. 1989	190			2,80			2,99			2,80
Yang et al., 1997a	4164			1,73			1,71			1,81
Åberg et al., 1996	2481			1,70						

many studies an index of "dampness" have been used meaning one or more of the mentioned characteristics.

The prevalence of "dampness" indicators shows a wide variation. In tropical monsoon climate, as in e.g. Taiwan, mould and water damage are found in many buildings, i.e. a prevalence of typically 23–79%, (Li et al., 1997b; Li et al., 1997c; Li et al., 1997d; Yang et al., 1997). In cold areas such as the Nordic countries "dampness" indicators are typically found in 4–25% of the buildings (Andrae et al., 1988; Norbäck et al., 1995; Smedje et al., 1997; Forsberg et al., 1997). On the other hand, smell and odour are frequently reported in these buildings.

Four Categories of Studies

Due to the risk of bias, the ideal study would include independent observers of the health effects and the ex-

Table 4 Case-Control studies including children 6–16 years on self-reported symptoms vs. self-reported dampness/mould in their home. Associations expressed as odds ratios. In the table "damp" means condensation on window pane, damp spots, flooding etc, "mould" visible mould, mould odour etc, and "index" is a summary measure used by the authors

Author(s)	No. of humans	Asthma			Cough			Wheeze			Comments
		damp	mould	index	damp	mould	index	damp	mould	index	
Ehrlich et al., 1996	368/294		1,35						1,11		Bedroom mould
Huang, Kimbrough, 1997	25/19										Cold symptoms associated with mould count
Li et al., 1997d	46/20/26		1,02	1,01							Odour/asthma 3.19, Water damage/ asthma 0.7
Mohamed et al., 1995	77/77	4,90									
Strachan and Carey, 1995	486/475										Mould in bedroom not associated with wheezing
Verhoeff et al., 1995	259/257	1,46	1,57		1,70	1,90					Reported damp/ mould
Verhoeff et al., 1995	259/257	1,22	1,53		1,18	1,26					Observed damp/ mould
Wickman et al., 1991	53/54/53										Weak association between HDM, asthma and mould
Williamson et al., 1997	102/196	1,93									Reported damp/ mould
Williamson et al., 1997	85/132	3,03	1,35								Observed damp/ mould

posure to "dampness". Objective tests of health effects, such as results of e.g. blood tests (RAST), skin prick tests (SPT), inflammatory markers and lung function tests should not be influenced by recall bias. In more than 20 studies results are presented from clinical examinations. These studies include tests of lung function, allergy tests and measurements of biomarkers of inflammation or atopy. Signs of bronchial obstruction have been diagnosed by physicians in some studies. Assessment of "dampness" by experienced inspectors unaware of health effects provides one method to reduce information bias.

The studies have been divided into one or more of 4 categories (I–IV) depending on the type of data for health effects and exposure (Table 1). Relative risks for health effects are usually expressed as odds ratios (OR) and/or as adjusted odds ratios (AOR) where adjustments have been made for, e.g. gender, smoking, age, etc. From each of the four groups a few studies are described illustrating the complexity of investigating associations between "dampness" in buildings and health effects.

I. Studies of Self Reported "Dampness" and Self reported Health

This group includes 51 studies, mainly with a cross-sectional and/or a case-control design. The studies include both infants (0–6 years) (Table 2), children (6–16 years) (Tables 3 and 4) and adults (Table 5). Most of the studies show an association between "dampness" at home and at workplaces and symptoms such as asthma, cough and wheeze. Examples are as follows:

One thousand four hundred and sixty residents (adults) in the Finnish county of Kuopio responded to questionnaire (76% response rate) regarding respiratory disease, symptoms, and home conditions, (Pirhonen et al., 1996). The questionnaire also contained "general complaint questions" such as on lumbar backache and recurrent stomachache, with the intent of correcting for overreporting of symptoms. The prevalence of "dampness" defined as water/moisture stains, or visible mould was 23.9%. Health effects such as rhinitis, atopy, allergic rhinitis, phlegm, fever and chills, impaired sense of smell, hoarseness, fatigue and difficulties in concentration, showed significant associations with "dampness", with AOR ranging between 1.5 and 2.2. Lumbar backache and recurrent stomachache were also significantly associated with "dampness" (OR 1.49 (CI: 1.15–1.93) and 1.65 (CI: 1.24–2.20) respectively). When using another definition of "dampness" with a greater degree of subjectivity (odour of mould) the AOR for association with backache and recurrent stomachache rose to 1.90 and 2.13, respectively. When subjects who had indicated such health problems were removed (about 2/3 of the subjects were excluded) significant associations with "dampness" were still present for eye irritation (AOR 1.69) and tiredness (AOR 2.06). The authors also analysed the material after removing subjects who accord-

Table 5 Studies including adults on self-reported symptoms vs. self-reported dampness/mould in their home and their workplaces. Associations expressed as odds ratios. In the table "damp" means condensation on window pane, damp spots, flooding etc, "mould" visible mould, mould odour etc, and "index" is a summary measure used by the authors

Author(s)	No. of humans	Asthma			Cough			Wheeze		
		damp	mould	index	damp	mould	index	damp	mould	index
Brunekreef et al., 1992b (men)	3148	3.00	4.23	1.29	2.90	2.52	2.56	1.57	1.58	1.63
Brunekreef et al., 1992b (women)	3288	1.26	1.28	1.25	1.45	1.40	1.75	1.39	1.17	1.43
Dales et al., 1991b	14948			1,56						
Hu et al., 1997	2041		2.0	1,3						
Hyndman et al., 1990	345	2,2	2,5							
Li et al., 1997b	264					1.53	2,3		1.58	17,45
Li et al., 1997c	612					1.38	2,14		1.39	2,87
Norbäck et al., 1995	47/47			3,9						
Pirhonen et al., 1996	1460			1,02		1,73	1,37			
Routsalainen et al., 1995	268						2,23			1,28
Waegemakers et al., 1989 (women)	164			4.16			3.48			4.79
Waegemakers et al., 1989 (men)	164			1.15			1.35			4.06
Williamsson et al., 1997 (reported)	102/196	1.93								
Williamson et al., 1997 (observed)	85/132	3.03	1.35							

ing to the questionnaire showed symptoms of stress and depression. This did not materially change the findings.

Dales et al. (1991a) performed in 1988 a study on 13,495 children (83% response rate) by a questionnaire in 30 Canadian communities. "Dampness" was present in 38% of the homes, defined as presence of mould or mildew during the preceding year, presence of wet spots (excluding basement) and flooding or leaks in the basement the preceding year. Questions about major accidents or severe illness unrelated to the chest in the past year were added to study possible over-reporting. Significant associations with "dampness" were found for a number of respiratory symptoms and diseases including wheeze, asthma, chest illness, eye irritation and non-respiratory symptoms. The adjusted OR ranged from 1.32 (CI: 1.18–1.48) for bronchitis to 1.89 (CI: 1.63–2.20) for cough. Non respiratory symptoms such as nausea, vomiting diarrhoea or headache were also associated (AOR 1.43 (CI: 1.33–1.55)) with presence of "dampness". The strongest association was found between cough and the number of damp spots (AOR 2.26 (CI: 1.80–2.83)). The risk estimates were not materially changed if the analysis was restricted to children who had not reported allergy to dust or mould. Similarly stratifying the material according to major illness/accident did not affect the risk estimates.

"Dampness" and respiratory symptoms were assessed by questionnaire in a Dutch study, Brunekreef (1992a), including 985 children (6–12 years) from 10 schools in 5 Dutch towns in 1987 (80% response rate). The prevalence of damp stains in the homes was 14.8% and the prevalence of visible mould growth on surfaces inside the house was 9.1%. In 1989, 2,475 children (6–9 years) from one town responded to a similar questionnaire (74% response rate). The prevalence of symptoms were nearly identical, however, the prevalence of reported damp stains and mould spots were much higher (23.6 and 15.0%). In both studies there was a significant association between reported "dampness"/ mould spots and respiratory symptoms, in 1987 cough/damp stains AOR 1.97 (CI: 0.88–4.41) and cough/mould spots 3.06 (CI: 1.29–7.26), and in 1989 1.57 (CI: 1.06–2.32) and 2.05 (CI: 1.35–3.19) respectively. In the 1989 study AOR for wheeze and asthma were also significantly related to mould spots (AOR between 1.5 and 1.9).

Åberg et al. (1996) made a cross-sectional study on 2,481 7- to year 9-year-old children in Sweden 1991. The study was carried out in Gothenburg (83 % response rate) and in Kiruna (91% response rate). Self reported "dampness" at home (i.e. moisture inside windowpanes and "dampness"/mould damage were significantly associated with self reported asthma, allergic rhinitis and eczema. The strongest reported risk factor was "dampness"/mould damage during first year of life. Furthermore, there was a significant association between "dampness" and the prevalence of upper respiratory tract infections in children.

Most studies show an association between self reported "dampness" and respiratory symptoms and diseases such as asthma, cough and wheeze with an OR in the range of 1.4–2.2, (Tables 2–5). The OR seems to be highest for cough. Some studies also report associations with other symptoms like headache, tiredness, difficulties in concentration, lumbar backache, recurrent stomach ache, nausea and vomiting, and diarrhoea and airway infections (see e.g. Pirhonen et al., 1996; Dales et al., 1991a; Åberg et al., 1996).

Table 6 Excluded studies in the review

Excluded studies	
Author	Comments
Andersson et al., 1997	Non-informative
Beck et al., 1989	Inconclusive
Bener et al., 1996	Inconclusive
Bråbäck & Kälvesten, 1991	Non-informative
Burr et al., 1980	Non-informative
Burr et al., 1988	Non-informative
Burr et al., 1989	Inconclusive
Chirila et al., 1981	Non-informative
Colloff, 1987	Non-informative
Colloff, 1992	Non-informative
Dotterud et al., 1995a	Inconclusive
Fagbule & Ekanem, 1994	Inconclusive
Finsnes, 1995	Non-informative
Gustafsson et al., 1996	Inconclusive
Gyntelberg et al., 1994	Non-informative
Harrison et al., 1992	Non-informative
Harving et al., 1990	Non-informative
Harving et al., 1994a	Non-informative
Harving et al., 1994B	Non-informative
Hirvonen et al., 1997	Non-informative
Horak et al., 1996	Non-informative
Kodama & Mc Gee, 1986	Non-informative
Korsgaard, 1982	Non-informative
Korsgaard, 1983	Non-informative
Koskinen et al., 1997	Inconclusive
Kuehr et al., 1994a	Non-informative
Kuehr et al., 1994b	Non-informative
Kuehr et al., 1995	Non-informative
Li & Kendrick, 1995	Inconclusive
Li et al., 1994	Non-informative
Li et al., 1995	Non-informative
Li et al., 1996b	Non-informative
Li et al., 1997a	Non-informative
Melia et al., 1982	Inconclusive
Murray et al., 1985	Non-informative
Nevalainen et al., 1998	Non-informative
Norbäck & Edling, 1991	Inconclusive
Nordvall et al., 1990a	Non-informative
Nordvall et al., 1990b	Non-informative
Nowak et al., 1996	Inconclusive
Placido et al., 1996	Non-informative
Rylander et al., 1992	Inconclusive
Rylander et al., 1997	Inconclusive
Strachan 1990	Non-informative
Su et al., 1992	Inconclusive
Sundell et al., 1994	Non-informative
Taskinen et al., 1997	Inconclusive
Teeuw et al., 1994	Non-informative
Verhoeff et al., 1992	Non-informative
Wessén & Schoeps, 1996	Non-informative
Wickman et al., 1994	Non-informative
Yang et al., 1997b	Non-informative

However, the evidence for an association to "dampness" is weaker for such symptoms, than for respiratory symptoms.

II. Studies on Self-Reported "Dampness" and Clinical Examination

This group include 14 studies (Table 1). In six studies, significant associations were reported between self-reported "dampness" and health effects diagnosed by clinical examination. Examples are:

Brunekreef (1992a) tested lung function in 985 children. There were no statistically significant associations between self-reported mould or "dampness" and lung function tests, except for a borderline significance for the association between decreased maximal mid-expiratory flow and self-reported mould spots. The author argues that if parents in damp homes over-report respiratory symptoms, the correlation between respiratory symptoms and impaired lung function should be attenuated in children from damp homes (because of over-reporting of symptoms in healthy children). Data did not suggest such attenuation.

Cuijpers et al. (1995) investigated 470 Dutch primary school children (6–12 years). Information on home "dampness" (damp stains and mould growth) and respiratory morbidity was obtained by a questionnaire answered by the parents of the children. The frequencies of damp stains and mould growth at home were 31.5% and 23.4%, respectively. A combination of both damp stains and mould growth was reported in 20% of the homes. In boys self-reported damp stains were significantly related to chronic cough (OR 3.0 (CI: 1.31–6.92)) but not to other symptoms. In girls no significant associations were observed between "dampness" and symptoms. In boys, a small but not statistical significant impairment of lung function was associated to damp stains and mould growth. No associations were found between lung function and home "dampness" for girls.

In a Swedish study, 193 children with asthma and 318 controls (1–4 years) were evaluated for atopic heredity, exposure to furred pets, tobacco smoke and home "dampness", (Lindfors et al., 1995). The cases had been referred to allergy clinics at three hospitals in Stockholm. Thirty-four cases were classified as cat and/or dog allergic on the basis of skin prick test. Window pane condensation in the bedroom or living room during winter time was used as a marker for home "dampness". The prevalence of "dampness" was 22% in controls, 26% in cases not sensitised to cat/dog and 35% in sensitised cases. A combination of high exposure to cat and/or dog allergens, environmental tobacco smoke and damp housing was associated with an OR of 8.0 (1.9–34.1) for asthma in the sub-group of children sensitised to cat and/or dog. However, there were no differences in reported prevalence of mould lesions between cases and controls.

Rönnmark et al. (1998) performed a cross-sectional study on 3,431 children aged 7–8 years old in three towns in northern Sweden (97% response rate) and 2,149 children were skin prick tested with 10 allergens. A questionnaire was used to obtain information about respiratory symptoms, family history of asthma, past or present house "dampness" and mothers' smoking habits. The prevalence of positive skin prick test for at least one allergen was 20%. The main risk factor for current asthma were a family history of asthma (OR 3.2), past or present "dampness" (OR 1.9), male sex (OR1.7), and a smoking mother (OR 1.6). With a combination of all such risk factors an OR of 8.3 was reported for asthma. Significant risk factors for sensitisation was a smoking mother (OR 1.6) and urban living (OR 1.4). "Dampness" was not a risk factor for sensitisation.

Clinical diagnosed asthma seems to show similar associations to "dampness" as self-reported asthma. However, tests of pulmonary function or sensitisation, show no or a weak association with "dampness". Furthermore, one study indicated that symptoms are not "over-reported" in "damp" buildings, (Brunekreef, 1992a).

III. Studies on Objective Signs of "Dampness" and Self-Reported Health Effects

Twenty-three studies present results from associations between objective signs or measurements of "dampness" and self reported symptoms (Table 1). Objective findings on "dampness" are from inspections by professionals, measurements of relative humidity in indoor air and measurements of microbials or other humidity related agents in indoor air or dust. In 5 studies out of 7 significant associations were found between inspectors reports of "dampness" and health effects. In 3 out of 4 studies a significant association was found between RH and self reported health effects. Examples are:

Smedje et al. (1997) used a questionnaire to study symptoms in 762 pupils aged 13–14 years from 11 randomly selected schools in Uppsala, Sweden. Exposure at schools was investigated by measurements and inspections in 28 classrooms. More pupils had current asthma in schools that were larger, had lower temperature, higher relative humidity, higher concentrations of formaldehyde, and viable moulds or bacteria. However, they found no significant association between observed signs of "dampness" in the homes or in the schools and health effects.

Ten out of 12 studies found significant associations between self-reported health effects and indoor humidity related exposures. In six studies significant associations were found between concentrations of mould spores in indoor air and health effects (Björnsson et al., 1995; Huang and Kimbrough, 1997; Li et al., 1997b; Li et al., 1997d; Smedje et al., 1997; Waegemaekers et al. 1989). In two studies no such association was found (Strachan et al., 1990; Hyndman et al., 1990). In one study a non-sporing fungi (mycelia sterilia) was found in significantly higher concentrations in homes of wheezy children (Strachan et al., 1990). In two studies, the concentration of airborne bacteria showed an association with health effects (Björnsson et al., 1995; Smedje et al., 1997).

The reviewed studies show that occupants mostly report more "dampness" than inspectors, commonly explained as a result of the longer time perspective of the occupants, as opposed to the "snapshot" of the inspectors (Andrae et al., 1988; Nafstad et al., 1998; Verhoeff et al., 1995). Generally the associations are stronger between health effects and inspectors observations than to occupants reports (see e.g. Nafstad et al., 1998; Williamson et al., 1997). High relative humidity in indoor air has been reported as a risk factor for health effects in a few studies but the findings are inconclusive. Results from studies measuring airborne mould spores or bacteria are inconclusive.

IV. Studies on Objective Signs of "Dampness" and Clinical Examinations of Health Effects

Ten studies with "objective" information on "dampness" and clinical findings (signs and tests) are included in the review. In seven of these studies significant associations were found between "dampness" and health (Table 1). Examples are as follows:

A cohort of 3,754 children born in Oslo during 1992 and 1993 was followed for 2 years for assessing the role of "dampness" problems and house dust mite exposure for development of bronchial obstruction, (Nafstad et al., 1998). Bronchial obstruction was defined as two or more episodes with symptoms and signs of obstruction or one episode lasting more than one month. A matched case-control study was carried out for 251 cases with bronchial obstructions and 251 matched controls. Information on home "dampness", house dust mite exposure, was collected during a home visit by inspectors and by a questionnaire. In a conditional logistic regression analyses, adjusted for confounding factors, parent reported "dampness" at home was significantly associated to bronchial obstruction in early childhood (AOR 2.5 (CI: 1.1–5.5)). However, "dampness" confirmed by inspectors was an even stronger risk factor (AOR 3.8 (CI: 2.0–7.2)). The association between "dampness" problems and bronchial obstructions was still evident after excluding cases and controls living in homes with high concentrations of mites (>2 μg/g dust).

In a cross-sectional study on 778 children (7 years) in Edinburgh, the respiratory effects of indoor air temperature and humidity was studied, Strachan and Sanders (1989). A random sample of children was chosen and contacted in a postal questionnaire including questions on respiratory symptoms and conditions in their home. Lung function measurements (FEV1 after exercise) was made. Technical measurements of indoor air temperature and relative humidity was obtained from 330 homes. Self-reported "dampness" was associated to wheeze, day cough, night cough and chesty cold. No associations were found between indoor temperature and relative humidity and the symptoms. Furthermore, no correlation was found between bedroom temperature or relative humidity and lung function measurements.

A Dutch case-control study included 259 children (6–12 years) with chronic respiratory symptoms and 257 controls with no symptoms, all selected from a random sample of 7,632 children whose parents answered a questionnaire (Verhoeff et al., 1995). Inspectors, who were blind regarding the case and control status of the children, visited all homes. Furthermore, total IgE and specific IgE against dust mites and a mould mixture and pulmonary function were determined. Approximately 50% of the parents of both cases and controls reported "dampness" or mould in their homes during the previous two years and a similar prevalence were reported by the inspectors. However, a significant association was found between chronic cough and self reported dampness, but there was no association with observed dampness by inspectors. Similar ORs were found in cases sensitised to mite or moulds compared to non-sensitised cases and sensitised and non-sensitised controls respectively. The authors interpret their results as indicating that the association between dampness and respiratory symptoms partly depends on sensitisation to mite/moulds. However, the results could also be interpreted as indicating that there is a difference between observed and reported dampness in that study.

One hundred and two patients with a physician diagnosed asthma (5–44 years) and 196 age- and sex-matched controls were investigated regarding "dampness" and asthma, (Williamson et al., 1997). All subjects completed an interview including questions on housing conditions and respiratory symptoms. The presence and severity of visible mould growth was graded subjectively on a four-point scale. An electronic resistance type moisture meter was used to obtain measurements of "dampness" on walls and "dampness" scores were calculated. An asthma severity score was calculated for each patient based on severity of asthma symptoms, medication, and FEV1. Inspectors surveyed 75% of the homes. Cases were more likely to live in a dwelling with observed "dampness" than controls. There were significant trends for the prevalence of both self-reported and observed measures of "dampness" with increasing severity of asthma. Furthermore, there was a significantly negative correlation between the total "dampness" score for the dwelling and lung function measurements. These associations remained significant after controlling for confounding factors. Patients living in homes in which the inspectors had observed "dampness" had a lower FEV1 and FVC than patients living in dry dwellings.

There are findings from several studies on associations between objective measurements of "dampness", mainly observed by inspectors, and clinical examinations. As in the studies of group II there are stronger associations between physician diagnosed health effects (e.g. asthma) and "dampness" than for pulmonary function tests. One study reports an association between S-ECP and concentration of airborne moulds and bacteria (Björnsson et al., 1995). Another study indicated a dose-response relationship between "dampness" and asthma severity (Williamson et al., 1997). In conclusion, most (7 of 10) of the studies with independent registration of health effects and "dampness" show an association and are thus in accordance with studies presented under I–III above.

Discussion

Which Health Effects are Associated with "Damp" Buildings?

The reviewed studies (including more than 100,000 humans) show, with few exceptions, that "dampness" in buildings are associated with respiratory symptoms such as cough and wheeze, and in lower degree to asthma. Relative risks are similar for infants, children and adults, in homes and at institutions such as schools and day-care centres, in the range of 1.4–2.2. Relative risks are in the same range regardless of the outdoor climate with reported and/or observed "dampness" problem prevalence ranging from 4–75%. Some studies also indicate an association between "dampness" in buildings and general symptoms such as tiredness and headache and symptoms of upper airway infections.

Are the Associations Between "Dampness" and Health due to Bias?

In most studies, validated, standard questionnaires on e.g. asthma are used. Usually it is asked for doctor diagnosed asthma. In three studies the validity of health and "dampness" reports have been reported. Platt et al. (1989) found a Kappa value of 26% for reports of "dampness" between experts and patients, while Dales et al. (1994) found of 73–82 % and Verhoeff et al. (1995) 43–70 %. For symptoms the Kappa values for repeatability were 60–96% and 73–82% respectively in two studies (Brunekreef et al., 1992; Dales et al., 1994). Most of the case control studies have used doctor diagnosed illness (mostly asthma) as the criterion for cases.

The reported association between "dampness" and health may be due to casual links or as a result of selection and information bias and/or as a result of confounding. Several authors have discussed such possibilities.

Selection bias occurs when there is a systematic difference between the characteristics of the humans included in the study and the characteristics of those who are not in the study. In most of the reviewed cross-sectional studies there have been rather high response rates typically in the range of 75–98% and non-response analysis have shown small differences between people in the study and people not participated.

Information bias occurs when the individual measurements or classifications of disease or exposure are incorrect. Recall bias has been discussed by many authors. The study group may be aware that there is a concern that "dampness" may cause health problems. Respondents with symptoms or symptomatic children might, thus, be more prone to observe, remember and report evidence of "dampness". The remedy is objective inspections and measurements of "dampness", which has been done in several studies. Generally inspectors report less "dampness" than respondents but the concordance is generally good. The association between "dampness" and health effects is generally higher for inspector reports of "dampness". Associations are generally weaker for measures of "dampness" such as relative humidity, mould spores etc.

Likewise, if "dampness" is present in a respondent's home he or she might be more inclined to observe, remember and report symptoms associated with "dampness". The remedy is objective evaluation of signs and tests, such as lung function changes, or, if possible symptoms. Generally associations between clinically observed symptoms and "dampness" are the same as for self-reported symptoms. The association between clinical tests, such as PEF, eosinophil counts etc and "dampness" are rather weak, but in total they are supportive of such an association. Some authors note that the associations were observed already in the late 1980s – at a time when the general public probably was not aware of a possible association between "dampness" and health. Thus, it is improbable that recall bias is a major explanation for the associations between "dampness" and health effects.

Another possible information bias could be named "criteria bias". Definitions of "dampness" used by most authors require a somewhat arbitrary choice between presence and absence of "dampness". In reality "dampness" is present or has been present in varying degrees in most homes, depending on how it is defined. Likewise, some symptoms such as cough may vary in intensity and over time, and there is an element of interpretation when responding to a question of the nature "do you usually cough". Some subjects may be more observant regarding present exposures and symptoms, and may better observe and remember previous exposures and symptoms than other respondents. If there is an association such that observant persons identify exposure and health symptoms with greater "sensitivity" than other less observant respondents do, the result is a false association between exposure and health. Such a bias would be independent of awareness of possible associations between exposure and effect.

Although, "criteria bias" is difficult to test, there are results that disprove that it can explain the associations. Dales et al. (1991b) reported a significant association between self reported current asthma and self reported "dampness" at home for 14,948 adults. A stratified analysis by responses to the question "Within the past year have you had any other major illnesses or accident" provided some evidence against criteria bias. Those who generally over-report are expected to respond positively more often to this question than those who under-report. When responses were stratified to control for reporting bias the observed association persisted. Further, the concordance in results (expressed as ORs) between questionnaire studies and studies involving clinical investigations and exposure measurements is not supportive of such an influence of "criteria bias". It seems very unlikely that OR in the order of 2 or greater could be caused by such a mechanism.

Confounding can occur when another exposure exists in the study population where such an exposure is associated both to the disease and the exposure being studied. In studies of Bengali residents in London (Hyndman, 1990) the authors interpreted some symptoms as stress-induced. In these studies absence of central heating was associated with "dampness", but probably also with other factors contributing to health problems. Thus, during winter months the temperature in the habitable area was only 15 °C and some rooms were then inhabitable. Living in single homes with flat roofs and/or cement slab on the ground is associated with "dampness" problems, and probably, at least in some areas, also with other life-style factors that may influence the health effects. However, the conspicuous agreement between studies performed in different parts of the world, with large differences in population characteristics suggest that confounding is probably not of sufficient importance to explain the general trend. Also, many authors have adjusted for socio-economic factors in the analysis with minimal changes in reported associations.

In epidemiological literature certain steps are conventionally involved in judging whether a shown association is a possible explanation for a true cause-effect relationship (e.g. Hill, 1965):

One criteria is *Temporal relation* (does the cause precede the effect). In most studies reports are on current exposure and current health effects. Such associations are generally positive. Associations between "early" exposure (in infancy) and current health effects are generally stronger. Thus the temporal relation is in favour of a true association. Another criterion is *Plausibility* (is the association consistent with other knowledge, mechanisms, and evidence from experimental animals). Besides allergy towards house dust mites, cockroaches, and mould there are no known mechanisms that can explain the observed associations. Such known mechanisms may explain some of the associations but not all. *Consistency* (have similar results been shown in other studies). The association is consistent between regions, age categories, and building types in a large number of studies. *Strength* (what is the strength of the association (relative risk)). Generally the reported OR is between 1.4 and 2.2. In a single study such an association would not be considered strong, but when reported in a large number of studies it indicates a strong association, especially as both the health effects and the exposure are vague and differently defined. *Dose-response relationship* (is increased exposure associated with increased effect). Most studies have reported on exposure of "dampness" as present or not. A few studies have, however, reported dose-response relationships. Generally they report an increased risk of health effects with increased exposure. *Reversibility* (does the removal of a possible cause lead to reduction of disease risk). No reviewed study deals with this topic. *Study design* (is the evidence based on a strong study design). Most studies have a cross-sectional or case-control design. Especially cross-sectional studies are often more prone to bias than cohort studies.

In conclusion, the evidence for a true association between "dampness" and health effects is strong. Bias or confounding may have contributed to some, but not all of the reported associations.

Which Agents due to "Dampness" is Health Relevant

"Dampness" is sometimes associated with mite growth that induces mite sensitisation and allergic disease. Sensitisation to mites is far more common than sensitisation to moulds and most subjects sensitised to moulds are also sensitised to mites or other allergen. Some authors attribute the association between "dampness" and health to allergy to mites. On the other hand, the association between "dampness" at home and bronchial obstruction in children was still evident (AOR 3.4) after excluding subjects with positive mite findings in their homes, (Nafstad et al., 1998). However, the used cut point for mites in that study may have been too high (*Der p* 1>2 μg/g dust). Furthermore, associations between "dampness" and health is also found in areas with little mite exposure, e.g. in northern Scandinavia with a dry indoor climate during winter-time. Several studies have showed that the prevalence of positive skin prick test to mites in these regions are less than 5 %, (Lindfors et al., 1995; Norrman et al., 1994) and less than 1% (Rönmark et al., 1998). Nafstad et al. (1998) found mite allergen (*Der p* 1>2 μg/m^3) in children's bed in 4.5% of 251 cases and in 1.2% of 251 controls. In countries with a more humid indoor climate the prevalence of sensitisation to mites is higher. Verhoeff et al. (1995) showed that the prevalence of sensitisation to mites among children aged 6–12 years was 12.3% among 257 controls and 37.8% among 259 cases. Furthermore, the association between allergies or asthma and "dampness" or mould were present whether or not the analyses were stratified by physician-diagnosed asthma or allergies to any mould, dust, pollen or animals in a cross-sectional study on 14,948 adults, (Dales et al., 1991b).

Other agents – than mite allergens – that in some studies have been shown to increase the risk for symptoms and signs are airborne moulds and bacteria. However, the literature is not consistent on this point. So, in conclusion it is not known which humidity-related agents in indoor air that is causing the health effects.

Is there a Health Relevant Definition of a "Damp" Building?

The conception of "dampness" includes both humidity in indoor air and moisture in the construction of which both have been associated with health problems. There is data indicating that different parts of the world, at least partly, have different kinds of "dampness" problems. In e.g. Scandinavia visible mould and condensation on walls seems to be rather rare while humidity in the construction with indications such as bad odour seems to be more frequent. In more humid climates as in e.g. Taiwan the frequency of e.g. visible mould and condensation on walls are much higher. However, the reported risks for health effects are in the same range regardless of the prevalence of such "dampness" indicators. In conclusion, it is not possible to give a more precise health relevant definition of a "damp" building.

Future Research

Although a consistent association between "dampness" in buildings and health effects has been found, little knowledge exists on mechanisms behind the association. To gain more information about mechanisms future research should test new hypothesis such as effects of specific chemical and, microbial agents. Furthermore, there are almost no studies of interventions against dampness.

Conclusions

Living or working in buildings that are "damp" appears to increase the risk for a number of health effects mainly respiratory symptoms (cough, wheeze and asthma), but also other health effects such as unspecific symptoms like tiredness and headaches. The review group concludes that the evidence for a true association between "dampness" and health effects is strong. However, it is not known which agents in indoor air due to "dampness" that causes the health effects. Sensitisation to mite allergen may explain some but probably not all associations. It is not possible to give a health relevant definition of a "damp" building.

The limited knowledge about the mechanisms behind the association between "dampness" and health effects is no excuse for not intervening about "dampness" problems in buildings. It is quite obvious that there is strong suspicion that "dampness" causes health effects and there is no indication that living in a damp building improves health. Thus, even if it is a great challenge to science to explain the associations, the practical advice is – "avoid dampness in buildings".

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