ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A NEW APPROACH FOR POST-OCCUPANCY EVALUATION RELATED TO OCCUPANT AND ENVIRONMENT IN LIGHTING SYSTEM DESIGN

Ph.D. THESIS

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Department of Architecture

Construction Sciences Programme

SEPTEMBER 2019

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AYDINLATMA SİSTEMİ TASARIMINDA KULLANICI VE ÇEVREYE İLİŞKİNKULLANIM AŞAMASI DEĞERLENDİRMESİNE YÖNELİK YENİ BİR YAKLAŞIM

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To my family,

FOREWORD

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June 2019

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ABBREVIATIONS

ASHRAE : American Society of Heating, Refrigerating, and Air-Conditioning Engineers

ANOVA : Analysis of variance

BEM : Building energy modeling

BPE : Building performance evaluation

BUS : Building Use Studies

CBE : Center for the Built Environment

CCT : Correlated colour temperature

CFI : Comparative fit index

CIE : International Commission on Illumination

COPE : Cost-effective Open-Plan Environments

CRI : Colour rendering index

DALI : Digital addressable lighting interface

DGP : Daylight glare probability

EBC : Energy in Buildings and Communities Programme

ECBCS : Energy Conservation in Buildings and Community Systems

HOPE : European Health Optimization Protocol for Energy-Efficient Buildings

IEA : International Energy Agency

IEQ : Indoor environmental quality

ITU : Istanbul Technical University

IWC : Integrated workplace concept

LED : Light-emitting diode

LEED : Leadership in Energy and Environmental Design

LPD : Lighting power density

NCS : Natural Colour System

POE : Post-occupancy evaluation

RMSEA : Root mean square error of approximation

SEM : Structural equation modeling

SLL : Society of Light and Lighting

SHC : Solar Heating and Cooling
UGR : Unified Glare Rating
USB : Universal Serial Bus
VDU : Visual display unit
WODI : Work Environment Diagnosis Instrument
XML : eXtensible Markup Language

SYMBOLS

α	: Alfa
AL	: Artificial lighting
E_{ave}	:Average illuminance level
BG	: Between-groups
X^2	:Chi-square
C	: Chroma
R_a	:Color rendering index
DL	: Daylighting
°	: Degree
df	: Degree of freedom
e	: Error
$F_{critical}$	: Critical F score
$F_{obtained}$	: Obtained F ratio
H	: Hue
K	: Kelvin
Li	: Lighting system
L	: Lightness
E_{max}	:Maximum illuminance level
E_{min}	:Minimum illuminance level
min	: Minute
p	: Probability
R^2	: Coefficient of determination
N	: Sample size
pt	: Point
SD	: Student desk
U_o	: Uniformity
Wa	: Wall colour
W	: Watt
WB	: White board
WS	: Within-subjects

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A NEW APPROACH FOR POST-OCCUPANCY EVALUATION RELATED TO OCCUPANT AND ENVIRONMENT IN LIGHTING SYSTEM DESIGN

SUMMARY

Post-occupancy evaluation (POE)has significanceas it assesses building performance and user satisfaction in built environment. Failures, which are identified through POE procedure, can be removed through improvements. Illuminance level, lighting, daylighting and artificial lighting, glare, view-out, lighting control systems, brightness, distribution of light, colour, colour temperature, health, wellbeing and performance have been investigated in relation to lighting in the POE and indoor environmental quality (IEQ) studies. Modifications that are carried out in order to improve user comfort in built environment are called adaptive behaviour. Impact of adaptive behaviour on visual comfort has been mentioned in literature; however, the impact of adaptive behaviour in visual environment has not been widely investigated. The aim of this PhD research is to evaluate visual environment holistically through adaptive behaviour, psychology and satisfaction of user, quality of lighting and space. Underlining standardisation of POE evaluation in the field of lighting, this research intends to transfer this holistic evaluation into a robust and consistent POE approach to be used in future lighting evaluation processes.

The methodology of this thesis included literature review, pilot studies, experimental study and proposal of POE methodology for lighting. The review of literature determined current knowledge of visual comfort, lighting quality, lighting appraisal, interior design of workplaces, lighting in the workplace, occupant behaviour, adaptive behaviour and POE.

The pilot studies contained two field studies and one improvement study. The field studies evaluated visual environment in different building typologies with a standard approach. The standard approach contained an occupant questionnaire, in which there were two question sets as standard questions for all typologies and typology-based questions for the typology under evaluation. The POE methodology was consisted of observation, occupant questionnaire and field measurement. The first pilot study was carried out for educational spaces. The second pilot study was conducted in office spaces. The third pilot study recommended various interventions in order to improve visual environment in the educational spaces following the POE and assessed their impact on the performance of daylighting system and artificial lighting system.

The experimental study integrated adaptive behaviour into evaluation of lighting, space and user in office function. The adaptive behaviour parameters were determined as furniture position and orientation, field of view, colour of internal surfaces and lighting system. An existing model identifying the relations between lighting appraisal, room appearance, pleasure and workplace satisfaction was utilized and adaptive behaviour parameters were integrated into this model. The experiments

were organized as between-groups and within-subjects tests. In the between-groups tests, different artificial lighting systems and wall colours were tested as the independent variables. In the within-subjects tests, different occupant positions and orientations were tested. The dependant variables were furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity. The results were statistically analysed. The illuminance level measurements were carried out on the horizontal workplane across the test room and the vertical workplanes on the wall surfaces. The 'Integrated POE in Lighting'methodology was proposed for evaluation in relation to lighting. The integration of adaptive behaviourinto assessment of user psychology, satisfaction, quality of light and space were transferred into an evaluation approach. The content of this methodology was defined and improvement flowcharts were prepared.

As results, the first two pilot studiesdemonstrated the significance of evaluating visual environment using standard and typology-based measures. Standard measures were evaluated similarly in two typologies. In education spaces, illuminance levels and reflections on desks and boards were investigated and learning performance was assessed. In office spaces, illuminance levels and reflections on desks and visual display units (VDUs) were investigated together with evaluating job performance. In pilot study-3, it was seen that different improvement recommendations affected daylighting and artificial lighting systems diversely. In the experimental study, the statistical analyses showed the most significant bivariate correlations (at the 0.01 level) containing the adaptive behaviour parameters. The model showed the statistically significant paths between the variables, which were were furniture position and orientation-field of view, lighting system-lighting appraisal, lighting appraisal-room appearance, room appearance-pleasure and lighting appraisal-workplace satisfaction (at the 0.001 level). The means of the dependant variables were compared for different lighting systems and wall colours. It was observed that the means of the dependent variables increased or decreased, some of which were statistically significant. In the illuminance level measurements; different illuminance levels were observed between different wall colours, in which the differences were higher on some walls. In the within-subjects tests, the ratings of the dependent variables increased, remained the same or decreased when occupant position and/or orientation changed. The illuminance levels in the field of views either increased or decreased. The majority of the illuminance levels declined.The participantsevaluated the dependent variables with higher, same or lower ratings when they observed a lower or higher average illuminance level. The 'Integrated POE in Lighting'methodology is a four-staged process. Each stage and their steps were explained. As part of the third stage, improvements were recommended through the improvement flowcharts between the variables. Using the improvement flowcharts, significant paths between the variables could be strengthened and failures in building could be improved.

In conclusion, post-occupancy evaluation assesses building performance and user satisfaction. Integrating typological requirements, adaptive behaviour, occupant experience, acceptance and preference into the evaluation procedure would result in more realistic and robust findings. Improvements thatare recommended based on these findings can enhance visual environment and the built environment through the assessment of other indoor environmental quality parameters.

AYDINLATMA SİSTEMİ TASARIMINDA KULLANICI VE ÇEVREYE İLİŞKİN KULLANIM AŞAMASI DEĞERLENDİRMESİNE YÖNELİK YENİ BİR YAKLAŞIM

ÖZET

Kullanım aşaması değerlendirmesinin, yapılı çevredebina performansını ve kullanıcı memnuniyetini değerlendirmek amacıyla kullanılan önemli bir yöntem olduğu bilinmektedir. Kullanım aşaması değerlendirme prosedürü ile tespit edilen sorunlar, iyileştirmeler ile giderilebilmektedir. Kullanım aşaması değerlendirme ve iç çevre kalitesi çalışmalarında aydınlık düzeyi, aydınlatma, doğalaydınlatma, yapma aydınlatma, kamaşma, dış görüş, aydınlatma kontrol sistemleri, parıltı, ışık dağılımı, renk, renk sıcaklığı, sağlık, esenlik ve performans konularınınincelendiği görülmüştür. Yapılı çevrede kullanıcı konforunu arttırmak amacıyla yapılan değişiklikler olarak adlandırılan adaptif davranışların görsel konfor üzerindeki etkisi literatürde belirtilmiştir.Fakat, adaptif davranışların görsel çevredeki etkisi geniş bir kapsamdaincelenmemiştir. Bu doktora çalışmasının temel amacı; görsel çevreyi adaptif davranış, kullanıcı psikolojisi ve memnuniyeti, aydınlatma ve mekan kalitesi ile bütüncül olarak değerlendirmektir. Kullanım aşaması değerlendirmesindestandartlaşmanınönemini vurgulayan bu araştırma,aydınlatma sistemi tasarımında kullanılması amacıyla bütüncül değerlendirmeyi sağlam ve tutarlı bir yaklaşıma aktarmayı amaçlamaktadır.

Tez kapsamında literatür taraması, pilot çalışmalar ile deneysel çalışma yürütülmüş ve aydınlatma alanındakullanım aşaması değerlendirmeyöntemiönerilmiştir. Literatür taramasında; görsel konfor, aydınlatma niteliği, aydınlatma değerlendirmesi, çalışma mekanlarının iç mimarisi, çalışma mekanlarında aydınlatma, kullanıcı davranışı, adaptif davranış ve kullanım aşaması değerlendirmesi ile ilgili güncel bilgiler değerlendirilmiştir.

Pilot çalışmalar kapsamında iki saha çalışması ve bir iyileştirme önerileri çalışması gerçekleştirilmiştir. Saha çalışmaları görsel çevreyifarklı yapı tipolojilerinde standart bir yaklaşımla değerlendirmiştir. Standart yaklaşım, tüm tipolojileri içeren standart sorular ve değerlendirilmekte olan tipolojiyi içeren tipoloji-bazlı sorular olmak üzere iki soru setinin yer aldığı bir anketi içermektedir. Kullanım aşaması değerlendirme yöntemi; gözlem, kullanıcı anketi ve saha ölçümünden oluşmuştur. Birinci pilot çalışma eğitim mekanlarında, ikinci pilot çalışma ofis mekanlarındadüzenlenmiştir. Üçüncü pilot çalışmada,eğitim alanlarında gerçekleştirilen kullanım aşaması değerlendirme çalışmasının ardından görsel çevreyi iyileştirmek amacıyla çeşitli öneriler yapılmıştır. Yapılan önerilerindoğal ileyapma aydınlatma sistemlerinin performansları üzerindeki etkileri değerlendirilmiştir.

Deneysel çalışma kapsamında;ofis fonksiyonunda aydınlatma, mekan ve kullanıcı değerlendirmesine adaptif davranışentegre edilmiştir. Adaptif davranış parametreleri;

mobilya konumu ve yönü, görüş alanı, iç yüzeylerin rengi ve aydınlatma sistemi olarak belirlenmiştir. Aydınlatma değerlendirmesi, hacimgörünüşü, memnuniyet ve çalışma yeri memnuniyeti arasındaki ilişkileri tanımlayan mevcut bir model kullanılmış veadaptif davranış parametreleri bu modele entegre edilmiştir. Deneyler, gruplar-arası ve denekler-içi testler olarak düzenlenmiştir. Gruplar-arası testlerde, farklı yapma aydınlatma sistemleri ve duvar renkleri bağımsız değişkenler test edilmiştir. Yapma aydınlatma sistemleri olarak, literatürde tartışılan aydınlık düzeyi ve benzer renk sıcaklığı ilişkisi kullanılmıştır. Vaka 1 olarak 500 lux ve 3000 K, Vaka 2 olarak 300 lux ve 6500 K incelenmiştir. Duvar renkleri olarak, ışık yansıtma katsayısı 0.72 olan bej (L90 C20 H55) ve ışık yansıtma katsayısı 0.74 olan mavi (L90 C10 H230) değerlendirilmiştir.Denekler-içi testlerde farklı kullanıcı pozisyonları ve yönleri test edilmiştir. Kullanıcı pozisyonları, hacmin yatay olarak ikiye bölünmesi ile Bölge 1 ve Bölge 2 olarak belirlenmiştir. Kullanıcı yönleri; 0°, 45° ve 90° olarak belirlenmiştir.Bağımlı değişkenler; kullanıcı pozisyonu ve yönü, görüş alanı, iç yüzeylerin rengi, aydınlatma sistemi, aydınlatma değerlendirmesi, hacim görünüşü, memnuniyet, çevresel memnuniyet ve kendi değerlendirdiği verimlilik idi.Sonuçlar istatistiksel olarak analiz edilmiştir.

Aydınlatma alanında değerlendirme çalışmalarında kullanmak amacıyla ‘Aydınlatmada Entegre Kullanım Aşaması Değerlendirme’yöntemi önerilmiştir. Önerilen yaklaşım ile adaptif davranış; kullanıcı psikolojisi ve memnuniyeti, ışık ve mekan kalitesi değerlendirmesineentegre edilmiştir. Değerlendirme yönteminiçeriği tanımlanmış ve iyileştirme akış diyagramlarıhazırlanmıştır.

Tezin sonuçları olarak, pilot çalışma-1 ve pilot çalışma-2 görsel çevreyistandart ve tipoloji-bazlı ölçütler kullanarak değerlendirmenin önemini göstermiştir. Standart ölçütler iki tipolojide benzer şekilde değerlendirilmiştir. Eğitim mekanlarında, masa ve tahta üzeri aydınlık düzeyleri ile yansımalar incelenmiş ve öğrenme performansı değerlendirilmiştir. Ofis mekanlarında ise, masa ve bilgisayar ekranları üzerindeki aydınlık seviyeleri ve yansımalar, iş performansının değerlendirilmesiyle birlikte incelenmiştir. Pilot çalışma-3’te, farklı iyileştirme önerilerinin doğal ve yapma aydınlatma sistemlerini farklı şekilde etkilediği görülmüştür. Deneysel çalışmada, istatistiksel analizler adaptif davranış parametrelerini içeren en önemli iki değişkenli korelasyonları (0.01 düzeyinde) göstermiştir.En önemli korelasyonlardan birinin mobilya pozisyonu ile yönü ve görüş alanı arasında olduğu görülmüştür. İç yüzeylerin rengi;memnuniyet, çevresel memnuniyet ve kendi değerlendirdiğiverimlilik ile önemli ölçüde ilişkilidir. Aydınlatma sistemi; aydınlatma değerlendirmesi, hacim görünüşü, çevresel memnuniyet ve kendi değerlendirdiğiverimlilik ile önemli ölçüde ilişkilidir. Aydınlatma değerlendirmesiilehacim görünüşü, memnuniyet, çevresel memnuniyet ve kendi değerlendirdiği verimlilik arasındaki korelasyonların önemli olduğu gözlenmiştir. Hacim görünüşü; memnuniyet, çevresel memnuniyet ve kendi değerlendirdiğiverimlilik ile önemli ölçüde ilişkilidir. Memnuniyet, çevresel memnuniyet ve kendi değerlendirdiğiverimlilik ile önemli ölçüde ilişkilidir. Çevresel memnuniyet ve kendi değerlendirdiğiverimlilik arasındaki korelasyon da önemli olarak gözlenmiştir. Model; mobilya konumu ve yönü-görüş alanı, aydınlatma sistemi-aydınlatma değerlendirmesi, aydınlatma değerlendirmesi-hacim görünüşü, hacim görünüşü-memnuniyet ve aydınlatma değerlendirmesi-çalışma yeri memnuniyeti değişkenleri arasında istatistiksel olarak önemli yollar göstermiştir (0.001 düzeyinde). Bağımlı değişkenlerin ortalamalarındaki farklılıklar, farklı aydınlatma sistemleri ve duvar renkleri için karşılaştırılmıştır. Bağımlı değişkenlerin ortalamalarının bazılarında istatistiksel olarak anlamlı olarak artış ya da azalış görülmüştür. Aydınlık düzeyi ölçümlerinde; farklı duvar renklerinin farklı aydınlık seviyelerine yol açtığı gözlemlenmiştir. Bazı duvarlarda farkların daha yüksek olduğu görülmüştür. Denekler-içi testlerde, kullanıcı pozisyonu ve/veya yönü değiştiği zaman bağımlı değişkenlerin puanları yükselmiş, aynı kalmış veya düşmüştür. Görüş alanındaki aydınlık düzeyleri artmış ya da azalmıştır.Aydınlık düzeylerinin çoğunluğu azalmıştır. Katılımcılar; görüş alanında daha düşük veya daha yüksek bir ortalama aydınlık düzeyi mevcut iken bağımlı değişkenleri daha yüksek, aynı veya daha düşük değerlendirmişlerdir.Önerilen ‘Aydınlatmada Entegre Kullanım Aşaması Değerlendirme’ yöntemi dört aşamalı bir süreçtir. Her aşama ve adımları açıklanmıştır. Üçüncü aşamanın bir parçası olarak, iyileştirme akış diyagramları aracılığıyla değişkenler arasında iyileştirmeler önerilmiştir. İyileştirme akış diyagramları kullanılarak, değişkenler arasındaki önemli yollar güçlendirilebilmekte ve binada mevcut bulunan sorunlu konulariyileştirilebilmektedir.

Sonuç olarak, kullanım aşaması değerlendirmesi bina performansını ve kullanıcı memnuniyetini değerlendirmektedir. Değerlendirme sonuçlarının tutarlılığını ve değerlendirmeye dayalı olarak geliştirilen iyileştirmelerin etkisini sağlam bir yöntem ile güçlendirmek mümkündür. Tipolojik gereklilikleri değerlendirme prosedürüne entegre etmek daha gerçekçi ve sağlam sonuçlar sağlayacaktır.Bunun nedeni;kullanıcı ile ilgili parametrelerin, iş özelliklerinin, mekansal düzen ve aydınlatma gereksinimlerinin bina tipolojisine bağlı olarak değişmesidir.Tez çalışması,pilot kullanım aşaması değerlendirmesi çalışmaları ile standart soruları ve tipoloji-bazlı soruları içeren tutarlı bir değerlendirme yaklaşımı belirlemiştir. Görsel çevrede tipolojik gereksinimler değerlendirilmiştir. Değerlendirmeye dayanılarak, doğal ve yapma aydınlatma sistemlerinin performansını iyileştirmeye yönelik öneriler yapılmıştır. Araştırmada,adaptif davranışgörsel çevrenin değerlendirilmesine entegre edilmiştir. Bu değerlendirme; kullanıcı psikolojisi ve memnuniyetinin, çevresel memnuniyetin, verimliliğin, aydınlatma kalitesinin ve mekan algısının değerlendirmesiyle birleştirilmiştir. Böylelikle görsel çevrenin değerlendirilmesine ilişkin bütüncül bir bakış açısı elde edilmiştir. Mobilya konumu ve yönü, görüş alanı, iç yüzey renkleri ve aydınlatma sistemi kullanıcı değerlendirmesini etkilemiştir.Bu nedenle; görsel çevrenin değerlendirilmesinde kullanıcı deneyimi, kabulü ve tercihi dikkate alınmalıdır. Adaptif davranışı, kullanıcıların deneyimini, kabulünü ve tercihini standartlara ve yönetmeliklere dahil etmek, yapılı çevrede tasarım kararlarının verilmesine değerli bir katkı oluşturabilir. Değerlendirme sonuçlarına dayanılarakönerilecek iyileştirmeler, görsel çevreyi ve diğer iç çevre kalitesi parametrelerinin değerlendirilmesi yoluyla da yapılı çevreyi geliştirebilir.

1. INTRODUCTION

The introduction defines the thesis's aim, background knowledge and research methodology.

1.1 Aim and Significance of Thesis

The relation between light, space and user is multifaceted. Evaluation of visual environment can be achieved holistically when the quantitative measures and qualitative attributes are evaluated as a whole within the spatial context of the user. The quantitative aspects of the visual environment can be predicted through the guidance of the lighting metrics. On the contrary, the qualitative aspects have been less included in the lighting regulations, research and building evaluations.

In addition to new buildings, assessment of existing buildings is significant as well. It is noteworthy to underline post-occupancy evaluation (POE) methodology as it probes how an indoor environment performs and how satisfied the users are when occupying a building. The evaluation of lighting has been often integrated into the studies appraising the indoor environmental quality (IEQ) and POE of building circumstances. Forming a distinct evaluation procedure on lighting can supply the practical base required for combining the quantitative and qualitative assessments of the visual environments in the existing buildings.

Adaptive behaviour has been underlined in literature as containing significant actions of occupants in order to enhance their comfort. While most research on adaptive behaviour focused on thermal comfort, a few studies highlighted how adaptive behaviour had a positive impact on visual comfort (Keyvanfar et al., 2014; O'Brien and Gunay, 2014).

The PhD research's aim is to evaluate visual environment holistically considering adaptive behaviour, satisfaction and psychology of user together with quality of lighting and space. Through the proposed holistic POE methodology, research intends to assess light, space and user through guidance of the qualitative and quantitative assessments of the visual environment. Determining the positive and negative aspects of the lighting-related measures on space and user is informative in order to carry out the related improvements in the visual environment.

1.2 Background and Problem

This section attempts to summarize the literature review of this thesis and identify the problems, which guided the hypotheses and research questions of the thesis. Veitch and Newsham (1998) revealed that lighting system provided needs related to "*visibility, task performance, social interaction, mood, safety and health and aesthetics*" (p.100). This multi-faceted context affects lighting quality.

Illuminance level is one of the quantitative aspects of lighting. Veitch and Newsham (1996) mentioned that various levels were observed for visual tasks in various researches. In the study of Manav (2007), the illuminance level of 2000 lux was preferred when compared to the illuminance level of 500 lux for the evaluation of comfort, spaciousness, brightness and saturation. As differing from this preference of a higher illuminance level, Fotios (2011) underlined the decrease in illuminance levels without having negative impact on spatial brightness. As for colour, correlated colour temperature (CCT) and illuminance had impact on appraisal of interior space in the experimental study of Manav et al. (2009).

Considering health and wellbeing, Boyce et al. evaluated how lighting quality affected health, well-being and visual performance in office as an experimental study. The authors found out that type of lighting system and availability of manual control had positive impact on occupant satisfaction (Boyce et al., 2006). As called '*the appraisal*' in the research of Veitch et al; when satisfaction of occupants from lighting increased, they assessed the office space as more attractive besides the increase in their happiness, comfort, environmental satisfaction and performance satisfaction (Veitch et al., 2008).

Occupant behaviour is a significant research topic. Occupant behaviour was defined as the influence between occupants and building systems for modifying indoor environment conditions for comfort. In terms of lighting, lighting systems and solar shading were classified as occupant behaviour, which affected energy consumption (Delzendeh et al., 2017). Adaptive behaviour was studied as being related to occupant behaviour and comfort. In their research Keyvanfar et al. (2014) highlighted user satisfaction as a result of adaptive behaviour. The validation study of the authors contained adaptive behaviour items for daylighting and electric lighting systems.

Evaluating buildings is significant to assess how they perform. Leaman et al. (2010) stated that building evaluation should carry out the investigation of performance as for at least three aspects: occupants and providing their requirements; environmental performance related to efficient use of water and energy; economical aspects as for payback following investment. POE methodology is based on assessing satisfaction of occupants regarding the built environment they occupy and building performance. Literature indicated that the evaluation findings could be used to provide feedback to the building under evaluation and the buildings that would be designed in the future (Mallory-Hill et al., 2012).

The criteria defining performance of lighting systems and visual comfort of occupants, which have been assessed in POE and IEQ studies, are wide-ranging. Through the literature review, it was found out that these criteria were lighting, illuminance level, daylighting and artificial lighting, glare, view-out, lighting control systems, brightness, distribution of light, colour, colour temperature, health, well-being and performance. Although all of the evaluation criteria had significance regarding visual environment and visual comfort; lighting, illuminance level, daylighting and artificial lighting systems, glare and lighting control systems were employed frequently.

The abovementioned background reflections have guided this research to a holistic extent. Lighting system should provide glare-free work environments together with achieving lighting quality and user satisfaction. Adaptive behaviour helps occupants to enhance visual comfort and satisfaction from the lighting conditions. However, published research mostly assessedimpact of adaptive behaviour on thermal comfort. Besides, it was indicated that furniture layout and occupant orientation were not considered in occupant behaviour models (O'Brien and Gunay, 2014). That is why, a holistic POE methodology is proposed in order to assess visual environment discretely considering adaptive behaviour. This holistic methodology evaluates parameters related to user, space and lighting.

1.3 Methodology of Thesis

The methodology of the thesis contained a literature review, three pilot studies, an experimental study and a proposal of POE methodology in the field of lighting:

- **Literature review:** In the thesis, current knowledge of visual environment, lighting quality, occupant behaviour and POE was reviewed.
- **Pilot studies:** Following the literature review, the first two pilot studies aimed at developing an approach for evaluating different building typologies. The POE studies were conducted in educational and office spaces in Istanbul Technical University. The standard approach contained the proposal of an occupant questionnaire, which was consisted of the two question sets as the standard questions for all typologies and the typology-based questions for typology under evaluation. The pilot studies provided experience on developing occupant questionnaire and carrying out POE study in real buildings. The POE procedure contained observation, occupant questionnaire and field measurement studies. The third pilot study assessed the impact of various interventions on visual environment in the educational spaces following the POE study.
- **Experimental study:** After the pilot studies, an experimental study was conducted in a test room in the lighting laboratory at Istanbul Kultur University with an office function. The experimental study aimed to integrate adaptive behaviour of users into evaluation of user satisfaction, lighting and spatial quality. Structural equation modeling (SEM) method evaluated links of variables. Descriptive statistics and analysis of variance (ANOVA) tests were carried out as well.
- **Proposal of a POE methodology in the field of lighting:** Following theintegration of adaptive behaviour into evaluation of lighting and spatial quality, user psychology and satisfaction through proposing a SEM model, the ‘Integrated POE in Lighting’methodology was proposed as an evaluation procedure for future use. The ‘Integrated POE in Lighting’methodology is a four-staged process, which utilizes the proposed SEM model for building evaluation. This methodology offers improvements based on the analysis of the relationships in the SEM. The improvements are offered through the improvement flowcharts prepared in this thesis.

2. LITERATURE REVIEW

The literature review was provided under the subtitles as visual comfort and lighting quality, lighting appraisal of occupant, interior design of workplaces, lighting in workplace, occupant behaviour, adaptive behaviour and post-occupancy evaluation (POE).

2.1 Visual Comfort and Lighting Quality

In a luminous environment, it is essential to provide visual comfort of occupants. Due to its vitality, the visual comfort conditions are one of the criteria that determine the lighting requirements of a space for a given function. The other criteria for the lighting requirements are given as wellbeing, visual performance and safety of occupants by the EN12464-1 standard. The design of a lighting system, which aim to provide the visual comfort, visual performance and safety conditions of occupants together with their wellbeing, form luminous environment of this space in built environment. The main parameters, which form a luminous environment, are luminance distribution, illuminance, directionality of light, variability of light, colour rendering of the light, colour appearance of the light, glare and flicker (EN12464-1, 2011).

The luminance distribution is a noteworthy parameter as it has impact on eye's adaptation and task visibility considering luminance in the field of view. The EN12464-1 standard (2011) highlights that luminance distribution in the field of view is also related to visual comfort. Thus; too high luminances should be avoided as they can cause glare, too high luminance contrasts should be prevented as fatigue can occur. Low luminance valuesand contrasts should be avoided due to their negative impact on the attractiveness of the space. Assessing the luminance distribution in a room requires the consideration of the all surfaces' luminances. It is indicated that the luminances are determined based on the reflectance and illuminance on the surfaces.

As another parameter of the visual environment, illuminance level is one of the quantitative measuresin relation to lighting. Veitch and Newsham (1996) underlined the wide range of levels observed when performing visual tasks in various researches. The authors indicated that the adaptation capability provided the users to perform in a good way under changing illuminance levels. In the experimental study in a test office, Manav (2007) mentioned that the illuminance level of 2000 lux was preferred when compared to the illuminance level of 500 lux for the evaluation of comfort, spaciousness, brightness and saturation. Fotios (2011) indicated a decrease in illuminance levels without having negative impact on spatial brightness in office spaces. Referencing the research of Akashi and Boyce (2006) in offices, Fotios highlighted the 33% decrease in illuminance levels through the guidance of light sources with higher correlated colour temperature (CCT) and higher colour rendering index (CRI). This would provide a decrease in energy consumption without affecting visual performance and brightness of visual environment negatively. This is due to the fact that lighting would appear brighter when compared to the light sources with lower CCT and lower CRI (Fotios, 2001). When maintaining brightness perception with lower illuminance levels, it was emphasized that the cold appearance of higher CCT lamps could be evaluated "*unpleasant*", thus a CCT of 5000 K would be risk-free when compared to a CCT of 6500 K (Akashi and Boyce, 2006; p. 599).

Colour is the other noteworthy medium in human visual perception. Küller et al. (2006) assessed how colour affected occupants' mood at real workplaces in four different countries. The assessment of the interior design was carried out through a scale between monotonous and vivid colours. The colourful interior design affected the mood of the occupants positively. However; as this evaluation was based on a low rate of experience (5%) in the overall research, the authors recommended benefiting from bright colours together with preventing highly saturated colours in interior spaces in order to enhance the mood. In their experimental study, Manav et al. (2009) assessed the appraisal of a test office under various lighting scenarios containing the illuminance levels of 300lux, 500lux and 750lux; the CCTs of 3000 K, 4000 K and 6500 K and the wall colours of light blue, dark blue, light salmon and dark salmon. The survey responses of the occupants showed that CCT and illuminance were affective for the appraisal of the interior space. For example, the same wall colour received different evaluations under different illuminance levels and CCTs. In the earlier experimental study by the first author of the above research, different CCTs stimulated different user evaluations; i.e. the CCT of 4000 K was favoured evaluating comfort and spaciousness and the CCT of 2700 K was favoured evaluating relaxation and saturation (Manav, 2007).

Visual comfort and quality of lighting can not be considered as being distinct from each other. Luminous environment is created by the lighting system design and it reveals the lighting quality. The luminous conditions as illuminance, luminance, uniformity, luminance distribution, spectral power distribution and flicker rate support the good lighting quality (Veitch and Newsham, 1998). Among the comments for this reference, Boyce and Cuttle suggested that differentiating the "*detail, color, form, texture, and surface finishes*" together with providing visual comfort conditions bring the lighting quality (p. 104). The EN12464-1 standard (2011) articulated that the requirements mentioned in the standard were related to the quantity and quality of lighting with additional indications resulting in good lighting practice. The standard indicated that additional quantitative and qualitative requirements should be met besides the illuminance requirements. This indication evidences that both quantitative meausres and qualitative attributes in relation to lighting should be considered as part of the design of the luminous environment. However; Lam argued that the qualitative aspects have been less included in the lighting regulations and research (Lam, 1977). That is why, it is significant to evaluate and assess a luminous environment and performance of a lighting system considering the qualitative and quantitative aspects of light starting from the early design process.

As affected by lighting system, ighting quality is a result of how the requirements of the lighting system have been met. The Society of Light and Lighting (SLL) Code for Lighting classifies quality of light into three groups:

- Under the bad quality lighting, it is not possible to see quickly and effortlessly besides the possibility of visual discomfort.
- The indifferent quality provides the conditions for seeing quickly and effortlessly without visual discomfort; however, it doesn't attract the occupants.

- When a lighting system provides good quality lighting, the visual activities can be carried out quickly and effortlessly without visual discomfort and the occupants are attracted by the luminous environment (SLL, 2012).

The relation between lighting and architecture is essential to evaluate when considering the quality of light. Tregenza and Wilson (2011) indicated that architectural design is about creating places and design decision-making on brightness and colour affects the design of place. The authors stated that how lighting systems and materials were designed in an architectural space determined quality of that space as being its essence.

2.2 Lighting Appraisal of Occupant

The assessment of how occupants perceive lighting quality and how lighting appraisal affects perception of space, user satisfaction and mood were widely studied. Most of these studies were conducted using experimental methodologies. The experimental studies are noteworthy as they can form the basis of field studies. As for the integration of experimental and field studies, Collins et al. (1990) advised conducting controlled experimental studies followed with POE as field studies for verification.

Following their publications in the second half of 1990s, Knez and Kers (2000) assessed how lighting conditions, age and gender affected mood and cognitive performance of users. In their experimental study, the between-subjects independent variables were type of lamp, age and gender. In terms of the brightness of the room, the age of the participants affected their evaluation. While the younger participants evaluated the room as brighter, the older participants found it as less bright. As for mood, only the positive mood was maintained better by older males than older females. Both positive and negative moods were maintained greater by younger females than younger males. In terms of the cognitive performance, the younger participants performed better than the older participants notably.

As the first publication of a larger and significant research project, Newsham et al. (2003) assessedeffect of four lighting systems and individual control on mood, satisfaction and discomfort. As an experimental study in a mock-up office space, the individual control enhanced mood, satisfaction and decreased discomfort of occupants. As another noteworthy research, Boyce et al. (2006) evaluated relation between lighting quality and health, wellbeing and visual performance in an office environment through experimental research and linked mechanism map. While there was not any direct impact of lighting on health and performance, observation of longer impact has been recommended as "*participants discriminated between the lighting conditions*" (p. 216). This research showed suspended direct / indirect lighting system and individual control opportunity of users had positive contribution on the user satisfaction. Time, surface reflectance and task features were identified as being in relation to lighting design. Field studies in real environments through long-term research have been advised to perceivehow lighting quality affected organizational productivity.

Following the research of Boyce et al. (2006), Veitch et al. (2008) extended linked mechanism map, which was created in the previously mentioned research. Generated the final linked mechanism map in their study, the authors expressed the significant relation between the lighting design and user evaluation called as '*the appraisal path*'. As the satisfaction of users related to lighting increased, they assessed the office space as more attractive besides the increase in their happiness, comfort, environmental satisfaction and performance satisfaction. In case the visual conditions related to the task became harder, a decline occurred in the task performance. This research was indicated as an initial attempt to create the entire path between lighting and health and wellbeing, underlining the fact that "*better quality lighting can support organisational productivity*" (p. 146). The authors added that long-term studies in field can provide the impact of lighting quality in the organizational level. Boyce (2014) recommended long-term field studies to test this model and "*quantify the strength of the links established*" (p. 597). Veitch et al. (2008) recommended a holistic framework for the assessment of lighting quality in these studies; which embraces the occupants, the architectural space and the external aspects such as energy and environment. This research emphasized enhancing task visibility, pleasing assessment of lighting quality and addressing illuminance, glare prevention and space appearance. The guidance underlined direct/indirect lighting systems with control opportunity for the direct system.

'*The Cost-effective Open-Plan Environments (COPE)*' research by Veitch et al. (2007) supported its two hypotheses, one of which included satisfaction with lighting as one of the determinants of environmental satisfaction. The other hypothesis indicated that environmental satisfaction affected job satisfaction. Newsham et al. (2009) built on the COPE research and defined that pleasure with management and employment compensation moderatedlink between overall environmental satisfaction and job satisfaction. The authors suggested that "*the quality of the physical environment*" that building management provided (pp. 141) and "*how employees feel valued*" through organization (pp. 142) affected the user evaluation of the management. This is highly notable as how building management acts and maintenance is processed can affect POE outcomes. In this open-plan office context, the enclosure through furniture panels had a positive impact on glare prevention as a physical symptom. On the other hand, decrease in lighting levels as a result of the enclosure affected the visual comfort of occupants negatively and thus they adapted themselves through changing their postures, which resulted in back-related problems. This research evidenced that increase in indoor environmental quality (IEQ) would enhance job satisfaction and improve organisational productivity. As affecting the organisational decision-making, which can be a result of POE studies, the authors underlined to analyse the model further. The recent experimental study of Veitch et al. (2013) investigated the links between user, perception of space, appraisal of light, task and satisfaction from workplace. In the study, it was found that lighting appraisal had impact on room appearance, which affected pleasure. Lighting appraisal and room appearance had impact on workplace satisfaction. Workplace satisfaction influenced environmental satisfaction and self assessed productivity.

2.3 Interior Design of Workplaces

Comfort and productivity of employees are two important targets that are aspired to achieve through the design of workplaces. Indoor environment is a significant parameter that influences occupant comfort and productivity in workplace. Starting his paper with referencing previous literature that mentioned the correlation between productivity and dissatisfaction from office environment, Haynes (2008) indicated that temperature, air quality and lighting would affect office comfort although there didn't exist a shared explanation for comfort in office. Interior design is another parameter, which affects occupant satisfaction and productivity. Giddings et al. (2013) revealed interior design's influence within a comprehensive frame. Spatial layout (type of office, sitting location), furniture, colour scheme, artworks and plants were indicated as being affective as the interior design variables. Al Horr et al. (2016) underlined that office layout design affected occupant performance and behaviour in workplaces. The authors also mentioned the ‘look and feel’ analysis method, which is based on assessing the occupant response related to preference for colour palette in offices as this parameter is related to occupant comfort and productivity. As the third parameter, personal control should be underlined. Occupants aspire to have the opportunity of personal control of indoor environment in their workplaces. In their survey study among office employees, Rothe et al. (2011) stated that adjustability of the indoor environment were among the factors that were relevant to ratio of the total work time. The employees, who spent most of time in office, thought that adjustability of indoor environment was important. Giddings et al. (2013) mentioned implementation of personal control within a holistic approach, in which every person’s requirements are provided in the absence of affecting others’ environment negatively.

As emerging approaches in the built environment; sustainable design strategies require user comfort and productivity, which should be integrated into the building design besides sustainability. The alliance between comfort and sustainable design has been widely studied as a recent research agenda. Feige et al. (2013) analysed this relation in 18 office buildings through an empirical study. The three buildings, which performed highest as for user comfort, were maintained well and developed with a consideration of energy efficiency and comfort during the design process.

People spend most of the daytime in offices. Considering the daylong working hours, the influence of time on workplace occupants is an interesting topic. The research of Giddings et al. (2013) is noteworthy as they found out how time of day affected occupant satisfaction and productivity. In the field study in the workplaces in the United Kingdom, there was a dramatic decrease in the levels of arousal in the afternoon following the lunch break. Among the tested solutions for this problem; providing artwork, temperature and ventilation control and systematic intervals were the effective ones.The way people share information and the complex tasks have required the workplaces to change. The term ‘autonomy’ means the opportunity of an individual to select when, where and how she / he will perform a task. “*A high degree ofautonomy*”, which provides the control of environments on individual and group levels, is highly linked with the changing workplaces and workstyles (BCO, 2006; p. 10). The office design variables have been defined over the lifecycle of buildings. The design variable ‘services’, which is related to a 15-20 years time frame, contains lighting. The design variable ‘settings’ is related to daily intervals related to furniture, equipment and group sizes. The business performance factors provide to assess the impact of office design on businesses. One of the four main areas of the business performance factors is adaptability and flexibility. The adaptability and flexibility of an office means to re-plan the space use comfortably and to be able to change the services (BCO, 2006). Giddings et al. (2013) stated an optional approach in design decision-making, in which architects should offer optional spatial layouts.

Activity-based workplace approaches and integrated workplace concept (IWC) has emerged in recent years as the way people work has changed. In activity-based workplaces; occupants are offered flexibility and interaction that they can utilize when performing various work patterns within intricate schedules and with the use of mobile technologies. The IWC integrates task-related procedures, space design and utilization of technology (Skogland, 2017). Skogland (2017) conducted an empirical study in an organization through interviews and semi-structured observations. Availability of activity-based workplaces, arrangement of different functions, free-seating guidelines, work characteristics and cultural and behavioural measures have had impact on the application of activity-based workplaces in the study. Brunia et al. (2016) underlined the significance of physical characteristics such as interior design and spatial layout on the satisfaction from activity-based workplaces. As for the design guidance; variety of work spaces, small open zones with partitions, natural materials, light colours and daylight have been recommended. Hoendervanger et al. (2016) worked on the switching behaviour and satisfaction of occupants in the activity-based workplaces. It was found that the percentage of frequent switching among the activity-based workplaces was low and approximately 40% of the occupants weren’t satisfied. Task profiles, social aspects and feeling attached to particular workspaces were the reasons explaining infrequent switching behaviour of the occupants. That is why, discussing and elaborating on the personal requirementsand preferences were advised for activity-based workplace to enhance its usage and flexibility.

2.4 Lighting in Workplace

Visual comfort in office spaces and workplaces focuses on design of lighting systems, which allow performing tasks accurately and easily. Health, wellbeing and satisfaction of workplace occupants related to lighting systems are also considered when designing lighting. Wide use of technology and computers have changed lighting requirements. The SLL Lighting Handbook highlights that most of the offices today accommodate both paper-based tasks and screen-based tasks. lighting requirements of these two tasks differ as paper is read through reflected light and computer screen is self-luminous. That is why, lighting systems in the office should be appropriate for both of these different tasks (SLL, 2009).

The design requirements of lighting conditions in a workplace have been determined and guided by standards and codes. The EN12464-1 standard indicates the required levels for the design parameters on the task area. Besides highlighting task area, immediate surrounding and background area have been also defined. The defined design parameters are average illuminance on reference surface, maximum Unified Glare Rating (UGR), minimum uniformity (U_o) and minimum color rendering index (R_a). The types of task determine the requirements indicated in the EN12464-1 standard. For the tasks such as reading and writing; the maintained illuminance of 500lux, the maximum UGR of 19, the minimum U_o of 0,60 and the minimum R_a of 80 is required. For the tasks involving technical drawing; the maintained illuminance of 750lux, the maximum UGR of 16, the minimum U_o of 0,70 is required with the same R_a as previously mentioned (EN12464-1, 2011).

Ceiling height is indicated as a significant design parameter for lighting design of offices. This dimension is an indicator of indirect lighting approach. Ceiling height between 2.5 meters and 3.5 meters is recommended in order to avoid hot spots on the ceiling under the indirect lighting approach. As another design parameter, obstructions should be considered during the design of the lighting systems in offices. The obstructions range from the partitions between workstations to the full-height partitions separating office rooms. The height of the partitions affect amount of light that falls on task area, thus decision-making of partition height should be made with considering how it affects the illuminance levels (SLL, 2009). In a POE study containing 912 workstations in 13 office buildings, Collins et al. (1990) mentioned partitions among the reasons for variability in illuminance levels as a function of lighting power density (LPD). In their experimental study, Boyce et al. (2006) analysed the partition reflectance through light and dark coloured partitions. The task performance during typing was affected positively by the partitions under the lighting system with an indirect component. In the same study, 39% of the respondents agreed with the questionnaire item stating that reflections from luminaires obstructed their work. The authors indicated that possibly this evaluation was a result of the reflected images by the luminous desk lamp.

In relation with architecture of office space, surface finishes have impact on distribution of light. Colour and surface reflectance are affective on this impact (SLL, 2009). The EN12464-1 standard (2011) advised surface reflectance between 0.7 and 0.9 for ceiling, between 0.5 and 0.8 for walls and between 0.2 and 0.4 for floor.

Circadian system, which operates human diurnal and seasonal rhythms, administers the body functions through the day and night cycle (SLL, 2012). Physiological systems in body reveals circadian or biological rhythms (Rea, 2015). Considering the diurnal cycle, bright light during daytime and less light during nighttime is recommended. Daylight accomplishes to stimulate the circadian system as its physiological affect (SLL, 2009). That is why, high levels of daylight are recommended in the mornings (SLL, 2012).

The recently discovered photoreceptor cells are affective for regulating the circadian rhythms through light. In terms of the visual effect of light, the illuminance on the workplane is significant. However; in terms of the biological effect of light, the light enters into the eye is important. As for the visual impact, when and for how long the light is required changes according to the viewing function. As for the biological impact, the time and duration the eye receives the light is noteworthy due to the biological rhythm. There is a link between spectral distribution of light and type of sensitivity for light. While the yellow-green wavelengths maximize the visual sensitivity, the blue wavelengths peak the biological sensitivity. That is why, the spectrum is significant to sustain the cycle of the body. The bluish, cool light influencesbody biology more. Thus, the bluish morning light is more alerting and the reddish evening light is more relaxing. In a workplace, employees should experience both alerting and relaxing time phases. This underlines the significance of personal preferences, flexibility and adaptability in lighting to enhance productivity (Van Bommel and Van den Beld, 2004).

Due to aforementioned information about the relation between light and circadian rhythm, the relation between time of the day and non-visual effects of light on occupants is important. Figueiro et al. (2018) revealed that difference in time would cause distinct effects on the circadian system even if the light quantity and spectrum would be same. Besides the time, the duration of the light exposure has impact on the body as well. Based on the evidences through the referenced researches, the authors indicated that being exposed to polychromatic white light following wake up would result in going to bed in an early time and waking up in an early time, whereas being exposed to light before bedtime would result in going to bed in a delayed time and waking up in a delayed time. Based on their previous works with colleagues, Duffy and Czeisler (2009) stated the maximum sensitivity of humans to light stimuli was during the biological night while the least sensitivity was during the middle of the biological day.

As for the relation between time and visual effects of light; how time affects visual comfort, perception, health and wellbeing should be considered. Smolders and de Kort (2012) worked on an experimental design and found out that the preferences of occupants for lighting didn't differ based on the time of the day. However, Boyce et al. (2006) revealed significant relations between time and room appearance, visual comfort and mood. In the experimental study with an office function; ratings of positive appreciations for room appearance, ratings of pleasure for mood and ratings of physical and visual discomfort increased in the afternoon when compared to the ratings in the morning. The authors interpreted the drop in the afternoon ratings as consistent with the fatigue occurring along the day.

2.5 Occupant Behaviour

Occupant behaviour is an insightful research area integrated into research and simulation tools on built environment. Recent researches have showed that the reason of gap between real measurements and simulation results was due to occupant behaviour. That is why, integrating occupant behaviour into building performance studies in a realistic way is very important. International Energy Agency (IEA) Energy in Buildings and Communities Programme (EBC) has worked on the ‘Annex 66 Definition and Simulation of Occupant Behaviour in Buildings’□project. According to text of Annex 66, comfort and satisfaction requirements of occupants shape their behaviour and occupant behaviour affect energy consumption depending on how occupants use equipment (Yan and Hong, 2014). Yan et al. (2017) indicated that occupant behaviour affected both energy consumption and saving strategies. As forenergy use, authors used evidences from studies that showed how the energy consumption out-of-office hours affected the building energy. The switched-on lights were indicated as one of the reasons. As for the energy saving strategies, occupants’ communication with technologies played a role according to the studies. The research of Hong and Lin evaluated impact of different behaviour types of building energy consumption. There were three groups of occupants as occupants who were active in saving energy called as ‘*austerity workstyle*’, average occupants called as ‘*standard workstyle*’ and occupants who wasted energy without care called as ‘*wasteful workstyle*’. Through simulation studies in an office room with single occupancy, it was evidenced that up to 50% less energy was consumed by austerity workstyle when compared to standard workstyle. Up to 90% more energy was consumed by wasteful workstyle when compared to the standard workstyle (Hong and Lin, 2013). In longitudinal research of Langevin et al. (2015) in an air-conditioned office building in a sub-tropical climate, occupant behavior related to thermal comfort and adaptive behaviour were observed. The range of thermal sensations that is satisfactory for an individual provide forecast information on thermal comfort and adaptive behavior. That is why, individual ranges should be considered during developing models for including personal distinctions. Moreover,it was stated that most immediate and unrestricted actions were chosen by the occupants as the initial behavior and for most of the time.

Integration of occupant behaviour data into building performance simulation tools is a significant research topic. This integration is noteworthy, because an accurate integration allow the occupant behaviour data during the design stages. In their research, Hong et al. evaluated measuring and integrating occupant behaviour accurately. As for measurement of occupant behaviour, use of objective and subjective techniques were advised by authors for gathering real occupant data. The objective techniques, which are called as ‘physical sensing’, include smart metering, indoor and outdoor environmental data together with interaction between occupant and control system. The subjective techniques, which are called as ‘non-physical sensing’, contain survey questions and self-reported data. Occupancy data belongs to both of the techniques. Benefits of integrating behaviour of occupant into building performance simulation tools have been highlighted. Providing the simulated performance as close as possible to the actual performance, enhancing building standards and considering adaptive behaviour for energy policy making are the benefits of integrating behaviour into performance analysis. The authors mentioned deterministic and stochastic occupancy models as two different approaches for this integration. The deterministic occupancy models depend on fixed occupancy profiles that are based on daily profiles such as the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 90.1 - 2004. The stochastic occupancy models provide varieties in the occupant behaviour. That is why, stochastic models are preferred in building performance simulation tools for decreasing gaps between simulations and real performances (Hong et al., 2017). Hong et al. developed a framework called ‘the DNAS occupant behaviour framework’ in order to describe occupant behaviour in a standard way. Forming the acronym ‘DNAS’; ‘drivers’ encourage occupants to satisfy their needs, ‘needs’ are occupant requirements that should be provided in terms of satisfaction, ‘actions’ are activities carried out to provide environmental comfort and ‘systems’ are tools that are encountered for environmental comfort (Hong et al., 2015a). In their following work, the authors used ‘eXtensible Markup Language (XML)’ and developed obXML in order to integrate occupant behaviour into building energy modeling (BEM) softwares (Hong et al., 2015b).

As for the relation between occupant behaviour and lighting, visual comfort was highlighted as triggering behaviour and actions to enhance comfort. Delzendeh et al. defined occupant behaviour as the influence between occupants and building systems for adjusting indoor environment conditions to provide health and thermal, visual and acoustic comfort. In terms of lighting, lighting systems and shading can be classified as occupant behaviour affecting building energy consumption. The authors underlined ‘social and personal (psychological and physiological) parameters’ and ‘architecture and interior design features’ among the factors that affected energy behavior of the occupants. The authors indicated age, gender, employment and awareness on energy among the social and personal factors. It was also added that some behavioural theories such as planned behaviour theory worked on the relation between occupant and its environment. However, the integration of these researches into building energy assessment tools was rare. As for architecture and interior design; colour, material and spatial layout affected occupant behaviour. However, the impact of interior design on occupant behaviour and energy consumption has not been widely investigated (Delzendeh et al., 2017).

2.6 Adaptive Behaviour

Adaptive behaviour of occupants is performed to maintain personal comfort. The adaptive actions contain operating artificial lights, window blinds, thermostats, adjusting clothing level, using fan and door (Yan et al., 2015). Adaptive behaviour was explained by ‘*the Adaptive Principle*’, which is the response of the occupants to arising discomfort conditions in order to return to their comfort conditions (Nicol, Humphreys and Roaf, 2012). Adaptive behaviour of occupants has been considered and studied as being in relation to occupant behaviour and comfort. The adaptive behaviour is located under IEQ discipline as a human factor (Ortiz et al., 2017). Integrating adaptive comfort model into the standards encouraged predicting how occupants behave to restore their comfort (Hong et al., 2015b). Individual requirements and different qualities are in the center of the relation between adaptive behaviour and comfort. Ortiz et al. highlighted that comfort related to IEQ was evaluated through the individual parameters such as air quality, thermal comfort, acoustic comfort and visual comfort in standards. How these parameters interacted and distinctions between occupants weren't considered (Ortiz et al., 2017).

Enhancing comfort conditions and allowing occupants for this target through sustainable design is remarkable. That is why, adaptive behaviour has a strong alliance with sustainable design approach. Brown et al. (2009) stated that increasing amount of buildings, which were designed within the sustainable approach, provided opportunities for controlling indoor environment. The adjustments made available to occupants include operating windows, operating blinds, modifying thermostats and using space with flexibility.

Adaptive behaviour of occupants in the literature has been mostly studied in terms of thermal comfort. Adaptive thermal comfort models evaluated thermal comfort of occupants extensively (Nicol, Humphreys and Roaf, 2012). Brager and de Dear (1998) underlined that scholar research considered adaptation of thermal comfort in three different ways: As the first group, the behavioural adjustments contain all conscious or unconscious changes made by a person. The second group of adaptations is physiological adaptation that includes physiological modifications operated by the autonomic nervous system. The third group contains psychological feedback that is based on cognitive and cultural measures. In the adaptive model in relation to thermal comfort, user's past and current thermal experiences are considered. In their research on thermal comfort, Baker and Standeven (1996) highlighted how stress and adaptive behaviour is related to each other. Stress occurs when the stimulus goes beyond the borders of the adaptive option, when the occupant can't perceive the existence of the adaptive option or when the occupant can't know or comprehend the source of the stimulus. Being aware of the source of the stimulus has been referred as 'cognitive tolerance'. In the research of Damiati et al. (2016) involving tropical climates, adaptive behaviour was observed in office buildings using various ventilation systems. Main aim for adaptation was based on maintaining thermal comfort. However, this was achieved through different adaptive actions. While most occupants used air-conditioning systemsin Malaysia, the occupants in Indonesia and Japan drank cold beverages. Mustapa et al. (2016) conducted a field research in two university office buildings with two different ventilation types in Japan. As for two types, free running mode was use of mechanical stand fans and operation of windows and doors. Cooling mode was using split type air-condition. It was seen that occupants' thermal preference and desire to change the thermal environment differed as the ventilation mode changed. Rupp et al. (2018) carried out a research in three mixed-mode (natural ventilation or air-conditioning) office buildings in Southern Brazil as subtropical climate. The thermal perception and adaptive comfort of occupants changed depending on the operation mode when two modes were tested individually. In the study of Gou et al. (2018), clothing adjustments were among the adaptive behaviour of occupants as well as opening doors / windows and operating mechanical fans. This has been different in the study of Mustapa et al. (2016), in which the adaptive behaviour related to clothing was low. In the longitudinal study of Langevin et al. (2015), the behaviour frequencies of occupants that aimed to improve their thermal comfort were studied in an air-conditioned office building. Drinking (cool and hot), use of fans, clothing and use of doors were some of the adaptive behaviour.

The relation between adaptive behaviour and lighting has been not widely studied. In their research Keyvanfar et al. (2014) interpreted pleasurethrough adaptive behaviour as a parameter not being included in the sustainable building assessment tools. Through their literature review, the authors indicated the adaptive behaviour options such as covering the room surfaces (i.e. use of wallpaper), blind control, changing the operative hours of the artificial lighting, using Universal Serial Bus (USB) desktop lamp as task lighting, changing the desktop or task surface (i.e. use of screen protector), changing position or direction of furniture and control of artificial lighting. Expert validation methodology supported all adaptive behaviour items for daylighting and artificial lighting. In the research of O'Brien and Gunay (2014), interior design was indicated as a parameter affecting occupant behaviour for enhancing comfort. In literature review of authors, flexibility of occupants related to changing their position or orientation was underlined for preventing glare. Besides, monitor orientation and furniture positioning were mentioned as being related to discomfort zones. In their contextual framework, the authors mentioned the rotational and translational freedom of a cubicle under the title ‘interior design’.

As one of the causes of the visual discomfort, glare changes based on occupant position and viewing direction. ‘Adaptive zone’ concept was developed in order to allow the occupants to change position and viewing direction for reducing their glare notion. ‘Adaptive zone’ concept showed that the duration that occupants feeling discomfort glare decreased and annual mean daylight availability on the workplane increased in the office setting. In their workplaces, the occupants operated the manual venetian blinds on the facade and changed their positions and view-directions in their workplaces. This research has indicated that the ‘adaptive zone’ concept depended on the layout of furniture and flexibility of task locations (Jakubiec and Reinhart, 2012). In a field study containing a university studio space with around 500 students by Jakubiec and Reinhart (2016), the long-term evaluation of visual comfort conditions was consisted of an occupant survey study and visual comfort simulations. In the survey study, some of the occupants indicated that they adapted themselves when they were disturbed by glare. This opinion supported the aim of the ‘adaptive zone’ concept. The occupants rated their notion of glare through the scale “*imperceptible, perceptible, disturbing, intolerable*” (p.4). The values of the metrics calculated in the simulation study like daylight glare probability (DGP) were coupled with occupant responses. The simulation results were presented showing the spatial and temporal aspects of daylight.

The alliance between maintaining comfort and decreasing energy consumption through adaptive behaviour is strong. In the study of Gunay et al. (2017), the authors developed an algorithm that was predicted the switching on actions of artificial lighting and closing actions of blinds through analysing the occupant behaviour in ten private identical offices. Following the analysis and development of the algorithm, the algorithm was tested in half of the studied office spaces. Approximately one-forth reductions were observed in artificial lighting consumption without a compromise on occupant comfort.

Feedback is a measure related to adaptive behaviour, which can enhance its impact on the indoor environment. Feedback is referred as the information shared with occupants regarding the building systems and control mechanisms in the building they occupy. Following the feedback provided to occupants in two green office buildings in the study of Brown et al. (2009), lighting was the system that had the highest overall control level. This was due to the availability of lighting control provided to the occupants.

2.7 Post-occupancy Evaluation (POE)

Post-occupancy evaluation (POE)has significance asthis methodology assessesuser satisfaction, identify problems in buildings and develop solutions. POE studies have been widely used for evaluating indoor environmental quality (IEQ) of built environment. In relation to lighting, these studies were mainly conducted for appraising visual comfort conditions.

2.7.1 POE in built environment

Providing occupant satisfaction and wellbeing are important aspects in built environment. This is the reason that POE, which contains users' own evaluations in the building they occupy, gains significance. POE methodology is utilized for determining the problematic areas and issues that are source of user dissatisfaction in a building. POE is assessing buildings with an organised approach after some time since their occupation starts. POE studies concentrate on user-related aspects like "*occupant performance, worker satisfaction and productivity*" and building-related aspects like "*acoustic and lighting levels, adequacy of space, spatial relationships, etc.*" (Preiser and Vischer, 2005; p.8). Besides identifying the particular problems in studied buildings, the evaluation results can be of advantage to design prospective buildings through preventing similar failures (Mallory-Hill et al., 2012).

As having been experienced since mid of twentieth century, POE is an established assessment approach in built environment. Preiser (2005) stated that first systematic evaluations of buildings concerning assessments of occupants emerged before 1970. It was mid of 1970s, when POE was used in a publication as terminology. The benefits of carrying out POE studies are especially more significant in case there are long-term occupants. Saving energy, decrease in the maintenance costs and increase in productivity all result in the net savings when cost and payback relation of a POE study are considered (Preiser, 2001).

POE is considered as a component of a wider assessment system called as building performance evaluation (BPE). BPE is responsible from building life cycle and assesses building through performance criteria such as health, requirements of building codes, functionality and psychological aspects (Preiser, 2005). Mallory-Hill et al. (2012) indicated that BPE concentrated on relation between building design and its performance regarding behaviour and requirements of occupants. This is due to the fact that experts, who work on BPE, assess a building through its performance in terms of occupants instead of considering building only as a physical product constructed from materials.

As a recent example, Maarleveld et al. developed an assessment system called as '*the Work Environment Diagnosis Instrument (WODI) toolkit*' for supporting POE studies. Toolkit mainly evaluates the occupants' satisfaction and productivity related to the organizational management and physical workspace characteristics. Classified under four different levels, the WODI key performance indicators contain factors such as aesthetics, appearance of the work environment, indoor climate, lighting and perceived productivity:

- Aesthetics: This factor is related to the material and colour use, furnitures and architecture;
- Appearance of the work environment: This factor assesses how the work environment affects well being and the quality of the workplace in terms of attractiveness and pleasantness;
- Lighting under indoor climate: This factor's evaluation is about the lighting systems as artificial lighting, daylighting and manual control of the lighting systems (Maarleveld et al., 2009).

In terms of lighting, POE studies provide identifying the successful and problematic issues related to lighting systems and lighting control systems. The occupant's experience invisual environment can be investigated. By underlining problematic issues, it is possible to plan and implement further enhancements (Hygge and Löfberg, 1999).

2.7.2 The criteria associated with lighting in evaluation studies

The evaluation criteria related to lighting, which were utilized in the existing POE and IEQ studies, were investigated. The aim of this investigation was to observe appreciation of lighting in the evaluation studies focusing on both particular lighting system and entire building systems.

A literature review of existing POE and IEQ studies was carried out. Review was scoped scholarly to explore peer-reviewed journal articles. As first step of review process, electronic database ScienceDirect has been employed for this review. Conducted search was carried out within a wide scope. Terms "*post-occupancy evaluation*" and "*indoor environmental quality*" was searched in ScienceDirect search engine. All building functions that were included in search results within the frame of the above-mentioned criteria were included in the review. This was mainly for observing distribution of evaluated functions instead of focusing on only one building function.

In second step, a spreadsheet was generated in the Microsoft Excel software in order to record the reviewed information in the existing studies. The categories in the spreadsheet were the bibliographic information, the case information and the evaluation information (in order as in the spreadsheet). The bibliographic information has included journal, title, date, volume/issue/page number and author. The case information has included function, number of buildings, number of participants and building locations. The evaluation information has included measure, question, scale and analysis (statistical analysis etc.) employed in the reviewed study. Each study was reviewed and the categories in the spreadsheet were filled in based on the categories. Once the reviewed information was recorded, the criteria for the evaluation of lighting employed in these studies were determined and grouped as third step.

Evaluation criteria, which were determined through investigating the current POE and IEQ studies, are provided as below. These criteria were lighting, illuminance level, daylighting and artificial lighting, glare, view-out, lighting control systems, brightness, distribution of light, colour, colour temperature, health, wellbeing and performance.

2.7.2.1 Criterion-1: Lighting

The lighting criterion assesses the impact of luminous environment on occupants. The studies investigated lighting with a very wide perspective. The measures, which were identified in the studies, have been classified as satisfaction, perception, acceptance, description, preference and quality of lighting. '*The Building Use Studies (BUS)methodology*' wasinitiated in the United Kingdom and evaluated user satisfaction in buildings (BUS, 2016). Among the parameters, through which '*the BUS methodology*' assesses the user satisfaction, lighting takes place as well. In their studies containing 36 commercial and institutional buildings with 2540 users, Baird and Thompson evaluated the satisfaction level with overall lighting (Baird and Thompson, 2012). Several studies including Schiano-Phan assessing four office and educational buildings; Gou et al. probing 14 green and traditional office buildings with 1251 participant employees and Baird and Lechat evaluating 30 office and educational buildings have used the same criterion (Schiano-Phan, 2012; Gou et al., 2014; Baird and Lechat, 2009; Baird et al., 2012; Lenoir et al., 2012). In '*the BUS methodology*', the evaluation of satisfaction is carried out with seven-point Likert scale changing between '*unsatisfactory*' and '*satisfactory*'. '*The ideal score*' was seven in the scale (Baird and Thompson, 2012).

In the frame of '*The European Health Optimization Protocol for Energy-Efficient Buildings (HOPE) project*', there was IEQ assessment in total 164 office and residential buildings including nine countries. In this project, the satisfaction level with lighting was assessed (Bluyssen et al., 2011).

In the evaluation studies, the assessment of users related to luminous environment has been also probed through perception of lighting. As an example, Toftum asked the time frequency of lighting that was uncomfortable for occupant under the '*perception*' title using the '*never, sometimes, every week and every day*' options (Toftum, 2010). Steemers and Manchanda conducted a study in twelve office buildings, half of which were located in the United Kingdom and the other half were located in India. In this evaluation, lighting was among the '*aspects the users considered most important in determining their overall satisfaction*' (Steemers and Manchanda, 2010).

In their study; Hua et al. investigated daylighting system in laboratory and office spaces through a two-weeks field study with 75 occupants. With the survey titled as '*the Visual Environment Satisfaction Survey*', the authors analysed the satisfaction of occupants related to the visual environment and visual comfort through a seven-point Likert scale. '*Quality of light in general*' was among the aspects to be rated as for satisfaction (Hua et al, 2011).

Lee et al. assessed acceptance of users regarding the visual environment through a semantic differential scale such as '*very bad, bad, less bad, neutral, less good, good, very good*' (Lee et al., 2012). In a study on residential function, the residents' evaluation on lighting quality was appraised through the scale between '*clearly acceptable*' and '*clearly unacceptable*' (Frontczak et al., 2012). Hirning et al. studied three green buildings with 64 participants and '*gloomy, dim, comfortable, bright, glary*' were given to the participants in order to define '*the lighting in their workspaces*' (Hirning et al., 2013).

As part of '*Building Environment Satisfaction Survey*' in the study of Hua et al., 46 occupants in educational function were asked about satisfaction with lighting in winter and summer months (Hua et al., 2014). Humphreys used '*the preference scales*' for evaluating the environment in his study of 26 offices. In terms of light, users selected '*much dimmer, a bit dimmer, no change, a bit brighter, much brighter*' for their work areas (Humphreys, 2005). Newsham et al. asked the '*overall lighting quality*' through a seven-point scale between '*low quality*' and '*high quality*'. In terms of visual appearance, the authors asked '*general quality of visual appearance of the office*' through seven-point scale changing from '*low*' to '*high*' (Newsham et al., 2009).

2.7.2.2 Criterion-2: Illuminance level

For providing visual comfort, required illuminance levels have been determined according to building usage functions and included in the related standards. In case these illuminance levels are not provided, user-related aspects such as performance and health can be affected. Based on this impact, the evaluation studies mostly asks if the illuminance levels on the user's workplanes are adequate or not. The studies using '*the BUS methodology*' asked the users to assess the light levels (Baird and Thompson, 2012; Gou et al., 2014; Baird et al., 2012; Lenoir et al., 2012). The seven-point Likert scale between '*too little*' and '*too much*' were used in this evaluation and four was identified as '*the ideal score*' (Baird and Thompson, 2012).

The light levels were assessed throughout a scale containing 'very bright', 'moderately bright' and 'dim' in 12 office buildings related to the light levels as part of the 'overall environmental perception' (Haghighat and Donnini, 1999). Similarly, Zhang and Altan requested the users in two office buildings with 223 employees to assess indoor environment through seven-point Likert scale changing from 'dull' to 'bright' (Zhang and Altan, 2011). In the evaluation study in a Leadership in Energy and Environmental Design (LEED)-certified laboratory building; Hua et al. asked if '*too bright even with all the lights off*' and '*too dark even with all the lights on*' caused any dissatisfaction (Hua et al., 2011).

'*The Occupant Indoor Environmental Quality (IEQ) Survey^{TM}*' is an online survey, which was created by '*the Center for the Built Environment (CBE)*'. The survey focuses on lighting in '*thecore question areas*' containing question sets for indoor environment. Besides, daylighting takes place as a module in '*the optional survey areas*' (IEQ Survey^{TM}, 2016). The studies on office function carried out by Kim and De Dear in 351 office buildings and Lee and Guerin in five different office types located in LEED-certified buildings were among examples using '*theCBE IEQ Survey^{TM}*'. They assessed the satisfaction related to '*amount of light*' in the workplace (Kim and de Dear, 2013; Lee and Guerin, 2010). Altomonte and Schiavon studied LEED-certified buildings and non-LEED-certified buildings. 144 buildings, 65 of which were LEED-certified, were evaluated through '*theCBE IEQ Survey^{TM}*' and satisfaction related to the '*amount of light*' using the scale between '*very satisfied*' and '*very dissatisfied*' was assessed (Altomonte and Schiavon, 2013). In field study located in a LEED-certified laboratory building, the amount of light for computer work and paper work were evaluated through the satisfaction scale (Hua et al., 2011).

A study, which assessed the university teaching rooms, used a dichotomous scale related to the illumination level. This evaluation had two scales as '*acceptable*' and '*unacceptable*' (Lee et al, 2012). In another study in the primary school context that was carried out in seven primary schools with 614 participant students, the authors asked the students how well their sights were regarding their desks and the board and the scale were '*no, a little, enough, yes*'. The students, who were also asked about their behaviour as a result of the inadequate sight of their desks, chose between the options '*I ask the teacher to switch on the lights*', '*I ask the teacher to open the blinds*', '*I move my desk*' and '*Nothing*' (De Giuli et al., 2012).

In evaluation study of long-term care facility that was carried out through facility managers, residents accommodated minimum threemonths and family members; Huang et al. asked the perceived importance of '*illuminance'* using the scale '*not important at all, not so important, neutral, important and very important*' (Huang et al., 2013).

In an office building with open plan, in which 95 workstations were evaluated during the study, the '*task visibility*' was assessed by (Newsham et al., 2009).

2.7.2.3 Criterion-3: Daylighting and artificial lighting

In the studies containing visual comfort parameters and luminous environment aspects, daylighting and artificial lighting have been evaluated separately. In '*the BUS methodology*' under Criteria-1, the adequacy of light has been asked separately for daylighting and artificial lighting (Baird and Thompson, 2012; Gou et al., 2014; Baird et al., 2012; Lenoir et al., 2012). Among questions in '*the HOPE project*' and in an evaluation study carried out in classrooms at higher education institutes, the satisfaction through daylight and artificial light was asked as separate (Bluyssen et al., 2011; Yang et al., 2013). Meerbeek et al. appraised user experience regarding daylight and artificial light through separate questions through five-point Likert scale between '*comfortable*' and '*uncomfortable*' (Meerbeek et al., 2014).

In terms of daylighting, a study investigating secondary schools focused on the impact of daylight affecting the desktops related to blocking the view of users, the adequacy of light levels and creating shadows (Katafygiotou and Serghides, 2014). McCunn and Gifford conducted a study on green office buildings and '*the Green Design Attributes Scale*' containing 36 items was created. In this scale, providing access to daylight was among the aspects constituting a healthy building (McCunn and Gifford, 2012). In a study carried out in residential function, the residents were asked about their evaluations related to daylight and direct sunlight through five-point Likert scale changing from '*very good*' to '*very bad*' (Malmqvist and Glaumann, 2009). Through another study on residential function, the residents assessed '*poor natural light*' and '*solar glare*' as mediums affecting themselves negatively using five-point Likert scale between '*very strongly*' and '*not at all*' (Voelker et al., 2013). In a study assessing three typical hostels in three different universities, '*adequate natural lighting*' was among the factors for users to assess '*the indoor conditions most influencing their comfort sensation in their room*' (Dahlan et al., 2009). In evaluation study of daylighting system in an open plan office building, Konis asked the relationship between '*the amount of daylight*' and user satisfaction using a seven-point Likert scale. In this study whether '*dynamic sky conditions*' has affected the visual discomfort of the occupants were assessed (Konis, 2013). In their long-term care facility study, Huang et al. assessed '*natural lighting*'s perceived importance using scale '*not important at all, not so important, neutral, important and very important*' (Huang et al., 2013). Kim et al. assessed daylighting in learning environment with 368 participating students. They have asked about the necessity of daylight in the classroom, impact of daylight on the learning performance, satisfaction with daylight in the classroom and whether more daylight was required in the classroom through the scale '*yes*', '*no*' and '*no idea*' (Kim et al., 2014).

Among the questions defining the physical environment and respondent's room in another study with 340 participants in public and private housing units, whether '*the overall daylighting effect in the resident's living room*' and '*the luminous environment in the resident's living room*' were satisfactory has been evaluated through the scale '*strongly disagree, disagree, just right, agree, strongly agree*' (Xue et al., 2014). In the same study, the amount of sky that was '*obscured above the horizontal view from the window of respondent's living room*' was asked through the scale '*almost all, much, a half, little, almost none*'. The authors also evaluated the duration that daylight is plentiful without supplementary artificial light. Furthermore, the duration of the actual direct sunlight penetration and residents' preference for duration of sunlight were asked for winter and summer (Xue et al., 2014). The '*overall daylight quality*' aspect was appraised by Newsham et al. using a seven-point scale, which started as '*low*' and ended as '*high*' (Newsham et al., 2009).

Window, as an architectural element and design parameter affecting visual comfort and daylight availability, has been included into the evaluation in some existing studies. The existence of window and time-based information related to direct sunlight penetration through window during summer has been evaluated in the work of Paul and Taylor (Paul and Taylor, 2008). In his study at the open-plan office context, Konis assessed the relation between the windows and visual discomfort at the moment of answering the question using the scale '*very uncomfortable, moderate, slightly, none*' (Konis, 2013).

In terms of artificial lighting, requirement of artificial lighting as supplementary to daylight was investigated through a scale; which was consisted of '*always*', '*sometimes*' and '*never*' (Katafygiotou and Serghides, 2014). Paul and Taylor asked the users to determine the existence of artificial lighting and its usage in summer months (Paul and Taylor, 2008). In one of questions that were asked at occupants at office context mentioned above, they were asked if they '*could work comfortably with the electric lights turned off right now*' (Konis, 2013).

Hua et al. evaluated satisfaction of occupants related to the '*amount of daylight*' and '*amount of artificial light*'. Besides, they asked occupants to determine satisfaction with '*visual comfort of the daylighting*' and '*visual comfort of the artificial lighting*'. Under the title as the '*facade design strategies*'; the impact of windows, horizontal shading systems and vertical shading systems were assessed. Among the choices for the '*source of dissatisfaction with the visual environment*'; the authors asked if not having overhead light on required locations, not having flexible task lighting, not having task lighting at all, '*toomuch daylight*', '*too much electric lighting'*, '*not enough daylight*', '*not enough electric lighting*' and flicker problem in the artificial lighting system had any impact on user dissatisfaction (Hua et al., 2011). Frontczak, Andersen and Wargocki asked the residents about their switching behaviour of the artificial lights in their homes (Frontczak et al., 2012).

In a residential study, duration for artificial lighting usage during daytime and type of main artificial light in living room such as '*incandescent lamp, energy saving lamp, fluorescent lamp, light-emitting diode (LED)*' were asked (Xue et al., 2014).

In another study in an office building with open plan by Newsham et al., whether flickering artificial lights disturbed the employees was asked through a seven-point scale starting with '*often*' and ending with '*never*' (Newsham et al., 2009).

2.7.2.4 Criterion-4: Glare

Glare causes visual discomfort, which is a result of direct sunlight or artificial light in the field of view. The EN12464-1 standard describes glare as can be caused by a luminaire in the field of view and transparent surfaces of a window or skylight with high brightness (EN 12464-1, 2011). The glare measures evaluated in the studies have been grouped as its existence, satisfaction, disturbance, blind operation and comfort. In evaluations using '*the BUS methodology*', the existence of glare was investigated separately by asking '*glare from sun and sky*' and '*glare from lights*' (Baird and Thompson, 2012; Gou et al., 2014; Baird et al., 2012; Lenoir et al., 2012). A seven-point Likert scale between '*none*' and '*too much*' was used for this evaluation. '*The ideal score*' was one in the scale (Baird and Thompson, 2012).

In two other studies, one of which used '*the CBE IEQ Survey*^{TM}'; the occupants were asked about their satisfaction related to '*glare*' (Kim and De Dear, 2013; Lee and Guerin, 2010). Meerbeek et al. asked the occupants whether they encountered with glare caused by daylighting and artificial lighting on survey day. If they did, a further question was about level of disturbance caused by glare using a scale as '*intolerable, disturbing, noticeable, barely perceptible*' (Meerbeek et al., 2014).

In the survey at '*the HOPE project*', which was based on '*the Office Environment Survey*'; glare related to '*sun and sky*' and '*artificial light*' were asked through a seven-point Likert scale measuring satisfaction (Bluyssen et al., 2011).

In their study evaluating hostels, Dahlan et al. asked about the response of residents to glare. They evaluated the time frequency of operating their curtains through a seven-point Likert scale between '*never*' and '*always*'. Moreover, the impact of glare from windows was among the factors for assessing '*the indoor conditions most influencing their comfort sensation in their room*' (Dahlan et al., 2009).

As investigating visual environment in laboratory building, Hua et al. assessed how occupant dissatisfaction was affected by glare from daylight and artificial light. Furthermore, authors asked if reflections on the users' computer screens caused by daylight and artificial light resulted in any dissatisfaction (Hua et al., 2011). In the primary school study mentioned above, the authors asked the students whether they were disturbed as a result of the blinding luminaires in their classrooms through a scale as '*never, sometimes and often*' (De Giuli et al., 2012).

In an open-plan office building, Konis asked at the occupants about '*view of direct sun*', '*glare from unshaded upper windows*', '*reflections of the solar disc off of the exterior perforated metal panel*' as the aspects that could cause visual discomfort (Konis, 2013). In a different study evaluating an open-plan office environment, the users were asked to indicate their opinion to the '*glare often is a problem in my work area*' sentence through seven-point scale between '*strongly agree*' and '*strongly disagree*' (Newsham et al., 2009).

Hirning et al. provided a diagram to the survey participants in order to describe the location of glare sources (Hirning et al., 2013). Liang et al. evaluated visual-related aspects of dissatisfaction such as '*glare from daylight*' and '*directly sunlit*' (Liang et al., 2014). '*Glare*' and '*fading object*' were rated as being the disturbing aspects of sunlight for the residents using the scale '*always, often, sometimes, rarely, never*' (Xue et al., 2014).

2.7.2.5 Criterion-5: View-out

A building providing view-out was included among the healthy building aspects in '*the Green Design Attributes Scale*' (McCunn and Gifford, 2012).

In their study within office function, Lee and Guerin asked the distance between the user and window together with the orientation of the nearest window (Lee and Guerin, 2010). In the evaluation at '*the HOPE project*', the amount of direct sunlight penetration was evaluated depending on the orientation. The users were also asked about their opinion on view-out using a seven-point Likert scale changing from '*do not like at all*' to '*like very much*' (Bluyssen et al., 2011).

In a study on residential function, the residents were asked about the impact of view-out on comfort (Frontczak et al., 2012). In office function, the '*visual connection to outdoors*' was among the IEQ measures rated in terms of satisfaction and the users were also asked about how the shades affected their view-out in terms of their satisfaction (Konis, 2013). In another study in the office context; the occupants evaluated their view-out through the scale '*window with urban view, window with only sky view, window with nature view, no viewing windows*' (Hirning et al., 2013).

Newsham et al. assessed the view-out from the employees' offices using a seven-point scale between '*low*' and '*high*' (Newsham et al., 2009).

2.7.2.6 Criterion-6: Lighting control systems

Under this criterion, both solar control and control of artificial lighting have been examined. In a study on office function, the impact of not being able to directly control the lighting system was asked (Monfared and Sharples, 2011). In the evaluations through '*the BUS methodology*' including commercial, institutional and educational functions; significance of lighting controlwas asked (Baird and Leaman, 2012;) Lenoir et al., 2012). In the survey at '*the HOPE project*', the frequency of individual control operations related to direct sunlight and artificial light were evaluated (Boerstra et al., 2013). In another study on '*the HOPE project*', the survey asked the occupants about the situation of their personal controls separately for '*control on shading from sun*' and '*control on lighting*' through a seven-point Likert scale changing from '*no control at all*' to '*full control*' (Bluyssen et al., 2011). In

LEED-certified office buildings, Lee and Guerin asked the users to choose their '*available personal lighting system control*' through the choices such as blinds and shading devices on the window (Lee and Guerin, 2010).

Personal control was among the questions related to lighting in the IEQ survey and long-term objective measurement study with 1000 valid surveys, which was carried out by Pei (Pei, 2015). In the study by Frontczak et al., the authors requested the residents to give feedback about their choices related to a difference in '*artificial light*', '*window opening*'and '*solar shading*' throughout choices '*manual*', '*automatic*' and '*combined*' (Frontczak et al., 2012).

The impact of '*amount of control over the daylighting*' and '*amount of control over the artificial lighting*' on user satisfaction were assessed by Hua et al. In terms of dissatisfaction; not having adequate sensitivity in the motion sensors, difficulty in operating the shading system, not having control regarding daylight and direct sunlight were listed in this study (Hua et al., 2011). De Giuli et al. evaluated behaviour of teachers related to operating the blinds with the scale '*never, sometimes and often*' (De Giuli et al., 2012). In his study, Konis evaluated the control of different lighting-related aspects such as '*overhead lighting*', '*task lighting*' and '*daylighting*' through a satisfaction-based seven-point Likert scale (Konis, 2013).

In the study at the public and private housing units, the general position of internal shading devices with the scale '*all drawn, drawn more than a half, drawn a half, drawn less than a half, not draw*' and the resident's main aim for using the internal shading device with the scale '*no shading, prevent direct light, prevent reflect light, prevent private, prevent heat*' were asked (Xue et al., 2014).

2.7.2.7 Criterion-7: Brightness

In the above-mentioned evaluation studies, users' satisfaction about '*reflections and contrast*' was asked (Kim and De Dear, 2013; Lee and Guerin, 2010; Altomonte and Schiavon, 2013).

Dahlan et al. aimed at understanding how the occupants assessed the brightness of their room through a seven-point Likert scale from '*dark*' to '*bright*' (Dahlan et al., 2009). In another study, if shadows appearing on the worksurface caused any dissatisfaction for the occupants were asked. Furthermore, '*too bright for computer work*' and '*too dark for paper-based tasks*' were listed among the aspects influencing the dissatisfaction (Hua et al., 2011).

2.7.2.8 Criterion-8: Distribution of light

Hua et al. asked occupants to rate their satisfaction considering distribution of daylighting and distribution of artificial lighting separately (Hua et al., 2011). Xue et al. requested the users to indicate their opinion on having uniform light distribution in their living rooms using the scale '*strongly disagree, disagree, just right, agree, strongly agree*' (Xue et al., 2014).

2.7.2.9 Criterion-9: Colour

Newsham et al. asked about the '*overall quality of colour scheme of the office*' using a seven-point scale between '*low*' and '*high*' (Newsham et al., 2009).

2.7.2.10 Criterion-10: Colour temperature

Hua et al. asked the users the impact of undesirable colour of the artificial lighting system on their dissatisfaction (Hua et al., 2011).

2.7.2.11 Criterion-11: Health, wellbeing and performance

The evaluation related to job satisfaction and performance was mostly carried out through the probe of general satisfaction. In Steemers and Manchanda's work, the impact of job satisfaction on overall satisfaction was evaluated (Steemers and Manchanda, 2010). Lee and Guerin asked the occupants how the lighting quality influenced their job performance using a seven-point Likert scale between '*enhances*' and '*interferes*' (Lee and Guerin, 2010).

User experience about supportive influence of visual environment and daylighting on work were appraised by Hua et al. (Hua et al., 2011).

In Collinge et al.'s evaluation, which included 48 respondents such as staff, undergraduate and graduate students, the impact of IEQ on productivity was assessed. Among the IEQ parameters, occupants considered that lighting and view-out had stronger positive impact on their productivity than thermal comfort, acoustics and air quality (Collinge et al., 2014).

Aries et al. assessed the impact of ‘*view quality*’, ‘*view type*’ and ‘*window distance*’ on ‘*physical andpsychological discomfort*’ including ‘*concentration problems*’, ‘*headache*’, ‘*bad vision*’ and ‘*dry eyes*’ and ‘*sleep quality’* variable (Aries et al., 2010).

2.8 Overview of the Literature Review: Guidance for This Research

The literature review of this PhD research demonstrated that occupant behaviour had a noteworthy contribution for the way the lighting systems performed. As a knowledge gap, the literature mentioned that furniture layout and occupant orientation were not considered in the occupant behaviour models (O’Brien and Gunay, 2014). In addition to this, adaptive behaviour is affective for modifying the environment and improving comfort. However, most of the adaptive behaviour studies concentrated on thermal comfort. How adaptive behaviour affected visual comfort was mentioned (Jakubiec and Reinhart, 2012; Keyvanfar et al., 2014; O’Brien and Gunay, 2014). However, how users perform adaptive behaviour in relation to architectural space and spatial layout has not been deeply researched. Moreover, in what way adaptive behaviour affected perception of space, mood and satisfaction has not been studied well.

Considering POE studies in the field of lighting; lighting, illuminance level, daylighting and artificial lighting systems, glare and lighting control systems were widely assessed. Based on the abovementioned research gaps, there is a need for a POE system in the field of lighting that includes adaptive behaviour in visual environment. The arguments for proposing a POE framework are systematic user assessment through standardisation, robust approach to interpret evaluation results and description of improvements. Moreover, a POE methodology would be efficient considering adaptive behaviour within a holistic frame. The holistic frame would evaluate parameters related to user, space, task and light.Standardisation of evaluation criteria, questionnaire items and scales used in POE studies on lighting can be valuable for comparing evaluation results and feedback of different buildings.

3. PILOT STUDIES ON POST-OCCUPANCY EVALUATION (POE) AND PERFORMANCE ANALYSIS OF LIGHTING SYSTEM

User satisfaction is an important aspect in buildings. POE, which contains user evaluations in the building they occupy, gains significance. Functions and tasks, occupants, occupancy times, visual comfort conditions of occupants and work plane change according to building typology. In offices, visual display units (VDUs) are significant.In classrooms and lecture halls, seeing blackboard is important. In museums and art galleries, exhibit'sperception is noteworthy. Lighting requirements, which determine visual comfort, differ. Parameters creating the visual environment are stated as luminance distribution, illuminance, directionality of light, variability of light, colour rendering, glare and flicker in "*EN12464-1:2011 Light and lighting - Lighting of work places - Part 1: Indoor work places*" Standard (2011). These measures create visual environment and differ in different building typologies. In order to assess visual environment in a building typology, diverse evaluation measures can be required in POE studies.

The report "*Post occupancy evaluation of daylight in buildings"* of IEA Solar Heating and Cooling (SHC) Task 21/ Energy Conservation in Buildings and Community Systems (ECBCS) Annex 29 (Hygge and Löfberg, 1999) recommends using questionnaires without removing questions for comparing buildings. Questions can be includedbased on evaluation parameters, i.e building attributes or daylight. Thus, typology-based aspects in relation to lighting can be considered.

The aim of pilot study-1 and pilot study-2, as field studies, was to propose occupant questionnaire, which evaluated the visual environment of different typologies in a consistent approach. Standardizingthrough common parameters and differingbased on function provided consistency and possibility of assessing typology specific lighting parameters. The questionnaire for occupants was proposed consisting of two different question sets: Standard questions contains questions common for all functions. Typology-based questions includetypology specific questions affecting requirements of lighting. The methodology of pilot study-1 and pilot study-2 contained three steps. In the first step, literature was reviewedfor determining common parameters and typology-based parameters evaluating visual environment. In the second step, the POE study was designed. This system contained the observation form for researchers, the proposed occupant questionnaire and the field measurements. The occupant questionnaire was proposed to evaluate typology-based lighting parameters on a standard base. The third step contained implementing and carrying out the evaluation system in the pilot study building in relation to the evaluated building typologies. In the pilot study-1, the occupant questionnaire was formed for education typology and the pilot study was carried out in the education spaces in Istanbul Technical University (ITU) Lecture Hall A Building. In the pilot study-2, the occupant questionnaire was developed for office typology. The field study was carried out in office spaces in pilot study building.

Following the building evaluation in POE studies, the next step is to recommend improvements in order to improve failures and enhance IEQ. That is why, pilot study-3 aimed at recommending improvements in relation to daylighting and artificial lighting systems. As the methodology, various interventions were designed in the educational spaces in pilot study-1. The impact of interventions on daylighting and artificial lighting performance were assessed through a simulation study.

3.1 Pilot Study-1: Post-occupancy Evaluation (POE) in Education Typology

The pilot study-1 included the implementation of the POE methodology to the education typology.

3.1.1 Post-occupancy evaluation (POE) methodology in the pilot study

The POE methodology was consisted of the observation form for researchers, the occupant questionnaire and the field measurements.

3.1.1.1 Observation form

The observation form was prepared and filled in throughout observing the architecture and lighting systems of the building. The architectural and electrical as-built projects have been also reviewed. The construction date of the building, the building typology and functions, the room orientation, the room dimensions and the interior surface materials were among the architectural parameters. As for the lighting system; the walls with windows, the window orientation, the window dimensions, the rooflight, the shading devices and the information of luminaires and lamps have been reviewed.

3.1.1.2 Occupant questionnaire

Satisfaction with the lighting system, health, impressions at the visual environment, glare from the windows and view-out are among the evaluation parameters that are in convenience with all building typologies (Hygge and Löfberg, 1999; Baird et al., 2012, Ander, 2003). The evaluation parameters, which are unique to education typology, are impact of daylighting and artificial lighting on student performance and view of board (Yang et al., 2013).

In the proposed questionnaire, the first set ‘Set-1 Standard Questions’ contain visual environment and visual comfort measures, which are common for all functions. These parameters have been identified through the conducted literature study. The standard parameters included age, gender, eye health condition, occupant’s general impression with the visual environment such as bright, dark, unevenly lit and good colours (Hygge and Löfberg, 1999), shadows and glare (Yang et al., 2013); satisfaction with lighting (Yang et al., 2013) (Baird et al., 2012), glare due to daylight and artificial light (Baird et al., 2012), view out (Newsham et al., 2012) (Ander, 2003) and health (Agha-Hossein et al., 2013) (Baird et al., 2012). In proposed questionnaire, these parameters were compiled under three titles in ‘Set-1 Standard Questions’ as ‘Personal’, ‘Lighting’ and ‘Health’. Related questions and scales have been formed accordingly:

- Under the ‘Standard-Personal’ title; age, gender and eye health condition;

- Under the ‘Standard-Lighting’ title; occupant’s general impression with the visual environment, satisfaction with lighting, glare due to daylight and artificial light, penetration of direct sunlight, colour temperature and view out;
- Under the ‘Standard-Health’ title; the relation between health (physiological and psychological) and visual environment were evaluated.

The second set ‘Set-2 Typology-based Questions’ contained lighting and visual comfort parameters specific to the evaluated typology, as supplementary of ‘Set-1 Standard Questions’. Typology-based questions for education typology were identified through the related literature as above-mentioned and ‘Set-2 Typology-based Questions’ was formed in pilot study-1. ‘Set-2 Typology-based Questions’ were consisted of four titles as ‘Personal’, ‘Lighting’, ‘Learning Performance’ and ‘Overall Evaluation’:

- Under the ‘Typology-Personal’ title; registered semester of student as occupant, course, lecture room and location of student in lecture room;
- Under the ‘Typology-Lighting’ title; illuminance levels on student desks and board, glare on student desks and board and satisfaction with daylighting and artificial lighting control systems;
- Under the ‘Typology-Learning Performance’ title; impact of daylighting system, artificial lighting system, sight of student desk and sight of board on learning performance;
- Under the ‘Typology-Overall Evaluation’ title, opinion of student regarding lighting conditions in lecture room were evaluated.

In ‘Set-1 Standard Questions’ under the ‘Standard-Lighting’ (except the general impression on the visual environment question) and ‘Standard-Health’ titles and in ‘Set-2 Typology-based Questions’ under ‘Typology-Lighting’ and ‘Typology-Learning Performance’ titles; 5-point Likert scale has been used. In addition, an overall evaluation question has been added as an open-ended question into ‘Set-2 Typology-based Questions’ under the ‘Typology-Overall Evaluation’ title.

3.1.1.3 Field measurements

As for the field measurements; horizontal illuminance levels on student desks, lecturer desks and vertical illuminance levels on board were measured by Konica Minolta T-10A illuminance meter.

3.1.2 The pilot study building and educational spaces

The pilot study building was Istanbul Technical University (ITU) Lecture Hall A Building in Ayazağa Campus, Istanbul (Figure 3.1). Having a total construction area 9200m^2, the architectural design was done by Prof. Hasan Şener, PhD and Prof. Ahsen Özsoy, PhD and completed in 2011. The architectural design has been awarded with the Building Category Success Award in 2014 National Architecture Awards (Mimarlık, 2014). This five-storey higher education building has a rectangular form. From exterior, the main element is the double-skin facade orientated towards southeast on long facade, southwest and northeast on short facades. The partially movable metal perforated panels are located on the outside of double-skin facade and provide diverse patterns according to their position. As the main lecture building of ITU, it contains café and retail spaces on ground floor and lecture rooms, seminar rooms and academic offices on the upper floors. The pilot study was conducted in the educational spaces of ITU Lecture Hall A Building in two consecutive days in March 2015. There are two types of educational spaces as lecture halls and seminar rooms. In the building, the lecture halls were coded with letter 'A' and the seminar rooms are coded with letter 'B'(Figure 3.2).

Figure 3.1 : ITU Lecture Hall A Building.

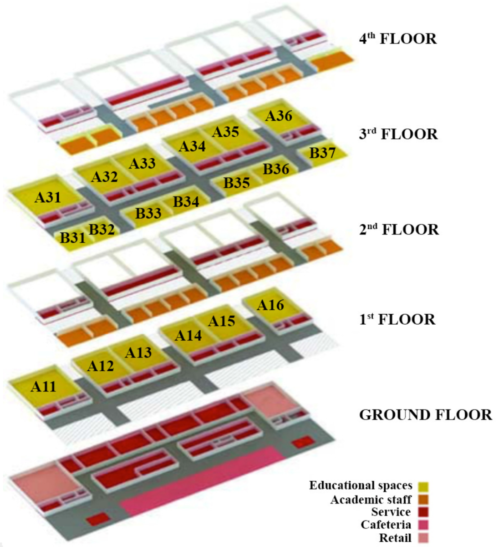


Figure 3.2 : The three-dimensional plan of ITU Lecture Hall A buildings (Mimarlık, 2014). The codes starting with the letter 'A' indicate the lecture halls and the letter 'B' indicate the seminar rooms (codes added by the author).

The architectural attributes and lighting systems of the lecture halls in ITU Lecture Hall A Building are given below (Figure 3.3):

- In ITU Lecture Hall A Building, there are twelve lecture halls. The lecture halls, which are two storeys high, are accessed from the 1st and 3rd floors.
- Theoccupantquestionnairestudywasconducted in threelecturehalls as A14, A33 and A36. Thefieldmeasurementswerecarriedout in twolecturehalls as A14 and A33.
- As being among the selected lecture halls, the lecture hall A14 on the 1st floor was 10.28 meter wide, 13.72 meter deep and 7.03 meter high. The lecture hall A33 on the 3rd floor was 10.23 meter wide, 13.72 meter wide and 7.03 meter high. The lecture hall A36 on the 3rd floor was 10.08 meter wide, 13.72 meter wide and 7.03 meter high.
- In terms of the internal surface materials in the lecture halls; the ceiling was metal sheet painted in dark colour, the walls had light colour paint and the cover of floorwas vinyl in medium colour.
- The furniture such as student and lecturer desks was in light colours. The furniture layout was consisted of the fixed linear student desks in rows together with the seats and the fixed linear lecturer desk in front of the board.

- As for the daylighting system, the side windows were 6.00 meter wide and 4.00 high. The windows were positioned towards the atriums, which were orientated towards north-west. There was not any shading device on the windows.
- As for the artificial lighting system, the linear fluorescent luminaires (2x58W) were aligned as three rows perpendicular to the board and controlled manually from the switch.

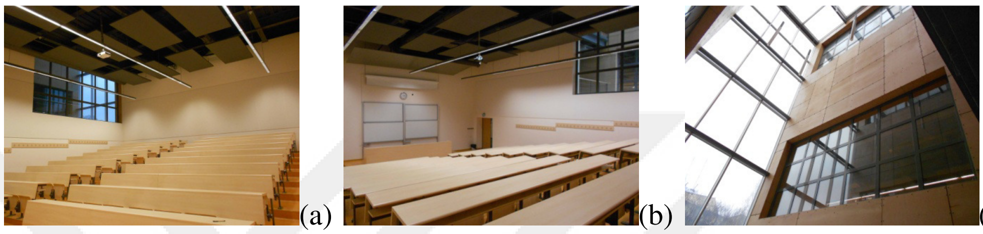

(a) (b) (c)

Figure 3.3 : The lecture halls in ITU Lecture Hall A Building: (a) and (b) The inner views of the lecture hall A14, (c) The side windows from the atrium.

The architectural attributes and lighting systems of the seminar rooms in ITU Lecture Hall A Building are given below (Figure 3.4):

- In ITU Lecture Hall A Building there are sevenseminar rooms, which are located on the 3rd floor.
- Theoccupantquestionnairestudywasconducted in sixseminarrooms as B31, B32, B33, B34, B35 and B36. Thefieldmeasurementswerecarriedout in twoseminarrooms as B31 and B36.
- As being among the selected seminar rooms, the seminar room B31 was 7.15 meter wide, 7.15 meter deep and 3.43 meter high. The seminar room B36 was 10.70 meter wide, 7.25 meter deep and 3.43 meter high.
- As for the internal surface materials in the seminar rooms; the ceiling was metal sheet painted in dark colour, the walls had light colour paint and the cover of floor was vinyl in medium colour.
- In terms of the furniture, the student desks were in dark colour and the lecturer desks were in light colour. The furniture layout, which was consisted of the desks and seats, was movable.

- As for the daylighting system, the double-skin facade of the seminar rooms was orientated towards south-east. The inside of double-skin facade was transparent glazing. The glazing was room-wide and 3.04 meter high. For the corner seminar rooms, the glazing covered the both walls. The outside of double-skin facade was the partially movable perforated metal panels as the solar control. The panels were manually controlled through the switches. The interior blinds were used to block daylight during the lectures when required.
- As for the artificial lighting system, linear fluorescent luminaires (2x58W) were located as two rows in parallel to the facade.


(a) (b) (c)

Figure 3.4 : The seminar rooms in ITU Lecture Hall A Building: (a) The inner view of theseminar room B31, (b) The inner view of the seminar room B33, (c) The inner view of the seminar room B36.

3.1.3 Results

The results include analyses of the occupant questionnaire and field measurements.

3.1.3.1 Analysis of the occupant questionnaire

The occupant questionnaire study was conducted in the lecture halls and seminar rooms. In total, 109 students participated into the questionnaire study in two consecutive days. The descriptive statistics was used for the evaluation of the questionnaires, in which the percentage and the weighted average of the responses were calculated (Agresti and Finlay, 2009). The weighted average was calculated through participant number who responded to related question.

The occupant questionnaire study was conducted in three lecture halls:in the lecture hall A14 on the 1st floor,in the lecture hall A33 on the 3rd floor on 9th March 2015 and in the lecture hall A36 on the 3rd floor on 10thMarch 2015 in the afternoons following maths courses. The students who were present in class in the survey dates responded to the questionnaire. The responses in three lecture halls (A14, A33 and

A36) were evaluated collectively. In the lecture halls, 69 students responded to the questionnaire. As the age and gender, 97% of the participants was below 29 years old and 71% of the participants was male. The percentage of the participants wearing either glasses or lens was 44.93%.

The responses to ‘Set-1 Standard Questions’ are given below (Figure 3.5):

- The participants’ general impression on visual environment indicated that majority of the participants evaluated the lecture halls as bright (57.97%).
- Satisfaction with the daylighting system in the lecture halls was close to neutral with the weighted average 2.77.
- Evaluation of glare and direct sunlight was positive with the weighted averages 4.16 and 3.76 respectively.
- The weighted average of the view out was 2.30.
- The participants stated that they were satisfied with artificial lighting system, colour temperature and glare in the lecture halls with the weighted averages 3.85, 3.84 and 3.66 respectively.
- Visual environment’s positive influence on health was stated with the weighted average 3.

Figure 3.5 : The weighted average of the student evaluation in the lecture halls related to ‘Set-1 Standard Questions’.

The responses to ‘Set 2 Typology-based Questions’ are given below (Figure 3.6):

- The students indicated that they were studying on the second semester on average.
- They evaluated illuminance level on student desk and board surfaces as adequate with the weighted averages 3.03 and 2.75 respectively.

- Reflections on student desk and board were rated as very scarce with the weighted average 3.24 and 3.11 respectively.
- The students indicated that sight of board had an impact on learning performance with the weighted average 4.03.
- In the overall evaluation; homogenous distribution of luminaires, warm colour as colour temperature, need to increase lighting of board and negative impact ofreflection on sight of board were stated.

Figure 3.6 : The weighted average of the student evaluation in the lecture halls related to illuminance level and reflection in 'Set-2 Typology-based Questions'.

The occupant questionnaire study was carried out in six seminar rooms as B31, B32, B33, B34, B35 and B36 on the 3rd floor on 10th March 2015 in the afternoon following various courses. The courses were related to film art, engineering and bio-chemistry. The responses in six seminar rooms (B31, B32, B33, B34, B35 and B36) were evaluated collectively. In the seminar rooms, 40 students responded to the questionnaire. All of the participants were smaller than 29 years old and the majority was male (53%). The percentage of the participants wearing either glasses or lens was 52.50%.

The responses to 'Set-1 Standard Questions' are given below (Figure 3.7):

- The participants' general impression on the visual environment indicated that half of the participants evaluated the seminar rooms as bright (50%).
- There was satisfaction with the daylighting system with the weighted average 3.60.
- Penetration of direct sunlight was indicated as sometimes with the weighted average 2.18.
- Glare was evaluated with the weighted average 3.45.
- View-out was evaluated with the weighted average 3.63.

- Evaluation of artificial lighting system, colour temperature and glare was positive with the weighted averages 3.60, 3.75 ve 3.53.
- The participants evaluated influence of visual environment on health as positive with the weighted average 3.23.

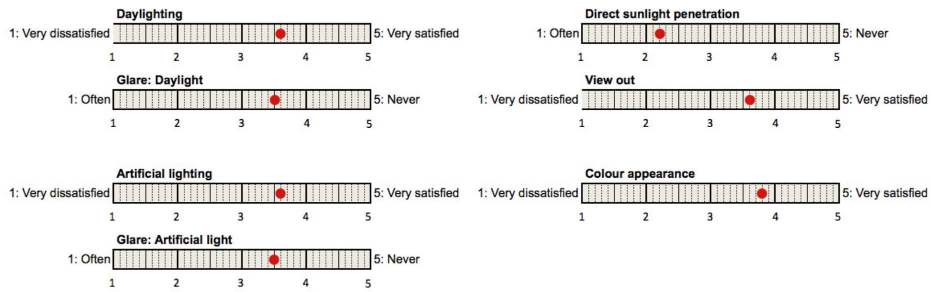


Figure 3.7 : The weighted average of the student evaluation in the seminar rooms related to 'Set-1 Standard Questions'.

The responses to 'Set 2 Typology-based Questions' are given below (Figure 3.8):

- The students indicated that they were studying in the seventh semester on average.
- Illuminance levels on student desk and board were adequate with the weighted averages 2.92 and 2.72 respectively.
- Reflection was very scarce on desk with the weighted average 3.28 and was close to never on board with the weighted average 2.53.
- The weighted average 3.33 of satisfaction with daylighting control system evidence that the students were satisfied with shading device.
- The students considered that sight of board had the largest impact on learning performance with the weighted average 3.68.
- In the overall evaluation, there were minor indications such as reflection due to artificial lighting system and shadow on desk.

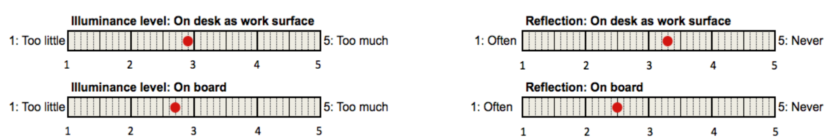


Figure 3.8 : The weighted average of the student evaluation in the seminar rooms related to illuminance level and reflection in 'Set-2 Typology-based Questions'.

3.1.3.2 Analysis of the field measurements

The field measurement study was conducted in two lecture halls as A14, A33 and in two seminar rooms as B31, B36 following the occupant questionnaire study. The illuminance levels were measured with Konica Minolta T-10A illuminance meter. The sky condition, under which all the measurements were done, was overcast sky. Daylighting and artificial lighting systems were measured together. Illuminance level measurements were carried out on the grid points on the work planes. The work planes were the student desk, the lecturer desk and the board. In the lecture halls (A14 and A33); the grid points were two ends of the longitudinal student desks, two ends and middle of the longitudinal lecturer desk and middle points of the board. In total, illuminance levels on 45 grid points were measured. In the seminar rooms (B31 and B36); the grid points were middle of every one desk (armchair with desk space) in two rows, two ends of the lecturer desk and middle points of the board. In total, illuminance levels were measured on 16 grid points in B31 as a corner seminar room and on 13 grid points in B36 as a middle seminar room.

For the measurements that were carried out in the lecture hall A33 on 9th March 2015 in the afternoon at 4.50pm, the illuminance levels on the student desks were measured between minimum 295 lux (E_{min}) and 447 lux (E_{max}). The average illuminance level on the student desks was calculated as 387 lux (E_{ave}). The average illuminance level on the lecturer desk was 303 lux (E_m). In the lecture hall A14 on 9th March 2015 in the afternoon at 5.15pm, the illuminance levels were measured between minimum 269 lux (E_{min}) and maximum 413 lux (E_{max}). The average illuminance level on the student desk was calculated as 357 lux (E_{ave}). The average illuminance level on the lecturer desk was 294 lux (E_{ave}). The average vertical illuminance level on the board was 155 lux (E_{ave}).

During the measurements in the seminar rooms, the exterior perforated metal panels were closed and the interior blinds were totally open. In the seminar room B31 on 10th March 2015 in the afternoon at 4.32pm, the illuminance levels on the student desks were measured between minimum 193 lux (E_{min}) and maximum 581 lux (E_{max}). The average illuminance level on the student desks was calculated as 389 lux (E_{ave}). The average illuminance level on the lecturer desk was 344 lux (E_{ave}). The average vertical illuminance level on the board was 140 lux (E_{ave}). In the seminar room B36 on 10th March 2015 in the afternoon at 5.03pm, the illuminance levels on the student desks were measured between minimum 186 lux (E_{min}) and maximum 563 lux (E_{max}). The average illuminance level on the student desks was calculated as 425 lux (E_{ave}). The average illuminance level on the lecturer desk was 343 lux (E_{ave}). The average vertical illuminance level on the board was 163 lux (E_{ave}).

3.1.4 Discussion and conclusion

This pilot study aimed at assessing POE in relation to lighting and evaluating different typologies in a consistent way. With this approach, the occupant questionnaire was proposed containing two sets as standard question set and typology-based question set. In the pilot study-1, education typology was evaluated. In ITU Lecture Hall A Building, half of students in seminar rooms and more than half of students in lecture halls evaluated the rooms as bright. Satisfaction with daylighting system increased in seminar rooms. In spite of the existence of direct sunlight from time to time in seminar rooms, disturbing glare due to daylighting was indicated as very scarce. It is possible to indicate positive impact of solar control, which had movable exterior and interior components, on the former evaluation. Sight of board was evaluated as adequate both in lecture halls and seminar rooms. Impact of board sight on learning performance was high (with the largest weighted average) in both types of classes. Satisfaction with view-out was higher in seminar rooms, in which there was a larger view-out when compared to lecture halls.

The minimum illuminance level 300 lux, which was indicated by the EN 12464-1 Standard for learning spaces, was maintained both in the lecture halls and the seminar rooms (EN 12464-1, 2011). However; the minimum illuminance level 500 lux, which was recommended for the lecture halls and adult education, was not provided. The illuminance level on the board was below the recommended level in the EN 12464-1 Standard (EN 12464-1, 2011). Nevertheless, the students evaluated it as adequate.

Through POE studies, occupants can assess the visual comfort conditions and the visual environment in the spaces they occupy. This evaluation provides to determine the positive attributes, to identify the problematic issues, to develop solutions and to compare the performance of different buildings. In the related literature, it was indicated to use standard evaluation procedure for different buildings by adding evaluation items based on building attributes. That is why, the pilot study-1 and pilot study-2 aimed at evaluating different building typologies with a standard methodology. For the pilot study-1, education typology was evaluated. The occupant questionnaire was proposed as two sets, which contain standard questions and typology-based questions separately. As evaluating the education typology, the students assessed their classrooms in relation to lighting, health and learning performance. The application and analysis of this first study provides guidance for applying this approach to different building typologies.

3.2 Pilot Study-2: Post-occupancy Evaluation (POE) in Office Typology

The pilot study-2 included the implementation of the POE methodology to the office typology.

3.2.1 Occupant questionnaire

In the pilot study-2, office typology was chosen for POE study regarding to lighting. A questionnaire was compiled containing standard questions that are common for all typologies under 'Set-1 Standard Questions' and office typology related questions under 'Set-2 Typology-based Questions'. 'Set-1 Standard Questions' are same with the standard questions in pilot study-1. However, the questions under 'Set-2 Typology-based Questions' were compiled based on office typology while they were compiled based on education typology in pilot study-1.

In order to include in 'Set-2 Typology-based Questions', the parameters related to office typology were identified through literature. These parameters contained information related to office type, workplace position (Altomonte and Schiavon, 2013) (Ander, 2003) (Baker and Steemers, 2002), VDU use and position (Baker and Steemers, 2002), adequacy of illuminance level on desk and VDU (Newsham et al., 2012) (Ander, 2003) (Hygge and Löfberg, 1999), disturbing reflections on desk and VDU (Ander, 2003) (Hygge and Löfberg, 1999), satisfaction with lighting control

(Fowler, 2011) and relation between performance and lighting (Yang et al., 2013) (Lee and Guerin, 2010). In the proposed questionnaire, these parameters were compiled under the three titles in ‘Set-2 Typology-based Questions’ as ‘Typology-Personal’, ‘Typology-Lighting’ and ‘Typology-Job Performance’.

In ‘Set-1 Standard Questions’ under ‘Standard-Lighting’ (except the general impression on the visual environment question) and ‘Standard-Health’ titles and in ‘Set-2 Typology-based Questions’ under ‘Typology-Lighting’ and ‘Typology-Job Performance’ titles; 5-point Likert scale was used. In addition, an overall evaluation question was added as an open-ended question into ‘Set-2 Typology-based Questions’ under ‘Typology-Overall Evaluation’ title.

3.2.2 Office spaces in the pilot study building

POE study in office typology was carried out in the academic offices of Istanbul Technical University Lecture Hall A Building in Ayazaga Campus, Istanbul. The evaluation was conducted in two consecutive days in May 2015. The academic offices were located on the 2nd and 4th floors.In the building, the offices were coded with letter ‘B’ (Figure 3.9).

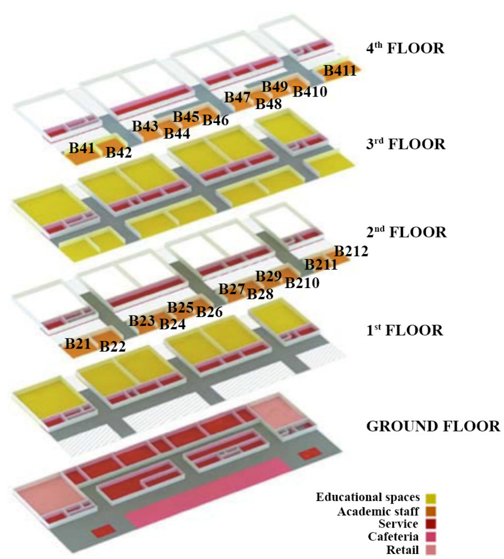


Figure 3.9 : The three-dimensional plan of ITU Lecture Hall A Building (Mimarlık, 2014). The codes starting with the letter ‘B’ indicate the offices (codes added by the author).

The architectural attributes and lighting systems of the office spaces in ITU Lecture Hall A Building are given below (Figure 3.10):

- There were twenty-three academic offices on the 2nd and 4th floors with a linear layout opening to the linear circulation corridor. The offices were research offices, academic staff offices, department offices and meeting rooms either private or shared offices for two, three, five and seven people.
- The occupant questionnaire study was carried out in twelve offices as B21, B22, B24, B27, B28, B29, B210 and B211 on the 2nd floor and B42, B44, B49 and B411 on the 4th floor. The field measurements were carried out in two offices as B22 on 2nd floor and B411 on 4th floor.
- Related to the colour of interior surfaces and furniture; ceiling was metal sheet painted in dark colour, walls were painted in light colour and floor was covered with vinyl in medium colour.
- The furniture, such as desks were in light colour.
- As for the daylighting system, most of the offices (19 offices) were intermediate offices and had one fully-glazed wall. The corner offices on both floors (4 offices) had two fully-glazed walls as the double-skin facade. The solar control was provided with the exterior partially movable perforated metal panels as outside of double-skin facade. Movable panels could be controlled through the switch on wall inside the office. In one of the offices (B22), interior blind use was observed.
- As for the artificial lighting system, linear lighting luminaires was located as two rows parallel to the double-skin facade.

3.2.3 Results

The results contain the analyses of the occupant questionnaire and field measurements.

3.2.3.1 Analysis of the occupant questionnaire

The occupant questionnaire study was carried out on 14th May 2015 and 15th May 2015 in the afternoons. For evaluating the questionnaires, descriptive statistics was used.The weighted average and the percentage of the responses were calculated

(Agresti and Finlay, 2009).The calculation of the weighted average was done through the total number of people answered the related question.


(a)


(b)

Figure 3.10 : The offices in ITU Lecture Hall A Building: (a) The intermediate office B22 on 2nd floor with exterior movablemetal panels as closed (left) and open (right), (b) The corner office B411 on 4th floor with exterior movable panels as closed (left) and open (right).

The participants responded the questionnaires in twelve academic offices as B21, B22, B24, B27, B28, B29, B210 and B211 on the 2nd floor and B42, B44, B49 and B411 on the 4th floor. The responses in the academic offices were evaluated collectively. In total, 20 people working in the academic offices participated to the study. In terms of demographics, half of the participants were between age 21 and 29 (50%). The majority of the participants were male (60%) and wore either glasses or lens (65%).

The responses to 'Set-1 Standard Questions' are given below (Figure 3.11):

- The participants' general impression on visual environment of the space they occupy indicated that majority of the participants evaluated their office spaces as bright (70%).
- The participants indicated that they were satisfied with daylighting in their offices with the weighted average 4.16.
- Glare due to daylight was evaluated as rare with the weighted average 3.05.
- View out was evaluated close to very satisfying with the weighted average 4.65.

- The participants indicated penetration of direct sunlight as often with the weighted average 1.40.
- In terms of artificial lighting, the weighted average 4.16 pointed out satisfaction of participants.
- The evaluation of glare from artificial lighting was between very rare and never with the weighted average 4.53.
- Colour temperature of artificial lighting was satisfactory with the weighted average 4.16.

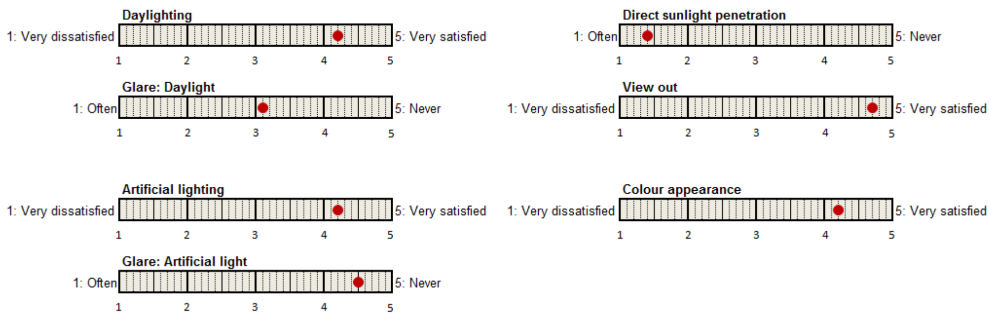


Figure 3.11 : The weighted average of the staff evaluation in the offices related to 'Set-1 Standard Questions'.

The responses to 'Set-2 Typology-based Questions' are given below (Figure 3.12):

- The current occupations of the participants were indicated as researcher, academic staff and administrative staff. The researchers contained postgraduate students (master and PhD students), post-docs and software developers.
- The duration they were working in office spaces they occupy was 15 months on average.
- Most of the participants occupied shared offices.
- In their offices, position of their work place was mostly along perimeter of rooms. Majority of occupants were working as perpendicular to facade with VDU positioned perpendicular to facade.
- The participants evaluated illuminance level on desk and on VDU as adequate with the weighted averages 3.20 and 3.35 respectively.

- Disturbance due to reflection on VDU surface was evaluated more than reflection on desk. Both were rare with the weighted averages 3.06 and 3.65 respectively.
- The participants' responses showed their satisfaction with daylighting and artificial lighting controls. The weighted averages were 4.17 and 4.21 respectively.
- Sight of VDU with the weighted average 4.40 and affected job performance most.

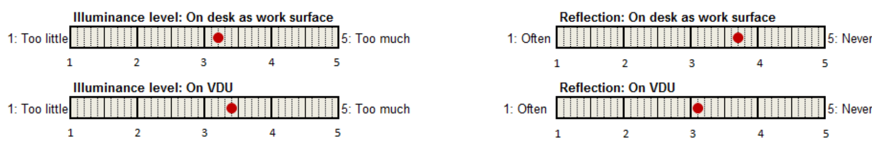


Figure 3.12 : The weighted average of the staff evaluation in the offices related to illuminance level and reflection in 'Set-2 Typology-based Questions'.

3.2.3.2 Analysis of the field measurements

The field measurements of the illuminance level were carried out in B22 on 2nd floor as an intermediate office and B411 on 4th floor as a corner officeright after the participants filled in the questionnaire. The measurements were carried out on 14th May 2015 in the afternoon at 4.36 pm in B22 and at 5.10 pm in B411. The sky condition, under which all the measurements were done, was clear sky. The daylighting and artificial lighting systems were measured together. The exterior movable metal panels were in closed position. The interior blind observed in B22 was fully open. The illuminance level measurements were carried out on the grid points on the work planes. The work plane was the desk of the participant. In the offices (B22 and B411); six grid points were determined on each main desk and four grid points were determined on each side desk. In total, illuminance levels were measured on 30 grid points in B22 as a middle office and on 46 grid points in B411 as a corner office.

In the office B22, the illuminance levels on the Desk 1 along the glazed facade were measured between 690 lux (E_{min}) and 823 lux (E_{max}) on. The average illuminance level was calculated as 764 lux (E_{ave}). The illuminance levels on the Desk 2 along the glazed facade were measured between 630 lux (E_{min}) and 801 lux (E_{max}). The average illuminance level was calculated as 722 lux (E_{ave}). The illuminance levels on the Desk 3 along the back wall opposite the glazed facade were between 407 lux (E_{min}) and 671 lux (E_{max}). The average illuminance level was calculated as 559 lux (E_{ave}).

In the office B411, the illuminance levels on the Desk 1 on the corner of two glazed facades (long-side and short-side) were measured between 577 lux (E_{min}) and 738 lux (E_{max}). The average illuminance level was calculated as 643 lux (E_{ave}). The illuminance levels on the Desk 2 were measured between 470 lux (E_{min}) and 734 lux (E_{max}). The average illuminance level was calculated as 621 lux (E_{ave}). The illuminance levels on the Desk 3 were measured between 444 lux (E_{min}) and 686 lux (E_{max}). The average illuminance level was calculated as 604 lux (E_{ave}). The illuminance levels on the Desk 4 were measured between 652 lux (E_{min}) and 675 lux (E_{max}). The average illuminance level was calculated as 664 lux (E_{ave}). The illuminance levels on the Desk 5 were measured between 550 lux (E_{min}) and 694 lux (E_{max}). The average illuminance level was calculated as 643 lux (E_{ave}). The illuminance levels on the Desk 6 in the centre of the room were measured between 540 lux (E_{min}) and 598 lux (E_{max}). The average illuminance level was calculated as 577 lux (E_{ave}). The illuminance levels on the Desk 7 along the back wall opposite of long-side glazed facade were measured between 613 lux (E_{min}) and 700 lux (E_{max}). The average illuminance level was calculated as 649 lux (E_{ave}).

3.2.4 Discussion and conclusion

Approach for evaluating visual environment of different building typologies was applied in office typology.

The researchers, the academic staff and the administrative staff working in the academic offices in Istanbul Technical University Lecture Hall A Building responded to questionnaire as participants. The participants evaluated the view out in the offices as very satisfying. The daylighting and artificial lighting systems provided satisfaction. The glare from artificial light was described as occurring rarer than the glare from daylight. This could be due to the penetration of direct sunlight, which was stated by the participants. The illuminance levels, both on the desk and the

VDU, were evaluated as adequate. The reflection on the VDU was evaluated as occurring more than the reflection on the desk. In terms of the job performance, the sight of the VDU had the largest impact. This was due to the fact that all participants used the VDU during working for most of the time. In the overall evaluation; the participants mentioned having maximum benefit from daylight and recommended larger apertures on the exterior metal panel when they opened it together with the use of interior blind.

The field measurements supported the participant evaluations on satisfaction and adequacy of light. The average illuminance levels on all measured desks provided the illuminance level 500 lux recommended for offices (reading, writing and data processing tasks) by the EN12464-1 Standard (EN12464-1, 2011).

Occupying a recently constructed building, having office spaces designed for this function and implementing innovative and technological systems (i.e. exterior partially movable metal panels as the solar control) resulted in the overall positive comments of the staff working in these academic offices. The participants mentioned glare from daylight as a result of the perforation on the exterior metal panels. The use of interior blinds was recommended in addition to the panels.

Following the pilot study-1 in education typology, distinguishing evaluation criteria of visual environment according to building typology resulted in considering typology-related lighting requirements and visual comfort conditions. Implementing this evaluation on a standard base provides consistency between different typologies. This is significant for POE of lighting as occupants are able to indicate their evaluation on visual comfort conditions, visual environment, problematic issues and make recommendations considering the typology they occupy.

3.3 Pilot Study-3: Analysis of Lighting System Performance

Studies that obtain information on user experience regarding to the lighting system's performance are significant as user satisfaction can be provided accordingly. Related to this, obtaining the information on user experience through these studies is noteworthy when analysing the performance of the lighting system.

This pilot study aimed at analysing the performance of the lighting system in the case study building following a formerly conducted POE study that focused on obtaining the user experience on the lighting system. Daylighting system and artificial lighting system were analysed. The methodology consisted of determining the design parameters for each system and developing different scenarios evaluating the determined parameters. Using the lighting simulation software DIALUX, the illuminance levels on the determined work planes were calculated and compared considering the project information and the generated scenarios. It was observed that the parameters resulted in distinct impacts on the performance of daylighting and artificial lighting systems.

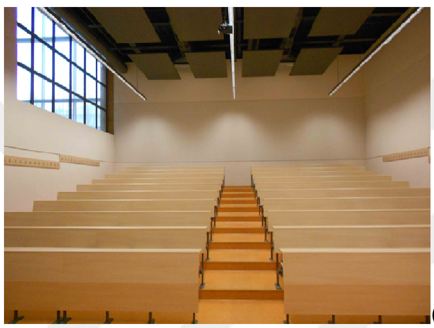
3.3.1 The pilot study

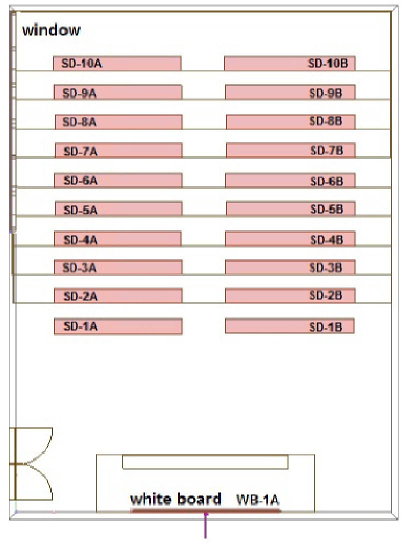
Istanbul Technical University (ITU) Lecture Hall A Building in the Ayazağa Campus (Maslak, Istanbul) has been evaluated as the case study building. As the first phase, a POE study was conducted in the lecture halls and seminar rooms of this case study building in March 2015 in order to obtain the evaluation of the students on the existing daylighting and artificial lighting systems. When the students were asked about the general impression related to the visual environment in the lecture halls in the former POE study, more than half of them evaluated the lecture halls as bright. Some of their general evaluations indicated that little light entered from the window and illumination of the board could be increased (Kaçel and Yener, 2015).

Based on the user evaluations obtained from the POE study in the pilot study-1, the performances of the lighting systems in the lecture halls were analysed in the pilot study-3. The width of the lecture hall studied in this paper was 10.28m, the depth was 13.72m and the height was 7.03m. The illuminance levels on the work planes in the lecture hall were calculated for the evaluation the lighting system performance considering the selected parameters. As the work planes, horizontal plane was assigned on the student desk (SD) surface and vertical plane was assigned on the white board (WB) surface on the wall opposite the desk rows (Figure 3.13).

The illuminance levels were calculated through the daylight simulation and artificial light simulation using the validated lighting simulation software DIALUX

(DIALUX, 2016). The daylight simulation was carried out for the Equinox date 23thMarch at noon. The International Commission on Illumination (Commission Internationale de l´Eclairage - CIE) intermediate sky model was used in the daylight simulation.


(a)



(b)

Figure 3.13 : The studied lecture hall: (a) The inner view,
(b) The representation of the workplanes used in the simulation study on the plan generated by DIALUX (diagram by the author).

3.3.2 Design parameters used in the pilot study

The design parameters, which have impact on providing the visual comfort conditions in the built environment, are defined as "*sky luminance distribution and illuminance; position of the sun, its impact on the luminance and illuminance; ground reflectance; dimension, location and reflectance of external obstructions (natural-artificial); window orientation; dimension, form and location of windows; light transmittance of windows; room dimensions; light reflectance of internal surfaces; qualitative and quantitative attributes of artificial light sources; qualitative and quantitative attributes of luminaires; location of artificial light sources or luminaires; equipment and control system of artificial lighting system*" (Küçükdoğu, 1982, p. 58-59).

Among the design parameters indicated in the scholar literature, three design parameters related to the daylighting system and three design parameters related to the artificial lighting were selected. The impact of the selected design parameters on the performance of the daylighting system and artificial lighting system in the studied lecture hall were evaluated. As the design parameters related to the daylighting system; dimension of window, light transmittance of window glazing and reflectance of internal surfaces were investigated. As the design parameters related to the artificial lighting system; type and specifications of lamp, type of luminaire and reflectance of internal surfaces were under consideration (Figure 3.14).

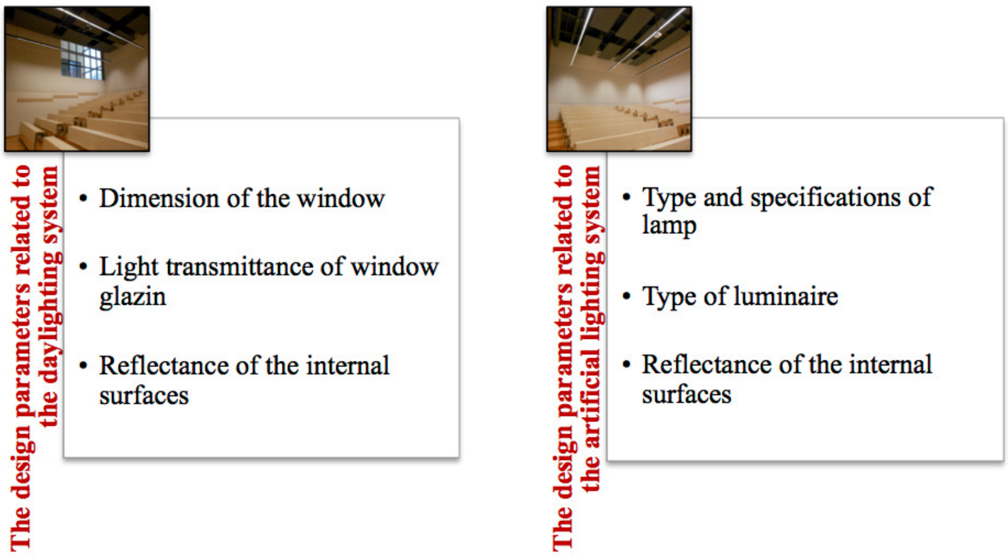


Figure 3.14 : The design parameters for the daylighting and artificial lighting systems analysed in this pilot study.

In the studied lecture hall in this pilot study, there was one side window looking towards the glazed gallery space between the two lecture halls. The dimension of the window was indicated 6.00m (width) and 4.00m (height) as the information on the project drawings. The light transmittance of the glazing was considered as 71% with the guidance of the manufacturer catalogue information for the type of glazing used in the building. The information for the artificial lighting system was indicated as linear 58W fluorescent luminaire on the project drawings. With the guidance of manufacturer catalogue information, direct linear 58W fluorescent luminaire providing luminous flux of 5240lm was evaluated in the artificial light simulation. The reflectance of internal surfaces were considered as 20% for the ceiling (ceiling material: metal sheet painted in dark colour), 73% for the walls (wall material: paint in light colour) and 46% for the floor (floor material: vinyl covering in medium colour) as a result of the materials determined during observing the lecture hall.

In this pilot study considering a lecture hall two evaluation matrices were generated, one of which focused on the daylighting system and the other one focused on the artificial lighting system, in order to investigate the impact of selected design parameters of the systems' performances. Each matrix contained four different scenarios by changing the design parameters. In the evaluation matrices, the grey-coloured boxes indicated the project information and the diagonally-hatched boxes indicated the changed design parameters:

- The evaluation matrix for the daylighting (DL) system (Figure 3.15):
  - Scenario *DL-1*: The dimension of the window 8.00m (width) x 3.00m (height)
  - Scenario *DL-2*: The light transmittance of the glazing 79%
  - Scenario *DL-3*: The reflectance of the ceiling 80%
  - Scenario *DL-4*: The simultaneously change of the above-mentioned three design parameters
- The evaluation matrix for the artificial lighting (AL) system (Figure 3.16):
  - Scenario *AL-1*: The type and power of lamp 40W light-emitting diode (LED) luminaire providing 4200lm luminous flux
  - Scenario *AL-2*: The type of luminaire as direct and indirect
  - Scenario *AL-3*: The reflectance of the ceiling 80%
  - Scenario *AL-4*: The simultaneously change of the above-mentioned three design parameters

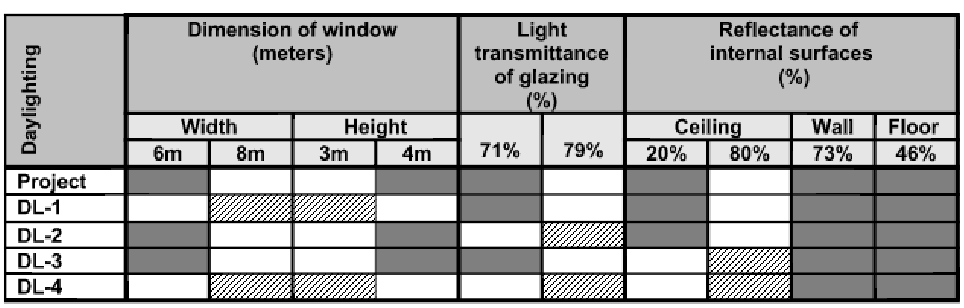


Figure 3.15 : The evaluation matrix for the design parameters of the daylighting system analysed in this pilot study.

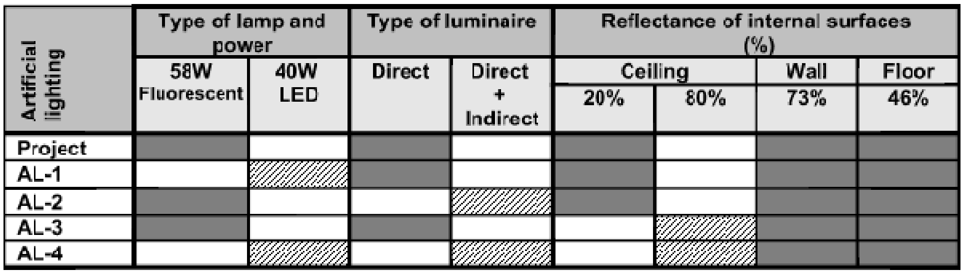


Figure 3.16 : The evaluation matrix for the design parameters of the artificial lighting system analysed in this pilot study.

As explaining the scenarios in detail, the scenario *DL-1* provided a longer window towards the middle of the lecture hall but kept the same window area as given on the project information. The scenario *DL-2* provided a higher light transmittance value chosen from the same manufacturer's catalogue information. The scenario *DL-3* applied the average of the recommended reflectances for the ceiling as between 70% and 90% in the EN 12464-1 (EN 12464-1, 2011). The scenario *DL-4* evaluated the impact of all three parameters within the evaluation matrix of the daylighting as a result of changing the parameters simultaneously. The scenario *AL-1* underlined a luminaire with less lighting power consumption when compared with the project information. The scenario *AL-2* considered the impact of artificial light reflecting from the ceiling surface. The scenario *AL-3* applies the same target as explained in the scenario *DL-3*. The scenario *AL-4* evaluated the impact of all three parameters within the evaluation matrix of the artificial lighting as a result of changing the parameters simultaneously.

3.3.3 Evaluation of the lighting system

The evaluation of the lighting system contains the evaluations of the daylighting system and artificial lighting system.

3.3.3.1 Evaluation of the daylighting system

In the evaluation of the daylighting system performance; minimum (E_{min}), average (E_{ave}) and maximum (E_{max}) illuminance levels on the work planes in the lecture hall were analysed (Table 3.1). The work planes were considered as being on the student desks and the white board on the wall.

Table 3.1 : The average illuminance levels (E_{ave}) on the student desks and white board in terms of the daylighting system.

Workplanes	Average illuminance levels (E_{ave})				
	Project	DL-1	DL-2	DL-3	DL-4
SD-1A	147	282	182	203	433
SD-1B	127	180	157	180	303
SD-2A	212	394	263	272	577
SD-2B	142	195	176	199	329
SD-3A	304	494	376	370	709
SD-3B	159	220	197	221	367
SD-4A	468	620	579	537	867
SD-4B	180	237	224	244	384
SD-5A	612	745	757	685	1028
SD-5B	192	243	238	262	396
SD-6A	732	885	907	809	1204
SD-6B	205	250	255	275	405
SD-7A	885	993	1096	962	1343
SD-7B	208	253	258	279	412
SD-8A	1015	1086	1259	1092	1455
SD-8B	213	247	265	280	400
SD-9A	1121	1166	1391	1196	1553
SD-9B	205	236	255	267	382
SD-10A	1211	1234	1504	1286	1635
SD-10B	201	230	249	263	372
WB-1A	95	113	117	124	183

Workplane on the student desks for daylighting

In the evaluation of the project information named as the *Project*, the average illuminance levels on the student desks on the window wall side (indicated with the work planes *A*) were higher than the average illuminance levels on the student desks opposite the window wall (indicated with the work planes *B*). This proved the contribution of the side window on the illuminance levels. The average illuminance levels on the student desks on the window wall side from the middle of the lecture hall towards the upper levels (from the work plane *SD-5A*) provided the maintained illuminance level 500 lux given by the EN 12464-1 in order to provide the visual comfort conditions in adult education and lecture halls. This given illuminance level could not be provided on the student desks opposite the window wall.

In the scenario *DL-1* evaluating the change in the dimension of the window, the width of the window was enlarged towards the middle of the lecture hall. The illuminance levels on the student desks both on the window wall side and opposite the window wall in- creased. The average illuminance levels on the student desks on the window wall side provided 500 lux starting from the work plane *SD-4A*. The scenario *DL-2* was about the light transmittance of the window glazing and more effective for increasing the illuminance levels provided in the *Project* than the scenario *DL-1*, starting from the middle of the lecture hall towards the up- per levels (from the work plane *SD-5A* for the student desks on the window wall side and the work plane *SD-6B* for the student desks opposite the window wall). In the scenario *DL-3*, which focused on the reflectance of the ceiling, a similar pattern was observed with the scenario *DL-1* in terms of the increase in the illuminance levels. It has been seen that the scenario *DL-4* changing the dimension of the window, the light transmittance of the glazing and the reflectance of the ceiling simultaneously has the largest impact on the illuminance levels. The average illuminance levels on the student desks on the window wall side was calculated as 577 lux (E_{ave}) on the work plane *SD-2A* and increased towards the upper levels of the lecture hall. The maintained illuminance level 500 lux given in the EN 12464-1 was not provided on the student desks opposite the window wall. The maximum illuminance level on the work plane *SD-6B* was calculated as 542 lux (E_{max}) and increased towards the upper levels of the lecture hall. When all the student desks were evaluated, the average illuminance level was calculated as 427 lux (E_{ave}) in the *Project*. In the scenarios providing the maintained illuminance 500 lux given in the EN 12464-1, the average illuminance level was calculated as 510 lux (E_{ave}) in the scenario *DL-1*, 529 lux (E_{ave}) in the scenario *DL-2* and 728 lux (E_{ave}) in the scenario *DL-4*.

Workplane on the white board for daylighting

The illuminance levels on the white board were evaluated (*WB-1A*). Starting from the scenario *DL-1*, each scenario increased the illuminance levels on the white board gradually. Having the largest impact, the average illuminance level was calculated as 183 lux (E_{ave}) in the scenario *DL-4*. The maintained illuminance 500 lux given in the EN 12464-1 for the boards could not be obtained on the white board surface.

3.3.3.2 Evaluation of the artificial lighting system

In the evaluation of the artificial lighting system performance; minimum (E_{min}), average (E_{ave}) and maximum (E_{max}) illuminance levels on the student desks and the white board on the wall were analysed as in the daylighting system evaluation (Table 3.2).

Table 3.2 : The average illuminance levels (E_{ave}) on the student desks and white board in terms of the artificial lighting system.

Workplanes	Average illuminance levels (E_{ave})				
	Project	AL-1	AL-2	AL-3	AL-4
SD-1A	631	788	465	735	639
SD-1B	643	796	472	749	640
SD-2A	652	803	478	758	658
SD-2B	667	812	487	774	661
SD-3A	663	809	486	770	670
SD-3B	681	823	497	791	677
SD-4A	666	809	488	770	666
SD-4B	687	826	500	794	683
SD-5A	659	803	484	763	657
SD-5B	684	822	500	792	682
SD-6A	641	786	472	740	638
SD-6B	671	812	494	775	675
SD-7A	616	766	458	711	615
SD-7B	647	793	482	748	652
SD-8A	576	733	432	668	588
SD-8B	607	761	458	706	628
SD-9A	514	671	394	596	536
SD-9B	544	699	420	638	573
SD-10A	445	579	346	524	470
SD-10B	473	605	372	565	508
WB-1A	285	328	219	347	292

Workplane on the student desks for artificial lighting

In the evaluation of the project in- formation named as the *Project*, it has been seen that most of the average illuminance levels on the student desks provided the maintenance illuminance 500 lux indicated in the EN 12464-1.

In the scenario *AL-1* that evaluated the type of lamp and power as 40W LED, all the average illuminance levels on the student desks increased when compared with the *Project* and provided the maintained illuminance 500 lux given in the EN 12464-1. The average illuminance level on the work plane *SD-1A* in the *Project* as 631 lux (E_{ave}) was calculated as 788 lux (E_{ave}) in the scenario *AL-1*. The scenario *AL-2* considered the impact of the direct and indirect luminaire on the artificial lighting performance. Due to the light reflected towards the dark-coloured ceiling with the reflectance 20%, the illuminance levels on the student desks decreased when compared with the *Project*. The number of student desks providing the maintained illuminance 500 lux largely decreased. The scenario *AL-3*, which increased the reflectance of the ceiling as 80%, had less impact than the scenario *AL-1*. However, the scenario *AL-3* increased the illuminance levels on the student desks when compared with the *Project*. All the student desks provided the maintained illuminance 500 lux given in the EN 12464-1. In the scenario *AL-4* evaluating the type of lamp and power, the type of the luminaire and the reflectance of the ceiling simultaneously, the illuminance levels increased when compared with the *Project*. Nevertheless, the scenario *AL-4* was less effective than the scenarios *AL-1* and *AL-3*. Except of one number of student desk, the maintained illuminance 500 lux given in the EN 12464-1 was obtained.

When all the student desks were evaluated, the average illuminance level was calculated as 618 lux (E_{ave}) in the *Project*. In the scenarios providing the maintained illuminance 500 lux given in the EN 12464-1, the average illuminance was calculated as 765 lux (E_{ave}) in the scenario *AL-1*, 718 lux (E_{ave}) in the scenario *AL-3* and 626 lux (E_{ave}) in the scenario *AL-4*.

Workplane on the white board for artificial lighting

The illuminance levels on the white board (*WB-1A*) were evaluated. The scenarios *AL-1*, *AL-3* and *AL-4* in- creased the illuminance levels. As the most effective scenario, the average illuminance level was calculated as 347 lux (E_{ave}) in the scenario *AL-3*. The maintained illuminance 500 lux given in the EN 12464-1 could not be obtained on the white board surface.

3.3.4 Discussion and conclusion

The performances of the daylighting system and artificial lighting system were evaluated by considering different design parameters in the lecture halls of ITU Lecture Hall A Building as the case study building. In terms of the daylighting system in the project, the side window provided higher illuminance levels on the student desks on the window wall side than on the desks opposite the window wall. The highest increase in the illuminance levels on the student desks as the work plane was provided by the simultaneous change of the three design parameters as the dimension of the window, the light transmittance of the glazing and the reflectance of the ceiling. However, the maintained illuminance 500 lux given for the lecture halls in the EN 12464-1 could not be provided by the average illuminance levels on the student desks opposite the window wall. The average illuminance level on all the student desks opposite the window wall was calculated as 375 lux (E_{ave}) and the average illuminance level on all the student desks on the window wall side was calculated as 1080 lux (E_{ave}).

The impact of the scenarios generated for the artificial lighting system was evaluated. The scenario changing the type and power of lamp as 40W LED was the most effective configuration on the increase in the illuminance levels on the student desks. The average illuminance level on all the student desks on the window wall side was calculated as 755 lux (E_{ave}) and the average illuminance level on all the student desks opposite the window wall was calculated as 775 lux (E_{ave}). Having an uniformity ratio 0.64 in the studied lecture hall, the uniformity ratio 0.60 given for the lecture halls in the EN 12464-1 was provided. In addition, comparing the performance of the 58W fluorescent luminaire and 40W LED luminaire showed the higher illuminance levels obtained with less lighting power consumption. This underlines the significance of energy efficient lighting approach.

None of the scenarios regarding to the daylighting system and artificial lighting system provided the maintained illuminance 500 lux given for the white boards in the EN 12464-1. As the highest values, the average illuminance level 183 lux (E_{ave}) was calculated in the daylighting system analysis when the all three design parameters were changed and the average illuminance level 347 lux (E_{ave}) was calculated in the artificial lighting system when the reflectance of the ceiling was increased. As the maintained illuminance 500 lux were not provided with any of the scenarios, it has been evaluated that a lighting system for the white board was needed as supplementary to the lighting of the lecture hall.

The scenarios, which were generated through the design parameters related to the daylighting system and artificial lighting system in the literature, were analyzed in the studied lecture hall as the pilot study. The analysis aimed at evaluating the performance of the daylighting and artificial lighting systems under the changing scenarios. Being considered in the scenarios, the impact of the design parameters on the performance of the lighting systems were analysed. The analysis results were evaluated through comparing them to the illuminance levels given for providing the visual comfort conditions. The scenarios created for both the daylighting system and the artificial lighting system have had different impacts on the performances of the systems. Through this kind of analysis studies, the most suitable lighting system design solution can be obtained for the evaluated space.

3.4 Discussion of the Pilot Studies and the Requirement for Proposing a Post-occupancy Evaluation (POE) Methodology

The pilot study-1 and pilot study-2 aimed at evaluating different building typologies with a standard methodology. The pilot study-1 evaluated education typology. The students assessed their classrooms considering lighting, health and learning performance. The pilot study-2 assessed office typology. In addition to the evaluation of lighting, illuminance levels and reflections both on desk and VDU were assessed together with job performance. These two pilot studies showed the significance of typology-based parameters. This underlines the impact of tasks on the visual environment and how each different typology or task should be assessed differently. The two pilot POE studies continued with recommending improvements to enhance the visual environment. Through the pilot study-3,how scenarios affected daylighting and artificial lighting systems were observed in a sample lecture hall evaluated in pilot study-1.

The literature review evidenced that occupant behaviour and furniture layout affected visual comfort. However; as a current research gap, how users perform behaviour in relation to interior space and spatial layout was not deeply researched. The modifications that can be performed in relation to the furniture layout and interior design have not been studied. Moreover, in what way behaviour of user affects perception of space, mood and satisfaction has not been previously assessed. The evaluated parameters in the pilot POE studies was in relation to the lighting system, health and performance. However, parameters related to the behaviour, modifications in the lighting system and interior design changes were not evaluated through the validated and designed questions in the user questionnaires. That is why, a POE methodology is required to assess the visual luminous environment holistically considering behaviour, task, interior design and spatial layout. In other words, the holistic frame would evaluate the parameters related to user, space, task and light. The standardisation of the criteria in POE studies on lighting, visual comfort and visual environment would be an asset.

Based on the aforementioned gaps in literature, the requirement for a holistic POE methodology in the field of lighting was observed. The pilot studies showed the significance of considering task-related and typology-based parameters when evaluating visual environment and recommending improvements. Developing a standard evaluation approach was also highlighted. That is why; an experimental study was designed to integrate adaptive behaviour into the evaluation of visual environment. The impact of adaptive behaviour related parameters on appraisal of lighting, assessment of space, mood and satisfaction was tested. The adaptive behaviour related parameters were in relation to user, interior space and lighting. The experimental study in Chapter 4 was transformed into a POE methodology in the field of lighting in Chapter 5. This POE methodology was called as 'the Integrated POE in Lighting' in order to assess visual environment.

4. AN EXPERIMENTAL STUDY EVALUATING ADAPTIVE BEHAVIOUR IN VISUAL ENVIRONMENT

Literature indicated modifying occupant behaviour, interior design and spatial layout in order to enhance visual comfort. These modifications were called as adaptive behaviour. Although being highlighted in literature, the impact of adaptive behaviour on visual environment has not been assessed. Moreover, adaptive behaviour related parameters have not been integrated into building evaluation.

This chapter aims to integrate parameters in relation to adaptive behaviour into assessment of visual environment. This assessment is also aimed to be holistic as considering user, space and lighting system. The chapter contains an experimental study in a test room with office function in order to test this integration. The model, which connected lighting appraisal, room appearance, pleasure and workplace satisfaction by Veitch et al. (2013), was extended through integrating adaptive behaviour related parameters. The model was tested through experiments involving different lighting systems and wall colours as the between-group tests and different occupant positions and orientations as the within-subject tests. This experimental study guided the development of a POE methodology called as 'the Integrated POE in Lighting' in Chapter 5.

4.1 Design of the Experimental Study

This section explains aims, hypotheses and methodology of experiments.

4.1.1 Aim

The aim of "good lighting" design comprehends the foundations of visual perception and requirements for visual information (Lam, 1977; p. 12). A "good luminous environment" is within a multi-faceted frame; which combines comfort, pleasantness and suitability. This frame is based on the requirements for visual information, which is needed for the functions in the space (Lam, 1977; p.30). When luminous environment is defined as 'good', the focus is on its evaluation. It is mentioned that individuals having different environmental interactions would have different assessments in places that they experience (Canter, 1977). This evidences that a user engages with a place, has experience during occupying there and evaluates this place based on his or her experience. Experience is predicted to affect evaluation related to lighting, which can be considered as the base of a POE system in the field of lighting.As for the relation between visual discomfort and behaviour, users would behave in order to prevent discomfort. In case behaviour-based changes occur, these would evidence discomfort being the reason (Boyce, 2014).

The knowledge gaps underlined discrete evaluation of luminous environment and integration of adaptive behaviour for visual comfort as being the limited research topics. That is why; this research proposed 'the Integrated POE in Lighting'methodology, which aimed to create a holistic and robust evaluation of lighting through;

- integrating space, user and task related parameters into the evaluation of lighting,
- exploring the alliance between occupant's use of space, perception of space and experience of lighting system and
- integrating adaptive behaviour of occupants, which aims to improve visual comfort and satisfaction, into the POE process.

The experimental study aimed to test adaptive behaviour related parameters and observe whether impact of adaptive behaviour on visual environment, perception of space and psychology of user could be assessed.

4.1.2 Hypotheses and research questions

For a holistic evaluation of lighting system considering adaptive behaviour of users, five hypotheses were written:

- **Hypothesis-1:** Furniture position and orientation, field of view, colour of internal surfaces and lighting system are indicators of adaptive behaviour.
- **Hypothesis-2:** Furniture position and orientation affect field of view.

- **Hypothesis-3:** Field of view has an effect on lighting appraisal.
- **Hypothesis-4:** Colour of internal surfaces has an effect on lighting appraisal.
- **Hypothesis-5:** Lighting system has an effect on lighting appraisal.

The hypotheses guided the research questions as below:

- **Research question-1:** How can furniture position and orientation, field of view, colour of internal surfaces and lighting system indicate adaptive behaviour?
- **Research question-2:** How does furniture position and orientation affect field of view?
- **Research question-3:** How does field of view affect lighting appraisal?
- **Research question-4:** How does colour of internal surfaces affect lighting appraisal?
- **Research question-5:** How does lighting system affect lighting appraisal?

4.1.3 Methodology

An experimental study was conducted. This research extends the model of Veitch et al. (2013). In their experimental research; Veitch et al. (2013) researched the relation between lighting appraisal, room appearance, pleasure, workplace satisfaction, work engagement and task performance. This was a significant model as it identified the relations between user, perception of space, appraisal of light and satisfaction. The experimental study of this thesis proposed extensions to this existing SEM model in order to integrate adaptive behaviour related parameters into the model. The existing SEM model and proposed extensions are described as below:

- Veitch et al. (2013) identified the relations between lighting appraisal, workplace satisfaction and work engagement. The lighting appraisal affected room appearance, which influenced pleasure. The lighting appraisal and the room appearance affected workplace satisfaction. The workplace satisfaction influenced environmental satisfaction and self-assessed productivity.
- O'Brien and Gunay (2014) indicated interior design as a parameter affecting occupant behaviour for enhancing comfort. In literature review of the authors, flexibility of occupants related to changing their position or orientation was

underlined for preventing glare. Besides, furniture positioning was mentioned as being related to discomfort zones. In their contextual framework, the authors mentioned the rotational and translational freedom of a cubicle under the title ‘interior design’.

- Keyvanfar et al. (2014) validated changing position and direction of furniture as an adaptive behaviour for artificial lighting.
- Glare depends on the occupant position and direction of view. This adaptability was mentioned to enhance visual comfort (Jakubiec and Reinhart, 2012). In their studies, Loe et al. (2000) (1994) defined that the horizontal 40° band intersected with the field of view and contained lighting of the space beyond the task area. Thus occupant position and orientation affect lighting appraisal.
- Al Horr et al. (2016) underlined the ‘look and feel’ analysis method, which assessed occupant response related to preference for colour palette in offices as this parameter is related to occupant comfort and productivity. Keyvanfar et al. (2014) indicated covering the room surface (i.e. use of wallpaper) as a validated adaptive behaviour for artificial lighting. These two studies provided evidence for the modification of internal surfaces as an adaptive behaviour in terms of colour and material.
- Boyce et al. (2006) evidenced the impact of non-task surface brightness on lighting appraisal. That is why, changing colour and material of internal surfaces would affect lighting appraisal.
- Dissatisfaction decreases when users can amend unpredicted discomfort sources as glare through small revisions (BCO, 2006). Satisfaction with lighting affects overall environmental satisfaction (Newsham et al., 2009). That is why; adaptive behaviour of occupants, which is performed to improve satisfaction with lighting and visual comfort, would affect environmental satisfaction (Figure 4.1).

4.1.3.1 Designing the questionnaire for evaluation of lighting

The existing questionnaire items and scales were used for the variables that were employed from the existing model in Veitch et al.’s research (2013).

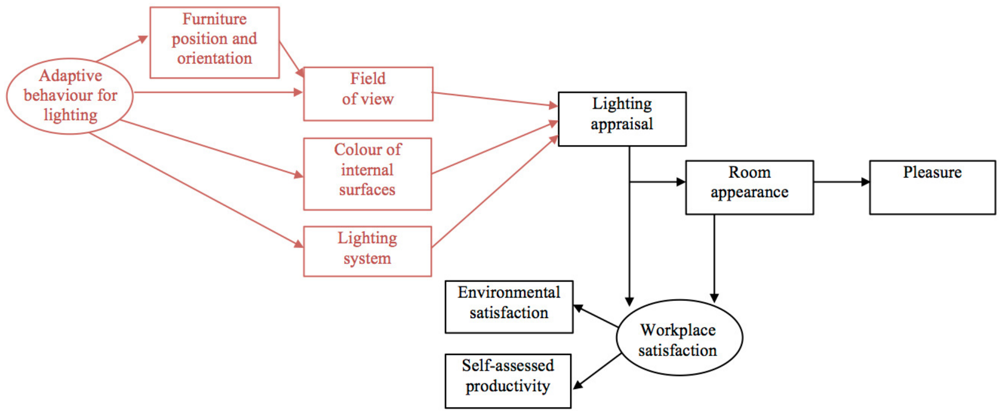


Figure 4.1 : The proposed SEM model in the experimental study: Black-coloured boxes and lines indicate the existing SEM model by Veitch et al. (2013). Red-coloured boxes and lines indicate the proposed extensions based on the references explained above.

The questionnaire items and scales in the Veitch et al.'s research (2013) are given below:

- **Lighting appraisal:** The lighting quality survey was used as taken from Veitch and Newsham (2000).
- **Room appearance:** The attractiveness scale between 0 and 100 through nine semantic differential items was provided to the occupants in the studies of Veitch et al. (2008).
- **Pleasure:** The eighteen semantic differential items were developed by Russell & Mehrabian (1974) and known as 'Russell and Mehrabian Three-Factor Mood Scale'. The scale defined pleasure, arousal and dominance in three groups. The six items for pleasure were used with a scale from 0 to 8. The scale was reached through Detandt et al. (2017).
- **Workplace satisfaction:** Workplace satisfaction was measured through environmental satisfaction and self-assessed productivity.
  - **Environmental satisfaction:** The 4-item scale, which was initiated by Sundstrom et al. (1994) to assess physical work environment, was used to evaluate environmental satisfaction using the scale between 'disagree strongly' and 'agree strongly'.
  - **Self-assessed productivity:** Self-rated productivity measure as a one-item scale was taken from Boyce et al. (2003).

For the variables that were proposed in the model, the questionnaire items and scales were designed. A questionnaire was designed in the scope of this research for investigating observed variables of latent variable 'adaptive behaviour for lighting' in proposed model. In the questionnaire design, validated items and scales were selected from literature and modified considering the evaluation of adaptive behaviour parameters. The selected items and the modifications were given for each observed variable as below:

- **Furniture position and orientation:** The two question items and scales asking about the acceptability of the current desk position and orientation were designed based on the sample question asking if the environment is thermally acceptable in the Informative Appendix L of the ANSI / ASHRAE Standard 55-2017 (ANSI / ASHRAE, 2017). The questions were 'Is current position of your desk (location of desk) acceptable?' and 'Is current orientation of your desk (direction ofdesk) acceptable?'. The scales contained 'very unacceptable, unacceptable, partly unacceptable, partly acceptable, acceptable, very acceptable'. During the design of the scales of these acceptability questions,explanations were added to the start and end categories of the response scale as endnotes as applied by Atli and Fotios (2011). Besides, neutral or middle category was omitted in order to prevent response contraction bias (Atli and Fotios, 2011). Six categories were applied as the literature indicated that categories above seven could cause uncertainties (Fotios and Houser, 2009). The two question items and scales asking about the preference for changing the desk position and orientation were designed based on the preference scale in the 'ASHRAE RP-884 project: *Developing an Adaptive Model of Thermal Comfort and Preference*' (de Dear and Brager, 1998) (ANSI / ASHRAE, 2017) and the preference scale in Nicol, Humphreys and Roaf (2012). For preference questions, two options regarding the desk position were given. The test room was divided horizontally into two zones on plan. The zone close to the virtual window was called 'Zone 1' and the zone close to the door was called 'Zone 2'. Two options regarding the orientation were provided on the plan of the test room.

The preference options were provided in boxes shown with arrows as in the questionnaire format of Dillman (Ekinci, 2015).

- **Field of view:** The two question items and scales asking about the acceptability of the current occupant position and orientation were designed based on the sample question asking if the environment is thermally acceptable in the Informative Appendix L of the ANSI / ASHRAE Standard 55-2017 (ANSI / ASHRAE, 2017). The questions were ‘Is current position you are sitting acceptable?’ and ‘Is current orientation you are sitting (direction of sitting) acceptable?’. The scales contained ‘very unacceptable, unacceptable, partly unacceptable, partly acceptable, acceptable, very acceptable’. During the design of the scales of these acceptability questions,explanations were added to the start and end categories of the response scale as endnotes as applied by Atli and Fotios (2011). Besides, neutral or middle category was omitted in order to prevent response contraction bias (Atli and Fotios, 2011). Six categories were applied as the literature indicated that categories above seven could cause uncertainties (Fotios and Houser, 2009).The two question items and scales asking about the preference for changing the occupant position and orientation were designed based on the preference scale in the ‘ASHRAE RP-884 project: *Developing an Adaptive Model of Thermal Comfort and Preference*’ (de Dear and Brager, 1998) (ANSI / ASHRAE, 2017) and the preference scale in Nicol, Humphreys and Roaf (2012). For preference questions, two options regarding the occupant position and three options regarding the occupant orientation were provided on the plan of the test room. The preference options were provided in boxes shown with arrows as in the questionnaire format of Dillman (Ekinci, 2015).
- **Colour of internal surfaces:** The three question items and scales asking about the acceptability of the current colour of the ceiling, wall and floor were designed based on the sample question asking if the environment is thermally acceptable in the Informative Appendix L of the ANSI / ASHRAE Standard 55-2017 (ANSI / ASHRAE, 2017). The questions were ‘Is current colour of ceiling acceptable?’, ‘Is current colour of wall acceptable?’ and ‘Is

current colour of floor acceptable?'. The scales contained 'very unacceptable, unacceptable, partly unacceptable, partly acceptable, acceptable, very acceptable'. During the design of these scales,explanations were added to the start and end categories of the response scale as endnotes as applied by Atli and Fotios (2011). Besides, neutral or middle category was omitted in order to prevent response contraction bias (Atli and Fotios, 2011). Six categories were applied as the literature indicated that categories above seven could cause uncertainties (Fotios and Houser, 2009).The three question items and scales asking about the preference for changing the colour of the ceiling, wall and floor were designed based on the preference scale in the 'ASHRAE RP-884 project: *Developing an Adaptive Model of Thermal Comfort and Preference*' (de Dear and Brager, 1998) (ANSI / ASHRAE, 2017) and the preference scale in Nicol, Humphreys and Roaf (2012). For preference questions; the options were provided for hue, lightness and chroma separately for the ceiling, wall and floor. As for the hue, four unique hues ('red', 'green', 'blue', 'yellow') together with 'white' and 'black' taking place in the Natural Colour System (NCS) were used for the preference options. As for the lightness, 'lighter' and 'darker' being the adjectives of the lightness were used for the preference options. As for the chroma, 'weaker' and 'stronger' being the adjectives of the chroma were used for the preference options (Hunt and Pointer, 2011). The preference options were provided in the boxes shown with arrows as in the questionnaire format of Dillman (Ekinci, 2015).

- **Lighting system:** The one question item and scale asking about the acceptability of the current artificial lighting system was designed based on the sample question asking if the environment is thermally acceptable in the Informative Appendix L of the ANSI / ASHRAE Standard 55-2017 (ANSI / ASHRAE, 2017). The question was 'Is current artificial lighting system acceptable?'. The scale contained 'very unacceptable, unacceptable, partly unacceptable, partly acceptable, acceptable, very acceptable'. During the design of the scale,explanations were added to the start and end categories of the response scale as endnotes as applied by Atli and Fotios (2011). Besides, neutral or middle category was omitted in order to prevent response contraction bias (Atli and Fotios, 2011). Six categories were applied as the literature indicated that categories above seven could cause uncertainties (Fotios and Houser, 2009). The one question item and scale asking about the preference for changing the artificial lighting system was designed based on the preference scale in the 'ASHRAE RP-884 project: *Developing an Adaptive Model of Thermal Comfort and Preference*' (de Dear and Brager, 1998) (ANSI / ASHRAE, 2017) and the preference scale in Nicol, Humphreys and Roaf (2012). For preference question; the options for the illuminance level were 'less' and 'more'. The options for the colour temperature were 'cooler (bluish white)' and 'warmer (reddish white)'. The preference options were provided in the boxes shown with arrows as in the questionnaire format of Dillman (Ekinci, 2015).

The existing questionnaires and the designed questionnaire were translated into Turkish and compiled on two-sided two A4 papers through the designed questionnaire layout.

4.1.3.2 Conducting the experimental design

This phase aimed to integrate the variables in relation to adaptive behaviour of lighting into the experimental design. The experiment contained between-groups (BG) and within-subjects (WS) designs as Boyce et al.'s (2006) and Veitch et al.'s researches (2013). Experiments were carried out in the lighting laboratory at Istanbul Kültür University Ataköy Campus. The daylighting system is excluded with no window as the laboratory is located on the basement floor. There is a virtual window with metal venetian blind covering it. The artificial lighting system has recessed TBS 631 luminaires in an array according to the plan layout of the laboratory. The luminaires have TL5 28W tubular fluorescent lamps (R_a: 85) and are controlled with Digital Addressable Lighting Interface (DALI) dimmable electronic ballasts.

The experiments contained two different artificial lighting systems. The parameters that differentiate the lighting systems were CCT of the lamps and illuminance level on the workplane. The first lighting system Case 1 had the CCT of 3000 K and the illuminance level of 500lux on the workplane. The second lighting system Case 2 had the CCT of 6500 K and the illuminance level of 300 lux on the workplane (Table 4.1). While the lighting systems and internal wall colours were the independent variables in the between-groups experiment, the occupant positions and orientations were the independent variables in the within-subjects experiment (Table 4.2).

Table 4.1 : The lighting systems in the experimental design.

	Case 1	Case 2
Luminaire	18 recessed TBS 631 luminaires	
Layout	Rectangular array: 9 luminaires x 2 rows	
Lamp	TL5 28W lamp	
Ballast	DALI dimmable electronic ballast	
Correlated colour temperature (CCT)	3000K	6500K
Illuminance level on the workplane	500 lux	300 lux

Table 4.2 : The scheme of the experimental design.

	Internal wall surface colour	Lighting System Case 1	Lighting System Case 2	Occupant Position	Occupant Orientation
Between-groups design	Beige L90 C20 H55	N = 17	N = 9	Zone 1 or Zone 2	0°
	Blue L90 C10 H230	N = 6	N = 4		
		N=36, each participant assigned to one condition.			
Within-subjects design	Beige L90 C20 H55	N = 9	N = 2	Zone 1 or Zone 2	0° or 45° or 90°
	Blue L90 C10 H230	N = 2	N = 0		
		N = 13, each participant participating twice to the same condition.			

The lighting laboratory contained a full-scale test office, with the length of 5.50m, the width of 3.50m and the height of 2.30m (Figure 4.2). The office furniture was two office desks, two office chairs and a locker. The colour of the ceiling was white with the light reflectance of 0.80 and the colour of floor was grey with the light reflectance of 0.32 (Manav et al., 2010). The multiple coloured panels on the walls could be moved on the sliding mechanism providing a change in the wall colour. In this research, two wall colours as blue and beige were tested as one of the independent variables. The wall colour as beige (L90 C20 H55) had the light reflectance of 0.72. The wall colour as blue (L90 C10 H230) had the light reflectance of 0.74. The plan of the test office was provided to demonstrate the field of view as the other independent variable (Figure 4.3). The reflected ceiling plan shows luminaire layout of artificial lighting system (Figure 4.4).

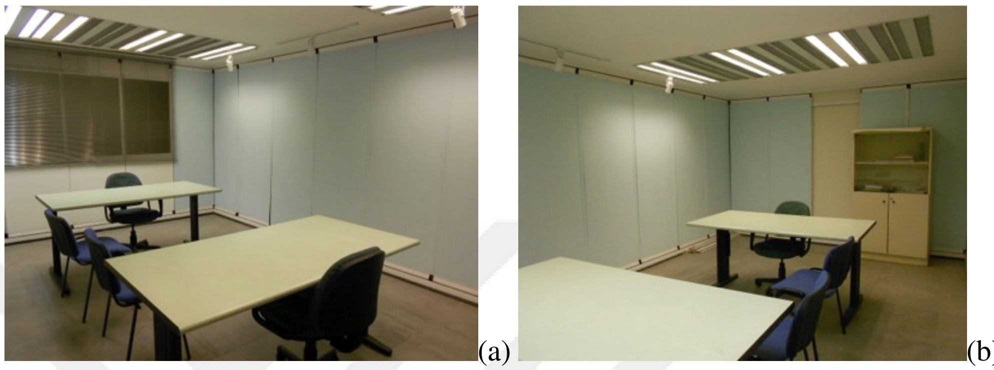


Figure 4.2 : The full scale test room with office function and the internal wall colour as blue: a) The inner wiew towards the virtual window, b) The inner view towards the door.

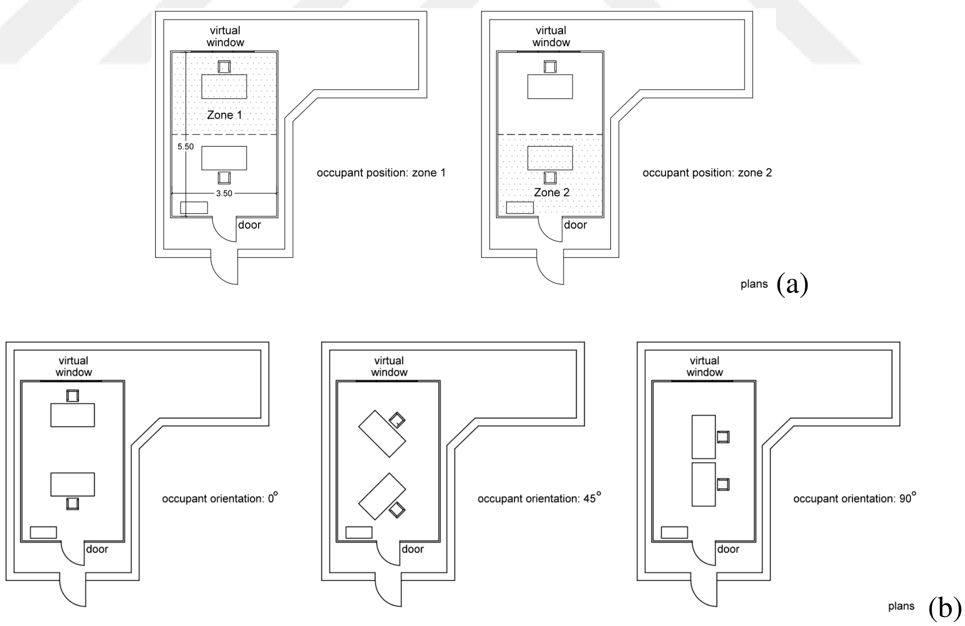


Figure 4.3 : The plans of the test room: a) The occupant position as Zone 1 and Zone 2, b) The occupant orientation as 0°, 45° and 90°.

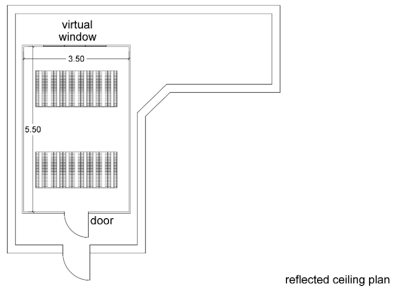


Figure 4.4 : The reflected ceiling plan of the test room showing the luminaire layout.

Concurrent to the questionnaires, field measurements were carried out. In the study of Newsham et al. (2003), the desktop illuminance and the partition illuminance were recorded after every control action automatically and at the start of the experiment and the breaks by the experimenter. In this research, the experimenter measured the illuminance levels of each case using Konica Minolta CL-200A Chroma Meter, which can measure both the illuminance level and CCT. The CCTs of the lighting systems were also checked with this chroma meter. The illuminance measurements were done horizontally on work plane as desk height (on desk and across room) and vertically on the wall surfaces. The field of view was determined according to horizontal 40° band within a vertical 90° area in the view direction (Loe et al., 2000) (Figure 4.5). The illuminance levels were measured on the pre-determined grid points according to the EN 12464-1 Standard (EN 12464-1, 2011). Besides, the pictures of the field of views were taken by the digital camera (Table 4.3).

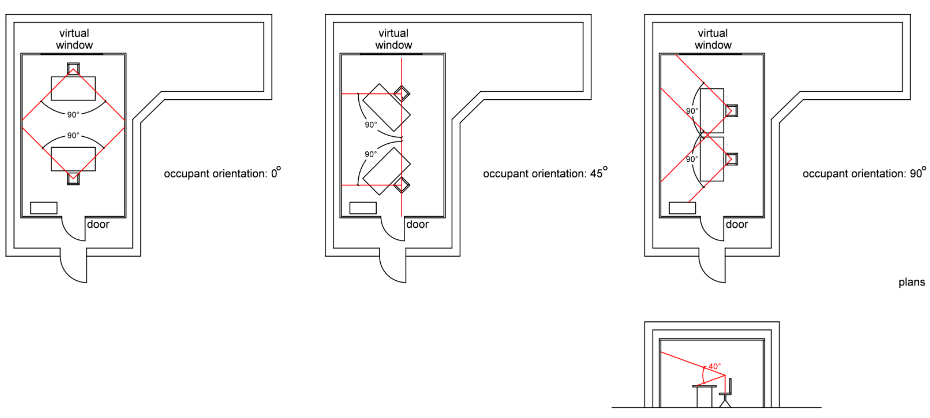
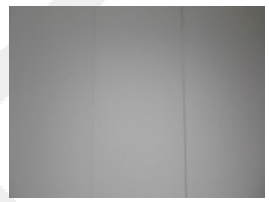


Figure 4.5 : The field of views in the test room shown on plan and section.

Table 4.3 : The images of the field of views under the lighting systems as Case 1 and Case 2 and the internal wall colour as beige.

Lighting system	Occupant position Zone 1 Occupant orientation		
	0°	45°	90°
Case 1 500lux 3000 K			
Case 2 300lux 6500 K			

The between-groups and within-subjects experiments were conducted in afternoon of same day (Newsham et al., 2003; Veitch et al., 2013). Boyce et al. (2003) demonstrated different results in comfort and pleasure from morning to afternoon, in which comfort became worse and pleasure decreased. That is why, the experiments in this research were carried out in the afternoon. Two sessions (one session contains the between-groups and within-subjects experiments consecutively) were planned for one afternoon. The between-groups experiment took approximately 40 minutes and the within-subjects experiment took approximately 30 minutes (Table 4.4). Following the arrival, the participants were given instructions on the between-groups experiment. While the experimenter was giving the instructions, participants walked around room for approximately one minute and then sit at the assigned desk for approximately four minutes. These five minutes instruction time was used by the participant to adapt to the assigned workspace, lighting and spatial conditions as applied by Saunders (1969). This was followed by the Ishihara colour blindness test (Manav et al., 2010; Boyce et al., 2003) and demographics survey (Newsham et al., 2003; Boyce et al., 2003). The task, which participants performed was a paper-based task as reading as applied by Saunders (1969). The reading text was taken from the coursebook on lighting written by Berköz and Küçükdoğu (1983). The text was typed by the experimenter with Times New Roman 11pt (same as the questionnaire) with single spacing and printed on white matt A4 paper.

Table 4.4 : The time schedule of the experiments.

Time	Duration	Experiment activity
$13.^{00}$ pm	-	Arrival
$13.^{00}$ - $13.^{05}$ pm	5 min.	Instructions to the between-groups experiment
$13.^{05}$ - $13.^{10}$ pm	5 min.	Ishihara colour blindness test
$13.^{10}$ - $13.^{15}$ pm	5 min.	Start of the experiment: The reading task
$13.^{15}$ - $13.^{25}$ pm	10 min.	Demographics survey 1
		Furniture position & orientation survey 1
		Occupant position & orientation survey 1
		Colour of internal surfaces survey 1
		Lighting system survey 1
$13.^{25}$ - $13.^{35}$ pm	10 min.	Lighting appraisal survey 1
		Room appearance survey 1
		Pleasure survey 1
$13.^{35}$ - $13.^{40}$ pm	5 min.	Environmental satisfaction survey 1
		Self-assessed productivity survey 1
$13.^{40}$ - $13.^{45}$ pm	5 min.	Instructions to the within-subjects experiment
$13.^{45}$ - $13.^{55}$ pm	10 min.	Demographics survey 2
		Furniture position & orientation survey 2
		Occupant position & orientation survey 2
		Colour of internal surfaces survey 2
		Lighting system survey 2
$13.^{55}$ - $14.^{05}$ pm	10 min.	Lighting appraisal survey 2
		Room appearance survey 2
		Pleasure survey 2
$14.^{05}$ - $14.^{10}$ pm	5 min.	Environmental satisfaction survey 2
		Self-assessed productivity survey 2
$14.^{10}$	-	End of the experiment
$14.^{10}$ - $15.^{00}$ pm	-	Break
$15.^{00}$ pm	-	Arrival
$15.^{00}$ - $15.^{05}$ pm	5 min.	Instructions to the between-groups experiment
$15.^{05}$ - $15.^{10}$ pm	5 min.	Ishihara colour blindness test
$15.^{10}$ - $15.^{15}$ pm	5 min.	Start of the experiment: The reading task
$15.^{15}$ - $15.^{25}$ pm	10 min.	Demographics survey 1
		Furniture position & orientation survey 1
		Occupant position & orientation survey 1
		Colour of internal surfaces survey 1
		Lighting system survey 1
$15.^{25}$ - $15.^{35}$ pm	10 min.	Lighting appraisal survey 1
		Room appearance survey 1
		Pleasure survey 1
$15.^{35}$ - $15.^{40}$ pm	5 min.	Environmental satisfaction survey 1
		Self-assessed productivity survey 1
$15.^{40}$ - $15.^{45}$ pm	5 min.	Instructions to the within-subjects experiment
$15.^{45}$ - $15.^{55}$ pm	10 min.	Demographics survey 2
		Furniture position & orientation survey 2
		Occupant position & orientation survey 2
		Colour of internal surfaces survey 2
		Lighting system survey 2
$15.^{55}$ - $16.^{05}$ pm	10 min.	Lighting appraisal survey 2
		Room appearance survey 2
		Pleasure survey 2
$16.^{05}$ - $16.^{10}$ pm	5 min.	Environmental satisfaction survey 2
		Self-assessed productivity survey 2
$16.^{10}$	-	End of the experiment

Sample was students at Istanbul Kültür University Atakoy Campus, where the lighting laboratory was located. As for the sample size; in between-groups design, each of 36 participants was assigned to one condition that contained the lighting systems Case 1 and Case 2 and the wall colours blue and beige. In within-subjects design, 13 students participated as having preferred a different occupant position and/or orientation during the between-groups test. Each of 13 participants participated twice to the same condition as in the between-groups test with a different occupant position and/or orientation.

The data of the experimental design was analysed statistically. Descriptive statistics were analysed. SEM was worked on for the test office room. Analysis of variance (ANOVA) tests were carried out.

4.2 Results of the Statictical Analyses

Results of statistical analyses are given under this title. Statistical analyses contained descriptive statistics, SEM and ANOVA tests.

4.2.1 Descriptive statistics

IBM SPSS Statistics software was used for statistical analyses. The average age of the participants was 21. As for the gender, 53% of the participants was female and 47% of them was male. The participants were undergraduate students studying architecture, interior architecture and environmental design, art management, mathematics and computer science, industrial engineering, civil engineering, computer engineering, language and literature and business administration. No outliers (standardized scores >3 and <-3) were detected. As no case was excluded, the sample size was numbered 36 cases. Analyses of descriptive statistics included mean, standard deviation, skewness, kurtosis and Cronbach's α for the composite scales (Table 4.5). All variables were tested for normality with skewness values between -3 and+3 and kurtosis between -8 and +8 (Kline, 1997) and met these criteria. Number of items and scales were stated for each variable.

Table 4.5 : Descriptive statistics (N=36).

Variable	Mean	Standard deviation	Skewness	Kurtosis	Cronbach's α	Items	Scale
Furniture position and orientation	4.0139	0.21592	-0.554	-0.255	0.789	2	(1)-(6)
Field of view	4.0556	0.22073	-0.898	0.085	0.793	2	(1)-(6)
Colour of internal surfaces	4.3704	0.16628	-0.418	-0.177	0.705	3	(1)-(6)
Lighting system	4.20	0.262	-0.707	-0.367	-	1	(1)-(6)
Lighting appraisal	3.4722	0.16630	-0.387	0.049	0.850	4	(1)-(5)
Room appearance	47.6698	3.95099	0.148	-0.395	0.913	9	(0)-(100)
Pleasure	4.2685	0.30249	-0.042	0.304	0.912	6	(0)-(8)
Environmental satisfaction	3.1806	0.15224	-0.051	-0.328	0.813	4	(1)-(5)
Self-assessed productivity	6.31	0.301	-0.807	-0.163	-	1	(-4)-(4)

The bivariate correlations were calculated, in which single asterisk showed significant correlations at the 0.05 level and double asterisks showed significant correlations at the 0.01 level (Table 4.6). Most significant correlations were analysed, which were significant at the 0.01 level. It can be observed that one of the most significant correlations was between furniture position and orientation and field of view. Colour of internal surfaces significantly correlated with pleasure, environmental satisfaction and self-assessed productivity. Lighting system correlated significantly with lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity. Correlations between lighting appraisal and room appearance, pleasure, environmental satisfaction and self-assessed productivity were significant. Room appearance correlated significantly with pleasure, environmental satisfaction and self-assessed productivity. Pleasure correlated significantly with environmental satisfaction and self-assessed productivity. Correlation between environmental satisfaction and self-assessed productivity was significant as well.

4.2.2 Structural equation modeling (SEM)

SEM was carried out in IBM SPSS Amos software. SEM analysis contained the participants of two lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux and 6500 K) and beige wall colour in the between-groups test. The number of participants was 26. Initially, indicators of goodness of fit for model were investigated. The indicators were chi-square (X^2), degrees of freedom for chi-square

(X^2/df), comparative fit index (CFI) and root mean square error of approximation (RMSEA).

Table 4.6 : Bivariate correlations.

	Furniture position and orientation	Field of view	Colour of internal surfaces	Lighting system	Lighting appraisal	Room appearance	Pleasure	Environmental satisfaction	Self-assessed productivity
Furniture position and orientation	-								
Field of view	0.728**	-							
Colour of internal surfaces	0.073	-0.092	-						
Lighting system	0.149	0.028	0.391*	-					
Lighting appraisal	0.149	0.093	0.396*	0.782**	-				
Room appearance	0.159	0.136	0.380*	0.475**	0.710**	-			
Pleasure	0.108	0.006	0.625**	0.425*	0.698**	0.842**	-		
Environmental satisfaction	0.200	0.210	0.439**	0.579**	0.717**	0.534**	0.489**	-	
Self-assessed productivity	-0.004	-0.048	0.495**	0.610**	0.723**	0.576**	0.694**	0.593**	-

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Proposed model was called Model 1 and the model fit was not good. Among the indicators, CFI was low and RMSEA was high. Model 1 was run one more time in order to obtain the modification indices by the software. The suggested actions were addition of a direct path between colour of internal surfaces and workplace satisfaction, addition of a direct path between colour of internal surfaces and pleasure and addition of a covariance path between error variable of colour of internal surfaces (e3) and error variable of pleasure (e7). As influence of colour on human factors is well-established, the three suggestions were applied and the modified model was called Model 2. When Model 2 was run, a better model fit was provided (Figure 4.6). It was observed that CFI increased and RMSEA decreased.

When the significance of the paths in Model 2 was observed, it was seen that five paths were statistically significant at the 0,001 level. These paths were furniture position and orientation-field of view, lighting system-lighting appraisal, lighting appraisal-room appearance, room appearance-pleasure and lighting appraisal-workplace satisfaction. When the statistically significant paths were evaluated, it was observed that furniture position and orientation predicted field of view. This is logical as furniture affects the field of view of the occupant. This relation supports that furniture layout should be considered in lighting evaluation. This is consistent with the literature that underlined impact of interior design on adaptive behaviour of occupants.

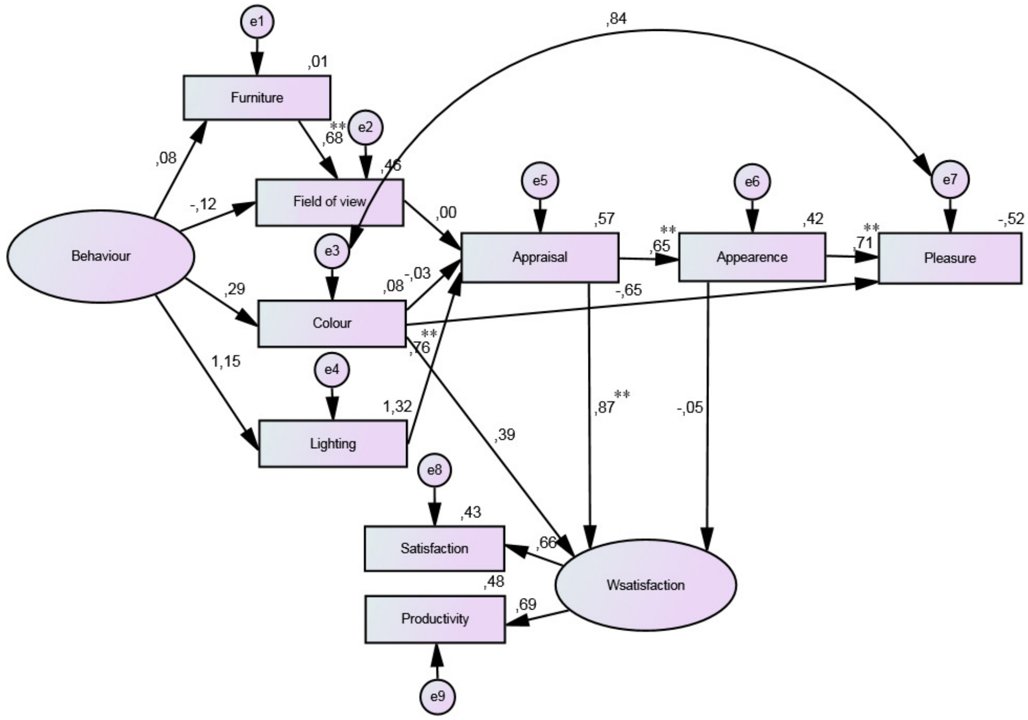


Figure 4.6 : The model showing the regression weights and statistically significant paths with double asteriks (p<0.001).

As another significant path, lighting system affected lighting appraisal. This means that an occupant who finds lighting system acceptable would appraise lighting as good. This path was also logical as the performance of lighting system and its acceptability affects lighting appraisal.

The rest of the significant paths, which were lighting appraisal-room appearance, room appearance-pleasure and lighting appraisal-workplace satisfaction supported the previous research and SEM model by Veitch et al. (2013).

The suggested paths for a better model fit were not statistically significant. These paths were the direct path between colour of internal surfaces and pleasure, the direct path between colour of internal surfaces and workplace satisfaction and the covariance path between e3 and e7.

The three negative relationships in Model 2 were unexpected. The negative paths were adaptive behaviour-field of view, colour of internal surfaces-pleasure and room appearance-workplace satisfaction. The relationship between adaptive behaviour and field of view was not expected to be negative as adaptive behaviour is a latent variable and field of view is one of its indicator according to literature. The negative relationship between colour of internal surfaces and pleasure was not expected as there is well-established literature indicating the impact of colour on mood. The negative relationship between room appearance and workplace satisfaction was also unexpected as this path was found out as significantly positive by the previous research and SEM model (Veitch et al., 2013).

The regression equations of the significant paths in Model 2 were written as below:

- Field of view = .68 x furniture position and orientation + e2 $R^2 = .46$
- Lighting appraisal = .76 x lighting system + e5 $R^2 = .57$
- Room appearance = .65 x lighting appraisal + e6 $R^2 = .42$
- Pleasure = .71 x room appearance + e7 $R^2 = - .52$
- Workplace satisfaction = .87 x lighting appraisal

4.2.3 Analysis of variance (ANOVA) tests

Analysis of variance (ANOVA) was used to test null hypotheses through comparing means of dependent variables. The null hypothesis defines that the populations that determine the samples would achieve the same means on the dependent variable (Healey, 2012). Null hypotheses were based on independent groups of independent variable lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and the independent groups of the independent variable wall colours (Beige: L90 C20 H55 and Blue: L90 C10 H230) in the frame of the between-groups tests. The dependent variables were furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity. The null hypotheses, which were analysed respectively in Chapter 4.2.3.1 and Chapter 4.2.3.2, are given as below:

- **Null hypothesis-1:** The evaluations of dependent variables under the lighting systems Case 1 (500 lux, 3000 K) and Case 2 (300 lux, 6500 K) do not vary for the beige wall colour.
- **Null hypothesis-2:** The dependent variables under the lighting systems Case 1 (500 lux, 3000 K) and Case 2 (300 lux, 6500 K) do not differ for the blue wall colour.
- **Null hypothesis-3:** The means of dependent variables for the beige and blue wall colours do not vary under the lighting system Case 1 (500 lux, 3000 K).
- **Null hypothesis-4:** The dependent variables for the beige and blue wall colours do not change under the lighting system Case 2 (300 lux, 6500 K).

Through the ANOVA, the means were evaluated and the differences in the means of groups were analysed for the between-groups study involving 36 participants. ANOVA tests were carried out between the independent groups of the independent variable lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and the independent groups of the independent variable wall colours (Beige: L90 C20 H55 and Blue: L90 C10 H230) separately.

- **Analysis of the null hypothesis-1:** For the beige wall colour, the ratings of colour of internal surfaces increased from Case 1 (500 lux, 3000 K) to Case 2 (300 lux, 6500 K). The ratings of furniture position and orientation, field of view, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity decreased. There was not any statistically significant difference in dependant variables between Case 1 and Case 2. All $F_{obtained}$ valueswere smaller than $F_{critical}$ of 4.26 (Healey, 2012) for the degree of freedom associated with between estimate of variance of 1 and the degree of freedom associated with within estimate of variance of 24 at the alpha value 0.05. That is why, the null hypothesis could not be rejected. All the significance values were bigger than 0.05 (p<0,05), which showed no statistical significance (Table 4.7).

Table 4.7 : The ANOVA test between Case 1 and Case 2 for the beige wall colour.

Dependant variable	The wall colour				
			Beige		
	The lighting system	Mean	Standard deviation	$F_{obtained}$	Significance
Furniture position and orientation	Case 1	4.0294	1.21797	0.135	0.717
	Case 2	3.8333	1.43614		
Field of view	Case 1	4.2353	0.92056	0.248	0.623
	Case 2	4.0000	1.50000		
Colour of internal surfaces	Case 1	4.2157	0.98560	0.011	0.917
	Case 2	4.2593	1.03786		
Lighting system	Case 1	4.06	1.600	0.060	0.808
	Case 2	3.89	1.833		
Lighting appraisal	Case 1	3.4412	1.01754	0.847	0.366
	Case 2	3.0556	1.01379		
Room appearance	Case 1	45.0654	22.49990	0.768	0.389
	Case 2	36.9136	22.67441		
Pleasure	Case 1	3.9608	1.76829	0.646	0.429
	Case 2	3.4074	1.45323		
Environmental satisfaction	Case 1	3.0147	0.78795	0.002	0.964
	Case 2	3.0000	0.73951		
Self-assessed productivity	Case 1	5.94	1.919	0.046	0.833
	Case 2	5.78	1.716		

- **Analysis of the null hypothesis-2:** For the blue wall colour; the ratings of all dependant variables decreased from Case 1 (500 lux, 3000 K) to Case 2 (300 lux, 6500 K). There were statistically significant differences in between Case 1 and Case 2. $F_{obtained}$ values of 5.863, 5.878, 5.494, 13.003 and 9.333 for lighting system, lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity respectively were larger than $F_{critical}$ of 5.32 (Healey, 2012) for the degree of freedom associated with between estimate of variance of 1 and the degree of freedom associated with within estimate of variance of 8 at the alpha value 0.05. It is possible to reject null hypothesis for these five dependent variables and it can be said that the evaluation of lighting system, lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity was different between Case 1 and Case 2 for the blue wall colour. The significances of 0.046, 0.042, 0.047, 0.007 and 0.018 were smaller than 0.05 ($p<0,05$), which evidences that differences were statistically significant.No statistically significant difference was observed in other dependant variables (Table 4.8).

Table 4.8 : The ANOVA test between Case 1 and Case 2 for the blue wall colour.

Dependant variable	The wall colour Blue				
	The lighting system	Mean	Standard deviation	$F_{obtained}$	Significance
Furniture position and orientation	Case 1	4.4167	1.31972	0.503	0.498
	Case 2	3.7500	1.65831		
Field of view	Case 1	4.2500	1.50831	0.951	0.358
	Case 2	3.1250	2.17466		
Colour of internal surfaces	Case 1	4.8333	1.04881	0.138	0.720
	Case 2	4.5833	1.03190		
Lighting system	Case 1	5.40	0.894	5.863	0.046
	Case 2	4.00	0.816		
Lighting appraisal	Case 1	4.3333	0.66458	5.878	0.042
	Case 2	3.2500	0.73598		
Room appearance	Case 1	72.5926	19.45767	5.494	0.047
	Case 2	45.5556	14.85181		
Pleasure	Case 1	6.2778	1.56584	3.878	0.084
	Case 2	4.5000	1.06284		
Environmentals atisfaction	Case 1	4.3333	0.66458	13.003	0.007
	Case 2	2.5625	0.89849		
Self-assessed productivity	Case 1	8.00	0.632	9.333	0.018
	Case 2	6.67	0.577		

- **Analysis of the null hypothesis-3:** For Case 1; the means of all dependant variables increased from beige to blue wall colour. There were statistically significant differences between beige and blue wall colours. $F_{obtained}$ values of 7.062, 8.027, 13.336 and 6.478 for room appearance, pleasure, environmental satisfaction and self-assessed productivity respectively were larger than $F_{critical}$ of 4.32 (Healey, 2012) for the degree of freedom associated with between estimate of variance of 1 and the degree of freedom associated with within estimate of variance of 21 at the alpha value 0.05. It is possible to reject null hypothesis for these four dependent variables and it can be said that the evaluation of room appearance, pleasure, environmental satisfaction and self-assessed productivity was different between beige and blue wall colours for Case 1. The significances of 0.015, 0.010, 0.001 and 0.019 were smaller than 0.05 ($p<0,05$), which shows that the differences were statistically significant.No statistically significant difference was observed in other dependant variables (Table 4.9).

Table 4.9 : The ANOVA test between beige and blue wall colours for Case 1.

Dependant variable	The lighting system Case 1				
	The wall colour	Mean	Standard deviation	$F_{obtained}$	Significance
Furniture position and orientation	Beige	4.0294	1.21797	0.430	0.519
	Blue	4.4167	1.31972		
Field of view	Beige	4.2353	0.92056	0.001	0.978
	Blue	4.2500	1.50831		
Colour of internal surfaces	Beige	4.2157	0.98560	1.688	0.208
	Blue	4.8333	1.04881		
Lighting system	Beige	4.06	1.600	3.149	0.091
	Blue	5.40	0.894		
Lighting appraisal	Beige	3.4412	1.01754	3.948	0.060
	Blue	4.3333	0.66458		
Room appearance	Beige	45.0654	22.49990	7.062	0.015
	Blue	72.5926	19.45767		
Pleasure	Beige	3.9608	1.76829	8.027	0.010
	Blue	6.2778	1.56584		
Environmental satisfaction	Beige	3.0147	0.78795	13.336	0.001
	Blue	4.3333	0.66458		
Self-assessed productivity	Beige	5.94	1.919	6.478	0.019
	Blue	8.00	0.632		

- **Analysis of the null hypothesis-4:** For Case 2; the means of colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure and self-assessed productivity increased from beige to blue wall colour. The means of furniture position and orientation, field of view and environmental satisfaction decreased. There was not any statistically significant difference in the dependant variables between beige and blue wall colours. All $F_{obtained}$ valueswere smaller than $F_{critical}$ of 4.84 (Healey, 2012) for the degree of freedom associated with between estimate of variance of 1 and the degree of freedom associated with within estimate of variance of 11 at the alpha value 0.05. That is why, the null hypothesis could not be rejected. All the significance values were bigger than 0.05 (p<0,05), which showed no statistical significance (Table 4.10).

Table 4.10 : The ANOVA test between beige and blue wall colours for Case 2.

Dependant variable	The lighting system Case 2				
	The wall colour	Mean	Standard deviation	$F_{obtained}$	Significance
Furniture position and orientation	Beige	3.8333	1.43614	0.009	0.928
	Blue	3.7500	1.65831		
Field of view	Beige	4.0000	1.50000	0.725	0.413
	Blue	3.1250	2.17466		
Colour of internal surfaces	Beige	4.2593	1.03786	0.271	0.613
	Blue	4.5833	1.03190		
Lighting system	Beige	3.89	1.833	0.013	0.911
	Blue	4.00	0.816		
Lighting appraisal	Beige	3.0556	1.01379	0.117	0.739
	Blue	3.2500	0.73598		
Room appearance	Beige	36.9136	22.67441	0.476	0.504
	Blue	45.5556	14.85181		
Pleasure	Beige	3.4074	1.45323	1.793	0.208
	Blue	4.5000	1.06284		
Environmental satisfaction	Beige	3.0000	0.73951	0.858	0.374
	Blue	2.5625	0.89849		
Self-assessed productivity	Beige	5.78	1.716	0.734	0.412
	Blue	6.67	0.577		

4.3 Analyses of the Field Measurements

The illuminance level measurements were carried out for two lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and two wall colours (Beige: L90 C20 H55 and Blue: L90 C10 H230). The horizontal illuminance levels on the workplane across the room (defined by the desk height) and the vertical illuminance levels on the four walls were measured. The walls were labeled as Wall 1, Wall 2, Wall 3 and Wall 4 (Figure 4.7). The lines of the sliding panels were shown on the elevations.

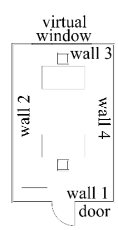


Figure 4.7 : The legend for the wall labels on the plan.

In the lighting system Case 1 (500 lux, 3000 K) and beige wall colour; the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 144 lux and the maximum illuminance level (E_{max}) was 581 lux (Table 4.11). The average illuminance level on the horizontal workplane was calculated as 362 lux (E_{ave}). On Wall 1, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 68 lux and the maximum illuminance level (E_{max}) was 151 lux. The average illuminance level on Wall 1 was calculated as 111 lux (E_{ave}). On Wall 2, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 35 lux and the maximum illuminance level (E_{max}) was 224 lux. The average illuminance level on Wall 2 was calculated as 126 lux (E_{ave}). On Wall 3, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 89 lux and the maximum illuminance level (E_{max}) was 254 lux. The average illuminance level on Wall 3 was calculated as 169 lux (E_{ave}). On Wall 4, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 70 lux and the maximum illuminance level (E_{max}) was 352 lux. The average illuminance level on Wall 4 was calculated as 186 lux (E_{ave}).

In the lighting system Case 2 (300 lux, 6500 K) and beige wall colour; the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 79 lux and the maximum illuminance level (E_{max}) was 366 lux (Table 4.12). The average illuminance level on the horizontal workplane was calculated as 232 lux (E_{ave}). On Wall 1, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 43 lux and the maximum illuminance level (E_{max}) was 120 lux. The average illuminance level on Wall 1 was calculated as 71 lux (E_{ave}). On Wall 2, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 31 lux and the maximum illuminance level (E_{max}) was 311 lux. The average illuminance level on Wall 2 was calculated as 101 lux (E_{ave}). On Wall 3, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 47 lux and the maximum illuminance level (E_{max}) was 164 lux. The average illuminance level on Wall 3 was calculated as 99 lux (E_{ave}). On Wall 4, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 47 lux and the maximum illuminance level (E_{max}) was 138 lux. The average illuminance level on Wall 4 was calculated as 87 lux (E_{ave}).

In the lighting system Case 1 (500 lux, 3000 K) and blue wall colour; the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 140 lux and the maximum illuminance level (E_{max}) was 662 lux (Table 4.13). The average illuminance level on the horizontal workplane was calculated as 398 lux (E_{ave}). On Wall 1, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 76 lux and the maximum illuminance level (E_{max}) was 177 lux. The average illuminance level on Wall 1 was calculated as 120 lux (E_{ave}). On Wall 2, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 53 lux and the maximum illuminance level (E_{max}) was 440 lux. The average illuminance level on Wall 2 was calculated as 196 lux (E_{ave}). On Wall 3, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 187 lux and the maximum illuminance level (E_{max}) was 420 lux. The average illuminance level on Wall 3 was calculated as 272 lux (E_{ave}). On Wall 4, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 82 lux and the maximum illuminance level (E_{max}) was 419 lux. The average illuminance level on Wall 4 was calculated as 220 lux (E_{ave}).

In the lighting system Case 2 (300 lux, 6500 K) and blue wall colour; the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 67 lux and the maximum illuminance level (E_{max}) was 517 lux (Table 4.14). The average illuminance level on the horizontal workplane was calculated as 268 lux (E_{ave}). On Wall 1, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 54 lux and the maximum illuminance level (E_{max}) was 141 lux. The average illuminance level on Wall 1 was calculated as 88 lux (E_{ave}). On Wall 2, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 35 lux and the maximum illuminance level (E_{max}) was 484 lux. The average illuminance level on Wall 2 was calculated as 176 lux (E_{ave}). On Wall 3, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 85 lux and the maximum illuminance level (E_{max}) was 351 lux. The average illuminance level on Wall 3 was calculated as 188 lux (E_{ave}). On Wall 4, the minimum illuminance level on the horizontal workplane across the room (E_{min}) was 62 lux and the maximum illuminance level (E_{max}) was 177 lux. The average illuminance level on Wall 4 was calculated as 114 lux (E_{ave}).

4.4 Analyses of Within-subjects Experiments

Following the between-groups tests; the within-subjects tests were carried out with 13 participants. The occupant positions were Zone 1 or Zone 2 and orientations were 0°, 45°or 90°. The distribution of these participants among the lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and the colour of internal surfaces (wall colours as beige: L90 C20 H55 and blue: L90 C10 H230) were same as in the between-groups test. The within-subjects analyses were carried out separately for 13 participants. Participant numbers were given from 1 to 13 in relation to the within-subjects test. These analyses contained the evaluation of the occupant questionnaires and the illuminance levels in the field of views.

4.4.1 Occupant questionnaires

In the occupant questionnaire, the same questions were asked when the participant worked with the modified position and orientation. The means of the same questions during the between-groups test and the within-subjects tests were evaluated (Table 4.15). Participant 1 in Zone 2 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 1 and 45° respectively. In the within-subjects test, the means of furniture position and orientation and lighting appraisal increased. While the means of field of view and pleasure remained the same; the means of colour of internal surfaces, lighting system, room appearance, environmental satisfaction and self-assessed productivity decreased.

Participant 2 in Zone 2 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 1 and 45° respectively. In the within-subjects test; while the ratings of field of view, room appearance and environmental satisfaction increased, the ratings of furniture position and orientation, pleasure and self-assessed productivity were the same. The ratings of colour of internal surfaces, lighting system and lighting appraisal decreased.

Table 4.11 : The illuminance level measurements of Case 1 and beige wall colour.

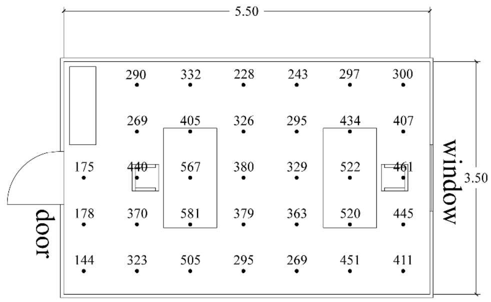
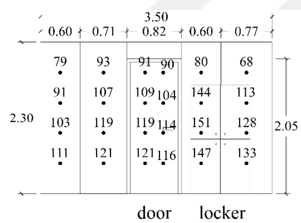
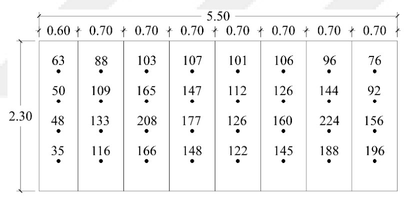
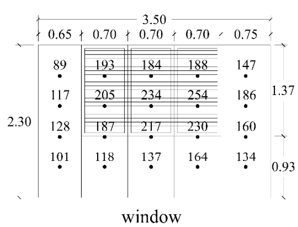
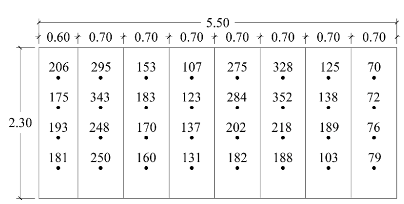
	Lighting system: Case 1 - 500 lux, 3000 K; Wall colour: Beige Illuminance levels (lux)	
Plan		E_{min} = 144 E_{ave} = 362 E_{max} = 581
Elevations — Wall 1		E_{min}= 68 E_{ave}= 111 E_{max} = 151
Wall 2		E_{min} = 35 E_{ave} = 126 E_{max} = 224
Wall 3		E_{min} = 89 E_{ave} = 169 E_{max} = 254
Wall 4		E_{min} = 70 E_{ave} = 186 E_{max} = 352

Table 4.12 : The illuminance level measurements of Case 2 and beige wall colour.

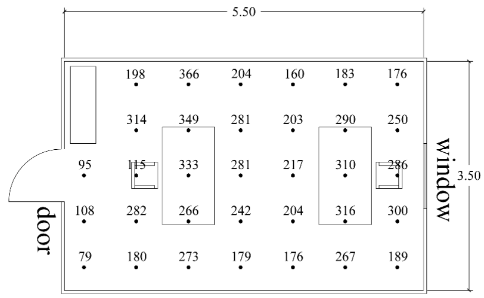
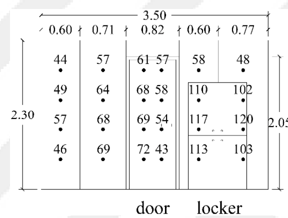
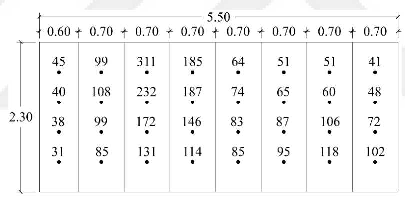
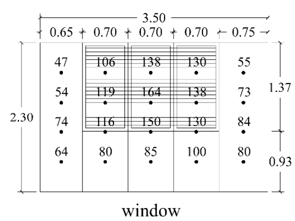
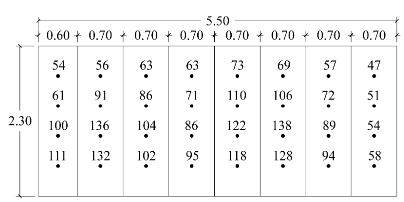
<table>
<tr><th colspan="3">Lighting system: Case 2 - 300 lux, 6500 K; Wall colour: Beige
Illuminance levels (lux)</th></tr>
<tr><td>Plan</td><td>
</td><td>E_{min} = 79
E_{ave} = 232
E_{max} = 366</td></tr>
<tr><td rowspan="4">Elevations</td><td>Wall 1

</td><td>E_{min} = 43
E_{ave} = 71
E_{max} = 120</td></tr>
<tr><td>Wall 2

</td><td>E_{min} = 31
E_{ave} = 101
E_{max} = 311</td></tr>
<tr><td>Wall 3

</td><td>E_{min} = 47
E_{ave} = 99
E_{max} = 164</td></tr>
<tr><td>Wall 4

</td><td>E_{min} = 47
E_{ave} = 87
E_{max} = 138</td></tr>
</table>

Table 4.13 : The illuminance level measurements of Case 1 and blue wall colour.

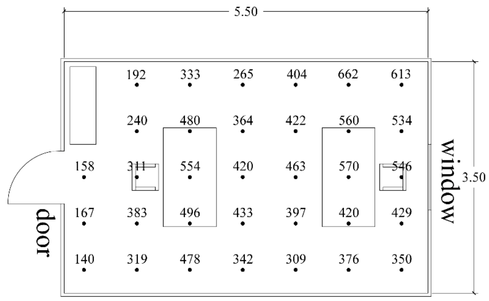
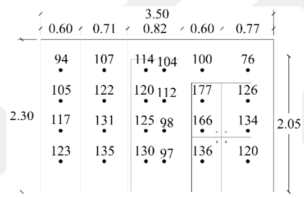
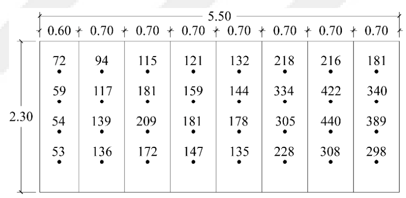
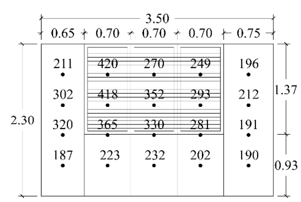
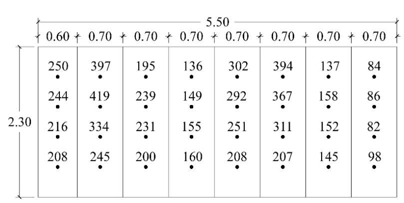
	Lighting system: Case 1 - 500 lux, 3000 K; Wall colour: Blue Illuminance levels (lux)	
Plan		E_{min} =140 E_{ave} = 398 E_{max} = 662
Elevations — Wall 1		E_{min} = 76 E_{ave} = 120 E_{max} = 177
Elevations — Wall 2		E_{min} = 53 E_{ave} = 196 E_{max} = 440
Elevations — Wall 3		E_{min} = 187 E_{ave} = 272 E_{max} = 420
Elevations — Wall 4		E_{min} = 82 E_{ave} = 220 E_{max} = 419

Table 4.14 : The illuminance level measurements of Case 2 and blue wall colour.

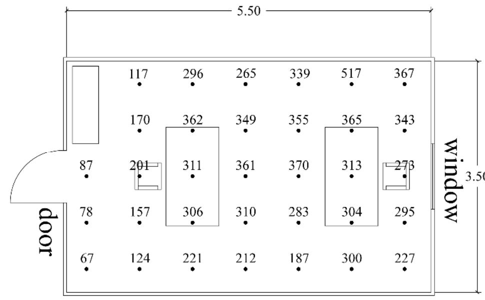
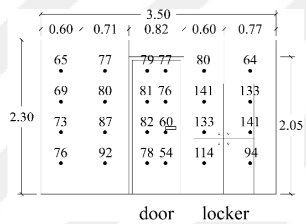
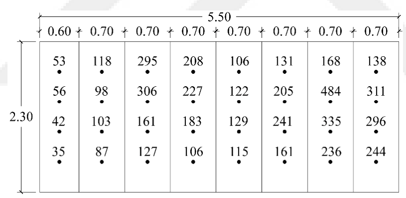
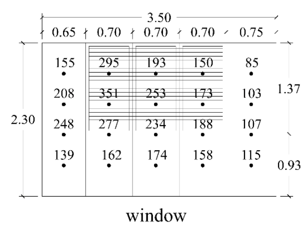
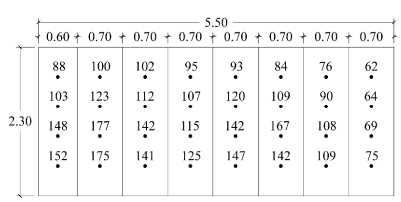
<table>
<tr><th colspan="4">Lighting system: Case 2 - 300 lux, 6500 K; Wall colour: Blue
Illuminance levels (lux)</th></tr>
<tr><td colspan="2">Plan</td><td>
</td><td>E_{min} = 67
E_{ave} = 268
E_{max} = 517</td></tr>
<tr><td rowspan="4">Elevations</td><td>Wall 1</td><td>
</td><td>E_{min} = 54
E_{ave} = 88
E_{max} = 141</td></tr>
<tr><td>Wall 2</td><td>
</td><td>E_{min} = 35
E_{ave} = 176
E_{max} = 484</td></tr>
<tr><td>Wall 3</td><td>
</td><td>E_{min} = 85
E_{ave} = 188
E_{max} = 351</td></tr>
<tr><td>Wall 4</td><td>
</td><td>E_{min} = 62
E_{ave} = 114
E_{max} = 177</td></tr>
</table>

Table 4.15 : The means of the dependent variables for each participant that took the within-subjects test.

Dependent variables	Furniture position and orientation		Field of view		Colour of internal surfaces		Lighting system		Lighting appraisal		Room appearance		Pleasure		Environmental satisfaction		Self-assessed productivity	
Participants of the within-subjects test	Mean (BG: Between-groups, WS:Within-subjects)																	
	BG	WS	BG	WS	BG	WS	BG	WS	BG	WS	BG	WS	BG	WS	BG	WS	BG	WS
Participant 1	3.00	4.00	3.00	3.00	4.00	3.67	5.00	4.00	3.50	4.25	41.11	25.56	2.33	2.33	4.25	3.50	7.00	4.00
Participant 2	4.00	4.00	3.00	4.00	4.33	3.67	2.00	1.00	3.00	2.00	20.00	24.44	3.50	3.50	3.00	3.25	7.00	7.00
Participant 3	3.00	3.00	5.00	1.00	2.00	3.00	4.00	4.00	3.75	2.25	58.89	54.44	1.67	2.67	3.50	2.75	5.00	5.00
Participant 4	1.50	2.00	4.50	1.00	5.33	6.00	3.00	2.00	3.25	3.25	56.67	55.56	5.17	3.17	3.00	2.25	8.00	6.00
Participant 5	3.00	3.50	2.50	3.50	5.33	5.67	5.00	5.00	4.50	4.50	71.11	71.11	6.33	7.00	3.50	4.75	7.00	8.00
Participant 6	4.00	6.00	3.50	6.00	4.33	6.00	6.00	5.00	4.75	5.00	78.89	96.67	5.83	7.00	3.25	5.00	5.00	9.00
Participant 7	3.00	2.50	4.00	4.00	5.00	5.00	4.00	4.00	3.00	3.00	38.89	38.89	3.67	3.67	2.50	2.50	4.00	4.00
Participant 8	6.00	6.00	5.00	6.00	4.33	5.00	6.00	6.00	4.00	4.00	65.56	70.00	5.50	6.83	3.25	3.25	8.00	8.00
Participant 9	4.50	2.00	4.00	2.00	4.67	4.67	4.00	5.00	2.50	2.75	38.89	55.56	4.00	6.50	2.25	2.25	7.00	8.00
Participant 10	4.50	5.00	4.00	5.00	4.67	4.67	4.00	4.00	3.50	3.50	42.22	46.67	3.67	3.67	3.00	4.00	6.00	5.00
Participant 11	2.00	2.00	2.00	2.00	3.67	3.67	3.00	3.00	2.25	2.25	14.44	14.44	2.33	2.33	2.25	2.25	6.00	6.00
Participant 12	4.00	4.00	3.50	3.50	4.33	4.33	4.00	4.00	3.25	3.25	64.44	64.44	5.50	5.50	4.00	4.00	7.00	7.00
Participant 13	3.50	3.50	2.00	2.00	4.33	4.33	6.00	6.00	4.25	4.25	58.89	58.89	4.33	4.33	4.25	4.25	8.00	8.00

Participant 3 in Zone 1 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position Zone 2 and remained the orientation the same as in the between-groups test (0°). In the within-subjects test; the ratings of colour of internal surfaces and pleasure were higher. The ratings of furniture position and orientation, lighting system and self-assessed productivity remained the same. The ratings of field of view, lighting appraisal, room appearance and environmental satisfaction decreased.

Participant 4 in Zone 2 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 1 and 90° respectively. In the within-subjects test; the means of furniture position and orientation and colour of internal surfaces increased. The ratings of lighting appraisal remained the same. The ratings of field of view, lighting system, room appearance, pleasure, environmental satisfaction and self-assessed productivity decreased.

Participant 5 in Zone 2 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 1 and 45° respectively. The means of furniture position and orientation, field of view, colour of internal surfaces, pleasure, environmental satisfaction and self-assessed productivity increased. The means of lighting system, lighting appraisal and room appearance remained the same.

Participant 6 in Zone 2 (Case 1: 500 lux, 3000 K and beige wall colour) also preferred to change the position and orientation to Zone 1 and 45° respectively. The ratings of furniture position and orientation, field of view and colour of internal surfaces, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity increased. Lighting system's rating decreased.

Participant 7 in Zone 1 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 2 and 45° respectively. The means of field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity remained same. Furniture position and orientation's rating decreased.

Participant 8 in Zone 1 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the orientation to 45° respectively. The position remained as in the between-groups test (Zone 1). The ratings of field of view, colour of internal surfaces, room appearance and pleasure increased. The ratings of furniture position and orientation, lighting system, lighting appraisal, environmental satisfaction and self-assessed productivity remained the same.

Participant 9 in Zone 1 (Case 1: 500 lux, 3000 K and beige wall colour) preferred to change the position and orientation to Zone 2 and 90° respectively. The means of lighting system, lighting appraisal, room appearance, pleasure and self-assessed productivity increased. The means of colour of internal surfaces and environmental satisfaction remained the same. The means of furniture position and orientation and field of view decreased.

Participant 10 in Zone 1 (Case 2: 300 lux, 6500 K and beige wall colour) preferred to change the position and orientation to Zone 2 and 45° respectively. The means of furniture position and orientation, field of view, room appearance and environmental satisfaction increased. The means of colour of internal surfaces, lighting system, lighting appraisal and pleasure remained the same. The rating of self-assessed productivity decreased.

Participant 11 in Zone 2 (Case 2: 300 lux, 6500 K and beige wall colour) preferred to change the position and orientation to Zone 1 and 45° respectively. The means of furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity remained the same.

Participant 12 in Zone 2 (Case 1: 500 lux, 3000 K and blue wall colour) preferred to change the position and orientation to Zone 1 and 90° respectively. The means of furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity remained the same.

Participant 13 in Zone 2 (Case 1: 500 lux, 3000 K and blue wall colour) preferred to change the position and orientation to Zone 1 and 90° respectively. The means of furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity remained the same.

4.4.2 Illuminance levels in the field of view

Field of views changed when participants changed their positions and orientations in the within-subjects test. In other words; the walls, which the participants were facing, changed when they changed their positions and orientations. Thus, the average illuminance level in the field of view changed (Table 4.16). Participant 1 (Case 1: 500 lux, 3000 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 165 lux (E_{ave}).

When the participant changed the position and orientation to Zone 1 and 45° respectively, the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level of the preferred case was 121 lux (E_{ave}). This comparison showed a decline in the illuminance levels when the field of view changed to the preferred case.

Table 4.16 : The average illuminance levels in the field of view in the between-groups test and within-subjects test.

Participants of the within-subjects test, lighting system and wall colour	Between-groups test			Within-subjects test			
	Position	Orientation	Average illuminance level (E_{ave})	Position	Orientation	Average illuminance level (E_{ave})	Difference in the average illuminance levels
Participant 1 Li • Wa +	Zone 2	0°	165 lux	Zone 1	45°	121 lux	44 lux ↓
Participant 2 Li •Wa +	Zone 2	0°	165 lux	Zone 1	45°	121 lux	44 lux ↓
Participant 3 Li •Wa +	Zone 1	0°	131 lux	Zone 2	0°	165 lux	34 lux ↑
Participant 4 Li •Wa +	Zone 2	0°	165 lux	Zone 1	90°	137 lux	28 lux ↓
Participant 5 Li •Wa +	Zone 2	0°	165 lux	Zone 1	45°	121 lux	44 lux ↓
Participant 6 Li • Wa +	Zone 2	0°	165 lux	Zone 1	45°	121 lux	44 lux ↓
Participant 7 Li •Wa +	Zone 1	0°	131 lux	Zone 2	45°	147 lux	16 lux ↑
Participant 8 Li •Wa +	Zone 1	0°	131 lux	Zone 1	45°	121 lux	10 lux ↓
Participant 9 Li •Wa +	Zone 1	0°	131 lux	Zone 2	90°	118 lux	13 lux ↓
Participant 10 Li ◆Wa +	Zone 1	0°	90 lux	Zone 2	45°	108 lux	18 lux ↑
Participant 11 Li ◆Wa +	Zone 2	0°	88 lux	Zone 1	45°	99 lux	11 lux ↑
Participant 12 Li •Wa ×	Zone 2	0°	259 lux	Zone 1	90°	235 lux	24 lux ↓
Participant 13 Li •Wa ×	Zone 2	0°	259 lux	Zone 1	90°	235 lux	24 lux ↓
Key	Lighting system (Li) •Case 1: 500 lux, 3000 K ◆Case 2: 300 lux, 6500 K			Wall colour (Wa) +Beige ×Blue			Difference ↑Increase ↓ Decrease

Participant 2 (Case 1: 500 lux and 3000 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was

165 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 45° respectively, the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level of the preferred case was 121 lux (E_{ave}). The difference was a decline in the illuminance levels in the preferred case.

Participant 3 (Case 1: 500 lux and 3000 K and beige wall colour) saw the entire Wall 1, the first five panels of Wall 2 and the last five panels of Wall 4 when worked in Zone 1 with the orientation 0°. The average illuminance level of this elevation was 131 lux (E_{ave}). When the participant changed the position to Zone 2 with no change in orientation (0°), the participant saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4. The average illuminance level of the preferred case was 165 lux (E_{ave}). The comparison demonstrated an increase from the initial case to the preferred case.

Participant 4 (Case 1: 500 lux and 3000 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 165 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 90° respectively, the participant saw the last six panels of Wall 2 and the first panel of Wall 3. The average illuminance level of the preferred case was 137 lux (E_{ave}). The preferred case had a lower average illuminance level in participant's field of view.

Participant 5 (Case 1: 500 lux and 3000 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 165 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 45° respectively, the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level of the preferred case was 121 lux (E_{ave}). The average illuminance level in field of view of the preferred case declined.

Participant 6 (Case 1: 500 lux and 3000 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 165 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 45° respectively, the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level of the preferred case was 121 lux (E_{ave}). This showed a decline in the illuminance levels when the participant changed the field of view to the preferred case.

Participant 7 (Case 1: 500 lux, 3000 K and beige wall colour) saw the entire Wall 1, the first five panels of Wall 2 and the last five panels of Wall 4 when worked in Zone 1 with the orientation 0°. The average illuminance level of this elevation was 131 lux (E_{ave}). When the participant changed the position to Zone 2 and 45° respectively, the participant saw the last six panels of Wall 2 and the first three panels of Wall 3. The average illuminance level of the preferred case was 147 lux (E_{ave}). There was a slight increase in the average illuminance level in field of view of preferred case.

Participant 8 (Case 1: 500 lux, 3000 K and beige wall colour) saw the entire Wall 1, the first five panels of Wall 2 and the last five panels of Wall 4 when worked in Zone 1 with the orientation 0°. The average illuminance level of this elevation was 131 lux (E_{ave}). When the participant changed the orientation to 45° respectively with the position remained the same as in the between-groups test (Zone 1), the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level of the preferred case was 121 lux (E_{ave}). This showed a slight decline in the illuminance levels when the participant changed the field of view to the preferred case.

Participant 9 (Case 1: 500 lux, 3000 K and beige wall colour) saw the entire Wall 1, the first five panels of Wall 2 and the last five panels of Wall 4 when worked in Zone 1 with the orientation 0°. The average illuminance level of this elevation was 131 lux (E_{ave}). When the participant changed the position and orientation to Zone 2 and 90° respectively, the participant saw the first six panel of Wall 2 and the last panel of

Wall 1, half of which was covered by the locker. The average illuminance level was 118 lux (E_{ave}). There was a decrease in the average illuminance level in field of view in the preferred case.

Participant 10 (Case 2: 300 lux, 6500 K and beige wall colour) saw the entire Wall 1, the first five panels of Wall 2 and the last five panels of Wall 4 when worked in Zone 1 with the orientation 0°. The average illuminance level of this elevation was 90 lux (E_{ave}). When the participant changed the position and orientation to Zone 2 and 45° respectively, the participant saw the last six panels of Wall 2 and the first three panels of Wall 3. The average illuminance level was 108 lux (E_{ave}). The average illuminance level in field of view of preferred case slightly increased.

Participant 11 (Case 2: 300 lux, 6500 K and beige wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 88 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 45° respectively, the participant saw the last three panels of Wall 1 and the first seven panels of Wall 2. The average illuminance level was 99 lux (E_{ave}). There was a slight increase in the average illuminance level in field of view of preferred case.

Participant 12 (Case 1: 500 lux, 3000 K and blue wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 259 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 90° respectively, the participant saw the last six panels of Wall 2 and the first panel of Wall 3. The average illuminance in the field of view dropped to 235 lux (E_{ave}) in the preferred case.

Participant 13 (Case 1: 500 lux, 3000 K and blue wall colour) saw the last four panels of Wall 2, the entire Wall 3 and the first four panels of Wall 4 when worked in Zone 2 with the orientation 0°. The average illuminance level of this elevation was 259 lux (E_{ave}). When the participant changed the position and orientation to Zone 1 and 90° respectively, the participant saw the last six panels of Wall 2 and the first panel of Wall 3. The average illuminance was 235 lux (E_{ave}). There was a decrease in the average illuminance level in field of view of preferred case.

4.5 Discussion of the Experimental Study

The experimental study aimed to integrate adaptive behaviour related parameters into the existing assessment of the relations between user, space and lighting. The adaptive behaviour parameters included furniture position and orientation, field of view, colour of internal surfaces and lighting systems through the literature review. The existing assessment was through the SEM model by Veitch et. al (2013), which contained lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity.

Experiments were carried out in the test room with office function in the lighting laboratory in Istanbul Kültür University. The experiments contained two stages as between-group tests and within-subjects test. The between-groups tests evaluated two different lighting systems and two different wall colours as the independent variables. The lighting systems were Case 1 with the illuminance level of 500 lux and the CCT of 3000 K and Case 2 with the illuminance level of 300 lux and the CCT of 6500 K. The wall colours were beige (L90 C20 H55) and blue (L90 C10 H230). The within-subjects tests assessed occupant positions and orientations as the independent variable. The occupant positions were Zone 1 or Zone 2 and orientations were 0°, 45°or 90°.

The statistical analyses included descriptive statistics, SEM and ANOVA. As the initial analysis, the descriptive statistics described that average participant age was 21 with 53% female and 47% male undergraduate students. The departments of the participants were diverse including architecture, art, engineering, language and business administration. The number of participants was 36. As for the bivariate correlations; the correlation between furniture position and orientation and field of view was among the most significant correlations as two of the adaptive behaviour parameters (at the 0.01 level). As another adaptive behaviour parameter; colour of internal surfaces significantly correlated with pleasure, environmental satisfaction and self-assessed productivity. Correlations between lighting system as an adaptive behaviour parameter and lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity were among the most significant correlations as well.

SEM analysis was carried out for two lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and beige wall colour involving 26 participants. The SEM model identified significant relations between the variables. The statistically significant paths at the 0,001 level were furniture position and orientation-field of view, lighting system-lighting appraisal, lighting appraisal-room appearance, room appearance-pleasure and lighting appraisal-workplace satisfaction. The significant paths between furniture position and orientation-field of view and lighting system-lighting appraisal were logical. The other significant paths supported the model of Veitch et al. (2013). The significant paths provided the impact of a variable on a dependent variable. This helps to improve the dependent variable through enhancing the variable that predicted it.

The ANOVA tests investigated the null hypotheses, which assessed differences between means of independent groups of independent variables for the dependent variables. For beige wall colour, the mean of colour of internal surfaces increased from Case 1 to Case 2. The means of other dependant variables decreased. These were not statistically significant differences. For blue wall colour, all dependant variables decreased from Case 1 to Case 2. The null hypothesis-2 indicating that the dependent variables under the lighting systems Case 1 (500 lux, 3000 K) and Case 2 (300 lux, 6500 K) do not differ for the blue wall colour can be rejected for lighting system, lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity. The differences for these five dependant variables were statistically significant. For Case 1, the means of all dependant variables increased from beige to blue wall colour. The null hypothesis-3, which stated that means of dependent variables for beige and blue wall colours do not vary under lighting system Case 1 (500 lux, 3000 K), can be rejected for room appearance, pleasure, environmental satisfaction and self-assessed productivity. The differences for these four dependant variables were statistically significant. For Case 2; the means of colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure and self-assessed productivity increased from beige to blue wall colour. The means of other dependant variables decreased. These were not statistically significant differences.

The illuminance level measurements were conducted for two lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and two wall colours (beige: L90 C20 H55 and blue: L90 C10 H230) horizontally and vertically. The illuminance level measurements showed that the horizontal illuminance levels in Case 1 were similar for beige and blue walls. This was also observed in Case 2. In Case 1 and Case 2; while the vertical illuminance levels on Wall 1 and Wall 4 were close to each other for beige and blue walls, the illuminance levels were much higher on Wall 2 and Wall 3 for blue wall than beige wall. When Case 1 and Case 2 were compared for the same wall colours, the horizontal illuminance levels (on workplane) and vertical illuminance levels (on walls) were higher in Case 1 for both colours. The highest differences were seen on the workplane, Wall 3 and Wall 4 for beige and blue walls.

The within-subjects tests were conducted with 13 participants as preferred to change their positions to Zone 1 or Zone 2 and orientations to 45°or 90°. Similar to the between-groups test, the dependent variables were furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity. Analyses of within-subjects tests included the evaluation of the occupant questionnaires and the illuminance levels in the field of view. The occupant questionnaires showed that most of the participants (11) preferred to change both position and orientation. Two of the participants preferred to change either position or orientation. When compared with the between-groups tests, the changes in the means of the dependent variables vary based on individual evaluation of participant. The means increased, remained the same or decreased. The dependant variables that increased most among the participants were furniture position and orientation, field of view, room appearance and pleasure (five participants for each variable). Colour of internal surfaces and environmental satisfaction improved for four participants. While lighting appraisal and self-assessed productivity improved for three participants, lighting system enhanced for one participant. The dependant variables that remained similar most among the participants were lighting system and lighting appraisal (eight participants for both variables). Pleasure and self-assessed productivity remained similar for seven participants. Furniture position and orientation, colour of internal surfaces and environmental satisfaction were similar for six participants. Field of view and room appearance remained the same for five participants. Lighting system decreased most among the participants. Room appearance and self-assessed productivity decreased for three participants. Furniture position and orientation, field of view, colour of internal surfaces, lighting appraisal and environmental satisfaction decreased for two participants. One participant evaluated pleasure with a lower rating than the evaluation in the between-groups test. The illuminance levels in field of views either decreased or increased when the field of views changed in the within-subjects test. Out of 13 participants, nine participants had a lower average illuminance level in field of view when compared with the between-groups test. Four participants experienced a higher average illuminance level in the field of view. As decrease, differences in the average illuminance level were 10 lux, 13 lux, 24 lux, 28 lux and 44 lux. As increase, the differences in the average illuminance level were 11 lux, 16 lux, 18 lux and 34 lux. The illuminance levels were assessed with responses to the occupant questionnaires in the within-subjects test. It was seen that when average illuminance level in field of view decreased; the means of variables increased, remained the same or decreased. Having experienced the same decrease in the illuminance level in field of view (44 lux), the evaluation of lighting appraisal and room appearance increased for participant 1 and participant 2 respectively. The evaluation of lighting system decreased for both participants. Participant 5 and Participant 6 had a similar decline in the average illuminance level in the field of view (44 lux), but had different evaluations. For Participant 5, the ratings of lighting system, lighting appraisal and room appearance remained the same with the between-groups test. Participant 6 evaluated furniture position and orientation, field of view and colour of internal surfaces, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity with higher ratings. Participant 12 and participant 13 experienced a decline in the average illuminance level in field of view (24 lux); however, their evaluation of all variables remained the same. As for the participants who experienced increase in the average illuminance level in field of view, the means of variables increased, remained the same or decreased. The evaluation of colour and pleasure increased for participant 3 (34 lux) and the evaluation of furniture position and orientation, field of view, room appearance and environmental satisfaction increased for participant 10 (18 lux). Most of the variable ratings for participant 7 (16 lux) and all of the variable ratings remained the same for participant 11 (11 lux) although they experienced increase in the average illuminance level in field of view. Ratings of field of view, lighting appraisal, room appearance and environmental satisfaction decreased for participant 3 and self-assessed productivity decreased for participant 10 although average illuminance level in field of view increased.

5. PROPOSED POST-OCCUPANCY EVALUATION (POE) METHODOLOGY: 'THE INTEGRATED POE IN LIGHTING'

The aim of proposing the SEM model in Chapter 4 was to assess how adaptive behaviour in relation to lighting affected user and visual environment. The SEM model identified the relationships between adaptive behaviour, lighting appraisal, room appearance, pleasure and workplace satisfaction in the test room with an office function.

In this chapter, the model and its methodology were implemented into a POE methodology for the field of lighting. The proposed POE methodology, which is called 'the Integrated POE in Lighting', aimed to assess visual environment holistically considering user behaviour, lighting conditions and internal surface attributes. 'The Integrated POE in Lighting'methodology is recommended for the upcoming evaluation studies of office spaces.

5.1 Content of 'the Integrated POE in Lighting' Methodology

'The Integrated POE in Lighting'methodology is consisted of four stages (Figure 5.1):

5.1.1 Stage-1: Observation and information

In the first stage of 'the Integrated POE in Lighting' methodology, the assessor observes the building that is under evaluation and information meetings are organised with the occupants of the building. Stage-1 contains two steps as observing the building and informing the occupants.

5.1.1.1 Step 1.1: Observing the building

The assessor visits the building and observes the attributes related to architecture, interior design, daylighting system, artificial lighting system, lighting control system and facade of the building. An observation form can be also filled in if prepared as a template by the assessor before the visit or notes can be taken. The problems observed in the visual environment can be noted. It is useful to take photographs from multiple-points in the building.

In this step, reviewing the as-built projects of the building (architectural, interior design, lighting and electrical projects) is useful to find required information about the building.

An interview can be done with facility manager of building for asking required information about building.

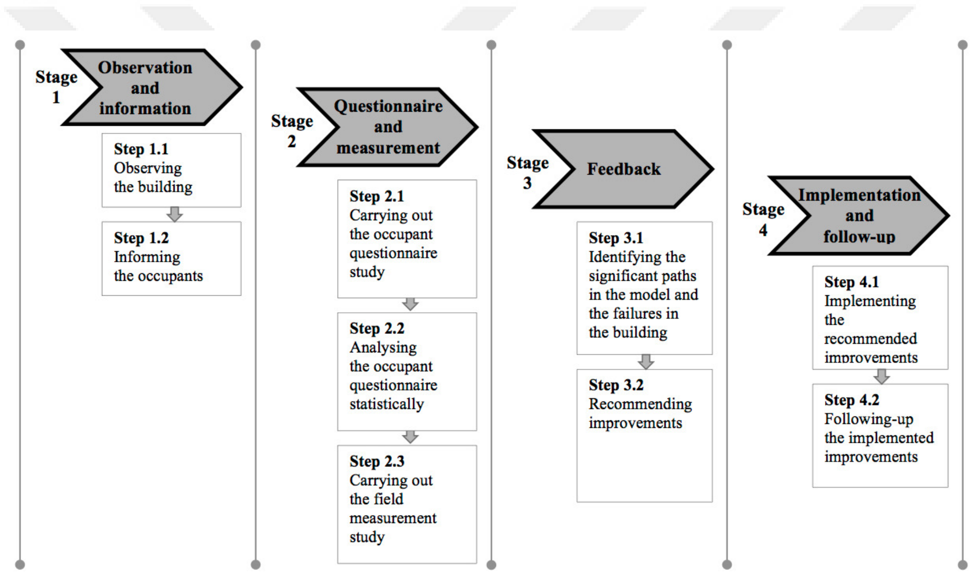


Figure 5.1 : The stages of 'the Integrated POE in Lighting' methodology.

5.1.1.2 Step 1.2: Informing the occupants

The assessor will organise meetings with the occupants in the building. Information about POE, visual environment, 'the Integrated POE in Lighting' methodology and improvements as the result of the POE studies will be shared with the occupants.

5.1.2 Stage-2: Questionnaire and measurement

In the second stage of 'the Integrated POE in Lighting' methodology, occupant questionnaire study and field measurement study are conducted. Stage-2 contains three steps as carrying out the occupant questionnaire study, analysing the occupant questionnaire statistically and carrying out the field measurement study.

5.1.2.1 Step 2.1: Carrying out the occupant questionnaire study

The model of visual environment, which was used in Chapter 4 (Figure 4.1), and its methodology containing the occupant questionnaire are utilized in this step. The occupants respond to the occupant questionnaire as paper-format during working in their offices.

5.1.2.2 Step 2.2: Analysing the occupant questionnaire statistically

The occupant questionnaires are statistically analysed. For the statistical analysis method, SEM is used. The model is generated, which identifies the relationships in the visual environment of the evaluated office building.

5.1.2.3 Step 2.3: Carrying out the field measurement study

The illuminance levels in the evaluated offices will be measured. As the measurement procedure applied in Chapter 4, horizontal illuminance levels (workplane: across the room including occupant desks) and vertical illuminance levels (workplane: internal wall surfaces) will be measured.

5.1.3 Stage-3: Feedback

In the third stage of 'the Integrated POE in Lighting' methodology, feedback is provided based on the model generated in the Stage-2. Stage 3 contains two steps as identifying the significant paths in the model and the failures in the building and recommending improvements.

5.1.3.1 Step 3.1: Identifying the significant paths in the model and failures in the building

The significant paths and variables in the model are identified. The failures and problems about these variables are determined through the occupant questionnaire, assessor observation and field measurements.

5.1.3.2 Step 3.2: Recommending improvements

Improvements are recommended to strengthen the significant paths and improve the problematic issues. The improvement flowcharts, which are given in Chapter 5.2, can guide the assessor for the decision-making process.

5.1.4 Stage-4: Implementation and follow-up

In the last stage of ‘the Integrated POE in Lighting’ methodology, the improvements recommended in Stage 3 are implemented and followed-up. Stage 4 contains two steps as implementing the recommended improvements and following-up the implemented improvements.

5.1.4.1 Step 4.1: Implementing the recommended improvements

The improvements, which are recommended in Step 3.2 in Stage 3, are implemented in the building.

5.1.4.2 Step 4.2: Following-up the implemented improvements

The implemented improvements are followed-up and maintenance is operated regularly.

5.2 Improvement Flowcharts in ‘the Integrated POE in Lighting’ Methodology

The improvement flowcharts were developed for the paths in the SEM model. They aim to guide the assessor during recommending the improvements. The SEM model would identify the statistically significant paths. Thus the assessor can recommend improvements to enhance the variables that are affected by the statistically significant path. The improvement flowcharts would guide the assessor through the steps, which should be applied for enhancing the variables. For example; if the SEM model of the evaluation study shows that the path between lighting appraisal and workplace satisfaction is statistically significant, this evidences that occupants with a better lighting appraisal have higher workplace satisfaction. The assessor can benefit from the improvement flowchart for the path between lighting appraisal and workplace satisfaction and recommend the steps on the flowchart. This would result in an enhancement in the lighting appraisal, which would improve workplace satisfaction.

The improvement flowcharts are labelled according to the paths in the SEM model. In total, there are eight flowcharts. The latent variables in the SEM model were not included in the development of the flowcharts as they are not directly measured. The improvement flowcharts are given as below:

5.2.1 Improvement flowchart-1: Furniture position and orientation - Field of view

The improvement flowchart between furniture position and orientation and field of view indicates improvement actions between these two variables (Figure 5.2). These actions aim at enhancing the evaluation of field of view.

The improvement flowchart starts with the evaluation of the furniture position and orientation. The improvement actions in the flowchart are determined according to the preference of the occupant for changing the furniture position and orientation. The improvement actions are to change the furniture position and orientation according to the occupant's preference. The occupant preference data is taken from the occupant questionnaire throughout the flowchart. In the occupant questionnaire, the evaluated room can be divided into zones and the occupant can select the zone he or she prefers for the furniture position.

The number of zones can be decided based on the room size. For the furniture orientation, three orientations can be given as multiple choices and the occupant can choose the orientation he or she prefers for the furniture. The orientations can be 0°, 45° and 90°. The improvement actions result in the enhancement in the evaluation of the field of view.

5.2.2 Improvement flowchart-2: Field of view - Lighting appraisal

The improvement flowchart between field of view and lighting appraisal indicates improvement actions between these two variables (Figure 5.3). These actions aim at enhancing the evaluation of lighting appraisal.

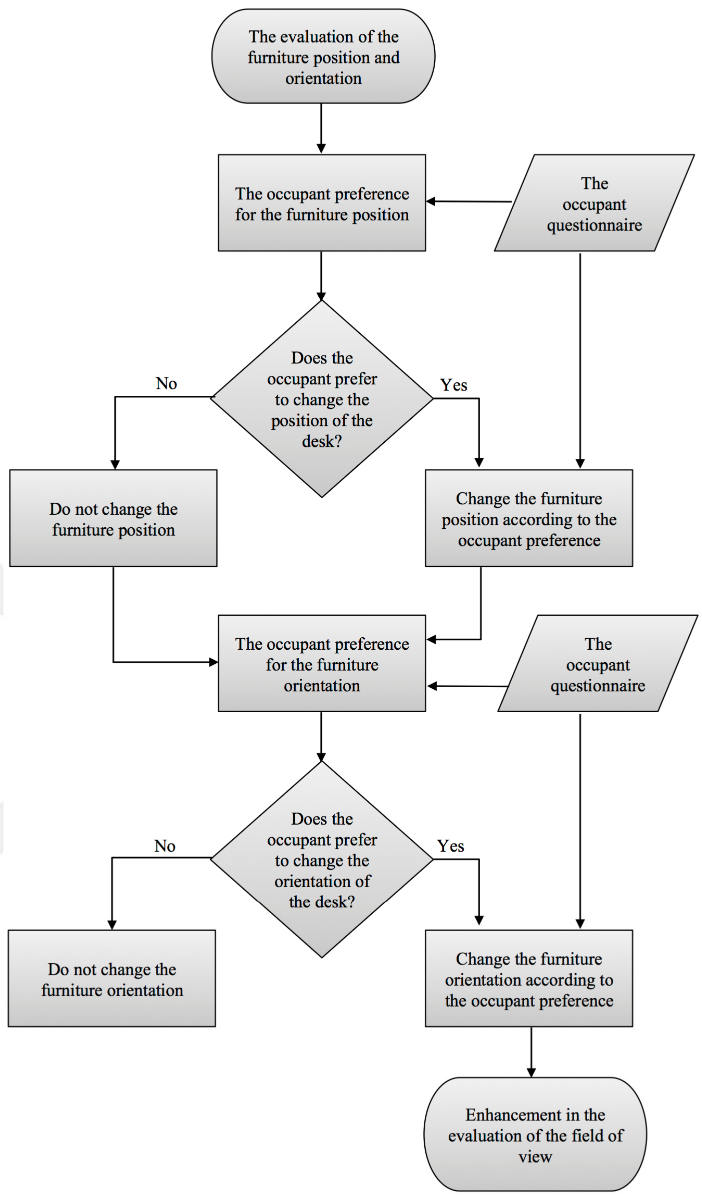


Figure 5.2 : The improvement flowchart between furniture position and orientation and field of view.

The improvement flowchart starts with the evaluation of the field of view. The improvement actions in the flowchart are determined according to the preference of the occupant for changing his or her field of view. The improvement actions are to change the field of view according to the occupant's preference. The occupant preference data is taken from the occupant questionnaire throughout the flowchart. Three orientations can be given as multiple choices and the occupant can choose the orientation he or she prefers for himself or herself. The orientations can be 0°, 45° and 90°. The improvement actions result in the enhancement in the evaluation of the lighting appraisal.

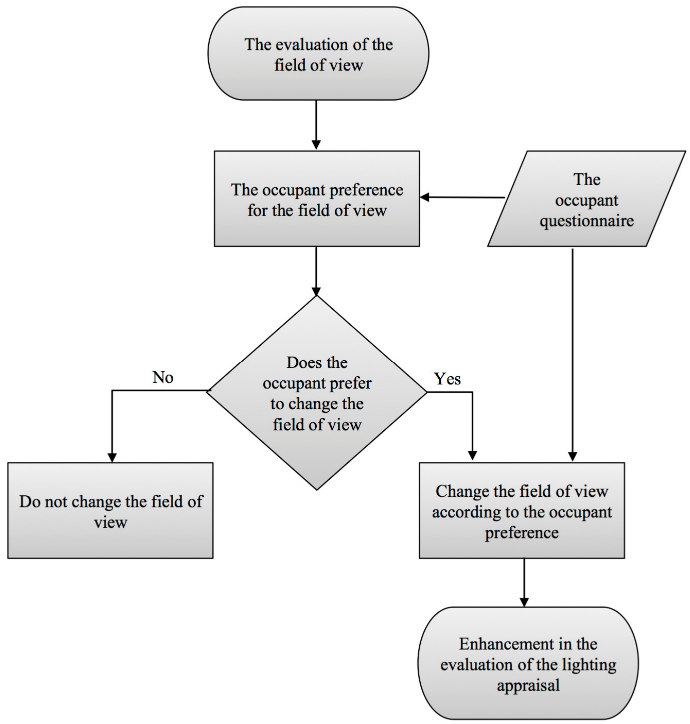


Figure 5.3 : The improvement flowchart between field of view and lighting appraisal.

5.2.3 Improvement flowchart-3: Colour of internal surfaces - Lighting appraisal

The improvement flowchart between colour of the internal surfaces and lighting appraisal indicates improvement actions between these two variables (Figure 5.4). These actions aim at enhancing the evaluation of lighting appraisal.

The improvement flowchart starts with the evaluation of the colour of the internal surfaces. The improvement actions in the flowchart are determined according to the preference of the occupant related to the colour of the internal surfaces. The improvement actions include changing colour of internal surfaces according to occupant's preference. The occupant preference data for colour of internal surfaces is indicated with the preferred hue, value and saturation. This data is taken from the occupant questionnaire throughout the flowchart. The reflectances of the internal surfaces are recommended in the EN 12464-1 Standard. The recommended reflectance for ceiling is between 70% and 90%, wall is between 50% and 80% and floor is between 20% and 40% (EN 12464-1, 2011). In case the colour of the internal surfaces is not changed according to the occupant preference, the reflectances of the

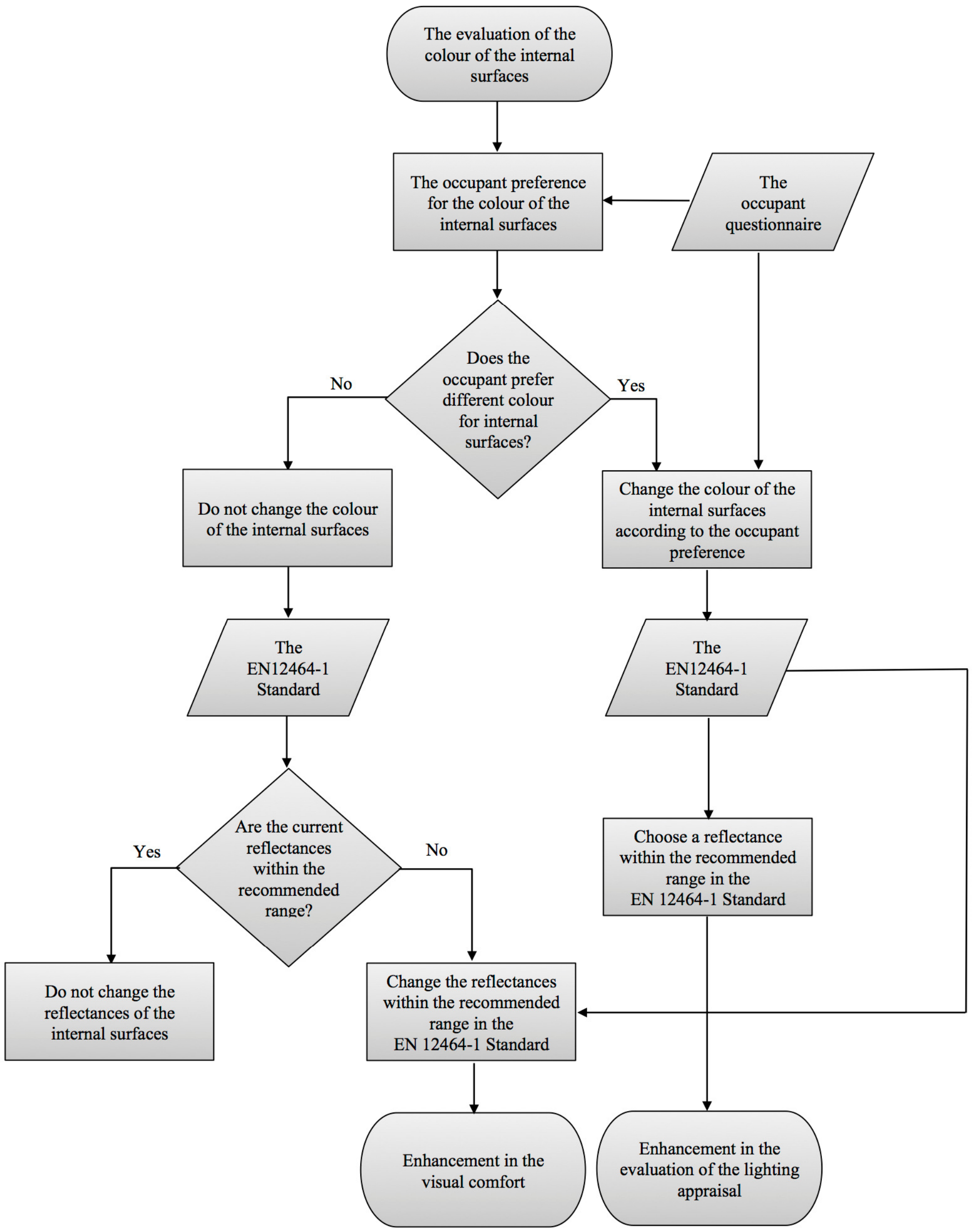


Figure 5.4 : The improvement flowchart between colour of internal surfaces and lighting appraisal.

colours are decided according to the EN 12464-1 Standard. This improvement action results in the enhancement in the evaluation of the lighting appraisal. In case the colour of the internal surfaces is not changed, the current reflectances of the internal surfaces should be controlled if they are within the recommended range in the EN 12464-1 Standard. If they do not, the reflectances should be changed. This improvement action results in the enhancement of the visual comfort conditions.

5.2.4 Improvement flowchart-4: Lighting system - Lighting appraisal

The improvement flowchart between lighting system and lighting appraisal indicates improvement actions between these two variables. These actions aim at enhancing the evaluation of lighting appraisal.

The improvement flowchart starts with the lighting system's evaluation. In the occupant questionnaire, lighting system is evaluated through illuminance level and CCT. In terms of the illuminance level, the improvement actions in the flowchart are determined according to the preferred illuminance level by the occupant (Figure 5.5). This data is taken from the occupant questionnaire throughout the flowchart. If the occupant preferred a different illuminance level, illuminance level is changed according to the occupant preference. This improvement action results in the enhancement of the lighting appraisal. For the cases in which occupant does not prefer to change the illuminance level, the current illuminance level is not modified.

In terms of CCT, the improvement actions in the flowchart are determined according to the preferred CCT by the occupant (Figure 5.6). This data is taken from the occupant questionnaire throughout the flowchart. If the occupant preferred a different CCT, the CCT should be changed according to the occupant preference. In literature, Fotios highlighted lower illuminance levels with higher CCTs (Fotios, 2011). The experimental study in Chapter 4 assessed the relation between illuminance level and CCT. High illuminance level together with low CCT (500 lux and 3000 K) and low illuminance level together with high CCT (300 lux and 6500 K) were evaluated.The relation between illuminance level and CCT is reflected on the improvement flowchart through merging illuminance level and CCT and considering them concurrently during POE process.

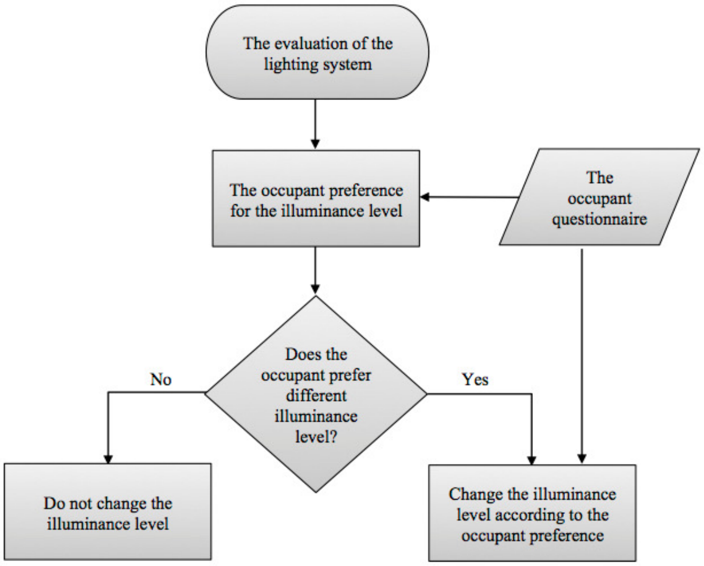


Figure 5.5 : The improvement flowchart between lighting system and lighting appraisal in terms of illuminance level.

The current or preferred CCT should be checked with the current or preferred illuminance level whether they align or not. If the current CCT aligns with the illuminance level, it should not be changed. If the current and preferred CCT does not align with the illuminance level, the CCT should be changed in alignment with the illuminance level. If the preferred CCT aligns with the illuminance level, the CCT should be changed according to the occupant preference. These two improvement actions are expected to enhance lighting appraisal.

5.2.5 Improvement flowchart-5: Lighting appraisal - Workplace satisfaction

The improvement flowchart between lighting appraisal and workplace satisfaction indicates improvement actions between these two variables (Figure 5.7). These actions aim at enhancing the evaluation of workplace satisfaction.

The improvement flowchart starts with the evaluation of lighting appraisal. The improvement actions in the flowchart are determined according to the evaluation of the illuminance level in the occupant questionnaire. If the rating of the illuminance level item is equal to and higher than four in the 5-points Likert scale, the illuminance level does not have to be changed. If the rating of the illuminance level is lower than four in the 5-points Likert scale, then the illuminance level should be increased. The improvement actions continue with the evaluation of the glare in the occupant questionnaire. If the rating of the glare that bothers occupants is equal to and lower than two in the 5-points Likert scale, the conditions related to the glare do not have to be changed. If the rating of the glare is higher than two in the 5-points Likert scale, the conditions related to glare should be improved. The maximum UGR limits, which are indicated in the EN 12464-1 Standard, should be applied for the UGR values in the room (EN 12464-1, 2011). The improvement actions result in theenhancement in the evaluation of the workplace satisfaction and visual comfort conditions.

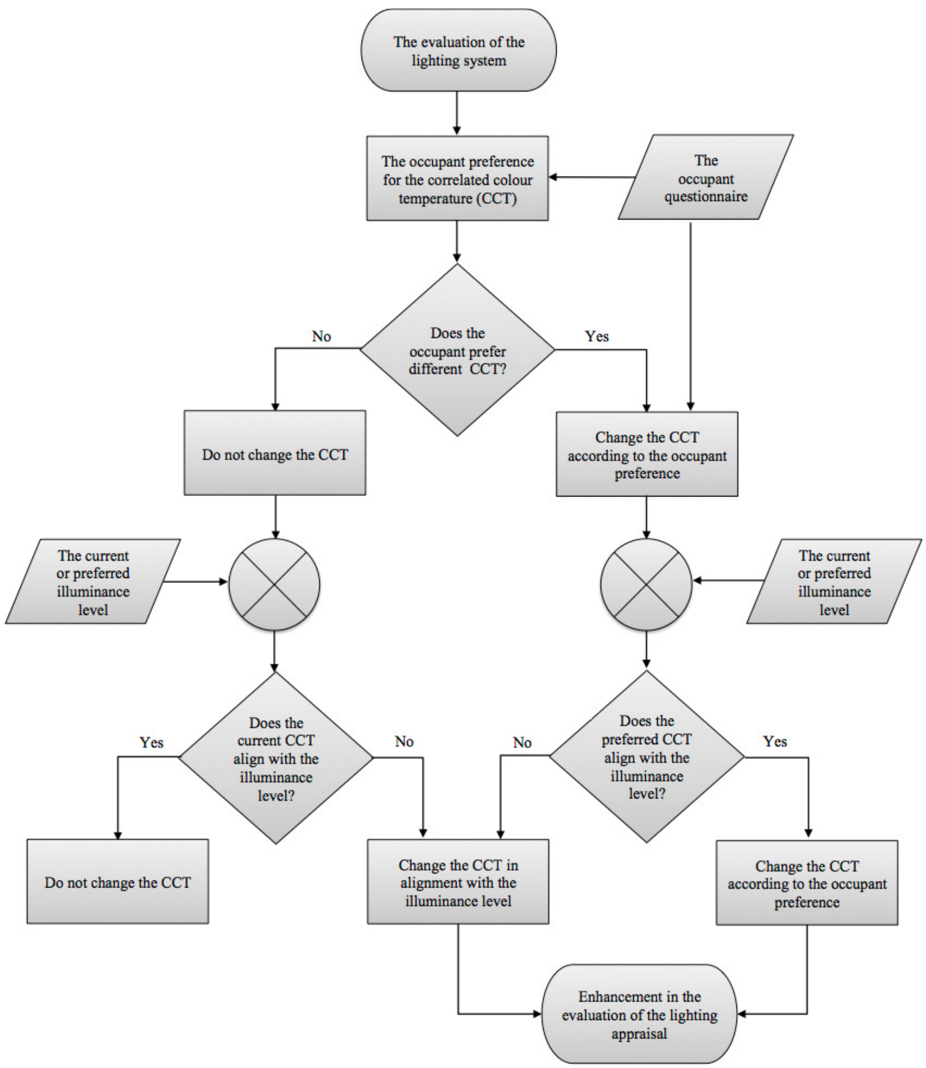


Figure 5.6 : The improvement flowchart between lighting system and lighting appraisal in terms of CCT.

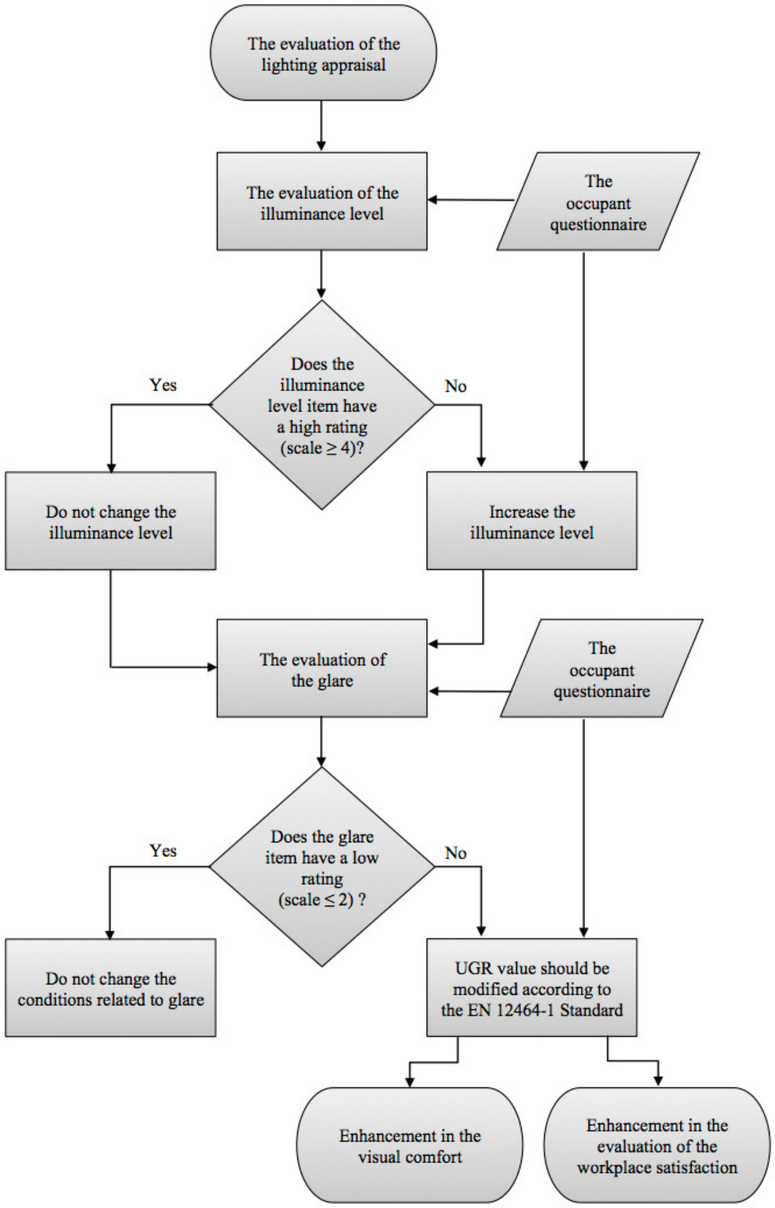


Figure 5.7 : The improvement flowchart between lighting appraisal and workplace satisfaction.

5.2.6 Improvement flowchart-6: Lighting appraisal -Room appearance

The improvement flowchart between lighting appraisal and room appearance indicates improvement actions between these two variables (Figure 5.8). These actions aim at enhancing the evaluation of room appearance.

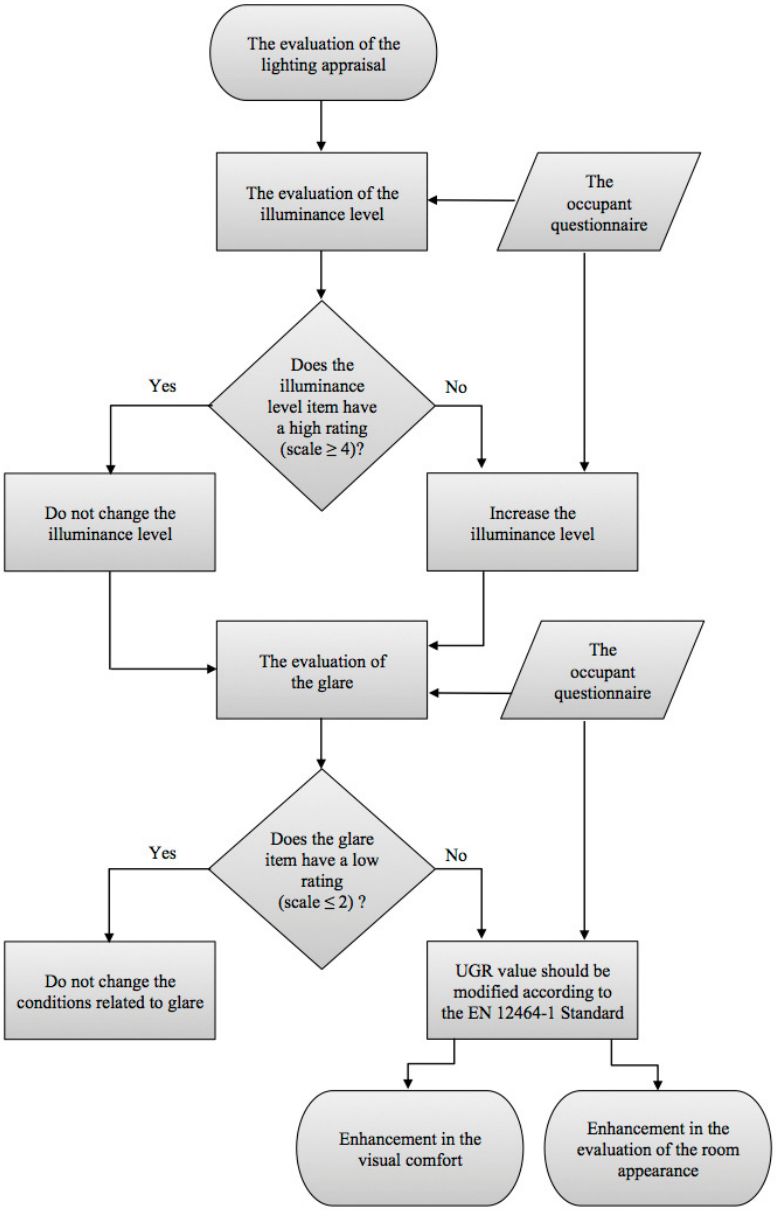


Figure 5.8 : The improvement flowchart between lighting appraisal and room appearance.

The improvement flowchart starts with the evaluation of lighting appraisal. The improvement actions in the flowchart are determined according to the evaluation of the illuminance level in the occupant questionnaire. If the rating of the illuminance level is equal to and higher than four in the 5-points Likert scale, the illuminance level does not have to be changed. If the rating of the illuminance level is lower than four in the 5-points Likert scale, then the illuminance level should be increased. The improvement actions continue with the evaluation of the glare in the occupant questionnaire. If the rating of the glare that bothers occupants is equal to and lower than two in the 5-points Likert scale, the conditions related to the glare do not have to be changed. If the rating of the glare is higher than two in the 5-points Likert scale, the conditions related to glare should be improved. The maximum UGR limits, which are indicated in the EN 12464-1 Standard, should be applied for the UGR values in the room (EN 12464-1, 2011). The improvement actions result in the enhancement in the evaluation of the room appearance and visual comfort conditions.

5.2.7 Improvement flowchart-7: Room appearance - Pleasure

The improvement flowchart between the room appearance and the pleasure indicates improvement actions between these two variables (Figure 5.9). These actions aim at enhancing the evaluation of pleasure.

The improvement flowchart starts with the evaluation of room appraisal. The improvement actions in the flowchart are determined according to the evaluation of the items as the attractiveness scale in the occupant questionnaire, which are nine items. If the rating of one item is equal to and higher than sixty in the scale from zero to hundred, the item does not have to be changed. If the rating of the item is lower than sixty in the scale from zero to hundred, then the item should be improved. The items can be improved through the guidance of the SLL Lighting Handbook (SLL, 2009). The improvement actions result in the enhancement in the evaluation of the pleasure.

5.2.8 Improvement flowchart-7: Room appearance - Workplace satisfaction

The improvement flowchart between room appearance and workplace satisfaction indicates improvement actions between these two variables (Figure 5.10). These actions aim at enhancing the evaluation of workplace satisfaction.

The improvement flowchart starts with the evaluation of the room appraisal. The improvement actions in the flowchart are determined according to the evaluation of the items as the attractiveness scale in the occupant questionnaire, which are nine items. If the rating of one measure is equal to and higher than sixty in the scale from zero to hundred, the item does not have to be changed. If the rating of the item is lower than sixty in the scale from zero to hundred, then the item should be improved. The items can be improved through the guidance of the SLL Lighting Handbook (SLL, 2009). The improvement actions result in the enhancement in the evaluation of workplace satisfaction.

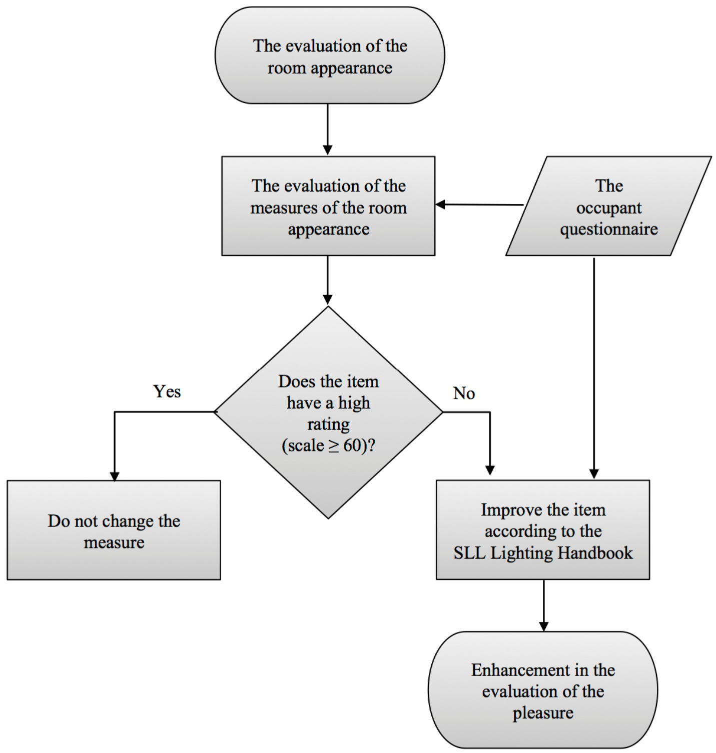


Figure 5.9 : The improvement flowchart between room appearance and pleasure.

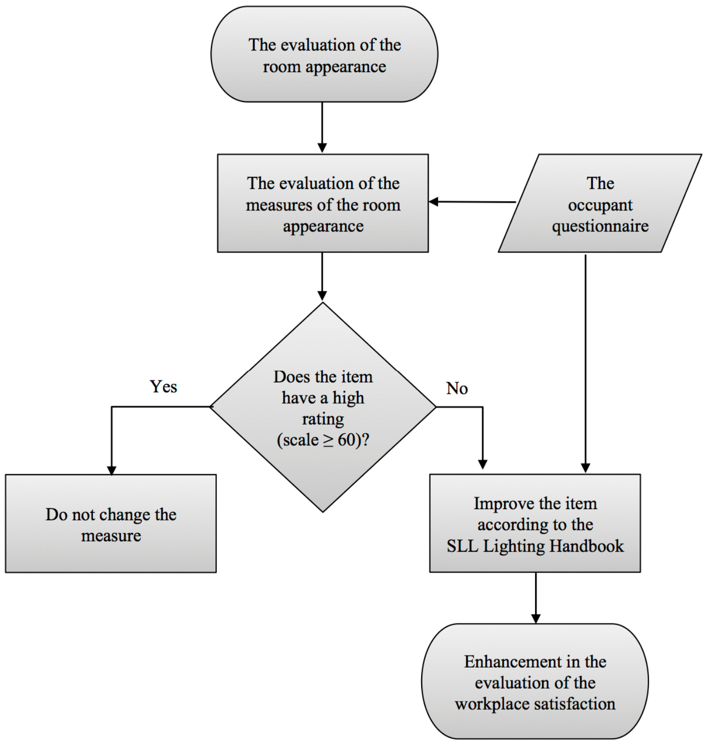


Figure 5.10 : The improvement flowchart between room appearance and workplace satisfaction.

6. DISCUSSION

This thesis highlighted POE process of visual environment holistically considering user, space and light related parameters in order to achieve a holistic assessment. Considering user in built environment, literature evidenced that impact of adaptive behaviour has been mostly studied in relation to thermal comfort. That is why, this thesis aimed to integrate adaptive behaviour into assessment of satisfaction and psychology of user together with quality of lighting and space in the visual environment.

The thesis was discussed through the subtitles literature review, pilot studies, experimental study and 'the Integrated POE in Lighting' methodology as below:

- **Literature Review:**The literature review of this thesis assessed visual comfort, lighting quality, lighting appraisal, interior design of workplaces, lighting in the workplace, occupant behaviour, adaptive behaviour and POE in a wide frame.

  Requirements and design of lighting system are determined by visual comfort conditions, visual performance, wellbeing and safety. Luminance distribution, illuminance, directionality of light, variability of light, colour rendering of light, colour appearance of light, glare and flicker were indicated as the main parameters of visual environment by the 'EN12464-1: Light and lighting - Lighting of work places, Part 1: Indoor work places' standard (2011). Illuminance level was discussed considering acceptance of various levels. There were researches recommending the combination of low illuminance levels with high CCTs and CRIs (Akashi and Boyce, 2006; Fotios, 2011). Fotios (2011) indicated that brightness perception would not be affected negatively under this combination. The impact of colour on perception is also significant. The assessment of colour was done considering different illuminance levels and CCTs (Manav et al., 2009). As for lighting quality; effortless performance of visual tasks, visual comfort and attractive visual environment were highlighted for good lighting quality (SLL, 2012).

Lighting appraisal defines assessment of lighting quality and visual environment by users. Through experimental and field studies; lighting appraisal was widely investigated through influence of lighting on mood, cognition, psychology, satisfaction, productivity, health and wellbeing (Knez and Kers, 2000; Newsham et al., 2003; Boyce et al., 2006; Veitch et al., 2007; Veitch et al., 2008; Newsham et al., 2009). The recent study of Veitch et al. (2013) evaluated the relations between lighting appraisal, room appearance, pleasure, workplace satisfaction, work engagement and task performance through SEM.

Indoor environment affects comfort and productivity in workplace. IEQ contains thermal, visual, acoustic comfort and air quality. Interior design including spatial layout, furniture layout, colour affect users' productivity and how they behave in their workplace (Giddings et al., 2013; Al Horr et al., 2016). Personal control and adjustability of indoor environment were important for users (Rothe et al., 2011). User preferences, autonomy, adaptability, flexibility and activity-based workplaces have been some of the recent concepts affecting workplace design (BCO, 2006; Brunia et al., 2016; Hoendervanger et al., 2016; Skogland, 2017).

As workplace design and tasks change, lighting requirements and design change as well. The lighting systems should be convenient for both paper-based tasks and computer-based tasks (SLL, 2009). The EN12464-1 standard (2011) defines design parameters as average illuminance, maximum UGR, minimum U_o and minimum R_a, which change based on the type of task. Colour and surface reflectance are significant for light distribution in a space (SLL, 2009). Recommended reflectances have been provided for ceiling, wall and floor (EN12464-1, 2011). Circadian system and how amount of light affects diurnal cycle are associated with lighting design in the built environment (SLL, 2012). Due to various impact of the spectral distribution on user's body cycle; i.e. bluish morning light being more alerting and reddish evening light being more relaxing, personal preferences and adaptability should be considered to improve productivity (Van Bommel and Van den Beld, 2004). In relation to adaptable lighting, how time of day affects human factors and visual environment has been widely studied (Boyce et al., 2006; Duffy and Czeisler, 2009; Smolders and de Kort, 2012; Figueiro et al., 2018). Thus it is noteworthy to consider time while designing lighting systems in workplace.

The focus of this thesis on adaptive behaviour started with the impact of occupant behaviour on built environment. Recent researches demonstrated that diverse occupant behaviour and occupant types affected both energy consumption and energy saving strategies (Hong and Lin, 2013; Yan et al., 2017). As for lighting, enhancing visual comfort was indicated as principal cause of occupant behaviour. Lighting systems and shading would affect building energy consumption. As for interior design; colour, material and spatial layout had impact on occupant behaviour. However, the link between interior space and occupant behaviour has not been deeply investigated (Delzendeh et al., 2017).

Adaptive behaviour is a result of providing and sustaining comfort (Nicol, Humphreys and Roaf, 2012; Yan et al., 2015). Adaptive behaviour of occupants has been widely studied considering thermal comfort as the adaptive thermal comfort models (Nicol, Humphreys and Roaf, 2012). Clothing, use of doors and windows, use of fans and drinking cool or warm drinks were among actions for enhancing thermal comfort (Langevin et al., 2015; Gou et al., 2018). The impact of adaptive behaviour on visual comfort has not been assessed as wide as thermal comfort. Actions such as covering room surfaces, use of blind, use and control of artificial lighting, use of task lighting, task surface, furniture position and orientation were indicated in relation to improving lighting conditions and visual comfort (Keyvanfar et al., 2014). In addition to furniture position and orientation, changing occupant's position or orientation and monitor orientation were mentioned to prevent glare (O'Brien and Gunay, 2014). The 'adaptive zone' concept was developed to provide occupants with changing position and view-direction together with use of blinds. The implementation of this concept in an office setting evidenced that duration of discomfort glare decreased and annual mean daylight availability on the workplane increased (Jakubiec and Reinhart, 2012).

POE is a noteworthy methodology for assessing successful measures and failures in built environment. There are well-established POE procedures that have been widely used and evaluate IEQ and user satisfaction. '*The Building Use Studies (BUS)methodology*' is an exemplar, which was initiated in the United Kingdom and has evaluated user satisfaction in buildings (BUS, 2016). The evaluation criteria in relation to lighting were investigated in order to understand how lighting has been assessed in POE and IEQ studies. These criteria contained lighting, illuminance level, daylighting and artificial lighting, glare, view-out, lighting control systems, brightness, distribution of light, colour, colour temperature, health, wellbeing and performance.

The literature review, which was outlined above, underlined design parameters of lighting systems, visual comfort conditions and change in lighting requirements through change in tasks and workplace design. It was reviewed that occupants adapt their behaviour to improve comfort. Having been studied as occupant behaviour, behaviour of users in built environment affected energy consumption and energy saving in buildings. As the knowledge gaps, furniture layout and occupant orientation were not assessed in the occupant behaviour models (O'Brien and Gunay, 2014). Most of the adaptive behaviour studies were carried out in relation to thermal comfort. Although how adaptive behaviour influenced visual comfort was mentioned (Jakubiec and Reinhart, 2012; Keyvanfar et al., 2014; O'Brien and Gunay, 2014), consequences of adaptive behaviour in visual environment has not been studied widely. How perception of space, mood and satisfaction would be affected by adaptive behaviour would be an insightful analysis. A POE system evaluating visual environment and assessing adaptive behaviour is needed. Thus visual environment can be assessed holistically comprehending user, space, task and light. Standardising evaluation criteria, questionnaire items and scales would provide more robust assessment and comparison of buildings.

- **Pilot studies on post-occupancy evaluation (POE) and performance analysis of lighting system:** Three pilot studies were conducted. Pilot study-1 and pilot study-2 were field studies for assessing visual environment of different typologies with consistent approach. Pilot study-1 evaluated the visual environment in education spaces (lecture halls and seminar rooms) and pilot study-2 assessed the visual environment in office spaces in Istanbul Technical University (ITU) Lecture Hall A Building through developing a standard approach. Through these two pilot studies, occupant questionnaire was designed in order to include the common parameters that were valid for all typologies and the distinct parameters based on attributes of building function. In occupant questionnaire, the first set of questions contained the standard questions and the second set included the typology-based questions. The methodology in these two pilot studies involved three steps. In first step, the common and typology-based parameters were determined through literature. In second step, a POE study was designed that contained the observation form, the occupant questionnaire and the field measurements. In third step, the POE study was carried out for the education and office spaces in ITU Lecture Hall A Building. 109 students studying in the education spaces and 20 people working in the academic offices participated into the occupant questionnaire study in pilot study-1 and pilot study-2 respectively. In pilot study-3, which was the follow-up study of pilot study-1, improvements in relation to the daylighting system and artificial lighting system were advised.

Pilot study-1 and pilot study-2 demonstrated that evaluating built environment through standard parameters and typology-based parameters was noteworthy. While learning performance was assessed in education spaces, job performance was evaluated in office spaces. As differing from the lecture halls and seminar rooms, illuminance levels and reflections both on desks and VDUs were investigated in offices. Pilot study-3 showed how different improvement scenarios resulted in different performance of daylighting system and artificial lighting system. Standard and typology-based parameters contained lighting, health and performance related criteria. Nevertheless, adaptive behaviour of users was not evaluated. Modifications of interior design, spatial layout, lighting system, furniture and occupant position or orientation were not investigated, some of which were mentioned as knowledge gaps in literature. Thus, requirement for a POE methodology was considered in order to evaluate adaptive behaviour in visual environment.

Changes in user's field of view, furniture layout, interior design and lighting system were considered as adaptive behaviour parameters. At first, an experimental study was designed to assess adaptive behaviour parameters in relation to user, task, lighting and space on appraisal of lighting, assessment of space, mood and satisfaction. Following the experimental study, 'the Integrated POE in Lighting' methodologywas developed in order to integrate adaptive behaviour parameters into assessment of visual environment and evaluate user, space and lighting holistically.

- **Experimental study evaluating adaptive behaviour in visual environment:** Experimental study's target was investigating adaptive behaviour and comprehendinghow adaptive behaviour affects visual environment, space's perception and user psychology. Parameters of adaptive behaviour were determined as furniture position and orientation, field of view, colour of internal surfaces and lighting system through the literature review. The SEM model of Veitch et al. (2013), which was extended through integrating the adaptive behaviour parameters, showed the relations between lighting appraisal, room appearance, pleasure, workplace satisfaction, work engagement and task performance. The experimental study aimed to assess the relations between adaptive behaviour (through furniture position and orientation, field of view, colour of internal surfaces and lighting system) and lighting appraisal, room appearance, pleasure and workplace satisfaction. For the variables that were in the SEM model of Veitch et al. (2013), the existing questionnaire items and scales were used. For the variables that were added, which were the adaptive behaviour parameters, questionnaire items and scales were designed. Validated items and scales were taken from literature and changed in relation to the adaptive behaviour parameters.

The experiments were carried out in the test room with office function in the lighting laboratory in Istanbul Kültür University Ataköy Campus. There were 36 participants, who were undergraduate students. Daylighting was excluded from the test room. Between-groups tests and within-subjects tests were carried out. In the between-groups tests, different artificial lighting systems and wall colours were tested. The lighting systems were Case 1 as 500 lux and 3000 K and Case 2 as 300 lux and 6500 K. The wall colours were beige

(L90 C20 H55) with the light reflectance of 0.72 and blue (L90 C10 H230) with the light reflectance of 0.74. The within-subjects tests evaluated different occupant positions and orientations. The occupant positions were Zone 1 and Zone 2 as if the room was divided into two zones horizontally. The occupant orientations were 0°, 45° and 90°.

The statistical analyses involved descriptive statistics, SEM and ANOVA. The bivariate correlations showed the significant correlations between the dependent variables. The most significant correlations (at the 0.01 level) containing the adaptive behaviour parameters were highlighted. The SEM analysis demonstrated the model generated for the test room through two lighting systems (Case 1: 500 lux, 3000 K and Case 2: 300 lux, 6500 K) and beige wall colour with 26 participants. The model showed the statistically significant relations between the variables. The statistically significant paths were furniture position and orientation-field of view, lighting system-lighting appraisal, lighting appraisal-room appearance, room appearance-pleasure and lighting appraisal-workplace satisfaction (at the 0,001 level). The significant paths between the variables showed how the variables affected and predicted each other. Thus, improvement in one variable can be possible by enhancing the variable that predicted it. The regression equations of the significant paths were written. The ANOVA tests were based on testing four null hypotheses in relation to the between-groups tests containing 36 participants. The null hypotheses defined that the dependent variables were same for the independent groups of the independent variable lighting system as Case 1 (500 lux, 3000 K) and Case 2 (300 lux, 6500 K) and independent groups of the independent variable wall colour as beige wall (L90 C20 H55)and blue wall (L90 C10 H230). Differences in means of dependent variables were provided. Although not statistically significant, the mean of colour of internal surfaces increased from Case 1 to Case 2 for beige wall. The means of other dependant variables decreased. For blue wall colour, the means of all dependant variables decreased from Case 1 to Case 2. The differences for lighting system, lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity were statistically significant, for which the null hypothesis was rejected. For Case 1, the means of all dependant variables increased from beige to blue wall colour. The differences for room appearance, pleasure, environmental satisfaction and self-assessed productivity were statistically significant, for which the null hypothesis was rejected. For Case 2; although not statistically significant, the means of colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure and self-assessed productivity increasedfrom beige to blue wall colour. The means of other dependant variables decreased. These variations in the ratings of the dependent variables highlighted the diversity of occupant acceptance. The statistically significant differences of dependent variables were determined through comparing $F_{obtained}$ and $F_{critical}$values. Thus, the null hypotheses for the related dependent variables could be rejected.

The illuminance level measurements were carried out on the horizontal workplane across the room and the vertical workplanes as the wall surfaces. Similar illuminance levels were observed in Case 1 for beige and blue walls. This was seen in Case 2 as well. As for the vertical illuminance levels, there were higher illuminance levels on Wall 2 and Wall 3 for blue wall than beige wall. Considering the high illuminance level of Case 1, the highest differences were on the workplane, Wall 3 and Wall 4 for beige and blue walls.

The within-subjects tests, which were conducted with 13 participants, were based on changing position to Zone 1 or Zone 2 and orientation to 45° or 90° based on preference during the between-groups tests. Means of dependent variables in between-groups tests and within-subjects tests were compared. Differences between means of dependent variables evidenced the diversity in occupant acceptance as similar to the between-groups tests. Ratings of dependent variables increased, remained the same or decreased. While the means of furniture position and orientation, field of view, room appearance and pleasure improved most, the means of lighting system both remained same and decreased most among the participants. As occupant position an orientation changed during the within-subjects test, the field of view changed accordingly. The illuminance levels in the field of views either increased or decreased in the within-subjects tests, the majority of which declined. The responses to the occupant questionnaires and illuminance levels were evaluated together. The participants, who had a lower or higher average illuminance level in the field of view, evaluated the dependent variables with higher, same or lower ratings.

Both the between-groups tests and within-subjects tests demonstrated the importance of occupant acceptance. It was seen that occupant evaluation of furniture position and orientation, field of view, colour of internal surfaces, lighting system, lighting appraisal, room appearance, pleasure, environmental satisfaction and self-assessed productivity varied based on occupant acceptance and experience in the visual environment. The experiments, in which illuminance level was decreased and CCT was increased, showed increase in the rating of one dependent variable, although it was not statistically significant. It can be evaluated that a visual environment could be accepted with a lower illuminance level and higher CCT if this combination was acceptable for occupant. This would result in decrease in energy consumption and provide energy savings.

The experimental study tested combining adaptive behaviour parameters with evaluation of lighting, spatial quality, user psychology and productivity. The between-groups tests and within-subjects tests underlined how noteworthy occupant acceptance and preference were. It would be an asset to integrate adaptive behaviour, which contained modifications to improve comfort, into POE procedure of visual environment in order to achieve a holistic assessment. In other words, evaluation of occupant acceptance and preference would be merged with POE procedure. That is why, 'the Integrated POE in Lighting' methodology was developed in order to convey the above-mentioned process as an evaluation methodology for visual environment.

The numbers of participants in the experimental study and SEM analysis were the limitations of this research. Age of participants in the experimental study was also limited. That is why, the experimental study and SEM analysis should be worked on with larger number of participants, various age groups and in different building typologies. Thus, the validation of the results in the experimental study can be done.

- **'The Integrated POE in Lighting' methodology:** 'The Integrated POE in Lighting' methodology aimed to evaluate visual environment through combining adaptive behaviour, which are carried out to improve comfort, with the assessment of light, space and user. It is believed that this methodology would provide a holistic evaluation for the assessment of visual environment in office spaces. The adaptive behaviour parameters were furniture position and orientation, field of view, colour of internal surfaces and lighting system as being tested in the experimental study in Chapter 4. The assessment of light, space and user were carried out through lighting appraisal, room appearance, pleasure and workplace satisfaction in Chapter 4.

  'The Integrated POE in Lighting' methodology organizes and performs evaluation of visual environment in various stages and steps. The methodology is consisted of four stages. 'Stage-1: Observation and information' contains two steps as observing the building and informing the occupants. In 'Stage-2: Questionnaire and measurement', there are three steps. First, the model that was utilized in Chapter 4 (Figure 4.1) and its methodology are processed. This includes the occupant questionnaire that should be responded by occupants of the building under evaluation. Secondly, the occupant questionnaires are analysed through SEM and the model identifying the relations between variables is determined. Thirdly, horizontal and vertical illuminance levels are measured. In 'Stage-3: Feedback', significant paths are identified through the model and failures are identified through the occupant questionnaires as the first step. Secondly, improvements are recommended through the improvement flowcharts. Thus, the significant paths between the variables can be strengthened and the failures can be enhanced. 'Stage-4: Implementation and follow-up' contains two steps as implementing the improvements and controlling them through maintenance.

  The improvement flowcharts, which are recommended in 'Stage-3: Feedback', aims to guide assessor through decision-making of improvements in visual environment. There are eight improvement flowcharts highlighting the variables and relations in SEM model. The assessor can choose the flowcharts, which contain the relations that should be strengthened in the building under evaluation, in order to use for enhancing visual environment. The improvement flowcharts are ‘The improvement flowchart-1: Furniture position and orientation - Field of view’, ‘The improvement flowchart-2: Field of view - Lighting appraisal’, ‘The improvement flowchart-3: Colour of internal surfaces - Lighting appraisal’, ‘The improvement flowchart-4: Lighting system - Lighting appraisal’, ‘The improvement flowchart-5: Lighting appraisal - Workplace satisfaction’, ‘The improvement flowchart-6: Lighting appraisal - Room appearance’, ‘The improvement flowchart-7: Room appearance - Pleasure’ and ‘The improvement flowchart-8: Room appearance - Workplace satisfaction’. The improvements are mainly based on occupant acceptance and preference. This information is taken from occupant questionnaires. In addition; for the improvements related to reflectance of internal surfaces, the reflectance ranges recommended in the EN12464-1 standard (2011) is referenced. Similarly, the EN12464-1 standard (2011) is referenced for the modification of UGR value.

The pilot studies evaluated both daylighting and artificial lighting. The experimental study was conducted under artificial lighting system in the test room in the lighting laboratory, where daylight was excluded. ‘The Integrated POE in Lighting’ methodology is considered to evaluate both daylighting and artificial lighting systems in real office buildings.

7. CONCLUSION

Post-occupancy evaluation (POE) is a methodology to assess user satisfaction and building performance. A robust evaluation procedure would enhance consistency of evaluation results and impact of improvement measures that are developed based on evaluation. Building typologies require different evaluation items. This is due to the fact that user related parameters, task attributes, spatial layout and lighting requirements change based on building typology. Distinguishing typology based questions in POE was recommended by literature. The pilot POE studies in this thesis aimed to determine a consistent evaluation approach through including standard questions and typology-based questions. Thus typological requirements in visual environment were assessed. Recommendations for improving performance of daylighting and artificial lighting systems were based on this robust evaluation. As a result; needs of user, task, space and light can be considered and guide the enhancement of visual environment.

The criteria, which have been widely assessed in the evaluation studies, were determined for the field of lighting. It was seen that in general evaluation has been carried out through widely used criteria. User related parameters have not been extensively investigated. Adaptive behaviour contains modifications for improving comfort. Literature identified adaptive behaviour in relation to lighting and visual comfort. However, it has not been widely evaluated in built environment. That is why, this research integrated adaptive behaviour into evaluation of visual environment. This evaluation was merged with assessment of user psychology, pleasure, environmental satisfaction, productivity, task performance, lighting quality and perception of space. Thus a holistic point of view in relation to evaluation of visual environment was achieved.

It was observed that occupant experience, acceptance and preference in relation to furniture position and orientation, field of view, colour of internal surfaces and lighting system were noteworthy. These aspects affected evaluation of users. That is why, occupant experience, acceptance and preference should be investigated during evaluating visual environment. How occupants experience spaces, accept visual conditions and prefer modifications should be combined with POE procedure. Integration of adaptive behaviour into evaluation of visual environment and transferring this into a POE methodology was accomplished in this research. Integrating experience, acceptance, preference and adaptive behaviour into standards and regulations can be an asset to design decision-making in built environment.

The relation between illuminance levels and CCT has been discussed in literature. This research showed that the combination of low illuminance level and high CCT enhanced user evaluation (colour of internal surfaces for beige wall colour) if this combination is in line with occupant acceptance and experience, although there was no statistically significant difference and null hypothesis could not be rejected. For blue wall colour, this combination decreased the evaluation of all dependant variables, in which some of them were statistically significant and the null hypothesis could be rejected (lighting system, lighting appraisal, room appearance, environmental satisfaction and self-assessed productivity). Using this combination can provide savings in artificial lighting energy consumption. It is well known that energy efficiency and carbon reduction is significant. This highlights maintaining both energy efficiency and user satisfaction when designing built environment. In relation to office buildings' high artificial lighting energy consumption, maintaining visual comfort conditions, enhancing daylight, providing a glare free visual environment and integrating lighting control systems with manual intervention can support energy-efficient lighting approach and user satisfaction. Recommending improvements in existing buildings should be in line with these aspects as well. Standards and regulations should be reviewed in line with these measures and discussions. For these discussions to be robust, experiments should be continued and processed with diverse age groups.

Post-occupancy evaluation is a valuable process to assess buildings and improve building performance. This process can enhance lighting energy performance, visual comfort and user satisfaction. Recommending improvements based on evaluation results can enhance quality in visual environment. This can contribute toimproved building energy performance and indoor environmental quality.

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