REVIEW ARTICLE

DAMPNESS AND MOLD EXPOSURE IN BUILDINGS AS A RISK FACTOR FOR HEALTH EFFECTS

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ABSTRACT

This study aims to review existing studies on the relations between indoor dampness and mould in different public occupied buildings with the risk of adverse health effects among both children and adults. This study specifically focused on the dampness-related problems from countries with tropical climate. A systematic literature search of ScienceDirect, PubMed, Google Scholar and Wiley Online Library from 2000 through December 2015 was conducted. Furthermore, the reference lists of recent reviews and of relevant articles were identified in our search. Cross-sectional, case-control, and cohort studies in children or adults were selected according to a priori criteria. The search yielded a total of 18 studies on damp buildings, dampness and mould in buildings and indoor mould. Dampness and mould exposure in buildings is a risk factors for respiratory symptoms, wheeze, cough, bronchitis, rhinitis, eczema and upper respiratory tract infection as well as general symptoms such as headache and tiredness. Evident strongly suggested increased asthma development and exacerbation of current or ever diagnosis of asthma in children. Based on the results of the review, indoor dampness and mould problems in buildings are associated with substantial and increases in prevalence of a variety of respiratory and asthma-related health outcomes.

***Keywords**: Indoor dampness; mold contamination; health; review*

INTRODUCTION

A considerable proportion of the world's population is exposed to indoor dampness-related exposures. Dampness in buildings which includes history of water damage, leakage, wet spots, visible mold, mold odor is a common problem in many countries. In a cold climate the prevalence of water damage and dampness exposures has been estimated to be 5% to 30%, whereas in moderate and warm climates it has been estimated to be 10% to 60% [1-3]. Dampness in buildings is believed to some extent associated with climatic factors. In the subarctic climate, building structure should be dry since the heating season is long, buildings are well-insulated, and indoor humidity is low during the cold period. However, moisture problems occur even in these conditions[3]. The damp and mold problem may have their own special features, due to the airtightness of the houses and the long hours spent indoors during cold weather. In tropical Singapore, the climate is hot and humid with little variation, while rainfall is throughout the year. Indoor mold has been reported to grow with ease on building material surfaces. Humidity of indoor air and building materials create suitable conditions for the growth of bacteria, fungi and even virus [5-6]. Biodeterioration and discolouration of painted walls, wallspapers, ceiling boards and glass panels by moulds inside buildings in Singapore constitute a major problem.

Since the 1990s, there is a constant interest and rapidly growing body of scientific literature examining the relationship between dampness and mold in buildings and associated health effects. Reviews by expert groups in Europe [6-7] and the United States[8] concluded that:

- There is sufficient scientific evidence to support that there is an association between dampness and mold in buildings and an increased risk of adverse health effects for the building occupants. Epidemiologic studies were conducted in countries including the temperate, cold, artic, and subtropical climates.
- The most common health effects is associated with the respiratory system, although a much broader array of health outcomes has been reported such as Sick Building Syndrome (SBS), dermal and eyes symptoms.

A review by World Health Organization (WHO) further expanded the scope of studies and documented associations to include asthma development, new-onset asthma, dyspnea, and respiratory infections. Mudarri and Fisk (2007) assessed public health risk and economic impact of dampness and mold exposure using current asthma as a health endpoint. Of the 21.8 million people reported to have asthma in the USA, approximately 4.6 million cases are estimated to be attributable to dampness and mold exposure in the home. The national annual cost of asthma is estimated to be $3.5 billion. While in the tropics, there is less information available on the association of dampness and indoor mold with health effects despite the year-round exposure to these conditions. The aim of this review is to reevaluate how high indoor dampness and mold exposure may impact the health of both adults and children. Another aim is to include experience and questions from other parts of Europe such as region with warm and humid climate.

METHODS

The search for published articles involved several strategies: online searched on electronic databases namely PubMed and ScienceDirect, an online search of the journal Indoor Air. Three groups of keywords were used during the search such as:

Exposures: "Dampness in buildings, humidity, mold".

Health effects: "Respiratory symptoms, respiratory infection, hypersensitivity, asthma, allergy, Sick Building Syndrome (SBS)".

Environments: "Indoor environment, public building, residential, houses, offices, domestic, school, buildings".

The search strategy is summarized in **Figure 1.** We also identified additional publications from reference list. Inclusion criteria for a primary study are as follows:

- Publication in a peer-reviewed journal from 2000 through December 2015
- Original research article with either one of the study designs: intervention, prospective, retrospective, longitudinal, or cross sectional
- No minimum study size, but if exposure was characterized only at building level, inclusion of > 10 buildings
- Including risk factors related to dampness or microbiologic organisms/components, but not other allergens (dust mites, cockroaches, pets)
- Providing adequate control, in study design or analysis, and confounding from key variables: sex, smoking and socio economic status.
- Only human studies included either children and/or adults

RESULTS

The literature search identified 603 articles. 520 articles were excluded as they were reviews, case studies, studies on mites or because they did not present data on both exposure and health effects or an analysis on associations between exposure and health. Subsequently, 83 articles were retrieved for further assessment. Later, 69 articles were excluded in the review work as they were judged as "non-informative' or "inconclusive". Non informative articles shows a lack of essential information regarding exposure or health effects or that analysis did not consider controlling confounding factors. Articles which is inconclusive indicates that data processing or reporting cannot provide conclusions concerning the relationship between dampness and related exposure health effects. An additional 4 articles were identified based on reference lists of the relevant articles. Consequently, 18 studies have been the foundation of this review.

In the following, reviewed studies have been divided into one or more of 3 categories depending on different kinds of data on dampness and health effects. Dampness have been characterized by questionnaires, inspections by professional staff, humidity measurements and/or by humidity related exposure indoors. Health effects have been investigated by questionnaires, and/or by clinical examinations.

DISCUSSION

The review provides evidence that dampness and mold exposure in buildings is a risk factor for various health effects among building occupants, both in commercial and residential environments. Several "dampness" indicators have been used in the reviewed articles, e.g. "visible mold", "damp stains", "condensation on window panes and/or walls", "water damage", "smell/odor", indicating different sources of dampness and problem in the buildings. "Visible mold" and "condensation" are indications of a high indoor relative humidity in combination with cold surfaces. "Damp stains and spots", "damp water damage" and "bad smell and odour" are frequently due to moisture in the construction. The prevalence of "dampness" indicators shows a wide variation. These dampness indicators are mostly self-reported in the studies and very few actual exposure measurements. The lack of objective measurement and exposure specificity in these studies limit the possibilities to identify the causative agents associated with respiratory diseases.

The review studies show that dampness in buildings is associated with atopics and non-atopics health effects. The most common self-reported and observed health effects are respiratory symptoms such as wheeze, cough, rhinitis, development and exacerbation of asthma in children and eczema. Some studies also show an association between dampness in buildings and SBS symptoms such as headache and tiredness. Such results were also seen in reviews by Bornehag et al. [6-7] The risk is increased for both children and adults, however, trend of the studies still focused more on children. Furthermore, the main part of the studies had a cross-sectional design, and very few prospective studies were identified.

Dampness and mold in buildings has been a concern in European countries since 1980. Estimates of the prevalence of dampness and mold problems in buildings are accessible from various sources and include the following: at least 20% in European countries, the U.S. and Canada [8];

14-40% in Europe, Russia, and North America [10]; and 50% in the U.S.[9]. There have been extensive studies on the associations of buildings dampness and moulds exposure and related health effects on children and adults conducted in European countries such as Finland and Sweden.

In recent years, China has paid more attention to the children's health associated with exposures at homes. This is due to the alarming increased prevalence of asthma and allergies in China over the past 10 years [11-13]. The China, Children, Homes, Health (CCHH) project studied associations between home environment and asthma and allergies in 10 cities in China. In China, home dampness has been found to be positively associated with childhood asthma and allergy, wheezing, rhinitis, eczema and dry cough [14-16]. Residents in some regions of China with subtropical monsoon climate probably experience more moisture-related problem than other regions of China. However, because of the outdoor weather is always wet, the residents have little awareness about associations between home dampness and childhood airway diseases. In Sweden, such awareness is high due to a nationwide campaign addressing allergy and risk factors[17], and in U.S., awareness is high due to media interest in "mold" as well as many lawsuits[18].

As for Malaysia, indoor air quality is getting more concern as the rapid urban environment changed due to modernization and mushrooming of high rise buildings. Several studies have been carried out to study relationship between indoor air quality and Sick Building Syndrome among office workers in different types of buildings such as libraries[19], old and new buildings[20], and comfort in pharmaceutical laboratories[21]. These studies reveals that ventilation, temperature, humidity, Total Volatile Organic Compound (TVOC) and bacteria are some important indoor air factors that can influence the prevalence of SBS. However, until now, there is limited studies in Malaysia regarding the associations of dampness and mold problem in buildings and related health effects.

As the neighbouring country of Singapore, Malaysia is situated near the equator of earth where the weather is hot and humid. The high moisture level and proper temperature in an indoor environment and adequate nutrient provided by paper dust and dead skin support the infestation of mould. Even air-conditioning which lowers the indoor humidity to 70% or less may still encourage mould growth, especially where the air-conditioning is intermittent or switched off after working hours. Water leakage is also one of the factors contributing to the mould contamination. If the contamination remains unaddressed, the whole building operation and functionality will be affected due to the widespread of spores indoor. One of the cases is the two months old newly open Hospital Sultan Ismail in 2004 is infested with deadly fungus and forced to shut down. The areas of the extensive visible mold growth (Aspergillus fumigatus) were widespread in the entire hospital 10 storey building. The remediation process took four months to complete. This incident is a reminder for building managers and construction management in Malaysia to take control and preventive measures to avoid development of a microbial reservoir in a building as prevention is better than cure.

CONCLUSION

This review clearly indicates that dampness and mold in buildings are associated with various respiratory symptoms and infections as well as onset of asthma. These associations are statistically significant in nearly all cases. There is strong suspicion that mold as the causal agents. The results of these review provide evidence and support for recommendations and guidelines to prevent indoor dampness and mold problems in buildings, and to take serious corrective actions where such problems occur.

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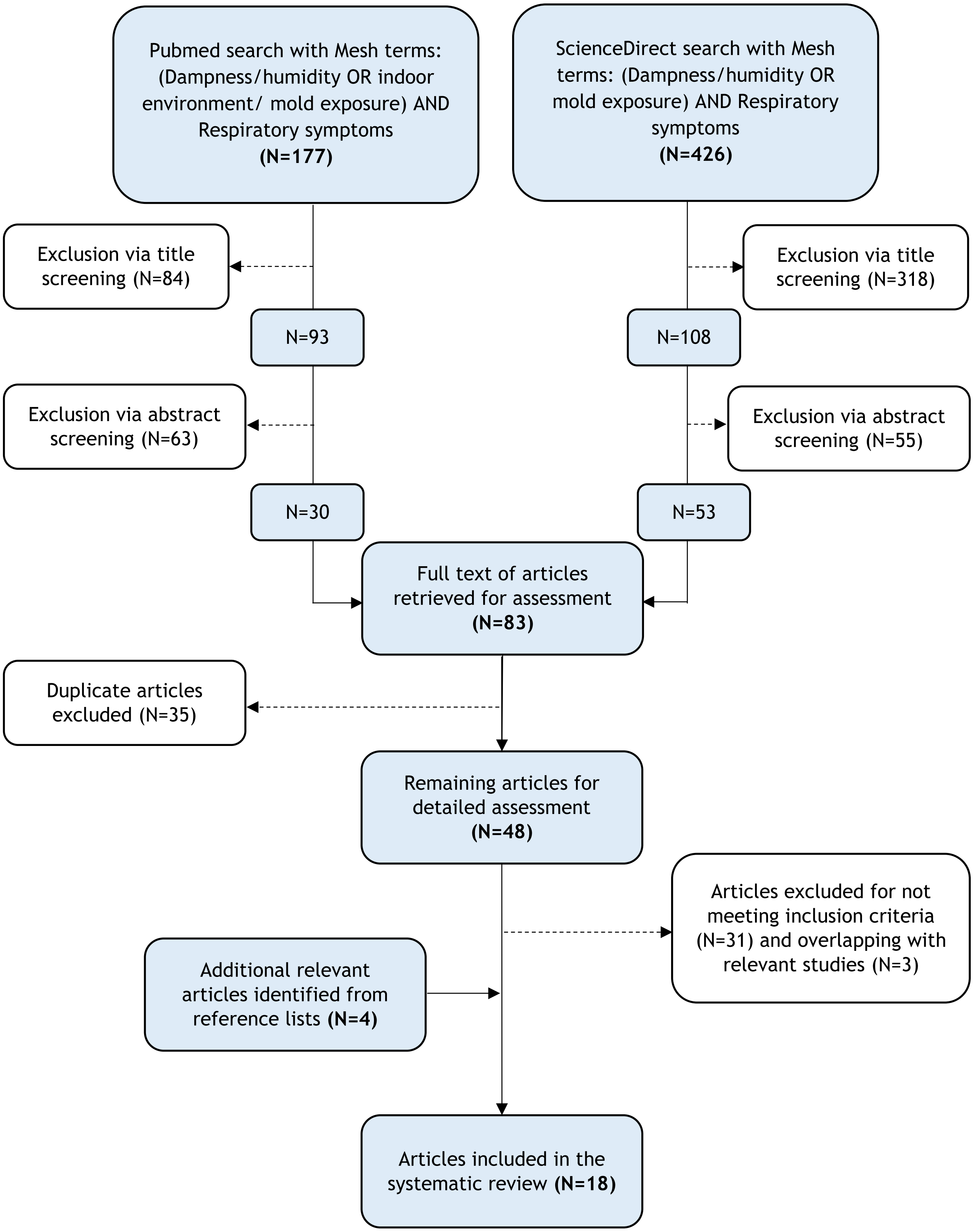

Figure 1. Flow diagram showing searches and study selection

Table 1 Studies on associations between self-reported dampness and self-reported symptoms

Author	Country/year of the study	Study design (CS/CC/ intervention / longitudinal)	No. of humans (adult/children)	Exposures (self-reported/inspections/ exposure measurements)	Health effects (self-reported/clinical examination)	Risk factors
Sun et al. (2015)	China/ 2013	CS	7570 Ch (0-8 years)	SR (Visible mould/mildew; Damp stains; Suspected moisture problem; Water leakage; Condensation on the inner windowpane in winter)	SR (Wheeze; Rhinitis; Eczema; Diagnosed asthma; Diagnosed rhinitis; Diagnosed eczema)	Visible damp, suspected dampness, water leakage, condensation on window pane and dry air perception had significant effects on children wheezing, rhinitis, eczema and diagnosed asthma with AOR 2.73, 95% CI 1.75-4.26, AOR 1.81, 95% CI 1.13-2.90, AOR 2.40, 95% CI 1.47-3.90, AOR 3.29, 95% CI 1.75-6.19 respectively.
Cai et al. (2015)	China/ 2012	CS	13,335 Ch (4-6 years)	SR (Visible mold spots; Visible damp stains; Damp clothing and/or bedding; Water damage; Condensation on window in winter; Mouldy odour)	SR (Eczema)	The more the total number of home dampness-related indicators, the higher the prevalence of eczema. The dose-response relationships were significant and strong, especially associations between the total number of home dampness-related indicators in the current residence and eczema (AOR 2.57, 95% CI 1.40-4.69).
Wang et al. (2015)	China/ 2011	CS	2917 Ch (3-6 years)	SR (Perinatal visible mould/damp stains; Perinatal condensation on windows; Perinatal mouldy odour; Current visible mould/damp	SR (Wheezing; Cough at night; Rhinitis; Eczema; Doctor-diagnosed asthma; Doctor-diagnosed rhinitis)	Risk of respiratory and allergic symptoms including wheezing (AOR 1.84, 95% CI 1.34-2.52), cough at night (AOR 1.54, 95% CI 1.10-2.14), rhinitis (AOR 1.40, 95% CI 1.06-1.85) and eczema (AOR 1.67, 95% CI

				stains; Current condensation on windows; Current mouldy odour)		1.28-2.19) is significantly increased with perinatal exposure to most dampness indicators.
Hu et al. (2014)	China / 2011-2012	CS	13,335 Ch (4-6 years)	SR (Visible mould; Damp stains; Water damage; Damp clothing/bedding; Mouldy odour; Condensation on the inner windowpane in winter)	SR (Asthma; Dry cough; Wheeze; Rhinitis; Hay fever)	In the current residence, children with visible mold spots (VMS) exposure had 32% higher risk of asthma (AOR 1.32, 95% CI 1.07-1.64); damp clothing and/or bedding was strongly associated with dry cough (AOR 1.78, 95% CI 1.37-2.30); condensation on windows was strongly associated with hay fever (AOR 1.60, 95% CI 1.27-2.01).
Weinmayr et al. (2013)	20 countries/2004	CS	46051 Ch (8-12 years)	SR (Damp spot at present/first year of life; Moulds at present/first year of life; Damp/ moulds at present; Damp/ moulds in the first year of life)	SR (Asthma; Rhinitis; Eczema; Bronchial hyperresponsiveness; Rhinoconjunctivitis; Coughed up phlegm without a cold; Coughed up phlegm frequently)	Current exposure to dampness was more common for wheezy children (OR 1.58, 95% CI 1.40-1.79), coughing up phlegm without a cold (OR 1.9; 95% CI 1.59-2.26), rhinitis (OR 1.51; 95% CI 1.37–1.66), rhinoconjunctivitis (OR 1.61; 95% CI 1.42–1.83), and reported eczema (OR 1.52; 95% CI 1.34–1.73).
Sun et al. (2009)	China/ 2006	CS	3436 A in dorm rooms	SR (Mould/damp spots on walls, ceilings and floors; Suspected or ever happened water damage; Condensation on windowpane in winter; Perceived odours)	SR (Wheezing; Dry cough during night; Rhinitis; Eczema; Cold/flu; Ear inflammation; Pneumonia; Tuberculosis)	There was a significant positive association between condensation and dry cough (AOR 1.64, 95% CI 1.06-2.54). Eczema was often reported in rooms with moisture problem (AOR 1.48, 95% CI 1.07-2.05).
Saijo et al. (2009)	Japan/ 2006	CS	480 A in homes	SR (Condensation on the windowpanes; Condensation	SR (Eye symptoms; nose symptoms; skin	As the number of the dampness indices increased the ORs for each SBS symptoms increased.

				on the walls and/or closets; Visible mould in the bathrooms; Visible mould on the walls, window frames, and/or closet; Moldy odour; Slow drying of the wet towels in bathrooms; Water leakage; Bad drainage in bathroom)	symptoms; throat symptoms; and general symptoms)	Eight positive dampness indicators had significant high OR in the range 16.6-57.5 for all SBS symptoms.
Han et al. (2009)	Taiwan/ 2004	CS	1725 Ch with asthma, 19646 Ch controls (6-15 years)	SR (Cockroaches; Water damage; Visible mold on the walls; Incense burning; Dehumidifier use; Carpet use; Pet ownership; Passive smoking)	SR (Perennial asthma; Winter asthma; Spring asthma; Summer/fall asthma)	Water damage was significantly associated with all subtypes of asthma. Visible mold on the walls was associated with an increased occurrence of winter and spring asthma (AOR 1.53, 95% CI 1.26-1.85) and AOR 1.34, 95% CI 1.10-1.62, respectively).
Gunnbjörnsdóttir et al. (2006)	Iceland, Norway,Sweden, Denmark, and Estonia/ 1999-2001	CS, FU	16190 A in homes	SR (Water damage on walls, floor or ceilings; Wet floors; Visible moulds)	SR (Wheeze; Nocturnal breathlessness; Nocturnal cough; Productive cough; Asthma)	Indoor dampness was significant risk factor for wheeze (AOR 1.38, 95% CI 1.24-1.53), nocturnal breathlessness (AOR 1.80, 95% CI 1.51-2.15), nocturnal cough (AOR 1.40, 95% CI 1.28-1.54), productive cough (AOR 1.27, 95% CI 1.20-1.50).
Bornehag et al. (2005)	Sweden/ 2000	CS	10851 Ch (1-6 years)	SR (Water leakage; Floor moisture; Visible dampness; Condensation on window)	SR (Wheezing; Cough at night; Doctor-diagnosed asthma; Doctor-diagnosed rhinitis; Eczema)	Reports of visible mould and/or damp spots indoors had the strongest association to symptoms such as wheezing (OR 1.53, 95% CI 1.08-2.18), cough at night (OR 2.50, 95% CI 1.63-3.82) and rhinitis (OR 2.70, 95% CI 1.36-5.35).

Simoni et al. (2005)	Italy/ 2002	CS	20,016 Ch (7 years) & 13,266 adolescents (13 years)	SR (Current mould/dampness exposure; Early exposure; Both)	SR (Wheeze; Asthma; Rhinoconjunctivitis; Eczema' Persistent cough)	Asthma was more strongly related to only early than to only current exposure, both in children (AOR 1.80, 95% CI 1.41-2.30) and adolescents (AOR 1.89, 95% CI 1.38-2.59).
Engvall et al. (2001)	Sweden/ 1991/93	CS	14235 A in homes	SR (Condensation on windows; High air humidity in bathroom; Mouldy odour in dwelling; History of water leakage)	SR (Eye irritation; Nasal symptoms; Throat symptoms; Cough; Facial skin irritation; Headache; Tiredness)	In dwellings with all four dampness indicators, very high AOR for ocular (6.5, 95% CI 5.61-7.61), nasal (7.1, 95% CI 6.20-8.17), throat (19.9, 95% CI 17.05-23.24), cough (5.8, 95% CI 4.95-6.85), dermal irritation (6.1, 95% CI 5.22-7.12), headache (9.36, 95% CI 8.13-10.78) and tiredness (15, 95% CI 12.44-17.98).

Abbreviations and Notes: *CS = cross-sectional, CC = case-control, FU = follow-up, A = adults, Ch = children, SR = self-reported, I = inspections, EM = exposure measurements, CE = clinical examination, OR = odd ratio, AOR = adjusted odd ratio.*

Table 2 Studies on associations between self-reported dampness and clinical findings including physician diagnose

Author	Country/year of the study	Study design (CS/CC/ intervention / longitudinal)	No. of humans (adult/children)	Exposures (self-reported/inspections/ exposure measurements)	Health effects (self-reported/clinical examination)	Risk factors
Zhang et al. (2012)	Sweden/ 1992-2002	FU 10 years	429 A	SR (Water leakage; Sign of floor dampness; Visible moulds; Mouldy odour; Any type of building dampness)	SR (Dermal symptoms; Mucosal symptoms; Headache; Nausea; Tiredness; Cold), CE (Forced vital capacity; Forced expiratory volume in 1s; Bronchial responsiveness	Dampness in the floor construction in any workplace building was associated with incidence of mucosal symptoms (OR 2.43, 95% CI 1.05-5.64).
Hagmolen et al. (2007)	Netherlands/ 2001	CO	526 Ch with asthma	SR (Damp stains/mould growth)	CE (Asthma symptoms; Peak expiratory flow variability; Forced expiratory volume in 1s; Inhaled corticosteroid prescribed)	Children exposed to indoor molds and dampness more often had severe airway hyperresponsiveness (AHR) compared with non-exposed (AOR 3.95, 95% CI 1.82-8.57).
Jaakkola et al. (2002)	Finland/ 1997-2000	CC	521 A with asthma, 932 A controls	SR (Water damage; Damp stains; Visible mould; Mould odour) both at home and work	CE (Forced vital capacity; Forced expiratory volume in 1s; Peak expiratory flow)	Increased risk of new asthma in adults was related to the presence of visible mold and/or mold odor in the workplace (AOR 1.54, 95% CI 1.01-2.32).
Kilpelainen et al. (2001)	Finland/ 1996-1996	CS	10667 A	SR (Visible mould; Damp stain/ water damage)	CE (Diagnosed asthma; Allergic rhinitis; Allergic	Strongest association was found between exposure to visible mould and asthma (AOR

					conjunctivitis; Atopic dermatitis; Common colds; Bacterial respiratory infections)	2.21, 95% CI 1.48-3.28) and common colds (AOR 1.49, 95% CI 1.18-1.87).

Abbreviations and Notes: *CS = cross-sectional, CC = case-control, CO = cohort, FU = follow-up, A = adults, Ch = children, SR = self-reported, I = inspections, EM = exposure measurements, CE = clinical examination, OR = odd ratio, AOR = adjusted odd ratio.*

Table 3 Studies on associations between observed dampness including exposure measurements and self-reported health effects

Author	Country/year of the sudy	Study design (CS/CC/ intervention / longitudinal)	No. of humans (adult/children)	Exposures (self-reported/inspections/ exposure measurements)	Health effects (self-reported/clinical examination)	Risk factors
Jones et al. (2011)	United States/2005	CC	50 Ch with asthma, 49 Ch controls (3-17 years)	EM (Total counts and viable counts of airborne fungal; Humidity levels; Dry bulb temperature)	SR (A history of hay fever; Eczema/ sinusitis; Allergies; Medication use and asthma symptoms)	Among children who lacked a family history of asthma, asthma cases had significantly higher exposures to viable *Aspergillus* than controls (AOR: 6.11, 90% CI: 1.37–27.19). Total spore count means for *Cladosporium*, ascospores, basidiospores and *Penicillium/Aspergillus* were significantly higher in the homes with ≥50 RH (ranged from 197 to 999 spores/m3).
Reinikainen and Jaakkola (2003)	Finland/ 1989	CS	368 A in offices	EM (Absolute humidity; Relative humidity; Temperature; Humidification)	SR (Skin dryness; Skin rash; Eye dryness; Pharyngeal dryness; Nasal dryness; Nasal congestion; Nasal excretion; Sneezing; Odour; Stuffiness)	In humidified conditions (temperature 19-26°C, relative humidity 27-41%), statistically significant increase was found between odour (OR 1.24, 95% CI 1.13-1.36) and sneezing (OR 1.13, 95% CI 1.00-1.28).

***Abbreviations and Notes**: CS = cross-sectional, CC = case-control, FU = follow-up, A = adults, Ch = children, SR = self-reported, I = inspections, EM = exposure measurements, CE = clinical examination, OR = odd ratio, AOR = adjusted odd ratio.*