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Building dampness and mold in European homes in relation to climate, building characteristics and socio-economic status: The European Community Respiratory Health Survey ECRHS II

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Abstract

We studied dampness and mold in homes in relation to climate, building characteristics and socio-economic status (SES) across Europe, for 7127 homes in 22 centers. A subsample of 3118 homes was inspected. Multilevel analysis was applied, including age, gender, center, SES, climate, and building factors. Self-reported water damage (10%), damp spots (21%), and mold (16%) in past year were similar as observed data (19% dampness and 14% mold). Ambient temperature was associated with self-reported water damage (OR=1.63 per 10°C; 95% CI 1.02-2.63), damp spots (OR=2.95; 95% CI 1.98-4.39), and mold (OR=2.28; 95% CI 1.04-4.67). Precipitation was associated with water damage (OR=1.12 per 100 mm; 95% CI 1.02-1.23) and damp spots (OR=1.11; 95% CI 1.02-1.20). Ambient relative air humidity was not associated with indoor dampness and mold. Older buildings had more dampness and mold (*P*<.001). Manual workers reported less water damage (OR=0.69; 95% CI 0.53-0.89) but more mold (OR=1.27; 95% CI 1.03-1.55) as compared to managerial/professional workers.

There were correlations between reported and observed data at center level (Spearman rho 0.61 for dampness and 0.73 for mold). In conclusion, high ambient temperature and precipitation and high building age can be risk factors for dampness and mold in homes in Europe.

KEYWORDS
building characteristics, building dampness, climate, environment, indoor, mould, socio-economic status

1 | INTRODUCTION

Building dampness and indoor mold growth is considered an important indoor exposure with implications for respiratory health and allergies. Review articles have concluded that there is consistent evidence for an association between damp housing conditions and incidence of asthma,[1,2] rhinitis[3] as well as bronchitis and respiratory infections.[4] Moreover, World Health Organization (WHO) concluded that there is sufficient evidence to show that occupants of damp or moldy buildings have an increased risk of respiratory symptoms, respiratory infections, and exacerbation of asthma.[5] There has been an initiative to create a common European approach to a healthy indoor environment in order to reduce asthma, allergies, and the sick building syndrome (SBS).[6] We have previously published two articles from the European Community Respiratory Health Survey (ECRHS) on associations between self-reported and observed dampness and mold in homes and incidence of asthma and lung function decline among adults in Europe.[7,8] As ECRHS includes both self-reported and inspection data from dwellings, it is a suitable study to investigate the interrelationship between climate, building characteristics, and socio-economic status (SES) determinants for building dampness and mold across Europe.

We can assume that climatological factors could influence the prevalence of indoor dampness and molds, but there are few studies on this issue, in particular in consideration of the global warming. One study from USA found a moderate association between outdoor and indoor relative air humidity but a strong indoor–outdoor association for absolute air humidity.[9] One study reported that indoor mold in dwellings was more common in warmer climate zones in Europe.[10] In this context, the global warming might have consequences for outdoor and indoor environment[11] and might have consequences for human health in many ways,[12] including respiratory and allergic disease.[13,14] The global warming may increase the building dampness and mold growth [11,14] and increase the risk for flooding.[12,15]

Furthermore, the prevalence of building dampness and indoor mold growth can be influenced by numerous types of building characteristics, such as ownership of the building, socio-economic factors, poor maintenance, or low ventilation flow[5,16–18] Water leakage through roofs, rising damp, and defective pluming installations were found to be the main reasons for water damage and organic building material containing cellulose, such as wood, jute, wallpaper, and cardboard are most likely to get mold growth.[19] One previous publication from the ECRHS-project found that the prevalence of indoor mold was higher in older homes and in homes with a basement.[20] Moreover, the construction period of the building can influence the prevalence of dampness and molds[17] and certain buildings are constructed in a way that they have an inherently increased risk for dampness problems inside the building construction ("risk constructions").[16] The reason for the dampness problems in these risk constructions is an unfavorable thermal profile in the walls or the floor construction causing the relative humidity in the building material to exceed the critical level for microbial growth. Indoor mold growth is often a consequence of condensation on colder internal surfaces ("cold wall effect").[5] It is well know that the crawlspace can get condensation problems in summer, when it is colder than the surrounding environment. This increased humidity can cause mold growth in the crawl space and transmission of mold spores and other microbial components into the house.[21,22] Finally, it has been observed that persons owning their apartment report less dampness and molds than those renting it.[17]

There is conflicting information in the literature on associations between socio-economic status (SES) and prevalence of building dampness and indoor mold growth in the dwelling. One review concluded that subjects with low SES, especially with low income, have poorer housing conditions and more building dampness at home.[23] In contrast, a previous analysis in the ECRHS study reported that indoor mold at home was somewhat more common in the highest socio-economic group.[24] The large PATY study including homes of 57 000 children in the Russian Federation, North America, and Europe reported inconsistent associations between social class and prevalence of mold and moisture at home.[25] Most epidemiological studies on building dampness and

Practical Implications

- There is an obvious need for further improvements of dampness conditions in European dwellings, especially in older buildings. Annual mean temperature rather than ambient relative air humidity can be of importance for indoor dampness and mold. There is a need for better adaption of the building constructions in Europe to the climate. Climate changes linked to the global warming may increase the risk of dampness and indoor mold growth.

indoor mold growth are based only on self-reported information obtained in questionnaire studies. Such studies can be influenced by recall bias.[26] Some validation studies exist comparing self-reported data with independent information collected by inspection or by measurement of indoor mold. Some of these studies report good agreement between self-reported information and observation,[27–30] while other studies found poor or slight agreement.[31,32] However, we found no larger multicenter study comparing self-reported and observed data on dampness and indoor mold in dwellings across countries.

The aim was to study the prevalence of self-reported and observed signs of building dampness and indoor mold growth in homes in the European centers of the European Community Respiratory Health Survey (ECRHS) in relation to type of building, building age, climatological conditions, and socio-economic status. Furthermore, we wanted to study the agreement between self-reported and observed information on dampness and indoor mold.

2 | MATERIAL AND METHODS

2.1 | Study population

The ECRHS I is an international multicenter cross-sectional study on respiratory health covering 48 centers in 23 countries, started in 1990-1994[33,34] which included a random selection of adults aged 20-44 year from the general population (random sample) Each center covers a source population within a defined geographical and administrative area. As it is a random sample of individuals, not a sample of buildings, there is only one participant from each building. Most study centers included an additional symptomatic sample of individuals reporting current asthma symptoms or asthma medication in a screening questionnaire in ECRHS I: However, this study is based only on the random sample. The study was approved by the local ethical comity in each center. The full protocol can be found at www.ecrhs.org. The ECRHS II is a follow-up study of participants in the ECRHS I. Mean follow-up time was 8.7 years. A total of 15 716 subjects took part in the random sample of the ECRHS I, and 8770 completed both the medical and the indoor questionnaires in ECRHS II (56%).

One adult participant from each home participated in the study. Information on the current home environment, job history, and education level was obtained from an interviewer-led questionnaire at the hospital in connection with the medical investigations in ECRHSII. Our study included subjects from the European centers who completed the main questionnaire in ECRHSI (1991-1993) and ECRHSII (1998-2002) and also participated in the Indoor Protocol. Two centers (Cardiff, Geelen) excluded all indoor environment questions from the main medical questionnaire and were consequently excluded from this study, and five centers (Bergen, Bordeaux, Melbourne, Montpellier, Portland) did not participate in the Indoor Protocol, leaving 22 centers (N=7127) all located in Europe. The Indoor Protocol included a home visit with building inspection and collection of dust samples from the bedroom mattress in a subsample of homes (N=3118).[35] The objective was to make inspections and measurements in 200 homes in each center, with priority to subjects who did not move home during the follow-up, provided blood sample for allergy testing and belonged to the random population sample. Meteorological data for year 2002 were obtained from all 22 centers, except missing data on outdoor relative humidity from the two UK centers (Ipswich and Norwich).

2.2 | Assessment of self-reported data on dampness and mold

Information on housing characteristics of the current home environment was obtained from an interviewer-led questionnaire performed in the beginning (ECRHS I) and in the end of the follow-up period (ECRHS II). Data included dampness, indoor mold, construction year of the building, and type of building. The living room was defined as the room used most at home during the days. There were questions on any history of water damage in the house (broken pipes, leaks, flooding), as well as water damage in the last 12 months. Information was collected on any history of "mold or mildew on any surface inside the home," the location of the mold growth, and the presence of the indoor mold or mildew in the last 12 months. Finally, ECRHS II contained an additional question on the presence of "wet or damp spots" on indoor surfaces other than the basement (eg on walls, wall paper, ceilings, or carpets) in the last 12 months.

2.3 | Assessment of observed building dampness

Building dampness was observed by trained fieldworkers in a subset of homes in the 22 centers which participated in an additional indoor environmental study ("The Indoor Protocol"). The fieldworkers were mainly nurses or other medical staff. They were trained to perform the building inspections in a standardized way in special workshops held before the project was started. The training was organized by specialists in indoor environmental research. This study protocol included a home visit with building inspection and collection of dust samples from mattresses performed by the field workers in approximately 200 homes in each center.[35,36] Information on observed building dampness and indoor molds was available from 3118 homes. In all centers, the same questionnaire containing eight questions on dampness and mold, grouped into three variables, was used for the building inspection.

2.3.1 | Observed dampness

Are there any damp patches on the walls or ceilings of the living room, bedroom and bathroom? (three questions). *Observed mold*. Is there any mold or mildew on the walls and ceilings in the living room, bedroom and bathroom? (three questions). *Window condensation*. Do you get condensation on your living room/bedroom window especially in the morning in the winter? (two questions to the participant during the home inspection). We used ECRHSII data to explore the agreement between self-reported and observed information on dampness and indoor mold. The observed dampness was compared with self-reported damp spots on indoor surfaces, other than the basement, in the last 12 months. The observed mold was compared with self-reported mold or mildew in the last 12 months.

TABLE 1 Self- reported and observed dampness and mold in ECRHS II centers, sorted by latitude

Center	Latitude (grades)	Number of homes with reported data (N)	Number of homes with observed data at inspection (N)	Reported water damage last 12 mo (%)	Reported damp spots last 12 mo (%)	Observed damp spots (%)	Reported indoor mold last 12 mo (%)	Observed indoor mold (%)	Window condensation[a] (%)
Huelva (HU)	37.27	192	99	11.8	38.2	28.7	25.5	16.2	64.4
Albacete (AL)	38.98	289	144	10.3	18.7	6.3	11.4	4.9	35.5
Barcelona (BA)	41.38	272	145	9.9	19.1	13.1	7.4	3.4	29.0
Galdakao (GA)	43.25	360	170	5.3	21.9	9.3	9.2	5.3	40.8
Oviedo (OV)	43.37	241	139	9.6	25.3	28.1	11.2	21.6	33.1
Turin (TU)	45.05	123	73	9.1	20.3	17.8	6.5	8.2	38.4
Grenoble (GN)	45.17	378	160	17.7	24.9	31.7	22.8	29.4	15.2
Pavia (PA)	45.17	192	90	10.9	29.2	16.7	37.5	25.6	33.3
Verona (VE)	45.45	202	117	9.5	34.3	18.8	38.1	12.8	24.1
Basel (BA)	47.55	445	90	8.3	14.4	18.7	12.8	22.2	29.7
Paris (PS)	48.87	424	161	23.3	30.5	29.4	17.0	19.3	25.6
Erfurt (ER)	50.97	287	185	4.9	13.6	8.6	14.6	12.4	29.5
Antwerp city (AC)	51.22	236	90	16.7	29.5	17.6	17.8	12.2	34.4
South Antwerp (AS)	51.22	293	172	14.3	22.7	19.8	13.7	14.5	25.9
Ipswich (IP)	52.07	278	85	9.7	29.6	26.7	36.0	38.8	65.1
Norwich (NO)	52.63	255	133	5.1	21.1	9.8	29.0	13.5	48.5
Hamburg (HA)	53.55	297	170	9.6	18.2	23.7	17.8	25.9	39.8
Goteborg (GO)	57.72	467	157	5.0	11.2	14.6	7.5	5.7	35.4
Tartu (TA)	58.38	254	120	16.0	23.2	26.4	26.0	15.5	43.0
Uppsala (UP)	59.87	501	148	7.1	9.2	2.0	10.0	2.0	19.5
Umea (UM)	63.83	400	167	4.8	6.6	13.1	4.0	1.8	33.5
Reykjavik (RE)	64.15	459	170	12.3	20.8	25.9	6.1	3.5	22.5
Total		6845	2985	10.5	20.5	18.1	15.8	13.5	33.6

[a]Window pane condensation in winter in living room or bedroom, reported at the home visit.

2.4 | Assessment of climatological conditions

Daily, monthly, and annual climate data (ambient temperature and precipitation) for the year 2002 were obtained for each city from national or local meteorological institutes. The difference between the coldest and hottest month was used as a proxy variable for continental climate. Geographical latitude was obtained from the route planning software Mapsonic (Michelin UK, London, www.viamichelin.com), where GPS degrees were obtained for a random inner city point and were included as a continuous variable.

2.5 | Assessment of age, sex, and occupational conditions (socio-economic status)

Information on age, sex, occupation, and education was collected from the interview-led questionnaires. Information on individual socio-economic status (SES) was derived from occupation and education. The occupational history during the follow-up period was recorded on a monthly basis, and based on the International Standard Classification of Occupations (ISCO) coding, and SES was defined for the longest held occupation during the follow-up period. Level of education was categorized by age at completion of full-time studies, as previously found to be useful for comparing educational achievement,[37] and was defined as low (age at completion <17 years, medium (age 17-20 years), and high (>20 years). As in previous studies on SES from the ECRHS study (eg,[38]) we analyzed SES based on the occupational classification and education level separately.

2.6 | Statistical methods

The analysis in this study was based on ECRHS II data (random sample). Agreement between self-reported and observed data was calculated by Cohen's kappa. Correlation between self-reported and observed data on center level was analyzed by Spearman rank order correlation (rho). As winter temperature gave similar associations as annual mean temperature, and as weaker associations were found for latitude as compared to annual mean temperature, we included annual mean temperature and annual precipitation in the multilevel statistical models. Outdoor relative air humidity was only associated with one indoor dampness variables in the bivariate analysis. It was a negative association between outdoor RH and window condensation in the living room. Moreover, data on outdoor RH were missing for two centers. Because of this, we did not include outdoor RH in the multilevel models. Odds ratios were calculated, using log-binomial models, adjusting for sex, age, and center. To detect heterogeneity between centers, the adjusted risk ratios and regression coefficients were thereafter calculated separately in each center. Average effect estimates were derived, and potential heterogeneity between centers was examined using standard methods for random-effects meta-analysis.[39] In the meta-analysis, centers with too low number of subjects were omitted.

Associations between dampness and molds and socio-economic and climate variables were analyzed using multilevel (or hierarchical) models. These models are indicated when there is a hierarchic structure in levels of data, with a single dependent variable measured at the lowest level, and a set of explanatory variables on each of the levels. As the response regarding the presence or absence of dampness or molds is binary, we fitted multilevel logistic models.[40] We followed the model-building procedure proposed by Hox.[41] We entered individual-level explanatory variables as random effects and added climate variables at center level. Associations between self-reported dampness and mold and social class, education level, annual temperature, annual precipitation, and construction year of the building were analyzed in a multilevel model, adjusting for age, sex, and center. Two separate models were used, one including annual temperature, annual precipitation, construction year of the building, age and sex of the participants, center, and occupational conditions as the proxy variable for socio-economic status (SES) (model 1). The second model included annual temperature, annual precipitation, construction year of the building, age and sex of the participants, center, and education level (model 2). OR for precipitation was expressed per 100 mm (called deciliter in the tables). The statistical analysis was performed using Stata 8.0 (Stata Corporation, College Station, Texas). In all statistical analysis, P-values <.05 were considered significant.

3 | RESULTS

The mean age of all participants was 42.7 year (SD=6.8), and 52.5% were females. There was a large variation among different centers in the prevalence of reported and observed dampness and indoor mold (Table 1). When comparing self-reported data on dampness and mold in the subsample with inspection data, as compared to those without any home inspection, there were minor and non-significant differences in reported dampness, mold, education level, sex, and occupational groups (0-2% difference) (data not shown). Due to the selection process for the home inspection, the proportion of subject who had lived in the same home during the 9 years follow-up period was higher in this subsample (65.5%) as compared to the total study population (48.3%). Meteorological data for the

TABLE 2 Climate conditions for the 22 ECRHS centers

		Median	Range
Mean winter temperature	°C	2.1	−10.4 to 11.1
Mean summer temperature	°C	20.1	11.1 to 26.7
Mean annual temperature	°C	11.4	3.2 to 18.1
Mean outdoor relative air humidity[a]	%	77	63 to 85
Annual precipitation	(mm)	735	327 to 1182
Altitude	(m)	55	5 to 700
Longitude	Grades	5.07	−21.85 to 26.72
Latitude	Grades	49.92	37.27 to 64.16

[a]Data missing for two centers.

22 centers are given in Table 2. The annual mean temperature ranged from +3.1 to 18.1°C, latitude from 37 to 64 degrees, and annual precipitation from 327 to 1182 mm per year. Mean winter temperature, annual mean temperature, and annual precipitation were the climate variables most strongly associated with self-reported and observed dampness and mold (Table S1). Correlations between annual mean temperature and precipitation and self-reported dampness and mold in the last 12 months are presented in Figure S1.

The prevalence of self-reported dampness and mold was stratified for size of house and type of house (Table S2). Buildings with 2-4 families had 3-5% higher prevalence of self-reported and observed dampness and mold as compare to those with one family or more than four families. Apartments had 2-5% lower prevalence of indoor dampness molds as compared to detached houses, and converted flats had the highest prevalence of dampness and molds. However, building age was the most important determinant of dampness and mold. There was a clear negative association between construction year and reported and observed dampness and molds. Generalized additive models (GAM) plots are presented in Figure S2. The only exception was for window condensation, where an inverse u-shaped curve was observed, with the highest prevalence in homes constructed approximately 1945-1965.

As a next step, data on dampness and mold were stratified for social class (based on occupation) and age when finishing last education (Table S3). The mean educational level was 20.8 years (SD=5.6). There was a substantial variation in social class between centers, with the highest proportion of manual workers (25-34%) in Albacete, Galdakao, Huelva, and Umeå, and the lowest proportion (6-15%) in Antwerp City, Antwerp South, Basel, Grenoble, and Paris. The center variation in education level was even higher. The proportion of subjects ending education before 17 years of age was 30-62% in Albacete, Barcelona, Ipswich, Norwich, Pavia, Verona, and Galdakao, but only 1-10% in Basel, Erfurt, Grenoble, Hamburg, Tartu, Umeå, and Uppsala. Managers and professionals, and those with long education, had the highest prevalence of reported water damage. Manual workers and those with shortest education had somewhat higher prevalence of reported molds, and the highest prevalence of observed dampness. A meta-analysis of the association between social class (manual worker versus managerial or professional workers [reference group]) and reported water damage, damp spots, and molds did not reveal any heterogeneity between centers (*P*-value for interaction .35 for water damage last 12 months and 0.48 for mold last 12 months) (Figs S3 and S4).

Manual workers reported less water damage as well as subjects living in older buildings and in centers with higher annual mean temperature and higher precipitation. Subject in centers with higher annual mean temperature, higher precipitation, and in older buildings reported more damp spots. Manual workers reported more mold as well as subjects living in older buildings and in centers with higher annual mean temperature (Table 3). In a similar way, associations were analyzed for observed dampness and mold and window condensation. Homes of manual workers had more observed damp spots, as well as homes in older buildings and in centers with more annual precipitation. Homes in older buildings and in centers with higher annual mean temperature and more precipitation had more observed mold. Homes of manual workers, and other workers without manual work had more window condensation. Moreover, buildings constructed before 1980 had more window condensation as compared to homes constructed 1990 or after (reference category) (Table 4). Similar associations for climate and building age were found in the models replacing occupation by level of educational (Tables 3 and 4). Moreover, those with lowest education level reported less water damage but more mold and had more often window condensation.

Finally, we analyzed agreement between self-reported and observed dampness and mold in ECRHS II data. Associations were strong on a center level, in an ecological analysis, but weak on individual home level. A comparison between observed and 12 months self-reported dampness and molds showed significant associations on a center level, with Spearman rho values of 0.61 (95% CI 0.32-0.84) (*P*=.002) for dampness and 0.73 (95% CI 0.52-0.90) (*P*=.001) for molds (Fig S5). Analysis on individual levels, however, revealed low kappa values, 0.30 for dampness and 0.34 for molds, with similar kappa values in men and women. Sensitivity was 48%, and specificity was 84% for reported dampness last 12 months, if observed dampness was used as the golden standard. For reported indoor mold last 12 months, sensitivity was 6% and the specificity was 85% if using observed mold as golden standard.

4 | DISCUSSION

Dampness and mold was common in Europe and related to higher annual mean temperature, higher annual precipitation and to some extent to socio-economic status. Among building-related factors, age of the building was the main determinant of dampness and mold. Southern Europe and regions with higher amount of precipitation had a higher risk for building dampness and indoor molds. The agreement between reported and observed dampness and molds was relatively high in an ecological analysis on center level, but poor on individual level.

We found that annual mean temperature was positively associated with reported and observed dampness and indoor mold, which is in agreement with some previous studies covering different climate zones. One early study on Housing and Health investigated 400 homes in Italy, and the inspectors found mold in 11.7% of the kitchens and in 13.9% of the bedrooms.[42] One meta-analysis of European buildings in 31 countries reported weighted prevalence estimates of 12.1% for dampness, 10.3% for molds, and 10.0% for water damage. The prevalence of mold was higher in warm and temperate climates as compared with cold climate[10] a similar result as in our study.

We found that annual precipitation was positively associated with reported and observed dampness and indoor mold. An increase of the annual precipitation by 100 mm was associated with

TABLE 3 Associations between self-reported dampness and mold and social class, education level, climate, and construction year

	Model 1				Model 2		
	OR	(95% CI)	*P*-value		OR	(95% CI)	*P*-value
Water damage last 12 mo							
Social class				*Education level*[a]			
Manager and professional	1	(Ref)		>20 y	1	(Ref)	
Technical	0.88	(0.69-1.12)	.30	17-20 y	0.86	(0.72-1.03)	.10
Other work not manual	0.86	(0.70-1.08)	.19	≤16 y	0.77	(0.60-0.98)	.04
Manual work	0.69	(0.53-0.89)	.004				
Unclear/unknown	1.00	(0.74-1.37)	.98				
Climate				*Climate*			
Temperature (per 10°C)	1.64	(1.02-2.63)	.04	Temperature (per 10°C)	1.74	(1.08-2.82)	.02
Precipitation (per deciliter)	1.12	(1.02-1.23)	.02	Precipitation (per deciliter)	1.13	(1.02-1.24)	.02
Construction year of current home				*Construction year of current home*			
Before 1950	2.13	(1.61-2.82)	<.001	Before 1950	2.09	(1.58-2.77)	<.001
1950-1969	1.47	(1.10-1.97)	.009	1950-1969	1.44	(1.08-1.93)	.01
1970-1979	1.88	(1.42-2.51)	<.001	1970-1979	1.88	(1.41-2.50)	<.001
1980-1989	1.16	(0.85-1.60)	.36	1980-1989	1.15	(0.84-1.59)	.33
1990 or after	1.00	(Ref)		1990 or after	1.00	(Ref)	
Missing data	1.97	(1.16-3.36)	.01	Missing data	1.88	(1.09-3.24)	.02
Damp spots last 12 mo							
Social class				*Education level*[a]			
Manager and professional	1			>20 y	1		
Technical	0.99	(0.82-1.19)	.88	17-20 y	1.02	(0.88-1.17)	.82
Other work not manual	0.94	(0.79-1.11)	.48	≤16 y	1.05	(0.88-1.26)	.56
Manual	1.12	(0.94-1.35)	.20				
Unclear/Unknown	0.96	(0.75-1.21)	.71				
Climate				*Climate*			
Temperature (per 10°C)	2.95	(1.98-4.39)	<.001	Temperature (per 10°C)	2.93	(1.97-4.36)	<.001
Precipitation (per deciliter)	1.11	(1.02-1.20)	.012	Precipitation (per deciliter)	1.11	(1.02-1.20)	.01
Construction year of current home				*Construction year of current home*			
Before 1950	224	(1.82-2.77)	<.001	Before 1950	2.26	(1.83-2.80)	<.001
1950-1969	155	(1.25-1.92)	<.001	1950-1969	1.56	(1.26-1.92)	<.001
1970-1979	177	(1.43-2.19)	<.001	1970-1979	1.78	(1.44-2.20)	<.001
1980-1989	130	(1.04-1.64)	.023	1980-1989	1.31	(1.04-1.65)	.020
1990 or after	100			1990 or after	1.00		
Missing data	253	(1.72-3.71)	<.001	Missing data	2.49	(1.69-3.69)	<.001
Mold last 12 mo							
Social class				*Education level*[a]			
Manager and professional	1			>20	1		
Technical	0.96	(0.78-1.19)	.71	17-20	0.91	(0.78-1.07)	.26
Other work not manual	0.90	(0.74-1.09)	.27	≤16	1.25	(1.03-1.52)	.03
Manual work	1.27	(1.03-1.55)	.02				
Unclear/Unknown	1.01	(0.78-1.32)	.94				
Climate				*Climate*			
Temperature (per 10°C)	2.28	(1.04-4.97)	.04	Temperature (per 10°C)	2.15	(0.99-4.67)	.05
Precipitation (per deciliter)	1.14	(0.97-1.33)	.11	Precipitation (per deciliter)	1.14	(0.98-1.34)	.09

(Continues)

TABLE 3 (Continued)

	Model 1				Model 2		
	OR	(95% CI)	*P*-value		OR	(95% CI)	*P*-value
Construction year of current home				*Construction year of current home*			
Before 1950	1.82	(1.43-2.30)	<.001	Before 1950	1.85	(1.46-2.35)	<.001
1950-1969	1.53	(1.21-1.95)	<.001	1950-1969	1.58	(1.24-2.01)	<.001
1970-1979	1.59	(1.25-2.03)	<.001	1970-1979	1.64	(1.29-2.09)	<.001
1980-1989	1.34	(1.04-1.73)	.03	1980-1989	1.36	(1.05-1.76)	.02
1990 or after	1.00			1990 or after	1.00		
Missing data	1.54	(0.96-2.48)	.08	Missing data	1.64	(1.02-2.65)	.04

[a]Age when finishing last education.
Model 1: Socio-economic status, annual mean temperature, annual precipitation, construction year of home, adjusted for age and sex as random effects.
Model 2: Education level, annual mean temperature, annual precipitation, construction year of home, adjusted for age and sex as random effects.

an increased odds ratio of 1.1 for reported water leakage, and damp pots and visible indoor molds. However, the ORs were higher for inspection data (OR=1.3 for observed damp spots and 1.4 for observed mold) suggesting that self-reported data may underestimate the effect of precipitation. Buildings in different parts of the world have adapted the building design to the local precipitation level, but our results suggest a need for further improvement of the building design to cope with heavy rain fall in some areas. As the climate change is expected to lead to higher annual mean temperature and more uneven distribution of precipitation over the year,[11,14] including flooding,[12,15] we can expect more problems with indoor dampness and molds associated with the climate change.

High building age was a risk factor for reported and observed dampness and molds, in a similar way for reported and observed data. The only exception was for window condensation, where there was an inverse U-shaped association with the highest levels in building constructed 1940-1960. It is reasonable to assume that older building will have more dampness problems related to leakage, because gradual degradation of water and sewage pipes, roof material, and ground insulation by age. We found no major difference in reported or observed dampness and indoor mold in relation to size of house or type of house. Single family houses tended to have less reported water damage and less observed damp spots and mold, as compared to homes with more than one family. Moreover, detached houses tended to have less reported damp spots and observed dampness and mold than other types of buildings but differences were much smaller than in the previous Swedish population study from Stockholm.[17] Converted flats had the highest prevalence of reported and observed dampness and molds. To our knowledge, this has not been reported previously. It has become more and more popular to convert industrial building in the city center to homes, especially in larger cities. As these buildings were not constructed as dwellings, dampness-related problems can occur when they are converted to flats. Dwellings have a dampness barrier in the wall construction to avoid air humidity to condensate in the wall construction in wintertime. Moreover, homes have a higher room temperature as compared to industrial buildings and this increased temperature could affect the transport of humidity into the building construction.

We found good agreement between self-reported and observed dampness and mold on center level but poor agreement on individual level. This could be due to the large number of home inspectors involves as it can be difficult to standardize the reporting of dampness between observers. Moreover, the time windows are different, as reported dampness referred to the last 12 months, while the inspection covered the situation the day the inspection was performed. The agreement between observed and self-reported data on individual level was especially poor for indoor mold, with only 6% sensitivity. This may indicate that data on self-reported mold on individual level can be on limited value. One study from Norway, sending two different observers to the same homes, found poor agreement on the judgment of dampness. The intra-observer reproducibility on the observations of home dampness showed a kappa value of 0.28.[43] However, the majority of the studies report good reproducibility of self-administered questions on building moisture, visible molds, and flooding has been reported from Canada.[44] The reported kappa values of 73% for visible molds, 82% for basement flooding, and 73% for any type of dampness or molds. One study from the Netherlands reported good agreement between self-reported and observed signs of dampness in homes.[27] One study from Sweden found good agreement between self-reported and observed dampness and indoor mold growth, with a sensitivity of 74% and a specificity of 71%, using observed data as gold standard.[30] One recent study on dampness and molds in schools in three countries (Finland, the Netherlands, Spain) found good agreement (overall kappa value 0.62) but with large differences (0.39-0.91) between countries.[29] One validation study from China in student dormitories found poor agreement between self-reported and inspection data for dampness and molds (kappa value <0.2).[32] Similarly poor agreement between self-reported and inspection data for dampness and molds has been reported from dwellings in Sweden.[31] Validation of self-reported dampness and indoor mold is a difficult issue, as there is no obvious gold standard, related to measured exposure.

TABLE 4 Associations between observed dampness and mold and socio-economic status, education level, climate, and construction year

	Model 1				Model 2		
	OR	(95% CI)	*P*-value		OR	(95% CI)	*P*-value
Observed damp spots at inspection							
Socio-economic status				*Education level*[a]			
Manager and professional	1.00	(Ref)		>20 y	1.00	(Ref)	
Technical work	0.86	(0.63-1.17)	.34	17-20 y	1.09	(0.88-1.36)	.42
Other work not manual	1.15	(0.88-1.51)	.29	≤16 y	1.12	(0.84-1.50)	.42
Manual work	1.55	(1.17-2.06)	.002				
Unclear/unknown	1.07	(0.71-1.61)	.76				
Climate				*Climate*			
Temperature (per 10°C)	1.51	(0.88-2.56)	.13	Temperature (per 10°C)	1.51	(0.89-2.57)	.12
Precipitation (per deciliter)	1.30	(1.17-1.46)	<.001	Precipitation (per deciliter)	1.28	(1.15-1.43)	<.001
Construction year of current home				*Construction year of current home*			
Before 1950	2.02	(1.38-2.94)	<.001	Before 1950	2.02	(1.39-2.95)	<.001
1950-1969	1.85	(1.28-2.67)	.001	1950-1969	1.89	(1.31-2.73)	.001
1970-1979	2.04	(1.42-2.95)	<.001	1970-1979	2.04	(1.41-2.94)	<.001
1980-1989	1.66	(1.14-2.43)	.008	1980-1989	1.66	(1.14-2.42)	.008
1990 or after	1.00	(Ref)		1990 or after	1.00	(Ref)	
Missing data	2.83	(1.42-5.62)	.003	Missing data	2.82	(1.42-5.59)	.003
Observed mold at inspection							
Socio-economic status				*Education level*[a]			
Manager and professional	1.00	(Ref)		>20 y	1.00	(Ref)	
Technical work	0.96	(0.68-1.35)	.80	17-20 y	0.93	(0.72-1.20)	.57
Other work not manual	0.98	(0.72-1.33)	.88	≤16 y	1.07	(0.77-1.48)	.71
Manual work	1.17	(0.84-1.64)	.35				
Unclear/unknown	1.79	(1.18-2.71)	.007				
Climate				*Climate*			
Temperature (per 10°C)	2.81	(1.19-6.63)	.02	Temperature (per 10°C)	2.97	(1.26-7.01)	.01
Precipitation (per deciliter)	1.40	(1.18-1.65)	<.001	Precipitation (per deciliter)	1.39	(1.18-1.65)	<.001
Construction year of current home				*Construction year of current home*			
Before 1950	1.71	(1.13-2.59)	.01	Before 1950	1.69	(1.12-2.56)	.01
1950-1969	1.53	(1.02-2.31)	.04	1950-1969	1.55	(1.03-2.33)	.04
1970-1979	1.78	(1.18-2.67)	.006	1970-1979	1.78	(1.19-2.68)	.005
1980-1989	1.39	(0.91-2.13)	.13	1980-1989	1.42	(0.93-2.16)	.11
1990 or after	1.00			1990 or after	1.00		
Missing data	1.62	(0.73-3.58)	.23	Missing data	1.63	(0.74-3.60)	.22
Window pane condensation							
Socio-economic status				*Education level*[a]			
Manager and professional	1.00	(Ref)		>20	1.00	(Ref)	
Technical work	1.10	(0.85-1.42)	.46	17-20	1.14	(0.95-1.37)	.16
Other work not manual	1.45	(1.17-1.81)	.001	≤16	1.80	(1.44-2.27)	<.001
Manual work	1.50	(1.19-1.90)	.001				
Unclear/unknown	1.89	(1.37-2.60)	<.001				
Climate				*Climate*			
Temperature (per 10°C)	1.22	(0.70-2.12)	.48	Temperature (per 10°C)	1.12	(0.66-1.93)	.67
Precipitation (per deciliter)	0.96	(0.86-1.08)	.47	Precipitation (per deciliter)	0.97	(0.87-1.08)	.57

(Continues)

TABLE 4 (Continued)

	Model 1				Model 2		
	OR	(95% CI)	*P*-value		OR	(95% CI)	*P*-value
Construction year of current home				*Construction year of current home*			
Before 1950	1.57	(1.17-2.11)	.003	Before 1950	1.55	(1.16-2.08)	.004
1950-1969	1.77	(1.33-2.34)	<.001	1950-1969	1.76	(1.33-2.33)	<.001
1970-1979	1.61	(1.22-2.13)	.001	1970-1979	1.61	(1.22-2.14)	.001
1980-1989	1.27	(0.95-1.69)	.11	1980-1989	1.26	(0.94-1.68)	.12
1990 or after	1.00	(Ref)		1990 or after	1.00	(Ref)	
Missing data	1.70	(0.92-3.16)	.09	Missing data	1.57	(0.84-2.91)	.16

[a]Age when finishing last education.
Model 1: Socio-economic status, annual mean temperature, annual precipitation, construction year of home, adjusted for age and sex as random effects.
Model 2: Education level, annual mean temperature, annual precipitation, construction year of home, adjusted for age and sex as random effects.

We found both positive and negative associations between social class and dampness/mold in our mutually adjusted models. There were more reported mold but less reported water leakage in the lower SES group. For observed data, manual workers had more damp spots, only. Moreover, window pane condensation was more common in lower SES groups, indicating lower ventilation flow in relation to degree of crowdedness. Meta-analysis revealed no heterogeneity across the study centers. Thus, different indicators of building dampness and molds may have different association with SES. The different associations between manual work and either self-reported or observed dampness could be due to a lower awareness of environmental risks in manual workers. The literature reports inconsistent associations between dampness, molds, and SES. One review on studies in Europe concluded that subjects with low SES, especially with low income, have poorer housing conditions and more building dampness at home.[23] In contrast, a previous analysis in the ECRHS study reported that indoor molds at home were somewhat more common in the highest socio-economic group.[24] This ECRHS study defined SES in the same way as in our study, based on occupation or level of education. Moreover, the large PATY study including homes of 57 000 children in the Russian Federation, North America, and Europe reported inconsistent associations between social class and prevalence of molds and moisture at home.[25] They defined social class based on parental level of education. Thus, if considering the overall burden of building dampness and indoor molds in dwellings in Europe, our study does not support the view that SES plays a major role.

The main strength of this study is that it contains information about self-reported as well as observed dampness and indoor mold in European homes from different climate zones around year 2002. An epidemiological study can be affected by selection bias. However, there were no significant difference in socio-economic status, education level, or reported dampness and molds between those participating and not participating in the home inspection. Certain limitations should also be acknowledged. The study base was mainly urban population in west Europe, data might not be representative for the dwellings in whole Europe. Moreover, we did not have any measurements on the ventilation flow in the buildings. The study included all types of buildings, both single family and multifamily buildings. Because of this, we did not analyze risk factors that are relevant only in certain types of dwelling, such floor level of the apartment or type of foundation in single family homes. This study did not include any objective measurements of microbial markers in household dust. However, geographical and domestic determinants of the concentration of microbial components (endotoxin, muramic acid, and bacterial and fungal DNA) in dust collected from the bed have been analyzed in two recent publications based on a subset of the ECRHS study.[45,46]

5 | CONCLUSIONS

In conclusion, dampness and molds in the dwelling is common in Europe and related to climate and building age in mutually adjusted models. There can be a reasonable agreement between self-reported and observed dampness and mold on a center level but poor agreement on individual level, especially for self-reported mold. There is an obvious need for further improvements of dampness conditions in European dwellings, especially in older buildings, and there should be special caution when converting industrial buildings to apartments. The north–south gradient related to annual mean temperature, as well as the association between annual precipitation and dampness and molds, indicates a need for better adaption buildings constructions to the climate. Future climate change with increased temperature and more uneven distribution of rain might increase building dampness and molds. This suggests an even larger need to adapt the building to the climate in the future.

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SUPPORTING INFORMATION

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