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Office characteristics and dry eye complaints in European workers—The OFFICAIR study

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ABSTRACT

Objectives: Ocular discomfort is a prevalent health complaint in offices. It is hypothesized that, in addition to individual and occupational factors, the buildings' indoor environment may affect eye complaints. However, insight in potential building-related causal factors, needed to allow development of effective prevention strategies in building design, operation and maintenance is limited. This study aimed to investigate the relations between modern office building characteristics and dry eye complaints.
Methods: Comprehensive characteristics of 167 office buildings in eight European countries, were linked to questionnaire data from 7441 office workers. Multilevel modeling was applied to explore relations between building characteristics and self-reported dry eye complaints, in a cross-sectional study.
Results: Among office workers investigated, 34% declared dry eye complaints during the past four weeks. Majority of workers (91.2%) experiencing these symptoms, reported improvement on days away from the office. After full adjustment, the regression model revealed a significant increased risk for: proximity (<100 m) to potential sources of outdoor air pollution (OR: 1.41, 95% CI: 1.06–1.88), absence of operable windows (OR: 1.70, 95% CI: 1.34–2.16), portable humidifiers in the offices (OR: 1.58, 95% CI: 1.18–2.11), exposed concrete and/or plaster (OR: 1.29, 95% CI 1.02–1.62) and dispersion and/or emulsion paint as wall covering in offices (OR: 1.20, 95% CI: 1.01–1.41). A negative association was found for cleaning surfaces at least once per week (OR: 0.75, 95% CI: 0.61–0.91).
Conclusions: Building characteristics were associated with dry eye complaints of office workers. Focused studies are recommended to investigate underlying causes to prevent these symptoms.

1. Introduction

Exposure to adverse indoor environmental conditions may affect occupants in office buildings. Large studies, such as the US EPA Building Assessment Survey Evaluation (BASE study), the European Audit Project, the European Health Optimization Protocol for Energy-Efficient Buildings (HOPE), and the British Whitehall II study, have provided insight in the substantial prevalence of health and comfort complaints in office buildings [1–4]. These inventories

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identified ocular discomfort (including dry, irritated or itchy eyes) amongst the most reported health complaints from office workers.

There are indications that the prevalence of these symptoms may be related to circumstances inside the building, where occupational and/or environmental factors may play a role: Not only have large differences been observed in symptom prevalence between office buildings [5]. In addition, previous studies have indicated that a majority of respondents reporting these complaints, report that the symptoms tend to decrease in severity, or even completely disappear when away from the office building [1,2,6].

The etiology of ocular discomfort in office environments is multifactorial, and is expected to include individual, occupational and environmental risk factors [7]. These factors may exert effects additively or through complex interactions. Relations may be confounded or modified by aspects of the psychosocial environment [3,8–10].

Individual risk factors for eye symptoms include e.g. age [11], gender [12], smoking status [13], and alcohol consumption [14]. While the relation between certain individual risk factors and eye symptoms is well established, it is unlikely that these factors alone can explain the differences in symptom prevalence between buildings.

Amongst prominent *occupational risk factors* in office workers, is the intensity of visually and cognitively demanding 'visual display unit (VDU) work' [7,15–17]. Also, certain work task related exposures have been associated with perceived eye symptoms, such as e.g. the use of carbonless paper [9]. In analogy to individual risk factors however, it seems unlikely that differences in occupational risk factors alone, could explain the prevalence differences between buildings.

Prominent *environmental risk factors* include the buildings' microclimate (high temperature, low humidity, and air velocity) [18–20]. In addition, lighting conditions may play a role [7,18,21]. Furthermore, it has been hypothesized that exposure to the indoor mixture of gaseous and particulate air pollution (originating from indoor and outdoor sources) may affect ocular (dis)comfort [7].

Building characteristics, including aspects of building design (e.g. building materials, installations, construction, office layout), operation and maintenance, may adversely affect ocular discomfort, directly or indirectly, e.g. through influencing these indoor environmental conditions.

To date, still little is known on building characteristics which may play a role into exacerbating these complaints. To our knowledge, very few studies exist that *integrally* investigated which physical characteristics of office buildings, are associated with dry eye complaints [22,23]. Such studies are needed to get clues to potential underlying causes, and to get insight in what might be promising directions towards practical abatement measures, to reduce the prevalence of these complaints in office buildings.

Within the framework of the EU project OFFICAIR, a large field investigation was carried out, resulting in an extensive database that comprises not only data about physical building characteristics, but also on individual and occupational factors as well as on health symptoms. Thus, the aim of this study was to investigate the associations between the office environment (especially physical building characteristics) and self-reported dry eye complaints, taking into account individual and occupational risk factors, as a first important step towards unravelling the office related causes of dry eye symptoms.

2. Methods

2.1. Study population and study design

OFFICAIR is a European collaborative project. The procedure is described in detail elsewhere [5], and is therefore only briefly be summarized here. A cross-sectional study was performed during the winter of 2011–2012, collecting data from 167 office buildings in eight European countries (Greece, France, Finland, Hungary, Italy, Portugal, Spain and the Netherlands) simultaneously with questionnaire data from 7441 office workers.

Office buildings were selected based on a range of criteria including: new or recently retrofitted buildings (e.g. preferably <10 years old, use of modern equipment and access to internet), operating in their current form for a minimum of 1 year prior to the start of the study (preferable 2 years), with no major renovation planned before the autumn of 2012. All office workers received an email invitation to participate to an online digital questionnaire. Office workers that gave their informed consent participated. The digital questionnaire could be complemented within two weeks after the invitation was sent. A reminder was sent to all invited workers.

2.2. Worker questionnaire

The digital questionnaire was voluntary, anonymous and available in the national language of the participating countries. It was based on standardized and validated questionnaires such as the HOPE questionnaire [4] and the effort reward imbalance and overcommitment questionnaires [24]. Socio-demographic data (e.g. sex, age, education level), lifestyle (e.g. smoking status, alcohol consumption), work related data (e.g. VDU use), psycho-social environment (work-related stress), and health complaints were collected.

The health outcome of interest was the occurrence of dry eye complaints defined by the following question: '*During the past four weeks, on how many days did you experience dry eyes when you were at work at your workstation (including today)?* The answer options ranged from '*not in the last 4 weeks*', '*1–3 days in the last 4 weeks*', '*1–3 days per week in the last 4 weeks*', and '*every or almost every workday*'. This questionnaire item was dichotomized into: *"Dry eyes experienced during the past four weeks?"* (Yes/No). In case of a positive answer, the following separate question was asked for '*Was it better on days away from the office (e.g. holidays, weekend)?*'.

2.3. Building checklist

Data on physical building characteristics were collected by a checklist filled out for each office building by a local investigator of the OFFICAIR consortium along with a building manager. Parameters potentially affecting different indoor environmental conditions (e.g. indoor air quality, air velocity, temperature, humidity, lighting conditions) were included in this checklist, such as: The outdoor environment (e.g. busy road, rural/surroundings), the building (construction materials (e.g. type of ceiling/floor/wall coverings), ventilation (e.g. type of ventilation, ventilation rates, re-circulating air, cleaning of ducts, localization of outdoor air intake), heating and cooling (e.g. type, control of temperature and humidity), lighting conditions (e.g. solar protections, type of artificial light, way of controlling main lights), the equipment (e.g. placement of printers), and cleaning services (e.g. cleaning frequencies of floor/surfaces, moment of cleaning, use of chemicals).

A total of 143 questions related to building characteristics were asked in the checklist.

2.4. Data analysis

2.4.1. Multilevel modelling strategy

In the exploration of the relations between physical building characteristics and dry eyes, a multilevel modelling strategy was used. Data were structured into three levels: office workers (level 1) clustered within the 167 buildings (level 2), clustered in the 8 European countries (level 3). The associations between self-reported dry eyes in the last 4 weeks and physical building characteristics were examined using multilevel logistic regression analysis taking into account the hierarchical structure using building and country as random effect and covariates as fixed effects. The deviance for the three level multilevel model which accounts for variation across countries and buildings was compared with a two-level model. The multilevel modelling process was stepwise.

The *first model*, an empty model (the intercept-only model), was without any determinant variable, i.e. a simple component of variance analysis (assessment of building-level, country-level variance in dry eyes across all). In the *second model* individual-level variables were added. At individual level, known and suspected dry eyes risk factors were taken into account in the model, including: gender, age (centered age and expressed per 5 years increase), level of education (categorized into: 1/none, primary school or less, 2/secondary school, 3/professional, 4/university, college or equivalent, 5/Master, PhD or specialization), smoking status (never, former or current), alcohol consumption (yes, no), number of hours working with a VDU (categorized into: no, less or 25 h per week, more than 25 h per week − 25 h is the first quartile of the number of hours working with VDU among VDU users). In addition, the psychosocial work environment was considered through the components of the effort reward model: effort/reward and over-commitment. Items to assess effort (5 items), reward (11 items) consisted of yes/no questions followed by 4-point Likert scales. Meanwhile, over-commitment was assessed with 6 items using only a 4-point Likert scale. The effort reward ratio was calculated as effort score used as the numerator and reward score multiplied by a correction factor of [5/11] to adjust for the number of items as denominator [24]. An effort reward ratio score of 1 represents a balance of effort and rewards, and higher scores reflect disproportionate effort. Over-commitment items were summed, higher scores indicate greater over-commitment. Effort-reward ratio was log-transformed and over-commitment without any transformation was included in the model. In the *third model* each building characteristic has been iteratively added to the second model to determine which variables were associated with dry eyes. All variables with a *P*-value below 0.2, with less than 25% of missing data and those with the strongest *P*-value if correlated ($r \geq 0.70$) with the outcome variable, were retained to be included in the next model. The *fourth model* included individual- and building-level determinants. The final model was obtained by eliminating variables associated with a *P*-value above 0.20. The linearity assumption of continuous variables has been checked by converting continuous variables into categories and using fractional polynomials. If the linear assumption was not satisfied even with transformation (e.g. logarithmic) or using quadratic or higher terms, continuous variables were categorized into categories.

The potential effect modification by psychosocial work environment was also examined.

The measures of association (fixed effects) were reported as odds-ratio (ORs) with their 95% confidence interval (CIs). The measures of variation (random-effects) included variance, intra-class correlation coefficient (ICC) and median odds ratio (MOR). MOR is a measure of unexplained cluster heterogeneity [25]. The amount of variance explained was calculated by the proportional change in variance (PCV), i.e. the percentage change from the estimated variance in the null model as a result of incorporating new factors in the model. The equation of the proportional change is $PCV = (V_0 - V_1)/_{V_0}$ where V_0 is the initial variance at country or building level (in the empty model) before any adjustment and V_1 is the country or building level residual variance after adjustment for covariates. The proportions of total variance related to country and building factors were estimated by the ICC using the formula $ICC = V/\left(V + \frac{\pi^2}{3}\right)$ where $V = V_0$ or V_1 and $\frac{\pi^2}{3}$ is the fixed variance at the office worker level as suggested by Snijders and Bosker [26]. Finally, a log-likelihood ratio test was applied, to analyze whether the model fit increased after controlling for individual-level and building-level determinants. The main additional relative fit criterion taken into account in the modelling process was minimization of the Akaike information criterion (AIC) and Bayesian information criterion (BIC).

2.4.2. Sensitivity analysis

Since buildings with a limited number of participants (less than 20 participants) may have affected the results, a sensitivity analysis was performed, excluding those buildings from the analyses.

The multilevel models were fitted with STATA statistical software (release 13.0; Stata Corporation, College Station, TX, USA). The statistical significance of covariates was calculated using the Wald test. All significance tests were two-tailed and statistical significance was defined at the 5% alpha level. All multilevel logistic regression models were fitted to the data using the adaptative Gauss-Hermite likelihood approximation.

3. Results

3.1. Characteristics of the study population

Table 1 shows the general characteristics of the study population. The study population included 7441 office workers, of which 52.1% was female and 47.9% male. Most of the office workers were highly educated (university, college or equivalent, master, PhD or

Table 1
General characteristics of the study population in OFFICAIR (N = 7441).

Characteristics	n (%)
Participants per country	
The Netherlands	1014 (13.6)
Italy	809 (10.9)
Portugal	508 (6.8)
Spain	698 (9.4)
Greece	1020 (13.7)
Finland	793 (10.7)
Hungary	1409 (18.9)
France	1190 (16.0)
Sex	
Men	3561 (47.9)
Women	3880 (52.1)
Age (years), mean (SD)	40.3 (10.1)
Level of education	
Master, PhD or specialization	2322 (31.4)
University, college or equivalent	3205 (43.3)
Professional	625 (8.5)
Secondary school	1117 (15.9)
Primary school or lower	68 (0.9)
Smoking status	
Current	1463 (20.0)
Former	1815 (24.7)
Never	4057 (55.3)
Alcohol consumption	
Yes	4733 (64.1)
No	2646 (35.9)
Hours working with a VDU, on average per week, mean (SD)	22.9 (16.7)
Effort reward ratio, mean (SD)	0.5 (0.3)
Over-commitment, mean (SD)	13.7 (3.5)

Except for age, hours working with VDU (visual display unit), effort-reward ratio and over-commitment, all values shown are numbers (percentages).
Number of office workers may vary because of missing information.
Abbreviation. SD, Standard deviation.

specialization). The mean (SD) age was 40.3 (10.1) years, with a broad age range: the youngest office worker was 16 and the oldest was 82. A total of 167 office buildings were included and the number of respondents per country ranged from 508 to 1409 (and ranged from 3 to 216 respondents per building). Participating office workers worked on average 36.7 (10.0) hours per week in the office environment. They operated a VDU on average 22.9 (16.7) hours per week. Concerning psychosocial work environment, the means of the effort reward ratio and over-commitment were equal to 0.5 (0.3) and 13.7 (3.5), respectively. Among all office workers investigated, complaints of dry eyes '*during the four past weeks*' were reported by 34% of them, and 91.2% of the office workers declared that complaints were better on days away from the office. The building mean prevalence of dry eyes was 30.5%, and ranged from 21.5% in Greece to 39.1% in the Netherlands, Fig. 1.

3.2. Relations between characteristics of office buildings and dry eye complaints

The variances in dry eyes among the countries and the buildings were 9% and 20%, respectively (results from Model 1, the empty model). After inclusion of individual variables (i.e. gender, age, level of education, smoking status, alcohol consumption, hours working with VDU, effort reward imbalance and over-commitment), the variances in dry eyes were 13% and 20% at country and building levels, respectively (Model 2). Table 2 presents the associations (with a P-value < 0.2) between dry eyes and the physical building characteristics entered iteratively to the model after adjustment for individual variables (Model 3). The strongest associations (P-value ≤ 0.01) were found for: general building characteristics (e.g. positive associations for number of occupants and floor area), construction materials (e.g. negative association for stone/ceramic as a floor covering), ventilation related aspects (e.g. positive association for 'No operable windows'), some other sources of indoor air pollution (e.g. location of printers and/or copy machines). Significant relations (0.01 < P-value < 0.05) were found for lighting characteristics (e.g. negative association for individual control of solar shading devices) and cleaning activities (e.g. negative association for frequency of surfaces dusted). In addition, a significant positive association was found with building procedures (e.g. a documented complaint procedure for problems of the indoor environment).

In Table 3, results from the multilevel logistic regression analyses are shown after adjustment for all covariates – individual and building characteristics (Model 4). The PCV indicates that 79.8% of the initial variance in dry eyes between buildings were explained by the covariates included in the model (between buildings variance was equal to 4.0% in the fourth model). After adjustment, a positive answer to the building checklist item "*proximity (i.e. < 100 m) to potential sources of outdoor air pollution that might influence the indoor environment* (yes, no)" was positively associated to dry eyes complaints (adjusted OR 1.41, 95% CI: 1.06–1.88). An increased risk for dry eyes complaints was found for absence of operable windows (adjusted OR 1.70, 95% CI: 1.34–2.16), portable humidifiers in the offices (adjusted OR 1.58, 95% CI 1.18–2.11), availability of a documented complaint procedure for occupants with problems relating to the indoor environment (adjusted OR 1.50, 95% CI 1.26–1.79). Concerning wall coverings in the offices, dry eyes was positively associated with exposed concrete and/or plaster (adjusted OR 1.29, 95% CI: 1.02–1.62) and dispersion and/or emulsion paint (adjusted OR 1.20, 95% CI: 1.01–1.41). High number of occupants and the presence of a cooling system, the presence of printers in a separate room (compared to 'on the corridor') tended to increase the risk of dry eyes (P-value < 0.20). Conversely, cleaning surfaces in the offices at least once per week was negatively associated with dry eyes (adjusted OR 0.75, 95% CI: 0.61–0.91).

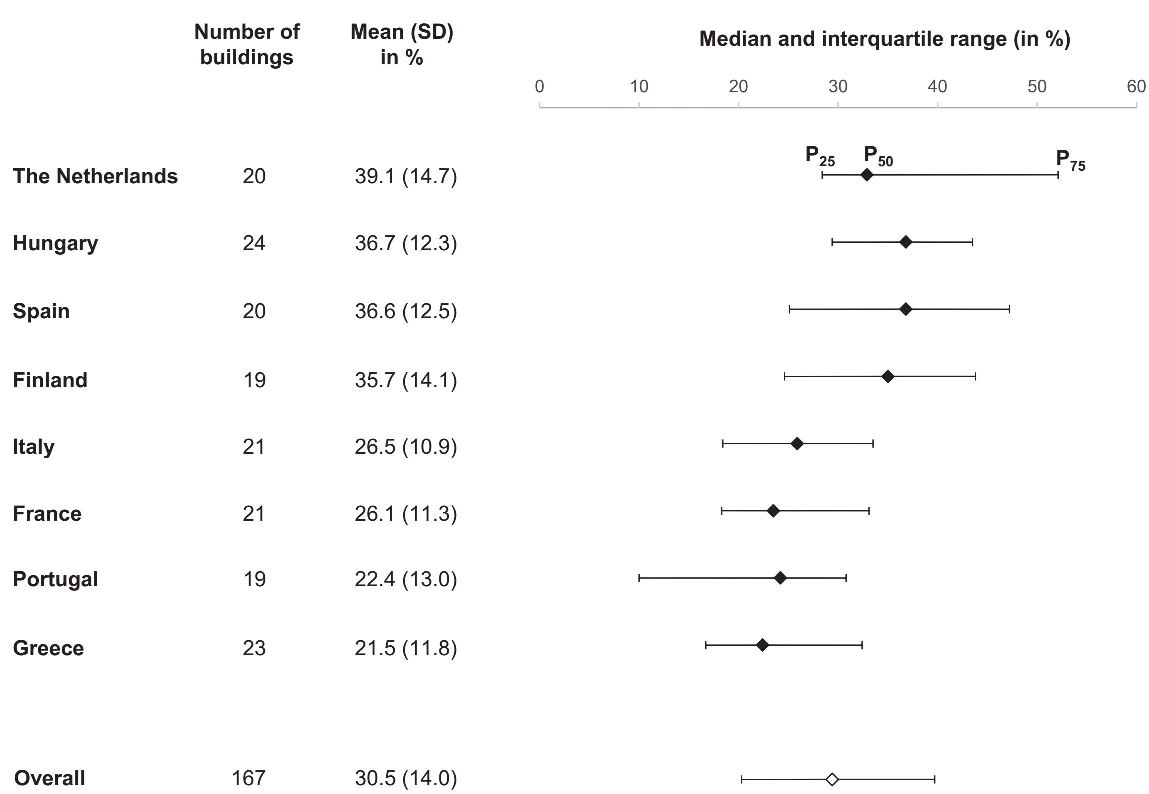

Fig. 1. Mean (SD: standard deviation) and median (P25-P75: 25th and 75th percentile) prevalence of dry eye complaints at building level.

Table 2
Relations[a] between dry eye complaints and physical building characteristics (results from the multilevel logistic regression analyses[b]) in OFFICAIR study.

Characteristics	n_1/N_1	n_2/N_2	OR (CI 95%)	*P*-value
General building description and building procedures				
Mixed industrial/residential area (vs. industrial area)	696/7441	14/167	0.86 (0.56–1.32)	0.494
Commercial area (vs. industrial area)	789/7441	18/167	1.32 (0.90–1.93)	0.154
Mixed commercial/residential area (vs. industrial area)	2279/7441	50/167	0.94 (0.68–1.30)	0.725
City centre, densely packed housing (vs. industrial area)	1344/7441	30/167	1.07 (0.75–1.52)	0.726
Town, with no or small gardens (vs. industrial area)	328/7441	8/167	0.71 (0.41–1.24)	0.230
Suburban, with larger gardens (vs. industrial area)	864/7441	22/167	**0.65 (0.44–0.95)**	**0.028**
Village in a rural area or rural area with no or few other homes nearby (vs. industrial area)	216/7441	7/167	0.83 (0.47–1.46)	0.519
Nearby (within 100 m) potential sources of outdoor air pollution (vs. no)	6888/7441	149/167	1.40 (0.99–1.98)	0.060
Attached garage (within 100 m) as a potential source of outdoor air pollution (vs. no)	1470/7441	26/167	1.19 (0.92–1.55)	0.177
Typical number of occupants[c]				
Between 71 and 170 (vs. ≤ 70)	2356/7438	55/166	**1.27 (1.01–1.61)**	**0.043**
> 170 vs. (≤70)	3664/7438	53/166	**1.69 (1.34–2.14)**	**<0.001**
Maximum number of occupants[c]				
Between 101 and 250 (vs. ≤ 100)	2288/7260	56/163	1.18 (0.93–1.49)	0.170
> 250 (vs. ≤ 100)	3544/7260	51/163	**1.70 (1.35–2.15)**	**<0.001**
Total floor area (in m^2)[c]				
Between 1441 and 3210 (vs. ≤ 1440)	2300/7234	53/160	1.27 (0.98–1.66)	0.071
> 3210 (vs. ≤ 1440)	3341/7234	54/160	**1.45 (1.11–1.90)**	**0.007**
Number total of storeys occupied[c]				
5, 6 storeys (vs. ≤ 4)	1671/7415	33/165	1.18 (0.92–1.52)	0.203
> 6 storeys (vs. ≤ 4)	2889/7415	55/165	1.26 (1.00–1.60)	0.051
Façades with adjacent buildings				
Two façades (vs. one façade)	1932/4664	37/102	1.31 (1.03–1.67)	**0.029**
Three façades (vs. one façade)	288/4664	9/102	1.16 (0.74–1.80)	0.492
Pesticide treatment plan (vs. no)	4890/7362	99/164	**1.26 (1.00–1.58)**	**0.045**
A documented complaints procedure for occupants with problems of the indoor environment (vs. no)	5112/7349	99/165	**1.65 (1.35–2.03)**	**<0.001**
Construction materials				
Stone, ceramic as floor covering in the offices (vs. no)	1755/7441	51/167	**0.74 (0.58–0.93)**	**0.010**
Exposed concrete, plaster as wall covering in the offices (vs. no)	1164/7441	24/167	**1.32 (1.00–1.73)**	**0.048**
Wood or wood laminate partitions within the offices (vs. no)	1478/7441	32/167	1.26 (0.98–1.61)	0.071
Lead components (vs. no)	296/7441	8/167	1.59 (0.97–2.62)	0.067
Lead paint (vs. no)	127/7441	3/167	1.83 (0.89–3.76)	0.103
Galvanised steel as duct of ventilation systems (vs. no)	6458/7196	132/158	**1.32 (1.01–1.72)**	**0.039**
Internally insulated duct of ventilation systems (vs. no)	1070/7196	17/158	1.25 (0.91–1.72)	0.164
Ventilation				
Operable windows				
Yes, but occupants not allowed to open them (vs. yes)	913/7441	20/167	**1.41 (1.02–1.95)**	**0.039**
No (vs. yes)	1035/7441	22/167	**2.09 (1.57–2.78)**	**<0.001**
Type of building ventilation				
Hybrid/mixed mode (vs. operable windows)	890/7441	24/167	1.32 (0.74–2.34)	0.352
Mechanical ventilation (vs. operable windows)	6306/7441	134/167	1.71 (0.99–2.94)	0.055
Type of mechanical ventilation				
Supply system only (vs. exhaust system only)	161/7091	7/156	1.15 (0.56–2.35)	0.709
Balanced system with VAV (vs. exhaust system only)	1034/7091	18/156	1.49 (0.84–2.63)	0.172
Balanced system with CAV (vs. exhaust system only)	2628/7091	54/156	1.56 (0.94–2.61)	0.088
Balanced system with dual ducts (vs. exhaust system only)	2479/7091	55/156	1.59 (0.96–2.65)	0.073
Balanced system with induction units (vs. exhaust system only)	249/7091	7/156	1.64 (0.81–3.23)	0.167
Other (vs. exhaust system only)	215/7091	6/156	1.68 (0.83–3.41)	0.152
Air handling unit (AHU)				
100% fresh air AHU (vs. AHU with recirculating)	4634/6610	95/142	**1.30 (1.04–1.64)**	**0.024**
Cooling in AHU (vs. no)	6004/6912	127/151	1.27 (0.95–1.68)	0.103
System equipped with water droplet eliminators (vs. no)	2492/6094	49/136	1.25 (0.97–1.59)	0.079
Exhaust ventilation of toilets etc is running continuously to provide the basic ventilation for the building (vs. no)	6137/6921	130/152	**1.38 (1.01–1.89)**	**0.041**
Humidification in mechanically ventilated buildings (vs. no)	2163/7048	34/154	**1.31 (1.03–1.67)**	**0.031**
Filter grade				
Fine, Extra-fine (vs. none)	3955/5184	82/109	1.81 (0.76–4.32)	0.180
Medium, coarse (vs. none)	1130/5184	25/109	2.04 (0.82–5.09)	0.125
Height of ventilation system intake above ground level (+10 m)	6592/7196	139/158	**1.06 (1.00–1.12)**	**0.038**
The horizontal shortest distance of system intake from exhaust outlets[c]				
Between 5 and 10 m (vs. ≤ 5 m)	1528/5553	31/117	1.07 (0.81–1.43)	0.621
> 10 m (vs. ≤ 5 m)	1678/5553	35/117	1.32 (0.98–1.77)	0.066
Shortest distance from intake to busy roads[c]				
Between 51 and 150 m (vs. > 150 m)	750/2316	14/40	1.18 (0.79–1.76)	0.418
≤ 50 m (vs. > 150 m)	990/2316	13/40	1.53 (0.91–2.58)	0.110
Heating, cooling and hot water				
Cooling production plant (vs. no)	7014/7441	156/167	1.44 (0.93–2.24)	0.102
Heat pump (heating + cooling) (vs. no)	1315/7014	31/156	1.22 (0.96–1.57)	0.108
Absorption type chiller and cooling tower (vs. no)	236/7014	8/156	1.55 (0.97–2.48)	0.065
Hot water or convectors as the heating and cooling terminal units (vs. no)	2231/7441	57/167	0.86 (0.69–1.07)	0.175
Electrical radiators or convectors as the heating and cooling terminal units (vs. no)	176/7441	5/167	0.66 (0.36–1.22)	0.186
Window units as the heating and cooling terminal units (vs. no)	137/7441	3/167	0.56 (0.27–1.16)	0.117
Control of room temperature by manual radiator valve (vs. no)	421/7441	10/167	0.73 (0.47–1.13)	0.157
Control of the relative humidity by a system (vs. no)	1861/7441	30/167	1.25 (0.98–1.60)	0.071

Table 2 (*continued*)

Characteristics	n_1/N_1	n_2/N_2	OR (CI 95%)	*P*-value
Type of heating and cooling distribution network				
Two pipe system (vs. refrigerant distribution system)	3961/7406	96/165	1.12 (0.72–1.74)	0.614
Three pipe system (vs. refrigerant distribution system)	167/7406	3/165	0.52 (0.23–1.15)	0.108
Four pipe system (vs. refrigerant distribution system)	2889/7406	54/165	1.43 (0.92–2.23)	0.112
Cases of Legionella, Aspergilla or humidifier-related fever in the last year (vs. no)	121/7313	3/163	0.48 (0.23–1.00)	0.051
Lighting				
Control of solar shading devices (vs. no)	5336/6735	123/147	0.77 (0.59–1.01)	0.062
Individual control of solar shading devices (vs. no)	5338/6735	122/147	**0.74 (0.58–0.96)**	**0.023**
Automatic control by time of main lights (e.g. ceiling or wall) (vs. no)	1411/7441	32/167	0.83 (0.63–1.08)	0.166
Automatic with manual end control of main lights (e.g. ceiling or wall) (vs. no)	1200/7441	30/167	0.84 (0.64–1.09)	0.196
(Other) sources of indoor air pollution				
Smoking permitted in a separately ventilated room (vs. prohibited)	887/7441	13/167	1.44 (1.00–2.07)	0.052
Underground car parking (vs. no)	2678/7441	44/167	**1.33 (1.04–1.70)**	**0.022**
Garage in the building (vs. no)	756/7441	18/167	1.24 (0.89–1.72)	0.192
Kitchen, restaurant in the building (vs. no)	3164/7441	60/167	1.17 (0.95–1.44)	0.145
Carpet as the main type of floor covering in the office (vs. no)	3607/7441	66/167	1.27 (0.99–1.63)	0.065
Dispersion, emulsion paint as wall covering in the offices (vs. no)	5183/7441	106/167	1.15 (0.94–1.40)	0.167
Percentage of office furniture less than one year old and made of particle board of medium density fibreboard				
< 50% (vs. none)	1688/7025	39/154	1.15 (0.88–1.48)	0.303
≥ 50% (vs. none)	516/7025	10/154	1.39 (0.90–2.13)	0.137
Location of the printers and/or copy machines				
In the offices (vs. on the corridor)	2976/7441	75/167	1.25 (0.97–1.60)	0.085
In a separate room (vs. on the corridor)	2501/7441	47/167	**1.59 (1.23–2.07)**	**<0.001**
Laser printers (vs. no)	5270/7441	125/167	0.81 (0.63–1.05)	0.105
Portable humidifiers (vs. no)	507/7441	9/167	1.48 (0.99–2.21)	0.057
Portable air cleaners (vs. no)	225/7441	5/167	1.70 (1.00–2.88)	0.050
Presence of any type of pets (vs. no)	490/7392	16/165	0.76 (0.53–1.09)	0.135
Cleaning activities				
Deep cleaning of the floors				
Workday (vs. never)	3047/6856	79/153	1.05 (0.77–1.44)	0.745
Weekend and/or holidays (vs. never)	2800/6856	51/153	1.35 (0.96–1.90)	0.087
Smooth floors polished in the communal areas of the buildings at least once a week (vs. no)	499/7186	16/158	0.76 (0.54–1.07)	0.119
Walls dry wiped, vacuumed in the communal areas of the buildings (vs. no)	5091/7164	104/158	1.26 (0.99–1.62)	0.063
Surfaces dusted in the communal areas of the buildings (vs. no)	6739/7330	149/162	0.70 (0.40–1.04)	0.081
Floor, carpets swept, vacuumed in the offices daily (vs. no)	4594/7366	94/163	1.17 (0.93–1.47)	0.177
Smooth floors polished in the offices daily (vs. no)	217/7164	6/157	0.65 (0.38–1.10)	0.110
Walls washed in the offices daily (vs. no)	61/7235	3/158	1.88 (0.82–4.28)	0.134
Surfaces cleaned in the offices at least once a week (vs. no)	5036/7308	119/161	**0.76 (0.60–0.98)**	**0.032**

P-values in bold refer to significant relations at 5% level.

[a] Adjusted for gender, age, level of education, smoking status, alcohol consumption, hours working with a VDU, effort reward ratio and over-commitment (level 1). Only factors associated with a *P*-value <0.20 are presented in the Table.

[b] Level 1 – Individual level, Level 2 – Building level, Level 3 – Country level.

[c] Categories were defined using the tertiles of the distribution.

Abbreviations. CI 95%, confidence interval at 95%; n1, N1: worker observations; n2, N2: building observations; OR, odd ratio; *P*, *P*-value of Wald test; vs., versus.

Working with a VDU (more than 25 h per week compared to no VDU use) was also associated with dry eyes complaints (adjusted OR 1.38, 95% CI: 1.17–1.63). With regard to psychosocial environment, high effort reward ratio was positively associated with dry eyes (adjusted OR 1.78, 95% 1.54–2.06) and no effect modification was identified.

Overall, associations were maintained in the sensitivity analysis.

4. Discussion

4.1. Synthesis of findings

This study provides data on the associations between self-reported dry eye complaints and a broad range of building characteristics, in the context of a large European office-worker population study, taking into account individual characteristics and occupational risk factors (high intensity of VDU work, work-related stress). The physical building characteristics that were identified to be associated with self-reported dry eyes, and are discussed hereafter, include: proximity (<100 m) to potential outdoor air pollution sources, absence of operable windows, exposed concrete and/or plaster wall coverings, dispersion and/or emulsion paint wall coverings, portable humidifiers, and intensity of surface cleaning activities. These findings suggest building characteristics that could be related to dry eyes.

4.2. Self-reported dry eye complaints by office workers

Comparison with previous studies is not straightforward due to differences in recall periods (‘at this moment’, ‘last week’, ‘past month’), and differences in frequency categories of the complaints. Nevertheless, the prevalence in this study – with 34% of all office workers investigated reporting dry eye complaints in the past four weeks(and a mean prevalence of 30.9% for the office buildings studied) seems comparable in order of magnitude with the prevalence estimated in European Audit project of 39% (expressed as ‘at least once during the preceding month’) [1].

4.3. Occupational factors and office building characteristics associated with dry eye complaints

4.3.1. Occupational risk factors

VDU-use is positively associated with reported dry eye complaints, in line with previous findings [15,17]. VDU work (compared with relaxed conditions) reduces the eye-blinking frequency by a factor 2–3, which may if prolonged lead to ocular discomfort [7,16].

Table 3
Associations between office building characteristics and dry eye complaints (results from the multivariate multilevel logistic regression model).

Factors	Adjusted OR (95% CI)	*P-value*
Work-related factors		
VDU		
Yes, ≤ 25 h per week (vs. no)	1.08 (0.87–1.33)	0.486
Yes, > 25 h per week (vs. no)	**1.38 (1.17–1.63)**	**<0.001**
Effort-reward ratio (↑ 1 log)	**1.78 (1.54–2.06)**	**<0.001**
Over-commitment (↑ 1 unit)	1.00 (0.98–1.02)	0.942
Building characteristics		
Nearby (within 100 m) potential sources of outdoor air pollution		
Yes (vs. no)	**1.41 (1.06–1.88)**	**0.018**
Typical number of occupants		
Between 71 and 170 (vs. ≤ 70)	1.10 (0.90–1.34)	0.373
More than 170 (vs. ≤ 70)	1.22 (0.99–1.50)	0.061
Operable windows		
Yes, but occupants not allowed to open them (vs. yes)	1.23 (0.95–1.59)	0.118
No (vs. yes)	**1.70 (1.34–2.16)**	**<0.001**
Cooling production plant		
Yes (vs. no)	1.36 (0.94–1.97)	0.099
Exposed concrete, plaster as wall covering in the offices		
Yes (vs. no)	**1.29 (1.02–1.62)**	**0.032**
Dispersion, emulsion paint as wall covering in the offices		
Yes (vs. no)	**1.20 (1.01–1.41)**	**0.034**
Location of printers/copy machines		
In offices (vs. on the corridor)	1.13 (0.92–1.39)	0.253
In a separate room (vs. on the corridor)	1.20 (0.96–1.50)	0.112
Portable humidifiers in the offices		
Yes (vs. no)	**1.58 (1.18–2.11)**	**0.002**
A documented complaint procedure for occupants with problems of the indoor environment		
Yes (vs. no)	**1.50 (1.26–1.79)**	**<0.001**
Surfaces dusted in the communal areas of the building		
Yes (vs. no)	0.74 (0.54–1.00)	0.051
Surfaces cleaned in the offices		
Yes, at least once per week (vs. no)	**0.75 (0.61–0.91)**	**0.003**
Country level		
σ^2_{uo}/ICC in %	0.09/2.57	
PCV in %	3.0	
MOR	1.33	
Building level		
σ^2_{uo}/ICC	0.04/1.16	
PCV in %	79.8	
MOR	1.21	
Log Likelihood	−3651.31	
AIC/BIC	7362.63/7564.50	

Adjusted for gender, age, level of education, smoking status and alcohol consumption.
Abbreviations. 95% CI, confidence interval at 95%; AIC, Akaike information criterion; BIC, Bayesian information criterion; ICC, intra-class correlation; MOR, median odds ratio; OR, odds ratio; *P*, *P*-value of Wald test; PCV, proportional change in variance, σ^2_{uo}, estimated variance.
ORs (95% CI) and *P*-values in bold refer to significant relations at 5% level.

4.3.2. Office building risk factors

In this study, a number of building characteristics were found to be associated with self-reported dry eye complaints, and explained a large amount of variance in dry eyes between buildings (building characteristics explained 76.3% of the variance in dry eyes between buildings - PCV determined by the only inclusion of building characteristics in the model relative to the null model - results not shown). Some of these characteristics may be qualified as potential air pollution sources. The association between ‘proximity (<100 m) to potential sources of outdoor air pollution’ and dry eyes for example, may be explained by elevated exposure to traffic related pollutants (e.g. nitrogen oxides, combustion related particles). In line with this finding, Bourcier et al. [27] reported an association between ambient air pollution levels (NO_2) in Paris and short term increases in ophthalmological emergency department visits. Saxena et al. [28] found an elevated risk of ophthalmic symptoms, including redness and irritation, in study participants travelling through highly polluted areas of Delhi, as compared to a control group. Results from an experimental study [29] provide further support for a causal relation between traffic related exposures and ocular discomfort as well as tear breakup time. Mendell et al. [30] examined the association between building related symptoms and heating, ventilation and air conditioning (HVAC) system characteristics, and reported a significantly increased risk of eye symptoms in buildings with the outdoor air intake closer to the ground level. They hypothesized that symptoms may be caused by increased level of traffic related pollutants inside buildings with air intakes closer to ground level.

In our study, the presence of portable humidifiers in the offices was positively associated with dry eyes, and a tendency was observed for presence of a cooling system. Similar findings have been previously reported. For example, Hedge et al. [22] reported a higher prevalence of dry eye symptoms in air conditioned buildings as compared to unconditioned buildings. Furthermore, Mendell et al. [30] observed an increased risk of eyes symptoms in buildings with humidification systems with poor maintenance/condition, and with less frequent cleaning of the coils and drain pans [30]. It may be hypothesized that this association may be explained by increased exposure to microbial exposures from insufficiently maintained ventilation systems [31]. Portable humidifiers and cooling systems may act as sources of exposure to microbiological contaminants (e.g. Ref. [32]). Previous studies have found associations between eye complaints and exposure to moisture related (biological) contaminants [33–35]. However, given the cross-sectional design of the study, reverse causality cannot be excluded for the association found with portable humidifiers that may be placed more often in buildings with building related problems. However, such explanation seems unlikely to underlie the similar association between the presence of a cooling system and dry eyes.

This study also revealed an association between the frequency of cleaning surfaces in the offices and dry eye complaints, with a decreased risk at a higher cleaning frequency. In line with this, previous studies have linked settled dust with eye symptoms (e.g. Refs. [35–37]). An experimental explorative study by Mølhave et al. [37] in 36 volunteers exposed to house dust, revealed a significant increase in perceived eye irritation during exposure to office dust. An epidemiological study by Smedbold et al. [35], into the relations between indoor environmental factors and eye irritation signs in 176 female workers of 36 nursing departments, showed an association between dust settlement rate and decreased tear-film stability.

In our study, also positive associations were found with construction materials (exposed concrete and/or plaster and dispersion and/or emulsion paint as wall covering in offices). It may be speculated that these associations may be explained by exposure to chemical pollutants. Like other types of wall coverings, these coverings are known to be a potential source of chemical pollutants (e.g. ammonia, volatile organic compounds - VOCs, aldehydes) [38,39], which may lead to eye irritation [40–42]. VOCs (including aldehydes such as e.g. formaldehyde) may be emitted either directly, or after ozone-initiated chemistry [19,43]. However, while a number of previous studies support a relation between *outdoor* air pollution and eye complaints (e.g. Refs. [27,29]), convincing evidence to support a causal relation between single specific organic indoor air pollutants or indoor particles at concentration levels typical in offices is lacking. In general, the lowest observed adverse effect levels (LOAEL) for organic pollutants is much higher than typical concentrations in offices [7]. However, associations with eye symptoms have been reported for exposure to environmental tobacco smoke (ETS) [44,45]. The assessment of long term exposure to the indoor air pollution mixture is difficult and it represents an open issue in epidemiological studies linking exposure to health, in particular considering the multiple components of indoor air pollution which may potentially interact and/or differ in effect. Investigating the association with building characteristics (as cause of adverse indoor microclimatological conditions, or as potential sources and/or exposure modifiers of indoor air pollutants) directly, might be a solution to get clues to potential underlying causes.

The 'tendency of an association' found for the location of the printers ('in a separated room' compared to 'on the corridor') may also be hypothesized to be related to exposure to chemical pollutants such as VOCs, ozone and particulate matter [46–48]. When equipment is placed on the corridor, office workers may be expected to be less exposed to high peak levels of emitted substances of printers/copy machines, as emissions on a corridor are probably better diluted by air exchange and extracted by the mechanical ventilation, than on a room.

The absence of operable windows was associated with an increased risk of eye complaints. It may be speculated that the absence of operable windows may – in combination with an inadequate air exchange rate – be related to increased exposure to indoor air pollution. However, perhaps more importantly, it may also be an indicator of unfavorable thermal and/or humidity conditions, without the possibility for the occupants to control their indoor environmental conditions (e.g. by opening a window). In line with these findings, previous studies have reported a relation with eye symptoms and the extent to which a building is 'sealed' or air conditioned as compared to being naturally ventilated (e.g. Refs. [49,50]). Similarly, a recent study into indoor environmental quality, perception and symptoms with different types of ventilation systems in classrooms indicated that while the classroom with the mechanical ventilation system had the highest estimated air change rate, the perceptions and symptoms reported by pupils were more favorable in the classroom with automatically operable windows with exhaust fan ensuring adequate ventilation at all times [51]. A recent review on the relation between ventilation rate and health symptoms revealed that while in general, higher ventilation rates have been linked to reduction of health outcomes, there is still a large discrepancy between studies [52]. These differences between studies, may be partly explained by the multifactorial nature of these relations.

In addition to the above, an association was found with the presence of 'a documented complaint procedure for occupants with problems of the indoor environment'. The availability of such procedure may be an indicator of 'a history of problems with the indoor environment' (leading to a stronger incentive to develop such procedure), or of building size (such procedure may be more commonly available in buildings with a larger number of occupants, which may tend to have a higher grade of procedural organization). It is important to note that the question dealt only with the availability of a procedure, not its effectivity or use.

4.4. Strengths and limitations

One strength of this study is its large scale, 7441 office workers in 167 modern office buildings with a wide geographical coverage and spread over Europe were investigated. Furthermore, information was collected on a broad range of individual risk factors and other potential confounders, including socio-demographic characteristics, lifestyle factors, as well as work related factors, and psycho-social characteristics of the working environment.

In addition, data was collected on a large number of building characteristics (e.g. location, size, construction materials, systems – aspects of operation, maintenance and control, equipment, cleaning activities – type and frequency), which potentially may affect different indoor environmental conditions (e.g. indoor air quality, temperature, acoustic and lighting conditions). This allowed an integral approach in the analyses, taking into account a broader spectrum of characteristics in combination, rather than focusing on just one (or few) characteristics. Furthermore, the availability of data on both individual characteristics as well as building characteristics, allowed for adjustment for an important number of potential confounders. The possibility of residual confounding by unmeasured variables still may not be fully ruled out.

There are several limitations in this study. The information of dry eye complaints comes from self-reports and the recall bias cannot be excluded. In large-scale studies, for reasons of convenience and/or cost, it is common to use self-reported health complaints [1,2]. Due to the large number of building characteristics considered, the risk of finding significant associations 'by chance' cannot be excluded. Nevertheless, the number of significant associations for dry eyes relative to the number of statistical tests performed exceeds the one in 20 expected by chance. Additionally, 91% of the office workers who reported dry eyes complaints declared that this complaint was better on days away from the office. So, it may seem reasonable to assume that the associations found in this study, particularly those which showed a high level of significance ($P < 0.01$), may be related to the office environment.

Another limitation is the cross-sectional design. Therefore no causality of the identified relations can be confirmed. However, results provide valuable clues to potential causes, and thereby an essential basis for further dedicated experimental studies (e.g. intervention studies, controlled laboratory experiments, epidemiological studies including objective measurement of indoor environmental characteristics), aimed at further elaborating these findings to increase insight in underlying potential causal factors.

5. Conclusions

In addition to work-related factors (e.g. 'Visual Display Unit'-use (VDU-use)), the high prevalence of self-reported dry eye complaints in offices may be explained by office building characteristics which may affect exposure to environmental conditions. Associations were found with a number of building characteristics, including nearby outdoor pollution sources, certain types of wall coverings, portable humidifiers, absence of operable windows and the frequency of surface cleaning activities. This study extends previous experimental and epidemiological studies on dry eye complaints in buildings, by providing important clues to potentially underlying causal factors.

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