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How Work From Home Has Affected the Occupant's Well-Being in the Residential Built Environment: An International Survey Amid the Covid-19 Pandemic

This paper presents the results from an international survey that investigated the impacts of the built environment on occupant well-being during the corona virus disease 2019 (COVID-19) pandemic when most professionals were forced to work from home (WFH). The survey was comprised of 81 questions focusing on the respondent's profiles, residences, home indoor environmental quality, health, and home working experiences. A total of 1460 responses were collected from 35 countries, and 1137 of them were considered complete for the analysis. The results suggest that home spatial layout has a significant impact on occupant well-being during WFH since home-life distractions and noises due to the lack of a personal workspace are likely to prevent productive work. Lack of scenic views, inadequate daylighting, and poor acoustics were also reported to be detrimental to occupant productivity and the general WFH experience. It is also revealed from this survey that temperature, relative humidity, and indoor air quality generally have higher satisfaction ratios compared with the indoor lighting and acoustic conditions, and the home layout. Hence, home design for lighting, acoustics, and layout should also receive greater attention in the future.
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Keywords: occupant well-being, built environment, indoor environmental quality, COVID-19, occupant-centric design and operation, international survey, building, occupant behavior, occupant productivity

1 Introduction

Worldwide, people spend significant time indoors. For example, Americans, Canadians, Europeans, British, and Koreans spend approximately 90% of their time indoors [1–4], and the quality of the built environment directly impacts their well-being. This paper aims to investigate how working from home (WFH) has affected occupant well-being in residential buildings in the context of the coronavirus disease 2020 (COVID-19) pandemic.

The present study improves our understanding of occupant well-being during WFH because of a global quarantine. To the best of our knowledge, there exist a limited number of articles or reports

on the impacts of the built environment on well-being during WFH at present. Findings from this study benefit the research community and public in at least two aspects: *First*, via a comprehensive global survey, it helps understand the present situation of global WFH in terms of how the home environment affects occupant well-being; *second*, based on the survey results, this paper provides insights on how we can enhance the design and operation of the indoor environment to better facilitate home-based working arrangements now and in the future.

1.1 Background. Since the outbreak of COVID-19 at the beginning of 2020, a wide range of governmental interventions [5] has been put in place all around the world in an attempt to control the impact of COVID-19 on the public health system. Of all these measures, lockdowns or stay-at-home orders were among the earliest strategies implemented across many countries

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[6,7], resulting in an increase in the time spent indoors for people. This self-imposed quarantine was effective in reducing disease spread and mortality during the pandemic [8]. It has also been shown to alleviate public anxiety [9,10], especially when being used in combination with other public health practices [11]. However, despite the benefits of suppressing the spread of the disease, quarantining can also pose detrimental consequences to psychological, physical, and social well-being [12–16].

In compliance with the stay-at-home orders [17], many companies have implemented work-from-home (WFH) protocols to allow their employees to continue working during the lockdown [18]. Despite its increased control over the virus spread, there were multiple negative impacts on employee's well-being and productivity as a result of WFH, which are strongly influenced by the home environment. By surveying the research, literature, and media coverage, five potential issues of WFH are summarized below.

First, full-time WFH made it hard to set a clear boundary between work and personal time [19] and thus may compromise the work-life balance [20]. A study by DeFilippis et al. [21] indicated that WFH increased the average workday span by 48.5 min after quarantine enforcement. Second, WFH may have led to a decline in employee's productivity [22], partly due to the distractions from other household members. Multiple studies [20,23,24] have

pointed out a slowdown in employee productivity after WFH [23,24]. Third, WFH could cause mental disorders and feelings of isolation due to a lack of communication [25]. Many WFH workers have experienced conditions of “time famine” (i.e., the feeling of having too much to do and not enough time to do it [26]) or “time confetti” (i.e., scraps of free time that gets filled with pesky tasks, household chores, etc. [27]) during home working [28]. Fourth, lack of physical exercise/movements and extended hours of screen exposure due to full-time computer work can lead to multiple physical symptoms such as fatigue, tiredness, headaches, and eye-related issues [29]. Last, the lack of social interaction during WFH may have impacted the worker's innovation and creativity [30,31]. A social experiment conducted in China showed that two-thirds of the employees who worked from home requested to return to the office due to a feeling of loneliness [31].

However, it is also noted that the perception and attitude toward WFH may vary depending on people's backgrounds. A survey carried out by Harvard Business School suggested that 27% ($n = 405$) of the respondents preferred to working remotely full-time while only 18% ($n = 270$) would like to go back into the office full-time [32]. The survey also found out that married people and workers with kids at home were more likely to fall into the latter group that wants to go back into the office.

COVID-19 has fundamentally changed society and everyday life. Multiple studies have shown that WFH may continue even after the pandemic ends [33,34]. In this context, a better understanding of occupant well-being and productivity during this global WFH movement is necessary for guiding future home design and operations [19,35].

1.2 Objectives. The remainder of this paper is organized into the following sections. Section 2 summarizes the literature on the impacts of the built environment on occupant well-being. The design and distribution of the questionnaire are introduced in Sec. 3. Detailed analysis on the independent variables including respondents, residence, and Indoor Environment Quality (IEQ) ratings are presented in Sec. 4, and dependent variables including health and WFH experience are presented in Sec. 5. The correlation analysis to evaluate the impacts of the various variables on occupant well-being during home working is presented in Sec. 6. Finally, Sec. 7 offers conclusions and summarizes key takeaway messages.

A flowchart that summarizes the process of data collection and analysis is presented in Fig. 1. The methodology of questionnaire design, distribution, and management is elaborated in Sec. 3. The collected responses are analyzed in Secs. 4, 5, and 6. The conclusions and discussions are presented in Sec. 7.

2 Literature Review

Well-being is defined by the U.S. Centers for Disease Control and Prevention (CDC) [36] and world health organization (WHO) [37] as a comprehensive metric that considers mental, physical, and social factors to indicate how people perceive their lives from their own perspectives. Given that people spend nearly 90% of their time indoors, the research on the residential built environment and its impacts on occupant well-being has attracted increasing attention.

A built environment is defined as the space in which people live and work daily. Studies have found that Indoor Environmental Quality (IEQ) can play a significant role in occupant's well-being and productivity [38,39]. The design and operation of a building's mechanical and heating, ventilating, and air-conditioning (HVAC) systems impact well-being [40]. Seppänen and Fisk [39] discovered from a literature review that low ventilation rates contributed to the prevalence of some types of communicable respiratory diseases. They also discovered a correlation between the hourly ventilation air change rates (ACH) and employee sick leaves [39]. In addition, the HVAC system was found to be closely correlated with the airborne transmissions of infectious diseases [40–42]. For instance,

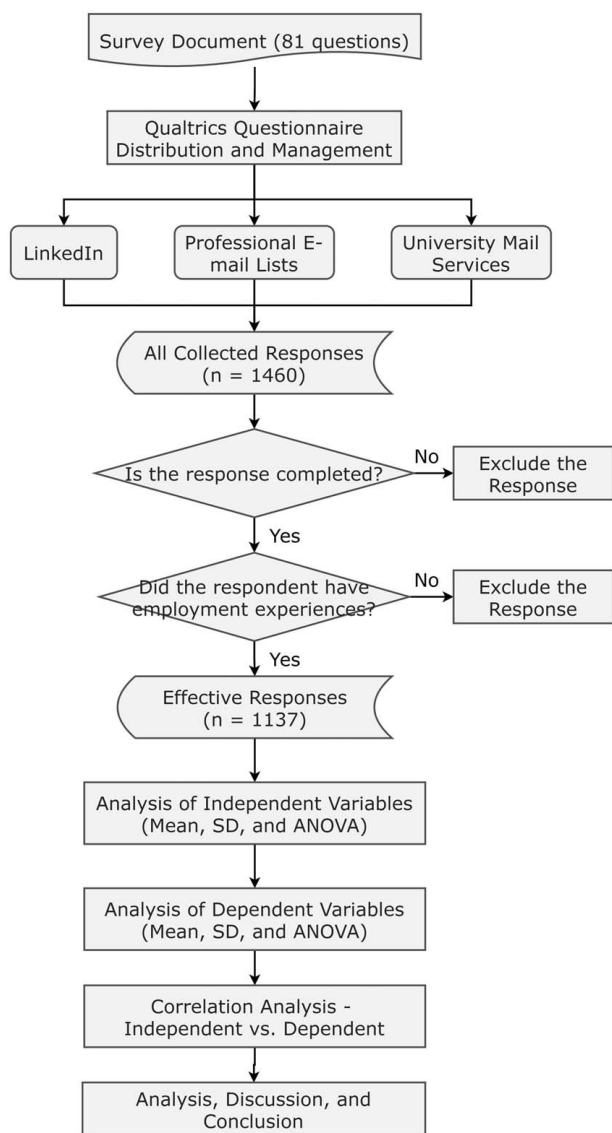


Fig. 1 A flowchart that summarizes the process of data collection and analysis

Eykelbosh [43] raised a concern that the spread of contagious diseases could happen in multi-unit residential buildings, which typically bring together tens to hundreds of people within the same space with shared common spaces and public facilities. Bhagat et al. [44] and Miller et al. [42] warned that inadequate ventilation of indoor spaces could increase the risk of aerosol transmissions of contagious respiratory disease.

Furthermore, the home layout and housing quality (which typically incorporates some aspects of structural quality, maintenance, etc.) could have impacts on occupant physiological health. A review by Evans [45] suggested that inadequate housing quality could result in great physiological distress, and psychological health could be linked to design elements of the home (furniture configuration, privacy, etc.). This is because the arrangement of furniture and access to rooms could enhance the occupant's ability to regulate social interactions. A researcher revealed in an interview [22] with Stanford News that many people he surveyed during the COVID-19 pandemic had worked in their bedrooms or shared common rooms, suffering the noise from their partners, family, or roommates during working. In contrast, a survey on 369 adults in 64 cities in China showed that those who worked at their offices during the COVID-19 pandemic were reported to have good mental and physical health, as well as a high level of life satisfaction [46].

Apart from the housing quality and home layout, Rautio et al. [47] further noticed that lack of green spaces, noise, and air pollution, could result in a dissatisfying residential built environment. This could also contribute to a depressive mood and pose negative impacts on occupant psychological health. Amerio et al. [16] found a strong dependency between poor residential built environment (e.g., small living spaces, poor views from windows, and bad air quality) and appearance/worsening of depression symptoms. Studies [16,35] also found that providing a window of natural landscapes in a residential working environment could relieve distress and enhance comfort. In addition, some researchers have found that the occupant's perception of IEQ, in general, could influence their productivity and comfort. For instance, Chen et al. [48] conducted an international survey to investigate the key factors influencing office occupants' IEQ-productivity belief (measured by the extent to which participants rated the influence of five IEQ aspects on their work productivity, positively or negatively). The results suggested that IEQ satisfaction is the strongest positive predictor of the IEQ-productivity belief. Also, the quality of natural lighting has the strongest positive effect on productivity compared with other IEQ metrics such as indoor air quality (IAQ) and indoor temperature.

There have been multiple literature reviews focusing on the link between the built environment and occupant comfort, productivity, and well-being. For instance, Al Horr et al. [49] conducted a literature review to identify the built environment-related factors that affect occupant productivity, as well as physical and mental well-being. Some of the most relevant factors summarized in the

review were, e.g., IAQ, ventilation, artificial lighting, and natural lighting, and noise and acoustic performance. Allen et al. [40] identified nine key factors related to the built environment that could have profound effects on healthy building design and operation. Awada et al. [50] discussed the role of the built environment on occupant well-being and health in the context of both normal operations and extreme events, especially amid the COVID-19 pandemic. The authors concluded that it is necessary to better understand the effects of buildings on occupant health, to achieve the goals of healthy and sustainable buildings.

The linkage between the built environment and occupant comfort, productivity, and well-being are summarized in Table 1.

The global-scale quarantine and the "new normal" of WFH are challenging and forced many to rethink the design and operation of residential built environments [52,53]. Although there have been studies to investigate employee productivity at offices [54,55], as well as the impact of home's IEQ on occupant performance and well-being during normal life [56–58], there is still a lack of understanding of how WFH impacted occupant well-being during the COVID-19 pandemic and post-pandemic era. Understanding the well-being of occupants when they work from home has never been as important and urgent as it is today, especially considering that multiple studies have predicted that widespread remote working might remain a prominent modality for the future working environment [30,33,59,60].

3 Methodology

3.1 Survey Design. A survey entitled "How Work from Home Affects Occupant Well-being during the COVID-19 Pandemic" was distributed to explore the perceptions and well-being of people across the globe when they worked from home. This survey was reviewed and approved by the Texas A&M University Institutional Research Board (IRB) to ensure that the questionnaire design and distribution, and the data analysis and storage complied with the requirements of the U.S. federal government's rules on the protection of human subjects.

This questionnaire was comprised of 81 questions which fall into five categories (summarized in Table 2):

- (1) Resident (12 questions in total): basic information of the respondent, e.g., nationality, age, and gender.
- (2) Residence (10 questions in total): basic information of the residence, e.g., ownership, layout, size, and thermostat installation.
- (3) IEQ (18 questions in total): ratings in terms of IEQ, e.g., the ratings of indoor temperature, natural and artificial lighting, and IAQ. Specifically, the respondents were asked to describe the quality of the indoor environment in which they worked and lived during the WFH period in terms of nine metrics of satisfaction towards (1) the home layout; (2) view from the window; (3) room temperature; (4) room

Table 1 A summary of the review literature that focuses on the linkage between the built environment and occupant's comfort, productivity, and well-being

Reference	Al Horr et al. [49]	Allen et al. [40]	Awada et al. [50]	Evans [45]	Altomonte et al. [51]
Thermal comfort and moisture	X	X	X		X
IAQ and ventilation	X	X	X	X	
Lighting and daylighting	X	X	X	X	X
Noise and acoustics	X	X	X	X	X
Building design (layout, organization, etc.)	X	X	X	X	X
Neighborhood quality				X	
Water quality		X	X		
Safety and security		X			
Window views	X				
Others	Biophilia	Dust and pests	Biophilic and ergonomic design	Housing quality, and privacy	Building operation

Table 2 List of the variables assessed by the survey

	Category	Questionnaire items	
		Subject	Variables
Independent variables	Resident (12 questions in total)	General	Location, zip code, gender, age, household income, and number of dependents in the household
		Behaviors	Daily routine of physical exercise, preferred temperature setpoint, behavior of opening window, and WFH hours
	Residence (10 questions in total)	General	Ownership, type, size, layout, and number of occupants.
		HVAC	Type of the HVAC system, and number of thermostats
	Ratings for IEQ (18 questions in total)	Functionality	View from the window, and window operability
		Home	Ratings of home layout design, view from the window, and cleanliness
		Thermal	Ratings of the indoor temperature and relative humidity (RH)
		IAQ	Rating of indoor air quality
		Lighting	Ratings of natural lighting and artificial lighting
		Acoustics	Rating of indoor acoustics
Dependent variables	Health (36 questions in total)	Mental	(1) Mood swings, (2) anxiety, (3) attention issues, (4) concentration issues, (5) stress, and (6) depression
		Physical	(1) Eyes-related issues; (2) nose-related issues; (3) throat-related issues; (4) skin-related issues; (5) musculoskeletal-related issues; (6) headache/migraine; (7) nausea/dizziness; and (8) fatigue/tiredness
	WFH experience (5 questions in total)	N/A	Ratings of general homeworking environment, productivity; ratings of physical health, and psychological health; general comment to the survey

relative humidity; (5) natural lighting; (6) artificial lighting; (7) room acoustics; (8) room cleanliness; and (9) the general IAQ.

- (4) Mental and Physical Health (36 questions in total): ratings for the severity levels of new mental and physical symptoms, e.g., eye-related problems, anxiety, and so on.
- (5) WFH Experience (five questions in total): the general ratings in terms of WFH experience, e.g., the ratings of homeworking environment and productivity, and so on.

In this study, the relationships between occupant well-being (i.e., physical health, mental health, and general WFH experience such as productivity) during the pandemic period and their demographic profiles, behaviors, the residence in which they live, as well as their ratings for the IEQ were analyzed. To determine the relationship between resident behaviors, residences, and IEQ parameters and how an occupant perceives their environment and their well-being, these categories were parsed into independent and dependent variables. The categories of Resident, Residence, and Ratings for IEQ are independent variables, and the categories of health (both mental and physical) and WFH experience are dependent variables.

A 7-point Likert scale was used for evaluating the level of satisfaction toward the IEQ (ratings for the indoor air temperature and indoor acoustics, etc.) and WFH experience (ratings for productivity, etc.), with the values of -3, 0, and 3 indicating “very dissatisfied,” “neutral,” and “very satisfied,” respectively. It is reminded that the rating IEQ are considered as independent variables and the ratings for WFH experience are considered as dependent variables in this study, as summarized in Table 2. Additionally, a 5-point Likert scale was used for evaluating the severity of new mental and physical symptoms emerging during the pandemic, with the value of 1 indicating “very slightly severe,” and 5 suggesting “very strongly severe.” If the respondent reported to have no such mental/physical symptom, the retrieved response would be 0. Choices of the 7-point scale and 5-point scale are made based on the principles [61,62] that (1) the survey should not frustrate or demotivate the participants under conditions of time pressure, and (2) the scale should allow the participants to express their feelings adequately. In practice, both scales are widely used in the occupancy- or occupant-related surveying studies; e.g., Hong et al. [63] and Day and Gunderson [64] used a 7-point scale to measure the occupant’s satisfaction toward building design and control, and ASHRAE Standard 55 Thermal Environmental Conditions for Human Occupancy [65] adopted a 7-point thermal

sensation scale, while Wagner et al. [66] and Kwon et al. [67] adopted a 5-point scale for the similar research purpose.

3.2 Questionnaire Collection and Pre-processing. As requested by the IRB of Texas A&M University, the survey was managed and distributed via Qualtrics Panel Services for data security. There was no limitation in terms of the nationalities and locations of the respondents. The questionnaire was open from April 27 to July 9, 2020, and it was distributed via various online networks: LinkedIn, professional email lists (including but were not limited to BLDG-SIM (a mailing list for users of building energy simulation programs) [68], International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Programme Annex 79 Occupant-Centric Building Design and Operation [69], International Building Performance Simulation Association (IBPSA) Project One [70], American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Technical Committee (TC) 7.5 Smart Building Systems [71], ASHRAE MTG OBB Occupant Behavior in Buildings [72], American Society of Civil Engineers (ASCE) [73], Building Technology Educators Society (BTES) [74], and Society of Building Science Educators (SBSE) [75]), university mail services (including but were not limited to Texas A&M University, University of Southern California, Arizona State University, Drexel University, Michigan State University, The University of Colorado Boulder, and University of Wyoming), etc. A total of 1460 responses were received from 35 countries on six continents. All the retrieved responses were anonymized to protect privacy.

Since this study is focusing on the impacts of the built environment on occupant well-being during WFH, the respondents who had no employment experiences before the COVID-19 pandemic were excluded using a filter question. In addition, the survey responses that did not provide information on ratings for IEQ, health, and WFH experiences were not included in the post-analysis. As a result, 1137 out of 1460 survey responses (77.9%) were analyzed in this study.

3.3 Statistical Analysis Method

3.3.1 Analysis of Variance. A single-factor ANalysis Of VAriance (ANOVA), which is also known as the one-way ANOVA, was conducted to determine whether there is a statistically significant difference between the means of the different groups (e.g., whether there is a significant difference between the means of the

severity level of mental disease among the respondents from different regions). The F statistic (i.e., F -ratio) obtained from the ANOVA is presented to allow for the analysis of multiple groups of data to determine the variability between samples and within samples [48]. A larger F statistic indicates that there is a larger variation among the sample means. The F statistics with a p -value smaller than 0.05, 0.001, or 0.005 are highlighted in this study. If the p -value is greater than 0.05, it usually indicates that the null hypothesis (i.e., there is no statistical significance) is true. These three threshold values were selected based on the common practice [48]. The details about ANOVA could be found in Ref. [76].

3.3.2 Spearman's Rank Correlation Coefficient. In this study, Spearman's rank correlation coefficient r_s [77] was computed to quantify the correlation between two variables. Spearman's rank correlation analysis works by replacing the raw values of the inputs and outputs with their ranks [78]. This feature makes it especially suitable to the monotonic relationship in which two variables tend to change together, but not necessarily at a constant rate.

It is noted that some questions were excluded from the ANOVA analysis or correlation analysis due to three reasons:

- (1) First, some questions are not directly associated with the residential built environment or health/well-being, e.g., the number of hours that the respondent spent on work in the workplace (before the quarantine) and at home (both before and during the quarantine). These questions were excluded from the analysis since the focus of this paper is the occupant's well-being and the residential built environment.
- (2) Second, some questions were asked after the voting questions (e.g., indicate the level of satisfaction with the indoor acoustic environment) as a follow-up. For instance, the respondent was asked the reason why he was dissatisfied with the acoustic condition if he indicated so. Although such questions were excluded from ANOVA/correlation analysis, they are analyzed in Sec. 6.3 to reveal why the respondents were dissatisfied with the residential built environment.
- (3) Third, we asked about the occupant's mental and physical health before and after the quarantine in the survey, with both scenarios (i.e., before and during the pandemic) having the same questions. However, since we did not provide an explanation for these questions, many respondents did not notice the difference and submitted the same or similar answers for the two scenarios. Hence, we decided to include only one scenario (i.e., after the COVID-19 pandemic) in the analysis.

4 Analysis and Discussions of the Independent Variables

This section discusses the results from the respondents, residences, and IEQ ratings. This analysis aims to reveal the composition of the respondent group and also provide a general description of the home working environment during WFH.

The locations of the respondents were visualized to show their distributions, as presented in Fig. 2. The shade of the color of the country/region/state suggests the number of the received responses. The size of the dots on the map represents the number of retrieved responses from a specific location, with a larger dot indicating a higher number of respondents. As shown, the majority of the respondents are from the United States (879, 77.1%). Other locations with a notably large respondent group include China (84, 7.4%), Europe (e.g., Greece (32, 2.8%), the U.K. (30, 2.6%), Italy (6, 0.5%), etc.), Middle East (e.g., Turkey (8, 0.7%), Qatar (6, 0.5%), etc.), Brazil (14, 1.2%), non-China Asia Pacific (e.g., South Korea (8, 0.7%), Singapore (6, 0.5%), Australia (5, 0.4%), etc.), and non-U.S. North America (i.e., Canada (15, 1.3%) and Mexico (5, 0.4%)). To facilitate the analysis, these countries were

categorized into four groups in the following text and analysis, which are North America (78.9%), Asia Pacific (9.5%), Europe (9.0%), and Others (2.6%, i.e., Brazil, Middle East, and North Africa).

Since 77.1% (877) of the total responses were from the United States, its respondent group was further analyzed by the state in Fig. 2(b). The retrieved responses covered 40 states in the United States, among which, the State of Texas has the highest prevalence, with 56% (492) of respondents in the country. Other states with large respondent size include Arizona (42, 4.8%), Pennsylvania (34, 3.9%), Wyoming (32, 3.6%), California (28, 3.2%), and Wisconsin (27, 3.1%). The numbers in the brackets show the actual numbers of respondents and their proportions.

The gender of the respondents, location of residence, and age of the respondents were analyzed in a Sankey diagram (Fig. 3). A Sankey diagram is a visualization used to depict a flow from one set of values to another. The length of the block (called nodes) and the width of the arrow (called connections) are proportional to the number of respondents that they represent. The exact percentage proportions were annotated in the brackets next to each block for detail.

This diagram shows that

- (1) There are more female participants (684, 60.2%) than male participants (422, 37.1%). The rest of the participants preferred not to reveal their genders.
- (2) Nearly 90% of the respondents are aged younger than 60. According to the U.S. Social Security Administration (SSA) [79], and Hofäcker and Unt [80], the Normal Retirement Age (NRA) varies from 60 to 67 in the United States and Europe, which means that the majority of the respondents of this study were in normal employment status during the pandemic.

Additionally, the working hours of the respondents in the workplace and at home before and during the COVID-19 pandemic are analyzed and presented below:

- (1) 57.8% (657) of the respondents reported that they worked from home for less than 10 h per week before the pandemic.
- (2) 92.1% (1047) of the respondents reported that their WFH hours had increased (821, 72.2%) or remained the same (226, 19.9%) after the outbreak of COVID-19; only 7.9% (90) reported that their WFH time was decreased.

The findings from survey responses are presented in Fig. 4. The y -axis contains the nine metrics, and the x -axis shows the percentages of the respondents. The seven color bars indicate the votings of dissatisfaction and satisfaction from left to right, respectively. As shown in the figure, more than 80% of the respondents cast a neutral or satisfied rating for all the metrics except for the house layout. Also, the house layout has the highest dissatisfaction rate among the nine metrics, with over 20% of respondents indicating that they were dissatisfied with the layout of their homes. Indoor acoustics is the metric with the lowest satisfaction rate, with only about half of the respondents casting satisfaction votes.

The results of the average satisfaction level in terms of IEQ are presented in Fig. 5. As shown, the respondents are grouped along the x -axis by the total number of dissatisfaction votes they cast, with N_D representing the number of dissatisfaction votes. The y -axis represents the mean values of the nine votes cast by each respondent, ranging from very dissatisfied (-3) to very satisfied ($+3$). Besides, the proportions of each group (R) in terms of all the respondents as well as the mean value of the satisfaction levels ($\bar{x}$) of each group were annotated at the bottom of each block. Take the $N_D = 0$ group as an example: 44.86% of the respondents did not cast any dissatisfaction vote toward the IEQ metrics, and the mean satisfaction level (i.e., a value of 1.72) is between "somewhat satisfied" (i.e., a value of 1) and "satisfied" (i.e., a value of 2).

The result shows that 55% (i.e., the sum of the respondent groups with $N_D > 0$) of the respondents cast at least one dissatisfaction vote

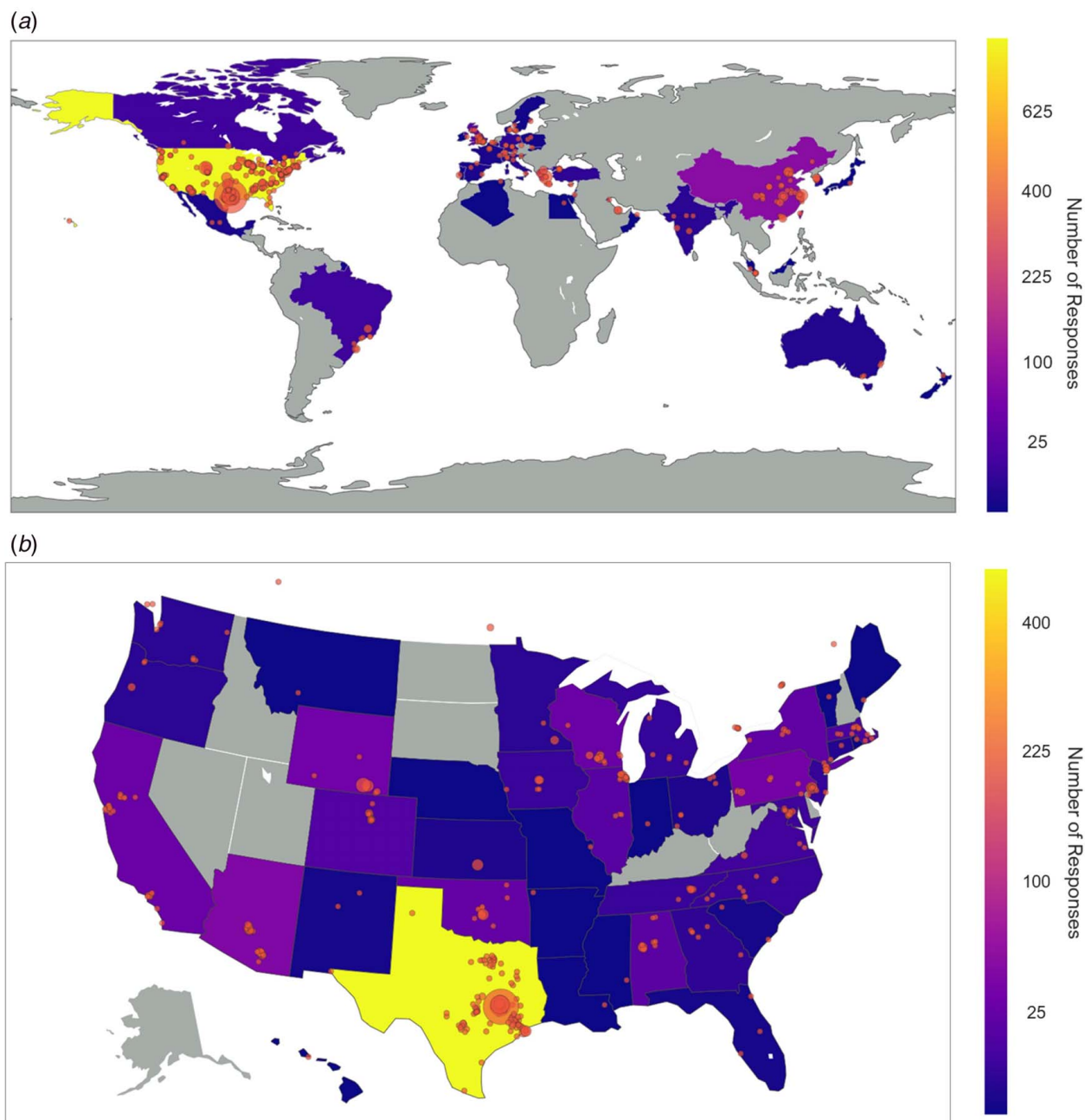


Fig. 2 (a) Distribution of the respondents by country/region; (b) distribution of the respondents in the United States

in terms of IEQ. In addition, over 21% cast at least three dissatisfaction votes. With the number of dissatisfaction votes increasing, the average satisfaction level drops from “satisfied” (for the respondents who have voted at least one dissatisfaction) to “somewhat dissatisfied” (for the respondents who have voted seven dissatisfactions).

A geographic analysis was conducted to understand how the respondents living in different regions rated their IEQ during WFH. The means, standard deviations (SDs), and F statistics of the nine IEQ ratings were computed by region, and the results are presented in Table 3. The geographical analysis was conducted to see whether there are correlations between the location and IEQ ratings.

As suggested by the results of ANOVA, the ratings for the room temperature control and humidity control by the respondents from different regions have a statistically significant difference (i.e., with a p -value less than 0.001). The respondents from the Asia Pacific are more dissatisfied with their IEQ compared with the

respondents from the other regions by comparing the mean values of the ratings. For instance, the mean of ratings for room humidity control is -0.041 (between neutral and slightly dissatisfied) for the Asia-Pacific group, while this value is 1.016 (between slightly satisfied and satisfied) for all of the respondents.

5 Analysis and Discussion of the Dependent Variables

This section discusses the results from the two dependent categories: health and WFH experience. This analysis aims to reveal the general perception of well-being during the WFH period.

5.1 Analysis of New Mental Symptoms. The returned responses in terms of new mental symptoms after WFH are presented in Fig. 6. The y -axis represents the different mental symptoms, and the x -axis represents the percentages of respondents

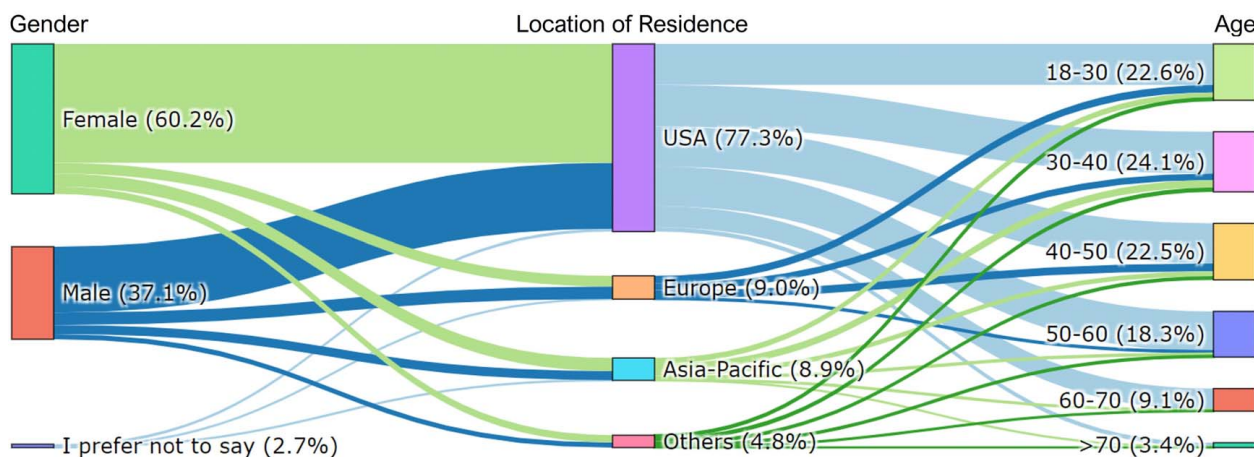


Fig. 3 The retrieved responses by gender, location of residence, and age

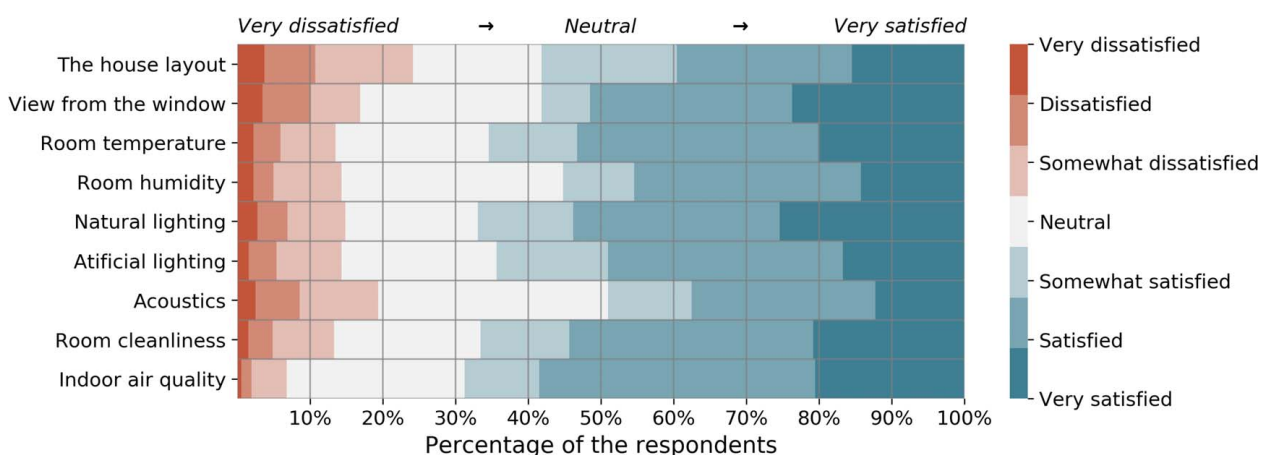


Fig. 4 Percentages of the respondents in terms of the rating for the IEQ metrics

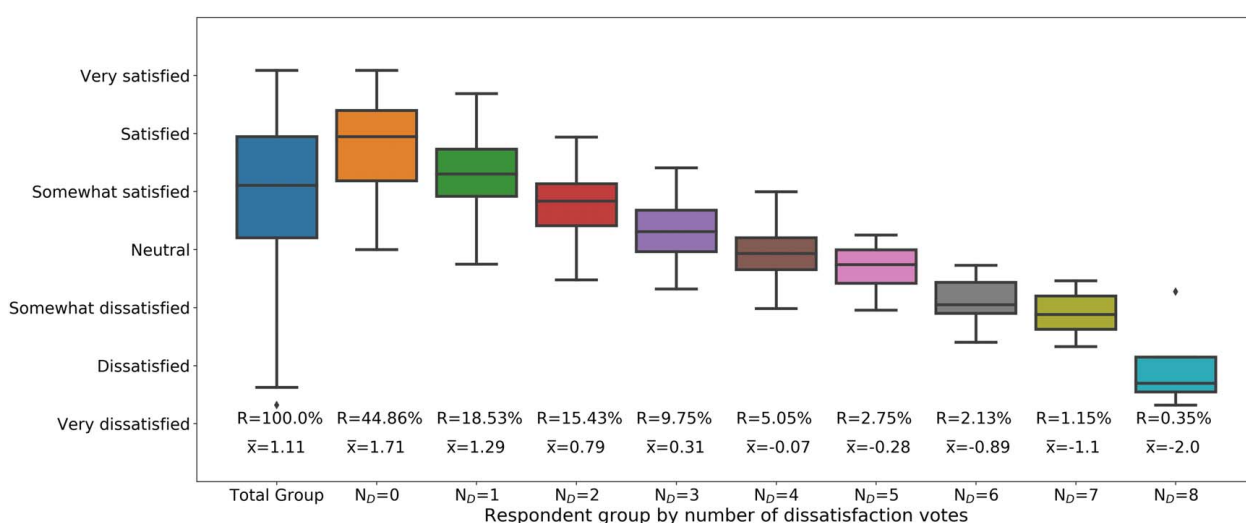


Fig. 5 The respondent group by the number of dissatisfaction votes and their mean satisfaction levels in terms of IEQ

who suffered from the new symptoms. The color of the bars indicates the severity level of the mental symptom, with a darker color suggesting a higher severity level.

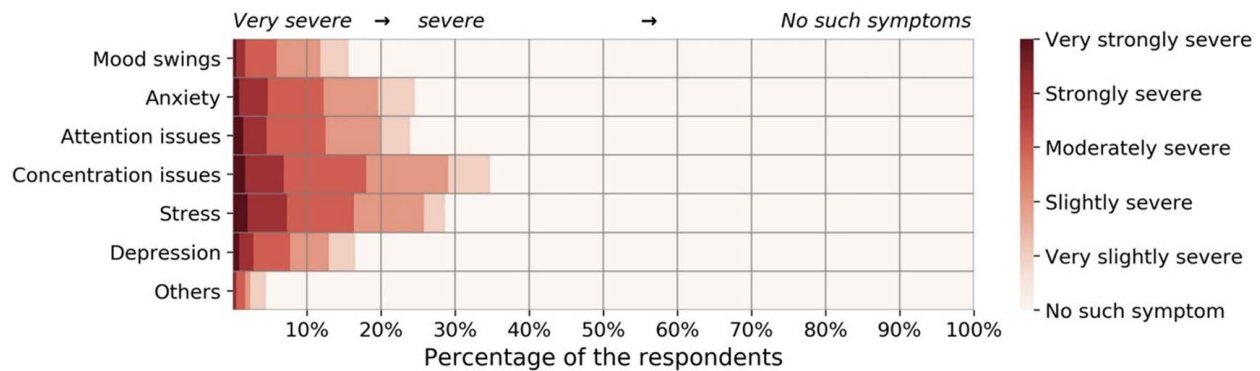
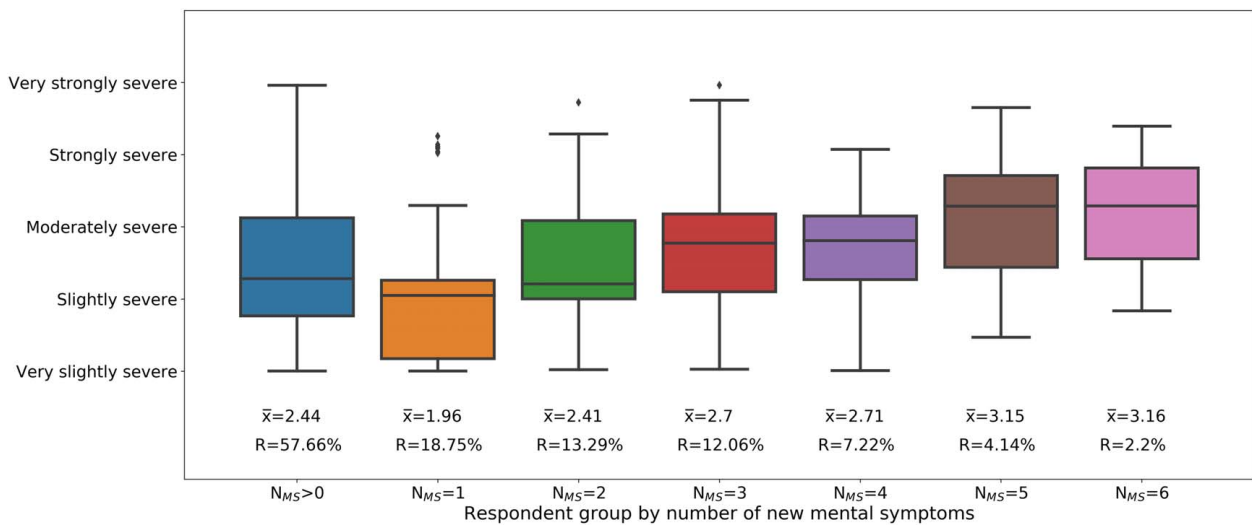
As shown in the figure, the concentration issue is the most frequent mental symptom reported in this survey, affecting over

30% of the respondents. This observation is in line with the evidence found in Refs. [22,23], where the researchers indicated that WFH could disrupt focus and concentration since the activities of other people at home, e.g., the parents and the children, could pose a distraction. Besides, three other mental symptoms affected

Table 3 Means, SDs, and *F* statistics of the IEQ ratings

Variable name	Overall (<i>n</i> = 1137, 100%)	North America (<i>n</i> = 897, 78.9%)	Asia Pacific (<i>n</i> = 108, 9.5%)	Europe (<i>n</i> = 102, 9.0%)	Others (<i>n</i> = 30, 2.6%)	<i>F</i> statistic
Rating—house layout	0.792 ± 1.694	0.823 ± 0.713	1.635 ± 1.558	0.629 ± 1.740	1.000 ± 1.439	0.84
Rating—window view	1.106 ± 1.735	1.177 ± 1.735	0.505 ± 1.671	1.113 ± 1.676	1.103 ± 1.809	4.56**
Rating—room temperature control	1.268 ± 1.541	1.355 ± 4.553	0.796 ± 1.339	0.917 ± 1.560	1.556 ± 1.311	6.01***
Rating—room humidity control	1.016 ± 1.054	1.172 ± 1.441	−0.041 ± 1.399	0.821 ± 1.624	0.731 ± 1.733	20.92***
Rating—natural lighting	1.333 ± 1.629	1.369 ± 1.647	0.854 ± 1.589	1.411 ± 1.448	1.692 ± 1.569	3.42*
Rating—artificial lighting	1.188 ± 1.496	1.219 ± 1.493	0.875 ± 1.474	1.253 ± 1.473	1.115 ± 1.681	1.6
Rating—acoustics	0.748 ± 1.586	0.778 ± 1.578	0.333 ± 1.513	0.915 ± 1.597	0.731 ± 1.888	2.65*
Rating—unit cleanliness	1.341 ± 1.053	1.358 ± 1.523	1.103 ± 1.381	1.426 ± 1.418	1.385 ± 1.602	0.95
Rating—indoor air quality	1.528 ± 1.289	1.574 ± 1.277	1.146 ± 1.306	1.452 ± 1.281	1.769 ± 1.451	3.6*

Note: The mean and SD values (presented as “Mean ± SD”) in this table are based on the satisfaction ratings towards the IEQ metrics. The values of −3, 0, and 3 indicate “very dissatisfied,” “neutral,” and “very satisfied,” respectively. The number of the asterisk symbols after the *F* statistic values indicates the *p*-value of the ANOVA. *, *p* < 0.05; **, *p* < 0.01; ***, *p* < 0.001. No asterisk symbol indicates a *p*-value larger than 0.05.

**Fig. 6 Percentages of the respondents in terms of the severity level of various new mental symptoms****Fig. 7 The respondent group by the number of new mental symptoms and their mean severity levels**

over 20% of the respondents, i.e., stress, anxiety, and attention issues. About half of the respondents who suffered from these symptoms rated the severity level to be moderately severe or strongly/very strongly severe.

The numbers and severity levels of the new mental symptoms suffered by respondents are presented in Fig. 7. The notation style is similar to that of Fig. 5, except that N_D is replaced with N_{MS} , which refers to the number of mental symptoms reported by each individual.

Figure 7 shows that 57.66% of the respondents reported being affected by at least one new mental issue during WFH, and

25.62% (i.e., the sum of the respondent groups with $N_{MS} \geq 3$) reported suffering from at least three new mental symptoms. With the number of new symptoms suffered by each respondent increasing from 1 to 5, the mean severity level gradually increased from “slightly severe” to “moderately severe” as well. In general, 57.7% of the respondents who have experienced at least one new mental symptom have a mean severity level in middle between “slight severe” and “moderately severe.”

A geographic analysis was carried out to understand whether the severity level of the new mental symptom during WFH may be associated with the country of residence. The means, SDs, and *F*

statistics of the severity level of new mental symptoms are computed by region. The results are presented in Table 4. As suggested, the severity levels of anxiety and stress of the occupants in different regions were found to have a medium statistically significant difference (i.e., the p -value is less than 0.01). Generally, the mean severity level of the new mental symptoms of the respondents from the Asia-Pacific group is smaller than the mean of all the respondents for most of the symptoms except for mood swings. For instance, the mean value of anxiety level is 0.316 for the Asia-Pacific group, while this value is 0.619 for all of the respondents and 0.693 for the Europe group.

5.2 Analysis of New Physical Symptoms During Home Working. Eight common physical symptoms were included in the analysis. Besides, the respondents could specify any other new physical issues that were not already included in the pull-down menu.

The results are shown in Fig. 8, with similar annotations used in the previous figures. The results show that the most frequent new physical symptom is the “musculoskeletal-related issues,” which affected over 30% of the respondents, and the second is fatigue and tiredness, affecting over 25% of the respondents. This high proportion could be probably due to the lack of daily physical exercise and social activities when working from home. Besides, the “eyes-related issues” were also found to affect almost 20% of the respondents.

Similar to Sec. 5.1, the count and mean severity levels of the new physical symptoms suffered by respondents are reported in Fig. 9. N_{PS} in the tick labels refers to the number of new physical symptoms.

The results show that 53.52% of the respondents reported suffering from at least one new physical symptom after working from home, and the average severity level of the symptoms (i.e., 2.15)

is approximate “slightly severe” (with 2 indicating “slightly severe”). With the number of physical symptoms increasing, there is an increase in the average severity level as well. In particular, the average severity level of the respondent group who suffered from only one new physical symptom is one level lower than the respondent group who suffered from seven or eight physical symptoms, i.e., “slight severe” versus “moderately severe.” In general, the majority (about 91.5%) of the respondents suffered from no more than three new physical symptoms after WFH, while only about 8.5% reported suffering from more than three new physical symptoms.

A geographic analysis was carried out to understand whether the severity level of the new physical symptoms during WFH may be associated with the country of residence. The means, SDs, and F statistics of the severity level of new physical symptoms are computed by region, and the results are presented in Table 5.

As suggested, the severity levels of headache and tiredness of the occupants in different regions were found to have a medium statistically significant difference (i.e., the p -value is smaller than 0.01). In general, the mean severity level of the new physical symptoms of the respondents from the Asia-Pacific group is always smaller than the mean of all the respondents. For instance, the severity level of tiredness is 0.685 and 0.742 for all the respondents and the North American group, respectively, while when it comes to the Asia-Pacific group, this value is only 0.456. This indicates that the mental and physical symptoms due to WFH may be associated with the countries where the respondents live in.

5.3 Analysis of the General Ratings for Work-From-Home Experience. Four questions on the respondent’s general ratings for WFH experience were asked at the end of the questionnaire, as shown in Table 2. The results are reported in Fig. 10. It is important to note that the ratings for physical and psychological health,

Table 4 Means, SDs, and F statistics of the severity level of new mental symptoms

Variable name	Overall ($n = 1137$, 100%)	North America ($n = 897$, 78.9%)	Asia Pacific ($n = 108$, 9.5%)	Europe ($n = 102$, 9.0%)	Others ($n = 30$, 2.6%)	F statistic
Severity level of mood swings	0.354 ± 0.915	0.321 ± 0.874	0.386 ± 0.936	0.554 ± 1.109	0.500 ± 1.161	2.34
Severity level of anxiety	0.619 ± 1.214	0.649 ± 1.237	0.316 ± 0.886	0.693 ± 1.310	0.618 ± 1.155	2.69*
Severity level of attention issues	0.621 ± 1.233	0.658 ± 1.245	0.421 ± 1.104	0.624 ± 1.310	0.324 ± 1.007	1.94
Severity level of concentration issues	0.901 ± 1.391	0.909 ± 1.384	0.763 ± 1.378	0.990 ± 1.480	0.882 ± 1.365	0.52
Severity level of stress	0.798 ± 1.389	0.831 ± 1.411	0.404 ± 1.019	0.990 ± 1.487	0.706 ± 1.382	3.96**
Severity level of depression	0.408 ± 1.025	0.424 ± 1.043	0.395 ± 0.974	0.327 ± 0.918	0.294 ± 1.031	0.43
Severity level of other mental symptoms	0.092 ± 0.494	0.105 ± 0.528	0.044 ± 0.309	0.069 ± 0.430	N/A	1.02

Note: The mean and SD values (presented as “Mean $\pm$ SD”) in this table are based on the severity level of the new mental symptoms. The value of 1 and 5 indicate “very slightly severe” and “very strongly severe” respectively. The number of the asterisk symbols after the F statistic values indicates the p -value of the ANOVA. *, $p < 0.05$; **, $p < 0.01$; and ***, $p < 0.001$. No asterisk symbol indicates a p -value larger than 0.05.

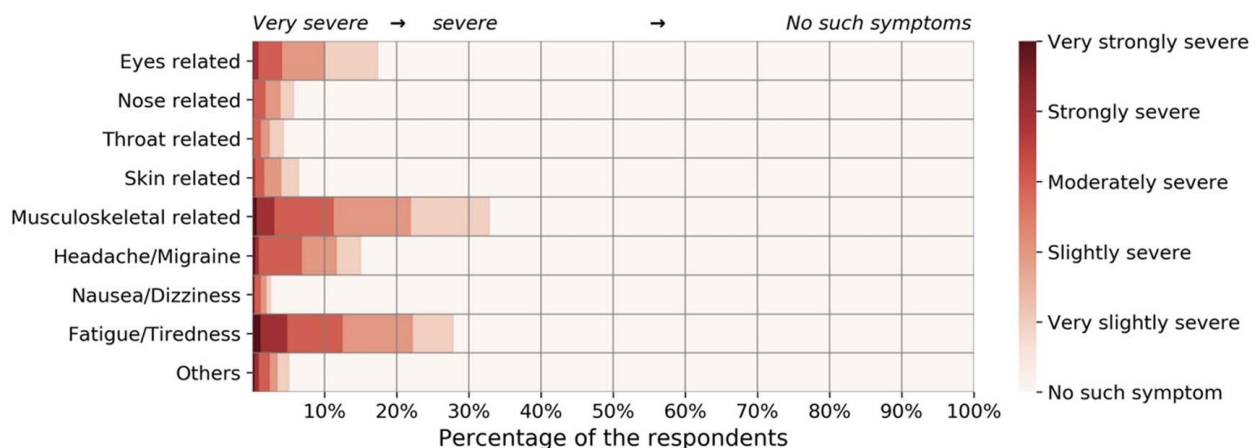


Fig. 8 Percentages of the respondents in terms of the severity level of various new physical symptoms

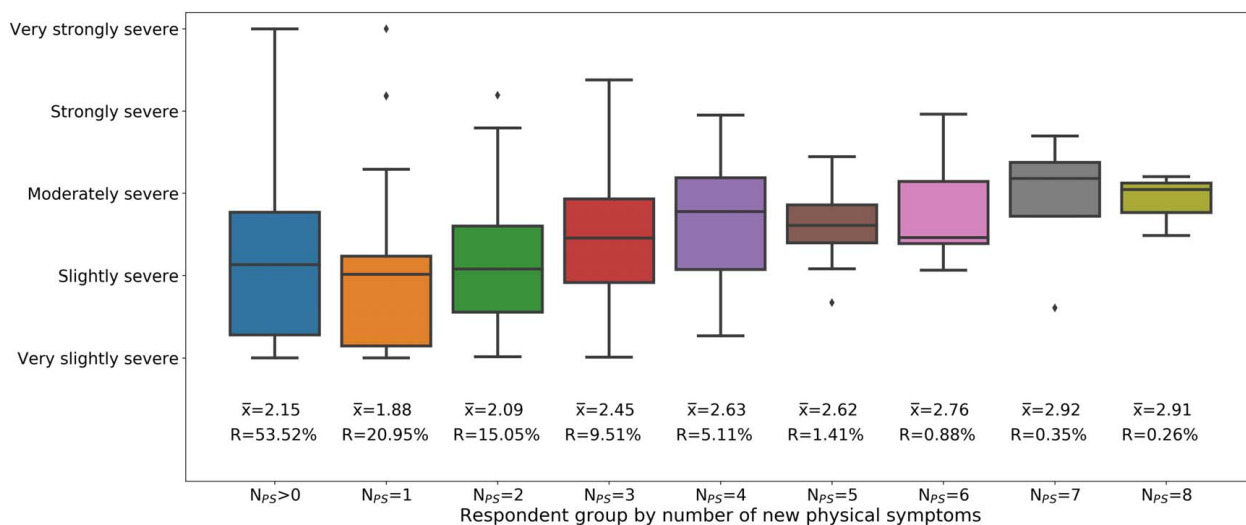


Fig. 9 The respondent group by the number of new physical symptoms and their mean severity levels

Table 5 Means, SDs, and F statistics of the severity level of new physical symptom

Variable name	Overall ($n = 1137$, 100%)	North America ($n = 897$, 78.9%)	Asia Pacific ($n = 108$, 9.5%)	Europe ($n = 102$, 9.0%)	Others ($n = 30$, $n = 2.6\%$)	F statistic
Severity level of eyes-related symptoms	0.327 ± 0.808	0.331 ± 0.809	0.325 ± 0.804	0.317 ± 0.824	0.235 ± 0.781	0.16
Severity level of nose-related symptoms	0.120 ± 0.531	0.134 ± 0.567	0.079 ± 0.424	0.050 ± 0.296	0.088 ± 0.379	1.07
Severity level of throat-related symptoms	0.084 ± 0.439	0.082 ± 0.442	0.079 ± 0.402	0.050 ± 0.357	0.235 ± 0.654	1.56
Severity level of skin-related symptoms	0.128 ± 0.541	0.140 ± 0.575	0.079 ± 0.444	0.109 ± 0.398	0.029 ± 0.171	0.87
Severity level of musculoskeletal-related symptoms	0.697 ± 1.156	0.714 ± 1.168	0.526 ± 1.115	0.802 ± 1.158	0.529 ± 0.896	1.41
Severity level of headache/migraine	0.350 ± 0.911	0.384 ± 0.961	0.175 ± 0.627	0.188 ± 0.628	0.529 ± 0.992	3.34**
Severity level of nausea/dizziness	0.065 ± 0.439	0.057 ± 0.414	0.035 ± 0.228	0.149 ± 0.713	0.118 ± 0.537	1.64
Severity level of tiredness	0.685 ± 1.242	0.742 ± 1.289	0.456 ± 1.203	0.554 ± 1.901	0.353 ± 0.917	3.11**
Severity level of other physical symptoms	0.125 ± 0.604	0.139 ± 0.637	0.018 ± 0.187	0.149 ± 0.669	0.059 ± 0.343	1.54

Note: The mean and SD values (presented as "Mean $\pm$ SD") in this table are based on the severity level of the new physical symptoms. The value of 1 and 5 indicate "very slightly severe" and "very strongly severe" respectively. The number of the asterisk symbols after the F statistic values indicates the p -value of the ANOVA. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. No asterisk symbol indicates a p -value larger than 0.05.

reported in the figure, are subjective ratings directly given by the respondents in the survey; they were not the post-processed results of new mental and physical symptoms (as analyzed in Secs. 5.1 and 5.2).

The results suggest that the respondents demonstrated a relatively high dissatisfaction and a low satisfaction toward the WFH experience. Nearly 30% of the respondents suggested that they were dissatisfied with either their mental health or physical health, or productivity during home working, while less than half of the respondents indicated that they were satisfied with them. In general, about 20% of the respondents were dissatisfied with the WFH environment.

Figure 11 shows the counts of the dissatisfaction votes and average levels of satisfaction reported by the individual respondents in terms of WFH experience. The notation is similar to the one in the previous figures. The results show that 48.06% (i.e., the sum of the respondents with $N_D > 0$) of the respondents were dissatisfied with at least one aspect of the WFH experience. Besides, about 18% of the respondents reported that they cast more than two dissatisfaction votes, which indicated that nearly one-fifth of the respondents were extremely dissatisfied with WFH.

A geographic analysis was carried out to understand the impact of the country of residence on the occupant's ratings of the WFH experience. The means, SDs, and F statistics of the general ratings for WFH experience are computed by region, and the results are presented in Table 6. The results suggest that the

ratings for the general WFH environment and productivity during WFH have a strong statistically significant difference (i.e., the p -value is less than 0.001), while the rating for physical health has a weak one (i.e., the p -value is less than 0.05). Although the respondents of Asia Pacific generally have a lighter severity level of mental and physical symptoms, their ratings for WFH experience are lower than the other three groups, as well as the overall ratings in terms of mean values. For example, the mean value of the ratings for the general WFH environment from Asia-Pacific respondents is 0.29, while the overall mean is 1.013.

6 Correlational Analysis

This section examines the correlations of the various variables involved in the questionnaire. The correlation analysis helps to identify the significant parameters in the design of the residential environment and operation of its mechanical systems. Occupant well-being could potentially be improved based on the identified correlation.

A comprehensive analysis was carried out to investigate the correlation between the various dependent variables and independent variables involved in the questionnaire. The independent variables include residents (divided into two sub-groups, i.e., the basic profile and occupant behavior), residences, and IEQ ratings. The

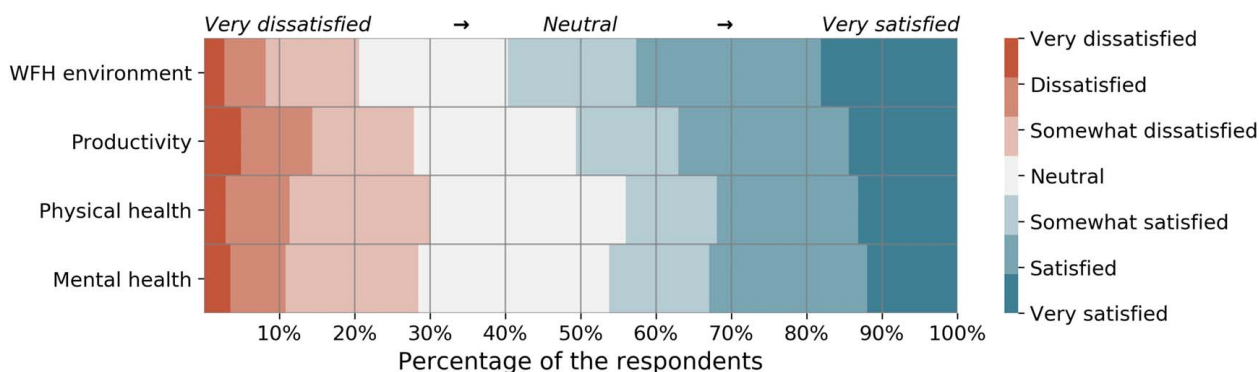


Fig. 10 Percentages of the respondents in terms of the rating for the general WFH experience

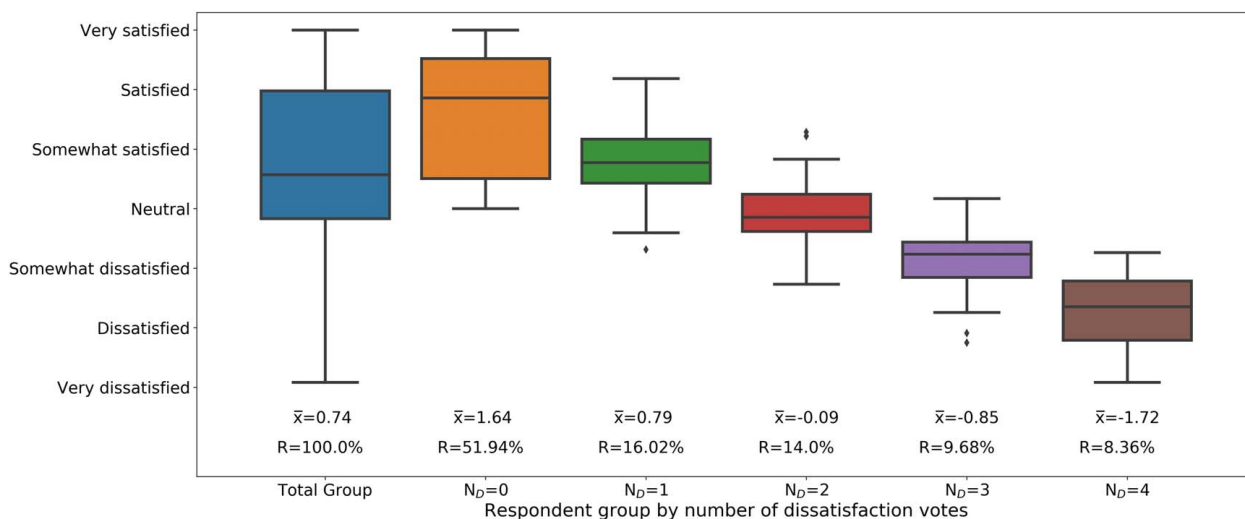


Fig. 11 The respondent group by the number of dissatisfaction votes and their mean satisfaction levels in terms of the general WFH experience

Table 6 Means, SDs, and F statistics of the general ratings for the WFH experience

Variable name	Overall ($n = 1137$, 100%)	North America ($n = 897$, 78.9%)	Asia Pacific ($n = 108$, 9.5%)	Europe ($n = 102$, 9.0%)	Others ($n = 30$, 2.6%)	F statistic
Rating for general home working environment	1.013 ± 1.676	1.099 ± 1.671	0.290 ± 1.612	1.045 ± 1.644	0.846 ± 1.617	6.67***
Rating for productivity during WFH	0.633 ± 1.828	0.738 ± 1.828	0.283 ± 1.692	0.629 ± 1.799	0.654 ± 1.765	8.73***
Rating for psychological health during WFH	0.519 ± 1.757	0.579 ± 1.757	0.194 ± 1.682	0.382 ± 1.682	0.346 ± 1.548	1.69
Rating for physical health during WFH	0.562 ± 1.723	0.631 ± 1.723	0.097 ± 1.588	0.551 ± 1.771	0.154 ± 1.515	3.22*

Note: The mean and SD values (presented as “Mean $\pm$ SD”) in this table are based on the satisfaction ratings towards the general WFH experience. The values of -3 , 0 , and 3 indicate “very dissatisfied,” “neutral,” and “very satisfied,” respectively. The number of the asterisk symbols after the F statistic values indicates the p -value of the ANOVA. *, $p < 0.05$; **, $p < 0.01$; and ***, $p < 0.001$. No asterisk symbol indicates a p -value larger than 0.05 .

dependent variables characterize the occupant’s well-being. These include the severity levels of the mental and physical symptoms and the respondent’s ratings for their working from home experience during the COVID-19 pandemic.

A heatmap is presented in Fig. 12, with a darker color indicating a larger r_s value. The r_s values of each pair of symptoms are annotated in the cells. The cell with an associated r_s value larger than 0.45 is marked with a star, and the cell of which the r_s value is larger than 0.25 is marked with a checkmark. The 0.45 threshold was selected to highlight the pairs of variables with the top ten highest correlation strength, while the 0.25 threshold was selected to highlight the pairs

of variables whose correlation strengths are in the 90th percentile. It is noted that as usual, a correlation coefficient of a value between 0.7 and 1 indicates a strong relationship, and a value between 0.3 and 0.7 indicates a moderate relationship [81]. Based on this rule, the selected top ten correlation relationships in this study are all moderate.

As mentioned in Sec. 3.2, a total of 43 questions were included in the analysis; 23 of them were independent variables (y -axis), and 20 of them were dependent variables (x -axis). Based on the sub-groups of dependent variables and independent variables, Fig. 12 was divided into 12 blocks by dashed lines to facilitate check and analysis.

6.1 The Impacts on Physical Symptoms. The physical symptoms were not found to have any strong correlation with the independent variables except that the work hardware has a weak correlation with the musculoskeletal-related issues. This is probably because with professional work hardware being accessible at homes, such as one or multiple monitors(s) and adjustable monitor stand(s), the home workers could work with proper and comfortable postures.

6.2 The Impacts on Mental Symptoms. The mental symptoms were not found to have any strong correlation with the independent variables except that the rating for home layout has a weak correlation with the concentration issue. As noted in the literature review, the home workers are faced with the challenges of noise and distractions from other household members and neighbors during working, which is not likely to happen in the office environment [22]. A home with a satisfying layout (e.g., there are multiple available rooms) could help create a good working environment by separating a quiet working space from the living area during the enforced WFH period. The impact of home layout design is further discussed in Sec. 6.3.2.

6.3 The Impacts on General Work-From-Home Experience. Unlike the mental and physical symptoms, general ratings for the WFH experience were found to strongly correlate with the independent variables, especially the ratings for indoor environmental quality.

6.3.1 The Impact of Respondent's Age. As shown in Fig. 13, the age of respondents poses potential impacts to productivity and physical health, and it also influences the rating for the WFH environment. In light of this, a further analysis was conducted to quantitatively investigate the impacts of age on the respondent's well-being during home working. The analysis results are reported in Fig. 13 and Table 7. For each rating of the WFH experience, the respondents were divided into three groups based on their age: 18–30-year-old group, 30–50-year-old group, and over 50-year-old group. The age grouping is consistent with the survey design.

As can be seen from Fig. 13 and Table 7, with the respondent's age increasing, the ratios of satisfaction increased dramatically as well. Compared with the 18–30-year-old group, the satisfaction rate of the 50+ group increased from 40% to nearly 80% in terms of the rating for the WFH environment, and meanwhile, the dissatisfaction rate was decreased from 25% to 12%. This trend was also found in the ratings for productivity and physical/mental health.

6.3.2 The Impacts of Indoor Environmental Quality. In Fig. 12, we can see that the block with the strongest correlation is the one calculated from IEQ and general WFH ratings. Every cell in that block was annotated with a yellow checkmark, indicating that they all exceed 0.25 in terms of the r_s value and thus have statistical significance. Besides, ten pairs of correlations were annotated with a star sign, meaning that they achieve a greater than 0.45 r_s value. These ten pairs of correlations are analyzed in detail, as presented in Fig. 14 and Table 8.

The rating for the home layout was found to have the strongest impact on occupant's well-being among the selected IEQ metrics.

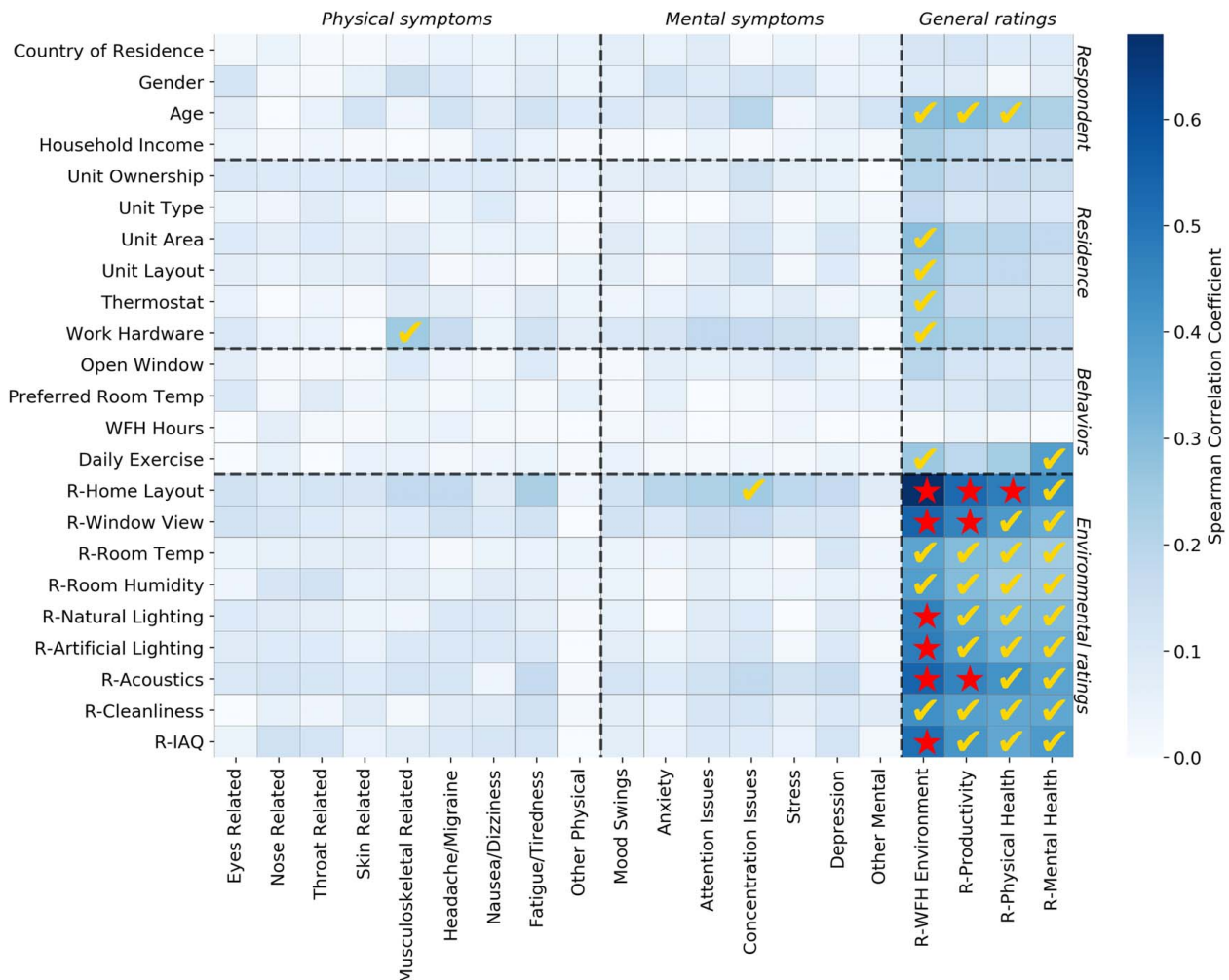


Fig. 12 Spearman's rank correlation coefficients considering all the survey variables

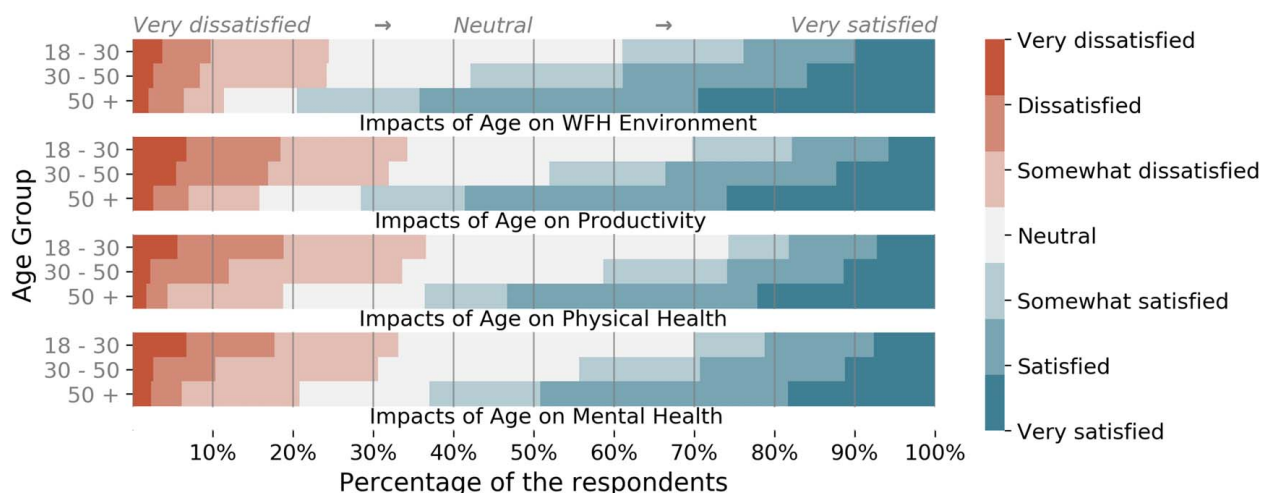


Fig. 13 The impacts of age on respondent's well-being and home working experience during the COVID-19 pandemic

As suggested by Fig. 14, the respondents who were satisfied with the home layout would be nearly three times more likely to feel satisfied with the general WFH environment. Meanwhile, the ratio of dissatisfaction dropped sharply from about 58% to 7%. Besides, the satisfaction with the home layout influenced the respondent's working productivity and physical health as well, as demonstrated by the 42% increase in satisfaction for both ratings.

In the following question that asked for the reason of dissatisfaction with the home layout, 66% of the respondents mentioned that the furniture in their home was not comfortable for long-time working. This partly explains the correlation between the home working furniture and equipment and physical health rating, as observed in Sec. 6.1. Besides, 62% ($n=705$) of the respondents suggested that there was not enough space in their homes for everyone to work or study simultaneously; 43% ($n=489$) of the respondents mentioned that the activities of other occupants at home, e.g., cooking and watching TV, had posed a distraction to their work; and 29% ($n=330$) of the respondents indicated that they were troubled by the noises due to poor home layout design. Some respondents admitted in the comment section that they felt the home working environment had worsened a lot compared with the pre-COVID period, since the other family members/roommates and neighbors also started to work from home at the same time, which caused a distraction.

Satisfaction with the window view was strongly correlated with the ratings of WFH environment and productivity. Dravigne et al. [82] found, through an online survey conducted in Texas and Midwest U.S., that individuals who worked in offices with plants and good window views typically felt better about their job and the work that they performed. This conclusion is also true for people in WFH status in this study. Nearly 68% of the respondents who were satisfied with their window views also felt positive about their working productivity, while among those who were not, only 25% were productive. As shown in Fig. 4, about 18% ($n=205$) of

the respondents were dissatisfied with their window views. When being asked about the reason, 56% ($n=637$) indicated that the view of outside surroundings was not good enough; 27% ($n=307$) complained that the neighboring units and/or trees blocked their views; 22% ($n=250$) said the window of their home office was too small.

Apart from the home layout, the respondent's satisfaction with the indoor acoustics was another factor that could pose positive impacts to productivity and general home working experience. Compared with those who were dissatisfied with or neutral to indoor acoustics, the respondents who cast a satisfaction vote would be two times more likely to feel satisfied with the working productivity and general WFH environment. In particular, 85% ($n=966$) of the respondents dissatisfied with indoor acoustics indicated that there were noises occurring in the daytime, and 21% ($n=239$) were troubled by the noises at nighttime. Additionally, 13% ($n=148$) of the respondents suggested that there were other unspecified noise sources.

A further analysis was carried out to investigate the impacts of residence on acoustic satisfaction, and the results are presented in Fig. 15. It is noted that all the respondent groups had a generally positive rating for acoustics (i.e., the mean satisfaction level has a value larger than "0"/"neutral"). As shown, the respondents who live in their own homes tend to feel more satisfied with the acoustic performance. Residents who live in detached single-family houses and townhouses have a higher satisfaction level than those who live in apartments and multi-family houses. It was also found that people who live in bigger houses that have more bedrooms and bathrooms are generally more satisfied with the acoustics. It is interesting to note that the people who live in three-bedroom one-bathroom homes have an obviously lower level of satisfaction toward acoustics compared with other groups.

Additionally, a further analysis was carried out to investigate how the ratings on artificial and natural lighting are correlated with the

Table 7 Means, SDs, and F statistics of the general ratings for WFH experience by different age groups

Variable name	18–30 ($n=255$, 22.4%)	30–50 ($n=541$, 47.6%)	50+ ($n=341$, 30.0%)	F static
Rating—WFH environment	0.44 + 1.7	0.86 + 1.66	1.59 + 1.5	35.30***
Rating—productivity	−0.11 + 1.78	0.44 + 1.83	1.35 + 1.62	47.96***
Rating—mental health	−0.15 + 1.78	0.34 + 1.65	1.19 + 1.58	45.42***
Rating—physical health	−0.03 + 1.83	0.46 + 1.65	1.06 + 1.61	27.06***

Note: The mean and SD values (presented as "Mean $\pm$ SD") in this table are based on the satisfaction ratings towards the general WFH experience. The values of −3, 0, and 3 indicate "very dissatisfied," "neutral," and "very satisfied," respectively. The number of the asterisk symbols after the F statistic values indicates the p -value of the ANOVA. *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$. No asterisk symbol indicates a p -value larger than 0.05.

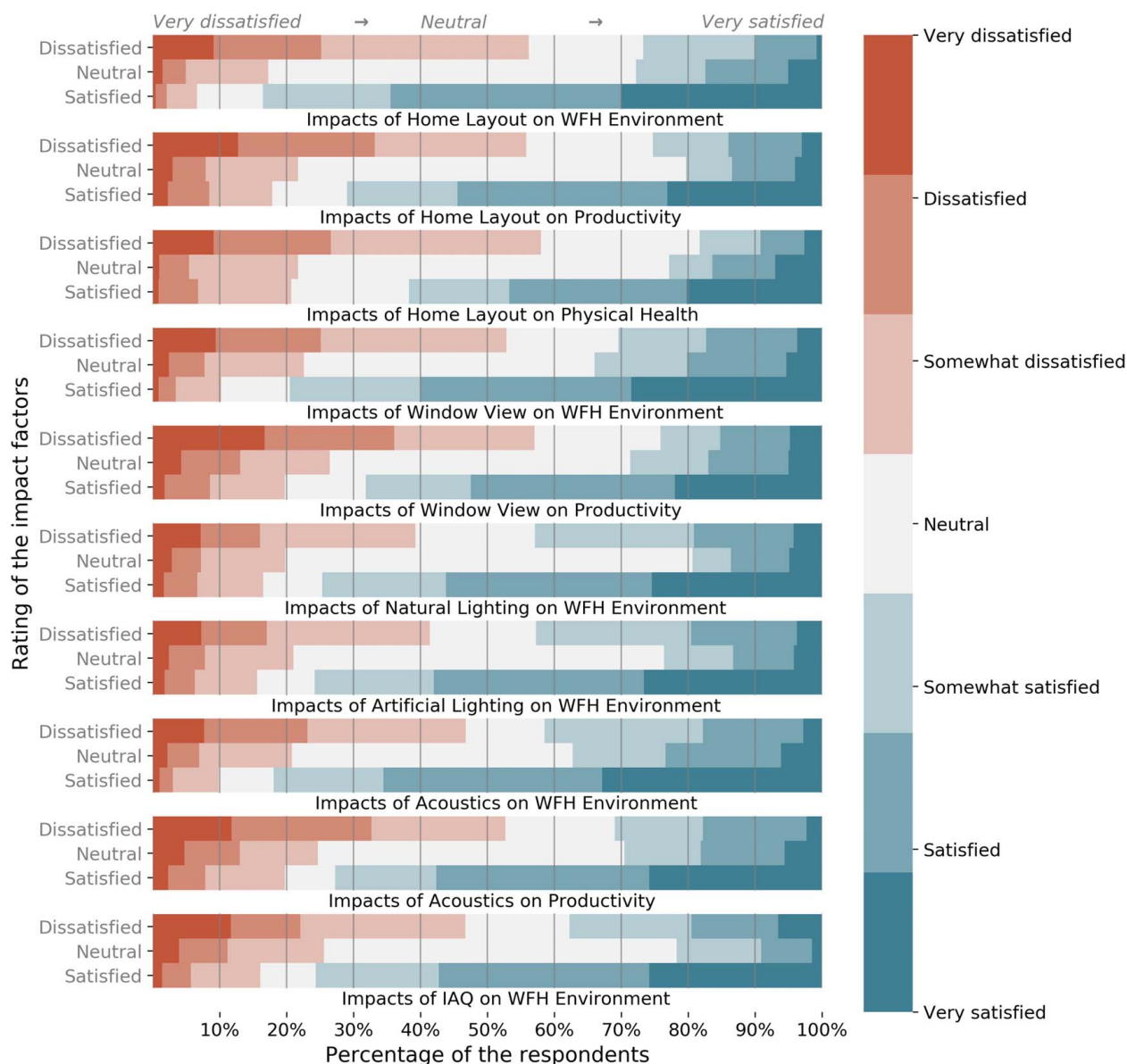


Fig. 14 The impacts of IEQ on respondent's well-being and home working experience during the COVID-19 pandemic

residence and window opening behavior. The results are presented in Fig. 16. As suggested, the respondents who live in their own homes are generally more satisfied with the lighting condition compared with those who live in rented homes; the respondents who live in detached single-family homes are more satisfied compared with those who live in apartments, multi-family homes, or townhouses. In general, the respondents who live in bigger houses or residences which have more bedrooms reported having a higher satisfaction level in terms of both artificial and natural lighting. It is noted that the residents living in studios and houses smaller than 50 m² have an obviously higher satisfaction level toward natural lighting than artificial lighting. This indicates that the designers and architects should pay more attention to the artificial lighting design of studios and smaller homes due to the current lower satisfaction levels. It is also interesting to find out that the frequency of opening window only has a limited impact on the satisfaction level toward artificial lighting, while in terms of natural lighting, a more frequent window opening behavior (from very seldom or seldom to very often) could improve the average satisfaction level by about 0.4 (by the 7-point Likert scale).

Further analysis on the impacts of residence and window opening behavior on the ratings on IAQ yielded similar results

to the previous two analyses on acoustics and lighting. As suggested in Fig. 17, the respondents tend to be more satisfied with the IAQ if they live in their own homes, detached single-family homes, or larger houses. The frequency of opening the window is found to have no significant impact on the satisfaction level of IAQ.

7 Discussions and Conclusions

This study presents the results of an international survey to investigate how work from home has affected occupant well-being during the COVID-19 pandemic. A questionnaire, which comprised of 81 questions about the respondent's profile, residence basic information, IEQ metrics, and home working experience, was designed and distributed through social media, and mail opt-in service.

7.1 Physical and Psychological Health. The respondents were asked to report new mental and physical symptoms that emerged after home working. The results suggest that attention issues, concentration issues, and anxiety were the three most

Table 8 Means, SDs, and F statics of the general ratings for the WFH experience by the respondent groups with different ratings for the indoor environmental quality

Dependent variable	Independent variable			
	Rating for the home layout			F statistic
	Dissatisfied (<i>n</i> = 256, 22.5%)	Neutral (<i>n</i> = 250, 22.0%)	Satisfied (<i>n</i> = 630, 55.5%)	
Rating—WFH environment	−0.57 + 1.491	0.212 + 1.06	1.767 + 1.229	360.91***
Rating—productivity	−0.643 + 1.682	0.036 + 1.061	1.258 + 1.632	157.75***
Rating—physical health	−0.476 + 1.55	0.121 + 1.052	1.038 + 1.616	103.08***
	Rating for the window view			F statistic
	Dissatisfied (<i>n</i> = 179, 15.7%)	Neutral (<i>n</i> = 317, 2.7%)	Satisfied (<i>n</i> = 640, 56.4%)	
Rating—WFH environment	−0.385 + 1.677	0.237 + 1.242	1.584 + 1.381	188.67***
Rating—productivity	−0.704 + 1.782	0.066 + 1.297	1.16 + 1.645	118.99***
	Rating for the natural lighting			F statistic
	Dissatisfied (<i>n</i> = 161, 14.2%)	Neutral (<i>n</i> = 233, 20.5%)	Satisfied (<i>n</i> = 742, 65.3%)	
Rating—WFH environment	0.037 + 1.6	0.069 + 1.116	1.345 + 1.565	96.39***
	Rating for the artificial lighting			F statistic
	Dissatisfied (<i>n</i> = 156, 13.7%)	Neutral (<i>n</i> = 267, 23.6%)	Satisfied (<i>n</i> = 713, 62.7%)	
Rating—WFH environment	0.0 + 1.622	0.086 + 1.129	1.398 + 1.552	110.51***
	Rating for the acoustics			F statistic
	Dissatisfied (<i>n</i> = 214, 18.8%)	Neutral (<i>n</i> = 376, 33.2%)	Satisfied (<i>n</i> = 546, 48.0%)	
Rating—WFH environment	−0.164 + 1.641	0.351 + 1.306	1.69 + 1.377	175.71***
Rating—productivity	−0.479 + 1.714	0.098 + 1.375	1.284 + 1.652	119.75***
	Rating for IAQ			F statistic
	Dissatisfied (<i>n</i> = 75, 6.6%)	Neutral (<i>n</i> = 293, 25.8%)	Satisfied (<i>n</i> = 768, 67.6%)	
Rating—WFH environment	−0.173 + 1.758	−0.082 + 1.129	1.376 + 1.531	128.25***

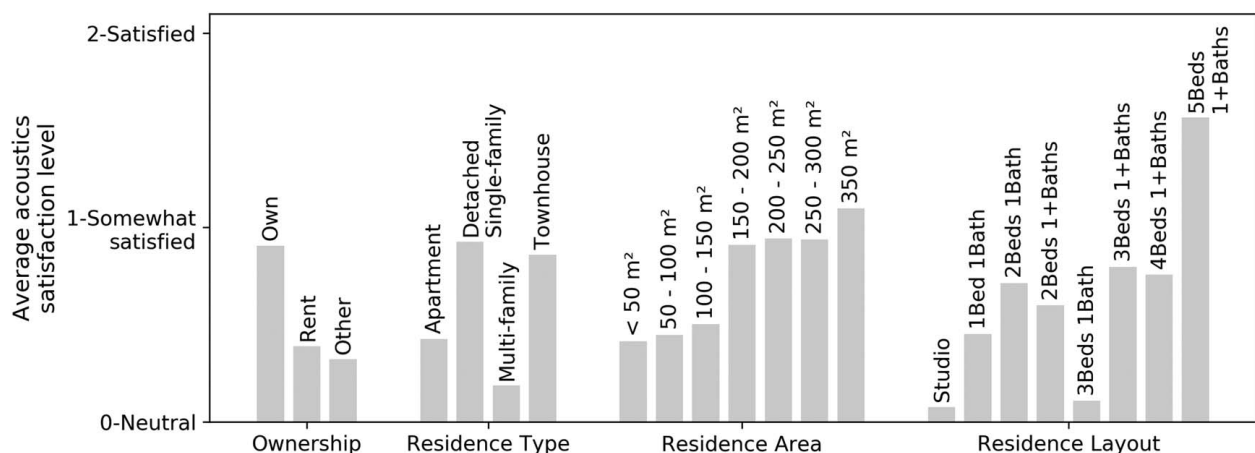
Note: The mean and SD values (presented as “Mean ± SD”) in this table are based on the satisfaction ratings towards the general WFH experience and IEQ. The values of −3, 0, and 3 indicate “very dissatisfied,” “neutral,” and “very satisfied,” respectively. 2The number of the asterisk symbols after the *F* statistic values indicates the *p*-value of the ANOVA. *, *p* < 0.05; **, *p* < 0.01; ***, *p* < 0.001. No asterisk symbol indicates a *p*-value larger than 0.05.

frequent mental symptoms found in this survey; the musculoskeletal-related issues, fatigue/tiredness, and eyes-related symptoms were the three most frequent physical symptoms.

Generally, more respondents suffered more from mental symptoms than physical symptoms during home working. The data show that 53.5% (*n* = 608) of the respondents reported suffering from at least one new physical symptom after working from home, and the average severity level of the symptoms is approximately “slightly severe.” On the other hand, 57.66% (*n* = 656) of

the respondents reported being affected by at least one new mental issue during WFH, and 44.10% (*n* = 501) reported suffering from at least three new mental symptoms.

7.2 Ratings for the Indoor Environmental Quality. The results show that the rating for the home layout was the IEQ metric that received the most complaints, with nearly 25% (*n* = 284) of the respondents being dissatisfied with the home layouts,

**Fig. 15 The impacts of residence on respondent's ratings on acoustics**

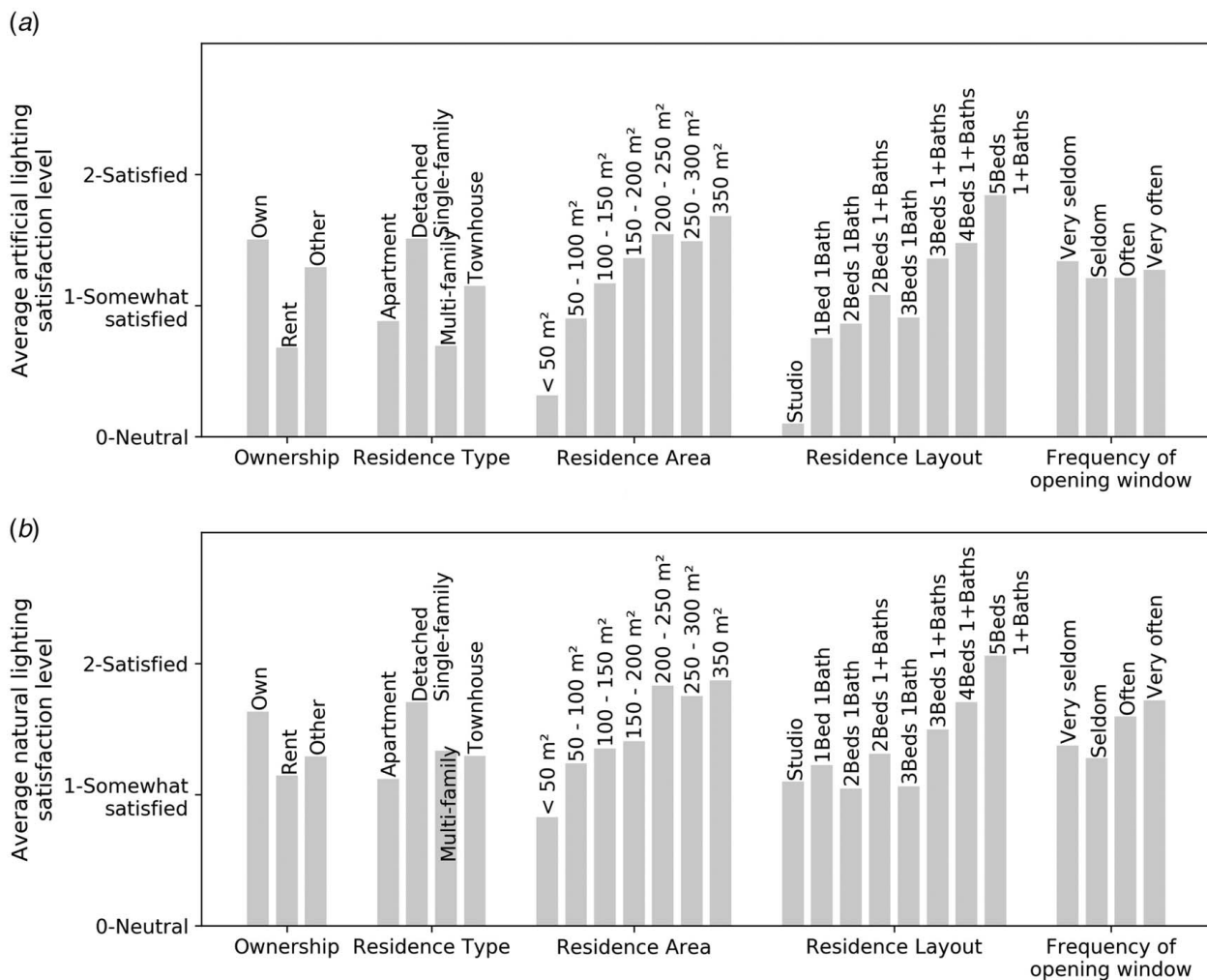


Fig. 16 The impacts of residence and opening window behavior on respondent's ratings on (a) artificial lighting and (b) natural lighting

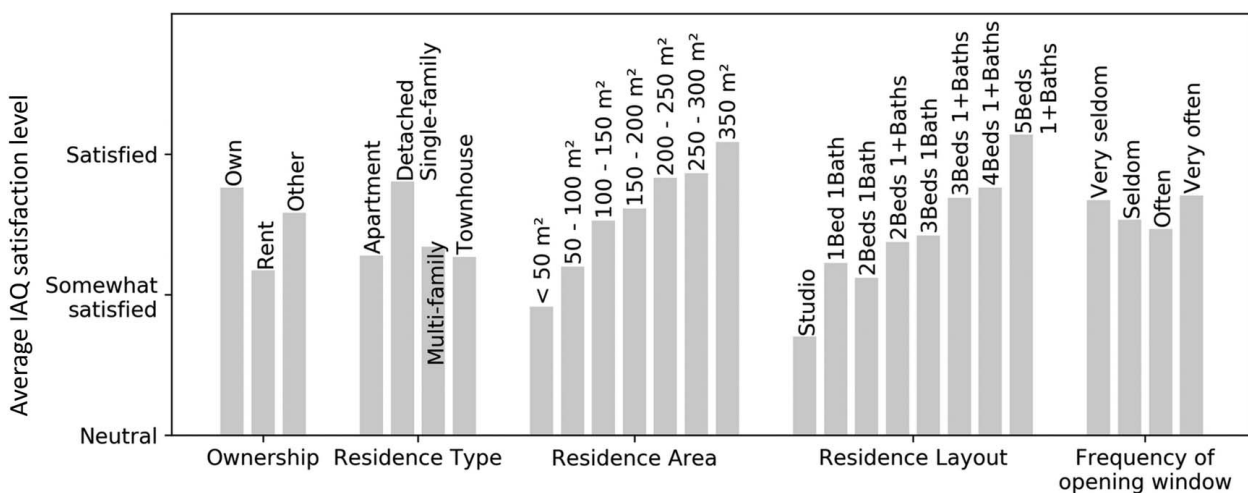


Fig. 17 The impacts of residence and opening window behavior on respondent's ratings on IAQ

followed by the ratings for indoor acoustics (about 19% ($n=216$)) and view from the window (about 16% ($n=182$)).

The analysis shows that 55% ($n=625$) of the respondents cast at least one dissatisfaction vote in terms of the IEQ. Among them, 38% ($n=432$) cast at least three dissatisfaction votes. With the

number of dissatisfaction votes increasing, the general satisfaction level of the respondent group dropped from "satisfied" (for the respondents who voted at least one dissatisfaction) to "somewhat dissatisfied" (for the respondents who have voted seven dissatisfactions).

7.3 Correlation Analysis. A correlation analysis was conducted to investigate the relationships between the dependent variables and independent variables in the questionnaire. The following conclusions could be summarized:

- (1) The age of the respondents influenced the WFH experience during the COVID-19 pandemic. Compared with the 18–30-year-old group, the satisfaction rate of the 50+ age group increased from 40% to nearly 80% in terms of the rating for the WFH environment, and meanwhile, the dissatisfaction rate decreased from 25% to 12%.
- (2) The rating for the home layout was found to have the deepest impact on occupant well-being among the selected IEQ metrics. The respondents who were satisfied with the home layout would be nearly three times more likely to feel satisfied with the general WFH environment. The most common issue identified in home layout design was the lack of space for simultaneous work or study for the family members. It was also found out that the concentration issue was correlated with the home layout design. This could be solved by planning some working space that is divided from the living area for new home design.
- (3) Satisfaction with the view from the window was strongly correlated with the ratings of WFH environment and productivity. Nearly 68% of the respondents who were satisfied with their window views also felt positive about their working productivity, while in terms of those who were not, this ratio is slightly below 25%.
- (4) Satisfaction with indoor acoustics is another factor with potential for positive impacts on occupant productivity and general home working experience. Compared with those who were dissatisfied or felt neutral with the indoor acoustics, the respondents who cast a satisfaction vote are two times more likely to feel positive about the working productivity and general WFH experience. The occupant's satisfaction toward indoor acoustics is highly correlated to the homeownership, area, and layout.
- (5) Satisfaction with natural lighting, artificial lighting, and IAQ are found to be closely correlated with the general rating of the WFH environment. A detailed analysis suggests that the respondents who live in their own homes, detached single-family homes, or larger houses tend to be more satisfied with these three IEQ metrics. A more frequent opening window behavior improves the satisfaction toward natural lighting.
- (6) In general, satisfaction ratings for temperature, relative humidity, and IAQ were higher than those of the home lighting, acoustic, and layout design. The prominent value and benefits of a good home design for lighting, acoustics, and layout should not be neglected by the designers, engineers, and homeowners.

7.4 Limitations. This study has some limitations. First, the responses retrieved from the survey could be skewed in terms of geographical locations. More than 70% of the respondents are from the United States, while 56% of the American respondents are from the State of Texas. This skewness may have some potential impacts on the results and conclusions of this study. Second, it is noted that a few questions in the questionnaire were not understood correctly by some respondents. Hence, the collected responses from those questions were not used for the analysis. For instance, although this survey included a question of the home HVAC system type, our analysis did not include this question. This is because many respondents could not accurately describe the HVAC system type in their homes (e.g., some respondents reported having both “no heating” and “heat pump system” simultaneously in their homes). There would be a need for the questionnaire to have more explicit explanations if technological aspects were considered in the survey for the general public.

7.5 Future Research and Applications. The results of this survey may benefit future research and applications, as summarized below:

- (1) The design of residential buildings should incorporate more considerations for acoustic comfort and spatial layout design. The results of this international survey suggest that the respondents are generally more dissatisfied with the home acoustics and layout, compared with the room temperature, relative humidity, and IAQ.
- (2) The current prevalent building energy codes/standards for the residential sector such as ASHRAE Standard 90.2-2018 Energy-Efficient Design of Low-Rise Residential Buildings [83] and International Energy Conservation Code (IECC) 2021 [84] put a significant focus on building energy efficiency and thermal comfort while do not fully take into account the significance of the other factors such as lighting comfort, acoustics, and layout. The future building energy standards/codes may need to consider the multiple metrics that pose an impact on occupant's well-being. The WELL Building Standard [85] might be a good reference.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request. Data provided by a third party are listed in Acknowledgment.

Abbreviations

AccelNet	= Accelerating Research through International Network-to-Network Collaborations
CHD	= coronary heart disease
IN2WIBE	= an international network of networks for well-being in the built environment
NSF	= U.S. National Science Foundation
SARS-CoV-2	= severe acute respiratory syndrome coronavirus 2
WMSD	= work-related musculoskeletal disorders

References

- [1] US Environmental Protection Agency, 1989, Report to Congress on Indoor Air Quality, Volume II: Assessment and Control of indoor air pollution. Technical Report No. EPA/400/1-89/001C.
- [2] European Commission, 2003, *Indoor Air Pollution: New EU Research Reveals Higher Risks Than Previously Thought*, https://ec.europa.eu/commission/presscorner/detail/en/IP_03_1278.
- [3] Diffey, B. L., 2011, “An Overview Analysis of the Time People Spend Outdoors,” *Br. J. Dermatol.*, **164**(4), pp. 848–854.
- [4] Leech, J. A., Nelson, W. C., Burnett, R. T., Aaron, S., and Raizenne, M. E., 2002, “It's About Time: A Comparison of Canadian and American Time-Activity Patterns,” *J. Exposure Sci. Environ. Epidemiol.*, **12**(6), pp. 427–432.
- [5] Hale, T., Petherick, A., Phillips, T., and Webster, S., 2020, *Variation in Government Responses to COVID-19*. Blavatnik School of Government Working Paper No. 31 (2020):2020-11, https://www.bsg.ox.ac.uk/sites/default/files/2021-06/BSG-WP-2020-032-v12_0.pdf
- [6] Parmet, W. E., and Sinha, M. S., 2020, “Covid-19—The Law and Limits of Quarantine,” *N. Engl. J. Med.*, **382**(15), p. e28.
- [7] Gostin, L. O., and Wiley, L. F., 2020, “Governmental Public Health Powers During the COVID-19 Pandemic: Stay-at-Home Orders, Business Closures, and Travel Restrictions,” *JAMA*, **323**(21), pp. 2137–2138.

- [8] Shen, M., Peng, Z., Guo, Y., Rong, L., Li, Y., Xiao, Y., Zhuang, G., and Zhang, L., 2020, "Assessing the Effects of Metropolitan-Wide Quarantine on the Spread of COVID-19 in Public Space and Households," *Int. J. Infect. Dis.*, **96**, pp. 503–505.
- [9] Nussbaumer-Streit, B., Mayr, V., Dobrescu, A. I., Chapman, A., Persad, E., Klerings, I., Wagner, G., Siebert, U., Christof, C., and Zachariah, C., 2020, "Quarantine Alone or in Combination With Other Public Health Measures to Control COVID-19: A Rapid Review," *Cochrane Database Syst. Rev.*, (4).
- [10] Yang, I.-H., Yeo, M.-S., and Kim, K.-W., 2003, "Application of Artificial Neural Network to Predict the Optimal Start Time for Heating System in Building," *Energy Convers. Manage.*, **44**(17), pp. 2791–2809.
- [11] Mubayi, A., Zaleta, C. K., Martcheva, M., and Castillo-Chávez, C., 2010, "A Cost-Based Comparison of Quarantine Strategies for New Emerging Diseases," *Math. Biosci. Eng.*, **7**(3), p. 687.
- [12] Saladino, V., Algeri, D., and Ariemma, V., 2020, "The Psychological and Social Impact of Covid-19: New Perspectives of Well-Being," *Front. Psychol.*, **11**, p. 2550.
- [13] Kivi, M., Hansson, I., and Bjälkebring, P., 2020, "Up and About: Older Adults' Wellbeing During the COVID-19 Pandemic in a Swedish Longitudinal Study," *J. Gerontology B.*, **76**(2), pp. e4–e9.
- [14] Gualano, M. R., Lo Moro, G., Voglio, G., Bert, F., and Siliquini, R., 2020, "Effects of Covid-19 Lockdown on Mental Health and Sleep Disturbances in Italy," *Int. J. Environ. Res. Public Health*, **17**(13), p. 4779.
- [15] Wang, C., Pan, R., Wan, X., Tan, Y., Xu, L., Ho, C. S., and Ho, R. C., 2020, "Immediate Psychological Responses and Associated Factors During the Initial Stage of the 2019 Coronavirus Disease (COVID-19) Epidemic Among the General Population in China," *Int. J. Environ. Res. Public Health*, **17**(5), p. 1729.
- [16] Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., Costantini, L., Odone, A., Costanza, A., and Signorelli, C., 2020, "COVID-19 Lockdown: Housing Built Environment's Effects on Mental Health," *Int. J. Environ. Res. Public Health*, **17**(16), p. 5973.
- [17] National Conference of State Legislatures, 2020, *COVID-19: Impact on Employment and Labor*, <https://www.ncsl.org/research/labor-and-employment/covid-19-impact-on-employment-and-labor.aspx>.
- [18] CNN, 2020, *Big Tech Firms Ramp up Remote Working Orders to Prevent Coronavirus Spread*, <https://www.cnn.com/2020/03/10/tech/google-work-from-home-coronavirus/index.html>.
- [19] International Labour Organization, 2020, *Working from Home: Estimating the Worldwide Potential*.
- [20] Bloom, N., 2020, "How Working From Home Works Out." Policy Brief, pp. 1–8.
- [21] DeFilippis, E., Impink, S. M., Singell, M., Polzer, J. T., and Sadun, R., 2020, *Collaborating During Coronavirus: The Impact of COVID-19 on the Nature of Work*, National Bureau of Economic Research.
- [22] Gorlick, A., 2020, *The Productivity Pitfalls of Working From Home in the Age of COVID-19*, <https://news.stanford.edu/2020/03/30/productivity-pitfalls-working-home-age-covid-19/>.
- [23] MSU Today, 2020, *Ask the Expert: How Can Employees Care for Their Mental Health While Working From Home?*, <https://msutoday.msu.edu/news/2020/ask-the-expert-how-can-employees-care-for-their-mental-health-while-working-from-home/>.
- [24] Bloom, N., Jones, C. I., Van Reenen, J., and Webb, M., 2020, "Are Ideas Getting Harder to Find?," *Am. Econ. Rev.*, **110**(4), pp. 1104–1144.
- [25] Butler, J., and Jaffe, S., 2021, "Challenges and Gratitude: A Diary Study of Software Engineers Working From Home During Covid-19 Pandemic," 2021 IEEE/ACM 43rd International Conference on Software Engineering: Software Engineering in Practice (ICSE-SEIP), Virtual (originally in Madrid, Spain), May 25–28.
- [26] Perlow, L. A., 1999, "The Time Famine: Toward a Sociology of Work Time," *Admin. Sci. Quarter.*, **44**(1), pp. 57–81.
- [27] Diaz, S. B., 2016, *Time Confetti: Use It Wisely*, <https://www.naspa.org/blog/time-confetti-use-it-wisely>.
- [28] Choudhury, P., Koo, W. W., and Li, X., 2020, *Working (From Home) During a Crisis: Online Social Contributions by Workers During the Coronavirus Shock*.
- [29] Xiao, Y., Becerik-Gerber, B., Lucas, G., and Roll, S. C., 2021, "Impacts of Working From Home During COVID-19 Pandemic on Physical and Mental Well-Being of Office Workstation Users," *J. Occup. Environ. Med.*, **63**(3), p. 181.
- [30] Organisation for Economic Co-operation and Development, 2020, *Productivity Gains From Teleworking in the Post COVID-19 Era: How Can Public Policies Make It Happen?*, Paris, France.
- [31] Bloom, N., Liang, J., Roberts, J., and Ying, Z. J., 2015, "Does Working From Home Work? Evidence From a Chinese Experiment," *Q. J. Econ.*, **130**(1), pp. 165–218.
- [32] Best, P., 2021, *Most Workers Want to Continue Working From Home in the Post-pandemic World, Survey Finds*, <https://www.foxbusiness.com/economy/most-workers-want-continue-working-from-home-post-pandemic-world>.
- [33] Gallup, 2016, *State of the American Workplace*, <https://www.gallup.com/workplace/238085/stateamerican-workplace-report-2017.aspx>.
- [34] Global Workplace Analytics, 2021, <https://globalworkplaceanalytics.com/work-at-home-after-covid-19-our-forecast>, *Work-At-Home After Covid-19—Our Forecast*.
- [35] Pinheiro, M. D., and Luís, N. C., 2020, "COVID-19 Could Leverage a Sustainable Built Environment," *Sustainability*, **12**(14), p. 5863.
- [36] U.S. Centers for Disease Control and Prevention (CDC), 2020, *Health-Related Quality of Life (HRQOL): Well-Being Concepts*, <https://www.cdc.gov/hrqol/wellbeing.htm>.
- [37] World Health Organization, 2006, *Constitution of the World Health Organization*.
- [38] Renalds, A., Smith, T. H., and Hale, P. J., 2010, "A Systematic Review of Built Environment and Health," *Fam. Comm. Health*, **33**(1), pp. 68–78.
- [39] Seppänen, O. A., and Fisk, W., 2006, "Some Quantitative Relations Between Indoor Environmental Quality and Work Performance or Health," *HVACR Res.*, **12**(4), pp. 957–973.
- [40] Allen, J., Bernstein, A., Xiadong, C., Eitland, E., Flanagan, S., and Gokhale, M., 2016, *The 9 Foundations of a Healthy Building*, Harvard TH Chan School of Public Health, Boston, MA.
- [41] Morawska, L., Tang, J. W., Bahnfleth, W., Bluyssen, P. M., Boerstra, A., Buonanno, G., Cao, J., Dancer, S., Floto, A., and Franchimon, F., 2020, "How Can Airborne Transmission of COVID-19 Indoors be Minimised?," *Environ. Int.*, **142**, p. 105832.
- [42] Miller, S. L., Nazaroff, W. W., Jimenez, J. L., Boerstra, A., Buonanno, G., Dancer, S. J., Kurnitski, J., Marr, L. C., Morawska, L., and Noakes, C., 2020, "Transmission of SARS-CoV-2 by Inhalation of Respiratory Aerosol in the Skagit Valley Chorale Superspreading Event," *Indoor Air.*, **31**(2), pp. 314–323.
- [43] Eykelbosh, A., 2020, *COVID-19 Precautions for Multi-Unit Residential Buildings*, <https://nceh.ca/sites/default/files/COVID-19%20Precautions%20for%20Multiunit%20Residential%20Buildings%20-%20March%2031%202020.pdf>.
- [44] Bhagat, R. K., Wykes, M. D., Dalziel, S. B., and Linden, P., 2020, "Effects of Ventilation on the Indoor Spread of COVID-19," *J. Fluid Mech.*, **903**, pp. F1–F18.
- [45] Evans, G. W., 2003, "The Built Environment and Mental Health," *J. Urban Health*, **80**(4), pp. 536–555.
- [46] Zhang, S. X., Wang, Y., Rauch, A., and Wei, F., 2020, "Unprecedented Disruption of Lives and Work: Health, Distress and Life Satisfaction of Working Adults in China One Month Into the COVID-19 Outbreak," *Psychiatry Res.*, **288**, p. 112958.
- [47] Rautio, N., Filatova, S., Lehtiniemi, H., and Miettinen, J., 2018, "Living Environment and Its Relationship to Depressive Mood: A Systematic Review," *Int. J. Soc. Psychiatry*, **64**(1), pp. 92–103.
- [48] Chen, C.-F., Yilmaz, S., Pisello, A. L., De Simone, M., Kim, A., Hong, T., Bandurski, K., Bavaresco, M. V., Liu, P.-L., and Zhu, Y., 2020, "The Impacts of Building Characteristics, Social Psychological and Cultural Factors on Indoor Environment Quality Productivity Belief," *Build. Environ.*, **185**, p. 107189.
- [49] Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Elsarrag, E., and Mishra, S., 2017, "Occupant Productivity and Indoor Environment Quality: A Case of GSAS," *Int. J. Sustainable Built Environ.*, **6**(2), pp. 476–490.
- [50] Awada, M., Becerik-Gerber, B., Hoque, S., O'Neill, Z., Pedrielli, G., Wen, J., and Wu, T., 2020, "Ten Questions Concerning Occupant Health in Buildings During Normal Operations and Extreme Events Including the COVID-19 Pandemic," *Build. Environ.*, **188**, pp. 107480.
- [51] Altomonte, S., Allen, J., Bluyssen, P., Brager, G., Hescong, L., Loder, A., Schiavon, S., Veitch, J., Wang, L., and Wargocki, P., 2020, "Ten Questions Concerning Well-Being in the Built Environment," *Build. Environ.*, **180**, p. 106949.
- [52] Keenan, J. M., 2020, "COVID, Resilience, and the Built Environment," *Environ. Syst. Decis.*, **40**(2), pp. 1–6.
- [53] Megahed, N. A., and Ghoneim, E. M., 2020, "Antivirus-Built Environment: Lessons Learned From Covid-19 Pandemic," *Sustainable Cities Soc.*, **61**, p. 102350.
- [54] Bergs, J., 2002, "Effect of Healthy Workplaces on Well-Being and Productivity of Office Workers," Proceedings of International Plants for People Symposium., Amsterdam, Netherlands, June.
- [55] Al Horr, Y., Arif, M., Kaushik, A., Mazroei, A., Kafatygiotou, M., and Elsarrag, E., 2016, "Occupant Productivity and Office Indoor Environment Quality: A Review of the Literature," *Build. Environ.*, **105**, pp. 369–389.
- [56] Andargie, M. S., Touchie, M., and O'Brien, W., 2019, "A Review of Factors Affecting Occupant Comfort in Multi-unit Residential Buildings," *Build. Environ.*, **160**, p. 106182.
- [57] Gidlöf-Gunnarsson, A., and Öhrström, E., 2007, "Noise and Well-Being in Urban Residential Environments: The Potential Role of Perceived Availability to Nearby Green Areas," *Landsc. Urban Plan.*, **83**(2–3), pp. 115–126.
- [58] Lee, J., Je, H., and Byun, J., 2011, "Well-Being Index of Super Tall Residential Buildings in Korea," *Build. Environ.*, **46**(5), pp. 1184–1194.
- [59] PricewaterhouseCoopers, 2020, *When Everyone Can Work From Home, What's the Office For: PWC's US Remote Work Survey*, <https://www.pwc.com/us/en/library/covid-19/us-remote-work-survey.html>.
- [60] Barrero, J. M., Bloom, N., and Davis, S. J., 2021, *Why Working From Home Will Stick*, National Bureau of Economic Research, Chicago, IL.
- [61] Preston, C. C., and Colman, A. M., 2000, "Optimal Number of Response Categories in Rating Scales: Reliability, Validity, Discriminating Power, and Respondent Preferences," *Acta Psychol.*, **104**(1), pp. 1–15.
- [62] Colman, A. M., Norris, C. E., and Preston, C. C., 1997, "Comparing Rating Scales of Different Lengths: Equivalence of Scores From 5-Point and 7-Point Scales," *Psychol. Rep.*, **80**(2), pp. 355–362.
- [63] Hong, T., Lee, M., Yeom, S., and Jeong, K., 2019, "Occupant Responses on Satisfaction With Window Size in Physical and Virtual Built Environments," *Build. Environ.*, **166**, p. 106409.
- [64] Day, J. K., and Gunderson, D. E., 2015, "Understanding High Performance Buildings: The Link Between Occupant Knowledge of Passive Design Systems, Corresponding Behaviors, Occupant Comfort and Environmental Satisfaction," *Build. Environ.*, **84**, pp. 114–124.

- [65] ASHRAE, 2020, ANSI/ASHRAE/IES Standard 55—2020—Thermal Environmental Conditions for Human Occupancy, The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.
- [66] Wagner, A., Gossauer, E., Moosmann, C., Gropp, T., and Leonhart, R., 2007, “Thermal Comfort and Workplace Occupant Satisfaction—Results of Field Studies in German Low Energy Office Buildings,” *Energy Build.*, **39**(7), pp. 758–769.
- [67] Kwon, S.-H., Chun, C., and Kwak, R.-Y., 2011, “Relationship Between Quality of Building Maintenance Management Services for Indoor Environmental Quality and Occupant Satisfaction,” *Build. Environ.*, **46**(11), pp. 2179–2185.
- [68] Bldg-sim—Users of building energy simulation tools, 2021, <http://lists.onebuilding.org/listinfo.cgi/bldg-sim-onebuilding.org>.
- [69] IEA EBC Annex 79, 2021. *IEA EBC—Annex 79—Occupant-Centric Building Design and Operation*, <https://annex79.iea-ebc.org/>.
- [70] IBPSA Project 1, 2021, <https://ibpsa.github.io/project1/>.
- [71] ASHRAE Technical Committee 7.5—Smart Building Systems, 2021, <http://tc0705.ashraetcs.org/>.
- [72] Section MTG—Multidisciplinary Task Groups, 2021, <https://www.ashrae.org/technical-resources/technical-committees/section-mtg-multidisciplinary-task-groups>.
- [73] American Society of Civil Engineers, 2021, <https://www.asce.org/>.
- [74] BTES, 2021. *Building Technology Educators Society*, <https://btes.org/BTES/>.
- [75] SBSE, 2021. *Society of Building Science Educators*, <https://www.sbse.org>.
- [76] Seltman, H. J., 2012, *Experimental Design and Analysis*, Carnegie Mellon University, Pittsburgh, PA.
- [77] Pang, Z., O'Neill, Z., Li, Y., and Niu, F., 2020, “The Role of Sensitivity Analysis in the Building Performance Analysis: A Critical Review,” *Energy Build.*, **209**, p. 109659.
- [78] de Wilde, P., and Tian, W., 2009, “Identification of Key Factors for Uncertainty in the Prediction of the Thermal Performance of an Office Building Under Climate Change,” *Building Simulation*, Springer, New York.
- [79] Social Security Administration, 2020. *Normal Retirement Age*, <https://www.ssa.gov/oact/progdata/nra.html>.
- [80] Hofäcker, D., and Unt, M., 2013, “Exploring the ‘new Worlds’ of (Late?) Retirement in Europe,” *J. Int. Comp. Soc. Policy*, **29**(2), pp. 163–183.
- [81] Ratner, B., 2009, “The Correlation Coefficient: Its Values Range Between+ 1/– 1, or Do They?,” *J Target. Meas. Anal. Market.*, **17**(2), pp. 139–142.
- [82] Dravigne, A., Waliczek, T. M., Lineberger, R., and Zajicek, J., 2008, “The Effect of Live Plants and Window Views of Green Spaces on Employee Perceptions of Job Satisfaction,” *HortScience*, **43**(1), pp. 183–187.
- [83] ASHRAE, 2018. *ANSI/ASHRAE/IES Standard 90.2-2018—Energy-Efficient Design of Low-Rise Residential Buildings*. ASHRAE.
- [84] IEC, 2021. *IECC—International Energy Conservation Code*, 2021.
- [85] International WELL Building Institute, 2021. *WELL Building Standard®*, <https://standard.wellcertified.com/well>.