A Real-world Study of the Relationship between Subjective Assessment of Productivity, Subjective Perception of Environmental Conditions and Objective Productivity Measures.

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Abstract
Improvements in staff productivity have been identified as a leading driver for commercial companies in the design of healthier and efficient buildings. However, evidencing improvements in productivity is difficult owing to the considerable number of environmental variables and behavioural differences between people. Consequentially, there are few real-world case studies evidencing how, why and if the environment has an impact on productivity.

Current methodologies are based on objective measurements such as absenteeism/presenteeism, staff turnover and medical/physical complaints but these data can be difficult to gather, are not collected to a set methodology and require significant resources to organise. An alternative and simpler method has been to ask staff how they perceive their own productivity which is used in many Post Occupant Evaluations (POE) included in the Building Use Studies (BUS) Methodology and the Leesman Index Survey. Whether this corresponds with actual productivity levels and environmental preferences is often questioned in real-world scenarios. This new study demonstrates this relationship through an evaluation of two office spaces.

Occupants were given subjective questionnaires, objective cognitive function tests and work type tests that replicate administrative tasks alongside a POE environmental evaluation on two days of each week over 8 weeks in summer. Passive interventions were placed in the two offices in the form of differing solar shading strategies to produce contrast in operative temperatures and lighting levels within the rooms. Window openings and air ventilation was controlled. The findings are briefly presented and discussed in this paper.

Keywords Productivity, Indoor Environment, Post Occupant Evaluations, Comfort

1.0 Introduction

The prime requirement for productivity is that the mind and body are in a state of health and well-being in order for work and concentration (1). There are a number of social benefits as well as the economic benefits that can be advantageous for society from improvements in productivity. In 2014, the World Green Building Council identified how staff costs account for 90% of a business's expenditure and energy costs account for just 1% (2). The subsequent energy saving impact has been highlighted in recent work by Harvard University. Where workers in green certified buildings (LEED) have been identified as achieving higher cognitive function scores (26%) and having 30% fewer sick days than those in non-certified buildings (3). However even though research suggests satisfaction with the indoor environment can lead to improved performance there are few real-world case studies that evidence the relationship between self-assessment of the indoor environment (its impact on occupant's overall comfort), improvements in objective productivity and self-assessed productivity.

There are several key factors that are considered within POEs:

- Lighting
- View
- Temperature
- Air Quality
- Noise
- Layout / Ergonomics
- Overall Comfort

The reason these variables are considered is due to a large body of research with most of the studies being conducted in laboratory settings although a handful have been conducted in real-world settings. Occupant dissatisfaction of individuals' workstations has been associated with the lack of access to a window through a study carried out in 2008 of 779 workstations in 9 different buildings (2). Work stress and dissatisfaction was quantified as being reduced if nurses were exposed to daylight for at least 3 hours a day (4). However, in these cases there was no analysis of the impact and importance of view. Where a study cited by Boyce (5) and by Marwaee and Carter (6) found that 65% of people working in spaces with windows were satisfied but only 45% of those working in windowless spaces were satisfied even though they had access to daylight delivered through a tubular guidance system. Supporting the theory that view and a connection with the outdoors has an overriding impact on the satisfaction of occupants.

Heschong Mahone Group, Inc (7) identified that the performance of call centre staff slowed by 2% when temperatures increased from 23°C to 24°C. Lan *et al* (8) tested occupants, in a laboratory setting, at air temperatures of 22°C and 30°C and it was found within the subjective questionnaires that occupants felt less willing to exert effort at 30°C and experienced more negative moods. They were also given a battery of work simulation tests such as text typing and addition to complete alongside a variety of cognitive function tests. The results yielded that at higher temperatures during the text typing test participants inputted more characters at 30°C but more errors were made reducing performance. Mental arithmetic, grammatical reasoning, stroop with feedback (which tests cognitive flexibility) and reaction time performances were also shown to be negatively affected by higher temperatures. High indoor temperatures are also evidenced to increase risk of Sick Building Syndrome (SBS) within Wargocki *et al*., (9) and Seppänen *et al*., (10). Similarly, a study carried out by Fang *et al* (11) which reviewed the effects air temperature and humidity on the perceived air quality, SBS and performance of office staff found that performance was not significantly affected although several symptoms of SBS were alleviated when occupants worked at the lower air temperatures of 20°C and RH of 40% compared to 23°C / 50% and 26°C / 60%. The study concluded that if the occupants in the study were subjected to longer exposure times there may have been a significant difference in work performance.

Pollutants within the work environment can also have a relative effect on cognitive function. A recent study conducted by Harvard University tested 24 participants under differing CO_2 loads of 945ppm (40cfm/person), 550ppm (20cfm/person) and 1,400ppm (40cfm/person). Concentration of VOC levels were also tested between low concentration (< 50 ug/m^3) and conventional office concentration (506 - 666 ug/m^3). It was found that a 400ppm increase in CO_2 decreased cognitive performance on tasks by 21% and a 20-cfm increase in outdoor air per person improved scores by 18% and lastly a 500-µg/m^3 increase in TVOCs was associated with a 13% decrease in cognitive function scores. Cognitive function in this case was tested by giving participants computer-based test that had been designed to test the effectiveness of management-level employees through assessments of higher-order decision making (12).

Acoustic comfort has been highlighted as being important to performance particularly within schools and when carrying office work. A study carried out in London Primary Schools found that external noise has a negative impact upon student performance and to have a greater impact upon older children (13). Memory, problem solving and reading attention have been found to be the most negatively affected cognitive functions. However not all noise has a negative impact on performance. In the short term, noise-induced arousal may improve performance of simple tasks but when cognitive performance starts to deteriorate for more complex tasks that may require a large capacity of working memory or sustained attention, such as complex analytical processes (14,15).

Wyon (16) revealed how occupant control over a temperature range of 4°C range can increase logical thinking performance by 3% and typing performance by 7%. Similarly, increased glare potential from windows was found to negatively affect the performance in three of five mental ability tests performed by 201 office staff within testing carried out by the Heschong Mahone Group Inc. (7). It was found that glare affected memory (short/long term memory), backward digit span (working memory - participants were presented with a sequence of numbers and asked to recall them in reverse order which progress in difficulty) and number search (visual acuity – a grid of numbers is presented, and participants are asked to search and count for a particular digit). Therefore, the need to control for glare issues through dynamic solar shading is prevalent.

Self-assessed productivity has been used as an alternative method to objective productivity measures in POEs as the testing of cognitive function/work related tests can be obstructive to the requirements of a business. Within BUS surveys and the Leesman index it is implemented through a -40% to +40% scale although it has been also executed through an evaluation of an individual's willingness to exert effort which was found to have a significant relationship with task performance (17,18). However the relationships between self-assessed productivity and perception of the environment have not been robustly significant (8, 9,19).

Humphreys reviewed the relationship between subjective assessment of productivity and subjective overall comfort measuring self-assessed productivity on a -2 to +2 Likert scale with extremes of “Much higher than normal” and “Much Lower than normal” accompanied by the question “Do you feel that at present your productivity is being affected by the quality of your work environment and if so to what extent?” and overall comfort presented on a 7-point Likert scale with the extremes of “Very Comfortable” and “Very Uncomfortable” which demonstrated a significant relationship with subjective assessment of productivity (19).

Improvement in productivity of staff is perceived as an attractive driver for companies as pay-back times are quicker for example Wargocki *et al* (9) identifies that an increase in work performance by 1% can off-set as much as the annual costs of ventilating a building and therefore subsequently energy costs can be additionally reduced. In addition, more recently the World Green Building Council (20) has highlighted how improved indoor environment quality can reduce absenteeism, improve perceptions of their own performance, perceptions of healthiness and performance in tracked tasks and an increase in property value.

Research and industry has clearly identified that air quality, lighting, acoustics, thermal sensation, layout and ergonomics particularly in office spaces, schools and healthcare have an impact on an individual's overall subjective productivity, objective productivity and subjective assessment of the environment. Although to what extent these variables influence each other, and an individual's objective performance, varies between buildings dependant on the objective environmental constraints experienced.

2.0 Methodology

2.1 Building

The case study building, The Clarence Centre, is a Grade II listed building which has been recently renovated (2012) and is situated on the London South Bank University (LSBU) Campus, parallel to a busy main road which leads to Elephant and Castle Underground/Overground station. This building is used primarily as office space for LSBU Research, Enterprise and Innovation teams but it is also home to LSBU student entrepreneurs, start-ups and select number of SMEs. The ground floor of the building has several meeting/function rooms, a Café and one of the local SMEs is a print shop.

Figure 1. (Above) External Façade of testing offices. (Below) Internal office layout of Room B office (Both images taken with a fisheye lens).

The participants taking part in the study were located on the second floor of the two-storey building and were located across four open-plan office spaces. These were divided into two groups Office A and Office B. Office A is situated in the centre of the building and Office B situated towards the east end of the building (Figure 2.). Each of the rooms can be occupied by between 14 – 16 occupants at one time but full capacity was rarely reached as hot-desking and use of meeting rooms frequently occurs. The offices within the building are orientated south-west (230.02□) and each segmented office has two south-west facing windows, one north-east facing window and a rooflight. The segmented offices were of almost equal size 39.19m^2 on average and have similar glazed areas with an average wall to window ratio of 12.

Figure 2. Layout view of 2nd Floor of the Clarence Centre.

All the offices were furnished to a similar style consisting of desks, chairs, metal/wooden cabinets and the walls and floors were finished and painted to the same standard - white matte paint and dark grey carpet. However, there were some differences between finishing and layout in furniture. In Office B (Figure 2.) all desks were finished with a white top and desks did not have partitions in place whereas in Room A desks were finished with a wood finish and had light green partitions. To ensure each occupant were exposed to a similar illuminance and acoustic conditions partitions were added to Office B two weeks prior to testing. Blind fabrics were also changed from a previously installed dim-out fabric with unknown solar transmittance values to a screen fabric with known values according to BS EN 14501:2005 (21).The electric lighting in the offices is provided by tube lighting (35W/840) which links to an occupancy sensor.

2.2 Participants

Twenty participants (9 Male and 11 Female) volunteered to participate in the study. The participants were spread over four offices and were briefed on the experiment. They were informed that they would be asked a series of subjective questions relating to their work environment and that they would be given some tasks to complete that would measure work skills associated with their level of productivity. It was also explained that interventions would be placed on the office environments and they were asked not to interfere with window, blind, light settings and refrain from using electric fans or heaters prior to the test.

On the night prior to all test days interventions were placed on the rooms once the staff had vacated the offices. Windows were positioned closed to control variation between the offices in ventilation, air quality and the impact of sound during tests. Electric fans and heaters were asked not to be used and electric lighting was consistently kept on in all offices. The only differing variable between rooms were the blind positions which were either positioned open or closed dependant on the test day. The blind position alternated between rooms and varied between test days.

2.3 Test Schedule

The test was given to participants between 12pm and 1pm on Tuesdays and Thursdays over an 8-week period. The participants were not informed of what interventions would be placed on what days however as the intervention was a physically visible (blind open or closed) they were aware of the differing conditions that they were being tested in.

The test was given to participants via an online platform (Inquisit) which was accompanied by a test booklet. Each day the participants would receive a link to the online test. To reduce practice effects, four isomorphic versions of the test were used, and the presentation of each test was counterbalanced.

2.4 Subjective Assessment of Productivity

Self-reported productivity (SUBJECTIVE PRODUCTIVITY) was assessed by asking the participants to report *'How willing they were to exert effort on the tasks set at this moment?'* which was presented to them as a VAS Scale going from 0 to 100 with a slider on screen that could be moved up or down.

2.5 Subjective Comfort

The occupants were asked to rate their overall comfort (SUBJECTIVE COMFORT) at their desk location which was presented as a 7-point Likert scale from -3 to +3. The extremes were "Very Comfortable" to "Very Uncomfortable" this was transposed to 1 – 7 point scale with the extremes mirrored.

2.6 Subjective Perception of Environment

The questionnaire included questions relating to thermal sensation air quality (humidity, freshness, odour), lighting, view and noise experienced to their own perceptions of the office environment at the current time each question was given on a 7-point Likert scale from -3 to +3 with the extremes of "Too Cold" or "Too Hot", "Too Dry" or "Very Humid", "Too Stuffy" or "Very Fresh", "Extremely Pleasant (Odours/Fragrances) or Extremely Unpleasant (Odours/Fragrances)", "Very Dark" or "Very Bright", "Extremely Satisfied (with View)" or "Extremely dissatisfied (with View)" and "Very Noisy" or "Very Quiet". These were then transposed to a 1 - 7 point scale in order to interpret the data with the extremes transposed for air odour and view.

2.7 Objective Productivity Measures

To assess objective productivity a text typing test, clerical checking test, plus and minus test and grammar test were produced by the research team. Three of the tests were a mix of on-screen and paper based exercises and one test was presented only on-screen replicating traditional administrative work.

2.7.1 Text Typing

The text for the text typing test was presented in the written booklet and the participants were asked to type the given text as accurately but as quickly as possible within one minute. The text typing test was marked based on number of words per minute (TEXT TYPE COUNT) and the number of errors (TEXT TYPE ERROR) made and a text typing accuracy (TEXT TYPE ACCURACY) was calculated.

2.7.2 Plus and Minus Test

The plus and minus test was given as a paper based task. Three printed pages of two-digit numbers were given to the participants. For the first page (addition) they add 3 to each number, on the second page (subtract) they subtract three and on the final page (switch task) they alternate between adding and subtracting 3 from each number. At the end of each page the participants were asked to click a button on screen to indicate when they finished each page of questions. The tests were marked based on the time cost of task switching (P&M – TASK SWITCH) and the accuracy of the task shift (P&M – ACCURACY).

2.7.3 Data Checking Test

The data checking test asks participants to read and analyse printed material within a spreadsheet and correctly transpose this into the results page which is given on-screen as a tick box exercise to be completed within 3.5 minutes. The test is marked by the number of questions answered within the timeframe (DATA CHECK COUNT), the number of those questions that were correct (DATA CHECK CORRECT) and the percentage of correct answers (DATA CHECK ACCURACY).

2.7.4 Grammar Test

Fifteen sentences were given to each participant presented on-screen. The first ten assessed their grammatical reasoning by asking participants to select the missing word from four – six given options. The last three questions asked participants to identify the grammatical meaning within a sentence again from a choice of four options. The test was marked based on the number of questions answered correctly (GRAMMAR CORRECT).

3.0 Results

3.1 Correlations

To be able to assess the relationship between subjective perception of the environment, subjective assessment of productivity, subjective overall comfort and objective productivity a correlation matrix using Spearman's Rho was used to identify the strength of relationships (Table 1) between variables and whether they were significant.

3.2 Multiple Regression

The initial investigation looked at the association between the subjective perceptions of the environment (Independent Variables) and the participants perception of subjective productivity and subjective comfort (Dependant Variables). The variables were entered a multiple (stepwise) regression with significance limit set at $p < 0.05$.

Further to these additional regressions were produced to establish what extent the subjective perception of environment, subjective productivity and overall comfort levels (Independent Variables) significantly predicted the participants performance on the objective productivity measures (Dependant Variables) that represent skills used in the office environment. All inputs were checked for multicollinearity; the tolerance was greater than 0.20 and the variance inflation factor was less than 5. Through the stepwise regression two models were produced for following dependant variables SUBJECTIVE PRODUCTIVITY, TEXT TYPE COUNT and GRAMMAR CORRECT. Where only one model was produced for SUBJECTIVE COMFORT, TEXT TYPE ERROR, TEXT TYPE ACCURACY, P&M – ACCURACY and DATA CHECK COUNT.

3.2.1 Subjective Assessment of Productivity

The initial regression looked at the impact on SUBJECTIVE PRODUCTIVITY, a significant regression was found in the 1st and 2nd model. In the 2nd model ($F (2,178) = 10.85$, $p < .001$), with an R^2 of 0.11. Participants predicted subjective productivity is equal to 30.87 + 5.78 (AIR FRESHNESS) + 3.74 (LIGHT). The R^2 of 0.11 tells us that their response to air freshness and light accounted for 11% of the variance in the sample. However subjective evaluation of air freshness accounted for the larger proportion of this variance at 6% as identified by the 1st model.

		Overall Comfort (*r*)	Subjective Productivity (*r*)	Subjective Perception of Environment: Air Temperature (*r*)	Humidity (*r*)	Air Freshness (*r*)	Air Odours (*r*)	Light (*r*)	View (*r*)	Noise (*r*)
	Subjective Comfort	N/A	0.12	-.498**	-.447**	.501**	.285**	-0.13	0.08	0.10
	Subjective Productivity	0.12	N/A	-.158*	-0.10	.227**	.224**	.200**	0.07	-0.07
Objective Productivity	Text Type - Count	-0.09	-0.02	.196**	.161*	-.278**	-.163*	0.06	.238**	0.09
	Text Type - Errors	-0.09	0.09	-0.01	0.10	-0.09	-0.04	0.01	.239**	0.04
	Text Type - Accuracy	0.07	-0.11	0.07	-0.07	0.03	-0.01	0.00	-.172*	-0.03
	P&M - Task Switch	0.03	0.10	-0.09	-0.10	0.02	0.08	0.09	0.13	-0.06
	P&M - Accuracy	-0.08	-0.02	.148*	0.07	-0.01	-0.07	0.03	-.259**	0.06
	Data Check - Count	-0.01	-.155*	0.07	0.09	-0.03	-.176*	-0.15	0.11	0.10
	Data Check - Correct	-0.03	-.175*	0.09	0.05	-0.09	-.181*	-.178*	0.03	0.07
	Data Check - Accuracy	-0.08	-0.09	0.14	0.05	-0.14	-0.13	-0.09	-0.12	0.00
	Grammar - Correct	0.09	-.182*	-0.11	-0.05	0.04	0.06	-0.08	0.05	0.02

* $p < 0.05$ ** $p < 0.001$

Table 1. Correlation Matrix of Subjective Assessment of Productivity, Subjective Perception of Environment, Overall Comfort and Objective Productivity Variables (N = 180 to 183).

3.2.2 Subjective Comfort

The regression evaluated the impact on SUBJECTIVE COMFORT, a significant regression was found (F (1,179) = 43.05, p < .001), with an R^2 of 0.19. Participants predicted subjective productivity is equal to 2.14 + 0.58 (AIR FRESHNESS). The R^2 of 0.19 tells us that their response to air freshness accounted for 19% of the variance in the sample.

3.2.3 Text Typing

The first regression looked at the impact on TEXT TYPE COUNT, a significant regression was found in the 1st and 2nd model. In the 2nd model (F (2, 177) =16.71, p < .001), with an R^2 0.16. Participants predicted typing word count is equal to 44.75 + 2.24 (VIEW) – 3.75 (AIR FRESHNESS). The R^2 tells us that their view and air freshness score accounted for 16% of the variance in the sample. However subjective evaluation of air freshness accounted for a larger proportion of the variance indicated by the 1st model which had a R^2 of 0.85 accounting for 9% of the variance in the 2nd model.

A second regression evaluated the impact on TEXT TYPE ERROR, a significant regression was found (F (1, 178) = 21.01, p < .001), with an R^2 0.11. Participants predicted TEXT TYPE ERROR is equal to 0.72 – 0.48 (VIEW). The R^2 tells us that their view accounted for 11% of the variance in the sample.

TEXT TYPE ACCURACY was also reviewed, a significant regression was found (F (1, 178) = 10.72, p < .001), with an R^2 0.06. Participants predicted text typing accuracy is equal to 97.60 - 0.91 (VIEW). The R^2 tells us that their view accounted for 6% of the variance in the sample.

3.2.4 Plus and Minus Test

The regression considered the impact on P&M – ACCURACY, a significant regression was found (F (1, 179) = 12.42, p < .001), with an R^2 0.07. Participants predicted P&M – ACCURACY is equal to 14.03 - 4.96 (VIEW). The R^2 tells us that their view accounted for 7% of the variance in the sample.

None of the variables met significance for the P&M – TASK SWITCH scores.

3.2.5 Data Checking Test

The impact on the DATA CHECK COUNT was reviewed, a significant regression was again found (F (1, 173) = 6.61, p < .011), with an R^2 0.04. Participants predicted DATA CHECK COUNT is equal to 10.31 – 0.03 (SUBJECTIVE PRODUCTIVITY). The R^2 tells us that their willingness to exert effort accounted for 4% of the variance in the sample.

None of the variables met significance for the DATA CHECK CORRECT and DATA CHECK ACCURACY scores.

3.2.6 Grammar Test

The final regression produced two models the 2nd model identified the impact on GRAMMAR CORRECT, a significant regression was found ($F (1, 178) = 6.01$, $p < .003$), with an R^2 0.06. Participants predicted GRAMMAR CORRECT is equal to 76.93 + 2.86 (AIR ODOUR) – 0.15 (SUBJECTIVE PRODUCTIVITY). The R^2 tells us that their perception of odours experienced, and subjective productivity accounted for 6% of the variance in the sample. Although we know that subjective productivity accounted for a larger proportion of the variance as the 1st model had an R^2 0.04 which represents 4% of the variance in the 2nd model.

4.0 Discussion

When considering the relationship between individuals' subjective perception of environment condition scores and subjective assessment of productivity only, responses relating to air freshness and light were found significant and contributed 11% of the variance. When subjective overall comfort with subjective perception of environment was reviewed air freshness was found to significantly contribute to the variance by 19%.

In the majority of work type tasks (6 of the 9) given to the participants their subjective perception of environmental conditions demonstrated significance in predicting their objective performance. The environmental perceptions accounted for between 2 - 16% of the variance on their objective performance, air odour, view and air freshness contributed. Their subjective assessment of productivity (willingness to exert effort on tasks) accounted for 4% of the variance within objective productivity however it was surprising to find that the participants overall comfort score did not show any significance in contributing to their overall objective performance.

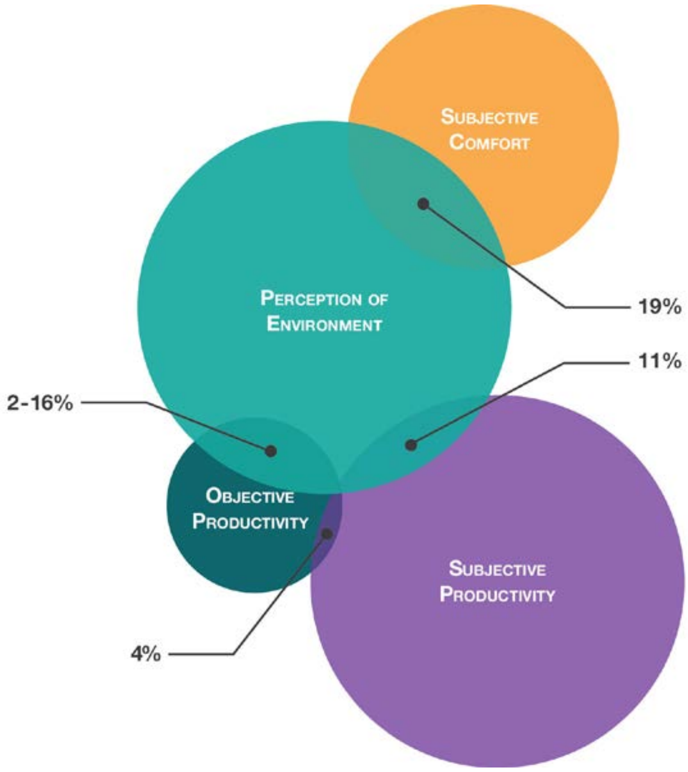

Figure 3. Model of the relationship between Perception of the Environment, Subjective Assessment of Productivity, Subjective Overall Comfort and Objective Productivity.

No significant ($p < 0.05$) relationship was also found between self-assessment of productivity and subjective overall comfort.

In this study participants perception of air quality and light influence their self-assessed productivity but most interestingly it is observed that perceptions of view contribute significantly to variation within objective productivity. The discussed methodology helps us understand the relationship between objective productivity, perceptions of environmental conditions and self-assessed productivity. A graphic representation of this relationship is presented in Figure 3.

5.0 Conclusion

The study provides supporting evidence that in this case study subjective perception of environmental conditions contribute to variances in objective productivity performance. Similarly, they contribute to a person's overall comfort level and self-assessment of productivity in terms of willingness to exert effort at work. However, the authors realise there are a number of limitations to the study including sample size, accountability of additional variables such as work apathy, self-esteem, testing fatigue, length of exposure and additional external factors affecting productivity that were out of the scope of the study such as participant lifestyles/preferences.

Although these limitations are noted as we reached significance in a number of the regression models we can still assume that changes in air quality, lighting and view will affect an occupant's perception of the indoor environment (leading to improvements in overall comfort), self-assessed productivity and most importantly objective productivity.

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