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Understanding and Estimating Patients' Indoor Environmental Quality Assessment: A Pilot Case Study in a Hospital Ward

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ABSTRACT

Hospitals' indoor environmental quality (IEQ) impacts on patients' comfort and well-being. Relationships between IEQ indicators and people's assessment are often investigated by examining the main IEQ parameters – thermal, visual, and acoustical comfort and indoor air quality – separately. People's assessment is multi-sensory and balances the positive sensations against the negative. To estimate it, IEQ models aggregate data from sensor measurements and/or surveys, expressing parameters' relative importance through regression coefficients. Yet, questions arise about the trustworthiness of these models. Comfort and well-being are to some extent socially constructed, and individuals and activities vary. Interactions between IEQ parameters occur, but are not yet fully understood. The wrong parameters might be focused on, and it is unclear how parameters' satisfaction level is affected by preferences regarding IEQ indicators that are perceived in the same way. Parameters' relative importance is likely to change continuously, possibly influenced by the level to which they (dis)satisfy. This paper aims to advance the understanding of how methodologies used to estimate patients' IEQ assessment can be improved based on insights from a pilot case study adopting a mixed-methods approach. At a hospital's traumatology ward, 84 patients completed a survey. Twelve of them and four others participated in semi-structured interviews about their experience of the indoor environment, while sensors measured IEQ indicators in their room (temperature, relative humidity, illuminance, CO2 and sound level). Based on sensor measurements and/or survey results, participants' IEQ assessment is estimated in different ways. Semi-structured interviews give insight into how and when IEQ indicators interact and their weight in participants' multi-sensory assessment. Combining qualitative and quantitative data informs about possible improvements of multi-sensory IEQ models and future methodologies. Multi-sensory IEQ models, which include both quantitative and qualitative variables, will allow to estimate IEQ more accurately.

INTRODUCTION

Indoor environmental quality (IEQ) research aims to understand what a comfortable indoor environment is, and how its quality can be estimated based on IEQ indicators (i.e. measurable quantities of the indoor environment like the sound, light, temperature, humidity, or CO_2 level) and IEQ parameters (i.e. indices that can be calculated based on one or more IEQ indicators). Thermal comfort (TC), visual comfort (VC), acoustical comfort (AC) and indoor air quality (IAQ) are considered the main IEQ parameters (Sakhare and Ralegaonkar 2014) and are often investigated separately (e.g. Fanger 1970; Fanger 1988; Maekawa, Rindel, and Lord 2011; Carlucci et al. 2015). Sensors measuring IEQ indicators and surveys questioning people's assessment are used in order to establish relationships between how people assess an IEQ indicator or parameter and values of the IEQ indicator(s).

As IEQ is increasingly understood to be experienced in a multi-sensory way (Bluyssen 2010), attention grew for

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IEQ parameters' contribution to and relative importance in people's multi-sensory IEQ assessment. To estimate their multi-sensory IEQ assessment, multi-sensory IEQ models are set up (e.g. Frontczak and Wargocki 2011; Ncube and Riffat 2012; Heinzerling et al. 2013; Sakhare and Ralegaonkar 2014; Fransson et al. 2007). A bottom-up approach is traditionally used (Bluyssen 2008). Multi-sensory assessments are expressed as the sum of IEQ parameters' actual or estimated satisfaction level multiplied by their regression coefficient (RC).

Questions arise about the trustworthiness of these models. The built environment and its indoor environment with occupants are a complex system and cross-correlations between environmental and human factors occur (Bluyssen 2014; Bluyssen 2019). Comfort is to some extent socially constructed, and individuals and activities vary (Humphreys, 2005; Bluyssen 2010). Interactions between IEQ parameters occur, but are not yet fully understood (Bluyssen 2010; Bluyssen 2020). The wrong parameters might be focused on, and it is unclear how parameters' satisfaction level is affected by preferences regarding conditions that are perceived in the same way (Humphreys 2005; Bluyssen 2010; Frontczak and Wargocki 2011). Moreover parameters' relative importance is likely to change continuously, possibly influenced by the level to which they (dis)satisfy (Humphreys 2005; Bluyssen 2010). An interactive top-down approach, next to the traditional bottom-up approach might be needed (Bluyssen 2008; Bluyssen 2019).

In view of these observations, we seek to improve methodologies used to understand and estimate people's multi-sensory IEQ experience and assessment. By way of first step, we conducted a pilot study at a hospital's traumatology ward. Quantitative and qualitative methods were combined into a mixed methods case study design. The aim of this paper is to advance the understanding of how methodologies used to estimate patients' IEQ assessment can be improved based on measurable IEQ indicators, patients' IEQ assessment and insight into their IEQ experience.

METHODOLOGY

We conducted our pilot *case study* at a hospital's traumatology ward in two periods: May 14 to 30, 2019 and July 9 to August 1, 2019. The building originates from 1984, the ward was refurbished in 2010. The indoor environment was regulated by a mechanical ventilation system, windows users could handle, indoor shading devices, outdoor shading devices (except in rooms with a NE oriented window), individual fans, and radiators (not in use during the study). No cooling system was present. The windows of single and double rooms were orientated to the NE (room 1-3), NW (9-16), E (20-24), SE (25-32), SW (4-8), and W (17-19) (Fig. 1). Staff rooms were located centrally in the ward.

To gain a comprehensive understanding of how methodologies used to estimate patients' IEQ assessment can be improved we applied a *mixed methods approach*. Combining quantitative and qualitative methods can offer more insights than the applied methods can offer in isolation (Creswell and Plano Clark 2011). Choosing a *convergent parallel design*, quantitative (sensor measurements, surveys) and qualitative data (semi-structured interviews, probes) were gathered concurrently, and the combined data were analyzed separately quantitatively and qualitatively. The quantitative and qualitative strand were given equal status, and integrated during data interpretation. Both strands were merged through comparison and connected as some methods (interviews, sensor measurements) were used with a subsample of participants involved in other methods (survey).

A self-reported survey gauged patients' overall satisfaction with their room (OS), and their assessment of IEQ parameters and indicators (e.g. satisfaction with the indoor temperature (ST), air quality (SA), light (SL) and sound level (SS)). The survey was inspired by the one of the Center for the Built Environment (CBE). This survey is used most often and advised by ASHRAE's Performance Measurement Protocols for Commercial Buildings (ASHRAE PMP 2010; Hyojin 2012; Peretti and Schiavon 2011), but was adapted to a hospital context based on insights from EBD research in hospitals (e.g. Ulrich et al. 2008; Huisman et al. 2012). 84 patients, agreeing to participate, completed it.

Twelve of these 84 plus four other patients, selected by nurses based on their ability and willingness to participate, participated in two in-depth semi-structured interviews, while sensors measured IEQ indicators in their room. In between both interviews they could fill in the survey and a probe. The interviews addressed how patients experienced their hospital stay, especially IEQ related. The probe – a form of self-documentation that invites participants to express e.g. experiences, feelings, attitudes, actions they would not think of during an interview (Gaver et al. 2004; Boehner et al. 2007) – consisted of a timeline or booklet for taking notes. On the timeline participants could indicate their experience using handed stickers, or write or draw about their experience themselves. The probe was filled in by eight participants. A HOBO's prov2 sensor from Onset measured the air temperature and relative humidity, and an EXTECH SD800 CO_2/Temperature/Humidity logger the CO_2 level, air temperature and relative humidity next to or above participants' bed at about 1-1.50m above the floor. One VersaSense Edge Gateway located in a staff room controlled a mesh network of VersaSense Wireless Devices (VWD). These acted as hub for plug-and-play sensors and were located in corridors and participants' room. In their room a VWD with a sound and light sensor, measuring variations in ambient sound levels and illuminance, was located above their bed at about 1.50m above the floor. The light sensor pointed to the ceiling. In July a HD32.1 Thermal Microclimate Data Logger additionally measured in the corridor and empty patient rooms the air and wet bulb globe temperature, air velocity and relative humidity. Outdoor temperatures and solar radiation measured at 3 km from the hospital were used.

Quantitative analysis of sensor measurements and surveys, using the software R, consisted of descriptive (means, medians, boxplots, and standard deviations) and inferential statistics (linear and multiple regression analysis). Interviews were audio-recorded, transcribed and, together with the data of the probes, surveys and sensor measurements, analyzed qualitatively, roughly following QuaGol's steps of the coding preparation process (Dierckx de Casterlé et al. 2012) and using NVIVO software. This allowed to gain insight into the participants' experience.

In this pilot study the research period and number of participants were limited and relatively inexpensive sensors were used. Rather than to determine 'the quality' of the hospital ward's indoor environment, the study aimed to gain insight into how methodologies used to estimate patients' IEQ assessment can be improved.

Fig. 1: (a) Plan of the hospital ward with north arrow and (b) a patient with the survey and a VWD in the background.

INDIVIDUAL IEQ INDICATORS & IEQ PARAMETERS

People's actual satisfaction with an IEQ indicator or parameter is typically estimated based on measurements with sensors, estimated percentages of dissatisfied people (PPD) calculated using measurements, or actual sensation votes (e.g. Fanger 1970; Fanger 1988; Maekawa, Rindel, and Lord 2011; Carlucci et al. 2015). In our pilot study, these allowed estimating actual satisfaction with the corresponding IEQ indicator or parameter to a certain extent but not completely.

Patients' *judgement* of the indoor environment varies over time and space: ST votes decrease as the outdoor temperature increases (mean day (8h-20h) temperature May 16.5°C/July before and after heat wave 21°C/July during heat wave 32°C) and in rooms with a SE or SW window orientation compared to those with NE or NW one; SS votes decrease as the distance to staff rooms decreases and for double compared to single rooms.

Indoor temperatures *measured with sensors* in patients' room correlate to some extent with their ST. Votes tend to lower as indoor temperature increases (Fig. 2A). Yet, for rooms with similar indoor temperatures, it is less clear why differences in patients' ST occur. Neither is clear how measured sound levels relate to patients' SS (Fig. 2D).[1,2]

IEQ parameter equations estimate people's assessment of IEQ parameters based on (the combination of) measurable IEQ indicators. For TC Fanger's PMV/PPD-model is used.[3] When PPD-values increase, patients' actual ST is in general lower (Fig. 2A & 2B). Yet, PPD-values indicate only which percentage of people is predicted to be dissatisfied. Patients' actual experience and assessment of IEQ indicators seems to be more nuanced than 'satisfied or not'. *Actual sensation votes* expressing how often temperature is dissatisfying correspond roughly with estimated PMV-values for TC and actual ST (Fig. 2A, 2B, 2C).

When an IEQ indicator reaches unacceptable levels according to the Flemish Indoor Environment Decree (Agentschap Zorg en Gezondheid 2018, Lazarov and Stranger 2017), insight into patients' *experience* provides possible explanations for variance in their satisfaction level. During a heat wave, measured indoor temperatures exceeded acceptable levels (Fig. 2A). In room 2, a participant expresses dissatisfaction, and considers air conditioning absolutely necessary. At the same time he is doing little to keep the heat out. In room 3, a participant would like airco, but thinks it is not allowed because it is unhealthy. Besides being more accepting of the situation, she takes several actions to improve the TC: an air cooler is brought from home, the fan is used continuously, the indoor shading device and curtains are closed. An outdoor shading device is preferred, but absent at this room. In room 17.2, a participant had expected a heat wave, which made the temperature more tolerable. In the survey he expresses tolerance for uncomfortable circumstances as a hospital has to be first and foremost functional. Moreover, he takes similar actions as the participant in room 3: outdoor and indoor shading device, curtains and window are closed. Participants' higher tolerance and acceptance in room 3 and 17.2 can partly explain their lower dissatisfaction compared to the participant in room 2. Yet, in acceptable conditions for an IEQ indicator, unexplained variation between satisfaction levels and measured values cannot be understood based on differences in psychological factors alone.

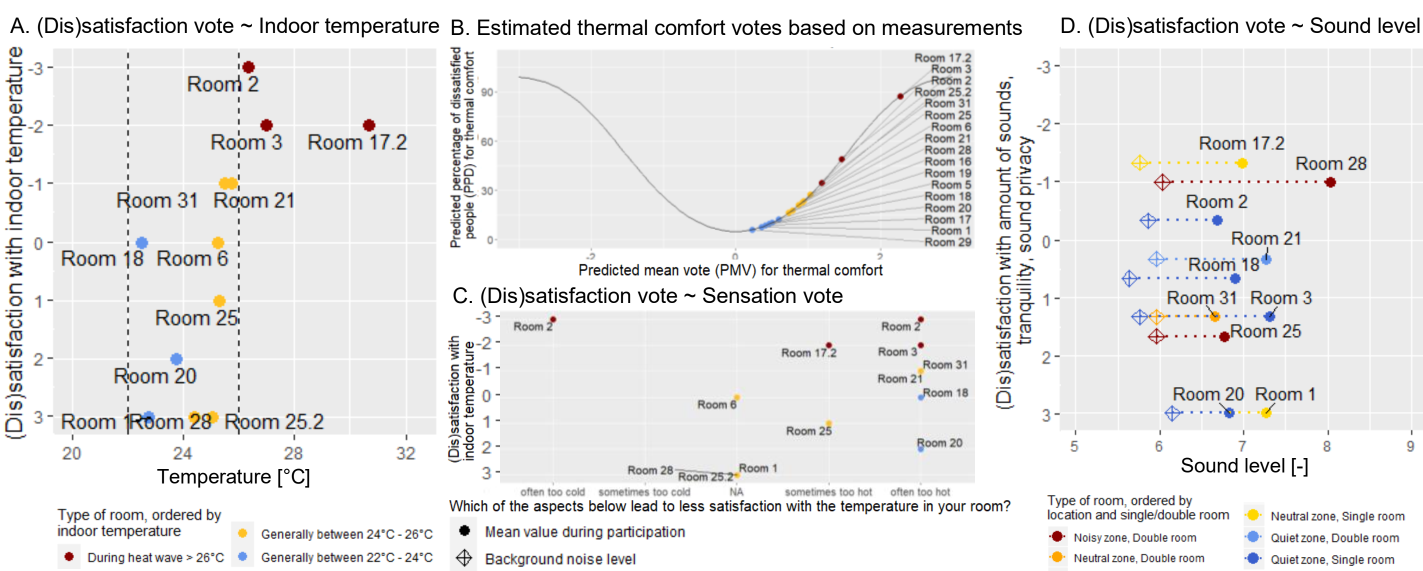


Fig. 2: Relationship between (dis)satisfaction with an IEQ indicator and its sensor measurements (for the indoor temperature (a), sound level (d)), between estimated PPDs and PMVs for thermal comfort (b), and between (dis)satisfaction with an IEQ indicator and actual sensation votes for the indoor temperature (c). The dotted line in (a) indicates the acceptable temperature interval according to the Flemish Indoor Environment Decree (Agency for Care and Health 2018, Lazarov and Stranger 2017).

[1] The sound levels measured in room 18 and 28 have been shifted 3.2 units to the right to align their background noise levels with background noise levels measured in other rooms. The measured difference is expected to be mainly caused by inaccuracies in the sensor measurements.

[2] Based on the measured sound levels in patient rooms the first quartile showed to be representative as background noise level.

[3] PMV- and PPD-values are calculated using measured air temperatures and relative humidity in participant's room. Air speeds are estimated: v=0.25 m/s when participants indicated in the survey to use a desk fan sometimes, v=0.08 m/s otherwise. The mean radiant temperature is taken equal to the air temperature. 0,8 met, a metabolic rate for lying people, is chosen (ISO 7730:2005), and a clothing insulation of 1,76 clo based on studies in sleeping and hospital environments (Lin and Deng 2008a; Lin and Deng 2008b, Verheyen et al. 2011) and assuming a conventional matrass, a blanket covering 59,1% of the body and half-slip sleepwear.

INTERACTIONS BETWEEN IEQ INDICATORS AND IEQ PARAMETERS

Variance in satisfaction with an *IEQ indicator* that cannot be explained by differences in its measured values or psychological factors, seems to relate to differences in other IEQ indicators' measured values and how patients assess these. Temperatures in interviewed patients' room help to explain why their SS differ despite similar measured sound levels (Fig. 3A). SS in rooms in quiet or noisy zones of the ward decrease as outdoor temperatures increase (Fig. 3B).

Although satisfaction with an IEQ indicator can differ due to other indicators' condition, participants' experience of this indicator does not necessarily change. E.g., 2 and 20 are single rooms located in a quiet zone of the ward. 2's indoor temperature exceeded 26°C several days (measured max. temp.=31,5°C), while in 20 it remained generally between 22 and 24°C. Patients staying in these rooms refer in the interviews to similar sounds: nurses in the corridor, outdoor sounds, and the radio or tv. Both like to hear some background noise and did not experience annoying sounds. Yet, their SS vote differs remarkably (Fig. 3A). Applying Mann-Whitney U tests to the survey's data indicates significant differences in SS between May and both July before ($\alpha=0.05$, $p=0.02$) and during the heat wave ($p=0.04$).

This suggests that IEQ indicators affect participants' experience jointly, and their experience affects how they assess IEQ indicators. This suggestion is supported by the rather strong, positive monotonic association – measured with Spearman's correlations (SC) – found between overall satisfaction with the room and satisfaction with IEQ indicators, and between satisfaction with different IEQ indicators (Table 1). It indicates that if satisfaction with an IEQ indicator increases, the overall satisfaction and satisfaction with other IEQ indicators increases simultaneously.

Interactions between *IEQ parameters* seem to occur as well. Within participants' experience IEQ parameters can be considered constructs. Terms as 'warm' or 'cold', corresponding with 'TC', refer to an aspect of participants' multi-sensory experience. Other constructs overlap between parameters. Reference is made to 'fresh air' and outdoor sounds coming in when a window is open. Some participants prefer this to closing the window, relying on mechanical ventilation, and hearing less outdoor sounds. The IAQ, TC and AC are evaluated simultaneously in this example, and this simultaneous evaluation differs from how the parameters would be evaluated independently. Although this highlights the need for multi-sensory IEQ models, it raises questions about the need for parameters as intermediating constructs between multi-sensory assessment and IEQ indicators. Firstly, parameters calculated based on sensor measurements are often expressed as PPD's, considering each parameter as independent from others. While this simplification allows to focus on one of the occurring variations, in reality parameters interact within each individual's experience (Table 2). Secondly, the extent to which the condition of IEQ indicators impact on one parameter is affected by interactions with other parameters. E.g., when the window is open, the extent to which the air temperature and velocity impact the TC assessment seems to change due to the simultaneous assessment of the IAQ. The impact of the clothing level on the TC assessment seems to change less in interviewed participants' experience as they consider adapting their clothing (Table 2). Yet, combining IEQ parameters into a multi-sensory model considers each parameter as a fixed relation of IEQ indicators. Thirdly, focusing on IEQ indicators in multi-sensory models can avoid problems occurring when there is a different estimated PPD for a parameter and similar actual preferences or the same estimated PPD but other actual preferences. The former happens when some patients prefer not to adapt their clothing when the window is open, and the latter when they adapt their clothing but prefer an open window over a closed one.

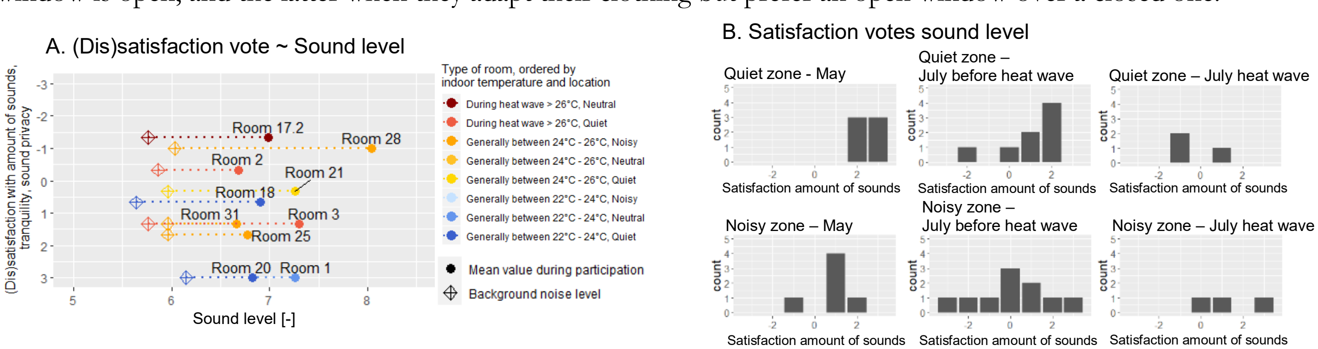
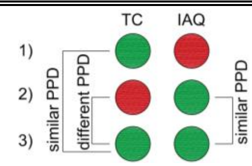
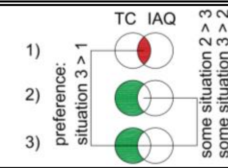


Fig. 3: Interaction between (dis)satisfaction with the sound level in the room and the indoor and outdoor air temperature.

Table 1. Spearman's correlation

	OS	ST	SL	SS
ST	0.56			
SL	0.56	0.42		
SS	0.64	0.46	0.57	
SA	0.58	0.56	0.66	0.5

Table 2. Interactions IEQ parameters

Situation	Separate estimation	Simultaneous experience
1) Closed window – poor IAQ		
2) Open window - no clothing adaptation		
3) Open window – clothing adaptation		

COMBINATIONS OF IEQ INDICATORS

IEQ indicators' combined effect results in a multi-sensory experience and assessment. Their combined effect on patients' IEQ assessment shows in the *survey results*. Patients' overall assessment of the room is simultaneously affected by the location in the ward (quiet/noisy) and outdoor temperature. Overall satisfaction votes are the highest in July before the heat wave in quiet zones, and decrease in noisy zones and during the heat wave in both zones (Fig. 4A).

The relationship between patients' overall satisfaction with the room and *measured values* of IEQ indicators is unclear (Fig. 4B) and the correlation between overall satisfaction and the sum of IEQ indicators' measured values expressed in percentages is weak (SC=-0.27). In patients' *experience*, mainly qualities of the indoor environment (i.e. its meaning and atmosphere) play a role. E.g., participants like to hear sounds from the corridor during the day as it keeps them from feeling lonely, but one participant finds it inappropriate to hear people playing as there are patients being ill. In both cases sound levels do not differ. IEQ indicators' values play a role as part of the qualities. E.g., participants who resided in different rooms prefer the lower background sound levels and the more restful atmosphere in the more quiet zones.

The *satisfaction votes* represent assessments of indoor environmental qualities. The correlation between overall satisfaction with the room and the sum of IEQ indicators' satisfaction votes is higher than between overall satisfaction and measured values (SC=0.76) (Fig. 4C). Assuming a linear relationship, simple linear regression results in (R^2=0.48)

Overall satisfaction = 0.81 + 0.19*(ST + SL + SS + SA)

Not all IEQ indicators are equally important in participants' experience, and they balance the positive features against the negative. Using multiple regression allows to estimate the relative contribution of different IEQ indicators' satisfaction level to the model's explained variance in overall satisfaction with the room. This results in (R^2 = 0.49)

Overall satisfaction = 2,01 + 0,22*ST + 0,21*SA + 0,06*SL + 0,23*SS

As previously shown, the multi-sensory experience is affected not only by the combined effect of IEQ indicators, but also by their interactions. Incorporating interactions in the multiple regression analysis results in (R^2 = 0.57)

Overall satisfaction = 38,02 – 11,05*ST – 6,08*SA – 8,48*SL – 6,95*SS + 2,01*ST/SA + 2,36*ST/SL + 2,03*ST/SS + 1,45*SA/SL + 1,43*SA/SS + 1,73*SL/SS – 0,41* ST/SA/SL – 0,40* ST/SA/SS – 0,32*SA/SL/SS – 0,43*ST/SL/SS + 0,08*ST/SA/SL/SS

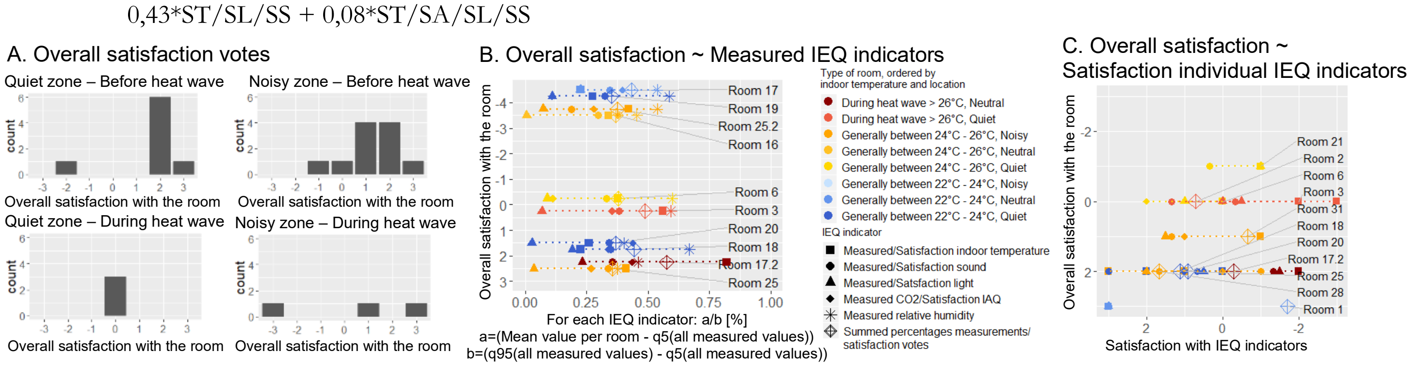


Fig. 4: Relationship between overall satisfaction with the room and (a) the combination of outdoor temperature and location in the ward, (b) IEQ indicators' measured values, and (c) satisfaction with individual IEQ indicators

VARIABLE IMPORTANCE OF IEQ INDICATORS

The presented multiple regression models assume that RCs do not change across situations, and thus that IEQ indicators' assessment and their interactions always contribute to the IEQ assessment to the same extent. Judging from patients' experience and measurements, however, RCs vary with differences in the corresponding and other IEQ indicators. E.g., during the heat wave participants paid in the interviews more attention to TC than in colder periods of the fieldwork. Next to this, measurements show that participants experienced similar indoor temperatures in room 28 and 20. Sound measurements in corridors and patients who resided in rooms at different locations of the ward indicate that 28 is located in a noisy and 20 in a quiet zone. Room 28's participant expresses during the interview to be mainly dissatisfied with the sound level in the room and satisfied with the indoor temperature. Improving the sound level is more important for her than improving the indoor temperature. Room 20's participant mentions to be satisfied with the sound level and the indoor temperature. For him TC, including indoor temperature, is most important.

That an IEQ indicator's importance changes depending on its condition is supported by the different RCs we found in regression models set up for satisfaction votes from surveys (a) completed in May and during the heat wave, and (b) in rooms located in quiet versus noisy zones (Table 3).[4] The indoor temperature's higher RC during the heat wave suggests that improving ST would have more impact on the room's overall assessment in this period than in May. Similarly, the same improvement in SS would have more impact in noisy than in quiet zones.

Table 3. Varying RCs depending on IEQ indicator's condition[4]

Corresponding IEQ indicator	RCs May	RCs July during heat wave	RCs quiet zones of the ward	RCs noisy zones of the ward
Intercept	3,55	3,51	0,38	0,88
Satisfaction indoor temperature	-0,01	0,76	0,06	0,34
Satisfaction IAQ	0,17	-0,23	-0,04	0,40
Satisfaction amount of light	0,09	-0,46	0,88	-0,02
Satisfaction sound level	0,22	0,58	**0,06**	**0,17**
R^2	0,55	0,65	0,94	0,50

These results might indicate as well that RCs vary with changes in the corresponding IEQ indicator's satisfaction level, but in the opposite direction. E.g., improving room 28's participant's SS will improve her IEQ assessment, but the relative weight of the indicator's satisfaction level might decrease as the sounds in the room will resemble more the sounds in rooms located in quiet zones of the ward (Table 3). Moreover, RCs of other IEQ indicators seem to vary simultaneously with changes in the satisfaction level and RC of an indicator.

Patients seem to search, continuously and within the perceived possibilities, the highest possible overall comfort. On the one hand they adapt the indoor environment when they perceive control possibilities. E.g., during the heat wave room 17.2's participant finds it most important to keep the heat outside. The window, shading devices and curtains are closed and the door to the corridor is opened to have some air circulation. Before the heat wave he preferred closing the door for privacy, and opening curtains and shading devices for daylight, and the window for outside air and air circulation. On the other hand, patients adapt themselves by adjusting the importance given to IEQ indicators. E.g., room 25's participant refers to a sound level increase when the visiting hour starts and is used to sleep in the dark, but 'it is a hospital' so he adapts himself to the situation. His SS and SL votes stay high. This search for the highest overall comfort reflects itself in how RCs and IEQ indicators' satisfaction level change towards an optimal balance.

DISCUSSION

In current IEQ research relationships between measured values of IEQ indicators and people's assessment of IEQ indicators, IEQ parameters and the multi-sensory IEQ are sought to estimate people's IEQ assessment (e.g. Fanger

[4] To enable a qualitative understanding of how the importance of each IEQ indicator changes in different situations, forward/backward selection are not applied.

1970; Fransson et al. 2007; Ncube and Riffat 2012). Although participants of our case study can single out an aspect (e.g. indoor temperature or TC), their experience is in essence *multi-sensory*. The condition of IEQ indicators seems to affect participants' experience, and their experience seems to affect how they assess individual IEQ indicators. Interactions between assessments of IEQ indicators that occur in this way can lead to compensating for or reinforcing the assessment of individual IEQ indicators. To estimate more accurately how patients assess IEQ, more attention for multi-sensory IEQ models seems needed.

Patients' IEQ assessment might also be estimated more accurately when *qualitative variables* are included. Sensors and satisfaction votes are ignorant for how moods or personality traits influence how participants deal with indicators, differences in the meaning given to sources that create the same condition of IEQ indicators, and the atmosphere.

Multi-sensory IEQ models might also avoid contradictions between defining more strict target values for individual IEQ indicators to improve the overall comfort and not necessarily achieving comfort increase, and the conflict between defining more strict target values and wishing to lower buildings' environmental impact. Making target values more strict and keeping all individual IEQ indicators within these target values can lead to more neutral environments and thus not necessarily comfort increases. Adhering to more strict target values impacts as well the operational energy. It is expected that focusing on overall comfort can reduce the requirements for individual IEQ indicators as some indicators might have in some situations a reduced weight in the overall comfort assessment or might be assessed more negatively than in other situations due to interactions with other IEQ indicators. Allowing that indoor conditions vary, and thus also IEQ indicators' effect on the overall comfort experience, can also make the IEQ experience interesting.

Improving the understanding of *how IEQ indicators impact on and interact in patients' assessment* benefits from combining sensor measurements and surveys with interviews and observations. Sensors inform about which conditions of IEQ indicators are to be assessed. Surveys can inform about conscious assessments, IEQ indicators' weight in the overall assessment and unconscious interactions. Surveys' votes assess IEQ indicators' qualities, but can be statistically linked to values of IEQ indicators. In-depth insights into patients' experience gained via interviews and/or observations inform about their prereflective, prepredicative, and nonreflective experience (i.e. unreflective consciousness) of the IEQ and their conscious reflection on it. This can be qualitatively linked to measured IEQ indicators and IEQ assessments.

CONCLUSION

Based on a pilot study with a mixed-methods approach (i.e. combining quantitative and qualitative methods) at a hospital's traumatology ward, we aimed to advance the understanding of how to improve methodologies used to estimate patients' IEQ assessment. In our study satisfaction with an IEQ indicator could be approximated only roughly with values measured by sensors, PPD-values for IEQ parameters and how often sensations differ from preferences.

As patients' assessment of one IEQ indicator seems to interact with the conditions and their assessment of other indicators, multi-sensory IEQ models are needed. Patients' assessment balances positively experienced IEQ indicators against negative ones. IEQ indicators' relative weight seems to vary with patients' satisfaction with the corresponding and other IEQ indicators. Patients seem to search the highest possible overall comfort, which can be viewed as an optimal balance between IEQ indicators' satisfaction level and RCs. Assessment estimations need to be able to include interactions between indicators' assessment and variations in RCs.

To develop multi-sensory IEQ models that estimate patients' IEQ assessment more accurately, qualitative data about patients' experience can complement quantitative data about measurable IEQ indicators and patients' IEQ assessment. In-depth insights into their experience advance the understanding of how to improve IEQ models, like reasons for differing interactions between IEQ indicators and variance in RCs. Moreover, as 'quality' of the indoor environment is subjectively experienced, models using quantitative variables only might not suffice. Combining quantitative and qualitative variables seems needed to estimate patients' multi-sensory IEQ assessment more accurately.

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