CATEGORIZATION OF MANUAL LIGHTING CONTROL BEHAVIOR PATTERNS BASED ON INTERIOR LAYOUT IN OFFICES

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ABSTRACT

CATEGORIZATION OF MANUAL LIGHTING CONTROL BEHAVIOR PATTERNS BASED ON INTERIOR LAYOUT IN OFFICES

To reduce energy consumption due to lighting, variety of methods such as energy efficient products, daylight and lighting control systems, simulation softwares are being used. However, these methods may fall short of their potential if the end user, occupants, are not taken into consideration. Energy consumption due to lighting can be reduced further by understanding building occupants' needs and behaviors. In this study, to understand user behavior for lighting, manual lighting control of occupants were examined. This examination compromises physical, temporal and architectural factors which affect manual lighting control behavior. Especially the focus was on interior layout to observe the relation between the architectural parameters and manual lighting control behavior.

The goal of the research and experiments of this dissertation was to obtain realistic manual lighting control data in offices. First of all, various parameters including physical, visual, occupancy and architectural were observed and statistically analyzed by the conducted questionnaire, to find the most triggering/inhibiting factors for manual lighting control. Secondly three private offices were equipped to monitor the change in manual lighting control behavior with regards to occupancy, daylight penetration and interior layout. Results used to generate from the fuzzy model which offers more detailed classifications on manual lighting control probabilities.

Gathered results showed that interior layout has a significant contribution to manual lighting control. As a result, if architects/lighting designers/researchers utilize the provided classifications of the tested parameters on the future studies, they can reduce energy consumption while increasing user satisfaction.

ÖZET

OFİSLERDE MANUEL AYDINLATMA KONTROLÜ DAVRANIŞ BİÇİMLERİNİN İÇ MEKAN DÜZENİNE DAYANILARAK SINIFLANDIRILMASI

Aydınlatma için harcanan enerji tüketimini azaltmak için, enerji verimli ürünler, günışığı-yapay aydınlatma kontrol sistemleri, simülasyon programları gibi pek çok yöntem kullanılmaktadır. Fakat yapıların kullanıcıları dikkate alınmadığı durumda bu yöntemler yetersiz kalabilir. Yapılarda aydınlatma amacıyla harcanan enerji tüketimi, yapı kullanıcılarının ihtiyaçlarını ve davranışlarını anlama ile de azaltılabilir. Bu çalışmada, aydınlatmada kullanıcı davranışı, manuel aydınlatma kontrolü açısından incelenmiştir. Bu incelemede, fiziksel, zamansal ve mimari faktörlerin manuel aydınlatma kontrolüne etkisi irdelenmiştir. Özellikle mimari parametreleri ve iç mekan biçimlenişinin manuel aydınlatma kontrolü ile olan ilişkisi gözlenmiştir.

Bu çalışma ve deneylerin amacı ofislerdeki manuel aydınlatma kontrolüne ilişkin gerçekçi veriye ulaşmaktı. Bunun için öncelikle fiziksel, görsel, varlık ve mimari değişkenlerin anket ile incelenmesi ve istatistik olarak analizi gerçekleştirilerek, manuel aydınlatma kontrolü tetikleyen/engelleyen faktörler belirlenmiştir. Sonrasında üç tek kişilik ofiste yerleştirilen sensörler aracılığı ile varlık, günışığı ve iç mekandaki değişikliklerin manuel aydınlatma kontrolündeki değişimler incelenmiştir. Elde edilen sonuçlar ile manuel aydınlatma kontrol olasılıklarını sınıflandırma amacı ile bulanık model oluşturmada kullanılmıştır.

Elde edilen sonuçlar, iç mekanın manuel aydınlatmayı kontrol etmede oldukça etkin rol oynadığını göstermiştir. Sonuç olarak eğer mimarlar/aydınlatma tasarımcıları/ araştırmacılar test edilen parametrelerden elde edilen sınıflandırmaları kullanırlarsa, aydınlatma için harcanan enerjiyi düşürürken, kullanıcı memnuniyetini arttırmayı sağlayabilirler.

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CHAPTER 1

INTRODUCTION

In this chapter, the initial idea and framework of the study are presented. First of all, the main motivation of the study is explained with relation to the existing studies. Which is followed by the main objectives and hypothesis of the study. To define the methods followed, procedure of the study is explained in the next part. The significance of the research is discussed besides the limitations. Finally, the contents of the study were briefly explained under overview of dissertation title.

1.1. Motivation

Vision is the first and main sense to experience architecture. Light, enables vision, and vision is the first sense to experience architecture. Therefore, light has been always an inseparable factor in architecture to create moods and reveal architecture. To tie light into the architecture, lighting design is a process of integrating light into the architecture (Gordon 2003). Lighting design covers daylight, artificial light, the user, shading, lighting control systems and the lighting application. Since currently world is experiencing problems related with extensive energy consumptions, the work of lighting designer has become highly complex.

In order to build an energy efficient building in terms of lighting, design phase is vital just like heating and cooling. In design phase, architects/designers have to take precautions in order to overcome this problem. Nowadays, awareness in energy consumption has risen and alternative methodologies/ways are searched through to minimize it.

One of the most critical aspects is to obtain energy savings without compromising architectural quality and user comfort. Thus lighting designers and architects have to come up with more sustainable solutions. Daylight is the most sustainable solution for lighting. However, since daylight is not stable, (it changes with time of the year, season, day, sky type as well as obstructions, openings, transmittance values etc.) each building requires a special treatment on design phase.

In order to reduce energy consumption of lighting for most in all buildings, technologic improvements such as the most energy efficient products and control systems are being used. However, both of these methods are costly investments, so they are not the first choices.

As the building simulation software improve rapidly and extensively; energy consumption can be predicted by using various of them. Due to this feature, they are commonly being used in the design phase. However once the building is completed, all these efforts may fall short of their full potential. This failure can depend on various aspects such as inaccurate building, climate or usage data. In addition to those, user behavior is one of the biggest uncertain aspects in simulation softwares. Simulation softwares, deal with user behavior cursory. They use the existing user profiles, which often do not reflect to reality. After all, if the user model/behavior is not realistic all these efforts may fall short of their full potential.

User behavior is the action which involves the presence of users and the way of performing their activities in the building. It should be treated as a building’s operational and architectural characteristic since it has a significant impact on the building energy performance (Hoes et al. 2009; Mahdavi and Pröglhöf 2009). The users’ activities and their control actions to improve indoor environmental conditions (thermal, air quality, light, noise effect the energy consumption of buildings (Hoes et al. 2009). However, studies on user behavior for lighting are found to be very limited in literature. Underestimating the importance of user behavior on lighting control might result with misassumptions.

To reduce energy consumption due to lighting, another method which is totally free and long-lasting should be considered: “efficient manual lighting control”. Minor interventions and regenerating user behavior towards efficient manual lighting control can significantly reduce energy consumption. If the users’ expectations, preferences and reasons laying underneath the decisions can be understood, manual lighting control can be modified to be more effective. As a result, the artificial lighting usage would be limited with only for the times where daylight penetration is not enough.

1.2. Research Objectives

As it stated above, efforts to reduce energy consumption due to lighting cannot always succeed as it planned to unless the end users are taken into account. Users' lighting preferences, possible factors which triggers or inhibits them from manual lighting control should be examined in detail.

Manual lighting control can be affected from various factors such as: "physical, physiological, psychological, social factors, age, gender and blinds" (Gu 2011, 11). As mentioned in Chapter 2, there are various studies which have dealt with these factors but yet interactions between them make the research of manual lighting control more complicated. This study focuses on the possible contribution of manual lighting control on energy savings from a different perspective; that is, from an architectural point of view. The effect of various interior layouts on the manual lighting control are observed in order to explore the interior architecture's contribution to energy savings.

The purpose of this research is to provide an in depth examination of the spatial, visual and contextual factors influencing user behavior for manual lighting control in office buildings and to propose categorizations of manual lighting control behavior patterns based on the most influencing architectural aspects. Once users' preferences, priorities and behaviors are understood, they can be also directed for good cause. Architects and designers may regenerate user behavior towards lighting system with some minor interventions to architecture. For example, if the factors which triggers users to turn on the lights or inhibits them from turn off the lights are determined, and if they can be related to the design aspects then design can play a role in users' lighting control behavior.

1.3. Hypothesis

This study focuses manual lighting control behavior in offices. The goal is to give insight to manual lighting control in offices; users' preferences, expectations and experiences. A further step is taken to identify the key factors of interior architectural features which supports energy efficient manual lighting control. The study aims to give answer to the intriguing question of "how to design offices for providing more energy efficient manual lighting control?”. Designers and architects can reap the benefit of the answer of this study while designing offices.

During this study, the tested hypotheses are as follows:

Hypothesis 1: The manual lighting control has a noteworthy impact on lighting energy consumption, especially in offices. So suggesting a method to reduce lighting energy consumption may significantly save energy.

Hypothesis 2: Even though occupants’ approaches and behaviors may be different still they use lighting fixtures consciously and consistently. Though often it is being considered as stochastic, it’s not arbitrary.

Hypothesis 3: Manual lighting control is strongly affected by interior layout which may be modified easily in existing offices.

Hypothesis 4: Users are affected by the direction of daylight penetration. The relation of desk and window can play a role on manual lighting control.

Hypothesis 5: Users’ manual lighting control can be affected by the distance between their window and desk.

Hypothesis 6: Interior surfaces’ colors (reflectance values) effect users’ perception as well as their manual lighting control.

Hypothesis 7: It is not possible to classify all users onto one group; however, a middle ground can be found.

Hypothesis 8: The frequency of manual lighting control depends on the actual location of the control with respect to the occupant’s work place.

1.4. Procedure

The aim of this study is to determine the factors contributing to manual lighting control in offices; and specifically to define impact of interior layout on manual lighting control by statistical analyses. Those analyses were used to generate behavior patterns in terms of interior layout aspects and available daylight illuminance. Prior to doing so the study was carried out by the following phases (Figure 1.1):

At first, a multi-sectioned questionnaire was conducted among 125 participants using the online survey system named Surveey (Surveey n.d.). Existing office environment, satisfaction with the current office environment, manual lighting control behavior, interior layout’s contribution to manual lighting control, manual lighting response to daylight penetration and personal information were covered in the questionnaire respectively. For the manual lighting response to daylight penetration part, a model was photographed on the same day during three different time intervals.

Secondly, the gathered data were analyzed by statistical methods (such as Chi-square test, crosstab query and reliability tests) to determine the factors which actively play role on manual lighting control.

In the third phase, three selected sample rooms on İzmir Institute of Technology (İYTE) were observed with eight different interior layouts in terms of occupancy, artificial light usage and daylight penetration. Desk positions were modified as left, right, back and front, and in each of the positions desks were adjusted to either close to window or apart from the window. Participants manual lighting controls were monitored by the installed illuminance meters and occupancy/light sensors.

In the fourth phase, fuzzy logic algorithm was used to obtain manual lighting probability classifications. The gathered output from the monitoring phase were used to form the rules of the fuzzy model, and behavior patterns were constructed.

In the fifth phase, the affecting factors were defined and their association between the manual lighting were stated.

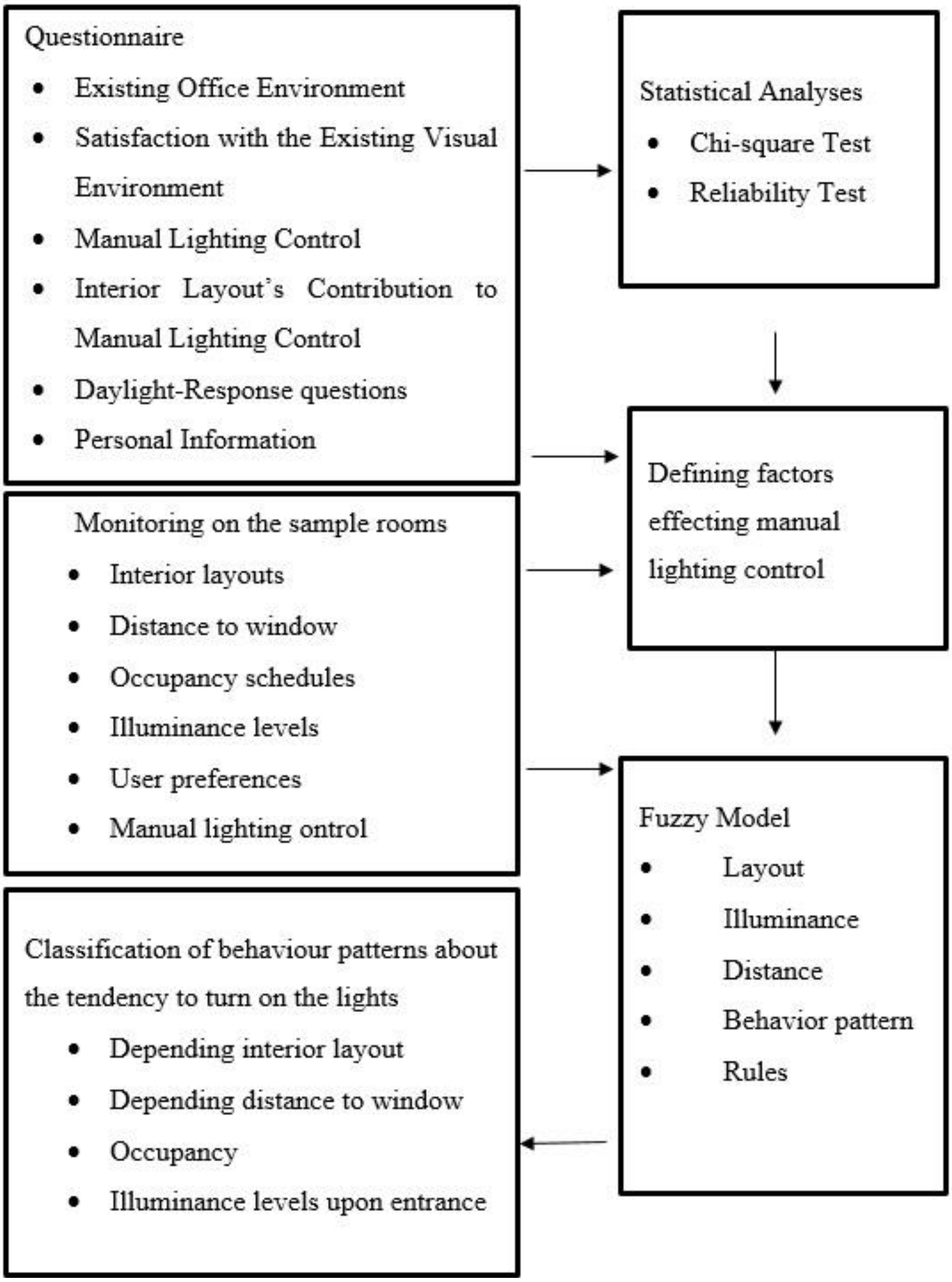


Figure 1.1. Structure of the study.

1.5. Significance of the Study

When we examine the literature, there are some researches about the manual lighting control but none of them tries to relate this topic with the architectural factors which may be modified easily. Besides users' lighting control behaviors were never classified according to significant interior layout parameters. This study can be the initiator research which focuses on manual lighting control with its relation to interior layout. Relevant studies which also focus on interior architecture can follow this study to widen the literature.

At the end of the study, the conclusion gives feedbacks and clues to reduce energy consumption with modifying interior architectural factors. These clues can be very helpful for architects and designers in reducing energy consumption and increasing the efficiency of manual lighting control. The obtained occupancy manual lighting control behavior pattern can be used in future for building energy performance simulations. The gathered model can be very helpful in terms of classifying users' tendencies and correct the "non-realistic" manual control assumptions which are being used currently.

1.6. Limitations

There are certain limitations and shortcomings of this study which are discussed individually.

The major limitation on this study is, despite of the various factors affecting manual lighting control only the selected parameters were analyzed. Within the scope of the study; thermal comfort (temperature distribution, humidity, air speed, heating, cooling, ventilation), visual parameters (luminance distribution, visual discomforts, color temperature, shadings) and personal variables (occupancy profile, metabolic rate, clothing insulation, privacy requirement, outside view) were not considered. These parameters can be investigated on future works.

Another limitation of the study is with the limited number of participant in monitoring (3 users) and questionnaire (125 participants). For questionnaire, a larger sample group possibly could give a somewhat different output. However, the time interval of monitoring and questionnaire was limited because it was decided to carry out the study during winter season were daylight penetration is minimum so the manual lighting control is higher. For the monitoring process the restriction was the number of monitoring tools available. Since there were only 3 sets of tools were available, the monitoring performed in three sample rooms. However, this study can be extended with higher level of participation in the future.

Another limitation is related with conducting the study in only İzmir. The optimal approach would have been to conduct the same study in other locations simultaneously to eliminate the influence of location, dominant sky type, weather conditions and users' cultural background. An enlarged study in terms of location and time could give more insight on manual lighting control.

Questionnaire and monitoring process were covered in 4-months period (November 2014- February 2015). There was not a restriction of office type on questionnaire, yet for the monitoring only three private offices of İYTE were observed. This study can be extended to longer periods of time and more office types (such as open plan offices, or multiple-user closed offices) could be involved. Besides, different layouts were monitored on different days, therefore the daylight penetrations could not have kept stable during the monitoring days.

Relating manual lighting control with interior layout is actually wide topic. Many alternative interior layouts, other interior architectural parameters could have been investigated to see the relation. Though, in this study, mainly relation of desk layout, distance to window and surface colors are examined.

1.7. Overview of Dissertation

Taking into account of all the previously mentioned issues, this study examines the contribution of manual lighting control in existing buildings where no control systems are being used. Particularly, this research is centered on users' manual lighting control behavior with a relation to the affecting interior factors. By testing various interior layouts on sample rooms and running a survey through the model, data to give insight into manual lighting control were provided. This study is divided into six chapters:

In chapter 1, the motivation and research objectives of this study are explained. In this chapter importance of manual lighting control is discussed to underline the significance of the study. The procedure is briefly presented and the limitations are argued.

Literature review takes place in Chapter 2 where elaborate literature (on lighting design, energy consumption due to lighting and the methods which are used to reduce it) are presented. Furthermore, it gives an overview of the dissatisfactions related with the commonly used methods; such as lighting control systems, energy efficient products and simulation software. Finally, the existing literature on manual lighting control models and interior layouts' contribution to user behavior are discussed.

Chapter 3 includes more detailed information related to the procedure. The structure of the questionnaire and the question forms are discussed as well as their analysis methods. For the monitoring process, determined conditions of the sample rooms are explained besides the followed monitoring phase. The sample room details and the chosen interior layout schemes can be seen on this chapter.

In chapter 4, the detailed statistical analysis of questionnaire is given with the results. The sub-divided headings provide the gathered outputs of each questionnaire section. Similarly, measurement results are presented numerically and graphically in detail (see Appendix B). The possible correlations are formed to reach solid outcomes.

Chapter 5, namely the Discussion explores the assembled results and discusses them while concluding remarks of analysis results.

The sixth chapter, namely the Conclusion, presents the most remarkable points of the study with recommendations for the future studies on lighting design.

CHAPTER 2

LITERATURE REVIEW

In this chapter, energy consumption due to lighting and various strategies (such as daylight design, lighting control systems, energy efficient products and simulations software) to reduce it are explained generally. Related previous researches and their findings are presented with their evaluation methods. Moreover, existing manual lighting control studies and behavior models are discussed in terms of their strengths and weaknesses. This chapter also includes interior architectural designs' contribution to user behavior considering consumption.

2.1. Energy Consumption for Lighting

Buildings require energy to be built, to be maintained, and eventually for their demolition. Requirements of energy are not just limited with these, building occupants' needs and their activities require continual energy use as well (Sattrup 2012). As a result of all the listed factors, buildings are one of the major energy consumers. Especially as the industrialization has gained speed, energy demand and consumption have raised in serious amounts. In the era of cheap fossil fuels, the fundamental relation of land, architecture, climate and inhabitants have seemed to be underestimated (Sattrup 2012). Yet, nowadays buildings are big contributors of energy consumption with a share of 40% (Thewes et al. 2014). Therefore, the role of energy efficient design and architecture should not be underestimated.

Increase of energy consumption has spread to many segments in buildings. For example, the end of the 19th century initiated a new era for architectural lighting. Dependency on daylight was expired with the introduction of artificial light and it became a crucial component for spatial quality (Kutlu 2007). Daylight was moved to a lower level of priority in the design process and this resulted with the increase of energy consumption due to lighting (Velds 2000). Since then, lighting is one of the biggest energy consumption sources with a share of 25% (Sattrup 2012). Nowadays world is facing environmental problems related with energy consumption, so new methods for reducing energy consumption are searched through. Since lighting is one of the biggest consumers of energy, lighting is the matter in the hand.

In spite of these efforts, energy use in office buildings has been increasing substantially through the recent years. Starting from 20th century, office buildings host at least 50% of the working population (Gu 2011). Therefore issues such as; personal comfort, aesthetics, health and safety are vital to obtain the most beneficial visual environment for task performance (Tabak 2009). Among them, lighting is often the largest electrical load in offices. However, it is often neglected because the cost of lighting energy consumption remains low when compared to the other costs, such as personnel costs etc. (IEA ECBCS 2010). Percentage of total energy consumption varies depending on the type of building, location, climate, user habits etc., but this energy consumption can reach up to 50% in European office buildings (IEA ECBCS 2010). Since it’s one of the biggest consumers of energy, various methods are being used to reduce lighting energy consumption.

Though, like buildings’ operational and architectural characteristics, user behavior is a very important factor in lighting energy performance of building though it is being generally ignored. In order to describe users’ presence and actions in buildings (or in a room), general assumptions are applied (Hoes et al. 2009). Preexisting simulation methods address this issue by automatically reproducing patterns of behavior found in historical occupant schedules (Goldstein et al. 2011). However in reality, this behavior is much more complex due to various factors such as flickering lamps, daylight, shadings, the type of task, adaptation of the eye, etc. (Hoes et al. 2009, Baker and Steemers 2002). Therefore, it is widely regarded as one of the most significant sources of uncertainty in the prediction of building energy use.

When user controls a specific indoor condition, it may influence other environmental conditions as well, which may lead to unintended results. For example, controlling shadings to have more daylight penetration may reduce artificial lighting energy consumption while increase heat gains due to solar radiation and result but increase of cooling loads. Therefore, manual control, which is a result act of only user behavior, should be investigated to foresee possible energy consumption.

Further concern is related to visual comfort and interior layout/design of the offices lighting. Interior design and layout can affect user behavior and thus lighting energy consumption too (Mohammadi et al. 2014). Mohammadi et al. (2014) claims “well-designed interior layout design able appropriately dealing with cost considerations to reduce the energy usage and energy consumption of different types of buildings". Similar to that, architectural lighting design, which only focuses on providing the adequate illumination level on visual tasks by avoiding glare problems, can effect energy consumption of lighting. Therefore, when it comes to reducing energy consumption of lighting, the factors are quite diverse.

As mentioned, though there are various methods for reducing lighting energy consumption, user behavior factor should not be estimated. Because since building occupants are the end users, they determine the efficiency of these systems.

With the introduction of personal computers and advanced information and communication technologies, the nature of office work has changed dramatically compared to the middle of twentieth century (Hua, 2007). Since there are various tasks (e.g. paper-based, computer-based, small group discussion) performed in office, lighting environment must meet the variety of needs of each task. To obtain visual comfort in offices, sufficient and well distributed horizontal illuminance (especially on the workplane) has to be supplied while avoiding discomfort glare (Linhart and Scartezzini 2011). Besides the listed fundamental aspects of office lighting design, a lighting design which can adapt to different tasks becomes a key for a success. Because the same visual environment can be a stimulus or a distraction (Wyon, 2000). While performing long-term tasks, viewing outside through a window helps to release eye-stress, therefore it is appreciated. However, during the tasks which requires 100% focus, these window openings may be undesirable due to lack of privacy and distraction (Gu 2011). It is not easy to accomplish a satisfying visual comfort for all the occupants by using only daylight.

Most of the visual comfort analyses make a point of discomfort glare or the presence of direct sunlight (Jakubiec and Reinhart 2013). However, those analyses can not reveal the whole story of visual comfort in daylight spaces due to the lack of criteria and tools to assess glare conditions. Currently there is not any annual metric to assess the visual satisfaction of occupants (Jakubiec and Reinhart 2013; C. Reinhart and Selkowitz 2006). Nevertheless, for interior lighting design, one of the main aims is to provide a well-lit, glare free zone where controlled daylight is being used and complemented by artificial lighting.

2.2. Daylighting Design

Daylighting refers to the use of sunlight and skylight to provide pleasing interiors, which are suitable to the functions of the space and occupants' needs (Integrated idl Design Lab n.d.). Daylight design has to be a major part in architectural design since it is related with; energy efficiency, human health and occupant preference. In Reinhart & Selkowitz 2006's words, "the dynamic interplay of building form, light and people is what makes daylighting design so challenging and so rewarding".

2.2.1. Advantages of Daylight Design

Since the early times, architects were aware of importance of daylight in their designs. Acknowledging the seriousness of daylight's contribution to design, including the very famous architects such as Le Corbusier, Frank Lloyd Wright, Vitruvius along with the others, declared the importance of daylight in their own words too. Vitruvius believed that the functions of the interiors should be determined considering the orientation of the space. While Alberti agreed on this idea and suggested that also climate and site of the building has to be considered (Gagne 2011).

In addition to the declarations, throughout history the importance of daylight for architectural design, in terms of occupant health and comfort, was understood both in architectural theory and practice (Gagne 2011). Various quantitative studies draw attention to the benefits of daylight for different building types. Heschong established that daylight helps students to improve their success in the class while increasing office workers productivity and retail sales (Gu 2011; Mardaljevic, Heschong, and Lee 2009). Daylight design may enhance spatial experience of occupants "by providing light, views, temporal and seasonal cues, and interesting visual effects such as sun patches and shadow patterns" (Gagne 2011). As a result of these factors, many studies point on the preference of daylight for lighting in offices. Great number of research has revealed that office workers prefers daylight for office lighting (Altomonte 2008; P. Boyce, Hunter, and Howlett 2003; G. Newsham, Brand, et al. 2009; J. a. Veitch et al. 2007). Despite of the possible drawbacks of daylight such as; glare and excessive heat gain, the mentioned studies indicate that workers would prefer to pay the price of having an overheated space or live with the high degree of glare resulting from daylight (Gu 2011). Besides, well designed daylighting can also maintain occupant comfort by limiting excessive heat gain, controlling glare and shading direct sunlight (Gagne 2011).

Daylight and building design has a swinging relation throughout the history. Initially it was the primary light source and a significant architectural form giver (Chiogna 2008). However, in the post-war era, fluorescent light and cheap energy have pushed daylight to the background. The interest towards daylighting has again rose as a result of the oil crises of the 1970s, and suffered again from declining interest in the 1980s and 1990s as energy concerns reduced (Sattrup 2012). Nowadays, architects and building owners have additional motivation to use daylight due to the global energy use concerns. These concerns arose from the substantial amount of energy which is consumed for lighting. The energy consumption due to lighting changes according to the type of the building however i.e. in commercial buildings, lighting constitutes generally 20-40% of electricity demand (Dubois and Blomsterberg 2011).

Daylight has the potential to conserve energy and protect the environment, hence it is sought after (Mayhoub and Carter 2011). Proper implemented daylighting can reduce energy consumption of lighting by 40-60% (Lawrence et al. 2008). Likewise, properly designed daylighting have psychological and physiological advantages (Chen et al. 2014). Daylight can provide better quality of light with its color rendering ability as well as its variability. Daylight offers the best color rendering which matches with human visual response. Therefore it has been proved that good daylighting can provide a more pleasant and attractive indoor environment that can contribute to higher productivity and performance (Chen et al. 2014). This impact also reflects to the perception of spaces, for instance when a daylight survey was conducted among the customers in day lit stores, 90% of customers judged the stores as “cleaner” and “more spacious” (Dubois 2003).

2.2.2. Dissatisfactions Related with Daylight Design

On the other hand, if not designed properly, maximizing daylight may cause undesirable results. Direct sunlight penetrations in workplane often produce unpleasant atmospheres and aggravate to work or view a computer screen. This aspect is related with a physical discomfort which is called glare. Glare, “a measure of the physical discomfort of an occupant caused by excessive light or contrast in a specific field of view, is dependent on the luminance distribution in the field of view of an observer” (Jakubiec and Reinhart 2011). In order to prevent possible glare from fenestration, users may limit the daylight penetration to the space (Sattrup 2012).

Controlling the amount of heat that enters a building is another critical aspect in terms of daylight design. Since sun is a very powerful source, it can also produce enormous amount of heat. If not designed properly, this excessive heat may ruin thermal comfort or increase cooling loads (Facilitiesnet_Staff 2014). For that reason, especially in hot climates, openings have to be carefully designed and, most likely to be shaded, otherwise they can ruin the thermal comfort of the occupants.

In addition to all the listed factors above, another important drawback of daylight that it is not stable, neither continuous. Daylight penetration depends on various aspects such as the location, time of the day, time of the year, sky conditions etc. Therefore, artificial lighting usage is a must as the complementary source to daylight. However this complementary source consumes 20 to 40% of total energy consumption in buildings (Ferron, Pattini, and Lara 2011; Zhou et al. 2013). Since artificial lighting energy consumption is considerably high, alternative ways are being used to reduce it. Usage of simulation softwares, lighting control systems and energy efficient products are foremost among them.

2.3. Using Lighting Control Systems

Lighting control systems are not new; it has existed for as long as we have had electric artificial lighting. Before building automation and energy management systems, manual lighting control was the only way to control lighting. However, currently this term refers to electronic/automatic control rather than manual ON/OFF switch (Lighting Industry Association 2012).

As the technology improved, lighting control turned to being automatic with various control types. The main aim is to reduce lighting energy consumption while maintaining visual comfort. The major lighting control systems are;

- clocks timed to turn on/off based on a predetermined schedule with user override;
- occupancy sensors that switch lights off when a space remains unoccupied for an extended period;

- daylight compensation that dims space lighting from luminaires, responding to daylight from a window or skylight" (ANSI/IESNA, 2004).

In addition to the above listed lighting control systems, there are also "less common strategies such as task tuning, lumen maintenance, and load shedding" (Jennings et al. 2000, 1) which also serve the same purpose.

2.3.1. Efficiency of Lighting Control Systems

All control systems serve to reduce lighting energy consumption while maintain visual comfort and since there is a wide range of them, deciding on which control system to be used is tricky. Various studies yielded different results for efficiencies of the lighting control systems. While "authors agree on the positive impact of these systems, there is a disagreement in quantifying their saving potential" (Roisin et al. 2008, 514).

According to the Lighting Handbook, engineer and lighting designer have to be aware of the diversity of the possible lighting control systems which are available and further to that, should be able to choose the most appropriate one and correctly apply it (C. F. Reinhart 2004). While deciding on which lighting control system to use, a cost analyses has to be made. These analyses have to consider the investment cost, equipment cost and maintaining cost whereas determining how it will reduce the operating costs. Cost analyses can be easily made however, The Handbook declares that the performance of the control system is not that easy to determine, since the savings are dependent on the site, daylight levels, space, work schedules and occupants (C. F. Reinhart 2004).

Many studies focused on quantifying the performance of the lighting control systems however as Williams et al. mentioned (2012) it's "difficult to understand the big picture of the opportunities of controls because the individual studies have had different goals, methods, coverage, and results". For example, some studies have been done on existing buildings in order to choose the most efficient lighting control system. However monitored, simulated, and measured lighting energy savings show a very large range of variation (Roisin et al. 2008, 514). For instance, in study of Jennings et al. (2000), they concluded that an occupancy sensor can save up to 20% while a daylight dimming control system save up to 26% when compared to manual control. So one by looking at this study's results may conclude to use a daylight dimming control system since it is more efficient. However, Galasiu et al.'s (2007) study contradicts with the previous study by revealing that occupancy sensors can save 35% of energy on average (Galasiu et al. 2007). On the other hand, Vonneida et al. (2000) in their study revealed that time-delay sensors can save energy up to 60% (Vonneida et al. 2000)s, which seems the most efficient lighting control system in general. Nonetheless choosing any of the lighting control systems by just looking at the one of the study's results may be misleading, since they conflict with each other. Besides, in these studies, the comparison is made considering the artificial lighting systems are active all through the office hours, which may not be the case always (C. F. Reinhart 2004).

Despite the problems, predicting user behavior is very complex due to many effects (such as psychological, physical, environmental etc.), therefore often control systems are being used to simplify this complexity.

2.3.2. Dissatisfactions with Lighting Control Systems

A further important issue with control systems is users' satisfaction with the systems. Though using lighting control systems is encouraged widely, there are some dissatisfactions related to them. The below discussion includes problems with the control systems.

2.3.2.1. Dissatisfactions with Occupancy Sensing Lighting Control Systems

Occupancy (motion) sensing control systems are one of the most common control systems. They are widely used in public spaces as well as commercial buildings. Their aim is to switch off the lights when there is no occupancy in that specific room. They regulate by the help of their sensors. Yet sometimes due to their sensors' inferiority or due to the architectural arrangement/position of the sensor etc., they switch off the light when there is still occupancy in the room. Occupancy sensors, which often fail to detect occupants' position, such as sitting or standing still, may result with insufficient accuracy for occupancy detection (Lam et al. 2009). These false responses can be annoying for the user, especially when they happen repeatedly.

Delay times of the occupancy sensing control systems may also reduce the effectiveness. Normally when the control system detects occupancy, it switches on lights on and when the system does not detect any activity, it considers the room as empty and switches off the lights. However due to the stillness of the occupants, sensors may switch off the lights. To prevent this to happen, a delay time is being set. This delay time changes between 1 minute to 15 minutes (IEA ECBCS 2010). This feature of the sensors disables the energy efficiency of controls up to some extent.

A different problem that comes up with the false regulation of these sensors is related with fluorescent lamps. Due to their low investment cost and energy efficiency, fluorescent lamps are commonly being used on commercial buildings. Yet another feature of fluorescent lamps is that their lamp life is quite related with switch on/off frequencies. Short burning cycles shortens the lamp life of fluorescent lamps. Therefore, when we use fluorescent lamps with occupancy sensing controls with a short sensor interval, we may also reduce lamp life too.

Another drawback is pointed out by Reinhart (2001) that the users do not interfere with the lighting control if they know there is a sensor. This adapted user behavior actually reduced energy savings of the occupancy sensors by 30% (C. Reinhart 2001). Since users tend to trust control systems and don’t turn off lights while leaving, energy savings don’t reduce as it was planned to.

2.3.2.2. Dissatisfactions with Daylight Dimming Systems

Daylight penetration changes according to many factors (orientation, glazing, fenestration, obstacles etc.), predicting user behavior towards daylight is even more complicated. In order to calculate possible energy savings due to daylight, it’s not sufficient just to consider working hours, orientation or sun path. Openings, shadings and again users’ actions have to be considered as well.

Daylight dimming systems are designed to keep desktop illuminance constant during the day. They are dimming the artificial lighting system according to the daylight penetration, therefore when daylight levels are sufficient they achieve energy saving. By using these control systems, illuminance levels keep constant no matter how the daylight penetration changes. In fact, studies revealed that users don’t prefer to work under constant illuminance levels. Newsham et al. (2008) mentions that issue by saying

"…several studies have shown that, given a free choice, people in day lit spaces do not use manual controls to maintain constant desktop illuminance. This has led to suggestions that occupant preferences are not driven by desktop illuminance, but by a desire to balance luminance or illuminance ratios, or by time-of-day effects".

Another important point is that the daylight dimming control systems dims the artificial lighting as a result of the daylight penetration. However, daylight penetration varies by region and it rarely penetrates homogenous throughout the space. Therefore these systems may fall short of their potential (Leslie et al. 2005).

2.3.2.3. Dissatisfactions with the Constant Illuminance Sensors

For visual comfort there are some reference illuminance levels for different tasks. Constant illuminance providing systems are designed to provide these "optimum" illuminance values constantly. These "optimal" values are generally determined by the standards. However, these optimum illuminance values are not always the values that individuals actually prefer to work with. For example, standards suggest 500 lux has to be maintained for desktop area to achieve visual comfort, however some studies revealed that this is not true for each occupant. For instance, in Veitch and Newsham's (2000) study, 22 lighting professionals were observed in two workstations. The preferred illuminance levels of the participants varied between 83-725 lux in the study. The outputs of the study showed that the participants decisions required 10-15% less power than what it is recommended by prevailing energy codes (G. Newsham et al., 2009, p. 3). Another published research by Boyce et al. (2000), gave out similar results with Newsham et al.'s (2002). In Boyce et al. (2000)'s study, participants' decision of illuminance was approximately 10% lower than what is proposed in the standards. These studies yield that, control systems, which aim to provide constant reference illuminance levels all day long, are less likely to be desired by occupants.

Constant control systems are programmed to keep illuminance level stable however, "required illuminance levels vary with the users' activities, age, degree of fatigue and cultural background" (C. F. Reinhart and Voss 2002, 2). Similar to the results of the previously discussed studies, occupants' visual needs differ and so their preferences. As a result, participants prefer to control lighting fixtures individually. manual control is preferred (DiLouie 2005; G.R. Newsham et al. 2008).

2.4. Energy Efficient Products

Similar to lighting control systems, using energy efficient lighting products is another common energy saver strategy. With the improvements in technology, lighting products and lamps became more energy efficient with higher lumen output and lower energy consumption. Therefore, using these products can be very useful to reduce energy consumption of lighting.

Since the first invented light bulb, efficacies of the lamps are improving. Lighting fixtures and lamps became more energy efficient with higher lumen output and lower energy consumption. For example an incandescent lamp, which is the oldest lamp type in use today, has approximately efficacy of 10 lm/W, while a new developed white LED lamps can reach to 200 lm/W as it can be seen on Figure 2.1 (Aalto University School of Science and Technology Department of Electronics Lighting Unit 2010). In addition to that, lamp life has extended significantly too. Incandescent lamps' lifetime were approximately 1000-2000 hours while latest LED's can reach up to 100000 hours. Therefore, replacing existing lamps with more efficient lamps is a common strategy for reducing lighting energy loads.

In Dubios et al. (2011) study, it is underlined that the improvement in lamp and luminaire technology can save energy up to 40% separately. (Dubois and Blomsterberg 2011). Therefore encouraging renewable energy production and use of energy efficient products are promising solutions, yet surprisingly they may offset by ever-increasing levels of energy consumption (Bourgeois 2005). Research reported that, using energy efficient products do not reduce energy consumption as predicted because users feel that they have done their duty and tend to act carelessly. For example users who use energy-saver lamps, started to consume more energy (Merritt, Effron, and Monin 2010). This fact is just like eating a huge cake after a long term diet and in social psychology, it is explained by the term “moral-licensing”. Despite all, using energy efficient products can save energy significantly, however the role of the users should not be under-estimated since these products are controlled by them.

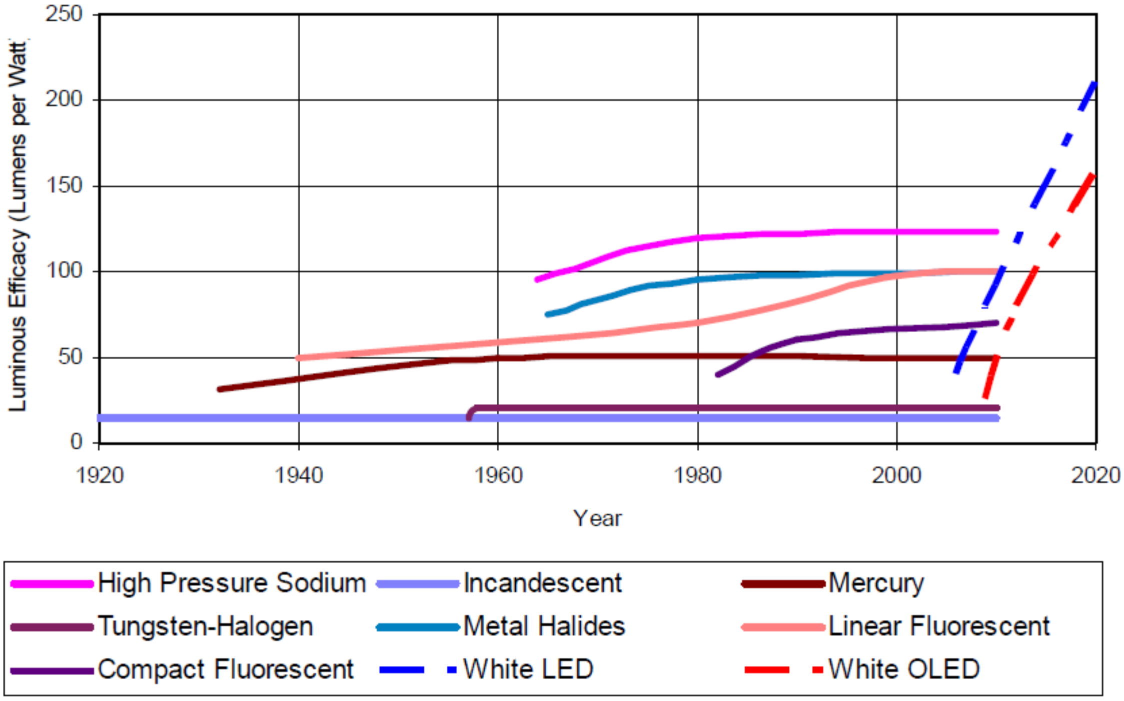


Figure 2.1. Luminous efficacy of different lamps.

2.5. Simulation Softwares

There is a growing concern on environmental issues and energy consumption. Especially starting with oil crisis, people start to worry for the enormous usage of energy. Buildings consume approximately one third of the total energy consumption (Page 2007). Therefore, this concern leads to more sensitivity in building industry and building research. To design more energy efficient buildings, CAD (Computer Aided Design) software, which are growing rapidly, are commonly being used.

2.5.1. Advantages of Simulation Softwares

By the help of this technology, it is much easier to combine comfort, low energy consumption and minimal impact on the environment. People are motivated by the possibility of analyzing the performance of the building in design phase, and take the precautions beforehand to design better performing buildings (Vincent Tabak 2009). Besides, simulations can be adopted for reproduce the behavior of the building in a short time interval. Various natural or social forces (such as climatic factors, material properties, service systems, users etc.) interact with the building. These forces may be simulated digitally using mathematical algorithms to calculate and to obtain a dynamic behavior model" (Sattrup 2012, 52).

There are large number of popular building performance simulations which focus on different aspects of building with various complexities such as; thermal load calculation, computational fluid dynamics (CFD), acoustics and finally interior lighting calculations (Vincent Tabak 2009). Besides there are some combined software packages which combine several domains of simulations into a logical model. For the combined software packages separate calculations should be made for environmental factors, e.g. solar gains, daylight, wind etc. The outcome of these simulations can be more or less sophisticated which can be judged by the environmental factors that it included (Sattrup 2012).

By entering some related data, softwares can predict possible energy consumption of the building throughout its life cycle. The requested data varies according to the features and output of the software but generally the location information, technical aspects of the space, materials/objects being used, utilization characteristics are vital. The outcomes of these simulations can be very helpful and sometimes with some minor/major changes, energy consumption can be reduced even before the building is built.

2.5.2. Dissatisfactions with Simulation Softwares

As a result of the advantages and diversity of simulation softwares, they are an integral part of the building design process and being used by both the engineers and architects commonly (V. Tabak 2009). During simulations, in order to have realistic results, simulation softwares need accurate input data on building geometry, construction details, environmental conditions and behavior of its occupants. The first three factors are quite certain and stable; therefore, it's easier to represent them in the softwares. However user behavior, which is very closely linked to the lighting energy performance of buildings, is usually regarded as one of the uncertain sources of energy use.

The main drawback of building simulation software is that they do not take into account of actual user behavior. Though they have undergone a substantial growth, modelling the behavior of humans is still abundant(V. Tabak 2009). They tend to assume people like they are fixed metabolic heat generators who are passively experiencing the indoor environment"(C. Reinhart 2001).

Since humans are instinctually unpredictable animals and they perform many difficult-to-predict and complex actions every day. These actions have a dramatic impact on indoor temperature, lighting conditions, and the state of a building control system. Users each kind of interaction with the building, such as actions, movement and usage, might result with alteration. However these software generally do not focus on that and shallowly model it but rely on the assumptions referring to human behavior(Nicol 2001; Vincent Tabak 2009). “Thus a simulation which oversimplifies human behavior is unlikely to yield an accurate prediction of a building’s energy requirements” (Goldstein et al. 2011).

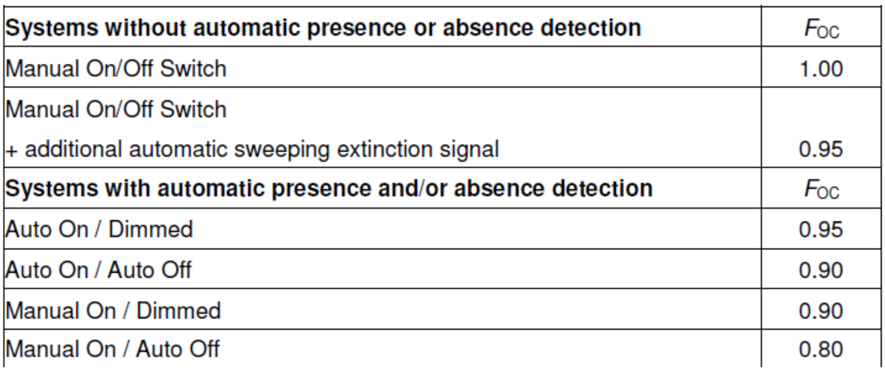
2.5.2.1. Dissatisfactions with Lighting Simulation Software

Simulation applications need accurate input data on building geometry, construction details and environmental conditions for calculation. These three factors are quite certain and stable therefore it’s easier to represent them in the applications. However, there is another factor which is very closely linked to lighting energy performance of buildings; which is user behavior.

A possible cause of error for simulation software is the data that they are using. During these simulations, rather than using descriptive and predicting models which are derived from measured observations, often reference data is being used. Especially while modeling existing buildings, not using the measured solar radiation data may cause errors of between 10%-25% (Chiogna et al. 2011). To obtain more realistic results, models which take its source from observations should be used (V. Tabak 2009).

User behavior is widely regarded as one of the most significant sources of uncertainty in the prediction of building energy use. In order to simulate the presence of occupants and their influence on building, pre-existing presence schedules are being used (Vincent Tabak 2009). These preexisting simulation methods address this issue by automatically reproducing patterns of behavior found in historical occupant schedules (Goldstein et al. 2011). These schedules originated from the general assumptions. For example, for an office space which works between 08:00-18:00, user presence and actions described as the lighting system was used from 8 o’clock in the morning till 18 o’clock in the afternoon. In reality, this behavior is much more complex due to various factors(Hoes et al. 2009).

This tendency of neglecting users' role on energy savings can also be seen on European standard (CEN/TC169 2006). For example in the standard, occupancy dependency factor for manual control is taken as 1.00 just as it is seen on Table 1. This 1.00 value means that during the whole working hours, artificial lighting was used constantly. While this value decreases when automatic presence and/or absence detections are involved.



Systems without automatic presence or absence detection	F_{OC}
Manual On/Off Switch	1.00
Manual On/Off Switch + additional automatic sweeping extinction signal	0.95
Systems with automatic presence and/or absence detection	F_{OC}
Auto On / Dimmed	0.95
Auto On / Auto Off	0.90
Manual On / Dimmed	0.90
Manual On / Auto Off	0.80

Figure 2.2. Occupancy dependency factor for various control types.

Since this standard is being used in many studies, this assumption is carried on in researches. Whereas, Hoes et al. (2009) indicates "user behavior is one of the most important input parameters influencing the results of building performance simulations" (Hoes et al. 2009).

2.6. Manual Lighting Control

Manual lighting control is the switch on/off control by the user without any automatic control systems involvement. Manual lighting control is a sub-branch of user behavior. Though the definition is that simple, taking into account of manual lighting control is a challenge and different approaches are present. Yet, it is an alternative way of reducing energy consumption without any cost, or advanced technology knowledge. Besides it can be used both in new and old buildings (Maleetipwan-Mattsson, Laike, and Johansson 2016).

2.6.1. Overall Definition of Manual Lighting Control

Before the invention of building automation and energy management systems, manual lighting control was the only way to control lighting. As the technology improved, lighting control turned to being automatic with various control types however user behavior is always a significant impact on energy performance of buildings, just like building's operational and architectural characteristics. "The user has influence due to his presence and activities in the building and due to his control actions that aim to improve indoor environmental conditions (thermal, air quality, light, noise)" (Hoes et al., 2009, p. 295). When user controls a specific indoor condition, it may influence other environmental conditions as well. So user behavior which was not well considered, can lead to unintended results. For example, controlling shadings to have more daylight penetration may reduce artificial lighting energy consumption while increase heat gains due to solar radiation and result but increase of cooling loads. Therefore manual control, which is a result act of user behavior, should be investigated to predict energy consumption.

Current lighting simulation software in the market do not demonstrate the necessary level of sophistication to reflect the complex user behavior. What they use is generally limited with the type of building (residential, commercial, educational etc.) and operational information (such as working hours). However, this information can only provide rough estimations on users' impact on building performance. For example, for an office which works between 08:00-18:00, if there is not any lighting control system involved, simulation softwares assume 10 hours of artificial lighting usage. Yun et al. (2012) mentions this issue by declaring "occupants tend to turn habitually on lighting as they first enter an office and keep the lighting on until they leave the office" (Yun et al. 2012). However users behavior is much more complicated than this assumption (Hoes et al. 2009). In order to have more extensive knowledge, more observational data have to be obtained (Mahdavi and Pröglhöf 2009).

2.6.2. Diversity and Factors Affecting in Manual Lighting Control

Lighting simulation softwares have improved however, this improvement did not reflect to the modelling user behavior an research is still poor on dynamic behavior of users (V. Tabak 2009).

For lighting energy simulations, generally geometry, construction details, weather conditions/location, user presence and control systems are required. In order to improve the accuracy of simulation performance, more realistic user models have to be obtained (Mahdavi and Pröglhöf 2009). “Preexisting simulation methods address this issue by automatically reproducing patterns of behavior found in historical occupant schedules” (Goldstein et al. 2011, 1073). However, users’ behavior can change with the changing conditions, or personal preferences. For example, if the lighting buzzes, flickers or is glaring, people may not switch them on. The type of task is also another factor; for example, people who work with display screens may require less lighting. “Pre-adaptation, for example before entering a room from a bright atrium or gloomy corridor, may influence switching, demonstrating that corridor luminance could influence how many people may find an office space gloomy upon entering it” (Baker ve Steemers 2002, 129). Even the duration of absence can play a role on users’ manual lighting control behavior (Mahdavi et al. 2008).

In order to obtain realistic manual lighting control data, commonly statistical algorithms which can predict probability of an action is being used. However, since most of the building simulation tools are based on heat transfer and thermodynamic equations, they limit user behavior with not-that related factors. For instance, opening of windows in a space commonly relates to the thermal comfort and temperature changes. However, user may decide to open the windows just to have fresh air (Parys 2013).

In consideration of the diversity of factors affecting on manual lighting control, during lighting simulations, automatic control systems’ predictions are more realistic. Control systems’ data is very easy to take into account compared to manual lighting, since control systems have some certain coefficients, whilst for manual control it is not that easy due to various factors affecting it.

2.6.3. Existing Manual Lighting Control Models

History of manual lighting control has a longer historical background compared to building automation, energy management or control systems. Though they are very rare, there are some user behavior models are done in the literature.

Hunt (1980) is the pioneer with his site observation. He observed switch on/off frequencies and possibilities as well as illumination level distribution in the room (C. F. Reinhart 2004, 3). According to Hunt's conclusion, users tend to switch on the lighting system as they enter the room and do not switch it off until they leave the office. His assumption was that users switch on the lights when arrival, left it on during the day and switch off while departure at the end of the day. Due to the unavailability of applicable field data, Hunt's model assumes the same switch on/off probability upon arrival is valid for intermediate hours (C. F. Reinhart 2004, 3).

Newsham (1994) revised Hunt's manual lighting control model. "According to Newsham's model, the electric lighting was switched on in the morning and after lunch if the minimum illuminance level on the work plane lay below 150 lux". In Newsham's model, switch on/off events during occupation period is not considered (Reinhart, 2004, p. 3).

Love (1998), divided users as "active" and "passive" according to their stochastic functionality and dynamic responses to short term changes in lighting conditions and occupancy patterns (Bourgeois 2005, 30). Here active user refers to users who seek for optimal use of daylight by controlling artificial lighting and shades, while passive user refers to no action towards lighting system. To give an example, in an office where people work between 09:00-18:00, a passive user switches on the lighting fixtures at 09:00 upon arrival and doesn't interfere until 18:00, while an active user controls lighting fixtures, as switching on/off and dimming, to get benefit from daylight through the day.

Diversity profiles, which describe the combined behavior of users, are commonly being used in simulations. For lighting, diversity profile describes the corresponding lighting loads. However, these profiles are considered to be constant, for all (working) days. Weather, physical properties and temporal variations are not taken into account. (Bourgeois 2005; Page 2007; V. Tabak 2009). As a result of that, using existing diversity profiles to any project might damage the accuracy of the simulations.

All above the previously described models use static thresholds to model users' manual lighting control. The Lightswitch Wizard, which was proposed by Reinhart, simulate users at the office based on a measured field data. Lightswitch is a dynamic and stochastic method which indicates whether the user is going to switch on the light or not by looking at the illuminance level, occupancy and blind position (C. F. Reinhart 2004). Within the context of Lightswitch, totally four user types were determined; two for switch on behavior (either turn active and passive) and two for blind control (active and passive). In fact, users can group into more than two groups. Because depending on the other effective factors, users' decisions may belong to intermediate behavior groups.

Lightswitch does not cover every related issue. For example, blinds and lighting fixtures are considered as fully closed or fully open, however users may prefer a partly closed blinds, or dimmed lights as an option. Other misanalysed issues are; thermal and privacy issues. Due to the any kind of discomfort related with these two factors may influence users' manual lighting control. More particularly, this study does not consider the interior layout (seating orientation), which influence the usage of lighting or blinds, since it determines occupants field of view (C. F. Reinhart 2004).

Up to this point, all the mentioned user models focus only on lighting. SHOCC, is a sub hourly whole building energy simulation model which considers, heating, cooling, blinds control as well as lighting, which is the strength of SHOCC. However, SHOCC only considers active users, who are defined as the most energy efficient users (Bourgeois, Reinhart, and Macdonald 2006). Though by using SHOCC, the energy saving possibilities are quite significant, since not every user is active, SHOCC results can be misleading in terms of energy consumption.

2.6.4. Comparison of Manual Lighting Control with Automatic Systems

It's very important to conduct user behavior studies with the assumption of a better understanding of individual user preferences leads to innovative design. These studies can improve task performance and also can pay off for the purchaser who buys this kind of a design solution. In addition to these two important aspects, also a real energy saving strategy can only be possible with the appreciation and cooperation of users (C. Reinhart 2001, 59)

In many studies user behavior is estimated as passive user, as if users don’t control lighting fixtures in no circumstances, which gives out nonrealistic energy performance outputs. “The electric lighting energy benefits of the dimmed lighting system were then compared to a non-dimmed system assuming that lighting systems are permanently activated during office hours (Lee, Selkowitz, 1995)”. While in Szerman’s study (1996), an assumption of using lighting fixtures by 60% flat utilization rate all day long was used. If one would simulate the same room both with Lee&Selkowitz’s and also with Szerman’s manual control model, the great difference due to the variation of “manual control” assumptions would be seen.

In addition to that some of the studies only focus on manual control (Bourgeois, Reinhart, and Macdonald 2005) while others also consider blinds and ventilation systems too (Correia da Silva et al. 2013; Galasiu, Atif, and MacDonald 2004; Mahdavi and Pröglhöf 2008). These studies depend on observations on site. When findings of these studies are evaluated, it is seen that savings of blinds and manual control systems can be up to 50%.

Relying on the users in terms of positively impact building’s energy consumption is contrary to the common conventional approach (Arens 2010). However, Reinhart in his study, claimed that depending on the user, annual artificial lighting consumption for manually controlled lighting may vary between 10 to 39 kWh/m^2 (C. F. Reinhart 2004). On the other hand, by the usage of lighting diversity profile in SHOCC, energy consumption reduced by 62%. Since one is almost the four times the other, it is hard to ensure if users can be relied on (Bourgeois 2005).

2.6.5. Manual Lighting Control’s Contribution to Space

Spaces which shaped according to the users’ personal preference are found to be more satisfactory and they show differences from the average recommended standardized conditions (Veitch & Newsham 2000,Gu 2011). There are various types of office work therefore personalized office lighting control is even more necessary. With the introduction of personal computers and advanced information and communication technologies, the nature of office work has changed dramatically when we compare it with the middle of 20th century (Hua, 2007). Since there are various tasks (e.g. paper-based, computer-based, small group discussion) performed in office, lighting environment must meet the variety of needs of each task. Besides the fundamental aspects of office lighting design, a lighting design which can adapt to different tasks becomes a key for a success. The same visual environment can be a stimulus or a distraction (Wyon, 2000).

Previous studies consistently stated that building occupants want to have more control over their environment in terms of lighting. The three main benefits of individual control on lighting are listed below (Gu 2011) and discussed individually:

- personal satisfaction
- energy savings
- suitability to various tasks

2.6.5.1. Personal Satisfaction of Manual Lighting Control

Personal satisfaction, well-being and work performance can be improved with users’ own act of control. Newsham et al. (2008) reported that users are more satisfied with the work environment and are more productive when their lighting system is not controlled by automatic systems but by them (G.R. Newsham et al. 2008).

Required illuminance vary according to complexity of the accomplished task, to age and cultural background of the user (Love 1998; C. Reinhart 2001). Therefore when asked, occupants differ significantly in terms of their preference on artificial lighting (Moore, Carter, and Slater 2002). In order to obtain satisfaction with the work environment and improve productivity, individual lighting control should be provided to the users (Miller 2007).

2.6.5.2. Energy Savings Due to Manual Lighting Control

As a result of the diversity on expectations of illuminances, some users prefers illuminance levels lower than the fix ones which leads to energy savings. Depending on the task they are performing, especially for computer based work, users tend to prefer lower illuminance levels than on recommended values on the standards (Moore, Carter, and Slater 2002). According to Maniccia et al., over 50% of occupants indicated they would prefer a dimmer luminaire for their workstation. Which shows that sometimes they prefer lower illuminance levels (Maniccia et al. 1999).

A significant energy savings can be obtained by the help of “active” users. For example, as Bourgeois et al. mentions, active users who are seeking for optimal daylight usage instead of relying on artificial lighting systems can save energy up to 40% (Bourgeois, Reinhart, and Macdonald 2006). A similar study was done by Moore et al., where also they concluded that users prefer illuminance levels which are 55% of the maximum output in average (Moore, Carter, and Slater 2002).

In addition to the above listed ones, in UK, BRE studies point on how occupants use switches manually; while entering a space, depending on the daylight level inside, people would choose whether to switch on the lighting. If they did switch it on, then they do not switch it off again until everyone had left the space. Therefore, it would be an energy saver strategy to obtain well-lit by daylight spaces where people do not need to switch on the lights upon entrance.

2.6.5.3. Various Tasks

Since various tasks (such as computer-based work, meetings, paper work etc.) are performed in an office environment, these tasks require different illuminances (Gu 2011). For example as it stated in EN12464-1 , for technical drawing 750 lux should be obtained while for filling, copying 300 lux is sufficient (12464-1 2003). According to the mock-up laboratory study, the preferred illuminance difference can reach to 50% due to the task taking place (Maniccia et al. 1999). Therefore, providing a constant illuminance all over the office work “user satisfaction” may not successful.

2.6.6. Drawbacks of Manual Lighting Control

Building researchers and experts around the world already realized the importance and advantages of personalized environment operation of thermal, air and visual comfort. Yet, they have some concerns about manual control. Their previous experience suggests that, generally building occupants don’t make the right adjustments. “They unintentionally or intentionally misuse or mis-set user side control devices because they don’t get feedback from the system in time or they don’t know how to set up comfortable conditions. It is very likely to cause dissatisfaction and energy waste” (Gu 2011, 16).

Studies point on the fact that generally users control lighting fixtures during arrival or departure. Therefore, the frequency of in and out also plays an important role. If the user is generally in her/his office for most of the day, the manual lighting control system might not that be effective in terms of energy savings. Since the daylight penetration is low during the beginning of work hours, user most probably would turn on the lights upon entrance, and would not switch it off until the departure even if the daylight penetration increases during that time.

There are many studies pointing on the efficiency of control system compared to manual lighting control (Bourgeois, Reinhart, and Macdonald 2005; Dubois and Blomsterberg 2011; Jennings et al. 2000). Those studies give solid proofs on the energy efficiency of lighting control systems. However, user types, expectations and activeness is not discussed in these examples.

Another important point which should be noted that, an active user who seeks for optimal use of daylight, and energy savings, may not continue this behavior on non-domestic buildings. Because people may feel less connected when they have no responsibility for the bills, so that they do not act as eco-friendly as they do at home (Maleetipwan-Mattsson, Laike, and Johansson 2016). However, this approach can flourish by the help of awareness campaigns. In addition to that, though there are some exceptions, still a eco-friendly user continue his/her behavior on many cases (Arens 2010).

2.7. Interior Architectural Factors’ Contribution to Manual Lighting Control

Architecture and human behavior are in close contact with each other. As Winston Churchill said, “we shape our buildings, and afterwards, our buildings shape us”. Design has a direct impact on humans on various ways. Yet interestingly, until 1960's psychologists largely ignored the relation between the physical setting and behavior. Since that time, plenty of studies investigated the relation of architecture and human in terms of psychology, satisfaction, behaviors and actions (Bitner 2014; Cleempoel 2009; Economics & Nudge 1966; Haynes 2008).

Buildings play a role of accommodating user’s organizations and activities. They provide users with indoor climate, technique services, and platforms for activities (Shen,

W. Shen 2010). Building’s design can change how users use the space, it can trigger customers to shop, leave a restaurant early or occupants to work more efficient or even change their habits.

As Sattrup mentioned, *“*buildings and their designs can also be understood as devices that serve technical purposes, as technology in a more narrow sense of the word, which integrates a wide range of other technologies in the processes of fabrication and to achieve the desired performance of the design*”* (Sattrup 2012). It’s obvious that we can use architecture to trigger people towards sustainability. We can awake their senses and lead them for being more responsible. For instance, “employees can change their physical setting to satisfy their needs (e.g. changing the orientation of a workplace to prevent arousal by bright sunlight or using headphones to prevent distraction by noise” (V. Tabak 2009, 27).

A variety of studies revealed how occupant behavior is triggered by design and interior layout (Bitner 2014; Cleempoel 2009; Economics and Nudge 1966; Haynes 2008). For example, a study which was published in American Journal of Public Health (2012), Anne Thorndike and her colleagues completed a six-month study to direct people to develop healthier eating habits without changing their willpower or motivation by using interior layout design. They proposed a new arrangement in displays which resulted with more water sales and less soda consume. This study argues against the usual argument on changing habits, and points out that design can be very important on guiding behavior (Clear 2014).

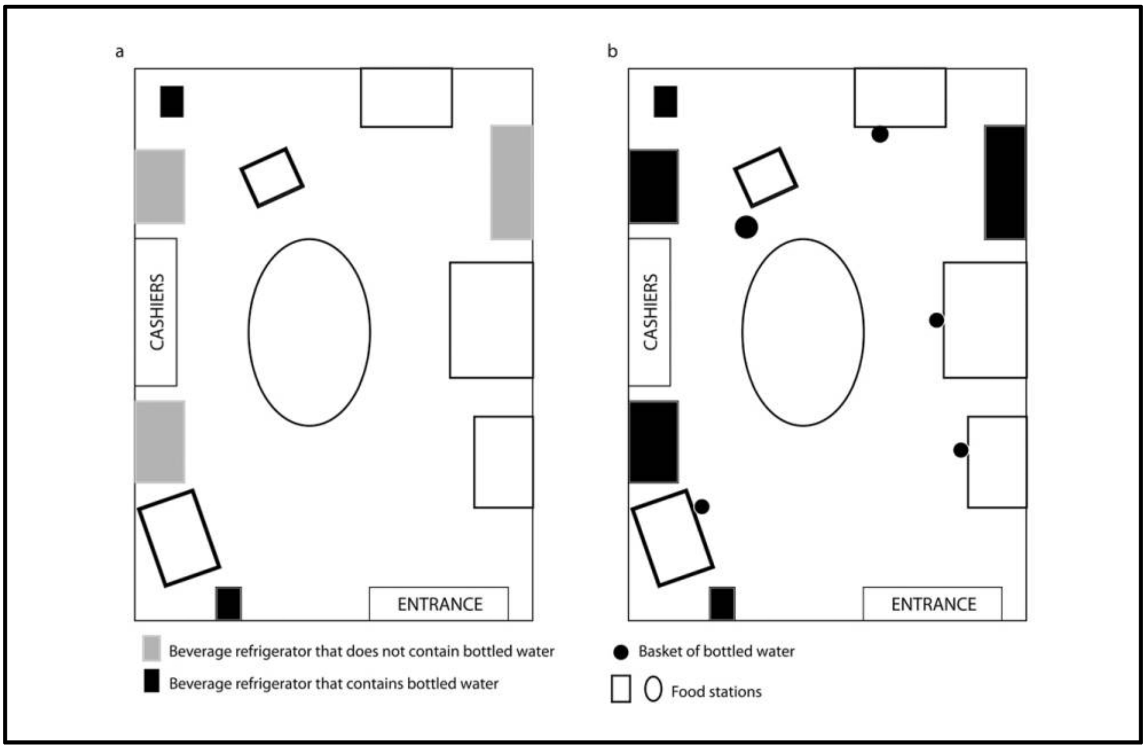


Figure 2.3. New and old arrangement of displays.
(Source: Clear 2014)

In addition to change of habits, interior design may affect energy consumption as well. Bahru (2011) mentions this as saying “well-designed interior layout design is able appropriately dealing with cost considerations to reduce the energy usage and energy consumption of different types of buildings” (Mohammadi et al. 2014). So we can use architecture to trigger people, awake their senses and lead them for acting more responsible.

Physical features like color, shape, texture may influence users’ perception and energy consumption (Maleetipwan-Mattsson, Laike, and Johansson 2016). For example, users are affected by the direction of daylight penetration. The relation of desk and window can play a role on manual lighting control. If you are sitting in front of the window and your back is facing the window, your own body might obstruct and cause shadow, therefore you may need to switch on the lights. Or on the contrary if you are facing the window, even though illuminance level is not sufficient, because of the luminosity, you may consider the room as well-lit and not switch on the lights.

Another parameter can be related with the distance between window and desk. Since illuminance levels decrease as it gets deeper in the room, the distance between the window and desk because more important in terms of illuminance levels on the workplane. So a user, whose desk is located far from window, might need to switch on lights more frequently than with someone whose desk is near to window. For example, the results' of Galasiu and Vetich (2006)' study showed that the need of artificial light (complimentary to daylight) depends greatly on the position of the occupant relative to the window (Galasiu and Veitch 2006). Likewise, the same light may be reflected differently on different surfaces due to their color and reflectance ratios (Zeyrek, Kürkçü, and Çakar n.d.). Since when the surface colors change, brightness perception changes as well.

David Kent Ballast (2006) pointed out that, switches generally are located at the door so that people can easily control it during entrance or leaving. While working, daylight availability might change and users might find it disturbing to go to switch and manually control the lighting. Because "occupants are less likely to interrupt their work and use a switch near the entrance than to use a control within easy reach of their work place" (Bordass et al., 1994).

Reinhart in his study (2002), pointed out how various (interior) spatial layout affects the daylight availability in offices (C. F. Reinhart and Canada 2002). Here interior layout refers to arrangement and relation of the furniture inside. So, an interior design not only arranges the utilization and circulation of the space but it affects other parameters like daylight penetration as well.

As a conclusion, in order to reduce energy consumption due to lighting (while obtaining visual comfort and user satisfaction) using daylight, energy efficient products or control systems are not sufficient by themselves. Because occupants influence the building due to their presence, activities and control actions that aim to improve indoor environmental conditions (thermal, air quality, light, noise). Therefore, energy use in buildings is closely linked to their operational and space utilization characteristics and the behavior of their occupants (Hoes et al. 2009).

CHAPTER 3

METHODOLOGY

Despite the widespread implementation of user behavior models in the field of lighting research, existing user profiles have not, been based on extensive user involvement (Goldstein et al. 2011). To understand and enhance manual lighting control behavior data, office users' behavior is evaluated since they correspond to one group consuming energy of electric lighting in terms of multiplying high rates (IEA ECBCS n.d.). The target group of this study was chosen as users of offices in universities; because, academic staff (due to lectures, seminars and meetings which happen regularly) commonly arrive and leave their offices more frequently, when compared to many other types of office users. The high rate of frequency in their access to their rooms leads to the necessity to observe their lighting manual control habits in this study.

This study examined the possible factors affecting manual lighting control. Methodology involves three steps to determine the affecting factors and to understand their contribution in manual lighting control considerations. First, a questionnaire was conducted among voluntary participants to figure out what type of aspects and interior layout have influence on manual control and how they are active on users' choice of turning on/off the lighting system. Second, on-site measurements were carried out to monitor users' actual behavior in their real working environment. Finally, gathering the above information and combining all necessary data, a fuzzy logic model was applied to propose a user behavior model classifying their type of behavior which depicts consequently the degree of their preference to switch on/off the lighting system.

3.1. The Structure of Questionnaire

A multiple-sectioned questionnaire was developed based on the previous research related to visual comfort, manual lighting control and interior layout (Hellinga 2013; Kim et al. 2015; MacMilan 2012; Powell 1998). The questionnaire contains a variety of questions such as multiple choice questions, Likert-scale and yes-no questions, was prepared using online survey system Surveey (Surveey n.d.). The questionnaire begins with an instruction about the content of the questionnaire and the objectives of this research. So, participants were informed before they filled in the questionnaire form. The questionnaire is composed of six sections. Respondents were asked to describe and assess their current workplace in the first two sections; while in the third and fourth sections, respondents' preferences regarding lighting conditions and manual lighting control were asked. The respondents gave their opinion on factors which increase or reduce their manual lighting control, and how often they manually control lighting systems. Subsequently, their attitude against manual lighting control was tested with photograph-involved questions. Participants decided to turn on or not to turn on the lights while looking at the photographs. Finally, their personal information including their age, gender and location were recorded.

Figure 3.1 displays how this questionnaire is structured in terms of these above criteria. Following sub-sections of this chapter involve detailed explanations.

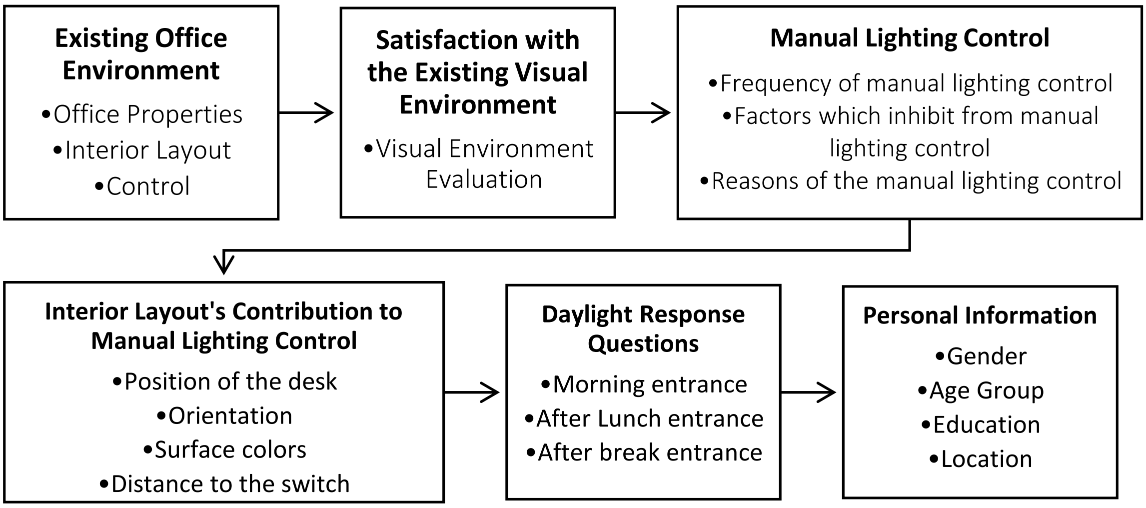


Figure 3.1. Structure of the questionnaire.

Respondents have got a list of 77 questions, partly multiple choice and partly scale questions. Irrelevant questions were excluded. For example, when the respondent indicated that there was no automatic control system in their current offices, questions about the automatic control system were skipped. Most of the questions were obligatory and the respondent could not proceed further when s/he skipped a question.

Limited amount of daylight penetration may trigger the manual lighting control behavior. Considering this knowledge, the questionnaire was conducted during winter, specifically in February 2015. Invitations to this survey were sent distributed via email to the academic staff in Yaşar University İzmir (TR), and TU Delft (NL). A total of 125 participants submitted the questionnaire forms through online system, Surveey. The participants could access the system when they are in their own offices and received questions in their own language. This software additionally was run to analyze the collected data extensively

3.1.1. Existing Office Environment

Office environment and user profiles vary significantly. Due to this variation, this section of the questionnaire primarily focused on the architectural/physical conditions of the participants' current offices, and aimed to relate them with participants' visual satisfaction and manual lighting control preferences which are gathered in subsequent sections. The first section involved a list of 9 multiple-choice questions. Gunay et al. (2013) mention that manual lighting control in shared offices are generally performed by the same group of occupants. Meaning that, there are still some others who don't interact with the lighting system (Gunay, O'Brien, and Beausoleil-Morrison 2013). Users can hesitate to interfere with the lighting system, avoiding to disturb their colleagues. So, it was assumed that manual lighting control could be influenced by the number of people occupied in the office, respondents were asked with how many people they share their working environment.

Figure 3.2 shows the respondents' office population.

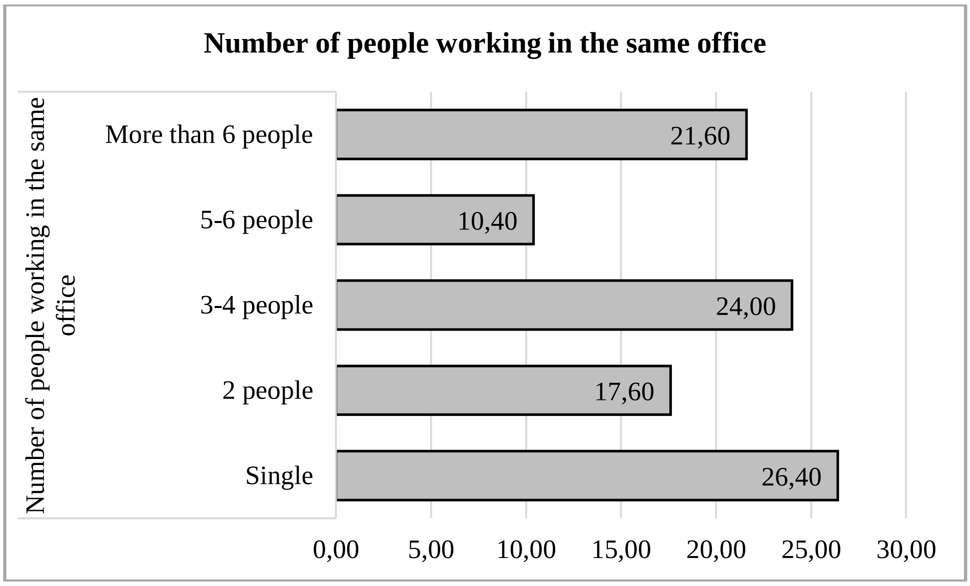


Figure 3.2. Number of people working in the same office.

Descriptions of respondents' offices on where the daylight is distributed were obtained from further questions about; the size of their office, windows and location of desks. Respondents were asked to indicate the orientation and the size of windows to learn about the physical aperture through which daylight is penetrated. Results can be seen on Figure 3.3 and Figure 3.4.

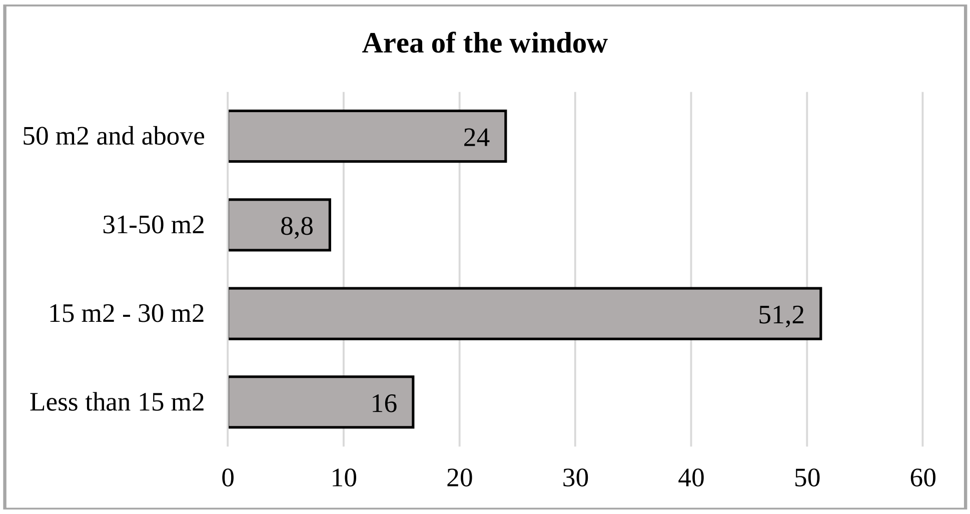


Figure 3.3. Respondents' existing offices' area of the window

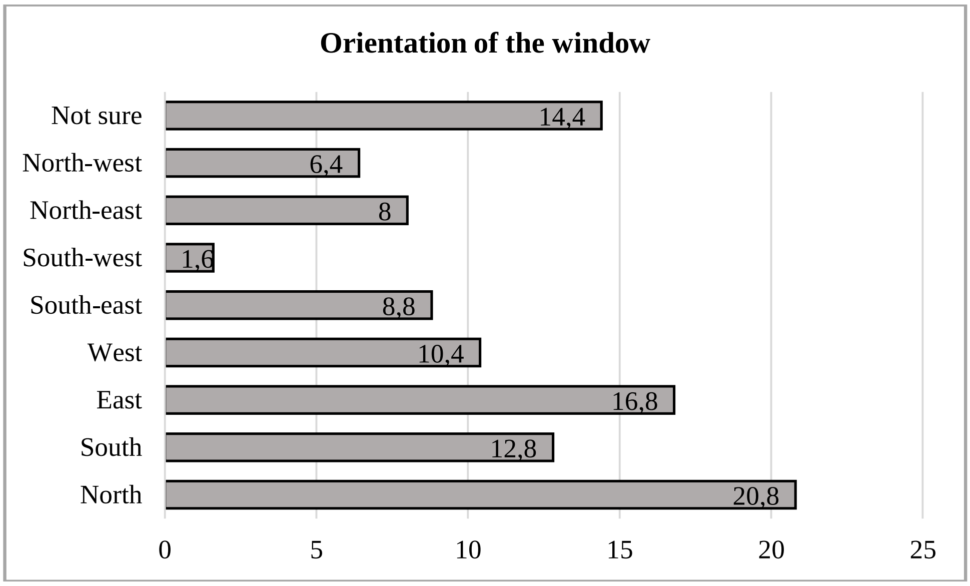


Figure 3.4. Respondents' existing office orientation.

The interior layout is identified by asking two questions. Knowing the distance between their desk and the window would be useful to interpret how daylight could/or couldn’t reach the workplace of each occupant. Collecting data about the position of the desk according to windows provides an insight how the daylight is directed towards the desk. An occupant facing windows and another one facing walls can declare distinct and varying evaluations about their visual environment; the daylight illuminance on their desk can vary as well (

Figure 3.5).

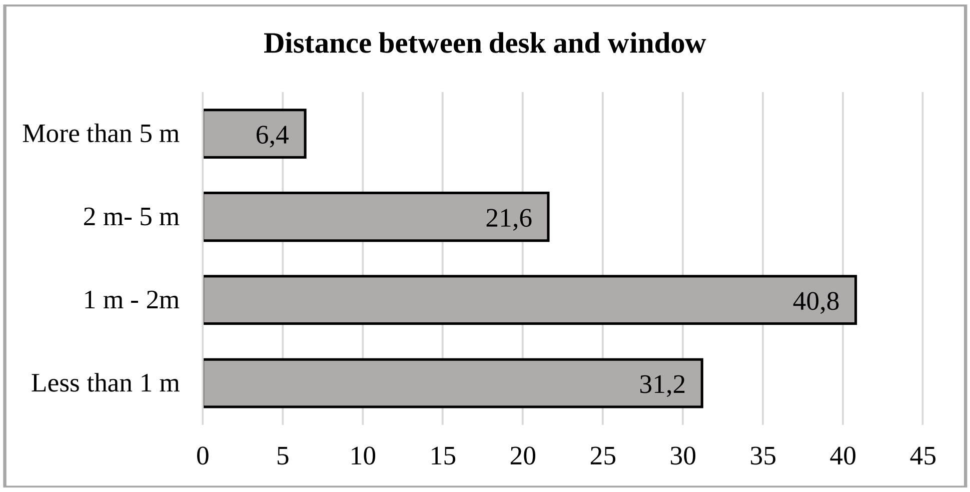


Figure 3.5. Distance between respondents' desk and window.

Having shading/blinds in the current office can effect respondents’ visual comfort. Therefore, questionnaire aimed to understand whether there are any sun controlling devices (interior or exterior) in the current offices. Results can be seen on

Figure 3.6.

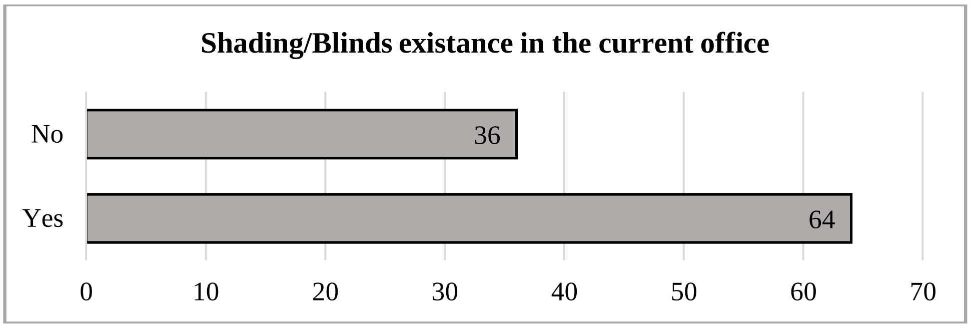


Figure 3.6. Shading/Blinds existence in the current office.

The final question is about visual comfort. Having only sufficient illumination levels on the workplane may not be enough to obtain visual comfort when glare is present. Therefore, participants were asked to indicate whether they suffer from glare or not. The objective is to accomplish a visual environment evaluation according to participants' point of view and to these physical/and geometric attributes (

Figure 3.7).

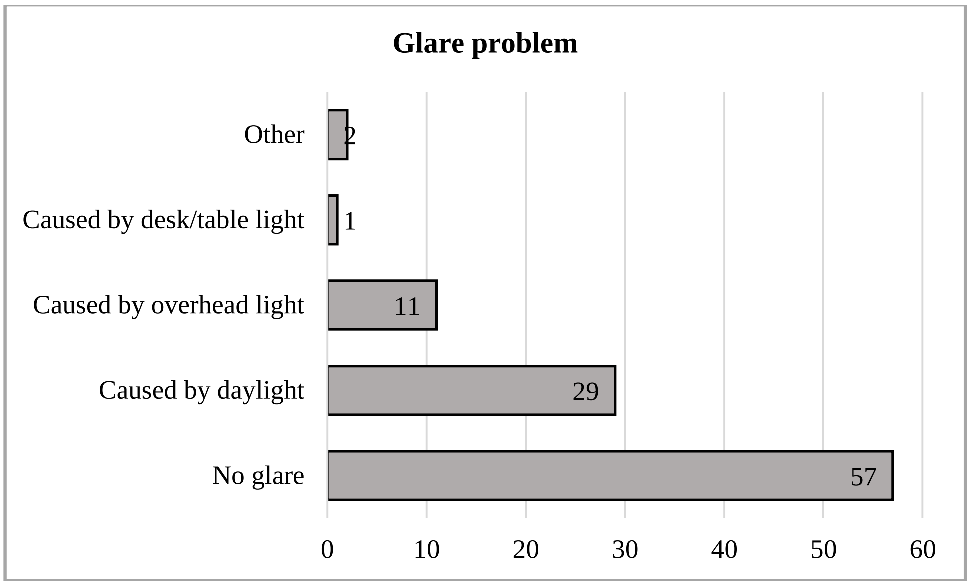


Figure 3.7. Glare problem.

In order to understand the physical conditions of the respondents' current office environment these questions were asked with those reply options. A short summary and focus of the first section can be seen on Table 3.1.

Table 3.1. Focus of the questionnaire.

Office and Aperture Descriptions
Area of the office Number of people working in the office Area of the window Orientation of the window
Interior Layout
Position of the desk Distance of desk and window
Shading devices or Sun light Control
Blinds/louvres
Visual Comfort
Causes of Glare

3.1.2. Satisfaction with the Existing Visual Environment

The second section of the questionnaire is developed involving both multiple-choice and Likert scale-questions based on users' assessments about the existing visual environment regarding both daylighting and artificial lighting (Table 3.2). Satisfaction with daylighting availability and artificial lighting environment was evaluated with a format of five level Likert rating designating as *1=not very satisfied, 2=unsatisfied, 3=medium, 4= satisfied, 5= very satisfied.* A subsequent semantic scale is constructed to collect information on how participants assess the amount of light in the room, on the desk and at the computer screen. The semantic scale ranged from *-2, too dim, to +2 too much* with a neutral value of 0 corresponding to the right amount. Besides that, users were asked to define the tasks, such as working with computer, reading or writing, which they accomplish, as well as their frequencies using a five scaled rating. The frequency scales are composed of five categories, such as, *1=all the time, 2=most frequent, 3=sometimes, 4=rarely and 5=never.* Multiple choice questions followed the preceding scaled questions. They are developed to get information whether there exist any sensor-based lighting control system and a personal desk lamp or not.

Table 3.2. Evaluation of current visual environment.

Visual Environment Evaluation
Satisfaction with the daylight availability
Satisfaction with the artificial lighting
Visual comfort for various common tasks
Satisfactions with the blinds (if there are any)

3.1.3. Manual Lighting Control

Third section of the questionnaire consist of questions which concentrate on manual lighting control habits and subjective reasons behind it respectively (Table 3.3). In order to reveal participants' manual lighting control actions, they were asked to describe the frequency of their manual lighting control through the day, i.e. several times during a day (depending on the absences or daylight penetration), twice a day (only when entering and when departing) or generally never. Questions about the reasons affecting on their manual lighting control (such as visual comfort needs, indicating occupancy, colleagues' request, creating an atmosphere etc.) were measured on a Likert scale from *1(always) to 5(never).* In addition to that, same scaling was used to determine some presumable subjective factors which affect manual lighting control in terms of inhibiting or triggering. The responses helped to provide information on the reasons and matters which trigger users to manually control the lighting system. Moreover, understanding these factors can give an insight of user behavior which was not previously considered in detail by other mentioned studies (P. R. Boyce, Eklund, and Simpson 2000; Hunt 1979; J. A. Veitch and Newsham 2000).

Table 3.3. Self-evaluation for Manual Lighting Control.

Manual Lighting Control
Frequency of manual lighting control
Reasons of the manual lighting control
Factors which inhibit from manual lighting control
Factors influence to turn on the lights
Factors influence to switch off (or not turn on) the lights

3.1.4. Interior Layout's Contribution to Manual Lighting Control

Bahru (2014) mentioned that interior design may affect energy consumption. Bahru claims "well-designed interior layout design is able appropriately dealing with cost considerations to reduce the energy usage and energy consumption of different types of buildings" (Bahru 2014). So we can use architecture to trigger people, awake their senses and lead them for acting more responsible. Therefore, fourth section of the questionnaire aims to examine interior design's contribution to manual lighting control (Table 3.4). By interior design what is meant is generally related with the amount of light falling on the desk such as; distance between the desk and window, area and orientation of the window, finish and colors of the interior materials and interior layout. All of the factors listed above effect the amount of daylight penetration falling on the desk, therefore can have an impact on manual lighting control. Respondents were asked to evaluate the seemingness of the given factors on their manual lighting control in Likert scale to from *1(always) to 5(never).*

Table 3.4. Interior Design Related Factors' Contribution to Manual Lighting Control.

Interior Layout's Contribution to Manual Lighting Control
Position of the desk
Distance between the desk and window
Area of the window
Orientation of the window
Color of the surfaces/objects in the room
Distance between switch and table

3.1.5. Daylight-Response Questions

Though participants declared their opinions about interior layouts' contribution to manual lighting in the previous section and evaluated their "activeness" on lighting system on the third and fourth section personally, photograph-response yes-no questions were prepared to test this self-evaluation. These questions are based on the 1/5 scale model of a private office room (which was built by Hester Hellinga's research) where a total of eight interior layouts which are dissimilar according to the orientation of the desk and its distance to the window (Hellinga 2013). The dimensions of the scale model are 1.08 m wide × 0.72 m long × 0.54 m high, so the model represents a room with dimensions of 3.6 x 5.4 m × 2.7 m (Figure 3.8) and become demonstrations for each photograph case.

Figure 3.8. 1/5 Scale model.
(Photograph by Arzu Cılasun)

In addition, surface colors which correspond to the reflectance can be effective on manual lighting control. Such as higher reflectance results in a considerable rise in daylight illuminance on workplane; that is the desk in this study. Consequently, interior surfaces of the scale model were covered with dark-colored paper firstly; then. with light colored paper secondly. Table 3.5 presents coefficients describing surface characterization. All layout variants are shown in Figure 3.9.

Table 3.5. Surface Reflectance of the scale model.

	Ceiling	**Walls**	**Floor**
Light	0.85	0.85	0.5
Dark	0.85	0.5	0.2

The scale model was placed in front of a north facing window in TU Delft Architecture and Built Environment Faculty, and pictured using a digital camera with fish eye lenses on 21 December 2014. North orientation was chosen to reduce high contrast differences and to avoid visual discomfort caused by direct sunlight. Diffuse daylight penetration provides relatively balanced daylight distribution during the day.

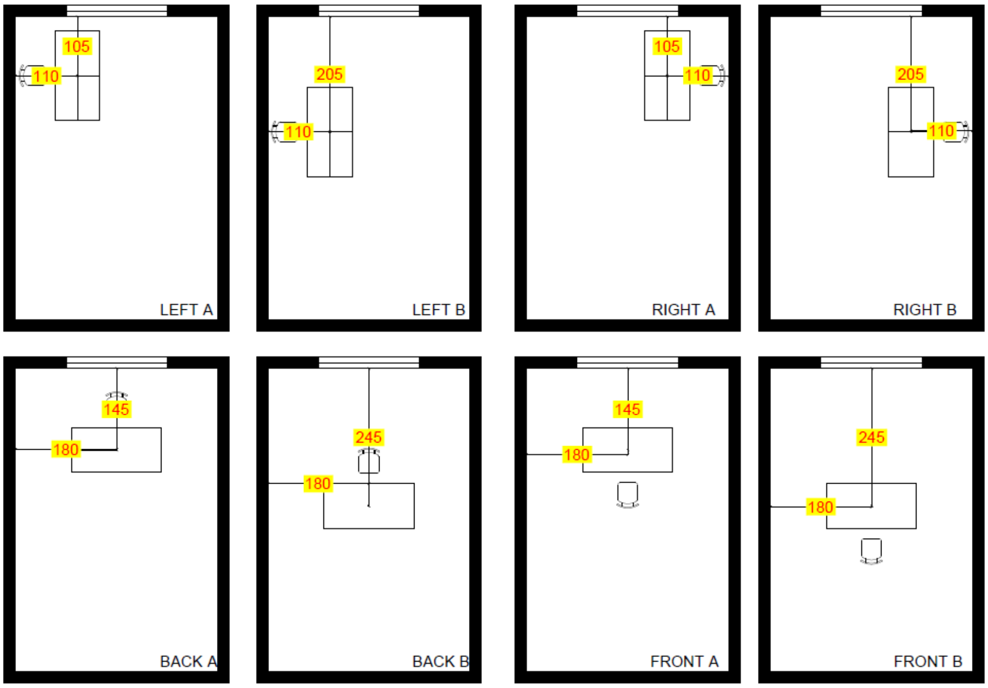


Figure 3.9. Eight determined interior layout schemes.

Model was photographed for three time intervals on the same day; entrance in the morning, at midday after lunch and in the afternoon after a short break. Exposure adjustments were implemented using Photoshop to avoid possible visual delusions.

Exposures were balanced by modifying brightness contrasts to overcome this problem. Participants were asked to indicate their manual lighting control action while looking at the photographs, (Figure 3.10) for these three time intervals. Based on the visual environment of the photographs, they stated their decisions as either “I would turn on the lights” or “I would not turn on the lights” upon entrance (Table 3.6).

Table 3.6. Photograph involved question response options.

Photograph Involved Questions
I would turn on the lights I would not turn on the lights

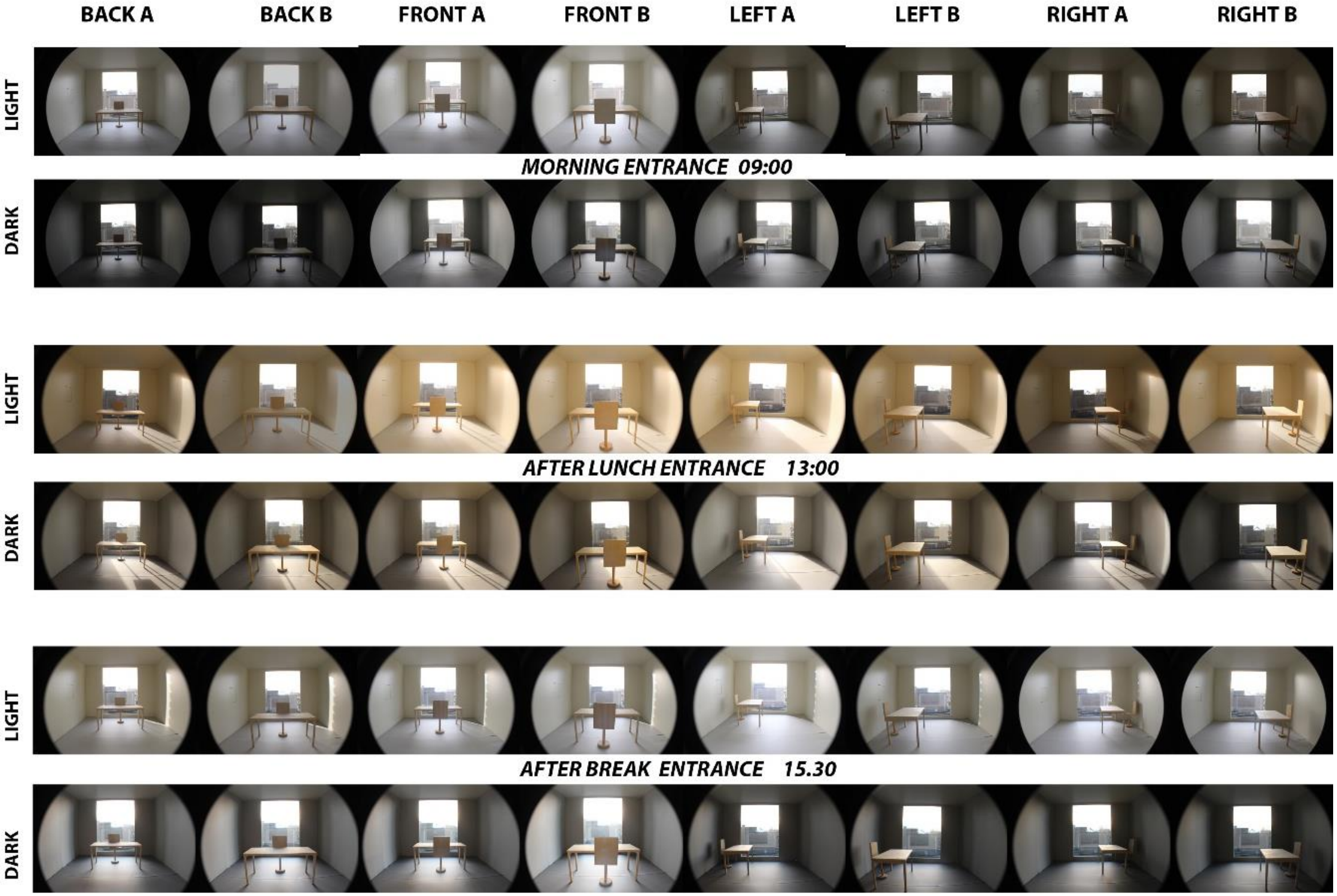


Figure 3.10. Photographs used to indicate for three time intervals and for all layouts.

3.1.6. Personal Information

The final section of the questionnaire seeks for personal information about the participants to analyze personal differences on user behavior. Therefore, personal information such as age group, gender, education levels and location were asked (Table 3.7).

Table 3.7. Personal information topics gathered from the respondents.

Personal Information
Gender
Age group
Education
Location

The number of respondents obtained in the research is 132. Regarding the responses, majority of the respondents were women and more than half of the respondents are below the age of 36. Since the questionnaire was conducted in between university, respondents' education levels are generally high. Table 3.8 and Table 3.9 respectively show the age and gender of the respondents.

Table 3.8. Age group of the respondents.

Age	**Percentage**
18-25	12,80%
26-35	53,60%
36-45	20%
46-55	8,80%
56-64	4,80%
65 and over	0

Table 3.9. Gender of the respondents.

Gender	**Percentage**
Women	60,80%
Men	39,20%

3.2. The Analysis of Questionnaire Data

The questionnaire of this study was prepared and distributed by using Surveey. Surveey is an online survey system which enables to create polls or survey with multi questions. It allows to use various types of question, set paths for respondents. Publishing the survey is possible through html link or script code. The online survey system also works in viewing the results and exporting the data to analysis software. It can individually prepare pie-charts, accomplish basic statistical analysis as well (Surveey n.d.).

3.2.1. Chi-Square Tests

To check whether there is a relation between the responses or not in questionnaire, Chi-square test, which is a common non-parametric test was used. The chi-square test can be generally used to test the hypothesis of no association between two or more groups, populations, or criteria. Here in this study, Chi-square test was used to find out whether there is a significant relationship between the following;

a. The distance between to the window from desk and manual lighting control behavior (i.e. Back A-Back B, Left A-Left B)

b. The relation between the position of the desk and manual lighting control behavior (Back A-Front A, Right A-Left A)

c. The relation between the time of the day and manual lighting control behavior (Back A morning -Back A lunch, Back A lunch - Back A afternoon, Back A morning - Back A afternoon).

3.3. Monitoring of Sample Rooms

The second part of the data collection procedure mainly includes obtaining realistic (actual) manual lighting control data. Starting point of this study is to increase manual lighting by interior layout , and office buildings are chosen for that, since they are one of the biggest energy consumers (Cilasun 2012). There are various density variations for office rooms, such as open-plan, shared or private offices. Occupants in either open-plan or shared offices are forced to put up with the present comfort conditions though which sometimes do not match to their preference. However “occupants in private offices were more likely to make environmental or behavioral changes to regain comfort, whereas occupants in open-plan spaces rely more on psychological coping mechanisms” (Gunay and Drive n.d., 18). Therefore, monitoring private offices can give more clear outputs on the users’ decisions.

3.3.1. Geometry of Sample Rooms

In university offices, generally users do not use their offices for whole day (due to lectures, seminars and meetings that happen frequently) and they go in and out more often compared to many other office types. Therefore, observing manual lighting control in university office rooms with frequent in/outs has found to be more reasonable.

To observe users’ manual lighting control behavior individually, three private offices were chosen for the monitoring stage of this study. These private rooms are located at Building C in Izmir Institute of Technology Faculty of Architecture. Two of the rooms are in the first floor (room 111 and 110) while one is located on the ground floor (Z06) (

Figure 3.11) (İYTE Mimarlık Fakültesi C Blok n.d.).

Figure 3.11. Building C in IYTE Faculty of Architecture (İYTE Mimarlık Fakültesi C Blok n.d.).

All three rooms have one sided windows which are facing north. For artificial lighting, rooms have two surface mounted luminaires operating with 2x35w T5 fluorescent lamps. None of the rooms have automatic lighting control systems, however all the three sample rooms have non-automated interior sun-blinds which can misdirect the measurements. In order to prevent that, in all three rooms, blinds were positioned to a standard position to achieve 500 lux (suggested optimum illuminance level on the workplane by (CEN/TC169 2006)) in 1 meter away from the window on the same day. Participants were asked to not interfere with the blinds' position during the measurements. Further information on the sample rooms can be found on Table 3.10 and Figure 3.12Figure 3.15.

Table 3.10. Properties of the sample rooms.

	Z06	110	111
Dimensions of the sample rooms (m)	5.68x3.4x3.25	4.20x3.40x3.25	4.20x3.40x3.25
Type of Office	Single occupied	Single occupied	Single occupied
Automatic Lighting Controls	No	No	No
Orientation	North	North	North
Current artificial lighting load	140 W	140 W	140 W

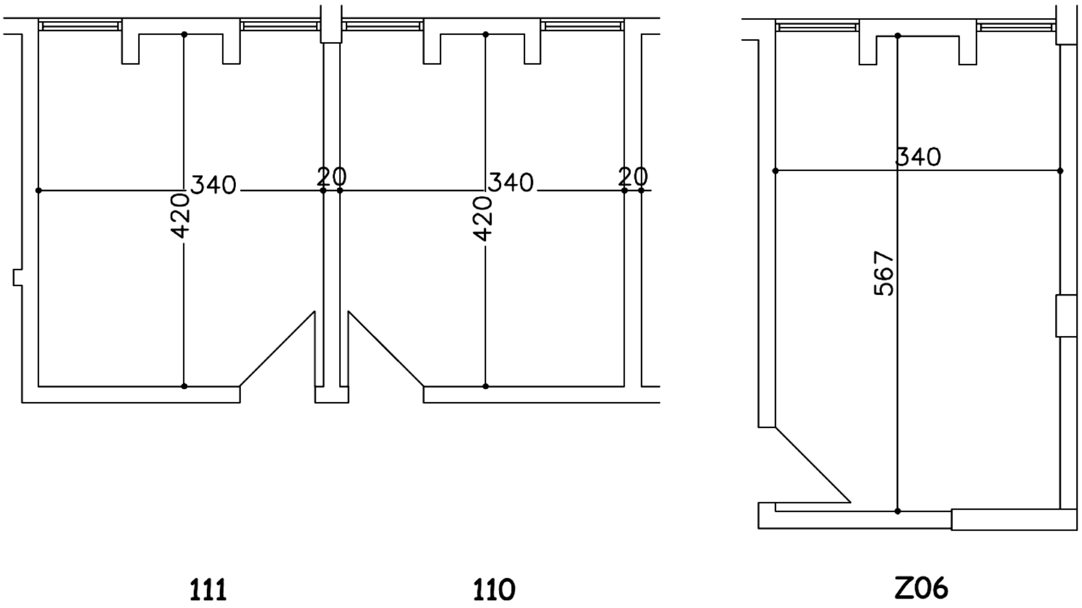


Figure 3.12. Geometry of sample rooms.

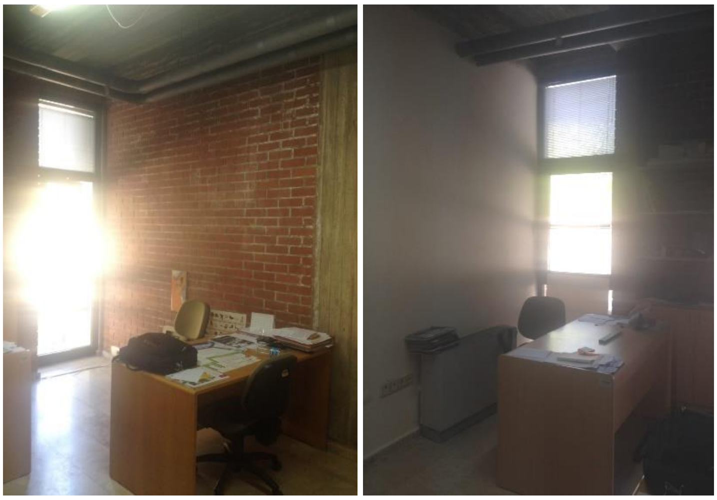


Figure 3.13. Different perspectives from room 110.

Figure 3.14. Different perspectives from room 111.

Figure 3.15. Different perspectives from room Z06.

3.3.2. Monitoring Phase

On winter season, daylight penetration is weaker compared to other seasons and this might trigger users' manual lighting control. To that end, this monitoring process took place on seasons where daylight was limited (between November 2014 - February, 2015).

Occupancy and light data loggers have been used in various lighting and energy consumption research (Wasilowski & Reinhart 2009; Yun et al. 2012). To observe occupancy and manual lighting control for long terms and energy consumption evaluations, these types of sensors are very helpful and useful. Within the monitoring phase, three measurements were carried out with two sensors, which will be described respectively.

- horizontal illuminance measurements on desks
- occupancy detection in the room
- artificial lighting operation

3.3.2.1. Horizontal illuminance measurement

The first data logger, HOBO U12-O12, used to record the horizontal illuminance level on the desk. It is placed on the desk to understand the total amount of light (both daylight and artificial lighting) falls on the workplane (Figure 3.16).

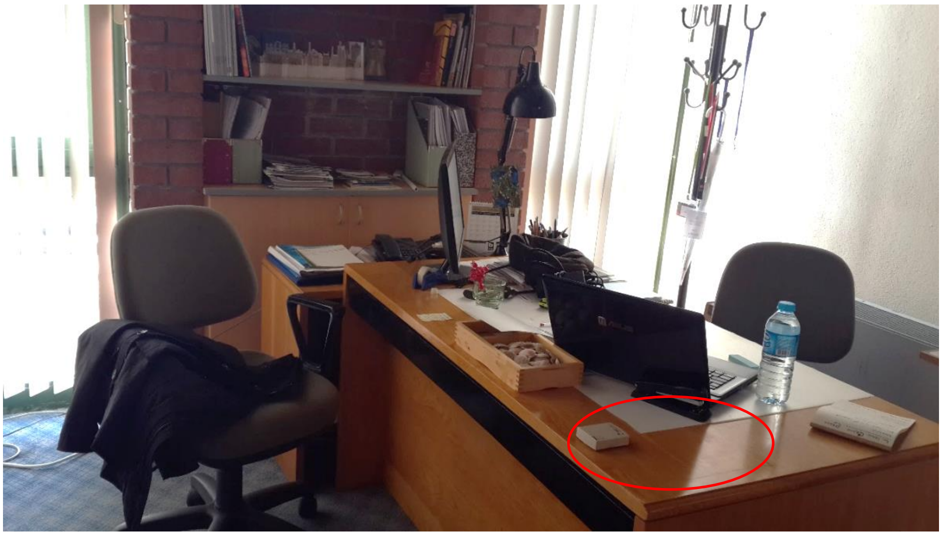


Figure 3.16. Illuminance data logger.

This sensor can give out the illuminance levels both numerically and graphically (

Figure 3.17). This device is capable of recording illuminance in 1 minute intervals. Owing to the frequency of records, any sudden significant change in the illuminance level can be interpreted as change off artificial lighting condition.

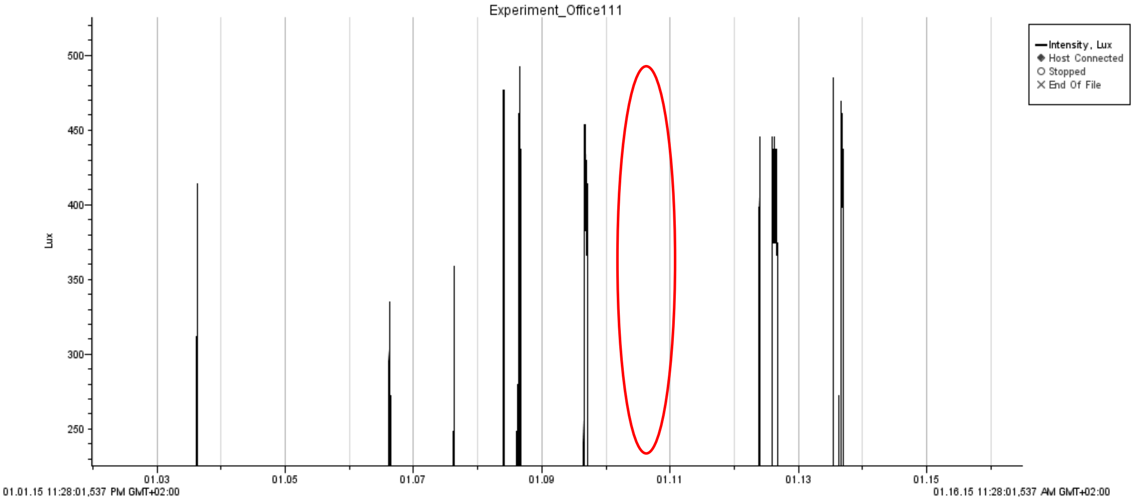


Figure 3.17. Illuminance level graph.

3.3.2.2. Occupancy and Light Detection in the Room

When dealing with the manual lighting control behavior, only monitoring interior illuminance level is not enough. Occupancy intervals is one of the important key aspects as “several researchers reported that the duration of absence followed by the departure as the primary predictor for light switch-off action” (Gunay and Drive n.d.). Therefore, in addition to illuminance levels, the connection of manual lighting control with the occupancy intervals have to be observed as well.

HOBO UX90-006 data loggers were chosen to hold the records for both occupancy and light on-off conditions (Figure 3.18). These devices perform in a large detection area (41 degrees horizontally and 47 degrees vertically) (Figure 3.19). They can monitor room occupancy to 5 meters away as well as indoor lighting level changes with its integrated sensors. The devices were set to capture any change in occupancy or lighting level in every second.

Figure 3.18. Occupancy/light data logger.
(Source: http://www.onsetcomp.com/products/data-loggers/ux90-005)

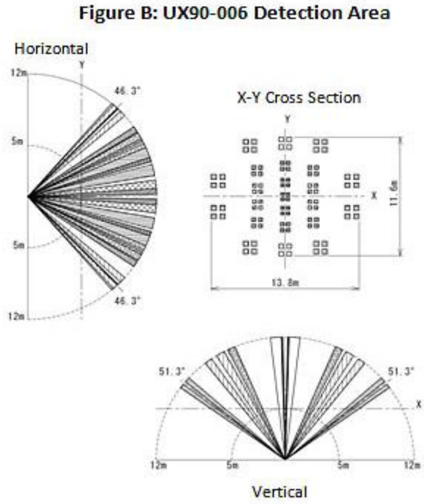


Figure 3.19. Detection area of the occupancy/light data logger.
(Source: http://www.onsetcomp.com/products/data-loggers/ux90-006)

For occupancy detection, the sensor is activated when there is any rapid/high change in its thermal sensation. For the light on-off records, two methods can be followed.

Either the default value of 65 lx can be used as a threshold value or a new threshold value can be defined with calibration. By turning on and off the lights, the sensor can be calibrated. After the calibration, the sensor can easily detect whether the lights are On or Off within the room. These sensors were mounted near the lighting fixture in each sample room (Figure 3.20)

Figure 3.20. Location of the occupancy/light sensor.

Matching and comparing these two sensors for illuminance data and occupancy&light On/Off data would produce an understanding and a deep interpretation on users' manual lighting control. For instance, during entrance, if the user does not turn on the lights over certain amount of illuminance level, then this can be used to interpret the user's expectation for interior illuminance level.

3.3.3. Interior Layout Arrangements

The first part of the data collection procedure mainly includes obtaining realistic (actual) manual lighting control data in sample offices. Four basic directions of getting the daylight penetration (from left, right, back and front) have become the variants (Figure 3.8). In order to understand the effect of distance from desk to window distance, on the manual lighting control each direction was tested with two different distances for 10 days.

In each direction, same direction was monitored with 1/1.5m (which is named as direction-A) and 2/2.5m (which is named as direction B). (

Figure 3.21). The layout schedule of the sample rooms can be seen on Table 3.11. Monitoring results were evaluated by fuzzy logic algorithm.

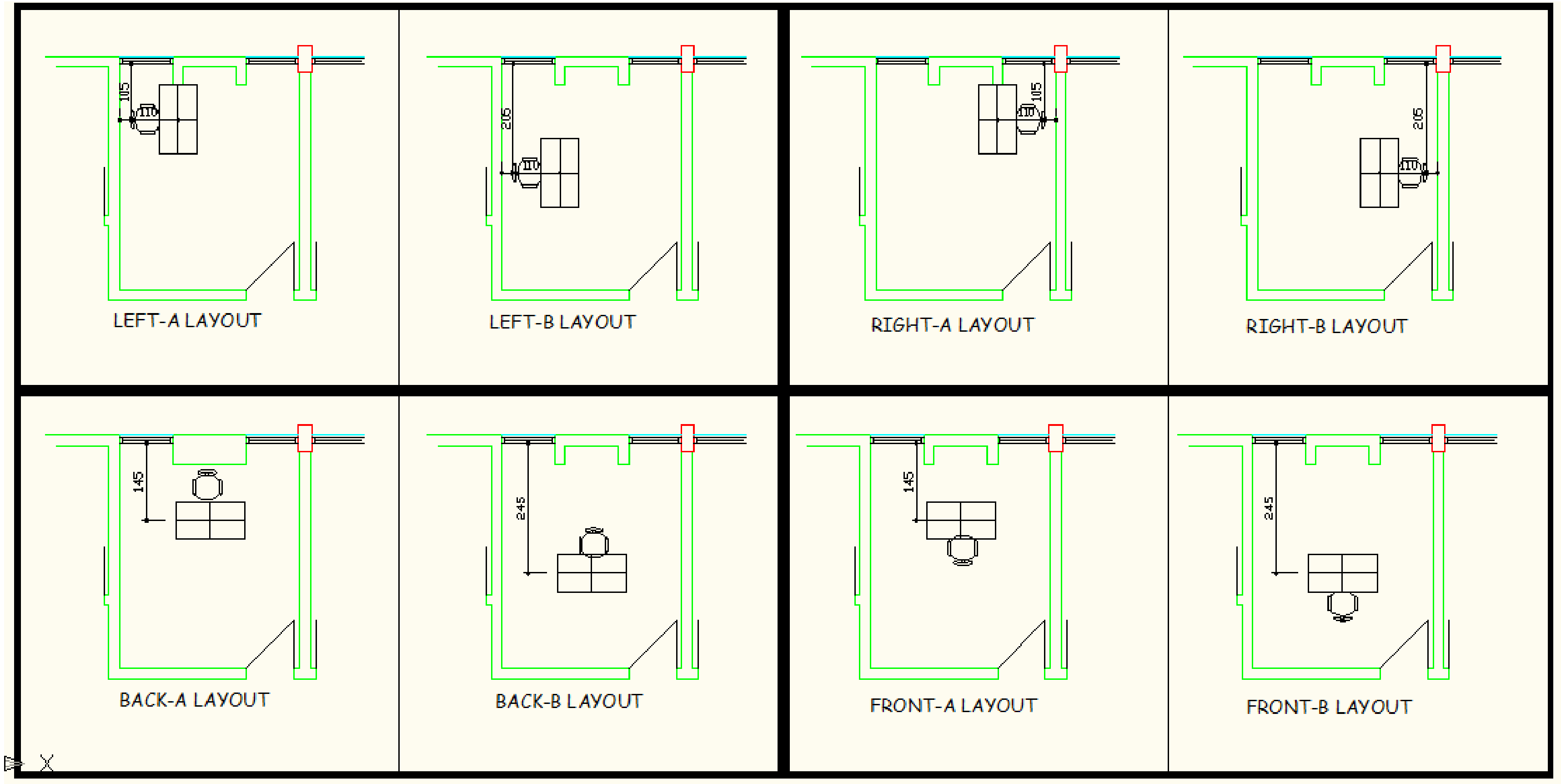


Figure 3.21. Interior layout arrangements in monitoring phase.

Table 3.11. Monitoring schedule of sample room.

INTERIOR LAYOUT	Room 1 (Z11)	Room 2(110)	Room 3(111)
LEFT A	31.10.2014-14.11.2014	31.10.2014-14.11.2014	31.10.2014-14.11.2014
LEFT B	17.11.2014-28.11.2014	17.11.2014-28.11.2014	17.11.2014-28.11.2014
RIGHT A	03.12.2014-11.12.2014	03.12.2014-11.12.2014	03.12.2014-11.12.2014
RIGHT B	12.12.2014-25.12.2014	12.12.2014-25.12.2014	12.12.2014-25.12.2014
BACK A	26.12.2014-06.01.2015	26.12.2014-06.01.2015	26.12.2014-06.01.2015
BACK B	07.01.2015-19.01.2015	07.01.2015-19.01.2015	07.01.2015-19.01.2015
FRONT A	19.01.2015-30.01.2015	19.01.2015-30.01.2015	19.01.2015-30.01.2015
FRONT B	02.02.2015-16.02.2015	02.02.2015-16.02.2015	02.02.2015-16.02.2015

3.4. Fuzzy Logic Concept

Fuzzy Logic (FL) “derives from the transformation of verbal expressions into analytical information for use in computing processes” (T. Kazanasmaz 2013). It is powerful technique which formulates approximate reasoning. It dates back to 1965, when Loutfi A. Zadeh proposed the “Fuzzy Set Theory” work (Turhan 2012). When the data is either unavailable or incomplete, or whenever the process is highly complex fuzzy logic computational paradigm can be used (Cziker, Chindris, and Miron 2007). Fuzzy logic basically provides partial truths and multivalued truths; therefore, it is generally used for problems which cannot be simply expressed by mathematical modelling. FL is a form of nonlinear mapping of the input data to obtain a scalar output data (Yager and Zadeh 2012).

In fuzzy system, the key idea is “the allowance of partial belongings of any object to different subsets of universal set instead of belonging to a single set completely” (Z. T. Kazanasmaz and Tayfur 2012). For this purpose fuzzy system have basically four steps; Fuzzification, Decision making unit, Rule base and Defuzzification which can be seen on Figure 3.22 .

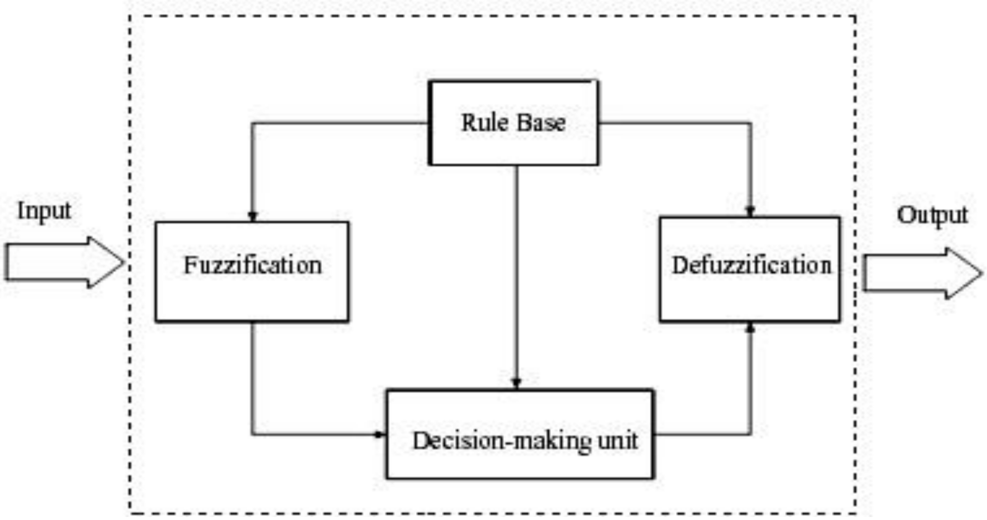


Figure 3.22. Structure of fuzzy system process.

The fuzzification” step converts each input data into grades of membership through membership functions of a fuzzy set (T. Kazanasmaz 2013; Turhan 2012). This membership function converts to a linguistic term; such as “high”, “medium” or “low”. Each input value corresponds to a value between 0 and 1 (T. Kazanasmaz 2013).

Fuzzy system is based on the concept of fuzzy If-Then rules which are the mathematical interpretation of linguistic expressions. These rules are created to determine a relation between input and output data. With this method, nonlinear relationships or uncertainties can be described, without any numerical equations or models but, with If/then or And/Or rules. (Bozokalfa 2005). The researcher constructs these rules by analyzing the input data (Gravani et al. 2007; Yager and Zadeh 2012).

3.4.1. Fuzzy Logic Model Construction

Measurement phase yielded many results on the manual lighting control of the users. Chi-square tests which are applied in the questionnaire phase, defined significant dependency of manual lighting control behavior on desk layout, distance to window and time. They have become the major factors to this kind of behavior. However, to propose behavior patterns about the tendency to turn on the lights, a fuzzy logic algorithm was used since it is capable of interpreting relations among the non-linear input data. A fuzzy logic model that briefly aims to interpret the manual lighting control of the users by the given three changing factors was formed. Using this model, it would be possible to predict and classify the users' control behavior patterns.

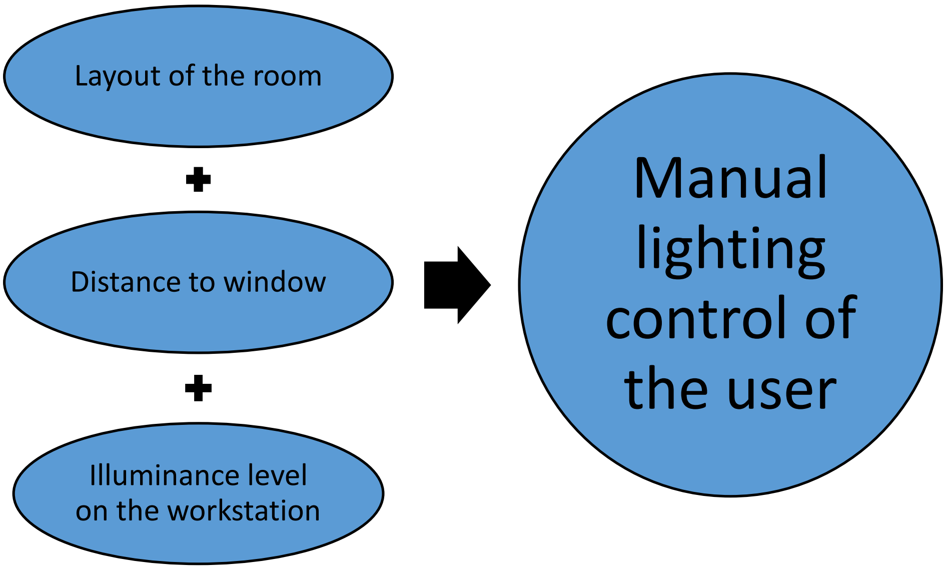
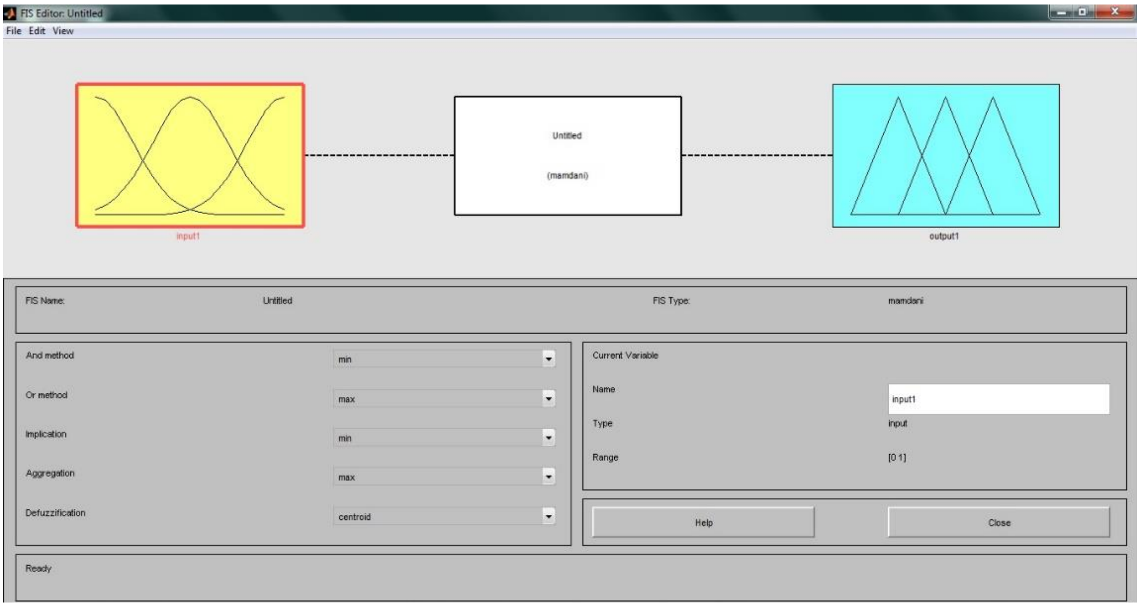


Figure 3.23. Three input data and 1 output data for the fuzzy logic model.

MatLAB (R2009b version) FIS toolbox was used to employ the fuzzy logic model using observational data during the onsite measurement phase (Sivanandam, Sumathi, and Deepa 2007). In the FIS editor, each input data group has to be determined by the name, range, method, implication and aggregations (Figure 3.24). The fuzzy rules and their membership functions were built in accordance with illuminance data set obtained from the actual rooms and desk arrangements. Intuition together with the existing knowledge on lighting research and the nature of data which cover the occupancy/light on/off conditions gathered from the onsite measurements were considered to construct the subdivisions of output variable, behavior pattern.



FIS Name: Untitled

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

Name: input1

Type: input

Range: [0 1]

Ready

Figure 3.24. FIS editor interface.

On site measurements were analyzed for each user, each layout and for each control action individually. Comprehensive evaluation method analyzed the occupancy, light usage and illuminance levels, which later used for the fuzzy model. For each layout, the illuminance level before the occupancy was noted as well as the light behavior of the user. For example as it can be seen on

Table 3.12, on Left A layout, User C entered the room on 03.11.2014 at 09:04, and the illuminance level upon entrance was 4 lux. The user turned on the lights during occupancy and stayed in the room for 43 minutes (09:04-09:47). During his stay, the average illuminance level (with daylight and artificial lighting) was 365 lux. While on 10.11.2014, the illuminance level upon entrance was 209 lux, and the user did not switch on the lights. Only daylight penetration supplied 138 lux during his occupancy (13:06-15:22). For each layout, the average lights on and average lights off illuminance levels were calculated to see the tendency and threshold of the users to turn on the lights.

According to the gathered results three input variables; layout, illuminance and distance, and one output variable named behavior were fuzzified in fuzzy subsets in MatLAB FIS editor.

Table 3.12. Analysis of monitoring in terms of lights usage and illuminance level.

Left A User C					
Date	Time	Occupancy	Light	Illuminance upon entrance	Average Illuminance during occupancy
3.11.2014	09:04	0	0	4	
3.11.2014	09:04-09:47	1	1		365
10.11.2014	13:06	0	0	209	
10.11.2014	13:06-16:22	1	0		138
11.11.2014	10:52	0	0	138	
11.11.2014	10:52-11:55	1	1		423
11.11.2014	14:48	0	0	128	
11.11.2014	14:48-16:12	1	0		254

3.4.2. Layout

Four basic layouts were experimented on the sample offices. For the fuzzy logic model, each desk layout expressed in terms of angular degree. For example, right layout (where the window is located on the right side of the desk) corresponds to 90°, while back layout corresponds to 180°, left layout to 270 ° and front layout corresponds to 360°. The initial desk position is set to be as facing the window (0°), then it rotates counterclockwise. So, the layout range was 0° - 360°, and five subsets into which it was subdivided- very low (VL), low (L), medium (M), high (H) and very high (VH)- were formed to have triangular membership functions as shown in Figure 3.25.

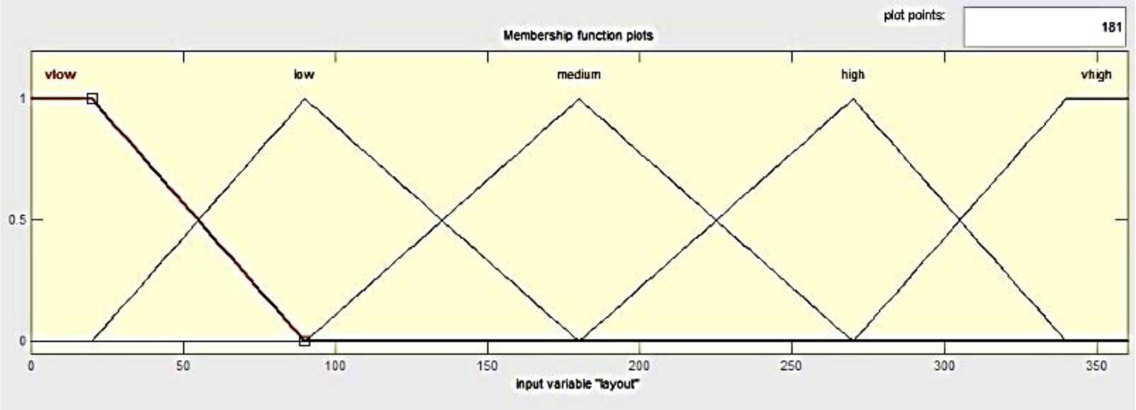


Figure 3.25. Membership functions of layout in the fuzzy logic model.

3.4.3. Illuminance

According to the average illuminance records defining the horizontal illuminance on desk surface, this input variable was grouped in three ranges as given lux values on Table 3.13. The triangular membership functions were set in three subsets namely low (L), medium (M), high (H), as shown in

Figure 3.26. Although the optimum workplane illuminance is recommended as 500 lux regarding the CIBSE standards, the maximum threshold value was defined to be 300 lux due to the records of actual measurements. Subsets, especially involving lower illuminance values, represent basic classifications that capture detailed deviations in any illuminance distribution.

Table 3.13. Illuminance variable classification.

	Min Lux value	Middle Lux value	Max Lux value
Low	0	20	70
Medium	20	70	300
High	70	300	300 and above

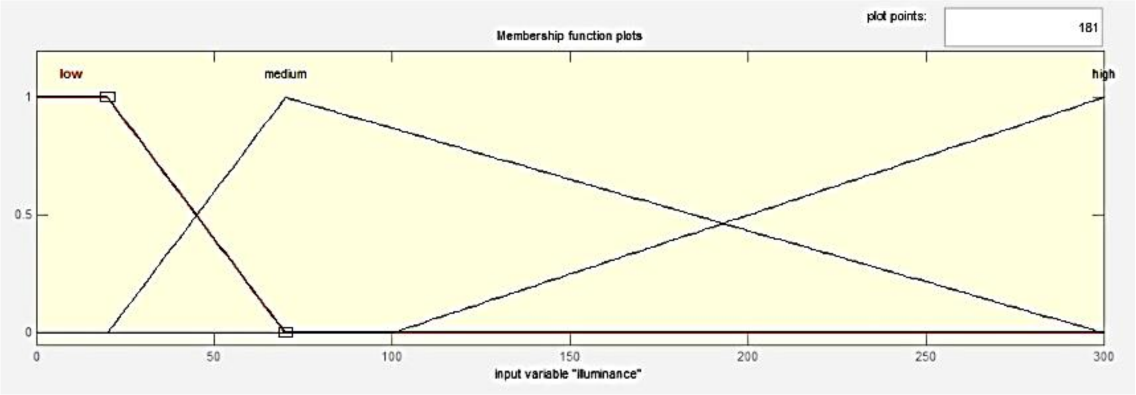


Figure 3.26. Membership functions of illuminance in the fuzzy logic model.

3.4.4. Distance

Distance has a significant impact on manual control habit when the responses of photograph-based questions in the questionnaire are analyzed using statistical findings. As the case rooms were single-occupied ones and small in dimensions, two subsets-low

(L) and high (H)- were considered to have triangular membership functions, as presented in Figure 3.27. Membership functions of distance in the fuzzy logic model. The minimum value was 1 m from the window and the maximum value is 2 m.

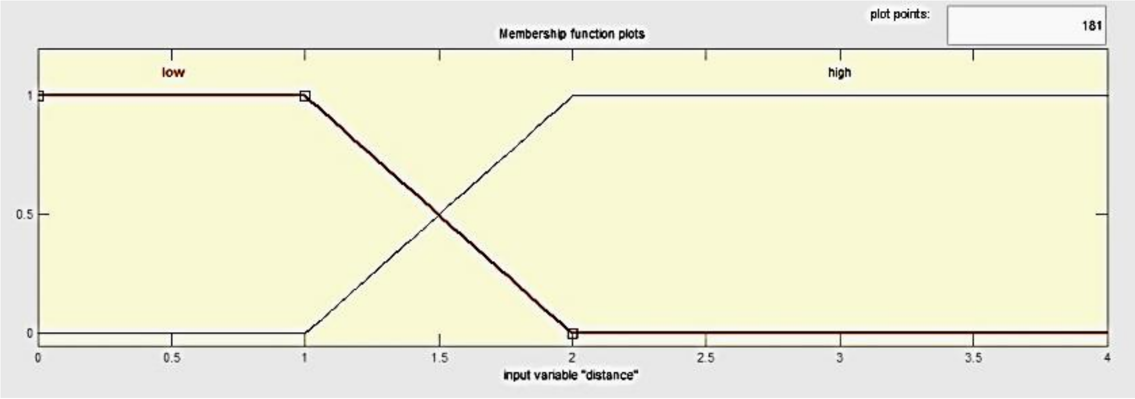


Figure 3.27. Membership functions of distance in the fuzzy logic model.

3.4.5. Behavior Pattern

Inputs were fuzzified in the above fuzzy subsets in order to cover the degree of behavior patterns which correspond to the users' attempt for turning on the lights. The subsets of fuzzy changes in behavior patterns present basic classifications which can be applied for any type of single occupied offices. Thus, behavior is considered to have a maximum value of 1 and its subdivision into three subsets as low (L), medium (M), and high (H) is considered to have triangular membership functions as represented in Figure 3.28.

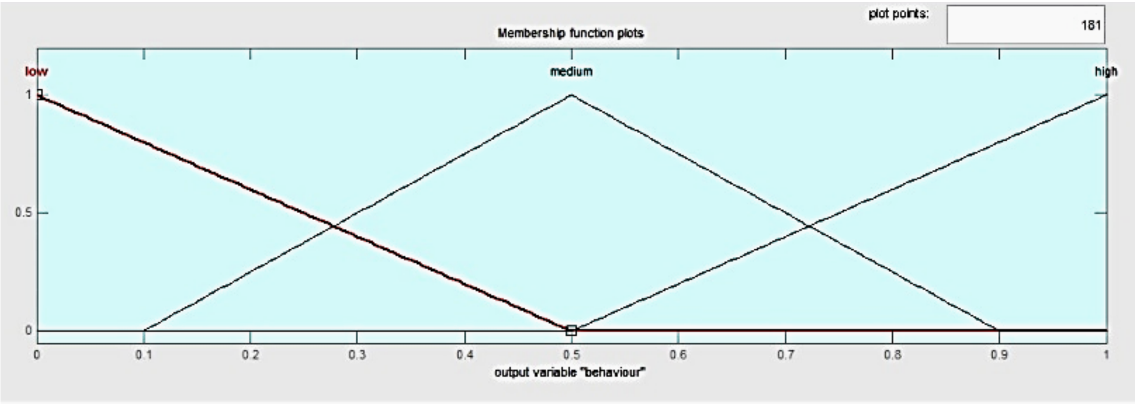


Figure 3.28. Membership functions of behavior pattern in the fuzzy logic model.

3.4.6. Rules

The fuzzy rule base, representing the relationships between the inputs, i.e., layout, illuminance and distance, and the output, i.e., behavior pattern, was then applied. Fuzzy rules were intuitively employed by taking into account the measured and observed data. They were also inferred from general knowledge presented in the literature. The commonly used Mamdani rule system is the basis of this model. The system is used to relate the input variables to the output variable verbally by constructing fuzzy rules (Çiftçioğlu 2003; Z. T. Kazanasmaz and Tayfur 2012; Vakili-Ardebili and Boussabaine 2007). The antecedent part of a rule--the part beginning with IF, up to THEN--included a statement on layout, illuminance, and distance, whereas the consequent part--the part beginning with THEN, up to the end-- included a statement on behavior. For example,

'IF the layout is 'Low', the illuminance is 'Low' and the distance is 'High', THEN the behavior is 'High'.

There were a total of 30 fuzzy rule sets, which were summarized in

Table 3.14. Fuzzy rule sets. The following fuzzy inferencing engine operators were used: the min operator was applied to define the firing strength of each rule, the max composition operator combined fuzzy output sets from each fired rule into a single fuzzy output set; and the centroid method was employed for defuzzification.

As workplane illuminance on the desks are to be more dominant factor of switching on/off behavior, due to physiological needs, all possible fuzzy rules in the fuzzy set were to be employed to transform these inputs to corresponding output by taking the importance of this input into consideration.

Table 3.14. Fuzzy rule sets.

	IF desk layout is	AND Illuminance is	AND distance to window is	THEN manual lighting behavior	COMMENT
1	VLOW	LOW	LOW	MEDIUM	Would expect medium probability of to turn on the lights
2	VLOW	LOW	HIGH	HIGH	Would expect high probability of to turn on the lights
3	VLOW	MEDIUM	LOW	LOW	Would expect low probability of to turn on the lights
4	VLOW	MEDIUM	HIGH	LOW	Would expect low probability of to turn on the lights
5	VLOW	HIGH	LOW	LOW	Would expect low probability of to turn on the lights
6	VLOW	HIGH	HIGH	LOW	Would expect low probability of to turn on the lights
7	LOW	LOW	LOW	MEDIUM	Would expect medium probability of to turn on the lights
8	LOW	LOW	HIGH	HIGH	Would expect high probability of to turn on the lights
9	LOW	MEDIUM	LOW	MEDIUM	Would expect medium probability of to turn on the lights
10	LOW	MEDIUM	HIGH	MEDIUM	Would expect medium probability of to turn on the lights
11	LOW	HIGH	LOW	LOW	Would expect low probability of to turn on the lights
12	LOW	HIGH	HIGH	LOW	Would expect low probability of to turn on the lights
13	MEDIUM	LOW	LOW	MEDIUM	Would expect medium probability of to turn on the lights
14	MEDIUM	LOW	HIGH	HIGH	Would expect high probability of to turn on the lights
15	MEDIUM	MEDIUM	LOW	HIGH	Would expect high probability of to turn on the lights
16	MEDIUM	MEDIUM	HIGH	HIGH	Would expect high probability of to turn on the lights
17	MEDIUM	HIGH	LOW	LOW	Would expect low probability of to turn on the lights
18	MEDIUM	HIGH	HIGH	MEDIUM	Would expect medium probability of to turn on the lights
19	HIGH	LOW	LOW	MEDIUM	Would expect medium probability of to turn on the lights
20	HIGH	LOW	HIGH	HIGH	Would expect high probability of to turn on the lights
21	HIGH	MEDIUM	LOW	LOW	Would expect low probability of to turn on the lights
22	HIGH	MEDIUM	HIGH	MEDIUM	Would expect medium probability of to turn on the lights
23	HIGH	HIGH	LOW	LOW	Would expect low probability of to turn on the lights
24	HIGH	HIGH	HIGH	LOW	Would expect low probability of to turn on the lights
25	VHIGH	LOW	LOW	MEDIUM	Would expect medium probability of to turn on the lights
26	VHIGH	LOW	HIGH	HIGH	Would expect high probability of to turn on the lights
27	VHIGH	MEDIUM	LOW	LOW	Would expect low probability of to turn on the lights
28	VHIGH	MEDIUM	HIGH	LOW	Would expect low probability of to turn on the lights
29	VHIGH	HIGH	LOW	LOW	Would expect low probability of to turn on the lights
30	VHIGH	HIGH	HIGH	LOW	Would expect low probability of to turn on the lights

After all the mentioned monitoring has done, the final gathered data includes switching on/off frequencies, occupancy periods, illuminance levels and daylight penetration. This collected data was analyzed to compare and formulate the common responses of the users.

CHAPTER 4

RESULTS

This chapter involves three subsections namely, general results obtained from conducted questionnaire, measurement results from the observation and fuzzy logic model. Statistical analyses were used to determined significant relationships between the manual lighting control and related interior factors in the questionnaire.

4.1. Questionnaire Process, Response Rates and Results

The questionnaire was developed and conducted via Surveey and ran during January-February 2015. The invitations were distributed by email among the academicians of Yaşar University. The questionnaire results allowed for assessment of:

- Participants existing office environment,
- Satisfaction with the existing office environment
- Their manual lighting control behavior
- Their opinion on interior layouts' contribution to manual lighting control
- Their manual lighting response according to the time of the day
- Their personal information

Among the invited and accepted respondents, 125 participants among 398 (which is approximately 30%) have completed the questionnaire.

4.1.1. Current Working Environment and Visual Comfort

Since lighting has a significant impact on participants' satisfaction, to know the conditions of their current working environment and their level of satisfaction with it, may help to relate it with their responses. Respondents may have reflected their current discomforts with the existing office to the manual lighting control habit questions. Moreover, their expectations or preferences may be as a result of their current office. For that reasons, conditions of current working environment were analyzed in sub-groups with relation to visual comfort.

4.1.1.1. Office Population and Artificial Lighting Satisfaction

The number of people working in the same office may play a role on the manual lighting control, because people may beware to change the lighting conditions not to discomfort their colleagues, or leave the decision up to his/her colleagues. Considering that, when respondents were asked to rate satisfaction of the artificial lighting condition in their office, highest "satisfactory" result was given by the participants who were working in single offices, while the highest "too much" response was given by the participants who were working in the 5-6 people-sharing offices (Figure 4.1). The majority of the participants who occupy the 3-4 people sharing offices also rated the artificial lighting environment as "sufficient" mostly.

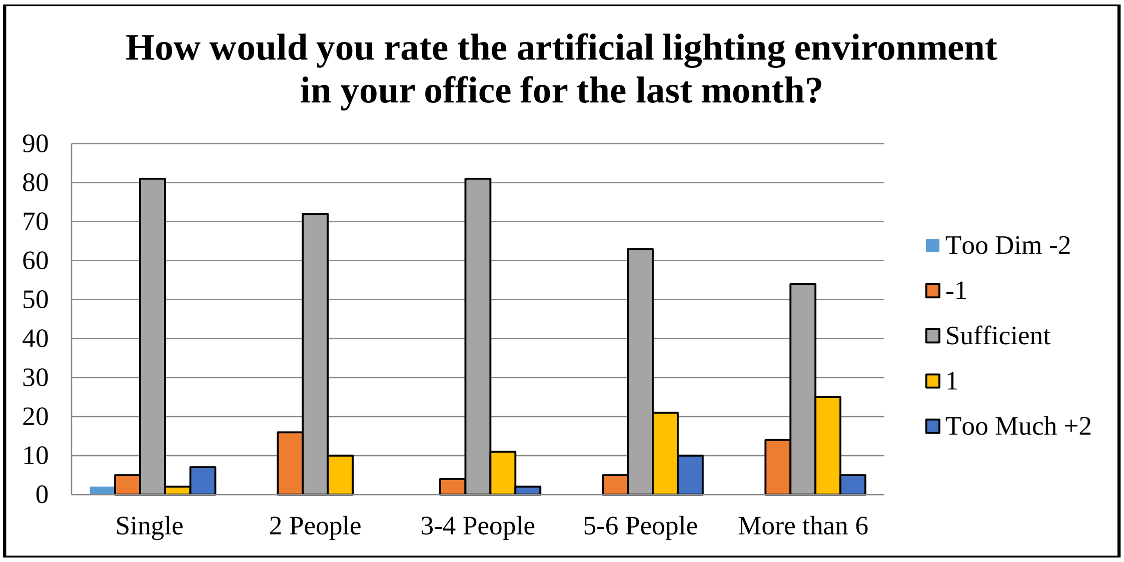


Figure 4.1. Satisfaction of artificial lighting condition vs office population.

4.1.1.2. Orientation-Daylight Satisfaction

Effective daylighting and daylight satisfaction depends on apertures of appropriate size and orientation. Concerning that, responses of daylight satisfaction and orientation were compared (Figure 4.2). Almost 50% of respondents whose offices face

North were satisfied with the daylighting condition in their working environment due their satisfaction choice of *4-very satisfied* in the questionnaire form. A similar rate of satisfaction was observed among respondents in North-East facing offices. To reach to a significant finding in the observation data whether satisfaction was independent of orientation or not, chi-square test of independence was applied.

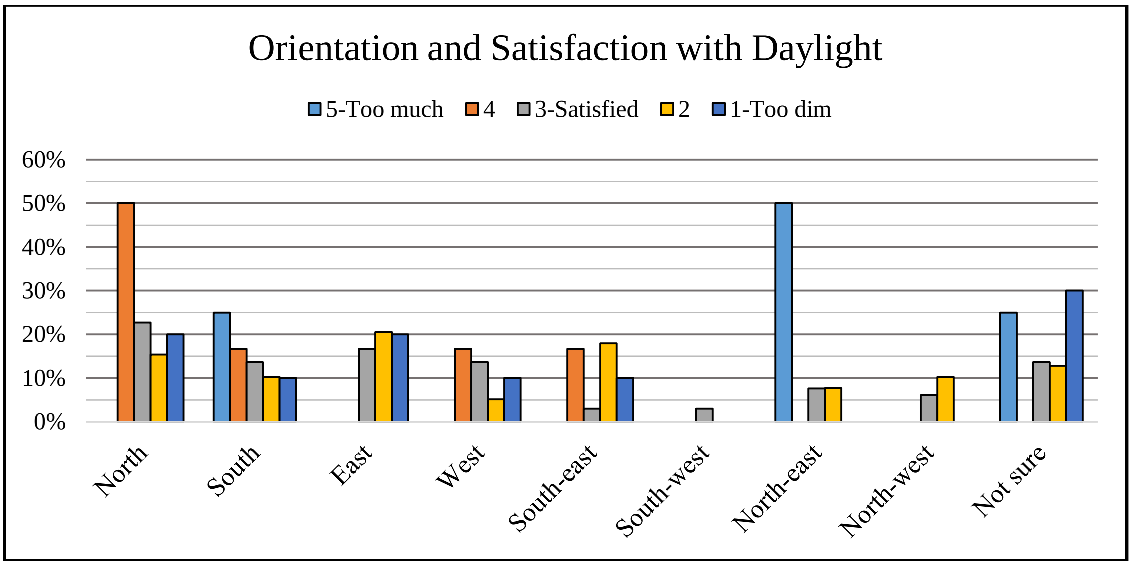


Figure 4.2. Orientation and satisfaction with daylight.

According to the chi-square test, there was no significant relation between daylight satisfaction and orientation of the window (Table 4.3). The null hypothesis was set to be,

$H_0:\tau_i=0$; there is no relation among daylight satisfaction according to orientation.

As a result, H_0 was accepted at 5% level of significance ($\alpha=0.05$), satisfaction with daylight was independent of orientation; meaning that, daylight satisfaction of respondents did not vary significantly according to orientation. To exemplify the cross tabulation of observed and expected values of data, Table 4.1 and Table 4.2 were prepared for this case. Findings depicted that the degrees of freedom (df) is found to be 32. As the value of Pearson chi-square (χ^2-crit) is 33.267 and p-value designated by "Asymp.Sig. (2-tailed)" is 0.405 ($>0.05 = \alpha$), the null hypothesis cannot be rejected (Table 4.3).

Table 4.1. Observed values of orientation versus daylight satisfaction.

How would you describe the daylighting availability in your office for the last month?						
		5-Too much	4	3-Satisfied	2	1-Too dim
Please choose the most appropriate orientation of the window in your office?	North	0	3	15	6	2
	South	1	1	9	4	1
	East	0	0	11	8	2
	West	0	1	9	2	1
	South-east	0	1	2	7	1
	South-west	0	0	2	0	0
	North-east	2	0	5	3	0
	North-west	0	0	4	4	0
	Not sure	1	0	9	5	3

Table 4.2. Expected values of orientation versus daylight satisfaction.

How would you describe the daylighting availability in your office for the last month?						
		5-Too much	4	3-Satisfied	2	1-Too dim
Please choose the most appropiate orientation of the window in your office?	North	0%	50%	23%	15%	20 %
	South	25%	17%	14%	10%	10%
	East	0%	0%	17%	21%	20%
	West	0%	17%	14%	5%	10%
	South-east	0%	17%	3%	18%	10%
	South-west	0%	0%	3%	0%	0%
	North-east	50%	0%	8%	8%	0%
	North-west	0%	0%	6%	10%	0%
	Not sure	25%	0%	14%	13%	30%

Table 4.3. Chi-square test results for daylight satisfaction and orientation of the window.

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	33.267[a]	32	.405
Likelihood Ratio	34.569	32	.346
Linear-by-Linear Association	.290	1	.591
N of Valid Cases	125		
a. 35 cells (77.8%) have expected count less than 5. The minimum expected count is .06.			

4.1.1.3. Position of the Desk and Satisfaction with Daylight Penetration

The position of the desk determines the direction of the daylight penetration to the user. It may cause shadow or glare on the workplane depending on the direction of the daylight. Therefore, it may be one of the factors having an impact on users' visual comfort satisfaction. Among the responses about the various desk positions, left positioned desks have the highest value of satisfaction (almost 50% of respondents rated this as *5-Too much*), while the back position has gathered the most *1-Too dim* response which is 30%. To obtain a statistical result, chi-square test of independence was applied.

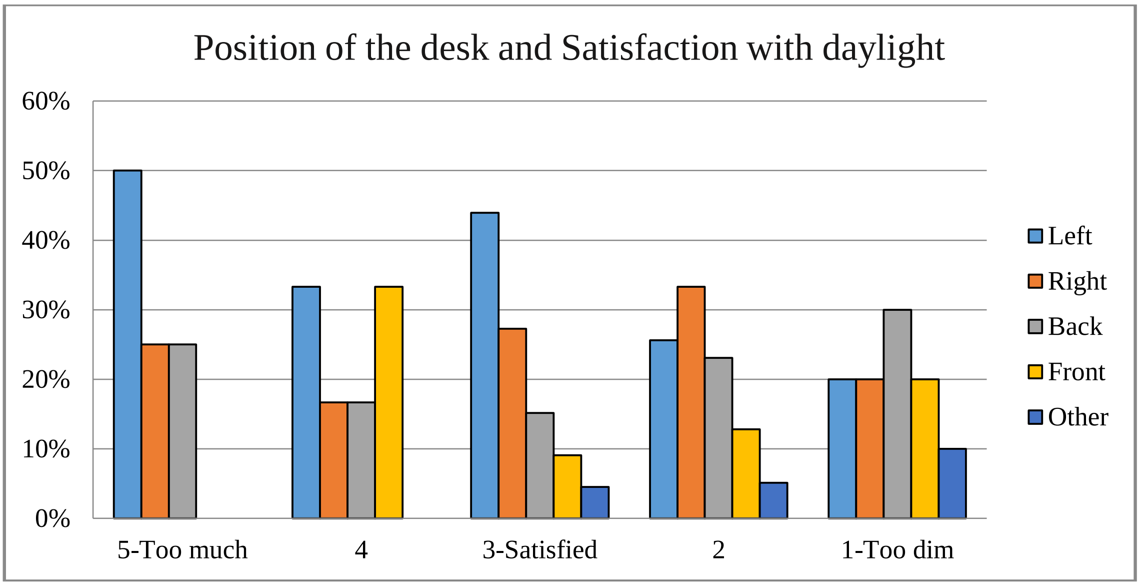


Figure 4.3. Position of the desk and Satisfaction with daylight.

According to the chi-square test (Table 4.4, 4.5), there was no significant relation between daylight satisfaction and position of the desk. The null hypothesis was set to be;

H_0:τ_i=0; there is no relation among daylight satisfaction according to desk position.

Findings depicted that the degrees of freedom (df) is found to be 16. As the value of Pearson chi-square (χ^2-crit) is 10.588 and p-value designated by "Asymp.Sig. (2-tailed)" is 0.834 ($>0.05 = \alpha$), the null hypothesis cannot be rejected (Table 4.6). This implies the independence of satisfaction with daylight due to position of the desk.

Table 4.4. Observed values of desk position versus daylight satisfaction.

How would you describe the daylighting availability in your office for the last month?						
		5-Too much	4	3-Satisfied	2	1-Too dim
When you are sitting on your desk, window is on your...	Left	2	2	29	10	2
	Right	1	1	18	13	2
	Back	1	1	10	9	3
	Front	0	2	6	5	2
	Other	0	0	3	2	1

Table 4.5. Expected values of desk position versus daylight satisfaction.

		How would you describe the daylighting availability in your office for the last month?				
		5-Too much	4	3-Satisfied	2	1-Too dim
When you are sitting on your desk. window is on your...	Left	50.00 %	33.33 %	43.94 %	25.64 %	20.00 %
	Right	25.00 %	16.67 %	27.27 %	33.33 %	20.00 %
	Back	25.00 %	16.67 %	15.15 %	23.08 %	30.00 %
	Front	0.00 %	33.33 %	9.09 %	12.82 %	20.00 %
	Other	0.00 %	0.00 %	4.55 %	5.13 %	10.00 %

Table 4.6. Chi-square test results for daylight satisfaction and desk position.

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	10.588[a]	16	.834
Likelihood Ratio	10.765	16	.824
Linear-by-Linear Association	3.395	1	.065
N of Valid Cases	125		
a. 18 cells (72.0%) have expected count less than 5. The minimum expected count is .19.			

4.1.1.4. Distance with Window and Satisfaction with Visual Environment

Distance between the desk and window may affect the visual satisfaction because distributing daylight to deep sides of an office requires more complex design strategies. Participants' responses verified that and the ones who have a distance of more than 5m between their desks and window, indicated they find daylight penetration too dim. Participants whose desks are 1-2m away from the window, were in majority in declaring the daylight penetration "sufficient", which was followed by less than 1m and 2-5m. The other percentages can be seen on Figure 4.4

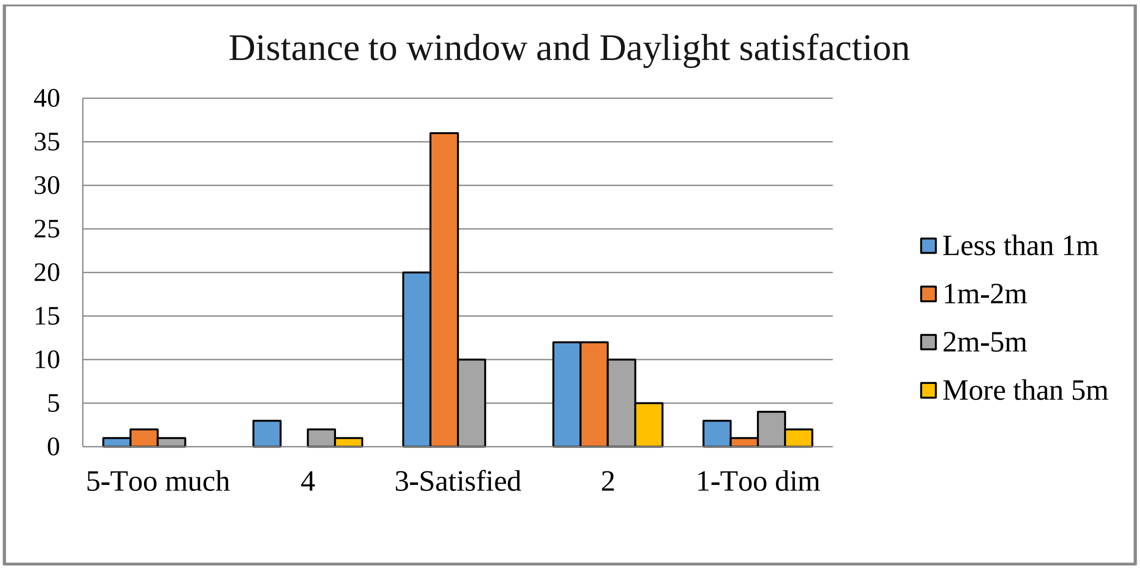


Figure 4.4. Distance between desk and window with daylight penetration.

According to the chi-square test (Table 4.7, 4.8), there was significant relation between daylight satisfaction and distance to window. The rejected null hypothesis was set to be;

$H_0:\tau_i=0$; there is a relation among daylight satisfaction according to distance with window.

Findings depicted that the degrees of freedom (df) is found to be 12. As the value of Pearson chi-square (χ^2-crit) is 24,034 and p-value designated by "Asymp.Sig. (2-tailed)" is 0,02 ($<0.05 = \alpha$), the null hypothesis can be rejected (Table 4.9).

Table 4.7. Observed values of distance to window versus daylight satisfaction.

How would you describe the daylighting availability in your office for the last month?						
		5-Too much	**4**	**3-Satisfied**	**2**	**1-Too dim**
What is the approximate distance between the window and your desk?	Less than 1m	1	3	20	12	3
	1m-2m	2	0	36	12	1
	2m-5m	1	2	10	10	4
	More than 5m	0	1	0	5	2

Table 4.8. Expected values of distance to desk versus daylight satisfaction.

How would you describe the daylighting availability in your office for the last month?						
		5-Too much	**4**	**3-Satisfied**	**2**	**1-Too dim**
What is the approxiamte distance between the window and your desk?	Less than 1m	25%	50%	30%	31%	30%
	1m-2m	50%	0%	55%	31%	10%
	2m-5m	25%	33%	15%	26%	40%
	More than 5m	0%	17%	0%	13%	20%

Table 4.9. Chi-square test results for daylight satisfaction and distance to window.

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	24,034[a]	12	,020
Likelihood Ratio	29,500	12	,003
Linear-by-Linear Association	3,617	1	,057
N of Valid Cases	125		
a. 14 cells (70,0%) have expected count less than 5. The minimum expected count is ,26.			

4.1.1.5. Area of the Window and Satisfaction with Daylight

Area of the window is directly related with the amount of daylight penetration. As the window area gets bigger, more daylight can enter. However, this can also result in excessive heat gain and visual comfort problems such as glare. To find out the relation, responses of window area and satisfaction with daylight were analyzed (

Figure 4.5). When the results have read out, highest satisfaction responses (approx. 42%) were given by the respondents who have 2m^2-5m^2 window area.

Chi-square test was applied to see the relation; the null hypothesis, (H_0:τi=0; there is no relation among satisfaction with daylight according to window area) was rejected with a 5 % level of significance (p-value $0.018 < 0.05 = \alpha$). As a result, satisfaction with daylight was dependent of window area (Table 4.10. Chi-square test results of chi-square test.

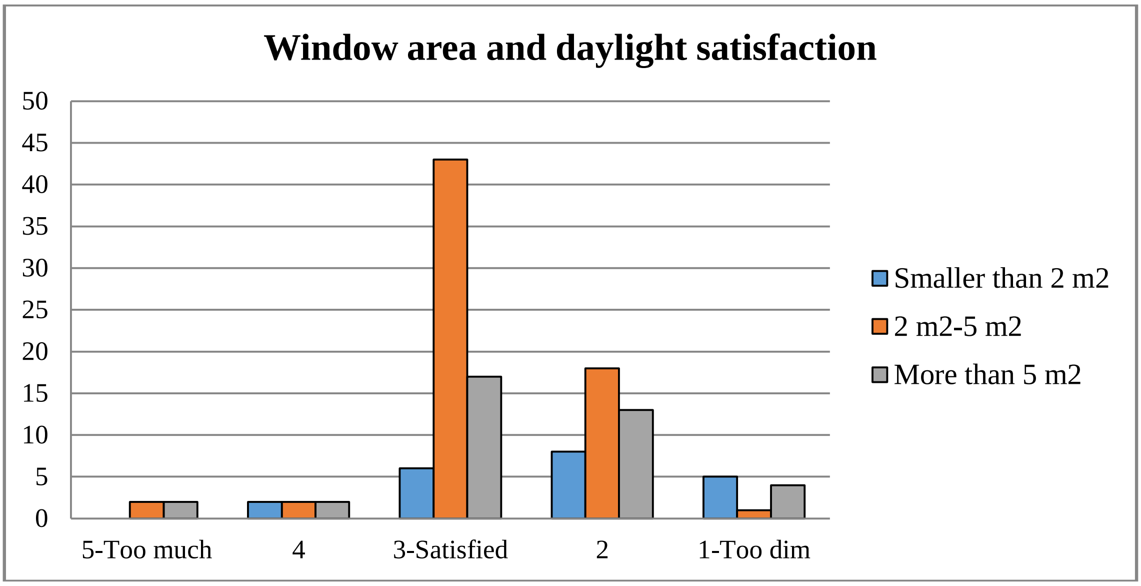


Figure 4.5. Area of the window and Daylight Penetration.

Table 4.10. Chi-square test results of chi-square test.

Chi-Square Tests			
	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.407[a]	8	.018
Likelihood Ratio	18.636	8	.017
Linear-by-Linear Association	1.308	1	.253
N of Valid Cases	125		
a. 8 cells (53.3%) have expected count less than 5. The minimum expected count is .67.			

On the other hand, uncontrolled daylight can ruin the visual comfort by causing glare. However, responses of the participants show that most of the respondents (approx. 57 %) don’t have a glare problem. Among the ones who suffer from glare, daylight is the main reason behind it. Only a few of them (only 11 %) declared that the overhead light (artificial light) caused glare (

Figure 4.6).

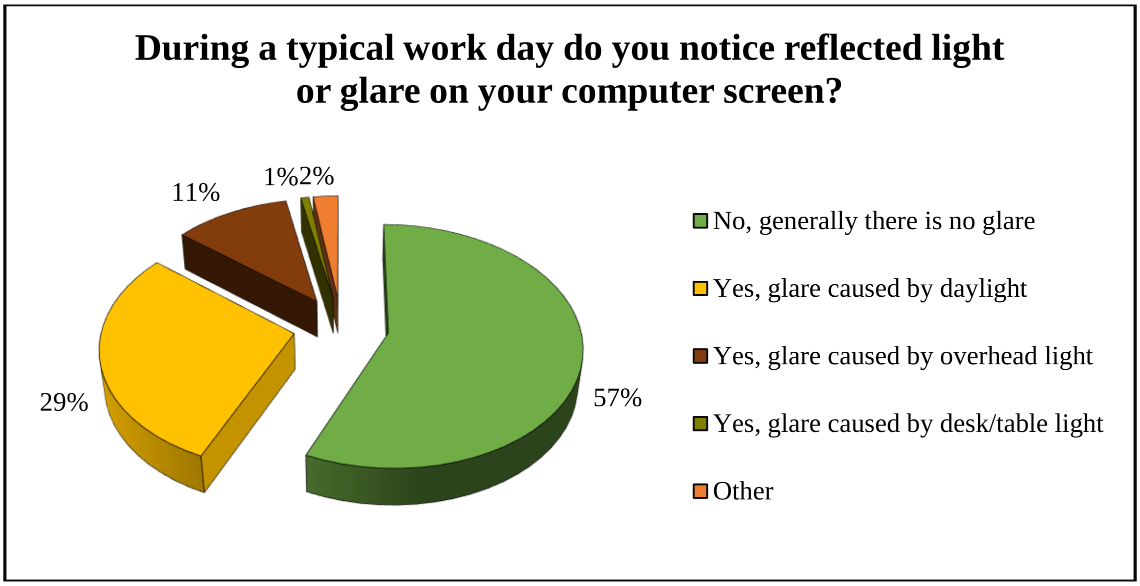


Figure 4.6. Glare problem.

4.1.2. Manual Lighting Control Behavior

Manual lighting control may contribute to energy savings on electric lighting however it is difficult to predict the contribution. To see the tendency and habits of respondents, questionnaire involved a self-evaluation for manual lighting control habits.

Figure 4.7 displays how manual lighting control habits can vary according to time intervals, absences, entrances and daylight penetration. Participants' responses revealed that generally 66% of participants control lighting system manually several times a day depending on either their absences or daylight penetration. According to these results, participants don't operate the lighting system only during entrance and departure. On the other hand, 21% of the participants claim that they control it twice a day (only when they enter in the beginning of the day and when they leave at the end of the day), while 13% of them indicated that generally they don't control lighting systems manually.

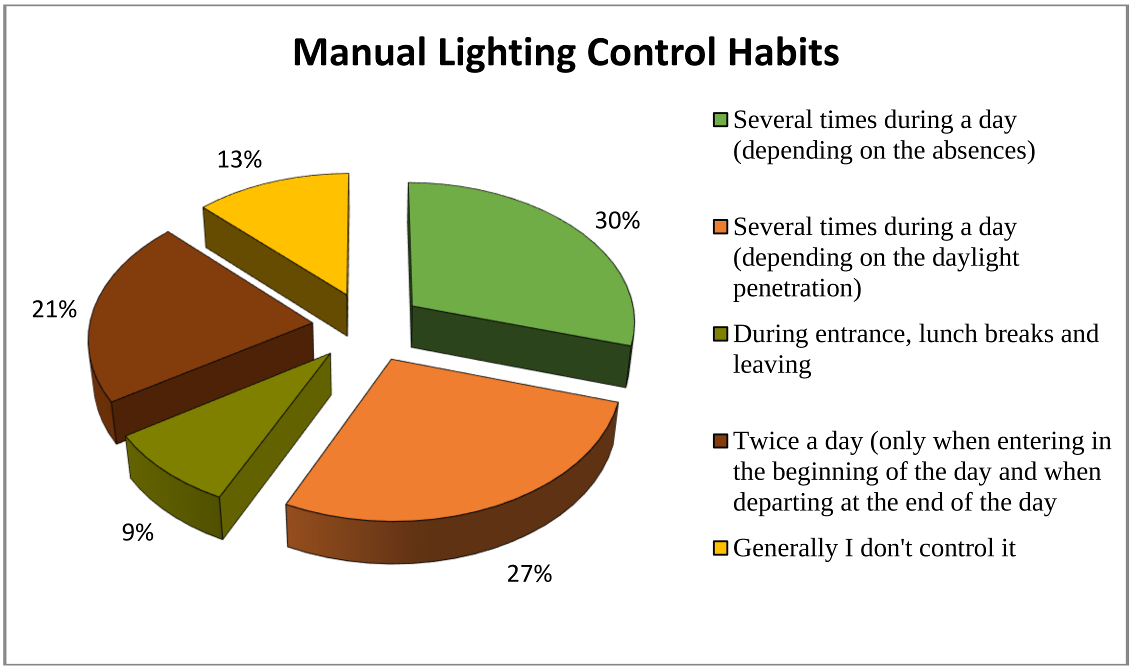


Figure 4.7. Manual Lighting Control Habits.

4.1.2.1. Factors Affecting Manual Lighting Control

There can exist various personal reasons which affect users' demand to control manual lighting. It is not striking to observe that the majority of participants (39% and 40% respectively) declare that the main reason for manual lighting control is to provide visual comfort and to create atmosphere for work; in other words, to accomplish their tasks. To save energy (by 21%) has become the second meaningful personal motivation to control the lighting system. On the contrary, indicating their occupancy/or absence has no or very slight impact on control decisions of 52 % and 20 % of respondents. Response rates for two factors, which are computer work and reading printed text are quite similar; meaning that, one type of task doesn't have a stronger effect on users' control behavior than the other has. Colleagues request sometimes make 32 % of participants to turn on/or off the lights even they don't prefer to. However, almost 27 % of them even never take into consideration of their colleagues' demand. Distribution mapping of ratings showing factors affecting manual lighting control are illustrated separately in Figure 4.8, while responses and their percentages are tabulated on Table 4.11.

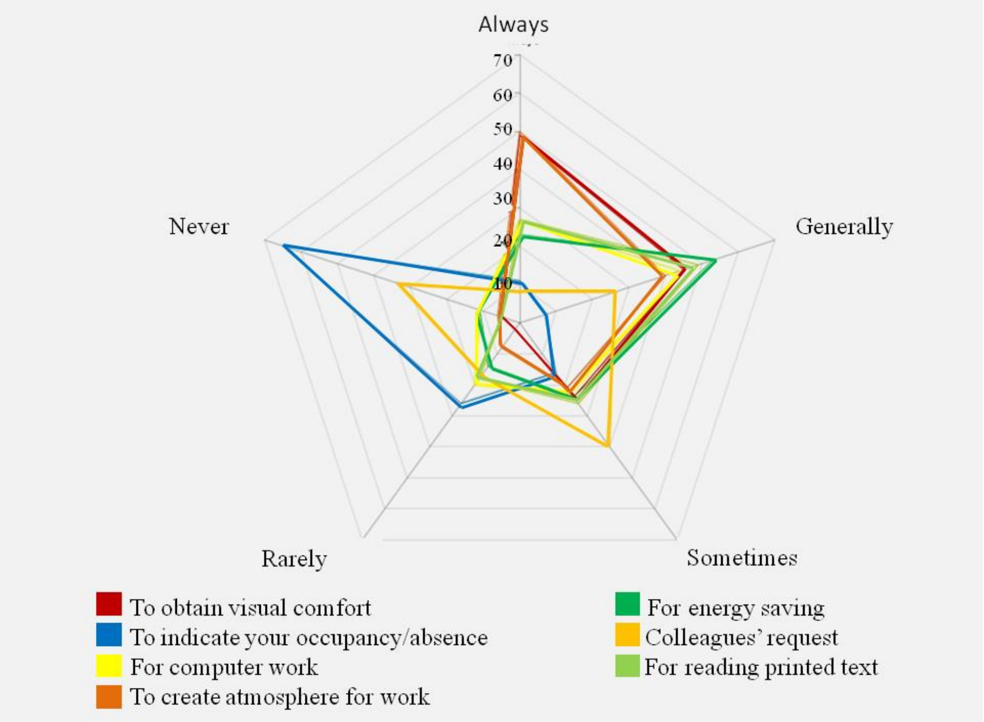


Figure 4.8. Rating distributions of factors affecting manual lighting control.

Table 4.11. Reasons for manual lighting control.

Please rate the following reasons on your manual lighting control over fixtures/systems?										
	Always		**Generally**		**Sometimes**		**Rarely**		**Never**	
To obtain visual comfort (increase/decrease illuminance level avoid glare)	49	39%	45	36%	24	19%	2	1%	5	4%
For energy saving	23	18%	53	42%	24	19%	14	11%	11	8%
To indicate your occupancy/absence	11	8%	7	5%	16	12%	26	20%	65	52%
Colleague request	8	6%	26	20%	40	32%	17	13%	34	27%
For computer work	27	21%	44	35%	23	18%	20	16%	11	8%
For reading printed text	27	21%	49	39%	26	20%	18	14%	5	4%
To create atmosphere for work	50	40%	40	32%	21	16%	8	6%	6	4%

4.1.2.2. Factors That Inhibit Manual Lighting Control

Questionnaire also aims to reveal the underlying personal reasons behind inhibiting their manual lighting control. Participants are asked for the factors which can inhibit them from manually control lighting fixtures. Majority of participants declare that one reason which restrains them from controlling the lighting fixtures manually is to focus on their work and not to stop what they are doing. Likewise, 59% of participants can restrict themselves to manually control lighting not to disturb their colleagues. According to 40 % of participants never consider that being far away from the switch location avoid them to turn on/or off the lights. Not to notice the changes in illuminance has never become an inhibiting concern for 36 % of participants. (Figure 4.9). Response rates are written on Table 4.12.

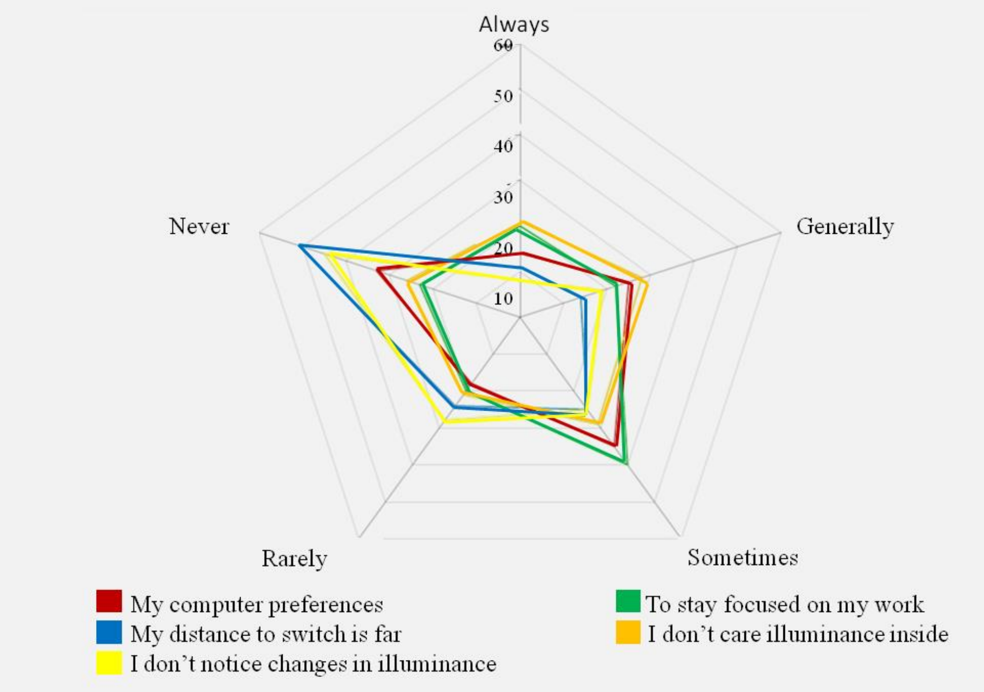


Figure 4.9. Rating distributions of factors inhibiting from manual lighting control.

Table 4.12. Factors inhibit from manual lighting control.

Which factors inhibit you from manually controlling lighting fixtures/systems?										
	Always		**Generally**		**Sometimes**		**Rarely**		**Never**	
My colleagues' preferences	14	11%	25	20%	35	28%	18	14%	33	26%
To stay focused on my work	20	16%	22	17%	40	32%	20	16%	23	18%
My distance to switch is far	11	8%	14	11%	25	20%	24	19%	51	40%
I don't care the illuminance level inside	21	16%	28	22%	29	23%	21	16%	26	20%
I don't notice the changes in illuminance levels	8	6%	19	15%	25	20%	28	22%	45	36%

4.1.2.3. Factors That Influence to Turn On the Lights

Understanding the factors or needs which trigger users to turn on the lights may serve a function in modifying users' manual lighting control. The reasons to turn on the lights are questioned and the results show that most of the time, insufficient daylight penetration and dark atmosphere are the driving forces for users to turn on the lights (Figure 4.10 - Table 4.13). The room darkness has the strongest impact regarding the 47 % of respondents' rates of *Always*; while preferring to work under artificial light has the slightest influence as only 2 % of them mark the *Always* choice (Table 4.13). To attempt indicating users' occupancy has no means of causing the behavior of turning on the lights among 57 % of respondents. Preferring to work with artificial light does not seem to affect the majority users' (almost 57 %) willingness to turn on the lights in general.

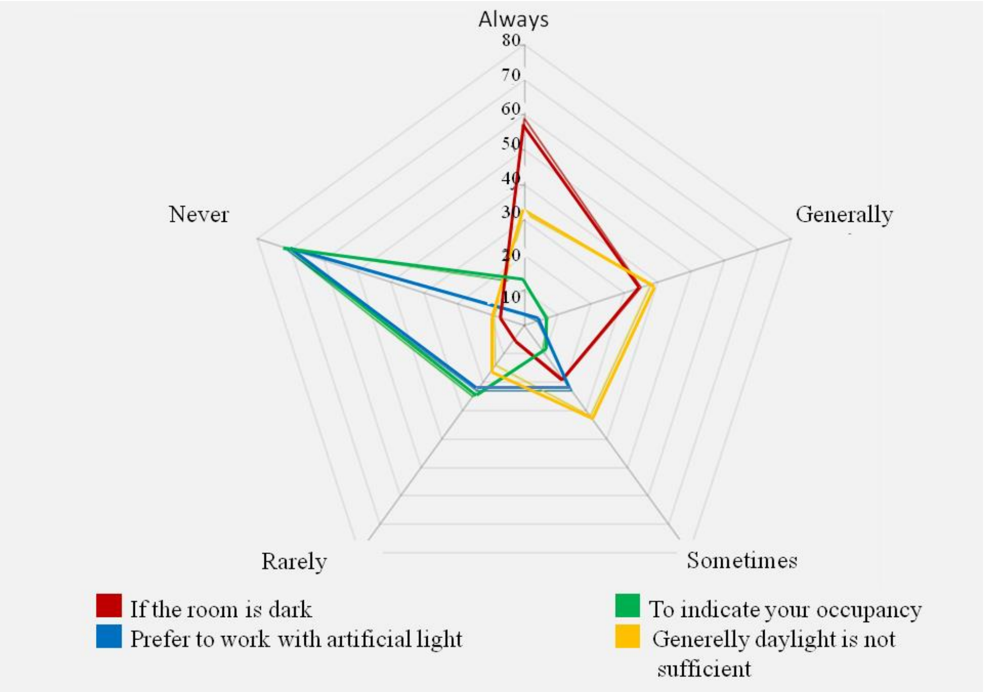


Figure 4.10. Rating distributions of influencing factors to turn on the lights.

Table 4.13. Factors influence to turn on the lights.

How the following factors influence you on turning lights ON manually upon your arrival										
	Always		**Generally**		**Sometimes**		**Rarely**		**Never**	
If the room is dark	59	47%	35	28%	19	15%	5	4%	7	5%
To indicate your occupancy	12	9%	7	5%	9	7%	25	20%	72	57%
Prefer to work with artificial light	3	2%	4	3%	23	18%	23	18%	72	57%
Generally daylight is not sufficient through the day	32	25%	38	30%	32	25%	14	11%	9	7%

4.1.2.4. Factors That Influence on Switch Off (or Not Turn On) the Lights

Users may have different approaches or reasons for switching off (or not turning on) the lights upon entrances/departures. To determine these factors may help to understand user behavior towards manual lighting control. Location of the light switch and not caring the illuminance value never affect their attempt to turn off the lights. The majority of the participants pay attention to the amount of lighting level, glare, energy saving and sufficient amount of daylight while turning off the lights. Their preference not to work under artificial lighting has a slighter impact on their behavior to turn off the lights. Almost 27 % of respondents never switch off the light because of this reason; and 16 % of them rarely executed this action due to their preference.

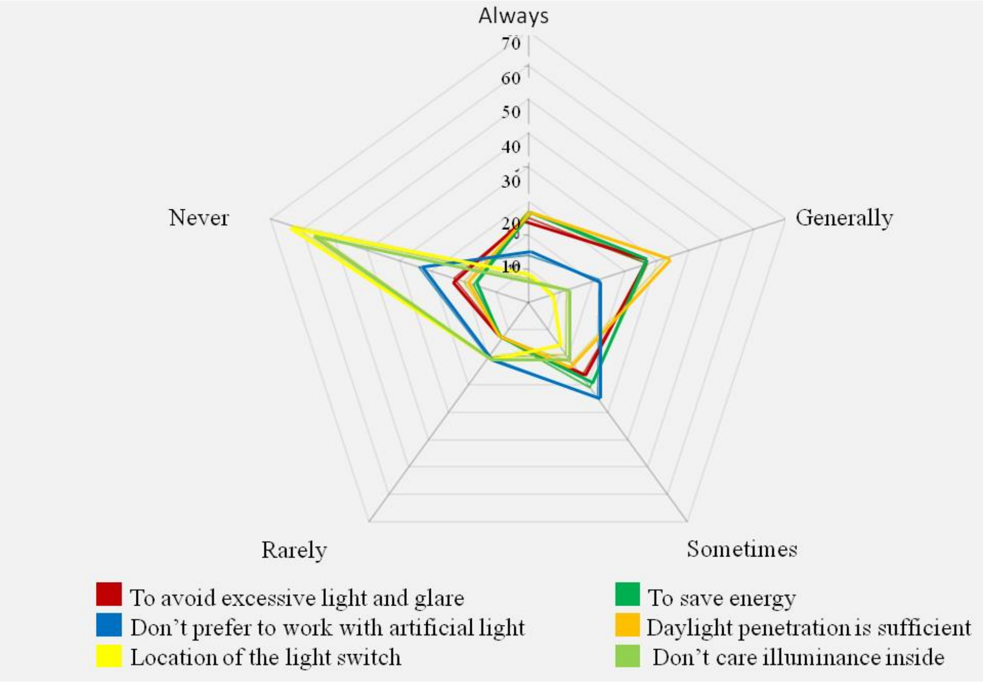


Figure 4.11. Factors that influence on switch off (or not turn on) the lights.

Table 4.14. Distribution of factors that Influence on switch off (or not turn on) the lights.

How the following factors influence you on switching OFF (or NOT turning lights ON manually) during a regular work day?										
	Always		**Generally**		**Sometimes**		**Rarely**		**Never**	
To avoid excessive light and glare	25	20%	37	29%	27	21%	13	10%	23	18%
To save energy	27	21%	37	29%	31	24%	13	10%	17	13%
Don't prefer to work with artificial lighting	14	11%	22	17%	35	28%	20	16%	34	27%
Usually daylight penetration is sufficient through the day	27	21%	43	34%	22	17%	13	10%	20	16%
Location of the light switch	8	6%	8	6%	16	12%	20	16%	73	58%
Don't care of the illuminance value inside	7	5%	12	9%	19	15%	20	16%	67	53%

4.1.3. Interior Layout’s Contribution to Manual Lighting Control

Interior layout may influence users’ behavior within the building. In order to understand what the respondents consider on this issue, they are asked whether interior modifications can affect their manual lighting control or not. 72% of respondents think that modifications on interior layout can be effective, while 28% disagrees with that opinion (

Figure 4.12).

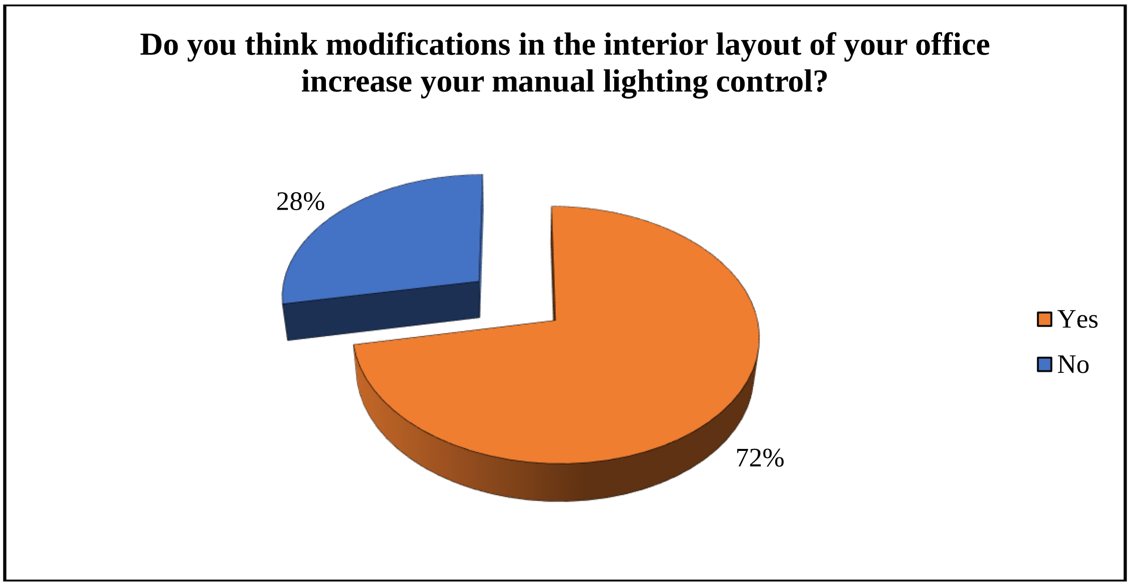


Figure 4.12. Interior layout's contribution to manual lighting control.

4.1.3.1. Factors Increasing Manual Lighting Control

Some interior elements can be more effective on users' manual lighting control. To find out their contribution to manual lighting control, several questions were prepared about the position of the desk, distance between desk and window, distance between switch and table, area of the window, orientation and colors of the surfaces. Responses provided information about these factors' contribution in users' manual control decisions. Accordingly, the window area, its orientation and position of the desk are the most effective factors while distance between switch and table is found to be the least effective factor. The other factors and their contribution are presented on Table 4.15 and Figure 4.13.

Table 4.15. Interior architectural factors' contribution to increasing manual lighting control.

How would you rate the following interior architectural factors in terms of increasing your manual lighting control?

	Always		Generally		Sometimes		Rarely		Never	
Position of your desk	47	37%	41	32%	15	12%	8	6%	14	11%
Distance between your desk and window	39	31%	54	43%	13	10%	10	8%	9	7%
Area of the window	49	39%	50	40%	17	13%	4	3%	5	4%
Orientation of the window	47	37%	56	44%	10	8%	4	3%	8	6%
Color of the surfaces/objects in the room	28	22%	37	29%	29	23%	11	8%	20	16%
Distance between switch and your table	14	11%	8	14%	20	16%	23	18%	50	40%

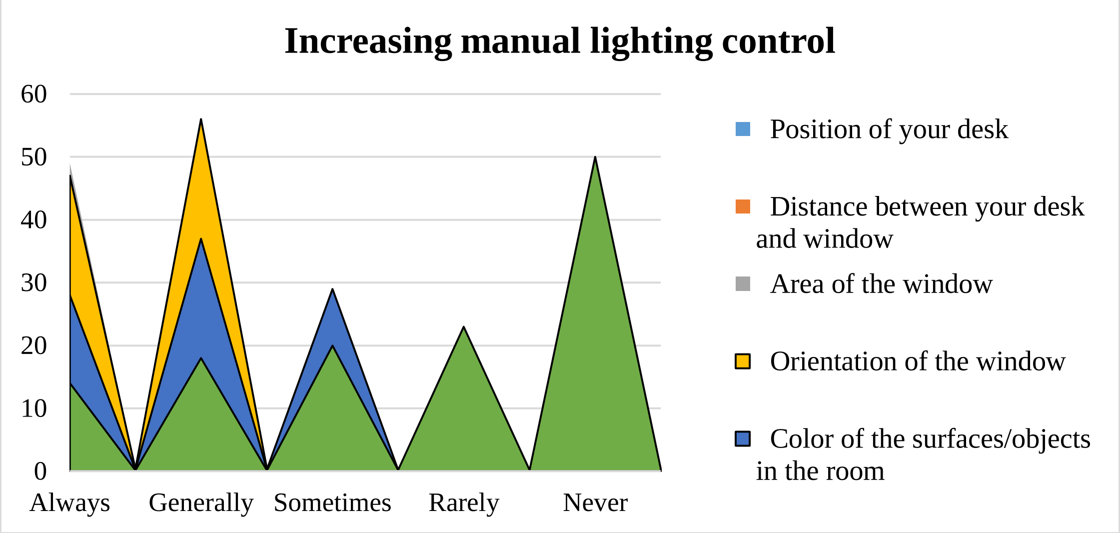


Figure 4.13. Interior architectural factors' contribution to manual lighting control.

4.1.3.2. Architectural Factors Affecting Manual Lighting Control

Besides all the listed factors to influence or to inhibit manual lighting control, respondents are asked to indicate their ideas to the given statements. Each given statement proposes a modification which may increase their manual lighting control. Responses to these statements show that orientation of the window and enlarging the window area are the two most effective factors to increase manual lighting control. Shortening the distance between the desk to window, changing colors of the surfaces and changing the desk's position can also be effective in increasing that. However, analyzing the responses, the least effective factor seems to be the distance between the switch and table (

Figure 4.14,Table 4.16)

Table 4.16. Responses to interior architectural modifications in terms of manual lighting control.

	5-Completely Agree		**4-Slightly Agree**		**3-Neither agree or disagree**		**2-Slightly disagree**		**1-Disagree**	
Will increase with a change in my desk's position related to window	31	24%	48	38%	14	11%	22	17%	10	8%
Will increase with shortening the area between my desk and window	33	26%	51	40%	17	13%	16	12%	8	6%
Will increase with enlarging the window area	43	34%	53	42%	15	12%	10	8%	4	3%
Will increase with a change of the orientation of the window	34	27%	63	50%	18	14%	7	5%	3	2%
Will increase with a change of color of the objects/surfaces/room	25	20%	43	34%	32	25%	17	13%	8	6%
Will increase with shortening the distance between switch and my table	17	13%	29	23%	18	14%	26	20%	35	28%

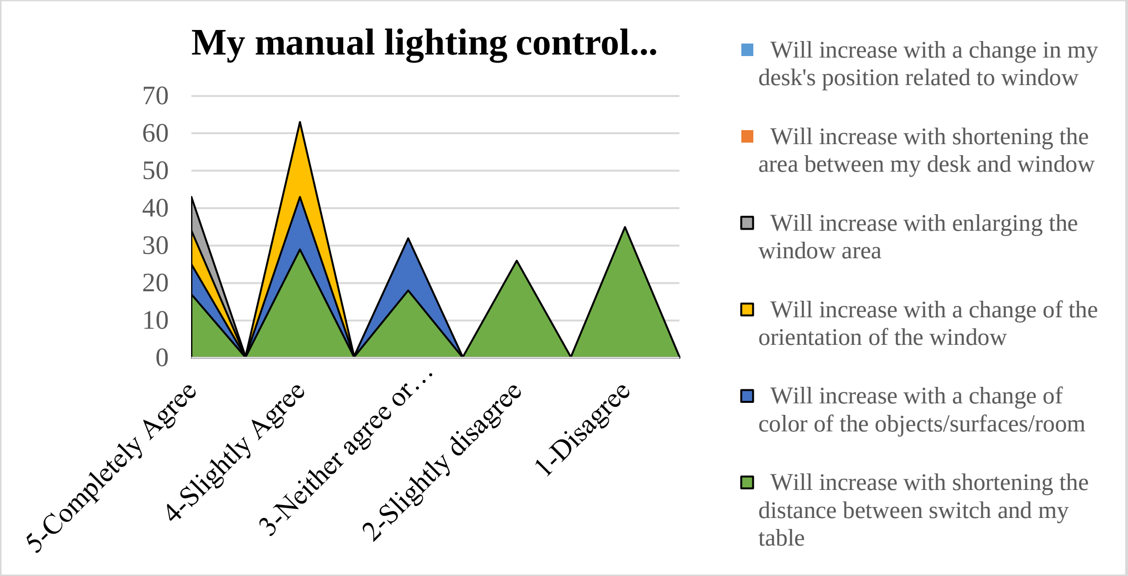


Figure 4.14. The contribution of changing interior parameters' effect to manual lighting control.

4.1.3.3. Switch Location Preference for Increasing Manual Lighting Control

Due to the interior layout of the office, the distance between the switch and desk may be distant with each other. Which may result with lesser manual lighting control. Thus, location of the switch can affect manual lighting control of the user. As a result of that, respondents are asked to choose the location which can increase their manual lighting control among the listed ones. Responses show that majority of the respondents preferred near or on the desk area (62%) for switch location. Only 14 % of them indicate their switch location preference as near the entrance; while 24 % of them have no preference for that (

Figure 4.15).

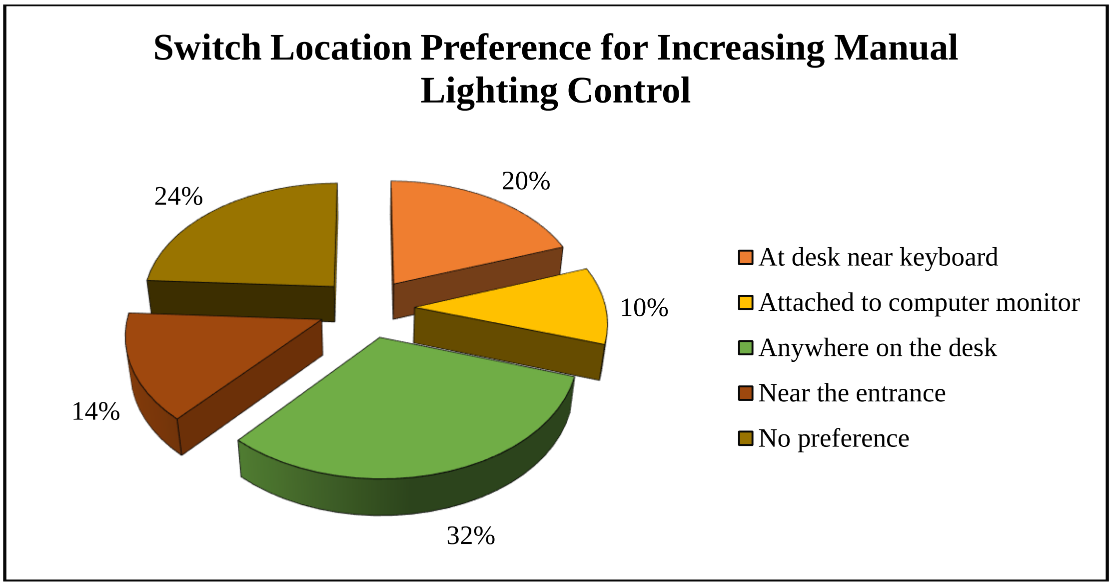


Figure 4.15 Switch location preference for increasing manual lighting control.

4.1.4. Photograph Involved Manual Lighting Response Questions

Up to this section, mainly respondents give their ideas on the modifying factors. However, in order to understand their real behavioral change to these factors, they are asked to give feedback by looking at the given images. Those feedbacks could be either “I would turn on the lights” or “I would not turn on the lights”. These presented images differed according various factors;

- Distance to window: near to window (A), close to window (B)
- Desk position: Back, Front, Left, Right
- Time of the day: morning, lunch and afternoon
- Surface colors: dark and light.

Participants responded to each of the changing condition. To reach to a significant finding in the observation data whether manual lighting control was independent of the listed interior factors or not, chi-square test of independence was applied. Responses to these photograph involved questions and response percentages can be seen on

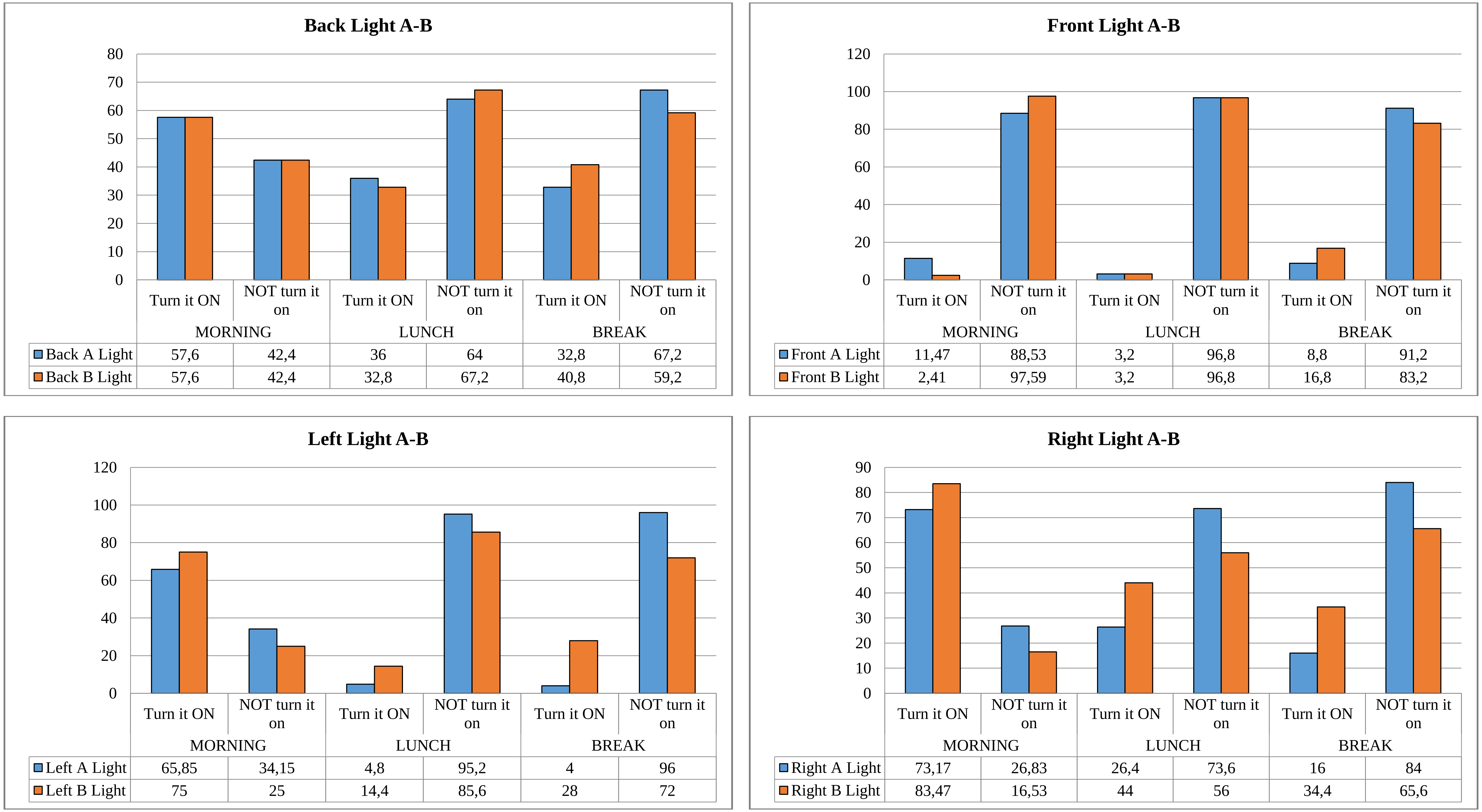
Table 4.17.

Table 4.17. Respondents' manual lighting control percentages.

	MORNING		**LUNCH**		**BREAK**	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Back A Light	57.6	42.4	36	64	32.8	67.2
Back B Light	57.6	42.4	32.8	67.2	40.8	59.2
Front A Light	11.47	88.53	3.2	96.8	8.8	91.2
Front B Light	2.41	97.59	3.2	96.8	16.8	83.2
Left A Light	65.85	34.15	4.8	95.2	4	96
Left B Light	75	25	14.4	85.6	28	72
Right A Light	73.17	26.83	26.4	73.6	16	84
Right B Light	83.47	16.53	44	56	34.4	65.6
Back A Dark	92	8	44	56	48	52
Back B Dark	94.4	5.6	48.8	51.2	46.4	53.6
Front A Dark	16	84	14.4	85.6	26.4	73.6
Front B Dark	24.8	75.2	23.2	76.8	13.6	86.4
Left A Dark	30.4	69.6	12.8	87.2	64.8	35.2
Left B Dark	78.4	21.6	36	64	66.4	33.6
Right A Dark	48.8	51.2	54.4	45.6	77.6	22.4
Right B Dark	60	40	26.4	73.6	69.6	30.4

4.1.4.1. According to Distance to Window

Participants’ manual lighting responses to two different distances to window (A and B) were compared, Figure 4.16 illustrate the frequency distribution of response percentages for each interior layout position regarding the distance (A-near versus B-far) and the wall surface color (light versus dark). When the desk is in Back position and the surfaces are light, control responses showed very slight or no variation when the desk is moved away from the window. After the break, the control action displays variation. The rate which corresponds to 32,8 % of respondents turning on the lights is raised up to 40.8 % when the desk moves to away from the window in B position. After lunch arrival, the reverse is happened. The responses of 36% for turning the lights on decrease to 32,8 % when the desk is in B position. When the desk is in Front position, the approx. 88-96% of respondents prefer not to turn on the lights during the day. In the morning, there observed a strong drop in rates of responses (11 % to 2.41 %) in turning on the lights when the desk is moved near the back wall in B position.



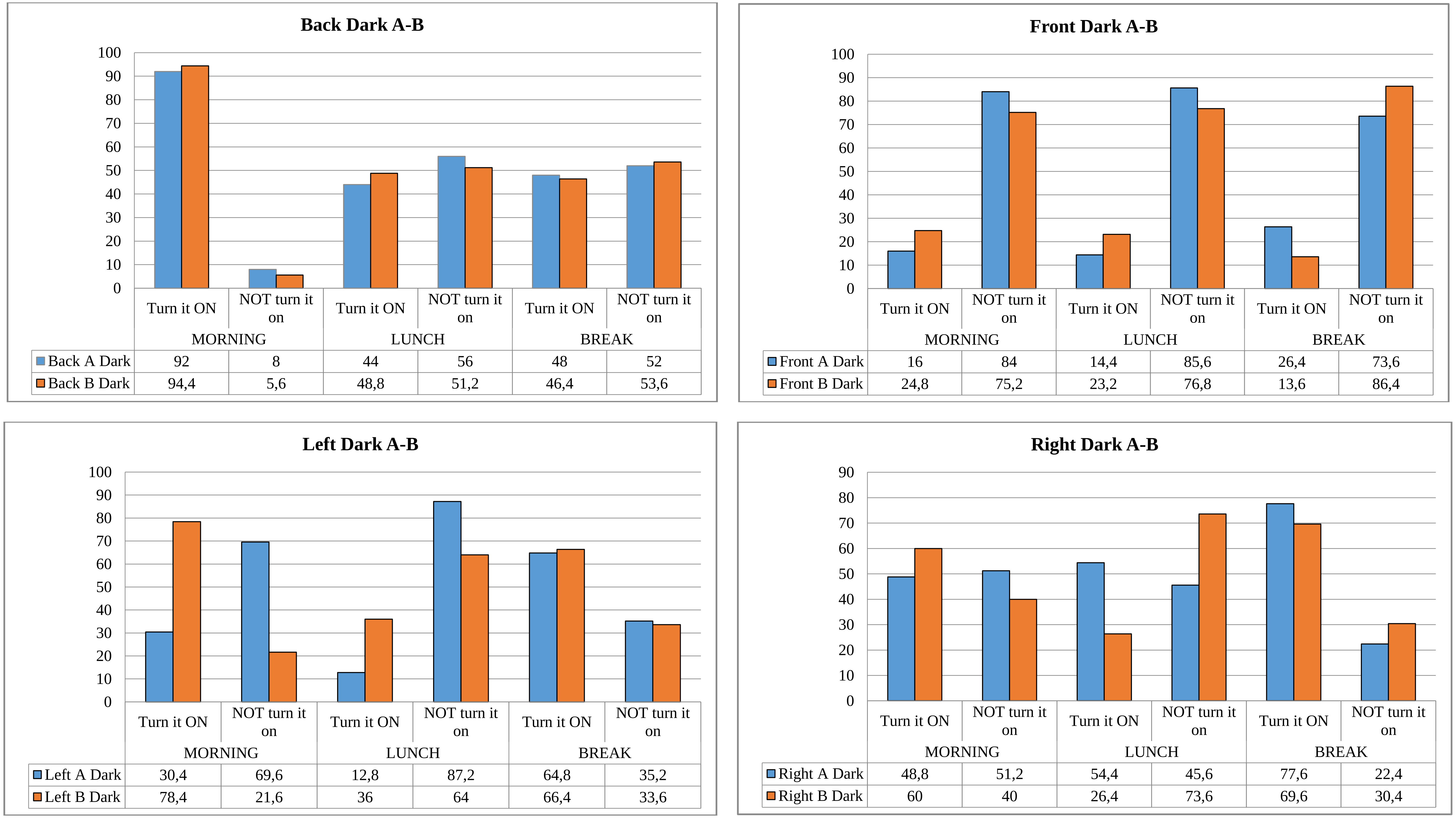
	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Back A Light	57,6	42,4	36	64	32,8	67,2
🟧 Back B Light	57,6	42,4	32,8	67,2	40,8	59,2

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Front A Light	11,47	88,53	3,2	96,8	8,8	91,2
🟧 Front B Light	2,41	97,59	3,2	96,8	16,8	83,2

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Left A Light	65,85	34,15	4,8	95,2	4	96
🟧 Left B Light	75	25	14,4	85,6	28	72

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Right A Light	73,17	26,83	26,4	73,6	16	84
🟧 Right B Light	83,47	16,53	44	56	34,4	65,6

Figure 4.16. Manual Lighting Control Responses between Light A-B in four layouts.



Back Dark A-B

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Back A Dark	92	8	44	56	48	52
Back B Dark	94,4	5,6	48,8	51,2	46,4	53,6

Front Dark A-B

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Front A Dark	16	84	14,4	85,6	26,4	73,6
Front B Dark	24,8	75,2	23,2	76,8	13,6	86,4

Left Dark A-B

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Left A Dark	30,4	69,6	12,8	87,2	64,8	35,2
Left B Dark	78,4	21,6	36	64	66,4	33,6

Right Dark A-B

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Right A Dark	48,8	51,2	54,4	45,6	77,6	22,4
Right B Dark	60	40	26,4	73,6	69,6	30,4

Figure 4.17. Manual Lighting Control Responses between Dark A-B in four layouts.

Table 4.18. Chi-square test results according to the distance to window.

3		**P value (α=0.05)**
MORNING	Back A-B	0.00000000142095561
	Front A-B	0.00007478690202317
	Left A-B	0.00000000000016134
	Right A-B	0.00000000000002664
	Dark Back A-B	0.00000000000000
	Dark Front A-B	0.00000000000017
	Dark Left A-B	0.00010513251633994
	Dark Right A-B	0.00000000209636
LUNCH	Back A-B	0.00000000000002234
	Front A-B	0.00000000000000000
	Left A-B	0.00000082606054576
	Right A-B	0.00000000323797818
	Dark Back A-B	0.00000000000000007
	Dark Front A-B	0.00000000000095950
	Dark Left A-B	0.00000001120686484
	Dark Right A-B	0.00000000087563391
AFTERNOON	Back A-B	0.00000000000000001
	Front A-B	0.00000000000581
	Left A-B	0.10384330751699500
	Right A-B	0.00000000048254834
	Dark Back A-B	0.00000000000000179
	Dark Front A-B	0.00000001796517940
	Dark Left A-B	0.00000000000000004
	Dark Right A-B	0.00000000000000035

Figure 4.17 includes graphical frequency distributions lead to a conclusion that on the same desk position, as the distance to window gets longer, users are most likely to turn on the lights. In addition, cross tabulations and chi-square tests are applied to figure out statistically whether there is any significant relation between distance and turn on/off behavior. The implication for each case of layout and surface color according to time (morning, lunch and afternoon) was iterated extensively. Consequently, results indicate that manual lighting control (turning on/off behavior) is dependent to distance to window (Table 4.18), since p-values are below 0.05=α in all cases except only Left A-B in the afternoon.

In addition to chi-square tests, the method of reliability analysis has been used to predict the consistency of manual lighting control with the relation of distance to window. Normally Cronbach’s alpha reliability coefficient ranges between 0 and 1 and as it gets closer to 1, the internal consistency of the items is bigger. So based upon the formula if the alpha coefficient is “_ > .9 – Excellent, _ > .8 – Good, _ > .7 – Acceptable, _ > .6 – Questionable, _ > .5 – Poor, and _ < .5 – Unacceptable” (Gliem and Gliem 2003). Regarding the readings on Table 4.19, all the manual lighting control behavior through different times of the day (morning, lunch and afternoon) are consistent with each other.

Table 4.19. Cronbach's alpha reliability test results.

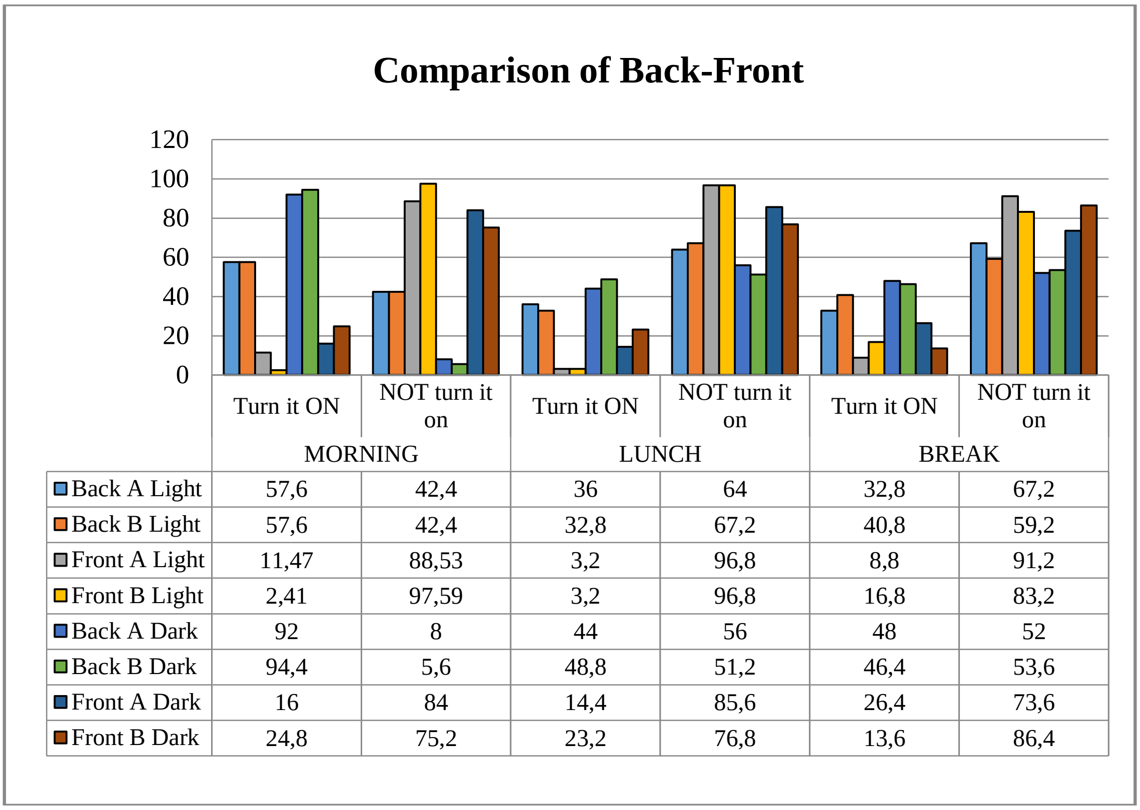
Reliability Statistics

MORNING	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
	.871	.867	16
LUNCH	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
	.901	.903	16
AFTERNOON	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
	.909	.907	16

4.1.4.2. According to The Desk Position

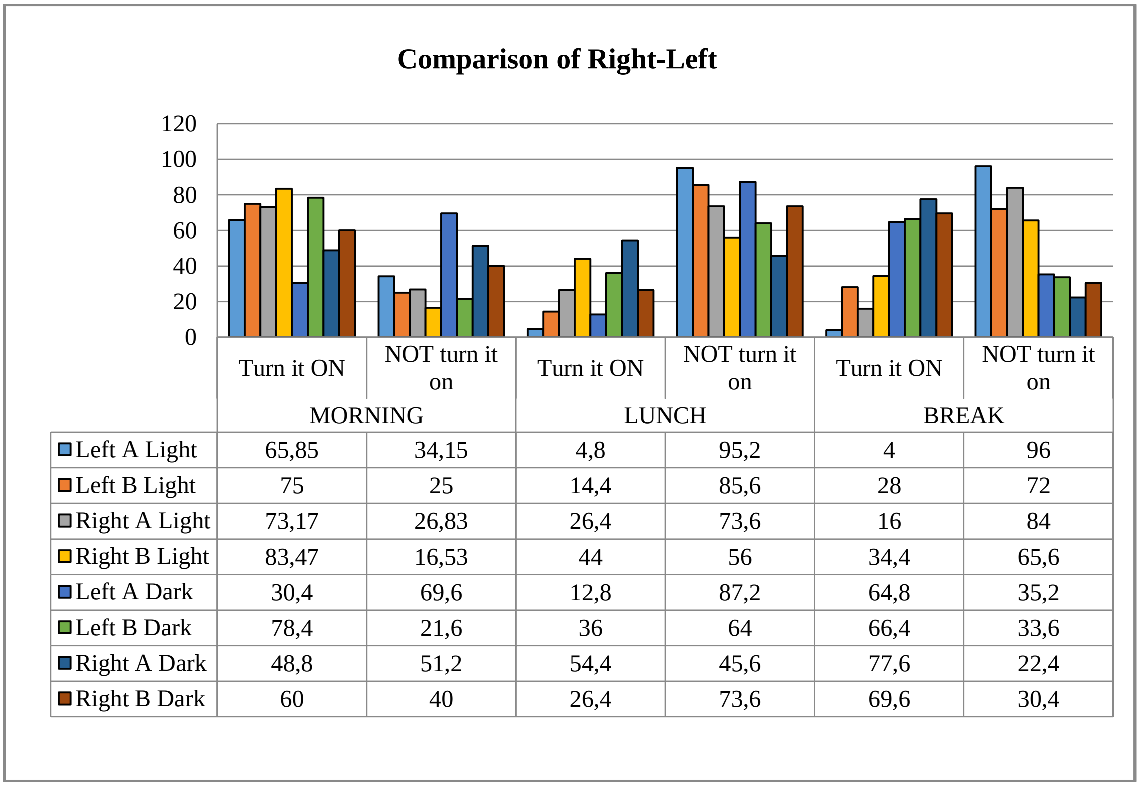
In this section. opposite desk positions; such as right-left and back-front are compared among each other in terms of manual lighting control responses. When manual lighting control responses of Back and Front are compared with each other, significant difference can be seen for all time intervals (morning, lunch and break). For example, during morning entrance “turn on the response” is 57,6% for Back B Light, while it falls to 2,41% in Front B Light under same conditions. Similar results can be seen for Back A Dark and Front A Dark during morning entrance. For Back A position the response of “not turn on the lights” is 8%, while it increases to 84% for Front A desk position. However, the response percentages of Right and Left desk positions do not vary significantly with each other compared to Back-Front. For instance, “not turn on the lights” response Left A Dark (after lunch) is 87,2%, while under same conditions Right A Dark positioned desk responses reduce to 45,6%. The extended results can be seen on

Figure 4.18Figure 4.19. Chi-square test results of the responses can be seen on Table 4.20.



	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
■ Back A Light	57,6	42,4	36	64	32,8	67,2
■ Back B Light	57,6	42,4	32,8	67,2	40,8	59,2
■ Front A Light	11,47	88,53	3,2	96,8	8,8	91,2
■ Front B Light	2,41	97,59	3,2	96,8	16,8	83,2
■ Back A Dark	92	8	44	56	48	52
■ Back B Dark	94,4	5,6	48,8	51,2	46,4	53,6
■ Front A Dark	16	84	14,4	85,6	26,4	73,6
■ Front B Dark	24,8	75,2	23,2	76,8	13,6	86,4

Figure 4.18. Comparison of back and front desk positions.



	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
■ Left A Light	65,85	34,15	4,8	95,2	4	96
■ Left B Light	75	25	14,4	85,6	28	72
■ Right A Light	73,17	26,83	26,4	73,6	16	84
■ Right B Light	83,47	16,53	44	56	34,4	65,6
■ Left A Dark	30,4	69,6	12,8	87,2	64,8	35,2
■ Left B Dark	78,4	21,6	36	64	66,4	33,6
■ Right A Dark	48,8	51,2	54,4	45,6	77,6	22,4
■ Right B Dark	60	40	26,4	73,6	69,6	30,4

Figure 4.19. Comparison of right and left desk positions.

Table 4.20. Chi-square test results for comparison of opposite desk positions.

	DESK POSITION	P VALUE
MORNING	Front A - Back A	0.003588001
	Front B - Back B	0.12979456781440200
	Left A - Right A	0.00000000000197683
	Left B - Right B	0.00000000000019249
	Dark Front A - Back A	0.58948512
	Dark Front B - Back B	0.11786561504091300
	Dark Left A - Right A	0.00000001738446519
	Dark Left B - Right B	0.00000001008677304
LUNCH	Front A - Back A	0.00672050625121791
	Front B - Back B	0.06767152316587200
	Left A - Right A	0.04666947952985690
	Left B - Right B	0.00000000316557063
	Dark Front A - Back A	0.00000316
	Dark Front B - Back B	0.00000000030890496
	Dark Left A - Right A	0.000000098
	Dark Left B - Right B	0.00000005561374384
AFTERNOON	Front A - Back A	0.00001719
	Front B - Back B	0.00000002622525669
	Left A - Right A	0.00006773766860746
	Left B - Right B	0.00000000000000185
	Dark Front A - Back A	0.00000000074057078
	Dark Front B - Back B	0.00000186523025610
	Dark Left A - Right A	0.00000000000000005
	Dark Left B - Right B	0.00000000000000135

4.1.4.3. According to the Time of the Day

In order to understand whether the time of the day reflect to respondents' manual lighting control or not, photographs were taken in three different time periods (morning. lunch and afternoon). The responses show during mornings users are most likely to turn on the lights for all desk positions and surface colors. For example, turn on the lights response for Left A Light condition is 65,85% during morning entrance while it reduces to 4,8% and 4% for after lunch and break entrances respectively. Generally, after Lunch and after Break manual lighting control responses are closer to each other when compared with after morning responses. Extended response rates can be seen on Table 4.21 and

Figure 4.20

Figure 4.22. Chi-square test was applied to see the relation; the null hypothesis, (H_0:$\tau i=0$; there is no relation among manual lighting response to time of the day) and null

hypothesis was rejected since the p-values are smaller than 0.05. So chi-square test results revealed that manual lighting control depends on the time of the day (Table 4.22).

Table 4.21. Turn on/Not turn on percentage changes according to layout and time.

	MORNING		**LUNCH**		**BREAK**	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
Back A Light	57,6	42,4	36	64	32,8	67,2
Back B Light	57,6	42,4	32,8	67,2	40,8	59,2
Front A Light	11,47	88,53	3,2	96,8	8,8	91,2
Front B Light	2,41	97,59	3,2	96,8	16,8	83,2
Left A Light	65,85	34,15	4,8	95,2	4	96
Left B Light	75	25	14,4	85,6	28	72
Right A Light	73,17	26,83	26,4	73,6	16	84
Right B Light	83,47	16,53	44	56	34,4	65,6
Back A Dark	92	8	44	56	48	52
Back B Dark	94,4	5,6	48,8	51,2	46,4	53,6
Front A Dark	16	84	14,4	85,6	26,4	73,6
Front B Dark	24,8	75,2	23,2	76,8	13,6	86,4
Left A Dark	30,4	69,6	12,8	87,2	64,8	35,2
Left B Dark	78,4	21,6	36	64	66,4	33,6
Right A Dark	48,8	51,2	54,4	45,6	77,6	22,4
Right B Dark	60	40	26,4	73,6	69,6	30,4

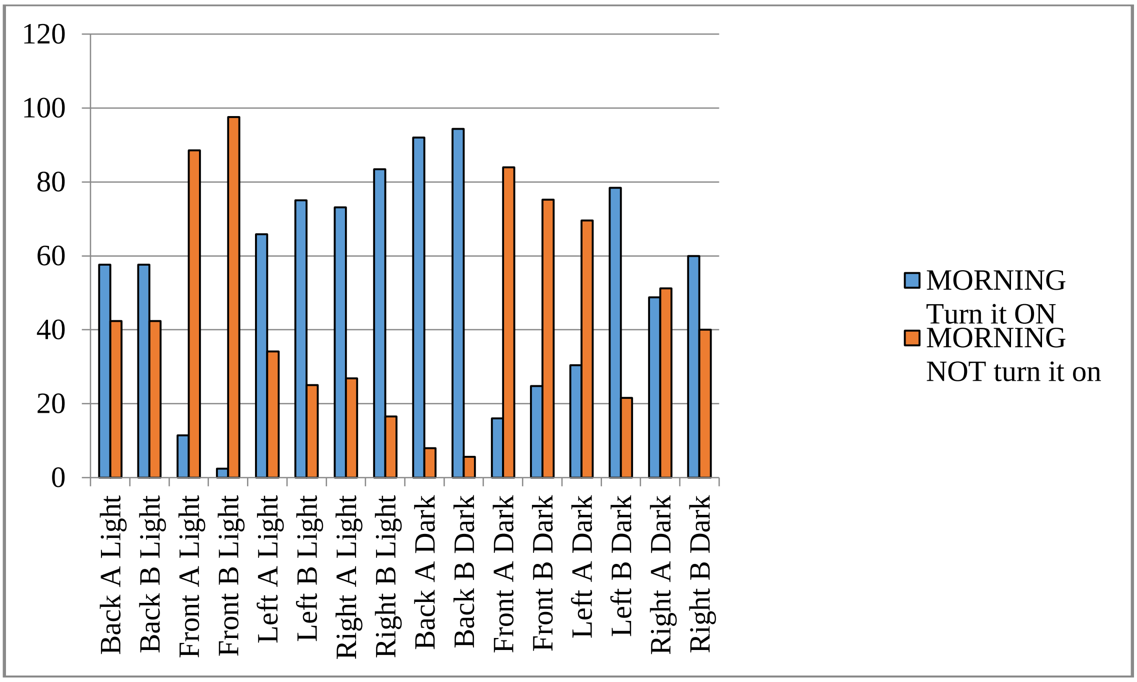


Figure 4.20. Manual lighting control responses in the morning.

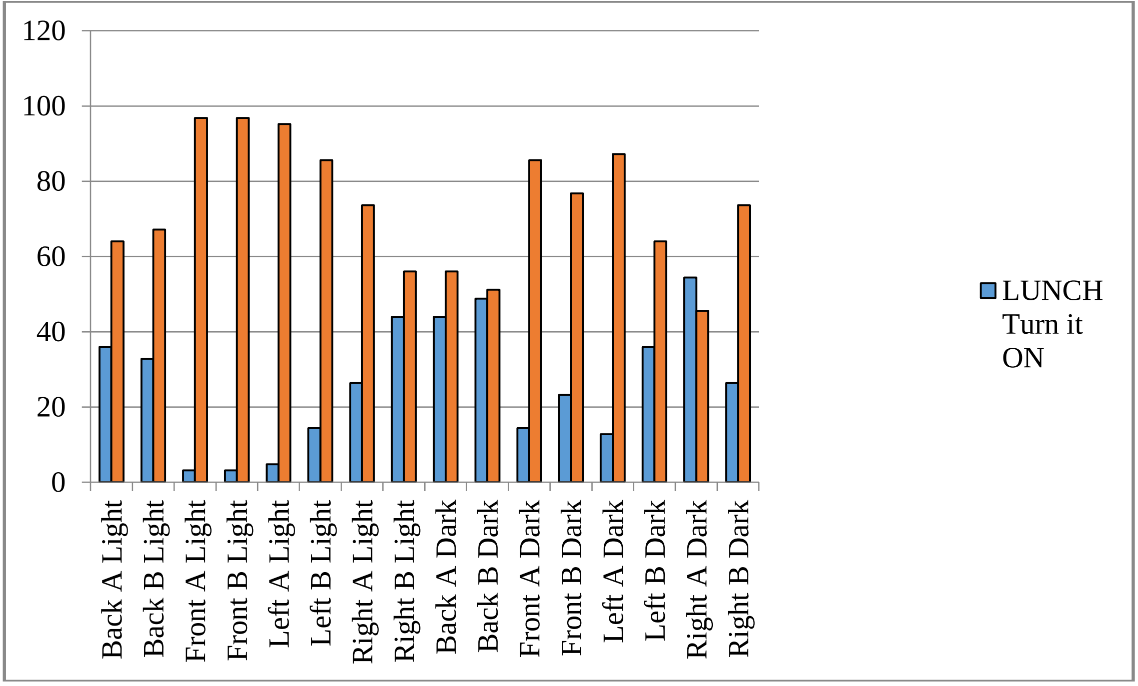


Figure 4.21. Manual lighting control responses after the lunch break.

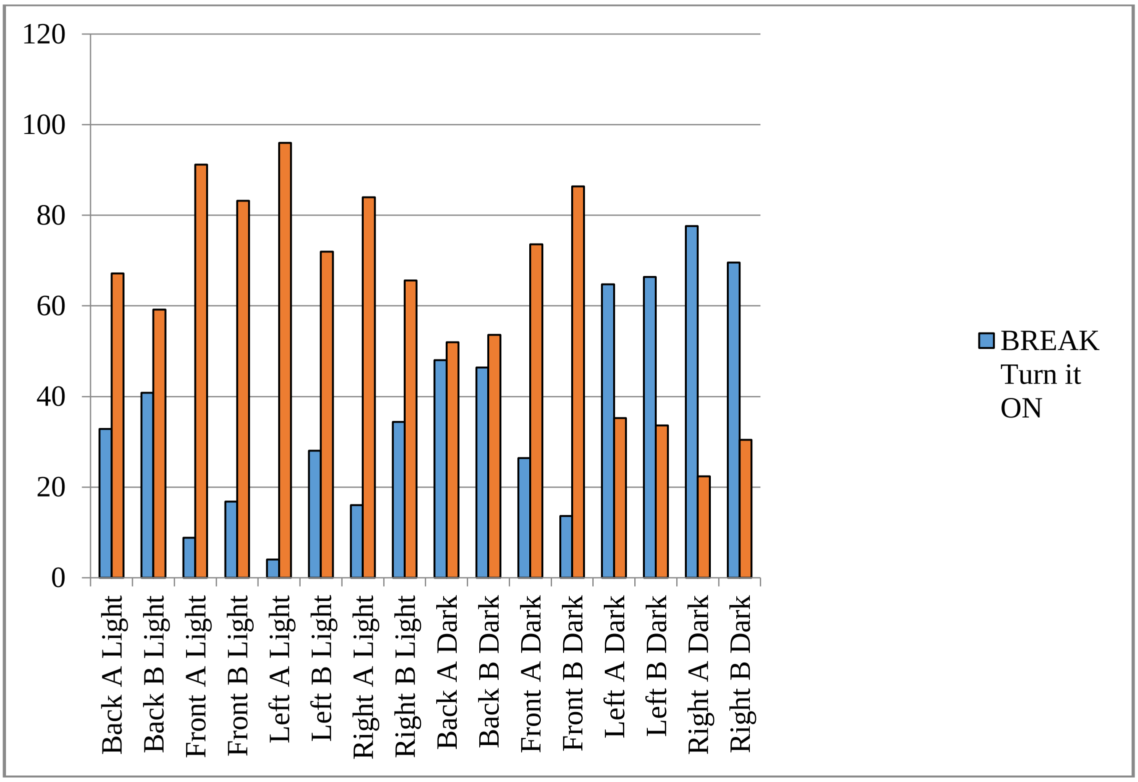


Figure 4.22. Manual lighting control responses after the break.

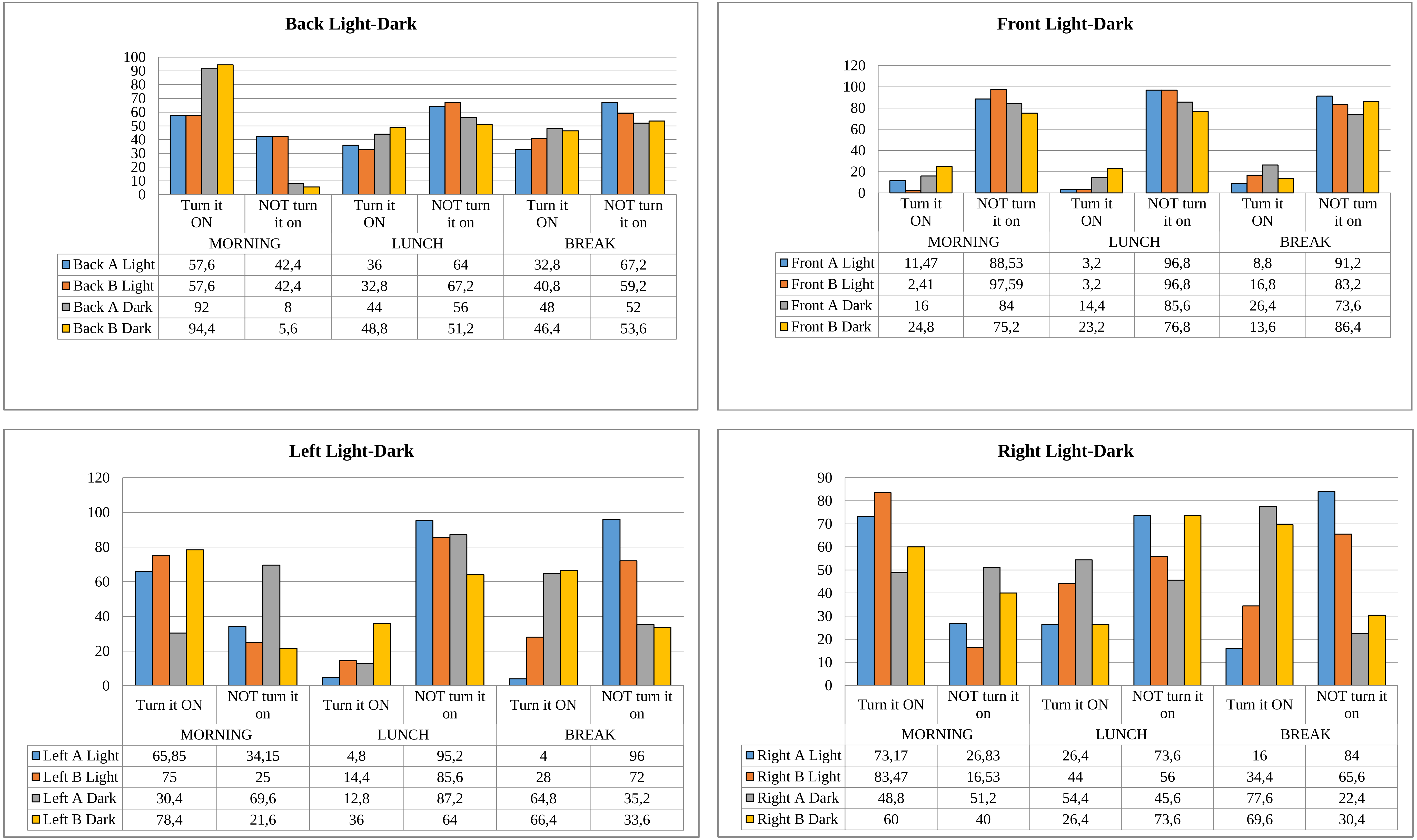
Table 4.22. Chi-square comparison according to the time of the day.

POSITION	**SURFACE COLORS**	**TIME OF THE DAY**	**P VALUE**
BACK A	LIGHT	Morning-Lunch	0.00000081419079223
		Morning- Afternoon	0.00001140924627968
		Lunch-Afternoon	0.00000118536528310
	DARK	Morning-Lunch	0.02393246468119130
		Morning- Afternoon	0.00153723278995177
		Lunch-Afternoon	0.00000000001968461
BACK B	LIGHT	Morning-Lunch	0.00029737884863272
		Morning- Afternoon	0.00000052420179993
		Lunch-Afternoon	0.00001245213771854
	DARK	Morning-Lunch	0.00784875130886689
		Morning- Afternoon	0.011289458
		Lunch-Afternoon	0.00000000209053542
FRONT A	LIGHT	Morning-Lunch	0.00239075812956934
		Morning- Afternoon	0.00313934631462215
		Lunch-Afternoon	0.00311338455619725
	DARK	Morning-Lunch	0.00000000023343265
		Morning- Afternoon	0.0000013904128560
		Lunch-Afternoon	0.00000187096314001
FRONT B	LIGHT	Morning-Lunch	0.00000000000000000
		Morning- Afternoon	0.00010309832453139
		Lunch-Afternoon	0.00155373401036665

	DARK	Morning-Lunch	0.00000000688197361
		Morning- Afternoon	0.00000011124161200
		Lunch-Afternoon	0.00000000050960114
LEFT A	LIGHT	Morning-Lunch	0.07052944677293090
		Morning- Afternoon	0.49584019989311800
		Lunch-Afternoon	0.00000000378843799
	DARK	Morning-Lunch	0.00035522074929559
		Morning- Afternoon	0.00013489099331542
		Lunch-Afternoon	0.00941737342430278
LEFT B	LIGHT	Morning-Lunch	0.0393433142268257
		Morning- Afternoon	0.00048907573238349
		Lunch-Afternoon	0.00005359180963128
	DARK	Morning-Lunch	0.000472792
		Morning- Afternoon	0.00000049407
		Lunch-Afternoon	0.00047279151462551
RIGHT A	LIGHT	Morning-Lunch	0.00000017786966932
		Morning- Afternoon	0.06341513401935810
		Lunch-Afternoon	0.00005570244338773
	DARK	Morning-Lunch	0.00002392303621903
		Morning- Afternoon	0.00000000035812998
		Lunch-Afternoon	0.00039541600372177
RIGHT B	LIGHT	Morning-Lunch	0.01436605414575170
		Morning- Afternoon	0.00035821665976068
		Lunch-Afternoon	0.00000006571816896
	DARK	Morning-Lunch	0.00000413705521062
		Morning- Afternoon	0.00000472060817672
		Lunch-Afternoon	0.00000131155938984

4.1.4.4. According to the Colors of the Surfaces

To comprehend the effect of surface colors on the manual lighting control, responses to photograph involved questions are compared with each other. The response rates indicate that participants are most likely to not turn on the lights upon entrance in light colored interior spaces. In all four desk positions with both A and B conditions, generally dark surfaces trigger participants to turn on the lights. For example, when Back A Dark and Light colored spaces' responses were compared, on morning entrance 57,6 would turn on the lights in light colored room while this rate increases to 92 for dark colored room. Similar responses can be seen upon after lunch and break entrances as well for Back A position. Comparison of all desk positions and time intervals can be seen on Figure 4.23.



Back Light-Dark

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Back A Light	57,6	42,4	36	64	32,8	67,2
🟧 Back B Light	57,6	42,4	32,8	67,2	40,8	59,2
⬜ Back A Dark	92	8	44	56	48	52
🟨 Back B Dark	94,4	5,6	48,8	51,2	46,4	53,6

Front Light-Dark

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Front A Light	11,47	88,53	3,2	96,8	8,8	91,2
🟧 Front B Light	2,41	97,59	3,2	96,8	16,8	83,2
⬜ Front A Dark	16	84	14,4	85,6	26,4	73,6
🟨 Front B Dark	24,8	75,2	23,2	76,8	13,6	86,4

Left Light-Dark

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Left A Light	65,85	34,15	4,8	95,2	4	96
🟧 Left B Light	75	25	14,4	85,6	28	72
⬜ Left A Dark	30,4	69,6	12,8	87,2	64,8	35,2
🟨 Left B Dark	78,4	21,6	36	64	66,4	33,6

Right Light-Dark

	MORNING		LUNCH		BREAK	
	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on	Turn it ON	NOT turn it on
🟦 Right A Light	73,17	26,83	26,4	73,6	16	84
🟧 Right B Light	83,47	16,53	44	56	34,4	65,6
⬜ Right A Dark	48,8	51,2	54,4	45,6	77,6	22,4
🟨 Right B Dark	60	40	26,4	73,6	69,6	30,4

Figure 4.23. Comparison of Light and Dark surfaces in four layouts.

4.2. Measurement Process

On-site measurement process took place between October 2014-February 2015 in three private office rooms in İYTE. During the measurements, each room was observed by two different sensors; one for motion and light detector, which was placed on the luminaire, and one illuminance meter on the desk (Figure 3.16Figure 3.20).

Since participants of the measurement were not at their office for the whole measurement period (due to their lectures, conferences, meetings etc.), the observed dates were filtered for the most active times of each day. Measurement results which were gathered from the occupancy and light sensors, were evaluated in terms of the following conditions for each day and each interior layout (

Figure 4.24).

- Lights on/Occupancy
- Lights off/No occupancy
- Lights off/No occupancy
- Lights on/No occupancy

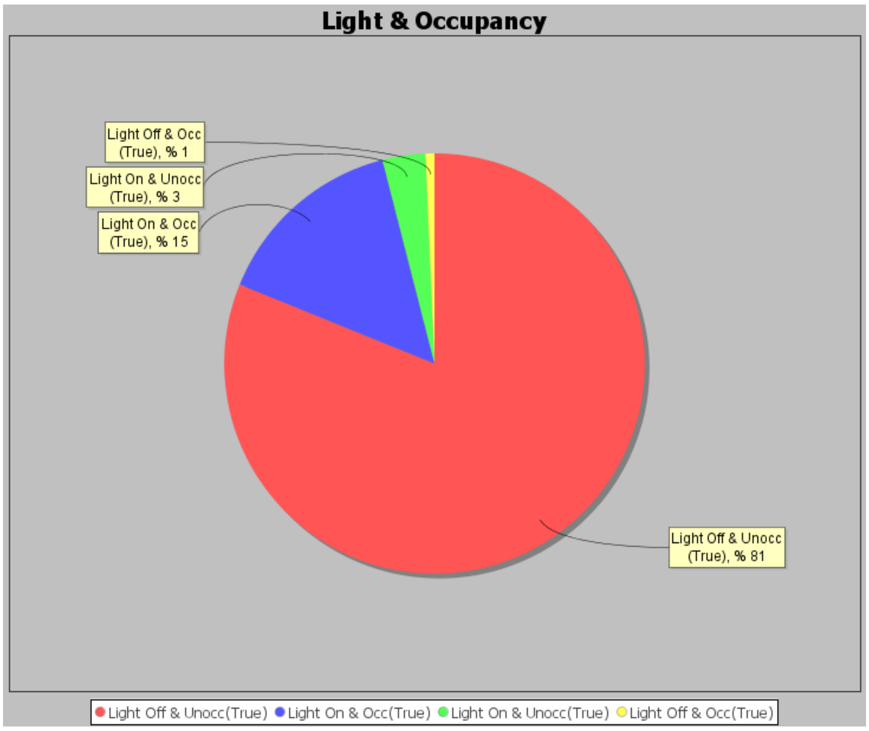


Figure 4.24. An evaluation of the four conditions on a sample day.

Illuminance meter which was placed on the desk monitored the horizontal illuminances on the workplane. The outputs of these measurements were read out from the graphs and used to relate the manual lighting control behavior with daylight penetration (

Figure 4.25).

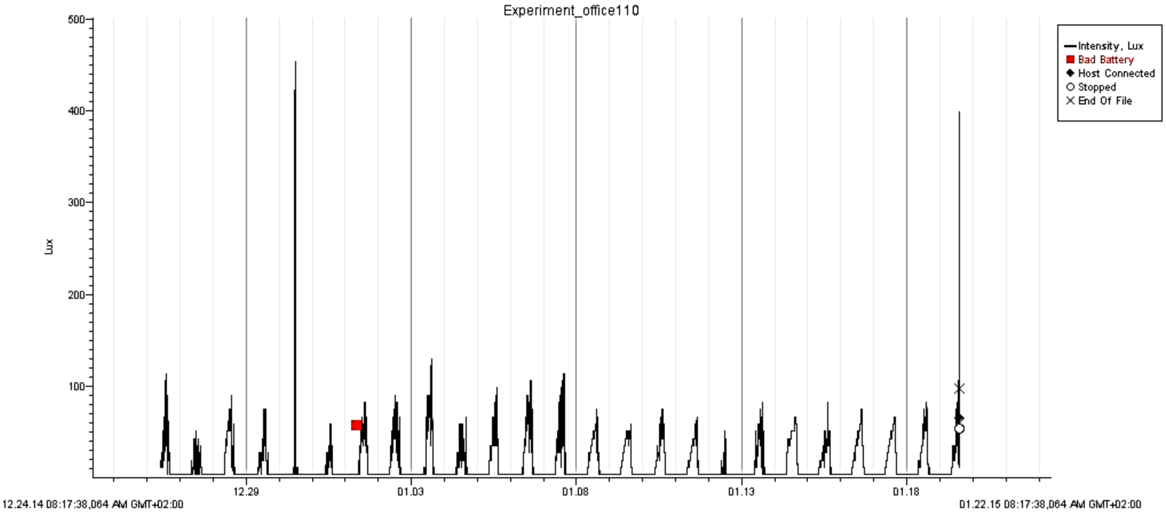


Figure 4.25. A sample illuminance level outputs of the luxmeter

In addition to illuminance meter, the other sensor (occupancy&light) detects whether there is any occupancy room and whether artificial lighting system is switched on or not for every second. As an output, all sorts of change in the occupancy or lighting system is noted in the given graphs Figure 4.35.

By comparing the values of the gathered from both of the sensors for the same time period, users' manual lighting control was related with their presence and indoor illuminance levels. HOBO software allows to have measurement results to visualize with the graphs, besides it gives the opportunity to export the outputs to excel. Therefore, after analyzing and comparing the outputs, obtained results will be used to establish relationship as it is seen on Table 4.23 .

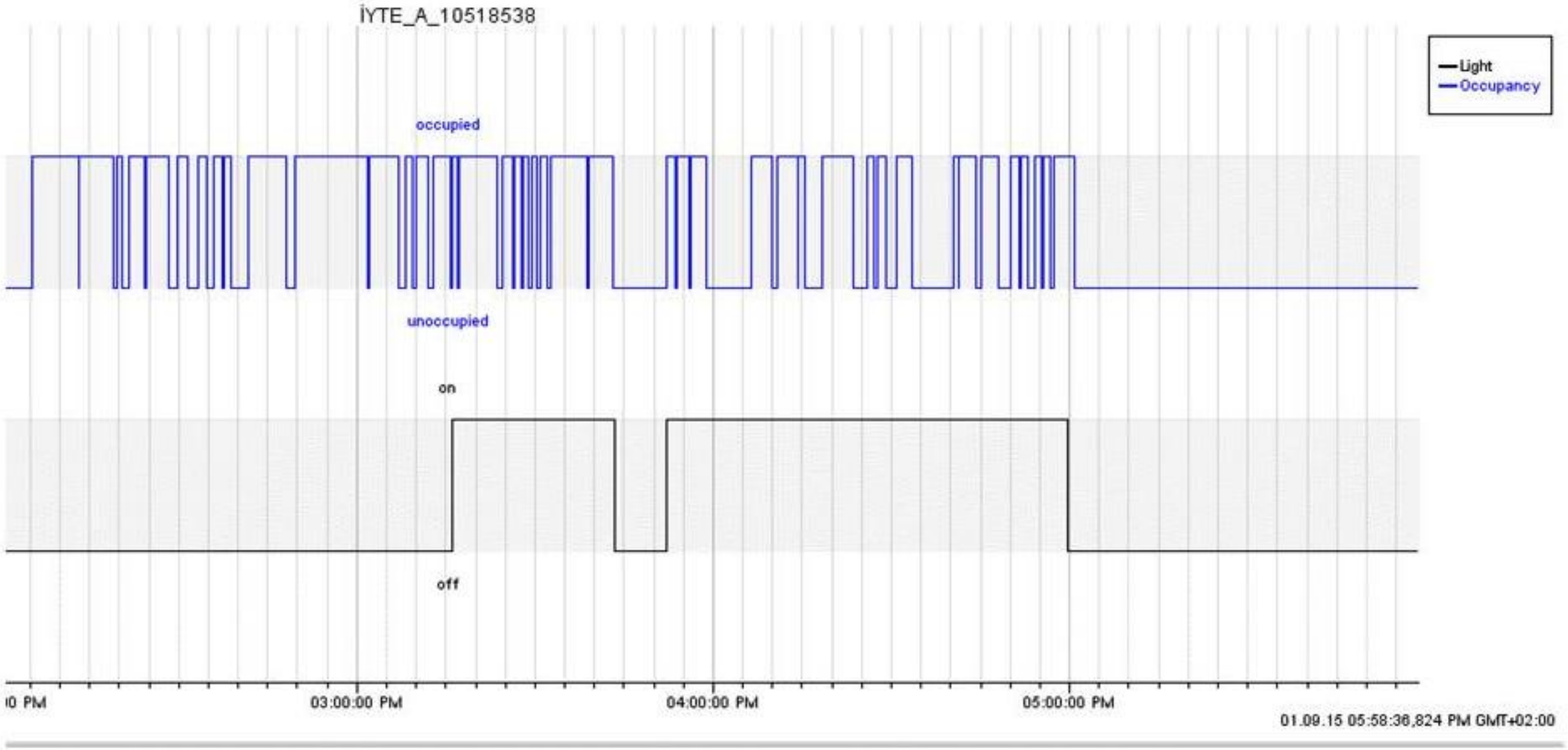


Figure 4.26. Light & Occupancy sensor output graphs.

4.2.1. Measurement Results

To determine the relation between occupancy and illuminance, the manual lighting control behavior was analyzed for each interior layout for each day with each user. In these analysis the following factors were determined.

- illuminance during entrance
- average illuminance during occupancy
- artificial light usage
- occupancy

A sample evaluation for two days on User B’s room in Left A layout is presented on Table 4.23. These analyses were additionally used to form the fuzzy rule sets which was mentioned on

Table 3.14.

Table 4.23. A sample evaluation for User B- Left A layout.

	Dates	**Time**	**Illuminance (Lux)**	**Light**	**Occupancy**
LEFT A		11:04	67,00		
	31.10.2014	11:04-12:35	70,00	0	1
	31.10.2014	15:47	153,00		
		15:47-16:57	39,00	0	1
		08:46	28,00		
	3.11.2014	08:46-08:58	172,00	1	1
		17:04	4,00		
	3.11.2014	17:04-17:17	4,00	0	1
		08:42	28,00		
	4.11.2014	08:42-08:46	28,00	0	1
		11:39	59		
	4.11.2014	11:39-12:09	222,00	1	1
		12:10	67,00		
	4.11.2014	12:10-13:30	109,00	0	1
		15:22			
	4.11.2014	15:22-16:33	199,00	1	1

4.2.2. Lighting and Occupancy Conditions in Different Interior Layouts

During October 31 2014 and February 16, in the sample rooms, desks were modified to have daylight penetration from 4 different directions and with two different distances to window as it can be followed on

Figure 3.21. These 8 different layouts were named as; Left A, Left B, Right A, Right B, Back A, Back B, Front A and Front B.

The occupancy and light percentages of each layout were analyzed to find out the relation between occupancy and artificial lighting usage. However, these results vary according to the interior layout and distance to window since different layouts effected users' manual lighting control. Occupancy and artificial lighting conditions of these eight different layouts are displayed on Figure 4.27 for user A at Left position on the days of October 31st – November 14th. Similar graphical presentations and percentage distributions for User B and User C on each day and for all positions are shown in Appendix B.

4.2.2.1. Left Layout

Regarding the Left layout, User A's and User C's artificial lighting usage differs in Left A and B positions. For example, in Left B position, the overall percentage of occupancy without lights on (Light off&Occ) for User A and C is less compared to Left A (where the desk is nearer to window). Correspondingly, the Light on&Occ, (where the users occupy the room with lights on) percentage is higher for Left B compared to Left A. Both of the findings are a sign of more lighting energy consumption during the occupancy intervals for User A and User C. However, User B does not show significant variation between Left A and Left B position.

4.2.2.2. Right Layout

Compared to Left layout, in Right layout, users' manual lighting control shows slightly changed. The most obvious difference from the Left layout, User B has longer periods of occupancy without artificial light usage (Light Off&Occ) in Right layout (for both A and B). On the other hand, User A and User C do not show that significant change in terms of artificial lighting usage between the Right and Left positions. Just like Left layout, again in Right layout, B position has more hours with artificial light usage compared to A position.

4.2.2.3. Back Layout

In Back layout, users' manual lighting controls have little in common. So instead of common statements which includes all users, each user has to be analyzed individually. For example, User B never turned on the lights during the Back Layout, both A and B measurements. While User C was rarely at the office therefore the percentage of occupancy was very low for that user. However, User A's manual lighting control was in parallel with the other layouts. User A used more artificial lighting in Back B position compared to Back A.

4.2.2.4. Front layout

In Front layout, artificial lighting usage percentage was higher compared to other three layouts. Even User B, who generally prefers to work without lights on, worked with the lights on during Front A position. Similar to User B, also User A and User C used artificial lighting more in Front layout. However, this time not only Light On& Occupied percentage was high but also Light On& Unoccupied percentage was higher. The increase in Light On & Unoccupied hours were higher especially for Front B position.

4.2.2.5. User Manual Lighting Control Analysis

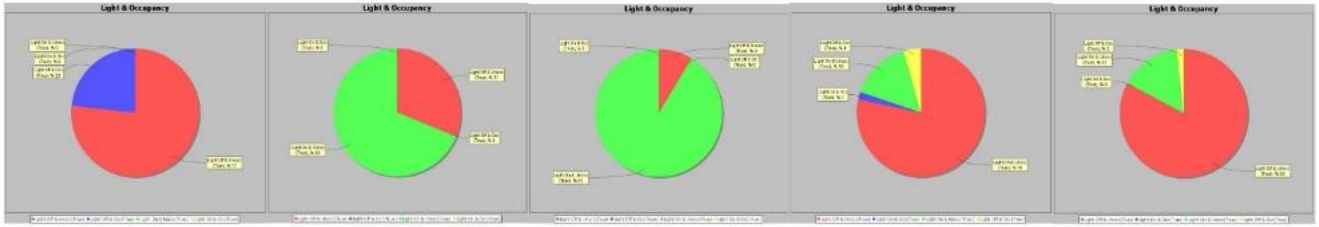
During the same time periods, weather conditions and orientation, three different users were observed in terms of manual lighting control behavior. Though the conditions were almost identical, the manual lighting control behaviors were not, during these two months of measurement. This fact underlines the importance of user's preferences, expectations and actions in manual lighting control behavior. Here each users' manual lighting control will be discussed by their own, and not compared with the other users.

When the measurement results of User A is analyzed, it is seen that User A has the highest Light On& Unoccupied percentage among all the users. This percentage is especially high in Front layout. However, this result may be a result of still-working of the user. Because when the sensor does not detect any motion in the room, it determines the situation of the room as unoccupied, though the user is in the room. Therefore, it is not easy to determine the actual situation. However, with and without occupancy, User A has the highest percentage of lights on among the other users.

User B generally prefers to work without the lights on. Independently of the layout, User B has the least ratio of artificial light usage. Among all the layouts, mostly in Front layout, User B preferred to switch on the lights. Besides this fact, User B's manual lighting control behavior does not show significant changes between A and B positions in any of the layouts. One another important point is that User B, generally does not stay in the office for long periods of time.

During the 2 months of measurement period, User C was out of the office most of the time. Therefore, the total number of office hours we measured were lower, when compared to the other users' working time. However, among the measured hours, User C preferred to work with artificial lights on Front layout mostly, and Left layout has the most Light Off& Occupied percentage.

PARTICIPANT: User A
LAYOUT: Left A
PERIOD: October 31- November 14



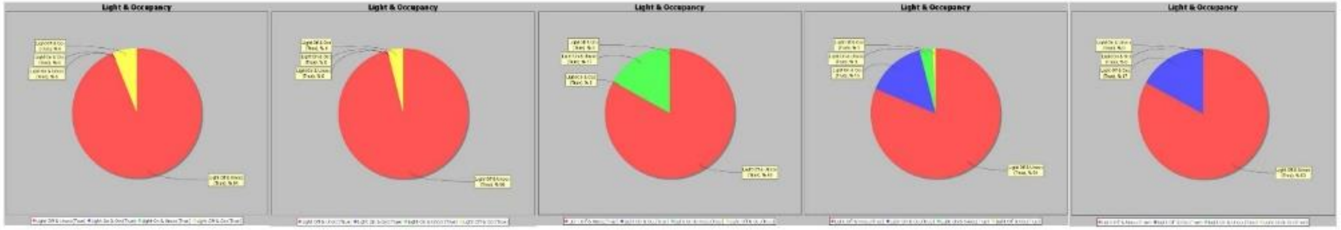
Oct. 31 11:00-11:40
Light off&Occ 23%
Light off&Unocc 77%
Light on&Unocc 0%
Light on&Occ 0%

Nov. 3 14:00-15:40
Light off&Occ 0%
Light off&Unocc 31%
Light on&Unocc 69%
Light on&Occ 0%

Nov. 4 15:00-15:40
Light off&Occ 0%
Light off&Unocc 9%
Light on&Unocc 91%
Light on&Occ 0%

Nov. 5 10:00-16:00
Light off&Occ 4%
Light off&Unocc 78%
Light on&Unocc 15%
Light on&Occ 2%

Nov. 6 11:00-18:00
Light off&Occ 2%
Light off&Unocc 83%
Light on&Unocc 15%
Light on&Occ 0%



Nov. 7 11:00-13:00
Light off&Occ 6%
Light off&Unocc 94%
Light on&Unocc 0%
Light on&Occ 0%

Nov. 10 10:00-13:00
Light off&Occ 4%
Light off&Unocc 96%
Light on&Unocc 0%
Light on&Occ 0%

Nov. 11 11:00-16:00
Light off&Occ 0%
Light off&Unocc 83%
Light on&Unocc 17%
Light on&Occ 0%

Nov. 12 16:00-18:00
Light off&Occ 1%
Light off&Unocc 81%
Light on&Unocc 3%
Light on&Occ 15%

Nov. 13 12:30-13:45
Light off&Occ 17%
Light off&Unocc 83%
Light on&Unocc 0%
Light on&Occ 0%

Figure 4.27. Occupancy and artificial lighting condition of User A in Left A layout.

4.3. Fuzzy Logic Model Application

A fuzzy logic algorithm was applied to classify behavior patterns about the tendency to turn on the lights. This kind of prediction of the light usage regarding to occupancy aims to foresee the “possible” manual lighting control behavior with the given conditions, defined by the desk layout, disk distance to window and workplane illuminance. A total of 30 rules were derived from the analysis of the monitoring process (

Table 3.14).

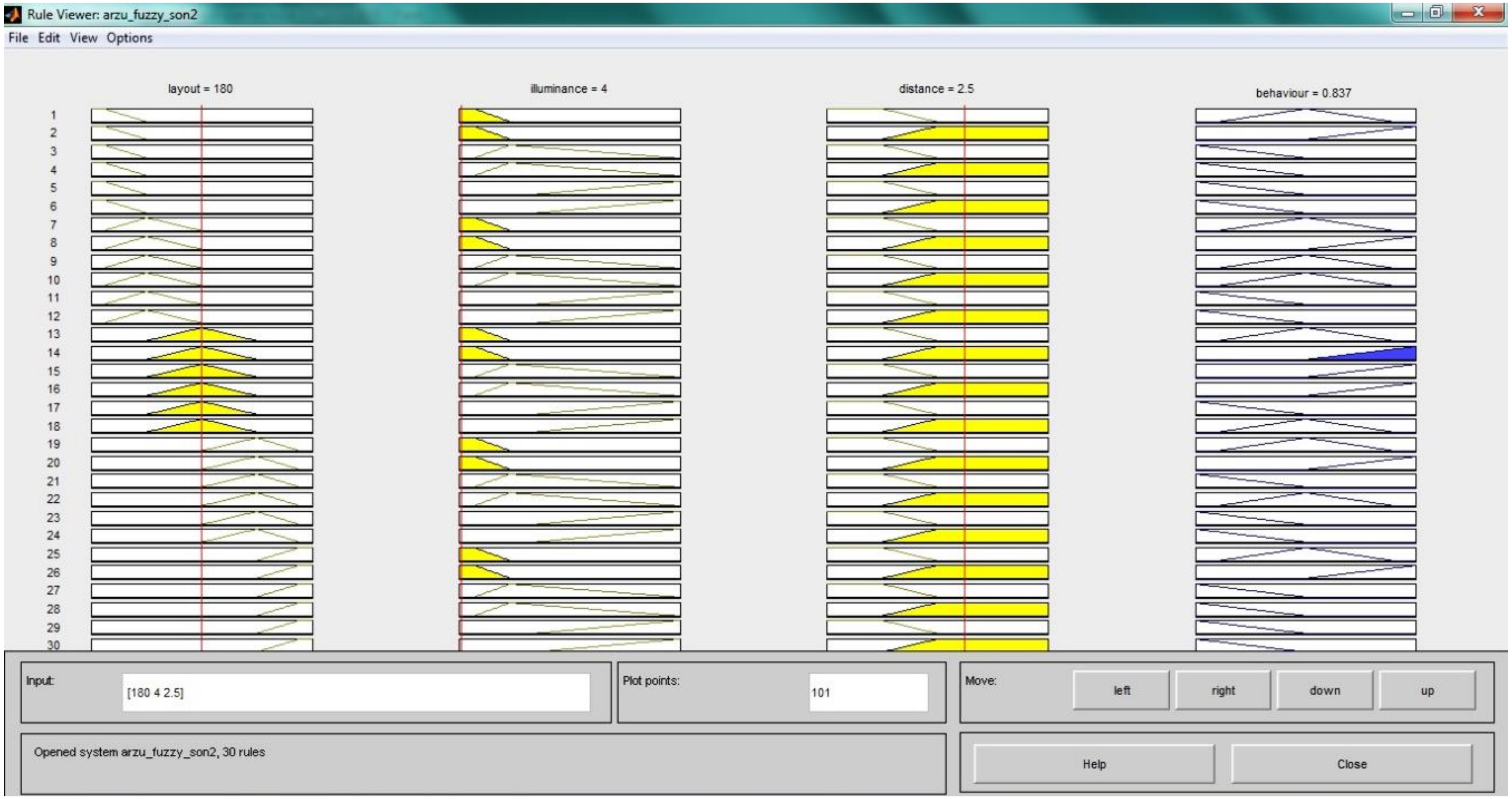
In order to check the accuracy of the predictions of the model, numerous simulations were done using MATLAB. In each model, values of workplane illuminance, desk position and distance to window were given and manual lighting control behavior was asked to be predicted. A sample prediction on MATLAB interface can be seen on

Figure 4.28.

To check the values of tendency to turn on/or off the lights, the value below or equal to 0.5 corresponds to the probability of not switching on the lights, while, the value above 0.5 correspond to the probability of switching on the lights. 24 sample sets were randomly chosen to compare the observed outputs (turning on / off) and the fuzzy model outputs. According to the randomly chosen sample sets, the probability of switching on the lights is 41% (

Figure 4.29). Besides among 24 randomly selected data sets 20 of them were matching up with the observations/and measurements. This result shows a high rate of accuracy with 83%, therefore, the fuzzy model predictions fit the measurement results very well. Following this validation and prediction process, the classifications were set and discussed as below.

The fuzzy subsets for the input and output variables are given on Table 4.24. As it can be concluded from that analysis, there are three classifications of manual lighting control behavior patterns in this fuzzy set. Although there are two options for the possibility of turning on the lights due to a regular/nominal judgement -that is the probability of switching on the lights and the probability of not switching on the lights-, this analysis provides the rating of users' tendency to turn on the lights setting up the classes of their behavior patterns. Thus, we can classify the tendency of behavior values predicted by this fuzzy application into three groups as: Low tendency group where the rate is less than 0.25; Normal tendency class where the rate ranges from 0.25 to 0.75; and High tendency class where the rate is greater than 0.75. Additionally, we can discuss to divide the Normal tendency class into two subsets as Low-Medium and Medium-High when commenting further on the individual findings.



Input: [180 4 2.5]

Plot points: 101

Opened system arzu_fuzzy_son2, 30 rules

Figure 4.28. A sample fuzzy model prediction on MATLAB.

Table 4.24. Prediction results for the behavior pattern values.

	Layout	Position	Illuminance	Tendency of behavior pattern value	Comment
1	Back	A	4	0,6	Back layout blocks some amount of daylight which is directed to the backwards of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
2	Back	B	36	0,823	Back layout blocks some amount of daylight which is directed to the backwards of the user. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the High class, can probably switch on the lights)
3	Front	A	28	0,572	Front layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
4	Front	B	51	0,438	Front layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights).
5	Left	B	209	0,188	Left layout provides the impact of sidelighting fully. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
6	Left	A	4	0.5	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights)
7	Right	B	28	0,729	Right layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights)
8	Right	B	4	0,837	Right layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the High class, can probably switch on the lights)

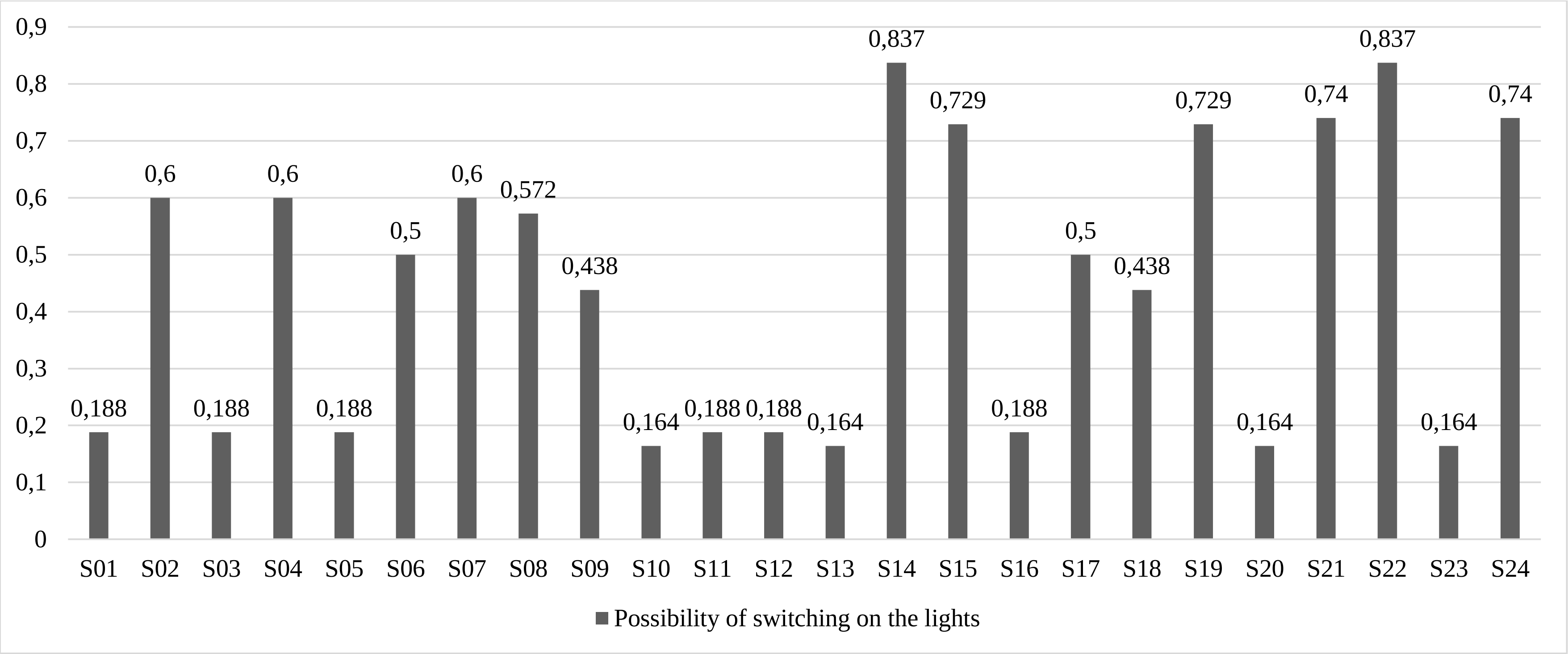


Figure 4.29. Distribution of tendency of behavior pattern to switch on the lights.

Regarding the Figure 4.38, 10 out of 24 observations are included in a class of Low tendency meaning that users in those situations do not switch on the lights. Users in only two observations (S09 and S18) with the value of 0.438 belong to a class of Low-Medium tendency. While 4 observations (S15, S19, S21, S24) belong to the Medium-High class of tendency with the values close to 0,75. It must be noted that only two observations have High class of tendency with the values above 0,75. Which shows among the 24 observations only in 2 of them users are most probably switch on the lights (8%).

CHAPTER 5

DISCUSSION

As the findings derived from questionnaire, onsite measurements and fuzzy model are involved extensively in the preceding section, it is now necessary to present the interpretations in regard to this study’s argument and objectives and in the view of the relevant literature. To avoid confusion, the section is outlined under four sub-topics subjected to research. Only the last sub-section is composed of discussions about the methodology which dominates this research.

5.1. Physical Factors Affecting Manual Lighting Control

Offices vary due to their environment and user profiles. Manual lighting control behavior can be classified primarily focusing on the architectural, physical and utilization conditions. As the questionnaire concerned this issue under several questions, some noteworthy results can be categorized into four factors; namely, office population, window properties, personal factors affecting and inhibiting manual control.

5.1.1. Office Population

Number of people working in the same office may influence users’ manual lighting control. Users may hesitate to interfere with the lighting system not to ruin the visual condition or leave it to the more active users just like Günay et al. mentions, lighting control is generally performed by the same group of occupants (Gunay, O’Brien, and Beausoleil-Morrison 2013).

The two questions of the questionnaire about the satisfaction of artificial lighting condition versus office population were analyzed and it was found that 3-4 people and single occupied people were the two most satisfied groups about the artificial lighting condition. Whilst, majority of the "too much" answer was given by occupants who work at offices more than 6 people. So this shows that if they have the chance to control the lights individually, they would prefer to work under lower illuminance levels and this would consume less energy. This output go along with Gu's study where the author suggests that with individual lighting control, there will be energy savings since there are always some occupants who prefer illuminance lower than the fixed lighting levels (Gu 2011).

Such a finding can provide feedback to architects in terms of promoting them to design single occupied or up to 3-4 people occupied working spaces to contribute in electricity saving.

5.1.2. Window Properties

Distributing daylight to deeper parts of the office requires more complex design strategies. Therefore, it's not surprising to get such an outcome that the majority of the participants (66%) who indicate that they define the daylight penetration as "*dim*" or "*too dim*" work in more than 5m distance to window. However, the highest satisfaction was observed among participants whose desk is 1-2 m (55%) and less than 1m (30%) away from the window respectively. The fact remains that the window openings may be also undesirable due to lack of privacy, heat gain, distraction or especially glare. For example, the questionnaire points out that, 67% of users who suffer from glare declare that it is caused by the daylight penetration.

Available daylight penetration is directly related with the window area and as the window area increase, so does the daylight penetration. Therefore, when responses were analyzed in terms of satisfaction, highest satisfaction responses (approx. 42%) were given by the respondents who have $2m^2$-$5m^2$ window area. While the least satisfied participants have window area less than $2m^2$. In furtherance, the questionnaire results show that only 5% of participants indicate that they prefer to work with artificial lighting. So as Newsham et al. mentions, office workers prefer daylight for office lighting, therefore small window openings are not desirable by occupants (G. Newsham, Brand, et al. 2009). Preferred window size differs according to the task however in general larger windows are preferred by the occupants (Chiogna 2008).

5.2. Personal Factors Affecting Manual Lighting Control

To understand the frequency of manual lighting control and the impulses which triggers users to manually control lighting system, the questionnaire involved various questions. The results revealed that generally 57% of participants control lighting system manually several times a day. Which shows that, participants do not operate the lighting system only during entrance and departure as it was stated in Hunt's model (Hunt 1979). For these reason, 66% of participants can be named as "active" users as Love (1998) proposes(Bourgeois, Reinhart, and Macdonald 2005). On the contrary, 34% of the participants can be named as "passive" users since they claim that they do not control lighting systems manually often (21% only during entrance and departure, 13% never). This data shows, during a study when it is assumed that all of the users are "passive" it is not realistic. The target group of this study shows the importance of taking the user behavior realistically and it is also parallel with the hypothesis 7, which indicates that it is not possible to classify all users' behaviors onto one group.

Besides entrance and departure, other factors such obtaining visual comfort can motivate users to manually control lighting. Among various given factors, the responses of the participants indicate that obtaining visual comfort and creating atmosphere for work are the two most triggering reasons behind manual lighting control respectively. These facts led to the conclusion of users tend to manually control the lighting to accomplish their work.

However, energy saving is the third most affecting factor on manual lighting control which can be interpreted as environmentally conscious is also an important motivation for users. Since 38% of users do not consider energy saving as a triggering factor, as Galasiu et al. mentions, by the help of eco-friendly awareness campaigns can improve sensitivity on lighting energy consumption (Galasiu et al. 2007).

Not surprisingly, insufficient daylight penetration (90%) trigger users to turn on the lights while sufficient daylight penetration influence users to switch off the lights (72%). Therefore, window openings have to be designed carefully since they have a significant contribution on reducing lighting energy consumption.

By comparison with the previously listed factors two factors are less influential in terms of manual lighting control. The first one is, the type of work. Either computer work or non-computer work, show little difference in terms of manual lighting control. This can be interpreted as one type of task doesn't have a stronger effect on users' control behavior than the other has. The second factor is colleagues' request. Almost 27% of the participants indicate that they never take into consideration of their colleagues' demand. However, these participants may be working on the private offices because 59% of participants indicated that they restrict themselves to manually control lighting for not disturbing their colleagues in the following question.

5.3. Personal Factors That Inhibit Manual Lighting Control

Some factors stop users from manually control lighting. After the analyzes of the responses, it is seen that focusing on the work, and probably due to that, not caring the illuminances inside are the top two reasons for inhibiting manual lighting control. On the contrary of the hypothesis 8, the distance to switch was the least inhibiting factor (19%) from manually switching on/off the lights. Although a total of 40% of respondents declare that the far distance of the switch from their present location does not inhibit their lighting control action, a larger group of them respond reversely in another question about their requirement of switch location. They stated that the switch needs to be placed on their desk or on the computer.

5.4. Relation Between Interior Layout and Manual Lighting Control

The below listed interior layout parameters were observed in terms of manual lighting control behavior.

5.4.1. Distance to Window

To understand how the distance to window effects manual lighting control, both questionnaire and measurement study was conducted. Chi square and Cronbach's alpha reliability tests and results point out the significant correlation between the distance to window and lighting control behavior. In every tested layout (left, right, back, front) users were least likely to turn on the lights when they were sitting near the window (in A position). However, as the distance gets higher (in B position) the probability of switching on the lights increased. Similar results were gathered from the observations as well. Therefore, locating desks near to window can reduce lighting energy consumption. However just as Chiogna mentions, the degree of glare is related with the distance from the window so conscious decisions have to be made (Chiogna 2008).

Although literature about window design and daylighting performance mention this general knowledge about the importance of distance inside the room to get benefit from daylighting, this study supported that once again together with finding out and relating it with an additional interior design variable which is “interior layout”. Regardless of being in i.e. the left, right or back seating position, distance to window strongly affects the manual lighting control. The impact of interior layout is reasonably notable as mentioned below.

5.4.2. Interior Layout

As supposed from previous studies (Clear 2014) , changes in the interior design can be very important on modifying behavior. Therefore, four different layouts (Back, Front, Right, Left) were tested both in photograph involved questions in the questionnaire and in the measurements. When Back responses were compared to Front responses, a significant difference was observed. Though the distinctness between Left and Right layouts were not that obvious when compared to Back and Front, still in Left layout users switch on the lights less frequently. Likewise, standards for office and educational spaces suggest light to penetrate from the left side of the user (Mesleki ve Teknik Eğitim Genel Müdürlüğü 2015).

Such an outcome is noteworthy not only in developing architectural design merits but also in enhancing technical ways to evaluate daylight performance and energy efficiency in working spaces. Users’ desk layout can be involved as a certain affecting variable/or constant in performance and energy calculating tools. Additionally, personal issues can be integrated to get a deep understanding and insight. A further study can analyze in detail how a left-hand writer receiving daylight from the left side satisfies differently than a right-hand writer in the same layout; and how the lighting electricity is consumed or saved in both cases.

5.4.3. Surface Colors

Color is one of the most dominant elements for interiors and it can affect the lighting of an interior by either enhance or nullify the distribution of light. Previous studies have proved that the one third of lighting energy consumption depends on the color of the surfaces (walls, ceiling, furniture etc.) (Singh and Rawal 2011). Similarly, response rates show that users are most likely to not switch on the lights upon entrance in light colored rooms. To reduce lighting energy consumption of spaces, it is proposed that light colored surfaces should be used to increase reflections within the space.

5.5. Relation between Daylight and Manual Lighting Control

Since daylight is not stable, the direction and brightness of daylight penetration changes during the day, which effects the illuminances inside. Regarding that, manual lighting control can change. During the questionnaire and measurements, the gathered responses show that generally users switch on the lights upon entrance in the morning, however this ratio falls significantly on entrances after lunch and break. In questionnaire based findings, responses including marking the choice of turning on or not turning on are based on the lightness or darkness of the image of the room and that implies the user’s attitude however we don’t know about numerical values of daylight illuminance. The written information about the period of time support their decision while making them imagine the real situation.

On the contrary, during measurements, this behavior was generally directly related with the illuminance levels inside upon entrance. Whenever the illuminances were low (less than 50 lux) the probability of users to turn on the lights were increased.

5.6. Regarding Methods and Manual Lighting Control Estimation

This section involves the interpretations about the flow of methodology and cause-effect relationship between three main applications – a survey based on a questionnaire, an experimental design based on-site illuminance and occupancy/light on-off measurements, a prediction soft modeling approach based on fuzzy algorithm – and factors of manual control. Determining realistic manual lighting control behavior may deserve a certain time, as it is interactive related with various factors and cannot be directly reproduced. By the help of previous studies (C. F. Reinhart and Canada 2002; Schiavon and Altomonte 2014), first the most influential factors were determined such as spatial layout, distance to window, surface reflectance, and time of the day. To observe users' behavior to the listed factors, real-time measurements were planned. Though it was not feasible to conduct the planned measurement by large mass, the number of participants were increased by the questionnaire method.

In order to find the most influential factors to manual lighting control, a wide range of questions were asked to participants on questionnaire. The first part of the questionnaire involved questions to understand the current office of the participants. Since their reactions, expectations might be as a result of the current situation, that information were also collected to be relate it with the outputs. An important advantage of the questionnaire was that a sight to users' expectations, triggering factors, inhibiting factors were found out. By analyzing the most effective factors—those of which are layout, distance to window and daylight illuminance-- to the users, the study was carried on with real time measurement.

To realistically interpret the outputs of the questionnaire, statistical analysis was used. However, to validate the questionnaire results, with a small scale participant group measurements were done. By modifying almost identical offices, three different users were observed with two sensors (illuminance meter and occupancy/light sensor). This study enabled to correlate manual lighting control action with the change of daylight penetration, occupancy and layout. The obtained results were used to form rules on manual lighting control. Specifically, fuzzy logic algorithm was applied to the results of the measurements to classify behavior patterns about the tendency to turn on the lights. It was found to be successful in estimation of turning on behavior with an 83% prediction rate. Additionally, the fuzzy model provided an alternative systematic way to define reliable manual control behavior classes. The construction of this model was basically based on data gathered from field measurements, previous studies and daylighting knowledge in literature. It can be improved widely when additional parameters, such as room geometry, orientation, surface color etc., are included in the prediction phase.

The classification of behavior has become an assisting tool to compare the user's attempt to switch on the light under certain conditions. It is now possible to estimate whether the user can turn on the light or not, even when examining the drafts of an architectural drawing including the location of desk and room geometry. Since the work plane illuminance can be calculated using varying software tools or mathematical calculations. It becomes a practical, less time consuming and easy tool for architects and interior designers. Furthermore, this kind of estimation would allow the professionals to concern the initial clues about how the lighting electricity can be consumed in such a designed environment on the drawing paper.

The outputs gathered from this study can be used to design more user-friendly and less energy consuming offices with no extra investment on systems. The study can be enriched by running campaigns for the awareness and users might decide to modify their workplace to reduce lighting energy consumption. Otherwise, these results can be used during simulating user behavior, since the output belongs to real-time observation and statistically determined responses. Accuracy of the simulations may increase if realistic user behavior involves the process.

CHAPTER 6

CONCLUSION

This study included analysis of manual lighting control with relation to the various factors and especially interior architectural factors to obtain realistic manual lighting control behavior of occupants in offices. With the help of the findings, it is aimed to offer certain significant probability values and classifications for manual lighting control to be used in both energy simulations and researches. As a result of this, it is thought that, during the design phase, predictions of the simulations and assumptions of the studies will be more accurate to determine actual manual lighting control.

In order to determine manual lighting control, the affecting factors affecting it with their contribution has to be seen. Thus, first a questionnaire was conducted among 125 participants which was followed by a real-time measurement process on three sample rooms and finally, a fuzzy model was constructed to classify users' manual lighting probability. The gathered data from questionnaire was analyzed using statistical methods (Chi-square test, reliability test) to associate occupancy tendencies. In addition to those, provided measurement results were analyzed and used to create rules for fuzzy models to achieve classifications.

Regarding the obtained results, the most remarkable factors on manual lighting control can be listed as; distance to window which is related with daylight penetration, and interior layout which is defined here as the desk position according to window. The illuminance upon entrance is critical in terms of switching the lights on during entrance. At the same time, window area, surface colors, and time of the day are other notable factors. Nonetheless, the location of the switch, orientation of window and the type of task (either computer based or paper based work) are ineffective factors on manual lighting control.

Despite of the passive user assumption on existing standards and simulation software, the findings of this study suggested that in the absence of automatic lighting control systems, users do not use artificial lighting all through the working hours. Therefore, each user cannot be defined as passive user. On the contrary, among the randomly selected participants of this study, there were more "active" users than "passive" users. Altogether, the suggested classification generated from the fuzzy model offers more detailed classifications on manual lighting control probabilities which can be used in future studies and energy saving estimations/or can be implemented in simulations. Besides, previous manual lighting control studies ignored the contribution of interior layout; however, it’s now clear that providing higher illuminance level over the desk (with either locating them near window area, or changing the layout) may increase manual lighting control and therefore reduce artificial lighting usage. Since the main decision to turn on or not turn on the lights is given upon entrance by looking at the luminance on the desk, the main focus should be to provide well-lit desk areas.

The listed findings, as the manual lighting tendencies, triggering and inhibiting factors can be used to design offices with higher energy savings, without using any automatic lighting control systems, but only the users. Furthermore, this study aimed to give insight to user preferences and raise awareness on manual lighting control.

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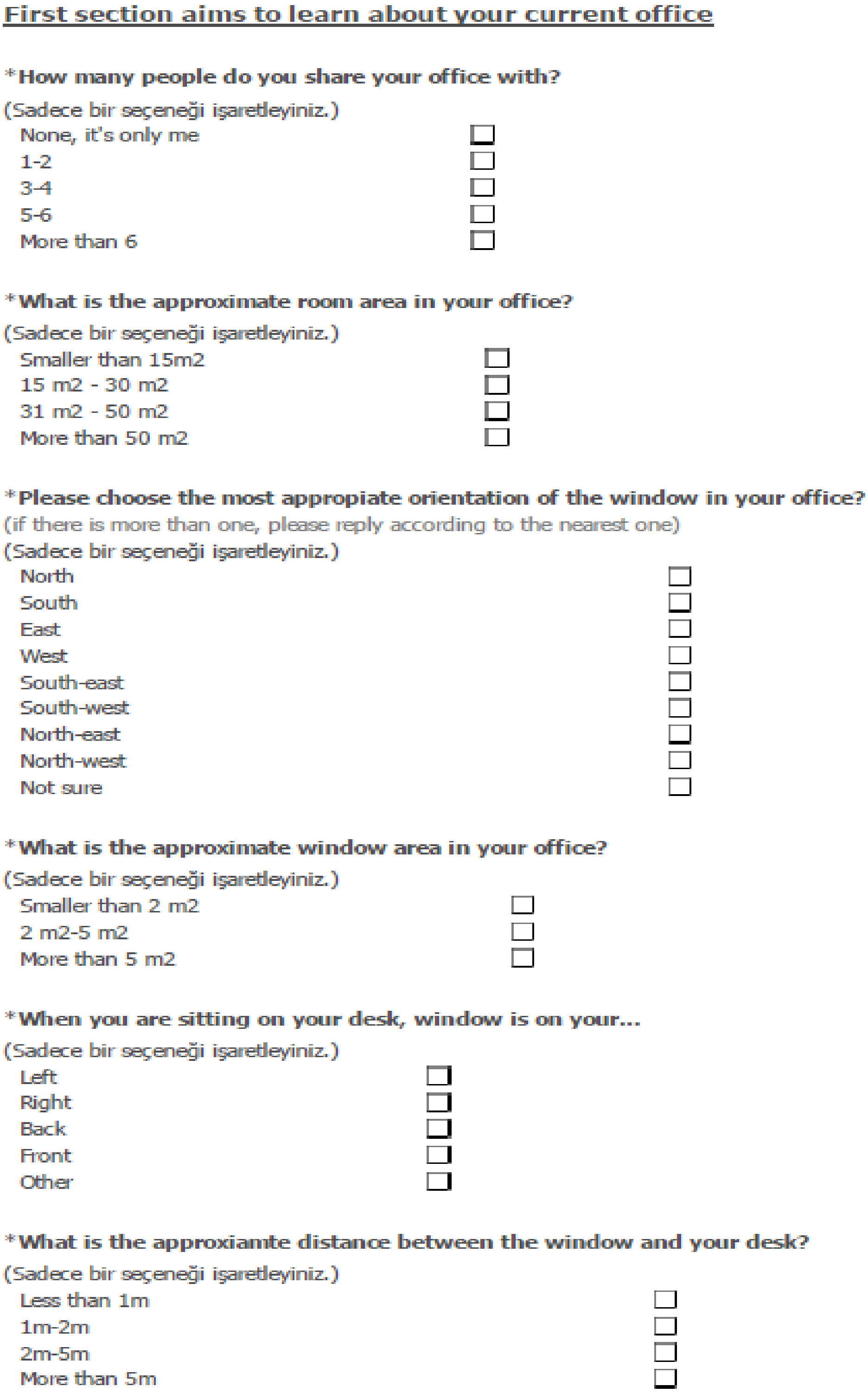
APPENDIX A

QUESTIONNAIRE QUESTIONS



First section aims to learn about your current office

***How many people do you share your office with?**

(Sadece bir seçeneği işaretleyiniz.)
None, it's only me ☐
1-2 ☐
3-4 ☐
5-6 ☐
More than 6 ☐

***What is the approximate room area in your office?**

(Sadece bir seçeneği işaretleyiniz.)
Smaller than 15m2 ☐
15 m2 - 30 m2 ☐
31 m2 - 50 m2 ☐
More than 50 m2 ☐

***Please choose the most appropiate orientation of the window in your office?**

(if there is more than one, please reply according to the nearest one)
(Sadece bir seçeneği işaretleyiniz.)
North ☐
South ☐
East ☐
West ☐
South-east ☐
South-west ☐
North-east ☐
North-west ☐
Not sure ☐

***What is the approximate window area in your office?**

(Sadece bir seçeneği işaretleyiniz.)
Smaller than 2 m2 ☐
2 m2-5 m2 ☐
More than 5 m2 ☐

***When you are sitting on your desk, window is on your...**

(Sadece bir seçeneği işaretleyiniz.)
Left ☐
Right ☐
Back ☐
Front ☐
Other ☐

***What is the approxiamte distance between the window and your desk?**

(Sadece bir seçeneği işaretleyiniz.)
Less than 1m ☐
1m-2m ☐
2m-5m ☐
More than 5m ☐

*Are there any shadings/blinds on your office?

(Sadece bir seçeneği işaretleyiniz.)

Yes ☐
No ☐

*During a typical work day do you notice reflected light or glare on your computer screen?

(Bir ya da birden çok seçim yapabilirsiniz.)

No, generally there is no glare ☐
Yes, glare caused by daylight ☐
Yes, glare caused by overhead light ☐
Yes, glare caused by desk/table light ☐
Other ☐

This part aims to understand your satisfaction with visual environment in your existing office

*How would you describe the daylighting availability in your office for the last month?

(Sadece bir seçeneği işaretleyiniz.)

5-Too much ☐
4 ☐
3-Satisfied ☐
2 ☐
1-Too dim ☐

*How would you rate the artificial lighting environment in your office for the last month?

(Sadece bir seçeneği işaretleyiniz.)

5-Too much ☐
4 ☐
3-Satisfied ☐
2 ☐
1-Too dim ☐

*The amount of light at your work area in the last one month is
(Her satırda sadece bir seçeneği işaretleyiniz.)

	5 Too much	4	3 Satisfied	2	1 Too dim
In the room (for general purposes)	☐	☐	☐	☐	☐
On the desk surface for paper based work	☐	☐	☐	☐	☐
At the monitor for computer tasks	☐	☐	☐	☐	☐

*Rank the following tasks according to the frequency during the last month
(Her satırda sadece bir seçeneği işaretleyiniz.)

	5- Always	4-Generally	3-Sometimes	2-Rarely	1-Never
Working with computer	☐	☐	☐	☐	☐
Reading	☐	☐	☐	☐	☐
Writing	☐	☐	☐	☐	☐

***Is there any lighting control systems in your office?**

(Bir ya da birden çok seçim yapabilirsiniz.)

No (manual-on/off) ☐
Yes, manual dimmer ☐
Yes, daylight sensor ☐
Yes, motion sensor ☐
Yes, time scheduled control ☐
I don't have an idea ☐

***Do you have a personal desk/table lamp which can be only controlled by you?**

(Sadece bir seçeneği işaretleyiniz.)

No ☐
Yes, but I never use it ☐
Yes, but I rarely use it ☐
Yes, I sometimes use it ☐
Yes, and I generally use it ☐
Yes, and I always use it ☐

***Son bir ayda, güneşkırıcı/gölgeleme elemanını ne kadar sık kontrol ettiniz?**

(Sadece bir seçeneği işaretleyiniz.)

Günden birden fazla ☐
Haftadan birden fazla ☐
Mevsime ve gök durumuna göre farklılıklar gösteriyor ☐
En uygun pozisyona getiriyor ve genellikle o durumda bırakıyorum ☐
Otomatik kontrol sistemi ile kontrol ediliyor ☐
Kontrol etmiyorum ☐

Bu bölümde aydınlatma elemanlarını manuel (elle) kontrol etme alışkanlığınıza ilişkin bilgi edinmek istiyoruz.

***Which one best describes the frequency of your manual lighting control through the day?**

(Bir ya da birden çok seçim yapabilirsiniz.)

Several times during a day (depending on the absences) ☐
Several times during a day (depending on the daylight penetration) ☐
During entrance, lunch breaks and leaving ☐
Twice a day (only when entering in the beginning of the day and when departing at the end of the day ☐
Generally I don't control it ☐

***Please rate the following reasons on your manual lighting control over fixtures/systems?**

(Her satırda sadece bir seçeneği işaretleyiniz.)

	Always	Generally	Sometimes	Rarely	Never
To obtain visual comfort (increase/decrease illuminance levelavoid glare)	☐	☐	☐	☐	☐
For energy saving	☐	☐	☐	☐	☐
To indicate your occupancy/absence	☐	☐	☐	☐	☐
Colleagues? request	☐	☐	☐	☐	☐
For computer work	☐	☐	☐	☐	☐
For reading printed text	☐	☐	☐	☐	☐
To create atmosphere for work	☐	☐	☐	☐	☐

***Which factors inhibit you from manually controlling lighting fixtures/systems?**
(Her satırda sadece bir seçeneği işaretleyiniz.)

	Always	Generally	Sometimes	Rarely	Never
My colleagues' preferences	☐	☐	☐	☐	☐
To stay focused on my work	☐	☐	☐	☐	☐
My distance to switch is far	☐	☐	☐	☐	☐
I don't care the illuminance level inside	☐	☐	☐	☐	☐
I don't notice the changes in illuminance levels	☐	☐	☐	☐	☐

***How the following factors influence you on turning lights ON manually upon your arrival**
(Her satırda sadece bir seçeneği işaretleyiniz.)

	Always	Generally	Sometimes	Rarely	Never
If the room is dark	☐	☐	☐	☐	☐
To indicate your occupancy	☐	☐	☐	☐	☐
Prefer to work with artificial light	☐	☐	☐	☐	☐
Generally daylight is not sufficient through the day	☐	☐	☐	☐	☐

***How the following factors influence you on switching OFF (or NOT turning lights ON manually) during a regular work day?**
(Her satırda sadece bir seçeneği işaretleyiniz.)

	Always	Generally	Sometimes	Rarely	Never
To avoid excessive light and glare	☐	☐	☐	☐	☐
To save energy	☐	☐	☐	☐	☐
Don't prefer to work with artificial lighting	☐	☐	☐	☐	☐
Usually daylight penetration is sufficient through the day	☐	☐	☐	☐	☐
Location of the light switch	☐	☐	☐	☐	☐
Don't care of the illuminance value inside	☐	☐	☐	☐	☐

***Do you think modifications in the interior layout of your office would increase your manual lighting control?**

(Sadece bir seçeneği işaretleyiniz.)

Yes	☐
No	☐

***How would you rate the following interior architectural factors in terms of increasing your manual lighting control?**
(Her satırda sadece bir seçeneği işaretleyiniz.)

	Always	Generally	Sometimes	Rarely	Never
Position of your desk	☐	☐	☐	☐	☐
Distance between your desk and window	☐	☐	☐	☐	☐
Area of the window	☐	☐	☐	☐	☐
Orientation of the window	☐	☐	☐	☐	☐
Color of the surfaces/objects in the room	☐	☐	☐	☐	☐
Distance between switch and your table	☐	☐	☐	☐	☐

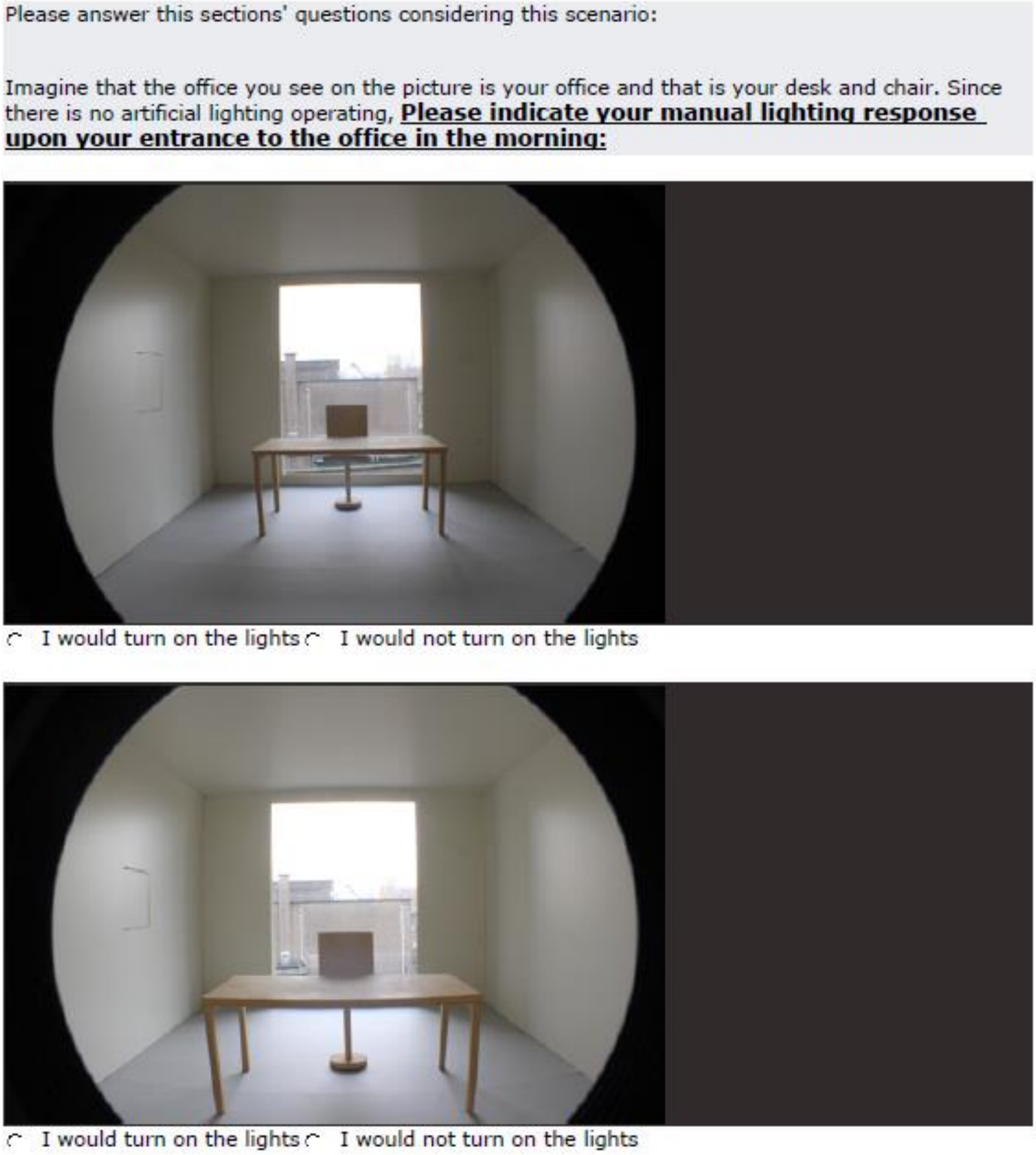
***To what extend do you agree with the following statement: My manual lighting control ...**
(Her satırda sadece bir seçeneği işaretleyiniz.)

	5-Completely Agree	4-Slightly Agree	3-Neither agree or disagree	2-Slightly disagree	1-Disagree
Will increase with a change in my desk's position related to window	☐	☐	☐	☐	☐
Will increase with shortening the area between my desk and window	☐	☐	☐	☐	☐
Will increase with enlarging the window area	☐	☐	☐	☐	☐
Will increase with a change of the orientation of the window	☐	☐	☐	☐	☐
Will increase with a change of color of the objects/surfaces/room	☐	☐	☐	☐	☐
Will increase with shortening the distance between switch and my table	☐	☐	☐	☐	☐

***Which of the below light switch locations would increase your manual lighting control?**

(Bir ya da birden çok seçim yapabilirsiniz.)

At desk near keyboard	☐
Attached to computer monitor	☐
Anywhere on the desk	☐
Near the entrance	☐
No preference	☐

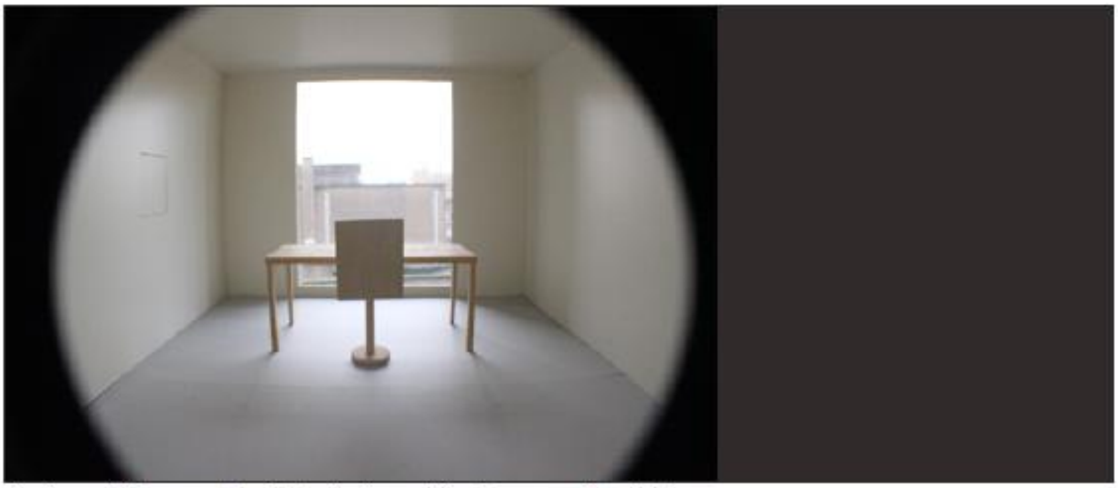


Please answer this sections' questions considering this scenario:

Imagine that the office you see on the picture is your office and that is your desk and chair. Since there is no artificial lighting operating, **Please indicate your manual lighting response upon your entrance to the office in the morning:**

○ I would turn on the lights ○ I would not turn on the lights

○ I would turn on the lights ○ I would not turn on the lights



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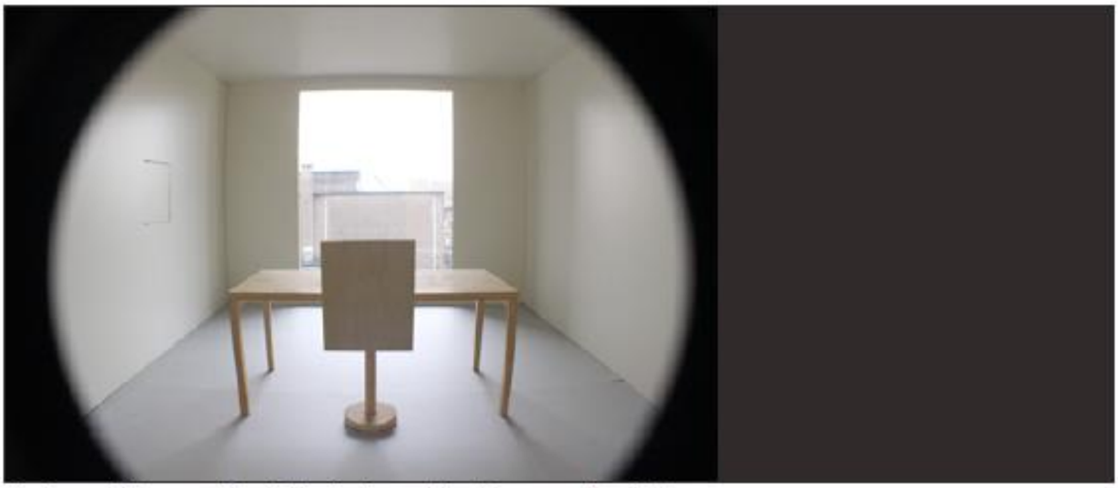

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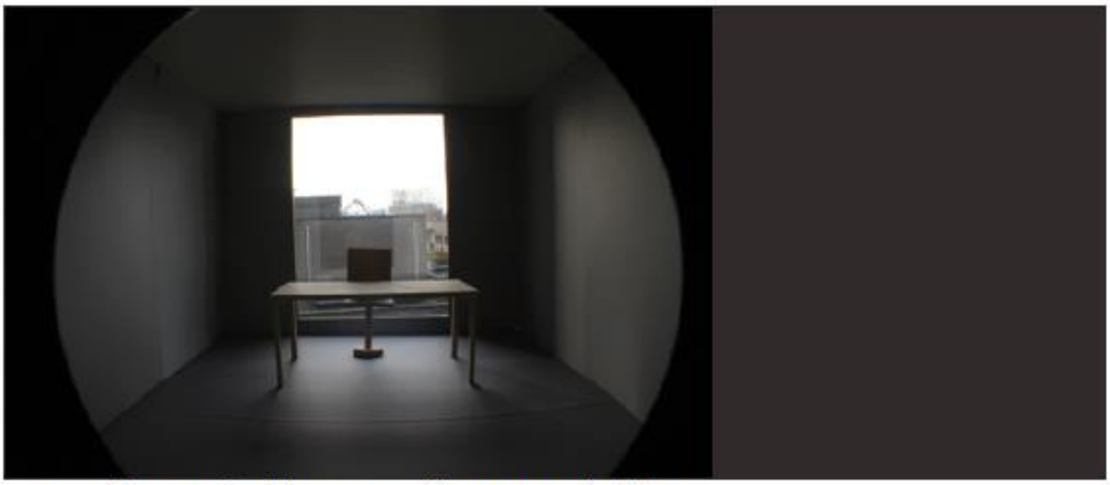

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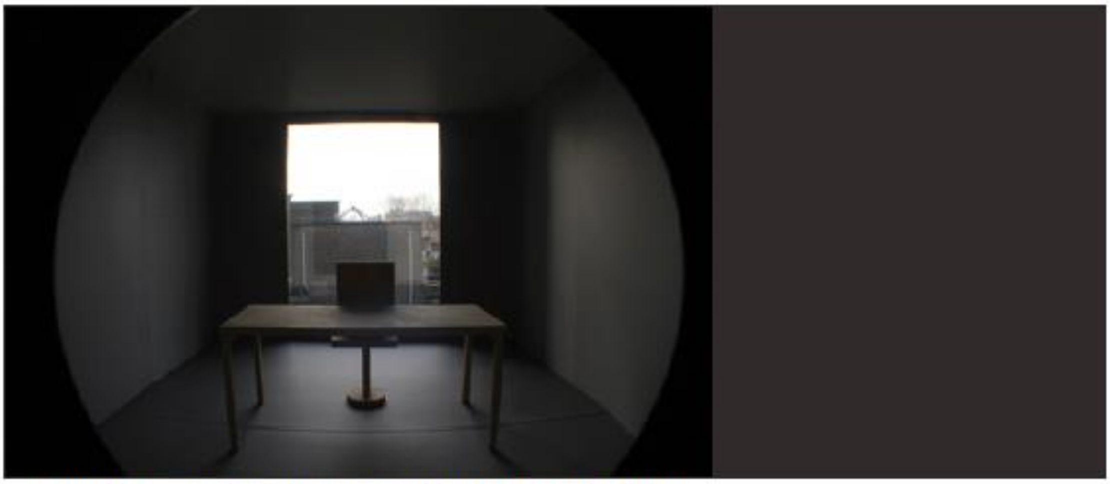

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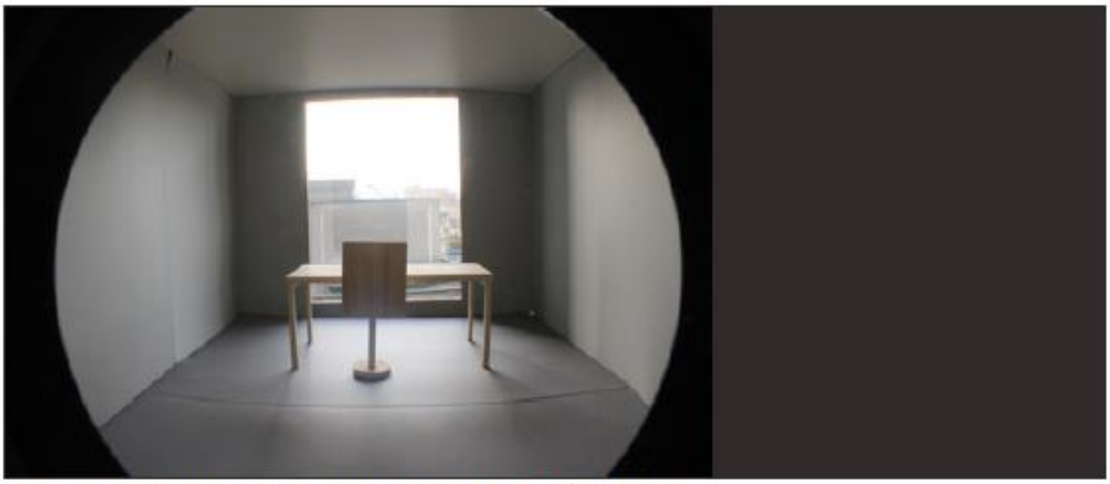
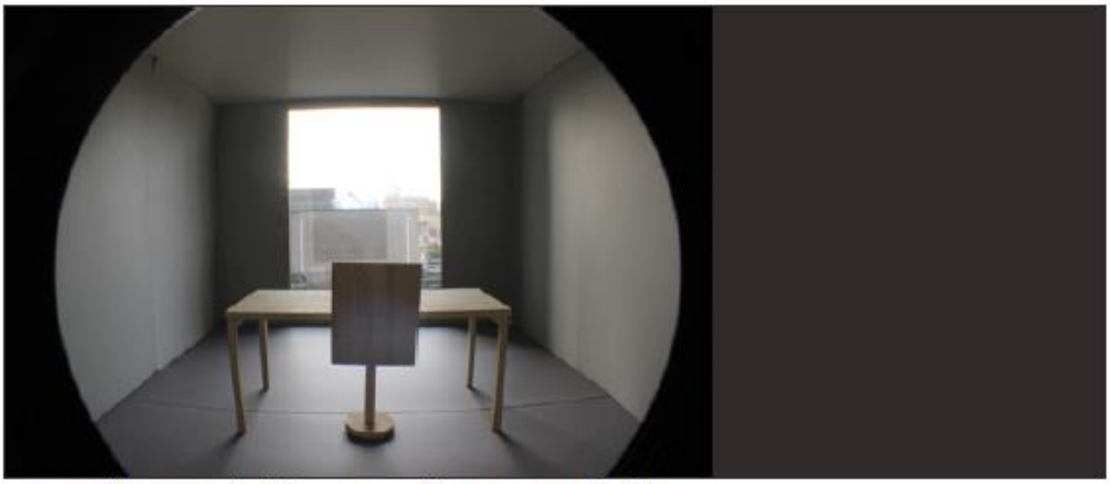


○ I would turn on the lights ○ I would not turn on the lights



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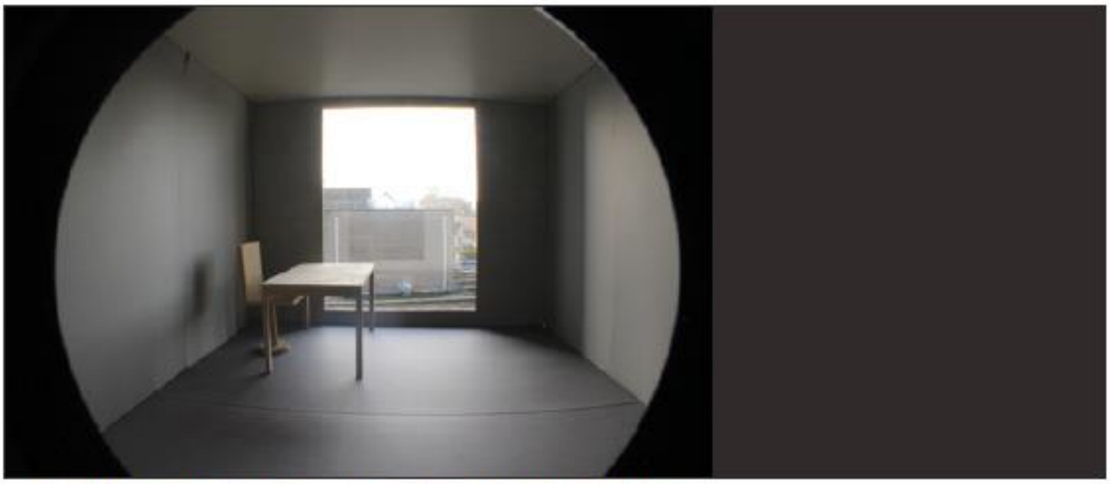

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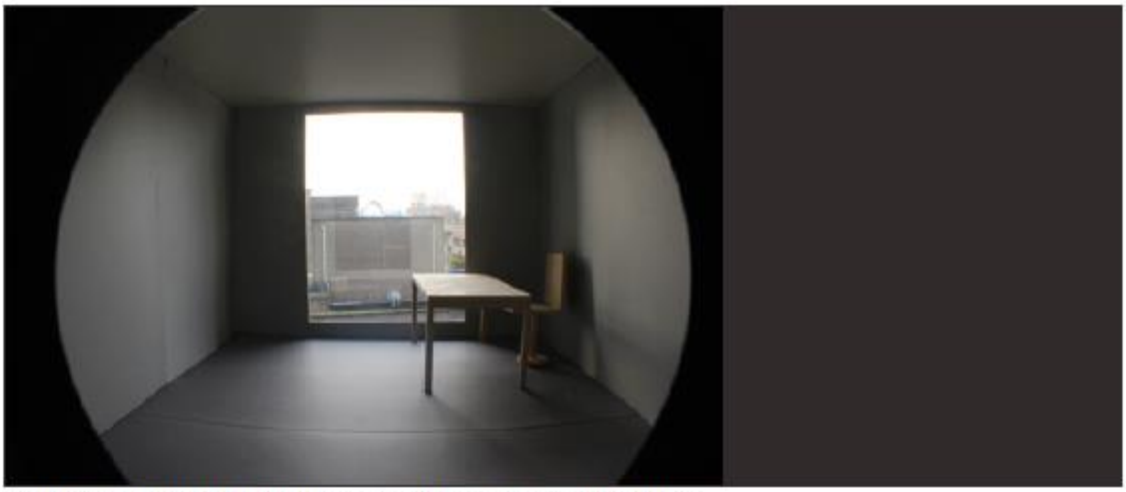
○ I would turn on the lights ○ I would not turn on the lights



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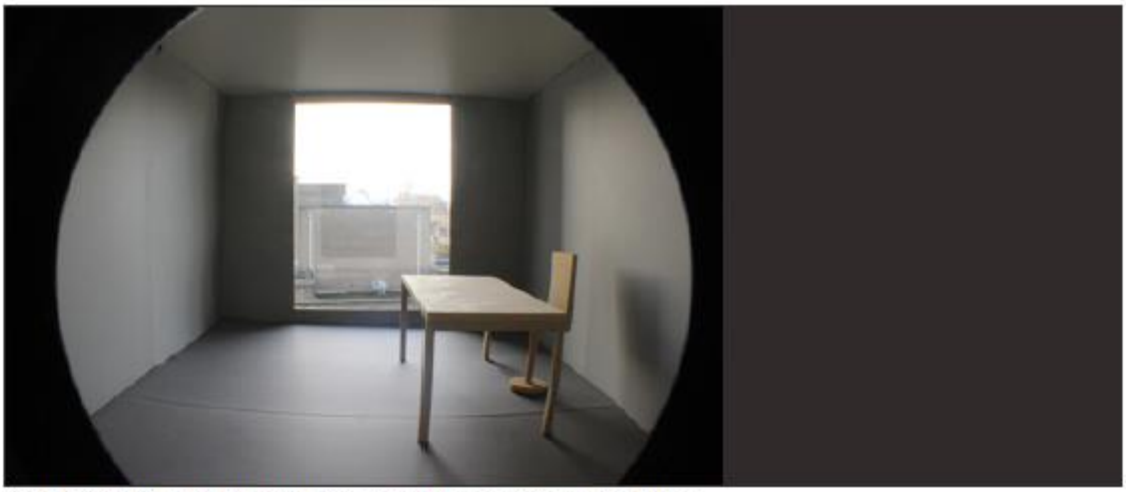

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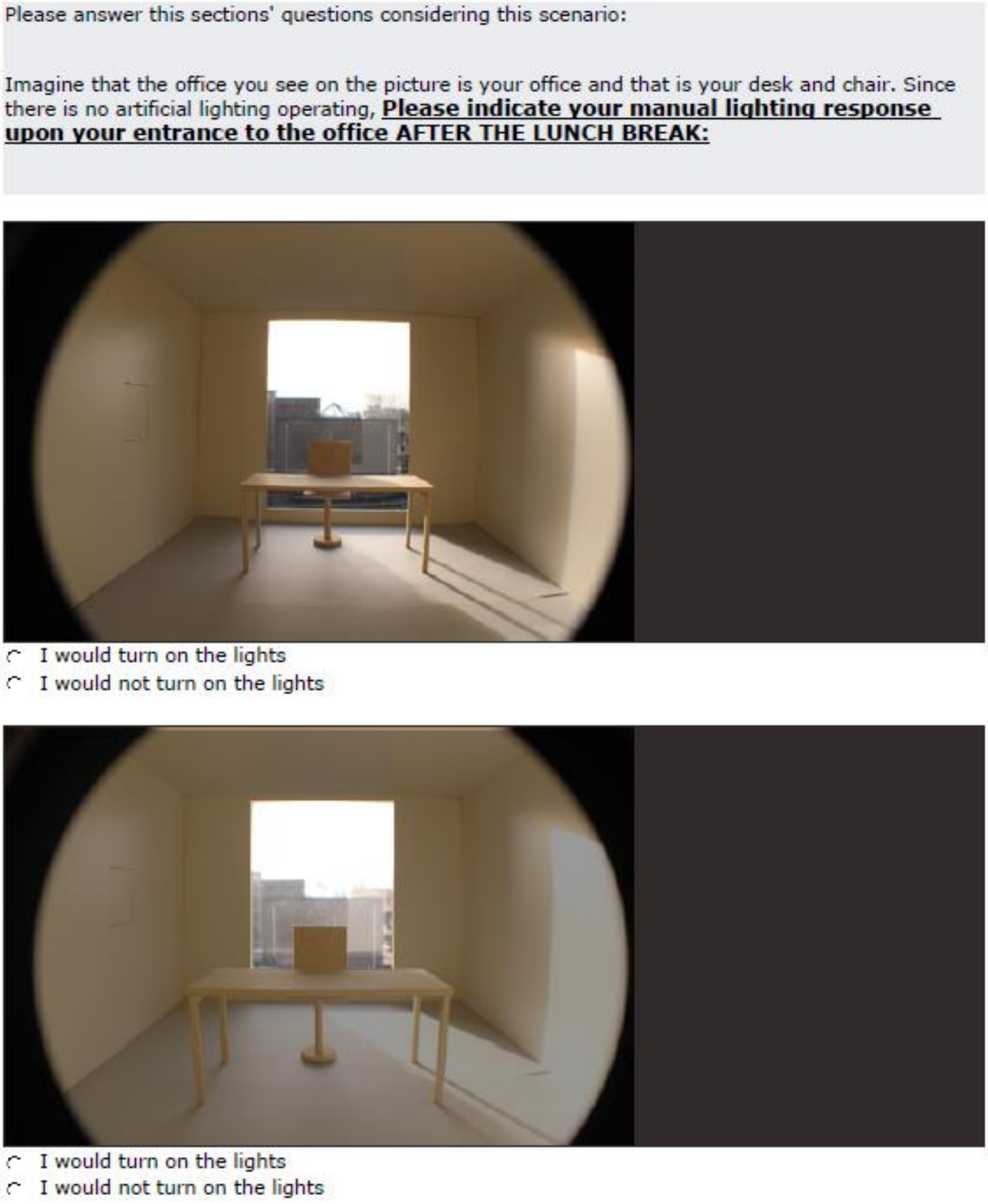


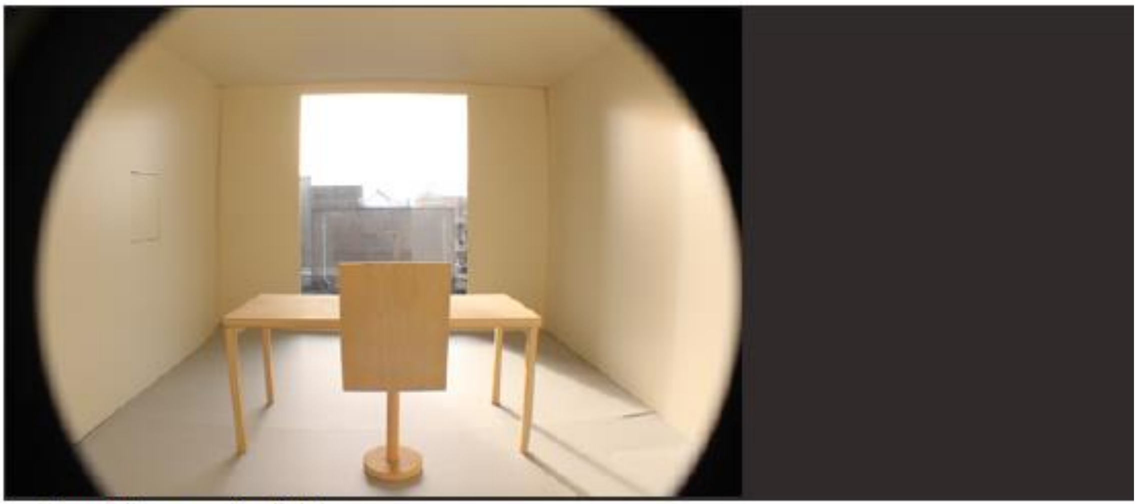
Please answer this sections' questions considering this scenario:

Imagine that the office you see on the picture is your office and that is your desk and chair. Since there is no artificial lighting operating, **Please indicate your manual lighting response upon your entrance to the office AFTER THE LUNCH BREAK:**

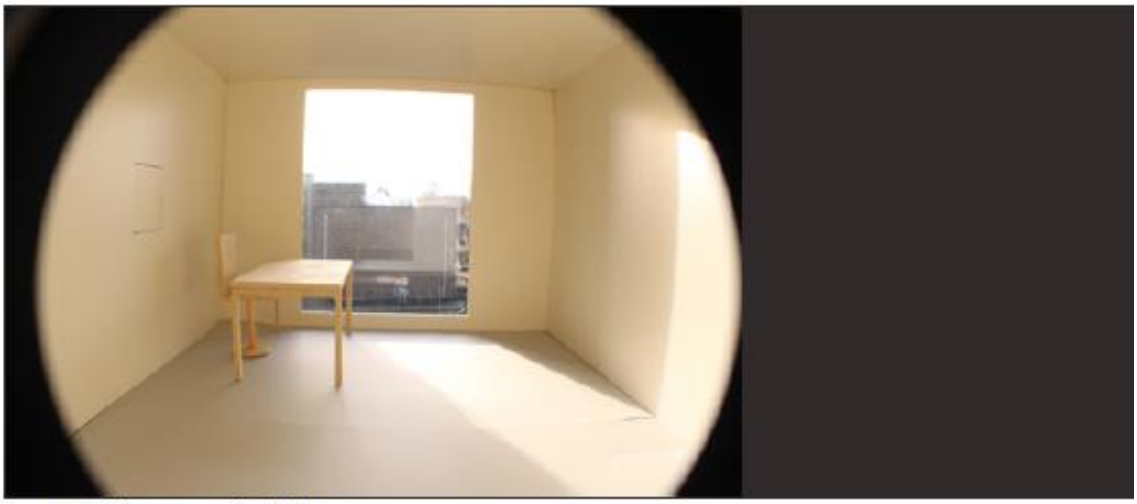
○ I would turn on the lights
○ I would not turn on the lights

○ I would turn on the lights
○ I would not turn on the lights

○ I would turn on the lights
○ I would not turn on the lights

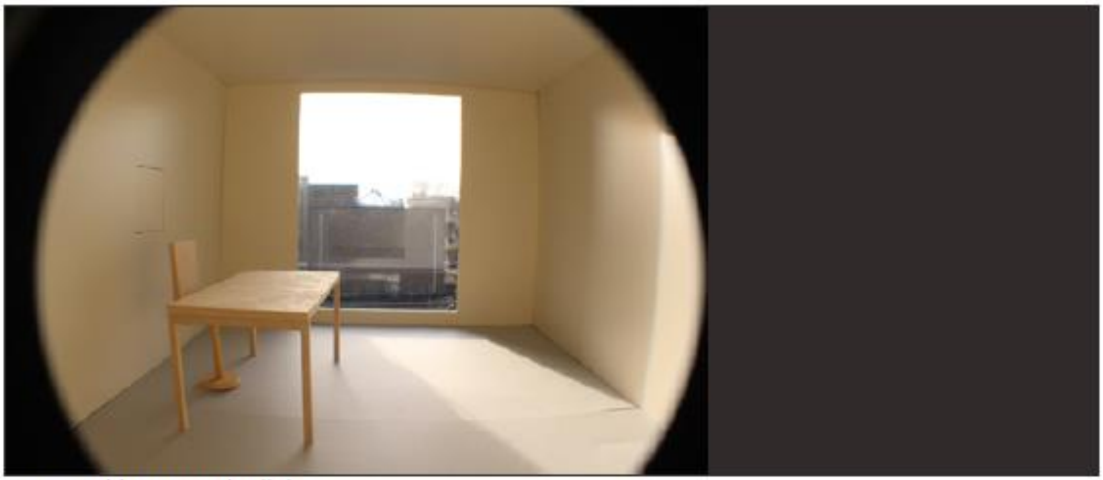


○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights

○ I would not turn on the lights



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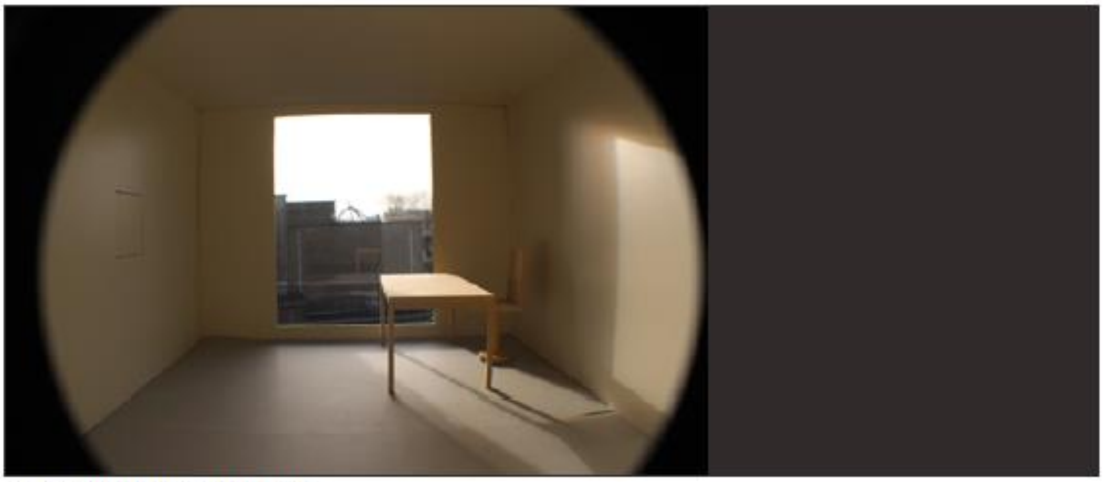

○ I would turn on the lights
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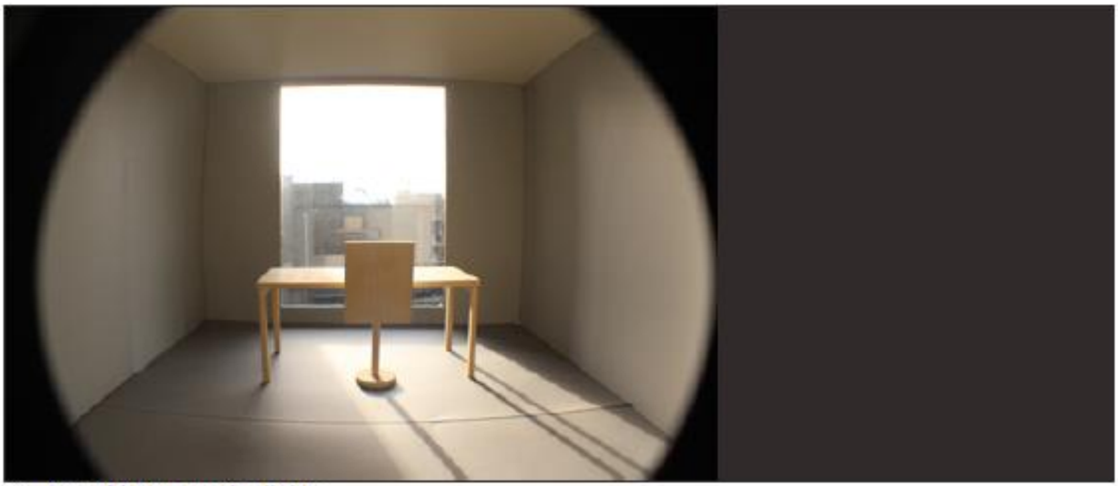
○ I would turn on the lights

○ I would not turn on the lights



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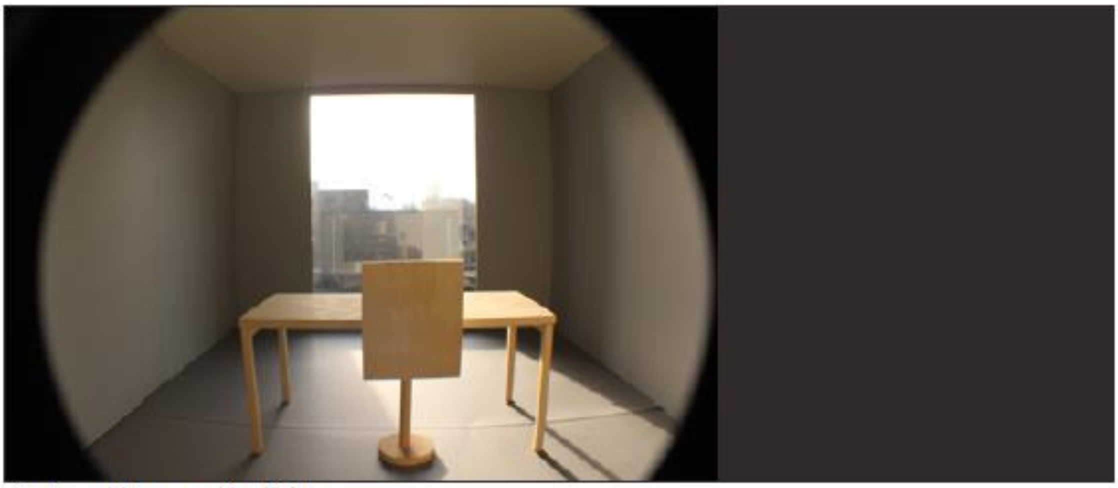
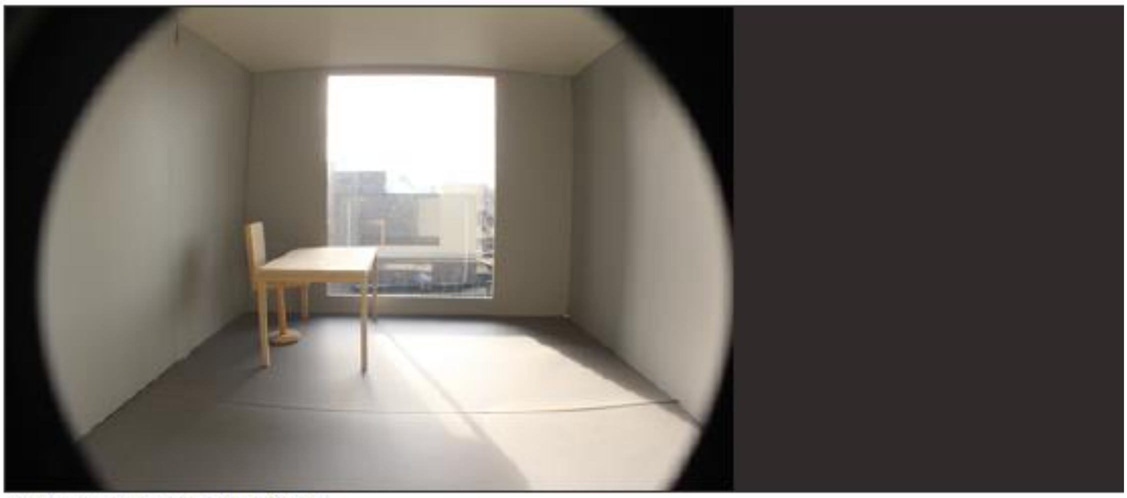
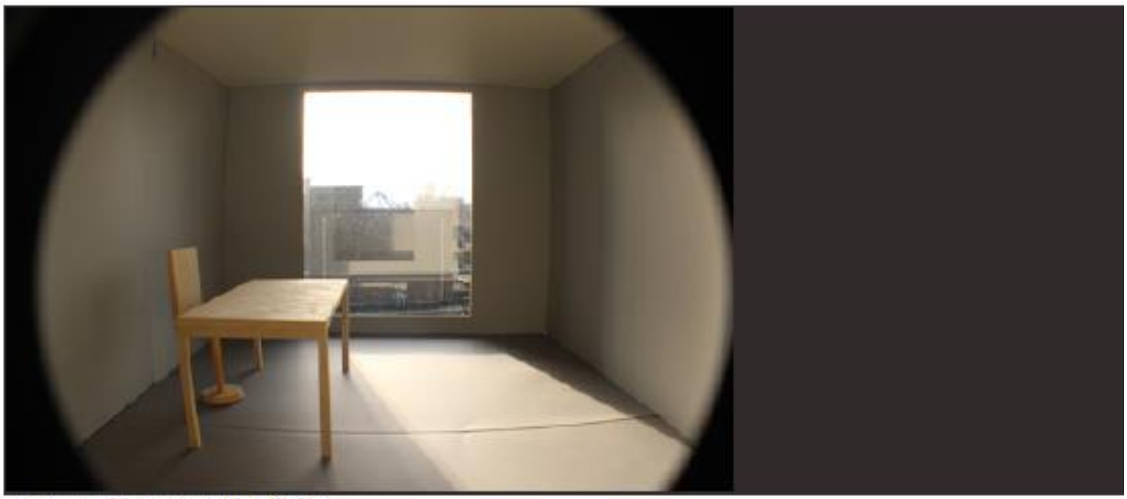


○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
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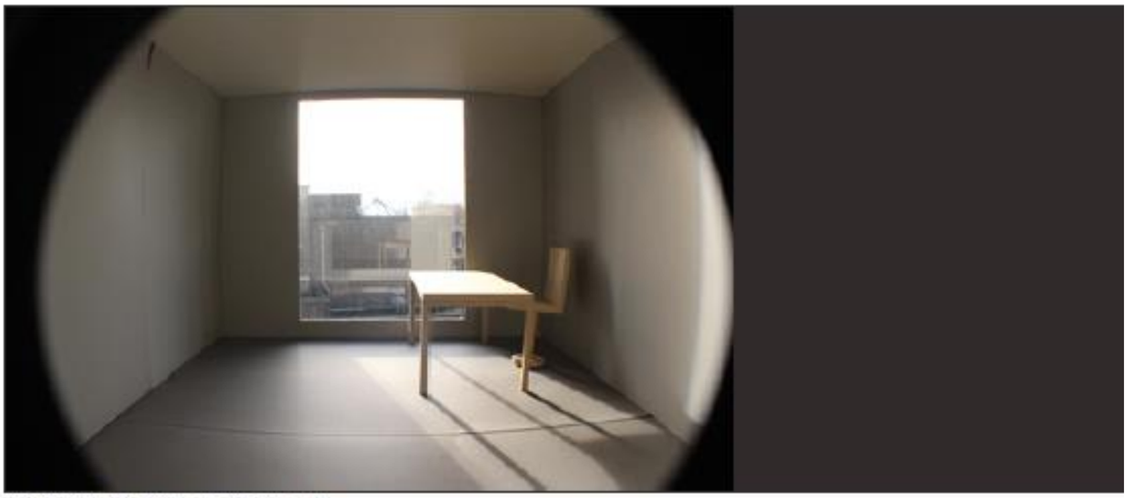


○ I would turn on the lights

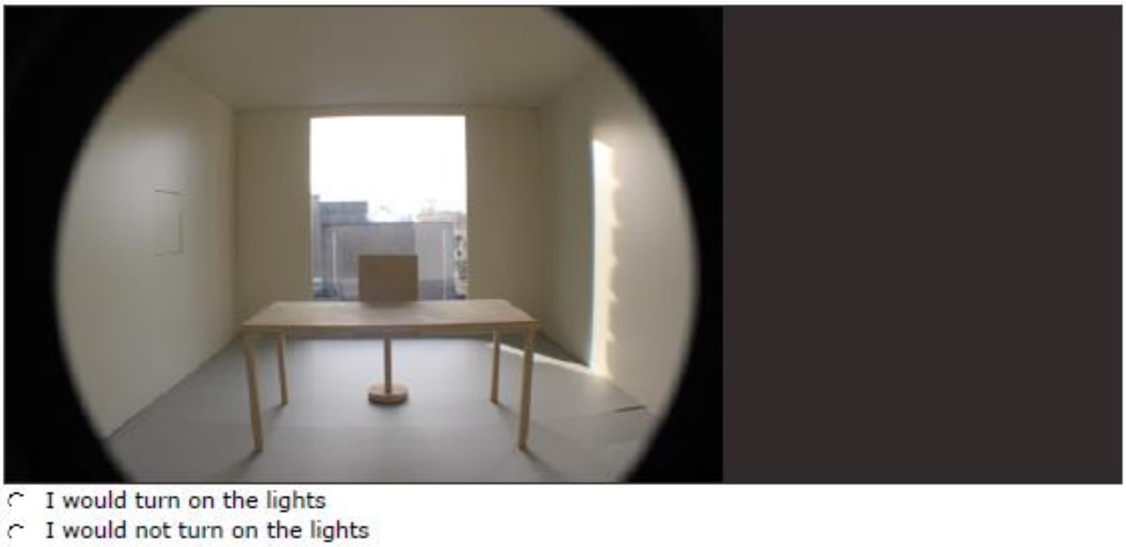
○ I would not turn on the lights

○ I would turn on the lights
○ I would not turn on the lights

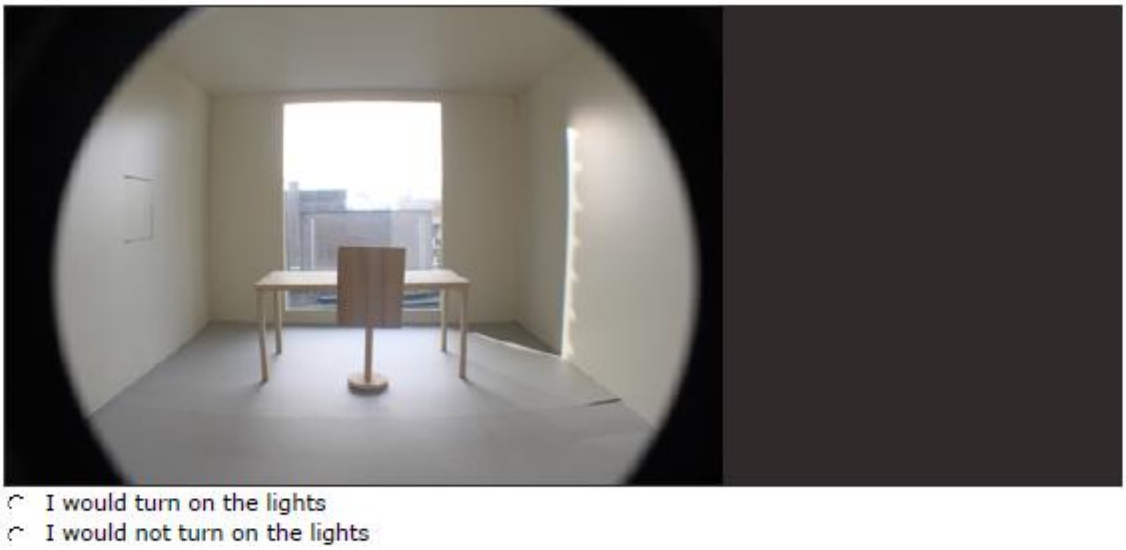
Please answer this sections' questions considering this scenario:

Imagine that the office you see on the picture is your office and that is your desk and chair. Since there is no artificial lighting operating, **Please indicate your manual lighting response upon your entrance to the office AFTER A SHORT BREAK IN THE AFTERNOON:**

○ I would turn on the lights
○ I would not turn on the lights

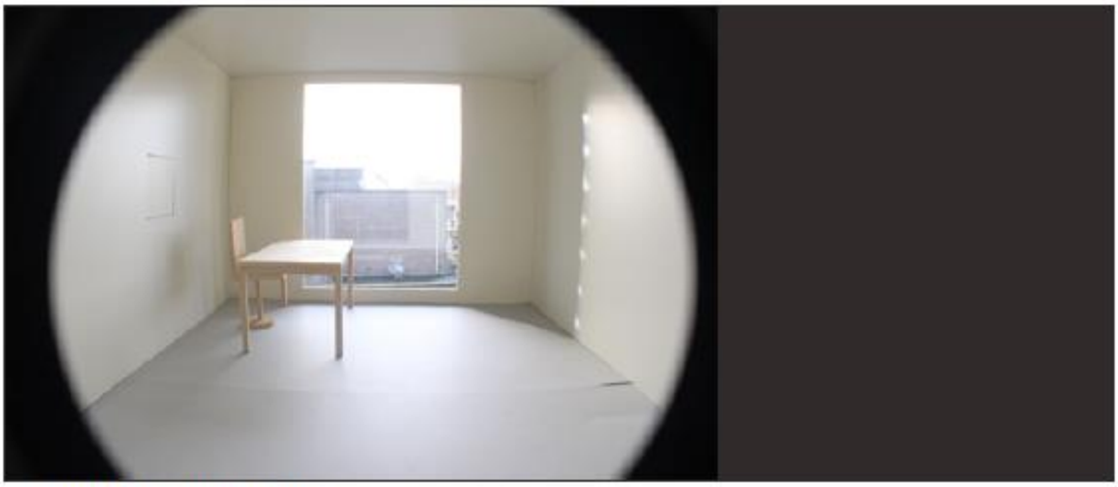


○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights

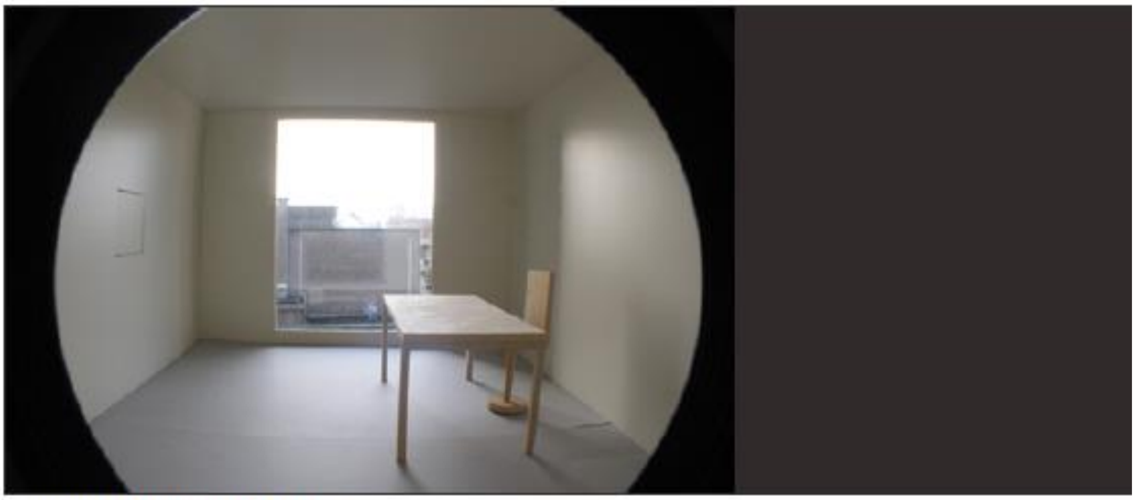
○ I would turn on the lights
○ I would not turn on the lights



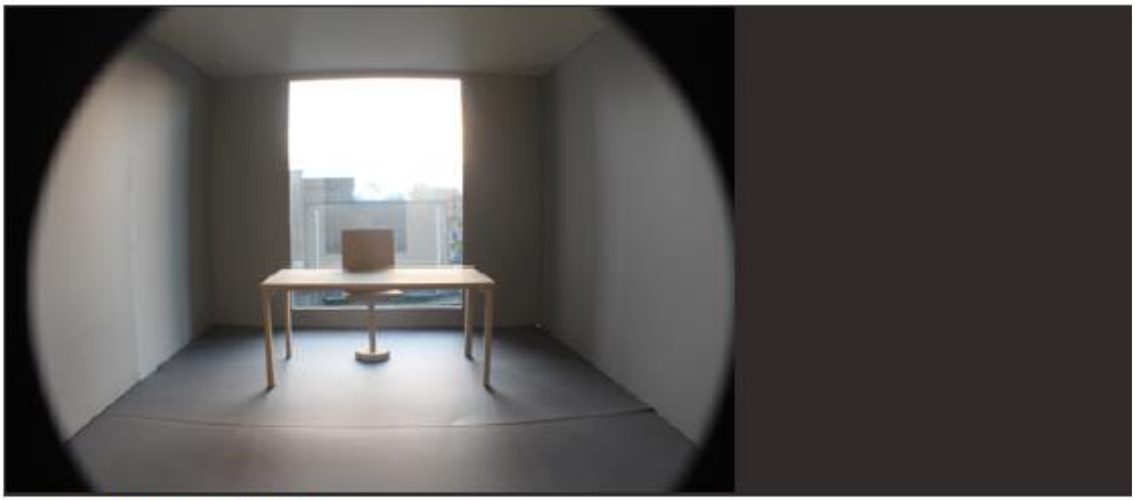
○ I would turn on the lights

○ I would turn on the lights
○ I would not turn on the lights

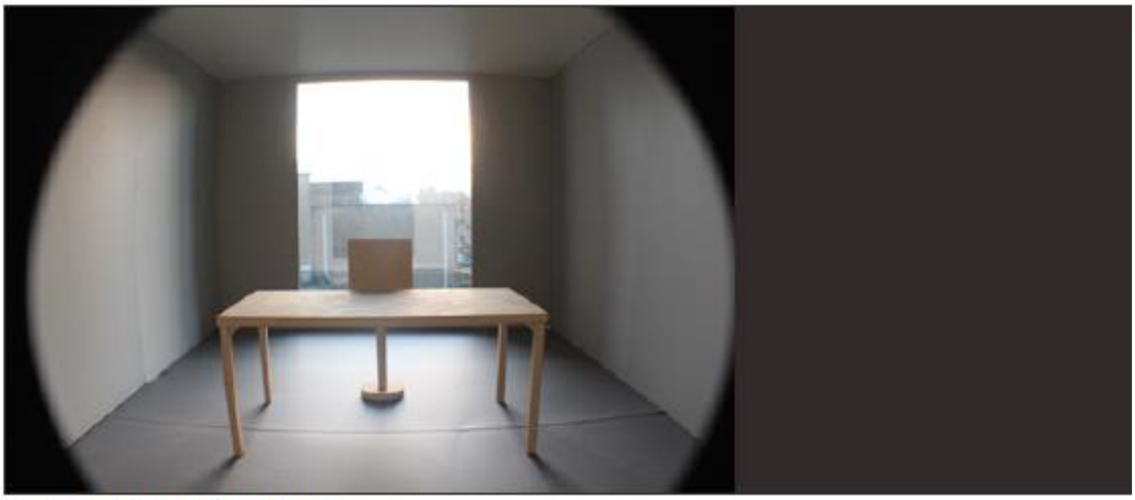
○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights

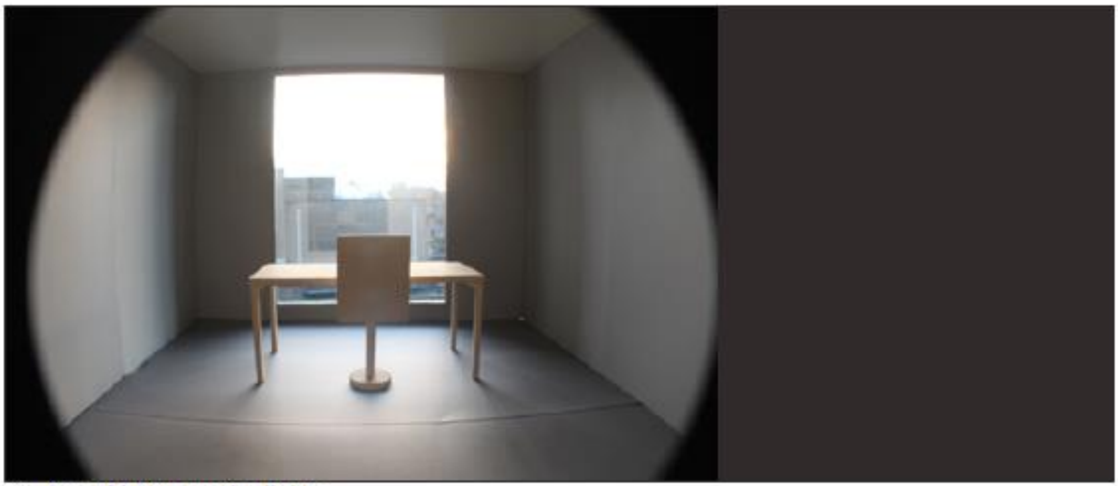


○ I would turn on the lights
○ I would not turn on the lights

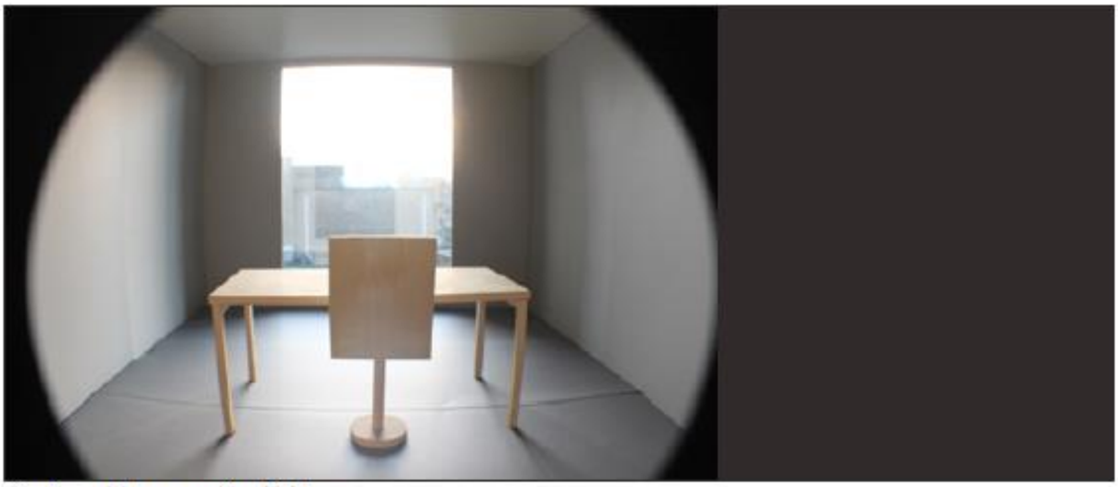


○ I would turn on the lights

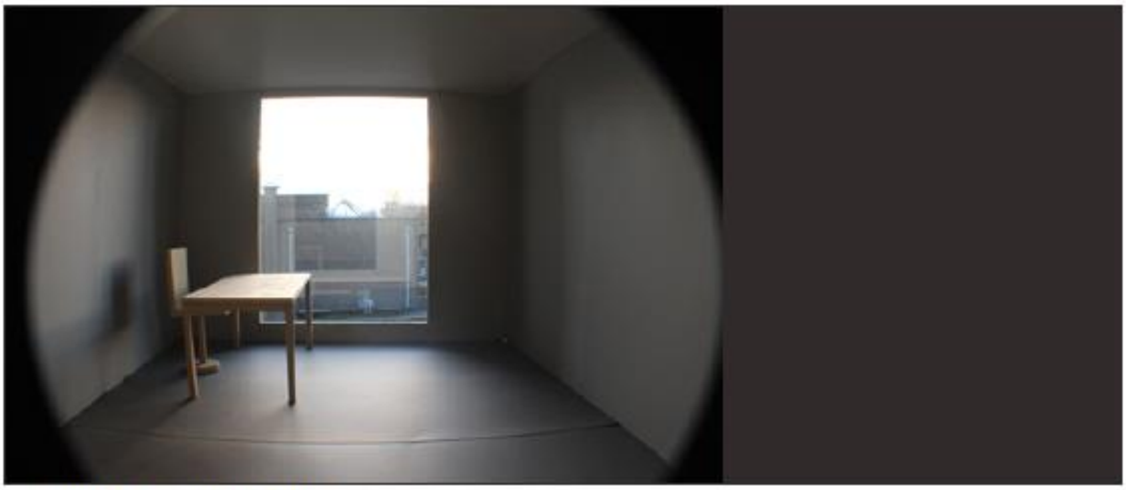
○ I would not turn on the lights



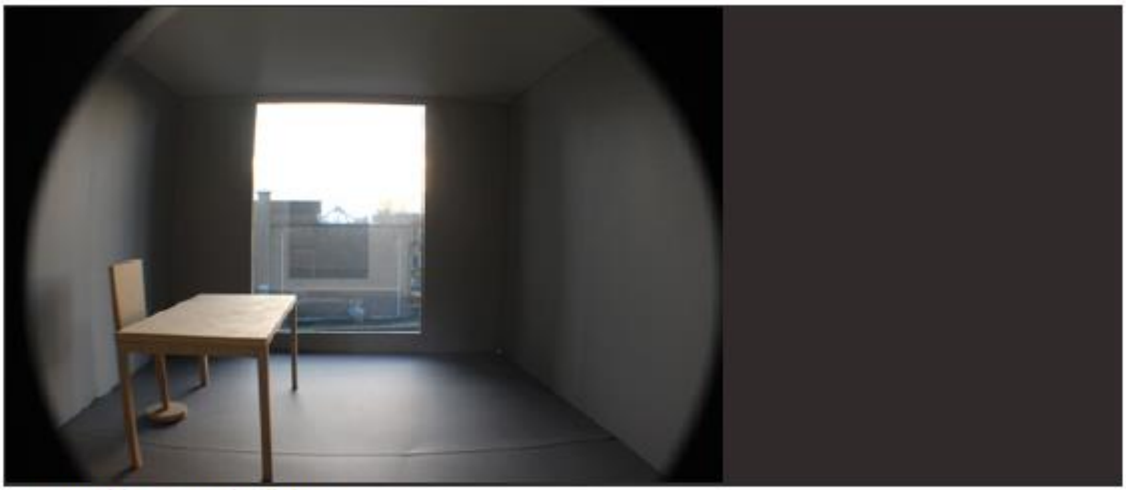
○ I would turn on the lights
○ I would not turn on the lights



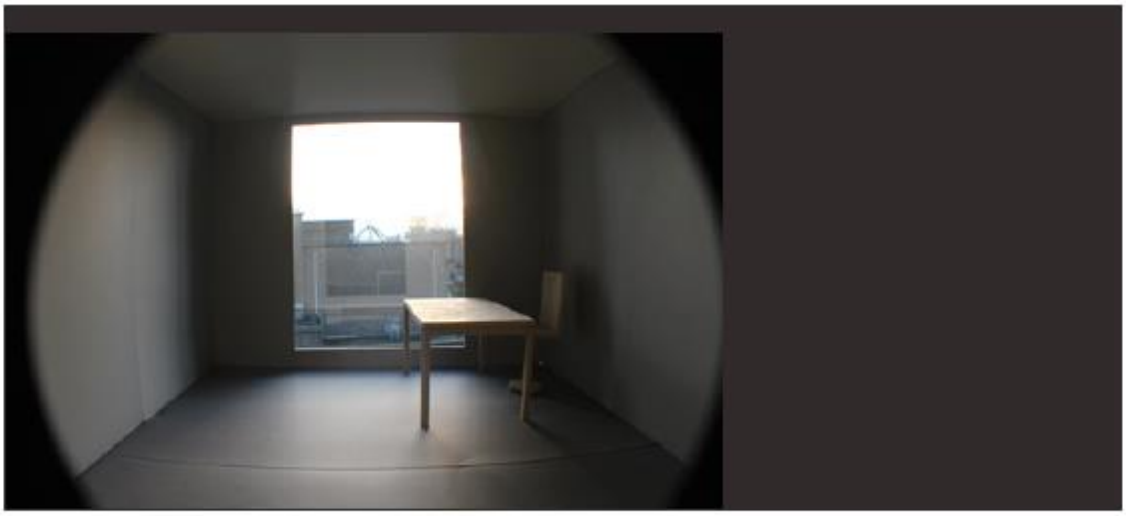
○ I would turn on the lights
○ I would not turn on the lights



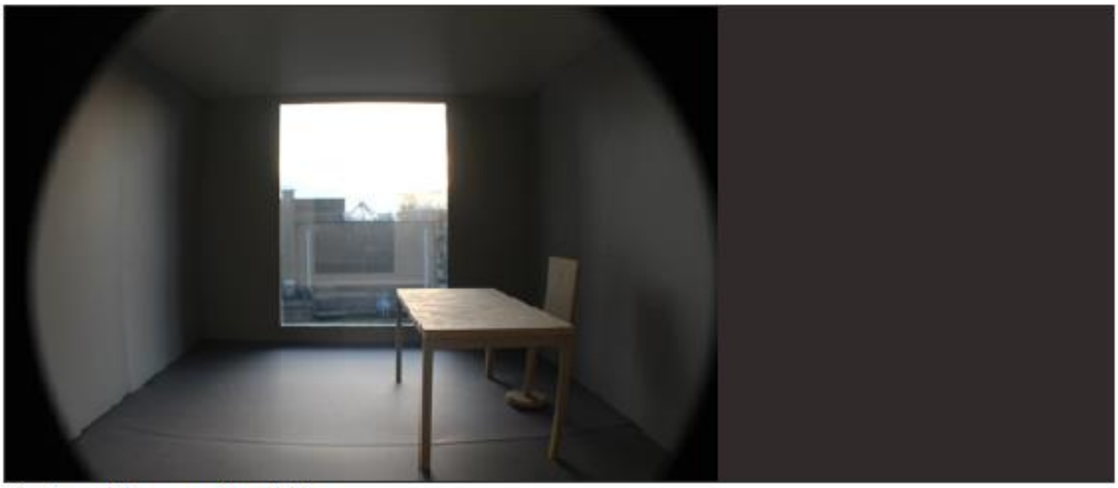
○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights



○ I would turn on the lights
○ I would not turn on the lights

In this section, we want to learn more about you.

***Gender**

(Sadece bir seçeneği işaretleyiniz.)

Woman ☐
Man ☐

***To which age group do you belong?**

(Sadece bir seçeneği işaretleyiniz.)

18-25 ☐
26-35 ☐
36-45 ☐
46-55 ☐
56-65 ☐
65 and above ☐

***Please indicate the last grade or year in school which you completed**

(Sadece bir seçeneği işaretleyiniz.)

Primary ☐
Secondary ☐
Bachelor Degree ☐
Graduate Degree ☐
Other ☐

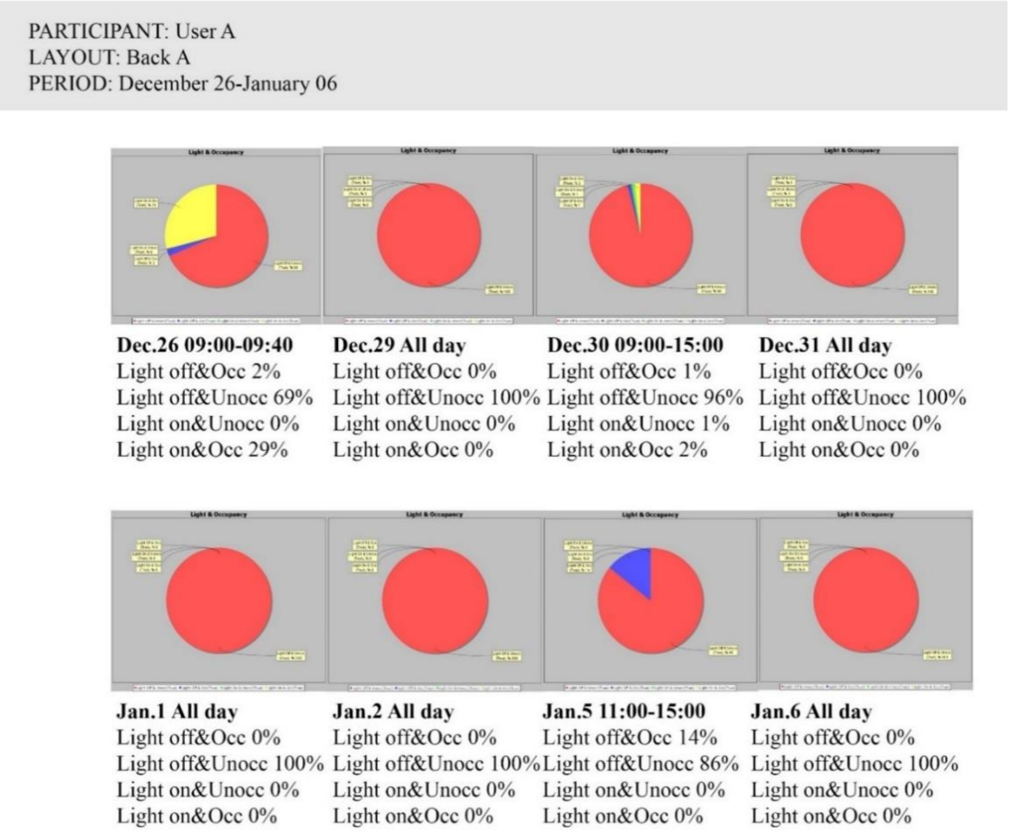
***Are you left handed or right handed?**

(Sadece bir seçeneği işaretleyiniz.)

I'm lefthanded ☐
I'm righthanded ☐

APPENDIX B

MONITORING RESULTS



PARTICIPANT: User A
LAYOUT: Back A
PERIOD: December 26-January 06

Dec.26 09:00-09:40
Light off&Occ 2%
Light off&Unocc 69%
Light on&Unocc 0%
Light on&Occ 29%

Dec.29 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.30 09:00-15:00
Light off&Occ 1%
Light off&Unocc 96%
Light on&Unocc 1%
Light on&Occ 2%

Dec.31 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.1 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

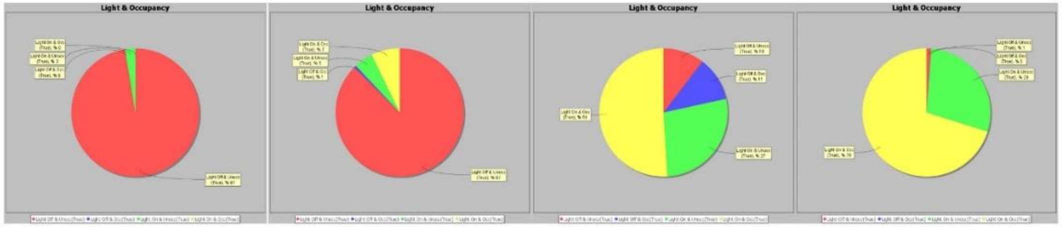
Jan.2 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.5 11:00-15:00
Light off&Occ 14%
Light off&Unocc 86%
Light on&Unocc 0%
Light on&Occ 0%

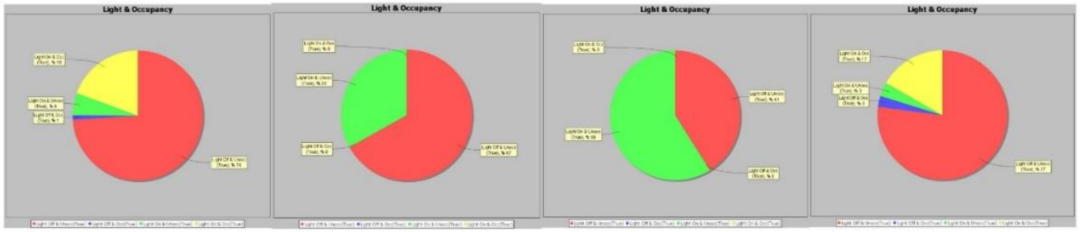
Jan.6 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Figure B.1. Occupancy and artificial lighting condition of User A in Back A layout.

PARTICIPANT: User A
LAYOUT: Back B
PERIOD: January 07-January 19



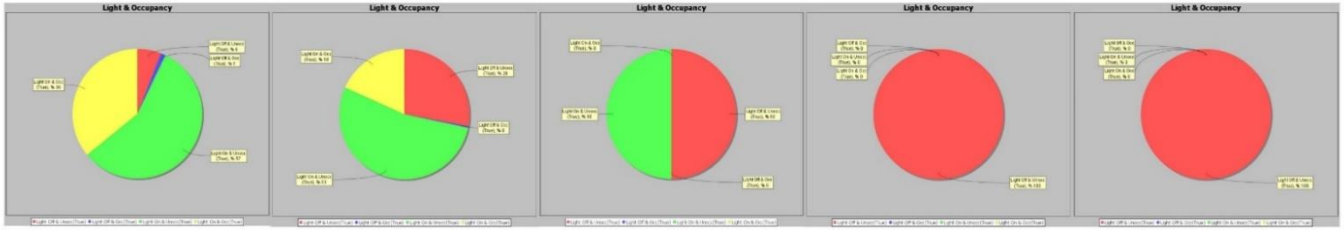
Jan.07 15:00-16:00	**Jan. 08 09:00-17:00**	**Jan.09 15:00-17:00**	**Jan.12 14:00-16:00**
Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 11%	Light off&Occ 0%
Light off&Unocc 97%	Light off&Unocc 87%	Light off&Unocc 10%	Light off&Unocc 1%
Light on&Unocc 3%	Light on&Unocc 5%	Light on&Unocc 27%	Light on&Unocc 29%
Light on&Occ 0%	Light on&Occ 7%	Light on&Occ 51%	Light on&Occ 70%



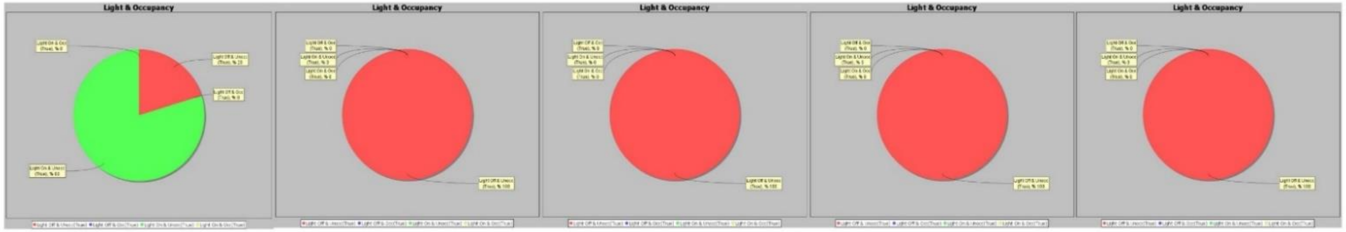
Jan.13 12:00-17:00	**Jan.14 15:00-16:00**	**Jan. 16 15:00-16:00**	**Jan.19 15:00-16:00**
Light off&Occ 1%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 3%
Light off&Unocc 74%	Light off&Unocc 67%	Light off&Unocc 41%	Light off&Unocc 77%
Light on&Unocc 6%	Light on&Unocc 33%	Light on&Unocc 59%	Light on&Unocc 3%
Light on&Occ 19%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 17%

Figure B.2. Occupancy and artificial lighting condition of User A in Back B layout.

PARTICIPANT: User A
LAYOUT: Front A
PERIOD: January 19-January 30



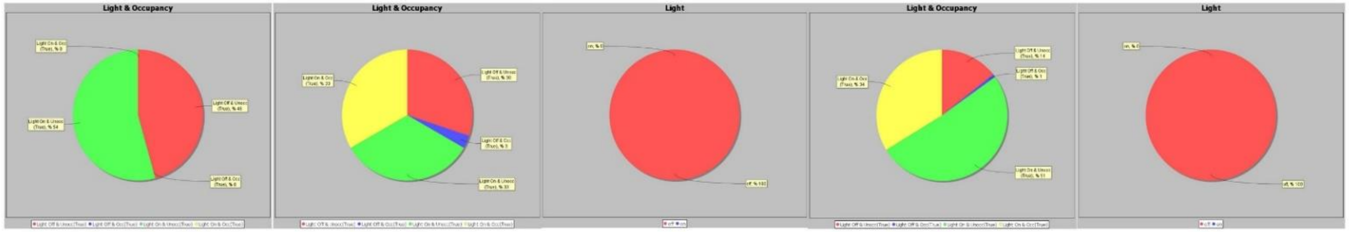
Jan.19 14:00-16:00	**Jan. 20 10:00-16:00**	**Jan.21 14:00-15:00**	**Jan.22 All day**	**Jan.23 All day**
Light off&Occ 1%	Light off&Occ 1%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%
Light off&Unocc 6%	Light off&Unocc 28%	Light off&Unocc 50%	Light off&Unocc 100%	Light off&Unocc 100%
Light on&Unocc 57%	Light on&Unocc 53%	Light on&Unocc 50%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 36%	Light on&Occ 18%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



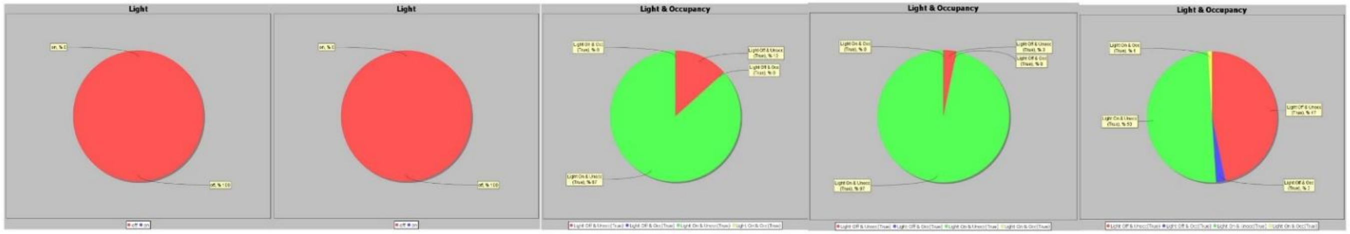
Jan.26 15:00-15:20	**Jan. 27 All day**	**Jan. 28 All day**	**Jan. 29 All day**	**Jan. 30 All day**
Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%
Light off&Unocc 20%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 100%
Light on&Unocc 80%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.3. Occupancy and artificial lighting condition of User A in Front A layout.

PARTICIPANT: User A
LAYOUT: Front B
PERIOD: February 2- February 16



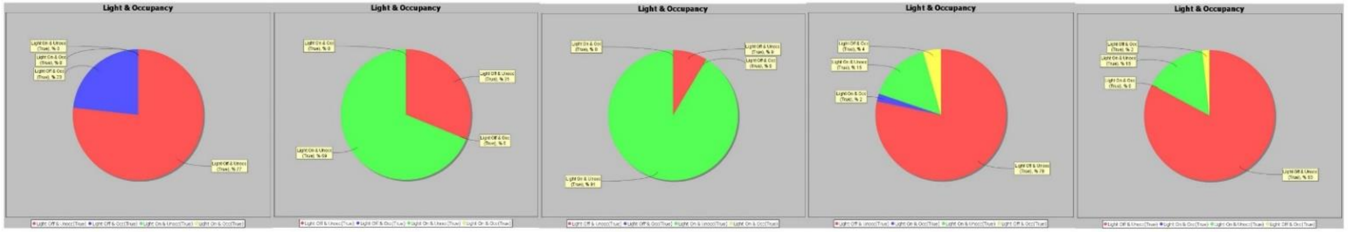
Feb.2 14:00-16:00	**Feb.3 13:00-14:00**	**Feb.4 All day**	**Feb.5 All day**	**Feb.6 All day**
Light off&Occ 1%	Light off&Occ 3%	Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 0%
Light off&Unocc 46%	Light off&Unocc 31%	Light off&Unocc 100%	Light off&Unocc 14%	Light off&Unocc 100%
Light on&Unocc 54%	Light on&Unocc 33%	Light on&Unocc 0%	Light on&Unocc 51%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 33%	Light on&Occ 0%	Light on&Occ 34%	Light on&Occ 0%



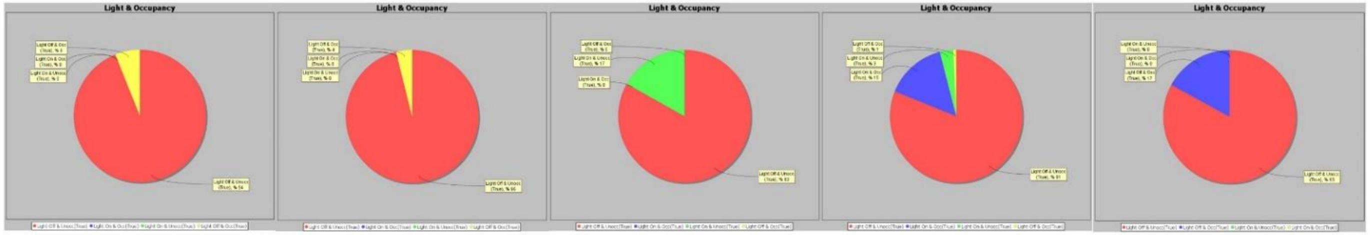
Feb.9 All day	**Feb.10 All day**	**Feb.11 All day**	**Feb.12 15:00-16:20**	**Feb.16 11:0-14:00**
Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 2%
Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 13%	Light off&Unocc 3%	Light off&Unocc 47%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 87%	Light on&Unocc 97%	Light on&Unocc 50%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 1%

Figure B.4. Occupancy and artificial lighting condition of User A in Front B layout.

PARTICIPANT: User A
LAYOUT: Left A
PERIOD: October 31- November 14



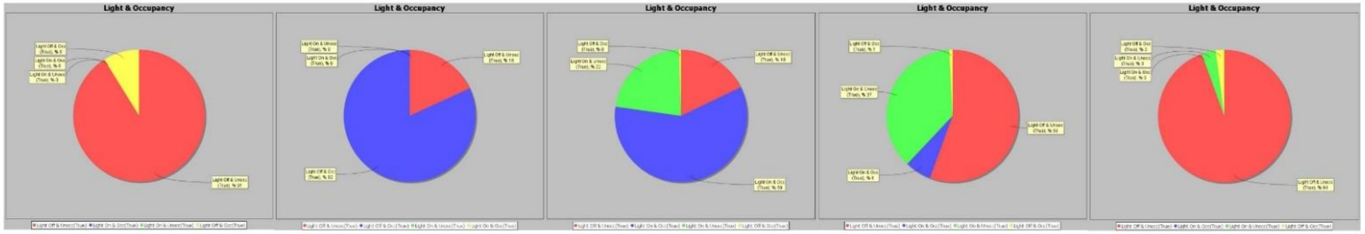
Oct. 31 11:00-11:40	**Nov. 3 14:00-15:40**	**Nov. 4 15:00-15:40**	**Nov. 5 10:00-16:00**	**Nov. 6 11:00-18:00**
Light off&Occ 23%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 4%	Light off&Occ 2%
Light off&Unocc 77%	Light off&Unocc 31%	Light off&Unocc 9%	Light off&Unocc 78%	Light off&Unocc 83%
Light on&Unocc 0%	Light on&Unocc 69%	Light on&Unocc 91%	Light on&Unocc 15%	Light on&Unocc 15%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 2%	Light on&Occ 0%



Nov. 7 11:00-13:00	**Nov. 10 10:00-13:00**	**Nov. 11 11:00-16:00**	**Nov. 12 16:00-18:00**	**Nov. 13 12:30-13:45**
Light off&Occ 6%	Light off&Occ 4%	Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 17%
Light off&Unocc 94%	Light off&Unocc 96%	Light off&Unocc 83%	Light off&Unocc 81%	Light off&Unocc 83%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 17%	Light on&Unocc 3%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 15%	Light on&Occ 0%

Figure B.5. Occupancy and artificial lighting condition of User A in Left A layout.

PARTICIPANT: User A
LAYOUT: Left B
PERIOD: November 17-November 28



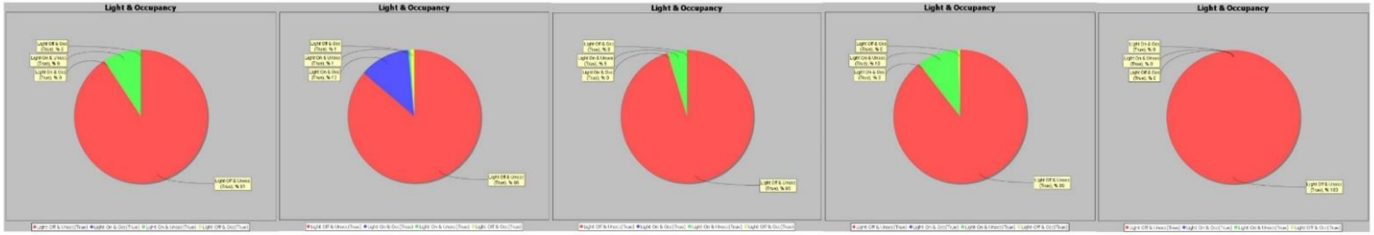
Nov. 17 14:00-15:00
Light off&Occ 9%
Light off&Unocc 91%
Light on&Unocc 0%
Light on&Occ 0%

Nov. 18 09:30-12:00
Light off&Occ 82%
Light off&Unocc 18%
Light on&Unocc 0%
Light on&Occ 0%

Nov. 19 09:00-13:00
Light off&Occ 1%
Light off&Unocc 18%
Light on&Unocc 22%
Light on&Occ 59%

Nov. 20 13:00-16:00
Light off&Occ 1%
Light off&Unocc 56%
Light on&Unocc 37%
Light on&Occ 6%

Nov. 21 12:00-16:00
Light off&Occ 2%
Light off&Unocc 95%
Light on&Unocc 3%
Light on&Occ 0%



Nov. 24 11:00-16:00
Light off&Occ 0%
Light off&Unocc 91%
Light on&Unocc 9%
Light on&Occ 0%

Nov. 25 12:00-15:00
Light off&Occ 1%
Light off&Unocc 86%
Light on&Unocc 1%
Light on&Occ 12%

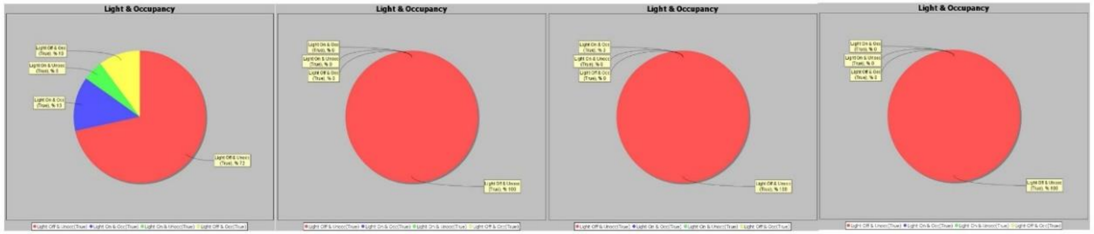
Nov. 26 11:00-16:00
Light off&Occ 0%
Light off&Unocc 95%
Light on&Unocc 5%
Light on&Occ 0%

Nov. 27 11:00-16:00
Light off&Occ 1%
Light off&Unocc 89%
Light on&Unocc 10%
Light on&Occ 0%

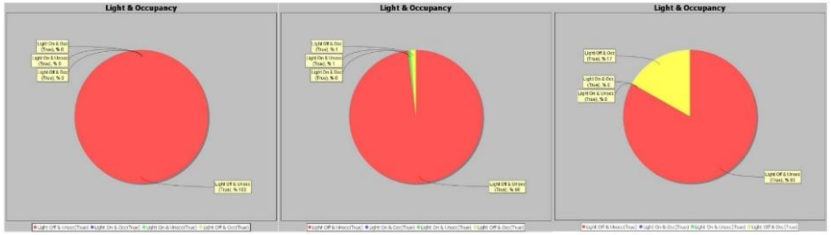
Nov. 28 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Figure B.6. Occupancy and artificial lighting condition of User A in Left B layout.

PARTICIPANT: User A
LAYOUT: Right A
PERIOD: December 3-December 11



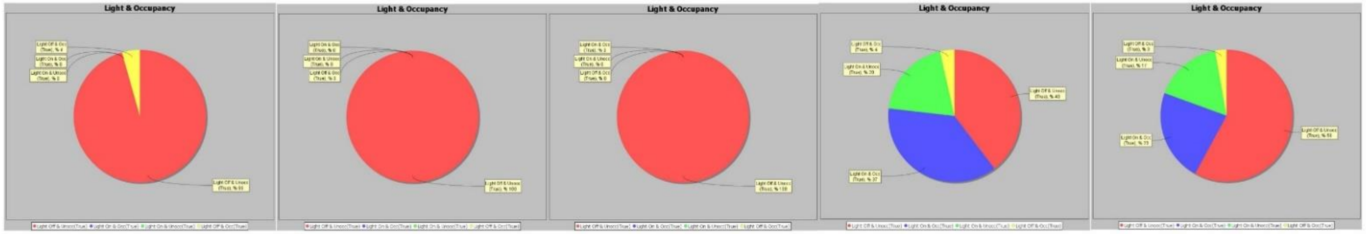
Dec. 3 14:00-17:00	**Dec.4 All day**	**Dec.5 All day**	**Dec.8 All day**
Light off&Occ 10%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%
Light off&Unocc 72%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 100%
Light on&Unocc 5%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 13%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



Dec.9 All day	**Dec.10 12:00-16:00**	**Dec.11 12:00-14:00**
Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 17%
Light off&Unocc 100%	Light off&Unocc 98%	Light off&Unocc 83%
Light on&Unocc 0%	Light on&Unocc 1%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.7. Occupancy and artificial lighting condition of User A in Right A layout.

PARTICIPANT: User A
LAYOUT: Right B
PERIOD: December 12-December 26



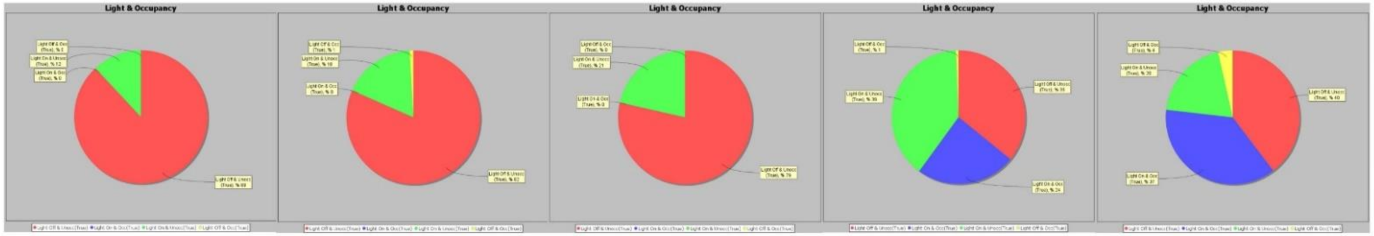
Dec.12 13:00-14:00
Light off&Occ 4%
Light off&Unocc 96%
Light on&Unocc 0%
Light on&Occ 0%

Dec.15 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.16 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.17 10:00-18:00
Light off&Occ 4%
Light off&Unocc 40%
Light on&Unocc 20%
Light on&Occ 37%

Dec.18 09:00-18:00
Light off&Occ 3%
Light off&Unocc 58%
Light on&Unocc 17%
Light on&Occ 23%



Dec. 19 All day
Light off&Occ 0%
Light off&Unocc 88%
Light on&Unocc 12%
Light on&Occ 0%

Dec.22 13:00-16:00
Light off&Occ 1%
Light off&Unocc 81%
Light on&Unocc 18%
Light on&Occ 0%

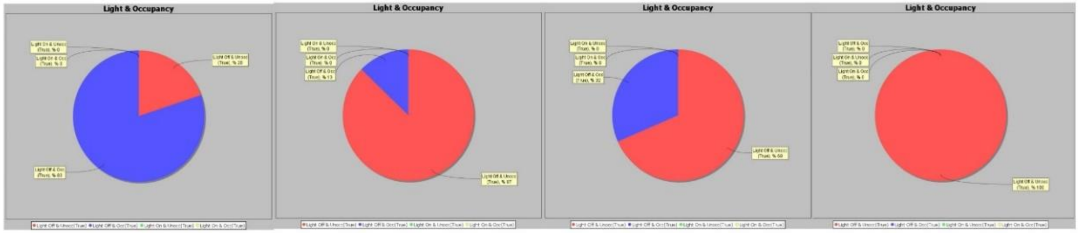
Dec.23 14:00-16:00
Light off&Occ 0%
Light off&Unocc 79%
Light on&Unocc 21%
Light on&Occ 0%

Dec.24 09:00-16:00
Light off&Occ 1%
Light off&Unocc 36%
Light on&Unocc 39%
Light on&Occ 24%

Dec.25 14:00-16:00
Light off&Occ 4%
Light off&Unocc 40%
Light on&Unocc 19%
Light on&Occ 37%

Figure B.8. Occupancy and artificial lighting condition of User A in Right B layout.

PARTICIPANT: User B
LAYOUT: Back A
PERIOD: December 26-January 6

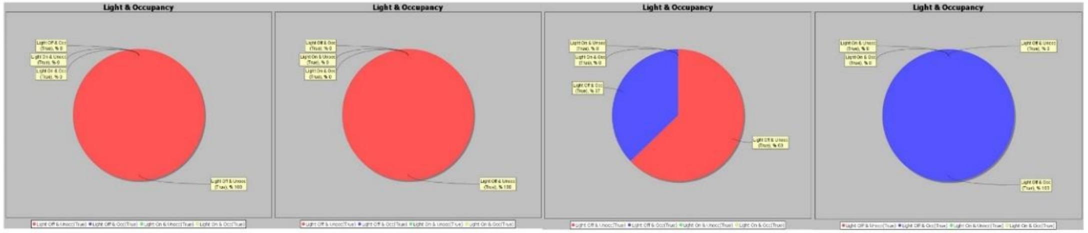


Dec.26 15:00-15:40
Light off&Occ 80%
Light off&Unocc 20%
Light on&Unocc 0%
Light on&Occ 0%

Dec.29 All day
Light off&Occ 13%
Light off&Unocc 87%
Light on&Unocc 0%
Light on&Occ 0%

Dec.30 17:00-17:40
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec. 31 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%



Jan.01 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

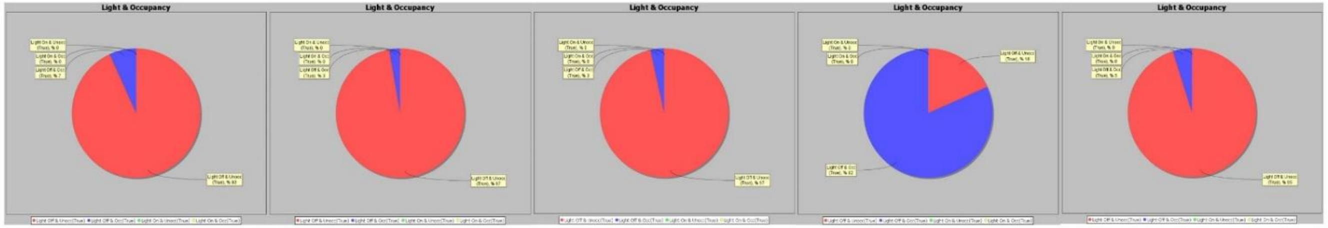
Jan.02 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.05 13:00-14:00
Light off&Occ 37%
Light off&Unocc 63%
Light on&Unocc 0%
Light on&Occ 0%

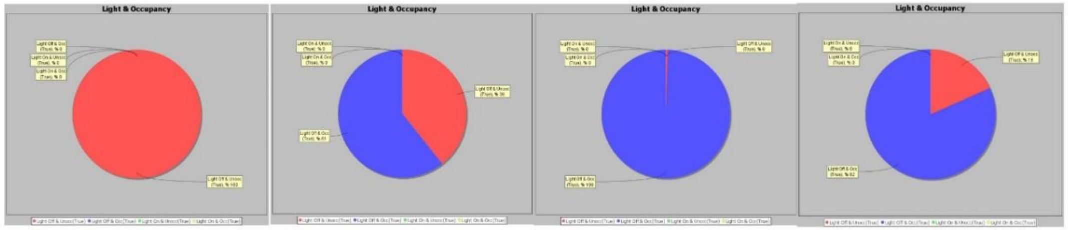
Jan.06 13:00-14:00
Light off&Occ 100%
Light off&Unocc 0%
Light on&Unocc 0%
Light on&Occ 0%

Figure B.9. Occupancy and artificial lighting condition of User B in Back A layout.

PARTICIPANT: User B
LAYOUT: Back B
PERIOD: January 07- January 19



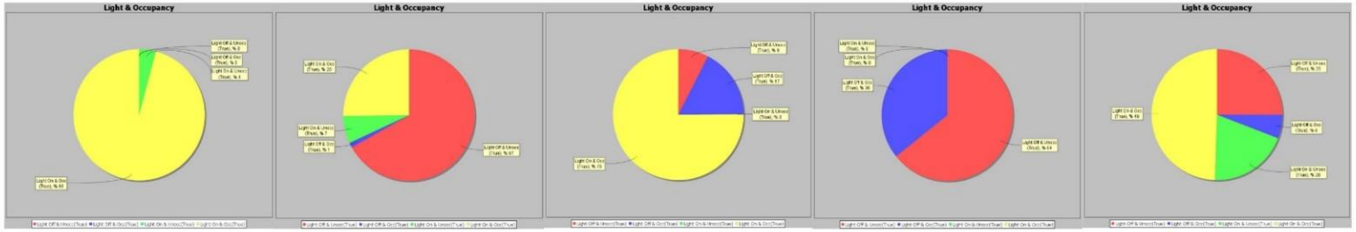
Jan.07 14:00-15:00	**Jan.08 13:00-13:40**	**Jan. 09 12:00-12:40**	**Jan.12 12:00-12:40**	**Jan.13 12:00-12:40**
Light off&Occ 7%	Light off&Occ 3%	Light off&Occ 3%	Light off&Occ 82%	Light off&Occ 5%
Light off&Unocc 93%	Light off&Unocc 97%	Light off&Unocc 97%	Light off&Unocc 18%	Light off&Unocc 95%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



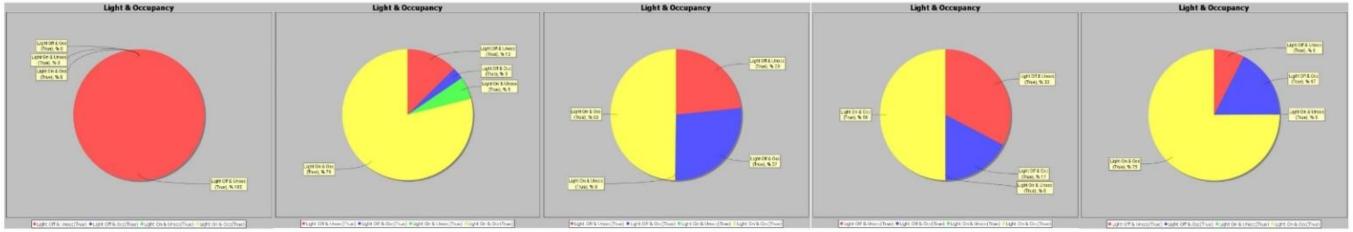
Jan.14 All day	**Jan.15 15:00-15:40**	**Jan.16 10:00-10:40**	**Jan.19 12:00-12:40**
Light off&Occ 0%	Light off&Occ 61%	Light off&Occ 99%	Light off&Occ 82%
Light off&Unocc 100%	Light off&Unocc 39%	Light off&Unocc 1%	Light off&Unocc 18%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.10. Occupancy and artificial lighting condition of User B in Back B layout.

PARTICIPANT: User B
LAYOUT: Front A
PERIOD: January 19- January 30



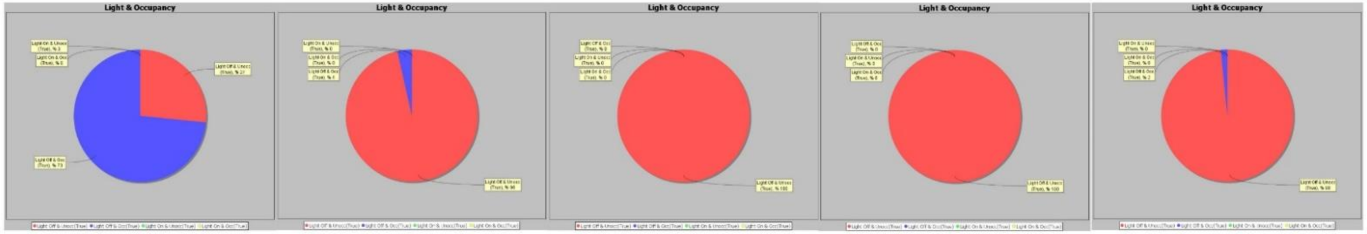
Jan.19 15:00-16:00	**Jan.20 10:00-11:00**	**Jan. 21 11:00-12:00**	**Jan.22 16:00-16:40**	**Jan.23 14:00-16:00**
Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 17%	Light off&Occ 36%	Light off&Occ 6%
Light off&Unocc 0%	Light off&Unocc 67%	Light off&Unocc 8%	Light off&Unocc 64%	Light off&Unocc 25%
Light on&Unocc 4%	Light on&Unocc 7%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 20%
Light on&Occ 96%	Light on&Occ 25%	Light on&Occ 75%	Light on&Occ 0%	Light on&Occ 49%



Jan.26 All day	**Jan.27 14:00-16:00**	**Jan.28 15:00-16:00**	**Jan.29 15:00-17:00**	**Jan.30 17:00-17:40**
Light off&Occ 0%	Light off&Occ 3%	Light off&Occ 27%	Light off&Occ 17%	Light off&Occ 17%
Light off&Unocc 100%	Light off&Unocc 13%	Light off&Unocc 23%	Light off&Unocc 33%	Light off&Unocc 8%
Light on&Unocc 0%	Light on&Unocc 5%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 79%	Light on&Occ 50%	Light on&Occ 50%	Light on&Occ 75%

Figure B.11. Occupancy and artificial lighting condition of User B in Front A layout.

PARTICIPANT: User B
LAYOUT: Front B
PERIOD: February 2- February 16



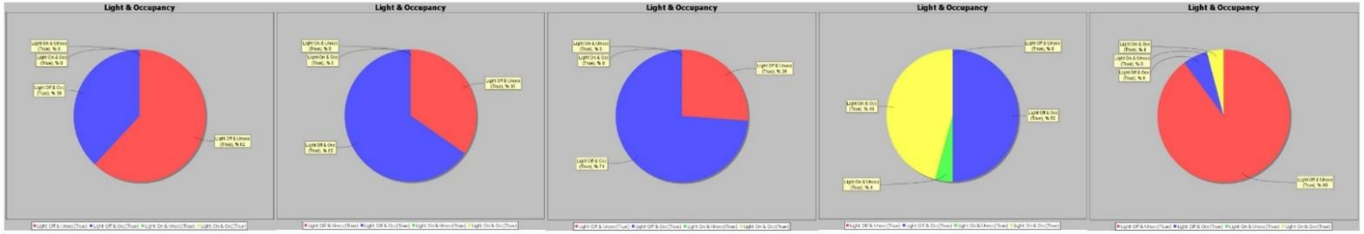
Feb.2 15:00-16:00
Light off&Occ 73%
Light off&Unocc 27%
Light on&Unocc 0%
Light on&Occ 0%

Feb.03 10:00-11:00
Light off&Occ 4%
Light off&Unocc 96%
Light on&Unocc 0%
Light on&Occ 0%

Feb.04 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Feb.05 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Feb.06 14:00-15:00
Light off&Occ 2%
Light off&Unocc 98%
Light on&Unocc 0%
Light on&Occ 0%



Feb.10 12:00-13:00
Light off&Occ 38%
Light off&Unocc 62%
Light on&Unocc 0%
Light on&Occ 0%

Feb.11 14:00-17:00
Light off&Occ 65%
Light off&Unocc 35%
Light on&Unocc 0%
Light on&Occ 0%

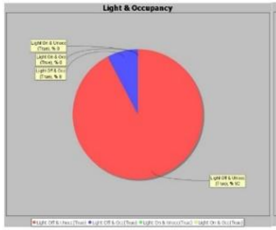
Feb.12 16:00-17:00
Light off&Occ 74%
Light off&Unocc 26%
Light on&Unocc 0%
Light on&Occ 0%

Feb.13 14:00-15:00
Light off&Occ 50%
Light off&Unocc 0%
Light on&Unocc 4%
Light on&Occ 46%

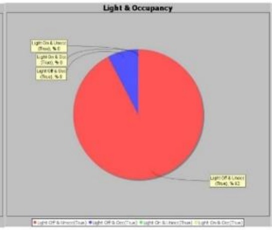
Feb.16 13:00-14:00
Light off&Occ 6%
Light off&Unocc 90%
Light on&Unocc 0%
Light on&Occ 4%

Figure B.12. Occupancy and artificial lighting condition of User B in Front B layout.

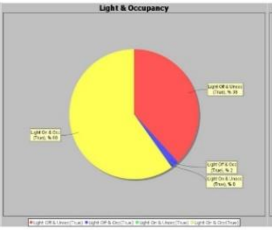
PARTICIPANT: User B
LAYOUT: Left A
PERIOD: October 31-November 14



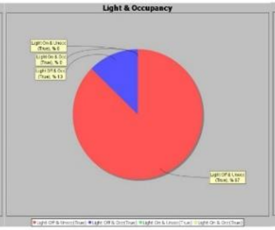
Oct.31 11:00-17:00
Light off&Occ 0%
Light off&Unocc 92%
Light on&Unocc 0%
Light on&Occ 8%



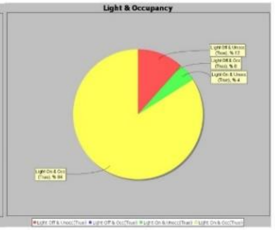
Nov.3 17:00-18:00
Light off&Occ 0%
Light off&Unocc 92%
Light on&Unocc 0%
Light on&Occ 8%



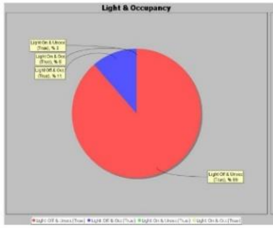
Nov.4 15:00-17:00
Light off&Occ 2%
Light off&Unocc 38%
Light on&Unocc 0%
Light on&Occ 60%



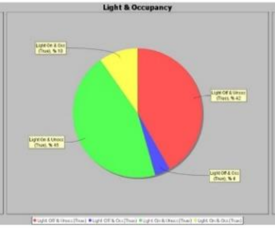
Nov.5 14:00-17:00
Light off&Occ 13%
Light off&Unocc 87%
Light on&Unocc 0%
Light on&Occ 0%



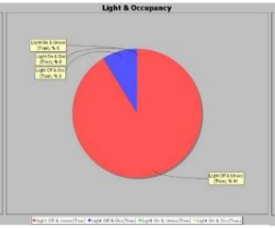
Nov.7 14:00-17:00
Light off&Occ 0%
Light off&Unocc 12%
Light on&Unocc 4%
Light on&Occ 84%



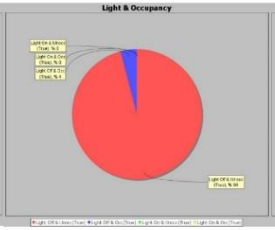
Nov. 10 13:00-14:00
Light off&Occ 11%
Light off&Unocc 89%
Light on&Unocc 0%
Light on&Occ 0%



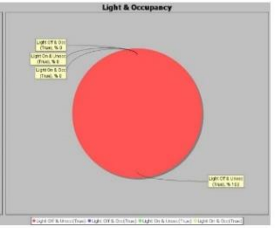
Nov.11 09:00-13:00
Light off&Occ 4%
Light off&Unocc 42%
Light on&Unocc 44%
Light on&Occ 10%



Nov.12 13:00-14:00
Light off&Occ 9%
Light off&Unocc 91%
Light on&Unocc 0%
Light on&Occ 0%



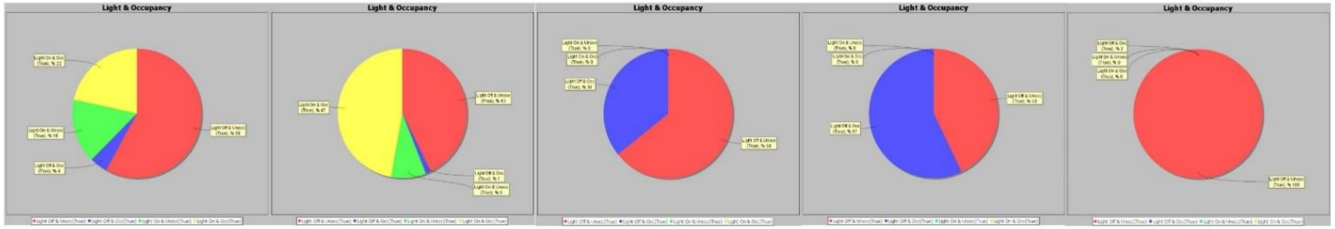
Nov.13 15:00-16:20
Light off&Occ 0%
Light off&Unocc 4%
Light on&Unocc 96%
Light on&Occ 0%



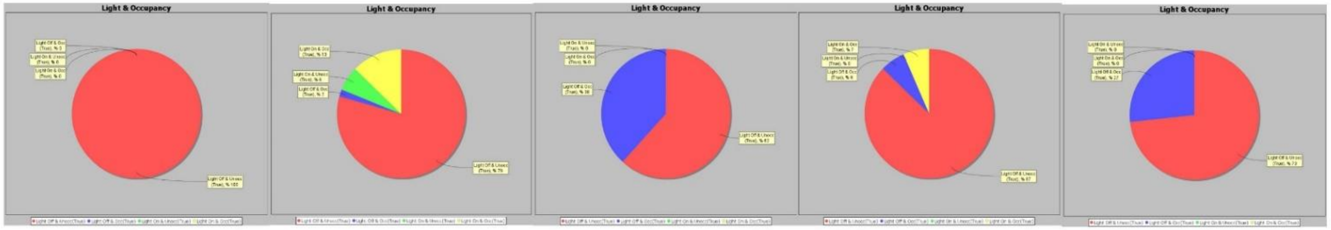
Nov.14 All day
Light off&Occ 0%
Light off&Unocc 0%
Light on&Unocc 100%
Light on&Occ 0%

Figure B.13. Occupancy and artificial lighting condition of User B in Left A layout.

PARTICIPANT: User B
LAYOUT: Left B
PERIOD: November 18-December 3



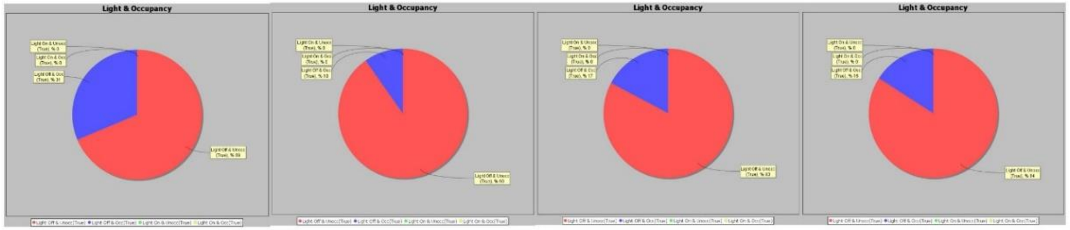
Nov.18 16:00-18:00	**Nov.19 16:00-18:00**	**Nov.20 16:00-17:00**	**Nov.21 14:00-15:00**	**Nov.24 All day**
Light off&Occ 4%	Light off&Occ 1%	Light off&Occ 27%	Light off&Occ 57%	Light off&Occ 0%
Light off&Unocc 58%	Light off&Unocc 43%	Light off&Unocc 73%	Light off&Unocc 43%	Light off&Unocc 100%
Light on&Unocc 16%	Light on&Unocc 9%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 22%	Light on&Occ 47%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



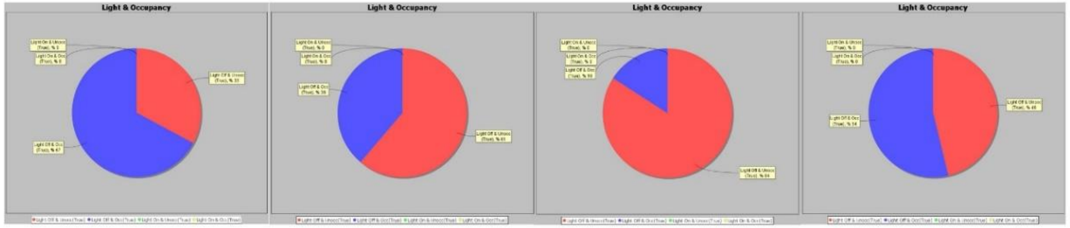
Nov. 25 All day	**Nov.26 17:00-18:00**	**Nov.27 14:00-16:00**	**Dec.02 09:00-09:30**	**Dec.03 09:00-09:30**
Light off&Occ 0%	Light off&Occ 2%	Light off&Occ 38%	Light off&Occ 6%	Light off&Occ 27%
Light off&Unocc 100%	Light off&Unocc 79%	Light off&Unocc 62%	Light off&Unocc 87%	Light off&Unocc 73%
Light on&Unocc 0%	Light on&Unocc 6%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 13%	Light on&Occ 0%	Light on&Occ 7%	Light on&Occ 0%

Figure B.14. Occupancy and artificial lighting condition of User B in Left B layout.

PARTICIPANT: User B
LAYOUT: Right A
PERIOD: December 3-December 12



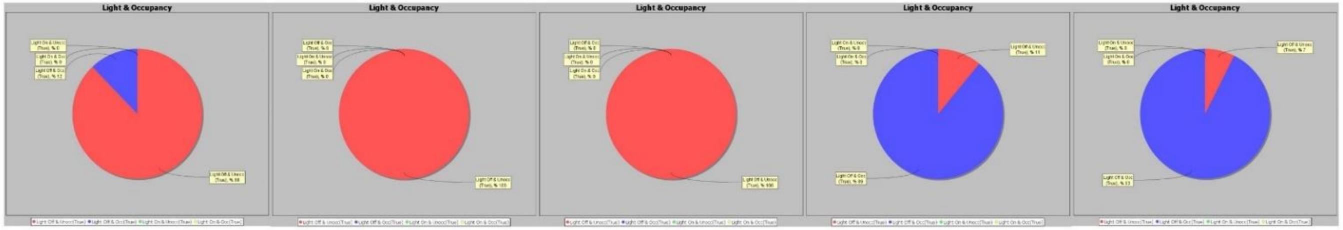
Dec.3 16:30-17:00	Dec.4 15:30-18:00	Dec.5 13:30-14:00	Dec.8 11:00-11:30
Light off&Occ 31%	Light off&Occ 10%	Light off&Occ 17%	Light off&Occ 16%
Light off&Unocc 69%	Light off&Unocc 90%	Light off&Unocc 83%	Light off&Unocc 84%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



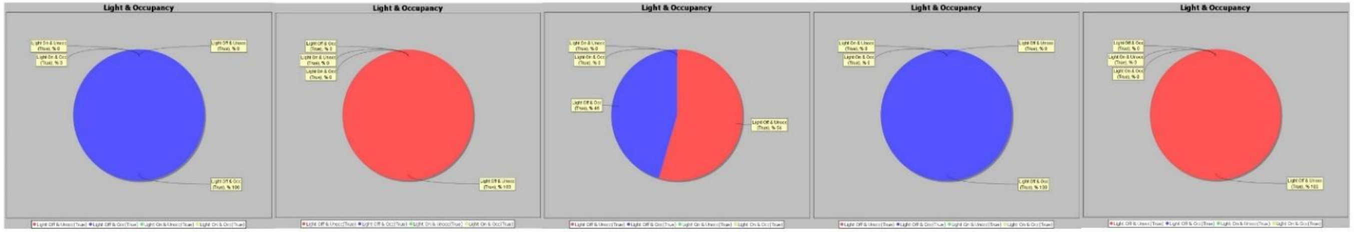
Dec.9 14:00-16:30	Dec.10 15:00-15:30	Dec.11 17:00-17:30	Dec.12 14:00-14:30
Light off&Occ 67%	Light off&Occ 39%	Light off&Occ 16%	Light off&Occ 54%
Light off&Unocc 33%	Light off&Unocc 61%	Light off&Unocc 84%	Light off&Unocc 46%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.15. Occupancy and artificial lighting condition of User B in Right A layout.

PARTICIPANT: User B
LAYOUT: Right B
PERIOD: December 15-December 26



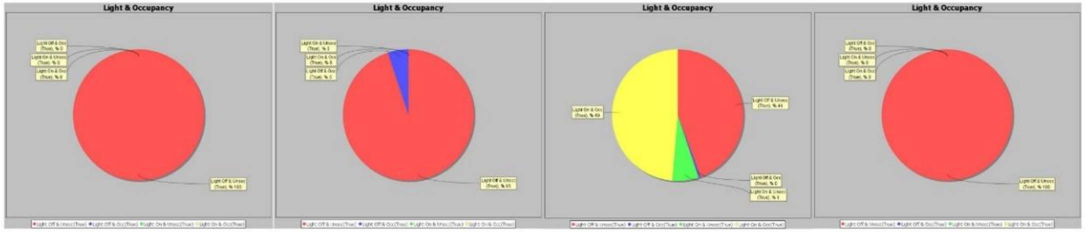
Dec.15 17:00-17:30	**Dec.16 All day**	**Dec.17 All day**	**Dec. 18 14:00-15:00**	**Dec. 19 15:00-16:00**
Light off&Occ 12%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 89%	Light off&Occ 93%
Light off&Unocc 88%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 11%	Light off&Unocc 7%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



Dec.22 11:00-12:00	**Dec.23 All day**	**Dec.24 11:00-12:00**	**Dec.25 11:00-12:00**	**Dec.26 All day**
Light off&Occ 100%	Light off&Occ 0%	Light off&Occ 46%	Light off&Occ 100%	Light off&Occ 0%
Light off&Unocc 0%	Light off&Unocc 100%	Light off&Unocc 54%	Light off&Unocc 0%	Light off&Unocc 100%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.16. Occupancy and artificial lighting condition of User B in Right B layout.

PARTICIPANT: User C
LAYOUT: Back A
PERIOD: December 26-January 06

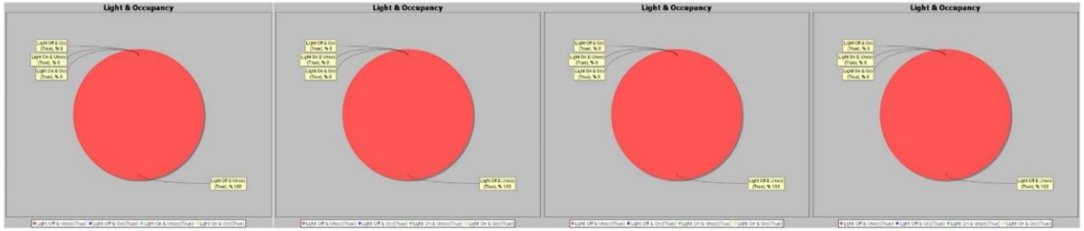


Dec.26 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.29 13:00-13:50
Light off&Occ 5%
Light off&Unocc 95%
Light on&Unocc 0%
Light on&Occ 0%

Dec.30 11:00-11:50
Light off&Occ 1%
Light off&Unocc 44%
Light on&Unocc 6%
Light on&Occ 49%

Dec.31 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%



Jan.01 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

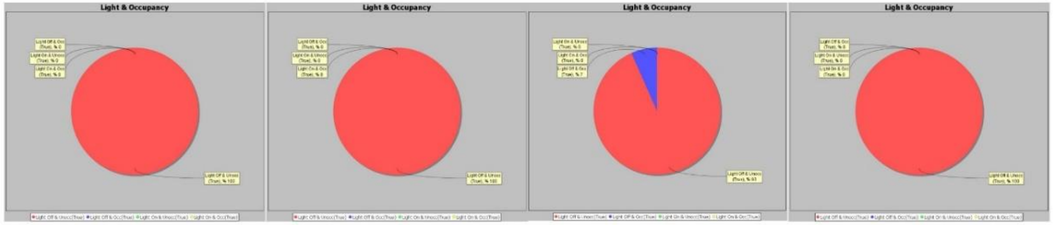
Jan.02 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.05 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.06 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Figure B.17. Occupancy and artificial lighting condition of User C in Back A layout.

PARTICIPANT: User C
LAYOUT: Back B
PERIOD: January 07-January 19

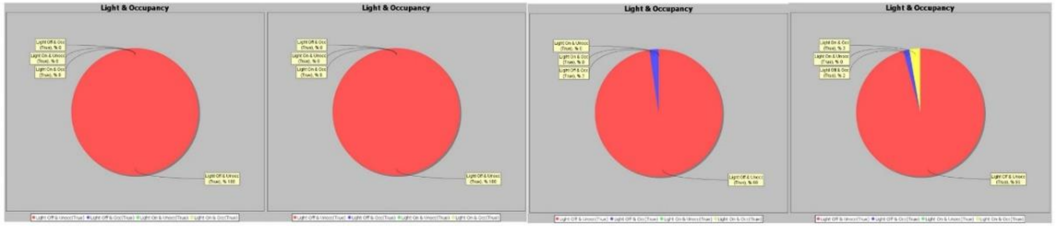


Jan.07 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.08 Al day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.09 13:00-13:50
Light off&Occ 7%
Light off&Unocc 93%
Light on&Unocc 0%
Light on&Occ 0%

Jan.12 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%



Jan.13 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

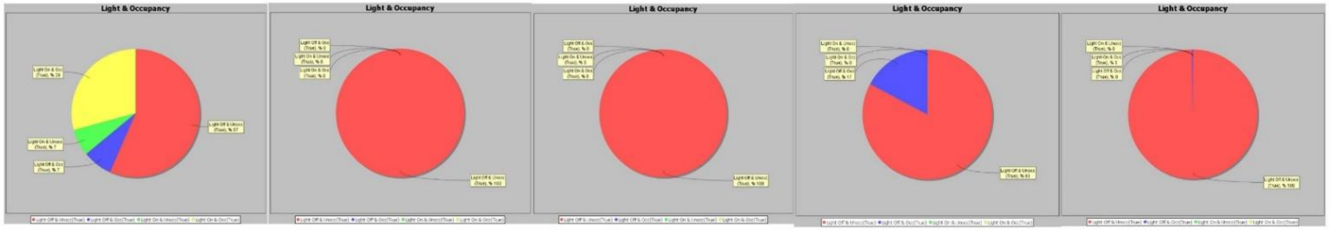
Jan.14 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Jan.16 All day
Light off&Occ 2%
Light off&Unocc 98%
Light on&Unocc 0%
Light on&Occ 0%

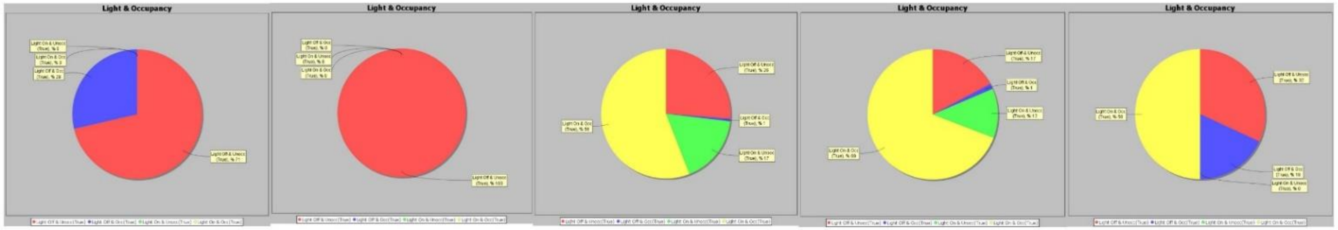
Jan.19 13:00-13:50
Light off&Occ 2%
Light off&Unocc 95%
Light on&Unocc 0%
Light on&Occ 3%

Figure B.18. Occupancy and artificial lighting condition of User C in Back B layout.

PARTICIPANT: User C
LAYOUT: Front A
PERIOD: January 19-January 30



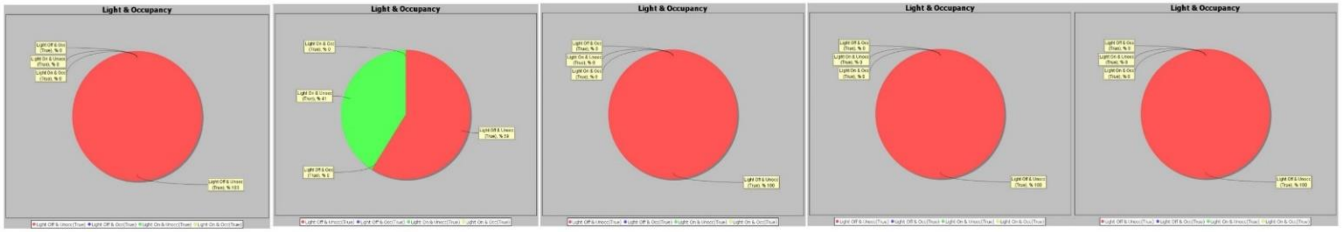
Jan.19 14:00-14:40	**Jan.20 All day**	**Jan.20 All day**	**Jan.22 17:00-17:40**	**Jan.23 13:00-13:50**
Light off&Occ 7%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 17%	Light off&Occ 1%
Light off&Unocc 57%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 83%	Light off&Unocc 99%
Light on&Unocc 7%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 29%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



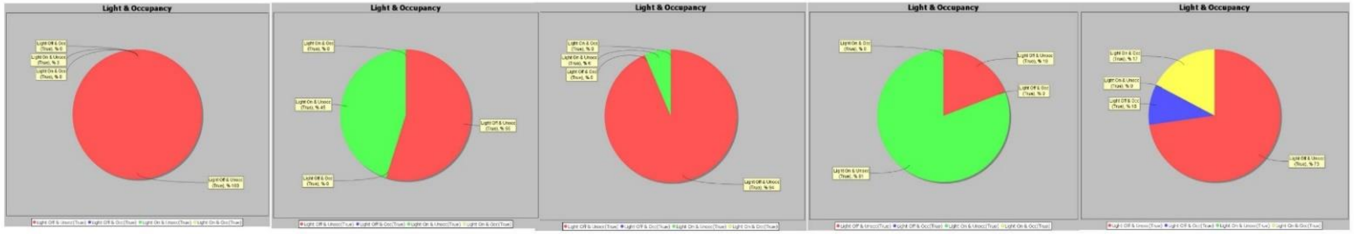
Jan.26 11:00-11:40	**Jan.27 All day**	**Jan.28 13:00-16:20**	**Jan.29 15:00-16:20**	**Jan.3014:00-15:20**
Light off&Occ 29%	Light off&Occ 0%	Light off&Occ 1%	Light off&Occ 1%	Light off&Occ 18%
Light off&Unocc 71%	Light off&Unocc 100%	Light off&Unocc 26%	Light off&Unocc 17%	Light off&Unocc 32%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 17%	Light on&Unocc 12%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 56%	Light on&Occ 69%	Light on&Occ 50%

Figure B.19. Occupancy and artificial lighting condition of User C in Front A layout.

PARTICIPANT: User C
LAYOUT: Front B
PERIOD: February 02- February 16



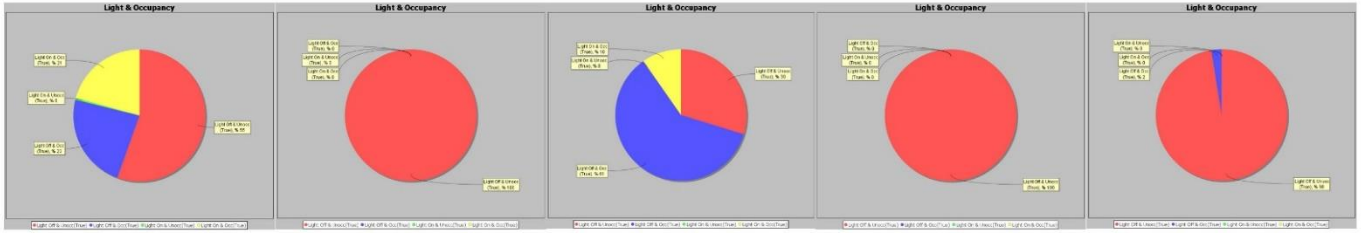
Feb.02 All day	**Feb.03 14:00-14:40**	**Feb.05 All day**	**Feb.06 All day**	**Feb.09 All day**
Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%
Light off&Unocc 100%	Light off&Unocc 59%	Light off&Unocc 100%	Light off&Unocc 100%	Light off&Unocc 100%
Light on&Unocc 0%	Light on&Unocc 41%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%



Feb.10 All day	**Feb.11 16:00-16:40**	**Feb.12 15:00-16:20**	**Feb.13 16:00-16:20**	**Feb.16 14:00-14:20**
Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 0%	Light off&Occ 10%
Light off&Unocc 100%	Light off&Unocc 55%	Light off&Unocc 94%	Light off&Unocc 19%	Light off&Unocc 73%
Light on&Unocc 0%	Light on&Unocc 45%	Light on&Unocc 6%	Light on&Unocc 81%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 17%

Figure B.20. Occupancy and artificial lighting condition of User C in Front B layout.

PARTICIPANT: User C
LAYOUT: Left A
PERIOD: October 31- November 14



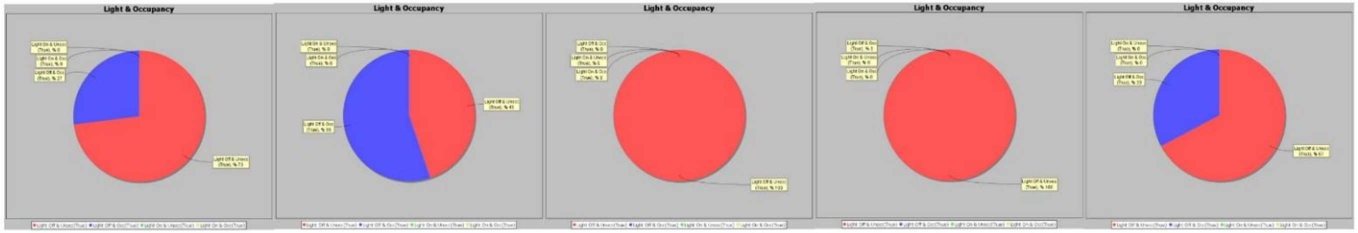
Oct.31 10:00-10:45
Light off&Occ 23%
Light off&Unocc 55%
Light on&Unocc 1%
Light on&Occ 21%

Nov.02 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Nov.03 16:00-16:45
Light off&Occ 61%
Light off&Unocc 29%
Light on&Unocc 0%
Light on&Occ 10%

Nov.04 10:00-10:45
Light off&Occ 33%
Light off&Unocc 64%
Light on&Unocc 0%
Light on&Occ 0%

Nov.07 15:00-15:45
Light off&Occ 2%
Light off&Unocc 98%
Light on&Unocc 0%
Light on&Occ 0%



Nov.10 13:00-13:45
Light off&Occ 27%
Light off&Unocc 73%
Light on&Unocc 0%
Light on&Occ 0%

Nov.11 11:00-11:45
Light off&Occ 55%
Light off&Unocc 45%
Light on&Unocc 0%
Light on&Occ 0%

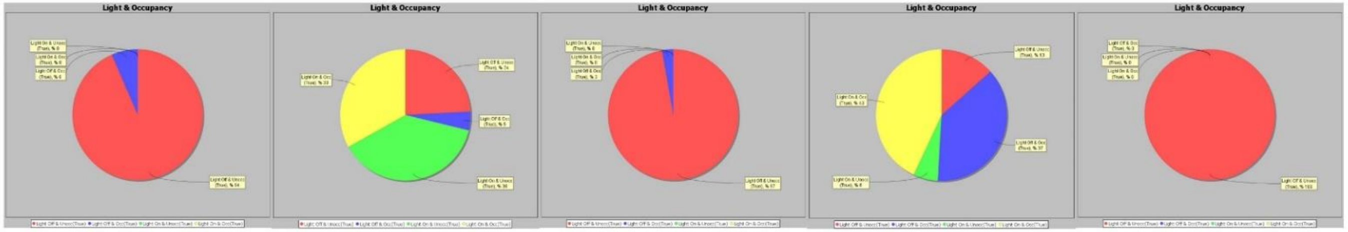
Nov.12 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Nov.13 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

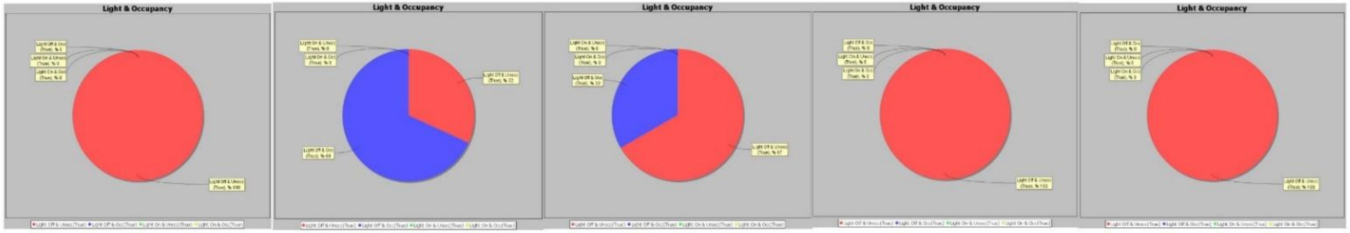
Nov.14 10:00-10:45
Light off&Occ 33%
Light off&Unocc 64%
Light on&Unocc 0%
Light on&Occ 0%

Figure B.21. Occupancy and artificial lighting condition of User C in Left A layout.

PARTICIPANT: User C
LAYOUT: Left B
PERIOD: November 17-November 28



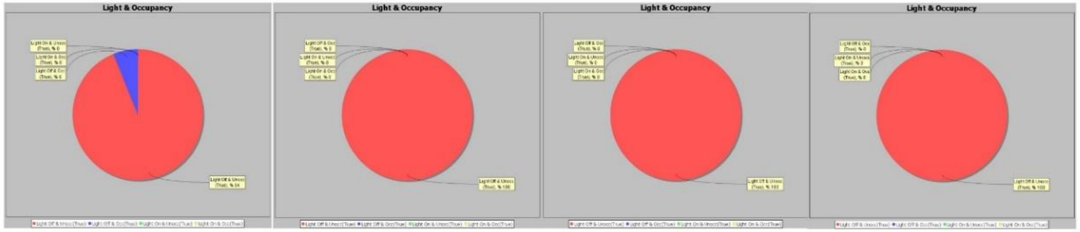
Nov.17 14:00-14:45	**Nov.18 16:00-16:45**	**Nov.19 14:00-14:45**	**Nov.20 15:00-16:45**	**Nov.21 All day**
Light off&Occ 6%	Light off&Occ 5%	Light off&Occ 3%	Light off&Occ 37%	Light off&Occ 0%
Light off&Unocc 94%	Light off&Unocc 24%	Light off&Unocc 97%	Light off&Unocc 13%	Light off&Unocc 100%
Light on&Unocc 0%	Light on&Unocc 38%	Light on&Unocc 0%	Light on&Unocc 6%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 33%	Light on&Occ 0%	Light on&Occ 43%	Light on&Occ 0%



Nov.24 All day	**Nov.25 11:00-11:45**	**Nov.26 11:00-11:45**	**Nov.27 All day**	**Nov.28 All day**
Light off&Occ 0%	Light off&Occ 68%	Light off&Occ 33%	Light off&Occ 0%	Light off&Occ 0%
Light off&Unocc 100%	Light off&Unocc 32%	Light off&Unocc 67%	Light off&Unocc 100%	Light off&Unocc 100%
Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%	Light on&Unocc 0%
Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%	Light on&Occ 0%

Figure B.22. Occupancy and artificial lighting condition of User C in Left B layout.

PARTICIPANT: User C
LAYOUT: Right A
PERIOD: December 3-December 11

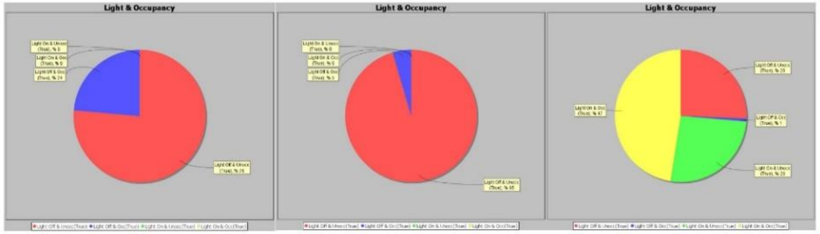


Dec.03 14:00-14:45
Light off&Occ 6%
Light off&Unocc 94%
Light on&Unocc 0%
Light on&Occ 0%

Dec.04 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.05 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.08 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%



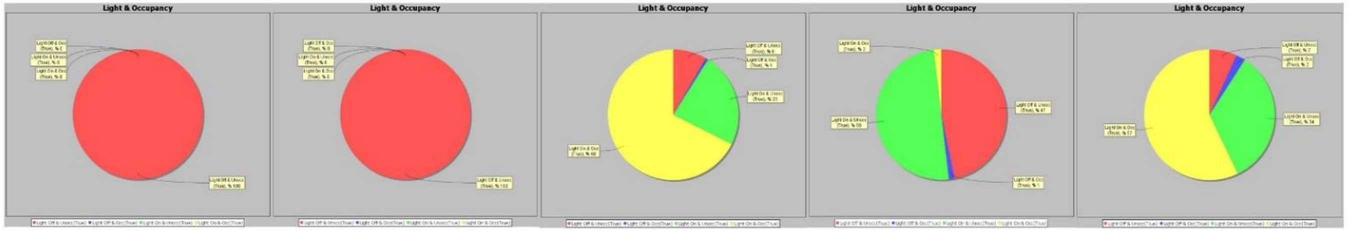
Dec.09 11:00-11:40
Light off&Occ 24%
Light off&Unocc 76%
Light on&Unocc 0%
Light on&Occ 0%

Dec.10 09:00-09:45
Light off&Occ 5%
Light off&Unocc 95%
Light on&Unocc 0%
Light on&Occ 0%

Dec.11 15:00-17:45
Light off&Occ 1%
Light off&Unocc 26%
Light on&Unocc 26%
Light on&Occ 47%

Figure B.23. Occupancy and artificial lighting condition of User A in Left A layout.

PARTICIPANT: User C
LAYOUT: Right B
PERIOD: December 12-December 26



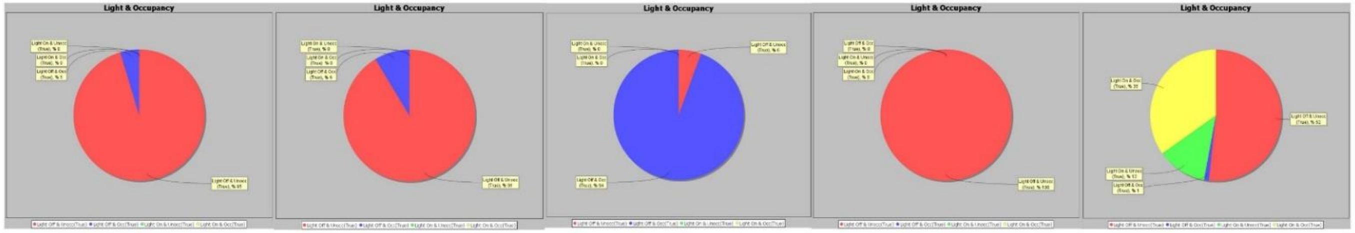
Dec.12 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.15 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.16 15:00-17:40
Light off&Occ 1%
Light off&Unocc 8%
Light on&Unocc 23%
Light on&Occ 68%

Dec.17 15:00-16:40
Light off&Occ 1%
Light off&Unocc 47%
Light on&Unocc 50%
Light on&Occ 2%

Dec.18 17:00-17:40
Light off&Occ 2%
Light off&Unocc 7%
Light on&Unocc 34%
Light on&Occ 57%



Dec.19 11:00-12:40
Light off&Occ 5%
Light off&Unocc 95%
Light on&Unocc 0%
Light on&Occ 0%

Dec.22 12:00-12:45
Light off&Occ 9%
Light off&Unocc 91%
Light on&Unocc 0%
Light on&Occ 0%

Dec.23 14:00-14:45
Light off&Occ 94%
Light off&Unocc 6%
Light on&Unocc 0%
Light on&Occ 0%

Dec.24 All day
Light off&Occ 0%
Light off&Unocc 100%
Light on&Unocc 0%
Light on&Occ 0%

Dec.26 09:00-09:40
Light off&Occ 1%
Light off&Unocc 52%
Light on&Unocc 12%
Light on&Occ 35%

Figure B.24. Occupancy and artificial lighting condition of User C in Right B layout.

APPENDIX C

FUZZY MODEL PREDICTONS

Table C.1. Fuzzy model predictions.

	Layout	Position	Illuminance	Tendency of behavior pattern value	Comment
S1	Left	A	209	0,188	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class, can probably not switch on the lights)
S2	Back	A	4	0,6	Back layout blocks some amount of daylight which is directed to the backwards of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
S3	Right	A	290	0,188	Right layout provides the impact of sidelighting. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class, can probably not switch on the lights)
S4	Front	A	4	0,6	Front layout blocks some amount of daylight which is directed to the backwards of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
S5	Left	B	209	0,188	Left layout provides the impact of sidelighting fully. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S6	Left	A	4	0.5	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights)
S7	Back	A	4	0,6	Back layout blocks some amount of daylight which is directed to the backwards of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
S8	Front	A	28	0,572	Front layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights).
S9	Front	B	51	0,438	Front layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights).
S10	Left	A	290	0,164	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S11	Left	B	265	0,188	Left layout provides the impact of sidelighting fully. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S12	Right	A	290	0,188	Right layout provides the impact of sidelighting. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class, can probably not switch on the lights)
S13	Left	A	301	0,164	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S14	Right	B	4	0,837	Right layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the High class, can probably switch on the lights)
S15	Right	B	28	0,729	Right layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights)
S16	Back	B	37	0,438	Back layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights).
S17	Left	A	4	0.5	Left layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights)
S18	Front	B	67	0,438	Front layout provides the highest possible amount of daylight which is directed to the face of the user. The desk is at the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Low-Medium class, can probably not switch on the lights).
S19	Left	B	16	0,729	Left layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights)
S20	Right	A	275	0,164	Right layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S21	Right	B	27	0,74	Right layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights)
S22	Left	B	7	0,837	Left layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the High class, can probably switch on the lights)
S23	Right	A	234	0,164	Right layout provides the impact of sidelighting fully. The desk is in the perimeter zone close to window. Daylight illuminance on the desk is strongly high. (User in the Low class can probably not switch on the lights).
S24	Left	B	36	0,74	Left layout provides the impact of sidelighting. The desk is in the edge of the perimeter zone. Daylight illuminance on the desk is strongly low. (User in the Medium-High class, can probably switch on the lights)

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PhD	Izmir Institute of Technology (IYTE)	2012-2016	Architecture GPA: 3.86 *Categorization of Manual Lighting Control Behavior Patterns Based On Interior Layout in Offices*

International Publications

Cılasun, A., Kazanasmaz, T. (2016). Assessing Manual Lighting Control in Offices. Integrated solutions for Sustainable and Smart Buildings & Cities, İstanbul, Turkey

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Academic Honours, Awards, Grants

BAP, İYTE, 2014 "Ofislerde kullanıcıların aydınlatma sistemi ve enerji tüketimi üzerindeki etkinliği: kullanıcı kontrolü" (with Doç.Dr. Tuğçe KAZANASMAZ)

2214-A, TÜBİTAK, 2014 "Factors Effecting Manual Lighting Control in Offices: Interior Architectural Impacts" Delft University of Technology Netherlands as Guest Researcher 30.09.2015-01.04.2016

3001, TÜBİTAK, 2014 "114M803-İzmir'de Üniversite Kampüsündeki Mimarlık Stüdyo Binasının Enerji Etkin İyileştirme (Retrofit) Önerisi" (with Doç.Dr. Başak Kundakçı Koyunbaba and Ioannis Chatzikonstantinou)