



# Dampness and mold at home and at work and onset of insomnia symptoms, snoring and excessive daytime sleepiness

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## ABSTRACT

**Aim:** To investigate whether exposure to dampness and mold at home and at work induce sleep disturbances and daytime sleepiness among adults.

**Materials and methods:** Associations between onset of sleep disturbances and dampness, mold and mold odor at home and at work were investigated in a cohort of 11,318 adults from the population in Iceland, Norway, Sweden, Denmark and Estonia. The participants answered a questionnaire at baseline and 10 years later, with questions on sleep disturbances, including difficulty initiating sleep (DIS), difficulty maintaining sleep (DMS), early morning awakening (EMA), insomnia symptoms, snoring and excessive daytime sleepiness (EDS). Multiple logistic regression models were applied to estimate associations adjusting for potential confounders including gender, age, smoking habit at baseline, change of smoking habit from baseline to follow up, BMI at baseline, change of BMI from baseline to follow up, education level at follow up, allergic rhinitis at baseline, doctor diagnosed asthma at baseline and chronic bronchitis at baseline.

**Results:** Baseline floor dampness, visible mold and mold odor at home increased onset of DIS, DMS, EMA, insomnia symptoms and snoring during follow up (OR 1.29–1.87). Any sign of dampness at baseline increased onset of DIS (OR 1.28, 95%CI 1.06–1.55), DMS (OR 1.17, 95%CI 1.02–1.34) and insomnia symptoms (OR 1.18, 95%CI 1.03–1.36). Dampness at home during follow up increased onset of DIS, DMS, EMA, insomnia symptoms and EDS (OR 1.17–1.36). Dampness at work during follow up increased onset of DIS, EMA, insomnia symptoms and EDS (OR 1.16–1.34). Combined dampness at home and at work during follow up increased the risk of onset of DIS, DMS, EMA, insomnia symptoms and EDS (OR 1.29–1.74).

**Conclusions:** Dampness and mold at home and at work can increase the development of insomnia symptoms, snoring and EDS among adults.

## 1. Introduction

A good night sleep is critical for health and wellbeing. Insomnia is the most common sleep disorder. Most studies have focused on three forms of insomnia symptoms: difficulty initiating sleep, difficulty

maintaining sleep and early morning awakening (Buysse, 2013). One review concluded that about one third of the general population suffer from at least one insomnia symptom (Ohayon, 2002) and recent studies have reported that 6–16% of the population in European countries have been diagnosed with insomnia (Riemann et al., 2017). Obstructive sleep

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apnea (OSA), characterised by loud habitual snoring and breathing pauses during sleep, is a worldwide highly prevalent disease with arousals during sleep followed by excessive daytime sleepiness, impairment of neurocognitive function and reduced daytime performance (Marin-Oto et al., 2019; Gislason et al., 2016; Franklin and Lindberg, 2015). Previous studies indicate that women suffer more often from insomnia but men suffer more often from OSA (Ohayon, 2002; Franklin and Lindberg, 2015; Bartlett et al., 2008).

Sleep disorders can increase sick leave (Riemann et al., 2017; Theorell-Haglow et al., 2006) and reduce quality of life (Moreno-Vecino et al., 2017; Effati-Daryani et al., 2017). Sleep problems are more common among older individuals (Ohayon, 2002; Bartlett et al., 2008) and smokers (Franklin et al., 2004; Nakata et al., 2008; Morioka et al., 2018). Sleep disorders can increase the risk of getting a number of important diseases. Common chronic diseases like cardiovascular diseases, chronic obstructive lung diseases and diabetes were all associated with sleep disturbances including insomnia, snoring, daytime sleepiness or OSA (Riemann et al., 2017; Marin-Oto et al., 2019; Owens et al., 2017). Increased risk of cardio-metabolic diseases (Cappuccio and Miller, 2017; Hoyos et al., 2017) and cancer (Shi et al., 2020) were found among people with sleep disorders. Recent studies also reported sleep disorders in relation to neurological disorders, including cognitive impairment and dementia (Riemann et al., 2017; Wennberg et al., 2017). Moreover, individuals with rhinitis (Young et al., 1997) and obesity (Cai et al., 2018; Palm et al., 2015) have more sleep disorders such as insomnia, snoring or excessive daytime sleepiness. Weight gain can be a risk factor for development of insomnia (Cai et al., 2018; Palm et al., 2015), snoring (Cai et al., 2018) and daytime sleepiness (Palm et al., 2015).

Noise is the most commonly investigated environmental risk factor for impaired sleep quality. Studies from Norway, Finland and Canada have demonstrated negative impact of traffic noise on insomnia or sleep disturbances among adults (Evandt et al., 2017; Halonen et al., 2012; Perron et al., 2016). There are few studies on indoor environment and sleep disturbances. Studies from Japan found that environmental tobacco smoke was associated with insomnia symptoms and insufficient sleep among pregnant women (Ohida et al., 2007) and adolescents (Morioka et al., 2018). Studies from Netherlands, Denmark and China showed that insufficient building ventilation can impair sleep quality among adults (Mishra et al., 2018; Strom-Tejsten et al., 2016; Wei et al., 2017).

Dampness and mold at home is the most well documented indoor risk factor for respiratory illnesses (WHO, 2009). Several studies from Europe showed that residential dampness increased incidence of asthma and rhinitis among adults (Wang et al., 2019; Gunnbjornsdottir et al., 2006; Jaakkola et al., 2002). However, few studies exist on associations between dampness and mold and sleep disturbances. Two cross-sectional studies reported associations between living in damp buildings and insomnia/sleep problems in adults (Packer et al., 1994;

Janson et al., 2005).

There are less studies available on indoor environmental risk factors for adult snoring. Environmental tobacco smoke was found to be associated with snoring among adults in Northern Europe and Japan (Franklin et al., 2004; Ohida et al., 2007). One study from Turkey showed that exposure to biomass smoke was associated with snoring and observed apnea among adults (Ekici et al., 2008). We found no studies on dampness/mold and snoring. There are no previous longitudinal cohort studies on onset of insomnia or snoring among adults in relation to dampness and mold.

Our aim was to investigate whether indoor dampness, mold and mold odor at home and at work increases insomnia symptoms, snoring and excessive daytime sleepiness during a 10 year follow up in the Respiratory Health in Northern Europe (RHINE) study. A population based cohort of adults (Wang et al., 2019).

## 2. Materials and methods

### 2.1. Ethics statement

This study was conducted with the approval from the appropriate ethics board at each centre. All participants gave informed consent prior to participation.

## 3. Study design and target population

The RHINE II study is a postal questionnaire follow up of subjects from seven centres in five Nordic countries from the European Community Respiratory Health Survey stage I (ECRHS I) performed in 1989–1992. The seven centres include Reykjavik in Iceland, Bergen in Norway, Umeå, Uppsala and Gothenburg in Sweden, Aarhus in Denmark and Tartu in Estonia. In the ECRHS I study, 3000–4000 subjects (20–44 y) were randomly selected from each centre through national population registers. A postal questionnaire was then sent to those subjects.

In total, 21,659 subjects participated in ECRHS I (response rate 86%) (Johannessen et al., 2014). The participants in RHINE II received a postal follow up questionnaire in 1999–2000. The RHINE II questionnaire included questions on sleep disturbances, respiratory health and the indoor environment at home and at work. The RHINE II participants (n = 15,990) were invited to join a second follow up (RHINE III) in 2010–2012, with identical questions on sleep disturbances as in RHINE II. Totally 11,318 participated in RHINE II and RHINE III (response rate 71%) (Fig. 1). Participation was defined as answering at least one of five questions on sleep disturbances (DIS, DMS, EMA, insomnia symptoms, snoring and EDS, see detailed description below). RHINE II is defined in the present article as the baseline study and the RHINE III as the follow up.

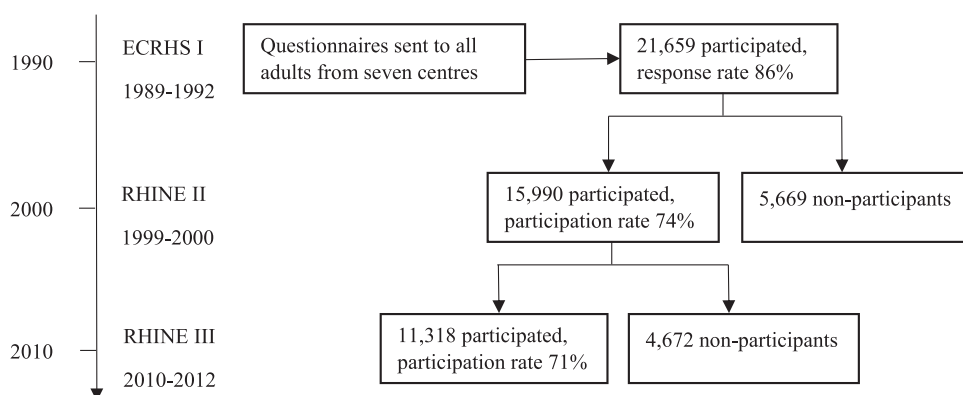


Fig. 1. The flow-chart of the study design.

### 3.1. Assessment of sleep disturbances

Sleep disturbances in the last months were estimated using a five-point scale according to the Basic Nordic Sleep Questionnaire (Partinen and Gislason, 1995): never, less than once a week, 1–2 nights/days per week, 3–5 nights/days per week, and almost nightly/daily. Difficulty initiating sleep (DIS) was defined as having trouble falling asleep in the evening at least three nights per week. Difficulty maintaining sleep (DMS) was defined as waking up several times during the night at least three nights per week. Early morning awakening (EMA) was defined as waking up early in the morning and being unable to go back to sleep at least three nights per week. Insomnia symptoms was defined as having at least one of DIS, DMS or EMA. Habitual snoring was defined as reporting loud and disturbing snoring at least three nights per week. Excessive daytime sleepiness (EDS) was defined as having problems with feeling drowsy or sleepy during the daytime at least three days per week. The questionnaire used at baseline and follow up had the same questions on sleep disturbances. Our well-established questions on sleep disturbances have been used in other international studies (Bengtsson et al., 2017; Mindus et al., 2018).

Onset of a particular symptom such as DIS, DMS, EMA, insomnia symptoms, snoring and EDS was defined as not reporting the particular symptom at baseline but reporting the particular symptom at follow up (Gunnbjornsdottir et al., 2006).

### 3.2. Assessment of indoor dampness, mold and mold odor

Four questions were asked at baseline about the following signs of dampness in the home environment in the last 12 months (Response options: Yes/No):

- (1) “Water leakage or water damage indoors on walls, floors or ceilings (‘water damage’)”;
- (2) “Bubbles or yellow discoloration on plastic floor covering or black discoloration of parquet floor (‘floor dampness’)”;
- (3) “Visible mold growth indoors on walls, floors or ceilings (‘visible mold’)”;
- (4) “Mold odor in one or several rooms other than the cellar (mold odor)”;

The variable “any dampness” was defined as answering yes on question (1), (2) or (3) above.

Two questions asked about home and workplace exposure to dampness during the follow up period (Response options: Yes/No):

- (1) “Any dampness damage, water leakage or visible mold at home during the past 10 years (‘dampness or mold at home during follow up’)”;
- (2) “Any dampness damage, water leakage or visible mold in the workplace building during the past 10 years (‘dampness or mold at work during follow up’)”.

Based on the two questions on home and work dampness or mold during follow up, a categorized variable with four alternatives was created: no dampness or mold, dampness or mold at home only, dampness or mold at work only, and dampness or mold both at home and at work.

### 3.3. Other independent variables

Information on gender, age, height, weight, asthma, rhinitis and chronic bronchitis were obtained from the baseline data. Body mass index (BMI) was calculated from self-reported height and weight (kg/m<sup>2</sup>) both at baseline and at follow up. Change of BMI from baseline to follow up was calculated. Education level (primary school/high school/university education) was only available at follow up. There were

information on smoking habits (never/ever smokers/current smokers) both at baseline and follow up. Change of smoking habit from baseline to follow up (no change/start smoking/stop smoking) was calculated.

Asthma was defined as a positive answer to both of these two questions: “Do you have or have you ever had asthma?” and “Have you ever had asthma diagnosed by a doctor?”. Allergic rhinitis was defined as a positive answer to the question: “Do you have any nasal allergies including hayfever?”. Chronic bronchitis was defined as positive answers to all three of the following questions: “Do you usually bring up phlegm or do you have phlegm in your airways which you have difficulty bringing up?”, “Do you bring up phlegm in this way almost daily at least three months every year?”, and “Have you had this kind of problem for at least two years in a row?”. Based on these questions, doctor diagnosed asthma, allergic rhinitis and chronic bronchitis at baseline and at follow up were created, respectively. Moreover, onset of doctor diagnosed asthma, onset of allergic rhinitis and onset of chronic bronchitis based on baseline and follow up data were created.

### 3.4. Statistical analysis

The analysis strategy in the present study including: firstly, investigating associations between dampness and mold exposure at baseline and onset of sleep disturbances; secondly, investigating associations between dampness or mold exposure during follow up collected retrospectively and onset of sleep disturbances.

We used Stata 15.1 (Stata Corporation, College Station, Texas, USA). Two level (centre, individual) logistic regression models were created to estimate associations between dampness indicators at baseline or during follow up and onset of sleep disturbances (DIS, DMS, EMA, insomnia symptoms, snoring and EDS), adjusting for gender, age, smoking habit at baseline, change of smoking habit from baseline to follow up, BMI at baseline, change of BMI from baseline to follow up, education level at follow up, doctor diagnosed asthma at baseline, allergic rhinitis at baseline and chronic bronchitis at baseline. Moreover, associations between combinations of dampness and mold at home and at work during follow up (categorized as none, at home, at work or both) and onset of sleep disturbances were estimated using similar logistic regression models. Similar logistic regression models were applied with extra adjustment of onset of doctor diagnosed asthma, onset of allergic rhinitis and onset of chronic bronchitis. In order to detect heterogeneity between centres on association between dampness and onset of insomnia, the adjusted OR was calculated separately in each centre. An average effects estimate was derived, and potential heterogeneity between centres was examined ( $p < 0.1$ ) using standard methods for random effects meta-analysis. Associations were expressed as odds ratios (OR) with a 95% confidence interval (CI).

## 4. Results

Totally 11,318 subjects who participated both at baseline and follow up were included. The mean follow up time was  $11.3 \pm 1.1$  years. Among the participants 54.3% were females, 26.1% current smokers and 26.4% were ex-smokers at baseline. Moreover, 7.9% had doctor diagnosed asthma, 23.5% had allergic rhinitis and 6.5% had chronic bronchitis at baseline. A total of 248 (2.4%) participants started smoking and 1248 (12.0%) participants stopped smoking during follow up. The mean age  $\pm$  SD of the participants was  $40 \pm 7.3$  years at baseline. Nonparticipants in RHINE III had slightly higher prevalence of all sleep disturbances except DMS in RHINE II as compared to participants (Table 1). However, the prevalences of dampness indicators at home at baseline (RHINE II) were similar among participants and nonparticipants in RHINE III (Table 1).

In total 2457 (29.2%) participants had new onset of insomnia symptoms. Among the three insomnia symptoms, onset of DMS was most common ( $n = 2210$ , 24.3%), followed by EMA ( $n = 1206$ , 11.8%), and the least common was DIS ( $n = 876$ , 8.4%). A total of

**Table 1**  
Sleeping disturbances and dampness indicators in RHINE II among participants and nonparticipants in RHINE III.

		Participants in RHINE III	Nonparticipants in RHINE III	p
Subjects n		n = 11,318	n = 4672	
Sleeping disturbances RHINE II	Difficulty initiating sleep (DIS)	6.9	10.1	< 0.001
	Difficulty maintaining sleep (DMS)	18.6	19.4	0.216
	Early morning awakening (EMA)	8.5	10.0	0.002
	Insomnia symptoms <sup>a</sup>	24.2	26.9	< 0.001
	Snoring	17.9	19.4	0.036
	Excessive daytime sleepiness (EDS)	21.4	23.0	0.022
Dampness RHINE II	Water damage	13.3	13.7	0.515
	Floor dampness	3.9	3.7	0.745
	Visible mold	6.7	6.8	0.696
	Mold odor	3.5	3.8	0.328
	Any dampness <sup>b</sup>	17.8	18.2	0.554

<sup>a</sup> Insomnia symptoms was defined as reporting at least one of the three symptoms including difficulty initiating sleep, difficulty maintaining sleep and early morning awakening.

<sup>b</sup> Any dampness was defined as water damage, floor dampness or visible mold in the last 12 months at baseline.

**Table 2**  
Onset over the study period of sleeping disturbances in different centres ordered by latitude (%) (n = 11,318).

		Reykjavik (%)	Umeå (%)	Bergen (%)	Uppsala (%)	Tartu (%)	Gothenburg (%)	Aarhus (%)	Total (%)
Onset	Difficulty initiating sleep (DIS)	10.4	8.5	9.7	7.9	8.1	9.8	5.4	8.4
	Difficulty maintaining sleep (DMS)	24.9	27.1	21.2	26.5	22.7	26.9	21.6	24.3
	Early morning awakening (EMA)	11.6	13.4	10.0	12.5	13.1	12.7	10.4	11.8
	Insomnia symptoms <sup>a</sup>	30.3	32.8	25.7	31.7	26.9	31.1	26.3	29.2
	Snoring	20.3	15.3	14.1	16.6	15.1	16.1	13.3	15.7
	Excessive daytime sleepiness (EDS)	16.1	13.9	14.8	13.8	10.7	12.9	13.4	13.8

<sup>a</sup> Insomnia symptoms was defined as reporting at least one of the three symptoms including difficulty initiating sleep, difficulty maintaining sleep and early morning awakening.

1359 (15.7%) participants had new onset of snoring and 1204 (13.8%) participants had new onset of EDS. Reykjavik had the highest onset rate for DIS, snoring and EDS, and Umeå had the highest onset rate for DMS, EMA and insomnia symptoms (Table 2, centres were ordered by latitude).

Water damage (13.3%) and visible mold (6.7%) were common at baseline (Table 3, centres were ordered by latitude). During follow up, 25.3% of the participants reported dampness or mold at home in current or previous home in the past 10 year, and 19.5% reported dampness or mold in the current or previous workplace building in the past 10 years. Tartu had the highest prevalence of all dampness indicators (at home or at work), except floor dampness. Reykjavik had highest prevalence of floor dampness. Totally 8.0% had dampness or mold both at home and at work, 17.2% reported dampness or mold only at home

and 11.5% only at work.

Onset of sleep disturbances in relation to dampness and mold are shown in Table 4. Floor dampness at home at baseline was related to onset of DIS, DMS, EMA and insomnia symptoms (OR = 1.53–1.87). Visible mold at home at baseline was associated with onset of DIS, DMS, insomnia symptoms and snoring (OR = 1.30–1.52). Mold odor at home at baseline was associated with DIS (OR = 1.67). Any dampness at home at baseline was related to DIS, DMS and insomnia symptoms (OR = 1.17–1.28). Dampness or mold at home during follow up was associated with onset of DIS, DMS, EMA, insomnia symptoms and EDS (OR = 1.17–1.36). Moreover, dampness or mold in the workplace building during follow up was related to onset of sleep disturbances, including onset of DIS, EMA, insomnia symptoms and EDS (OR = 1.16–1.34).

**Table 3**  
Prevalence of signs of indoor dampness and mold at home and in the workplace building in seven centres ordered by latitude (%) (n = 11,318).

		Reykjavik (%)	Umeå (%)	Bergen (%)	Uppsala (%)	Tartu (%)	Gothenburg (%)	Aarhus (%)	Total (%)
Baseline (at home)	Water damage	20.0	10.0	13.4	8.9	23.5	8.0	13.4	13.3
	Floor dampness	6.7	5.7	2.2	4.0	3.0	4.2	1.5	3.9
	Visible mold	6.1	3.9	4.7	6.4	13.0	4.6	9.8	6.7
	Mold odor	4.9	2.5	2.3	3.2	5.9	2.4	4.3	3.5
	Any dampness <sup>a</sup>	22.7	14.1	16.4	15.0	31.7	12.4	17.9	17.8
Follow up	Dampness or mold at home during follow up	32.8	21.0	24.8	23.2	34.4	20.9	24.0	25.3
	Dampness or mold in the workplace building during follow up	22.3	21.0	17.4	23.5	24.0	19.5	11.6	19.5
Combined dampness or mold during follow up	None	57.2	64.6	65.1	61.3	53.3	66.9	70.0	63.3
	Only at home	20.7	14.4	17.6	15.4	22.6	13.5	18.5	17.2
	Only at work	10.4	14.4	10.1	15.6	12.3	12.2	6.1	11.5
	Both	11.8	6.6	7.2	7.7	11.8	7.4	5.4	8.0

<sup>a</sup> Any dampness was defined as water damage, floor dampness or visible mold in the last 12 months at baseline.

**Table 4**  
Adjusted odds ratio (OR) with 95% confidence intervals (CI) for onset of sleeping disturbances (n = 11,318).

	Water Damage	Floor dampness	Visible mold	Mold odor	Any dampness <sup>a</sup>	Dampness or mold at home during follow up	Dampness or mold in the workplace building during follow up
Onset of difficulty initiating sleep (DIS)	1.12(0.90,1.39)	1.70(1.22,2.37)**	1.52(1.15,2.00)**	1.67(1.18,2.36)**	1.28(1.06,1.55)*	1.23(1.03,1.46)*	1.34(1.11,1.61)**
Onset of difficulty maintaining sleep (DMS)	1.05(0.90,1.23)	1.56(1.19,2.04)**	1.29(1.05,1.60)*	1.17(0.88,1.56)	1.17(1.02,1.34)*	1.23(1.09,1.39)**	1.13(0.99,1.30)
Onset of early morning awakening	1.07(0.88,1.30)	1.87(1.40,2.49)***	1.09(0.84,1.42)	1.26(0.90,1.76)	1.12(0.95,1.33)	1.19(1.03,1.38)*	1.32(1.12,1.55)**
Onset of insomnia symptoms	1.09(0.93,1.28)	1.70(1.30,2.23)***	1.30(1.06,1.62)*	1.14(0.85,1.52)	1.18(1.03,1.36)*	1.17(1.03,1.31)*	1.16(1.02,1.33)*
Onset of snoring	1.00(0.82,1.21)	1.29(0.93,1.80)	1.38(1.08,1.77)*	0.97(0.68,1.39)	1.13(0.95,1.33)	1.14(0.98,1.32)	1.02(0.86,1.20)
Onset of excessive daytime sleepiness (EDS)	1.16(0.96,1.41)	1.03(0.71,1.50)	1.20(0.92,1.57)	1.40(0.99,1.97)	1.17(0.98,1.39)	1.36(1.17,1.58)***	1.29(1.09,1.52)**

Two level logistic regression models (centre, individual), adjusted for age (baseline), gender (baseline), smoking (baseline), change of smoking habit from baseline to follow up, BMI (baseline), change of BMI from baseline to follow up, education level (follow up), doctor diagnosed asthma (baseline), allergic rhinitis (baseline) and chronic bronchitis (baseline).

\*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ .

<sup>a</sup> Any dampness was defined water damage, floor dampness or visible mold in the last 12 months at baseline.

Associations between dampness or mold during follow up (four categories: none, n = 6993; only at home, n = 1905; only at work, n = 1271; and both, n = 880) and onset of sleep disturbances are shown in Table 5. Exposure to dampness or mold both at home and at work during follow up had the strongest associations with onset of DIS, DMS, EMA, insomnia symptoms and EDS (OR 1.29–1.74). Extra adjustment including onset of doctor diagnosed asthma, onset of allergic rhinitis and onset of chronic bronchitis showed similar associations (Tables S1 and S2).

Meta-analysis was used to detect heterogeneity between the centres (Fig. 2, Fig. S1 and S2). The estimates from meta-analyses were almost identical to those derived when analysing the pooled data by multilevel logistic regression. There was no significant centre heterogeneity between any dampness at home at baseline and onset of insomnia symptoms (Fig. 2). No significant centre heterogeneity was found between dampness or mold at home during follow up and onset of insomnia symptoms (Fig. S1). In contrast, significantly centre heterogeneity was found between dampness or mold at work during follow up and onset of insomnia symptoms (Fig. S2). The strongest associations were found in Gothenburg and Tartu.

### 5. Discussion

This is the first prospective study on onset of sleep disturbances in a population-based samples of adults in Nordic countries. The main finding was that the risk to develop sleep disturbances were more common in subjects living in damp houses or working in damp buildings. Dampness and mold at home at baseline increased onset of insomnia symptoms and snoring. Moreover, dampness or mold at home during follow up was related to onset of insomnia symptoms and EDS. Furthermore, our study found that dampness or mold at work during follow up was associated with onset of sleep disturbances, including insomnia symptoms and EDS. Combined dampness or mold at home and at work during follow up showed the strongest associations with onset of DIS, DMS, EMA, insomnia symptoms and EDS.

Nearly one third of the participants had developed insomnia symptoms (any of the three insomnia symptoms) during 10 years of follow up, and one fourth of the participants suffered from new onset of DMS at follow up. Moreover, onset of snoring (15.7%) and EDS (13.8%) were also common.

The observed association between damp and moldy buildings and onset of sleep disturbances is a novel finding. We found only two previous studies reporting associations between prevalence of sleep problems among adults and building dampness, none of them were longitudinal (Packer et al., 1994; Janson et al., 2005). One study from England reported that damp housing was related to impaired sleep (Packer et al., 1994). However, questions regarding sleep and damp housing in that study were not as detailed as in our study. A previous prevalence study from Northern Europe reported that water damage, visible mold and floor dampness were associated with insomnia, and the association was strongest between floor dampness and insomnia (Janson et al., 2005).

Our study found that floor dampness was related to higher onset of DIS, DMS, EMA and insomnia symptoms. Among all types of dampness indicators at baseline, floor dampness had the most associations with onset of sleep disturbances. Dampness in the concrete floor construction is common in Northern Europe. One explanation can be that the concrete becomes wet during building process. This type of floor construction can cause chemical degradation of di-ethyl-hexylphthalate (DEHP) used in PVC materials or acrylate-polymers in water based floor glues. The degradation process causes emission of 2-ethyl-1-hexanol to the indoor environment. Previous studies from Northern Europe have reported that dampness in the floor construction was the dampness indicator with the strongest association with prevalence of asthma (Norback et al., 1999) and prevalence of insomnia (Janson et al., 2005). Dampness in concrete floors were found to be related to nasal

**Table 5**

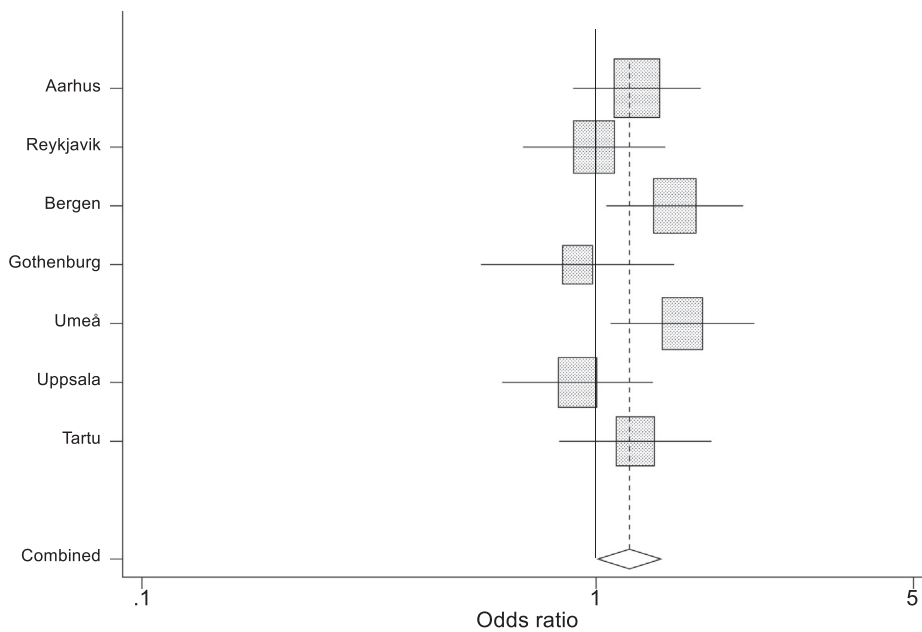
Associations between onset of sleeping disorders and dampness or mold during follow up (four categories: none, at home, at work and both). Adjusted odds ratio (OR) with 95% confidence intervals (CI) (n = 11,318).

	None (n = 6993)	Only at home (n = 1905)	Only at work (n = 1271)	Both (n = 880)
Onset of difficulty initiating sleep (DIS)	1.00	1.07(0.86,1.33)	1.12(0.87,1.43)	<b>1.74(1.35,2.25) ***</b>
Onset of difficulty maintaining sleep (DMS)	1.00	<b>1.25(1.08,1.45) **</b>	1.13(0.95,1.34)	<b>1.30(1.06,1.59) *</b>
Onset of early morning awakening (EMA)	1.00	1.13(0.94,1.35)	<b>1.24(1.01,1.52) *</b>	<b>1.52(1.21,1.92) ***</b>
Onset of insomnia symptoms	1.00	<b>1.16(1.01,1.34) *</b>	1.14(0.97,1.34)	<b>1.29(1.05,1.57) *</b>
Onset of snoring	1.00	1.08(0.90,1.28)	0.90(0.73,1.13)	1.21(0.96,1.54)
Onset of excessive daytime sleepiness (EDS)	1.00	<b>1.33(1.11,1.58) **</b>	1.23(0.99,1.53)	<b>1.60(1.26,2.03) ***</b>

Two level logistic regression models (centre, individual), adjusted for age (baseline), gender (baseline), smoking (baseline), change of smoking habit from baseline to follow up, BMI (baseline), change of BMI from baseline to follow up, education level (follow up), doctor diagnosed asthma (baseline), allergic rhinitis (baseline) and chronic bronchitis (baseline).

\*\*\*  $p < 0.001$ , \*\* $p < 0.01$ , \* $p < 0.05$ .

$p$  value for test for heterogeneity = 0.259



**Fig. 2.** Adjusted odds ratios and 95% CIs of insomnia symptoms in subjects living in homes with any dampness at baseline with a combined odds ratio (diamond indicates 95% CI) from the model with centre as the random effect. The model was adjusted for age (baseline), gender (baseline), smoking (baseline), change of smoking habit from baseline to follow up, BMI (baseline), change of BMI from baseline to follow up, education level (follow up), doctor diagnosed asthma (baseline), allergic rhinitis (baseline) and chronic bronchitis (baseline).

symptoms, nasal inflammation (Wieslander et al., 2010) and asthma symptoms (Norback et al., 2000).

Visible mold was associated with onset of DIS, DMS, insomnia symptoms and snoring in the present study. An association between visible mold and prevalence of insomnia has been reported in one previous study (Janson et al., 2005). Presence of visible mold is not common in Nordic countries due to the cold and dry climate.

Mold odor was related to increased onset of DIS in our study. Fungi and bacteria can cause emission of microbial volatile organic compounds (MVOC) during their metabolic processes (Korpi et al., 2009). Some of MVOC compounds have a typical moldy or pungent smell. Higher level of MVOC at home were found to be associated with mucus membrane symptoms among adults (Sahlberg et al., 2013; Araki et al., 2010). Moreover, reported mildew odor at home was associated with impaired sleep among adults in America (Shiue, 2015).

We further found that the combined effect of dampness/mold at home and at work had the highest impact on the onset of DIS, DMS, EMA, insomnia symptoms and EDS. Our study is the first study investigating combined dampness/mold at home and at work in relation to sleep disturbances among adults.

The meta-analyses showed significant centre heterogeneity between dampness/mold at work during follow up and onset of insomnia symptoms. This indicates that there can be differences in dampness in workplace buildings in relation to the risk of onset of insomnia. More

detailed studies on type of dampness in workplace are needed in future studies.

### 5.1. Potential biological explanations to the associations

The biological mechanism for dampness/mold and impairment of sleep is not clear. A humid indoor environment, with signs of dampness, benefits growth of house dust mites and microorganisms such as mold and bacteria. Previous studies have showed associations between dampness and mold in association with adverse respiratory health effects (Fisk et al., 2007; Quansah et al., 2012; Jaakkola et al., 2013). We therefore adjusted for doctor diagnosed asthma, allergic rhinitis and chronic bronchitis at baseline in the analysis. The associations between building dampness and sleep disturbances remained significant after adjusting for those respiratory disorders, indicating that the effects of dampness and mold on sleep quality is mainly mediated by other mechanisms than induction of respiratory illnesses.

One possible explanation is that damp and moldy environment may cause irritation and inflammation in mucus membrane or airways. One main mold cell wall component,  $\beta$ -1,3-glucan, was reported to cause airway inflammation (Thorn and Rylander, 1998) and fatigue (Wan and Li, 1999). Working in mold contaminated buildings has found to be associated with adult nasal inflammation (Hirvonen et al., 1999; Wieslander et al., 2007; Walinder et al., 2001). Nasal obstruction is a

well-known risk factor for sleep disturbances (Bengtsson et al., 2015; Hellgren et al., 2007). Moreover, odors can lead to unpleasant perceptions (sensory impairment) during sleep causing sleep disturbances. Studies from Sweden and Japan have demonstrated that higher level of MVOC compounds can be related to mucous membrane symptoms (Sahlberg et al., 2013; Araki et al., 2010). Indoor dampness can cause mold growth as well as chemical degradation of building materials, causing emission of VOC compounds (Walinder et al., 2001; Wieslander et al., 1999). VOC emissions in moisture damaged buildings can be related to nasal mucosal swelling and inflammation (Wieslander et al., 2010; Wieslander et al., 1999). It has been suggested that insufficient ventilation flow can influence cerebral blood flow which can trigger migraine during sleep and in turn impair sleep quality among occupants with migraine (Schwarzberg, 1993). Some other environmental factors may have similar impacts on sleep quality.

## 5.2. Strengths and limitations

Our study is the first longitudinal study investigating dampness and mold in relation to adult onset of sleep disturbances in several countries. Our results are less likely to be influenced by selection bias since the participation rate in the initial ECRHS I postal questionnaire was high (86%) (Johannessen et al., 2014) and the participation rate from RHINE II to RHINE III was reasonable (71%). Most dampness indicators were assessed at baseline to avoid recall bias, which diminishes the likelihood of reverse causality. There is a large amount of evidence indicating negative effects of building dampness on respiratory disorders (Fisk et al., 2007; Quansah et al., 2012; Jaakkola et al., 2013). We therefore adjusted for respiratory disorders, including doctor diagnosed asthma, allergic rhinitis and chronic bronchitis in our study (extra adjustment of onset of these symptoms in one additional model). Moreover, smoking habits and education level were adjusted for in the analyses. Thus, our results are less likely to be affected by selection or information bias, or be due to other factors related to low socio-economic status.

Our study has some limitations. It was performed in a limited geographic area (Northern Europe), characterized by cold climate and lack of daylight in winter due to short days. The cold climate is linked to less dampness and indoor mold as compared to warmer climate zones in Europe (Norback et al., 2017). The lack of daylight in winter can cause depressive symptom in subjects with seasonal affective disorder (Kurlansik and Ibay, 2012), but it is unclear how seasonal variation of daylight affects insomnia in the general population in northern Europe. One population study from Norway found that lack of daylight increased difficulties with falling asleep and daytime fatigue (Friborg et al., 2012) but another Norwegian population study found no seasonal variation of insomnia (Sivertsen et al., 2011). Ventilation can be worse in damp buildings with visible mold growth and mold odor. Studies from Denmark and Finland have reported decreased ventilation in association with increased daytime sleepiness (Strom-Tejsen et al., 2016; Vehvilainen et al., 2016). Unfortunately, we had no data on ventilation flow in the homes. Moreover, other possible environment risk factors for sleep disorders such as traffic noise, cooking fumes, biomass smoke, environmental tobacco smoke and illumination were not adjusted for in our study. However, these factors are less likely to be associated with building dampness, and are therefore unlikely confounders.

## 6. Conclusions

Dampness and mold at home and at work increase the risk for sleep disturbances, including insomnia symptoms, snoring and EDS, especially with the combined exposure for both dampness and mold at home and at work. Floor dampness was the strongest risk factor for DIS, EMA and insomnia symptoms. This study further emphasizes the importance of reducing indoor dampness and mold both at home and at work due to the risk of impairing sleep quality. Further studies from other

geographical areas are needed on this topic.

## CRediT authorship contribution statement

**Juan Wang:** Data curation, Formal analysis, Funding acquisition, Software, Visualization, Writing - original draft, Writing - review & editing. **Christer Janson:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Software, Validation, Writing - review & editing. **Eva Lindberg:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Mathias Holm:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Thorarinn Gislason:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Bryndís Benediktsdóttir:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Ane Johannessen:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Vivi Schlünssen:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Rain Jogi:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Karl A. Franklin:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Validation, Writing - review & editing. **Dan Norbäck:** Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing - review & editing.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary material

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