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cross-sectional studies from 2000 and 2021

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Original Research

Socioeconomic patterns in indoor environment in Denmark: cross-sectional studies from 2000 and 2021

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ABSTRACT

Objectives: To examine changes and socioeconomic patterns in indicators of a poor indoor environment in 2000 and 2021.
Study design: Cross-sectional data from the Danish Health and Morbidity Survey in 2000 and 2021.
Methods: The study included 27,068 participants. Indicators of indoor environment (annoyances from mould, temperature, draught, traffic and neighbour noise, and presence of water damage) were obtained from questionnaires (2021) and partly by interview (2000). Socioeconomic status included home ownership, educational level, and household income. The degree of social inequality in the indoor environment was estimated using the concentration index of inequality.
Results: The prevalence of annoyances due to draught, temperature, and noise increased significantly from 2000 to 2021 (e.g., temperature 5.9%–25.1%, odds ratio (OR) 6.72, 95% confidence interval (CI) 6.12–7.38), whereas the prevalence of water damage decreased (17.7%–13.8%, OR 0.85, 95% CI 0.76–0.96). No difference was seen in annoyances due to mould (3.1% in 2000 and 2.5% in 2021, OR 0.90, 95% CI 0.69–1.17). Social inequality was present for thermal conditions, annoyances due to noise and presence of water damage when assessed by income but not by educational level. Conditions were more prevalent among individuals with low income in both 2000 and 2021.
Conclusions: The proportion of individuals reporting a poor indoor environment due to thermal conditions and noise increased in the period 2000–2021. Social inequality was observed in all indicators of a poor indoor environment for household income, whereas the inequality was less pronounced when assessed by educational level.

Introduction

The importance of a healthy indoor environment has gained increasing attention over the last decades.[1] The World Health Organization defines the indoor environment as components of the thermal environment, air quality, noise, and light.[2] Poor indoor environment is associated with adverse human health and well-being.[3,4] Low indoor temperatures are associated with both respiratory and cardiovascular morbidity and mortality ([5], pp 35), whereas high indoor temperatures are associated with sleep disturbances ([5], pp 49,[6]). Dampness and mould are associated with symptoms of wheezing, aches and pain, and headaches[7–9] with children being particularly affected.[10] Road traffic noise has consistently been associated with higher risk of ischemic heart disease, heart failure, diabetes, and all-cause mortality.[11] For example, the risk of ischemic heart disease increases with 8% per 10 dB L_{den} increase in road traffic noise.[12] Likewise recent studies have indicated that road traffic noise is associated with breast cancer, dementia, and tinnitus.[11] Noise annoyance from neighbours has been associated with poor mental health[13] and symptoms (e.g., sleep disturbances).[14]

In Europe, approximately one-third of households are exposed to at least one of the following: dampness, mould, noise, excess cold or lack of daylight ([1], pp 22). In Denmark, a high proportion of people report problems related to their indoor environment.[15,16] In

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year 2000, the most prevalent annoyances in a Danish survey were too low or high temperature, draught, and noise from traffic and neighbours.[17]

However, problems in the indoor environment are not equally distributed in the population. Low-income earners are more likely to live in housing that exposes them to health risks ([5], pp 10). In a multi-centre study across Europe, dampness and mould were more prevalent among lower socioeconomic groups whereas water leakage was less prevalent.[18] Socioeconomic patterns have also been seen in presence of mould and moisture in Denmark.[7] In Japan, lower household income was correlated with lower indoor temperatures.[19] Exposure to noise was more common among people with lower income, however, results are conflicting when other markers of socioeconomic status is used such as educational level.[20]

Understanding how indicators of the indoor environment are distributed across the population allows for improvement of the indoor environment and subsequent health outcomes.[21] Therefore, our aim was to examine changes and socioeconomic patterns in indicators of a poor indoor environment in Denmark in 2000 and 2021.

Methods

Study population and study design

The study was based on cross-sectional data from the Danish Health and Morbidity Survey in the years 2000 and 2021. The sampling procedure and data collection have been described in detail elsewhere.[22–24] In brief, random samples of 22,486 and 25,000 individuals (aged ≥16 years) were drawn from the Danish Civil Registration System in 2000 and 2021, respectively. In the year 2000, data were collected via a face-to-face interview at the respondent's home. Following the interview, a subsample of the respondents was asked to complete a self-administered questionnaire with further questions about their indoor environment (referred to as the indoor subsample). The subsample followed the same random sampling procedure as the overall sample. Further, weighting was used to account for non-response and to ensure adequate geographic distribution. In the year 2021, data were primarily collected using a self-administered web questionnaire.[24] In all, 16,688 individuals completed the questionnaire in 2000 (74.2%) and 11,346 individuals in 2021 (45.4%). In 2000 3800 (65.5%) answered the additional questions about their indoor environment. Data were linked at the individual level with sociodemographic information using the unique personal identification number carried by all residents in Denmark.[25,26]

Assessment of indoor environment indicators

We included six indicators of a poor indoor environment. The included indicators consisted of both self-reported annoyances related to the indoor environment and self-reported presence of water damage. Annoyances were assessed by asking individuals if they had been annoyed by: smell of mould or mildew, too low or high temperatures, draught, and noise from traffic or neighbours within the last two weeks. For each annoyance, the response options were 'Yes, very annoyed', 'Yes, little annoyed' and 'No, not annoyed'. Information about water damage was collected by asking individuals 'Do you currently have moisture shields or mould spots on walls, ceilings, or floors in your home?' In 2000, information about mould and water damage was only collected in the indoor subsample. The response for the six indoor environment indicators was dichotomized into 'Yes' and 'No' (appendix A (Method) for more details). Number of missing values on indoor environment indicators are displayed in Appendix A Table A1.

Two new variables were derived by combining thermal conditions (sum of annoyance due to draught and temperature) and noise (sum of annoyances due to noise from traffic and neighbours). Both variables were categorized into 0, 1, or 2 annoyances.

Assessment of socioeconomic status

Socioeconomic status was measured by educational level, income, and home ownership. All information was retrieved at an individual level from Statistic Denmark using the unique personal identification number that is given to all Danish residents at birth or migration.[25,26]

Individual-level educational level was assessed as the highest attained educational level obtained from the Danish Education Register.[27] If information about educational level was not available in the register, information from the questionnaire was used whenever available. Education was categorized as; Elementary (International Standard Classification of Education (ISCED) 0–2), Upper secondary or vocational (ISCED 3–4) and Higher education (ISCED 5–8).

Information about equivalized disposable household income was obtained from the Income Statistic Register[28] and grouped into quartiles.

Information about home ownership was obtained from the Building and Housing Register[29] and categorized as owned or rented. People living in shared owner property were categorized as rented homes.

Other variables

Information on sex (male, female), age (16–24, 25–44, 45–64, 65–74, ≥75 years) and cohabitation (cohabiting, living alone) was obtained from the Danish Civil Registration System.[25] Information about smoking status was obtained from the questionnaires.

Statistical analysis

For descriptive analysis, counts and proportions were used. To account for non-response, we applied weights computed by Statistics Denmark based on information on sex, age, education, income, marital status, ethnic background, and number of visits to general healthcare practitioner.[30] Hence, all reported proportions related to the indoor environment are reported as weighted proportions.

The differences in the six indoor environment indicators between the years 2000 and 2021 were tested using a binary logistic regression. The differences in thermal conditions and noise between the years 2000 and 2021 were tested using an ordinal logistic regression. The analyses were adjusted by age and sex and weighted based on weights computed by Statistics Denmark (see description above). The results are presented as odds ratios (OR) with a corresponding 95% confidence interval (CI).

The degree of social inequality in the indoor environment for income and educational level was quantified using the concentration index of inequality.[31,32] The concentration index is a relative measure of inequality and presents proportional differences in indoor environment among socioeconomic subgroups. It takes values in the interval between −1 and 1. A concentration index of 0 indicates no inequality. A positive concentration index value indicates that a good indoor environment is disproportionally concentrated among individuals with a high socioeconomic status, and inequality is thereby in favour of individuals with higher socioeconomic status. The concentration index with a corresponding 95% CI was estimated using linear regression adjusted for age and sex and stratified by year.

Sensitivity analyses

As a sensitivity analysis mould was included in thermal conditions (with draught and temperature) since temperature affects the growth of mould[33,34] and thereby might express some of the same underlying problems in the indoor environment.

The analyses were repeated excluding individuals at age 16–24 years since a large proportion may still be in education and have not yet reached their final educational level.

Results

Descriptive analysis

The study included 28,034 individuals. Individuals with missing information on socioeconomic status (education, income and/or home ownership) were excluded (831 and 135 in 2000 and 2021). This resulted in a total of 27,068 individuals (15,857 in 2000 and 11,211 in 2021) (Appendix A Fig. A1). In 2000, a total of 3691 individuals were included in the indoor subsample.

Some differences were seen in baseline characteristics of the study populations in 2000 and 2021 (Table 1). In 2021, the study population included a larger proportion of females, a larger proportion of individuals ≥65 years, a larger proportion of never-smokers and a higher proportion with a higher educational level. The baseline characteristics of the individuals in the indoor subsample in 2000 were similar to the full sample.

Development in indoor environment indicators

The prevalence of annoyances due to draught, temperature, and noise due to traffic and neighbours increased significantly from 2000 to 2021 (Fig. 1). The largest increases were seen for draught which increased from 4.5% to 14.6% (OR = 4.10, 95% CI: (3.69; 4.54)) and temperature which increased from 5.9% to 25.1% (OR = 6.72, 95% CI: (6.12; 7.38)). No difference was seen in annoyance due to mould (3.1% in 2000 and 2.5% in 2021). Annoyances due to thermal conditions (draught and temperature) increased significantly from 7.5% in 2000 to 19.5% in 2021 for 1 problem and 1.4%–10.0% for 2 problems (OR = 5.40, 95% CI: (4.98; 5.85)). A moderate increase was seen in annoyance due to noise. In 2000, 6.3% and 8.1% reported annoyance due to noise from traffic and neighbours. This increased to 13.5% (OR = 2.46, 95% CI: (2.23; 2.71)) and 16.0% (OR = 2.42, 95% CI: (2.21; 2.66)) in 2021, respectively. Annoyances due to noise (traffic and neighbours) increased significantly from 11.9% in 2000 to 18.8% in 2021 for 1 problem and 1.2%–5.3% for 2 problems (OR = 2.38, 95% CI: (2.21; 2.57)). Presence of water damage decreased significantly from 17.7% in 2000 to 13.8% in 2021 (OR = 0.85, 95% CI: (0.76; 0.96)).

Social inequality in indoor environment indicators

Social inequality due to home ownership and income disparity is seen in annoyances due to thermal conditions, whereas no clear pattern is seen in relation to educational level (Fig. 2a). This is seen in both years 2000 and 2021. A similar social gradient is seen in annoyances due to noise in relation to both home ownership and income (Fig. 2b). This is seen in both years 2000 and 2021. Presence of water damage stratified by socioeconomic status (Fig. 3) indicates social inequality in relation to home ownership with a higher prevalence of water damage in rented homes than in owned homes. However, an inverse social inequality is seen in relation to educational level. No clear pattern is seen in relation to income.

The concentration index of inequality was estimated for the combined measures of annoyances (thermal conditions and noise) and presence of water damage (Fig. 4). For income, negative values

Table 1
Characteristic of the study population included in year 2000 (indoor subsample and full sample) and 2021.

	2000				2021	
	Indoor subsample		Full sample			
	n	%	*n*	%	*n*	%
Sex						
Male	1799	48.7	7799	49.2	4931	44.0
Female	1892	51.3	8058	50.8	6280	56.0
Civil status						
Cohabiting	2534	69.0	10,776	68.4	7470	66.6
Living alone	1138	31.0	4967	31.6	3741	33.4
Age (years)						
16–24	429	11.6	2060	13.0	1126	10.0
25–44	1289	34.9	5576	35.2	2263	20.2
45–64	1321	35.8	5396	34.0	3892	34.7
65–74	371	10.1	1545	9.7	2220	19.8
≥75	281	7.6	1280	8.1	1710	15.3
Smoking status						
Never	1423	38.6	6230	39.4	5394	50.9
Former	924	25.0	3735	23.6	3564	33.6
Current	1342	36.4	5862	37.0	1636	15.4
Educational level						
Elementary	1346	36.5	6011	37.9	2455	21.9
Upper secondary or vocational	1584	42.9	6684	42.2	4506	40.2
Higher education (Short, medium, or long)	761	20.6	3162	19.9	4250	37.9
Income						
Q_1	882	23.9	3965	25.0	2803	25.0
Q_2	934	25.3	3964	25.0	2803	25.0
Q_3	920	24.9	3964	25.0	2803	25.0
Q_4	955	25.9	3964	25.0	2802	25.0
Home ownership						
Owned	2423	65.6	10,526	66.4	7209	64.3
Rented	1268	34.4	5331	33.6	4002	35.7

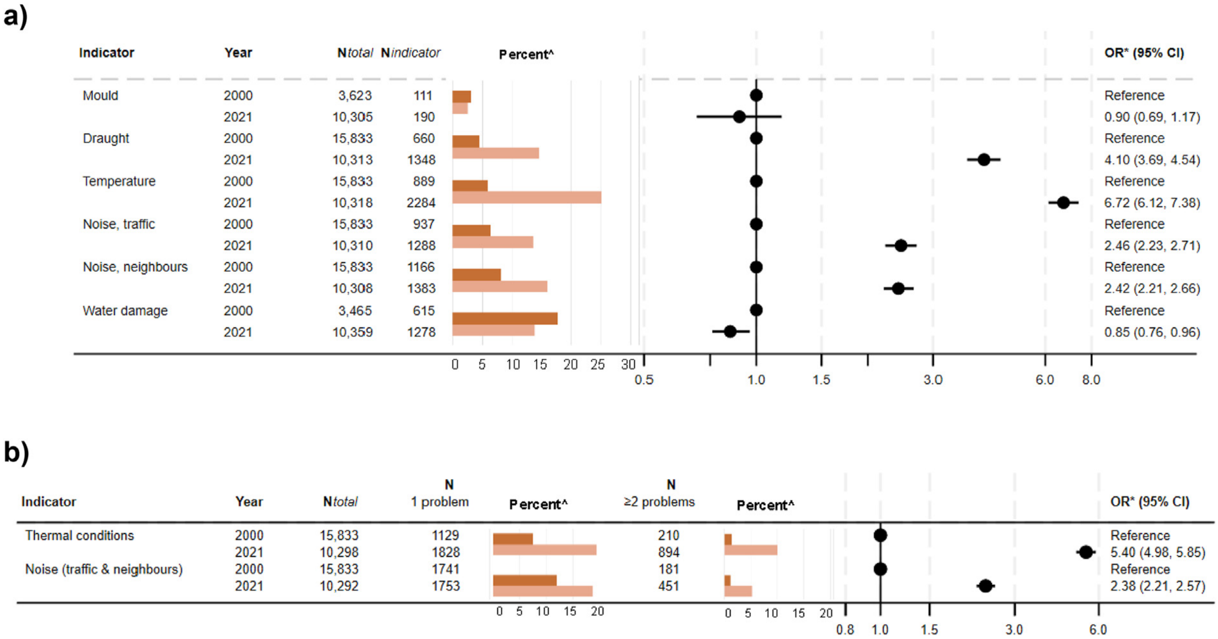

Fig. 1. Prevalence and test of differences in (a) indoor environment indicators (b) thermal conditions, and noise annoyances, between year 2000 and 2021, given by numbers of individuals each year, and number of individuals with the indicator, percent and odds ratio (OR) with 95% CI.
^Weighted
*Adjusted for age and sex.

of the concentration index of inequality were estimated for both thermal conditions, noise, and presence of water damage. This indicates that individuals with low income more often experience annoyances in the indoor environment. For educational level, values of the concentration index of inequality close to 0 indicate no social inequality due to educational level. Overall, this indicates that income contributes to social inequality in annoyances in thermal conditions, noise, and presence of water damage.

Supplementary analysis

The supplementary analyses of accumulated annoyances due to thermal conditions based on three indicators support the findings based on two indicators (Appendix A Figs. A2 and A3, Table A2).

Excluding individuals aged 16–24 years showed overall the same patterns for educational level as in the main analysis (Appendix A Figs. A4a, A4b, and A5).

Discussion

The main findings of the study are the increasing proportion of individuals with annoyances in the study period and the persistence of social inequality in the indoor environment in a representative sample of the general population. The largest increase in annoyances was related to temperature. A significant increase was also seen in annoyances due to draught and noise from traffic and neighbours. Social inequality in annoyances due to thermal conditions and noise was seen in relation to income but not in relation to educational level. This indicates that income contributes to social inequality in annoyances in the indoor environment where individuals with a low income more often experience annoyances.

Other studies also found an increase in poor indoor environment indicators over time. Annoyances from noise from the street and neighbours are also monitored in the Eurostat EU-SILC survey.[16] The prevalence in Denmark varied between 15.6% and 20.1% in the period from 2011 to 2020,[16] which is slightly lower compared to our study. This might partly be due to differences in noise from street and noise from traffic. Annoyances from noise from traffic and neighbours also increased in the Danish Health and Morbidity Survey in the period between 2000 and 2013.[35] The mechanism behind the increase in annoyances over time might be a result of several factors, e.g., people's attention to the indoor environment and quality expectations might have increased, thereby resulting in a higher reporting of annoyances. For example, traffic noise levels have only increased slightly from 55.3 dB in 1995 to 55.6 dB in 2015.[36] However, based on the available data, the causes of the identified changes cannot be identified.

We found that both thermal conditions, noise and water damage were unequally distributed between individuals with low and high income. The prevalence of each indoor environment indicator was higher among individuals with low income compared to individuals with high income. Similar findings were found for noise in Europe,[20] and temperature in Japan.[19] However, insulation and heating practices differ between Japan and Europe. Also, the prevalence of mould is higher among individuals with low income in both Denmark[7] and Europe.[18] The prevalence of water damage was higher among individuals with higher income in both Denmark[7] and Europe[18] which is opposite to our findings.

Nevertheless, results were less consistent regarding educational level. For both thermal conditions and noise there was no difference in the distribution across educational levels. In the studies by Groot et al. (2021) and Norbäck et al. (2017), they found a higher prevalence of mould among individuals with shorter education. Existing literature has shown opposing results for the association between educational level and noise.[20] For water damage the prevalence was higher among people with higher education and thus the opposite of what we saw for income, but in line with existing literature.[7,18] In general, Groot et al. found a similar socioeconomic pattern for both maternal educational level and household income, whereas we found a similar socioeconomic pattern for household income but not for educational level. However, the study populations differ. The study by Groot et al. is based

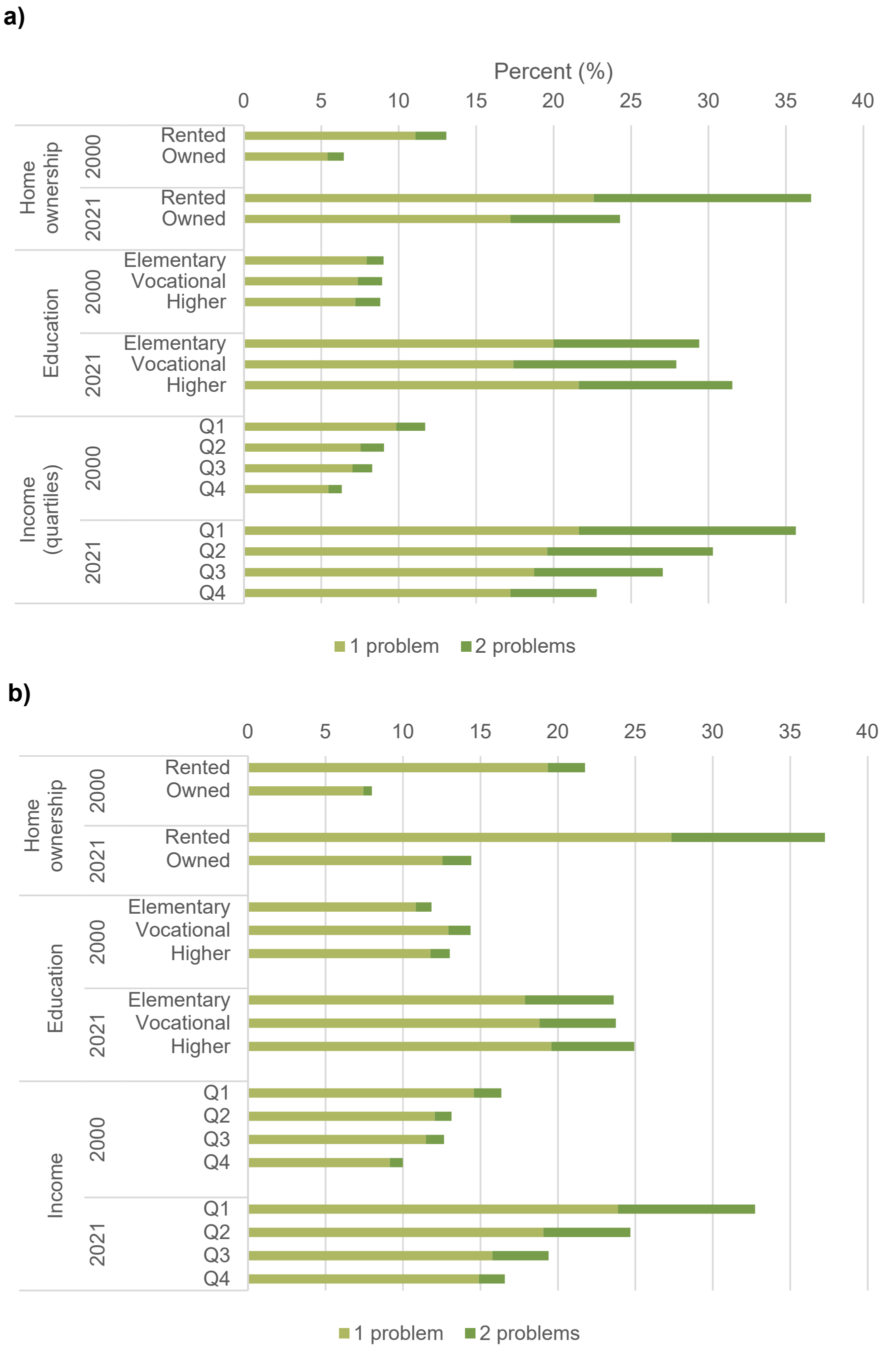

Fig. 2. Prevalence of (a) accumulated annoyances due to thermal conditions (sum of draught and temperature) and (b) accumulated annoyances due to noise (sum of noise from traffic, and neighbours) by home ownership, educational level, and income. Year 2000 and 2021.

on the 11-year follow-up of The Danish National Birth Cohort which includes mothers and children enrolled during pregnancy in the 1990s, whereas our study is based on a national representative sample of the Danish population aged ≥16 years. Further, the proportion of home ownership is 86% in the study by Groot et al., whereas it is around 65% in the present study. This might affect the association between educational level and indoor environment.

Our findings indicate that household income might have a larger impact on the indoor environment than education. Household income might have an influence on both the quality of the dwelling a family is living in and the opportunity to repair damage, etc. It can also have an impact on the ability to maintain the quality of the dwelling. Homeownership and income are mainly markers of material circumstances.[37] We see the same social gradient for both home ownership and household income in our study. Education is often used as a socioeconomic indicator that captures the knowledge assets of a person,[37] and might therefore be of less importance when studying social inequality in indoor environments where the purchasing power might be more important. As the indoor environment is associated with health, and poor health outcomes might affect income, there is an interplay between housing conditions and income which can potentially influence each other over time.

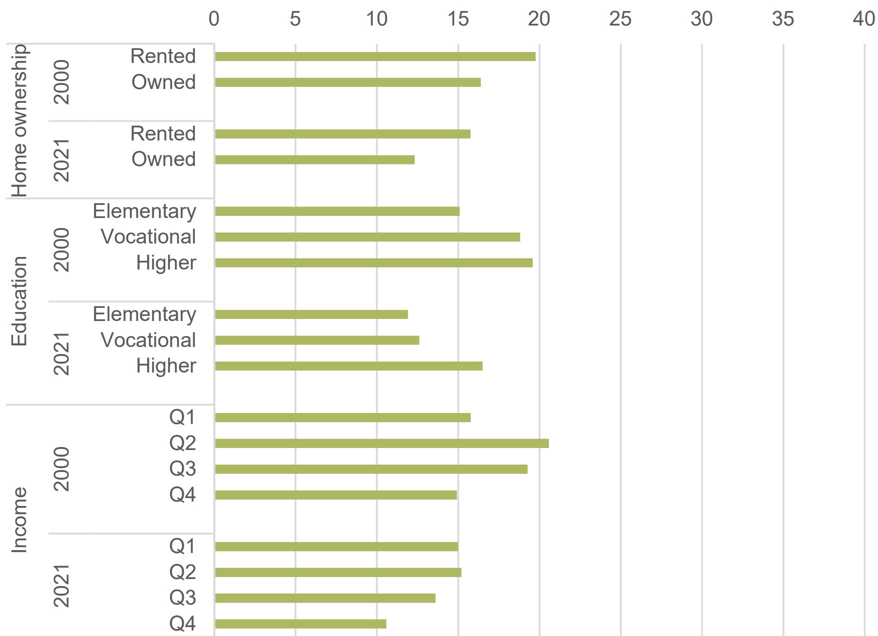

Fig. 3. Prevalence of water damage by home ownership, educational level, and income. Year 2000 and 2021.

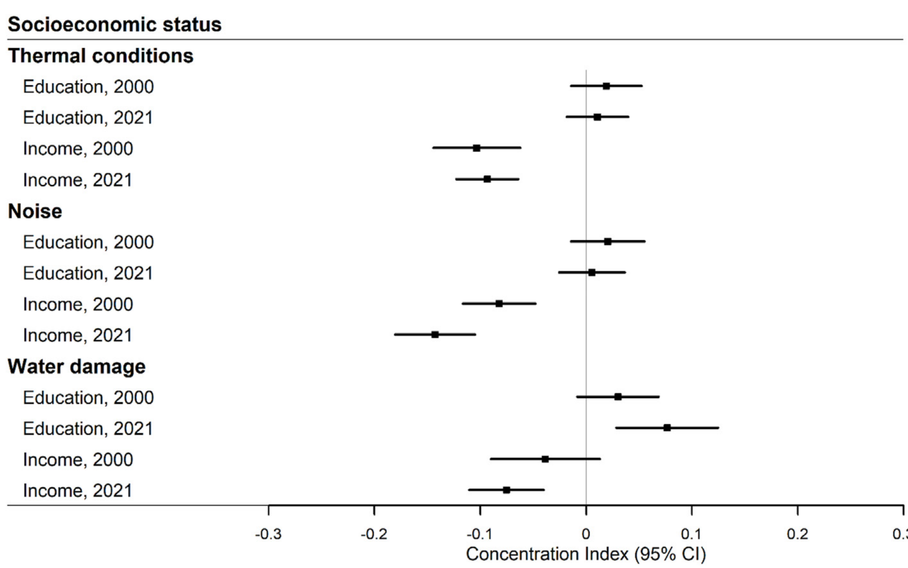

Fig. 4. Concentration index of inequality in accumulated annoyances due to thermal conditions (sum of draught and temperature), noise (sum of noise from traffic and neighbours), and presence of water damage by education and income level, stratified by year.

In Denmark, house prices differ among regions (e.g., rural and urban areas) and the development over time has been different with very high increases in most urban areas compared to rural areas.[38] This might also contribute to differences in socioeconomic positions.

Our results show that not only is the prevalence of annoyances due to noise and thermal discomfort more prevalent among the low-income group, but the proportion of individuals being very annoyed is also higher compared to individuals in the high-income group. This indicates that the amount of poor indoor environmental indicators accumulates among the more vulnerable individuals but also that conditions are more critical.

A major strength of the study is the large sample of the Danish population combined with individual-level register-based information about socioeconomic status. The study population was a representative national random sample of individuals aged ≥16 years which makes it possible to generalize the study findings to the population in Denmark. To reduce the potential impact of non-response bias, weights were applied in the estimation of the prevalences of poor indoor environment indicators and test of differences in indoor environment indicators between the years 2000 and 2021. The study used information about self-reported perception of the indoor environment with few missing values. The register-based information on socioeconomic status is of high validity and completeness which limits the risk of misclassification. Further, the concentration index of inequality was adjusted for sex and age, thereby minimising the effect of the demographic development during the study period.

The study has also some limitations. Data were collected in different periods in 2000 and 2021 (February, May, and September in 2000 and February to May in 2021). This can potentially influence the perception of annoyances since some might be related to season, e.g., draught and noise. Another limitation is that data were collected using both interviewer-assisted and self-reported surveys. In 2021, only a self-reported survey was applied whereas both types of surveys were applied in 2000. A previous validation study showed that the prevalence of annoyances from too low or high temperature and noise from neighbours was higher when collected by self-administered questionnaire compared to by interview, whereas the prevalence of annoyances from traffic noise was unaffected.[39] Therefore, the absolute increase in annoyances due to temperature and noise from neighbours should be interpreted in that light. Information about water damage and mould was collected as self-administered questionnaire in both 2000 and 2021.

In summary, a poor indoor environment due to thermal conditions and noise increased in the period 2000–2021. Furthermore, the indoor environment indicators were unequally distributed across the population with poorer indoor environment among people with lower household income. The same social pattern was not seen for educational level.

Addressing health risks associated with housing is likely to particularly benefit low-income groups, as these groups are more likely to live in inadequate housing.

Author statements

Ethical approval

The study is registered at the University of Southern Denmark Research and Innovation Organization (registration number: 11.128). Before the interview participants received an introduction letter that emphasized that participation was voluntary. Danish legislation does not require ethical approval for surveys and register-based research that does not involve human material. See section 14 (2) https://www.retsinformation.dk/eli/lta/2020/1338. This implied that participation in the survey was regarded as giving informed consent.

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Competing interests

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.puhe.2024.08.024.

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