Mohamad Awada
Department of Civil and
Environmental Engineering,
University of Southern California,
Los Angeles, CA 90089
e-mail: awadam@usc.edu

Burcin Becerik-Gerber
Department of Civil and
Environmental Engineering,
University of Southern California,
Los Angeles, CA 90089
e-mail: becerik@usc.edu

Gale Lucas
USC Institute for Creative Technologies,
University of Southern California,
Los Angeles, CA 90089
e-mail: lucas@ict.usc.edu

Shawn C. Roll
Chan Division of Occupational Science and
Occupational Therapy,
University of Southern California,
Los Angeles, CA 90089
e-mail: sroll@usc.edu

Associations Among Home Indoor Environmental Quality Factors and Worker Health While Working From Home During COVID-19 Pandemic

The outbreak of SARS-CoV-2 virus forced office workers to conduct their daily work activities from home over an extended period. Given this unique situation, an opportunity emerged to study the satisfaction of office workers with indoor environmental quality (IEQ) factors of their houses where work activities took place and associate these factors with mental and physical health. We designed and administered a questionnaire that was open for 45 days during the COVID-19 pandemic and received valid data from 988 respondents. The results show that low satisfaction with natural lighting, glare, and humidity predicted eye-related symptoms, while low satisfaction with noise was a strong predictor of fatigue or tiredness, headaches or migraines, anxiety, and depression or sadness. Nose- and throat-related symptoms and skin-related symptoms were only uniquely predicted by low satisfaction with humidity. Low satisfaction with glare uniquely predicted an increase in musculoskeletal discomfort. Symptoms related to mental stress, rumination, or worry were predicted by low satisfaction with air quality and noise. Finally, low satisfaction with noise and indoor temperature predicted the prevalence of symptoms related to trouble concentrating, maintaining attention, or focus. Workers with higher income were more satisfied with humidity, air quality, and indoor temperature and had better overall mental health. Older individuals had increased satisfaction with natural lighting, humidity, air quality, noise, and indoor temperature. Findings from this study can inform future design practices that focus on hybrid home-work environments by highlighting the impact of IEQ factors on occupant well-being. [DOI: 10.1115/1.4052822]

Keywords: indoor environmental quality (IEQ), health, well-being, COVID-19, work from home, indoor environment quality, occupant behavior

1 Introduction

The outbreak of the COronaVIrus Disease 2020 (COVID-19) has altered all aspects of our life, including the way we work. To slow down the spread of the virus, people were required to practice physical distancing and many office workers switched from working in an office space to working from home. In fact, within just two months after the declaration of a nationwide emergency, more than one-third of the U.S. workforce switched to working from home [1]. These employees were obliged to conduct their daily work activities over a long period of time (e.g., months) within their homes, most spaces which were not designed to support full-time office work [2].

Studies have been conducted to demonstrate the links between indoor environmental quality (IEQ) factors (lighting, glare, temperature, humidity, air quality, noise, etc.) on occupant health and well-being at work in traditional office environments [3–5]. Despite the obligatory full-time work from home due to the COVID-19 pandemic, there has been limited examination of occupants' satisfaction with IEQ factors in home environments and their relationship with individual health issues while working from home. Previous studies have examined the indoor environmental quality of households as places to live but not to work. For instance, Ref. [6] investigated the effects of the temperature and air quality in bedrooms on sleeping quality. Their results suggest that occupants prefer low indoor air temperature and that poor air quality decreases the quality of sleep. Another study showed that, when reporting sick building-related symptoms, occupants of residential buildings perceive their household environment's overall IEQ to be poor [7]. Nose-related symptoms were the most common home-related sick building syndrome; however, the noise was the major IEQ problem.

Compared with traditional offices, which are usually controlled by centralized building systems, occupants have more control over their home environments. For example, an office worker at home might be able to choose a workspace with better conditions compared to traditional fixed cubicles or open space offices [8]. This sense and ability of control might lead them to be more satisfied with their indoor environment and experience better health conditions [9]. On the other hand, home environments are usually not designed for office use and work purposes, and they might result in an increased sense of dissatisfaction with the environment and the emergence of health issues. Moreover, workers with lower socioeconomic status might not have access to the space needed for work activities and thus might have to work in a suboptimal workspace, resulting in reduced satisfaction with IEQ. To that end, with the pandemic-introduced work from home practices, a research opportunity emerged to examine worker satisfaction with their home IEQ and its relationship with their health.

IEQ assessment comes in two forms: (1) subjective assessment using surveys to determine how occupants perceive IEQ and how satisfied they are with IEQ factors and (2) objective assessment through physical measurements of IEQ using monitoring equipment [10]. However, objective assessment becomes difficult when a large

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sample is under study, especially during a pandemic. On the other hand, surveys are more practical instruments especially when a large sample with wide geographic distribution is targeted. Therefore, in this study, we employed a survey-based methodology to study the associations among satisfaction with IEQ factors and workers' physical and mental health while working from home during the COVID-19 pandemic. The research questions answered in this paper include the following: (1) How did satisfaction with the IEQ factors relate to the prevalence of physical and mental health symptoms while working from home? (2) What worker demographics (i.e., age, gender, and income) were associated with satisfaction with IEQ and overall mental and physical health while working from home? (3) What insights regarding the impact of IEQ factors on health can be concluded based on the transition from traditional office environments to home office environments? The paper is organized as follows: Sec. 2 provides a summary of previous work that relates to the impact of IEQ factors on health and well-being of occupants; Sec. 3 outlines our survey-based methodology to answer the above-mentioned research questions; Sec. 4 introduces the results of the analysis; Sec. 5 provides discussions of our findings including the limitations and future research directions. Finally, Sec. 6 summarizes the conclusions.

2 Indoor Environmental Quality Factors and Health in Workplace

Indoor Environmental Quality (IEQ) is defined as the conditions of the built environment in relation to the comfort, health, and well-being of occupants [11]. Different IEQ parameters can trigger various physical and psychological responses among people that depend on the intensity and duration of exposure in the indoor environment. Because we spend a significant portion of our lives at work and much of this work occurs indoors, it is important to understand the relationships among IEQ parameters and health, particularly within the workplace environment. Key IEQ factors related to office workplaces include noise, lighting, temperature, humidity, and air quality, each of which can impact physical and mental health.

Of all IEQ factors, noise is considered to be a primary reason for dissatisfaction for employees, especially those in open-plan offices [12]. Office noise can be generated by building systems, outdoor traffic, electronic devices, drawers and doors being opened and closed, and conversations among coworkers, both comprehensible and incomprehensible [13]. Evans argues that noise, an environmental stressor, has profound psychological, behavioral, and cognitive consequences on workers [14]. On the psychological aspect, office employees subjected to lower levels of noise experience less cognitive stress and hypertension [15]. Also, Ref. [16] found that noise results in deteriorated mood and increased risk of headaches. Behaviorally, a study showed that when workers are exposed to prolonged durations of noise, they were less likely to make postural adjustments which could increase their risk to be affected by musculoskeletal disorders [17]. Regarding the cognitive effects, an experiment conducted by Ref. [18] showed that the exposure to noise reduces the motivation to work and reduces the memory span.

In addition to noise, the luminous environment plays an important role in supporting healthy indoor working conditions. Access to natural lighting has been associated with long-lasting effects on the physical and mental well-being of occupants [19], such as improved mood, better sleep quality [20], and reduction in eye strain [21]. On the other hand, poor access to daylight can disturb the human circadian rhythm [22]. The circadian system is the biological clock of the human body, which allows humans to stay synchronized with a 24-h day cycle [23]. Such disturbance of the circadian rhythm affects sleep, alertness, and the physiological and psychological body functions [24].

The color temperature and intensity of electric lighting also affect the psychological and mental states of occupants. For example, in a laboratory experiment, Ref. [25] found that bright and cool color lighting induced positive effects and improved the mood of office workers. Reference [26] exposed 94 office workers to two lighting conditions: blue-enriched-white light (17,000 K) and white light (4000 K). Workers presented improved alertness, mood, performance, concentration, less fatigue, and eye discomfort under the blue-enriched-white light condition in comparison to the white light.

Another factor related to visual conditions in built environments is glare, which is a visual sensation caused by poor light distribution and excessive brightness in the field of view. Glare limits people's ability to see clearly and creates a feeling of annoyance and discomfort that can lead to a loss of concentration and attention [27]. Sustained exposure to glare can result in eyestrain and eye fatigue that can lead to impaired vision and, in extreme cases, eye injuries [28].

Inadequate indoor thermal conditions represent another factor that can degrade occupants' well-being and health [29]. Reference [13] found that office workers who were uncomfortable with typical thermal conditions in their workspace showed a higher prevalence of headache, throat, and eye irritation. In addition, Ref. [30] suggested that rapid temperature swings aggravate sick building syndrome symptoms and have detrimental effects on cognitive performance. Furthermore, extreme thermal events can result in conditions such as hypothermia or heat stroke and can increase cardiovascular mortality, especially among children and the elderly [31].

Humidity, or the relative amount of moisture in the air, can also affect the health of occupants in indoor environments. Low humidity levels can stimulate the evaporation of the tear film leading to a dryness sensation of the eye, which results in increased irritation and eyestrain [32]. Also, low humidity levels can cause the skin and nose to dry out and lead to itching, chapped lips, and skin and nose irritation [33]. On the other hand, high humidity levels accelerate the growth of mold which can reduce overall air quality and aggravate allergies, asthma, and cause other breathing problems [34].

Over the last two decades, increasing attention has been given to the effect of indoor air quality (IAQ) on occupants' health in buildings, and this focus has intensified with the spread of COVID-19. The indoor air in buildings is a mix of outdoor air contaminants brought into the building through the mechanical or natural ventilation systems, and indoor air contaminants associated with building materials, tap water, appliances, excessive moisture, pets, and human behaviors [35]. Indoor gases like radon, carbon monoxide, ozone and oxides of nitrogen, volatile organic compounds and particulate matters can cause short-term health issues such as eye, nose, and throat irritation, headaches, and vomiting. They can also cause long-term health problems associated with cancer, and damage to the liver, kidney, and central nervous system, asthma and chronic obstructive pulmonary diseases [36–38]. In addition to the direct effects, the indoor air pollutants have on the physical health of occupants, several research studies demonstrated the relationship between increased indoor air pollution and mental health issues and disorders. Both observational and experimental procedures have proven that indoor air contaminants are linked with deteriorated mood, amplified aggressive behaviors, degraded attention, mental fatigue and higher depression and stress rates [39,40]. Furthermore, several studies examined the detrimental effect of degraded IAQ on office workers' cognitive performance. For instance, Ref. [41] concluded that office workers showed higher cognitive function scores when carbon dioxide and total volatile organic compounds concentrations were minimal. Similarly, other studies found that better indoor air quality in green buildings is associated with fewer sick building syndrome symptoms, higher sleep quality, and higher cognitive test scores [42,43]. Reference [44] found that degraded air quality lessens the ability to think clearly, while decreasing the answering speed, response time, and number of correct answers in several cognitive tests.

Prior to the pandemic, office workers with different income levels shared the same office environment, experiencing similar IEQ conditions. Thus, within the same office environment, office workers' income had less effect on workspace IEQ conditions, satisfaction with IEQ and their associations with health. When workers shifted to working from home, their income level, which is a direct indicator of housing quality, might have influenced the IEQ conditions. Several studies found that low-income families, in comparison to high-income families, were exposed to higher noise and indoor air pollution levels [45] and had more crowded homes with lower structural quality [46]. In another study, Ref. [47] found that the renovation of low-income family houses increased overall satisfaction with the thermal environment from 36.4% to 78.7%.

People with low income are more likely to live in substandard housing conditions, which inevitably creates major health disparities between high- and low-income house owners [48]. Substandard houses are characterized by low structural quality, water leakages, lack of proper ventilation, degraded thermal conditions, and insufficient lighting leading to poor physical and mental health and well-being among building occupants [49]. Reference [50] proved that substandard houses increase the risk of asthma, and physical injuries and aggravate mental health problems. To that end, Ref. [51] showed that when housing quality is better, occupants' psychological distress drops, while Ref. [52] postulated that living in degraded housing conditions is generally associated with intense depressive symptoms. Additionally, children's emotional health was found to be worse in households with deteriorated interior and exterior physical conditions [53].

IEQ conditions vary not only with income but also with age and gender. A survey study by Ref. [54] found that people in the 35- to 54-year age group were less satisfied with IEQ than both younger and older groups. Furthermore, it was found that workers between 46 and 55 years old were more satisfied with noise in comparison to others, and the youngest and oldest groups showed higher satisfaction with the air quality compared to workers between 46 and 66 years [5]. Regarding gender, male workers were found to have higher satisfaction with the indoor environment, including electric lighting, noise, and thermal conditions, when compared to female workers [55]. Finally, women were found to be more comfortable and satisfied with the thermal environment at 24 °C, while men were comfortable at lower indoor temperatures, i.e., 23 °C [56].

During the COVID-19 pandemic, the necessity for a comfortable and healthy workplace has been pushed into the spotlight and the conversation about IEQ has exploded. This pandemic exposed the weaknesses in our indoor environments to protect us not only against COVID-19—but also from other indoor air contaminants. In addition to air quality, it quickly became apparent that the indoor environments within workers' homes were not prepared to support the sudden shift to work from home. Importantly, many workers might not have a dedicated workspace at home, nor a comfortable or healthy workspace that lacks proper IEQ conditions to continue working effectively and in a health-promoting manner. Even when the pandemic is resolved, many workers may continue to work from home. To that end, it is necessary to further understand the IEQ within workers' homes to identify which IEQ factors are most salient to support workers' physical and mental health when working at home.

3 Methodology

3.1 Procedure. Using Qualtrics [57], an online survey was administered for a period of 45 days from April 27, 2020, to June 11, 2020. An invitation to complete the survey was distributed through newsletters and was posted on social media platforms (Facebook, LinkedIn, and Twitter). This study was approved as exempt research by the Institutional Review Board of the University of Southern California (UP-20-00339 IRB study number). Participants were screened through an initial question that asked if they had transitioned to working from home during the stay-at-home mandates due to the COVID-19 pandemic, and if their job required them to use a workstation (e.g., desk, computer terminal, and laptop) most of the day. A total of 1409 responses were collected, of which 91 responses were eliminated because they did not meet the inclusion criterion (i.e., screening question). Responses were further screened based on the percentage completion of the survey; a response was considered incomplete when less than 25% of the survey was completed. The final number of responses included for analysis was 988.

3.2 Participants Characteristics. Of the 988 valid responses, 56.5% were from female respondents, 32.1% were from male respondents, and the remaining 11.4% were unreported. Respondents were between the ages of 18 and 80, with an average age of 40.9 years (standard deviation (SD) = 13.1 years). Most of the respondents reported an annual income between $50 K and $100 K (40.6%), with the remaining respondents almost equally dispersed among those making less than $50 K (19.0%), $100 K—$150 K (21.7%), and more than $150 K (18.8%). The race and ethnicity were distributed with 60.9% of the respondents being Caucasians, 24.5% being Asians, 9.4% being Hispanic/Latinx, 2.8% being African American, and the remaining 2.4% were reported as other. About 59.6% of the responses were received from the West region of the United States., 7.7% from the Northeast region, 9.0% were from the Midwest region, 6.8% were from the South region,6.4% were from outside the United States (International), and 10.5% were unreported. The U.S. regional division was adopted based on the U.S. Census Bureau [58]. The level of education among respondents was distributed as follows: 28.6% had a 4-year college degree or less, 37.21% had a graduate or professional degree, and 34.19% had a doctorate degree. Responses were received from office workers working in a variety of occupations including business (29.1%), engineering and architecture (24.6%), education and arts (22.1%), healthcare and social services (9.3%), computer sciences and mathematics (8.2%), basic science (4.2%), and service and physical occupations (2.6%). Most of the respondents were full-time employees (82.8%), while the remaining respondents were students (8.7%), part-time workers (5.9%), or contractors (2.6%).

We conducted chi-square analyses for all combinations between the demographic variables (gender, income, race, and region), and only two significant relationships emerged: between income and gender ($\chi^2 = 54.07$, $df = 3$, and $p < 0.001$), as well as income and region ($\chi^2 = 46.05$, $df = 12$, and $p < 0.001$). Not only were these two relationships the only ones that reached significance, but they would be expected based on the literature [59,60]. Thus, although the current sample is biased in terms of income and region (skewed toward higher income and West region) because there are no interactions with other demographics, such interactions could not be further biasing the sample.

3.3 Measures

3.3.1 Indoor Environmental Quality Factors. Respondents rated their satisfaction with different IEQ factors in their home workspace using a 5-point Likert scale, with 1 being extremely dissatisfied and 5 being extremely satisfied. Questions regarding satisfaction with natural lighting (access to daylight), electric lighting (brightness, no shadows), glare (no reflection on work surface and on computer screen), indoor temperature, humidity (comfortable levels), air quality (fresh, clean air without unpleasant odor, etc.), and noise were included in the survey.

3.3.2 Physical Health. Respondents provided a rating of their overall physical health status relative to that before the stay-at-home mandate using a 5-point Likert scale [61], with 1 being much lower and 5 being much higher. In addition, respondents indicated the physical symptoms they experienced an increase in since working from home using a predefined list of physical symptoms (selecting all that apply). The list was established based on a thorough literature review of all the possible physical issues related to the indoor environment that building occupants usually experience. The list included a total of nine symptoms: (1) cardiovascular symptoms (chest pain, blood pressure, and heart rate), (2) chest/lung symptoms (shortness of breath and chest tightness/pain), (3) digestive symptoms (appetite changes, abdominal discomfort, and irregularity), (4) eye-related symptoms (burning, blurry, and/or dry), (5) fatigue or tiredness, (6) headaches or migraines, (7) nose/throat-related symptoms (dry, runny, or bloody nose; hoarseness) (8) skin-related symptoms (chapped, itchiness, and redness), and (9) musculoskeletal discomfort(discomfort or pain in muscles or joints).

3.3.3 Mental Health. Respondents provided a rating of their overall mental health status relative to that before the stay-at-home mandate using a 5-point Likert scale, with 1 being much lower and 5 being much higher. In addition, respondents indicated the mental symptoms they experienced an increase in since working from home using a predefined list of mental symptoms (selecting all that apply). Again, the list was established based on a literature review of the possible mental issues related to the indoor environment that building occupants could experience. The list included eight symptoms: (1) anxiety or nervousness; (2) depression, sadness or feeling blue (3) insomnia or trouble sleeping; (4) low motivation or slowed actions; (5) mental stress, rumination or worry; (6) mood swings; (7) social isolation or decreased interest in social engagement; and (8) trouble concentrating, maintaining attention, or focus.

3.4 Data Analysis. The analysis was conducted in three phases. First, we conducted descriptive analyses for IEQ satisfaction, and physical and mental health-related responses. Second, we examined the effects of demographics on IEQ satisfaction, and overall physical and mental health statuses through a series of Pearson correlations, *t*-tests, and ANOVA analyses. Finally, logistic regression models were utilized to further investigate the link between IEQ satisfaction, demographic variables, and physical and mental health symptoms.

4 Results

4.1 Descriptive Analysis. The means and standard deviations for satisfaction with IEQ factors and overall physical and mental health status are presented in Table 1. Respondents were least satisfied with noise and most satisfied with air quality. Satisfaction with IEQ data is skewed toward the upper side of the Likert scale. Respondents reported worse overall physical health and mental health when working from home during the pandemic relative to that before the stay-at-home mandate.

Fatigue, musculoskeletal discomfort, eye-related symptoms, and headaches were the most frequently reported physical conditions that increased after transitioning to work from home, each experienced by more than 20% of the respondents. Conversely, except for mood swings, at least 1 in 5 respondents reported an increase in all mental health symptoms. The number of responses related to questions about the different physical and mental health symptoms is presented in Table 2.

Table 1 Descriptive statistics of IEQ satisfaction and overall mental and physical health

Variable	Mean	Standard deviation	Median	Mode
Satisfaction with air quality	4.19	0.90	4.00	5.00
Satisfaction with natural lighting	4.11	1.09	4.00	5.00
Satisfaction with humidity	4.08	0.94	4.00	5.00
Satisfaction with indoor temperature	4.00	1.07	4.00	5.00
Satisfaction with electric lighting	3.98	0.99	4.00	4.00
Satisfaction with glare	3.70	1.06	4.00	4.00
Satisfaction with noise	3.48	1.22	4.00	4.00
Overall physical health	2.84	0.87	3.00	3.00
Overall mental health	2.70	0.93	3.00	3.00

4.2 Associations Among Demographics and Indoor Environmental Quality Satisfaction and Health. We compared satisfaction with IEQ factors and the overall physical and mental health ratings among respondents of different income levels using ANOVA tests and by gender using independent *t*-tests. No significant differences were noted by gender, but statistically significant differences were noted among the income groups for ratings of satisfaction with humidity ($F(3, 780) = 4.49$, $p = 0.004$), air quality ($F(3, 780) = 2.93$, $p = 0.033$), indoor temperature ($F(37, 80) = 3.32$, $p = 0.019$), and overall mental health ($F(3, 776) = 4.05$, $p = 0.007$). Mean and standard deviations by income category for these variables are presented in Fig. 1. It is worth noting that the value of N changes between different tests because not every respondent answered all the questions. Tukey Honestly Significant Difference (HSD) test [62] was used to test differences in IEQ satisfaction across the four income categories for significance. This test is generally used to test all pairwise differences among sample means for significance. The results showed that the satisfaction with humidity for the income category "more than \$150 K" was statistically significantly higher than every other income category: "less than \$50 K," "between \$50 K and \$100 K," and "between \$100 K and \$150 K." Satisfaction with air quality was statistically significantly higher for the income category "more than \$150 K" than the income category "less than \$50 K." Also, the income

Table 2 Number of responses related to the physical and mental health symptoms

	Symptom	Yes, I experienced an increase in this symptom	No, I did not experience an increase in this symptom
Physical symptoms	Fatigue or tiredness	380	542
	Musculoskeletal discomfort	350	597
	Eye-related symptoms	261	661
	Headaches or migraines	201	721
	Digestive symptoms	133	789
	Skin-related symptoms	82	840
	Nose/throat-related symptoms	43	879
	Cardiovascular symptoms	34	888
	Chest/lung symptoms	28	894
Mental symptoms	Trouble concentrating, maintaining attention or focus.	342	587
	Anxiety or nervousness	329	600
	Low motivation or slowed actions	328	601
	Mental stress, rumination, or worry	307	622
	Insomnia or trouble sleeping	245	684
	Depression and sadness	236	693
	Social isolation or decreased interest in social engagement	197	732
	Mood swings	144	785

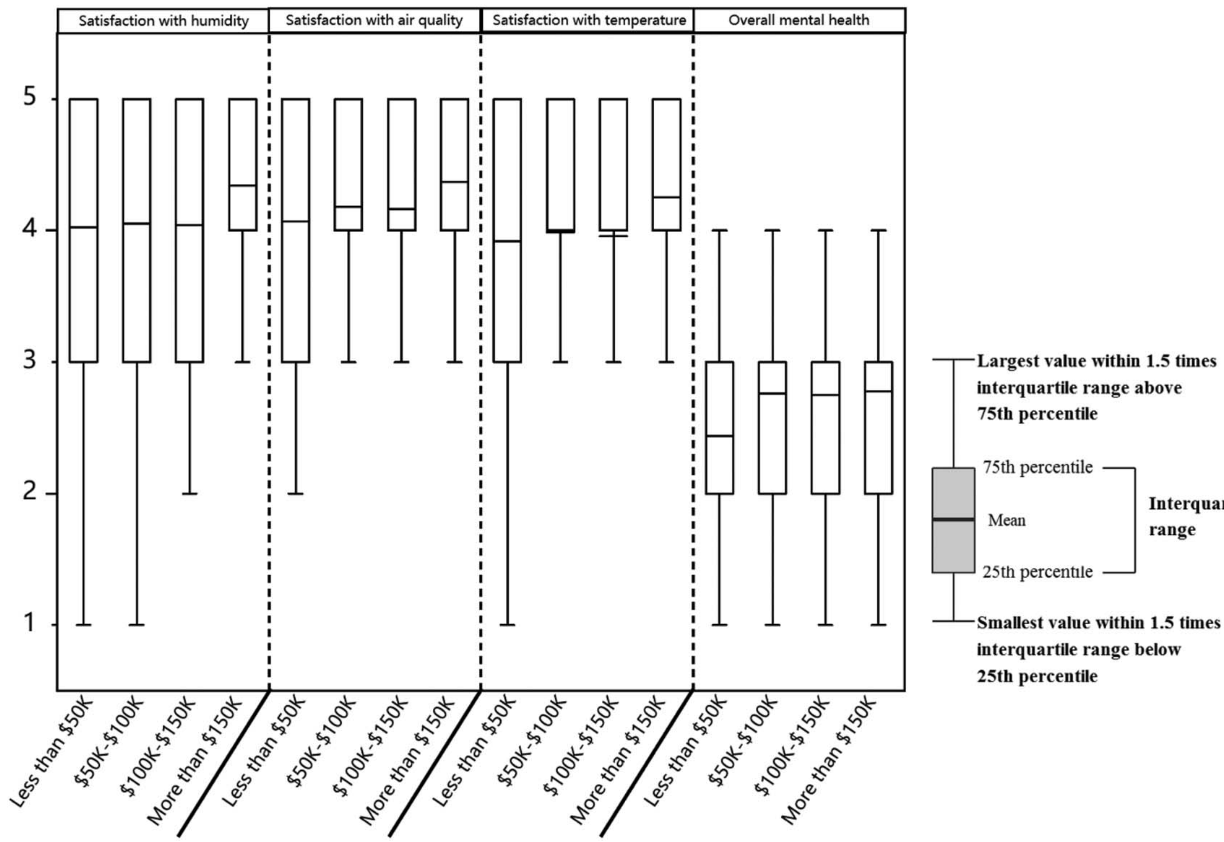

Fig. 1 Plots of the sample distribution in ratings of satisfaction with humidity, air quality, indoor temperature, and overall mental health where significant differences were noted across income categories

category "more than $150 K" showed statistically significantly higher satisfaction with the indoor temperature, when compared to the categories "less than $50 K" and "between $100K and $150 K." Finally, the results suggest that the income category "less than $50 K" presented a statistically significantly lower overall mental health rating than the "between $50 K and $100 K" and "between $100 K and $150 K" categories.

Additional ANOVA analysis was conducted to determine the effect of region and race on the IEQ satisfaction and the physical and mental health ratings. The results indicate that statistically significant differences were noted among regions for ratings of satisfaction with noise only ($F(4, 788) = 3.21$, $p = 0.012$). Additional Tukey HSD tests showed that the satisfaction with noise in the South region ($M = 3.76$, $SD = 1.18$) was statistically higher than the West region ($M = 3.37$, $SD = 1.21$).

A correlation matrix among satisfaction with IEQ factors, overall physical and mental health statuses, and age is presented in Table 3. It is worth noting that, given the previous ANOVA results, a partial correlation analysis was performed in Table 3 to control for the effect of income on the variables. Pairwise correlations among the seven IEQ factors were all statistically significant and positive, ranging from 0.21 to 0.67. A similar moderate, positive correlation was found between overall physical health and overall mental health ($r = 0.45$, $N = 881$, and $p < 0.001$). Satisfaction with air quality was the only IEQ factor significantly associated with overall physical health rating ($r = 0.10$, $N = 878$, and $p < 0.001$), whereas satisfaction with humidity was the only IEQ factor not significantly correlated with overall mental health. We note that although statistically significant, the correlations between overall mental health and IEQ satisfaction were weak, including natural

Table 3 Correlation matrix: Satisfaction with IEQ factors, overall physical and mental health, and age

	1	2	3	4	5	6	7	8	9	10
1	1.00									
2	0.53**	1.00								
3	0.31**	0.46**	1.00							
4	0.28**	0.34**	0.35**	1.00						
5	0.36**	0.36**	0.28**	0.63**	1.00					
6	0.17**	0.25**	0.27**	0.34**	0.33**	1.00				
7	0.29**	0.31**	0.27**	0.64**	0.52**	0.34**	1.00			
8	0.06	0.01	−0.03	0.01	0.10*	0.05	0.03	1.00		
9	0.09*	0.09*	0.10*	0.06	0.12**	0.16**	0.12**	0.45**	1.00	
10	0.09*	0.07	−0.02	0.05	0.06	0.17*	0.11*	0.03	0.06	1.00

Note: 1: Satisfaction with natural lighting, 2: Satisfaction with electric lighting, 3: Satisfaction with glare, 4: Satisfaction with humidity, 5: Satisfaction with air quality, 6: Satisfaction with noise, 7: Satisfaction with indoor temperature, 8: Overall physical health, 9: Overall mental health, 10: Age.
$^{**}p < 0.001$ $^{*}p < 0.01$.

Table 4 Logistic regression analysis: Predicting the prevalence of physical health symptoms from satisfaction with IEQ factors

	Physical health symptoms																	
	P1		P2		P3		P4		P5		P6		P7		P8		P9	
	b	SE	*b*	SE	*b*	SE	*b*	SE	*b*	SE	*b*	SE	*B*	SE	*b*	SE	*b*	SE
Natural lighting	0.04	0.18	−0.10	0.21	−0.09	0.10	**-0.25^{**}**	**0.08**	−0.04	0.08	−0.07	0.09	0.25	0.19	−0.10	0.13	−0.12	0.08
Electric lighting	−0.37	0.20	0.21	0.27	−0.07	0.12	0.14	0.10	−0.07	0.09	−0.05	0.11	0.05	0.21	0.26	0.16	0.03	0.09
Glare	−0.33	0.18	−0.13	0.21	−0.07	0.10	**-0.36^{**}**	**0.08**	−0.12	0.07	−0.01	0.09	−0.05	0.17	−0.11	0.13	**-0.18^{*}**	**0.07**
Humidity	0.06	0.28	−0.12	0.31	−0.17	0.15	**-0.25^{*}**	**0.12**	−0.14	0.11	−0.20	0.13	**-0.69^{**}**	**0.22**	**-0.48^{**}**	**0.18**	−0.08	0.11
Air quality	0.12	0.27	−0.13	0.28	−0.04	0.14	0.01	0.11	0.02	0.11	0.11	0.12	−0.10	0.21	−0.18	0.16	0.01	0.11
Noise	0.04	0.16	0.06	0.18	−0.15	0.08	−0.09	0.07	**-0.35^{**}**	**0.06**	**-0.36^{***}**	**0.07**	−0.20	0.14	−0.14	0.10	−0.13	0.06
Indoor temperature	0.14	0.23	0.02	0.25	−0.02	0.12	0.10	0.10	0.06	0.09	−0.04	0.10	0.14	0.19	0.21	0.15	−0.05	0.09

Note: P1, cardiovascular symptoms; P2, chest/lung symptoms; P3, digestive symptoms; P4, eye-related symptoms; P5, fatigue or tiredness; P6, headaches or migraines; P7, nose/throat-related symptoms; P8, skin-related symptoms; and P9, musculoskeletal discomfort.

lighting ($r=0.11$, $N=885$, and $p=0.01$), electric lighting ($r=0.11$, $N=876$, and $p=0.001$), glare ($r=0.13$, $N=874$, and $p<0.001$), air quality ($r=0.15$, $N=879$, and $p<0.001$), noise ($r=0.21$, $N=877$, and $p<0.001$) and indoor temperature ($r=0.15$, $N=879$, and $p<0.001$). Age had a statistically significant but minimally positive correlation with the satisfaction of natural lighting ($r=0.11$, $N=747$, and $p=0.003$), humidity ($r=0.11$, $N=749$, and $p=0.002$), air quality ($r=0.12$, $N=750$, and $p=0.001$), noise ($r=0.17$, $N=750$, and $p=0.001$), and indoor temperature ($r=0.15$, $N=750$, and $p=0.002$). The results seem to be highly significant, meaning that they are highly unlikely to have arisen by chance. However, we found some weak correlations between the variables under study, which means that the variation in one of the variables is not strongly associated with variation in the other.

4.3 Associations Among Satisfaction With Indoor Environmental Quality Factors and Physical Health Symptoms. Logistic regression analyses were conducted to examine if satisfaction across the IEQ factors is associated with experiencing a new onset of symptoms within each of the physical health categories. The Maximum Likelihood function in logistic regression analysis results in a chi-square (χ^2) value. This value determines the ability to predict a dependent variable by an independent variable [63]. Satisfaction with the IEQ factors was able to predict participants who experienced new eye-related symptoms ($\chi^2=72.35$, $df=7$, and $p<0.001$), fatigue and tiredness ($\chi^2=65.03$, $df=7$, and $p<0.001$), headaches and migraines ($\chi^2=47.61$, $df=7$, and $p<0.001$], nose/throat-related symptoms ($\chi^2=22.19$, $df=7$, and $p=0.002$), skin-related symptoms ($\chi^2=23.60$, $df=7$, and $p=0.001$), and musculoskeletal discomfort ($\chi^2=47.16$, $df=7$, and $p<0.001$]. Regression models for predicting cardiovascular symptoms ($\chi^2=11.06$, $df=7$, and $p=0.136$], chest/lung symptoms ($\chi^2=1.94$, $df=7$, and $p=0.96$), and digestive symptoms ($\chi^2=13.21$, $df=7$, and $p=0.067$) were not significant.

The models, presented in Table 4, show that low satisfaction with natural lighting ($b=-0.25$, $p=0.002$), glare ($b=-0.36$, $p=0.001$), and humidity ($b=-0.25$, $p=0.037$) predicted individuals with eye-related symptoms. Low satisfaction with noise was a strong predictor of fatigue or tiredness ($b=-0.35$, $p=0.002$) and headaches or migraines ($b=-0.36$, $p<0.001$). Nose/throat-related symptoms ($b=-0.69$, $p=0.003$) and skin-related symptoms ($b=-0.48$, $p=0.007$) were only uniquely predicted by low satisfaction with humidity. Finally, low satisfaction with glare ($b=-0.18$, $p=0.02$) uniquely and significantly predicted increased musculoskeletal discomfort.

4.4 Associations Among Satisfaction With Indoor Environmental Quality Factors and Mental Health Symptoms. Logistic regression analyses were also conducted to examine satisfaction across the IEQ factors on experiencing new mental health symptoms. The results show that satisfaction with IEQ factors significantly predicted anxiety ($\chi^2=52.73$, $df=7$, and $p<0.001$), ($\chi^2=43.36$, $df=7$, and $p<0.001$); insomnia or trouble sleeping ($\chi^2=23.60$, $df=7$, and $p=0.001$); mental stress, rumination or worry ($\chi^2=47.29$, $df=7$, and $p<0.001$); mood swings ($\chi^2=28.47$, $df=7$, and $p<0.001$); and trouble concentrating, maintaining attention or focus ($\chi^2=52.65$, $df=7$, and $p<0.001$). IEQ factors were unable to predict individuals with low motivation or slowed actions ($\chi^2=13.91$, $df=7$, and $p=0.053$) and social isolation or decreased interest in social engagement ($\chi^2=13.75$, $df=7$ and $p=0.056$).

The results presented in Table 5 show that low satisfaction with noise ($b=-0.20$, $p=0.002$) was the only unique significant predictor of anxiety. Depression and sadness symptoms were significantly predicted by low satisfaction with natural lighting ($b=-0.22$, $p=0.003$) and noise ($b=-0.22$, $p=0.002$). Furthermore, low satisfaction with air quality ($b=-0.18$, $p=0.045$) significantly predicted symptoms related to insomnia and trouble sleeping. Symptoms related to mental stress, rumination, or worry were significantly predicted by low satisfaction with air quality ($b=-0.30$, $p=0.009$) and noise ($b=-0.33$, $p<0.001$), while those related to mood swings were predicted by low satisfaction with noise only ($b=-0.32$, $p<0.001$). Finally, low satisfaction with noise ($b=-0.29$, $p<0.001$) and indoor temperature ($b=-0.33$, $p<0.001$) significantly predicted the prevalence of symptoms related to trouble concentrating, maintaining attention, or focus.

5 Discussion and Recommendations for Future Work

5.1 Associations Among Demographics and Indoor Environmental Quality Satisfaction and Health. The literature suggests that socioeconomic status has a major effect on the perception of IEQ among occupants and consequently on their health and well-being [64,65]. Our results—in agreement with the literature—show that respondents with high income (more than \$150 K) are more satisfied with humidity, air quality, and indoor temperature, which might indicate that low-income (less than \$50 K) residents lack proper heating, ventilation, and air conditioning (HVAC) systems. We also found that the low-income category presented a significantly lower overall mental health rating than the high-income categories (between \$50 K and \$100 K, between \$100 K and \$150 K). This outcome could be attributed to (1) the inability of low-income households to afford satisfactory housing conditions leading to increased levels of anxiety, distress, and depression [66]; or (2) the economic uncertainty, fear of unemployment, falling in debt during the pandemic resulting in psychological stress, and poor mental state [67]; or (3) a combination of both.

Table 5 Logistic regression analysis: Predicting the prevalence of mental health symptoms from satisfaction with IEQ factors

	Mental health symptoms															
	M1		M2		M3		M4		M5		M6		M7		M8	
	b	SE	*b*	SE	*b*	SE	*B*	SE	*B*	SE	*b*	SE	*b*	SE	*B*	SE
Natural lighting	−0.12	0.08	**−0.22****	**0.08**	−0.03	0.08	−0.04	0.08	−0.05	.082	−.09	0.10	−0.04	0.09	0.01	0.08
Electric lighting	−0.09	0.09	0.04	0.10	−0.02	0.10	−0.15	0.09	−0.06	0.09	−0.03	0.12	−0.01	0.11	−0.06	0.09
Glare	−0.10	0.08	−0.12	0.08	−0.12	0.08	−0.13	0.07	−0.03	0.08	0.25	0.11	.015	0.09	−0.01	0.08
Humidity	−0.26*	0.12	0.14	0.13	−0.09	0.12	0.01	0.11	−0.08	0.11	−0.23	0.15	−0.05	0.13	0.07	0.12
Air quality	0.04	0.11	−0.03	0.12	**−0.18***	**0.11**	0.12	0.11	**−0.30****	**0.11**	0.16	0.14	−0.02	0.12	0.11	0.11
Noise	**−0.20****	**0.06**	**−0.22****	**0.07**	−0.14	0.07	−0.10	0.06	**−0.33*****	**0.06**	**−0.32*****	**0.08**	−0.13	0.07	**−0.29*****	**0.06**
Indoor temperature	0.04	0.09	−0.29	0.10	0.01	0.10	−0.15	0.09	−0.16	0.09	−0.01	0.12	−0.14	0.10	**−0.33*****	**0.09**

Note: M1, anxiety; M2, depression and sadness; M3, insomnia or trouble sleeping; M4, low motivation; M5, mental stress, rumination, or worry; M6, mood swings; M7, social isolation or decreased interest in social engagement; and M8, trouble concentrating, maintaining attention or focus.

Similar reasoning could also be employed to understand the positive correlation between age and satisfaction with natural lighting, humidity, air quality, noise, and indoor temperature. Studies have shown strong associations between age and income [68]; as workers gain more experience, their income levels tend to get higher which can lead to better housing conditions and consequently an increase in IEQ satisfaction levels. Furthermore, several research studies have shown that older individuals were more tolerant to IEQ conditions, leading to higher acceptance and satisfaction with the indoor environment [69]. On the other hand, our results are inconsistent with other reports [54], where middle-age workers (35–54 years) were less satisfied with IEQ conditions in comparison to their younger and older counterparts. These conflicting findings indicate the need for further research efforts to understand how people perceive the indoor environment with age.

Finally, our results showed no statistical difference in IEQ satisfaction between female and male office workers at home. Among the various IEQ parameters, the literature heavily focuses on gender differences in terms of thermal comfort and satisfaction; previous work found that female office workers were less satisfied and comfortable with their office indoor temperature in comparison to their male coworkers [70]. Traditional offices do not take these individual preferences into consideration which results in thermal satisfaction differences across gender. Working from home might have allowed both female and male workers to set IEQ conditions based on their personal preferences which might have led to similar satisfaction levels.

5.2 Associations Among Satisfaction With Indoor Environmental Quality Factors and Physical Health Symptoms. Our regression analysis shows that all else being equal, respondents with higher satisfaction with natural lighting, glare, and humidity were less likely to present eye-related symptoms. This finding is consistent with previous studies conducted in office buildings where workers who are satisfied with the spatial distribution of light in their indoor environment—whether electric or natural lighting—are less irritated by glare and present less eye fatigue [71]. Our results also agree with Shin et al. (2018) who found that workers who reported low satisfaction with humidity were prone to more eye problems in office buildings. Furthermore, our results suggest that respondents who were more satisfied with noise presented less prevalence of fatigue, tiredness, headaches, and migraines. Reference [13] found that workers reported increased levels of fatigue and headache intensity and dissatisfaction with acoustic conditions of their workspace when background noise levels increased in their open-plan office. In addition, our results show that low satisfaction levels with humidity predicted a higher prevalence of skin (chapped skin, itchiness, and redness) and nose/throat-related symptoms (dry, runny, or bloody nose, hoarseness). Similar findings were reported in Ref. [72], where low satisfaction with humidity was associated with a feeling of irritation at the level of noise and throat. Finally, our analysis shows that low levels of satisfaction with glare predicted higher prevalence of musculoskeletal discomfort. When a person is exposed to glare, gaze stabilization becomes challenging which requires head, neck, or even body posture adjustment to reach a comfortable visual state. These adjustments might not be optimal and can contribute to muscle pain development [73]. Recently, Ref. [74] concluded that constant exposure to direct glare conditions leads to visual discomfort, affects the trapezius muscle (back muscle), and leads to the development of neck pain.

5.3 Associations among Satisfaction With Indoor Environmental Quality Factors and Mental Health Symptoms. We found that lower satisfaction levels with noise predicted higher prevalence of anxiety and depression among respondents. Reference [75] also found that disturbance and annoyance caused by excessive noise were associated with an increased tendency to show symptoms of anxiety and depression among white-collar employees in office buildings. In our study, depression was also predicted by low satisfaction with natural lighting. Similar findings were reported by Ref. [76] who found that subjects reporting inadequate natural lighting in their residential apartments were 1.4 times more likely to show symptoms of depression compared with those who have sufficient access to daylight.

Furthermore, our results show that respondents who were less satisfied with the air quality were more likely to have insomnia and to experience trouble sleeping. This is in agreement with previous studies that lower concentrations of CO_2 and particulate matter and higher ventilation rates in the sleeping area showed an improvement in the quality of sleep and sleep latency (time needed to go from being fully awake to sleeping) while reducing the number of awakenings during the night [77,78]. We also found that the prevalence of mental stress symptoms was predicted by low satisfaction levels with air quality and noise. Similarly, Ref. [79] conducted an environmental health assessment of several office buildings and concluded that higher satisfaction with air quality and noise levels was associated with reduced stress.

The results from our logistic regression in Table 5 show that respondents who were less satisfied with noise conditions in their houses were more likely to present symptoms related to mood swings. Reference [80] showed that background noise caused by irrelevant speech in open-plan offices can lead to an increased sense of annoyance, which builds up negative effects. When workers were forced to work from home, many of them were sharing the workspace with others in their household, creating a similar scenario to open-plan offices. Finally, our results show that low satisfaction with noise and indoor temperature predicted the prevalence of symptoms related to trouble concentrating and maintaining attention or focus. The ability to concentrate and be attentive is directly related to productivity; therefore, many research studies examined the effect of IEQ on workers' concentration and attention capabilities in office buildings. Similar findings were reported by Ref. [81] during a controlled experiment, in an office-like environment; it was found that subjects who were exposed to high noise levels were less satisfied with the acoustic conditions of their environment and had reduced attention levels. Our results are also in agreement with the findings of Ref. [82] who concluded that workers' concentration and alertness levels increased with a higher level of thermal satisfaction in office buildings.

5.4 Implications for Research and Applications in Future Home Office Environments. Based on Table 1, respondents, on average, were highly satisfied with IEQ conditions in their homes. This high satisfaction level can be attributed to the concept of control over one's indoor environment. For example, most traditional office buildings are equipped with HVAC systems that operate between 22 °C and 25 °C [83] based on ASHRAE's Standard 55 [84], which does not take into consideration individual preferences and can result in occupants being dissatisfied with the indoor thermal conditions. Also, controlling the indoor environment in an open-plan office becomes difficult when several workers working in the same office space have different preferences [85]. The same complexity applies to other IEQ factors; one worker might prefer to open the shades to have access to natural lighting, but this might create glare on the screen of coworkers. At home, office workers might be able to control their indoor environment to increase their satisfaction or they might have the option to choose a location that pleases them or choose a location that does not negatively affect others sharing the same space. Therefore, future research directions should investigate the difference in control over the indoor environment a worker has between traditional office environments and home offices and the relation between IEQ satisfaction and overall satisfaction with house layout area.

Our results demonstrate that respondents were most satisfied by air quality but least satisfied with noise. From a building design perspective, satisfaction with air quality can be attributed to high ventilation rates through either HVAC systems or natural ventilation. Higher satisfaction with air quality could be attributed to the fact that most houses have operable windows, different than most office buildings in the United States with non-operable windows. The low level of satisfaction with noise can be associated with the number of people in the same house; following the stay-at-home mandate, children, adults, and elderly were all obliged to remain indoors which inevitably increased the noise within a house. It is worth noting that during the period of survey distribution, stay-at-home mandates were in order in most of the world which limited outside noise (e.g., traffic). Despite that, our results show that satisfaction with noise was the lowest among all IEQ parameters, which means that when outside noise is restored, satisfaction with noise will be even worse. Therefore, assuming work from home will persist after the end of the pandemic, satisfaction with noise would remain the worst among all IEQ conditions, thus maintaining the same conclusions. However, to better understand the reasons behind these satisfaction levels and how they differ among different houses, future research should focus on examining the house conditions and establish standard evaluation schemes to assess satisfaction considering the physical attributes of home environments and its surrounding.

Furthermore, our results conclude that income has a significant effect on IEQ satisfaction. Before the pandemic, workers with different incomes were sharing the same office environment, perceiving similar IEQ conditions. In other words, workers' income had no direct effect on the indoor environmental conditions of the workspace. When workers were forced to work from home, their income level—a direct indicator of the housing quality—might have become a major driver of IEQ conditions and the workers' satisfaction and health- and well-being-related consequences. To that end, future research directions can focus on understanding the interrelations between the socioeconomic status of people, their housing conditions, and the associated mental and physical health consequences; such research effort could create a foundation for policy-makers to integrate social equity and justice with the concept of healthy buildings [65].

Finally, our findings on IEQ satisfaction and its relation to various physical and mental health symptoms showed a strong agreement with previous work conducted in traditional office environments. Therefore, it is safe to conclude that the relation between IEQ satisfaction and workers' health and well-being is universal and not restrained to the physical environment that work is being conducted within. Thus, special consideration should be given to home office environment design for work, considering more remote work is likely to take place even after the pandemic [86]. To that end, employers can support their employees in creating a more comfortable workspace at home. For example, employers can purchase furniture and equipment to enhance the setup of their home workstations (ergonomic desk and chair, desk light, desk fan, etc.) or allow their workers to bring items from their formal offices to make their home workstations more comfortable.

5.5 Limitations and Future Research Directions. While this study provides important contributions to the literature on the relationship of IEQ factors and occupant health within a home office workspace, findings should be interpreted with some limitations in mind. First, most of the respondents were from the United States and nearly two-thirds of them were from the West region which may limit the generalizability of the results. Similarly, although the income categories were well distributed, the sample under study had a relatively high average income, was comprised of highly educated respondents, and showed a high discrepancy of ethnicities which restricted the analysis based on education level and race. In consideration of the foregoing, the uneven distribution of the sample could explain the correlations between satisfaction with the IEQ and between the physical and mental health measures. To that end, future research should examine the regional, and cultural differences, as well as other demographic factors in considerations of home office IEQ and worker health. Second, it is important to note that the abrupt transition to work at home and the additional psychological and physical manifestations caused by the pandemic itself likely impacted the health and well-being of workers who responded to this survey. However, we did not ask whether or not the respondents had had COVID-19. As such, our investigations and conclusions relative to satisfaction with IEQ factors in the home office and responses to health-related symptoms are limited to associations and do not serve to indicate any direct cause or effect between the environment and health conditions. Instead, these data provide insight into potential areas where further investigation or support may be needed as working-from-home decisions are made in future work. In addition, spatial-related data was limited to the name of the state the worker is in, without going into the details of the counties. Given that climate zones are best identified based on counties [87], our analysis could not examine the effect of climate or living in a rural versus an urban area on the IEQ satisfaction and as such its mediator effects on the physical and mental health symptoms. Such analysis becomes even more complicated when looking at participants outside the United States because international participants were not asked about their country of residence. Finally, future research directions should investigate the means to collect physical measurements rather than relying on questionnaires and subjective assessment of regulations, codes, standards, and design and construction guidance are to be developed.

6 Conclusions

Following the spread of COVID-19, work from home became a necessity for many office workers, creating an opportunity to evaluate the relationship between home office environments and worker health. In our survey sample, higher income workers were more satisfied with humidity, air quality, and indoor temperature of their work environment at home, and these workers reported better overall mental health in comparison to low-income workers. Age was positively correlated with satisfaction with natural lighting, humidity, air quality, noise, and indoor temperature. Low satisfaction with natural lighting, glare, and humidity significantly predicted the onset of new instances of eye-related symptoms, while low satisfaction with noise was a strong predictor of increased fatigue or tiredness, headaches, or migraines. Nose/throat-related symptoms and skin-related symptoms were only uniquely predicted by low satisfaction with humidity, and low satisfaction with glare uniquely predicted increased musculoskeletal discomfort. Low satisfaction with noise predicted new anxiety symptoms, and low satisfaction with air quality predicted symptoms related to insomnia and trouble sleeping. Low satisfaction with noise and air quality together predicted increased mental stress, rumination, or worry. Finally, low satisfaction with noise and indoor temperature predicted the prevalence of symptoms related to trouble concentrating, maintaining attention or focusing. The findings provide new insights into IEQ factors within home environments and their associations to workers' health where further investigation or support may be needed to ensure positive health for employees who opt to continue or transition to working from home in future work.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The data sets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request. The authors attest that all data for this study are included in the paper. No data, models, or code were generated or used for this paper.

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