GU J Sci, Part B, 7(2): 239-255 (2019)

Gazi Üniversity

Journal of Science

PART B: ART, HUMANITIES, DESIGN AND PLANNING

http://dergipark.gov.tr/gujsb

LEED CERTIFIED OFFICE BUILDINGS' POST OCCUPANCY EVALUATIONS OF ENERGY PERFORMANCE VALUES

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Article Info

Received: 22/03/2019
Accepted: 28/05/2019

Keywords

Sustainability, Green Office Building, Energy Efficiency, Post Occupancy Evaluation

Abstract

The green buildings increased in the 2000s are about designing and operating structures in the light of sustainable principles. Although the certification systems encourage the development of the green building industry, certificated buildings' expected performance difference in the occupancy leads to some problems. In order to identify the problems affecting the energy performance of buildings, six green LEED-NC certified office buildings in America were examined and benchmarked. In this research, sampling analysis method was used. Consequently, obtained data from both the demands for reduction of energy use and the increased demand for comfort in buildings were analyzed.

1. INTRODUCTION

The natural environment, which prepares the environment for the existence of man, is again damaged by human interventions [29, 30]. Today, various solutions are produced and ideas are presented. Despite taking measures, ecological problems are getting more and more serious day by day [31, 34] . Many concepts such as 'global warming', 'ecology', 'sustainability', 'renewable energy', 'environmental design', 'green architecture', 'intelligent building' and 'energy efficiency conservation' have emerged to prevent problems in the building sector [3, 32]. In this sense, the last 30-40 years of building development process, first of all, intelligent buildings are on the agenda. Following the addition of the developing technologies to the building and the building envelope, there was a transition process towards 'energy efficient', 'environment friendly' and 'sustainable' buildings [27, 33].

Depending on this situation, green building developments are supported to alleviate the negative effects of the buildings [4]. The most common certification systems developed and implemented by different countries can be listed as BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen e.V.), IISBE (International Initiative for Sustainable Built Environment), Green Star, CASBEE (Comprehensive Assessment System for Built Environment Efficiency), HK-BEAM (The Hong Kong Building Environmental Assessment Method) [36, 37, 38, 39, 40, 41, 42]. Previous studies have shown that these rating tools are very useful for promoting the development of the green building industry [35].

A number of studies have shown that certified green buildings provide significant environmental benefits, such as generally less energy consumption, improved energy efficiency, less construction and demolition wastes and improved water efficiency [7]. Along with research on the benefits of green buildings, some studies question the alleged benefits of green building developments [50].

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LEED buildings use 18-39% less energy per floor area than their conventional counterparts on average, when energy use of green buildings is analyzed by LEED certification level and the energy-related credits obtained during the certification process. Nevertheless, 28-35% of LEED buildings spent more energy than their conventional counterparts. In addition, the restrained energy performance of LEED buildings varies with the certification level of the building or the number of energy credits earned by the building at design time. For example, the work of Newsham and his colleagues found that about 30% of LEED-certified buildings consume more energy than similar buildings, despite an average level of energy efficiency [9]. Continuous improvement of green building rating certification is necessary.

The study by Roaf revealed that green buildings are rarely seen and reassessed when green buildings are delivered to users of buildings. In this work, it is stressed that this lack of evaluation and study is due to countless reasons. Because of each building being a unique example and repeated design mistakes, the building needs to be re-evaluated. Unless a systematic approach to the comparison of buildings is made, it is noted that existing practices are not going to improve [8, 15].

Green building projects are designed in line with targets such as energy, CO2, ecology, economy, health and welfare, indoor environmental quality, innovation, land use, management, materials, environmental pollution, renewable technology, transportation, waste and water management; however, the result is can be different than expected. Green buildings should be assessed for initial investment costs, ongoing savings in use, energy savings, health and well-being of the users [16].

For green and energy-efficient buildings, post occupancy evaluation has an important role in providing feedback. For instance, post occupancy evaluation study of a solar neighborhood in Israel has shown inconsistencies between planners' eco-friendly goals and the end result [28].

In this context, the subject has been systematically investigated in the light of the researches made on post occupancy evaluation and energy performance.

2. POST OCCUPANCY EVALUATION (POE)

In 1980, post occupancy evaluations (POE) have been identified as ‘examinations of the effectiveness for human users of occupied design environments’ [52]. It is in conflict with the demand for energy reduction and the increased comfort demand in the buildings [8, 51]. Should post occupancy evaluation (POE) compromise the comfort and satisfaction of users, or can it provide a balance of energy consumption and user demand for physical, physiological, and psychological needs? Knowing how POE functions and is perceived by the buildings, answering these and other questions could be easy [8].

POE serves as a way to provide subjective and objective feedback that informs planning and implementation from the initial design through to the building's life cycle [43, 44]. The benefits of POE can be short, medium and long-term:

- Short-term benefits include the determination of users' views and solutions on issues at the premises,
- Medium-term benefits include the transfer of learned and negative lessons into the next building cycle,
- Long-term benefits are aimed at creating databases and updating, upgrading and producing planning, design protocols and paradigms [14].

Nowadays, the main aim of POE is user satisfaction. POE ensures that a building's environment and community influence is positive for everyone [53]. Thus POE strengthens the living environment and society. Adapting to the development process and being aware of current developments is an indispensable part of design development. POE can be seen as an effective way to understand how buildings in use are deviating from design expectations [45].

Some important parameters that can be measured after use include temperature, relative humidity, air movement, light intensity, noise levels, pollutants, allergens and pathogens, volatile organic compounds of various compounds and forms, electromagnetic fields and amount of radiation. Although these seem to be the most concrete and explanatory aspects of the building, it has been understood that these measurements are not sufficient after post occupancy evaluation [12]. For instance, while there are national and international standards for some of these parameters, recent investigations have questioned the validity of some of them, for example the thermal comfort standards defined by ASHRAE Standard 55 (2004). This is not flexible at the upper and lower thresholds, but it is an expandable structure in terms of thermal comfort. An alternative adaptive model advocated by Nicol and Humphreys (2002) includes behavioral and cultural differences, as well as environmental conditions beyond these rigid thresholds. Therefore, accumulating evidence may not be sufficient to measure the physical factors and thermal parameters in a given environment, since the psychological factors on the physiology of the person are significantly influential [8, 10].

Methods of post occupancy evaluation can be shown as sampling and monitoring. Additional complexities may arise at the sampling method and at the level of the standard. The sampling and monitoring of various compounds differs from one country to another and even where these standards exist; this is usually standard and not absolute [8]. One of the application methods of post occupancy evaluation is surveys [46]. Although the measurement of air temperature in one area may seem quite simple, how this temperature is perceived by the individual is a different matter that is entirely influenced by parameters other than physiology or temperature. Such surveys are used to measure the subjective perception of indoor parameters by asking the interviewee to rate the temperature, light, noise, ventilation, general satisfaction and other parameters by five or seven degrees. Surveys can be filled in by the interviewee or researchers or by hard copy [8].

Another application method of post occupancy evaluation is sensors. Sensors play an important role in the data collection process for evaluation after use. The data is collected by the information from the detection devices. These devices can monitor both the building environment and movements of objects and people in the building. By collecting data effectively, a building information model as well as a building operation model can be created [11].

3. POST OCCUPANCY EVALUATION AND ENERGY PERFORMANCE

In developed countries, buildings account for 20-40% of total energy use. In economically growing countries, the annual average growth rate of energy use is 3.2%, while in developed countries it is 1.1% on average [13]. Green building programs are being developed to target more sustainable buildings in many countries. In North America, such a program is LEED (Leadership in Energy and Environmental Design), led by the US and Canada Green Building Councils (USGBC, CaGBC) [36].

When the energy use of green buildings is analyzed by the LEED certification level and the credits for the energy obtained during the certification process, on average, LEED buildings use 18-39% less energy per floor area than their conventional counterparts. However, 28-35% of LEED buildings use more energy than their conventional counterparts. In addition, the measured energy performance of LEED buildings varies with the certification level of the building or the number of energy credits earned by the building at design time [9].

Energy consumption seems to be a parameter that can be quantitatively measured easily. However, a wider analysis of this parameter can be developed by defining basic measures such as building qualities, characteristics and problems, a basic state, or targets for energy consumption [8]. One of the highest scoring criteria of certification systems, "energy and atmosphere", focuses on making energy performance efficient, making energy resources more efficient to use, and reducing carbon emissions. However, the process can be ignored after the certificate is received. At the community level, green buildings can save a considerable amount of energy, but more work needs to be done to define the green building rating plans so that they can show more consistent success on the individual building scale.

One of the most energy-intensive studies of post occupancy evaluation was carried out by the New Building Institute (NBI) in accordance with a contract with the USGBC [55].

One full year of measured post-occupancy energy usage data were collected from 121 buildings with LEED certification. The research focuses on the remaining 100 buildings, such as laboratories, data centers and supermarkets, where high-energy buildings have been eliminated. The baseline and design models in the beginning and national building inventory data were compared in more than 5000 buildings and the same or similar building activity types in the 2003 Commercial Building Energy Consumption Survey (CBECS database). The study showed that the average use energy density of LEED buildings is 32% lower than the average use energy density of the CBECS database. For office buildings that are the most common and easily comparable type of activity, the median use energy density of LEED buildings is 33% lower than the average use energy density of the CBECS database [9].

In another US study, the post occupancy evaluation of energy performance was conducted on six sustainable buildings. In research, monitoring and analysis are used as a tool. Energy flows have been extensively monitored for at least one year, including lighting loads, HVAC loads and plug loads. The data were recorded every 15 minutes and used to calibrate energy simulation models. Analyzes have shown that all buildings are performing worse than predicted, but all provide significant savings (energy cost or energy use) when compared to similar buildings. However, it has been found that the amount of deviation from predicted savings does not meet the needs and that the designs for which they are designed to work do not work as designed [17].

In a study by Fowler, multidimensional performance data for 12 US government buildings was analyzed. All of these buildings are designed with energy efficiency targets and some have LEED certification. Energy use per floor area of all buildings was 25-30% lower than average US commercial building stock [6]. In another research, features of LEED commercial buildings in the US Pacific Northwest were examined and compared to non-LEED regional buildings. Average energy use per floor area for 12 LEED units is 10% lower than for 39 similar non-LEED units in the same area [1].

The first year of occupancy is vital due to building occupant factor [48]. For instance, a study showed that Malaysia Green Technology Corporation office building, the most energy-efficient building in Malaysia, not able to reach expected energy which was planned during its design process [49].

4. LEED CERTIFIED OFFICE BUILDINGS' POST OCCUPANCY EVALUATIONS OF ENERGY PERFORMANCE VALUES

Both green design and the interaction between building occupants are major factors to determine the energy performance. If these factors are considered separately, identifying to energy performance problems could be crucial. Accordingly, Post Occupancy Evaluation (POE) may develop current certifications and solve problems between occupants and designing decisions. From this point of view, six LEED certified office buildings are chosen to examine and benchmark. The study focused on energy performance parameter.

4.1 Case Study

Post occupancy evaluations of 22 green buildings in the U.S.A were conducted by the General Services Administration (GSA) [5]. The post occupancy values of the energy performances of the San Francisco Office Building, Department of Transportation Lakewood Building, EPA Region 8 Headquarters Building, NPS Midwest Regional Office Building, Rockville Office Building and US Census Bureau Headquarters Building were analyzed by sampling analysis. In this study, post-use energy performance values collected and evaluated by GSA, PNNL and 'University of California Berkeley Center for the Built Environment' (CBE) officials, building managers and engineers were taken as basis.

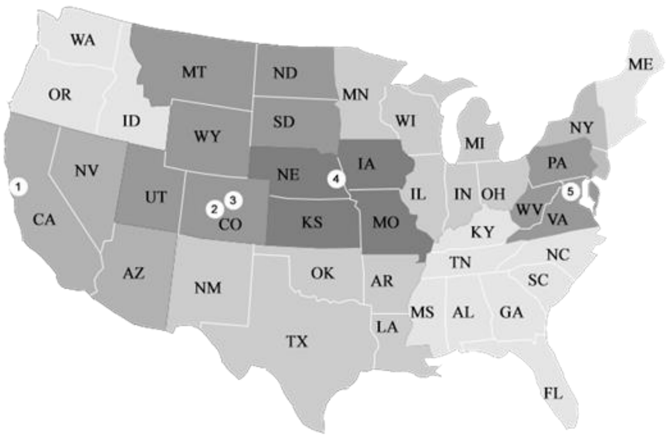


Figure 1. (1) San Francisco Office Building, (2) Department of Transportation Lakewood Building, (3) EPA Region 8 Headquarters Building, (4) NPS Midwest Regional Office Building, (5) Rockville Office Building and US Census Bureau Headquarters Building [5]

						
	San Francisco Office Building	**Department of Transportation Lakewood Building**	**EPA Region 8 Headquarters Building**	**NPS Midwest Regional Office Building**	**Rockville Office Building**	**US Census Bureau Headquarters Building**
Building Architect	Thom Mayne, Morphosis	Opus Architects and Engineers	Zimmer Gunsul Frasca Architects LLP	Leo A. Daly	JBG	SOM
Building Location	San Francisco, California, U.S.	Lakewood, Colorado, U.S.	Denver, Colorado, U.S.	Omaha, Nebraska, U.S.	Rockville, Maryland, U.S.	Suitland, Maryland, U.S.
Building Function	Office	Office	Office	Office	Office	Office
Project Type	New Construction	New Construction	New Construction	New Construction	New Construction	New Construction
Year Built	2007	2004	2006	2004	2004	2006
Number of Floors	18	3	9	3	9	8
Regular Occupants	1,314	318	922	125	720	6,000
Weekly Operating Hours	70	70	68	70	60	70
Usage Rate	%100	%100	%100	%100	%100	%100
Gross Square Meter	60,613 m^2	11,923 m^2	27,990 m^2	6,317 m^2	21,553 m^2	217,485 m^2
Design Certification	LEED-NC Silver	LEED-NC Silver	LEED-NC Gold	LEED-NC Gold	LEED-NC Silver (Registered)	LEED-NC Silver (Registered)

Table 1. Building Information [5]

	LEED Total Credits	Energy Star Score	Total Energy Use (mBtu)
San Francisco Office Building	34	96	31,501
Department of Transportation Lakewood Building	35	84	8,810
EPA Region 8 Headquarters Building	40	94	22,863
NPS Midwest Regional Office Building	40	82	4,586
Rockville Office Building	33	80	16,638
US Census Bureau Headquarters Building	41	91	175,795

Table 2. Energy Properties [5]

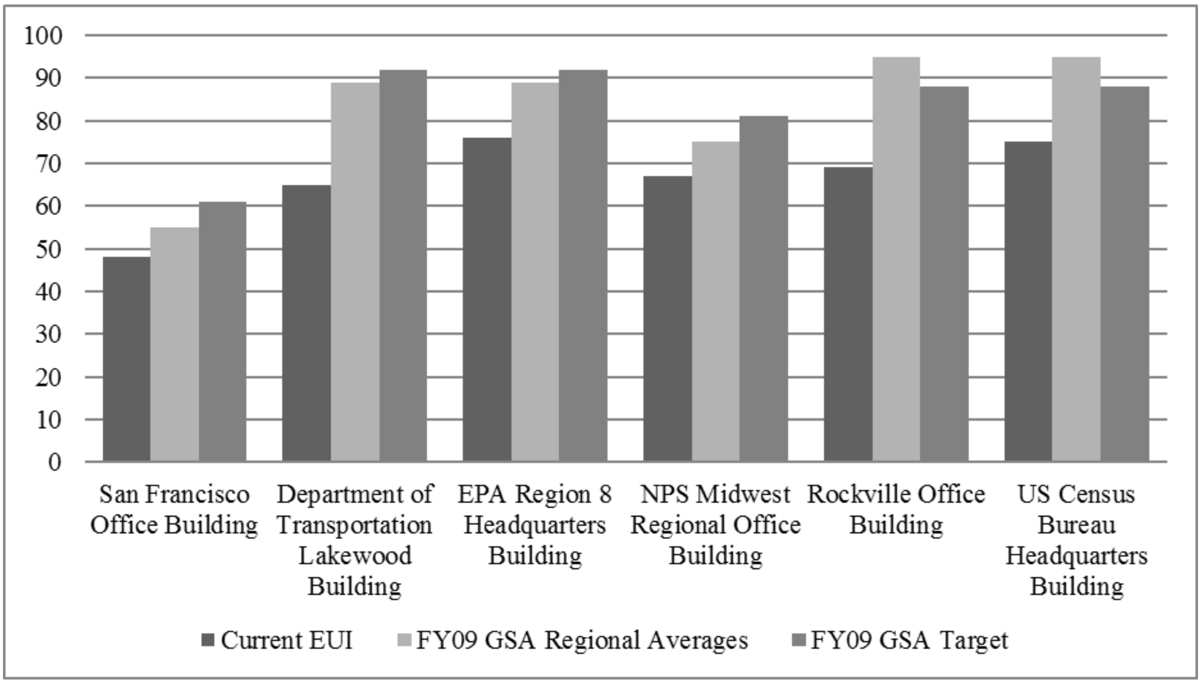


Table 3. Energy Use Intensity (EUI) [5]

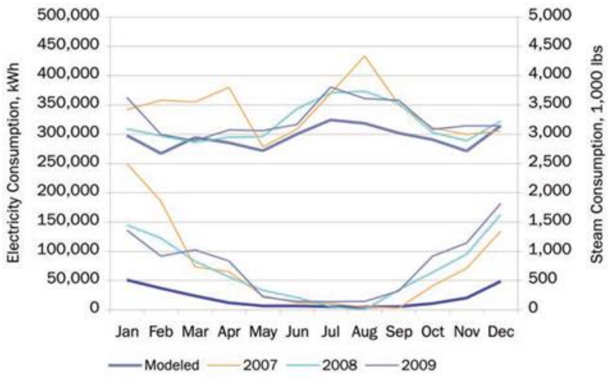
Table 3 summarizes the EUI data available for each building. Within the table, “Current EUI” is the EUI calculated in Energy Star from data provided by the sites and GSA’s EUAS database. “FY09 GSA Regional EUI” values were provided by GSA energy professionals. “GSA FY09 Target” is the EUI goal documented in the Public Buildings Service (PBS) [5]. According to Table 3, all of green office buildings current energy use intensity are under the expectations.

The San Francisco Office Building is located in a region with warm and temperate climate characteristics [18]. EPA Region 8 Headquarters Building, Department of Transportation Lakewood Building, Rockville Office Building and US Census Bureau Headquarters Building have hot, temperate and rainy days in areas with hot & temperate climates, while the NPS Midwest Regional Office Building has cold and temperate climates [19, 23, 24, 54]. This leads to decisions taken within the context of energy. Natural ventilation in buildings, a way to take advantage of the benefits of daylight and solar energy were monitored. For example, the EPA Region 8 Headquarters building LEED certification system has the following characteristics in terms of energy and atmosphere:

- The project complies with ASHRAE 90.1-1999 standard.
- Compared to ASHRAE 90.1-1999, a targeted savings of 35.7% was achieved. Energy efficiency measures include a better building envelope, effective lighting with daylight and underground air distribution.
- The measuring equipment is installed in accordance with the existing systems.
- 100% of the systematic burden of the building is provided by renewable energy meeting the definition of Green-e.
- The HVAC and R systems of the project do not contain CFC-based refrigerants [20]

Figure 2. EPA Region 8 Headquarters Building (Foto. Robert Canfield)

A variety of sustainable materials have been used in the EPA Region 8 Headquarters Building. More than 89% of the wood-based materials and products used in the building are certified according to the principles and criteria of the 'Forest Stewardship Council'. Construction waste is reduced; 80% of the total waste generated is recycled or removed from local storage areas. The green roof is absorbing heat and CO_2, and rainwater flow is reduced [21].



Graphic 1. Post Occupancy Evaluation Values of EPA Region 8 Headquarters Building within the Context of Energy [2]

Graphic 1 compares DOE-2 energy model data with real energy consumption data during the building's first three years of operation. The energy modeling data reflects the final figures for the LEED certification system that are not calibrated after use [2]. This result showed that when compared to the actual data and design model data, differences arise between model data and actual service invoice data.

The Department of Transportation (DOT) Lakewood Building has a glass-walled main entrance, granite floors, wall fabric, wood paneling, gypsum board and granite wainscot [47]. In addition, local, low-emitting and recycled content materials were used mostly. Building incorporated daylight and views in 91% of regularly occupied spaces. Green office building has light and motion sensors, carbon dioxide monitors, air-side economizers. A booklet was distributed to all building residents to inform them about design and operation of the building [5].

Figure 3. Department of Transportation Lakewood Building [47]

The San Francisco Office Building has an 18 story tower, four story annex, cafeteria, and day care center. The tower has a thin footprint at 20 meters wide, with floors six through 18 using natural ventilation strategies to minimize mechanical heating and cooling. Also, 11th floor consist of a three story open air sky garden [5]. Similarly to EPA Region 8 Headquarters Building, the San Francisco Office Building has reduced construction waste and used industrial wastes in its construction. It is targeted that the energy used in the building will be obtained from solar and wind energy close to 50% [22].

Figure 4. San Francisco Office Building (Photo. Cody Andresen and Tim Griffith)

The NPS Midwest Regional Office Building is designed as part of the urban transformation project. This green office building has a passive solar design; daylighting for 75% of building occupants. It has high-efficiency windows and floor air distribution. There are sensors for heating, ventilation, air conditioning and artificial lighting adjustment by daylight. Green building features are known by the building occupants. Consequently, occupants helped in the selection of office furniture. The green office building has exposed concrete interior walls and beams to reduce materials during construction. Operation of the facility includes green reconnaissance applications [5].

Figure 5. NPS Midwest Regional Office Building [25]

Rockville Office Building was planned to accommodate the needs of the Metropolitan Service Center. The LEED Silver office building has a reflective white roof, 90% daylighting factor in occupied spaces and occupancy sensors. Renewable, local, and recovered materials were used building’s interior finishes and furniture. Additionally, building got an Energy Star certification in 2009. Also, green office building has a fitness center, library, locker room and tenant supported nurse’s office. Rockville Office Building is close to the train station, and building has a bus shuttle which is provided by the building management [5].

Figure 6. Rockville Office Building [56]

LEED Registered US Census Bureau Headquarters Building has a curved design with shallow floor plate. Thus design of the building benefit to natural daylighting. Building's design features can be sorted as underfloor air distribution, vertically mounted wood fins shades the curtain wall to reduce the solar glare, vegetative roofs, and a retention pond with bioswales [5]. Moreover, recycled building materials were used at the US Census Bureau Headquarters Building. Decisions were made to minimize energy consumption and use of natural daylight. In addition to these anticipated sustainability measures, design decisions were made to reduce energy consumption in the form of a building, on the outside ceiling and on the roof [26].

Figure 7. US Census Bureau Headquarters Building [26]

The six green office buildings in the study were evaluated within the parameters affecting the energy performance. The parameters affecting energy performance are the impact of energy consumption on the overall quality of the office building, the effect of the overall comfort level of office rooms on energy consumption, thermal comfort in office rooms / indoor air temperature, the effect of natural and artificial ventilation on indoor air quality, the effect of ventilation on energy consumption, the effect of daylight adequacy in office rooms on energy performance, and the adequacy of artificial lighting levels in office rooms. The buildings were graded from -1 to 4 within the selected parameters.

If green building features are known to the building occupants, the overall quality can significantly increase. Accordingly, many green office buildings have various cautions. For instance, NPS green building occupants were informed about building's features. Also, a booklet was prepared distributed to all building residents to inform them about design and operation of the Lakewood Building. Their results showed that informing occupants significance. According to the Table 4, San Francisco Office Building and US Census Bureau Headquarters Building have the lowest scores in parameters: overall quality of the office building, overall comfort level of office room, thermal comfort in office rooms / indoor air temperature, the effect of natural ventilation on indoor air quality, the effect of artificial ventilation on indoor air quality, ventilation. Building workplaces display various heights and types. While Rockville' workplace has private offices, other buildings have cubicle workspaces and open office spaces. Among the buildings EPA and Rockville have the highest overall comfort level of office room scores.

To understand daylight adequacy in office rooms and adequacy of artificial lighting levels, vital questions should be answered: What is the satisfaction level of light to work effectively, what is the degree of visual comfort level about lighting? NPS Midwest Regional Office Building has the highest daylight adequacy score, due to having daylighting for 75% of building occupants and high-efficiency windows. On the other hand, EPA Region 8 Headquarters Building has the lowest daylight adequacy score because amount of daylight in your general office area and access to a window view are not enough to satisfy. Other buildings have the similar daylight adequacy scores. San Francisco designed to have effective lighting with daylight. In addition, Lakewood planned to integrate daylight and increase to rate of accessing to a window view in occupied spaces.

Moreover, Rockville has 90% daylighting factor in occupied spaces. Census's plan is designed to benefit from natural daylighting; but, result values are not corresponding to expectations. San Francisco and Census Buildings have the lowest adequacy of artificial lighting levels among the buildings. These buildings are similar in many ways. For instance, their certifications are LEED-NC Silver, their regular occupant number and their gross square meters are higher than others. Due to these similarities, controlling adequacy of artificial lighting levels may not reach the expectation. NPS and Lakewood have the sensor, a post occupancy evaluation method, for artificial lighting adjustment by daylight. Additionally to occupant surveys, sensors play an important role while determining adequacy of artificial lighting levels. Lakewood has carbon dioxide monitors, air-side economizers. Also, NPS has the sensor for ventilation and air conditioning. Thus their score of ventilation affected positively. Althought San Francisco has the underground air distribution system, its ventilation score is the lowest.

1. The image can present scientific facts in the form of visual depiction and it can specify abstract concepts and thus makes it easier to learn. It is a method for learners to enrich their perception it and to consider ideas in a new way.

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Energy Performance Criteria (Effects on energy consumption)	Pre Occupancy and Post Occupancy Compatibility					
	San Francisco Office Building	Department of Transportation Lakewood Building	EPA Region 8 Headquarters Building	NPS Midwest Regional Office Building	Rockville Office Building	US Census Bureau Headquarters Building
1. Overall quality of the office building	+0-1	+3	+2-3	+2-3	+2-3	+1
2. Overall comfort level of office rooms	+1-2	+2-3	+3-4	+3	+3-4	+2
3. Thermal comfort in office rooms / indoor air temperature	-1	+2-3	+2-3	+2	+2-3	-1
4. The effect of natural ventilation on indoor air quality	-1	+3	+3-4	+3-4	+3	-1
5. The effect of artificial ventilation on indoor air quality	-1	+2	+2-3	+2-3	+2-3	-1
6. Ventilation	+1	+3	+3-4	+3	+3	+2
7. Daylight adequacy in office rooms	+2-3	+2-3	+1	+3-4	+2-3	+2
8. Adequacy of artificial lighting levels	-1	+2-3	+2	+1-2	+2-3	-1

Table 4. Post Occupancy Values of Energy Performance

5. CONCLUSION

Decreasing to negative effects of the buildings, green building developments are supported. Accordingly, Pre Occupancy and Post Occupancy Compatibility need to assess. In this context, green certified office buildings' post occupancy evaluations of energy performance values have a vital role.

From the data obtained study by Fowler [5], six green LEED-NC certified office buildings in America were benchmarked against energy performance criteria. Although green office buildings current energy use intensity are under the expectations, post occupancy surveys showed that examined green office buildings do not provide the targeted energy performance. Certification systems should compare the actual data and the design model data with post occupancy tools, such as surveys, sensors. Consideration of users' satisfaction with the purpose of the buildings by the users can have a significant effect on the energy performance of the building.

In addition, in order to design a high performance building, alternative strategy decisions should be made by modeling the total building performance. In the building construction process, the energy model as well as the performance values after use should be included in the process without being overlooked. When architects design the building, they need to be informed about how the building is performing after use, so they can be collected to ensure the continuity of the building's energy performance. Despite the extensive literature available in the green building, there is a need of study which is focuses on post occupancy evaluation on the building after being occupied by users. The result of the study showed that green building certification will not only lead to sustainable design, but will also guide the next sustainable energy performance from building to construction and operation if post occupancy evaluation for green office buildings' energy performance is made routine in the long run.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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