Tool Development and Application for Vital Workspace: A Dutch Example of Facility Management Valorisation

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ABSTRACT

Background and aim – The aim of this paper is present how application of the innovative Indoor Comfort Index (ICI) method reveal the actual indoor environmental quality (IEQ) and the perceived IEQ and its influence on office workers productivity. Application of this tool in a pre and post-test after an office refurbishment, will reveal the effectiveness of this intervention. The development and application of this tool, emerged from education and research in facility management, led to a spin-off consultancy firm Vital Workplace.

Methods – Actual measurements of the IEQ conditions, combined with users' perceptions of the IEQ, before and after an office refurbishment, reveals the effectiveness of a refurbishment by analysing the differences between the pre and post-test with multiple statistical analyses.

Results – Regarding the IEQ, the ICI reveals not only the actual performance of an office building, also if improved conditions contribute to improved comfort of office workers. In addition, the possible influence of the IEQ on office workers productivity is revealed. This allows facility managers to determine and improve the alignment of environment quality with workers' activities and performance.

Originality – The tool combines actual and perceived environmental quality at office buildings.

Practical or social implications – Education and research can be used to create spin-offs in facility management. The developed tool can be used to diagnose the current state of the office, a basis for discussion on related improvements, and by doing so, for a cost-benefit analyses of design interventions at organizations. Showing if design impact on users outweigh the costs of real estate, refurbishment, and changes in operations.

Type of paper – Research paper.

KEYWORDS

Facts, health, indoor environment quality, office, perceptions, performance, spin-off.

INTRODUCTION

Organisations invest a substantial amount of time, money and attention to establish an attractive physical environment (Veldhoen, 2004) and one workstation costs employers 9,000 euros per year (Chang, 2019). For organisations, it is vital that these costs are well spend and will contribute to employee welfare. However, surprisingly little is known about the difference between fact and perception in relation to the indoor environment (IE), which is a system of the indoor air quality (IAQ), thermal conditions, acoustic conditions, and lighting conditions (Frontczak & Wargocki, 2011). In this study the Indoor Comfort Index (ICI) is presented, a tool which measures the actual indoor environmental quality (IEQ) in offices and the perceived IEQ of office workers. The purpose of this tool is to provide information about how well the office building performs and how office workers perceive the quality of this building. Based on this information, employers are able to determine if improvements should be made, or if an intervention is successful. By combining objective with the perceptions of users, the ICI provides a powerful insight into the effectiveness of office management measures and facilitate innovative building management. Based on the outcome of the ICI, organisations can make adjustments and implement improvements in order to provide a healthier indoor environment for office workers, and by doing so, contributing to improved office workers welfare.

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The IEQ influences office workers health and well-being. Exposure to low-quality air, for example, can have serious consequences for human health (Boerstra, Beuker, Loomans, & Hensen, 2013). Poor indoor environmental conditions can cause building-related health issues, causing a sick building syndrome (SBS). An important characteristic of these health issues, such as sore throats and dry coughs, is that they usually disappear quickly once employees have left the 'sick' building. For employers it is essential to know if their buildings cause SBS related complaints among their office workers, the ICI will provide employers with information about the presence and the amount of complaints. However, further research is required to conclusively establish this as fact, when the ICI is only been used once as an assessment tool. Nevertheless, in the meantime building managers can still use the ICI results to optimise their buildings in order to provide a comfortable place for office workers to work. Office buildings should never be detrimental to employees' health and these buildings should contribute to improved performance and job satisfaction.

In order to determine the comfort level of a building, the quality of the working environment and the extent to which the working environment can be adapted to the wishes of office workers has to be assessed (NEN-EN 16798, 2019). The ICI determines the comfort level of office workers on the basis of seven factors. The first factor is thermal comfort. Thermal comfort of people can be defined as a subjective response, or state of mind, where a person expresses satisfaction with the thermal environment (Olesen & Brager, 2004). While it may be partially influenced by a variety of personal (e.g. clothing and activity), contextual, and cultural factors, a person's sense of thermal comfort is primarily a result of the body's heat exchange with the environment. In the context of an office building, seated office workers may also be exposed to local discomfort (NEN-EN-ISO 7730, 2005), and individual differences should be taken into account (Brink & Mobach, 2016) . The second factor is indoor air quality (IAQ). Aspects that play a role are how fresh air is supplied and the ventilation rate within the building (NEN-EN 16798, 2019). The third factor is acoustic comfort. Acoustic comfort is determined by the noise that can be heard by employees at their workplace. Noise can originate from noise sources from as well as outside as inside the building (NEN-EN 16798, 2019). The fourth factor is visual comfort. Aspects which determine visual comfort are the perception of light in the building and the amount of artificial and daylight in relation to the necessary light to perform well (NEN-EN 16798, 2019). The fifth factor is view. View can play a role in the way an individual office worker experiences comfort. Aspects that play a role here are what can be seen by office workers from their workplace. The sixth factor is privacy. This factor is not explicitly mentioned in the NEN-EN 16798 (2019). Nevertheless, research by Newsham, Veitch, and Charles (2008), for example, shows that the sound experience is strongly related to the employees' sense of privacy. In fact, they claim that these two factors combined form a scale. Boerstra, van Dijken, Marinus, Hulsman, and Snepvangers (2018) also link sound perception to the feeling of privacy. The ICI includes privacy as a separate factor in order to investigate possible relations between this factor and other factors. The seventh, and last factor, is individual controllability. The ICI analyses the extent to which users of the office building- per person or per room- can influence light, air, temperature and noise to their personal needs.

DESIGN, PARTICIPANTS, PROCEDURES AND ANALYSES

The ICI was originally developed, a number of years ago, as an educational tool within the 'Healthy and sustainable buildings' (HSB) course for first-year students of Facility Management at Hanze University of Applied Sciences (UAS). In order to give first-year students an insight in the IEQ an office building, groups of students were given the assignment to measure the air temperature, indoor humidity, CO_2 concentration, sound pressure level, and illuminance levels. Based on this information, the students gained insights in the actual IEQ of a building. This measurement method was later supplemented with office workers perceptions in relation to the IEQ, rating of the IEQ and the perceived influence of the actual IEQ on their productivity.

The ICI method consist of two parts. The first part involves direct observations and equipment-based measurements, resulting in a set of independent variables. The physical measurements consisted of air temperature, relative humidity, carbon dioxide concentration, ambient sound pressure, and illuminance level. Appendix 1 presents the measured physical indoor environmental parameters, the applied measuring equipment and the accuracy of this equipment.

The second part is a perception study, when office workers are interviewed at their workplace. The personal characteristics and the perceived IEQ is collected with a self-composed questionnaire. Table 2 presents the topics covered in this questionnaire. In addition, office workers are asked to rate the actual IEQ on a scale from 1 (very poor) to 10 (excellent) and are asked if the actual IEQ negatively influence their productivity on a 5-point-Likert scale. This results in a set of dependent variables.

In order to obtain reliable measurements, a representative sample of the population must be interviewed. Longitudinal measurements boost reliability and validity, enabling more accurate conclusions to be drawn in relation to actual performance of the office building and level of comfort of office workers. Both cross-sectional and longitudinal measurements will increase the knowledge about the actual performance en level of comfort of an office building over a period of time.

In this study the findings are presented of the actual performance of an office building, located in the middle of the Netherlands, and the perceived level of comfort of office workers before and after a complete office refurbishment. Junior researchers and a supervisor of the School of Facility Management of the Hanze UAS Groningen, The Netherlands, collected data of workstations and their occupants in the June 2016 and in June 2019. First, the internal validity of the PIEQ was analysed. Therefore, seven scales for the PIEQ were composed, i.e. indoor air quality, warm thermal comfort sensation, cold thermal comfort sensation, acoustic comfort, visual comfort, view, and privacy. Based on the response of 2016, a Cronbach's alpha was conducted to test internal consistency. This analysis showed that all statements for perceived comfort contributed to the reliability of the composed scales. Table 2 shows the seven perception scales for the IEQ, the topics which were covered by the statements and the alpha of the composed scale. Because all alphas were higher than 0.70, perception scales for all six categories were composed. Furthermore, the actual IEQ and the perceived IEQ of 2019 were compared with the conditions of 2016 and independent T-tests (two-tailed) were performed in order to determine if the differences between the observed values was significant. To determine the influence of the PIEQ on the perceived productivity, a multiple linear regression analyses was performed. All statistical analyses were performed with IBM SPSS Statistics version 25.

Table 2 Perceived Indoor Environmental Quality categories, Topics, and Cronbach's Alpha's

Category	**Topics covered**	α
Perceived indoor air quality	Odour intensity and character; ventilation; moisture	0.83
Thermal comfort- warm	Thermal sensation; warm body parts; radiation	0.80
Thermal comfort- cold	Thermal sensation; cold body parts; draught; radiation	0.81
Acoustic comfort	Noise from within and outside the office; noise disturbance	0.90
Visual comfort	Reflections; glare; contrast; colour sensations; (day)light	0.86
View	Quality of view	0.83
Privacy	Need for more quit circumstances	0.89

RESULTS

We collected in 2016 data of 344 workstations and in 2019 data of 59 workstations and their occupants. Table 3 presents the demographic characteristics of the respondents in 2016 and 2019. During the pre-test in 2016, data were collected from all workplaces and their occupants, which were spread across the seven floors of the office building. During the post-test in 2019, the data were collected of the workplaces and their occupants on the first and second floor, because only on these floors the refurbishment was completed. This explains the difference in number of respondents in 2016 and 2019, 11 respondents participated as well as in 2016 as in 2019. These respondents, who worked in 2019 on the first and second floor, worked on different floors in 2019.

Table 3 Demographic characteristics of respondents

	2016	**2019**
Number of respondents (n)	344	57
Mean age (s.d.)	43 (10.0)	39 (10.1)
Male	47%	28%
Female	54%	72%

Furthermore, the actual indoor environmental conditions of 2019 were compared with the conditions of 2016 and analysed if the differences between two observed values were significant. Table 3 presents the actual indoor environmental conditions of the two periods, the calculated differences and the significance level of these differences.

Table 4 Actual indoor environmental conditions in 2016 and 2019

	2016 (n=344)		**2019 (n=57)**		**Difference 2019-1016**	
	M	SD	M	SD	M	SD
T_{out}	18.0	2.3	15.2	1.2	-2.8	-1.1
T_a	23.8	1.1	23.7	0.5	-0.1	-0.6
T_a^{fl}	23.7	1.1	23.7	0.5	0	-0.6
RH_i	62.7	4.6	47.8	4.6	-14.9	0
RH_o	78.4	13.1	76.5	7.0	-1.9	-6.1
CO_2	591.0	86.2	551.7	47.5	-39.3***	-38.7
BGN_{av}	51.8	7.5	39,5	5.4	-12.3***	-2.1
E_{amb}	625.1	338.8	698.6	402.4	73.5	63.6
View	2.5	0.9	2.9	0.4	0.3	-0.5
***p≤ 0.001						

Finally, the average perception scores was calculated for all categories. The PIEQ of 2019 was compared with the PIEQ of 2016 and analysed the differences between two observed values. Table 4 presents the PIEQ of the two periods of all seven categories, the calculated differences and the significance level of these differences.

Table 5 Perception scores of the indoor environmental conditions in 2016 and 2019

	2016 (n=344)		**2019 (n=57)**		**Difference 2019-1016**	
Category	M[1]	SD	M[1]	SD	M1	SD
Perceived indoor air quality	3.0	0.8	3.6	0.8	0.6***	0.0
Thermal comfort – warm[2]	2.6	0.9	2.2	0.8	-0.4**	-0.1
Thermal comfort – cold[3]	1.8	0.8	1.9	0.8	0.1**	0.0
Acoustic comfort	3.8	0.7	3.9	0.7	0.1	0.0
Visual comfort	4.0	0.6	4.4	0.6	0.4	0.0
View	3.2	0.9	2.8	0.8	-0.4**	-0.1
Privacy	3.5	0.9	3.5	1.0	0.0	0.1

[1] Lowest score is 1 (very poor) and the highest score is 5 (very good)
[2] A low mean score (1) means that the respondents do not experience warm thermal conditions, a high mean score (5) means that the respondents experience very warm thermal conditions
[3] A low mean score (1) means that the respondents do not experience cold thermal conditions, a high mean score (5) means that the respondents experience very cold thermal conditions
**p≤ 0.01 ***p≤ 0.001

The respondents rated the perceived IEQ in 2016 with a score of 5.8 and in 2019 with a score of 7.0 (two-tailed, $p<0.001$). The respondents rated the negative influence of the actual IEQ on their productivity in 2016 with a score of 2.95 and in 2019 this score was 2.32 (two-tailed, $p<0.001$). A multiple linear regression analyses was performed to determine which of PIEQ conditions contribute to the overall influence on office workers productivity. The contribution of perceived influence of IAQ and thermal comfort contributed to the overall model ($p<0.001$) significantly, with respectively a beta of 0.31 ($p<0.001$) and 0.43 ($p<0.001$) in 2016 and with respectively a beta of 0.39 ($p<0.001$) an 0.49 ($p<0.001$) in 2019

DISCUSSION AND CONCLUSIONS

Only 11 respondents participated in the pre and post-tests. An independent T-test (two-tailed) was chosen due to size differences of the populations in the pre and post-tests. The demographic characteristics of the two populations are different and might explain the significant difference in warm thermal sensation in the post-test, due to the fact that relatively more female workers participated in the post-test. Males in general are feeling hotter and react more rapidly to changes in temperature (Wyon, Andersen, & Lundqvist, 1972). Based on the measured variables, the actual IEQ differs only significantly regarding the IAQ, background noise level, and view. Although the observed CO_2 concentration is relatively low in as well as 2016 as 2019, based on current guidelines (NEN-EN 16798, 2019), the improved conditions in 2019 led also to a higher perceived IAQ. Surprisingly, the significant reduction of background noise only led to a minor, not significant, improvement of the perceived acoustic comfort. This might be explained by the more open plan office design which was implemented in 2019. Noise is the most frequent reason for complaints about environmental conditions in the workplace, specifically in open plan offices (Lee & Aletta, 2019). Although the actual quality of view increased, the perceived quality of view declined significantly and cannot be explained. Overall, the perceived indoor environmental quality improved after the refurbishment. Respondents rated the overall indoor environmental quality 13% higher. Therefore, it is concluded that, based on the outcome of the ICI tool, that the actual IEQ only improved only little after refurbishment. However, the perceived thermal comfort and IAQ improved significantly and reduced perceived productivity loss of the office workers.

THE SPIN-OFF

Evidently, improvements offices are urgent, but how can research help? After all, the challenge to such problems is to provide decision makers, designers, and users with evidence about a current situation, and at the same time inspire them to make the right design interventions for improvement. Vital WorkSpace, a spin-off firm of the Hanze UAS Groningen, offers application of the ICI tool to all companies. This firm was founded by a member of the Hanze research group Facility Management (FM) of the Hanze UAS and will be supported by the research group and all collected data will remain accessible for research and innovation purposes. Validated instruments were developed by the research group allowing solid practical applications. Focal points are workplace quality and user perceptions. Results enable organisations to advance workspace quality. Vital WorkSpace has already acquired a number of regular clients providing them with information about actual and perceived working conditions. Moreover, the spin-off provides organisations with evidence about the effectiveness of office refurbishments, for instance, with longitudinal comparative case study designs, as presented in this study. By doing so, it compares changes in judgements of fact and value judgements, such as worker experiences. This creates a basis for a cost-benefit analyses of design interventions: does design impact on users outweigh the costs of real estate, refurbishment, and changes in operations?

ENTREPRENEURSHIP

The ICI already provided multiple scientific contributions, for instance, on the quality and satisfaction of thermal comfort in Dutch offices (Brink & Mobach, 2016). Together with doctoral candidates and student researchers, Vital WorkSpace will remain to contribute to research and the research group FM will continue to deliver high-quality measurement tools, developed by the Research Group FM, Research Centre on Built Environment, and Centre of Expertise for Entrepreneurship of the Hanze UAS. The start-up was established with the aid of a grant from the National Taskforce for Applied Research (SiA), which is part of the Netherlands Organisation for Scientific Research (NWO).

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APPENDIX 1:

INDOOR ENVIRONMENTAL PARAMETERS, SYMBOLS AND DESCRIPTION OF MEASURING

Variable	Symbol	Description Of Measuring
Outdoor air temperature	T_{out}	The outside temperature and the outside humidity was derived from a reliable open source, www.weerplaza.nl, at the moment the occupant was questioned
Indoor air temperature at desktop height	T_a	Air temperature in degrees Celcius (°C) and is measured with an TESTO 610 temperature and humidity sensor at desktop height (average 0.7m), accuracy ±0.5 °C @ -10 to +50 °C
Indoor air temperature at floor	$T_a$fl	Air temperature in degrees Celcius (°C) and is measured with an TESTO 610 temperature and humidity sensor at desktop height (average 0.7m), accuracy ±0.5 °C @ -10 to +50 °C
Indoor relative humidity	RH_i	Indoor relative humidity in percentage (%) and is measured with a TESTO 610 temperature and humidity sensor at desktop height (average 0.7m), accuracy ±2.5 % RH_i @ 5 to 95 %RH_i
Background noise	BGN	Average sound pressure level in dB(A) over a period of 45 seconds and is measured with a Velleman DEM201, accuracy +/- 1.4 dB 94 dB @ 1 kHz
Carbon dioxide concentration	CO_2	Parts per million carbon dioxide concentration (ppm CO_2) is measured with a Atal ENV-MB350NV carbon dioxide sensor on the desktop, accuracy ±30 ppm + 5% of the actual reading
Ambient illuminance	E_{amb}	Illuminance level in Lux and is measured with a VOLTCRAFT MS-1300, accuracy ± 5% + 10 digits @ < 10.000 lux

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Deltapremie

The 'Deltapremie' or Delta Prize is a new leading research prize in the Netherlands focusing on practice-oriented research by professors. The prize is developed for professors who have managed to repeatedly make a special difference with the social impact of their research over the years. It shows where practice and research can come together in an innovative way. Practice-oriented research has acquired a solid place in Dutch society. Almost 700 professors and more than 3,000 teacher-researchers are currently involved. The starting point of the research is always to find solutions for practice-based problems, also by partnering with practice. In this way, practice-oriented research provides applicable solutions to societal challenges.

An independent selection committee selected the winners. The committee consisted of six experts from Erasmus University Rotterdam, Innofest, Delft University of Technology, Netherlands Study Centre for Technology Trends, and the Association of Netherlands Municipalities. In the report the selection committee tributes Mark Mobach and his research group for the impact that they have on the crossroads of various domains from public transport to mental health. Mobach: "We see the prize as enormous encouragement to continue our research into space and organisation in healthcare, education, offices, and cities together with our partners. We extend our research to areas where there are perhaps fewer financial possibilities, such as research with the arts and frailty."

Research focus area

With his research group, Prof. Mobach wants to contribute to the best buildings for people and organisations. He does so by devising better space and services in a multidisciplinary setting together with students, lecturer-researchers, Ph.D.-students, and postdocs. Better spaces and services for education, offices, and even cities that stimulate healthy behaviour, better healthcare buildings that reduce stress, but also prisons and stations that better meet the needs of society.