Human-Centered Design and User Experience, Vol. 114, 2023, 306–312
https://doi.org/10.54941/ahfe1004248

IEQ Visual Data to Building Occupants for Personal Control of Indoor Environmental Quality

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ABSTRACT

Indoor Environmental Quality (IEQ) profoundly influences occupants' health, productivity, and comfort in built environments. Effective interaction with occupants to comprehend and control IEQ conditions is crucial in human-centered design for IEQ optimization. This paper presents a preliminary study that leverages three-dimensional (3D) virtual space to deliver IEQ data to occupants, enabling them to understand indoor conditions better and exercise personal control of IEQ. A survey was conducted with participants in a virtually simulated educational environment. For a comparative study, participants experienced 3D virtual space with and without IEQ data information on IEQ variables such as temperature, humidity, air quality, lighting, and noise levels. The proposed framework addresses the effectiveness of IEQ visual data on occupants' responses to ways of indoor environmental controls. Regarding the effectiveness of IEQ visual data for occupants' engagement in IEQ controls, the percentage of positive tendency, that responses strongly agree and agree, ranges from 86 to 88% for thermal comfort, from 84 to 92% for visual comfort, from 71 to 81% for acoustic comfort, and 85% for indoor air quality. Findings also show that specific directions on pictograms would help participants take active engagement to improve comfort levels rather than visual data solely. In conclusion, this paper indicates a preliminary approach utilizing 3D virtual space to determine how participants respond to IEQ visual data for personal control of IEQ. By merging immersive visualization with interactive control, our framework bridges human factors and indoor design for occupants' comfort and productivity. The demand for human-centered design continues to expand to IEQ management with emerging technologies such as electroencephalography, resulting in the design of optimized, healthier, productive, and energy-efficient indoor spaces.

Keywords: Personal control, Indoor data visualization, Indoor environmental quality, Virtual space, Human-centered design

INTRODUCTION

Research Goal

The effective communication of Indoor Environmental Quality (IEQ) data is crucial for informing design, policy, and decision-making processes that impact occupants' health, comfort, and productivity. Data visualization, as a dynamic means of representation, has emerged as an indispensable tool for translating intricate datasets into comprehensible visual forms that facilitate more meaningful interpretations. These visual formats encompass the integration of augmented reality, virtual reality, immersive 3D visualization, and interactive dashboards.

The primary objective of this preliminary research is to investigate the effectiveness of indoor data visualization in enhancing occupants' understanding and facilitating informed decisions to improve Indoor Environmental Quality (IEQ). The study is designed to assess how occupants comprehend and interpret IEQ data in three-dimensional visual formats. It will examine whether immersive visualization improves occupants' ability to grasp the IEQ parameters for their personal control of IEQ. By evaluating the impact of data visualization on occupant engagement, this study aims to contribute to advancing human-centered design strategies that empower individuals to take proactive control over IEQ parameters (Parkinson et al., 2019; Shah et al., 2020).

Human-Centered Design for IEQ

Human-centered design (HCD) in architecture places human needs, behaviors, and experiences at the forefront of the design process, resulting in optimized spaces to accommodate user preferences, comfort, and well-being. Its emphasis on understanding and responding to human behaviors and preferences ensures that architectural environments align seamlessly with their occupants' physiological and psychological requirements. HCD also introduces a holistic approach to IEQ control, acknowledging that diverse users have varying requirements for thermal comfort, lighting, acoustics, and indoor air quality. Incorporating HCD principles allows building occupants to engage with environments that optimize IEQ parameters, leading to increased occupant satisfaction, reduced stress, and improved cognitive performance. This realization has led to a growing focus on enhancing IEQ through various strategies, ranging from technological interventions to informed decision-making. A pivotal aspect of this evolution lies in empowering individuals to control IEQ variables, aided by effectively delivering indoor data to building occupants (Magnavita, 2014; Geng et al., 2018).

RESEARCH METHODOLOGY

Preliminary Study Set

The research will focus on assessing occupants' recognition of indoor data visualization. The study will consider various IEQ parameters, including temperature, humidity, illuminance, sound pressure level, and indoor pollutants embedded in a 3-dimensional virtual model. The research methodology includes quantitative data analysis, such as measuring occupant comprehension and decision-making effectiveness. Figure 1 shows the entire research procedure, and this paper highlights the component of Phase 3.5: real-time visual data to occupants as a fragment of the structure as a whole.

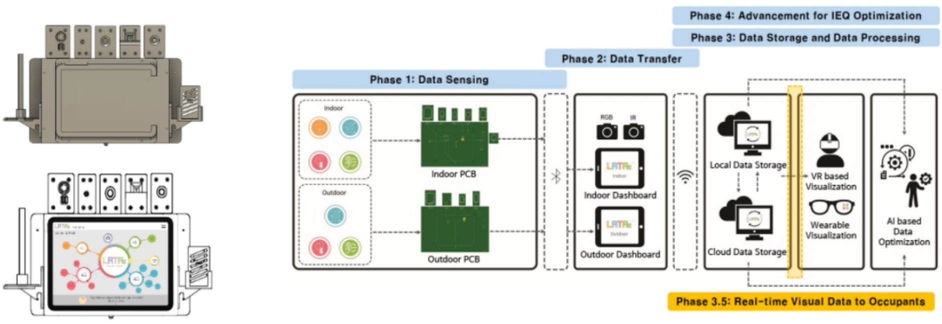

Figure 1: Data sensing, transfer, and visualization.

For the advancement of real-time IEQ data delivery to occupants' comfort, integrating advanced technologies, such as data sensing, storage, and real-time data transfer, is pivotal. Besides, the multifaceted benefits of comprehensive data collection are in delivering accurate, holistic, and actionable insights into the complex interactions between various IEQ parameters and occupants' experiences. Extensive data collection simultaneously measures multiple IEQ parameters and captures their temporal and spatial variations. As the existing LATAC+ as an extended IEQ data collector in Figure 1, the confluence of data sensing, storage, and real-time data transfer holds immense potential in advancing IEQ control and enhancing occupants' comfort and well-being.

Indoor Data to Building Occupant

In conveying complex IEQ data visualization in a three-dimensional virtual model, pictograms, as graphic symbols representing complex information, are examined for their efficacy in describing thermal, visual, acoustic, and indoor comfort parameters as in Tabe 1. Pictograms are intuitive, enabling rapid comprehension without extensive data interpretation to capture the essence of various IEQ parameters, fostering a quick and efficient understanding of environmental conditions, as in Figure 2 (Ludwigsdorff et al., 2016; Yin et al., 2020). Table 1 shows target IEQ parameters to be tested in a virtual space, as in Figure 2.

Table 1. IEQ parameters and data visualization.

IEQ Categories	IEQ Parameters	Contents
Thermal Comfort	Temperature (°C) Humidity (%)	• Colored pictograms on IEQ parameters • Concentration level on each parameter • Warning Levels • Directions for improvements
Visual Comfort	Illuminance (lux)	
Acoustic Comfort	Sound Pressure Level (dB)	
Indoor Air Comfort	Particulate Matters (mg) CO2 (ppm)	

Experimental Design

Pictograms are applied to augment occupant spatial experience and perceptions within 3D virtual environments. The efficacy of integrating pictograms into virtual spaces is examined to communicate information, guide interactions, and shape occupant perceptions, ultimately enriching the user experience. Strategically placing visual cues helps occupants perceive, interact, and enhance their overall experiences of IEQ conditions. In virtual environments, each participant experienced each virtual scenario without visual cues and with visual cues, including illuminance (lux) level for visual comfort, noise level (dB) for acoustic comfort, indoor pollutant concentrations (CO2, Pm2.5, PM10) for air quality, and temperature (°C)/relative humidity (%) for thermal comfort in Figure 2. Participants responded to the survey after watching 3 minutes of virtually-modeled office conference rooms in Figure 2.

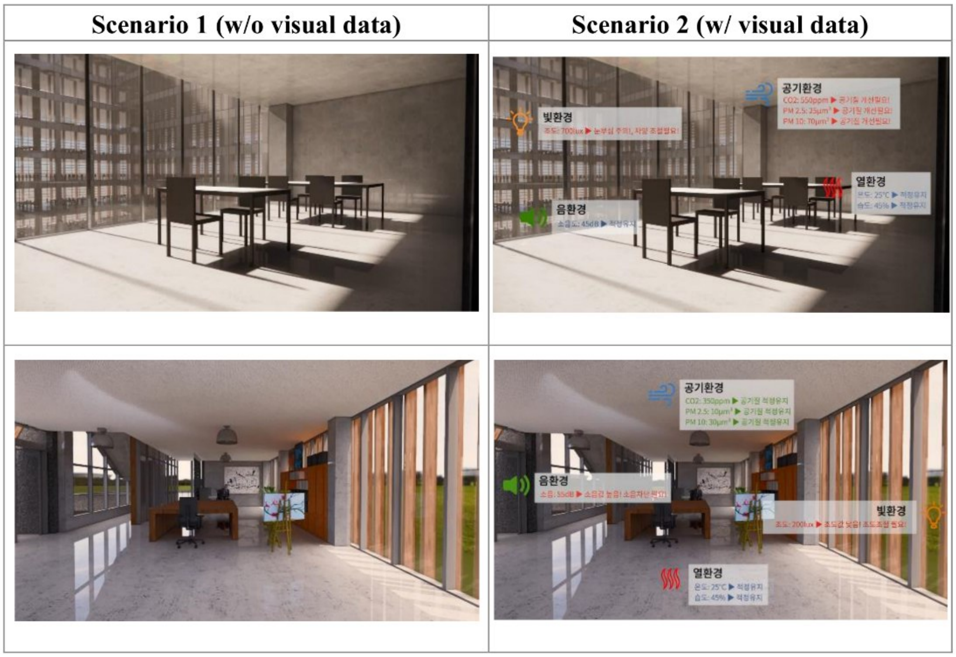

Figure 2: Example of IEQ visual data in pictograms in a 3D virtual space.

Survey Design

The survey design for this research involves a structured approach to gather valuable insights from student participants. The aim is to assess their perceptions and preferences regarding the effectiveness of IEQ visual information in a three-dimensional virtual model and its potential impact on occupants' engagement for IEQ improvement. The survey design encompasses participant selection, survey size determination, Likert scale implementation, and question formulation. The Likert scale will consist of a range of response options, typically ranging from "Strongly Disagree" to "Strongly Agree."

Table 2. IEQ parameters and data visualization.

IEQ Categories	Questions
Thermal Comfort	1. Visual data on temperature (°C) and humidity (%) levels has helped me understand the indoor thermal environment. 2. Visual data on temperature (°C) and humidity (%) levels has helped me engage in controlling the indoor thermal environment. 3. More specific directions on pictograms would help me take active engagement to improve thermal comfort than visual data solely.
Visual Comfort	4. Visual data on illuminance (lux) has helped me understand the indoor visual environment. 5. Visual data on illuminance (lux) has helped me engage in controlling the indoor visual environment. 6. More specific directions on pictograms would help me take active engagement to improve visual comfort rather than visual data solely.
Acoustic Comfort	7. Visual data on sound pressure levels (dB) has helped me understand the indoor acoustical environment. 8. Visual data on sound pressure levels (dB) has helped me engage in controlling the indoor acoustical environment. 9. More specific directions on pictograms would help me take active engagement to improve acoustic comfort rather than visual data solely.
Indoor Air Quality	10. Visual data on indoor air quality has helped me understand the indoor air environment. 11. Visual data on indoor air quality has helped me engage in controlling the indoor air environment. 12. More specific directions on pictograms would help me take active engagement to improve indoor air quality than visual data.
Misc.	13. Other comments

RESULT AND CONCLUSION

The study aimed to investigate the efficacy of utilizing IEQ visual data presented through 3-dimensional virtual models in enabling building occupants to exercise personal control over their indoor environment. Through a systematic empirical exploration, the study sought to discern whether the immersive 3D visualizations fostered a heightened sense of understanding, engagement, and empowerment among occupants, consequently leading to informed decisions for IEQ enhancement. Regarding the effectiveness of IEQ visual data for occupants' engagement in IEQ control, the percentage of positive tendency, that responses strongly agree and agree, ranges from 86 to 88% for thermal comfort, from 84 to 92% for visual comfort, from 71 to 81% for acoustic comfort, and 85% for indoor air quality. Findings also show that specific directions on pictograms would help participants take active engagement to improve comfort levels rather than visual data solely.

Table 3. Survey responses for positive tendency.

Questions	Response (N = 87)
1. How much do you agree that visual data on temperature (°C) and humidity (%) levels helped me understand the indoor thermal environment?	**% of Positive Tendency: 77.0** (Strongly Agree and Agree)
2. How much do you agree that visual data on temperature (°C) and humidity (%) levels helped me engage in controlling the indoor thermal environment?	**% of Positive Tendency: 86.2** (Strongly Agree and Agree)
3. How much do you agree that more specific directions on pictograms would help me take active engagement to improve thermal comfort than visual data solely?	**% of Positive Tendency: 88.5** (Strongly Agree and Agree)
4. How much do you agree that visual data on illuminance (lux) has helped me understand the indoor visual environment?	**% of Positive Tendency: 81.6** (Strongly Agree and Agree)
5. How much do you agree that visual data on illuminance (lux) has helped me engage in controlling the indoor visual environment?	**% of Positive Tendency: 83.9** (Strongly Agree and Agree)
6. How much do you agree that more specific directions on pictograms would help me take active engagement to improve visual comfort rather than visual data solely?	**% of Positive Tendency: 91.9** (Strongly Agree and Agree)
7. How much do you agree that visual data on sound pressure levels (dB) has helped me understand the indoor acoustical environment?	**% of Positive Tendency: 59.7** (Strongly Agree and Agree)
8. How much do you agree that visual data on sound pressure levels (dB) has helped me engage in controlling the indoor acoustical environment?	**% of Positive Tendency: 71.2** (Strongly Agree and Agree)
9. How much do you agree that more specific directions on pictograms would help me take active engagement to improve acoustic comfort rather than visual data solely?	**% of Positive Tendency: 80.5** (Strongly Agree and Agree)
10. How much do you agree that visual data on indoor air quality (CO2, PM2.5, PM10) has helped me understand the indoor air environment?	**% of Positive Tendency: 77.0** (Strongly Agree and Agree)
11. How much do you agree that visual data on indoor air quality has helped me engage in controlling the indoor air environment?	**% of Positive Tendency: 85.1** (Strongly Agree and Agree)
12. How much do you agree that more specific directions on pictograms would help me take active engagement to improve indoor air quality than visual data solely?	**% of Positive Tendency: 85.0** (Strongly Agree and Agree)
13. Other comments	- Needs better design of visual information - Needs effective ways of info-graphics

The study's findings affirm the positive impact of IEQ data visualization on building occupants' responses to IEQ controls in 3D virtual models. The heightened understanding, engagement, and empowerment experienced by occupants provide a compelling rationale for integrating such technologies into architectural design and building management practices. This research contributes to the discourse on human-centered design strategies that empower occupants to actively shape their indoor environment, thereby fostering enhanced comfort, health, and well-being.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korean government(MSIT) (No. NRF-2021R1G1A1008000).

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