Satisfaction with Indoor Environmental Quality in BREEAM and non-BREEAM Certified Office Buildings

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This paper presents preliminary analysis of occupant satisfaction with indoor environmental quality in BREEAM and non-BREEAM certified offices in UK. Results from cross-sectional questionnaires (N=121) showed that BREEAM certification per se did not seem to substantively influence building and workspace satisfaction. Conversely, occupants of BREEAM offices tended to be less satisfied with air quality and visual privacy than users of non-BREEAM buildings. Lower satisfaction was also detected in BREEAM offices for occupants having spent over 24 months in their building, and for users working in open-plan spaces. To interpret these findings, a methodology for data analysis was adopted whereas responses to point-in-time surveys (N=82) were paired with environmental measurements. Broadening the perspective for appraising occupants' perceptions, these combined techniques led to conclude that certification schemes should balance criteria addressing energy performance with design solutions considerate of issues of privacy, proxemics, and perceived control over the qualities of the indoor environment.

Keywords: Indoor Environmental Quality; Occupant Satisfaction; BREEAM; Cross-sectional Questionnaire; Non-environmental Factors; Point-in-Time Survey; Environmental Measurements; Control.

Introduction

In December 2015, at the UN Conference of Parties in Paris, almost 200 nations set the goal to "*accelerate the reduction of global greenhouse gas emissions*" (COP21 2015), pushing energy efficiency at the core of the building industry's sustainability agenda. These ambitions reinforce the prominent role that green certification schemes such as the *Building Research Establishment Environmental Assessment Method* (BREEAM) and *Leadership in Energy and Environmental Design* (LEED) are assuming at a global level. However, although these schemes embrace a wide range of environmental issues, there is a risk that a prevailing emphasis given to energy performance may depart attention from the physical, physiological, and psychological impacts that the indoor environment has on building occupants.

Indoor Environmental Quality (IEQ) can be defined as "*the quality of a building's environment in relation to the health and wellbeing of those who occupy the space within it*" (NIOSH 2015). IEQ includes factors such as temperature, air quality, noise, natural and artificial lighting, views, visual and sound privacy, etc. In the workplace, users' IEQ satisfaction has been associated to their comfort, health, wellbeing, and self-estimated job performance (Frontczak et al. 2012). Considering that occupants greatly impact on buildings' energy use (Janda 2011), a vast body of research has studied the influence of physical parameters of the indoor environment on user perception (Frontczak and Wargocki 2011), and the contribution of rating tools to occupant satisfaction. Among other studies, the authors previously analysed a subset of the Center for the Built Environment (CBE, UC Berkeley) Occupant Indoor Environmental Quality Survey database featuring 21,477 responses from 144 buildings (of which, 65 were LEED-rated) to investigate if LEED certification leads to higher, equal, or lower occupant satisfaction. The results showed that users of LEED-rated buildings were equally satisfied with the building, workspace, and several indicators of IEQ than occupants of non-LEED offices (Altomonte and Schiavon 2013). These outcomes were independent of sex, age, office type, spatial layout, distance from windows, building size, work type, and working hours. However, evidence was detected for LEED-rated buildings to be more effective in delivering IEQ satisfaction in open rather than in enclosed offices, and in small rather than in large buildings. Also, tendencies suggested that occupants of LEED buildings might be more satisfied with air quality and less satisfied with amount of light, and that the positive value of certification may decrease with time (Schiavon and Altomonte 2014).

Although research has furthered knowledge on the impact that certification schemes have on occupant satisfaction, with relatively few exceptions (Gou, Lau, and Shen 2012) (Gou, Prasad, and Lau 2013) (Liang et al. 2014) (Thatcher and Milner 2014), studies have been mostly conducted in the US, Canada (Newsham et al. 2012), Singapore (Tham, Wargocki, and Tan 2015) and Australia (Menadue, Soebarto, and Williamson 2013) (Menadue, Soebarto, and Williamson 2014). Conversely, the contribution of rating tools such as BREEAM to workplace experience in the British context is yet to be comprehensively investigated.

In response, this paper offers a preliminary analysis of occupant IEQ satisfaction in recently built BREEAM-rated office buildings in the UK, and compares responses with those provided by users of non-BREEAM certified buildings similar in age, function, size, and location. In addition, this study explores how factors that are unrelated to conventional measures of environmental quality (e.g., time spent in the building, spatial layout, etc.) might affect IEQ satisfaction in BREEAM and non-BREEAM buildings. This paper also aims to propose and test a methodology for interpreting the findings related to the evaluation of occupant IEQ satisfaction in buildings. Consistent with earlier studies, in fact, responses were primarily collected via cross-sectional (transversal) questionnaires based on the CBE survey (CBE 2016). However, to support inferences, point-in-time (right-now) surveys were also administered to occupants while basic physical measurements were taken at their workspace.

Methods

The BREEAM Programme

In 1990, the UK Building Research Establishment (BRE) published a method for assessing, certifying, and rating buildings based on "s*ustainable values […] ranging from energy to ecology*" (BRE 2016a). Being the longest established method globally, BREEAM has awarded to date more than 550,000 certificates in 77 countries, and more than 2.2 million buildings have been registered for assessment since the scheme was launched. BREEAM had an initial focus on new office buildings at the construction stage. However, the scheme was gradually expanded to also cover in-use buildings, refurbishments and fit-outs, infrastructure, and communities (BRE 2016a).

The BREEAM system awards credits under nine categories: Energy; Health and Wellbeing; Land Use; Materials; Management; Pollution; Transport; Waste; and, Water. Further credits can be gained under the Innovation area. BREEAM encompasses both mandatory and optional credits. It is, however, a flexible system that can trade credits, i.e. non-compliance in one area can be offset through compliance in another. The performance of a project assessed by BREEAM is determined by a number of elements: the scope of the assessment; the rating level benchmarks; the minimum standards required; the environmental section weightings; the BREEAM assessment 'issues' and credits, and how these elements combine to produce a BREEAM rating.

As an example, for international fully-fitted non-residential new construction buildings (BRE 2016b), the Health and Wellbeing category weighs 14% of the total score attainable, and assigns credits to the following issues: visual comfort; indoor air quality; safe containment in laboratories; thermal comfort; acoustic performance; accessibility; hazards; private space; and, water quality. Some issues include minimum standards that require compliance depending on the targeted rating level: visual comfort (high frequency ballast), indoor air quality (no asbestos), accessibility, private space, and water quality (minimise legionellosis risk). Other issues are not compulsory for certification, although they contribute to the final score. The BREEAM rating benchmarks achievable are: Unclassified (percentage score <30), Pass (≥30), Good (≥45), Very Good (≥55), Excellent (≥70), and Outstanding (≥85) (BRE 2016b).

Building Selection

The criteria for the selection of the buildings featured in this study required them to be comparable in terms of design brief, geographical location, size, age of construction, distribution and type of occupants' activities, function, etc., and to have received – or have applied for – certification with the BREEAM rating system. This aimed to ensure that differences in the data could be associated essentially to the buildings' BREEAM certification, and that no other physical or organizational factor affected the comparison.

Four buildings were chosen for this preliminary study, all hosting office-type activities. The buildings all included private, shared and open-plan workspaces, had a number of floors ranging between 3 and 4, a size from 3,000 to 3,200 m^2, were built between 2011 and 2012, were owned by the same institution, and were located in the UK's East Midlands area. In terms of operation strategies, all buildings featured a mixed-mode ventilation system and relied on a balance between natural and artificial lighting. Although all buildings responded to the same sustainable building strategic brief, two achieved certification by BREEAM in 2013 (respectively, Outstanding and Excellent), while two marginally failed to obtain the minimum score required for the targeted Excellent BREEAM rating, and lower certification was not pursued since two mandatory credits related to commissioning and microbial contamination were found to be not achievable. The BREEAM-certified buildings received, respectively, 10 and 7 points in the Health and Wellbeing category including, among others, credits for glare control, internal and external lighting levels, thermal comfort, and acoustic performance.

Data Collection

Data were collected in two successive phases, based on two methodologies: cross-sectional (transversal) questionnaires; and, point-in-time (right-now) surveys (Privitera 2016). Table 1 summarises the two datasets used in the analysis.

Suggested location of Table 1

Cross-sectional questionnaires (online) were sent to all the occupants of the selected buildings. Coherent with the structure of the CBE survey, the questionnaire featured an initial section enquiring about participants' sex, age, time spent in the building and at their current workspace, the location of the workspace, its orientation, proximity to windows, and spatial layout (i.e., private office, shared office, cubicle, open space). The questionnaire then asked occupants to rate – on a Likert scale ranging from very dissatisfied (-3) to very satisfied (+3) with a neutral midpoint (0) – their satisfaction with: building; workspace; ease of interaction; building cleanliness; amount of light; colors and textures; amount of space; visual comfort; air quality; visual privacy; noise; temperature; and, sound privacy. Further questions required participants to indicate whether the quality of their workspace enhanced or interfered with their ability to get their job done, and lastly, finished with an open section providing subjects with the opportunity to add comments on the perceived quality of their indoor working environment.

Point-in-time surveys (paper-based) were distributed to volunteering occupants for them to fill in while physical measurements of basic environmental parameters were taken at their workstation with calibrated hand-held equipment. The survey collected information on satisfaction with luminous, acoustic, and thermal conditions, and perceived control over these factors, and offered users the opportunity to give comments on the characters of their workspace. While the survey was filled, a monitoring sheet was completed where measurements were recorded. Table 2 illustrates the equipment and environmental parameters used in this study. All surveys were administered in the month of June, during fully-occupied working hours, between 9am and 11am. For each variable, three measurements were taken, and values were mean averaged for data analysis. Vertical illuminance was taken from the point of view of the user facing the visual task (e.g., computer screen).

Suggested location of Table 2

To perform statistically robust comparisons between occupants' responses in BREEAM and non-BREEAM certified buildings, the two independent groups needed not only to be homogenous in terms of location, size, function and year of construction of the buildings featured in each, but also had to be similar in sample size. In addition, distribution of responses based on several non-environmental factors – i.e., "*factors unrelated to environmental quality that influence whether indoor environments are considered to be comfortable*" (Frontczak and Wargocki 2011) – was also considered, since earlier research had revealed that these might affect significantly the IEQ satisfaction of occupants at their workplace (Schiavon and Altomonte 2014). Table 3 presents a distribution of occupants' responses to the cross-sectional questionnaires based on consideration of non-environmental factors, showing that the two groups (BREEAM and non-BREEAM) provide comparable subsets for the purpose of this study. To be noted that, in terms of spatial layout, two of the categories of workspace type normally featured in the CBE survey – cubicles with high and low partitions – were merged together to obtain a more evenly distributed sample.

Suggested location of Table 3

Statistical Analysis

Cross-sectional questionnaires

The analysis of cross-sectional questionnaires (N= 121) initially consisted in calculating descriptive statistics (e.g., mean, standard deviation, median, interquartile ranges) of votes of satisfaction with the building, workspace, and various categories of indoor environmental quality in BREEAM and non-BREEAM buildings.

Exploratory inspection of the data (e.g., Q-Q plots and Kolmogorov-Smirnov tests) revealed non-normal distribution of statistical values, thus violating one of the assumptions for the adoption of parametric tests. Since data had an ordinal character, the statistical significance (NHST, Null Hypothesis Significance Testing) of the difference in median votes of satisfaction between the two independent groups (ΔMdn, BREEAM minus non-BREEAM) was tested with a two-tailed non-parametric Wilcoxon rank-sum test. Individual responses in each independent group were considered in the analysis instead of average building values. This was to avoid loss of information (e.g., variance) considering that, at the building level, the sample size was small. Results were declared statistically significant when the probability that a difference could have arisen by chance was below 5% ($p \leq 0.05$). However, one of the limitations of NHST is that the *p*-value depends both on the size of the sample and on the size of the influence tested. Therefore, the mean ranks for each group were calculated, and the effect size was estimated for each comparison (Field 2013).

The effect size coefficient places the emphasis on the most essential element of the analysis – i.e., the standardised size of the difference between groups, and not just its statistical significance – therefore providing a more reliable estimator to infer whether the differences detected have any practical relevance (Nuzzo 2014) (Schiavon and Altomonte 2014). In this study, the effect size was calculated by making use of equivalence with the Pearson's r correlation coefficient, using the equation: Effect size= Z-score / √N, where the Z-score was provided by the Wilcoxon tests, and N was the number of observations (Field 2013). The interpretation of the outcome was derived from (Ferguson 2009), where benchmarks are provided for small, moderate, and large effect sizes ($r \geq 0.20$, 0.50, and 0.80, respectively). Values of $r < 0.20$ were considered negligible, and therefore not providing any substantive – i.e., practically relevant (Field 2013) – effect. In this analysis, the interpretation of the effect size was based on its absolute value, i.e. the magnitude of the effect was benchmarked irrespective of its sign. It should be noted that the detection of effect sizes of small magnitude is customary in user-assessment studies. The use of this terminology, however, should not detract from the substantive value of the outcome, and reflects the practical relevance of the effects detected (Field 2013). The same methods were adopted for consideration of differences based on distribution of responses according to non-environmental factors.

Point-in-time surveys

Measurement of environmental parameters taken in BREEAM and non-BREEAM buildings during the administration of point-in-time surveys (N= 82) were statistically compared using two-tailed non-parametric Wilcoxon rank-sum tests (data were non-normally distributed), and the effect sizes of differences were calculated (Pearson's r).

In order to correlate physical measurements with the responses provided by participants, Jonckheere-Terpstra (J-T) tests were performed. These are rank-based non-parametric tests that require independent groups divided into ranked orders to search for statistically significant trends between (continuous or ordinal) independent and dependent variables (Jonckheere 1954). Dependent variables were measured at the ordinal level based on 7-point Likert scales (e.g., from "*no discomfort*" to "*a lot of discomfort*"). In this case, the effect size (Pearson's r) was used to measure both the magnitude and the directionality of the trend, i.e. whether there was a direct or inverse relationship (positive or negative sign) between variables. The interpretation of the outcome was again derived from (Ferguson 2009). For lighting and noise, the physical readings – illuminance (lux) and sound pressure levels (dB(A)) – were directly used in the statistical tests. For thermal sensation, since the buildings were not free-running, measures of dry bulb temperature, humidity, air speed, and mean radiant temperature (derived from globe temperature), were combined with estimations of metabolic rate and clothing levels to determine the Predicted Mean Vote (PMV), which was calculated via the CBE Thermal Comfort Tool web application (comfort.cbe.berkeley.edu) according to ASHRAE Standard 55 (Schiavon, Hoyt, and Piccioli 2014).

The analysis was performed with SPSS statistical software version 21.

Results

Occupant satisfaction in BREEAM and non-BREEAM buildings

Table 4 provides the descriptive and inferential statistics from the analysis of the cross-sectional questionnaires (N= 121). For each category, the table presents the mean, standard deviation, median and interquartile ranges of occupants' satisfaction votes in BREEAM and non-BREEAM buildings, the median differences (ΔMdn) and the interpretation of their two-tailed statistical significance (NHST, Null Hypothesis Significance Testing expressed in terms of *p*-value), the mean ranks of independent groups, the Wilcoxon test statistic (W), and the effect sizes (r). The plotting order of categories follows the ranking presented in (Altomonte and Schiavon 2013) so as to facilitate a visual comparison of results with previous work. Values in bold italic are statistically significant ($p \leq 0.05$) and have substantive magnitude of effect ($r \geq 0.20$, absolute values were considered for interpreting the practical relevance of effect sizes).

Suggested location of Table 4

Analysis of descriptive statistics in both independent groups revealed positive mean (M) and median (Mdn) scores of satisfaction with the building and with the workspace. The inferential tests showed that users of BREEAM and non-BREEAM offices expressed equal satisfaction with these two categories, as per the non-statistically significant median differences between groups (ΔMdn) and the effect sizes of negligible magnitude (r=-0.16) (Table 4).

For other IEQ categories, satisfaction votes in both BREEAM and non-BREEAM buildings showed positive or neutral mean and median values, except for visual privacy and sound privacy. The inferential tests revealed that BREEAM-rated buildings had equal or lower median scores of satisfaction with these IEQ categories than non-BREEAM buildings (ΔMdn values are, in fact, always zero or negative), although the differences detected were statistically significant only for satisfaction with amount of space, air quality, visual privacy, and sound privacy.

Satisfaction with air quality showed a significant median difference with the largest practically relevant effect size (r= -0.27). This suggests a trend for higher occupant satisfaction with air quality in buildings not certified by BREEAM. Consideration of visual privacy detected higher occupant satisfaction in non-BREEAM buildings, as denoted by a statistically significant difference between groups and an effect size of substantive relevance (r= -0.20). Inferential results for amount of space and sound privacy showed tendencies for higher satisfaction in non-BREEAM buildings, this being supported by statistically significant differences, although effect sizes were slightly lower than the borderline of practical relevance (r= -0.18) (Table 4). The results of the inferential tests are graphically summarised in Figure 1.

Suggested location of Figure 1

Influence of non-environmental factors on occupant satisfaction

Table 5 to 9 present selected results of the inferential tests for the satisfaction votes expressed by occupants upon consideration of their sex (Table 5), time spent in the building (Table 6), time spent at the workspace (Table 7), distance from windows (Table 8), and spatial layout (Table 9). Data related to the age groups of users have not been reported in tables since no statistically significant differences were detected. The tables present the sample sizes of independent groups (x_0= BREEAM, x_1= non-BREEAM), the median and interquartile range of satisfaction votes, the median differences (ΔMdn) and the interpretation of their two-tailed statistical significance (NHST), the mean ranks, the Wilcoxon test statistic (W), and the effect sizes (r).

Sex

As shown in Table 5, the inferential tests based on consideration of occupants' sex did not detect statistically significant differences in satisfaction with the building and with the workspace for male and female users of BREEAM and non-BREEAM buildings. Analysis of differences in satisfaction for all other IEQ categories revealed that median votes given by males were often higher than females both in BREEAM and non-BREEAM buildings, and were consistently positive except for sound privacy and visual privacy. When comparing satisfaction scores given by males in BREAAM and non-BREEAM buildings, no statistically significant differences were detected. Conversely, analysis of votes from female users detected statistically significant and practically relevant higher satisfaction with amount of space (r= -0.27), air quality(r= -0.55), visual privacy (r= -0.43), temperature (r= -0.28), and sound privacy (r= -0.29) in buildings not certified by BREEAM.

Suggested location of Table 5

Age

Analysis of satisfaction votes expressed by occupants from different age groups (under 30, 30-40, 41-50, over 50) did not show statistically significant differences between BREEAM and non-BREEAM buildings, and for this reason these data have not been reported in a table format. However, effect sizes of substantive magnitude were detected for several comparisons. For example, occupants over 50 years of age tended to be more satisfied with the building (r=-0.34), workspace (r= -0.22), ease of interaction (r= -0.22), air quality (r= -0.27), noise (r= -0.35), visual privacy (r= -0.33), and sound privacy (r= -0.35) in non-BREEAM buildings. This suggests that age could have an effect on differences in satisfaction with the qualities of the indoor environment, although the small sample sizes of independent groups used in this analysis might not have allowed detection of statistical significance.

Time spent in the building

For occupants who spent less than 12 months in their building, the median votes of satisfaction were consistently positive for all variables considered, except for the satisfaction with temperature expressed by users having occupied their BREEAM building for 6- 12 months (Mdn= -0.50). Among other inferential tests, Table 6 presents the results for the satisfaction votes provided by users having spent over 24 months in their building. The data reveal in non-BREEAM offices a statistically significant and practically relevant higher satisfaction with workspace (r= -0.38), building cleanliness (r= -0.30), amount of space (r= -0.33), visual comfort (r= -0.28), air quality (r= -0.40), visual privacy (r= -0.46), noise (r= -0.35), temperature (r= -0.33), and sound privacy (r= -0.34). An analogue tendency was detected for satisfaction with the building, although such difference had a substantive effect size (r= -0.27), but it was not statistically significant. Similar results of practically relevant but not statistically significant differences were also found for higher satisfaction with noise (r= -0.25) and sound privacy (r= -0.36) in non-BREEAM offices for users having occupied their building for 12-24 months.

Suggested location of Table 6

Time spent at the workspace

As per the data of Table 7, participants who spent over 24 months at their workspace in a non-BREEAM building expressed statistically significant and practically relevant higher satisfaction with building cleanliness (r= -0.39), amount of space (r= -0.37), visual privacy (r= -0.49), and sound privacy (r= -0.36). For this group of users, similar tendencies were detected also for satisfaction with workspace (r= -0.28), visual comfort (r= -0.33), air quality (r=-0.23), noise (r= -0.32), and temperature (r= -0.22); these differences were not statistically significant, yet suggesting a trend for higher satisfaction in non-BREEAM buildings. For other groups of occupants, differences in satisfaction between BREEAM and non-BREEAM offices were consistently not statistically significant, with the exception of a significant higher satisfaction with air quality in non-BREEAM buildings expressed by users having occupied their workspace for 6-12 months (r= -0.52).

Suggested location of Table 7

Distance from windows

Satisfaction votes provided by occupants whose workstation was within 4.6 m (15 feet) from windows were consistently higher than those expressed by users sitting far from the perimeter in both BREEAM and non-BREEAM buildings, as shown in Table 8. However, no statistically significant differences in satisfaction could be detected for this group of occupants between certified and non-certified offices. Conversely, users sitting further than 4.6 m from windows expressed statistically significant and substantive higher satisfaction with the building, workspace, and almost all IEQ categories in non-BREEAM buildings. These significant differences in satisfaction ranged from small (colors and textures, r= -0.29) to moderate (sound privacy, r= -0.50) effect sizes. The only exceptions were represented by satisfaction with ease of interaction and temperature, which resulted in non-statistically significant differences and effect sizes marginally lower than the benchmark for practical relevance (r= -0.19 and -0.17, respectively), although following a trend for higher satisfaction in non-BREEAM buildings.

Suggested location of Table 8

Spatial layout

Median satisfaction votes expressed by occupants of enclosed offices (private and shared) were positive in both BREEAM and non-BREEAM buildings. For these spatial layouts, inferential tests did not detect statistically significant differences, even if effect sizes of mostly practical relevance suggested higher satisfaction in non-BREEAM buildings. For users of cubicles, differences varied depending on IEQ category, but were consistently not significant. The inferential data related to the satisfaction expressed by users working in open-plan offices is presented in Table 9. For these occupants, statistically significant and substantive higher satisfaction with the building, workspace, and almost all IEQ categories was detected in non-BREEAM buildings.

Suggested location of Table 9

Point-in-time surveys and physical measurements

Table 10 provides descriptive and inferential statistics for the comparison of physical measurements taken in BREEAM and non-BREEAM buildings. The table presents the environmental parameters, the building groups and their size (N), the mean, standard deviation, median, interquartile range, minimum and maximum of measured values, the Wilcoxon test statistic (W) and the statistical significance of the differences between independent groups (*p*-value, calculated with a two-tailed test), and the effect sizes (r). Horizontal and vertical illuminances are presented in total values (natural plus artificial light) to fully describe the luminous environment characterising the workspaces, and air speed measures are not reported due to the low values recorded (mostly ranging between 0.0 and 0.1 m/s). All differences between values measured in BREEAM and non-BREEAM buildings were non-statistically significant nor practically relevant, with the only exception of relative humidity (r= -0.50).

Suggested location of Table 10

Since the environmental conditions of workspaces in BREEAM and non-BREEAM buildings were substantially similar, and in line with regulatory values for office spaces, the responses to the point-in-time surveys were paired by Jonckheere-Terpstra (J-T) tests with the physical measurements taken onsite for light, sound, and thermal sensation (N= 82). This aimed to detect direct or inverse relationships between responses from users and measured data, explore differences between BREEAM and non-BREEAM buildings, and contribute to the interpretation of the results from the cross-sectional questionnaires.

Tables 11-13 present the data from the J-T tests for light, sound, and thermal sensation. The tables provide uniquely the results of the tests for which statistical significance or practical relevance was detected. For each measured variable, the tables report the building group, the J-value, the test statistic (Z-score), the two-tailed statistical significance of differences (*p*-value), and the effect sizes (r). The estimation of statistical significance was supported by calculation of Monte Carlo simulated lower and upper 99% confidence intervals (not reported in tables). Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes ($r \geq 0.20$, the magnitude of the effect size was interpreted considering its absolute value).

Light

In BREEAM buildings, no statistically significant nor practically relevant relationships were detected between measured horizontal and vertical illuminance, users' assessment of lighting availability (ranging from "*too little*" to "*too much*"), perceived control, and reported discomfort (Table 11). Conversely, in non-BREEAM offices, substantive direct associations (i.e., positive effect size) were detected between assessments of natural lighting availability and measured horizontal (p= 0.01**, r= 0.43) and vertical (p= 0.03*, r= 0.38) illuminance. Direct trends were also found in non-BREEAM buildings between perceived control over light and horizontal illuminance (natural: p= 0.02*, r= 0.39; artificial: p= 0.02*, r= 0.40). Statistically significant and practically relevant inverse relationships (i.e., negative effect size) were detected in non-BREEAM offices between discomfort from light and horizontal (natural: p= 0.05*, r= -0.33; artificial: p= 0.01**, r= -0.43) and vertical (artificial: p= 0.01**, r= -0.43) illuminance.

Suggested location of Table 11

Sound

A statistically significant and practically relevant direct relationship was detected between users' description of noise (ranging from "*very quiet*" to "*very loud*") and measured sound pressure in BREEAM buildings (p= 0.002**, r= 0.44). This trend was not found in non-BREEAM buildings (Table 12). A significant and substantive inverse relationship appeared between perceived control over noise and dB(A) levels in BREEAM offices (p= 0.01**, r= -0.37), while a significant and practically relevant direct trend was detected in non-BREEAM buildings (p= 0.02*, r= 0.39).

Suggested location of Table 12

Thermal sensation

A highly significant and practically relevant direct relationship was detected between users' description of thermal sensation (ranging from "*cold*" to "*hot*") and calculated PMV in BREEAM buildings (p< 0.001***; r= 0.51). This trend was also substantiated by results in non-BREEAM buildings, although at lower level of significance and effect size (p= 0.01**; r= 0.44). The tests considering the relationships between perceived control over the thermal environment and calculated PMV did not detect any significant nor substantive trend, and therefore have not been reported in Table 13.

Suggested location of Table 13

Discussion

This study sought to provide a preliminary analysis of occupant IEQ satisfaction in BREEAM and non-BREEAM rated office buildings, and investigate if BREEAM certification has a statistically significant and practically relevant influence on satisfaction with the building, workspace, and several IEQ categories.

Although, consistent with the literature (Frontczak et al. 2012), occupants were in general reasonably satisfied with their indoor environment (i.e., mostly positive mean and median satisfaction votes), rigorous statistical analysis of the data from the cross-sectional questionnaires leads to infer that the achievement of BREEAM certification *per se* does not have a significant and substantive influence on satisfaction with the building and the workspace. Conversely, users of non-BREEAM buildings expressed a statistically significant and practically relevant higher satisfaction with air quality and visual privacy. Tendencies also suggested that users of non-BREEAM offices might be more satisfied with sound privacy and amount of space (Table 4). These results are coherent with previous research by the authors (Altomonte and Schiavon 2013), where the achievement of LEED certification was found not to substantively affect occupant satisfaction with the building and the workspace. Also, in line with earlier studies, satisfaction with sound privacy, visual privacy, temperature, air quality, and noise corresponded to the lowest mean and median scores in BREEAM buildings. Issues related to lack of privacy are recurrent in green-buildings research (Kim and De Dear 2013), likely due to the incentive towards the design of open spaces that can support the achievement of credits for natural ventilation and daylight penetration. However, previous studies on LEED-rated buildings detected higher satisfaction with air quality (Newsham et al. 2013), a result that is not supported by our study. This could be explained by the two prerequisite credits for minimum indoor air quality performance and environmental tobacco smoke control that are compulsory for a new building to obtain LEED certification (USGBC 2016), while only one air quality credit related to the absence of asbestos is mandatory for BREEAM rating (BRE 2016a).

In terms of the influence of non-environmental factors on occupants' responses, consideration of sex did not lead to detect significant differences in satisfaction with the building and the workspace between BREEAM and non-BREEAM offices, although female users expressed higher satisfaction with various IEQ categories in buildings not certified by BREEAM. Analysis of satisfaction votes also revealed that males tended to be more satisfied with the qualities of their indoor environment than females (Table 5). These findings are consistent with those of (Kim et al. 2013), who found that female occupants were significantly more likely to express dissatisfaction with IEQ than males.

In line with the findings of (Frontczak and Wargocki 2011), age groups could not be associated to significant differences in occupant satisfaction.

Inferential tests revealed that IEQ satisfaction tended to decrease with the increase in time spent in the building and at the workspace, this being particularly evident in BREEAM-rated offices. In addition, users who spent over 24 months in their BREEAM-certified building and workspace expressed statistically significant and practically relevant lower satisfaction with their workspace and with several IEQ categories than occupants of non-BREEAM buildings (Tables 6 and 7). These results are consistent with those of (Schiavon and Altomonte 2014), who concluded that users of LEED-rated offices having spent less than one year at their workplace had higher IEQ satisfaction than users who occupied their building for more than 12 months. In this context, (Singh et al. 2010) suggested that IEQ satisfaction might be higher immediately after moving into a new green building, hence questioning the positive effect of green certification on occupants' perception over time. It must be emphasised that the number of study participants having occupied their building and their workspace for over 24 months was broadly similar between BREEAM and non-BREEAM buildings (Table 3). Conversely, a larger percentage of users had occupied their workspace for less than 6 months in non-BREEAM buildings (41% against 28% in BREAAM offices). This could have brought a potential source of bias in comparing occupants' assessments of the qualities of their indoor environment. However, no statistically significant differences in satisfaction between BREEAM and non-BREEAM offices were detected for users who had only recently (0-6 months) moved to their workspace.

Results related to consideration of distance from windows (Table 8) and spatial layout (Table 9) are in line with those of (Leder et al. 2016), who stated that access to a window positively affects workplace experience and suggested that IEQ satisfaction is higher in enclosed offices, a conclusion that is supported by our data. In our study, the spatial layout had considerable influence on the difference in satisfaction between BREEAM and non-BREEAM buildings, although – contrary to previous research (Schiavon and Altomonte 2014) – occupants of open-plan offices showed to be significantly and substantively more satisfied with almost all IEQ categories in buildings not certified by BREEAM. These results can be explained by the findings from the pairing of the point-in-time surveys with the physical measurements, as discussed below.

The Jonckeere-Terpstra tests related to consideration of the luminous environment, in fact, detected no significant or practically relevant relationship in BREEAM buildings between measured illuminance levels (horizontal and vertical), users' assessment of lighting availability, their perception of control over it, and reported discomfort. Conversely, direct associations were found between reported luminous qualities and measured parameters in non-BREEAM offices (Table 11). These findings lead to infer that perception of lack of control over lighting in BREEAM buildings – particularly in open-plan layouts, as per the analysis of the comments provided – could have resulted in a luminous assessment that was effectively detached from fluctuations in illuminance levels. This might have ultimately led to lower satisfaction with the qualities of the indoor luminous environment. Conversely, perception of personal control over lighting was reported in non-BREEAM buildings, allowing users to directly intervene at the occurrence of temporary visual discomfort, and therefore enhancing feelings of satisfaction with illuminance conditions.

In terms of the aural environment, in BREEAM buildings a direct relationship was found between measured acoustic parameters and users' description of noise, while an inverse trend was detected between decibel levels and perception of control over noise. Conversely, a direct relationship was found between sound measurements and reported level of control in non-BREEAM offices (Table 12). In interpreting these findings, it should be reminded that statistically and practically significant lower satisfaction with noise and sound privacy was detected in the cross-sectional questionnaires for users working in BREEAM-certified open spaces. Similar results were also found for occupants whose workstation was located further than 4.6 m from a window, this being often the case in an open-plan office (respectively, satisfaction with noise: $r = -0.43$; satisfaction with sound privacy: $r = -0.50$). This suggests that users of

BREEAM offices might have been more sensitive to sound and to disturbance from noise than occupants of non-BREEAM buildings. This higher sensitivity might be more evident in open workspaces where direct control over the aural environment could be perceived as more challenging (Kim and De Dear 2013).

Finally, for the thermal environment, a direct relationship was detected between reported thermal sensation and calculated PMV in BREEAM buildings. This relationship had larger magnitude than the same tendency found in non-BREEAM offices (Table 13). This leads to infer that occupants of BREEAM-rated workspaces might have been more sensitive to changes in their thermal environment than users of non-BREEAM buildings. However, no significant trend was detected in either groups of buildings for the relationship between perception of thermal control and calculated PMV. This is in contrast with the analysis of open-ended comments provided by occupants of BREEAM buildings, who often related their higher dissatisfaction with temperature to a perceived lack of control. This suggests that, in rich dynamic working spaces, the complex influence of a number of physical, physiological, and psychological variables should be comprehensively considered when evaluating thermal expectations and experience (Parkinson and De Dear 2015) (Brager, Zhang, and Arens 2015).

Conclusions

The main conclusions to be drawn from this study are:

- In the dataset analysed, BREEAM rating per se did not seem to significantly and substantively affect occupant satisfaction with the building and the workspace.
- Occupants of non-BREEAM rated buildings showed trends for significant and substantive higher satisfaction with air quality and visual privacy than users of BREEAM-certified offices. Tendencies were also detected for users of non-BREEAM buildings to be more satisfied with sound privacy and amount of space.
- Lower satisfaction with most IEQ categories was detected in BREEAM offices for occupants having spent more than 24 months at their building and workspace, and for users working in open-plan layouts.

- Pairing of occupants' responses with physical measurements led to infer that lower satisfaction in BREEAM buildings, particularly in open workspaces, might be associated with a perceived lack of control over the luminous, aural, and thermal environments.

In interpreting these results, some limitations should be acknowledged. First of all, only a narrow sample of buildings and a limited number of responses were used for the analysis. Also, the buildings were chosen to be as similar as possible for them to be statistically comparable, and they were all located in the same geographic area, so they cannot be representative of all buildings certified by BREEAM. Moreover, only basic environmental parameters were recorded in the workspaces analysed. Finally, occupant responses have not been related to the distribution of BREEAM credits targeted or attained by buildings in the Health and Wellbeing category.

Regardless these limitations, this study has provided some useful preliminary data on which further research, on larger samples and supported by the recording of more detailed and varied environmental parameters (e.g., air quality), can be developed. In the sample used for this analysis, occupants were reasonably satisfied with their building and workspace. This is a testament to the efforts devoted by designers and green certification systems to provide comfortable working environments. However, consistent with previous research on other rating systems (e.g., LEED), the findings from this study suggest that, to improve workplace experience, BREEAM might benefit from balancing the credits that directly address criteria of visual, acoustic, air quality, and thermal performance, with design solutions and spatial strategies that are considerate of issues of privacy and proxemics (e.g., amount of space), and are conducive to perceived control over the qualities of the indoor environment. The results also suggest the need for rating systems to reinforce mandatory criteria that can guarantee minimum standards in specific areas (e.g., air quality), and support the requirement for further research on the sustained benefits of certification over time.

Far from being a criticism of BREEAM or other rating schemes, studies such as that presented in this paper can provide evidence-based data to improve the standards promoted and achieved in green certification, whereas the emphasis given to energy performance should not come to the detriment of indoor environmental quality and user satisfaction. Also, they can propose and test methodologies – relatively new to green-building research – for assessing the effectiveness of certification schemes from the occupants' point of view through a combination of cross-sectional questionnaires, point-in-time surveys, and physical measurements. The use of these techniques, and the application of appropriate methods of statistical testing, can reinforce the rigour of the analysis and broaden the perspective for interpreting the information provided by users. As pointed out by (Allen et al. 2015), in fact, one of the strongest limitations of the research in this field is related to the frequent reliance on indirect and abstract indicators, without a direct appraisal of the factors that mostly impact on the perception that occupants have of the qualities of their indoor environment. This study has intended to offer a methodological contribution in this direction.

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References

Allen, J.G., P. Macnaughton, J.G.C. Laurent, S.S. Flanigan, E.S. Eitland, and J.D. Spengler. 2015. "Green buildings and health." *Current Environmental Health Reports* 2:250-8.

Altomonte, S., and S. Schiavon. 2013. "Occupant satisfaction in LEED and non-LEED certified buildings." *Building and Environment* 68:66-76.

Brager, G., H. Zhang, and E. Arens. 2015. "Evolving opportunities for providing thermal comfort." *Building Research & Information* 43 (3):274-87.

BRE, 2016a. "What is BREEAM?" Building Research Establishment, Accessed 05 November. http://www.breeam.com/.

BRE, 2016b. "BREEAM International New Construction 2016 - Technical Manual SD233 1.0." In. London: Building Research Establishment.

CBE. 2016. "Livable Analytics." Center for the Built Environment, University of California, Berkeley, Accessed 06 November. http://www.cbe.berkeley.edu/survey/.

COP21. 2015. "Adoption of the Paris Agreement." In. Paris: United Nations Framework Convention on Climate Change.

Ferguson, C.J. 2009. "An effect size primer: a guide for clinicians and researchers." *Professional Psychology: Research and Practice* 40 (5):532-8.

Field, A. 2013. *Discovering Statistics Using IBM SPSS Statistics*. London: Sage.

Frontczak, M, S Schiavon, J Goins, E Arens, H Zhang, and P Wargocki. 2012. "Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design." *Indoor Air* 22 (2):119-31.

Frontczak, M, and P Wargocki. 2011. "Literature survey on how different factors influence human comfort." *Building and Environment* 46:922-37.

Gou, Z., S. S.-Y. Lau, and J. Shen. 2012. "Indoor environmental satisfaction in two LEED offices and its implications in green interior design." *Indoor and Built Environment* 21 (4):503-14.

Gou, Z., D. Prasad, and S. S.-Y. Lau. 2013. "Are green buildings more satisfactory and comfortable?" *Habitat International* 39:156-61.

Janda, K. 2011. "Buildings don't use energy: people do." *Architectural Science Review* 54:15-22.

Jonckheere, A.R. 1954. "A distribution-free k-sample test against ordered alternatives." *Biometrika* 41 (1-2):133-45.

Kim, J., and R. De Dear. 2013. "Workspace satisfaction: the privacy-communication trade-off in open-plan offices." *Journal of Environmental Psychology* 36:18-26.

Kim, J., R. De Dear, C. Candido, H. Zhang, and E. Arens. 2013. "Gender differences in office occupant perception of indoor environmental quality (IEQ)." *Building and Environment* 70:245-56.

Leder, S., G.R. Newsham, J.A. Veitch, S. Mancini, and K.E. Charles. 2016. "Effects of office environment on employee satisfaction: a new analysis." *Building Research & Information* 44:34-50.

Liang, H.-H., C.-P. Chen, R.-L. Hwang, W.-M. Shih, S.-C. Lo, and H.-Y. Liao. 2014. "Satisfaction of occupants toward indoor environment quality of certified green office buildings in Taiwan." *Building and Environment* 72:232-42.

Menadue, V., V. Soebarto, and T. Williamson. 2013. "The effect of internal environmental quality on occupant satisfaction in commercial office buildings." *HVAC&R Research* 19:1051-62.

Menadue, V., V. Soebarto, and T. Williamson. 2014. "Perceived and actual thermal conditions: case studies of green-rated and conventional office buildings in the City of Adelaide." *Architectural Science Review* 57:303-19.

Newsham, G.R., B.J. Birt, C. Arsenault, A.J.L. Thompson, J. A. Veitch, S. Mancini, and G. J. Burns. 2012. "Do Green Buildings Outperform Conventional Buildings? Indoor Environment and Energy Performance in North American Offices." In. Ottawa, Canada: Research Report RR-329, National Research Council.

Newsham, G.R., B.J. Birt, C. Arsenault, A.J.L. Thompson, J. A. Veitch, S. Mancini, and G. J. Burns. 2013. "Do 'green' buildings have better indoor environments? New evidence." *Building Research & Information* 41 (4):415-34.

NIOSH. 2016. "Indoor Environmental quality." National Institute for Occupational Health - US Department of Health & Human Services Accessed 06 November. https://www.cdc.gov/niosh/topics/indoorenv/.

Nuzzo, R. 2014. "Scientific method: Statistical errors." *Nature* 506 (7487):150-2.

Parkinson, T., and R. De Dear. 2015. "Thermal pleasure in built environments: physiology of alliesthesia." *Building Research & Information* 43 (3):288-301.

Privitera, G.J. 2016. *Research Methods for the Behavioral Sciences* 2nd ed. London: Sage.

Schiavon, S., and S. Altomonte. 2014. "Influence of factors unrelated to environmental quality on occupant satisfaction in LEED and non-LEED certified buildings." *Building and Environment* 77:148-59.

Schiavon, S., T. Hoyt, and A. Piccioli. 2014. "Web application for thermal comfort visualization and calculation according to ASHRAE Standard 55." *Building Simulation* 7 (4):321-34.

Singh, A., M. Syal, S.C. Grady, and S. Korkmaz. 2010. "Effects of green buildings on employee health and productivity." *American Journal of Public Health* 100:1665-8.

Tham, K.W., P. Wargocki, and Y. F. Tan. 2015. "Indoor environmental quality, occupant perception, prevalence of sick building syndrome symptoms, and sick leave in a Green Mark Platinum-rated versus a non-Green Mark-rated building: A case study." *Science and Technology for the Built Environment* 21:35-44.

Thatcher, A., and K. Milner. 2014. "Changes in productivity, psychological wellbeing and physical wellbeing from working in a 'green' building." *Work* 49:381-93.

USGBC. 2016. "LEED - Leadership in Energy and Environmental Design." In.: United States Green Building Council.

Figures

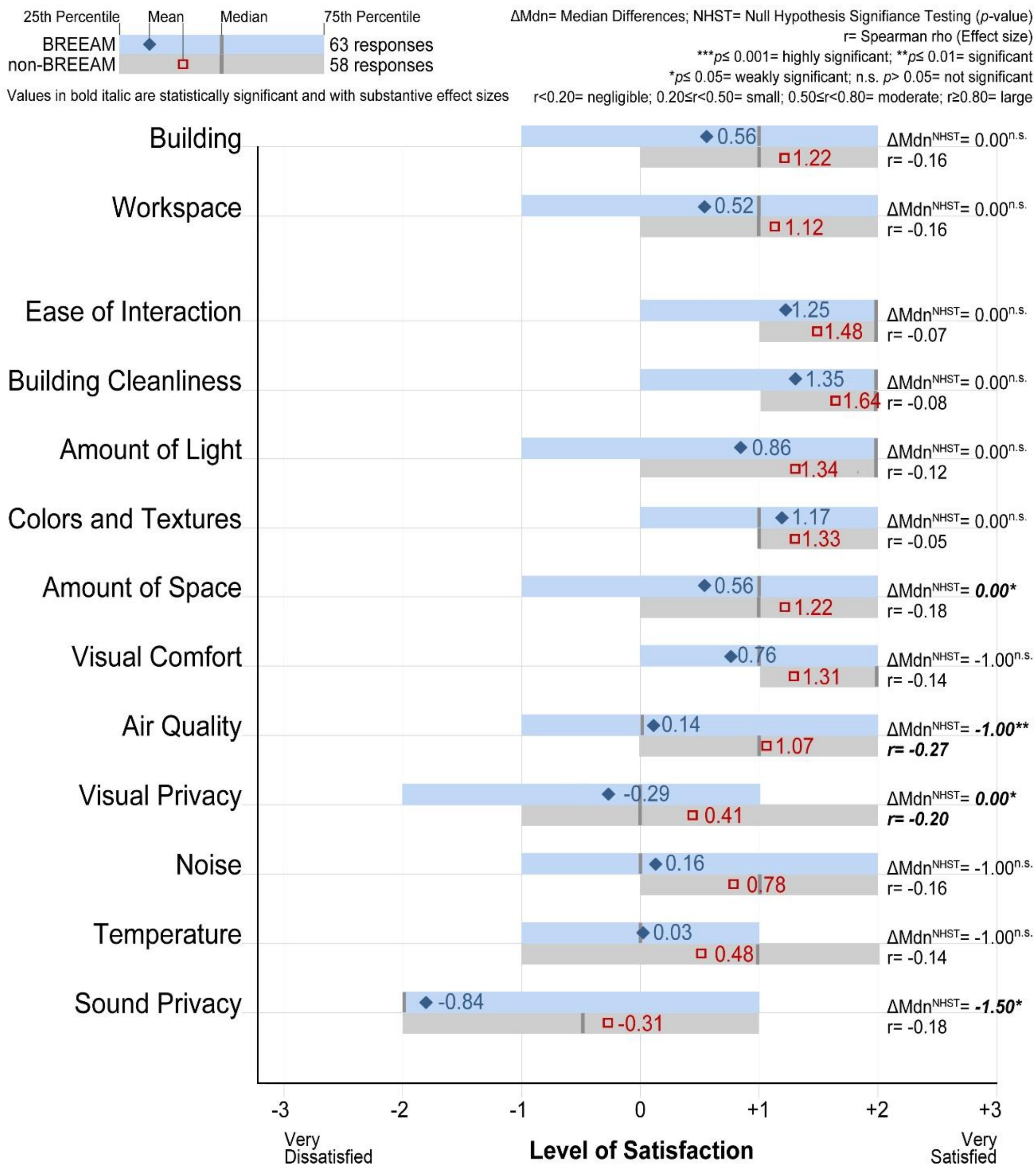

Figure 1. Mean, median, first and third quartile, and inferential statistics of occupant satisfaction in BREEAM and non-BREEAM certified office buildings (N= 121)

Tables

Table 1. Description of the datasets

Occupants' Responses	BREEAM	Non-BREEAM	Total
Cross-sectional questionnaires	63	58	121
Point-in-time surveys	49	33	82
Total	**112**	**91**	**203**

Table 2. Measurement equipment and environmental parameters

Measurement Equipment	Environmental Parameter	Unit	Sensor Accuracy
Kestrel 4400 Heat Stress Meter	Dry Bulb Temperature	˚C	±0.5˚C
	Globe Temperature	˚C	±1.4˚C
	Relative Humidity	%	±3.0%
	Air Speed	m/s	±3.0%
Minolta CL 200A Chromameter	Horizontal Illuminance	lux	±2% ± 1 digit of
	Vertical Illuminance	lux	displayed value
CEM DT-8820 Environment Meter	Sound Pressure Level	dB(A)	±3.5dB at 94dB

Table 3. Distribution of responses based on non-environmental factors (N=121)

Non-Environmental Factors	**Occupants' Responses**		
	BREEAM	**Non-BREEAM**	**Total**
Sex			
Female	40 (63%)	32 (55%)	72 (60%)
Male	23 (37%)	26 (45%)	49 (40%)
Age			
Under 30	17 (27%)	20 (34%)	37 (30.5%)
30-40	18 (29%)	19 (33%)	37 (30.5 %)
41-50	11 (17%)	12 (21%)	23 (19%)
Over 50	17 (27%)	7 (12%)	24 (20%)
Time spent in the building			
0 – 6 months	16 (25%)	17 (29%)	33 (27%)
6 – 12 months	6 (10%)	12 (21%)	18 (15%)
12 – 24 months	12 (19%)	8 (14%)	20 (17%)
Over 24 months	29 (46%)	21 (36%)	50 (41%)
Time spent at the workspace			
0 – 6 months	18 (28%)	24 (41%)	42 (35%)
6 – 12 months	10 (17%)	12 (21%)	22 (18%)
12 – 24 months	18 (28%)	5 (9%)	23 (19%)
Over 24 months	17 (27%)	17 (29%)	34 (28%)
Distance from windows			
Within 4.6m	37 (59%)	39 (67%)	76 (63%)
Further than 4.6m	26 (41%)	19 (33%)	45 (37%)
Spatial layout			
Enclosed, private	9 (14%)	8 (14%)	17 (14%)
Enclosed, shared	12 (20%)	13 (22%)	25 (21%)
Cubicles	21 (33%)	15 (26%)	36 (30%)
Open office, no partitions	21 (33%)	22 (38%)	43 (35%)
Total	**63 (52%)**	**58 (48%)**	**121 (100%)**

Table 4. Descriptive and inferential statistics of cross-sectional questionnaires (N= 121)

Category	**Mean (SD) BREEAM**	**Mean (SD) non-BREEAM**	**M_{dn} (IQR) BREEAM**	**M_{dn} (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	0.56 (1.80)	1.22 (1.45)	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	55.83	66.61	3517.5	-0.16
Workspace	0.52 (1.65)	1.12 (1.21)	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	55.75	66.70	3512.5	-0.16
Ease of interaction	1.25 (1.38)	1.48 (1.16)	2.00 (2.00)	2.00 (1.00)	0.00 n.s.	58.78	63.41	3703.0	-0.07
Building cleanliness	1.35 (1.44)	1.64 (1.24)	2.00 (2.00)	2.00 (1.00)	0.00 n.s.	58.21	64.03	3667.5	-0.08
Amount of light	0.86 (1.82)	1.34 (1.46)	2.00 (3.00)	2.00 (2.00)	0.00 n.s	57.17	65.16	3601.5	-0.12
Colors and textures	1.17 (1.31)	1.33 (1.05)	1.00 (2.00)	1.00 (1.00)	0.00 n.s.	59.26	62.89	3733.5	-0.05
Amount of space	0.56 (1.80)	1.22 (1.45)	1.00 (3.00)	1.00 (2.00)	***0.00****	55.10	67.41	3471.0	-0.18
Visual comfort	0.76 (1.77)	1.31 (1.30)	1.00 (2.00)	2.00 (1.00)	-1.00 n.s.	56.30	66.10	3547.0	-0.14
Air quality	0.14 (1.76)	1.07 (1.40)	0.00 (3.00)	1.00 (2.00)	***-1.00*****	52.17	70.59	3286.5	***-0.27***
Visual privacy	-0.29 (1.87)	0.41 (1.52)	0.00 (3.00)	0.00 (3.00)	***0.00****	54.48	68.09	3432.0	***-0.20***
Noise	0.16 (1.96)	0.78 (1.44)	0.00 (3.00)	1.00 (2.00)	-1.00 n.s	55.79	66.66	3515.0	-0.16
Temperature	0.03 (1.72)	0.48 (1.76)	0.00 (2.00)	1.00 (3.00)	-1.00 n.s.	56.33	66.08	3548.5	-0.14
Sound privacy	-0.84 (2.05)	-0.31 (1.67)	-2.00 (3.00)	-0.50 (3.00)	***-1.50****	54.91	67.61	3459.5	-0.18

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 5. Non-environmental factors: Sex

Category	**Group**	**N($_{x0,x1}$)**	**Mdn (IQR) BREEAM**	**Mdn (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	Male	23, 26	1.00 (1.00)	2.00 (1.00)	-1.00 n.s.	23.43	26.38	539.0	-0.11
	Female	40, 32	1.00 (3.00)	1.00 (1.00)	0.00 n.s.	33.11	40.73	1324.5	***-0.22***
Workspace	Male	23, 26	1.00 (2.00)	1.50 (2.00)	-0.50 n.s.	23.63	26.21	543.5	-0.09
	Female	40, 32	0.00 (3.00)	1.00 (1.00)	-1.00 n.s.	32.89	41.02	1315.5	***-0.23***
Ease of interaction	Male	23, 26	2.00 (1.00)	2.00 (1.00)	0.00 n.s.	25.17	24.85	646.0	0.12
	Female	40, 32	1.00 (2.00)	2.00 (1.00)	-1.00 n.s.	34.36	39.17	1374.5	-0.12
Building cleanliness	Male	23, 26	2.00 (2.00)	2.00 (2.00)	0.00 n.s.	34.93	34.23	534.0	-0.12
	Female	40, 32	1.50 (2.00)	2.00 (1.00)	-0.50 n.s.	30.31	25.66	616.5	-0.04
Amount of light	Male	23, 26	2.00 (2.00)	2.00 (3.00)	0.00 n.s.	23.22	26.58	538.0	-0.11
	Female	40, 32	1.50 (3.00)	1.00 (2.00)	-0.50 n.s.	35.91	37.91	1373.5	-0.14
Colors and textures	Male	23, 26	2.00 (1.00)	1.50 (1.00)	0.50 n.s.	25.15	23.10	600.5	-0.15
	Female	40, 32	1.00 (2.00)	1.00 (1.00)	0.00 n.s.	33.49	40.27	1339.5	***-0.20***
Amount of space	Male	23, 26	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	24.20	25.71	556.5	-0.05
	Female	40, 32	0.00 (3.00)	1.50 (2.00)	***-1.50****	31.54	42.70	1261.5	***-0.27***
Visual comfort	Male	23, 26	1.00 (1.00)	2.00 (2.00)	-1.00 n.s.	23.13	26.65	532.0	-0.13
	Female	40, 32	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	33.84	39.83	1353.0	-0.17
Air quality	Male	23, 26	2.00 (1.00)	2.00 (2.00)	0.00 n.s.	25.26	24.77	644.0	-0.02
	Female	40, 32	-1.00(3.00)	1.00 (2.00)	***-2.00******	27.91	47.23	1116.5	***-0.55***
Visual privacy	Male	23, 26	0.00 (3.00)	-1.00 (2.00)	1.00 n.s.	26.26	23.88	621.0	-0.08
	Female	40, 32	-1.00 (3.00)	0.50 (2.00)	***-1.50*****	29.70	45.00	1188.0	***-0.43***
Noise	Male	23, 26	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	23.70	26.10	545.0	-0.09
	Female	40, 32	0.00 (3.00)	1.00 (3.00)	-1.00 n.s.	33.21	40.61	1328.5	***-0.21***
Temperature	Male	23, 26	1.00 (2.00)	1.50 (3.00)	-0.50 n.s.	24.89	25.10	572.5	-0.01
	Female	40, 32	-1.00 (3.00)	0.00 (2.00)	***-1.00****	32.10	42.00	1284.0	***-0.28***
Sound privacy	Male	23, 26	-1.00 (4.00)	0.00 (3.00)	-1.00 n.s.	23.78	26.08	547.0	-0.08
	Female	40, 32	-2.00 (3.00)	-1.00 (3.00)	***-1.00****	32.03	42.09	1281.0	***-0.29***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 6. Non-environmental factors: Time spent in the building (group: over 24 months)

Category	**$N_{(x0,x1)}$**	**Mdn (IQR) BREEAM**	**Mdn (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	29, 21	0.00 (2.00)	1.00 (1.00)	-1.00 n.s.	22.26	29.98	645.5	***-0.27***
Workspace	29, 21	-1.00 (3.00)	1.00 (2.00)	***-2.00*****	20.83	31.95	604.0	***-0.38***
Ease of interaction	29, 21	1.00 (2.00)	2.00 (1.00)	-1.00 n.s.	23.83	27.81	691.0	-0.14
Building cleanliness	29, 21	1.00 (3.00)	1.00 (1.00)	***0.00****	21.93	30.43	636.0	***-0.30***
Amount of light	29, 21	0.00 (4.00)	1.00 (2.00)	-1.00 n.s.	23.21	28.67	673.0	-0.19
Colors and textures	29, 21	1.00 (2.00)	1.00 (2.00)	0.00 n.s.	23.86	27.76	692.0	-0.14
Amount of space	29, 21	0.00 (4.00)	2.00 (3.00)	***-2.00****	21.43	31.12	621.5	***-0.33***
Visual comfort	29, 21	1.00 (4.00)	1.00 (1.00)	***0.00****	22.07	30.24	640.0	***-0.28***
Air quality	29, 21	-1.00 (3.00)	1.00 (2.00)	***-2.00*****	20.57	32.31	596.5	***-0.40***
Visual privacy	29, 21	-1.00 (2.00)	1.00 (3.00)	***-2.00******	19.81	33.36	574.0	***-0.46***
Noise	29, 21	-1.00 (3.00)	1.00 (2.00)	***-2.00*****	21.26	31.36	616.5	***-0.35***
Temperature	29, 21	-1.00 (3.00)	0.00 (3.00)	***-1.00****	21.48	31.05	623.0	***-0.33***
Sound privacy	29, 21	-2.00 (3.00)	-1.00 (3.00)	***-1.00*****	21.36	31.21	619.5	***-0.34***

****p*≤ 0.001= highly significant; ***p*≤ 0.01= significant; **p*≤ 0.05 =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences (*p*≤ 0.05) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 7. Non-environmental factors: Time spent at the workspace (group: over 24 months)

Category	**$N_{(x0,x1)}$**	**Mdn (IQR) BREEAM**	**Mdn (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	17, 17	0.00 (3.00)	1.00 (2.00)	-1.00 n.s.	16.53	18.47	281.0	-0.10
Workspace	17, 17	0.00 (4.00)	1.00 (2.00)	-1.00 n.s.	14.71	20.29	250.0	***-0.28***
Ease of interaction	17, 17	1.00 (2.00)	1.00 (2.00)	0.00 n.s.	17.18	17.82	292.0	-0.03
Building cleanliness	17, 17	0.00 (2.00)	1.00 (1.00)	***-1.00****	13.74	21.26	233.5	***-0.39***
Amount of light	17, 17	0.00 (4.00)	1.00 (3.00)	-1.00 n.s.	15.91	19.09	270.5	-0.16
Colors and textures	17, 17	2.00 (2.00)	1.00 (2.00)	1.00 n.s.	17.71	17.29	294.0	-0.02
Amount of space	17, 17	0.00 (3.00)	2.00 (3.00)	***-2.00****	13.82	21.18	235.0	***-0.37***
Visual comfort	17, 17	0.00 (4.00)	1.00 (1.00)	-1.00 n.s.	14.26	20.74	242.5	***-0.33***
Air quality	17, 17	0.00 (4.00)	1.00 (3.00)	-1.00 n.s.	15.54	19.76	259.0	***-0.23***
Visual privacy	17, 17	-1.00 (2.00)	1.00 (4.00)	***-2.00*****	12.65	22.35	215.0	***-0.49***
Noise	17, 17	-1.00 (4.00)	1.00 (3.00)	-2.00 n.s.	14.35	20.65	244.0	***-0.32***
Temperature	17, 17	0.00 (3.00)	0.00 (3.00)	0.00 n.s.	15.35	19.65	261.0	***-0.22***
Sound privacy	17, 17	-2.00 (3.00)	0.00 (3.00)	***-2.00****	14.00	21.00	238.0	***-0.36***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 8. Non-environmental factors: Distance from windows

Category	**Group**	**N($_{x0,x1}$)**	**Mdn (IQR) BREEAM**	**Mdn (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	Within 4.6 m	37, 39	1.00 (1.00)	1.00 (2.00)	0.00 n.s.	39.68	37.38	1458.0	-0.05
	Further than 4.6 m	26, 19	0.00 (2.00)	2.00 (1.00)	***-2.00*****	18.10	29.71	470.5	***-0.45***
Workspace	Within 4.6 m	37, 39	1.00 (2.00)	1.00 (2.00)	0.00 n.s.	38.24	38.74	1415.0	-0.01
	Further than 4.6 m	26, 19	-0.50 (3.00)	1.00 (1.00)	***-1.50****	19.00	28.47	494.0	***-0.36***
Ease of interaction	Within 4.6 m	37, 39	2.00 (1.00)	2.00 (1.00)	0.00 n.s.	38.54	38.46	1500.0	0.00
	Further than 4.6 m	26, 19	1.00 (2.00)	2.00 (1.00)	-1.00 n.s.	20.96	25.79	545.0	-0.19
Building cleanliness	Within 4.6 m	37, 39	2.00 (2.00)	2.00 (1.00)	0.00 n.s.	40.61	36.50	1423.5	-0.10
	Further than 4.6 m	26, 19	1.00 (2.00)	2.00 (1.00)	***-1.00*****	18.83	28.71	489.5	***-0.39***
Amount of light	Within 4.6 m	37, 39	2.00 (2.00)	2.00 (2.00)	0.00 n.s.	41.64	35.53	1385.0	-0.14
	Further than 4.6 m	26, 19	0.00 (3.00)	2.00 (3.00)	***-2.00*****	18.00	29.84	468.0	***-0.45***
Colors and textures	Within 4.6 m	37, 39	2.00 (2.00)	1.00 (1.00)	1.00 n.s.	41.15	35.99	1403.5	-0.12
	Further than 4.6 m	26, 19	0.00 (1.00)	1.00 (1.00)	***-1.00****	19.79	27.39	514.5	***-0.29***
Amount of space	Within 4.6 m	37, 39	2.00 (2.00)	2.00 (2.00)	0.00 n.s.	36.88	40.04	1364.5	-0.07
	Further than 4.6 m	26, 19	0.00 (3.00)	1.00 (2.00)	***-1.00****	19.37	27.97	503.5	***-0.33***
Visual comfort	Within 4.6 m	37, 39	1.00 (3.00)	1.00 (1.00)	0.00 n.s.	38.19	38.79	1413.0	-0.01
	Further than 4.6 m	26, 19	0.50 (2.00)	2.00 (2.00)	***-1.50****	19.50	27.79	507.0	***-0.32***
Air quality	Within 4.6 m	37, 39	1.00 (3.00)	1.00 (2.00)	0.00 n.s.	34.77	42.04	1286.5	-0.17
	Further than 4.6 m	26, 19	-1.00 (3.00)	1.00 (2.00)	***-2.00*****	18.48	29.18	480.5	***-0.41***
Visual privacy	Within 4.6 m	37, 39	0.00 (3.00)	0.00 (3.00)	0.00 n.s.	37.39	39.55	1383.5	-0.05
	Further than 4.6 m	26, 19	-1.50 (2.00)	0.00 (3.00)	***-1.50*****	18.73	28.84	487.0	***-0.39***
Noise	Within 4.6 m	37, 39	1.00 (4.00)	1.00 (3.00)	0.00 n.s.	38.28	38.71	1416.5	-0.01
	Further than 4.6 m	26, 19	-1.00 (2.00)	1.00 (2.00)	***-2.00*****	18.29	29.45	475.5	***-0.43***
Temperature	Within 4.6 m	37, 39	0.00 (3.00)	1.00 (3.00)	-1.00 n.s.	35.99	40.88	1331.5	-0.11
	Further than 4.6 m	26, 19	0.00 (3.00)	1.00 (3.00)	-1.00 n.s.	21.10	25.61	548.5	-0.17
Sound privacy	Within 4.6 m	37, 39	0.00 (4.00)	-1.00 (3.00)	1.00 n.s.	38.95	38.08	1485.0	-0.02
	Further than 4.6 m	26, 19	-2.00 (1.00)	0.00 (3.00)	***-2.00******	17.56	30.45	456.5	***-0.50***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 9. Non-environmental factors: Spatial layout (group: open-plan offices)

Category	**$N_{(x0,x1)}$**	**Mdn (IQR) BREEAM**	**Mdn (IQR) non-BREEAM**	**ΔM_{dn}^{NHST}**	**Mean Rank BREEAM**	**Mean Rank Non-BREEAM**	**Wilcoxon W**	**Effect Size (r)**
Building	21, 22	0.00 (2.00)	1.50 (1.00)	***-1.50****	15.79	27.93	331.5	***-0.50***
Workspace	21, 22	-1.00 (3.00)	1.00 (1.00)	***-2.00****	15.93	27.80	334.5	***-0.49***
Ease of interaction	21, 22	2.00 (2.00)	1.50 (1.00)	-0.50 n.s.	20.86	23.09	438.0	-0.09
Building cleanliness	21, 22	1.00 (4.00)	2.00 (2.00)	-1.00 n.s.	20.48	23.45	430.0	-0.12
Amount of light	21, 22	0.00 (3.00)	2.00 (2.00)	***-2.00****	18.05	25.77	379.0	***-0.31***
Colors and textures	21, 22	1.00 (2.00)	1.00 (1.00)	0.00 n.s.	20.81	23.14	437.0	-0.10
Amount of space	21, 22	0.00 (3.00)	1.00 (2.00)	***-1.00*****	16.98	26.80	356.5	***-0.40***
Visual comfort	21, 22	0.00 (3.00)	2.00 (2.00)	***-2.00****	17.83	25.98	374.5	***-0.33***
Air quality	21, 22	-1.00 (2.00)	1.50 (2.00)	***-2.50****	15.26	28.43	320.5	***-0.53***
Visual privacy	21, 22	-1.00 (2.00)	0.00 (2.00)	***-1.00****	17.29	26.50	363.0	***-0.37***
Noise	21, 22	-1.00 (2.00)	1.00 (2.00)	***-2.00****	15.26	28.43	320.5	***-0.53***
Temperature	21, 22	-1.00 (2.00)	1.00 (3.00)	***-2.00*****	17.05	26.73	358.0	***-0.39***
Sound privacy	21, 22	-2.00 (2.00)	0.50 (2.00)	***-2.50****	14.38	29.27	302.0	***-0.60***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 10. Descriptive and inferential statistics of physical measurements (N= 82)

Environmental Parameter	Building Group	N	Mean (SD)	Median (IQR)	Minimum	Maximum	Wilcoxon W	*p*-value	Effect size (r)
Horizontal Illuminance [total, lux]	BREEAM	49	656 (293)	617 (371)	175	1470	892.0	0.43 n.s.	-0.09
	Non-BREEAM	33	665 (438)	501 (275)	181	1820			
Vertical Illuminance [total, lux]	BREEAM	49	445 (313)	394 (195)	94	2254	774.5	0.75 n.s.	-0.03
	Non-BREEAM	33	564 (556)	372 (380)	117	3163			
Sound Pressure Level [dBA]	BREEAM	49	45 (4)	44 (5)	35	54	744.5	0.55 n.s.	-0.07
	Non-BREEAM	33	46 (3)	45 (4)	39	56			
Dry Bulb Temperature [˚C]	BREEAM	49	24.4 (1.4)	24.0 (2.4)	22.2	27.3	886.5	0.46 n.s.	-0.08
	Non-BREEAM	33	24.1 (1.3)	24.3 (2.2)	21.6	26.2			
Globe Temperature [˚C]	BREEAM	49	24.1 (1.4)	23.9 (2.3)	21.8	26.9	705.0	0.33 n.s.	-0.11
	Non-BREEAM	33	24.3 (1.0)	24.2 (1.7)	22.5	25.6			
Relative Humidity [%]	BREEAM	49	47.6 (3.2)	48.0 (5.2)	42.0	52.8	326.5	***<0.001****	***-0.50***
	Non-BREEAM	33	51.4 (3.0)	50.8 (3.0)	47.3	58.0			

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
$r < 0.20$= negligible; $0.20 \leq r < 0.50$= small; $0.50 \leq r < 0.80$= moderate; $r \geq 0.80$= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes ($r \geq 0.20$, in absolute value).

Table 11. Point-in-time survey: Jonckeere-Terpstra tests for light

Environmental Parameter	Building Group	J-value	Test Statistic	*p*-value	Effect size (r)
Availability of natural light					
Horizontal Illuminance	BREEAM	342.5	0.93	0.35 n.s.	0.13
	Non-BREEAM	153.5	2.48	***0.01*****	***0.43***
Vertical Illuminance	BREEAM	352.5	0.58	0.56 n.s.	0.08
	Non-BREEAM	153.5	2.19	***0.03****	***0.38***
Perceived control over natural light					
Horizontal Illuminance	BREEAM	468.0	0.58	0.56 n.s.	0.08
	Non-BREEAM	222.0	2.25	***0.02****	***0.39***
Vertical Illuminance	BREEAM	488.5	0.94	0.35 n.s.	0.14
	Non-BREEAM	222.0	1.62	0.11 n.s.	***0.28***
Perceived control over artificial light					
Horizontal Illuminance	BREEAM	477.0	0.31	0.76 n.s.	0.04
	Non-BREEAM	228.0	2.27	***0.02****	***0.40***
Vertical Illuminance	BREEAM	496.0	1.35	0.18 n.s.	0.19
	Non-BREEAM	228.0	1.80	0.07 n.s.	***0.31***
Discomfort from natural light					
Horizontal Illuminance	BREEAM	283.0	1.00	0.32 n.s.	0.14
	Non-BREEAM	140.5	-1.92	***0.05****	***-0.33***
Vertical Illuminance	BREEAM	290.5	-0.22	0.82 n.s.	-0.03
	Non-BREEAM	140.5	-1.36	0.17 n.s.	***-0.23***
Discomfort from artificial light					
Horizontal Illuminance	BREEAM	338.0	0.66	0.51 n.s.	0.09
	Non-BREEAM	125.0	-2.50	***0.01*****	***-0.43***
Vertical Illuminance	BREEAM	347.5	-0.31	0.76 n.s.	-0.04
	Non-BREEAM	152.0	-2.46	***0.01*****	***-0.43***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
$r < 0.20$= negligible; $0.20 \leq r < 0.50$= small; $0.50 \leq r < 0.80$= moderate; $r \geq 0.80$= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes ($r \geq 0.20$, in absolute value).

Table 12. Point-in-time survey: Jonckeere-Terpstra tests for sound

Environmental Parameter	Building Group	J-value	Test Statistic	*p*-value	Effect size (r)
Description of noise					
Sound Pressure Level	BREEAM	417.0	3.02	***0.002***	***0.44***
	Non-BREEAM	170.5	-0.09	0.93 n.s.	-0.01
Perceived control over noise					
Sound Pressure Level	BREEAM	439.5	-2.52	***0.01***	***-0.37***
	Non-BREEAM	203.5	2.27	***0.02****	***0.39***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).

Table 13. Point-in-time survey: Jonckeere-Terpstra tests for thermal sensation

Environmental Parameter	Building Group	J-value	Test Statistic	*p*-value	Effect size (r)
Description of thermal sensation					
Predicted Mean Vote	BREEAM	342.0	3.52	***<0.001*****	***0.51***
	Non-BREEAM	146.5	2.54	***0.01***	***0.44***

***$p \leq 0.001$= highly significant; **$p \leq 0.01$= significant; *$p \leq 0.05$ =weakly significant; n.s.= not significant
r< 0.20= negligible; 0.20 ≤r< 0.50= small; 0.50 ≤r< 0.80= moderate; r≥ 0.80= large
Values in bold italic denote statistically significant differences ($p \leq 0.05$) and substantive effect sizes (r≥ 0.20, in absolute value).