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Identification of Factors Influencing Satisfaction with Interaction Strategies by Clustering Occupants in Buildings

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Abstract. Control systems in buildings that prioritise occupant preferences have gained attention recently, intending to enhance the acceptability of automated systems. However, effective human-building interaction strategies remain challenging to design due to the lack of understanding of building occupant preferences. This study aims to identify factors influencing occupant satisfaction with building control systems to provide insights for improvement in interaction strategies. Surveys conducted in buildings located in Riga (Latvia) and Delft (The Netherlands) collected data on satisfaction with indoor environmental quality (IEQ), building controls, productivity, control importance, and social-subjective norms. Analysis categorised respondents into high and low satisfaction clusters and identified significant factors influencing satisfaction with IEQ through non-parametric tests. Logistic regression and coefficient analysis were used to assess the relationship between satisfaction and these factors. Findings suggest factors influencing satisfaction with IEQ, personal control, and automation, underscoring the developed methodology's potential. The identification of these factors informs actions that might enhance Human-Building Interaction (HBI) strategies, emphasising tailored approaches and addressing control system limitations. Further research is necessary to evaluate these strategies and understand how insights into human-building interaction strategies can lead to higher satisfaction levels.

Keywords: Human-Building Interaction · Questionnaire · Comfort · Preferences · Occupant · Influencing factors

1 Introduction

Recent advancements in the field of information technology have facilitated the application of smart technology in buildings [1]. These advancements include improvements in sensing, communication, interfaces, and controls, which enable different modes of interaction between occupants and buildings. This interaction between buildings and humans, known as Human-Building Interaction (HBI), is currently under exploration to enhance the quality of life and experiences of building occupants [2, 3].

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Occupant behaviour in the indoor environment affects building operation and overall performance. Previous research highlights occupants as pivotal in building energy consumption, suggesting that integrating their preferences into HBI control systems could enhance operations and result in energy savings [4, 5]. Several factors influence occupants' interaction with building control systems, such as occupants' profiles [6], their behavioural and occupancy patterns [7], as well as socio-demographic characteristics such as gender, age [8], and background [9]. These factors shape occupants' comfort needs, attitudes [10], habits, and preferences, consequently affecting how they engage with the controls provided in their office environment. Despite the knowledge of the influence of occupants on building control, particularly in areas such as heating, cooling, ventilation, and lighting systems, there is still a lack of understanding of how to define HBI strategies based on occupant characteristics to impact building operations positively. To achieve this, it is necessary to uncover the factors that influence occupant satisfaction with building controls and understand how these factors may vary across different building contexts.

This study aims to identify factors that impact occupant satisfaction with building operation and control to provide recommendations for improving HBI strategies. A survey is conducted in Riga (Latvia) and Delft (The Netherlands) to collect data on satisfaction with Indoor Environmental Quality (IEQ), building controls, productivity, control importance, and subjective norms. Respondents are grouped into high and low satisfaction clusters, and key factors influencing satisfaction with IEQ are identified using non-parametric tests. Logistic regression and coefficient analysis are employed to examine the relationship between satisfaction and these factors. Finally, a list of recommendations for improving human-building interaction strategies at the Delft and Riga case studies is developed.

This study contributes to enhancing our understanding of occupant control dynamics, providing insights into the connection between perceptions of building automated control and satisfaction levels regarding personal control and IEQ.

2 Methodology

2.1 Case Studies

Two buildings were investigated: The Faculty of Architecture and the Built Environment (ABE) of the Technical University of Delft (TU Delft) located in The Netherlands, and the Riga City Hall located in Latvia.

ABE (Fig. 1) is a 30,000 square meters historical building. In this study, the Department of Architectural Engineering and Technology (AE+T), in particular the section on Building Technology (BT), was considered as the investigated area. BT is a space of 200 square meters composed of 40 desks on two floors, in which 30 people work as professors, assistant professors, and researchers. The schedules of occupancy may vary over time. Every office is heated by radiators as part of a central heating system, regulated manually by thermostatic valves. There is no cooling. A fully automated mechanical ventilation system supplies air in most of the offices. The façade is composed of manually controlled windows and semi-automatic roller blinds. The roller blinds control logic is centralized based on solar irradiance. Lighting is semi-automated with occupancy sensors and task lights at every desk with manual control.

The Riga City Hall is the administrative building of the Riga Municipality, located in the Historic Centre of Riga (Fig. 1). The area of intervention has three floors, with around 30 desks of office workers. The occupancy patterns follow mostly fixed schedules. Heating control is primarily manual with thermostatic valves. Cooling systems operate with basic on/off control, and there is no interlock to prevent simultaneous heating and cooling. The lighting relies on manual switches, and the building envelope, including window shading and operation, is manually controlled. The building has a glazing facade orientated towards the south, providing views of the City and the Daugava River.

Fig. 1. Case studies front view (Left: Delft, Right: Riga).

2.2 Survey Design

We surveyed occupants from both case studies to collect information on (i) their level of importance for indoor temperature, view outside, acoustic environment, air quality, daylight, acoustic environment, artificial lighting, glare and privacy; (ii) their intention of interaction with the building services regarding perceived behavioural control, attitudes toward control and the social norms [11]; and (iii) their satisfaction levels per domain and personal and automated control of those services. All questions were answered by rating statements on a Likert scale from 1 to 5. In total, 28 and 30 survey respondents from Riga and Delft respectively were considered in this study.

2.3 Data Analysis Framework

The data analysis included several steps to find the factors influencing occupants' satisfaction and the direction of this influence. Initially, respondents were grouped into two clusters based on their satisfaction levels: those with high satisfaction and low satisfaction (Fig. 2a). Next, among different factors potentially explaining satisfaction IEQ, such as automation and personal control, we identified the statistically significant ones by using a non-parametric test, specifically the Mann-Whitney U Test, due to the non-normal distribution of our sample (Fig. 2b). This helped to explain the variability between the two satisfaction clusters. Subsequently, we conducted a logistic regression analysis to determine the relationship between satisfaction and these influential factors, focusing on the satisfaction objective variable (Fig. 2c). Finally, we analysed the magnitude and direction of coefficients to understand how changes in the influencing factors impact satisfaction levels (Fig. 2d).

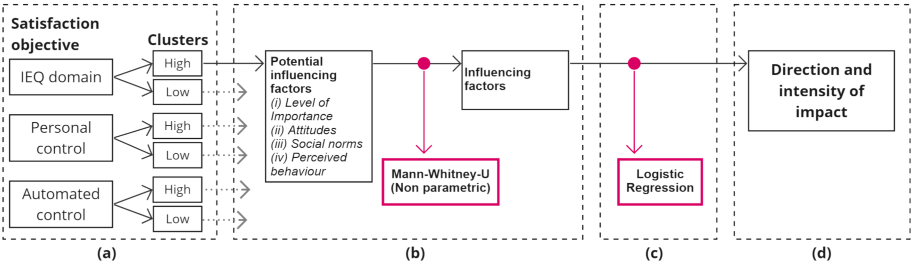

Fig. 2. Workflow of data analysis to identify factors influencing occupant satisfaction with IEQ, personal control and automated building operation.

3 Results and Discussion

Tables 1 and 2 shows the influencing factors on satisfaction levels for the Delft and Riga case studies respectively. The column "description" provides a direct interpretation of the results.

In Delft (Table 1), social norms such as approval-seeking and the significance of diverse opinions (when others' opinions impact individual actions) influence most of the satisfaction objectives, such as personal control of the window, indoor temperature,

Table 1. Results for the statistical analysis on the influencing factors affecting satisfaction with IEQ, personal control and automated building operation in the Delft case study.

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description
Personal control of window	L - 35% H - 65%	Approval-seeking for operating windows	0.046	1.32	Increasing common approval for window operation is positively correlated with personal window control satisfaction
Automated heating	L - 67%	Personal control of HVAC	0.038	0.90	Increasing the perceived personal control increases satisfaction with automated heating control

(*continued*)

Table 1. (*continued*)

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description
	H - 33%				
Indoor temperature	L - 76% H - 24%	Approval-seeking for operating heating	0.009	1.60	Increasing common approval for operating the heating system increases satisfaction with indoor temperature
Daylight	L - 68% H - 32%	Significance of diverse opinions for operating shadings	0.015	−1.66	Decreasing the significance of diverse opinions in operating the shadings results in higher satisfaction with daylight
Absence of glare	L - 68% H - 32%	Significance of diverse opinions for operating shadings	0.077	−1.16	When having more diverse opinions for operating the shadings decreases the satisfaction with the absence of glare
Absence of glare	L - 71% H - 29%	Outside View	0.015	−2.21	Having less importance of having outside views enhances satisfaction with the absence of glare
Acoustic environment	L - 60% H - 40%	Time schedules for window operation	0.076	−0.76	Decreasing the dependency on time schedules for window operation increases satisfaction with the acoustic environment

daylight, and the absence of glare. The satisfaction level with automated heating is influenced by personal control with HVAC, while time schedules for the windows operation influence satisfaction with the acoustic environment.

In Riga (Table 2), social norms and perceived behavioural control towards the control are influencing the satisfaction level with personal control of temperature and automated heating operation. Additionally, lowering the level of importance of indoor temperature and the absence of glare improves satisfaction with automated cooling and absence of glare.

Table 2. Results for the statistical analysis on the influencing factors affecting satisfaction with IEQ, personal control and automated building operation in the Riga case study.

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description
Personal control of temperature	H - 47% L - 53%	Approval-seeking for operating heating	0.036	1.01	Increasing common approval for adjusting the temperature increases satisfaction with personal temperature control
Personal control of temperature	H - 44% L - 56%	Perceived behavioural control in operating the cooling system	0.069	1.07	Increasing the perceived behavioural control in operating the cooling system is positively correlated with personal temperature control satisfaction
Personal control of temperature	H - 41% L - 59%	Approval-seeking for operating cooling	0.098	0.84	Increasing common approval for operating the cooling system increases satisfaction with personal temperature control
Automated heating	H - 33% L - 67%	Perceived behavioural control in operating the heating system	0.042	1.23	Increasing the perceived behavioural control in operating the heating system is positively correlated with automated heating automation satisfaction

(*continued*)

Table 2. (*continued*)

Satisfaction objective	Cluster	Influencing factor	P-Value	Coeff	Description
Automated heating	H - 39% L - 61%	Time schedules for heating operation	0.017	0.98	Increasing the time-based operation for heating systems is positively correlated with automated heating automation satisfaction
Automated cooling	H - 50% L - 50%	Indoor temperature	0.072	−1.72	Having a lower level of importance of indoor temperature levels is correlated with cooling automation satisfaction
Absence of glare	H - 32% L - 68%	Absence of glare	0.022	−2.11	Having a lower level of importance of glare is correlated with daylight satisfaction
Indoor air quality	H - 27% L - 73%	Silent work environment	0.077	1.04	A silent work environment correlates positively with indoor air quality satisfaction
Acoustic environment	H - 27% L - 73%	Silent work environment	0.031	1.48	Having a higher level of importance to a silent work environment increases satisfaction with the acoustic domain

Figure 3 illustrates how satisfaction objectives, explained by influencing factors, differ between the Delft and Riga case studies. In Delft, satisfaction with automated control correlates with perceived control levels, while in Riga, satisfaction with personal control is tied to social norms, in particular approval-seeking. Differences between case studies are also related to IEQ. In Delft, satisfaction with indoor temperature, daylight, and absence of glare is affected by social norms such as the significance of diverse opinions. In Riga, satisfaction with indoor air quality, acoustic environment, and absence of glare is correlated to noise levels and personal characteristics.

These differences can be attributed to distinct working setups. In Delft, where occupants spend less time in the office, automated systems may be perceived as intrusive without effective personal control. Conversely, in Riga, where occupants spend more time within a consistent social environment, the balance between personal preferences and common requirements influences perceived personal control.

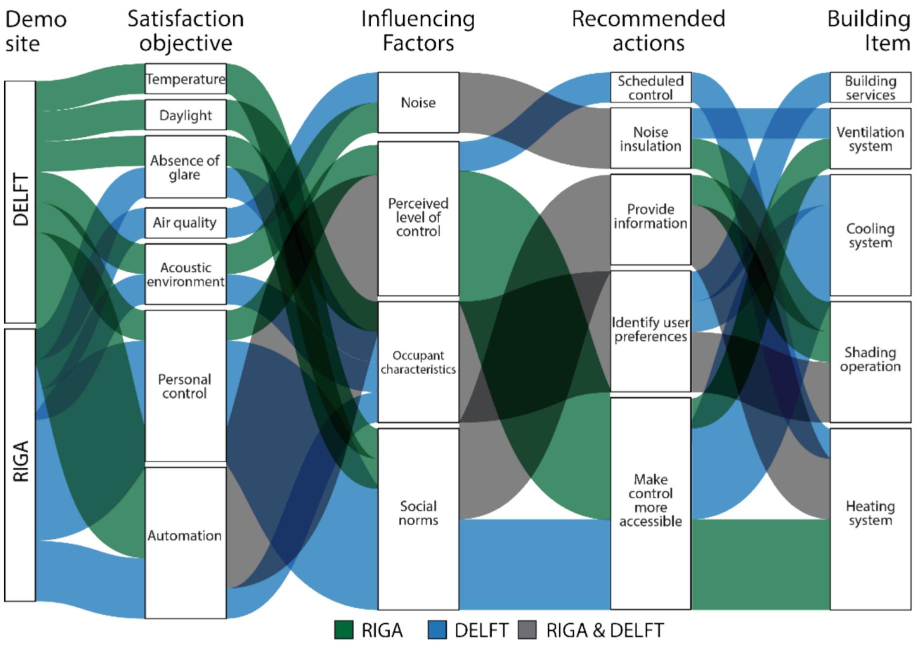

Fig. 3. The diagram illustrates the factors influencing satisfaction levels with IEQ, personal control, and automation across the Delft and Riga demo sites. Furthermore, it correlates recommended actions for each influencing factor, linking them to specific building items.

Additionally, Fig. 3 links influencing factors with recommended actions for the Delft and Riga case studies, showing distinct approaches regarding their specific needs. In Delft, the focus lies on enhancing accessibility across multiple systems, including heating, cooling, and ventilation. Delft emphasises the provision of information, particularly regarding heating systems and shading operations, alongside prioritising occupant preference identification, particularly for shading operations. Additionally, Delft underscores the importance of noise insulation, specifically on shading operations. In contrast, Riga's recommendations centre on improving accessibility for cooling and heating systems, with emphasis on implementing schedule-based control strategies for the heating system. Riga also highlights the importance of identifying occupant preferences, not only for cooling systems and shading operations but also for building services in general. Furthermore, Riga suggests noise insulation measures, particularly for the ventilation system. These differences show the specific challenges and priorities of each site, influenced by factors such as working environments, occupant preferences, and existing infrastructure.

Besides the differences spotted between the two case studies, the results provide general insights about the improvement of HBI strategies in buildings, such as (i) tailored HBI strategies needed to address specific occupants' preferences within a specific building environment, in which social norms, personal characteristics, building services and work dynamics play a pivotal role; (ii) a user-centred approach is needed to enhance occupant satisfaction with building automation and control by improving accessibility, customisation, and understanding of the control systems; (iii) a need to address existing limitations with the current control systems such as noise from blinds operation, effective control of discomfort glare, daylight, temperature and ventilation, and improve information from the building actuation system.

There are limitations in this study. Firstly, the sample size used for statistical analysis was limited, potentially affecting the correlation between influencing factors and satisfaction objectives. This limitation could result in missing key aspects affecting satisfaction with specific building features. Secondly, the study was conducted at a single point in time, without considering seasonal variations. Conducting surveys across different seasons would provide more accurate and comprehensive data for making suggestions. Thirdly, the absence of survey questions about HBI interfaces in buildings, including types, accessibility, and configuration access, makes it challenging to provide precise recommendations. Lastly, to validate the proposed framework, implementing these suggestions in a real building environment and measuring their effectiveness would be necessary. Addressing these limitations is needed to improve the reliability and applicability of the study's findings.

4 Conclusion

This study aimed to identify factors influencing occupant satisfaction with building services and offer insights for enhancing occupant experience with building automation and controls. Surveys conducted in buildings in Riga (Latvia) and Delft (The Netherlands) collected data on satisfaction with IEQ, building controls, productivity, control importance, and social-subjective norms. Our framework employed statistical analysis methods to determine the following findings:

1. Factors influencing satisfaction levels with IEQ, personal control, and automation at both the Delft and Riga case studies were identified, demonstrating the potential of the developed methodology.
2. Those influencing factors affecting satisfaction levels are not universally applicable, as contextual factors such as building type, occupant characteristics, available building services, and internal social dynamics play significant roles.
3. Social norms, such as approval-seeking (when occupants look for agreement among themselves) and the significance of diverse opinions (when others' opinions impact individual actions) have been shown to play a role in the satisfaction level with personal control of the window, automated heater, indoor temperature, daylight, and the absence of glare.
4. Identifying influencing factors on occupants' satisfaction with building control presents opportunities for informed actions to improve HBI strategies.

The results offer insights into the need for improvements in HBI strategies, emphasising the need for tailored interaction approaches, a user-centred focus, and addressing existing limitations with control systems. Future research should focus on assessing the effectiveness of these strategies and testing the framework in real buildings to gain insights into HBI dynamics and optimise satisfaction levels.

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