Design of online platform and visualization system based on three-dimensional spatial information for occupant satisfaction with indoor environment quality

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Abstract. Prior evaluations of building energy performance have focused on quantitative performance based on mathematical models while overlooking the value of quality of residential life. The Post-Occupancy Evaluation (POE) method is regarded as an important component of the value judgment process for enhancing the quality of actual building performance. Accordingly, we developed a cost-effective open-source survey platform to collect data on occupant satisfaction. This study focuses on the evaluation indexes of indoor environment quality (IEQ) and conducted a pilot test. The difference of this platform compared with existing online survey systems is that the survey information is linked with the shape and spatial information of the building. This study’s online platform for surveying occupant satisfaction is expected to significantly reduce the time and costs required for conventional IEQ occupant satisfaction surveys. In addition, the collected survey responses are analyzed through a database and visualized as a prototype based on 3D spatial information, providing more intuitive feedback to the owner and occupants of the building.

1. Introduction

Various policy research has been conducted to evaluate the energy performance and efficiency of buildings. Accordingly, the Korean Ministry of Land, Infrastructure, and Transport (MOLIT); the Ministry of Trade, Industry and Energy (MOTIE); the Ministry of Environment (ME); and other Korean government ministries have implemented systems and regulations for reducing building energy use and increasing energy efficiency. Most of these regulations are based on engineering calculation methods, e.g. ISO 52016:2017 (formerly ISO 13790:2008), compelling the market to satisfy the minimum requirements. For example, the Korean Green Standard for Energy and Environmental Design (G-SEED), a green building certification system, includes the evaluation of “energy performance” regarding calculated energy demands. In addition, the Korean Building Energy Efficiency Certification (BEECS), an energy efficiency rating system, also includes the evaluation of (calculated) primary energy demands for cooling, heating, hot water supply, lighting, and ventilation. However, even if the total energy demands of buildings are reduced, preventing occupants from enjoying a pleasant residential life would conflict with Article 35 (1) of the Constitution of the Republic of Korea, which states the following: “All citizens shall have the right to a healthy and pleasant environment.” Moreover, previous studies have found that the indoor environment impacts the health and wellbeing of the occupants; furthermore, occupants spend nearly 90% of their time indoors. Therefore, evaluations of building energy performance should also account for how efficiently energy is used by occupants, for example, in a healthy and pleasant residential environment [1-3].

In brief, evaluations of building energy performance have focused on quantitative performance based on mathematical models, while overlooking the value of quality of residential life. Accordingly, the Post-Occupancy Evaluation (POE) method has gained importance as a tool to address this issue. POE is
regarded as an important part of the value judgment process to enhance the quality of actual building performance [3-7].

POE has generally incorporated surveys and interviews of occupants, with the survey method gradually gaining prominence [7-8]. However, as the survey method requires researchers or surveyors to directly visit each respondent, the time and costs spent during investigation increase dramatically with the scale of the survey. In other words, the surveys have been limited to certain buildings because of the cost and time constraints. Furthermore, such constraints also restrict generalization and dissemination of the POE studies [7]. Therefore, more subjects must be covered with a wider distribution.

To address such limitations, the Center for the Built Environment (CBE) of the University of California, Berkeley, developed the CBE Occupant Indoor Environmental Quality (IEQ) satisfaction survey, a web-based questionnaire and reporting tool [9]. This tool visualizes the collected measurement information in the targeted building based on 2D images (floor plans from CAD files). Although another study has attempted to visualize POE results by linking 3D building information model (BIM) data [10], it is difficult to apply this to diverse buildings owing to the limited time and cost for BIM. Such online platforms have achieved the expected results but still face obstacles. First, for most old or small buildings, it is difficult to obtain CAD files (for floor plans). Second, BIM is computationally expensive or sometimes too resource heavy for processing. In short, it is difficult to collect and express the 3D spatial information cost-effectively with regard to indoor environmental factors (e.g., temperature, humidity, and pollutant concentration), occupant satisfaction, and interviews reported.

Accordingly, in this study, we developed a cost-effective open-source platform to overcome previous limitations. This platform includes the following features: (1) information collection (e.g., occupant satisfaction), (2) connection of collected information and 3D spatial information, and (3) information visualization.

2. Design of online platform for occupant satisfaction

2.1. Occupant satisfaction survey

"Occupant satisfaction" refers to an occupant’s subjective evaluation of the residential environment, while “residential environment” refers to the internal and external environmental conditions of a living space. In this way, evaluations of occupant satisfaction must consider residential environment factors. Many previous studies have classified residential environment factors by physical (climate, temperature, humidity, etc.), socio-cultural (geography, ethnicity, psychology), and economic (costs, etc.) characteristics [11]. Among these many indexes, IEQ, which requires a substantial amount of energy, was found to have the greatest impact on residential satisfaction [12-15]. Thus, this study prioritizes IEQ in its analysis.

We performed a meta-analysis of the factors affecting indoor residential environment used in existing literature and regrouped the common factors. We identified thermal quality, acoustic quality, lighting quality, and indoor air quality as universal factors affecting indoor environment quality for the evaluation of building performance [16-19]. This study aims to build a prototype of a platform for collecting information on indoor environment quality. Therefore, rather than reflecting all physical (climate, temperature, humidity, etc.), socio-cultural (geography, ethnicity, psychology), and economic (costs, etc.) factors, this study includes four evaluation indexes of IEQ. Table 1 shows the online survey indexes for occupant satisfaction. We have developed a seven-point rating scale to analyze the mean response.
Table 1. Occupant Satisfaction Survey Criteria

| Classification      | Details                                                                 |
|---------------------|-------------------------------------------------------------------------|
| Thermal quality     | Level of heat in summer (cooling adequacy)                              |
|                     | Level of coldness in winter (heating adequacy)                         |
|                     | Presence/absence of condensation on windows and doors                  |
|                     | Presence/absence of mold on walls                                     |
|                     | Level of indoor humidity                                               |
| Acoustic quality    | Level of internal noise                                                |
|                     | Level of external noise                                                |
| Lighting quality    | Indoor brightness (ceiling lighting, window)                            |
|                     | Presence/absence of window on walls                                   |
| Indoor air quality  | Ventilation satisfaction                                               |
|                     | Level of internal air quality                                          |
|                     | Level of unpleasant smells                                            |

2.2. Development of Public Open-Source Online Platform

The online platform of this study was built on WordPress using an open-source database. First, we collected and analyzed public information provided by the Korean government, including that from the open API operated by Vworld of the Korean Spatial Information Industry Promotion Institute [21], as well as the geographic information system (GIS) integrated building information provided by the Korea Land and Geospatial Information Corporation (LX). From the latter, we collected the buildings’ polygon data through the institution’s open API.

This system uses Leaflet, which is an open-source library of online maps. We transformed the coordinates of the coordinate system provided by the LX. To represent the buildings as polygons on the map, a function must be used that draws lines on the map in Leaflet; to draw lines in Leaflet, a list of latitude and longitude coordinates based on the EPSG:4326 coordinate system must be used. Accordingly, we transformed the EPSG:5174 latitude and longitude coordinates provided by the LX to EPSG:4326. The primary reason for utilizing open-source libraries and public data is to reduce the costs of development and data collection. Furthermore, the public data from government agencies provides high reliability and availability with annual update.

The difference of this platform compared with existing online survey systems is that the survey information is linked with the shape and spatial information of the building. Thus, the collected data can be visualized in 3D to determine the existence of problems in the space (x, y, z). To perform 3D visualization, we collected latitude (x), longitude (y), and height (z) information, mapped the survey results (s), and displayed the information in multilevel colors such as red, yellow, and green. The user directly clicks [x, y] latitude and longitude points on the map to record two dimensional location, after which the user directly enters height [z] information. The IEQ survey results are displayed in this manner. The interior of the building is visualized using the Indoor3D API. The prototype was developed online in this manner to enhance the accessibility and openness of the survey. Above all, while other existing studies are conventionally displayed through primary methods (mainly graphs or floor plans), this study displays results in a 3D space to enhance spatial intuitiveness for the user.
2.3. System functions and working process
The developed system consists of three functions: Investigation Function, Survey Function, and Visualization Function.

- Investigation Function. This function is accessed by the surveyor (researcher, facilities manager, building owner, etc.). After logging in, the surveyor selects the building to be surveyed and then creates and distributes the questionnaire. The building to be surveyed is selected from the building registry database (via API) provided by MOLIT. The process of creating the questionnaire is similar to Google Forms; one difference is that this system requires the respondents to enter geo-spatial information (latitude [x], longitude [y], height [z]). Furthermore, the system can be customized for various purpose owing to open-source libraries.

- Survey Function. This function is accessed by the survey respondent. The respondent accesses the distributed survey on the webpage and confirms the location and shape polygon of the building to be surveyed. Initially, Leaflet is used to display the online map. Afterward, the
respondent clicks on the 3D spatial information \([x, y, z]\) of him/herself in the shape polygon of the building. The shape polygon and the satellite photo displayed are called by the API provided by Vworld [20]. After inputting the respondent’s location information, the occupant satisfaction survey commences. The final responses and location information are saved together in the database.

- Visualization Function. This function is accessed by the surveyor and the respondent. The survey responses are displayed as shown at the right of Figs. 2 and 3. To create a 3D visualization of the collected dataset, OpenStreetMap (OSM) API is used for the online map, while Indoor3D API is used for the 3D space.

![Diagram of system operational process](image)

**Figure 4.** Operational process of the system: investigation, survey, and visualization.

### 3. Conclusion

This study’s online platform for surveying occupant satisfaction is expected to significantly reduce the time and costs required for conventional IEQ occupant satisfaction surveys. In addition, the collected survey responses are analyzed through a database and visualized, providing more intuitive feedback to the owner and occupants of the building. Most importantly, as a prototype based on 3D spatial information, this platform is significant as it provides a framework for combining spatial information and survey responses. In addition, by providing the survey results through an online database, the collected information can be used as basic data for developing a rational IEQ evaluation methodology, thereby promoting evidence-based policy research.

In addition, we plan to supplement the design of the practical survey questions through a validity review of questionnaire indicator development and surveyor testing. Furthermore, a method is required to confirm the consistency of survey responses and ensure the objectivity of survey responses. Finally, the ultimate goal of this study is to develop a platform that can be utilized in the industry as well as in academia. Therefore, we anticipate the need to consult with target users (building managers, surveyors from public institutions, human resources personnel who wish to survey the indoor environment satisfaction of employees, etc.) to evaluate the applicability of this platform.
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