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Post-occupancy evaluation in indoor comfort conditions for green office buildings

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Research Paper

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Post-occupancy evaluation in indoor comfort conditions for green office buildings

This paper aims to reveal the relationship between the post-occupancy evaluation (POE) and indoor comfort conditions for green office buildings. First, six office buildings in Turkey with Leadership in Energy and Environmental Design-New Construction (LEED-NC) certification were evaluated for their envelope features. Second, a post-occupancy survey was conducted to investigate the indoor comfort of green office building users. The post-occupancy questionnaire (Cronbach's alpha reliability of 0.956) was evaluated with regression and cross-tabulation methods using the Statistical Package for the Social Sciences (IBM SPSS Statistics) Program. The results show that envelope characteristics are important for POE of building performance and occupant indoor comfort satisfaction levels are related to a personal workplace location.

Key words:
green office buildings, building envelope, post-occupancy evaluation, user satisfaction, indoor comfort

Prethodno priopćenje

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Procjena uvjeta ugodnosti nakon useljenja u prostorima zelenih poslovnih zgrada

Cilj je ovog istraživanja otkriti odnos između procjene kvalitete nakon useljenja i udobnosti u unutrašnjem prostoru zelenih poslovnih (uredskih) zgrada. Najprije su ocijenjene značajke fasada na šest poslovnih zgrada iz Turske s LEED-NC certifikatom (Leadership in Energy and Environmental Design-New Construction). Zatim je provedeno je istraživanje, nakon useljenja, kako bi korisnici ocijenili udobnost uredskih prostora. Upitnik nakon useljenja ocijenjen je regresijskim metodama i metodama unakrsnih tablica statističkim programom za društvene znanosti, IBM SPSS Statistics. Rezultati pokazuju da su značajke ovojnice važne za procjenu energetske učinkovitosti zgrade nakon useljenja, a razine zadovoljstva udobnosti korisnika u unutrašnjem prostoru povezane su s položajem radnog mjesta svake osobe.

Ključne riječi:
zelene poslovne zgrade, ovojnica zgrade, procjena nakon useljenja, zadovoljstvo korisnika, udobnost u zatvorenom prostoru

1. Introduction

Studies on environmental risks and climate change show that the growth of the construction sector to meet rapid urbanization causes global climate risk, environmental pollution, and widespread use of natural resources [1, 2]. Consequently, new concepts such as sustainability, renewable energy, green architecture, and climate control have emerged [3]. Green building certification systems (e.g., Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM)), which aim to achieve the best internal and external comfort levels, are supported to reduce the negative effects of buildings [4]. The LEED identifies high-performance green buildings that are beneficial to health, the environment, and the economy [5]. Moreover, LEED-New Construction (LEED-NC) provides a roadmap for designing and building commercial structures that include design–construction teams, building users, and the environment [6]. The green building certification systems often do not have post-occupancy criteria [7] and generally focus on the design and before the occupancy phases [8]. The primary goal of sustainable design should be to maximize user comfort and satisfaction while minimizing environmental impact and costs. The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) commonly describes Indoor Environmental Quality (IEQ) as construction properties that directly affect users. The IEQ of a business reflects the holistic interaction of air, light, and the environment with users [9, 10].
The existing building stock must be evaluated to minimize the margin of error in estimating indoor environmental quality, occupant satisfaction, indoor comfort level, and energy-cost use for the construction, operation, and maintenance of buildings [11]. These sustainability goals can be achieved by evaluating buildings in occupation more regularly and effectively [12]. After the occupancy of indoor or outdoor spaces, the evaluation of the space by the users is called post-occupancy evaluation (POE) [13]. Advanced data collection, sampling, observation, interviews, questionnaires, and sensor applications are shown as POE methods. The POE of office buildings generally uses questionnaires and indoor environmental quality in-situ measurements based on user satisfaction and productivity [14].
The energy demand of buildings worldwide increased by 20 % between 2000 and 2017, and the building sector accounts for about 30 % of the total energy consumption [15]. Three-quarters of this energy consumption are from commercial and public buildings [16]. The heating and cooling requirements of commercial buildings are listed among the main parameters that affect energy performance [17]. Office buildings, which have the highest energy consumption rate in the commercial building sector, have high internal heat gain [18]. Energy usage per unit floor area in fully ventilated office buildings can be 10–20 times higher than in residential buildings [19]. Green office buildings have different heating and cooling loads depending on climate zones [20]. Conversely, the transparency of the building envelope has increased since the mid-twentieth century, leading to high energy heating and cooling loads, particularly in green office buildings [21, 22]. There are advanced system solutions in the building envelope to ensure the comfort of green office users, such as external shading, which has real-time environmental response; dynamic automation systems with built-in microprocessors; advanced materials; wireless sensors–actuators; double skin envelope with controlled ventilation; etc. [23]. Considering that energy and atmospheric parameters have the highest score in the green building certification systems, energy performance of the building envelope is expected to be high. In this context, the performance of office buildings' envelopes after occupancy is determined through simulation studies. For instance, research shows the importance of building envelope simulations in terms of office building energy performance and indoor climate comfort for occupants [24]. In addition, the energy-conscious design for office buildings contributes to taking energy measures, increases the indoor comfort level, provides aesthetical aspects, and ensures cost optimization [25]. The shape and orientation of a building have a significant impact on its energy performance and thermal comfort [26]. The transparency ratio and position of the fenestration system, combination of shading devices, and effective window opening strategies have the best solutions for solar control in the summer, reducing heat loss in the winter and promoting natural ventilation. Advanced facade systems provide indoor–outdoor climate control by using automation systems (e.g., thermostat, wind, and sensor) and improve building performance. Monitoring is an important parameter for controlling the total building performance and user satisfaction [27]. Energy efficiency measures and periodic maintenance of green office buildings during the occupancy phase can enhance the performance of the building [28]. Material selection and access to sustainable building materials in green office buildings also affect energy performance [29]. Attention should be paid to technical properties of building materials that do not contain harmful materials, such as volatile organic compounds or formaldehyde with low buried energy [30]. Therefore, according to design decisions, climatic characteristics, and building characteristics (building envelope, level of internal gains), the indoor climate comfort of green office buildings has become important after occupancy.
One of the largest energy-related studies of POE showed that the median use energy density of LEED buildings was found to be 33 % lower than the average use energy density in the database of the Commercial Buildings Energy Consumption Survey for office buildings [31]. Conversely, some studies on green buildings investigate whether high-performance office buildings provide a comfortable working environment for their users [32, 33]. For example, a study showed that green office building employees have low levels of satisfaction with indoor climate and environmental control systems [34]. Although green building user satisfaction has been highlighted in some

studies, the amount of data on user perception and satisfaction remains limited [35]. User satisfaction is often not included as a part of measuring sustainability. However, the evaluation of the post-occupancy process to address the needs, activities, and perceptions of users is considered critical. The success of green office buildings in achieving design goals is determined by energy performance and user satisfaction [36, 37]. In summary, examination of green office buildings in the post-occupancy period is important for comparing the building envelope characteristics and user satisfaction values.

2 Materials and methods

2.1. Theoretical background

The LEED system is a term that encompasses a number of grading systems adapted for specific building types [38]. As of 2019, there are 46,069 LEED-certified buildings and 94 LEED-NC-certified office buildings worldwide. Despite some efforts, Turkey lacks a customized local green building certification system for office buildings. LEED is the most common green certification system, and BREEAM is the second common green certification system in Turkey (373 LEED, 13 LEED-NC offices, and 126 BREEAM certified buildings) [39]. Despite an increasing interest in green office building investment in Turkey [40], no studies have been focusing on the POE of green office buildings and user satisfaction. Moreover, there is no access to data on the expected-actual values of energy performance for green office buildings in Turkey. Accordingly, this research is important for the development of future green office buildings and post-occupancy studies. In the LEED green building certification system, the "energy and atmosphere" parameter accounts for approximately 40 % of all scores. From Table 1, optimizing energy performance in the "energy and atmosphere" parameter has a significant contribution.

Table 1. LEED energy and atmosphere contents [38]

Energy and atmosphere contents	New construction
Fundamental commissioning of building energy systems	prerequisite
Minimum energy performance	prerequisite
Fundamental refrigerant management	prerequisite
Optimize energy performance	19 points
On-site renewable energy	7 points
Enhanced commissioning	2 points
Enhanced refrigerant management	2 points
Measurement and verification	3 points
Green power	2 points
Total point	35 points

2.2. Methodology

In this study, a two-step method was used within the scope of the "energy and atmosphere" parameter. Initially, the six LEED-NC-certified office buildings from Turkey were evaluated regarding their envelope features. Green office buildings designed under energy and atmospheric parameters are expected to have energy-efficient envelope performance. It aims to determine the role of climate-compatible envelope design decisions in green office buildings' energy performance. Second, a post-occupancy survey was conducted to investigate the indoor climate comfort of green office building users in Turkey. Six green office building administrations in Turkey, such as Izmir Chamber of Commerce (ICC), Eurasia Tunnel O&M Building (ETOMB), Bursagaz New Administration Building (BNAB), Prokon-Ekon Group of Companies Administration Building (PEGCAB), Eser Holding Headquarters (EHH), and Turkish Contractors Association Headquarters (TCAH), agreed to participate in the POE survey. Questionnaires taken with the decision numbered 56497898-302.08.01 were prepared on the Internet and delivered to the selected green building office employees by the relevant department of the institution. Then, information regarding the validity of the POE survey in terms of scientific ethics was transmitted to the green office buildings. Then, managements of the green office buildings were informed about the satisfaction levels and research summary-aim-method. The results of the post-occupancy satisfaction survey, completed between 06/05/2019 and 06/06/2019, were taken online and analyzed in the Statistical Package for the Social Sciences (IBM SPSS Statistics) Program. In this study, three different questions were selected within the scope of thermal comfort or indoor air temperature in the office room. Its goal was to collect data on employee satisfaction with workplace temperature and relative humidity (RH), as well as the variety of individually adjusted or controlled thermal comfort components. The employees of the green office buildings were asked to score from 1 to 5 for the temperature satisfaction and RH in the workplace. POEs often do not include the location of the users in the building. [41]. However, determining the personal workplace floor level, the personal workplace location (south, north, east, or west), and whether the working area is near the outer wall-window will increase the reliability of the studies and provide better indoor climate comfort. To determine how green office building office users perceive the indoor air temperature, hypotheses were established between "thermal comfort questions" and "personal workplace location" and tested using regression analysis in IBM SPSS Statistics. This study's research model was displayed in Figure 1. In IBM SPSS Statistics, the Cronbach's Alpha reliability analysis and cross-tabulation of "thermal comfort questions" and "personal workplace location" were performed.

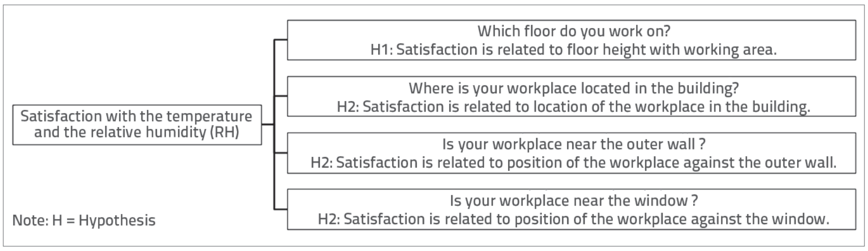

Figure 1. Research model

2.3. Examination of the selected examples

The selected LEED-NC-certified office buildings have different regions, climate zones, orientations, building designs, and envelope characteristics. To increase the relevance of the survey results and general research, green office buildings were evaluated in three independent groups depending on the climate zone (Figure 2). Each group (Aegean-ICC, Marmara-ETOMB, BNAB, and Central Anatolia-PEGCAB, EHH, TCAH) was compared within their climate zone.

Table 2 presents the selected green office buildings' characteristics. Energy-efficient design, methods, and measures increase the importance of envelope design regarding user comfort. In this context, the detailed information LEED-certified buildings according to building shape, office layout, envelope-glazing design, green feature, shading device position and type, facade component, facade material, energy, and indoor climate comfort was given in Appendices 1–6. The comparison of six green office buildings is presented in Table 3.

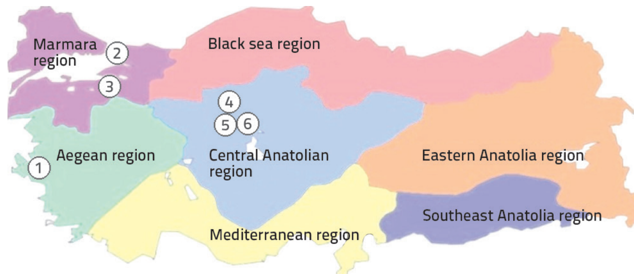

Figure 2. (1) Izmir Chamber of Commerce. (2) Eurasia Tunnel O&M Building. (3) Bursagaz New Administration Building. (4) Prokon-Ekon Group of Companies Administration Building. (5) Eser Holding Headquarters. (6) Turkish Contractors Association Headquarters

Table 2. Buildings' characteristics [6]

Building's feature	 Izmir Chamber of Commerce (ICC)	 Eurasia Tunnel O&M Building (ETOMB)	 Bursagaz New Administration Building (BNAB)	 Prokon-Ekon Group of Companies Administration Building (PEGCAB)	 Eser Holding Headquarters (EHH)	 Turkish Contractors Association Headquarters (TCAH)
	ICC	**ETOMB**	**BNAB**	**PEGCAB**	**EHH**	**TCAH**
Region	Aegean	Marmara	Marmara	Central Anatolia	Central Anatolia	Central Anatolia
Climate characteristics	Hot and dry in summers		Summers are less rainy than the Black Sea climate		The temperature difference between winter and summer is mostly observed	
	Mild and rainy in winters		Winters are warmer than the Continental climate and cooler than the Mediterranean climate		Winters are rainy Summers are dry	
LEED type (v2009)	BD +C: NC Gold	BD +C: NC Gold	BD +C: NC Platinum	BD +C: NC Platinum	BD +C: NC Platinum	BD +C: NC Platinum
Certificate import date	April 2018	July 2017	April 2017	February 2016	February 2011	May 2014
Sustainable sites	19/26	24/26	25/26	19/26	25/26	22/26
Energy & atmosphere	22/35	13/35	28/35	31/35	24/35	19/35
Material & resources	7/14	5/14	4/14	6/14	8/14	8/14
Indoor environmental quality	8/23	6/23	7/23	13/23	13/23	13/15
LEED total credits	70	64	83	89	92	81

Table 3. Comparison of green office buildings in terms of building envelope features

Envelope feature	ICC	ETOMB	BNAB	PEGCAB	EHH	TCAH
Building shape	square shape plan	rectangular shape plan	square shape plan	rectangular shape plan	rectangular shape plan	rectangular shape plan
	ground+7-storey	ground+2-storey	ground+7-storey	ground+5-storey	ground+4-storey	ground+4-storey
Office layout	cubicle and private					
Envelope-glazing design and green feature	single skin facade	double skin facade	double skin facade	single skin facade	single skin facade	double skin facade
	curtain wall	aluminum sliding window	triple glazed curtain wall	double glazing	semi-reflective triple glass	transparent curtain wall
	atrium	daylight chimney	solar lighting	daylight chimney	daylight chimney	atrium
Shading device position and type	Northwest Southwest Southeast	Southwest Northeast	Northwest Northeast Southwest	Southwest	West East South	Northeast Southeast Southwest
	solar screening eaves at roof level	fixed perforated metal sheet	PV glass in the form of a mosaic	fixed louver	vertical solar control device PV panels	fixed stainless steel metal mesh
Facade components	exterior curtain system	perforated metal sheets	solar panels painted glass	aluminum curtain wall	perforated culvert panels	stainless steel metal mesh
Green material	yes	yes	yes	yes	yes	yes
Energy efficient material	yes	yes	yes	yes	yes	yes
Automation system	wind	-	motion and daylight	occupancy, daylight and timing	motion daylight, and CO_2	occupancy, motion and daylight
Energy efficiency	fabric solar curtain system	efficient lighting	PV panels	automation system	PV panels	envelope design
Thermal comfort systems	controllable and high	high	light control	controllable and high	controllable and high	automatic dampers
Daylight	yes	yes	yes	yes	yes	yes
Fresh air	yes	yes	yes	yes	yes	yes

2.4. Evaluation of green office buildings' envelope design

The green office buildings' envelope characteristics are presented in Table 4.

The optical and thermo-physical properties of the building envelope are effective in determining the amount of heat passing through the opaque and transparent components. Internal climatic conditions, heating loads, and air conditioning loads vary depending on the total amount of heat lost and gained from the building envelope. Depending on the geographical location of the building in Turkey, the heating costs on the northern side are higher than the cooling costs. Therefore, it is necessary to keep the energy to be used for heating at the lowest level by making the maximum use of solar heat in winter. As the northern facade will not overheat in summer, there will be no negative impact on cooling costs. On the southern front, cooling costs are higher in summer. Accordingly, the solar heat gain must be controlled by selecting a glass with a low solar heat gain (low SHGC glass, low g value), enough visible transmittance (V_t), adequate daylight performance level, and coolness index ($D_x = V_t/SHGC > 1,0$).

The Izmir Chamber of Commerce (ICC), which is located in the hot climate zone, cannot make efficient use of the northeast facade, where the cooling load is less, due to the site shape. The northwest, southwest, and southeast facades are surrounded by the streets. Despite having a single-layer glass facade, a climate-compatible design strategy was followed in the ICC. The energy performance is kept high by using the exterior curtain system controlled by automation as a shading component. Solar shading and wind sensors are used in the exterior curtain system. because the ICC is in a hot climate zone, the glass with a low U value was selected. As the lower SHGC value implies better solar control, the SHGC of the glass used on the facades is lower than 0,40 (0,34) to prevent overheating in the ICC (ICC's $D_x > 1,0$). The decisions taken for the choice of glazing used for the building envelope were given correctly. In the ICC's design strategy for climate and user satisfaction, atriums and windows with wide open areas for cross-flow ventilation were applied.

Due to the location, the ETOMB and BNAB, which are located in the mild climate zone, cannot make efficient use of the

Table 4. Envelope characteristics [42]

	ICC	ETOMB, BNAB	PEGCAB, EHH, TCAH
Fenestration system-optical and thermo physical properties of the building envelope			
Glazing type	Curtain wall	Aluminijski klizni prozor Aluminum sliding window Triple glazed curtain wall	Sun-controlled double glazing window, Semi-reflective triple glass, Transparent curtain wall
Thermo physical- optical values (U Value, W/m²K)	U = 1.30	ETOMB U = 1.60 BNAB U = 1.60	PEGCAB U = 1.60 EHH U = 1.80 TCAH U = 1.66
Solar heat gain coefficient (SHGC-g)	0.34	ETOMB 0.44 BNAB 0.12	PEGCAB 0.43 EHH 0.46 - TCAH 0.42
Visible transmittance V_t)	0.49	ETOMB 0.71 BNAB 0.20	PEGCAB 0.71 EHH 0.50 - TCAH 0.70
Coolness index ($D_x = V_t$/SHGC)	1.44	ETOMB 1.61 BNAB 1.66	PEGCAB 1.65 EHH 1.08-TCAH 1.66
Daylight strategy	Solar screening	Perforated metal sheet PV glass	Fixed louver, Solar control device, Metal mesh
Ventilation strategy	Single skin Operable windows	Double skin Operable windows	Single skin, Double skin Operable windows
Solar control system			
Najčešće su komponente toplinske udobnosti	25,5% Operable windows, 21,6% room air conditioning unit,20,6% Window blinds-shading components	24,1% Window blinds or shading components, 17,2% room air conditioning unit, 13,8% operable windows	24,5% Operable windows, 18,9% room air conditioning unit, 18,2% window blinds or shading components
Solar control strategy			
Facade control position	Northwest, Southwest, Southeast	Northwest, Southwest, Northeast	West, East, South, Northeast, Southeast, Southwest
Facade component (fixed or operable)	Operable	Fixed	Fixed
Direction type	Horizontal	Horizontal	Horizontal, Vertical
Percentage of transparent surface area (Transparency ratio)			
North	-	-	EHH 23 %
West	-	-	EHH 21 %
South	-	-	EHH 32 %
East	-	-	EHH 23 %
Northwest	ICC 63 %	ETOMB 30 %. BNAB 80 %	PEGCAB 63 %. TCAH 5 %
Southwest	ICC 90 %	ETOMB 70 %. BNAB 80 %	PEGCAB 80 %. TCAH 30 %
Southeast	ICC 60 %	ETOMB 90 % . BNAB 70 %	PEGCAB 61 %. TCAH 50 %
Northeast	ICC 0 %	ETOMB 70 %. BNAB 80 %	PEGCAB 23 %. TCAH 60 %

southeast facade, where the heating load is less. Owing to having double-layered glass facades, a climate-compatible design strategy was followed in the ETOMB and BNAB. The energy performance is kept high by using various fixed shading components. Because ETOMB and BNAB are in a mild zone, the glass with a low U value was selected. ETOMB's SHGC of the glass used on the facades is between 0,40 and 0,55 (0,44), which is appropriate for mild climates. However, BNAB's SHGC is lower than 0,40 (0,12). Meanwhile, owing to BNAB's low V_t value, BNAB is providing better D_x.

The Prokon-Ekon Group of Companies Administration Building (PEGCAB), Eser Holding Headquarters (EHH), and Turkish Contractors Association Headquarters (TCAH) are located in the continental climate zone. While TCAH has double-skin envelope, PEGCAB and EHH have single-skin envelopes. The energy performance is kept high by using various fixed shading components. According to the continental climate, heat should be kept out and used in building energy in summer. In addition, sunlight should be utilized as much indoors as possible in winter. Because their outside air temperature changes noticeably throughout the year, the glass with a low U value and a medium level of SHGC values was selected. PEGCAB-EHH-TCAH' SHGC of the glass used on the facades is between 0,40 and 0,55, which is appropriate for the continental climate. However, EHH has a lower V_t value than PEGCAB-TCAH. Therefore, PEGCAB and TCAH have better D_x. Although most of the facades of PEGCAB-EHH-TCAH have a high transparent surface ratio, their shading components are not enough to meet user satisfaction, the temperature, and RT levels.

3. Results of the survey

High-quality tests are performed to measure the reliability of study data. Developed by Lee Cronbach in 1951, Alpha is a frequently referenced test reliability index. It takes a value between 0 and 1, which is a function of the test length. As the test length increases, the reliability of the test increases independent of homogeneity [43]. The result of the reliability analysis indicates that Cronbach's Alpha value of the POE survey was 0,956. Cronbach's Alpha (a) reliability coefficient between 0,80 and 1,00 indicates that the scale is highly reliable. Regression analysis, which is used in many fields such as engineering and architecture, is applied to determine the relationships between various variables and to make predictions and policies [44]. It also is used to measure the relationships between two or more variables [45]. In the regression analysis, the resultant variable (thermal comfort satisfaction) is the dependent variable. To determine the reason for the changes in the dependent variable, a relationship is established with the independent variables (personal workplace location questions). From Table 5, the regression model established to test the effect of personal workplace location questions on thermal comfort satisfaction is statistically meaningful (0,045 and 0.039 < 0,05). The relationship hypotheses are supported due to the coefficient values being less than 0.05. The explanatory capacity of the four variables in the model is 39 % and 41 %.

3.1. Survey distribution rates

Six different LEED-NC-certified office buildings' users participated in the POE survey. All green office buildings involved in the survey are headquarter buildings. The total number of participants is 369 and the average participation percentage is 56 % (Table 6).

3.2. Personal workplace location distribution rates

The majority of the participants in the green office buildings work on the second floor (overall average 32,6 %). The ratios of workplace position in the green office buildings vary by direction (overall averages: north, 18,4 %; south, 26,09 %; east, 23,91 %; west, 31,16 %). The "yes" rates of the users' workplace near the outer wall obtain an average of 54,35 %. In addition, the "yes" rates of the users' workplace near the window show an average of 75,36 %. Detailed results are given in Appendix 7.

3.3. Comfort condition satisfaction rates

When the green building office users are examined within the context of the temperature and the RH in the workplace, post-occupancy satisfaction levels in terms of the temperature and RH in the workplace show a proportional graph. Detailed results are given in Appendix 7. From Table 7, the thermal

Table 5. Results of the regression analysis on thermal comfort and personal workplace location questions

Thermal comfort / Position of the workplace	How satisfied are you with the temperature in your workplace?			How satisfied are you with the relative humidity in your workplace?		
Personal workplace location Questions	Adjusted R square	ANOVA Regression significant	Coefficients	Adjusted R square	ANOVA Regression significant	Coefficients
Which floor do you work on?	0.39	0.045	0.030	0.41	0.039	0.006
Where is the location of your workplace in the building?			0.038			0.040
Is your workplace near the outer wall?			0.042			0.045
Is your workplace near the window?			0.033			0.037

Table 6. Six green office buildings' number of participants and participation percentages

	Number of participants	Participation percentage [%]
Izmir chamber of commerce (ICC)	68	70
Eurasia tunnel O&M building (ETOMB)	52	65
Bursagaz new administration building (BNAB)	53	45
Prokon-Ekon group of companies administration building (PEGCAB)	75	62
Eser holding headquarters (EHH)	65	48
Turkish contractors association headquarters (TCAH)	56	46

Table 7. Percentages of the thermal comfort components

Components of thermal comfort / Green office buildings	ICC [%]	BNAB, ETOMB [%]	PEGCAB, EHH, TCAH [%]	General usage rates [%]
Window blinds or shading components	20.6	24.1	18.2	19.2
Operable windows	25.5	13.8	24.5	24.0
Thermostat	7.8	13.8	10.9	10.4
Portable heater	2.0	0.0	2.6	2.3
Permanent heater	2.0	3.4	1.3	1.6
Room air conditioning unit	21.6	17.2	18.9	19.4
Portable fan	1.0	0.0	1.3	1.2
Ceiling fan	1.0	0.0	0.0	0.2
Adjustable ventilation on the wall or ceiling	7.8	3.4	5.0	5.5
Opened to the interior	6.9	10.3	12.9	11.3
Door to outside (garden terrace, etc.)	0.0	13.8	3.3	3.2
None	3.9	0.0	1.0	1.6

Table 8. Cross-tabulation results of personal workplace location and thermal comfort questions

Location of the workplace	ICC	ETOMB, BNAB	PEGCAB, EHH, TCAH
Which floor do you work on?	The working areas are between -3 and 5 floors. The majority of the participants work on the second floor (overall average 32,6%).		
Where is the location of your workplace in the building?	Max. south (30.2 %) At least north (14.0 %)	Max. west (42.9 %) At least east-south (14.3 %)	Maximum west (31.8 %) At least north (20.5%)
Is your workplace near the outer wall?	No rate high (55.8 %)	Yes rate high (85.7 %)	Yes rate high (56.8 %)
Is your workplace near the window?	Yes rate high (69.8 %)	Yes rate high (100.0 %)	Yes rate high (76.1 %)
How satisfied are you with the temperature in your workplace? How satisfied are you with the relative humidity in your workplace?	(+) 2nd floor (100.0 %) (+) East (62,45 %), West (70.75 %) (-) South (34,65 %), North (41.65 %) (+) not near the outer wal (66.65 %) (+) not near window (61.6 %)	(+) 2nd floor (100.0 %) (+) North, East (100.0 %) (-) West (33.3 %) (+) not near the outer wal (100.0 %)	(+) ground-1st floors (98.0 %) (+) South (91.0 %) (-) North (13.9 %) (+) being next to the outer wall (93.0 %) (+) being next to the window (94.75 %)
(+) most satisfied, (-) most dissatisfied			

comfort components commonly used by green office building users are window blinds or shading components (19,2 %), operable windows (24,0 %), and room air conditioning units (19,4 %).

3.4. Cross-tabulation analysis

From Table 8, the ICC's post-occupancy satisfaction levels in terms of the temperature and RH in the workplaces show that green office buildings' most unsatisfactory parts are the south (34,65 %) and the north (41,65 %). Although high-performance glass and operable shading components were used in the ICC, the user satisfaction level is low in the building's southern part because of the ICC's high transparent surface area percentage. If climate-based design decisions with a low transparency ratio are used in the southern part, green office building post-occupancy satisfaction levels in terms of the temperature and RH in the workplaces will increase. ETOMB-BNAB' post-occupancy satisfaction levels in terms of the temperature and RH in the workplaces show that green office buildings' most unsatisfactory part is the west (33,3 %). Although high-performance glazing and shading components were used in ETOMB's southwest and BNAB' southwest-northwest facades, the western parts have a low satisfaction level because of fixed horizontal shading components. Despite that solar control systems were used in the facades, user satisfaction was negatively affected because of the high transparency surface ratio in the southwest and northwest. Green office building post-occupancy satisfaction levels in terms of the temperature and RH in the workplaces will rise if operable shading components are preferred in the facades. The survey result indicates that the expected envelope performances of the selected green office buildings do not coincide during the post-occupancy period. The climate effect is prominent in the satisfaction differences of green building office employees in terms of the temperature and RH in working areas according to regions. For example, the number of sunny days throughout the year in the ICC is higher than that in the PEGCAB, EHH, and TCAH. This is reflected in the low satisfaction levels of temperature in the southern part of the ICC (34,65 %) and in the northern part of the PEGCAB-EHH-TCAH (13,9 %). The indoor satisfaction levels vary because of climatic differences between the regions. By positioning the windows and shading components, an increase in the temperature satisfaction rates can be achieved.

4. Conclusion

The POE offers a detailed methodology for analyzing LEED-NC office buildings located in Turkey. It is an effective method to determine the level of satisfaction of users and improve building performance. This study was based on a post-occupancy survey in the selected green office buildings, with questions that can detect the level of indoor climate satisfaction. To elaborate on the results of the post-occupancy satisfaction survey, the envelope features of green office buildings were examined under the energy and atmosphere parameter. The result of the survey and examination showed that the satisfaction rates of indoor climate comfort conditions and envelope feature decisions are important for the POE of building performance and user satisfaction. The opaque-transparent ratio and material selection in the facade design affected the satisfaction levels of green office buildings in the same and different climatic zones (Aegean-ICC, Marmara-ETOMB, BNAB, and Central Anatolia-PEGCAB, EHH, TCAH). Similar satisfaction levels are observed in green office buildings in the same climate zone. The envelope-glazing design and occupancy of green office building decisions should be made according to their climatic characteristics.
Per "personal workplace location questions" and "thermal comfort questions" cross-tables, it has been determined how indoor air temperature in green office buildings is perceived by the users. Obtained data from the questionnaire demonstrated that personal workplace location and indoor climate comfort should not be considered separately from each other.
The energy performance of the envelope in green office buildings is significant. The thermal performance of the envelope must be compatible with the climate as the internal heat gain of the office buildings is high even in temperate regions. When choosing a glazing type for the envelope, a low solar heat gain coefficient (SHGC) value should be preferred. The fact that the glazing visible transmittance (V_t) and coolness index (D_x) values and transparency ratio are suitable for the climate positively affects the total energy performance. In Turkey, green office facade design has gained importance for energy performance. In high-performance green office buildings, solar control is achieved not only by the choice of glazing type but also by solar control device systems. The shading components, in particular those operable ones, have a positive effect on user satisfaction and energy performance. However, building envelope and indoor air quality can provide significant energy savings in green office buildings. However, further POE studies are required to implement real-time monitoring of temperature and humidity automation systems. This study will be a guide to increasing the energy performance and user satisfaction of green office buildings in Turkey with the POE.

Acknowledgments

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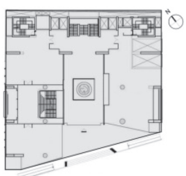
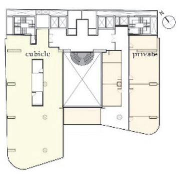
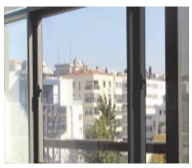
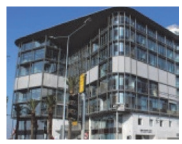
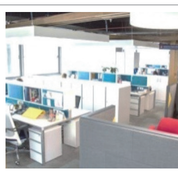
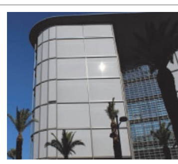
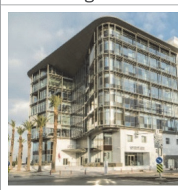
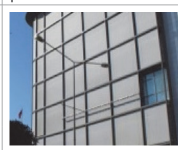
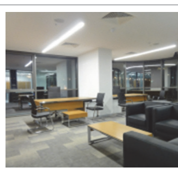
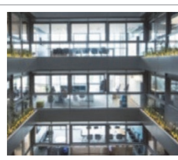
Appendixes

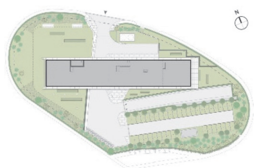
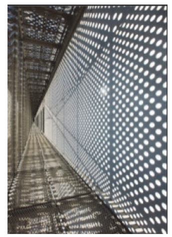
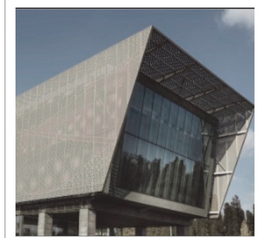
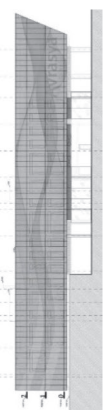
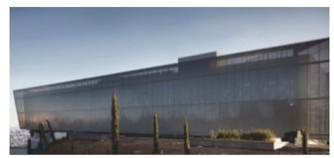
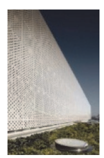
Appendix 1. Izmir Chamber of Commerce (ICC)

LEED Type: (v2009) BD+C:NC Gold
Certificate Import Date: April 2018
Sustainable Sites: 19/26 - Energy & Atmosphere: 22/35 - Material & Resources: 7/14 - Indoor Environmental Quality: 8/23 - LEED Total Credits: 70

Building shape	Office layout	Envelope-glazing design and green feature	Shading device position and type	Facade component	Energy efficient project, methods and measures
					***Facade material*** Green material Local-recycled materials, marble, sun-controlled glass Energy-efficient material Thermal insulated sliding doors, aluminum joinery, and sliding window systems in gallery
Square shape plan	Cubicle and private	Single skin facade	Northwest, solar screening	Fixed glass panel profile	***Energy***
					Automation system Exterior curtains integrated in building automation and are supported by wind sensors. Energy efficiency Photovoltaic (PV) panels Fabric solar curtain system controls the light and saves up to 70% in cooling costs.
Ground+7-storey	Cubicle	Curtain wall	Southwest, solar screening + eaves at roof level	Auto-exterior curtain system	***Indoor climate comfort***
*Northeast facade has no any shading device. Due to the sunny summer months and the direction of light arrival, shading devices were used the other facades.					Thermal comfort systems Controllable high thermal performance Daylight 75% of the available space can benefit from daylight with atrium.
	Private	Atrium	Southeast, solar screening	Exterior curtain system detail	Fresh air Intake above the rate specified by the ASHRAE standards

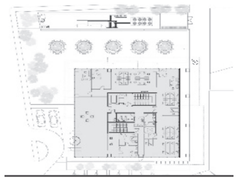
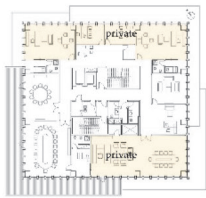
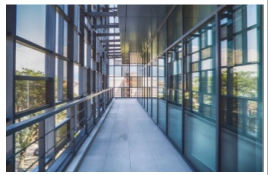
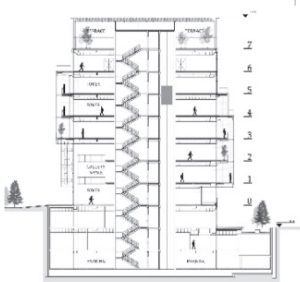
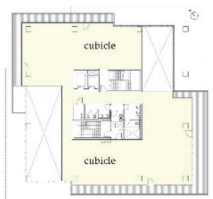
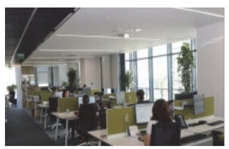
Appendix 2. Eurasia Tunnel O&M Building (ETOMB)

LEED Type: (v2009) BD+C:NC Gold
Certificate Import Date: July 2017
Sustainable Sites: 24/26 - Energy & Atmosphere: 13/35 - Material & Resources: 5/14 - Indoor Environmental Quality: 6/23 - LEED Total Credits: 64

Building shape	**Office layout**	**Envelope-glazing design and green feature**	**Shading device position and type**	**Facade component**	**Energy-efficient design, methods, and measures**
					***Facade material*** Green material Reused and recycled materials Energy-efficient material Perforated metal sheets provide solar protection.
Pravokutni tlocrt		Double skin facade	Southwest, fixed perforated metal sheet	Southeast, perforated metal sheets	***Energy***
					Automation system Mechanical equipment considering international standards Energy efficiency Providing efficient lighting
		Aluminum sliding window	Northeast, fixed perforated metal sheet	Northwest, perforated metal sheets	***Indoor climate comfort***
			Northeast, fixed perforated metal sheet *ETOMB's only southwest and northeast facades have fixed perforated metal sheet as shading device. *ETOMB's southwest and northeast facades are double skin; southeast and northwest facades are single skin.		Thermal comfort systems High thermal performance Daylight Perforated metal sheets provide
Ground+2-storey	Cubicle and private	Daylight chimney			Fresh air Intake above the international standards' fresh air

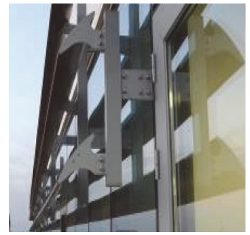
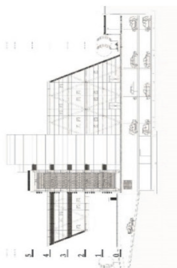
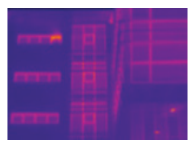
Appendix 3. Bursagaz New Administration Building (BNAB)

LEED Type: (v2009) BD+C:NC Platinum
Certificate Import Date: April 2017
Sustainable Sites: 25/26 - Energy & Atmosphere: 28/35 - Material & Resources: 4/14 - Indoor Environmental Quality: 7/23 - LEED Total Credits: 83

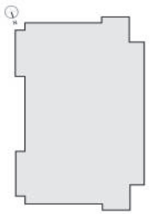
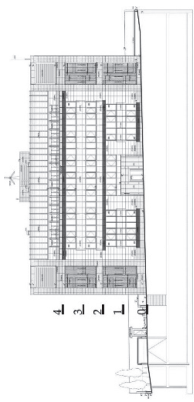
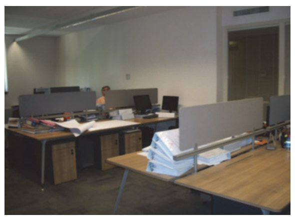
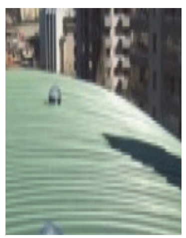
Building shape	Office layout	Envelope-glazing design and green feature	Shading device position and type	Facade component	Energy-efficient design, methods, and measures
				Features 315 amorphous silicon glass modules [500 mm x 700 mm (1.6 x 2.3 Ft)], 20% permeable thin film solar panels and painted glass	***Facade material*** Green material Local and recycled materials, international green building standards Energy-efficient material Insulation thicknesses and glass thermal conductivity above local regulations, according to ASHRAE 90.1-2007 criteria
Square shape plan	Private	Double skin facade	Northwest, photovoltaic (PV) glass in the form of a mosaic		***Energy***
				*BNAB's northwest, northeast, and southwest facades are double skin; southeast facade is single skin. *BNAB's southeast facade has no any shading device.	Automation system Motion and daylight sensors Energy efficiency Wind turbines and PV panels on the facade are designed to meet 3% of the building's energy needs.
	Cubicle	BIPV glazing system	Northeast, photovoltaic glass in the form of a mosaic		***Indoor climate comfort***
					Thermal comfort systems Shading components are created by calculating comfortable interior spaces with light control. Daylight Maximum daylight design for workplaces Illumination of areas that do not benefit from daylight enough with Parans Fresh air Fresh air quantity limit values given to each space at a minimum 30% above
Ground+7-storey	Cubicle	Parans solar lighting	Southwest, photovoltaic glass in the form of a mosaic		

Appendix 4. Prokon-Ekon Group of Companies Administration Building (PEGCAB)

LEED Type: (v2009) BD+C:NC Platinum
Certificate Import Date: February 2016
Sustainable Sites: 19/26 - Energy & Atmosphere: 31/35 - Material & Resources: 6/14 - Indoor Environmental Quality: 13/23 - LEED Total Credits: 89

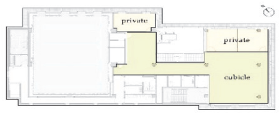
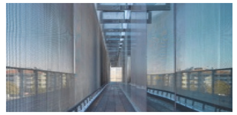
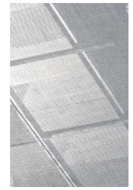
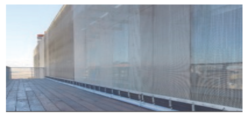
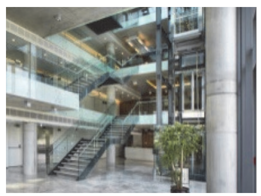
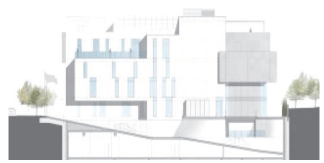
Building shape	Office layout	Envelope-glazing design and green feature	Shading device position and type	Facade component	Energy-efficient design, methods, and measures
					***Facade material*** Green material Sustainable and recyclable materials Energy-efficient material Recycled steel and wood materials
Rectangular shape plan	Private and cubicle	Single skin facade	Southwest, fixed louver	Aluminum curtain wall with horizontal cover	***Energy***
					Automation system Occupancy, daylight, and timing sensors Energy efficiency 10 cm insulation on walls Automation system that automatically activates and outputs the electrical-mechanical systems
	Private	Sun-controlled double glazing window	Southwest, fixed louver	Ceramic cladding	***Indoor climate comfort***
				* PEGCAB's all facades are single skin. * PEGCAB's only southwest facade has shading devices.	Thermal comfort systems Controllable temperature and lighting in office rooms Daylight High level of daylight usage ensures low electricity consumption Fresh air The designed ventilation system is above the required air quantity ratio by ASHRAE
Ground+5-storey	Cubicle	Daylight chimney	POE thermal imaging		

Appendix 5. Eser Holding Headquarters (EHH)

LEED Type: (v2009) BD+C:NC Platinum **Certificate Import Date: February 2011** **Sustainable Sites: 25/26 - Energy & Atmosphere: 24/35 - Material & Resources: 8/14 - Indoor Environmental Quality: 13/23 - LEED Total Credits: 92**					
Building shape	**Office layout**	**Envelope-glazing design and green feature**	**Shading device position and type**	**Facade com-ponent**	**Energy-efficient design, methods, and measures**
				Features Perforated culvert facade panels 80 millimeters of thermal insulation was applied on the walls.	***Facade material*** Green material 75% of the con-crete, 70% of the brick, 60% of the steel, 20% of the glass, and 65% of the insulation materials were obtained from renewable sources. Energy-efficient material Granite facade coating on opaque sur-faces Semi-reflective heat-insulating low-e glasses on transparent surfaces
Rectangular shape plan	Private and cubicle	Single skin facade	West, vertical solar control device	*EHH's all facades are single skin.	***Energy***
					Automation system Motion, daylight, and CO_2 sensors Energy efficiency Located pho-tovoltaic panels on the south façade With the insulation deci-sions taken in the building, heat losses have been reduced to a lower level.
	Cubicle	Semi-reflective triple glass	East, vertical solar control de-vice		***Indoor climate comfort***
				*EHH's north facade has no any shading device.	Thermal comfort systems Controllable temperature and lighting in office rooms Daylight Providing daylight to 78% of the spaces used continuously Fresh air 50 m^3/hour fresh air is provided per person. 30% more ventilation than the ASHRAE Standard
Ground+4-storey	Private	Daylight chimneys	South, photovoltaic panels		

Appendix 6. Turkish Contractors Association Headquarters (TCAH)

LEED Type: (v2009) BD+C:NC Platinum
Certificate Import Date: May 2014
Sustainable Sites: 22/26 - Energy & Atmosphere: 19/35 - Material & Resources: 8/14 - Indoor Environmental Quality: 13/15 - LEED Total Credits: 81

Building shape	Office layout	Envelope-glazing design and green feature	Shading device position and type	Facade component	Energy-efficient design, methods, and measures
					***Facade material*** Green material Local products and environmentally friendly construction materials Energy-efficient material Stainless steel metal mesh provides solar protection.
Rectangular shape plan	Cubicle and private	Double skin facade	Northeast, fixed stainless steel metal mesh	Stainless steel metal mesh	***Energy***
				*Northeast, southeast, and southwest facades' some parts have double skin façade; northwest facade is single skin facade.	Automation system Occupancy, motion, and daylight Energy efficiency With the envelope design, the heat gain from the sun is minimized, and the cooling energy requirement of the building is kept to a minimum.
	Cubicle	Transparent curtain wall	Southeast, fixed stainless steel metal mesh		***Indoor climate comfort***
				*Depending on the climate and the direction of the sun's rays, steel mesh of different transmittance values was used on TCAH's facades.	Thermal comfort systems Natural ventilation is provided by automatic dampers on the glass roof at the top of the courtyard by taking advantage of the chimney effect principle together with the central courtyard. Daylight Maximum daylight with atrium
Ground+4-storey	Private	Atrium	Southwest, fixed stainless steel metal mesh		Fresh air Intake above the international standards' fresh air

Appendix 7. Personal workplace location distribution rates and comfort condition satisfaction rates