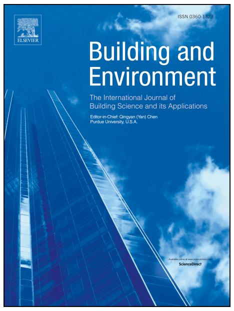


A GIS-based approach to assess the influence of the urban built environment on cardiac and respiratory outcomes in older adults

Hélène Niculita-Hirzel, Alexandre H. Hirzel, Pascal Wild

PII: S0360-1323(24)00204-X

DOI: https://doi.org/10.1016/j.buildenv.2024.111362

Reference: BAE 111362

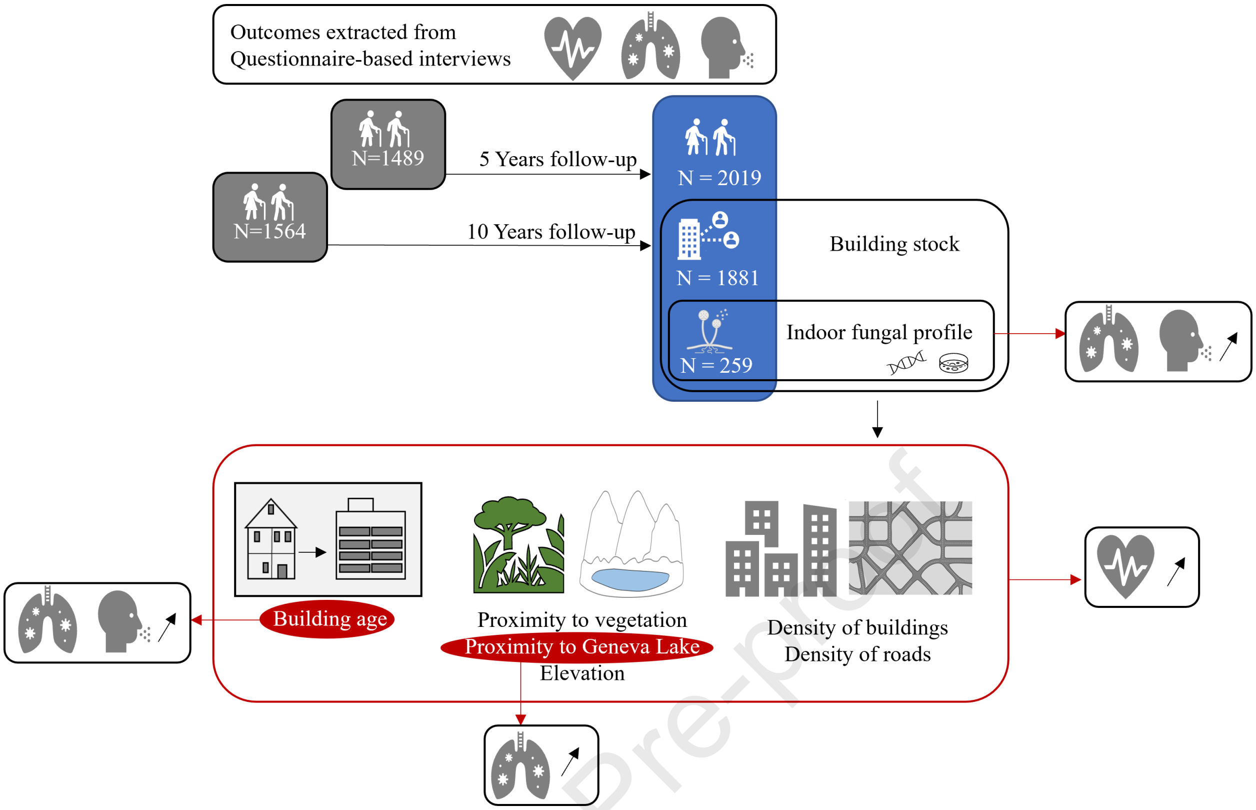
To appear in: *Building and Environment*

Received Date: 1 November 2023

Revised Date: 23 February 2024

Accepted Date: 26 February 2024

Please cite this article as: Niculita-Hirzel Héè, Hirzel AH, Wild P, A GIS-based approach to assess the influence of the urban built environment on cardiac and respiratory outcomes in older adults, *Building and Environment* (2024), doi: https://doi.org/10.1016/j.buildenv.2024.111362.


Outcomes extracted from
Questionnaire-based interviews
N=1489
N=1564
5 Years follow-up
10 Years follow-up
N = 2019
N = 1881
Building stock
N = 259
Indoor fungal profile
Building age
Proximity to vegetation
Proximity to Geneva Lake
Elevation
Density of buildings
Density of roads

A GIS-Based Approach to Assess the Influence of the Urban Built Environment on Cardiac and Respiratory Outcomes in Older Adults

Hélène Niculita-Hirzel [a,*], **Alexandre H. Hirzel** [b], **Pascal Wild** [a]

[a] *Department Work, Health & Environment, Center for Primary Care and Public Health (Unisanté), University of Lausanne, 1066 Epalinges-Lausanne, Switzerland*

[b] *Computer Science Center, Amphimax Building, Quartier Sorge, University of Lausanne, 1015 Lausanne, Switzerland*

***** *Corresponding author:*

Email address: helene.hirzel@unisante.ch (Hélène Niculita-Hirzel)

Keywords: Building age, Geographic Information System (GIS), Urban landscape, Indoor air quality, Public health, Building associated microbiome, Next Generation Sequencing (NGS)

Abstract

The impact of the urban built environment on cardiovascular and respiratory health has been studied extensively in children and adults. However, limited research exists on this topic in older adults. To fill this gap, we conducted a ten-year retrospective study of a cohort of elderly people living in Lausanne. We extracted cardiac and respiratory health outcomes of people living at the same address. A Geographic Information System (GIS) application was used to join spatial data between participant address and characteristics of the built environment (building age, building density, road density, proximity to vegetation and lake, elevation). To capture the impact of the urban landscape characteristics on the health of older people, the built environment descriptors, were considered alone and aggregated. Principal Component Analysis (PCA) was employed to resolve the multicollinearity among the built environment descriptors, while Agglomerative Hierarchical Clustering was used to reveal underlying patterns and relationships within built environment variables. In addition, to better assess the effectiveness of ventilation in their homes, we characterized indoor air-associated mycobiomes in a representative sample of homes. This involved employing both culture-based methods and metabarcoding of the Internal Transcribed Spacer 1 (ITS1) of the ribosomal DNA. The analysis revealed a significant association between exposure to the built environment as a whole and heart disease in the elderly. A higher prevalence was observed for the cluster of buildings near the lake/highway. The period of building construction showed an association with the prevalence of chronic lung disease and chronic cough, with a higher prevalence observed in houses built between 1975 and 2013. The contribution of indoor air pollution to worsening respiratory health was confirmed by higher *Aspergillus* spore loads and increased relative abundance of *Gloeophyllum* and *Aureobasidium* in indoor air, all of which were associated with respiratory outcomes. This research highlights the crucial influence of the built

environment on the health status of the elderly population, with implications for targeted interventions and public health policy development.

1 Introduction

The demographic landscape of the Organization for Economic Cooperation and Development (OECD) countries is undergoing profound change, with a significant increase in the proportion of older adults. Recent estimates suggest that by 2060, adults aged 65 and older will represent a staggering 30% of the total population in these countries [1]. This demographic shift has significant implications for public health and healthcare systems. Ensuring a high quality of life for this growing elderly population and containing future healthcare costs have become paramount concerns. Central to these efforts is the recognition that there are substantial benefits to be gained from promoting healthy aging and facilitating the ability of older adults to age in place - remaining at home for as long as possible.

Crucially, the built environment, including the design and condition of housing, plays a central role in influencing the health and well-being of older people and has a profound impact on their quality of life. Previous studies have highlighted the complex relationship between the built environment, housing quality and human health. On the one hand, certain environmental factors, such as air pollution and noise pollution steaming from heavy road traffic, have been extensively linked to deterioration in respiratory and cardiovascular health [2-4]. On the other hand, several environmental factors, such as the presence of green spaces near residential areas, have been shown to have a protective effect on mortality, including among the elderly [5]. In addition, the influence of residential density, a factor that promotes walkability and community connectivity, has emerged as a significant contributor to improved health outcomes in older adults [6, 7]. However, the influence of the built environment goes beyond external factors. It is common for older adults to spend a significant portion of their time indoors is commonplace, often due to reduced mobility, weather-related limitations, or environmental barriers for older people in unfamiliar places [8]. This prolonged indoor exposure not only affects their lifestyles, but also raises the specter of increased vulnerability to indoor air pollutants, which have been linked to several health problems, including respiratory disease.

Older adults are particularly vulnerable to air pollutants due to normal and pathological aging processes that lead to a decline in respiratory function and immune defenses, making them more susceptible to respiratory infections. In addition to the effects of aging, older adults face a number of chronic diseases, including cardiopulmonary disease, cancer, diabetes, and renal failure. In particular, chronic obstructive pulmonary disease (COPD) and asthma are prevalent in this population, further increasing their vulnerability to the adverse effects of air pollution. When exposed to air pollution, the elderly experience an increased frequency of hospital admissions for asthma and COPD, as well as a higher COPD mortality rate than others [9].

Moreover, this vulnerability extends beyond ambient air pollutants to include indoor air pollutants. Previous studies have examined the relationship between indoor air quality and health outcomes in older adults. These studies have demonstrated the increased susceptibility of this population to specific indoor air pollutants, including total volatile organic compounds (TVOC), particulate matter $PM_{2.5}$, and bioaerosols [10, 11]. However, there is limited data on the long-term effects of indoor air pollution on the overall health decline in older adults.

Given the multitude of built environments that potentially impact the health of older adults, the challenge is to identify which of these environments promote long-term health and which do not. Deciding on the most effective overall solutions to improve healthy aging becomes a complex task. To effectively address these issues, it is imperative that we shift our focus from short-term assessments to understanding the lasting effects of the built environment on an aging population. What sets our study apart is its innovative approach: we are conducting a retrospective study of individuals living in the same built environments over the course of a decade. This will allow us to assess the long-term impact of the built environment on the collected health outcomes related to the progression of cardiac and respiratory disease in the elderly population. To identify built environments that either significantly worsen the health of older people or, conversely, serve as protective factors, we implemented a dual-method strategy using Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering. This approach allows us to comprehensively analyze the association of built environment characteristics, join through Geographic Information System (GIS) applicationwith health outcomes in the elderly. PCA helps to address multicollinearity of the environmental variables, while Agglomerative Hierarchical Clustering reveals underlying patterns and relationships within built environment variables. Furthermore, since building age serves as a proxy for indoor exposure, we investigate in a representative number of buildings whether specific construction periods contribute to the development of unhealthy fungi in indoor environments. This involved employing both culture-based methods and metabarcoding of the Internal Transcribed Spacer 1 (ITS1) of the ribosomal DNA.

2. Materials and methods

The proposed approach to identify characteristics of the built environment that influence the cardiac and respiratory health of the elderly at a citywide scale includes the following steps: i) extraction of ten years of retrospective data on the cardiac and respiratory health of residents of the Lausanne Cohort 65+ (Lc65+) who have lived in the same location throughout the study period, ii) collection of building age and building environment characteristics based on participants' addresses, iii) investigation of associations between variations in building age and building environment gradient with changes in cardiac or respiratory health, and iv) investigation of whether specific indoor fungal profiles can predict exposure to the built environment and serve as indicators of health deterioration. A visual representation of the methodology is provided in Figure 1.

2.1. Cohort involved

The data used in this study are derived from the Lausanne Cohort 65+ (Lc65+), an ongoing cohort study of 4668 adults aged 65 years and older in Lausanne, Switzerland [12]. The cohort represents a diverse sample of residents of the city of Lausanne in the canton of Vaud, which has a population of approximately 120000. The cohort was established to include individuals born before, during, and after World War II. The study population initially included 1564 participants enrolled in 2004, followed by an additional sample of 1489 participants recruited in 2009, and a further 1615 participants recruited in 2014. At the time of enrollment and every three years thereafter, all Lc65+ participants underwent an interview, completed a health questionnaire, and underwent a physical examination. The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of the Canton of Vaud (initial protocol code 19/04; 2014, amendment approved on June 23, 2014). For the purposes of this study, only participants enrolled in 2004 and 2009 who did not move after enrollment were included. Those with incomplete data for the building environment variables were excluded.

2.2. Built environment variables

The city of Lausanne is located in Switzerland. It has a wide range of elevations from 400 meters to 700 meters, and a variety of environmental features, including proximity to Lake Geneva (one of the largest lakes in Europe), forests, and highways. The city has a long history of construction dating back to the 1600s. According to the Köppen climate classification system [13], Lausanne's climate is classified as warm-summer ("Dfb"). Due to its proximity to the lake, the average relative humidity in Lausanne varies between 65% and 78% depending on the season. The concentration of various pollutants in Lausanne’s ambient air has steadily decreased over the past twenty-five years. For example, the annual average concentration of particulate matter PM_{10} decreased from 36 $\mu g \cdot m^{-3}$ in 1997 to 25 $\mu g \cdot m^{-3}$ in 2007, fell below 20 $\mu g \cdot m^{-3}$ in 2010, and has remained consistently between 16 $\mu g \cdot m^{-3}$ and 13 $\mu g \cdot m^{-3}$ since 2014. These data are provided by the National Air Pollution Monitoring Network (NABEL) [14]. Similarly, the annual average NO_2 concentration was recorded at 60 $\mu g \cdot m^{-3}$ in 1991, fell below 50 $\mu g \cdot m^{-3}$ in 1997, and has remained relatively stable between 40 $\mu g \cdot m^{-3}$ and 45 $\mu g \cdot m^{-3}$ until 2018, according to data from the same network.

The characteristics of buildings and the effectiveness of their insulation have changed over the years [15]. Prior to 1944, buildings primarily had cement slab floors with metal joists in unheated areas, wood floors in heated areas, solid walls, and single-pane windows. Between 1945 and 1974, concrete slab floors were introduced in both heated and unheated spaces, walls were often uninsulated or partially insulated and windows consisted of two simple panes of glass without insulation. Starting in 1975, insulation improvements were implemented. These included integrated insulation in both heated and unheated floors, mixed insulation in walls, and the use of double-glazed windows. All of the featured buildings had natural ventilation and central heating. Therefore, the construction period was chosen as an indicator of insulation effectiveness and as a proxy for the potential accumulation of indoor pollutants. The participants of our study inhabited a representative sample of dwellings from distinct construction periods, as shown in Table S1.

Using the 1881 addresses of the 2019 eligible participants, we collected relevant data from different databases. We used a Geographic Information System (GIS) application (ArcGIS [16]) to comprehensively assess the spatial relationships between built environment features relevant to our investigation (Figure S1) . First, each address was geolocated within the study area to get its geographic coordinates. All GIS analyses were performed on these coordinates. . The building elevation was obtained by extracting the elevation from the swissALTI^{3D} raster dataset [17]. Information on proximity to forests, fields, and parks was obtained from Swiss cadastral data by computing Euclidian distance analyses. Information on proximity to the lake was obtained in the same way from the swissTLM^{3D} database [18]. Building density information was computed in the GIS using the following process: First, the vector data of the swissTLM^{3D} database [18] was converted into raster (gridded) data with a cell size of 2 x 2 meters where each cell indicates the presence or absence of a building. Second, a 1500 meter diameter circle was drawn around each address and the number of cells with building presence was counted. The same procedure was applied to street density. In addition, building characteristics such as year of construction, heating system, ventilation system, and any renovation history were obtained from the ‘Registre Cantonal des Bâtiments’ (RCB) database [19], by making a spatial join between the addresses and the RCB’s coordinates, a method commonly used in Geographic Information System (GIS) applications. This method links the spatial information, such as building coordinates, with the relevant building characteristics.

To guarantee the privacy and confidentiality of the volunteers, measures were taken to avoid any possibility of identification. Specifically, the explanatory variables characterizing built environment, corresponding to a radial number of pixels on a digital map, were reported in quintiles. These quintiles were determined based on the distribution of variables across all addresses recorded in the Lc65+ database, with each quintile representing a 100 m x 100 m area within 500 m radius.

2.3. Quantification of cultivable fungi in settled dust in indoor environments

A subsample of 259 dwellings was analyzed to investigate the relationship between building age and the accumulation of indoor pollutants. Indoor fungal load was chosen as an indicator of poor ventilation in buildings because of its proven effectiveness in previous studies [20-22]. To capture indoor fungal communities over a representative period of time, we used passive sampling with Electrostatic Dust Collectors (EDCs), a well-established method that has been validated for this purpose [23]. Participant recruitment, sampling protocols, and fungal community characterization have been described in detail elsewhere [24]. Briefly, the study was proposed during follow-up consultations of the Lc65+ cohort, and 287 eligible participants agreed to participate. Each participant was provided with an electrostatic dust collector (EDC) and instructed to place it in their main living room at a height of 1.20 to 1.60m above the floor. Participants were also given a letter with instructions to return the EDC to the laboratory after 10 weeks. Upon arrival at the laboratory, dust samples were extracted from the EDC by washing with 0.1% Tween 80 (Merck®, Darmstadt, Germany) in Stomacher™ (AES®, Combourg, France). Cultivable fungal diversity was determined by culturing an aliquot of the harvested liquid on Dichloran Glycerol 18% (DG18) agar medium at 25°C for five days. The overall composition of the fungal communities was characterized using next generation sequencing of internal transcribed spacer 1 (ITS1) with ITS1F and ITS2 universal fungal primers, as previously described [24] (Bioproject: PRJNA1033586, Biosample: SAMN38035622). Cultures revealed that *Penicillium* and *Aspergillus* were the most commonly detected fungal genera. ITS1 metabarcoding analysis revealed the presence of 248 different fungal genera indoors [24].

2.4. Health outcomes

Two primary health outcomes were evaluated: worsening of heart disease or worsening of respiratory disease over a five-year period, with a sensitivity analysis conducted to extend this period to 10 years. These outcomes were determined based on the data collected at enrollment and follow-up interviews. The following measures were considered for each outcome:

- Self-reported medical diagnoses: Participants were asked if a physician had ever told them about specific chronic respiratory diseases (e.g., asthma, chronic bronchitis, other) and/or heart diseases (e.g., coronary heart disease, other heart disease) within the past 12 months. This self-report method allowed for the identification of individuals with existing medical diagnoses.
- Medication use: Participants were asked about their current medication use for chronic respiratory or cardiac conditions, specifically whether they took medication once a week or more frequently. This information provided insight into the ongoing management and treatment of their respective conditions.
- Chronic symptoms: Participants were asked to report the presence of chronic symptoms experienced within the past 6 months, including cough and dyspnea. These symptoms served as indicators of respiratory distress and provided additional context regarding participants' respiratory health.

2.5. Covariates

Individual-level covariates assessed at baseline included age, sex, education level, smoking status (categorized as current, former, or never), and household size. These covariates were chosen to capture important demographic and lifestyle factors that could potentially influence the association between the built environment and cardiac and respiratory outcomes in older adults.

2.6. Statistical analysis

Descriptive statistics – frequencies with proportions and means with standard deviations (SD) – were used to describe the sociodemographic and clinical characteristics of respondents at enrollment, 5 years, and 10 years after enrollment. To assess eventual differences in socio-demographic characteristics between participants enrolled in 2004 and 2009 included in the present study, we employed statistical tests tailored to the nature of the variables. Continuous variables, such as age, were compared using a 2-sample t-test. For categorical variables, such as gender or education level, we utilized the chi-squared test.

The variables characterizing the built environment around the 2019 addresses of the Lc65+ retained participants, as generated by the GIS application, were initially, tested one by one, for their association to health outcomes, assuming a linear effect of the categories, in the absence of a priori hypotheses. However, it is important to note that environmental variables, such as green space and traffic-related variables, may exhibit temporal and/or spatial correlations, and are often correlated with demographic and socioeconomic determinants. When including correlated variables in regression models, it is crucial to consider the potential for erroneous estimation of effect size, and broad confidence intervals, which can lead to inaccurate interpretation. To mitigate the effects of multiple correlated variables, we reduce the dimensionality of the dataset by conducting a principal component analysis (PCA) on the nine built environment characteristics (proximity to forest, field, garden, water body other than lake, the Lake Geneva, road density, building density around the address of interest, elevation, and building construction period), prior to conducting statistical tests for association with health outcomes. PCA is a commonly used method in epidemiological studies [25, 26] that transforms a set of correlated variables into a smaller group of independent variables, called principal components (PCs). These PCs, rather than individual variables, are used in regression analysis to eliminate multicollinearity. However, the main drawback of PCA is its lack of interpretability, as each principal component is a combination of variables, making inference impossible. Furthermore, variables grouped under a single principal component may have opposing effects on health outcomes. To control for such side effects, we also used a method that allowed us to group the addresses based on the similarity of the overall neighborhood descriptors [27, 28], the agglomerative hierarchical clustering (AHC) method. The eight landscape descriptors were used employing the complete linkage method, and measuring cluster distance using the Euclidean distance between the built environment variables generated by the GIS application. This method complements PCA by providing additional insights into the structure of the data and identifying clusters of dwellings with similar built environment characteristics. Considering the number of dwellings with available information on their surrounding characteristics, a maximum of ten clusters were considered in order to maintain sufficient statistical power in each cluster. The dendrogram of cluster analysis is shown in supplementary material Figure S2. The results indicated that five clusters fitted best the data. In the manuscript, we referred to these five distinct neighborhood types (Table S1) as the "built environment score" (BES) to facilitate the presentation of the results. The algorithm was applied to all unique addresses available in the Lc65+ cohort with no missing variables.

Multilevel mixed-effects logistic regression analysis was conducted to explore associations between discrete environmental variables and the prevalence of individual health outcomes. For each symptom, selected confounding factors are adjusted using a backward modeling approach. Initially, all factors were included, and subsequently, those found to have no significant influence were iteratively eliminated using a significance level of 5%, considering the large sample size of the population. Additionally, interactions between the remaining factors, gender, and cohort were documented. Separate models were generated for each environment variable considered, including the built environment descriptor, the built environment PCA component, the BES, or the presence/absence of individual fungal species.

In our analyses, we systematically quantified the impact on health outcomes using odds ratios (ORs), with adjustments made for age, sex, and smoking status.

To investigate the relationship between each symptom and a continuous variable representing the built environment microbiome, encompassing either the overall mycobiome or the relative abundance of individual fungal species, multivariate analysis of variance (MANOVA) followed by multivariate regression was used. For statistical robustness, all fungal concentrations, whether expressed as relative abundances or colony forming units, were log-transformed to approximate a normal distribution. Statistical analyses were performed with STATA version 17.0 (StataCorp LLC, College Station, TX, USA).

3. Results

3.1. Population health status

Among the 2019 participants included in the study (as shown in Table 1), 70% reported good or very good perceived health at enrollment, and this proportion remained relatively constant five years later (70%). However, ten years after enrollment, the proportion reporting good or very good perceived health decreased slightly to 62%. Regarding heart disease, 16% of participants reported having a heart condition (chronic heart disease and/or taking heart medication once a week) at enrollment. This percentage increased to 19% at five years and to 28% at ten years. In addition, 13% of these participants reported taking regular medication for their heart condition at enrollment, which increased to 16% at five years and 25% at ten years. The results suggest that the risk of having a heart condition, particularly regular use of heart medication, increases with age (odds ratio [95% confidence interval] = 1.13 [1.09 - 1.18], p = 0.000; odds ratio [95% confidence interval] = 1.14 [1.09 - 1.18], p = 0.000, respectively).

Furthermore, the prevalence of heart disease is higher in men than in women, with 26% of men and 17% of women reporting heart disease.

In terms of respiratory outcomes, 19% of participants reported having a respiratory condition at enrollment, including chronic lung disease, asthma medication use, and/or chronic cough. This percentage increased slightly to 21% at five years and further to 27% at ten years. Specifically, 7% of participants had chronic lung disease at enrollment, while 4% reported taking asthma medication. After five years, the percentages increased to 9% for chronic lung disease and 5% for asthma medication use. These percentages remained relatively stable ten years after enrollment, with 10% reporting chronic lung disease and 5% taking asthma medication. Those who were active smokers during the entire study period had an increased risk of developing chronic lung disease (odds ratio [95% confidence interval] = 2.80 [1.86 - 4.22], *p* = 0.000), regardless of age or sex. Active smokers also had a higher prevalence of chronic cough (odds ratio [95% confidence interval] = 2.02 [1.19 - 3.43], *p* = 0.008). In contrast, the prevalence of asthma medication use was higher in women than in men (odds ratio [95% confidence interval] = 1.89 [1.19 - 3.00], *p* = 0.007).

3.2. Built environment components

Principal component analysis (PCA) of the built environment variables yielded three eigenvalues greater than 1.0, as shown in Table 2. The first principal component (PC1) accounted for 47% of the total variance in the built environment data, while the second and third principal components (PC2 and PC3) explained 12.4% and 11.6% of the variance, respectively. PC1, with an eigenvalue of 4.2, primarily consisted mainly of variables related to proximity to forests and urbanization density (density of buildings and roads in the surrounding area). PC2, with an eigenvalue of 1.1, was mainly influenced by the proximity to the lake. PC3, with an eigenvalue of 1.0, was mainly influenced by the age of the building and the proximity to gardens / to water body other than lake. To effectively integrate the information provided by these three components (urbanization density, proximity to the lake, and age of the building), an agglomerative hierarchical clustering method was applied to the nine built environment variables of the 2019 addresses. This analysis led to the identification of five distinct urban landscape clusters across Lausanne. For the purpose of describing the results, this indicator was named Built Environment Score (BES). Cluster 1 includes dwellings mainly located in rural suburbs surrounded by forests and fields, with low densities of roads and buildings. Cluster 2 consists of buildings almost located in urban suburbs with nearby gardens. Cluster 3 groups buildings in the historical town center characterized by high road and building densities, and a lack of vegetation in the surroundings. Cluster 4 includes dwellings located in the urban center with high road and building densities, not far from the lake. Cluster 5 comprises buildings located near the lakeside with low road and building densities but in close proximity to a highway (see Table S2-S9).

3.3. Association between components of the built environment and health outcomes

Regarding heart disease outcomes, none of principal component analysis (PCA) components were significantly associated with an increase in heart disease prevalence (Table 3). Therefore, we researched for an association between the overall characteristics of urban landscape, as described by the five clusters generated by Agglomerative Hierarchical Clustering analysis, and these health outcomes. A worsening of heart disease was positively associated with the built environment score (BES), with individuals living in dwellings within cluster 5 of the urban landscape environment being the most affected (Table 3, Figure S3). The OR was even higher when only weekly medication for heart disease was considered (data not shown).

Regarding respiratory outcomes, principal component 2 (proximity to the lake) of the PCA was associated with a higher prevalence of asthma medication use and chronic lung disease (Table

2). The principal component 3 (building age, and proximity to the garden /water source other than lake) was negatively associated with the use of asthma medication (Table 3). However, notice that the correlation coefficients between building age / proximity to the garden and PC3 were also negatives (Table 2). Therefore, lake proximity and building age were considered as individual variables in the multivariate adjusted model for each respiratory outcome. The analysis confirmed that lake proximity was statistically significantly associated with a higher prevalence of asthma medication use (OR [95% confidence interval] = 1.22 [1.07 - 1.40], *p* = 0.004) and chronic lung disease (OR [95% confidence interval] = 1.18 [1.06 - 1.31], *p* = 0.001) (Figure S3). Building age was found to be associated with chronic lung disease (OR [95% confidence interval] = 1.13 [1.04 - 1.23], *p* = 0.003) and chronic cough (OR [95% confidence interval] = 1.12 [1.01 - 1.25], *p* = 0.035), with more recent buildings showing a tendency towards exacerbating respiratory conditions (Figure S3).

To further confirm the impact of the built environment on respiratory health, bioaerosols were monitored in a representative sub-sample of 259 homes, as the concentration and composition of bioaerosols are sensitive to the effectiveness of home ventilation. The results showed that individuals exposed to a higher concentration of fungal spores, especially *Aspergillus*, had a higher risk of developing chronic cough (OR [95% confidence interval] = 1.19 [1.04 - 1.36], *p* = 0.009; OR [95% confidence interval] = 1.25 [1.08 - 1.45], *p* = 0.003, respectively), after adjustment for age, sex, and smoking status. However, no significant associations were observed between fungal community diversity or composition and health outcomes, even after adjusting for proximity to green space (data not shown). Only specific associations between the relative abundance of certain fungal taxa and respiratory outcomes were identified, such as the relative abundance of *Gloeophyllum* and the prevalence of chronic lung disease (OR [95% confidence interval] = 10.38 [1.41 - 76.48], *p* = 0.022), or the relative abundance of *Aureobasidium* and the prevalence of asthma medication use (OR [95% confidence interval] =

14.08 [1.32 - 150.64], $p = 0.029$). However, it is important to note that these results are based on a small number of patients with chronic cough (N=7), chronic lung disease (N=8), and asthma medication use (N=2), as the mycobiome was successfully sequenced in the built environment of 136 participants.

4. Discussion

Our study offers several notable contributions to the fields of environmental health, urban planning, and gerontology. First, it allows us to observe trends in the health status of older adults by providing a rare and comprehensive longitudinal dataset spanning a decade. Second, it takes an interdisciplinary approach, integrating data on the built environment, air quality, and health outcomes, to help us better understand the complex interactions among these factors over time. Finally, it exploits the spatial variability of health outcomes within urban areas to identify distinct urban landscape features that are associated with the deterioration of specific health outcomes.

The findings of our study on the changing health status of older adults are consistent with previous research showing that perceived health remains relatively stable with age but declines rapidly as death approaches [29]. The observed increase in heart disease prevalence over the ten-year period is consistent with previous research showing an increase in cardiovascular disease with age [30]. The gender disparities found, with higher prevalence in men, are consistent with known gender differences in heart disease incidence and mortality [31]. In addition, our findings of increased use of cardiac medications over time support the notion that older individuals are more likely to require pharmacological interventions to manage cardiac disease [32]. Interestingly, older women in our study had a higher prevalence of asthma medication use than men of similar age, a finding consistent with limited European[33] and extensive Asian research [34]. Several factors may contribute to this discrepancy. Hormonal fluctuations during menopause, common in older women, may influence asthma symptoms by affecting airway inflammation and bronchial hyperresponsiveness [35]. In addition, unique environmental exposures, including indoor air pollutants, allergens, and occupational hazards, may disproportionately affect older women and contribute to the development and exacerbation of asthma. In particular, older women in this age group were more likely to be exposed to indoor air pollutants such as those from gas cooking [36], household use of cleaning products, especially spray cleaners [37], and passive smoking [38], factors that have previously been shown to increase the risk of asthma development and exacerbation. These specific environmental factors may contribute significantly to the prevalence of asthma in older women.

One of our key findings highlights the significant impact of the overall built environment, which includes factors beyond proximity to green space or heavy traffic identified in previous studies, on the health of older adults. Specifically, our study finds a significant association between the built environment score (BES) and the prevalence of heart disease. In light of our findings and the existing body of research, it is becoming increasingly clear that a holistic approach is needed when assessing the impact of the built environment on the mental and physical health of older adults. This holistic perspective remains relevant, even as we recognize the importance of identifying specific elements within the built environment that contribute to the creation of healthier living spaces, so that we can take actionable steps to intervene and transform the environment. Previous epidemiological studies have consistently shown robust associations between exposure to air pollutants and the incidence of cardiovascular disease [4, 39, 40]. In particular, these studies have highlighted the significant health effects of exposure to $PM_{2.5}$ and NO_2. $PM_{2.5}$ is of particular concern because of its ability to penetrate deeply into the respiratory system and even enter the bloodstream, potentially leading to systemic inflammation and oxidative stress [4, 40, 41]. NO_2, a major component of traffic-related air pollution, has been linked to adverse cardiovascular effects, including increased blood pressure and atherosclerosis [42]. While proximity to busy roads has been shown to increase exposure to noise and traffic-related pollutants such as $PM_{2.5}$ and NO_2 [4], access to green spaces and natural environments has consistently been consistently shown to provide several health benefits, including stress reduction [43], promotion of physical activity [44], improvement of cardiovascular health, and reduction of mortality risk [5, 45, 46]. Similarly, the presence of water bodies in urban environments, such as lakes or rivers, has been associated with positive health outcomes, including improved mental health, and promotion of physical activity [47, 48]. In addition, neighborhood walkability, characterized by features such as sidewalks, pedestrian-friendly infrastructure, and proximity to essential services, has been associated with increased levels of physical activity and improved perceptions of physical health [6]. Studies have shown that older adults living in walkable neighborhoods tend to engage in more physical activity, which leads to improved mobility, fitness, and overall perceptions of physical health.

Another key finding of this study is the increased prevalence of respiratory conditions among the older adult population over the ten-year period. While it is well-established that aging itself can bring about physiological changes that impact respiratory health, it is essential to consider the potential influence of air pollutants in either exacerbating or mitigating these changes. Our study revealed specific features of the built environment associated with a decline in respiratory health among older adults. Proximity to the lake, which cannot be distinguished from proximity to the highway, was associated with a higher prevalence of asthma medication use, while building age was associated with a higher prevalence of chronic lung disease and chronic cough. These findings suggest that living near a lake/highway or in buildings constructed between 1975 and 2013 may worsen respiratory conditions in older adults.

The choice of building materials and the effectiveness of ventilation systems in residential buildings have been shown to have a significant impact on indoor air quality [49, 50]. The age of the building serves as a reliable indicator of the indoor air quality because of the different materials used during each construction period, and the specific emissions they generate. Some materials tend to deteriorate and generate more fine particulate matter ($PM_{2.5}$) than others [51]; also, materials tend to emit higher levels of volatile organic compounds (VOCs) in the first years after the construction than later [50]. It is noteworthy that while the role of $PM_{2.5}$ in asthma is still debated, the effects of VOCs on respiratory health, particularly their association with asthma, have been established in systematic reviews [52]. The accumulation of indoor pollutants in buildings constructed after 1975, compared to those constructed before 1975, was facilitated by improved insulation standards and the lack of implementation of efficient ventilation systems. This oversight often leads to the accumulation of moisture in these buildings, creating favorable conditions for indoor mold growth [22]. Such accumulation is of particular concern for older adults who are already susceptible to respiratory issues due to age-related changes in lung function [53, 54]. Living in damp indoor environments has been recognized as a contributing factor to respiratory health issues [55, 56]. Damp indoor environments can lead to mold growth, which is associated with the release of mycotoxins and allergenic spores. Prolonged exposure to these indoor contaminants can exacerbate respiratory conditions [57, 58]. In contrast, well-designed and maintained ventilation systems, combined with appropriate building materials, have the potential to significantly improve indoor air quality. Adequate ventilation can reduce indoor pollutant concentrations, including particulate matter, VOCs, and allergens, thus promoting a healthier indoor environment [59]. Furthermore, building designs that prioritize the use of low-emitting materials and promote proper air exchange can play a pivotal role in the respiratory health of older populations [60].

Our findings suggest that increased insulation in buildings constructed after 1975 may lead to the accumulation of indoor air pollutants in the absence of efficient ventilation systems. To further explore whether the influence of the built environment on respiratory health is associated with inefficient ventilation leading to dampness and mold growth, we characterized mycobiome composition by culture and metabarcoding in a representative subsample of homes. Indeed, mold growth is known to thrive in environments with excess moisture due to inadequate ventilation. Our results showed that individuals exposed to higher concentrations of fungal spores, particularly *Aspergillus*, had an increased risk of developing chronic cough.

Numerous studies have shown that indoor air quality, influenced by building age, ventilation systems, and the presence of moisture or dampness, can significantly affect respiratory health. It is worth exploring whether the observed associations between specific fungal taxa and respiratory outcomes are exacerbated or attenuated by characteristics of the built environment such as the presence of green space or the age of the building. The associations between fungal spores load and respiratory outcomes prevalence are consistent with studies highlighting the role of indoor air quality and the mycobiome composition in respiratory health [61, 62]. However, the unique associations between specific fungal taxa and respiratory outcomes underscore the complexity of indoor mycobiome interactions with health, and warrant further investigation [63].

The strength of our study lies in the use of diverse statistical methods, including hierarchical clustering and principal component analysis (PCA), to explore the relationships between urban landscape characteristics and health outcomes. Hierarchical clustering revealed the importance of considering the built environment as a whole in elucidating its contribution to the long-term development of cardiac outcomes. Conversely, PCA proved to be more effective in identifying the environmental variables that exert an influence on the respiratory health of older adults. This could be explained by the fact that the size of the population followed up in each cluster of urban landscape considered was not large enough to detect a clear association between this built environment score and the worsening of the respiratory health in the elderly. Furthermore, the inclusion of indoor air quality data underscored the importance of collecting such data to refine our understanding of the interplay between indoor and outdoor environmental factors and their impact on respiratory health. This holistic approach highlights the importance of employing various statistical methods to comprehensively capture the multifaceted effects of the built environment on human health. However, while our study provides valuable insights into the association between the built environment and cardiac and respiratory outcomes in older adults, it is important to acknowledge several limitations. First, the study was conducted in a specific geographic location (Lausanne, Switzerland), which may limit the generalizability of the findings to other settings. Future research should aim to replicate these findings in different populations and geographical contexts. Second, some respiratory outcome categories had relatively small sample sizes, resulting in limited statistical power. This limitation may have affected our ability to detect significant associations between the fungal community composition and health outcomes. Future studies with larger sample sizes are warranted to validate these findings and explore the potential role of fungal diversity in respiratory health. Furthermore, although we have discussed the potential mediating role of the built environment, causality cannot be definitively established within the scope of this observational study. Intervention studies would be needed to elucidate causal relationships between specific characteristics of the built environment, air quality, and health outcomes in older adults,. Finally, the generalizability of our findings to diverse populations and geographic regions should be approached with caution, as our study focused on a specific urban area. Despite these limitations, our research provides a valuable foundation for future investigation and urban planning initiatives aimed at promoting healthier aging.

In conclusion, our study highlights the significant influence of the built environment on cardiac and respiratory health outcomes in older adults. These findings underscore the importance of built environment factors, such as proximity to green space, urbanization density, and building age, in promoting healthy aging. Such findings have profound implications for urban planning and public health interventions aimed at creating age-friendly environments that support the well-being of older populations. Our research offers practical implications for urban planning and policy development, suggesting that designing age-friendly urban environments with better access to green spaces and improved air quality could promote better health and well-being among older populations. Furthermore, the findings have the potential to inform evidence-based policies aimed at improving urban living conditions for older adults, such as initiatives to reduce air pollution, improve green infrastructure, and create age-friendly neighborhoods. By examining health disparities within urban areas, our research also highlights the need for targeted interventions to address the specific health needs of vulnerable populations. Ultimately, this study lays a solid scientific foundation for future investigations into the relationships between the built environment, air quality, and health, and serves as a reference point for designing more focused studies and interventions in this important area of research.

5. Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

6. Author Contributions

Conceptualization, H.N-H. and P.W.; methodology, H.N-H. and P.W.; data extraction and GIS analysis, A.H.H.; formal analysis, H.N-H. and P.W; investigation, H.N-H. resources, H.N-H.; writing—original draft preparation, H.N-H. and P.W; writing—review and editing, H.N-H. All authors have read and agreed to the published version of the manuscript.

7. Funding

This research received no external funding.

8. Acknowledgments

We thank Prof. Brigitte Santos-Eggimann for submitting the amendment concerning this study to the Vaud Ethics Committee and for anonymizing the data, the people of her group involved in collecting data and in the distributing the electrostatic dust collectors.

9. Supplementary Material

The Supplementary Material for this article can be found online at:

Figure S1. Geospatial localization of dwellings considered in the study.

Figure S2. Dendrogram of agglomerative hierarchical cluster analysis

Figure S3. Marginal predicted mean of health outcomes by built environment descriptor, with 95% confidence intervals. **A**. Proportion of heart medication by urban landscape cluster; **B**. Proportion of medication for asthma by quantile of proximity to the lake; **C**. Proportion of chronic lung disease by construction period of the building.

Table S1. Number of participants residing in buildings from each construction period

Table S2. Descriptive statistics of road density variable in the five urban landscape clusters.

Table S3. Descriptive statistics of building density variable in the five urban landscape clusters

Table S4. Descriptive statistics of elevation variable in the five urban landscape clusters

Table S5. Descriptive statistics of proximity to Geneva Lake variable in the five urban landscape clusters.

Table S6. Descriptive statistics of proximity to water other than lake variable in the five urban landscape clusters.

Table S7. Descriptive statistics of proximity to forest variable in the five urban landscape clusters.

Table S8. Descriptive statistics of proximity to garden variable in the five urban landscape clusters

Table S9. Descriptive statistics of proximity to field variable in the five urban landscape clusters.

Data Availability Statement

The data presented in this study are available on request from the authors. The NGS data are available at NCBI under the Bioproject: PRJNA1033586 and Biosample: SAMN38035622.

10. Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-3.5 in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

11. References

[1] OECD, OECD Economic Surveys: Switzerland 2019, in: O. Publishing (Ed.) Paris, 2019.

[2] H. Mustafic, P. Jabre, C. Caussin, M.H. Murad, S. Escolano, M. Tafflet, M.C. Perier, E. Marijon, D. Vernerey, J.P. Empana, X. Jouven, Main Air Pollutants and Myocardial Infarction A Systematic Review and Meta-analysis, Jama-J Am Med Assoc 307(7) (2012) 713-721. doi: 10.1001/jama.2012.126

[3] W. Babisch, Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis, Noise Health 16(68) (2014) 1-9. doi: 10.4103/1463-1741.127847

[4] H. Heritier, D. Vienneau, M. Foraster, I.C. Eze, E. Schaffner, K. de Hoogh, L. Thiesse, F. Rudzik, M. Habermacher, M. Kopfli, R. Pieren, M. Brink, C. Cajochen, J. MarcWunderli, N. Probst-Hensch, M. Roosli, SNC Study Grp, A systematic analysis of mutual effects of transportation noise and air pollution exposure on myocardial infarction mortality: a nationwide cohort study in Switzerland, Eur Heart J 40(7) (2019) 598-603. doi: 10.1093/eurheartj/ehy650

[5] D. Vienneau, K. de Hoogh, D. Faeh, M. Kaufmann, J.M. Wunderli, M. Roosli, SNC Study Grp, More than clean air and tranquillity: Residential green is independently associated with decreasing mortality, Environment International 108 (2017) 176-184. doi: 10.1016/j.envint.2017.08.012

[6] D.W. Barnett, A. Barnett, A. Nathan, J. Van Cauwenberg, E. Cerin, E. Council on Environment and Physical Activity (CEPA) – Older Adults working group, Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis, Int J Behav Nutr Phys Act 14(1) (2017) 103. doi: 10.1186/s12966-017-0558-z

[7] B.de Lapasse, É. Prévost, La mobilité des retraités à tous les âges, Retraite et société 86 (2021) 211-228. doi: 10.3917/rs1.086.0212

[8] J. Phillips, N. Walford, A. Hockey, N. Foreman, M. Lewis, Older people and outdoor environments: Pedestrian anxieties and barriers in the use of familiar and unfamiliar spaces, Geoforum 47 (2013) 113-124. doi: 10.1016/j.geoforum.2013.04.002

[9] M. Bentayeb, M. Simoni, N. Baiz, D. Norback, S. Baldacci, S. Maio, G. Viegi, I. Annesi-Maesano, G.S.E.H. Effect, Adverse respiratory effects of outdoor air pollution in the elderly, Int J Tuberc Lung D 16(9) (2012) 1149-1161.

[10] J. Belo, P. Carreiro-Martins, A.L. Papoila, T. Palmeiro, I. Caires, M. Alves, S. Nogueira, F. Aguiar, A. Mendes, M. Cano, M.A. Botelho, N. Neuparth, The impact of indoor air quality on respiratory health of older people living in nursing homes: spirometric and exhaled breath condensate assessments, Journal of Environmental Science and Health Part a-Toxic/Hazardous Substances & Environmental Engineering 54(12) (2019) 1153-1158. doi: 10.1080/10934529.2019.1637206

[11] M. Bentayeb, C. Billionnet, N. Baiz, M. Derbez, S. Kirchner, I. Annesi-Maesano, Higher prevalence of breathlessness in elderly exposed to indoor aldehydes and VOCs in a representative sample of French dwellings, Resp Med 107(10) (2013) 1598-1607. doi: 10.1016/j.rmed.2013.07.015

[12] B. Santos-Eggimann, A. Karmaniola, L. Seematter-Bagnoud, J. Spagnoli, C. Bula, J. Cornuz, N. Rodondi, P. Vollenweider, G. Waeber, A. Pecoud, The Lausanne cohort Lc65+: a population-based prospective study of the manifestations, determinants and outcomes of frailty, BMC Geriatr 8 (2008) 20.

[13] W. Köppen, Das geographische System der Klimate [The Geographical System of the Climate, Handbook of Climatology], Borntraeger, Berlin1936.

[14] EMPA, OFEV, National Air Pollution Monitoring Network (NABEL) https://www.empa.ch/web/s503/nabel

[15] S. Schwab, J.-L. Rime, L. Rinquet, S. Citherlet, G.-A. Morand, Approche globale pour l'enveloppe du bâtiment. Renovation énergétique, 2016.

[16] ESRI 2020. ArcGIS Desktop 10.8. Redlands, CA: Environmental Systems Research Institute.

[17] swisstopo, swissALTI3D. https://www.swisstopo.admin.ch/fr/geodata/height/alti3d.html

[18] swisstopo, swissTLM3D. https://www.swisstopo.admin.ch/en/home.html

[19] Etat de Vaud, 'Registre Cantonal des Bâtiments' https://www.vd.ch/themes/territoire-et-construction/cadastre-et-geoinformation/registre-cantonal-des-batiments-rcb

[20] R. Aynsley, J.J. Shiel, Ventilation strategies for a warming world, Archit Sci Rev 60(3) (2017) 249-254. doi: 10.1080/00038628.2017.1300764

[21] S. Roussel, G. Reboux, A.P. Bellanger, S. Sornin, F. Grenouillet, J.C. Dalphin, R. Piarroux, L. Millon, Characteristics of dwellings contaminated by moulds, J Environ Monitor 10(6) (2008) 724-729. doi: 10.1039/b718909e

[22] H. Niculita-Hirzel, Latest Trends in Pollutant Accumulations at Threatening Levels in Energy-Efficient Residential Buildings with and without Mechanical Ventilation: A Review, Int J Env Res Pub He 19(6) (2022). doi: 10.3390/ijerph19063538

[23] M. Frankel, M. Timm, E.W. Hansen, A.M. Madsen, Comparison of sampling methods for the assessment of indoor microbial exposure, Indoor Air 22(5) (2012) 405-414. doi: 10.1111/j.1600-0668.2012.00770.x

[24] H. Niculita-Hirzel, P. Wild, A.H. Hirzel, Season, Vegetation Proximity and Building Age Shape the Indoor Fungal Communities’ Composition at City-Scale, Journal of Fungi 8(10) (2022). doi: 10.3390/jof8101045

[25] M. Mamouei, Y.J. Zhu, M. Nazarzadeh, A. Hassaine, G. Salimi-Khorshidi, Y.T. Cai, K. Rahimi, Investigating the association of environmental exposures and all-cause mortality in the UK Biobank using sparse principal component analysis, Sci Rep-Uk 12(1) (2022).

[26] L.K. Welker-Hood, H.P. Hynes, T. Heeren, J. Snell, D. Helmes, Principal component analysis as a new methodology for developing sensitive exposure measures for building dampness, Epidemiology 15(4) (2004) S157-S158.

[27] C. Atkinson-Palombo, L. Varone, N.W. Garrick, Understanding the Surprising and Oversized Use of Ridesourcing Services in Poor Neighborhoods in New York City, Transport Res Rec 2673(11) (2019) 185-194.

[28] T. Calinski, A Dendrite Method for Cluster Analysis, Biometrics 24(1) (1968) 207-&.

[29] D. Gerstorf, N. Ram, G. Mayraz, M. Hidajat, U. Lindenberger, G.G. Wagner, J. Schupp, Late-Life Decline in Well-Being Across Adulthood in Germany, the United Kingdom, and the United States: Something Is Seriously Wrong at the End of Life, Psychol Aging 25(2) (2010) 477-485. doi: 10.1037/a0017543.

[30] R.M. Conroy, K. Pyörälä, A.P. Fitzgerald, S. Sans, A. Menotti, G. De Backer, D. De Bacquer, P. Ducimetière, P. Jousilahti, U. Keil, I. Njolstad, R.G. Oganov, T. Thomsen, H. Tunstall-Pedoe, A. Tverdal, H. Wedel, P. Whincup, L. Wilhelmsen, I.M. Graham, S.P. Grp, Estimation of ten-year risk of fatal cardiovascular disease in Europe:: the SCORE project, Eur Heart J 24(11) (2003) 987-1003. doi: 10.1016/S0195-668x(03)00114-3

[31] L. Mosca, E. Barrett-Connor, N.K. Wenger, Sex/Gender Differences in Cardiovascular Disease Prevention What a Difference a Decade Makes, Circulation 124(19) (2011) 2145-2154. doi: 10.1161/Circulationaha.110.968792

[32] J.L. Fleg, W.S. Aronow, W.H. Frishman, Cardiovascular drug therapy in the elderly: benefits and challenges, Nat Rev Cardiol 8(1) (2011) 13-28. doi: 10.1038/nrcardio.2010.162

[33] R. Isoaho, H. Puolijoki, E. Huhti, S.L. Kivela, E. Tala, Prevalence of Asthma in Elderly Finns, J Clin Epidemiol 47(10) (1994) 1109-1118. doi: 10.1016/0895-4356(94)90097-3

[34] S.Y. Park, J.H. Kim, H.J. Kim, B. Seo, O.Y. Kwon, H.S. Chang, H.S. Kwon, T.B. Kim, H. Kim, C.S. Park, H.B. Moon, Y.S. Cho, High Prevalence of Asthma in Elderly Women: Findings From a Korean National Health Database and Adult Asthma Cohort, Allergy Asthma Immun 10(4) (2018) 387-396. doi: 10.4168/aair.2018.10.4.387

[35] D.S. Postma, Gender differences in asthma development and progression, Gender Med 4 (2007) S133-S146. doi: 10.1016/s1550-8579(07)80054-4.

[36] S.E. Moran, D.P. Strachan, I.D.A. Johnston, H.R. Anderson, Effects of exposure to gas cooking in childhood and adulthood on respiratory symptoms, allergic sensitization and lung function in young British adults, Clinical and Experimental Allergy 29(8) (1999) 1033-1041. doi:10.1046/j.1365-2222.1999.00561.x

[37] P. Lemire, O. Dumas, S. Chanoine, S. Temam, G. Severi, M.C. Boutron-Ruault, J.P. Zock, V. Siroux, R. Varraso, N. Le Moual, Domestic exposure to irritant cleaning agents and asthma in women, Environment International 144 (2020). doi: 10.1016/j.envint.2020.106017.

[38] M.S. Jaakkola, Environmental tobacco smoke and health in the elderly, European Respiratory Journal 19(1) (2002) 172-181. doi: 10.1183/09031936.02.00270702

[39] R.W. Atkinson, Long-term Exposure to Outdoor Air Pollution and Incidence of Cardiovascular Diseases (vol 24, pg 44, 2013), Epidemiology 24(2) (2013) 339-339. doi: 10.1097/EDE.0b013e318276ccb8

[40] T. Bourdrel, M.A. Bind, Y. Béjot, O. Morel, J.F. Argacha, Cardiovascular effects of air pollution, Arch Cardiovasc Dis 110(11) (2017) 634-642. doi: 10.1016/j.acvd.2017.05.003

[41] P. Thangavel, D. Park, Y.C. Lee, Recent Insights into Particulate Matter (PM)-Mediated Toxicity in Humans: An Overview, Int J Env Res Pub He 19(12) (2022). doi: 10.3390/ijerph19127511

[42] A. Faustini, R. Rapp, F. Forastiere, Nitrogen dioxide and mortality: review and meta-analysis of long-term studies, European Respiratory Journal 44(3) (2014) 744-753. doi: 10.1183/09031936.00114713

[43] D.E. Bowler, L.M. Buyung-Ali, T.M. Knight, A.S. Pullin, A systematic review of evidence for the added benefits to health of exposure to natural environments, BMC Public Health 10 (2010). doi: 10.1186/1471-2458-10-456

[44] M.J. Ali, M. Rahaman, S.I. Hossain, Urban green spaces for elderly human health: A planning model for healthy city living, Land Use Policy 114 (2022). doi: 10.1016/j.landusepol.2021.105970

[45] P. James, J.E. Hart, R.F. Banay, F. Laden, Exposure to Greenness and Mortality in a Nationwide Prospective Cohort Study of Women, Environ Health Persp 124(9) (2016) 1344-1352. doi: 10.1289/ehp.1510363

[46] P.J. Villeneuve, M. Jerrett, J.G. Su, R.T. Burnett, H. Chen, A.J. Wheeler, M.S. Goldberg, A cohort study relating urban green space with mortality in Ontario, Canada, Environ Res 115 (2012) 51-58. doi: 10.1016/j.envres.2012.03.003

[47] M. Gascon, W. Zijlema, C. Vert, M.P. White, M.J. Nieuwenhuijsen, Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies, Int J Hyg Envir Heal 220(8) (2017) 1207-1221. doi: 10.1016/j.ijheh.2017.08.004

[48] N. Smith, M. Georgiou, A.C. King, Z. Tieges, S. Webb, S. Chastin, Urban blue spaces and human health: A systematic review and meta-analysis of quantitative studies, Cities 119 (2021). doi: 10.1016/j.cities.2021.103413

[49] A.P. Jones, Indoor air quality and health, Atmospheric Environment 33(28) (1999) 4535-4564. doi: 10.3390/ijerph14111286

[50] D.A. Missia, E. Demetriou, N. Michael, E.I. Tolis, J.G. Bartzis, Indoor exposure from building materials: A field study, Atmos Environ 44(35) (2010) 4388-4395. doi: 10.1016/j.atmosenv.2010.07.049

[51] H. Yuk, S.W. Yang, S. Wi, Y. Kang, S. Kim, Verification of particle matter generation due to deterioration of building materials as the cause of indoor fine dust, Journal of Hazardous Materials 416 (2021). doi: 10.1016/j.jhazmat.2021.125920

[52] C.A. Paterson, R.A. Sharpe, T. Taylor, K. Morrissey, Indoor PM2.5, VOCs and asthma outcomes: A systematic review in adults and their home environments, Environ Res 202 (2021). doi: 10.1016/j.envres.2021.111631

[53] D.M.E. Bowdish, The Aging Lung Is Lung Health Good Health for Older Adults?, Chest 155(2) (2019) 391-400. doi: 10.1016/j.chest.2018.09.003

[54] S.P. Eckel, T.A. Louis, P.H.M. Chaves, L.P. Fried, H.G. Margolis, Modification of the Association Between Ambient Air Pollution and Lung Function by Frailty Status Among Older Adults in the Cardiovascular Health Study, American Journal of Epidemiology 176(3) (2012) 214-223. doi: 10.1093/aje/kws001

[55] W.J. Fisk, Q. Lei-Gomez, M.J. Mendell, Meta-analyses of the associations of respiratory health effects with dampness and mold in homes, Indoor Air 17(4) (2007) 284-296. doi: 10.1111/j.1600-0668.2007.00475.x

[56] J. Wang, K. Engvall, G. Smedje, D. Norbäck, Rhinitis, Asthma and Respiratory Infections among Adults in Relation to the Home Environment in Multi-Family Buildings in Sweden, Plos One 9(8) (2014). doi: 10.1371/journal.pone.0105125

[57] D. Norbäck, J.P. Zock, E. Plana, J. Heinrich, C. Svanes, J. Sunyer, N. Künzli, S. Villani, M. Olivieri, A. Soon, D. Jarvis, Lung function decline in relation to mould and dampness in the home: the longitudinal European Community Respiratory Health Survey ECRHS II, Thorax 66(5) (2011) 396-401. doi:10.1136/thx.2010.146613

[58] I. Pirhonen, A. Nevalainen, T. Husman, J. Pekkanen, Home dampness, moulds and their influence on respiratory infections and symptoms in adults in Finland, European Respiratory Journal 9(12) (1996) 2618-2622. doi: 10.1183/09031936.96.09122618

[59] S. Vardoulakis, E. Giagloglou, S. Steinle, A. Davis, A. Sleeuwenhoek, K.S. Galea, K. Dixon, J.O. Crawford, Indoor Exposure to Selected Air Pollutants in the Home Environment: A Systematic Review, Int J Env Res Pub He 17(23) (2020). doi: 10.3390/ijerph17238972

[60] E.C. Alexopoulos, C. Chatzis, A. Linos, An analysis of factors that influence personal exposure to toluene and xylene in residents of Athens, Greece, BMC Public Health 6 (2006). doi: 10.1186/1471-2458-6-50

[61] G. Reboux, S. Rocchi, A. Laboissière, H. Ammari, M. Bochaton, G. Gardin, J.M. Rame, L. Millon, Survey of 1012 moldy dwellings by culture fungal analysis: Threshold proposal for asthmatic patient management, Indoor Air 29(1) (2019) 5-16. doi: 10.1111/ina.12516

[62] Y. Sun, Y. Meng, Z.Y. Ou, Y.L. Li, M. Zhang, Y. Chen, Z.F. Zhang, X.Y. Chen, P.Q. Mu, D. Norbäck, Z.H. Zhao, X. Zhang, X. Fu, Indoor microbiome, air pollutants and asthma, rhinitis and eczema in preschool children - A repeated cross-sectional study, Environment International 161 (2022). doi: 10.1016/j.envint.2022.107137

[63] K.C. Dannemiller, J.F. Gent, B.P. Leaderer, J. Peccia, Influence of housing characteristics on bacterial and fungal communities in homes of asthmatic children, Indoor Air 26(2) (2016) 179-192. doi: 10.1111/ina.12205.

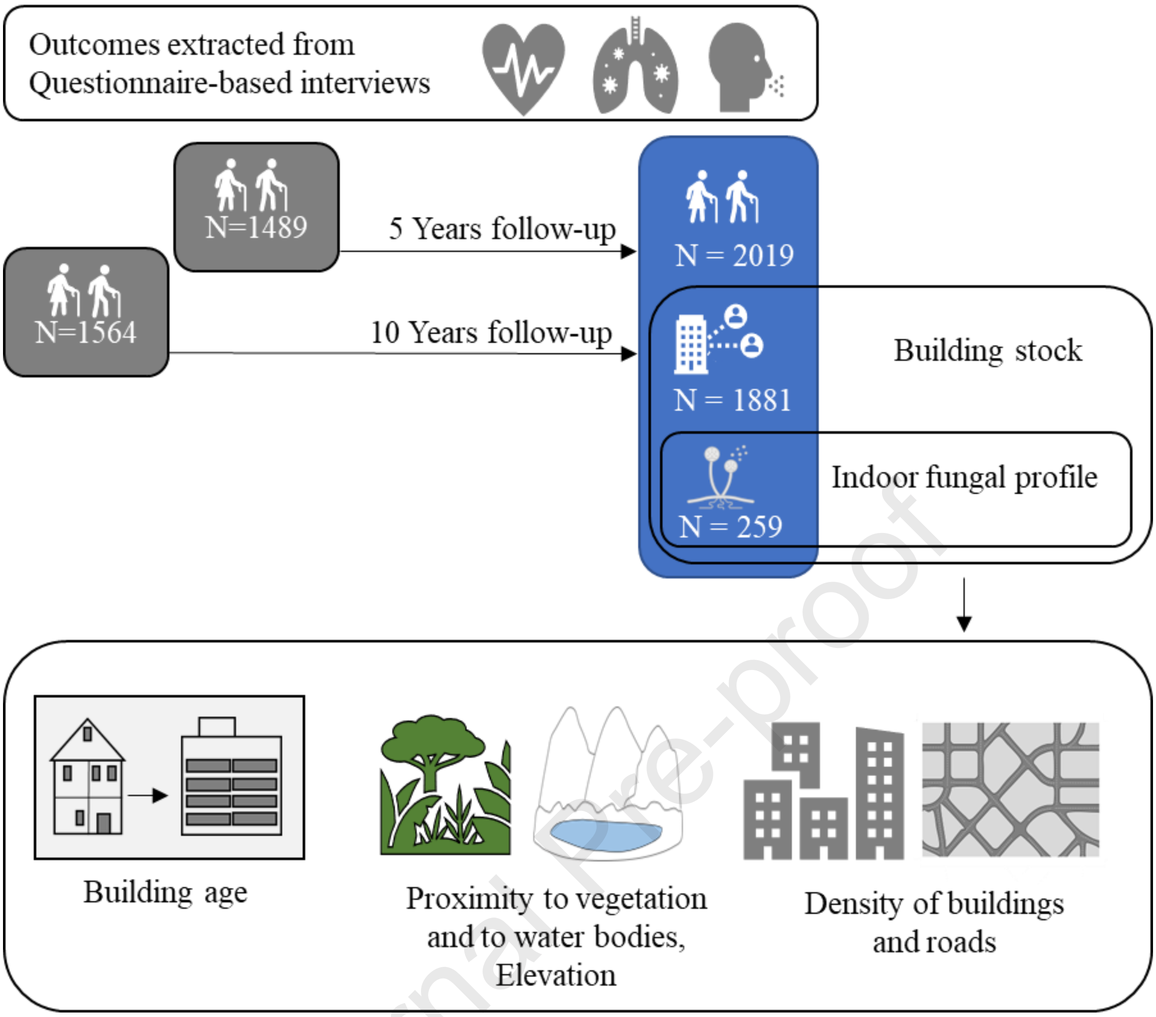


Figure 1. Study Design: This city-wide study was conducted in Lausanne, a city characterized by significant variations in elevation and environmental characteristics. The Lc65+ cohort, established in Lausanne, is designed to monitor health deterioration in the city's elderly population. We included participants who had not changed their residence since their initial inclusion and extracted cardiac and respiratory outcomes from questionnaire interviews conducted at inclusion, as well as 5 and 10 years later. Participants' addresses were used to retrieve relevant data from various datasets, such as building age, elevation, proximity to green spaces and the lake, and information on building and road density. Indoor fungal profiles were assessed using next-generation sequencing and cultivation in a representative subset of dwellings. Multilevel mixed-effects logistic models were employed to examine the associations between health outcomes and the built environment.

Table 1. Sociodemographic characteristics of the studied population, N = 2019

Characteristic	**Male** **(N = 784)**	**Female** **(N = 1235)**
Age, years (Mean ± SD)	75.2 ± 2.9	75.2 ± 2.9
Smoking status		
Non-smokers, N (%)	211 (27%)	622 (51%)
Ex-smokers, N (%)	439 (57%)	438 (36%)
Active smokers, N (%)	124 (16%)	162 (14%)
Education		
Compulsory education	98 (13%)	315 (26%)
Federal Diploma of Vocational ET[1]	339 (43%)	473 (38%)
High school diploma	37 (5%)	135 (11%)
Advanced Federal Diploma of Professional ET[1]	135 (17%)	189 (15%)
University diploma	174 (22%)	120 (10%)
Household size		
single	183 (24%)	711 (59%)
couple	555 (72%)	481 (40%)
more of two	30 (4%)	20 (2%)

[1] ET = Education and Training

Table 2. Correlation coefficients between the nine built environment variables and the three principal components (PCs) obtained through Principal Component Analyses (PCA) using data extracted from 1881 addresses. Here, a correlation was considered moderate when the correlation coefficient exceeded 0.4 or fell below -0.4, and strong when it exceeded 0.5 or fell below -0.5.

Built environmental variable	**PC1**	**PC2**	**PC3**
Building age	0.25	-0.13	-0.44
Proximity to the forest within a 500 m radius	0.41	-0.07	0.21
Proximity to the field within a 500 m radius	0.34	0.12	0.13
Proximity to the garden within a 500 m radius	0.29	-0.02	-0.54
Proximity to the lake within a 500 m radius	-0.15	0.79	-0.26
Proximity to the water body other than lake within a 500 m radius	0.28	0.38	0.53
Density of roads within a 500 m radius	-0.40	0.05	0.25
Density of buildings within a 500 m radius	-0.41	-0.35	0.08
Elevation	0.37	-0.25	0.21
Eigenvalue	4.24	1.12	1.04
% of variance explained	47.1	12.4	11.6

Table 3. Associations between health outcomes and built environmental variables (radius: 500 m) or exposure to moulds

	Cardiac condition	Medication for heart condition	Medication for asthma	Chronic lung disease	Chronic cough
Variable	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
BES^{Model1}	1.11 [1.00 – 1.24]*	1.15 [1.03 – 1.28]*	1.01 [0.83 – 1.24]	1.06 [0.91 – 1.22]	0.89 [0.72 1.10]
PC 1^{Model2}	0.97 [0.92 – 1.02]	0.95 [0.90 – 1.00]	1.06 [0.96 – 1.16]	1.03 [0.96 – 1.10]	1.06 [0.96 1.12]
PC 2^{Model3}	1.05 [0.95 – 1.16]	1.06 [0.96 – 1.17]	1.24 [1.06 – 1.46]**	1.23 [1.08 – 1.39]***	0.94 [0.77 1.15]
PC 3^{Model4}	0.96 [0.87 – 1.07]	0.99 [0.89 – 1.11]	0.81 [0.67 – 0.99]*	0.91 [0.79 – 1.05]	0.83 [0.69 1.01]
Building age ^{Model1}	0.97 [0.92 – 1.02]	0.95 [0.90 – 1.01]	1.08 [0.98 – 1.20]	1.13 [1.04 – 1.23]***	1.12 [1.01 – 1.25]*
Proximity to the lake^{Model5}	1.04 [0.96 – 1.14]	1.05 [0.96 – 1.15]	1.22 [1.07 – 1.40]***	1.18 [1.06 – 1.31]***	0.99 [0.83 1.18]
Total CFU^{Model6}	0.95 [0.87 – 1.05]	0.94 [0.85 – 1.03]	1.06 [0.88 – 1.28]	0.91 [0.78 1.07]	1.19 [1.04 – 1.36]**
Aspergillus CFU^{Model7}	0.93 [0.79 – 1.09]	0.94 [0.80 – 1.10]	0.86 [0.49 – 1.52]	0.82 [0.54 1.24]	1.25 [1.08 – 1.45]***
Gloeophyllum abundance^{Model8}	2.00 [0.54 – 7.44]	2.04 [0.54 – 7.64]	5.80 [0.15 – 217.59]	10.38 [1.41 – 76.48]*	0.53 [0.04 – 7.91]
Aureobasidium abundance^{Model9}	0.81 [0.38 – 1.75]	0.87 [0.41 – 1.85]	14.08 [1.32 – 150.64]*	1.69 [0.57 4.98]	0.12 [0.00 – 5.55]

OR = odd ratio ; CI = confidence interval ; CFU = colonies forming units

Separate models were constructed to estimate the effect of each environmental variable (BES, PCA component, or built environment variable) on health outcomes. Health effects were systematically quantified using odds ratios (ORs) adjusted for age, sex, and smoking status.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.005$

Supplementary material

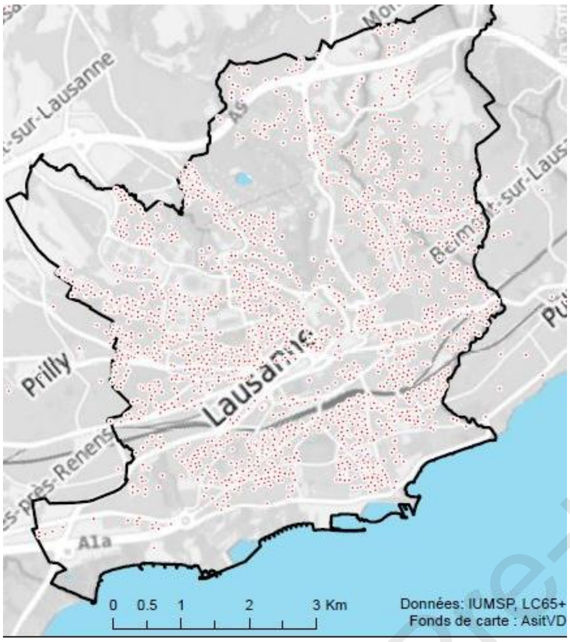


Figure S1. Geospatial localization of dwellings considered in the study.

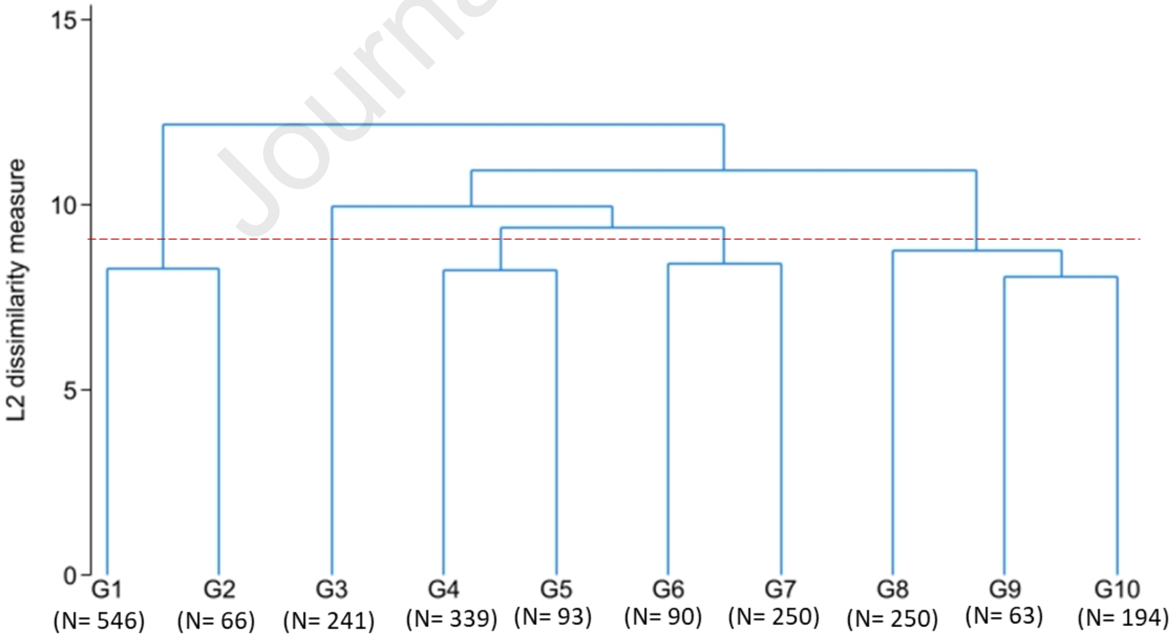


Figure S2. Dendrogram of agglomerative hierarchical cluster analysis

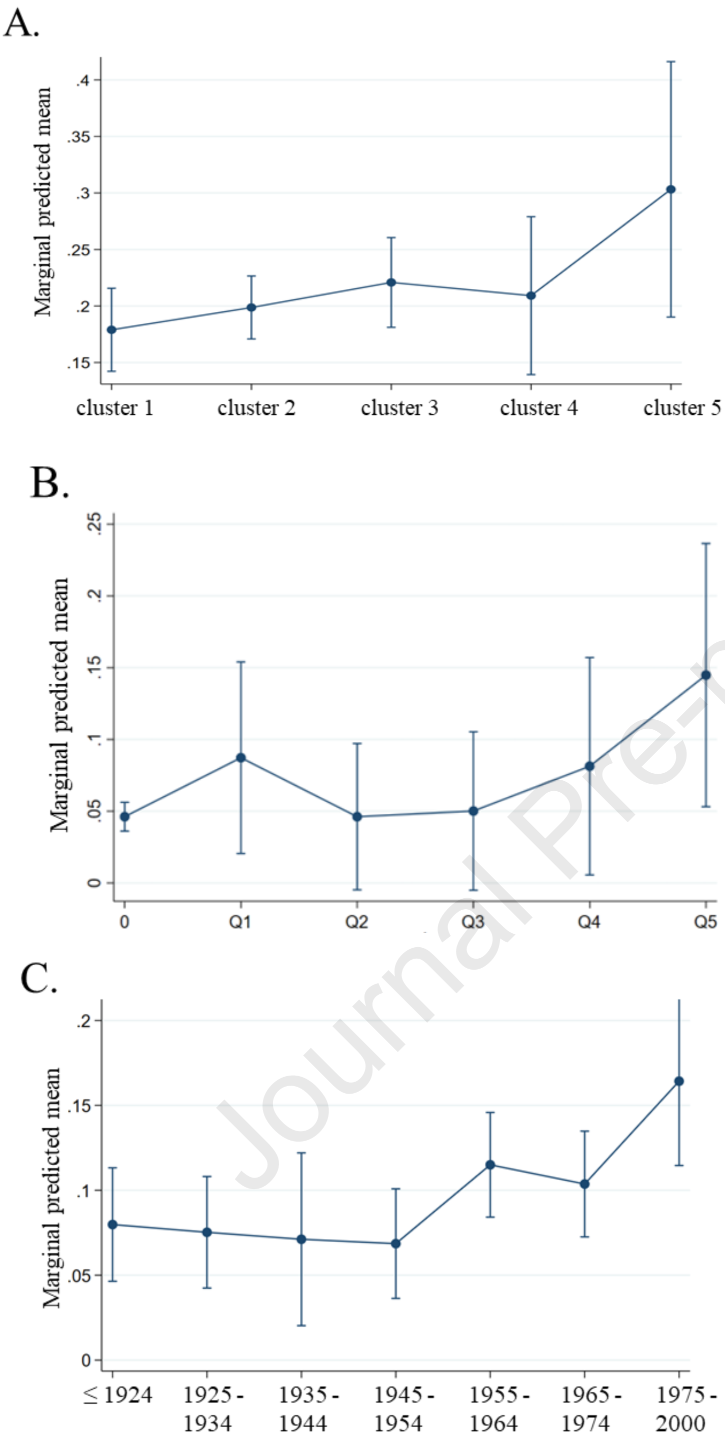


Figure S3. Marginal predicted mean of health outcomes by built environment descriptor, with 95% confidence intervals. **A**. Proportion of heart medication by urban landscape cluster; **B**. Proportion of medication for asthma by quantile of proximity to the lake; **C**. Proportion of chronic lung disease by construction period of the building.

Table S1. Number of participants residing in buildings from each construction period

Building constuction period	Participants
before 1925	258
1925-1934	256
1935-1944	102
1945-1954	257
1955-1964	447
1965-1974	423
1975-2014	258

Table S2. Descriptive statistics of road density variable in the five urban landscape clusters.

Cluster	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	213	155	74	31	0	473
1 (%)	45.03	32.77	15.64	6.55	0	100
2 (N)	183	219	277	203	34	916
2 (%)	19.98	23.91	30.24	22.16	3.71	100
3 (N)	0	35	61	106	307	509
3 (%)	0	6.88	11.98	20.83	60.31	100
4 (N)	0	0	3	37	98	138
4 (%)	0	0	2.17	26.81	71.01	100
5 (N)	28	11	8	28	6	81
5 (%)	34.57	13.58	9.88	34.57	7.41	100
Total (N)	424	420	423	405	445	2117
Total (%)	20.03	19.84	19.98	19.13	21.02	100

Table S3. Descriptive statistics of building density variable in the five urban landscape clusters

Cluster	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	295	165	13	0	0	473
1 (%)	62.37	34.88	2.75	0	0	100
2 (N)	97	251	319	211	38	916
2 (%)	10.59	27.4	34.83	23.03	4.15	100
3 (N)	0	0	30	136	343	509
3 (%)	0	0	5.89	26.72	67.39	100
4 (N)	1	5	36	85	11	138
4 (%)	0.72	3.62	26.09	61.59	7.97	100
5 (N)	33	18	29	1	0	81
5 (%)	40.74	22.22	35.8	1.23	0	100
Total (N)	426	439	427	433	392	2117
Total (%)	20.12	20.74	20.17	20.45	18.52	100

Table S4. Descriptive statistics of elevation variable in the five urban landscape clusters

Cluster	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	27	55	43	48	300	473
1 (%)	5.71	11.63	9.09	10.15	63.42	100
2 (N)	112	84	224	397	99	916
2 (%)	12.23	9.17	24.45	43.34	10.81	100
3 (N)	130	226	151	2	0	509
3 (%)	25.54	44.4	29.67	0.39	0	100
4 (N)	77	61	0	0	0	138
4 (%)	55.8	44.2	0	0	0	100
5 (N)	81	0	0	0	0	81
5 (%)	100	0	0	0	0	100
Total (N)	427	426	418	447	399	2117
Total (%)	20.17	20.12	19.74	21.11	18.85	100

Table S5. Descriptive statistics of proximity to Geneva Lake variable in the five urban landscape clusters.

Cluster	NA	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	440	3	0	30	0	0	473
1 (%)	93.02	0.63	0	6.34	0	0	100
2 (N)	912	2	1	1	0	0	916
2 (%)	99.56	0.22	0.11	0.11	0	0	100
3 (N)	443	63	3	0	0	0	509
3 (%)	87.03	12.38	0.59	0	0	0	100
4 (N)	0	1	60	29	24	24	138
4 (%)	0	0.72	43.48	21.01	17.39	17.39	100
5 (N)	0	0	0	2	38	41	81
5 (%)	0	0	0	2.47	46.91	50.62	100
Total (N)	1,795	69	64	62	62	65	2117
Total (%)	84.79	3.26	3.02	2.93	2.93	3.07	100

842 **Table S6**. Descriptive statistics of proximity to water other than lake variable in the five
843 urban landscape clusters.

Cluster	NA	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	0	0	49	82	129	213	473
1 (%)	0	0	10.36	17.34	27.27	45.03	100
2 (N)	531	109	103	101	72	0	916
2 (%)	57.97	11.9	11.24	11.03	7.86	0	100
3 (N)	348	84	40	31	6	0	509
3 (%)	68.37	16.5	7.86	6.09	1.18	0	100
4 (N)	137	1	0	0	0	0	138
4 (%)	99.28	0.72	0	0	0	0	100
5 (N)	27	1	21	10	13	9	81
5 (%)	33.33	1.23	25.93	12.35	16.05	11.11	100
Total (N)	1,043	195	213	224	220	222	2117
Total (%)	49.27	9.21	10.06	10.58	10.39	10.49	100

844

845 **Table S7**. Descriptive statistics of proximity to forest variable in the five urban landscape
846 clusters.

Cluster	NA	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	0	0	0	47	168	258	473
1 (%)	0	0	0	9.94	35.52	54.55	100
2 (N)	14	51	188	274	246	143	916
2 (%)	1.53	5.57	20.52	29.91	26.86	15.61	100
3 (N)	47	239	153	65	5	0	509
3 (%)	9.23	46.95	30.06	12.77	0.98	0	100
4 (N)	30	76	32	0	0	0	138
4 (%)	21.74	55.07	23.19	0	0	0	100
5 (N)	14	19	32	8	8	0	81
5 (%)	17.28	23.46	39.51	9.88	9.88	0	100
Total (N)	105	385	405	394	427	401	2117
Total (%)	4.96	18.19	19.13	18.61	20.17	18.94	100

847

848 **Table S8**. Descriptive statistics of proximity to garden variable in the five urban landscape
849 clusters.

Cluster	NA	Q2	Q3	Q4	Q5	Total
1 (N)	41	106	104	93	129	473
1 (%)	8.67	22.41	21.99	19.66	27.27	100
2 (N)	1	66	261	297	291	916
2 (%)	0.11	7.21	28.49	32.42	31.77	100
3 (N)	319	170	19	1	0	509
3 (%)	62.67	33.4	3.73	0.2	0	100
4 (N)	37	61	25	15	0	138
4 (%)	26.81	44.2	18.12	10.87	0	100
5 (N)	5	18	24	15	19	81

5 (%)	6.17	22.22	29.63	18.52	23.46	100
Total (N)	403	421	433	421	439	2117
Total (%)	19.04	19.89	20.45	19.89	20.74	100

Table S9. Descriptive statistics of proximity to field variable in the five urban landscape clusters.

Cluster	NA	Q1	Q2	Q3	Q4	Q5	Total
1 (N)	42	6	65	109	104	147	473
1 (%)	8.88	1.27	13.74	23.04	21.99	31.08	100
2 (N)	540	93	51	49	110	73	916
2 (%)	58.95	10.15	5.57	5.35	12.01	7.97	100
3 (N)	269	72	76	82	10	0	509
3 (%)	52.85	14.15	14.93	16.11	1.96	0	100
4 (N)	99	37	2	0	0	0	138
4 (%)	71.74	26.81	1.45	0	0	0	100
5 (N)	23	35	14	1	5	3	81
5 (%)	28.4	43.21	17.28	1.23	6.17	3.7	100
Total (N)	973	243	208	241	229	223	2117
Total (%)	45.96	11.48	9.83	11.38	10.82	10.53	100

Highlights:

- Urban landscape impacts heart disease in the elderly;
- Living in homes built between 1975 and 2013 worsens the respiratory health;
- Fungal indicator species link indoor air pollution to respiratory outcomes
- Individuals exposed to a higher concentrations of Aspergillus spores had a higher risk of developing chronic cough.

Declaration of 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.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: