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Occupants' Awareness of and Satisfaction with Green Building Technologies in a Certified Office Building

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Abstract: With growing awareness of the need to reduce greenhouse gas emissions, much effort has been made to achieve “sustainability” in the building sector. Across the globe, many architects and building owners are striving to realize mandatory or voluntary building certification, in order to affirm the environmental performance of their buildings. Various sustainable design strategies and green building technologies have been adopted to improve buildings’ environmental performance as well as to achieve higher levels of certification. These technologies and strategies could affect building occupants’ satisfaction as well as productivity. This paper presents the results of post occupancy evaluation (POE) surveys to investigate occupants’ awareness of various green building technologies and their satisfaction levels and causes of dissatisfaction for selected technologies. A questionnaire survey was conducted for an office building in Korea that had received the highest grades in rating and certification systems. Some technologies showed higher levels of awareness and satisfaction, but there were also a few technologies with lower levels of satisfaction than we had expected. If these technologies are applied to buildings in the future, after improvisation or modification based on the POE results, it could serve as an effective strategy to increase people’s satisfaction as well as improve environmental performance.

Keywords: green building technologies; post occupancy evaluation; occupant awareness; occupant satisfaction

1. Introduction

Buildings are a major end-use in the global energy market. The International Energy Agency (IEA) has identified that buildings account for over 40% of primary energy consumption in many IEA member countries [1]. In Korea, the building sector represents about 22% of the total energy consumed in the country. The Korean Government has recently revised a National Roadmap for greenhouse gas reduction, and the reduction target for the building sector was 32.7%, relative to business-as-usual (BAU), by 2030 [2]. In light of an increasing need to promote energy efficiency and carbon reduction, much effort has been made to achieve “sustainability” in the building sector. An array of green building technologies such as passive design strategies, energy-efficient building technologies, and renewable energy systems have been developed and introduced to mitigate the environmental impact of buildings.

Energy efficiency ratings and certification schemes have been widely introduced as one of the key policy measures for reducing energy consumption in buildings [3,4]. In addition, various sustainability assessment and certification programs for buildings are available worldwide, including LEED (Leadership in Energy and Environmental Design) in the U.S., BREEAM (Building Research Establishment Environmental Assessment Method) in the U.K., Green Mark in Singapore, Green Star in Australia, etc. [5]. These certification systems are used as a strategy to not only assess and rate a building’s environmental performance, but also encourage and help designers and clients improve

the performance of their buildings [6,7]. Many buildings have been designed and built in accordance with these high standards of sustainable design and construction. Architects and building owners strive to achieve a higher level of certification by adopting various green building technologies, in order to confirm and ensure the environmental performance of their buildings.

These building technologies may influence occupants' satisfaction with their work environment as well. It is very important to ensure that energy-efficient and low-impact technologies do not have a negative impact on occupants' comfort and productivity. Many previous studies showed that overall occupants' satisfaction, health, and productivity are generally higher in green buildings compared to conventional buildings [8–11]. However, the pros and cons of green buildings are still debatable, considering that some studies could not find enough evidence to believe that there is a positive association between occupants' satisfaction and green buildings [5,12]. Thus, there needs to be a clarification as to whether the green technologies currently applied in buildings are satisfying their occupants. While some of the green building technologies can have a positive effect on occupants' satisfaction, some of the technologies for reducing energy or water consumption do not necessarily fulfill occupants' expectation of comfort [13]. In this context, there is an increasing demand for additional information on how occupants interact with technologies applied in green buildings. It is also necessary to offer suggestions as to how to improve these technologies to increase occupants' satisfaction.

The POE can be used to investigate this issue, because it has become the most prevalent and important tool for the improvement of building design and operation [14,15]. Recently, extensive POE research has been conducted relating to the association of occupants' satisfaction and green buildings. Birt [16] emphasized the need to identify whether the "certified" buildings deliver expected benefits by reviewing various POE studies of energy performance and indoor air quality in green buildings. Since improved indoor environment quality (IEQ) directly influences the satisfaction and productivity of occupants, most previous POE studies of green buildings have focused on physical environmental condition and psychological satisfaction. Paul and Taylor [12] compared occupants' comfort and satisfaction in terms of aesthetics and IEQ between a green university building and two conventional university buildings in Australia. Lee and Guerin [17] compared the IEQ between five different office types in LEED-certified buildings in relation to employees' environmental satisfaction and their job performance, based on data from the Center for the Built Environment (CBE) Occupant Indoor Environmental Quality Survey. An analysis of a more extensive subset of the CBE database was also presented in a study by Altomonte and Shiavon [5], which concluded that there was no significant influence of LEED certification on occupant satisfaction with IEQ. Khoshbakht et al. [18] disclosed that the occupants of green buildings were more consistently satisfied with building design and facility management compared to those of non-green buildings, but also detected weakness in regard to indoor environmental quality parameters. However, the POE study by Agha-Hossein et al. [11] showed that employees expressed higher satisfaction with their work environment at their recently refurbished office building that had received a BREEAM "Very Good" rating, compared with their previous office. In Taiwan, Liang et al. [10] found a statistically significant difference between the mean score of occupants' satisfaction in certified green buildings and conventional office buildings.

Some studies [13,14,19,20] focused on the association of occupants' satisfaction, attitude, behavior, expectation, and perception. Bordass and Leaman [18] suggested that occupants of green buildings tend to forgive and are satisfied with green buildings, despite experiencing discomfort in certain environmental aspects. In the U.K., Monfared and Sharples [13] conducted a longitudinal study in two government office buildings that had received BREEAM "Excellent" ratings. This study is particularly interested in not only examining the relationship between the "green" identity of an office building and its occupants' attitude toward the building, but also the effect of occupants' expectation and perceptions on their overall satisfaction. Through POE studies in two green office buildings in Australia, Deuble and de Dear [14] also found that green building users were more forgiving of their building. These studies suggest that the "green" profile or identity of the building has a positive impact on their environmental perception and behavior. Holmgren et. al [21] found that a green label of a building can have an positive

influence on the occupants' perception of the indoor environment. Day and Gunderson [22] developed an approach to investigate the effect of occupant training in relation to occupants' understanding of high performance buildings features and found that occupants who received training were more likely to be satisfied with the environment than those who did not. Although it must be difficult for the awareness of green building technologies to directly lead the occupants' low carbon lifestyle, previous research shows that occupants of green buildings tend to forgive and are satisfied with green buildings, despite experiencing discomfort in certain environmental aspects.

The majority of these previous POE studies of green buildings focused on the satisfaction of the indoor thermal, visual, and acoustic environment and indoor air quality. They have investigated specific aspects of the thermal, visual, and acoustic environment and indoor air quality, such as temperature, thermal comfort, amount of light, glare, stuffiness, noise, and sound privacy [5,8,10,12–18,22]. However, because building technologies have a complex impact on the environment, it is difficult to directly determine what the factors of satisfaction and dissatisfaction with individual technologies are. If a green building technology makes occupants uncomfortable and causes frequent complaints, the owners will not try to use it even though it has a good effect on the environment or energy consumption. In the long term, these green premiums cannot be maintained unless these buildings offer their intended performance advantages in terms of indoor environment quality, convenience, or energy consumption [16]. More specific understanding of the cause of satisfaction or dissatisfaction of individual technologies can lead to improvements in those technologies. If we identify the aspects to be improved and take action by conducting a POE, it will be possible to maintain good awareness of the green building. In terms of technology development, efforts should be made to alleviate users' inconveniences as well as to improve the satisfaction level by allowing them to be aware in more detail what these technologies mean in terms of sustainability. Monfared and Sharples [13] stated that the ultimate goal in a 'sustainable design' is to achieve a building that will fulfil its prior intentions when it becomes occupied. In this respect, the purpose of this study is to investigate occupants' awareness and satisfaction focusing on various green building technologies. Furthermore, this study examined the cause of occupants' dissatisfaction with some technologies in order to provide suggestions for improving these technologies. For this purpose, a post-occupancy online survey was conducted at an office building in Korea that had received the highest grades in various green building ratings and certification systems. A questionnaire was developed for evaluating green building technologies applied in the building in terms of awareness and satisfaction. Based on the results, strategies were recommended to improve occupants' satisfaction and comfort by investigating the potential problems of each green building technology and seeking a solution.

2. Method

2.1. Building Description

Since this study focused on occupants' awareness and satisfaction of energy-efficient and green building technologies, we selected a building accredited by various building ratings and certification schemes. The study was performed on an office building located in Seongnam, Korea. Through the preliminary reviews at the design stage as well as the on-site reviews after the construction, the building obtained the highest grades in main certification schemes: LEED "Platinum" rating (55 points / maximum possible 69 points), Korea Green Standard for Energy & Environmental Design (G-SEED) "Excellent" rating (110 points/maximum possible 136 points), and the "First" grade of Korea Building Energy Efficiency Rating. G-SEED is a building environmental performance rating and certification program launched in 2002. It has been developed and operated by the Ministry of Land, Infrastructure and Transport and the Ministry of Environment. G-SEED comprises seven major categories: land use and transportation, energy, materials and resources, water, environment contamination, and IEQ. It categorizes green buildings into four distinct levels from "Excellent" to "Certified," and the building studied in this paper achieved the highest level—"Excellent." The Korea

Building Energy Efficiency Rating (BEER) scheme is a building energy performance rating system based on the calculated annual primary energy consumption according to ISO 13790 [4]. It was launched in 2002 for multi-unit residential buildings, and later expanded to cover office buildings in 2010 and all types of buildings in 2013. Since 2010, all new office buildings considered public property have been required to be certified as the “First” grade of BEER. More than 2,000 visitors from academia, local and foreign governments, civil societies, and green building businesses associations visited this site during the first one-and-a-half years after construction was completed.

The building has a total floor area of approximately 47,500m², and it is nine stories high with five basement floors. The building consists of an office block and a research block, as shown in Figure 1. It is used as the head office and annex research center of a chemical company. The employees had previously been working in a conventional office building in a neighboring city. The office block is designed as an open-plan space with a few meeting rooms on each floor, while the research block consists of enclosed office space and laboratories. A 9 × 39 m central atrium is located between the two blocks, within which two pedestrian bridges connect the office block and the research block on the second and fourth floors. The atrium is also intended to facilitate natural ventilation and daylighting of each block. A wall fountain is installed within the atrium to control the internal temperature, humidity, and the overall cooling load of the large atrium space. Figure 1 shows the typical floor plan of the target building. These two building blocks are not only structurally connected but also under the same management.

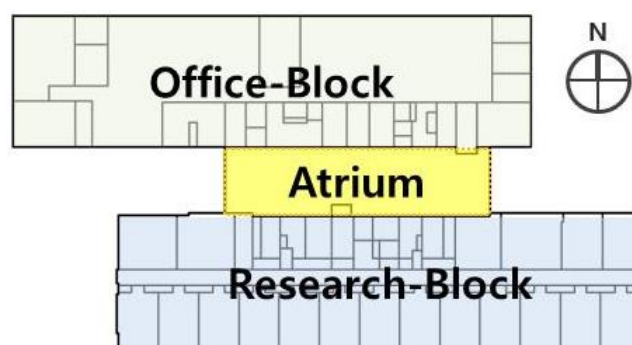


Figure 1. Floor plan of the building surveyed.

Table 1 shows major selected energy-efficient and green technologies applied to the building. A high performance curtain wall is a prominent feature of the building envelope, with low e-coated triple glazing, argon gas fill, low-conductance edge spacers, and extremely airtight gaskets. A building-integrated photovoltaic system (BIPV) is installed on a part of the south façade of the research block. Shading is achieved by roller shading, controlled by daylight sensors. Most of these technologies were adopted for the entire building, but several technologies such as an underfloor air distribution system and radiant heating and cooling systems were applied depending on the building use. The occupied organization manufactures chemical products, pharmaceuticals, and vaccines and has set up its mission of “We care for the future: healthcare, earthcare”, which means to promote human health and protect the environment of earth. The organization has been publishing sustainability reports for about 10 years to strengthen their commitment to sustainability and has been operating an in-house Green Point program in order to spread the concept of ‘eco-friendliness’ to employees, including a zero food waste campaign, carbon calculator, collecting waste paper, watching environmental films, etc. In this context, the building is a declarative meaning of pursuing a sustainable future as a symbol of the company’s mission. Although energy efficiency ratings and green building certification are not compulsory for private buildings, they tried to obtain the highest level of certification. This building reflects the company’s willingness to respond to climate change. Occupants can get some information

on the sustainable and energy-efficient features of the building through an introduction brochure and video as well as digital information display panels in the lobby.

Table 1. Summary of selected green building technologies applied in the building.

Category	Technology
Low-impact transportation	Bike parking area
	Electric vehicle charging station
Water efficiency	Low-flow toilet
	Rainwater harvesting system
	Grey water system
Building envelope	High performance curtain wall
Renewable energy	Geo-thermal heat pump
	Building integrated photovoltaic (BIPV)
Comfort and environment control	Radiant heating and cooling system ^a
	Underfloor air distribution system ^b
	Daylight-linked dimming control ^c
	Daylight-linked roller shade
	LED lighting fixture ^b
	Automatic lighting control in the underground parking lot
	Low-emission materials
Information for occupants	Natural ventilation with atrium opening
	Energy consumption display

^a installed only in research block; ^b installed only in office block; ^c installed only from the 3rd floor to 4th floor in the office block.

2.2. Questionnaire Survey and Analysis

A questionnaire survey was conducted to investigate the occupants' awareness of and satisfaction with the building's technologies through the company's intranet system. The questionnaire consisted of three sections, as shown in Table 2. The first section requested information from occupants on a potential covariate that might contribute to the effect of personal group on the results, including gender, age, location of workstation (building block, floor, zone), and means of commute (own car/public transportation/walking/bike). The second section was intended to determine occupants' awareness of and satisfaction with each building technology. The respondents were asked to answer either yes or no, based on their awareness of each technology. The satisfaction survey was conducted on six technologies, including the LED lighting fixture, daylight-linked dimming control, daylight-linked roller shade, underfloor air distribution system, natural ventilation with atrium opening, and low-flow toilet, which are closely related to the occupants' comfort and convenience in the workspace. The technologies related to commuting methods such as bike, car, and electric vehicle were excluded from the survey, considering that only a few people experience them. Building envelope and renewable energy technologies, which are difficult to evaluate from the standpoint of the occupants, were also excluded. Since the selected technologies included for satisfaction evaluation are evaluated especially in the G-SEED certification, on-site performance for these technologies was checked through the field inspection. A Likert-type scale was used with five-point scales [11] ranging from "very satisfied" (5) to "very dissatisfied" (1) to evaluate satisfaction with selected technologies. Since most technologies are likely to have pros and cons, it is important to identify the disadvantages that can cause dissatisfaction. For example, water resources can be saved by using the low-flow toilet, but it may cause discomfort to users due to clogging and bad odor. The daylight-linked dimming control and roller shade can reduce lighting energy consumption and prevent glare problems by controlling direct sunlight and adjusting the illumination level, but excessive frequent control and operating noise can cause unexpected inconvenience to occupants. Therefore, if the respondent selected positive ("satisfied" or "very satisfied") or negative perception ("dissatisfied" or "very dissatisfied") in the question, he or she was requested to select

the cause of satisfaction or dissatisfaction from the lists of answer options [10] in Table 3, which were derived from previous research and interviews with building operators. Furthermore, respondents were allowed to make open-ended comments on causes of satisfaction or dissatisfaction. In the last part, the occupants' overall awareness of and satisfaction with the building was evaluated.

Table 2. Structure of the questionnaire.

Section	Question
General information	Age; gender; location of workstation
Awareness and satisfaction of each technology	Q1. Do you know that the following technology is applied in this building? Q2. How satisfied are you with the functioning of the technology? Q3. What is the reason for the satisfaction or dissatisfaction?
Awareness and satisfaction of the building	Q4. Do you know that this building is a certified green building? Q5. How satisfied are you with the environmental performance of this building? Q6. Do you think that the environmental performance of this building has a positive effect on your productivity?

Table 3. List of answer options for cause of satisfaction and dissatisfaction.

Technology	Answer Options	
	Cause of Satisfaction	Cause of Dissatisfaction
LED lighting fixture	- Visual comfort - Sufficient illumination level - Ease of maintenance	- Visual discomfort - Insufficient illumination level - Too frequent maintenance
Daylight-linked dimming control	- Visual comfort - Proper adjustment	- Visual discomfort - Improper adjustment
Daylight-linked roller shade	- Visual comfort - Proper positioning - Automatic adjustment	- Visual discomfort - Improper positioning - Too frequent adjustment
Underfloor air distribution system	- More comfortable than conventional overhead system - Direct contact with supplied air - Occupant's individual control	- Less comfortable than Conventional overhead system - Direct contact with supplied air - Possibility of dust and odor
Natural ventilation with the atrium opening	- Comfort by natural air flow - Openness to outside	- Inflow of outdoor pollutants - External noise
Low-flow toilet	No difference with conventional toilet system	- Bad odor - Insufficient flush-out

Awareness was analyzed using a ratio of the number of respondents who are aware of the technology to the total number of respondents. The relationship between age and awareness of green building technologies was investigated using a t-test and ANOVA. The statistical analysis was carried out with SPSS (v.21) software. The satisfaction scores of different technologies were calculated by averaging satisfaction choices of each respondent in the whole dataset [5]. In addition, a t-test and ANOVA were conducted to determine whether there is a significant difference in satisfaction with these green building technologies according to the demographic hypotheses. The gender and age breakdown is often used in the data analysis of POE studies [10,15,18]. In this study, we attempted to investigate the occupants' physiology and physical perception [10,21] of environmental comfort

and convenience from the green building technologies, based on their experiences. The relationship between satisfaction with environmental performance of the building (Q5) and its positive effect on work efficiency (Q6) was analyzed. Since Q5 and Q6 were asked in rank scales expressed as scores (1~5), Spearman's rank correlation analysis was conducted.

3. Results and Discussion

3.1. Questionnaire Respondents

A total of 215 valid questionnaires were collected from the 980 employees with a 22% response rate, which satisfied 95% confidence level and $\pm 10\%$ margin of error from the overall population. Table 4 summarizes the demographic information of the respondents. It shows that male respondents (67.4%) outnumbered female respondents (32.6%), and the largest age group of respondents was 30–39 (56.3%). Female respondents accounted for the highest proportion of participants in the age group of 20–29, and it decreased significantly with increasing age. Males accounted for all the employees aged over 50. Regarding the work locations, 66.0% and 25.6% of employees work at offices and R&D buildings; and a relatively large number of employees work in office buildings. Further, a majority of them work within 4–8 floors. There were not any significant differences in the respondents' workspaces, whether they were within 5 meters from windows in an interior zone or further away from windows. Since all the respondents belong to the company, which requires at least a university degree, personal information did not include educational level.

Table 4. Respondents' demographic data.

Description		Male		Female	
		N	%	N	%
Age	20–29	12	8.3	27	38.6
	30–39	81	55.9	40	57.1
	40–49	41	28.3	3	4.3
	Over 50	11	7.6	0	0.0
Location of workstation	Office block	98	67.6	44	62.9
	Research block	36	24.8	19	27.1
	Both	11	7.6	7	10.0
	Lower floors (2~3)	12	8.3	10	14.3
	Middle floors (4~5)	32	22.1	25	35.7
	Upper floors (6~8)	101	69.7	35	50.0
	Perimeter zone	86	59.3	26	37.1
	Interior zone	59	40.7	44	62.9
Total		145	100.0	70	100.0

3.2. Awareness of Green Building Technologies

Figure 2 shows the percentage of occupants who were aware of each technology. The average awareness of the technologies was 61.4%. The highest level of awareness was regarding the "Energy consumption display" (98.1%) and "low-flow toilet" (97.2%), suggesting that almost all the residents were aware of these technologies. In contrast, the lowest level of awareness was concerning "electric vehicle charging station" (15.3%) or "daylight-linked dimming control" (24.4%). Even though the employees were aware of the fact that the buildings were designed based on the concept of sustainability and energy efficiency, there was a large difference in awareness according to the types of green building technology. This variance seems to be attributed to the differences in the occupants' exposure to the technologies. The technologies applied to highly accessible and approachable areas in daily life such as lobbies and restrooms were related to a high level of awareness. Conversely, technologies which are not often used or cannot be easily recognized by a majority of occupants were related to a lower

level of awareness. For example, it is estimated that “electric vehicle charging station” had the lowest awareness since there is not much demand for electric cars yet. The “daylight-linked dimming control” and “radiant heating and cooling system” have been found to have a lower level of awareness, since it is not easy for occupants to perceive the minute automatic variation of illumination or temperature by these technologies unless separate information is provided in advance.

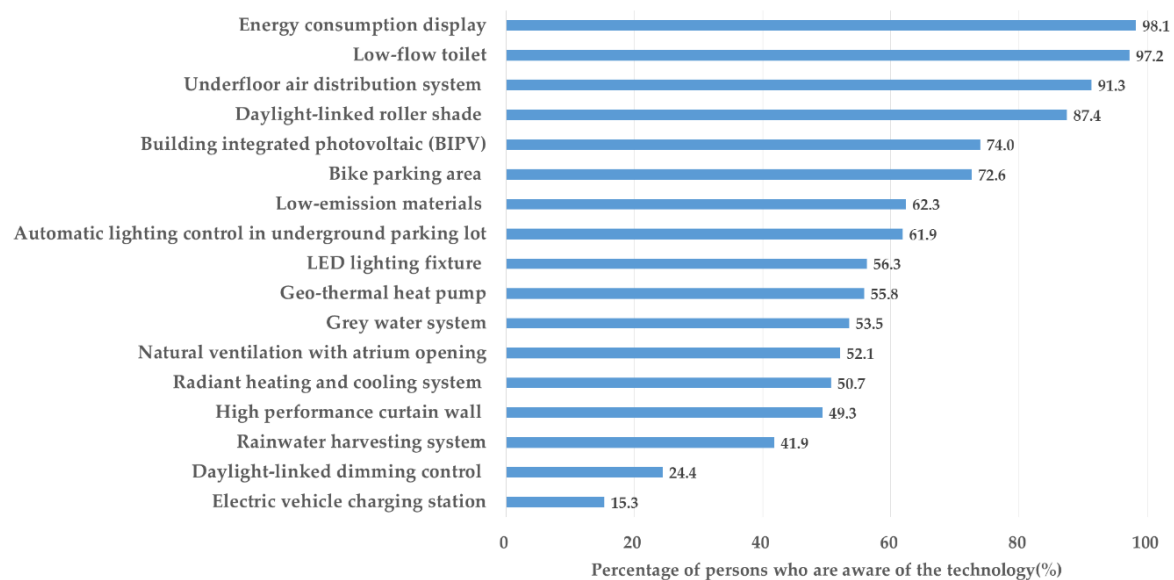


Figure 2. Occupants' overall awareness of each technology.

In most cases, the higher age group had a higher level of awareness, as shown in Table 5. This tendency is more evident when we divide the age groups into 20–39 and over 40. Considering that at higher ages, people are more likely to occupy higher positions in the company, they can have more opportunities to receive some information on the technologies through business reports and meetings during the building design and construction process. This result suggests that the degree of information disclosure may affect the level of occupants' awareness of green building technologies.

Table 5. Occupants' awareness (%) and p-value by age.

Green Building Technology	Age Group 1					Age Group 2		
	20–29	30–39	40–49	Over 50	p-Value	20–39	Over 40	p-Value
Bike parking area	66.7	70.2	84.1	72.7	0.26763	69.4	81.8	0.07442
Electric vehicle charging station	2.6	14.9	22.7	36.4	0.01470 *	11.9	25.5	0.01594 *
Low-flow toilet	94.9	97.5	100.0	90.9	0.29557	96.9	98.2	0.61173
Rainwater harvesting system	35.9	39.7	47.7	63.6	0.31129	38.8	50.9	0.11483
Grey water system	53.8	52.9	54.5	54.5	0.99758	53.1	54.5	0.85543
High performance curtain wall	38.5	47.1	59.1	72.7	0.10369	45.0	61.8	0.03139 *
Geo-thermal heat pump	35.9	56.2	68.2	72.7	0.01629 *	51.3	69.1	0.02154 *
Building integrated photovoltaic (BIPV)	76.9	71.9	75.0	81.8	0.84433	73.1	76.4	0.63686
Radiant heating and cooling system	40.0	57.1	35.3	83.3	0.14234	52.0	47.8	0.74037
Underfloor air distribution system	96.6	88.5	93.1	100.0	0.45697	90.4	94.3	0.47209
Daylight-linked dimming control	16.7	21.4	50.0	100.0	0.16916	20.0	60.0	0.04974 *
Daylight-linked roller shade	82.1	87.6	90.9	90.9	0.65103	86.3	90.9	0.36839
LED lighting fixture	51.7	51.0	69.0	100.0	0.04874 *	51.2	74.3	0.01496 *
Automatic lighting control in parking lot	33.3	60.3	81.8	100.0	0.00000 **	53.8	85.5	0.00003 **
Low-emission materials	59.0	60.3	65.9	81.8	0.49136	60.0	69.1	0.23004
Natural ventilation with atrium opening	38.5	53.7	61.4	45.5	0.19173	50.0	58.2	0.29473
Energy consumption display	97.4	97.5	100.0	100.0	0.70501	97.5	100.0	0.23655

* $p < 0.05$, ** $p < 0.001$.

3.3. Satisfaction with Green Building Technologies

The satisfaction survey was limited to those who were aware of the technology. For example, since the LED lighting fixture and the underfloor air distribution system are only installed in the office-block, the number of persons surveyed was 90 and 146, respectively, who were aware of these technologies, among the 160 people working in the office block. Furthermore, since the daylight-linked dimming control is only installed at the 3rd and 4th floor in the office block, the satisfaction survey was conducted on 11 persons who were aware of it among the 45 occupants on these floors. Table 6 shows the number of responses and the satisfaction scores. The average satisfaction score is 3.14, a slightly positive mean value.

Table 6. Occupants' satisfaction score with selected technologies.

Green Building Technology	Number of Respondents	Number of Responses (Percentage)					Satisfaction Score
		1	2	3	4	5	
LED lighting fixture	90	0(0%)	10(11%)	30(33%)	42(47%)	8(9%)	3.53
Daylight-linked dimming control	11	2(18%)	1(9%)	5(45%)	1(9%)	2(18%)	3.00
Daylight-linked roller shade	188	6(3%)	37(20%)	82(44%)	56(30%)	7(4%)	3.11
Underfloor air distribution system	146	10(7%)	44(30%)	56(38%)	30(21%)	6(4%)	2.85
Natural ventilation with atrium opening	112	1(1%)	8(7%)	60(54%)	35(31%)	8(7%)	3.37
Low-flow toilet	209	17(8%)	59(28%)	58(28%)	65(31%)	10(5%)	2.96

The LED lighting fixture shows the highest satisfaction level (3.53). Fifty positive respondents attributed “visual comfort” (46%), “sufficient illumination level” (24%), and “ease of maintenance” (16%) to their satisfaction. All negative respondents selected “insufficient illumination level” as the reason for their dissatisfaction. The LED lighting fixtures enhance overall occupants' visual comfort, but there might be a difference in satisfaction with the illumination level since the preference for illumination levels varies from occupant to occupant.

The daylight-linked dimming control shows the median value (3.00) of the satisfaction score. Although the number of respondents is small, the reasons for satisfaction were “proper illumination adjustment” and “visual comfort without annoyance from the illumination fluctuation,” while the reasons of dissatisfaction were “no illumination adjustment” and “visual discomfort due to the low illumination level.” All three respondents who answered “normal” to the satisfaction score replied that they did not sense any difference compared with the conventional fluorescent lighting systems that they have experienced before.

The daylight-linked roller shade shows a slightly positive level (3.11) of satisfaction. The main reasons for satisfaction were “proper positioning” of roller shade (47.6%) and “automatic adjustment” (40%). The main reason for dissatisfaction was “too frequent adjustment” of roller shade (60.5%), followed by “noise annoyance” (23.3%) and “improper positioning” of roller shade (16.4%). Even though “noise annoyance” was not included in the list of answer options, it was commented in open-ended answers by ten respondents. According to the building operators, some of the occupants turned off the automatic control of the roller shade and operated it manually.

The underfloor air distribution system shows the lowest satisfaction level (2.85), and only 25% of respondents selected a positive satisfaction scale. The major attribute of their satisfaction was “more comfortable than conventional overhead system” (63.9%). Some of the other reasons for satisfaction were “direct contact with supplied air” (19.4%) and “occupant's individual control” (11.1%). Meanwhile, 70.3% of unsatisfied respondents selected “direct contact with supplied air” as the major reason of dissatisfaction, followed by “dust and odor” (20.4%), “less comfortable than conventional overhead system” (7.4%), and “noise” (1.9%). The result shows that most occupants do not prefer to directly feel the air movement of the supplied air.

The natural ventilation strategy with the atrium opening shows the highest percentage (54%) of respondents who answered “normal.” Even though they were aware of this technology, it seemed

that they could not directly recognize the effect of natural ventilation. “Comfort by natural air flow” (55.8%) and “openness to the outside” (41.9%) were the reasons for satisfaction, while “external noise” was the main reason of dissatisfaction. The low-flow toilet shows a slightly negative level (2.96) of satisfaction. Most of the satisfied respondents answered that they did not feel uncomfortable, nor did they recognize any difference from conventional toilet systems. “Bad odor” (63.2%) and “insufficient flush-out” (36.8%) were the reasons for dissatisfaction.

Table 7 shows occupants’ satisfaction by different demographic groups. There was a significant difference in satisfaction with one or more demographic characteristics, except for the daylight-linked dimming control and natural ventilation with atrium opening. In the case of the daylight-linked dimming control, the sample size was too small to make any meaningful conclusion, since only 11 responses were classified by demographic characteristics.

Table 7. Occupants' satisfaction by demographic groups.

Group		LED Lighting Fixture					Daylight-Linked Dimming Control					Daylight-Linked Roller Shade					Underfloor Air Distribution System					Natural Ventilation with Atrium Opening					Low-Flow Toilet					
		N (90)	M	SD	t-f	p-Value	N (11)	M	SD	t-f	p-Value	N (188)	M	SD	t-f	p-Value	N (146)	M	SD	t-f	p-Value	N (112)	M	SD	t-f	p-Value	N (209)	M	SD	t-f	p-value	
Gender	Male	64	3.47	0.854	−1.19	0.237	7	3.43	1.40	1.48	0.172	125	3.19	0.886	1.79	0.076	97	3.01	0.974	2.91	0.004 **	88	3.42	3.42	1.46	0.147	143	2.78	1.06	−3.9	0.000 **	
	Female	26	3.69	0.679			4	2.25	0.957			63	2.95	0.831			49	2.53	0.868			24	3.17	3.17			66	3.36	0.939			
Age	20–29	15	3.80	0.561			2	1.50	0.50			32	3.19	0.821			28	2.61	0.195			15	3.20	0.676			7	3.43	0.929			
	30–39	49	3.45	0.867			6	3.67	0.42			106	3.03	0.822			85	2.79	0.103			65	3.37	0.821			118	2.75	1.06			
	40–49	20	3.60	0.821	0.883	0.454	2	2.50	1.50	1.73	0.247	40	3.43	0.903	3.93	**	27	3.30	0.158	2.73	*	27	3.48	0.700	0.520	0.669	44	3.20	0.978	5.40	0.001 **	
	Over 50	6	3.33	0.816			1	3.00	-			10	2.50	1.08			6	2.83	0.401			5	3.20	0.447			10	2.70	1.06			
Location of workstation	Office block	79	3.48	0.798			11					123	3.15	0.846			129	2.84	1.01			81	3.38	0.663			138	2.93	1.08			
	Research block	0	-	-	−1.66	0.101	0					48	3.17	0.907	2.05	0.132	0	-	-	0.174	0.677	23	3.39	0.783	0.431	0.651	53	3.08	1.05	0.484	0.617	
	Both	11	3.91	0.831			0					17	2.71	0.920			17	2.94	0.429			8	3.13	1.46			18	2.83	0.924			
	Upper floors	70	3.43	0.791			0	Excluded ***					118	3.14	0.880			103	2.89	0.979			78	3.36	0.683			131	2.96	1.07		
	Middle floors	19	3.95	0.780	3.46	0.036 *	11					52	2.92	0.904	2.65	0.074	40	2.75	0.954	0.370	0.692	22	3.23	1.02	1.32	0.272	56	2.88	1.08	0.665	0.515	
	Lower floors	1	3.00	-			0					18	3.44	0.616			3	2.67	0.577			12	3.67	0.651			22	3.18	0.907			
	Perimeter zone	46	3.35	0.822			5	2.80	1.10			102	3.09	0.902			69	2.80	0.948			64	3.31	0.774			110	2.93	1.04			
	Interior zone	44	3.73	0.758	−2.27	0.025 *	6	3.17	1.60	−0.43	0.675	86	3.14	0.842	−0.40	0.689	77	2.90	0.981	−0.62	0.537	48	3.44	0.741	−0.86	0.391	99	3.00	1.08	−0.50	0.620	

* $p < 0.05$, ** $p < 0.005$, *** Comparisons are excluded because only occupants on the middle floors (3rd and 4th) in the office block were surveyed.

For the LED lighting fixture, there were significant differences in satisfaction depending on the floor and zone where the workstation is located. The satisfaction of the occupants on the middle floors was the highest, followed by the upper floors and lower floors. Since the number of samples in the lower floors could not be considered as a significant group, it was excluded from the comparison. Instead, a t-test was performed between the middle floors and the upper floors, and the satisfaction of the middle floor occupants was significantly higher than that of the upper floor occupants. The upper floors were mainly occupied by general office departments such as management support teams, where the occupants remained at their workstations all day except during lunch time. On the other hand, occupants on the middle floors had a shorter stay at the workstations due to the frequent out-of-office tasks and collaborative work with the research and office staff. Therefore, it seems that workers on the upper floors, who are exposed to LEDs for a longer time, are more sensitive to the technology, resulting in lower satisfaction than workers on the middle floors. The occupants in the perimeter zone were less satisfied with the LED lighting fixtures than those in the interior zone. While the interior zone maintained a relatively constant illuminance from LED lighting fixtures, the perimeter zone seemed to have a high fluctuation in illuminance due to the flow of direct sunlight and daylight because daylight-linked dimming control technology was applied to only a few perimeter zones.

There was a significant difference in satisfaction with the daylight-linked roller shade according to age, but there was no tendency for satisfaction to increase or decrease with age. In particular, the satisfaction level (2.5) of the age group over 50 was significantly lower than other age groups (average 3.15). This is mainly because they are more senior and preside over meetings, and it seems that they are dissatisfied with the distraction due to the excessive movement and operation noise of roller shade.

Satisfaction with the underfloor air distribution system was significantly different according to gender and age groups. Female satisfaction was lower than male satisfaction. The female group seemed to be more sensitive to direct contact of lower body with supplied air. In terms of satisfaction according to age groups, the higher the age of females, the lower the satisfaction, which is similar to the analysis result with gender. However, in the age group of 50 and above, the satisfaction level decreased even though the percentage of females was 0%, since the higher the age, the more likelihood of being sensitive to the indoor thermal environment.

Satisfaction with the low-flow toilet was also significantly different according to gender and age groups. Contrary to the satisfaction with the underfloor air distribution system, the satisfaction with low-flow toilets was lower for males than for females. This low level of satisfaction was due to the bad odor and poor flush-out of water-saving urinals installed in the male restrooms. There was a significant difference in satisfaction with the low-flow toilet by age groups, but there was no tendency to increase or decrease with age. Taking into account satisfaction by gender, the 20s group is the highest with the maximum number of females, while the 50s group is the lowest with 100% being males.

Since most females belong to younger age groups under 40, the difference in satisfaction according to age group can be seen as the difference in satisfaction according to age group of males. Table 8 shows the results of a combined breakdown by age and gender analysis. Since most respondents in their 40s or older are males, the differences in satisfaction between males and females in Table 7 were analyzed in more detail in the younger age range, as shown in Table 8. Daylight-linked roller shade showed a significant difference in satisfaction according to gender in the 30s age group, and underfloor air distribution system showed a significant difference in the 20s age group. Females were less satisfied with both technologies than males. That is, females seem to be more sensitive to noise or controls of daylight-linked roller shade and to air contact from the underfloor air distribution system. In the low-flow toilet, there was a significant difference in satisfaction according to gender in both 20s and 30s. Males were less satisfied with the toilet than females, where the differences in satisfaction by gender are more obvious than with other technologies.

Table 8. Occupants' satisfaction by gender and age groups.

Group		LED Lighting Fixture					Daylight-Linked Dimming Control					Daylight-Linked Roller Shade				Underfloor Air Distribution System					Natural Ventilation with Atrium Opening					Low-Flow Toilet					
		N (90)	M	SD	t-f	p-Value	N (11)	M	SD	t-f	p-Value	N (188)	M	SD	t-f	p-Value	N (146)	M	SD	t-f	p-Value	N (112)	M	SD	t-f	p-Value	N (209)	M	SD	t-f	p-Value
Age	20–29	Male Female	3	4.00	0.00		0	-	-			10	3.30	0.48			9	3.44	0.88			8	3.50	0.76			12	2.92	0.90		
			12	3.75	0.62	0.68	0.51	2	1.50	0.71		22	3.14	0.94	0.52	0.61	19	2.21	0.85	3.49	0.00 **	7	2.86	0.38	2.03	0.06	25	3.68	0.85	-2.46	0.02 *
	30–39	Male Female	36	3.39	0.90		4	4.00	1.15			68	3.16	0.84			56	2.82	1.01			50	3.42	0.78			80	2.54	1.05		
			13	3.62	0.77	-0.87	0.39	2	3.00	0.00	1.73	0.18	38	2.79	0.74	2.36	0.02 *	29	2.72	0.84	0.47	0.64	15	3.20	0.94	0.82	0.42	38	3.18	0.95	-3.32
	40–49	Male Female	19	3.58	0.84		2	2.50	2.12			37	3.41	0.93			26	3.31	0.84			25	3.44	0.71			41	3.22	0.99		
			1	4.00	-	-0.49	0.63	0	-	-		3	3.67	0.58	-0.71	0.53	1	3.00	-	0.36	0.72	2	4.00	0.00	-1.09	0.28	3	3.00	1.00	0.37	0.74
	Over 50	Male Female	6	3.33	0.82		1	3.00				10	2.50	1.08			6	2.83	0.98			5	3.20	0.45			10	2.70	1.06		
			0	-	-		0	-	-		0	-	-		0	-	-		0	-	-		0	-	-		0	-	-		

* $p < 0.05$, ** $p < 0.005$.

3.4. Awareness and Satisfaction of the Building

Meanwhile, 97% of the respondents, 209 out of 215, replied that they were aware that the building earned at least one type of green building certification (Q3), which is considerably higher than the average awareness of 64.1% for individual green building technologies. With regard to the overall environmental performance of the building (Q5), the majority of the respondents were very satisfied (58.6%) and satisfied (30.2%), and the mean score of satisfaction was 4.45. Occupants were asked as to what extent they agreed with the question “do you think that the environmental performance of this building has a positive effect on your productivity?” (Q6). The respondents also used 5-point scales, where “5” means “strongly agree” and “1” means “strongly disagree.” The survey found that 20.5% of respondents strongly agreed and 40% of them agreed with the positive effect on their productivity, and the mean score was 3.70.

Regarding the relationship between satisfaction with environmental performance of the building (Q5) and its positive effect on work efficiency (Q6), the correlation coefficient(r) was 0.364, and the significance probability (p) was less than 0.01. The broadly accepted standards consider a correlation coefficient(r) of 0.5 and greater as “large”, between 0.5 and 0.3 as “medium”, and between 0.1 and 0.3 as “small” [11,23]. The result showed that although occupants’ level of satisfaction with the environmental performance of the building was not regarded as a major factor, it was a statistically significant factor for improving employees’ productivity.

4. Conclusions

A range of green building strategies and technologies have been adopted to mitigate the environmental impact of buildings. These technologies and strategies may affect the building’s environmental performance as well as the building occupants’ satisfaction and comfort. In this study, a post-occupancy evaluation was conducted for an office building to evaluate awareness and satisfaction regarding a variety of green building technologies. Answers from 215 occupants were collected and analyzed. Even though almost all the occupants were aware of the building’s certification level due to promoting through the introduction brochure and video, awareness of individual technologies was relatively low. A higher level of awareness was shown in higher age groups who may have had more opportunities to receive some information on the technologies through business reports and meetings during the building design and construction process.

There were also a few technologies with lower levels of satisfaction. A further attempt was made to identify the causes of satisfaction and dissatisfaction with individual technologies in order to seek ways to improve them. More specific understanding of the cause of satisfaction or dissatisfaction with individual technologies can lead to improvements in those technologies. For example, in the case of ‘daylight-linked roller shade’, there were complaints about ‘inappropriate location’ among the dissatisfaction, mainly for controlling the light environment, but many complaints about ‘noise’ were also raised. In other words, it is important to advance control algorithms to better control the light environment in the future, but it is also necessary to develop a technology that can reduce operating noise. If these technologies are applied in future buildings after improvisation or modification based on the POE results, it can serve as an effective strategy to increase people’s satisfaction as well as improve environmental performance. It was also found that even though occupants’ level of satisfaction with the environmental performance of the building was not regarded as a major factor, it was a statistically significant factor for improving employees’ productivity. This result is in agreement with the findings by previous studies [9,24] in which the degree of work productivity increased considerably in sustainable buildings.

POE has not yet been actively conducted on green buildings in Korea. However, as an increasing number of green and energy-efficient buildings are being built, POE should be conducted to investigate end-users’ interaction with technologies. The POE study and the questionnaire research may provide great opportunities for correcting the negative or ambiguous perceptions of the general public on green buildings and for introducing various new green building technologies. Whilst the study

only represents a “green” certified building in Korea, it highlights the increasing awareness of and satisfaction with green building technologies.

However, further studies across a broader sample of buildings are needed for a comprehensive understanding of the occupants’ responses and perceptions. Furthermore, another limitation consists of the fact that there was no approach to investigate the effect of occupant training in relation to occupants’ awareness of building technologies, as Day and Gunderson [22] did. It is necessary to conduct research on a ‘before’ and ‘after’ scenario in an awareness-raising campaign to test differences. In addition, further research is needed to compare occupants’ awareness of and satisfaction with technologies in green buildings and non-green buildings [5,12,18,25].

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