Archives of Environmental & Occupational Health, Vol. 65, No. 1, 2010
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Dampness and 2-Ethyl-1-hexanol in Floor Construction of Rehabilitation Center: Health Effects in Staff

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ABSTRACT. The authors evaluated changes of symptoms and biomarkers in health care staff ($N = 18$) for people with different physical dysfunctions and similarly in an external office control group in a nondamp building ($N = 15$). The first workplace had verified dampness in the floor construction, with formation of 2-ethyl-1-hexanol from water-based glue. Tear film break up time (BUT), nasal patency, biomarkers in nasal lavage (NAL), and dynamic spirometry were measured. Both buildings had low indoor air levels of CO_2 (510 to 630 ppm), low levels of respirable particles (6 to 7 $\mu g/m^3$) and formaldehyde ($<5\ \mu g/m^3$), and no indication of microbial growth. Pronounced increase of butanols and 2-ethyl-1-hexanol levels were found in the damp floor material samples, but very low air levels of 2-ethyl-1-hexanol. The staff had been previously exposed to floor construction with alkaline degradation of floor glue, as well as formation of 2-ethyl-1-hexanol. This led to an increase in their ocular, nasal, and respiratory symptoms, a decrease in nasal patency, and slight airway obstruction after 2 days of reexposure, possibly related to neutrophilic inflammation, after a 4-month exposure-free period.

KEYWORDS: floor dampness, myeloperoxidas (MPO), nasal patency, respiratory symptoms, tear film break up time (BUT)

It has been concluded that building dampness and mold growth are associated with an increase of asthma and asthmatic symptoms and symptoms compatible with the sick building syndrome (SBS).[1–3] Most of these studies have dealt with the health effects of dampness in the home environment, with fewer studies on dampness in workplace buildings. The causative factors in damp buildings remain unclear. One factor could be allergic or irritative effects of indoor molds.[4,5] In addition, building dampness may cause chemical degradation of building material, including degradation of phthalate esters in polyvinyl chloride (PVC) or polyacrylate materials in floor coatings or water-based floor glue, causing emission of 2-ethyl-1-hexanol.[6] Toxicological data on water-based glues, adhesives, and paints show that these compounds, which were previously used as pesticides, transform into acrylic esters and have pronounced irritative effects on skin, eyes, and throat.[7] In addition, they react with alkali, forming 2-ethyl-1-hexanol.

In geriatric hospitals with dampness in the floor construction and 2-ethyl-1-hexanol emissions to indoor air, there was an increase of ocular and nasal symptoms, decreased tear film break up time (BUT), increase of lysozyme in nasal lavage (NAL),[6] as well as an increase of asthmatic symptoms.[8] One study from a damp office building in Finland, experiencing emission of 2-ethyl-1-hexanol from PVC floor coverings, had an increased incidence of asthma among office workers during a 3-year follow-up period.[9] Another study found an increased prevalence of both SBS and asthmatic symptoms among pupils in a damp school with 2-ethyl-1-hexanol emission from PVC floor coverings.[10] Finally, one Japanese case

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report[11] and another Japanese school study[12] reported associations between 2-ethyl-1-hexanol in indoor air and SBS symptoms. Apart from one Swedish study in schools with dampness in the floor construction where ventilated floors were installed,[13] we found no epidemiological intervention studies in buildings with 2-ethyl-1-hexanol emission from the floor construction. More knowledge is needed to explain symptoms in people with asthma and allergy and with aggravated symptoms in relation to emissions from dampness in damaged floor constructions.

The aim was to study changes of symptoms and physiological signs in health staff reexposed to a building with floor dampness and 2-ethylhexanol emission after an exposure-free period. The effects on the eyes and upper and lower airways were registered with a doctor's administered questionnaire, combined with a medical investigation that included measurement of tear film break up time (BUT), acoustic rhinometry, NAL, and dynamic spirometry.

METHODS

The study was performed in a building in mid-Sweden, a center for the training of dysfunctional and disabled people that was built in 1985. It is a 2-story building made of a concrete slab with thermal insulation between the concrete and the floor construction. The floor material is linoleum, fixed by water-based glue.

A detailed building investigation was performed, showing abnormal emissions of 2-ethyl-1-hexanol and butanols from the floor material, and remaining building dampness, both in the concrete slab and the concrete floor construction on the second floor. There were no signs of microbial growth in any building materials, and the total volatile organic compounds (TVOCs) levels in the air were low. In September, all staff members moved to an alternative office building in a central part of the city. There were no signs of building dampness in this building.

In November the same year, all employed daytime personnel ($n = 19$) were invited to participate in the investigation, and a total of 18 consented to the arrangement (95%). The investigation included a doctor's administered symptom-scale questionnaire and a medical investigation. The medical investigation comprised measurement of tear film break up time (BUT), acoustic rhinometry, nasal lavage, and dynamic spirometry. The medical investigations were performed in December, which of course is off-pollen season. The staff was initially investigated in the reference building with no building dampness, where they had been working for 4 months, on a Monday. Then they all moved back to their ordinary workplace, where there was building dampness, and were reinvestigated on the following Wednesday, after 2 days of exposure. All were reinvestigated at the same time of the day, within 1 hour, to control for diurnal variations. Because some effects on the mucous membranes may be transient, all medical examinations were performed inside the reference building and inside the damp building, respectively. All subjects had been in the building at least 1 hour prior to examination. None of the participants had had any respiratory infections during the previous 7 days. The study was approved by the Ethical Committee of the Medical Faculty of Uppsala University.

External control group

In order to control for weekday effects, we investigated an external control group of 15 office workers during the same season (winter), working in an office building with no current dampness or mold growth. They were investigated on Monday and Wednesday of the same week, in the same office. Changes in symptoms and clinical signs during the week were calculated. For practical reasons, lung function unfortunately could not be measured.

Assessment of personal factors

A general medical questionnaire was used to gather information on personal factors, including medical disorders, medication, occupational data, the home environment, and smoking habits.[6]

Atopy was defined as having a history of childhood eczema or current history of allergic manifestations related to exposure to common immunoglobulin E (IgE)-mediated allergens in Sweden (tree pollen, grass pollen or furry animals). Current smoker was defined as reporting actual smoking in the interview (>1 cigarette/day), or ceasing smoking less than a year ago. Like most workplace buildings in Sweden, it was smoke-free.

Information on current symptoms

The medical questionnaire contained 10 rating scales on current ocular, nasal, throat symptoms, dyspnea, malodor, and systemic symptoms.[14,15] Answers were given on a 100-mm visual analogue rating scale (VAS scale) adapted from Kjellberg et al[16] and based on the Borg scale.[17] These scales have been used in previous exposure chamber tests on health effects of volatile organic compounds. Each scale has endpoints graded from "no perceived symptoms at all" (0%) to "intolerable symptoms" (100%). In addition, it has fixed points with verbal expressions at certain points of the line, with 7% meaning hardly any perceived symptom, 22% meaning some perceived symptom, and 50% meaning fairly considerable symptoms. It was administered on Monday and Wednesday.

Assessment of tear film stability

Tear film stability was estimated using a standardized method, self-reported BUT (SBUT), measuring the time the subject could keep his or her eyes open without pain while watching a fixed point at the wall. The method has been used previously and been shown to correlate well with the conventional fluorescine method for measuring tear film break-up time.[18] Moreover, it has been shown that SBUT is lower in

subjects reporting ocular symptoms.[6] Medication, diseases (including eye diseases), mascara, and lens-wearing were asked for at the time of testing, as well as asthma and asthma medication, but were all negated.

Acoustic rhinometry

Acoustic rhinometry (Rhin 2000; wideband noise; continuously transmitted) was applied to measure nasal patency. This method measures internal dimensions of the nasal cavity at different distances from the nose opening, by means of reflection of ultrasound. Smaller nasal volumes or cross-sectional areas indicate swelling of the nasal mucosa and nasal congestion. The measurements were made under standardized forms (sitting), after 5 minutes of rest. By means of acoustic reflection, the minimum cross-sectional areas (MCAs) on each side of the nose were measured from 0 and 22 mm (MCA1) and from 23 and 54 mm (MCA2) from the nasal opening. The volumes of the nasal cavity on the right and left sides were also measured from 0 and 22 mm (VOL1) and from 23 to 54 mm (VOL2). The mean values were calculated from 3 subsequent measurements on each side of the nose. Data on nasal dimensions in the present study are presented as the sum of the values recorded for the right side and the left side.

On Wednesday only, a third rhinometric measurement was performed 10 minutes after nasal decongestion (2 douches of 140 μg xylometazoline hydrochloride each, 5 minutes apart).[19] Reversible mucosal swelling was expressed as the rhinometric parameter value after decongestion minus the value before decongestion, divided by the value after decongestion, expressed as percent.

Nasal lavage

Lavage of the nasal mucosa was made using a 20-mL plastic syringe attached to a nose olive. The subjects were standing, with their head flexed ca 30° forward. The room-temperature (20°C to 22°C) sterile 0.9% saline solution was introduced into the nasal cavity. Each nostril was lavaged with 5 mL solution, which was flushed back and forth 5 times via the syringe at an interval of a few seconds. The fluid was transferred into a 10-mL polypropylene centrifuge tube. Samples were kept on ice and the solution was centrifuged within 300 minutes at 800 $\times$ g for 5 minutes. The supernatant was recentrifuged at 1,400 $\times$ g for 5 minutes and immediately frozen to −20°C. Lysozyme was analyzed by radioimmunoassay.[20] The concentrations of eosinophilic cationic protein (ECP) and myeloperoxidase (MPO) were measured by means of a double-antibody radioimmunoassay (Pharmacia Diagnostics, Uppsala, Sweden).[21,22] The intra- and interassay coefficients of variation for all 3 tests were less than 11%. Albumin was measured by the rate nephelometry on an Array protein system (Beckman Instruments). The analysis was done at the Department of Clinical Chemistry and Asthma Research Centre, University Hospital, Uppsala, Sweden.

Lung function tests

Respiratory function was studied by dynamic spirometry. Vital capacity (VC), forced vital capacity (FVC), peak expiratory flow (PEF), and forced expiratory flow in 1 second (FEV_1) were measured using a Vitalograph (Vitalograph, Buckingham, England), which was calibrated daily. In addition, FEV_1/FVC was calculated. All the tests were carried out by a trained nurse in a standardized way with the same spirometer. In order to avoid disturbance of nasal patency, a nose clip was not used. The measurements were performed 3 times on each subject, and the highest values were noted. A test was considered adequate when the deviation between the 2 best tests was less than 5%. The results were expressed as a percentage of normal values based on standardization to age, sex, and height using a reference material.

Test sequence

All physiological measurements and questionnaires were administered by a physician, using the same test sequence on both occasions (Monday and Wednesday). Moreover, smokers were not allowed to smoke for 1 hour before the test period, which lasted 15 minutes, during which the subjects answered the 2 symptom questionnaires and then participated in the SBUT test. After about 5 minutes, acoustic rhinometry was performed, followed by the nasal lavage and ending with the dynamic spirometry. No nose clip was used during the lung function measurements. The study was performed from 9:00 AM to 12:00 PM and from 1:00 PM to 3:00 PM. On Wednesday only, nasal mucosal decongestion was measured after all other investigations. The test sequence was identical in the external control group, except for the lung function measurements, which could not be performed.

Environmental measurements

The technical investigation comprised a building survey and measurements. The indoor measurements included room temperature, relative air humidity, illumination, carbon dioxide (CO_2), formaldehyde, VOC, respirable particles, and airborne microorganisms, both viable and total molds and bacteria. The measurements were performed during the same day as the medical investigation, both in the reference building on Monday and in the damp building on Wednesday. Outdoor measurements of temperature, air humidity, CO_2, respirable particles, and VOC were performed in parallel outside both buildings.

Room temperature and relative air humidity were measured by an Assman psychrometer. Respirable particles and CO_2 were recorded over 15-minute periods by direct reading instruments, the Sibata P-%H2 and Riken RI 411-A, respectively. The Sibata was calibrated at the factory (Sibata Scientific Technology, Tokyo); the Riken was calibrated at the

Department of Occupational and Environmental Medicine in Uppsala. Temperature, air humidity, respirable particles, and CO_2 were measured 12 times during each investigation day. Illumination was measured by a Hagner (EC1) instrument (L. Hagner, Solna, Sweden) on the desks of the office workers.

Indoor concentrations of formaldehyde were measured with glass fiber filters impregnated with 2,4-dinitrophenylhydrazine,[23] the air sampling rate being 0.2 L/min during 6 hours. The filters were analyzed by liquid chromatography, at the Department of Occupational Medicine, Örebro, Sweden. Volatile organic compounds (VOCs) were sampled on charcoal tubes (Anasorb 747), the air sampling rate being 0.2 L/min during 6 hours. The charcoal tubes were desorbed by 2 mL of carbon disulphide and analyzed for specific VOC, including butanols and 2-ethyl-1-hexanol, and total VOC (TVOC).[24] Airborne microorganisms were sampled on 25-mm nucleopore filters with a pore size of 0.4 μm and a sampling rate of 1.5 L/min for 6 hours. The filters were washed and part of the liquid was used to determine the total concentration of airborne molds and bacteria, respectively, using the CAMNEA method,[25] which is based on acridine orange staining and epifluorescence microscopy. Viable molds and bacteria species were cultivated on 3 media: tryptone glucose agar (TGEA), malt extract agar, and DG18 at 22°C (± 1°C). The incubation time was 7 days for all media and all microorganisms, with the exception of *Streptomyces* sp., for which the incubation time was 21 days. For statistical reasons, the number of viable microorganisms per m^3 of air is only reported by the laboratory if there are at least 3 colonies per plate. When there are 1 or 2 colonies per plate, species are identified but the level is reported as being below the detection limit (<70 colony forming units [cfu] per m^3 of air). The detection limit for total molds or bacteria was 8,000 organisms per m^3 of air. Two measurements of formaldehyde, VOC, and microorganisms were performed in each building.

Investigation of building material

Several building material samples were taken from the floor, wall, and roof of the damp building. Both total molds and bacteria were determined using the CAMNEA method, by which microorganisms are transferred to a solution via washing, and counts are achieved with epifluorescence microscopy, following staining with acridine orange.[25] Viable molds and bacteria were determined by incubation on two different media. We applied empirical reference values from the microbial laboratory where we analyzed for microbial growth. For mineral fiber insulation, we classified samples of less than 10^4 organisms/g insulation of total molds and bacteria as "normal" and samples of more than 10^6 organisms/g as "elevated." For gypsum board, wall paper, and wood samples, microorganisms were transferred to a solution by washing a predefined surface area. In such samples, normal values were less than 10^3 organisms/m^2, and samples with more than 10^5 organisms/cm^2 were classified as "elevated surface contamination."

In addition, a field laboratory emission cell (FLEC) was placed on the concrete floor surface after removing the linoleum floor covering to measure the emission profile of VOCs from the floor. The concrete floor surface had an upper surface of self-leveling mortar. In addition, presence of smell from floor samples was investigated as the relative humidity in the concrete. We collected VOCs by pumping air through Tenax adsorption tubes. The analysis of VOCs included thermal desorption and gas chromatography–mass spectrometry (GC-MS). The results from the individual VOCs and total VOC (TVOC) were given in microgram per square meter multiplied by the time in hours ($\mu g/m^2 \cdot h$). The emission factors (EFs) for 2-ethyl-1-hexanol, 1-butanol, and TVOC were compared with reference values from floors in healthy buildings and floors with known floor dampness according to the Swedish Building Research Council Report, 1994.[26] The EFs in "healthy" reference concrete floor surfaces were 9, 46, and 87 $\mu g/m^2 \cdot h$ for 2-ethyl-1-hexanol, 1-butanol, and TVOC, respectively. The EFs from previous objects with damp concrete floor surfaces with alkaline degradation of plasticizers were 841, 107, and 1150 $\mu g/ m^2 \cdot h$ for 2-ethyl-1-hexanol, 1-butanol, and TVOC, respectively.[26]

Statistical methods

Differences in VAS scales, nasal patency, and lung function before and after exposure to damp building were analyzed using Student's test for paired comparisons. As the biomarkers in nasal lavage fluid (NAL) and tear-film break up time (BUT) were not normally distributed, changes in these variables were analyzed using the Wilcoxon matched-pairs signed-rank test. Changes in symptoms, measured as a dichotomous outcome variable, were measured using McNemar's test. In addition, we compared changes of symptom ratings (VAS scales) in the intervention group with changes during the same weekday (Monday to Wednesday) in the external control group. Student's *t* test was applied for comparing changes in VAS scales and lung function data in the 2 groups. Mann-Whitney *U*-test was used for NAL biomarkers and BUT.

RESULTS

Indoor hygienic measurements

Room temperature was similar in the reference and damp workplace buildings and relative air humidity was low. Both buildings were well ventilated, with CO_2 levels well below the current ventilation standard of 1,000 ppm.[27] The mean personal outdoor air flow rate, estimated from the CO_2 levels, was 18 L/s in the control building and 31 L/s in the damp building. The indoor level of respirable particles was low in both buildings (5 to 9 $\mu g/m^3$) and similar to the outdoor air (8 $\mu g/m^3$). Moreover, the indoor concentration of formaldehyde was below the detection limit in both buildings

Table 1.—Indoor Climate and Indoor Exposures in the Damp Building, and the Control Building Without Building Dampness

	Control building			Damp building			
Type of exposure factor	*N*	*M*	min–max	*N*	*M*	min–max	Outdoor environment
Temperature (°C)	6	21.7	21.0–22.5	7	21.9	20.5–23.0	2
Relative air humidity (%)	6	35	33–37	7	26	23–30	100
Illumination (lux)	26	510	200–1000	30	410	100–1800	NA
Carbon dioxide (ppm)	6	630	550–850	7	510	450–580	390
Respirable particles (μg/m^3)	6	6	5–7	7	7	6–9	8
Formaldehyde (μg/m^3)	2	<5	< 5–5	2	<5	< 5– < 5	NA
2-ethyl-1-hexanol (μg/m^3)	2	<1	< 1– < 1	2	<1	< 1– < 1	<1
TVOC (μg/m^3)	2	74	73–74	2	61	52–69	50
Indoor microorganisms							
Viable bacteria (cfu/m^3)	2	110	70–150	1	70		NA
Total bacteria (10^3/m^3)	2	<8.0	< 8.0– < 8.0	1	<8.0		NA
Viable moulds (cfu/m^3)	2	150	70–230	1	<70		NA
Total moulds (10^3/m^3)	2	<8.0	< 8.0– < 8.0	1	<8.0		NA

(<5 μg/m^3) (Table 1). The total concentration of VOC (TVOC) was 74 μg/m^3 in the control building and 61 μg/m^3 in the damp building. The sum of butanols was 2.4 μg/m^3 in the control building, 2.1 μg/m^3 in the damp building, and 0.1 μg/m^3 in the outdoor air. Traces of 2-ethyl-1-hexanol (0.3 to 0.6 μg/m^3) in indoor air were found in air samples from the damp building but not in the dry building. The concentration of total and viable molds and bacteria was very low in all samples. Among viable species, *Penicillium* sp., *Steptomyces* sp., *Paecilomyces* sp., *Cladosporium* sp., and sterile mycelia could only be detected in the reference building. No viable species could be detected in the air samples from the building with dampness in the floor construction.

Investigation of building material

All 11 wall samples from wood materials and mineral fiber insulation contained normal levels of microorganisms. Identified species included *Bacillus* sp., *Ulocladium* sp., *Trichoderma* sp., *Penicillium* sp., and *Cladosporium* sp. The mean EFs from 3 FLEC samples from concrete floor surfaces were 690, 2310, and 90,000 μg/m^2·h for 2-ethyl-1-hexanol, 1-butanol, and TVOC, respectively. The EFs for 2-ethyl-1-hexanol, 1-butanol, and TVOC were well above (>100 times) the reference values in dry buildings in all samples, and also higher than previously reported EF values from known damaged floor constructions with casein containing floor putty. The mean EFs for the plasticizer compounds Texanol (2,2,4-trimethyl-1,3-pentanediol monoisobutyrate) and TXIB (2,2,4-trimethyl-1,3-pentanediol diisobutyrate) were low: 5 and 22 μg/m^2·h, respectively. The relative humidity in the upper part of the concrete on the second floor was 63% to 73%, which is somewhat higher than the normal range of 50% to 60% to be expected in a 11-year-old building. A strong smell of plasticizers could be noticed from all sampling points in the floor construction.

Personal factors and home environment

Seventeen of the 19 participants were women (94%), and the mean age was 42 years. All subjects were nonsmokers, 26% were ex-smokers, 26% reported hay fever, 16% reported allergy to furry pets, and 37% had a history of atopy (pollen or pet allergy or childhood eczema). None had a history of asthma, doctor's diagnosed asthma, or medication. Three had dwellings that were painted indoors with water-based paints during the last 12 months, but none had regular environmental tobacco smoke (ETS) exposure (>1 time/week) at home. None reported any signs of mold growth, mold odor, water leakage, or dampness in floor construction at home. Seven participants had furry pets, including 5 cats, 5 dogs, and a guinea pig.

VAS scales

After 2 days of reexposure in the damp building, a pronounced and significant increase of ocular, nasal, and throat symptoms was noted, as well as a perception of intoxication when analyzing the 100 mm VAS scales (Table 2). The results were similar regardless of whether the significance test was performed by Student's *t* test or by a nonparametric test. The most common symptoms after reexposure were ocular, nasal, throat, a sensation of catching a cold, headache, fatigue, and facial itching.

When analyzing changes in the control group only, there was a nonsignificant (3 to 6 mm) reduction of most symptoms from Monday to Wednesday, and a significant but minor reduction of throat symptoms by 5 mm ($p < .05$). When comparing changes in the intervention group with changes during the same weekdays in the external control group,

Table 2.—Average Ratings on 10 Questions[a] Before and After 2 Days of Reexposure in a Damp Building

	Intervention group ($N = 18$)[b]					Change during the week in				
	Before reexposure		After reexposure			Intervention group		External controls[d]		
Type of rating	M	SD	M	SD	2-tailed p value[c]	ΔM	SD	ΔM	SD	2-tailed p value[e]
1. Ocular irritation	16	22	42	26	.001	26	25	1	16	.005
2. Nasal irritation	18	27	36	29	.007	18	22	−6	14	.002
3. Throat irritation	16	21	33	28	.009	16	21	−5	8	.002
4. Difficulty in breathing	5	8	11	13	.16	6	15	−5	9	.03
5. Odour	2	3	13	21	.07	11	21	−5	17	.04
6. Headache	12	19	22	24	.25	10	31	−5	9	.10
7. Fatigue	22	20	36	29	.11	13	30	0	23	.20
8. Nausea	2	3	5	9	.22	3	9	−3	7	.04
9. Dizziness	4	7	8	9	.19	4	11	−4	18	.19
10. Intoxication	2	3	10	11	.02	8	12	−3	10	.009

[a]Visual analogue rating scales 0 to 100 mm (Nihlen et al[15])
[b]Symptom rating at both times available from 15 subjects.
[c]Calculated by Student's t test for paired comparison.
[d]External control group of 15 office workers staying in the same workplace building during the week.
[e]Calculated by Student's t test for 2 groups
M, SD = arithmetic mean with standard deviation; ΔM, SD = arithmetic mean change with standard deviation.

there was a significantly greater increase of ocular, nasal, and throat irritation, as well as difficulties in breathing, nausea, and perception of intoxication (Table 2).

Physiological signs

There was a significant decrease of anterior nasal volume (VOL2) and a significant but slight (2%) decrease of VC and FEV_1 after reexposure to the damp building, but no increase of any NAL biomarker (Table 3). For ECP, 3 samples on Monday and 5 samples on Wednesday were below the detection limit. For MPO, 13 samples on Monday and 11 samples on Wednesday were below the detection limit. For lysozyme, all samples were well above the detection limit. For albumin, 17 samples on Monday and 13 on Wednesday were below the detection limit.

When analyzing changes in the control group only, there was a numerical but nonsignificant decrease of albumin and MPO and a significant increase of posterior nasal patency ($p < .01$) from Monday to Wednesday. There was no significant change in SBUT or anterior nasal patency. When comparing changes in the intervention group with changes during the same weekdays in the external control group, there was a significantly greater increase of NAL albumin and VOL2 in the intervention group, as compared to the control group (Table 3).

Finally, we analyzed the associations between changes in NAL biomarkers and nasal patency during the week and the degree of nasal decongestion after application of adrenergic spray at the end of the investigation. This was analyzed in the intervention group only. Increase of MPO was related to decreased MCA2 and increased decongestion of MCA2 and VOL2. Increase of albumin was related to decrease of MCA2 ($p = .05$) (Table 4).

COMMENT

We were able to demonstrate that in office workers reexposed to a well-ventilated workplace building with a history of dampness in the floor construction, there was an increase in mucosal symptoms, dyspnea, and certain general symptoms, accompanied by less posterior nasal patency and a slightly reduced lung function. The physiological methods applied have been previously used in epidemiological studies.[28] The use of an external control group enabled us to control for weekday effects. There were no signs of microbial growth in any building materials and the total volatile organic compounds (TVOC) levels in the air were low.

The participation rate was high, which would have minimized selection bias. It was not possible to perform a "blinded" study, and although awareness of the exposure may have influenced symptom reporting, it is less likely to influence physiological measurements. The study was small, which might motivate caution about the interpretation of the results, but it is one of the few available intervention studies in damp buildings. Another limitation could be confounders such as home environment, but there were no reports on dampness, mold growth, or environmental tobacco smoke (ETS) in any residence, and only a few had recently painted the interior of their homes. Moreover, home environmental factors remained constant during the intervention period. Thus, it is less likely that they would affect the validity of the study.

Table 3.—Physiological Data Measured Before and After 2 Days of Reexposure to a Damp Building

	Intervention group ($N = 18$)[a]					Change during the week in				
	Before reexposure		After reexposure			Intervention group		External controls[d]		
Physiological parameters	*M*	*SD*	*M*	*SD*	2-tailed *p* value[b,c]	Δ*M*	*SD*	Δ*M*	*SD*	2-tailed *p* value[e,f]
Tear film stability SBUT	18	18	14	12	.07	−4	14	−1	6	.46
NAL biomarkers										
ECP	1.1	.7	1.0	.4	.12	−.1	.7	−.4	1.8	.15
MPO	6.4	12.7	5.3	6.1	.21	−1.1	12.3	−5.7	21.0	.12
Lysozyme	1.14	1.17	1.12	1.24	.38	−.03	1.6	−1.04	3.54	.59
Albumin	2.0	1.9	2.1	1.5	.16	.2	2.1	−3.2	6.1	.02
Rhinometric data										
MCA1 (cm^2)	1.15	.26	1.10	.24	.46	−.04	.23	.05	.19	.26
MCA2 (cm^2)	1.54	.38	1.42	.64	.45	−.11	.60	.16	.19	.12
VOL1 (cm^3)	3.99	.62	3.92	.53	.43	−.07	.34	.19	.37	.06
VOL2 (cm^3)	9.36	2.32	7.93	2.06	.03	−1.43	2.39	1.06	1.34	.001
Lung function data										
VC (% predicted)	106	9	104	10	.03	−1.5	2.6	NA		NA
FEV_1 (% predicted)	105	11	103	11	.03	−1.5	2.8	NA		NA

[a]SBUT, NAL-biomarkers, rhinometric data, and lung function data at both times available from 18, 16, 17, and 17 subjects, respectively.
[b]Calculated by Student's *t* test for paired comparison for rhinometric and lung function parameters.
[c]Calculated by Wilcoxon matched pairs signed rank test for BUT and NAL biomarkers.
[d]Change in external control group of 15 office workers staying in the same workplace building during the week.
[e]Calculated by Student's *t* test for 2 groups for rhinometric and lung function parameters.
[f]Calculated by Mann-Whitney *U*-test for BUT and NAL biomarkers.
M, SD = arithmetic mean with standard deviation; Δ*M, SD* = arithmetic mean change with standard deviation.

Table 4.—Change of Rhinometry[a] and Nasal Decongestion[b] in Relation to Change of Biomarkers in Nasal Lavage,[c] After Intervention ($N = 18$)[d]

	Change of NAL-Biomarker in the intervention group			
	ECP	MPO	Lysozyme	Albumin
Change of rhinometry				
MCA1	−0.13	−0.23	−0.15	−0.36
MCA2	−0.29	−0.43*	0.07	−0.42(*)
VOL1	−0.13	−0.35	−0.05	−0.23
VOL2	−0.13	−0.30	−0.03	−0.30
Nasal decongestion[e]				
ΔMCA1 (%)	0.27	−0.33	−0.22	0.33
ΔMCA2 (%)	0.22	−0.50*	−0.16	0.36
ΔVOL1 (%)	0.11	−0.33	0.05	0.14
ΔVOL2 (%)	0.19	−0.43*	−0.18	0.30

*$p < .05$; (*)$p = .05$.
[a]Rhinometric value after re-exposurew minus value before reexposure.
[b]Nasal decongestion (%) by adrenergic nasal spray after reexposure.
[c]Concentration after reexposure minus concentration before reexposure.
[d]Correlation coefficients (Kendals Tau-beta) with 2-tailed *p* values given in the table.
[e]Calculated as value after decongestion minus value before decongestion, divided by value after decongestion, expressed as %.

There are few studies on ocular effects of building dampness. One increase of ocular symptoms has been reported, in a comparison between hospital workers in buildings with floor dampness and emission of 2-ethyl-1-hexanol and those in dry control buildings.[6] Finally, one intervention study reported increased ocular symptoms and reduced tear film stability after 2 days' reexposure to a damp office building with a history of flooding.[29]

In our study, we found an increase of nasal symptoms, decrease of nasal patency, and an association between nasal congestion and MPO in NAL. This indicates that building dampness with emissions of 2-ethyl-1-hexanol may cause neutrophilic inflammation in the nasal mucosa, a conclusion supported by some, but not all previous studies. In one office study, there was an increase of ECP, MPO, and albumin in NAL among office workers in a building with pronounced microbial growth, including *Stachybotrys* spp. and emission of 2-ethyl-1-hexanol.[30] An increase of ECP, lysozyme, and albumin but not MPO in NAL was observed among school personnel in a school building with water leakage in the roof, as compared to schools with no building dampness.[31] An increase of nasal symptoms and lysozyme but not MPO in NAL was reported in a study of hospital workers working in geriatric hospitals with dampness in the floor construction and emission of 2-ethyl-1-hexanol.[6]

Our study was not designed to identify the causative factor in the building with dampness in the floor construction, but a pronounced smell of plasticizers from drilled holes in the

floor construction was noted. Moreover, we could measure increased emission of 2-ethyl-1-hexanol and 1-butanol from the concrete and self-leveling mortar in the floor construction. All material samples from the wall construction contained normal levels of microorganisms in the damp building. Moreover, the air measurements did not reveal any obvious contrast of exposure to microorganisms, formaldehyde, or VOC, when comparing the damp building with the control building. The relative air humidity was 26% in the control building and 30% in the damp building. Such a small difference in air humidity is unlikely to explain the observed health effect of the reexposure. In a previous experimental air humidification study in geriatric hospitals, an 8% increase of relative humidity (RH) reduced dermal symptoms but had no effect on other symptoms or tear film stability, nasal patency, or nasal biomarkers.[32]

Traces of 2-ethyl-1-hexanol (0.3-0.6 $\mu g/m^3$) in indoor air were found in air samples from the damp building but not the dry building. The odor threshold for 2-ethyl-1-hexanol is much higher (245 ppb or 1320 $\mu g/m^3$),[33] suggesting that the observed health effects were not mediated by odor perception of this compound. There is some experimental evidence that 2-ethyl-1-hexanol can cause ocular and nasal mucosal effects. One experimental exposure chamber study in 24 subjects exposed to 1.5 to 42 ppm (8,000 to 220,000 $\mu g/m^3$) 2-ethyl-1-hexanol for 4 hours showed a dose-related increase of ocular and nasal symptoms, reduced nasal flow, and increase of substance P in NAL.[34] Moreover, the sensory irritation potential, calculated as 3% of the RD_{50} value, is estimated to be 7,000 $\mu g/m^3$.[35] These exposure levels are much higher, however, than the levels of 2-ethyl-1-hexanol in indoor air found in our study. The compound 2-ethyl-1-hexanol is emitted from plastic material, including new computers.[36] Moreover, 2-ethyl-1-hexanol can be emitted by degradation of 2-ethylhexylacrylate, leaving acrylic acid as a by-product. Increased indoor levels of this compound are associated with alkaline degradation of the plasticizer di-etyl-hexyl-phtalate (DEHP) in damp floor constructions.[6,10,12] During this degradation, other compounds such as monoethyl-hexyl phthalate (MEHP) are produced. Moreover, it has been suggested that microbes can degrade phthalate plasticizers,[37] with consequent formation of 2-ethyl-1-hexanol and 2-ethylhexanoic acid.[38] Because we did not find any increased levels of molds or bacteria in material samples from the floor construction, and none of the floor coatings were PVC, the most likely source is degradation of the acrylate in the water-based glue used to fix the linoleum carpet floor. Because health effects were observed despite only traces of 2-ethyl-1-hexanol in the air, further studies are needed to study exposure levels of by-products from the alkaline degradation, including particle-bound levels.

In conclusion, subjects previously exposed over several years to a building with floor dampness and increased levels of 2-ethyl-1-hexanol in the floor construction reported an increase of ocular, nasal, and throat symptoms, and reduced nasal patency after 2 days of reexposure. There were indications of an association between the nasal mucosal swelling and mild neutrophilic inflammation. The results indicate that quasi-experimental studies with physiological measurements can be a useful method for studying the mechanisms behind observed health impairments in damp buildings. From a preventive point of view, chemical degradation of building material due to building dampness should be avoided. There is a need to minimize dampness in floor construction and avoid a combination of building material that causes an increased emission of 2-ethyl-1-hexanol. The lack of any obvious exposure contrast in air samples from the damp building as compared to the control building illustrates the limitations of air measurements of exposures in damp buildings. Moreover, we have had several patients who have experienced increased levels of 2-ethyl-1-hexanol of this kind in floor construction but where there were low levels in air samples and reports of increased mucosal symptoms nonetheless. If possible, building materials that have been exposed to increased humidity levels should be analyzed for increased levels of microorganisms or dampness-related chemical compounds, using dry building materials as reference material for accurate information.

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