Post-Occupancy Evaluation of Green Technologies for a High-Rise Building Based on User Experience

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Abstract: Post-occupancy evaluations of buildings help us understand the effectiveness of building designs. Most of such evaluations focus on the overall building performance and on the indoor air environment, and few focus on individual technologies. In this paper, we report a user experience-based evaluation on multiple green technologies applied in a high-rise building constructed 17 years ago. These technologies include a circular building design, innovative floor plans, a corridor-type, double-skin facade with cavity shading, and three-dimensional greening design. Data were obtained through a questionnaire for the building occupants and on-site measurements of environmental variables. The results show that the occupants were most satisfied with the three-dimensional greening, natural lighting and ventilation in the public spaces, and the sound and thermal environment of the rooms with the double facade. They were not satisfied with room ventilation, solar shading, or lighting adjustment provided by the double facade. In addition, the aesthetic appearance of the circular building was not recognized by the occupants, who appeared to pay more attention to its space efficiency than the external appearance. This was true especially for older occupants. The users expressed a strong demand for outdoor leisure spaces and green vegetation. However, the practicality and functionality of three-dimensional greening, along with the interference of the glass curtain wall on vegetation growth, calls for more attention to the design. The female occupants were found to be more sensitive to the thermal and acoustic environment. Based on these results, we provide recommendations on the maintenance of the building and the future design of these measures.

Keywords: post-occupancy evaluation; green technologies; questionnaire; double-skin facade; vegetation; circular building

1. Introduction

Green technologies ensure the resource-saving and sustainable development of the building industry [1,2]. In China, green building standards have evolved from a focus on design and construction stages [3,4] to an emphasis on operation stages [5]. The latest standard [5] requires some of the operation outcomes to be evaluated to support the green building labeling. Therefore, post-occupancy evaluation (POE) studies of existing buildings are becoming popular.

The POE is a systematic evaluation method for buildings or the built environment [6,7]. It originated from the field of environmental psychology in the 1960s, and a relatively complete theory was proposed by Preiser [8]. Nowadays, the scope of the POE has expanded from environmental psychology to urban spaces, green buildings, etc., [9–11]. In building performance evaluations, the POE has become an effective method in building an evaluation in addition to objective indicators such as measurable thermal parameters.

In recent years, studies on the POE of green buildings have shown different directions, including the indoor environmental quality (IEQ), operating performance, and stakeholder
impact analysis. Lin et al. [12] used both physical parameter measurements and a satisfaction survey to evaluate the IEQ of several green office buildings in China. The results show that the users’ satisfaction with thermal comfort, indoor air quality (IAQ), and the operation of green buildings is higher than those of the ordinary buildings. Through subjective and objective measurements of the IEQ, Lee et al. [13] found that the IEQ of green-certified buildings is better than that of ordinary buildings. Polina et al. [14] showed that zero-carbon buildings also have higher user experience satisfaction. However, Leaman et al. [15] argued that green buildings could be associated with high costs of management and maintenance and demanding skills in the operation and maintenance of various applied technologies. Nevertheless, several studies [10,16] that have focused on the overall operational performance of green buildings by collecting the building energy consumption, environmental measurements, and user satisfaction found that the actual operational performance of green buildings was better than conventional buildings in the same region. In addition, Li et al. [17] proposed that the POE of green buildings needs to include various stakeholder groups, such as the government, architects, end-users, regulatory agencies, etc. These groups could provide personal opinions from their perspectives to promote a more comprehensive and democratic green building development in the future.

The above reviews show that the existing POEs focus more on the overall performance of green buildings, including the IEQ, operating performance, and stakeholder impact analysis [18]. However, such evaluation could not differentiate the actual performance of individual technologies. Although a green building typically includes multiple major green measures, the designers and engineers may actually need to know the applicability and effects of each green technology for certain projects. Therefore, it is equally important to conduct evaluations for individual technologies to gain a deeper and more comprehensive understanding. Unfortunately, fewer POE studies have focused on individual green technologies, especially based on user experiences.

With this study, we attempt to fill this gap and report a POE study of multiple green technologies in a Chinese office building from the users’ perspectives. The objective of this paper is to examine the user feedback of these green technologies against their original design goals and to provide insights for their future applications. One of the prominent features of the building was the double-skin facade (DSF), the applicability of which has been much debated. However, few studies report the DSF evaluation based on user experiences. As a pilot study, we collected the data using an online questionnaire and on-site measurements. These data will add to the database of DSF studies. In addition, the result will provide a guide for the building maintenance and future renovations.

2. Methods
2.1. The Studied Building

The studied building is the Lishui Electrical and Power Building (LEPD), which is in Lishui city in eastern China, about 400 km south of Shanghai. Constructed in 2005, it is one of the early high-rise office buildings in China that adopted multiple green technologies for energy efficiency and low environmental impact. The main building is 99.50 m high with 23 stories aboveground. There is a 3-story annex building to its north (see photos in Table 1). The building covers an area of 3938 m² with a total floor area of 33,220 m². It is one of the tallest landmark buildings in the local urban area [19].

Lishui is a basin city surrounded by low to medium mountains. The local climate features hot summers and cold winters. The summer typically lasts more than three months from June to September (Figure 1). Therefore, efficient cooling, heat barriers, natural ventilation, and vertical vegetation were among the major considerations in designing the building. Multiple green technologies were adopted in the LEPD, including circular building, innovative floor plans, corridor-type DSF [20], solar shading, three-dimensional greening design [21], etc. Their main features and design goals are summarized in Table 1.
Table 1. Green building technologies of Lishui Electric and Power Building.

<table>
<thead>
<tr>
<th>Green Technologies</th>
<th>Circular Building</th>
<th>Innovative Floor Plans</th>
<th>Corridor-Type Double-Skin Facade</th>
<th>Sun-Shading System</th>
<th>Three-Dimensional Greening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goals</td>
<td>Energy efficiency, architectural esthetic appearance</td>
<td>Energy saving; natural lighting and ventilation; flexible layout; design freedom</td>
<td>Architectural esthetic appearance; energy efficiency in heat barrier; lighting, insulation; sound barrier; daylight and natural ventilation</td>
<td>Glare control; energy efficiency</td>
<td>Encourage outdoor relaxing; close to nature; social promotion</td>
</tr>
<tr>
<td>Method</td>
<td>Round shape of volume, small S/V ratio</td>
<td>The rooms in the south and north directions have the most lighting and visibility, and the unfavorable orientation is optimized, 8 m × 8 m column grid, concave gaps</td>
<td>Corridor-type DSF, staggered placements of inlets and outlets, single glazing for the external layer, double glazing for the inner layer, manually adjustable aluminum blinds in the cavity</td>
<td>Blinds in DSF cavity, vertical shading device in the east/west, horizontal external shading on the south of the annex building</td>
<td>Ground-level lawn and vegetation landscape around the building with selected deciduous trees, mostly shrub vegetation on the accessible roof top level and balcony garden with waterproof wooden battens</td>
</tr>
</tbody>
</table>

Photos or sketch

Figure 1. The daily highest and lowest temperatures of 2020 in Lishui, Zhejiang, China [22].

The circular shape has a small surface to volume (S/V) ratio, which helps reduce the overall heat transfer area for the same build volume. In addition, the tall, round building stands out as a landmark in the city. The building boasts an innovative floor plan that moved the traffic and auxiliary spaces to the east and west sides, which were the unfavorable spots due to strong solar irradiation. Such an arrangement also provides maximum daylight and window views from the north and south sides. The plan adopted a large span (8 m), which provides flexibility and freedom in space design. In addition, several concaves are located along the edge to bring daylight and natural ventilation to the public spaces. The corridor-type DSF provides an energy-efficient layer with better solar shading and air control. The external layer consists of single panes and has inlets at the bottom and outlets at the top of each level. The internal layer consists of double-glazed panes. Each room has one openable pane as a horizontal pivot window. The glazing facade also adds to the aesthetic appearance of the building.

The 600 mm-deep cavity of the DSF is equipped with aluminum blinds. There are also vertical shutters for solar shading on the west and east sides of the building. In addition,
there are horizontal shading shutters on the annex building. The three-dimensional greening of the building includes ground-level greening, indoor greening, and roof garden. The ground-level lawn and vegetation landscape around the building comprise deciduous trees. The vegetation on the accessible roof top level and the balcony garden is mainly shrubs.

2.2. Research Design

A POE method combining an online questionnaire and field measurements was used. Firstly, the statistical methods of analytic hierarchy process (AHP) [23], Likert scale [24], and correlation analysis [25] were used for data post-processing. The questionnaire was designed to understand users’ experience-based satisfaction. The correlation analysis was used to obtain the relationship between different factors. The survey was distributed online through a commercial survey platform between 19 July and 23 July 2021 and between 4 January and 8 January 2022. Secondly, some of the occupants were interviewed to further understand their perception of, and experiences with, these technologies. Thirdly, some key environmental variables were measured to provide a quantitative understanding of the IEQ of the building. Table 2 shows the measurements used. The physical environmental data and spatial experiences within the building and its site vicinity were analyzed in a relatively comprehensive way.

Table 2. The measurements of built environment.

<table>
<thead>
<tr>
<th>Environmental Parameters</th>
<th>Type</th>
<th>Accuracy and Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>T-type thermocouple</td>
<td>±0.5 °C; −200~350 °C</td>
</tr>
<tr>
<td>Illuminance</td>
<td>JTG01 Illuminance meter</td>
<td>±4%; 0.1~100,000 Lux</td>
</tr>
<tr>
<td>A-weighted sound level</td>
<td>AWA6228 + Multifunctional sound level meter</td>
<td>1000 Hz ± 1%; 10~20 kHz</td>
</tr>
<tr>
<td>Wind speed</td>
<td>TSI9545 handheld anemometer</td>
<td>±0.015 m/s; 0.00~30.00 m/s</td>
</tr>
</tbody>
</table>

2.3. Participants

With the help of the facility management team, the questionnaire was distributed online to the employees in this building. In total, 150 occupants of the building participated in this study between 9 August and 13 August 2021. All occupants had been working in this building for at least one year. Figure 2 shows the background of these occupants. Among them, 67.7% were male, and 60% were between 31 and 50 years old. The number of respondents near windows was close to that of respondents who were not near a window. In addition, the respondents were almost equally distributed among the four sides of the building.

Figure 2. Background of 150 participants.
3. Analysis and Results

3.1. Satisfaction Analysis

The design of the questionnaire followed “The Technical Guide for Post Evaluation of Green Buildings” (office and store construction edition) [26], with 46 questions focused on the features shown in Table 1. There were 21 Likert scale questions, 18 multiple choice questions, and 7 questions related to personal background (See Appendix A). By using the AHP, the Likert scale questions were divided into three aspects with eight factors, and there are several questions pertaining to each factor (Table 3). Following the Likert scale, there were five grades of satisfaction: “very good”, “good”, “neutral”, “poor”, and “very poor”, each corresponding to the values of 1, 2, 3, 4, and 5, respectively.

Table 3. Descriptive statistics of users’ satisfaction.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Factor</th>
<th>Question</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior space</td>
<td>Appearance (A)</td>
<td>Aesthetic perception of the circular volume</td>
<td>2.25</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aesthetic perception of the DSF</td>
<td>2.47</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>Site environment (B)</td>
<td>Satisfaction with the space flexibility due to large-span offices</td>
<td>2.75</td>
<td>1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satisfaction with freedom in daily working position changes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Space experience (C)</td>
<td>Satisfaction with the natural lighting in traffic spaces and public spaces on all floors of the main building</td>
<td>1.45</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>Ventilation (D1)</td>
<td>Satisfaction with natural ventilation in the office</td>
<td>3.09</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>Lighting environment (D2)</td>
<td>Satisfaction with natural light in the office during daylight hours on a sunny day</td>
<td>2.40</td>
<td>2.46</td>
</tr>
<tr>
<td></td>
<td>Acoustic environment (D3)</td>
<td>Satisfaction with sound insulation of the DSF</td>
<td>2.04</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>Thermal environment (D4)</td>
<td>Satisfaction with the performance of air conditioning systems</td>
<td>1.78</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>Building maintenance (E)</td>
<td>Easy to maintain the DSF</td>
<td>2.68</td>
<td>2.58</td>
</tr>
</tbody>
</table>

The average value of occupants' satisfaction was 2.27, somewhere between “good” and “neutral”. Among them, the average values for day lighting in the public and auxiliary spaces and the thermal and acoustic environments of the DSF were less than 2, indicating high satisfaction. The three-dimensional greening received positive feedback, with an average value of 2.03. However, the site environment and the space flexibility received fair satisfaction (2.75). The ventilation perception towards the DSF was 3.09, indicating that more occupants are not satisfied with the ventilation performance of the DSF.

3.2. Assessment of Major Green Technologies

The Pearson correlation coefficients between personal factors (i.e., gender, age, floor level, office area, office orientation) and satisfaction with green technologies were obtained using SPSS26.0 and are shown in Table 4. There were weak but significant correlations between age and the satisfaction with the building appearance, space flexibility, and thermal environment of the DSF rooms. There were also significant correlations between gender
and satisfaction with the acoustic and thermal environment of the DSF. For the lighting environment of DSF, there were differences among floor levels and office areas for different users. The following analyses focus on four aspects: circular building, innovative floor plans and public spaces, IEQ associated with DSF, and three-dimensional greening.

Table 4. The Pearson correlation coefficients between participants’ background and satisfaction with green building techniques.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Gender</th>
<th>Age</th>
<th>Floor</th>
<th>Office Area</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance (A)</td>
<td>0.156</td>
<td>0.361</td>
<td>0.099</td>
<td>0.182 *</td>
<td>0.010</td>
</tr>
<tr>
<td>Site environment (B1)</td>
<td>0.031</td>
<td>−0.023</td>
<td>0.033</td>
<td>0.125</td>
<td>−0.064</td>
</tr>
<tr>
<td>Vertical vegetation (B2)</td>
<td>0.028</td>
<td>0.172</td>
<td>0.038</td>
<td>0.054</td>
<td>−0.134</td>
</tr>
<tr>
<td>Office space (C1)</td>
<td>0.025</td>
<td>0.267</td>
<td>0.056</td>
<td>0.047</td>
<td>0.061</td>
</tr>
<tr>
<td>Public space (C2)</td>
<td>0.053</td>
<td>−0.098</td>
<td>0.076</td>
<td>0.043</td>
<td>0.006</td>
</tr>
<tr>
<td>Auxiliary space (C3)</td>
<td>0.106</td>
<td>−0.077</td>
<td>0.080</td>
<td>0.029</td>
<td>0.066</td>
</tr>
<tr>
<td>Wind environment (D1)</td>
<td>0.012</td>
<td>0.098</td>
<td>0.011</td>
<td>0.066</td>
<td>0.085</td>
</tr>
<tr>
<td>Lighting environment (D2)</td>
<td>0.049</td>
<td>−0.041</td>
<td>−0.162</td>
<td>0.183 *</td>
<td>0.188 *</td>
</tr>
<tr>
<td>Acoustic environment (D3)</td>
<td>0.174</td>
<td>0.115</td>
<td>0.022</td>
<td>0.022</td>
<td>0.118</td>
</tr>
<tr>
<td>Thermal environment (cold) (D4)</td>
<td>−0.213</td>
<td>0.181</td>
<td>0.099</td>
<td>0.059</td>
<td>−0.049</td>
</tr>
<tr>
<td>Thermal environment (warm) (D4)</td>
<td>0.121</td>
<td>−0.191</td>
<td>0.149</td>
<td>−0.005</td>
<td>−0.082</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

3.2.1. Circular Building

Table 3 shows that the satisfaction rating with the circular building (2.25) and the use of the DSF facade (2.47) were slightly higher than neutral. Age had significant influence on the perception of the building’s appearance (Table 4). Figure 3a shows that fewer people had a positive attitude towards the circular shape as age increased. Figure 3b shows that, among all age groups, the rectangular shape was the favored building shape. The interviews revealed that the occupants were more concerned with the space efficiency than the appearance, which is only visible from the outside. This was more obvious in the older groups. Such a preference may have affected their views on the building shape. The circular building may be more energy efficient and add aesthetic value to the neighborhood. However, it has disadvantages in terms of internal space usage. Therefore, the future design should consider a more balanced way of designing circular buildings. For example, a two-layer facade, such as the DSF, with uneven cavity depth may reconcile the contradiction.

Figure 3. Satisfaction and tendency of different age groups towards appearance: (a) satisfaction with appearance vs. age; (b) preferred building shape among different age groups.

Table 3 shows that the occupants had a satisfactory perception (2.88 < 3.0) of the site’s wind environment. An earlier study showed that circular buildings may have a more evenly distributed wind environment [27]. The user perceptions of wind at eight spots in the vicinity of the building at the ground level (Figure 4a) were collected in the questionnaire in summer. In addition, wind speeds at these spots were measured on 6 January 2022, as shown in Figure 4b. The results show that the respondents expressed the highest wind feeling at points 1 and 4, which were at the main entrance at the south side, the weakest...
feeling at the north side of the building complex, and modest feeling at the two sides. Interestingly, the sensory results agreed with the field measurements, which showed that point 1 had the highest wind speed and points 7 and 8 had the lowest speeds, with the rest being in between. Note that the average speeds at these points were mostly below 1.0 m/s, indicating a relatively uniform wind speed distribution around this circular building.

![Figure 4](image)

**Figure 4.** Site wind environment measurements: (a) user perception of wind speed and the 8 measuring points numbered in solid circles; (b) box plots of measured wind speeds (max.–75%–median–50%–min.) at 1.5 m above ground (sunny on 19 January 2022).

### 3.2.2. Innovative Floor Plans and Public Spaces

The innovative floor plan has resulted in a frequently visited public space in the middle and auxiliary spaces on the east and west sides. Such arrangements favor daylight and natural ventilation in the public spaces.

Table 3 shows that the daylight in the public spaces received the highest satisfaction (1.45). Illuminance was measured at 62 points on the 17th floor on a sunny day. Some of the points are shown in Figure 5. All artificial lights were turned off and all blinds were rolled up in the public spaces. The measuring points were 0.8 m above the floor and the results are shown in Figure 6. The illuminance values were generally below 150 Lux, except for points near the window (28, 29, 62). According to a Chinese standard, 150 Lux is the minimal value for public spaces in office buildings [28]. This means that most of the internal spaces would fail to meet this requirement with only daylight. In fact, the artificial lights were normally on in these public spaces. Therefore, the user perception of the daylight may be biased because they were rarely exposed to 100% daylight during working hours. The frequent use of artificial lighting may indicate that the actual daylight was insufficient. Despite the glazing facade, the lighting penetration of the DSF may not be sufficient to meet the lighting need in spaces away from the facade.

![Figure 5](image)

**Figure 5.** The layout of illuminance measuring points (numbered in solid circles) on the standard floor (0.8 m high).
Ventilation in the public spaces was not measured in the questionnaire. However, wind speeds were measured at the 62 points with some of them shown in Figure 5. The average wind speeds at these positions were very low (<0.10 m/s), as shown in Figure 6, except for a window inlet (28, at east window). The wind speed at the window opening was 0.56 m/s, which corresponded to a ventilation rate of four air change rates per hour for the public spaces, which was considered acceptable.

The space flexibility was not recognized by the occupants, as the space experience received a “neutral” value (Table 3). From the interview with the employees, the job positions in the electric and power service sectors had been relatively stable and fixed. Few people experienced job changes that would require changes in office. Therefore, the demand for space flexibility was not strong in this building.

However, the occupants did express a strong interest in outdoor social and leisure spaces. Figure 7 shows that more than 90% of participants wanted outdoor spaces. Among them, more than 65% of them preferred outdoor public activity spaces to indoor spaces. Approximately 58.0% of the participants are more interested in leisure and sports in public spaces, such as sidewalks, garden landscapes, and gyms. These data show that people in modern society have an increasing demand for a green, healthy, and comprehensive office environment.

Figure 6. Illumination (sunny at 12:00 on 21 July 2021) and wind speed value (6 January 2022, average wind speed of the day in Lishui was 1.16 m/s [22]) in the public space on the 17th floor.

Figure 7. Survey results on public spaces: (a) preferences for indoor and outdoor spaces; (b) preferences for space functions.

3.2.3. Indoor Environmental Quality Associated with DSF

In terms of the thermal environment of the DSF rooms, the occupant satisfaction was “good” (1.78). The main building had an all-air type air-conditioning system, and it was on during the working hours in summer and winter. Measurements in one of the DSF offices on the south side of the 17th floor (Figure 8) show that the air-conditioned rooms typically reached a relatively low temperature (22–24 °C) in summer and a relatively high temperature (24–25 °C) in winter. The room set points were 20 °C in winter and 24 °C in summer. The indoor temperature in summer was well controlled. However, in winter, the room could be over-heated on a sunny day due to the large area of glazing facade and various internal heating sources (humans, machines, etc.). The calculated Predicted Mean Vote (PMV) index was within the neutral range (−0.5 < PMV < +0.5, Figure 9b), which
meets the international standard [29]. This indicates that the thermal comfort of the DSF room is good. The correlation analysis (Table 4) shows that the female respondents were more sensitive to the cold, and the demand for indoor thermal environment increased with age.

![Diagram of three indoor thermocouple temperature test points](image)

**Figure 8.** The layout of the three indoor thermocouple temperature test points on the 17th floor (sunny days with shading): 1—internal surface of the double glazing, 2—0.15 m above the table, 3—internal wall surface.

![Graphs showing indoor temperature and PMV values](image)

**Figure 9.** Indoor thermal comfort measurement and calculated PMV values: (a) variation diagram of indoor temperature in summer (from 8:00 a.m. to 6:00 p.m. on 22 July 2021); (b) PMV variation diagram of indoor central areas and near the windows in summer and winter.

Using the nearby road traffic as the sound source, we measured the weighted standardized level difference for both the DSF room (4th floor, south room) and the single-skin facade room (17th floor, south room) during the morning and evening commute periods (one-hour intervals). The value for the single-layer glass (14 dB) was 9 dB lower than that of the DSF (23 dB). Meanwhile, the sound insulation effect of the DSF can be further improved through the noise treatment of ventilation structure.

Survey results showed that the female respondents were more sensitive to noise than the males (Table 4). External noise, operating equipment, and the sound of adjacent offices were identified as the three major noise sources (Figure 10a). One noticeable external source was the square-dance activity, a popular Chinese group social activity among the elderly. The square was only 50 m away from the southwest corner of the building. There were normally two such events, one from 8:00 to 10:00 and one from 19:00 to 22:00. Such source factors are rarely accounted for in the design stage of a building. This shows that the noise caused by public activities in urban areas needs appropriate attention. The indoor noise mainly came from the machine room. Even with the sound insulation structure in the equipment room (Figure 10b), the louvers at the vents directly face the public space, resulting in an obvious noise impact. The room-to-room noise transmission was mostly facilitated by the corridor type of the DSF cavity, which was designed for better ventilation. Apparently, noise transmission requires more consideration in the DSF design.
The DSF provides a proper way of shading device installation for lighting and energy control. However, the contradictory needs of a lighting and heat barrier need to be balanced, and a better understanding of the user behavior towards the operation of the blinds is needed in the future selection of solar shading devices.

In terms of the lighting environment, the occupant satisfaction was “neutral”, and the differences were significant among different office areas (Table 4). The window area received the highest satisfaction. The indoor illuminance was measured in a typical office (8 m × 10 m) on the south side during office hours in the morning and afternoon of 19 July. As shown in Figure 11a, the blinds’ status had a great impact on the illumination level. Only when the blinds were fully open could the window area (<3 m) meet the required minimal value of 450 Lux for an indoor office, according to Ref. [27]. The illuminance value decreases rapidly away from the window. The survey results indicate a strong desire for blind control. Approximately 69.3% of respondents hoped that the sun-shading louver could be completely pulled down with the proper amount of light transmission when shade was needed (Figure 11b). The DSF provides a proper way of shading device installation for lighting and energy control. However, the contradictory needs of a lighting and heat barrier need to be balanced, and a better understanding of the user behavior towards the operation of the blinds is needed in the future selection of solar shading devices.

For the ventilation and wind sensation, the occupant satisfaction was “poor” (3.09). It is known that people in the south of China generally have a preference for natural ventilation with open windows and doors. This was reflected in our survey results, which showed that 91% of the respondents preferred natural ventilation to mechanical ventilation (Figure 12a). Approximately 72% reported no sense of airflow in the DSF rooms, and 37% felt the air was uncomfortably “stagnant” (Figure 12b). In terms of desk location choices, 76% preferred to be close to windows. Ventilation and daylight effects seemed more important than window views (Figure 13). The strong desire for “natural ventilation” should be accounted for in the building design.
When it comes to the location of indoor greening, the respondents seemed to have specific preferences. Only 11% were indifferent about the greening location. Figure 16a shows that individual offices, centralized social spaces, and traffic corridors on each level were preferred for greening. Ventilation and daylight effects seemed more important than window views (Figure 13). The strong desire for "natural ventilation" should be accounted for in the building design. It is known that people in the south of China generally have a preference for natural ventilation with open windows and doors. This was reflected in our survey results, which showed that 91% of the respondents preferred natural ventilation to mechanical ventilation (Figure 12a). Approximately 72% reported no sense of airflow in the DSF rooms, and the airflow in the cavity was noticeable. An airflow velocity varying from 0.08 m/s to 0.15 m/s was measured in the cavity. The corresponding external wind speed was around 1.22 m/s, which was close to the average annual wind speed in Lishui (1.05–1.72 m/s). Because the room airspeed was generally lower than that in the cavity, the room airflow was likely below the perceptible value. Therefore, the airflow was unlikely to be stagnant but more likely not perceivable by most people. Further work should focus on how to create perceivable air speed in the DSF room and the proper maintenance of the DSF.

The airflow movement is perceptible when the speed is higher than 0.20 m/s [30]. There were two mosquito screens at the inlets of the DSF cavity (Figure 14). These screens had a large number of meshes and effectively reduced the airflow through the DSF. However, the facility management team was not aware of this. After removing these meshes, the airflow in the cavity was noticeable. An airflow velocity varying from 0.08 m/s to 0.15 m/s was measured in the cavity. The corresponding external wind speed was around 1.22 m/s, which was close to the average annual wind speed in Lishui (1.05–1.72 m/s). Because the room airflow was generally lower than that in the cavity, the room airflow was likely below the perceptible value. Therefore, the airflow was unlikely to be stagnant but more likely not perceivable by most people. Further work should focus on how to create perceivable air speed in the DSF room and the proper maintenance of the DSF.

### Figure 12. Ventilation performance of DSF: (a) preferences for ventilation types; (b) user responses to ventilation in rooms with DSF (transition seasons).

<table>
<thead>
<tr>
<th>Ventilation Type</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural ventilation</td>
<td>91.3%</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>4.7%</td>
</tr>
<tr>
<td>Indifferent</td>
<td>4.0%</td>
</tr>
</tbody>
</table>

Total number=150

### Figure 13. Preferences for desk locations and the primary reason for such choices.

- 76.0% By the window
- 6.7% Middle position
- 0.7% Close to the door
- 16.6% Indifferent

Total number=150

### Figure 14. Details of the DSF at the inlet/outlet to/from the cavity.

#### 3.2.4. Three-Dimensional Greening of Building

The building’s three-dimensional greening design included three parts: ground-level greening, indoor greening, and roof garden. The vegetations were well maintained and had multiple layouts with diverse species (Figure 15). The visual experience was appreciated, and the overall occupant satisfaction was “good” (Table 3). However, the interview with the greening manager revealed the high maintenance cost, partially due to the reflection of the glazing facade, which hindered the growth of plants within a certain distance in summer and has even led to plant death. There have been few studies on the interaction between glazing curtain walls and the plant growth around high-rise buildings. The future study on the light pollution of the glass curtain wall should include its effect on vegetation.
Figure 15. Three-dimensional greening of building (left: the ground-level lawn and vegetation landscape around the building; right: roof garden).

When it comes to the location of indoor greening, the respondents seemed to have specific preferences. Only 11% were indifferent about the greening location. Figure 16a shows that individual offices, centralized social spaces, and traffic corridors on each level were all in proper locations for the placement of vegetation. For the studied building, only the main entrance of the building and the elevator lobbies had an appropriate number of plants. There is room for the improvement of the vegetation planning and maintenance.

![Figure 16. Users' views on indoor greening and reasons for not going to the roof garden: (a) preferences for vegetation; (b) reasons for not visiting the roof garden.](image)

There were two roof gardens, one on the terrace of the 17th floor and one on the 22nd floor (top). They were visited frequently, especially in spring and autumn. Most of the visitors were from the top floors. Although most of the respondents expressed a positive attitude towards these roof gardens, over 45% thought they were inconvenient to reach, and 35% thought they lacked rest facilities (Figure 16b). In comparison, there were no major complaints on the environmental quality of these roof gardens. However, the roof garden could not be reached directly using normal passenger elevators. The occupants needed to transfer to the firefighter’s elevator to reach the rooftop garden. This inconvenience might have contributed to the reduced visits.

4. Implications and Recommendations to Current Standards

By comparing with the latest standards that are related to energy saving and green buildings, we present the following recommendations:

1. In the latest standard for “Design Standard of Green Buildings” [31] in Zhejiang Province, there are no detailed provisions on the shape coefficient and its impact on energy savings. As this is quite relevant to energy efficiency, it is worth studying to then include the factor in the standard;

2. The latest national standard “Design Standard of Office Building” [32] has no detailed provisions on the sound insulation of DSF office rooms and public spaces. It is important to consider this index in future revisions;

3. The latest national standard “Evaluation Standard for Green Building” [3] weakens the consideration of the lighting guide and sun-shading design compared with the
national standard “Evaluation Standard for Green Office Building” [33]. In future revisions, it is suggested to fully study the relationship between daylighting, light guide, and shading before giving guiding suggestions;

4) There is still a lack of understanding of the DSF regarding its balance of ventilation, shading, and lighting; caution should be taken in its promotion in the current “De-sign Standard for Energy Efficiency of Public Buildings” [34] in Zhejiang Province.

5. Conclusions

We conducted a post-occupancy evaluation of multiple green technologies applied in a building 15 years after its construction using a combined method of questionnaire survey and field measurements. The following can be concluded:

1) The circular building, chosen for its excellent shape coefficient, visual effect, and possibly neighborhood-friendly wind environment, received less satisfaction than expected from the building users, who apparently paid more attention to the space efficiency. Data showed that the older occupants tended to be more concerned with the availability of effective internal spaces. Therefore, future designs of circular buildings may consider a reconciliation between user needs for space efficiency, energy efficiency, etc., and the public need for environmental friendliness and aesthetic appearance;

2) The innovative floor plans of public spaces reached the design goal for better daylight and natural ventilation. However, the design freedom and space flexibility provided by the floor plan due to column grid arrangement were not recognized because the occupants had relatively fixed and stable job positions and had little need for space changes;

3) The DSF was satisfactory regarding the thermal environment, noise reduction, and daylight. However, the DSF’s capacity for natural ventilation remained a concern as the occupants expressed a strong preference for natural ventilation, especially during transition seasons. In addition, the glazing facade may only guarantee sufficient lighting within a 3 m distance. Balancing the contradictory needs of shade and daylight remains a challenging task and may require a smart control system or improved user accessibility;

4) The occupants expressed a strong need for social spaces, leisure sports, and outdoor activity places, which should have easy access. The design of the rooftop and terrace gardens were well acknowledged. Major complaints stemmed from the inadequate accessibility of the rooftop garden;

5) The occupants displayed a frequent recognition of the three-dimensional greening design of the building. The maintenance experiences indicated the importance of plant selection and location so as to avoid inaccessibility to users and the negative interference of reflected light by the glazing facade.

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Appendix A. The Questionnaire

♦ Basic information:
1. Gender: □ Male, □ Female
2. Floors of the office: ( ) F; Directions (□ East, □ South, □ West, □ North); (□ Shared, closed to window, □ Shared, away from window, □ Individual office with window)
3. Age group: □ 18~30 age group, □ 31~50 age group, □ 51~65 age group
4. Daily working hours: □ 0~4 h, □ 4~8 h, □ 8 h above

♦ Please tick the appropriate option. “☐” (Some questions may be multiple choice.)

I. [Lighting environment]
1. Satisfaction with natural light in the office during daylight hours on a sunny day (□ very good, □ good, □ neutral, □ poor, □ very poor)
2. How long do you leave the lights on during the day when you are at work? (□ all day, □ more than 4 h, □ 2~4 h, □ less than 2 h, □ No lights)
3. If you have a choice, you would prefer to work in (□ by the window, □ middle position, □ close to the door, □ indifferent), Which of the following factors will influence your choice of workplace? (□ Orientation, □ natural lighting, □ ventilation, □ vision & landscape)
4. How would you prefer the sun-shading louver in the double skin façade (DSF) to be when there is a lot of light outside? (□ fully stowed, □ fully stowed and blinds fully closed, □ fully stowed, but with proper light transmission)
5. Do you adjust the sun-shading louver during the summer day? (□ yes, □ no)
6. If you are not satisfied with the natural light in your work area, what do you think needs to be improved most? (□ The depth of the space is too large and there is not enough light in the middle, □ Too much shading, □ The height of the room is not enough, □ Interior materials too dark, □ Others)

II. [Acoustic environment]
1. Do you feel that it is too noisy outside when you are in the office? If so, what do you think is the main source of the noise (□ External noise, □ the sound between upper and lower offices, □ the sound of adjacent offices, □ operating equipment, □ no obvious feeling)
2. Satisfaction with sound insulation of the DSF between adjacent rooms (□ very good, □ good, □ neutral, □ poor, □ very poor)
3. Satisfaction with sound insulation of the DSF throughout the building (□ very good, □ good, □ neutral, □ poor, □ very poor)

III. [Wind environment]
1. Satisfaction with natural ventilation in the office (□ very good, □ good, □ neutral, □ poor, □ very poor)
2. Satisfaction with ventilation of the DSF (□ very good, □ good, □ neutral, □ poor, □ very poor)
3. If you had a choice, you would prefer (□ natural ventilation, □ mechanical ventilation, □ indifferent)
4. What is your opinion on glass facade openings when working in a high-rise building? (□ More and larger openings, □ Partial openings are sufficient to meet the necessary ventilation requirements, □ If you have a fresh air system, it doesn’t matter, □ It doesn’t matter)
5. Which seasons do you think it is necessary to open windows? (□ Spring, □ Summer, □ Autumn, □ Winter)
IV. [Air-conditioning usage]
1. How much do you set your air conditioning to when you use it in summer? (□<21; □21~22; □23~24; □25~26; □>26) °C; Satisfaction with the performance of air conditioning systems (□very good, □good, □neutral, □poor, □very poor)
2. How much do you set your air conditioning to when you use it in winter? (□<21; □21~22; □23~24; □25~26; □>26) °C; Satisfaction with the performance of air conditioning systems (□very good, □good, □neutral, □poor, □very poor)
3. Do you open the windows in the summer when you use the air conditioning? (□yes, □no)
4. Do you open the windows in the winter when you use the air conditioning? (□yes, □no)
5. Which of the following factors most affect the comfort of office air conditioning in your opinion? (□Low number of air conditioning supply outlets, □Air conditioning supply air outlet positioned away from the workplace, □The type of air conditioning supply air outlet does not match, □Excessive concentration of air conditioning supply outlets, □The air conditioner is running excessively noisy)

V. [Three-dimensional greening]
1. Satisfaction with the space flexibility due to large-span offices (□very good, □good, □neutral, □poor, □very poor)
2. Satisfaction with freedom in daily working position changes (□very good, □good, □neutral, □poor, □very poor)
3. Satisfaction with the natural lighting in traffic spaces and public spaces on all floors of the main building (□very good, □good, □neutral, □poor, □very poor)
4. Satisfaction of the natural lighting in the bathrooms on each floor of the main building (□very good, □good, □neutral, □poor, □very poor)
5. Do you think the existing public spaces in the building are adequate? (□enough, □barely enough, □few)
6. If additional public spaces could be added to the building, what types of public spaces would you prefer to add? (□leisure and sports spaces; □living service spaces; □serviced office spaces)
7. Would you prefer public spaces to be outdoors or indoors? (□outdoors, □indoors, □both, more outdoors, □both, more indoors)
8. What are your views on the form of greening in buildings? (□centralized greening shall be set on each floor, □large greening shall be set in multiple floor, □inside their respective offices, □indifferent)
9. The upper part of the building is landscaped (22th floor and roof), do you usually go there? (□often, □occasionally, □know but rarely □don’t know); if you do go, what season do you usually visit? (□Spring, □Summer, □Autumn, □Winter)
10. Satisfaction with the vertical vegetation (□very good, □good, □neutral, □poor, □very poor), If unsatisfactory, mainly because (□Inconvenient to arrive, □The wind is too strong, □The sun is too hot, □Greening is not good enough, □No rest facilities)

VI. [Base wind environment]
1. Satisfaction with ground level wind around the building during normal times. (□too large, □large, □normal, □small, □too small)
2. Have you ever felt excessive wind speed at ground level near a building and which of the following locations is more noticeable? (□South entrance of building, □Main and auxiliary atrium Garden, □West entrance of auxiliary building, □East side of main building, □North side of auxiliary building)
3. What are the wind speeds felt in rooms in the building that are not DSF with windows open? (□too large, □large, □normal, □small, □too small)
VII. [The building appearance]

1. Aesthetic perception towards the circular volume (Ⅰvery good, Ⅱgood, Ⅲneutral, Ⅳpoor, Ⅴvery poor)
2. If the shape of the building is optional, you will choose (Ⅰrectangular, Ⅱcircular, Ⅲothers, Ⅳindifferent)
3. Aesthetic perception towards the DSF (Ⅰvery good, Ⅱgood, Ⅲneutral, Ⅳpoor, Ⅴvery poor)
4. Easy to maintain the DSF (Ⅰvery good, Ⅱgood, Ⅲneutral, Ⅳpoor, Ⅴvery poor)

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