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Design of a Retrospective Survey for Occupant Satisfaction with IEQ in Classrooms

Quinten Carton **Jakub Kolarik** **Hilde Breesch**

ABSTRACT

The occupants' satisfaction with the indoor environmental quality (IEQ) of a building is a key factor to determine if the indoor climate can be considered as acceptable. Current standards, evaluating the IEQ, do not always guarantee sufficiently high occupant satisfaction levels, since these standards do not handle all satisfaction influencing parameters, such as, personal preferences or perceived control. Therefore, the assessment of occupant satisfaction with the IEQ remains an important issue. The most widespread tool for occupant satisfaction evaluation are post-occupancy evaluation (POE) surveys. However, surveys are time consuming and intrusive for participants, therefore, it is important to tailor the surveys to their specific use. The objective of this paper is to design a retrospective survey to determine the occupants' satisfaction with the IEQ in classrooms and evaluate the survey's usefulness.

The retrospective survey was distributed among three classes of a secondary school questioning the 58 participants' perception and satisfaction with the IEQ in their classroom during heating season. Results showed that the designed retrospective survey was suitable for assessing the occupants' perception and satisfaction with the IEQ in classrooms. The survey was able to give a general overview of the satisfaction levels in each classroom and to distinguish causes of dissatisfaction during courses in the morning or afternoon. However, the survey could not explain the considerable discrepancy among the satisfaction score, which could be linked to occupant preferences. More in-depth analysis showed that assuming thermal satisfaction from perceptions regarding the thermal environment is inaccurate.

A longitudinal monitoring of both the IEQ and occupants' satisfaction, using on the spot surveys, in the three classrooms is required, in order to determine the occupants' preference regarding the IEQ in the classroom.

INTRODUCTION

The indoor environmental quality (IEQ) in buildings strongly affects the occupants' satisfaction, wellbeing and productivity. However, current standards for evaluating the IEQ are often inadequate to guarantee an acceptable occupant satisfaction level (Frontczak and Wargocki 2011; Kocaman, Kuru, and Calis 2019). Even green-certified buildings with an improved IEQ do not necessary lead to higher occupant satisfaction levels compared to non-green-certified buildings (Altomonte et al. 2019; Altomonte and Schiavon 2013). The main reason for the deviation between the expected satisfaction levels by standards and real-life occupant satisfaction levels is the lack of including subjective parameters, influencing occupant satisfaction, in current standards. On the one hand, occupant satisfaction is influenced by IEQ-related parameters, i.e., thermal, acoustic, visual comfort and indoor air quality (IAQ) (Ilter et al. 2016). On the other hand, non-IEQ-related factors such as

Quinten Carton is a PhD candidate at KU Leuven, Department of Civil Engineering, Building Physics and Sustainable Design, Ghent Technology Campus, Belgium. **Jakub Kolarik** is an Associate Professor at Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark. **Hilde Breesch** is an Assistant Professor at KU Leuven, Department of Civil Engineering, Building Physics and Sustainable Design, Ghent Technology Campus, Belgium.

perceived control over the indoor environment also influence the occupant satisfaction levels (Hellwig 2015). In order to accurately assess the IEQ both an objective and subjective approach is needed (De Giuli et al. 2014).

The most common subjective approach to assess occupants' satisfaction is the use of post-occupancy evaluation (POE) in the form questionnaires (Lassen et al. 2020). The main advantage of surveys is that it is possible to gain detailed information regarding the occupants' perceptions of the IEQ. However, surveys are time consuming and intrusive for the occupants, therefore, surveys can only be distributed periodically. As a result, surveys should be case-specific and their usefulness must be evaluated. An alternative method in assessing occupants' satisfaction is through longitudinal monitoring using shorter, on the spot, surveys. Longitudinal monitoring often uses occupant voting systems (OVS) for determining the occupants' perception and satisfaction with the IEQ (Jung and Jazizadeh 2019; Berquist, Ouf, and O'Brien 2019; Lassen et al. 2020; Sheikh Khan, Kolarik, and Weitzmann 2020). The main advantage of using an OVS-method is the possibility to continuously acquire satisfaction data.

In this paper a POE or retrospective survey for occupants' perception and satisfaction with the IEQ in a classroom is designed and evaluated. This paper aims to determine the utility of retrospective surveys for assessing occupants' satisfaction with the IEQ in secondary school classrooms.

METHOD

An online retrospective survey regarding occupants' perception and satisfaction with the IEQ was designed and distributed among three classes of a secondary school in Belgium. Each class filled in the survey for one specific classroom where the participants followed courses during the past weeks. The survey was completed by 58 participants in March 2021 and the recall period for their responses was the passed heating season.

This paragraph describes the methodology used in this study. Firstly, the cases study buildings and three selected classrooms, used in this study, are described. Afterwards, the structure and content of the retrospective survey are presented. Finally, the correlation analysis of the survey results is described.

Case study buildings

A secondary school in Haacht (Belgium) was used as a case study for this research. In total three classrooms were selected, which will be referred to as classrooms A, B and C (**Figure 1**). Classrooms A and B had a similar layout and positioning of the inlet air openings. Both classrooms were situated on the top floor of a new school building that finished construction in 2019. This recent school building consisted of 4 floors, basement included, and was equipped with a balanced mechanical ventilation system. This ventilation system had a total ventilation rate of 11500 m^3/h and a rotary heat recovery with an efficiency of 81%. A constant air flow rate was maintained during occupancy in classrooms A and B through two inlet air openings in each classroom. The extraction opening for classrooms A and B was situated in the hallway. Furthermore, both classrooms were equipped with a floor heating system.

Classroom C was located in an older school building dating back to 1961. This older building lacked a mechanical ventilation system, leading to classroom C being naturally ventilated. Hydronic radiators in the room provided heating for classroom C. The properties of the three selected classrooms are shown more in detail in Table 1.

Figure 1. Inside views of classrooms A (left), B (middle) and C (right)

Table 1 Properties selected Classrooms

	Classroom A	Classroom B	Classroom C
Surface (m²)	66	66	52.3
Volume (m³)	175	175	164
Orientation	S	N	E
Window surface (m²)	10.7	8.6	14.2
Air flow rate (m³/h)	690	690	/
Solar shading	Outdoor solar screens	/	Curtains
Window operability	Tipping only	Tipping only	Fully opened

Retrospective survey

The retrospective survey was divided into the following 8 parts: participants' characteristics, classroom properties, thermal comfort, IAQ, acoustic comfort, visual comfort, IEQ and adaptation satisfaction and wellbeing. The topics of the questions in each survey part are summarized in Table 2. The survey started with information regarding GDPR and the participants were asked to give their informed consent. The parents of the scholars participating in the study were informed before the start of the survey, since the scholars were still minors. The participants were asked to fill in a unique identification code at the start of the questionnaire. Participants were given multiple opportunities to provide feedback on the survey, with optional comment sections placed both throughout and at the end of the survey. Based on this feedback, the suitability of the survey in a secondary school could be evaluated. The survey was designed in Dutch, which is the native language of the participants. The ASHRAE 7-point scale (ASHRAE 2013) was translated into Dutch and used to assess thermal sensation. Odd scales were used in the survey to allow the participants to give a neutral vote, thus avoiding confirmation bias in the survey results (Bunn 2020).

Table 2. Overview of the retrospective Survey

	Question	Answer options	Goal
Participants' characteristics	Please enter your unique identification code (Class letter + Class number). (For example: Class 4A + class number 5 = A5)	Free text	Identification code
	What is your sex?	Male / Female	Participants' gender
	What is your age?	Free text (numbers only)	Participants' age
	Click on your place in the classroom on the picture below	Indicate on floor plan classroom with desks marked	Participants' place in classroom (e.g. close to window or hallway)
Classroom properties	How often was the window opened in room A/B/C during the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Window opening frequency
	How often was the door opened in room A/B/C during the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Door opening frequency
	How often were the solar shading or curtains closed in room A/B/C during the past week of classes?	Always / Often / Regularly / Rarely / Never	Solar shading/ curtains closing frequency
Thermal comfort	How did you experience the temperature in room A/B/C during the past weeks of classes?	ASHRAE 7- point Likert scale: cold / cool / slightly cool / neutral / slightly warm / warm / hot	Thermal sensation
	How would you have liked to adjust the temperature in room A/B/C during the past weeks of classes?	3-point Likert scale: warmer/ no change/ cooler	Thermal preference
	How often have you felt a draft in room A/B/C during the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Draft frequency
	What did the draft usually feel like?	Pleasant/ Unpleasant/ no opinion	Draft sensation
	Do you have any comments about the thermal comfort (temperature, heat / cold) in room A/B/C?	Optional free text	Optional comments on thermal comfort
IAQ	How did you experience the air quality in room A/B/C during the past week of classes?	5-point Likert scale: stuffy / slightly stuffy / neutral / slightly fresh / fresh	IAQ sensation

	How often did you experience odour nuisance in room A/B/C in the past few weeks?	Always / Often / Regularly / Rarely / Never	Odour frequency
	How humid was the air in room A/B/C during the past weeks of classes?	5-point Likert scale: humid / slightly humid / neutral / slightly dry / dry	Humidity sensation
	Do you have any comments about the air quality (smell, freshness, humidity) in room A/B/C?	Optional free text	Optional comments on IAQ
Acoustic comfort	How often have you experienced noise nuisance in room A/B/C in the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Noise nuisance frequency
	What was the cause of the noise nuisance?	In the classroom / outside the school building / hallway / ventilation system / others (+ free text)	Cause of noise nuisance
	Do you have any comments about the acoustic comfort (noise) in room A/B/C?	Optional free text	Optional comments on acoustic comfort
Visual comfort	How did you experience the lighting in room A/B/C during the past weeks of classes?	5-point Likert scale: underexposed / slightly underexposed / neutral / slightly overexposed / overexposed	Visual sensation
	How often have you experienced a glare in room A/B/C during the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Glare frequency
	Do you have any comments about visual comfort (illuminance, lighting) in room A/B/C?	Optional free text	Optional comments on visual comfort
IEQ and adaptation satisfaction	How satisfied were you with the following characteristics of the indoor climate in room A/B/C during the past weeks of classes? (1 star = dissatisfied) / (3 stars = satisfied) / (5 stars = very satisfied)	5-star rating for each IEQ domain	Satisfaction with different IEQ domains, i.e., IAQ, thermal, acoustic and visual comfort
	How satisfied were you with the indoor climate in general (thermal, acoustic, visual comfort and air quality) in room A/B/C during the past weeks of classes? (1 star = dissatisfied) / (3 stars = satisfied) / (5 stars = very satisfied)	5-star rating	Satisfaction with IEQ in general
	What activities can you perform in room A/B/C to improve your satisfaction with the indoor climate?	Changing clothes / open, close window / open, close door / open, close curtains or blinds / adjust indoor temperature / adjust ventilation air flow / others (+ free text) / none of the above	IEQ adaptation options
	What activities do you want to perform in room A/B/C to improve your satisfaction with the indoor climate?	Changing clothes / open, close window / open, close door / open, close curtains or blinds / adjust indoor temperature / adjust ventilation air flow / others (+ free text) / none of the above	IEQ adaptation wishes
	How satisfied are you with the possibilities of adjusting the indoor climate in room A/B/C? (1 star = dissatisfied) / (3 stars = satisfied) / (5 stars = very satisfied)	5-star rating	Satisfaction with IEQ adaptation possibilities
	At what moment were you least satisfied with the indoor climate in room A/B/C?	Morning / afternoon / no opinion	Moment of day least satisfied
	Why were you less satisfied with the indoor climate in room A/B/C in the morning/afternoon?	Temperature too cold / temperature too warm / draft nuisance / stuffy air / noise nuisance / overexposure / underexposure / glare / others (+ free text	Cause of lower satisfaction in morning/afternoon

Wellbeing	How often have you experienced physical discomforts in room A/B/C in the past weeks of classes?	Always / Often / Regularly / Rarely / Never	Frequency physical discomforts
	What physical discomfort did you feel?	Tearing eyes / headache / sore throat / tired or sleepy / dizziness / running nose / others (+ free text)	Which physical discomfort
	How concentrated could you pay attention / work in room A/B/C during the past weeks of classes?	5-point Likert scale: Concentrated / slightly concentrated / neutral / slightly unconcentrated / unconcentrated	Concentration level
Additional remarks	Do you have any comments about this survey? (For example, unclear questions)	Optional free text	Participants' feedback

Survey results analysis

The results of the retrospective survey were analysed in three steps. Firstly, the participants' demographics and feedback were investigated. The distribution of the sample size over the three classrooms and the feedback from scholars and teachers was described. Based on the feedback, the usability of the survey in a school environment was evaluated and possible adjustments for future surveys were considered. Afterwards, the participants' satisfaction with the IEQ and adaptation possibilities were analysed. The satisfaction levels were assessed using an 80% threshold for occupant satisfaction, which is based on the ASHRAE 55 standard and often used in literature to determine if an acceptable number of occupants is satisfied with the IEQ (Cheung et al. 2021). Finally, the survey results were statistically analysed more in depth. The relationships between the perception and satisfaction with the IEQ were investigated. A majority of the survey questions consisted of answers on a Likert scale. Therefore, the Spearman's ϱ correlation was used as correlation coefficient since it is stated to be suitable for ordinal data (Ferguson 2009). The effect sizes were categorised as neglectable ($\varrho < 0.2$), weak ($0.2 < \varrho < 0.5$), moderate ($0.5 < \varrho < 0.8$) and strong ($\varrho > 0.8$). *R software* (R Core Team 2020) was used for the statistical analysis together with the *ggcorrplot* package for visualizing the correlation matrix (Kassambara 2019). An adapted version of the thermal sensation and thermal preference votes was added to the correlation analysis. The thermal sensation and thermal preference votes were re-coded in the adapted version so that the neutral or no change vote was coded the highest and the cold/hot or warmer/cooler vote the lowest. These adapted versions were used to investigate the relationship between the thermal perception and satisfaction, assuming that a more neutral vote would lead to a higher satisfaction.

RESULTS AND DISCUSSION

Participants demographics and feedback

A total of 58 participants filled in the retrospective survey. Two of the participants were female teachers in the age category of 35 – 40 years old, while the other participants were scholars with ages ranging from 14 – 17 years old. Table 3 gives an overview of the participants distribution over the three classrooms.

Table 3. Participants Demographics

	Classroom A	**Classroom B**	**Classroom C**
Number of participants	23	20	15
Fraction of total number of scholars in group	92%	73%	71%
Males	11 (48%)	7 (35%)	9 (60%)
Females	12 (52%)	13 (65%)	6 (40%)
Teachers	1	1	0

The feedback and suggestions filled in by the participants in the various comment sections of the survey are analysed and the process of completing the survey was discussed with two guiding teachers. No comments on unclear questions were given in the comment sections and the guiding teachers did not have to clarify the questions for the scholars. Which means the questions are understandable and suitable for scholars of 14 – 17 years old. However, some parts of the survey could be more specified to certain classroom conditions. Based on the participants' comments, the beamer and invisibility of the blackboard should be added as causes of noise nuisance and visual discomfort respectively. The visibility of the blackboard has been shown to be a significant classroom requirement for scholars (De Giuli et al. 2014) and should be included in a survey for evaluating the satisfaction with the IEQ in classrooms.

Occupant satisfaction levels

A general overview of the participants' satisfaction with the IEQ in their classroom is described in Table 4, which shows the percentage of participants satisfied, and the minimum, maximum, mean and median satisfaction score for the IEQ and adaptation possibilities. A satisfaction level is indicated in red if the satisfaction rate is less than 80%, otherwise the parameter is indicated in green. The survey used a 5-star rating scale for questions regarding the occupants' satisfaction (Table 2). Following levels of satisfaction were related to the rating: 1 star = dissatisfied, 3 stars = satisfied and 5 stars = very satisfied. Scores of < 3 are categorised as not satisfied, while scores ≥ 3 are categorised as satisfied.

Table 4. Satisfaction Results

	Satisfaction level [%]			Min - max			Mean			Median		
	A	B	C	A	B	C	A	B	C	A	B	C
Thermal comfort	91.3	65	60	2 – 5	2 – 4	1 – 5	3.48	3.05	2.87	3	3	3
IAQ	78.26	50	66.67	1 – 5	1 – 4	2 – 5	3.43	2.65	2.8	4	2.5	3
Acoustic comfort	91.3	75	86.67	2 – 5	1 – 5	1 – 5	3.70	3.5	4	4	4	4
Visual comfort	86.96	95	73.33	2 – 5	2 – 5	1 – 5	3.48	4.05	3.6	4	4	4
Adaptation possibilities	78.25	50	40	1 – 5	1 – 5	1 – 4	3.3	2.6	2.33	3	2.5	2
IEQ general	95.65	90	73.34	2 – 5	2 – 5	2 – 5	3.48	3.5	2.93	3	3.5	3

The highest satisfaction levels are noted in classroom A with nearly all parameters reaching the 80% threshold. Only satisfaction with IAQ and adaptation possibilities have a satisfaction level just below 80%, although the difference is neglectable especially for this limited sample size. The lowest satisfaction levels are noted in classroom C where only the satisfaction with acoustic comfort exceeds the 80% threshold, which could be due to the outdated infrastructure compared to classrooms A and B. In none of the three classrooms an acceptable satisfaction level was reached for IAQ and adaptation possibilities. The low satisfaction levels with adaptation possibilities could be an effect of the restricted possibilities of scholars in adjusting the IEQ in their classroom.

The satisfaction levels with the overall IEQ remain relatively high in the classrooms, although, the satisfaction levels with certain IEQ domains and adaptation possibilities are low. Even at low satisfaction levels with the thermal environment and IAQ, the overall IEQ satisfaction remains acceptable. This could indicate that only questioning the satisfaction with the IEQ in general is not sufficient to accurately assess the occupants' satisfaction. This deviates from the existing findings stating a strong effect of parameters regarding the thermal environment on the overall IEQ satisfaction (Kim and de Dear 2012).

The minimum and maximum satisfaction scores show a high distribution of the satisfaction among the participants of the same class. This large distribution could be due to the personal preferences of the participants regarding the IEQ or due to the large recall period causing a recall bias (Raphael 1987). A longitudinal monitoring, using short "here and now" surveys, is needed to determine whether the deviations are due to the recall bias or due to differences in occupant preferences.

Table 5. Morning and Afternoon Satisfaction Comparison

	Classroom A			Classroom B			Classroom C		
	Morning	Afternoon	Equal	Morning	Afternoon	Equal	Morning	Afternoon	Equal
Voting rate least satisfied	39% (9)	26% (6)	35% (8)	25% (5)	35% (7)	40% (8)	33% (5)	47% (7)	20% (3)
Cause n°1	Too cold 57% (8)	Stuffy air 27% (3)	/	Too cold 50% (5)	Too hot / Stuffy air 40% (6)	/	Too cold 50% (4)	Stuffy air 50% (7)	/
Cause n°2	Draft nuisance/ Stuffy air 14% (2)	Too hot / Overexposure /Glare 18% (2)	/	Draft nuisance / Stuffy air 20% (2)	Noise nuisance 20% (3)	/	Too hot 25% (2)	Too hot 36% (5)	/

The survey also looked more in detail to the participants' satisfaction during the day by asking when the participants were the least satisfied with the IEQ in their classroom. Three possible answers could be given, i.e., morning, afternoon or no opinion. Based on the participants' answer a follow-up question appeared in which they could indicate multiple causes for their lower satisfaction during the morning or afternoon. The results, summarized in Table 5, show that it is not possible to indicate a clear

preferred moment of the day for the whole class. The causes of a lower satisfaction are in general similar for the three classrooms, with a too cold environment and stuffy indoor air as the main causes of dissatisfaction during, respectively, the morning and afternoon. However, the mentioned causes of lower satisfaction in classroom C during the morning are clear opposites, i.e., too cold and too hot indoor environment. As mentioned above, on the spot surveys are needed to determine whether these are preference differences between the participants or due to the large recall period for this survey.

Statistical analysis

A more in-depth analysis of the survey data is described in this paragraph. Potential relationships are investigated by determining the statistically significant correlations between the survey answers for the full dataset (N= 58). **Figure 2** shows the correlation matrix of the Spearman's ϱ correlations with a statistical significance of $p < 0.05$. The majority of the significant relevant correlations are weak, while a minority has a moderate or negligible effect size. No strong, statistically significant, correlations were found, due to the survey type and sample size. The moderate correlations of the correlation matrix are summarized in Table 6.

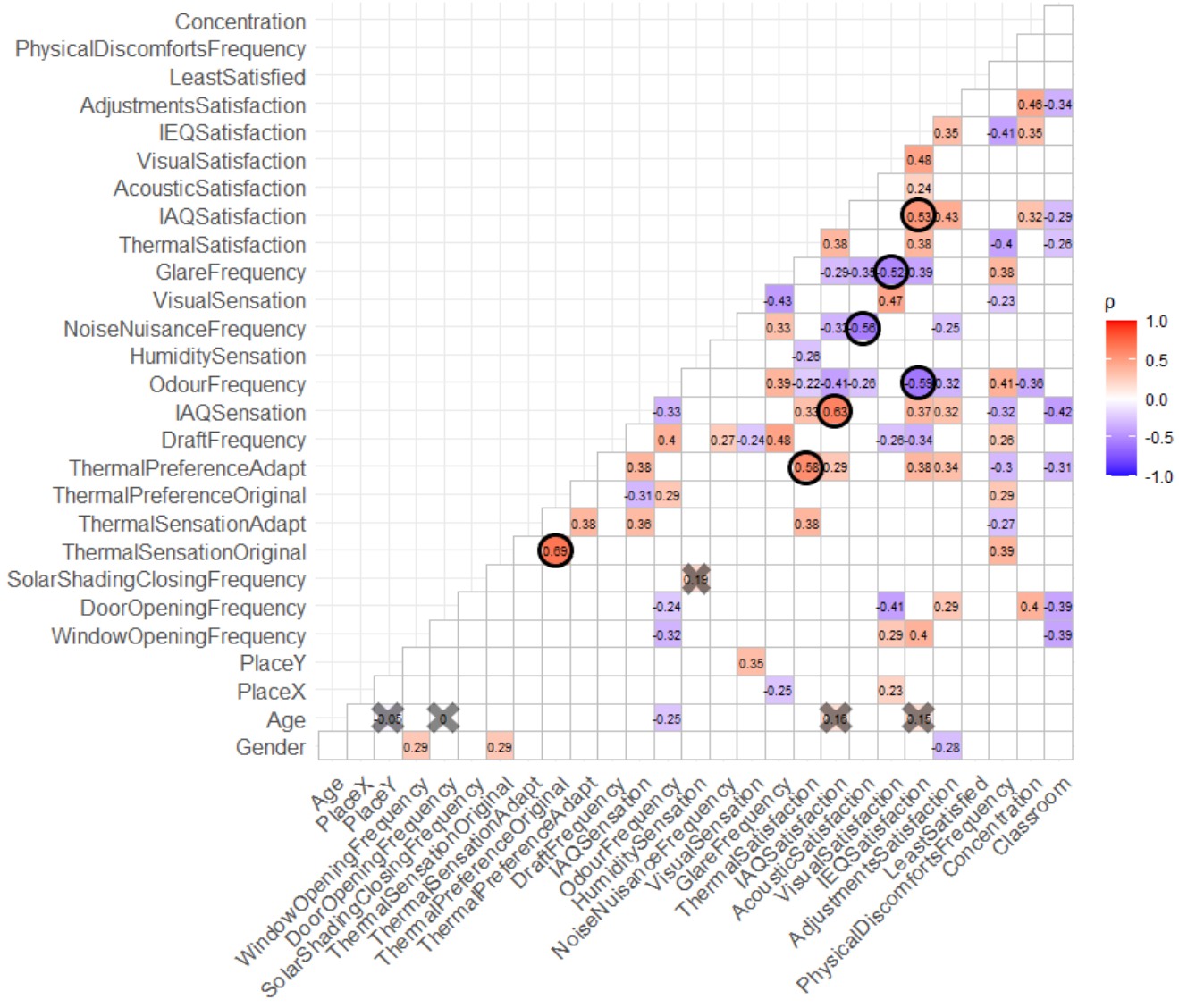

Figure 2. Correlation matrix of the Spearman's ϱ correlations ($p<0.05$). Negligible and moderate effect sizes are respectively crossed out and encircled.

Table 6 Summarization of Moderate Correlations

Correlated parameter 1	Correlated parameter 2	ρ-coefficient	Meaning
Thermal preference original	Thermal sensation original	0.69	The participants that perceived the indoor environment as warm or hot (cool or cold), prefer a cooler (warmer) indoor environment.
IAQ satisfaction	IAQ sensation	0.63	The participants that perceive the air as fresh are more satisfied with the IAQ
IEQ satisfaction	Odour frequency	-0.59	The participants that perceive less odours are more satisfied with the overall IEQ
Thermal satisfaction	Thermal preference adapt	0.58	The participants that do not prefer a warmer or cooler environment are more satisfied with the thermal environment
Acoustic satisfaction	Noise nuisance frequency	-0.56	The participants that perceive less noise nuisance are more satisfied with the acoustic comfort
IEQ satisfaction	IAQ satisfaction	0.53	The participants that have a high satisfaction with the IAQ are more satisfied with the overall IEQ
Visual satisfaction	Glare frequency	-0.52	The participants that perceive less glare are more satisfied with the visual comfort

IEQ satisfaction. In order to determine satisfactory IEQ conditions, the relationships between the different parameters and the overall IEQ satisfaction should be investigated. Existing literature still lacks consistency regarding the effects of individual parameters on the overall IEQ satisfaction (Tang, Ding, and Singer 2020). Based on the results in Table 6, it can be stated that in this case study the IEQ satisfaction is most affected by the odour frequency and IAQ satisfaction. In addition, the results show a weak effect sizes for adaptation satisfaction and the remaining IEQ parameters on the overall IEQ satisfaction. This indicates that adaptation possibilities or perceived control of the occupants should not be neglected when assessing the occupants' satisfaction with the IEQ.

Occupants perceptions vs satisfaction. The survey consists of questions regarding the occupants' perception of the IEQ (e.g., thermal, visual and IAQ sensation) and questions directly asking the occupants' satisfaction with the IEQ domains (i.e., IAQ, thermal, acoustic and visual comfort). In order to determine the occupants' satisfaction from the occupants' perception, a correlation should be noticed between both parameters. Table 6 shows moderate correlations between the occupants' satisfaction and perception with the IAQ, acoustic and visual comfort. In the case of thermal comfort, only a weak correlation was found between the adapted thermal sensation votes and the thermal satisfaction. The lower effect size of the correlation between thermal perception and satisfaction shows the difficulty of determining the occupants' satisfaction with the thermal environment based on the conventional 7-point thermal sensation scale, which is discussed in other literature (De Dear 2011; Humphreys and Hancock 2007; Shahzad et al. 2018). Therefore, occupant satisfaction should be directly assessed and not be assumed though perceptions of the IEQ.

CONCLUSION AND FUTURE RESEARCH

In this paper a retrospective survey for determining occupants' satisfaction in classrooms of a secondary school was designed and evaluated. The survey was completed by 56 scholars from 14 – 17 years old and two guiding teachers. The participants' feedback showed that the usability of the survey for classrooms can be enhanced by adding specific requirements for schools, i.e., beamer noise and blackboard invisibility as causes of dissatisfaction.

The survey was capable of giving a general overview of the participants' satisfaction with the IEQ in the different classroom. In addition, more detailed information regarding the occupants' satisfaction during morning and afternoon courses was captured by the survey. Large distributions of the satisfaction scores among the participants of the same class were noticeable but could not be explained by the retrospective survey. Further analysis of the survey results shows that the participants' perception of odours and satisfaction with the IAQ have the strongest effect on the overall IEQ satisfaction. Only a weak correlation was found between the adapted thermal sensation votes and the thermal satisfaction votes, indicating the importance of directly asking the occupants' satisfaction in surveys and not assuming the satisfaction from certain perception scales.

Further research will consist of longitudinally monitoring the participants' satisfaction with the IEQ in the three selected classrooms, in order to determine if and how frequent satisfaction deviations between occupants occur. Simultaneously, different IEQ parameters (e.g., temperature, CO_2, VOC, sound level,…) will be measured in the classrooms and statistical relationships between the occupants' satisfaction levels and IEQ parameters will be investigated.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the cooperation of the scholars, teachers and board of the secondary school Don Bosco Haacht. Furthermore, the authors acknowledge the support of the Renson Chair: "Data-driven servitization in creating healthy spaces".

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