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Occupant satisfaction with indoor environmental quality, sick building syndrome (SBS) symptoms and self-reported productivity before and after relocation into WELL-certified office buildings

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ABSTRACT

Recent green building certification programs have put a strong emphasis on occupant health and well-being. For recently emerged WELL certification, we lack evidence about its effectiveness in relation to occupant satisfaction, productivity and health. Here, we compared the results of occupant satisfaction with the indoor environmental quality (IEQ) obtained from the same cohort of employees who transitioned from three non-WELL (two BREEAM and one conventional) to three WELL-certified office buildings. For two out of three building pairs, we found a statistically significant increase in building and workspace satisfaction after relocation to WELL buildings. However, for 55 % of compared cases, there was insignificant difference as the result of relocation. The positive effect of WELL certification was evident for parameters such as building cleanliness and furniture, but there was no difference in satisfaction with noise and visual comfort. Relocation from BREEAM to WELL buildings had insignificant effect on satisfaction with IEQ, except for air quality in one case. Regardless of the certification label, buildings usually did not attain the 80 % standard satisfaction threshold. The satisfaction scores did not alter during the first year of working in WELL buildings. We also observed that the level of certification did not scale with the overall building satisfaction scores. Comparisons between the occurrence of Sick Building Syndrome (SBS) symptoms and self-reported productivity scores revealed insignificant differences between WELL and non-WELL buildings, except for symptom of tiredness that was lower in WELL buildings. The effect of Covid-19 measures interfered with the self-reported work abilities of 78 % of occupants.

1. Introduction

Following the energy crisis in the 1970s and resulting one-directional attention to building energy conservation measures, we have witnessed the appearance of Sick Building Syndrome (SBS) symptoms and more severe, cardiovascular and respiratory illnesses. Common SBS symptoms include headache, tiredness, respiratory and eye irritations and other illnesses [1,2], which come with enormous costs through the loss of human productivity and health [3]. These costs far exceed the potential benefits related to energy savings in buildings [3,4]. These findings spurred increased interest in indoor environmental quality (IEQ) and occupant satisfaction worldwide through a revision of existing and development of new green building certification schemes aiming to put a stronger emphasis on occupant satisfaction and health [5].

Occupant satisfaction in green-certified buildings has been studied extensively, but the number of studies that quantified potential benefits of green-certified buildings in terms of occupant satisfaction relative to non-certified buildings is limited. Among the existing green building certification programs, LEED has been studied the most [6]. Majority of studies comparing the occupant satisfaction with IEQ in LEED and conventional buildings reported improved perceived air quality [7–9] and thermal comfort [7,8,10] in the green-certified buildings. On the other hand, Altomonte and Schiavon [11] found insignificant differences between the same building types for air quality and thermal comfort. For lighting, the results are disparate, with studies indicating indifferent [7,8,11], lower [9] or higher satisfaction [12] in LEED compared to non-LEED buildings. Noise is the most commonly reported complaint in LEED buildings with no significant satisfaction differences relative to conventional buildings [7,8,11] or even lower satisfaction scores [9]. In another study comparing the subjective satisfaction data from two BREEAM-certified and two conventional buildings, Altomonte et al. [13] showed significantly worse results for visual privacy and air

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quality in BREEAM buildings and insignificant difference for overall building and workspace satisfaction.

While the majority of the studies comparing the performance of green-certified and non-certified buildings have focused on physical aspects of environmental quality, non-environmental influences such as features of the workspace layout, occupant characteristics and work activities also affect occupant satisfaction and productivity [14]. Frontzcak et al. found the satisfaction with amount of space had the greatest impact on the workspace satisfaction [15]. In a building occupant survey conducted by BOMA [16], more than 90 % of surveyed occupants rated the following six IEQ factors as 'very important': air temperature, air quality, acoustics, quality of building maintenance work, the responsiveness of building management, and the building management's ability to meet the needs of tenants. Schiavon and Altomonte [17] found that several non-environmental factors influence the reported differences in satisfaction scores between LEED and non-LEED certified buildings.

A common feature of studies examining occupant satisfaction in green-certified versus non-certified buildings is that they include direct comparison of subjective results between different groups of occupants. These studies typically lack control for potential confounding factors and rely on insufficiently robust statistical analyses [18]. Additionally, comparing different occupants from different buildings increases the risks of the representativeness of the comparison groups. While being sparse, cohort studies, which follow occupants who transitioned from non-certified to green-certified buildings, are useful to mitigate bias associated with diversity in human nature, organizational difference, social relations, culture, and others.

Among a few studies that directly compared satisfaction before and after relocation into a green-certified building with a same cohort of occupants, Agha-Hossein et al. [19] found that the occupants who moved into a BREEAM-certified building were more satisfied with their workspace in terms of indoor temperature in summer, air quality, and use of space and facilities. Colton et al. [20] collected environmental data and conducted health surveys for relocating residents with a control group in green-certified and conventional houses. They found lower concentrations of fine particles, nitrogen dioxide and nicotine in green-certified buildings, while the surveys showed 47 % lower occurrence of SBS symptoms. MacNaughton et al. [21] relocated occupants into a simulated green office space with control groups and a full control of the ventilation rate. They found that simulated green office led to fewer reports of SBS symptoms relative to conventional conditions, and that the occurrences of the symptoms better matched with the IEQ perceptions than with measured IEQ. Singh et al. [22] examined the relocation of occupants into two LEED buildings; they found an improved perceived IEQ in LEED buildings along with statistically significant decrease in self-reported absenteeism linked to asthma and respiratory allergies, less work hours affected by stress and depression, and increase in employee productivity.

Relocation into a green-certified building can result in "halo effect" [23] by influencing the judgement of occupants because of the existence of a certification label or the excitement with the new workspace environment. Studies that administered surveys repeatedly from a day of moving into a green-certified building do not exist. We hypothesize that the amount of time spent in a green-certified building (in the present study referred to as "time-effect") may influence occupant satisfaction scores. This was suggested by studies in LEED [17] and BREEAM-certified buildings [13], albeit these findings are based on statistical analyses applied to existing datasets in which occupants were not repeatedly surveyed.

While the widely adopted international green building certification programs such as LEED and BREEAM have traditionally paid attention to IEQ, recent emergence of new green building certification programs such as WELL [24] and Fitwel [25] has aimed to put human well-being into the center of building design and operation cycles. In that context, the WELL v2 is the recent and fastest growing international rating system for green buildings with primary emphasis on occupant health. To date, the effectiveness of WELL certification in terms of occupant satisfaction has not been investigated, nor has the success of this program been compared against other green-certified or conventional buildings. To address this and other aforementioned knowledge gaps, we quantitatively compared the results of occupant satisfaction with IEQ between three pairs of non-WELL and WELL-certified office buildings with the same occupant cohorts. The analyses also include exploration of the effectiveness of WELL-certification program in relation to the occurrence of Sick Building Syndrome (SBS) symptoms and self-reported productivity. Furthermore, we report the time-effect after relocation on occupant satisfaction, common sources of dissatisfaction, comparison of satisfaction scores against conventional standards, and impact of Covid-19 measures on the ability to work.

2. Methods

2.1. Description of buildings

We selected three companies (A, B and C) according to their intention to relocate into a WELL-certified office building. In total, we administered the study in three building pairs: three buildings prior to relocation ("pre-WELL") and three buildings after the relocation ("post-WELL"). We conducted a pre-study survey of the building managers to collect information about characteristics of six buildings, including certification type and level, construction and renovation year, heating ventilation and air-conditioning (HVAC) system, area occupied by the company, number of occupants and workstations. This information is summarized in Table 1.

All buildings were located in an urban city area. Specifically, the WELL-certified building of Company A was located near a highway and a gas station, which posed a potential negative effect by the outdoor surroundings. Buildings of companies A and B already had BREEAM certification labels before the relocation, whereas a building of Company C had no certification label (conventional building). Relocation into the new buildings were not far from the previous buildings – within 7 km for each company. On the interior side, all buildings primarily had open plan offices with low partitions, along with several private offices, meeting rooms, kitchen space and corridors. Based on the information provided by the companies, the highest occupant densities were reported in Company A, with similar allocated areas per person in BREEAM (9.1 m^2/person) and WELL buildings (8.7 m^2/person). In Company B, the occupant density was generally low and it further decreased with the relocation (12.8–15.8 m^2/person). In Company C, the occupant density remained constant with the relocation (17.3–17.4 m^2/person).

2.2. Survey protocol

In each company, we collected the survey data in 3 rounds (total of 9 surveys). We administered the first round of surveys within six months before the relocation; the second round within three months after the relocation; and the third round seven to eight months after the second round of survey (Fig. 1). We used the first and third rounds for direct before-after comparisons since the data were collected in the same season, but one year apart. To understand if the time spent in a WELL-certified building significantly affects occupant satisfaction, we assessed the time effect by comparing the results of the second and third round of surveys. The third round of survey in Companies B and C coincided with Covid-19 pandemic, which led us to investigate if the upgraded hygiene practices and mask wearing affected occupants' ability to work in the WELL-certified offices.

Data for each round of survey was collected throughout 3 weeks. We disseminated the survey links to all employees working in a building through building facility managers. This anonymous survey took on average up to 12 min to fill. To increase the response rate (RR), two

Table 1
Characteristics of the three building pairs of Companies A, B and C.

	Company A		Company B		Company C	
Location	The Netherlands	The Netherlands	Germany	Germany	The Netherlands	The Netherlands
Certification	BREEAM-NL	WELL v2	BREEAM-DE	WELL v2 and LEED	None	WELL v2 and BREEAM
Certification level and type	Asset "Very Good", Building Management "Good"	WELL Platinum/ Core&Shell;	Building "Very Good", Building Management "Good"	WELL Gold; LEED Platinum	None	WELL Platinum Core&Shell; BREEAM Excellent; New construction
Construction year	2009	1960	2006	2020	1950	2020
Renovation year	None	2020	2019	None	2002	None
Mechanical ventilation	100 % outdoor air	100 % outdoor air	100 % outdoor air	100 % outdoor air	100 % outdoor air	100 % outdoor air
Heating/Cooling	Fan-coil	Fan-coil	Fan-coil	Fan-coil	Fan-coil	Radiant ceiling
Area occupied by company (m^2)	4223	4361	3080	3800	1210	1220
No of employees	464	500	240	240	70	70
No of workstations	288	309	210	236	64	84

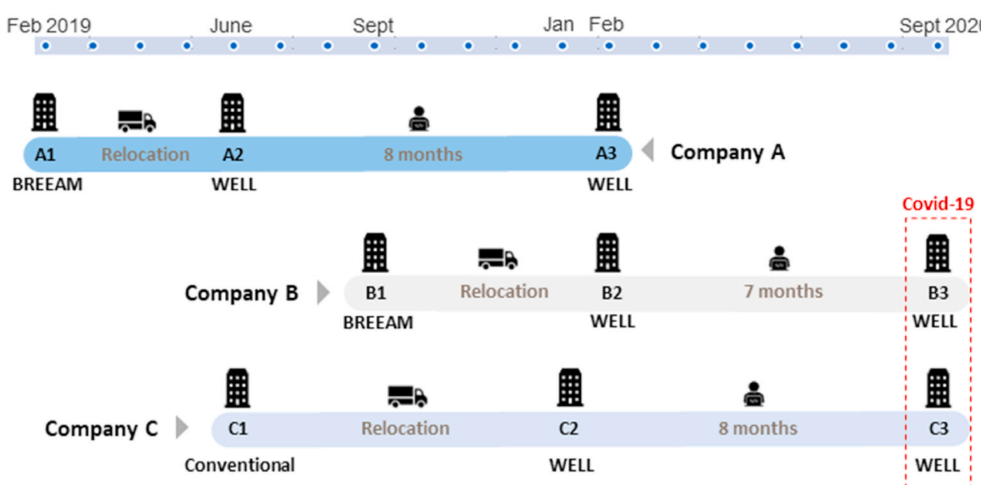

Fig. 1. Illustration for relocation times and data collection periods associated with each company.

follow-up emails were sent. There were no incentives given to respondents.

2.3. Survey design

We developed an online voluntary survey which combines the Center for the Built Environment (CBE) occupant satisfaction survey [26,27] with small customizations, with additional questions about SBS symptoms, and self-reported productivity. The CBE survey covers both environmental and non-environmental parameters of buildings. Our survey contained questions about occupant demographics, satisfaction with environmental (temperature, air quality, lighting and acoustics) and non-environmental parameters (cleanliness and maintenance, and various building features), overall satisfaction with building and workspace, SBS symptoms, self-reported productivity and direct comparison with the previous building. Questions related to SBS symptoms, self-reported productivity and direct comparison with the previous building are summarized in Table S1. During the last round of data collection in the summer of 2020, we incorporated Covid-19 related questions about the effects of mask wearing and hygiene practices.

The satisfaction ratings were evaluated on a 7-point Likert scale; from −3 (very dissatisfied) to +3 (very satisfied), where zero denoted neutral state (neither satisfied nor dissatisfied). The dissatisfied answers prompted the follow-up questions to make the occupants evaluate their source of dissatisfaction. There, the occupants could select one or more reasons and add their comments.

For questions such as self-reported productivity and direct before-after comparison of satisfaction, we also adapted the 7-point Likert scale. For instance, productivity during the working hours was assessed by answers that ranged from −3 (very unproductive) to +3 (very productive). For the direct before-after comparison, we asked the occupants of WELL buildings if the current building enhances or interferes with their satisfaction and overall building experience compared to the previous buildings, and the answers again ranged from −3 (significantly interferes) to +3 (significantly enhances).

2.4. Data analysis and statistical methods

In our study survey, we collected satisfaction votes on an ordinal scale, and we used a comparative approach for the data collected in the three building pairs. The responses to the questions for SBS symptoms, self-reported productivity and direct comparison with the previous building were also recorded on an ordinal scale. We focused on the significance of the differences of mean values for comparing the results as median values may not provide sufficient granularity. The results are presented with the mean, the median, the 1st and 3rd quartiles of votes in boxplots.

We checked all datasets on ordinal scales with Shapiro-Wilk (S–W) normality test [28] and found them as non-normally distributed, which suggested the use of non-parametric statistical tests. To assess the statistical significance of the differences of means of the 2 sample groups with NHST (Null Hypothesis Significance Testing), we used Wilcoxon rank sum test. Also known as Mann-Whitney test, Wilcoxon rank sum test is the non-parametric alternative to *t*-test and gives p-value for variables with an ordinal scale [29]. We considered the calculated p-values to show a statistically significant mean difference when $p < 0.05$, indicating that the probability of a mean difference appearing by chance is less than 5 %. However, the p-value can be affected by the size of the effect and the size of the sample (as the higher number of answers more easily yields a more significant difference) [30,31]. To check if Wilcoxon rank-sum test gives significant results due to the size of the effect, we calculated Spearman's rho values to estimate the standardized size of the mean difference between groups. Since the data was categorical and non-normally distributed, the standardized size of the mean difference and Spearman's rho were equivalent [32,33]. The effect sizes, presented with Spearman's rho, were between −1 and +1, where 0 denoted no association. Spearman's rho values were classified as small (≥0.20), moderate (≥0.50) and strong (≥0.80), and the values lower than 0.20 were considered insignificant [31].

To assess the relationship between occupant responses and building certifications for the before/after cases, we used the individual responses rather than the average values for each buildings. We assigned dummy variables to each answer coming from different groups as 0 for non-WELL and 1 for WELL building. This annotation method was also used to assess the time effect in WELL buildings (i.e. 0 denoting first data collection and 1 denoting data collection after 7–8 months of working). The dummy variable column and satisfaction votes were used in Wilcoxon rank-sum and Spearman rank correlation tests. All data analyses were performed in R Software 3.6.2 [34].

3. Results and discussion

3.1. Description of the dataset

Table 2 summarizes the numbers of collected responses and the response rates for the nine administered surveys. From the total votes obtained, the "newcomers" (new employees that started working after the first survey) were filtered out from the second and the third round of surveys to obtain a cohort group that relocated into the WELL-certified buildings. The newcomers were identified based on the answer "I did not work in the previous building". Thus, "Non-newcomers" indicate only occupants who worked in a company before the relocation.

For surveys, a 50 % response rate rule is generally used to decrease the non-response bias [35]. Standard ASHRAE 62.1 suggests a minimum 30 % response rate [36]. Standard ASHRAE 55 states if the number of occupants who receive a survey is greater than 45, the response rate should exceed 35 % [37]. The low response rates can be misleading because dissatisfied occupants are more likely to fill the survey. However, in a web-based IEQ survey study, Zagreus et al. [26] showed that the relationship between response rate and occupant satisfaction level is not statistically significant. In our study, the response rate for non-newcomers varied between 31 % and 76 % (47 % on average), which was considered suitable for the subjective IEQ assessment. The lowest recorded response rate of 31 % was deemed acceptable.

The respondents were mostly 31–40 years old employees with close distribution of male and female, except for Company C having substantially more male occupants. Most of the occupants did professional, administrative and managerial work. The percentage of occupants that reported different types of allergies were around 20 % in each company. In non-WELL buildings, time spent at a workspace was more than a year for most of the occupants. Most of the occupants worked in an open plan space, with relatively few (≤14 %) working in private offices or focus rooms. Workstations near a window (within 4 m) were more common in BREEAM-certified buildings (90 %). In the conventional building (Company C), around 75 % of occupants worked near a window. The percentage of workstations near a window in the WELL-certified buildings varied between 50 % and 90 %.

3.2. Occupant satisfaction comparison in the pre-WELL and WELL buildings

Fig. 2 illustrates comparison of the mean, median, 1st and 3rd quartiles of the satisfaction votes for overall building and workspace, and environmental and non-environmental parameters in the three building pairs. Table 3 summarizes the comparison of mean votes and their statistical significance before and after relocation. The presented results are one-year apart. Overall, the mean difference before and after relocation across various parameters was not statistically significant in 55 % of compared cases (Table 3). Positive effect on satisfaction owing to relocation was found in 43 %, whereas the negative effect was present only in 2 % of cases. The positive effects of the WELL buildings on satisfaction scores was more evident when the relocation was from the conventional building (Company C), relative to the relocations from BREEAM-certified buildings (Companies A and B). In Company C, for 12 out of 18 parameters of satisfaction, we found statistically significant differences in the mean values. These included overall building and workspace, environmental parameters such as amount of light, air quality and temperature as well as most of the non-environmental parameters including comfort of furnishings, building maintenance and cleanliness.

In Companies B and C, increases of satisfaction with the overall building and workplace after relocation were statistically significant. In Company C (from conventional to WELL-certified), the mean differences in overall satisfaction with building and workspace were larger and statistically more significant (lower p-values and higher Spearman's rho values) compared to the Company B (from BREEAM to WELL-certified). Occupants of Company B moved into a WELL Gold building, whereas occupants of Company C transitioned into WELL Platinum building. The corresponding overall satisfaction scores in WELL Gold (Company B) and WELL Platinum (Company C) buildings were 1.72 and 2.00, respectively (Table S3). These results suggest that the higher relative improvement in the satisfaction scores in Company C could be caused by the higher WELL certification level attained after relocation but also owing to the absence of certification label before relocation. In contrast, overall building satisfaction scores in Company A (WELL-Platinum) was 1.01, which was much lower than the overall building satisfaction of WELL Gold building (1.72). While these results suggest a non-linear relationship between satisfaction scores and the level of certification, analysis of individual credit achievement (not available in the present study) is needed for deeper result interpretation.

In Company A, the overall satisfaction with building decreased after relocation into the WELL Platinum building but this difference was not

Table 2
Number of respondents and response rates (%) in the three building pairs. Non-newcomer votes exclude the votes from new employees that did not work in the pre-WELL buildings.

	Company A			Company B			Company C		
	BREEAM	WELL initial	WELL after 8 months	BREEAM	WELL initial	WELL after 7 months	Conventional	WELL initial	WELL after 8 months
All votes	202 (51)	203 (51)	253 (63)	81 (34)	81 (34)	100 (42)	53 (76)	39 (56)	36 (51)
Non-newcomers	202 (51)	185 (46)	201 (40)	81 (34)	74 (31)	82 (34)	53 (76)	39 (56)	36 (51)

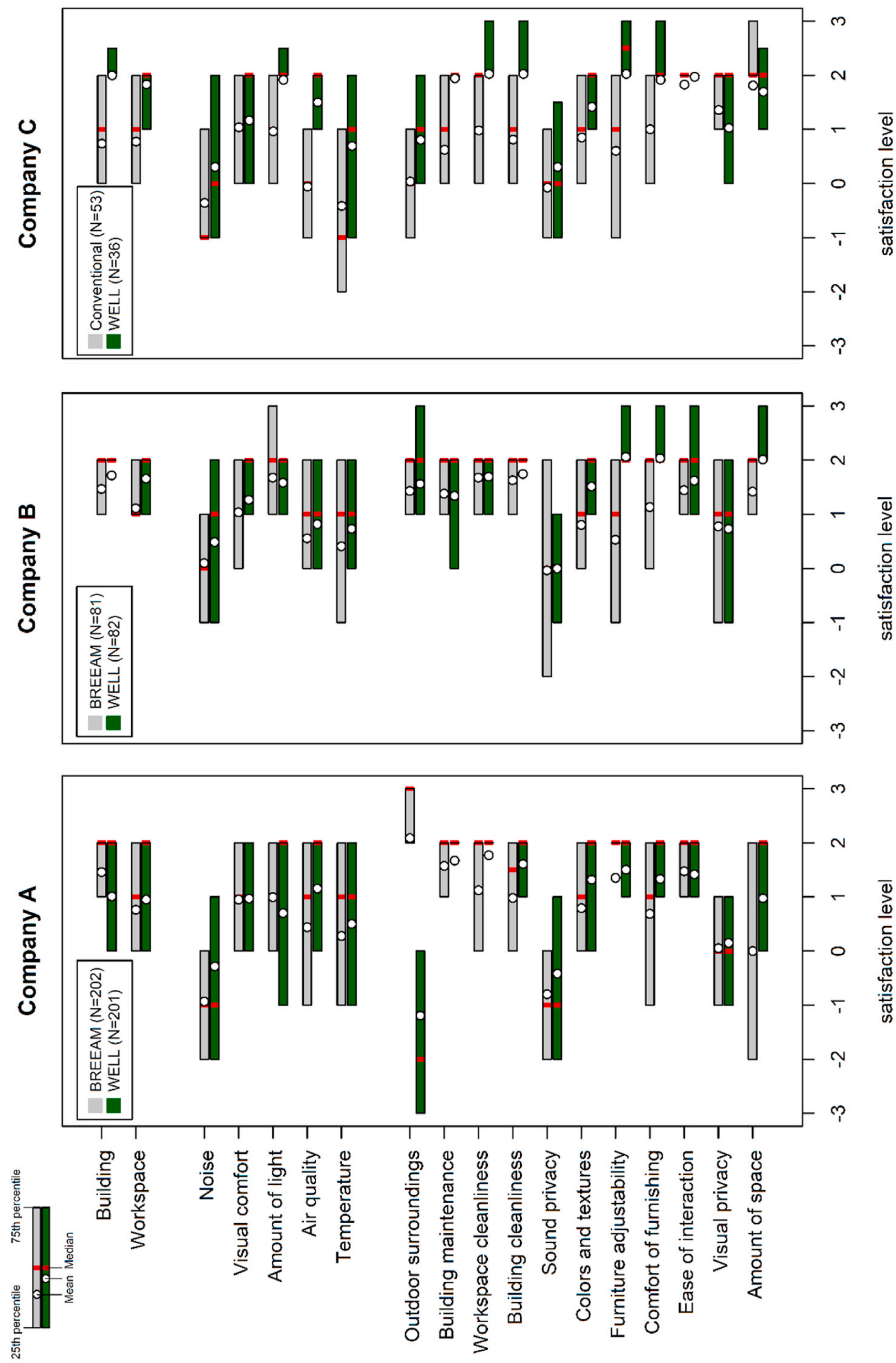

Fig. 2. Comparison of occupant satisfaction votes in the pre-WELL and WELL-certified buildings. Boxplots show 25th and 75th percentiles, mean and median values for each parameter. The outliers, minimum and maximum values were omitted due to the ordinal and limited range of data between −3 (very dissatisfied) and 3 (very satisfied). The newcomers were excluded from the WELL building datasets.

statistically significant (ΔMean = −0.45, $p < 0.01$, Spearman's rho = −0.15). The reduced satisfaction could have been caused by the dissatisfaction with outdoor surroundings after relocation, as it was the only factor with a highly significant decrease in the mean values (ΔMean = −3.28, $p < 0.001$, Spearman's rho = −0.74). This dissatisfaction was likely caused by the proximity of the WELL building to a highway and gas station, and the increased commuting time — which eventually outweighed the potential benefits anticipated by the WELL certification.

As shown in Table 3, when the Companies A and B relocated from BREEAM to WELL buildings, the satisfaction levels with environmental parameters were similar except for the air quality of Company A that significantly improved. In Company C, relocation from conventional to WELL buildings led to significantly improved satisfaction scores with the amount of light, air quality and temperature; the most significant increase in the mean values was seen for air quality (ΔMean = 1.56, $p < 0.001$, Spearman's rho = −0.22). Noise was the most problematic environmental parameter both in WELL and non-WELL buildings with

Table 3
Results of statistical analysis between pre-WELL and WELL buildings that include the mean difference and the significance with respect to p-values and effect sizes (Spearman's rho). Mean differences were calculated by subtracting the mean satisfaction votes in pre-WELL buildings from the mean votes in WELL buildings. Statistically significant mean differences are shown in bold. The mean and standard deviation of satisfaction values for each investigated building are reported in Table S2.

Satisfaction with	Company A		Company B		Company C	
	ΔMean	Spearman's rho	ΔMean	Spearman's rho	ΔMean	Spearman's rho
Building	−0.45**	−0.15	**0.25****	**0.21**	**1.26*****	**0.51**
Workspace	0.19*	0.10	**0.55*****	**0.29**	**1.06*****	**0.39**
Noise	0.65***	0.19	0.39 n.s.	0.12	0.67 n.s.	0.19
Visual comfort	0.02 n.s.	0.05	0.23 n.s.	0.09	0.13 n.s.	0.09
Amount of light	−0.29 n.s.	−0.03	−0.09 n.s.	−0.02	**0.95****	**0.32**
Air quality	**0.71*****	**0.27**	0.26 n.s.	0.12	**1.56*****	**0.48**
Temperature	0.23 n.s.	0.08	0.32 n.s.	0.12	**1.11****	**0.31**
Outdoor surroundings	**−3.28*****	**−0.74**	0.13 n.s.	0.04	**0.77***	**0.26**
Building maintenance	0.10 n.s.	0.07	−0.04 n.s.	0.03	**1.32*****	**0.47**
Workspace cleanliness	**0.65*****	**0.27**	0.02 n.s.	0.05	**1.05****	**0.29**
Building cleanliness	**0.63*****	**0.23**	0.11 n.s.	0.08	**1.22*****	**0.39**
Sound privacy	0.38*	0.12	0.04 n.s.	0.01	0.38 n.s.	0.09
Colors and textures	**0.53*****	**0.21**	**0.71*****	**0.30**	**0.57***	**0.23**
Furniture adjustability	0.15 n.s.	0.01	**1.53*****	**0.48**	**1.42*****	**0.48**
Comfort of furnishing	**0.65*****	**0.24**	**0.90*****	**0.38**	**0.92*****	**0.37**
Ease of interaction	−0.06 n.s.	−0.02	0.18 n.s.	0.14	0.14 n.s.	0.03
Visual privacy	0.10 n.s.	0.04	−0.05 n.s.	−0.02	−0.33 n.s.	−0.08
Amount of space	**0.98*****	**0.27**	0.59*	0.19	−0.12 n.s.	−0.07

***p < 0.001; **p < 0.01; *p < 0.05; n.s., not significant.

close to neutral or even negative mean satisfaction scores (Table S3). With the relocation to WELL Platinum, Company A had an increase in noise (di)satisfaction from −0.93 to −0.28 (ΔMean = 0.65, $p < 0.001$, Spearman's rho = 0.19), but the mean score was still negative. Companies B and C also did not have statistically significant differences in noise satisfaction before and after relocation. We also probed the effect of proximity of workstations to windows. As summarized in the Supplementary Information (Fig. S1, Table S4, Table S5), occupants whose workstations were within 4 m from windows were generally more satisfied with physical IEQ parameters, although this difference was significant only for the amount of light and noise.

In all companies, the positive effect of WELL buildings on satisfaction with non-environmental parameters was evident for comfort of furnishings and colors and textures. Mean satisfaction values with the workspace and building cleanliness were significantly higher in the WELL building of Companies A and B, compared to non-WELL pairs. No significant differences in satisfaction with sound and visual privacies, and ease of interaction were found for non-WELL and WELL building pairs.

In their comparison of non-LEED and LEED buildings, Altomonte and Schiavon [11] found significant p-values for most of the parameters including overall building and workplace, but calculated effect sizes were always negligible (Spearman's rho<0.2). They reported that the occupants tend to be more satisfied with air quality and dissatisfied with the amount of light in the LEED buildings, even though the differences were statistically insignificant. Other study reported that the satisfaction levels with air quality and visual privacy in BREEAM buildings were statistically significantly lower compared to non-BREEAM buildings [13]. In all WELL buildings, we found higher satisfaction with air quality compared to non-WELL, although the mean differences were statistically significant in Companies A and C only. We observed decreased mean satisfaction scores with visual privacy in Companies B and C after the relocation, as similarly reported for BREEAM buildings by Altomonte et al. [13], but in our case the differences were statistically insignificant. For the amount of light in Companies A and B, the mean values were slightly lower in WELL buildings relative to pre-WELL, as similarly found for LEED buildings [11], but the differences were not statistically significant.

As an additional exploration, the occupants of WELL buildings were asked if the current building enhances or interferes with their satisfaction and overall building experience compared to the previous building, which allowed for the direct comparison of the building pairs. As shown in Fig. 3, the mean values were always positive, suggesting that the WELL-certified buildings were generally perceived to enhance the occupant satisfaction in all three companies.

3.3. Time effect after relocation

To probe the time effect on satisfaction after relocation into the WELL-certified buildings, two surveys were administered 7–8 months apart. No major differences were generally found between the two surveys with a few exceptions (Fig. S2, Table S6). Based on this, we deem that halo effect played a minimal role. In Company A, satisfaction with outdoor surroundings became significantly worse after 8 months (ΔMean = −0.72, $p < 0.001$, Spearman's rho = −0.22). This can be a result of increased occupants' fatigue with the unideal location of the

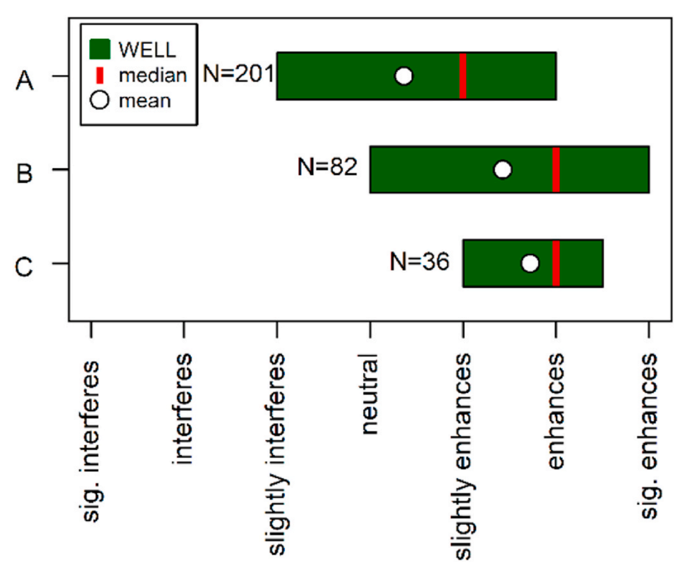

Fig. 3. Response results to the question "Compared to the previous building (location), does the current building enhance or interfere with your satisfaction and overall building experience?" In all three companies, the question was administered 7–8 months after the relocation and ~1 year after the first survey. Boxplots show 25th and 75th percentiles, mean and median values. The newcomers were excluded from the datasets.

WELL building, which was near a highway with limited access to public transportation. In Company B, there was no statistically significant time effect for any parameter; albeit, increase in the satisfaction with temperature was near the statistical significance (ΔMean = 0.52, $p < 0.05$, Spearman's rho = 0.18). In Company C, statistically significant improvements in the amount of light (ΔMean = 1.15, $p < 0.01$, Spearman's rho = 0.35) and workspace cleanliness (ΔMean = 0.51, $p < 0.05$, Spearman's rho = 0.24) were reported after 8 months. The amount of light could be affected by season, since the later survey was administered in the late summer. Satisfaction with the workspace cleanliness in Company C could be attributed to introduced Covid-19 hygiene measures.

Positive effects of green certifications is suspected to decrease with time spent in a building. Schiavon and Altomonte [17] demonstrated that occupants who spent <1 year in the LEED-certified buildings were more satisfied with the overall building and workspace. Altomonte et al. [13] showed a similar trend in their study, with lower satisfaction for occupants who worked more than 24 months in the BREEAM buildings. Unlike these studies, our study re-examined the same group of occupants. More longitudinal studies are needed to confirm that occupant satisfaction with IEQ in WELL office buildings does not significantly change after moving in.

3.4. Comparison with the 80 % satisfaction threshold

In order to put our results in the context of conventional standards, it is useful to use an 80 % satisfaction threshold target from the conventional IEQ standard as a reference point. Fig. 4 compares the percentages of satisfaction with environmental parameters with bare requirements of conventional standard of the 80 % satisfaction threshold in relation to generous (0–3) and strict (1–3) standard criteria. Regardless of the certification label, buildings did not meet the bare 80 % threshold for the majority of environmental factors. The percentages of satisfaction were especially low for noise, temperature and air quality, which is aligned with the existing knowledge from the U.S. office buildings [15]. Furthermore, by examining 26 buildings with radiant systems from the CBE database, Karmann et al. [38] reported that the percentages of satisfaction with noise and temperature were below the 80 % threshold even if more generous standard criteria (from 0 to +3) is used. In seven Green-Mark certified commercial buildings, Cheung et al. [39] also found less than 80 % of satisfaction with noise and temperature. Andersen and Pastore [40] showed that IEQ factors in Minergie-certified green buildings failed to meet the 80 % satisfaction threshold, and that temperature and air quality were the most problematic IEQ parameters.

The results from Fig. 4 suggest that all buildings were far from providing acoustic comfort to the occupants. The lowest percentages of satisfaction with noise were recorded in the BREEAM building of Company A (21 %), which also had the least floor area per occupant (9.1 m^2/person) compared to other companies. With the relocation into the WELL-certified building, the occupancy density remained similar (8.7 m^2/person), but the percentage of dissatisfied occupants with the noise was slightly reduced to 37 %. Interestingly, none of the WELL-certified buildings attained the 80 % satisfaction threshold for noise and temperature, regardless of the adopted criteria for comparison. Even though the conventional building of Company C fell behind the WELL building in parameters such as temperature and air quality, it outperformed the WELL building in noise satisfaction and was over the 80 % threshold if the neutral votes (0–3) were considered. Within the same 0 to 3 interval, the satisfaction with noise was low in the building pairs Companies A and B. Overall, the results suggest that relatively low percentages of occupants are satisfied with building IEQ regardless of the certification label.

3.5. Sources of occupant dissatisfaction in WELL buildings

Fig. 5 shows the sources of dissatisfaction, derived from additional answers from occupants who indicated any level of dissatisfaction with the environmental parameters in WELL buildings. Noise was the primary cause of dissatisfaction in all WELL-certified buildings. Occupants who were dissatisfied with the noise mostly complained about other people talking on the phone, private conversations from their colleagues and ringing phones; which is expected in the open plan offices with low partitions present in this study. Thermal comfort had the second highest number of negative votes with the leading sources of dissatisfaction too cold air, thermostat inaccessibility and inertness of the HVAC system.

3.6. Self-reported productivity

The occupants were asked to rate their productivity in the workplace during the working hours. As shown In Fig. 6a, all answers collected from pre- and post-WELL buildings fell between "somewhat productive" and "productive". No significant difference was observed between pre-WELL and WELL buildings across the three companies. However, when we examined the effect of IEQ on self-reported productivity

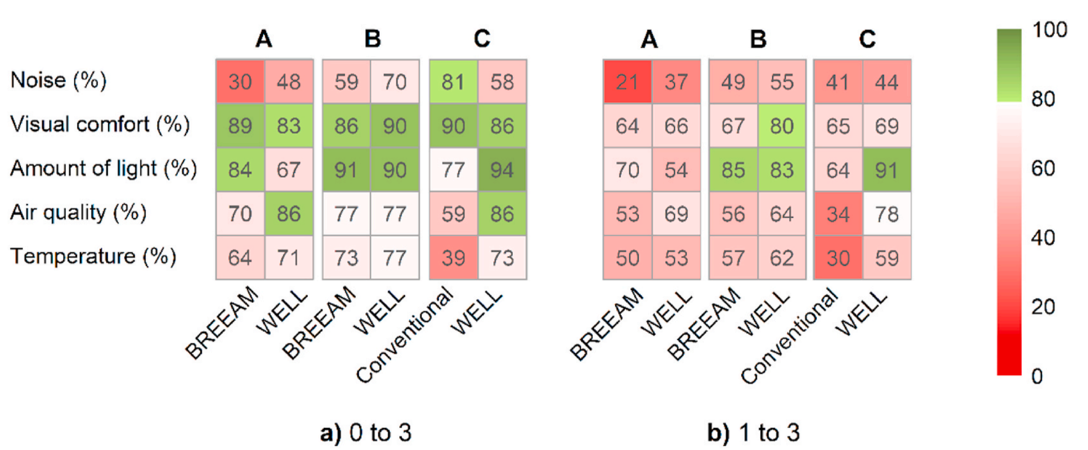

Fig. 4. Percentages of satisfaction with environmental parameters compared to the 80 % satisfaction threshold with respect to adopted scales for positive votes of a) 0 to 3 and b) 1 to 3. For indoor air quality, ASHRAE 62.1–2019 [36] sets the acceptability as 80 % of occupants not expressing dissatisfaction, which is analogous to taking the positive votes from "neutral (0)" to "very satisfied (3)". For thermal comfort, ASHRAE 55–2013 [41] takes the positive votes from "somewhat satisfied (1)" to "very satisfied (3)". In this study, the more generous scale "somewhat dissatisfied (−1)" to "very satisfied (3) from ASHRAE 55–2017 [37] was excluded due to the unfairness of including somewhat dissatisfied into positive votes, especially in the context of green certified buildings. Instead, two other intervals were used (0–3, and 1 to 3) for the purpose of comparison with the 80 % threshold. The newcomers were excluded from the WELL building datasets. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

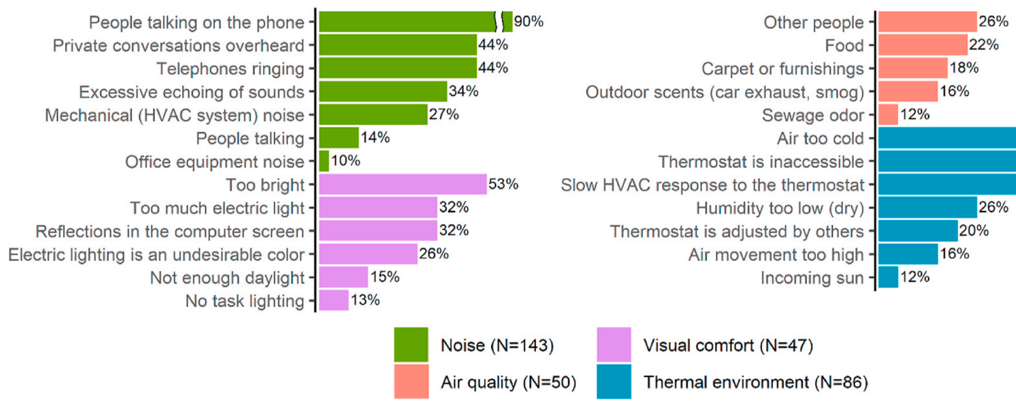

Fig. 5. Source of dissatisfaction with IEQ categories in WELL certified buildings. The responses are aggregates from the three WELL-certified buildings collected 7–8 months after the relocation. The percentages were calculated by dividing the frequency of occurrence of each problem within the negative votes. The reported problems with the occurrence <10 % were omitted. The votes from newcomers were excluded from the datasets.

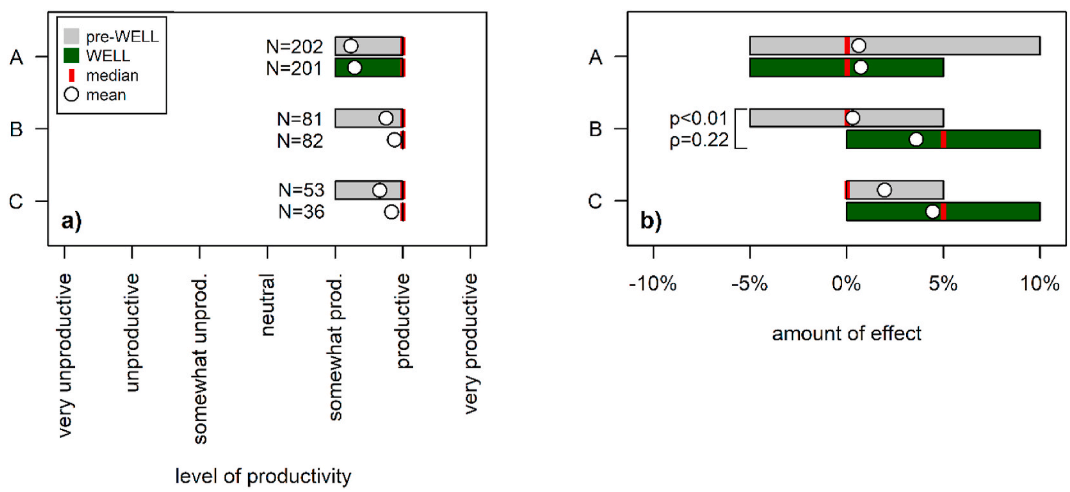

Fig. 6. a) Self-reported productivity and **b)** The effect of IEQ on self-reported productivity. The occupant responses for both questions are sourced from the same pre-WELL and WELL datasets about one year apart. The number of votes were the same for both questions. Boxplots show 25th and 75th percentiles, mean and median values for each parameter. Each interval on the scale is considered as a unit of 1 for statistical tests. The newcomers were excluded from the WELL building datasets.

(Fig. 6b), the occupants of Company B perceived a significant effect of IEQ on their productivity (ΔMean = 0.66, $p < 0.01$, Spearman's rho = 0.22). The results also show that occupants of Company C perceived the positive effect of IEQ in their WELL buildings on self-reported productivity, but the mean differences were statistically insignificant (ΔMean = 0.50, p = n.s., Spearman's rho = 0.19). Summary of the statistical analysis for the three companies is presented in Table S7. Additional regression analysis of self-reported producticity scores agains the worplace and IEQ satisfaction scores expectedly revelased general positive dependance (Fig. S3).

A double-blinded study in controlled environments using computer based decision making tests conducted by Allen et al. [42] reported improved cognitive functions in green office buildings compared to conventional buildings. In our study, mean values of IEQ effect on self-reported productivity between conventional and WELL building of Company C increased by 2.5 % but this result was not significant. However, the recorded increase in the effect of IEQ on self-reported productivity by 3.3 % in Company B with the relocation was significant.

3.7. Sick building syndrome (SBS) symptoms

The percentages of occurrence of SBS symptoms are compared with the 20 % threshold to determine if any of the buildings should be classified as "sick" [43]. The SBS symptom occurrences were reported in one of the following forms: "never (0)", "sometimes (1)" and "often (2)". As shown in Fig. 7, "often" experienced SBS symptoms were generally low (<20 %). The exception was the symptom of tiredness, which exceeded the 20 % threshold in non-WELL buildings of Companies A, B and C. By using the 3-point scale from "never" to "often", statistical analysis (Table S8) showed the decreases in tiredness symptoms as a result of relocation to WELL buildings were not statistically significant, but for Company B it was close to the significance threshold (ΔMean = -0.18, $p < 0.05$, Spearman's rho = −0.18). Comparing the SBS symptom reports in conventional and WELL-certified building of Company C revealed that the percentages decreased after the relocation for all symptoms. The statistical significance was found for irritated eyes only (ΔMean = -0.39, $p < 0.01$, Spearman's rho = −0.29).

3.8. The effect of Covid-19 office regulations

Fig. 8 shows the distributions of facemask wearing and the effect of the upgraded hygiene protocols on the work performance based on the data collected in Companies B and C during the Covid-19 pandemic (September 2020). The face masks were worn regularly only by two thirds of occupants. As many as 78 % of occupants experienced that hygiene protocols (primarily wearing masks) interfered with their work performance, whereas 7 % of them reported neutral and 15 % enhanced effects.

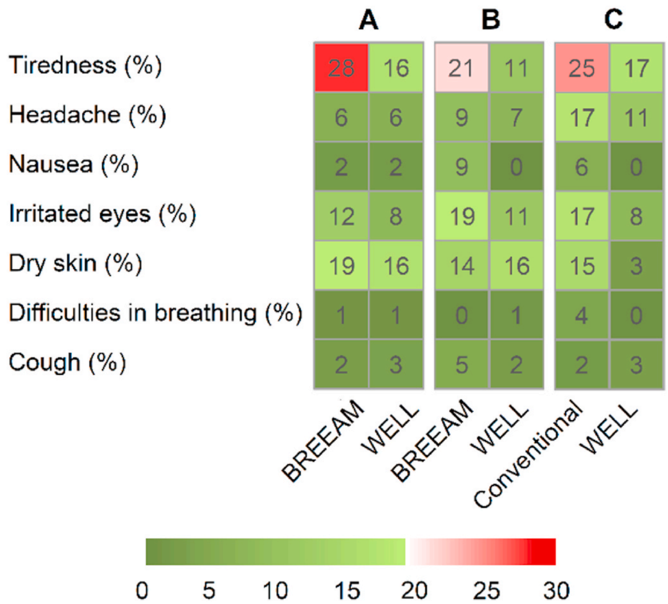

Fig. 7. Percentage of occupants "often" experiencing different Sick Building Syndrome (SBS) symptoms. The newcomers were excluded from the WELL building datasets.

Facemask wearing has become a common measure to minimize the transmission of the SARS-CoV-2 virus [44,45]. Recent research found that doing an office work with a facemask results in approximately 2200 ppm carbon dioxide inhalation exposure [46]. Exposure to carbon dioxide with concentrations above 1000 ppm may lead to physical symptoms like drowsiness and loss of attention [47]. Another possible reason for the reported interferences with the work performance may be resulting from the physical distancing measures and reduced interaction with colleagues. These factors were not isolated with our survey.

3.9. Benchmarking WELL against other office buildings

The data we collected for WELL buildings was compared to the published datasets from subjective IEQ satisfaction studies. The published data taken into consideration were collected with the same 7-point Likert scale and CBE survey [27], thus permitting direct comparisons [11,13]. The comparison buildings included both conventional and green-certified office buildings. The datasets by Altomonte and Schiavon [11] covered 65 LEED and 79 non-LEED buildings, which is a subset of buildings analysed by Frontzcak et al. [15]. In the surveys administered by Frontzcak et al. [15], 86 % of buildings were conventional and 78 % were located in the US. As a result, in this comparison, the non-LEED buildings were treated as conventional buildings. Furthermore, a dataset from BREEAM buildings by Altomonte et al. [13], included two BREEAM buildings located in the UK. Since our study is the first to investigate satisfaction in WELL buildings, none of the comparison studies contained data from WELL buildings.

Fig. 9 shows that the investigated WELL buildings were generally perceived to perform better relative to conventional, LEED- and BREEAM-certified office buildings. The most notable differences were observed in furniture adjustability and thermal environment. Additional notable improvement in WELL buildings was sound privacy, albeit all investigated buildings perform poorly in that category. The qualitative comparison showed no difference in satisfaction between WELL and other buildings for amount of light, visual comfort and privacy, and noise. However, these results should be interpreted with care as 1) the sample size in WELL-certified buildings was relatively small (N = 389); and 2) no statistical analysis could be performed due to the absence of raw datasets from non-WELL buildings.

3.10. Study limitations

In interpreting the reported results, several limitations should be acknowledged. Surveys are useful for obtaining a qualitative understanding of the indoor environment and for detecting potential issues. Yet, the subjective measurements can be biased with other factors. Since the survey participants were generally informed that they were study participants, the 'Hawthorne effect' could have occurred resulting in alteration of the survey responses [48–50]. Secondly, awareness of the existence of a green certification label could have stimulated positive perception of the IEQ [51]. The study occupants knew that they moved into a green-certified building, which could have created bias in their perception. In addition, when occupants are more mindful about the environmental issues, they tend to be more forgiving about the IEQ in the green-certified building [52]. Therefore, not only the actual conditions of the building, but people filling up the surveys are important to assess the final IEQ results. By having the same cohorts, this effect on the comparisons between pre-WELL and WELL buildings was eliminated. Finally, we acknowledge that the Covid-19 pandemic could have influenced satisfaction scores of occupants in buildings B and C, because of introduction of new social distance measures, mask wearing and other protocols. While we quantified the effects of these new protocols on the ability to get the job done, future studies should be designed to quantify their impact on satisfaction scores.

Another limitation was the lack of more detailed information about the obtained green certifications. We could not obtain information about which credits were exactly met. For LEED buildings, Altomonte et al. [50] found that achieving certain IEQ credit does not lead to increased satisfaction with that parameter. Linking the specific credits with survey responses could result in better understanding of the impact of WELL certification on occupant satisfaction.

This study focused on the subjective surveys and aimed to have a

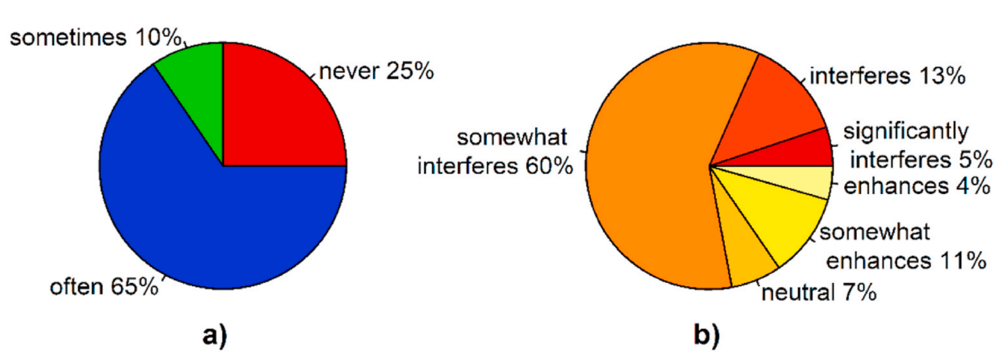

Fig. 8. a) Face mask wearing in the offices of WELL buildings during Covid-19 and **b)** The effect of hygiene protocols on the ability to get the job done during Covid-19. Data were collected in September 2020 in Company B and C. The presented results include responses from all occupants (N = 136, both newcomers and non-newcomers) since there was no comparison with the pre-WELL buildings.

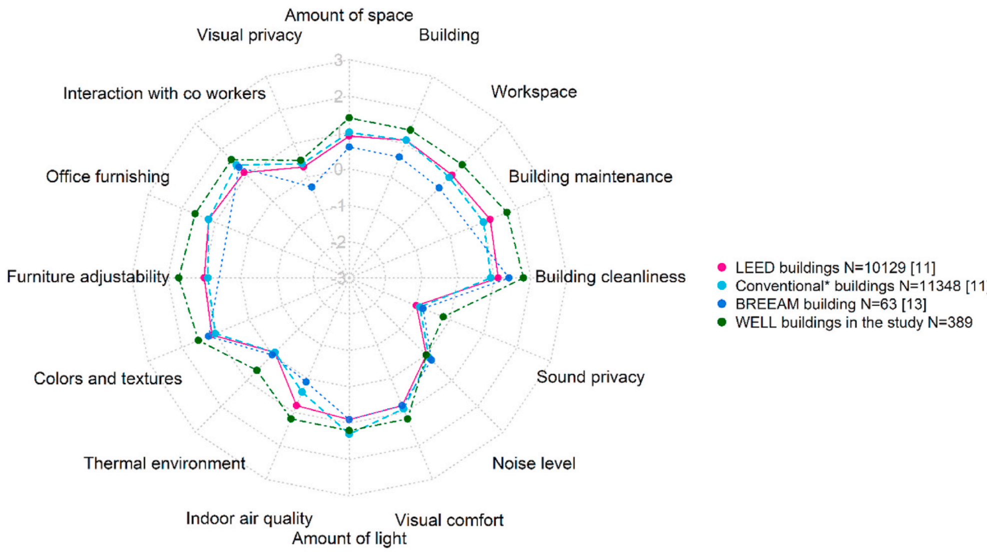

Fig. 9. Comparison between occupancy satisfaction dataset from the three WELL-certified buildings (N = 389) and other three IEQ satisfaction studies. For WELL buildings, the weighted average was calculated from the third round of data collection in WELL buildings (7–8 months after relocation). Votes of newcomers were included. *Conventional buildings included buildings that have not received the LEED certification (the possibility of having another green certification was excluded by Altomonte and Schiavon [11]). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

short filling time and as high as possible number of responses. Rather than using the self-reported productivity, physical measurements of IEQ could be used to assess the real impact of WELL buildings on cognitive performance. If combined with physical data for relevant indoor air pollutants, the cognitive function scores from exposure studies [42] can be compared to the subjective evaluations done in this study. The results could be also coupled with reports of absenteeism, number of working hours per week, employee turnover, number of grievances, and other performance indicators [53], but none of them was available in this study. Even though multiple studies reported the improved IEQ leads to improved productivity by qualitative methods similar to those reported in this study [54,55], future quantitative studies should validate these findings [22,56]. Finally, the presented results provide a snapshot of occupant satisfaction with IEQ; more buildings should be taken into account in order to better benchmark WELL-certified office buildings relative to the existing stock of green-certified buildings.

4. Conclusions

We used questionnaire surveys to assess occupant satisfaction with IEQ before and after relocation into three WELL-certified office buildings. After relocation, occupants reported improved building satisfaction scores in two out of three WELL buildings. The relative improvements were higher after relocating from a conventional to a WELL-certified building, and smaller or absent after relocating from BREEAM-to WELL-certified buildings. Overall, occupant satisfaction due to relocation into WELL buildings improved in 43 % of compared cases, whereas insignificant and negative effect was found in 55 % and 2 % cases, respectively. The relative improvements owing to relocation into WELL buildings were attributed mostly to non-environmental factors, such as building and workplace cleanliness, colors and textures and furniture. Concerning the key IEQ factors (noise, visual comfort, amount of light, air quality and temperature), improvements were evident only when relocating from conventional to WELL building. Transitioning from BREEAM to WELL buildings had insignificant effect to satisfaction with IEQ, except in one case that resulted in improved satisfaction with air quality. We also found that the level of achieved certification (Gold versus Platinum) did not scale well with the overall building satisfaction scores.

Based on repeated surveys, we found that occupant satisfaction scores did not change during the first year of working in WELL buildings. Few exceptions in one of the buildings include increased satisfaction scores with amount of light and workspace cleanliness, and increased dissatisfaction with outdoor surroundings.

Analysis of the occurrence of SBS symptoms revealed that the percentage of occupants who experienced the symptoms “often” was mostly below 20 %. The most common symptom was tiredness, which in BREEAM and conventional buildings exceeded 20 %; the same symptom was lower in WELL-certified buildings, albeit this difference was not significant. Correspondingly, in comparing the self-reported productivity scores before and after relocation to WELL-certified buildings, we found no statistically significant difference.

Supplementary data analyses revealed the following findings:

- All buildings, regardless of the certification label, were unable to attain the 80 % standard satisfaction threshold across most of the IEQ categories. The most problematic factors were noise, followed by temperature and air quality. Common sources of dissatisfaction included noise from other people, too cold air and thermostat inaccessibility.
- Based on the data from two survey campaigns that coincided with the Covid-19 pandemic, 78 % of the occupants reported that hygiene protocols including wearing facemasks interfered with their work abilities.
- Qualitative comparison between the acquired satisfaction dataset in WELL buildings and satisfaction scores from published datasets revealed that occupants in WELL buildings tend to be more satisfied with furniture adjustability and thermal environment, and less dissatisfied with sound privacy. There is, however, no observed difference for the amount of light, visual comfort and privacy, and noise.

To reduce the dependent measurement error, future green building certification studies should adopt a combination of subjective assessments and physical measurements of IEQ. WELL and several other emerging green building schemes prioritize human health, and our study is the first to examine their effectiveness. While the employed statistical approaches were rigorous, our study provides only a snapshot on the overall occupant satisfaction with IEQ in WELL-certified versus non-WELL buildings. Future studies benchmarking the performance of WELL buildings relative to other green-certified or conventional buildings should adopt larger sample sizes to draw conclusions with higher statistical power.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence

the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.buildenv.2021.108183.

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