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# Is indoor and outdoor greenery associated with fewer depressive symptoms during COVID-19 lockdowns? A mechanistic study in Shanghai, China

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## ABSTRACT

Increasing numbers of studies have observed that indoor and outdoor greenery are associated with fewer depressive symptoms during COVID-19 lockdowns. However, most of these studies examined direct associations without sufficient attention to underlying pathways. Furthermore, few studies have combined different types of indoor and outdoor greenery to examine their effects on the alleviation of depressive symptoms. The present study hypothesized that indoor and outdoor exposure to greenery increased the perceived restorativeness of home environments, which, in turn, reduced loneliness, COVID-related fears, and, ultimately, depressive symptoms. To test our hypotheses, we conducted an online survey with 386 respondents in Shanghai, China, from April to May 2022, which corresponded to strict citywide lockdowns that resulted from the outbreak of the Omicron variant. Indoor greenery measures included the number of house plants, gardening activities, and digital nature exposure as well as semantic image segmentation applied to photographs from the most viewed windows to quantify indoor exposure to outdoor trees and grass. Outdoor greenery measures included total vegetative cover (normalized difference vegetation index [NDVI]) within a 300 m radius from the home and perceived quality of the community's greenery. Associations between greenery and depressive symptoms/clinical levels of depression, as measured by the Patient Health Questionnaire-9 (PHQ-9), were examined using generalized linear and logistic regression models. Structural equation modeling (SEM) was used to test pathways between greenery exposure, restorativeness, loneliness, fear of COVID-19, and depressive symptoms. The results showed that: 1) indoor and outdoor greenery were associated with fewer depressive symptoms; 2) greenery could increase the restorativeness of the home environment, which, in turn, was associated with fewer COVID-related mental stressors (i.e., loneliness and fear of COVID-19), and ultimately depressive symptoms; and 3) gender, education, and income did not modify associations between greenery and depressive symptoms. These findings are among the first to combine objective and subjective measures of greenery within and outside of the home and document their effects on mental health during lockdowns. Comprehensive enhancements of greenery in living environments could be nature-based solutions for mitigating COVID-19 related mental stressors.

## 1. Introduction

The global Coronavirus disease 2019 (COVID-19) pandemic exacerbated mental and physical health issues among urban residents. Lockdown policies helped contain the viral spread but also negatively

impacted many people's mental health [1]. Long-term quarantines, self-isolation, loneliness, and associated stressors (e.g., fear of COVID infection), heightened levels of depression, anxiety, and post-traumatic stress symptoms globally; furthermore, these negative impacts were particularly severe in low-income and middle-income countries (LMICs)

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[2–4].

Substantial evidence suggests that exposure to nature might promote well-being, life satisfaction, and reduce mental illnesses [5,6]. Two widely recognized theories support the positive mental effects of nature exposure: stress reduction theory (SRT) [7] and attention restoration theory (ART) [8]. Both of these theories suggest that exposure to nature (e.g., trees, grass, flowering plants, and other forms of greenery) could improve mental health by accelerating recovery from stress and mental fatigue, which, when left unchecked, can impair mood, self-control, social relationships, and the ability to meet personal goals [9]. However, most research on nature contact has considered generalized measures of outdoor greenery such as total vegetative cover, park cover, and to a lesser extent, street view greenery [10–12]. Access to many larger of these public green spaces were impeded during the COVID-19 pandemic due to lockdowns while the usage of smaller residential green spaces increased for many populations [13,14].

Several studies have documented the positive effects of indoor greenery on mental well-being during COVID-19 lockdowns [14–16]. A recent review on the health impacts of nature during the pandemic identified four dimensions of greenery engagement available for mental restoration: private gardens, house plants, green views through windows, and digital nature [13]. Private gardens in particular have been identified as crucial types of green spaces for residents' mental well-being during the pandemic. Recent studies have suggested that the frequency and duration of access to private gardens increased during lockdowns and aided with mental health outcomes while allowing social distancing and avoiding COVID-19 exposure [17,18]. Gardening activities in private gardens and balconies have also been identified as forms of nature that can buffer mental stressors resulting from forced home confinement [19,20]. Evidence from several cross-sectional studies have found indoor potted plants are correlated with more positive emotions [19,21]. Additionally, recent studies have consistently documented positive associations between window views of greenery and mental outcomes during lockdowns [15,22]. A few studies have also examined the potential effects of digital greenery exposure (i.e., photos, videos, documentaries, or more immersive media) on mental health and argued that digital nature can partially substitute for real nature and reduce negative emotions during lockdowns [13,23,24]. However, very few studies have combined these different metrics of indoor and outdoor greenery to comprehensively examine their effects on mental health [21, 22].

While most studies have found beneficial effects of indoor and outdoor greenery on depression during COVID-19 lockdowns, they have primarily examined the direct relationships between exposure and health outcomes [16,17,22]. Few studies have deciphered the underlying mechanistic pathways explaining these relationships [20,21]. For instance, one potential pathway is that greenery exposure could be perceived as restorative and thus alleviate mental stressors through experiences that promote the ART of occupants, including being away, fascination, and compatibility [21,25–28]. Given that loneliness and fear of COVID-19 are potential risk factors for depression during lockdowns [29,30], it is necessary to shed light on whether or to what extent indoor and outdoor greenery could provide perceived restorativeness, which, in turn, could mitigate COVID-19 related mental stressors, such as loneliness and fear of COVID-19, and thus reduce depressive symptoms.

Current evidence on the impacts of greenery on depressive symptoms is also limited in its geographic scope. Most research has been conducted in high-income Western countries, while relatively few studies are available in LMICs [13,16,17,22]. Due to differences in socioeconomic backgrounds, culture, and population densities, Western and Eastern populations may differ in their attitude and behavior with respect to contact with nature. For example, home gardens are not always accessible in China, as most urban residents live in apartment buildings in cities with very high population densities; instead, many Chinese residents' opportunities for contact with nature are focused on greenery in

their community parks [31,32]. Few studies have examined whether the mental health benefits of greenery during lockdowns in LMICs with high population densities are consistent with those reported in Western studies.

Additionally, disadvantaged groups worldwide experience higher prevalences of certain diseases than more privileged groups [33]. Recent evidence has found disadvantaged groups also show higher rates of COVID-19 impacts [34]. Although green space might be an effective tool to advance health equity, disadvantaged groups might be less likely to have access to high-quality urban natural settings and therefore derive different benefits from greenery than more privileged groups [35]. Such relationships should be re-examined during the pandemic, as lockdown policies resulted in residents being unable to access larger public green spaces, while indoor greenery, such as low-cost gardening activities, indoor plants, and digital nature, became more available to many people across the socio-demographic spectrum [20]. Few studies have examined how associations between indoor and outdoor greenery exposure and mental benefits varied by socioeconomic status or other demographic profiles during home confinement [16,36], and the limited findings, which are mainly from Western countries, showed mixed results [13].

In response to these research gaps, this study aimed to disentangle associations and underlying pathways between types of indoor and outdoor greenery with depressive symptoms, loneliness, and fear of COVID-19 during home confinement periods and investigate whether these associations, if any, were mediated by perceived restorativeness and moderated by sociodemographic variables. Shanghai, China, was selected as the study site. The study period of early April 2022 corresponded to strict citywide lockdowns due to the outbreak of the Omicron variant. We hypothesized that indoor and outdoor exposure to greenery increased the perceived restorativeness of the home environments, which in turn reduced loneliness, fear of COVID-19, and, ultimately, depressive symptoms. The intertwined pathways are described in the conceptual framework (Fig. 1) and theoretical foundations to develop hypotheses are presented in Supplementary Materials Section S1.

## 2. Methodology

### 2.1. Study design, setting, and sampling

This study was conducted in Shanghai City, one of the most densely populated cities in the world, which has endured a strict city-wide lockdown since April 3, 2022 due to the outbreak of Omicron. Shanghai imposed its first city-wide strict lockdowns at the beginning of April 2022 when Omicron cases surged. The city only allowed residents in precautionary areas to leave their gated communities if they followed health protocols and remained in their sub-districts. Two weeks later (April 17–May 7), we conducted an online questionnaire survey with a sample of approximately 400 participants, recruited through the widely used the questionnaire platform [Credamo.com](https://www.credamo.com), a Chinese data-collection platform similar to Amazon's Mechanical Turk (mTurk). Credamo has provided scientific research and educational data services for teachers and students in more than 2000 universities around the world (<https://www.credamo.com/#/aboutUs>). Respondents in the platform's database cover a wide range of locations, age groups, and occupations. These respondents were well qualified to respond to the questionnaire and were informed not to speculate on the purpose of the survey. Questionnaires with a response time of more than 5 min were considered valid data. Adult respondents (over age 18) who confirmed their current check-in location being in Shanghai City were eligible to complete the questionnaire. Each participant could only answer once, and respondents with a duplicate Internet Protocol (IP) address could not complete the questionnaire a second time. A small monetary remuneration (approximately 0.5 USD) was paid to participants who completed the questionnaire. The online questionnaire consisted of six parts: sociodemographic variables (i.e., gender, age, education, and

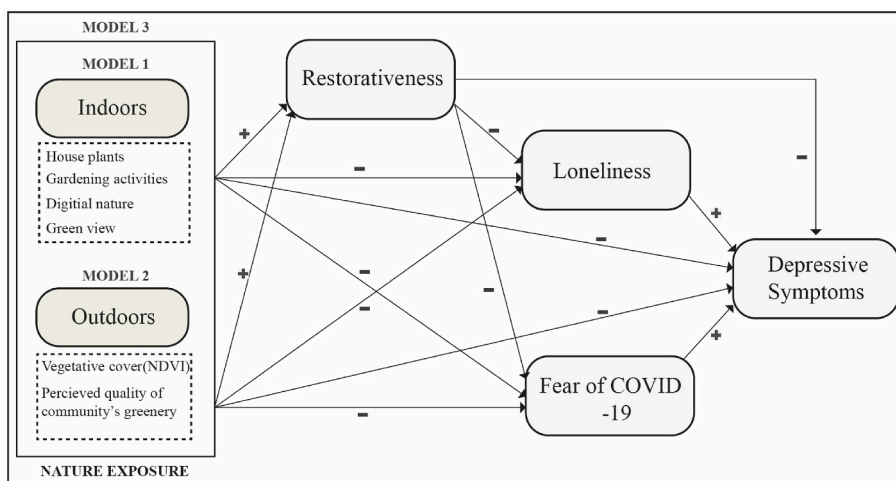


Fig. 1. The mechanistic framework linking indoor and outdoor greenery to depressive symptoms.

income), greenery exposure indoors and outdoors, perceived restorativeness, loneliness, fear of COVID-19, and depressive symptoms. In total, 386 valid questionnaires were obtained. Fourteen participants who did not upload or provided invalid photos taken from the most viewed windows were excluded from the study.

### 2.2. Greenery exposure indoors and outdoors

The number of house plants, gardening activities, and digital nature were obtained using self-reported questionnaires informed by previous literature [20–22]. Participants were required to rate the presence/number of house plants in a room or balcony, frequency of gardening activities such as pruning and watering of green plants during lockdowns, and whether they were exposed to digital natural senses through photos, videos, documentaries, or other forms of digital contact.

Participants were given a 10-point scale to report their opportunities for exposure to the types of indoor greenery mentioned above, with 1 representing ‘not at all’ and 10 representing ‘completely’.

Green window views were calculated with the green view index (GVI) of photos taken by respondents from their most viewed windows with the best viewing angle in the daytime. Photos were requested to be taken with the smartphone’s rear camera within 0.2 m of the most viewed window. We standardized all respondent photographs to 1000 × 750 pixels (Fig. 2). A fully convolutional neural network for semantic image segmentation (FCN-8s) [37] was employed to extract green elements (e.g., trees and grasses) based on the ADE20K dataset [38].

Given that most of the participants were confined to their residential gated communities during the lockdown, we calculated the quantity and quality of residential community greenness to examine outdoor greenery exposure. The quantity of greenness (i.e., total vegetation cover) was

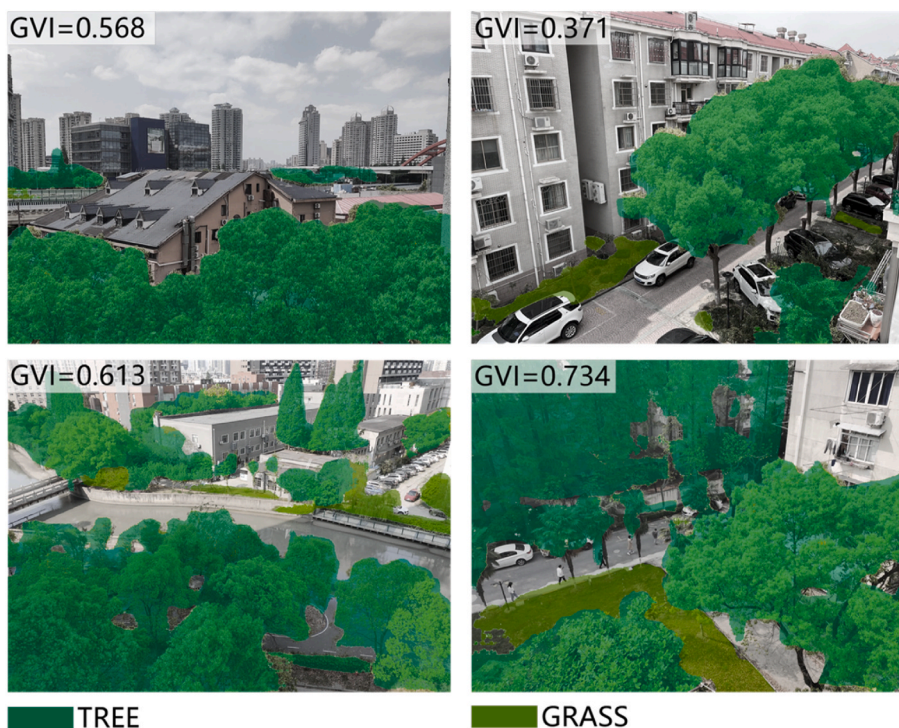


Fig. 2. Green window view index (values ranging from 0 = no greenery to 1 = complete greenery) in photographs taken by participants from their most viewed window and best viewing angle. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)



estimated using the normalized difference vegetation index (NDVI), obtained from diachronic images with  $10 \times 10$  m resolution captured in September 2021 by the Sentinel-2 satellite. NDVI values ranged between  $-1$  and  $1$ , with higher values suggesting greater greenness. The NDVI average within 300 m buffer of check-in locations was calculated applying the Google Earth Engine (GEE) platform. Although blue space might degrade greenness values, we did not specifically remove pixels below 0 due to the small buffer radius and very small amount of water coverage (Supplementary Materials, Fig. S1). The perceived quality of community's greenery was obtained from the self-reported data, with 1 representing 'the worst perceived quality' and 10 representing 'the best perceived quality'.

### 2.3. Perceived restorativeness of greenery

The perceived restorativeness scale (PRS) was used to calculate the restorative quality of home environment [27]. Three dimensions of PRS were measured: being away, fascination, and compatibility. To minimize respondent fatigue, we reduced the length of the questionnaire by integrating some PRS items into a single item, following past research [21,39]. Specifically, the questionnaire included one item for being away: "Being here is an escape experience and gives me a break from my day-to-day routine"; one item for fascination: "This place has fascinated qualities and my attention is drawn to many interesting things"; and one item for compatibility: "Being here suit my personality and I can find ways to enjoy myself here". Participants were given a 10-point response scale, with 1 representing 'not at all' and 10 representing 'completely'. The Cronbach's  $\alpha$  was 0.874.

### 2.4. Mental health outcomes

The Fear of Coronavirus-19 Scale (FCV-19s) [40] was employed to assess COVID-19-related mental stressors. This scale has shown good internal consistency and reliability in many countries, including China [41]. The FCV-19s consists of two dimensions: emotional reactions and physical experience. Emotional reactions included four items: "I am most afraid of COVID-19"; "It makes me uncomfortable to think about COVID-19"; "I am afraid of losing my life because of COVID-19"; and "When watching news and stories about COVID-19 on social media, I become nervous or anxious". Physical experience contained three items: "My hands become clammy when I think about COVID-19"; "I cannot sleep because I'm worrying about getting COVID-19"; and "My heart races or palpitates when I think about getting COVID-19". Participants were given a 7-point response scale, with 1 representing 'not at all' and 7 representing 'completely'. The seven items were integrated into one latent variable, and the internal consistency in our study was high (Cronbach's  $\alpha = 0.887$ ).

The UCLA 3-Item Loneliness Scale was used to evaluate loneliness conditions during the lockdown [42,43]. It measured three dimensions: relational connectedness, social connectedness, and self-perceived isolation. Items included: "Do you feel that you lack companionship"; "Do you feel left out"; and "Do you feel isolated from others." Respondents were given a 5-point response scale with 1 representing 'not at all' and 5 representing 'completely'. The Cronbach's  $\alpha$  was 0.858, indicating good internal consistency.

The severity of depressive symptoms over the past two weeks was assessed using the Patient Health Questionnaire 9-item (PHQ-9). This measures the frequency of depressive symptoms, such as hopelessness, appetite changes, fatigue, anhedonia, and thoughts of death [44]. Respondents were given a 4-point response scale with 0 representing 'not at all' and 3 representing 'nearly every day'. The nine items were loaded onto one latent variable, and the internal consistency was high (Cronbach's  $\alpha = 0.878$ ). Additionally, the sum of the PHQ-9 item responses was calculated, and scores of 10 or above were consistent with moderate depression, according to previous studies [21,45].

### 2.5. Statistical analysis

Spearman rank correlations tested unadjusted relationships between the various types of greenery exposure, mediators, and mental health outcomes. Spearman correlation coefficients could show weak (i.e.,  $0 \leq |r| < 0.3$ ), moderate (i.e.,  $0.3 \leq |r| < 0.7$ ), or strong associations (i.e.,  $|r| \geq 0.7$ ) [46].

Generalized linear regression was developed with continuous scores (i.e., sum of the PHQ-9 item responses) considered as the dependent variables, with each dimension of indoor and outdoor greenery exposure included simultaneously as independent variables. We also developed a logic regression model for sensitivity analyses with dichotomized scores (PHQ-9 < 10 vs. PHQ-9  $\geq$  10) considered as the dependent variables to examine associations between indoor/outdoor greenery and clinical levels of depression. Models were adjusted for sociodemographic confounders, including age, gender, education, and income according to past research [16,21,22,47].

Structural equation modeling (SEM) was then used to examine the indirect and direct effects of indoor/outdoor greenery on depressive symptoms. Effects were calculated based on the approach proposed in previous studies [48,49]. Maximum likelihood estimation was employed with kurtosis and departures from normality using the bootstrap method (5000 samples). Each regression path was calculated using bootstrap-generated confidence intervals (CIs) and standard errors to obtain bias-corrected (BC) and 95% CIs. A multi-group analysis was used to examine the heterogeneity of the paths (structural weight) between genders and levels of education and income. An unconstrained (baseline) model was first established to ensure that the parameters were freely estimated. Then, a constrained model was established, requiring equivalent structural weights between the groups. The structural weight invariance of multi-group models was tested by comparing the significant chi-square changes ( $\Delta\chi^2$ ) between the unconstrained and constrained models. Changes in the Comparative Fit Index (CFI) and Tucker Lewis Index (TLI) (i.e.,  $\Delta\text{CFI}/\text{TLI} > 0.01$ ) were used to examine the heterogeneity of SEMs when Chi-square values were sensitive to sample size [50,51]. Data analysis was performed using SPSS 26.0 and AMOS v.26.

## 3. Results

### 3.1. Descriptive analyses and correlations among the variables

Table 1 shows that most participants (66.6%) were female. Of the participants, 79.5% had a bachelor's degree or a higher education level. The majority (73.3%) were young and middle-aged (18–30). Household income was divided into three groups (i.e., low, middle, and high): 44.8% of the participants had a total annual household income of less than 200,000 *yuan* (~30,000 USD); 28.5% had an income between 200,000 and 300,000 *yuan* (~30,000–45,000 USD); and 26.7% had an income of more than 300,000 *yuan* (~45,000 USD). More than half (50.3%) reported moderate depression during the lockdown (i.e., PHQ-9  $\geq$  10).

Bivariate correlations between the variables are summarized in Fig. 3. Most indoor and outdoor greenery exposure metrics were weakly or moderately correlated with each other. Indoor and outdoor greenery were also moderately and positively related to perceived restorativeness. Fear of COVID-19, loneliness, and depressive symptoms were positively correlated with each other. Each of these mental health outcomes was negatively related to the various dimensions of indoor and outdoor greenery exposure.

### 3.2. Results of regression analysis

Associations between indoor and outdoor greenery exposure and depressive symptoms are shown in Table 2. Three types of indoor greenery (i.e., house plants, digital nature, and green views through

**Table 1**  
Participant characteristics (N = 386).

Characteristics	N	Category/Description	Mean	Median	SD	Range
<b>Sociodemographics</b>						
Gender	129	Male				
Education	79	Non-bachelor				
Income (million yuan)	173	Low (<0.2)				
	110	Middle (0.2–0.3)				
	103	High (>0.3)				
Age (yrs)	50	18–20				
	233	20–30				
	73	30–40				
	30	>40				
<b>Greenery indoors</b>						
House plants	386		5.18	5.00	3.144	1–10
Gardening activities			4.89	5.00	3.235	1–10
Digital nature			5.36	5.50	2.600	1–10
Green view			0.33	0.30	0.21	0–1
<b>Greenery outdoors</b>						
Vegetative cover	386		0.43	0.43	0.12	-1–1
Perceived quality of greenery			7.08	8.00	2.843	1–10
<b>Restorativeness</b>						
Being away	386		6.98	8.00	2.181	1–10
Fascination			6.42	7.00	2.337	1–10
Compatibility			6.70	7.00	2.237	1–10
Fear of COVID-19	386		20.56	20.00	8.962	7–49
Loneliness	386		6.89	6.00	3.289	3–15
Depressive symptoms	386		10.29	10.00	6.039	0–27
Depression	194	PHQ-9≥10				

**Table 2**  
Adjusted associations<sup>a</sup> between indoor and outdoor greenery and depressive symptoms.

Model 1: Indoor greenery					
Exposure metrics	Depressive symptoms (PHQ-9)		VIF	Depression (PHQ-9≥10)	
	Beta (95% CI)	p-value		OR (95% CI)	p-value
House plants	<b>-0.15 (-0.55, -0.04)</b>	<b>0.02</b>	1.98	<b>0.91 (0.83, 1.00)</b>	<b>0.05</b>
Gardening activities	-0.10 (-0.42, 0.07)	0.15	2.10	0.94 (0.86, 1.03)	0.20
Digital nature	<b>-0.20 (-0.68, -0.24)</b>	<b>0.00</b>	1.10	<b>0.85 (0.78, 0.93)</b>	<b>0.00</b>
Green view	<b>-0.24 (-0.935, -4.11)</b>	<b>0.00</b>	1.06	<b>0.25 (0.01, 0.71)</b>	<b>0.01</b>
Model 2: Outdoor greenery					
Exposure metrics	Depressive symptoms (PHQ-9)		VIF	Depression (PHQ-9≥10)	
	Beta (95% CI)	p-value		OR (95% CI)	p-value
Vegetative cover	<b>-0.16 (-14.30, -3.77)</b>	<b>0.00</b>	1.41	0.25 (0.02, 2.94)	0.27
Perceived greenery quality	<b>-0.49 (-1.23, -0.83)</b>	<b>0.00</b>	1.39	<b>0.71 (0.64, 0.79)</b>	<b>0.00</b>

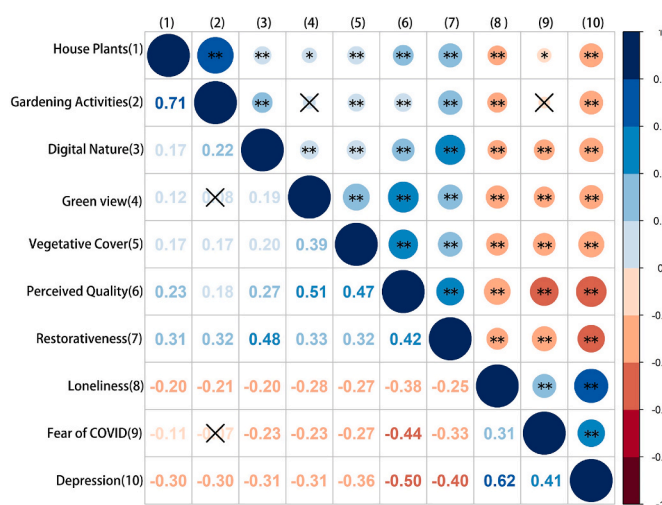
<sup>a</sup> Coefficients are standardized linear regression coefficients (beta) or odds ratios (OR) with 95% confidence intervals adjusted for gender, age, education, and income. Betas/ORs with significant p-values ( $p < .05$ ) are shown in bold.

3.3. Results of serial mediation models

The SEM that examined the links between indoor greenery exposure and depressive symptoms had an acceptable fit to the data:  $\chi^2/df = 2.448$ , RMSEA = 0.061, SRMR = 0.060, CFI = 0.920, TLI = 0.906. This model (Model 1 in Fig. 1) explained 0.59 of the variance in depressive symptoms. Table 3 indicates the direct and indirect effects of indoor greenery exposure and depressive symptoms. Exposure to digital nature was directly associated with fewer depressive symptoms, while the other three measurements did not show direct links with depressive symptoms that were statistically significant. However, these other types of indoor greenery were indirectly associated with depressive symptoms via perceived restorativeness, which, in turn, was associated with less fear of COVID-19 or loneliness and thus depressive symptoms. Notably, the green view was directly associated with less loneliness and fear of COVID-19, which in turn was associated with less depressive symptoms.

The SEM in relation to outdoor greenery exposure and depressive symptoms also showed an acceptable model fit:  $\chi^2/df = 2.572$ , RMSEA = 0.064, SRMR = 0.054, CFI = 0.922, TLI = 0.910, and IFI = 0.922. This model (Model 2 in Fig. 1) explained 0.61 of the variance in depressive symptoms. The direct and indirect effects of indoor greenery exposure and depressive symptoms are shown in Table 4. Perceived quality of community's greenery was directly associated with fewer depressive symptoms. Both perceived greenery quality and total vegetative cover of community were indirectly associated with depressive symptoms via perceived restorativeness, and in turn, less fear of COVID-19 and loneliness. Perceived quality of community's greenery was also associated with less fear of COVID-19 and loneliness, and thus, less depressive symptoms.

Additionally, we developed an acceptable SEM model to simultaneously examine greenery exposure indoors and outdoors and depressive symptoms:  $\chi^2/df = 2.288$ ; RMSEA = 0.058; SRMR = 0.049; CFI = 0.926; TLI = 0.910; IFI = 0.927. This model explained 0.63 of the variance in depressive symptoms (Table 5). Perceived quality of community's greenery was directly associated with fewer depressive symptoms, while nearly all other metrics of greenery exposure (indoors



**Fig. 3.** Bivariate correlations between variables. Note: The crossed numbers indicate no statistical significance.

windows) were inversely associated with depressive symptoms or clinical levels of depression. Gardening activities were also inversely related to depressive symptoms or clinical levels of depression; however, associations did not reach statistical significance. Both types of outdoor greenery (i.e., vegetative cover and perceived quality of community greenery) were inversely associated with depressive symptoms, but only one type – perceived quality - was statistically related to clinical levels of depression.

**Table 3**  
Direct/indirect effect between greenery exposure indoors and depressive symptoms.

Path relationship	Estimates	Boot SE	p-value	Bias-corrected 95%CI		Percentile 95%CI	
HP→DEP	-0.105	0.055	0.067	-0.215	0.007	-0.215	0.007
<b>HP→RS→CF→DEP</b>	<b>-0.009</b>	<b>0.006</b>	<b>0.043</b>	<b>-0.026</b>	<b>0.001</b>	<b>-0.025</b>	<b>0.001</b>
HP→CF→DEP	-0.010	0.015	0.441	-0.044	0.018	-0.041	0.021
HP→RS→LON→DEP	-0.011	0.009	0.057	-0.036	0.001	-0.031	0.002
HP→LON→DEP	-0.048	0.045	0.282	-0.134	0.040	-0.133	0.042
GA→DEP	-0.073	0.057	0.209	-0.185	0.036	-0.186	0.036
<b>GA→RS→CF→DEP</b>	<b>-0.013</b>	<b>0.007</b>	<b>0.004</b>	<b>-0.031</b>	<b>-0.004</b>	<b>-0.028</b>	<b>-0.003</b>
GA→CF→DEP	0.027	0.018	0.054	-0.001	0.071	-0.003	0.066
<b>GA→RS→LON→DEP</b>	<b>-0.015</b>	<b>0.01</b>	<b>0.033</b>	<b>-0.043</b>	<b>-0.001</b>	<b>-0.038</b>	<b>0.001</b>
GA→LON→DEP	-0.050	0.046	0.266	-0.141	0.041	-0.142	0.040
<b>DN→DEP</b>	<b>-0.086</b>	<b>0.045</b>	<b>0.045</b>	<b>-0.176</b>	<b>-0.002</b>	<b>-0.175</b>	<b>-0.001</b>
<b>DN→RS→CF→DEP</b>	<b>-0.034</b>	<b>0.011</b>	<b>0.000</b>	<b>-0.062</b>	<b>-0.016</b>	<b>-0.060</b>	<b>-0.015</b>
DN→CF→DEP	-0.016	0.012	0.151	-0.044	0.007	-0.041	0.008
<b>DN→RS→LON→DEP</b>	<b>-0.038</b>	<b>0.021</b>	<b>0.045</b>	<b>-0.085</b>	<b>-0.001</b>	<b>-0.083</b>	<b>-0.001</b>
DN→LON→DEP	-0.047	0.037	0.205	-0.121	0.026	-0.122	0.025
GV→DEP	-0.042	0.043	0.336	-0.128	0.045	-0.128	0.045
<b>GV→RS→CF→DEP</b>	<b>-0.018</b>	<b>0.007</b>	<b>0.000</b>	<b>-0.038</b>	<b>-0.008</b>	<b>-0.035</b>	<b>-0.007</b>
GV→CF→DEP	-0.028	0.014	0.006	-0.063	-0.007	-0.058	-0.006
<b>GV→RS→LON→DEP</b>	<b>-0.021</b>	<b>0.012</b>	<b>0.037</b>	<b>-0.051</b>	<b>-0.001</b>	<b>-0.048</b>	<b>-0.001</b>
GV→LON→DEP	-0.130	0.034	0.000	-0.201	-0.066	-0.198	-0.065

Note: HP, house plants; GA, gardening activities; GV, green view; DN, digital nature; RS, restorativeness; CF, COVID-19 fear; LON, loneliness; DEP, depressive symptoms; 5000 bootstrap samples. Estimates with significant p-values ( $p < .05$ ) are shown in bold.

**Table 4**  
Direct/indirect effect between greenery exposure outdoors and depressive symptoms.

Path relationship	Estimates	Boot SE	p-value	Bias-corrected 95%CI		Percentile 95%CI	
VC→DEP	-0.070	0.047	0.150	-0.161	0.025	-0.162	0.023
<b>VC→RS→CF→DEP</b>	<b>-0.007</b>	<b>0.004</b>	<b>0.003</b>	<b>-0.018</b>	<b>-0.002</b>	<b>-0.015</b>	<b>-0.001</b>
VC→CF→DEP	-0.013	0.010	0.057	-0.043	0.001	-0.037	0.003
<b>VC→RS→LON→DEP</b>	<b>-0.014</b>	<b>0.008</b>	<b>0.034</b>	<b>-0.036</b>	<b>-0.001</b>	<b>-0.032</b>	<b>0.001</b>
VC→LON→DEP	-0.050	0.033	0.115	-0.116	0.013	-0.115	0.015
<b>PQ→DEP</b>	<b>-0.220</b>	<b>0.054</b>	<b>0.000</b>	<b>-0.324</b>	<b>-0.115</b>	<b>-0.322</b>	<b>-0.113</b>
<b>PQ→RS→CF→DEP</b>	<b>-0.011</b>	<b>0.006</b>	<b>0.004</b>	<b>-0.027</b>	<b>-0.003</b>	<b>-0.025</b>	<b>-0.002</b>
<b>PQ→CF→DEP</b>	<b>-0.043</b>	<b>0.019</b>	<b>0.005</b>	<b>-0.089</b>	<b>-0.013</b>	<b>-0.084</b>	<b>-0.011</b>
PQ→RS→LON→DEP	-0.022	0.014	0.051	-0.056	0.0010	-0.054	0.001
<b>PQ→LON→DEP</b>	<b>-0.206</b>	<b>0.041</b>	<b>0.000</b>	<b>-0.292</b>	<b>-0.130</b>	<b>-0.290</b>	<b>-0.129</b>

Note: VC, vegetative cover; PQ, perceived quality of community's greenery; RS, restorativeness; CF, COVID-19 fear; LON, loneliness; DEP, depressive symptoms; 5000 bootstrap samples. Estimates with significant p-values ( $p < .05$ ) are shown in bold.

or outdoors) were indirectly associated with depressive symptoms. These metrics were positively associated with perceived restorativeness quality, which, in turn, were associated with less fear of COVID-19 and thus lower levels of depressive symptoms. In this model, perceived quality of community's greenery was also directly associated with less fear of COVID-19 and loneliness, and thus, less depressive symptoms.

### 3.4. Results of multi-group analysis of SEMs

Table 6 shows the results of the multi-group analysis of SEMs in relation to greenery exposure and depressive symptoms among genders and levels of education and income. In Models 1 and 2, the changes in chi-square ( $\Delta\chi^2$ ) between the unconstrained and constrained models were not statistically significant ( $p > .05$ ). In addition, the changes in TLI and CFI were less than 0.01, indicating no differences between sociodemographic groups in the associations between greenery exposure indoors/outdoors and depressive symptoms. Model 3 simultaneously considered greenery exposure indoor and outdoor indicators and depressive symptoms. This model also did not show differential effects among these sociodemographic variables.

## 4. Discussion

### 4.1. Multiple greenery exposure metrics and depressive symptoms during the lockdown

We examined associations between objective and subjective measures of indoor vs. outdoor greenery and depressive symptoms/prevalence of clinical depression levels during the Omicron COVID-19 lockdown in Shanghai, China. As hypothesized, occupants with more exposure to greenery, both indoors and outdoors, were less likely to experience depressive symptoms.

In line with recent studies conducted in Western countries [19,21,22], we found that house plants were negatively associated with depressive symptoms. However, contrary to some past findings [20,52], we did not find significant associations between gardening and depressive symptoms. One possible explanation is that most urban residents in Shanghai live in gated communities with high-rise apartment buildings [32]. Therefore, our respondents might not have had private gardens at their residences. Another possibility is that our sample was relatively young, and gardening was not a common leisure occupation for these respondents.

Self-reported digital nature exposure (e.g., the frequency of watching natural videos or photos) was also associated with fewer depressive symptoms. This finding is consistent with previous experimental studies that reported the positive effects of digital nature videos on mental health [24,53]. These findings are also supported by a recent narrative

**Table 5**  
Direct/indirect effect between greenery exposure outdoors/indoors and depressive symptoms.

Path relationship	Estimates	Boot SE	p-value	Bias-corrected 95%CI		Percentile 95%CI	
HP→DEP	-0.086	0.053	0.114	-0.191	0.021	-0.192	0.021
HP→RS→CF→DEP	-0.003	0.003	0.081	-0.011	0	-0.009	0.001
HP→CF→DEP	-0.001	0.009	0.767	-0.023	0.016	-0.021	0.019
HP→RS→LON→DEP	-0.001	0.004	0.679	-0.013	0.006	-0.01	0.008
HP→LON→DEP	-0.026	0.038	0.474	-0.1	0.05	-0.099	0.052
GA→DEP	-0.062	0.054	0.255	-0.169	0.046	-0.169	0.046
<b>GA→RS→CF→DEP</b>	<b>-0.004</b>	<b>0.003</b>	<b>0.008</b>	<b>-0.014</b>	<b>-0.001</b>	<b>-0.012</b>	<b>-0.001</b>
GA→CF→DEP	0.016	0.011	0.053	-0.001	0.049	-0.002	0.042
GA→RS→LON→DEP	-0.001	0.006	0.797	-0.015	0.01	-0.014	0.011
GA→LON→DEP	-0.048	0.041	0.244	-0.128	0.034	-0.13	0.032
DN→DEP	-0.067	0.042	0.106	-0.151	0.012	-0.151	0.012
<b>DN→RS→CF→DEP</b>	<b>-0.011</b>	<b>0.006</b>	<b>0.005</b>	<b>-0.027</b>	<b>-0.003</b>	<b>-0.025</b>	<b>-0.002</b>
DN→CF→DEP	-0.008	0.008	0.169	-0.028	0.005	-0.025	0.008
DN→RS→LON→DEP	-0.002	0.015	0.863	-0.032	0.026	-0.032	0.026
DN→LON→DEP	-0.037	0.031	0.221	-0.1	0.023	-0.1	0.023
GV→DEP	0.044	0.043	0.295	-0.04	0.128	-0.041	0.127
<b>GV→RS→CF→DEP</b>	<b>-0.002</b>	<b>0.002</b>	<b>0.042</b>	<b>-0.009</b>	<b>-0.001</b>	<b>-0.008</b>	<b>-0.01</b>
GV→CF→DEP	0.004	0.008	0.48	-0.01	0.023	-0.011	0.021
GV→RS→LON→DEP	-0.001	0.004	0.71	-0.012	0.006	-0.01	0.007
GV→LON→DEP	-0.038	0.03	0.211	-0.096	0.02	-0.096	0.02
VC→DEP	-0.067	0.045	0.153	-0.153	0.023	-0.154	0.022
<b>VC→RS→CF→DEP</b>	<b>-0.005</b>	<b>0.003</b>	<b>0.004</b>	<b>-0.015</b>	<b>-0.001</b>	<b>-0.012</b>	<b>-0.001</b>
VC→CF→DEP	-0.014	0.01	0.051	-0.044	0.001	-0.038	0.002
VC→RS→LON→DEP	-0.001	0.007	0.811	-0.015	0.012	-0.014	0.014
VC→LON→DEP	-0.045	0.031	0.149	-0.106	0.016	-0.107	0.016
<b>PQ→DEP</b>	<b>-0.205</b>	<b>0.054</b>	<b>0.001</b>	<b>-0.309</b>	<b>-0.099</b>	<b>-0.308</b>	<b>-0.096</b>
<b>PQ→RS→CF→DEP</b>	<b>-0.006</b>	<b>0.004</b>	<b>0.005</b>	<b>-0.018</b>	<b>-0.001</b>	<b>-0.016</b>	<b>-0.001</b>
<b>PQ→CF→DEP</b>	<b>-0.044</b>	<b>0.02</b>	<b>0.007</b>	<b>-0.093</b>	<b>-0.011</b>	<b>-0.09</b>	<b>-0.01</b>
PQ→RS→LON→DEP	-0.001	0.008	0.821	-0.02	0.012	-0.019	0.013
<b>PQ→LON→DEP</b>	<b>-0.174</b>	<b>0.04</b>	<b>0</b>	<b>-0.262</b>	<b>-0.101</b>	<b>-0.261</b>	<b>-0.101</b>

Note: HP, house plants; VC, vegetative cover; PQ, perceived quality of community’s greenery; GV, green view through windows; GA, gardening activities; DN, digital nature; RS, restorativeness; CF, COVID-19 fear; LON: loneliness; DEP: depressive symptoms. 5000 bootstrap samples. Estimates with significant p-values ( $p < .05$ ) are shown in bold.

**Table 6**  
Heterogeneity analysis of SEMs among gender, education, and income.

Group variables	$\chi^2$	df	$\Delta\chi^2$	$\Delta df$	p-value	$\Delta TLI$	$\Delta CFI$
<b>Model 1: Indoor greenery</b>							
<b>Gender (male/female)</b>							
Unconstrained model	1051.185	554					
Constrained model	1076.557	574	25.372	20	0.188	-0.003	-0.001
<b>Education (non-bachelor/bachelor or higher)</b>							
Unconstrained model	1059.477	554					
Constrained model	1071.832	574	12.355	20	0.903	-0.006	0.001
<b>Income (low/middle/high)</b>							
Unconstrained model	1525.520	885					
Constrained model	1564.408	925	38.888	40	0.520	-0.006	0.000
<b>Model 2: Outdoor greenery</b>							
<b>Gender (male/female)</b>							
Unconstrained model	928.144	482					
Constrained model	947.969	494	19.825	12	0.070	-0.001	-0.001
<b>Education (non-bachelor/bachelor or higher)</b>							
Unconstrained model	951.700	482					
Full constrained model	966.588	494	14.888	12	0.248	-0.002	-0.001
<b>Income (low/middle/high)</b>							
Unconstrained model	1368.083	770					
Constrained model	1393.579	794	25.496	24	0.379	-0.004	-0.001
<b>Model 3: Indoor and outdoor greenery</b>							
<b>Gender (male/female)</b>							
Unconstrained model	1146.135	626					
Constrained model	1182.956	654	36.821	28	0.123	-0.003	-0.001
<b>Education (non-bachelor/bachelor or higher)</b>							
Unconstrained model	1138.443	626					
Constrained model	1167.715	654	29.271	28	0.399	-0.005	0.000
<b>Income (low/middle/high)</b>							
Unconstrained model	1655.869	1000					
Constrained model	1722.207	1056	66.338	56	0.162		-0.001



review [13] that argued digital nature had the potential to reduce COVID-19 related mental stressors when actual nature exposure (e.g., access to public parks) was not available during strict lockdowns.

Consistent with several previous studies [16,21,22,47], green views from windows showed stronger associations with lower depressive symptoms than other indoor greenery exposure metrics. Unlike self-reported green view measures in past research, we employed an objective metric, the green window view index, which was estimated by vegetative visibility through semantic image segmentation [37]. This deep learning approach allowed us to more objectively evaluate green window views by calculating the percentage of green elements in photos taken from the best angle of respondent's most-viewed window.

Regarding outdoor greenery, we measured the total vegetative cover (NDVI) and perceived quality of community's greenery, because respondents were confined to their gated communities during the lockdowns. In line with previous studies [15,16,54], our findings demonstrated that outdoor greenery exposure was associated with less depressive symptoms. The quality aspects of community's greenery might be more influential in promoting health benefits than quantity (i.e., total vegetative cover), supporting past findings [12] that addressed the necessity of incorporating a quality index into the framework of greenery exposure assessment.

#### 4.2. Underlying mechanisms between greenery exposure and depressive symptoms

This study examined the role of three putative mediators: perceived restorativeness of the home environment, loneliness, and fear of COVID-19. As hypothesized, exposure to greenery indoors and outdoors was positively associated with perceived restorativeness, which, in turn, was associated with less COVID-19 related mental stressors such as loneliness and fear of COVID-19, and, ultimately, less depressive symptoms. These serial mediation models demonstrated that loneliness and fear of COVID-19 were associated with depressive symptoms during the home confinement periods, supporting the similar findings of recent studies [29,55–57]. Importantly, we found that COVID-19 related mental stressors might be lower with more exposure to indoor and outdoor greenery, which was mediated by perceived restorativeness, such as feelings of being away and fascination. In accordance with the present results, a recent cross-sectional study [21] also demonstrated that the mental positive effects of greenery exposure indoors were largely explained by increased feelings of perceived restorativeness of the home environment (i.e., being away) during lockdowns in Bulgaria. For further comparison, although current studies primarily examined direct associations between greenery exposure and mental outcomes during COVID-19 lockdowns [16,22], others addressed the mediating effects of restorative environmental quality between greenery exposure and mental benefits in pre-COVID-19 periods [58–61]. One example [62] stated that the mental benefits of natural views were mediated by perceived restorativeness, including fascination and feelings of being away.

Gender, education, and income did not modify the observed associations between greenery and depressive symptoms in the current study. These results are consistent with a systematic review [13] that stated there was no consistent modification effect of sociodemographic variables in most nature-health cases during COVID-19 lockdowns [16,63,64]. In contrast, other research [36] found differences in associations between natural exposure and mental health by gender and social class in the United Kingdom. This divergence could be explained by different sample sizes, characteristics, and exposure measurements. Overall, while most studies report few differences in nature and health associations by sociodemographic variables, the current evidence is too limited to understand why and in what contexts these variables could modify these associations [13].

#### 4.3. Implications for health-based green interventions

Despite our data being cross-sectional, the robustness of our findings and use of SEM provides suggestive evidence that occupants' exposure to greenery indoors and outdoors could reduce depressive symptoms during the COVID-19 lockdowns. Improving greenery exposure might be a nature-based solution for promoting mental well-being during periods of confinement. Biophilic design is encouraged to introduce more natural elements into indoor spaces, such as indoor green walls or ornamental plants [65]. A recent experimental study [66] revealed that a biophilic environment with edible plants (e.g., strawberries) had positive effects on occupants' emotions and cognition. Home gardens may be more efficient in mitigating mental stress than other forms of green infrastructure (e.g., urban parks and green views) during lockdowns [17,52]; however, most Chinese urban dwellers living in apartment with high population density (e.g. Shanghai) do not have home gardens. Instead, Shanghai residents may have more opportunities for nature contact via club (inner) parks in gated communities [32]. Therefore, the habits and preferences of urban residents regarding contact with multiple forms of green infrastructure need to be considered at a local, city, or regional geographic scope when implementing green intervention policies. Lastly, residents should be encouraged to engage with greenery both indoors and outdoors through a variety of means during lockdowns. In our case, the city implemented a 3-tiered control system based on recently reported cases, including closed, controlled, and precautionary areas. Virtual/digital nature might be an effective alternative when actual nature contact cannot be arranged. Residents who live in precautionary areas should also be encouraged to relax in community parks (i.e., actual nature) while maintaining social distancing.

#### 4.4. Limitations

Although reasonable evidence was provided to support our research hypotheses, this study has several limitations. First, the retrieval of self-reported data through an online survey is more acceptable for young and middle-aged people (73.3%) than older people, who are less prone to using smartphones or computers and are less likely to respond [67]. Respondents were not uniformly distributed geographically, and most were urban dwellers as indicated by their check-in locations (Supplementary Materials, Fig. S1). Therefore, limitations in generalizability are inevitable. Although a single item assessing various dimensions of self-reported greenery exposure was functional in facilitating acquisition [21,22], it may have yielded biases in obtaining accurate greenery exposure data. For example, digital nature exposure was measured by self-reported ratings of how often respondents watched nature scenes on digital devices such as phones, computers, or TVs during confinement periods; such a single item cannot specify the types of interactions and greenery exposure doses. Neighborhood socioeconomic confounders (e.g., percentage of manual workers and percentage of people without a university degree) were not adjusted for in our models due to the lack of current neighborhood-level census data in Shanghai. Additional confounders, such as housing type, living alone or with other people, financial burden, and job loss, should be accounted for in future studies, since they may influence the feelings of loneliness and depression [68–70]. Finally, this study could not determine cause-and-effect relationships between indoor and outdoor greenery exposure with reductions of depressive symptoms owing to its cross-sectional design.

#### 5. Conclusions

Shanghai residents exposed to greenery experienced better mental health during the Omicron COVID-19 lockdown. Four types of indoor greenery (house plants, gardening activities, digital nature, and window views of greenery), and two types of outdoor greenery (vegetative cover and perceived quality of community's greenery) were directly or indirectly associated with less depressive symptoms induced by loneliness

and fear of COVID-19. The restorativeness of home environments partially explained how greenery was linked to less loneliness, fear of COVID, and, ultimately, less depressive symptoms. These findings support the idea that indoor and outdoor greenery exposure should be considered as nature-based solutions for mitigating COVID-19 related mental stressors. Examining the long-term effects and dose-response relationships of exposure on mental health is necessary to determine the robustness and hypothesized causal relationships between these variables in future studies.

#### CRedit authorship contribution statement

**Jinguang Zhang:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Matthew H.E.M. Browning:** Writing – review & editing, Methodology, Conceptualization. **Jie Liu:** Writing – review & editing, Investigation, Conceptualization. **Yingyi Cheng:** Investigation, Data curation, Conceptualization. **Bing Zhao:** Supervision, Conceptualization. **Payam Dadvand:** Writing – review & editing, Methodology, Conceptualization.

#### Declaration of competing interest

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.

#### Data availability

Data will be made available on request.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.buildenv.2022.109799>.

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