TECHNISCHE UNIVERSITÄT WIEN
Vienna | Austria

DIPLOMARBEIT

Performance Evaluation of Lighting in Home Office Spaces: Case Studies in Izmir, Turkey

ausgeführt zum Zwecke der Erlangung des akademischen Grades

einer Diplom-Ingenieurin

unter der Leitung von

Univ.-Prof. Dipl.-Ing. Dr. techn. Ardeshir Mahdavi

Univ.Ass. Dipl.-Ing. Dr. techn. Ulrich Pont

E 259-3 Abteilung für Bauphysik und Bauökologie

Institut für Architekturwissenschaften

eingereicht an der Technischen Universität Wien

Fakultät für Architektur und Raumplanung

von

B.Arch. Ceren Sarikaya

01528425

Wien, Juni 2019

KURZFASSUNG

Ordnungsgemäße Beleuchtungsverhältnisse beim Arbeiten in geschlossenen Räumen können nicht nur die visuelle Performance und den Sehkomfort verbessern, sondern auch den überflüssigen Gebrauch von künstlichen Lichtquellen und dem damit verbundenen Energieverbrauch und etwaige Blendungen vermeiden. Dies trifft selbstverständlich für Räumlichkeiten, die explizit von einem Konsulenten für Lichttechnik geplant wurden, genauso zu wie für kleinmaßstäbliche Home Offices. Jedoch werden während des Designprozesses von Heimbüros, welcher zumeist von den Nutzern selbst durchgeführt wird, Entscheidungen oft in Abhängigkeit der aktuellen Bedürfnisse der Nutzer getroffen und die Wichtigkeit einer ausreichenden Beleuchtungsleistung wird unterschätzt. Die Beleuchtungsanforderungen für Arbeitsplätze in Räumen sind in den entsprechenden Beleuchtungsstandards klar definiert und kategorisiert, wobei hierbei verschiedene Berufsgruppen berücksichtigt werden. Im Weiteren werden diese Kategorien weiter in spezifische Aufgaben und Aktivitäten unterteilt, welche im Detail ausgeführt werden können. Im Gegensatz dazu gibt es aber keine formellen Beleuchtungsstandards für Wohnbereiche, es gibt lediglich Empfehlungen in verschiedenen wissenschaftlichen Quellen bezüglich Beleuchtung und Sehkomfort. Aus diesem Grund ist das Entwerfen von Heimbüros an einem Ort, der diese beiden verschiedenen Funktionen erfüllt, noch herausfordernder. Diese Masterarbeit konzentriert sich auf neun verschiedene Fallstudien unterschiedlicher Berufsfelder, welche in Izmir /Türkei durchgeführt wurden. Die Daten der Beleuchtungsstärke des Tageslichtes und die künstlichen Beleuchtungen der Heimbüros wurden sowohl vor Ort gemessen wie auch mittels Lichtsimulation untersucht. Alle Messungen vor Ort wurden an zwei verschiedenen Uhrzeiten des Tages unter anderen Bedingungen durchgeführt: Einmal morgens ausschließlich mit Tageslicht und einmal am Abend nur mit künstlicher Beleuchtung. Der genaue Tag und die genaue Uhrzeit der Messung, der Himmelszustand, sowie aus Messungen abgeleitete Oberflächenreflektionswerte, Befunde, Einschränkungen und Schwierigkeiten bei jeder Messung wurden genau festgehalten. Danach wurden die Heimbüros mittels einer Lichtsimulationssoftware (DIALux) dreidimensional modelliert und entsprechende Simulationen unter den zuvor festgehaltenen Informationen durchgeführt. Ein wesentliches Ergebnis dieser Arbeit ist das Evaluieren der aktuellen Beleuchtungsleistung der Heimbüros und einem Vergleich der erhaltenen Ergebnisse mit den Kriterien der relevanten Beleuchtungsstandards zur Qualifikations- und Mängelbestimmung. Zusätzlich werden Vorschläge zur Verbesserung der Beleuchtungsleistung für jedes Heimbüro vorgestellt, welche hauptsächlich durch die unterstützenden Lichtplanungsinstrumente der verwendeten Simulationsumgebung erstellt wurden und einer anschließenden Nutzen-Analyse unterzogen wurden.

ABSTRACT

Having proper lighting conditions in an indoor workplace not only can improve visual performance and visual comfort, but also prevents unnecessary artificial lighting consumption or glare effects. This is true for any kind of indoor workspace, independent from size and organizational background. The illumination of large-scale offices often is conducted by lighting design specialists or at least under consultancy by specialists. The design process of small-scale home offices regularly does not encompass such specialists. Rather, the lighting design is implicitly performed by the later occupants themselves. During the design process of home offices, decisions are often taken depending on the current needs of the user and the importance of lighting performance is often underestimated. In addition, the lighting requirements of indoor workplaces are clearly defined in the relevant lighting standard and categorized by taking various job disciplines into consideration. Furthermore, those categories are later subdivided into specific tasks and activities that can be carried out in detail. On the other hand, there is no formal lighting standard for residential areas, but there are only recommendations in various scientific sources on lighting and visual comfort. For this reason, having these two different functions together in one single place makes the lighting design of a “home office” space even more challenging. This master thesis focuses on nine different case studies in İzmir, Turkey and each is being used for different professional purposes. Illuminance data of daylight and artificial lighting of those home offices were obtained by the in-situ measurements as well as through the lighting performance simulations. All in-situ measurements were performed at two different times of the day and under different conditions: in the morning with only daylight and in the evening with only artificial lighting. The exact day and time of the measurements, sky conditions, calculated reflection values, findings, limitations and difficulties of each measurement were recorded in detail. Then, home offices were modeled in 3D with lighting simulation software (DIALux) and simulations were performed considering all previously recorded information. The workflow of this thesis involves evaluating the current lighting performance of home offices, and then comparing these obtained results with the criteria of the relevant lighting standards for the determination of qualifications and deficiencies. Thereby, the results of both simulation and measurements also are compared to each other. The subsequent step is to provide lighting performance improvement proposals for each home office mainly by using and analysing suggestions generated via the supportive lighting design routines of the used simulation tool.

Keywords

Visual performance, visual comfort, home office, data measurement, daylight analysis, artificial lighting analysis, lighting standards, DIALux.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the entire staff of the Building Physics and Building Ecology department, especially to Univ.-Prof. Dipl.-Ing. Dr. techn. Ardeshir Mahdavi and Univ.Ass. Dipl.-Ing. Dr. techn. Ulrich Pont. Their support and positivity motivated me a lot. I am feeling happy and honored to prepare this master thesis under their guidance.

My special thanks go to the Buschmann family through Simon Buschmann. Their support and sincerity played a major role in achieving this work. I see them as my second family.

Finally, I would like to thank especially my beloved parents Cigdem Sarikaya and Mustafa Orhan Sarikaya. I owe everything to them because without their support, none of this would be possible. I am very grateful to my parents for everything that they have done for me and I will always be proud of them.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Overview

Since the indoor environment plays an important role in concentration, enthusiasm and productivity, the design of the places that are often in use should be conducted carefully. As one of the most influencing aspects in design, lighting can play a vital role in how people perceive their environment. Due to its ability to transform a place significantly in terms of perception regarding size, shape and color, lighting also affects the aesthetic judgment and mood of the occupants. Therefore, it can be stated that having an ergonomic and efficient lighting design in an environment has a positive effect on visual comfort, visual performance, mood and eye health of the user.

As considerable amount of time passes in work and home, having a stimulating atmosphere in a home office space is even more importance, if people have these to function in the same place. Lighting of such places should be suitable for effectively performing visual tasks with good visibility and at the same time should provide a comfortable living space. Although it is important to examine the luminous environment of working areas and living areas individually in a home office space, eventually they either must cooperate, or the same lighting system should contribute both (Rea 2000).

Within the framework of this thesis, lighting performance of nine different home office areas in İzmir/Turkey will be evaluated. Each home office is used for a different job discipline and all include both working area and living area in the same room. After the evaluations, considering all obtained data and observations, different scenarios for the improvement of artificial lighting will be provided with DIALux (DIALux 4.13 2016) and the usability of these scenarios will be discussed.

In the first chapter of this thesis, objectives, motivation and fundamental theoretical background will be given. The second chapter includes the introduction of all home office spaces including pictures, technical drawings and 3D models. The used measurement equipment, the applied simulation software and the relevant recommendations that are given in the related lighting standard will be presented. Moreover, the applied methods will be discussed in detail. Subsequently, all obtained results will be presented in the third chapter in detail with the corresponding optimization scenarios. At the end of this chapter, overall cumulative result analysis of all examined home offices is executed and discussed. Finally, the master thesis will be concluded with the discussion of general findings, challenges, shortcomings and future research opportunities.

1.2 Objective

The objective of this work consists of several interconnected steps. As briefly mentioned before, the first step is to evaluate the current lighting levels of nine different home office space. The information regarding the lighting performances will include not only illuminance levels, but also analysis of different indicators, such as uniformity, daylight factor, unified glare rating, cylindrical illuminance and modelling. Furthermore, the information will be gathered by on-site measurements and simulations, which will be performed twice for each home office, in different time periods and under different conditions: once in the morning with only natural lighting and once in the evening with only artificial lighting. The underlying reason is to assess the availability and quality of both daylight and artificial lighting. Also, in each place, measurement day and time, sky type, rotation of home offices and reflectance values of all major surfaces will be taken into consideration in order to ensure maximum accuracy in result interpretations. Whether the current lighting conditions of home offices are satisfactory or not will be decided according to the recommendations of the relevant lighting standard (TS EN 12464-1 - Lighting and lighting - Lighting workplaces - Part 1: Indoor workplaces).

In addition to comparing field measurement and simulation results with recommendations of the lighting standard, another objective is to compare them with each other. The purpose of this step is to observe whether the results are showing similarity, if not, to determine the causes in case of having unacceptably high deviations. At the same time, this step will be done for detecting whether there is a certain similarity between deviations and whether a common solution can be produced.

Last but not least, by considering the failures and weaknesses of the existing artificial lighting, an improvement scenario will be provided to each home office. These scenarios will be created mainly with the "field arrangement" feature of the DIALux and changes to the proposal of software will be kept to a minimum. The goal is to determine the usefulness and advisability of the software suggestions.

1.3 Motivation

The concept of “home office” is getting more and more popular due to ever-developing technology, the increase in the number of freelancers and the fact that many companies now allow their employees to work full-time remotely (Crosbie and Moore 2004). The percentage growth of home office amount between 1999 and 2014 is expressed in Figure 1.

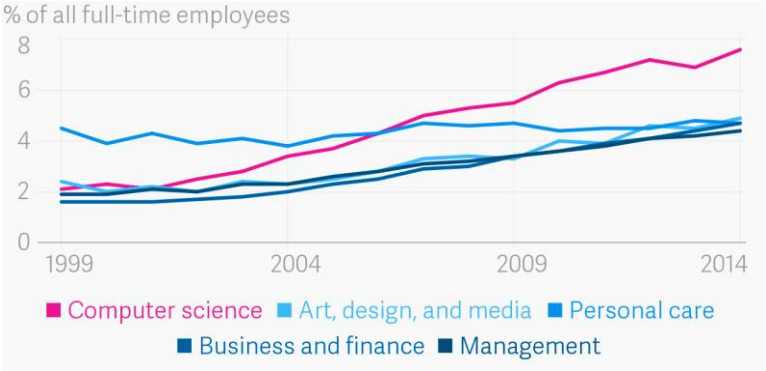

Figure 1: Percentage growth of home office work spaces in specific job categories between 1999-2014 (Source: IPUMS, 2017)

However, home offices are often designed to meet the demands of future users and lighting is often not seen as an essential requirement, but rather a dispensable improving element of design. Although we perceive the world around us with our eyes and do a constant visual work, we often have very imperfect knowledge about whether we do it effectively. Therefore, in the design phase of many places, including home offices, the performance of lighting is not considered enough or even ignored (DiLaura et al. 2011, Ganslandt and Hofmann 1992).

Nonetheless, even though there is an extended and detailed lighting standard for indoor working places, there are just recommendations for residential areas. For this reason, as a combination of both working space and living space, the lighting design of a home office becomes even more challenging. Although today there is already a considerable number of home offices (Figure 2), and although this concept is spreading more and more every day, there are still hardly any sources to obtain detailed information about how to achieve an efficient lighting design in such areas.

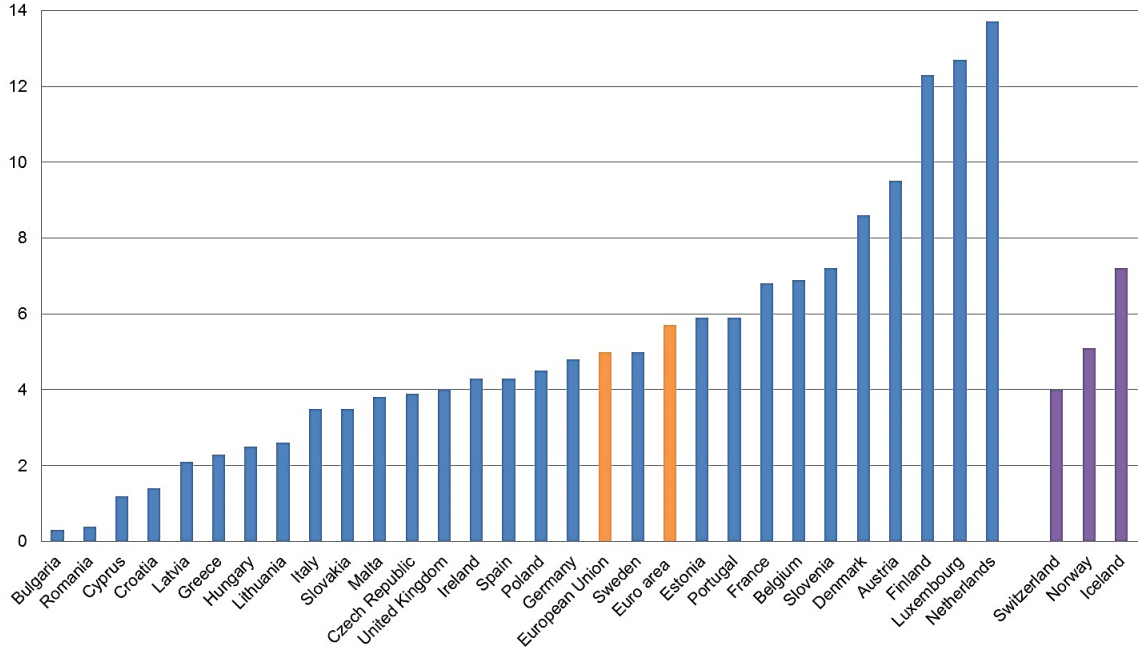

Figure 2: Percentage of people working from home between age 15-64 in EU Countries, 2017 (% of total employment) (Source: Eurostat 2018)

In fact, lighting is a complex and inseparable component of design, and should be considered from the very beginning. The cooperation between the architect and the civil engineer right from the start can provide future user an efficient and user-friendly lighting as well as energy, labor and cost savings.

1.4 Background

1.4.1 Overview

In the following chapters, the theoretical background which is fundamental for this thesis will be provided. First, as the keystone of this thesis, several components of lighting and lighting design will be discussed. Criteria and concepts that play an important role on lighting design will be presented. Additionally, the reference lighting standard will be introduced, which is essential for this thesis and all similar works that are related with lighting design.

1.4.2 Quantitative aspects of lighting

The quantity of illumination depends on the aspects that are mentioned below:

Luminous flux

Luminous flux (or luminous power) is to the total light amount that received by a surface or emitted through a light source. In other words, it refers to the visually evaluable radiant flux. (DiLaura et al. 2011, Laughton and Warne 2003). This visual evaluation is done *"wavelength-by-wavelength using either of the two standard action spectra for vision: the photopic or scotopic luminous flux" (*DiLaura et al. 2011, p. 5.9). However, the luminous flux can be considered as it is referring to photopic luminous flux unless otherwise is stated. The unit of luminous flux is lumen (lm) (DiLaura et al. 2011).

Luminous intensity

Luminous intensity is used to define the luminous flux density of a point source per unit solid angle and in a certain direction. The unit of the ratio is candela (cd), which refers lumens per steradians (lm/sr). As solid angle refers to spatial extent of an imaginary open-ended cone, it is obvious that luminous intensity concept is invariant with the corresponding light sources' distance (DiLaura et al. 2011, Rea 2000).

Illuminance

Illuminance, denoted by the letter Ē, is the measure of incident luminous flux per unit surface area. It can be expressed in lux (lx, lm/m^2) as well as in foot-candle (fc, lm/ft^2). Since the orientation of a surface is definable (e.g., vertical, horizontal), the orientation of illuminance

can also be defined in the same way, for example, vertical illuminance, horizontal illuminance, etc.

Illuminance does not provide an information about the direction of incident luminous fluxes, but refers only to total incident amount. Therefore, some conditions with very different luminous intensity distribution may have the identical illuminance and this may mislead the lighting designer, in case of not having any additional information.

(DiLaura et al. 2011, TSE 2011)

Luminance

Luminance specifies the total emitted light from unit surface area and within given solid angle. In other saying, it is the total received luminous power amount by eye when looking at a surface from a certain angle. The unit of luminance is candela per square meter (cd/m^2) (Laughton and Warne 2003).

DiLaura et al. (2011, p.5.14) states, that *"luminance is perhaps the most important quantity in lighting design and illuminating engineering, as it is one of the direct stimuli to vision and many measures of performance and perception have been shown to depend on luminance."*

1.4.3 Qualitative aspects of lighting

The quality of illumination is dependent upon below mentioned aspects:

Uniformity

The uniformity (U_o) can be expressed as the ratio of the lowest measured illuminance to average illuminance in a given space or surface. According to Laughton and Warne (2013), performing a visual task in an area, where the distribution of illumination homogeneous is, is not only important for visual comfort, but also increases the visual performance. Since the human eye needs time for adapting to each new different lighting conditions, sudden illuminance decreases or frequent illuminance changes within the visual field may cause fatigue, stress and discomfort.

Discomfort glare

Performance of a working task can be significantly influenced by the discomfort glare, which can be categorized into two main types by taking the origin of a light source into consideration: direct glare (when the light source is within sight) and reflected glare (which is caused not directly by the light source, but the reflective surfaces within sight). An exemplification is shown below in Figure 3.

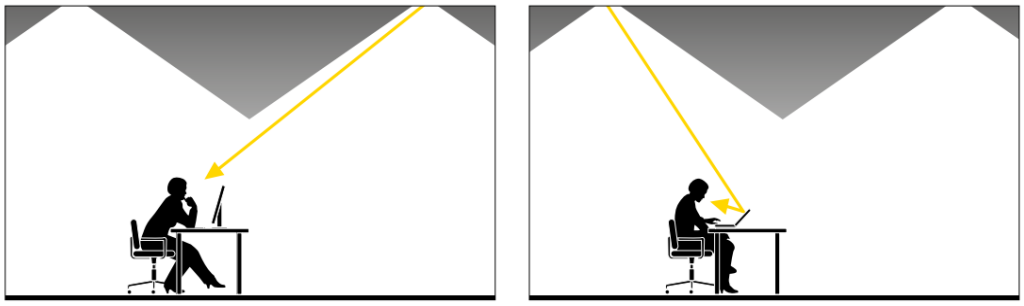

Figure 3: Glare types: Direct glare (left) and reflected glare (right) (Source: Zumtobel 2018, p.14)

Besides the location of the light source, the magnitude of glare sensation depends upon also the factors:

- Luminance of the light source
- Size of the light source
- Amount of the light sources
- State of the eye adaptation

(Rea 2000, Zumtobel Lighting GmbH 2018)

The International Commission on Illumination (CIE) provided a standardised method for predicting the rating of direct glare that can be caused by electric lighting sources. This method, which is named as Unified Glare Rating (UGR) method, is also specified in the standard TS EN 12464-1 and can be applied by using Equation 1.

$$UGR = 8\,log\left(\frac{0.25}{L_B}\sum\frac{L^2\omega}{p^2}\right) \quad (1)$$

where

L_B is the background luminance in cd/m^2,

L is the luminance (in cd/m^2) of the luminaires that are in observer's field of view,

ω is the solid angle of the light sources in sight (in steradian),

p is the Guth position index for each luminaire that is in observer's field of view.

The resulting values derived by the UGR method must be varied in between 10 to 30. The bigger the resulting UGR value, the greater the possibility of glare (TSE 2013).

Mean cylindrical illuminance and modelling

In order to have a satisfying visual comfort and enhance the object recognition in a space, adequate level of illumination must be provided. This can be fulfilled with sufficient mean cylindrical illuminance, which refers to the average vertical illuminance on the outside surface of an imaginary cylinder (Figure 4) (Zumtobel Lighting GmbH 2018).

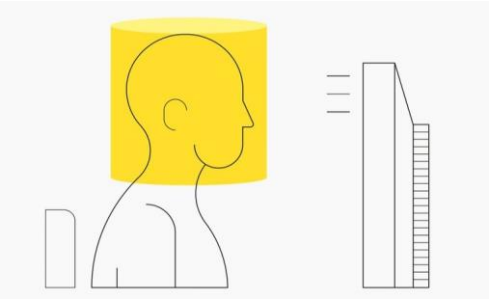

Figure 4: Representation of mean cylindrical illuminance (Source: DIAL GmbH, 2011)

TRILUX (2018) describes the term modelling as the ratio between cylindrical illuminance ($\bar{E}_z$) to horizontal illuminance ($\bar{E}_h$) at a certain point and it is an important aspect of indoor space lighting, since it is the balance between direct and diffused light. The horizontal illuminance plane should be taken at a height of 1,20 meter above the floor where the task is performed by sitting and 1,6 meter above the floor when the task is done by walking and/or standing (Nag 2019).

Luminance contrast and color contrast

According to DiLaura et al. (2012), visibility of a target is possible only if it is different from its immediate surrounding in terms of luminance or color. In case of having this difference, it can be said that the target has contrast.

Tai (2013) conducted an experiment in a computer-generated environment and within the scope of this experiment, several spaces were modelled, each with different luminance contrast characteristics. As the conclusion, it was indicated that contrast is an important architectural design parameter for having the sense of depth perception in a space and with a well-balanced contrast between a visual target and its background, spatial experience can be considerably enriched.

1.4.4 Characteristics of artificial light sources

Luminous efficacy

The term luminous efficacy is used for defining the quotient of emitted lumens to the total power consumption of an electric source and quantified in lumens per watt (lm/W). It refers to the measure of how effective an electric light source is in converting its power to visible light (luminous flux). Theoretically, the greatest photopic luminous efficacy can be reached at 555 nanometres (nm) wavelength, which is 683 lm/W (DiLaura et al. 2011).

Color rendering index

Color Rendering Index (CRI) quantifies the ability of an electric light source in terms of reproducing colors of surfaces faithfully in comparison with an ideal light source.

It is calculated by testing the electric light source on 8 sample colors (R1 to R8) and the average score is denoted as Ra, which refers to CRI. Numerically, 100 is the best possible Ra value which can only be given to a perfect light source identical with black body. When the Ra is more than 80, it indicates a good color rendering quality (Nag 2019). Electric light sources with a CRI less than 80 should not be preferred at indoor work places (Zumtobel Lighting GmbH 2018). The effect of CRI exemplified below in Figure 5.

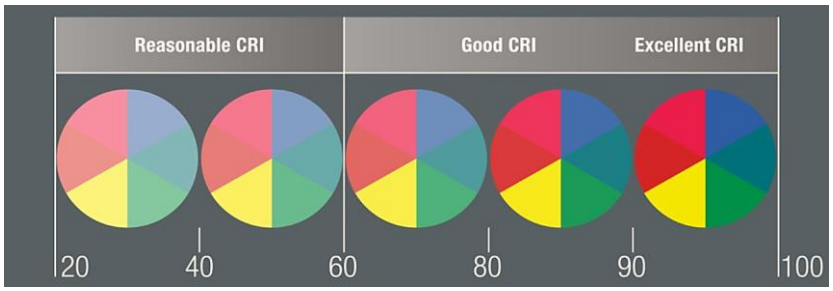

Figure 5: The difference between reasonable, good and excellent CRI (Source: Supacell Led Technology 2019)

Correlated color temperature

The Correlated Color Temperature (CCT, T_{CP}) of an electric light source indicates the apparent color (or chromaticity) of the light emitted from it. The less the CCT value of a light source, the warmer the color appearance of a light (Gordon 2015)

The selection of the color appearance in a place is a subjective matter based on many factors such as psychology, aesthetics, comfort, furniture colors and walls and average illuminance of the space in question (TSE, 2013). "*Experiments examining the psychological effects of varying CCT and illuminance have suggested that using lamps with high CCT values at low illuminances will make a space appear cold and dim. Conversely, using lamps with low CCT values at high illuminances will make a space appear artificial and overly colorful."* (Rea 2000, p.145)

1.4.5 Daylight factor

Daylight factor (DF) is the ratio of the measured illumination on a horizontal plane at a certain point, to the horizontal outside illuminance. The DF is calculated by the Equation 2.

$$DF = \frac{E_p}{E_{out}} x\ 100 \tag{2}$$

where

E_p is the illuminance of a certain point measured inside in lx,

E_{out} is the outside illuminance in lx.

The detailed analysis of the daylight amount in a place dependent upon various factors, for instance, orientation and geometry of the place, window amount, size and location of windows, neighbour buildings, the sky conditions of the day that measurement took place etc.; therefore, the above-mentioned method is simplified and low-precision (Kittler et al. 2012). This method can be applied only under overcast sky, hence direct sunlight is excluded and the sky is assumed as it is uniform. Furthermore, it is presumed that incidence of light is not partially blocked by some obstructions outside of the window and all reflected light from both interior and exterior surfaces are included (Rea 2000, TRILUX 2018). It can be consequently said that this method is useful for providing information about the daylight distribution in a space and should be taken into consideration, however it is not representative of the precise environmental conditions (Dave 2012).

1.4.6 Reflectance of surfaces

The term reflectance specifies the ratio of the reflected luminous flux to the total luminous flux that are incident to a specific surface (Laughton and Warne 2003). Reflectance values of major surfaces and all the furniture in a room are the parameters which are generally out of lighting designer's control, however, they can make a significant contribution to increase the illuminance in an indoor space. Reflectance can be determined according to the Equation 3 (Rea 2000).

$$\rho = \frac{L\,\pi}{E} \tag{3}$$

where

ρ is the reflectance value,

L is the luminance of a given point in cd/m^2,

E is the horizontal illuminance of a given point in lx.

1.4.7 Lighting maintenance

All luminaires have a limited life span and until the failure time, their performance tend to reduce over time. Lighting maintenance can be described as the main determinant between the predicted performance and the actual performance of a light source. (DiLaura et al. 2011, TRILUX 2018).

According to Rea (2000), the effect caused by the combination of equipment age and dirt accumulation can reduce the illuminance by 25% to 50%. Suitable luminaire selection right along with correct and regular cleaning is essential for having maximum performance from a

light source before its failure. The effect of maintenance over average illuminance in a place is exemplified in Figure 6 below.

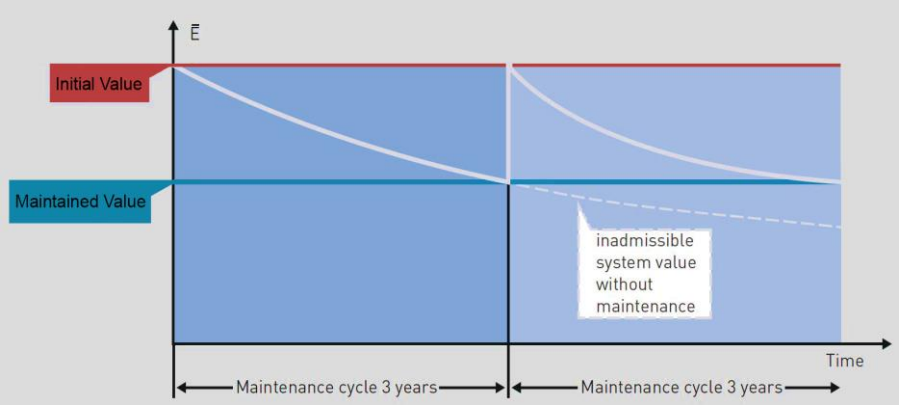

Figure 6: Average illuminance variation over the operation time of a lamp under three-year maintenance cycle. (Source: TRILUX 2018, p.65)

1.4.8 Lighting standard TS EN 12464-1

EN 12464-1 is the European Standard for lighting of the indoor working places which is written and approved by the technical committee of European Committee for Standardisation (CEN). Turkey, as a member country of CEN since 2012 (DIN 2014, CEN 2019) had to give EN 12464-1 a national standard status, as it is the responsibility of all CEN member countries (Figure 7). Accordingly, Turkish Standards Institution (TSE), as the sole body that has been authorized for standardization in Turkey, implemented the above-mentioned standard identically under the name of “TS EN 12464-1”. The latest version of the standard is approved by TSE in 20.03.2013 and still in use (TSE 2019).

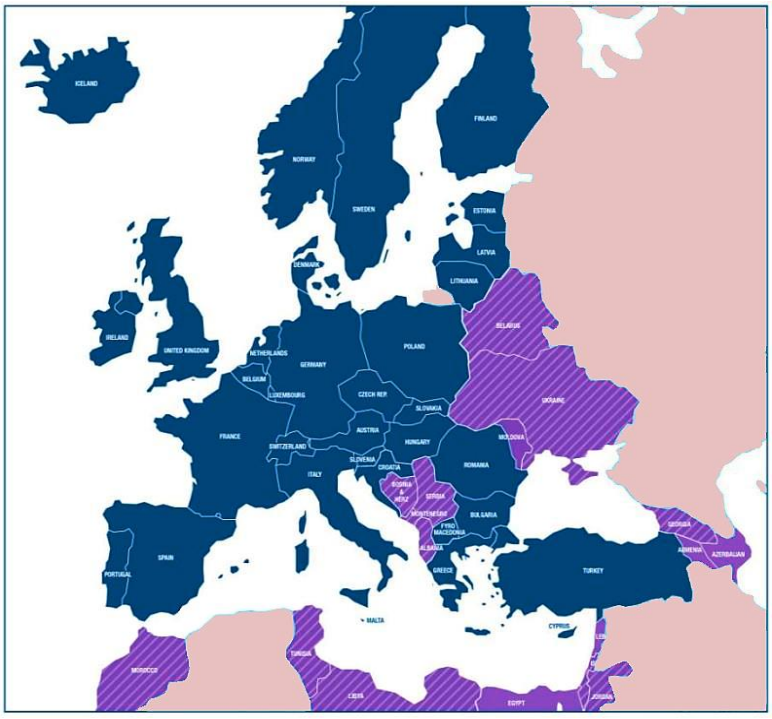

Figure 7: CEN member countries (blue) and the affiliates (purple) (Source: CEN 2019)

"This standard specifies requirements for lighting solutions for most indoor work places and their associated areas in terms of quantity and quality of illumination. In addition, recommendations are given for good lighting practice" (TSE 2013, p.6). In the standard, specific solutions are not offered to lighting designers for not limiting their freedom and promoting the use of innovative techniques and equipment. It is stated that the illumination requirements can be achieved with daylight, artificial lighting or with a combination of them.

Also, it provides a 27 pages long list of various possible tasks and activities that can be performed in an indoor working place. The lighting requirements of each task area are defined in the following four main criteria:

- The minimum required maintained illuminance ($\bar{E}_m$), which is average illuminance
- The maximum limit of Unified Glare Rating (UGR)
- The minimum required uniformity (U_o)
- The minimum required Color Rendering Index ($R_{a)}$

(TSE 2013)

1.4.9 Definition of task area and immediate surrounding area

Principally, an indoor place can be illuminated entirely (from one wall to another) with general lighting. However, another possibility is: to prepare a lighting plan to the same place by focusing on its separate areas, based on the performed task and activity there. Likewise, the requirements and recommendations in the European Standard EN 12464-1 are given by taking task-area-specific lighting into consideration. (TRILUX 2018). Therefore, lighting designers should be able to understand the terms "task area" and "immediate surrounding area" take them into consideration at the lighting planning stage.

Task area can be defined as the area, where visual elements of an activity are being carried out within. The size and location of the task area should be determined by the lighting designer, which can be horizontal, vertical or tilted (TRILUX 2018). According to TS EN 12464-1, when the spatial dimension of the task area is unknown or cannot be defined precisely, the whole place can be considered as the task area. In addition to this, when the task type cannot be certainly determined, an assumption has to be made by the lighting designer about the likely definition of task and related lighting requirements (TSE 2013).

According to the TS EN 12665 (Turkish Standard, Light and lighting – Basic terms and criteria for specifying lighting requirements), immediate surrounding area can be defined as the band that is adjacent to the task area and at least 0,5-meter-wide. A representation of the immediate surrounding area can be seen below in Figure 8 in yellow.

Figure 8: Representation of immediate surrounding area (Source: OMS 2015)

For a proper and complete illumination of a task area, its immediate surroundings also must be considered. Sudden decrease of illuminance in the immediate surrounding area may cause problems, such as concentration impairment, unnecessary strain and stress, fatigue, glare in the task area and non-stimulating working environment (DiLaura et al. 2011, TSE 2013). The lighting standard TS EN 12464-1 therefore specifies several requirements for both areas (TSE 2013) and those related to this work will be discussed in the Chapter 2.3.

1.4.10 Measuring grid

According to the TS EN 12464-1, in an in-situ illuminance and luminance measurement, the grid system should be applied to the area that is in question (TSE 2013). The measuring grid should be defined by using Equation 4:

$$p = 0.2\ x\ 5^{\log_{10}(d)} \tag{4}$$

where

- p is the maximum possible size of a grid cell ($p \leq$ 10m),
- d is longer dimension of the targeted measurement area (m), except that the ratio of the long side to the short side is 2 or more. If so, then shorter side of the area should be taken as d.

Consequently, the first higher whole number that comes after division d/p indicates the minimum amount of measuring points, which should be taken in the regarding side of the area. The center of each grid cell refers to points, where measurements should be taken. Additionally, according to TS EN 12464-1, ideally grid cells should be square. If it is not possible, maximum approximation to a square should be provided.

The other important points that must be considered during the assignment of a measuring grid are:

- The center point of grid cells should not coincide with luminaire layout. In such cases, the amount of the cell grids should be increased.
- The band of 0.5 meter adjacent to the walls and columns should be ignored and not included into measurement area, if the task area is not within the borders of this band.

(TSE 2013, TRILUX 2018).

Figure 9 exemplifies an assigned measuring grid considering all above-mentioned points.

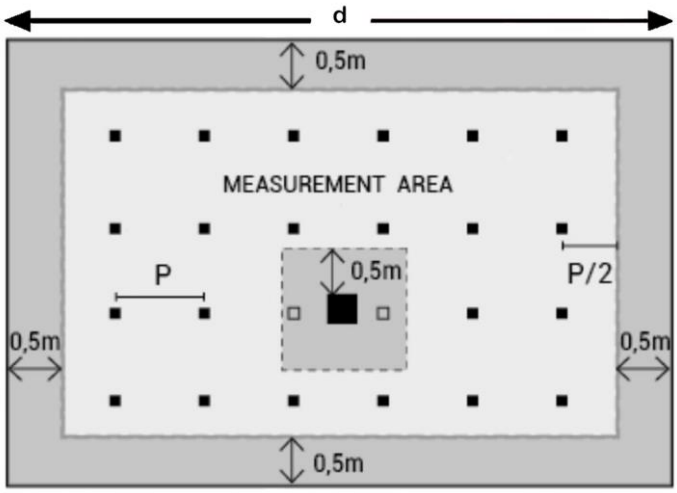

Figure 9: A measuring grid example (Source: Esseci 2019)

2 METHOD

2.1 Overview

In this section, all nine home offices selected for this work will be described in detail. Thereafter, the relevant points of the lighting standard (see sub-section 1.3.8) will be introduced, which have been considered during measurements and taken as basis for the lighting performance evaluations. Finally, the measurement equipment and the simulation software used for this work will be introduced.

As is known, all home offices are located in Izmir, Turkey and their locations are shown on the map below (Figure 10). Each home office is assigned a number based on the alphabetical order of the user occupations and the same numbering will be used later in following chapters of this thesis.

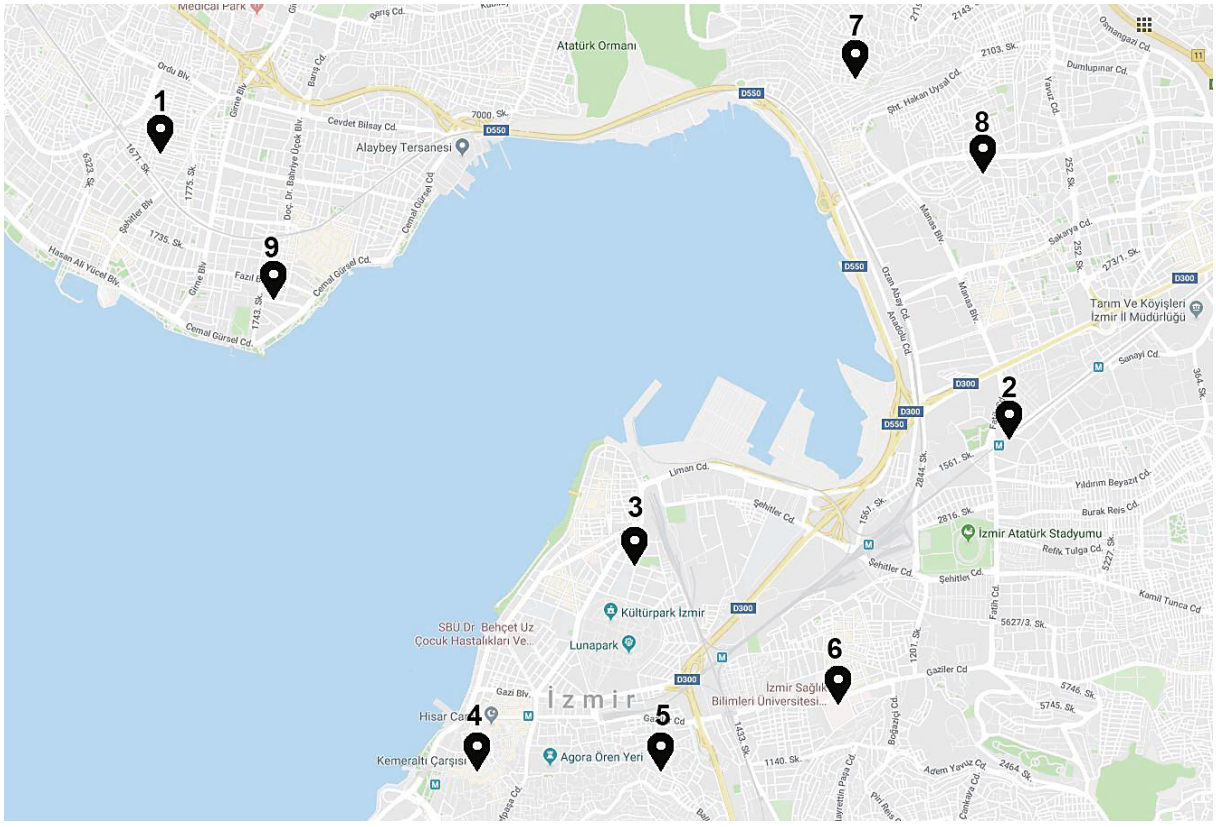

Figure 10: Map locations of home offices (1: Architect, 2: Book editor & Graphic designer, 3: Computer technician, 4: Industrial Designer, 5: Journalist, 6: Lawyer, 7: Private teacher, 8: Tailor & Fashion designer, 9: Translator) (Source: Google Maps)

2.2 Introduction of home office spaces

2.2.1 Home office 1: Architect

The user of the first home office space is a freelancer architect. It is a rectangular room with dimensions of 4 x 4.3 m, with a ceiling height of 2.55 m and total 17.2 m^2 surface area. It has within a living area and a working area. The room is north-northwest oriented and located on the fourth floor of the building. On the south-facing wall, it has one window with 1.1 m width and 1.2 m height. The entrance door is a white wooden door with the width of 0.9 m and the height of 2 m. In addition, there is a 0.75 x 2.1 m glass door to the balcony on the west-facing wall of the room.

Light brown parquet strips were used as floor material and there is a bright red, square carpet with dimensions of 1.6 x 1.6 m. The north-facing wall is black and the other three walls are grey. The finishing of the ceiling is bright white plaster. Additionally, the large black wardrobe in the corner of the room, the matt white wooden working table and the mirror standing just in front of the table can be considered as the other main objects in the room, which may significantly affect lighting conditions there.

The floor plan, the photos and the 3D model of the room can be seen in Figure 11 below.

Figure 11: Home office 1: Architect- Floor plan (top left), 3D model (bottom left) and photos (right)

2.2.2 Home office 2: Book editor & Graphic designer

The second home office is a studio flat with one large room and a separate bathroom, which is used by both a book editor and a graphic designer. The flat is on the first floor and southwest oriented. It is a rectangular flat with dimensions of 6 x 7 m, with a height of 2.5 m and total 42 m^2 surface area. Within the main L-shaped room, there is a living area, two working areas and a kitchenette. There is one large window space on the east faced wall, with in total 2 m width and 2 m height and consists of three small windows: 1 x 2 m on right, 1 x 1.3 m on top left and 1 x 0.7 m on bottom left (w x h). The workspace located in front of this window area is used by the graphic designer. The entrance door and the bathroom door are made of dark brown wood and both are in dimension of 0.9 x 2 m.

The floor material of the L-shaped room is light grey linoleum and the finishing of ceiling is bright white plaster. The wall to the right of the main entrance is clean concrete and all other walls are light grey. In addition, two cabinets and four bookshelves that are bright grey, two wooden and bright white working tables and light grey kitchen counters with metallic countertop are the other main objects of the room.

The floor plan, the photos and the 3D model of the room can be seen in Figure 12 below.

Figure 12: Home office 2: Book editor & Graphic designer- Floor plan (top left), 3D model (bottom left) and photos (right)

2.2.3 Home office 3: Computer technician

The third home office space is used by a computer technician as living room, bedroom and working place. It is an L shaped room with a length of 5 m, with a wide width of 3.7 m and narrow width of 3 m. The room is 3 meters high and total surface area is 18 m^2. The room is southeast oriented and located on the fourth floor of the building. There is one window on the north facing wall with the width of 1.15, with the height of 1.3 m and is located 0.85 m above the floor. The entrance door is made of light brown wood and it is in dimension of 0.9 x 2 m. The material of the two big wardrobes in the room are same as the door and their dimensions are 2 x 0.7 x 2.5 m (the wardrobe located to the left of the entrance) and 1.5 x 0.6 x 2.5 m (the wardrobe located to the right of the entrance).

Light brown parquet strips were used as the floor material and the finishing of ceiling is bright white plaster. All walls are light grey. Also, the long wooden dark brown working table with dimensions of 2 x 0.6 x 0.75 m and the light grey sofa, which is also used as bed by the user, are the other main objects of the room. These surfaces may play an important role in the lighting of the room.

The floor plan, the photo and the 3D model of the room can be seen in Figure 13 below.

Figure 13: Home office 3: Computer technician- Floor plan (left), 3D model (top right) and a photo (bottom right)

2.2.4 Home office 4: Industrial designer

The user of the fourth home office space is an industrial designer who is working full-time remotely. The room is used both as work place, living room and bedroom. It is an attic room located in the third floor of a single-family house and south-southeast oriented. It is rectangular with dimensions of 6.8 x 4.5 m, with total 30,6 m^2 surface area. The east facing short wall is 1.5 meters long and the west facing wall is 2.5 meters long, therefore the room has a sloped ceiling. There are two windows in the room: one is on the west-facing wall and rectangular, with the width of 1.5 m and the height of 1.1 m. Second one is on the north facing wall and due to being on the sloped wall, it is in right trapezoid shape.

Medium brown parquet strips were used as the floor material. The finishing of ceiling and all walls are bright white plaster. Besides, the wooden light brown wardrobes that are next to working table and in the corner of the room, bright white working table with dimensions of 1.5 x 0.8 x 0.73 m are the other main surfaces that may have a considerable impact on the lighting conditions of the room.

The floor plan, the photo and the 3D model of the room can be seen in Figure 14 below.

Figure 14: Home office 4: Industrial designer- Floor plan (left), 3D model (top right) and a photo (bottom right)

2.2.5 Home office 5: Journalist

The fifth home office is used by a journalist as both working place and living room. It is an attic room located on the fourth floor of a single-family house. The room is north-northwest oriented and rectangular, with dimensions of 7.4 x 4 m and total 29.6 m^2 surface area. The west facing long wall is 2.8 meters long and the east facing wall is 1.96 meters long, therefore the room has a sloped ceiling. There are three big windows in the room with the width of 2.1 m and the height of 1.75 m and the one on the north-facing wall is also used as a sliding door for going out to the terrace. The entrance door is in dimension of 0.9 x 2 m and was made of dark brown wood, which is also the material of all window frames.

The floor material is light pale brown parquet strips and all walls are beige. The ceiling is made of mohawk red oak butterscotch wood and all rafters and purlins are visible. The L-shaped working table is a wooden and beige. Mixed patterned sofas that are in orange and red as well as the black wooden table located in the middle of sofas with dimensions of 1.2 x 0.7 x 0.35 m can be considered as the other main objects in the room, which may significantly affect lighting conditions there.

The floor plan, the photo and the 3D model of the room can be seen in Figure 15 below.

Figure 15: Home office 5: Journalist- Floor plan (left), 3D model (top right) and a photo (bottom right)

2.2.6 Home office 6: Lawyer

The user of the sixth home office space is a lawyer. The room is southeast oriented and located on the ground floor of a single-family house. Originally, the room was rectangular, and it has within a living area, a dining area and a working area. Afterwards, the east facing wall of the room was partially demolished and the room is connected to the adjoining dining room with a wooden flat arch. Therefore, it is currently a L-shaped room, with a length of 5.9 m, with a wide width of 6.2 m and narrow width of 3.8. The room is in total 30 m^2 and the ceiling height is 2.65 m. There are 3 doors with dimensions of 0.9 x 2.1 m and made of dark brown wood. The door located on the north facing wall is used as the main entrance and the other two are interior door. Also, there are two windows on north-facing wall: one is to the immediate left of the main entrance with dimensions of 1.1 x 2.2 m, and the other one is 1.1 x 1.65 m (w x h). The daylight is partially blocked by the trees in front of the windows.

The room has beige marble floor, beige walls and a bright white ceiling. Additionally, all other main surfaces that may have an impact on the lighting conditions are made of dark brown wood (working table, the flat arch, bookshelves, dining table etc.). The dimensions of the working table are 0.8 x 1.5 x 0.74 m and dining table are 0.76 x 1.4 x 0.75 m.

The floor plan, the photos and the 3D model of the room can be seen in Figure 16 below.

Figure 16: Home office 6: Lawyer- Floor plan (top left), 3D model (bottom left) and photos (right)

2.2.7 Home office 7: Private teacher

The user of the first home office space is a private teacher. The room is on the fourth floor of the building, southeast oriented and is used as living room and workspace. It is an L-shaped room with a length of 3.9 m, with a wide width of 4.3 m and narrow width of 4 m. It is in total 16.9 m^2 and the ceiling height is 2.5 m. There is one wooden bright white door located on the west-facing wall with dimensions of 1 x 2 m and a window on the east-facing wall, with 1.1 m width and 1.25 m height.

Light brown parquet strips were used as the floor material, but a large part of the floor was covered by the beige carpet with dimensions of 2.25 x 2.65 (l x w). All walls are light pink and the finishing of the ceiling is bright white plaster. In addition to these, except the mixed patterned sofa in colors of red, green and beige, all other main surfaces that may have a significant effect on the lighting conditions of the room are wooden and bright white (working table, three bookshelves, television table etc.). The dimensions of the working table are 0.8 x 1.5 x 0.73 m and located in front of the window.

The floor plan, the photos and the 3D model of the room can be seen in Figure 17 below.

Figure 17: Home office 7: Private teacher- Floor plan (top left), 3D model (bottom left) and photos (right)

2.2.8 Home office 8: Tailor & Fashion designer

The eighth home office space is used by a tailor and a fashion designer. The room is north oriented, located in the basement floor and it has within three working areas, a kitchenette and a living area. It is in right trapezoid shape with width of 4.3 m, with short length of 2.3 m and long length of 7.1 m. The room has total 41.2 m^2 surface area and the ceiling height is 2.78 m. It has two big windows with dimension of 1.1 x 1.6 m (w x h) and a glass door with dimensions of 1 x 2.3 m. The sunlight is obstructed to a great extent by the large concrete staircases and trees in front of these windows and the glass door. Also, there is one wooden dark brown interior door located on the east-facing wall, with dimensions of 0.9 x 2.1 m.

White ceramic square tiles with dimension of 0.2 x 0.2 m were used as the floor material and the finishing of the ceiling is bright white plaster. The columns and beams of the room are pink and all walls are beige. Additionally, the working table located in the middle is made of medium brown wood, with dimensions are 1 x 1.8 x 0.87 m. The other two working tables are bright white, with dimensions of 1 x 1.x 0.72 m and 2.1 x 0.6 x 0.76 m.

The floor plan, the photos and the 3D model of the room can be seen in Figure 18 below.

Figure 18: Home office 8: Tailor & Fashion designer- Floor plan (top left), 3D model (bottom left) and photos (right)

2.2.9 Home office 9: Translator

The ninth home office is a studio flat with one large room and a separate bathroom, which are used by a translator. The flat is on the second floor of the building and is west oriented. The main room has a workspace, a kitchenette, a dining area and a living area. It is a rectangular room (excluding the small corridor) with width of 6.2 m and length of 3.75 m. It has total 23.3 m^2 surface area and the ceiling height is 2.7 m. It has 2 windows on the south facing wall, with dimensions of 1 x 1.95 m (w x h). Also, both main entrance door and interior door are wooden bright, with dimensions of 1 x 2 m.

Medium brown parquet strips were used as the floor material. The finishing of the ceiling is bright white plaster. All walls are light blue. Besides, the wooden medium brown wardrobes that are next to west-facing wall, dark brown wooden kitchen counters, light brown wooden working table with dimensions of 1.4 x 0.8 x 0.73 m (w x l x h) and long white dining table with dimensions of 0.4 x 1.2 x 1.1 m (w x l x h) are the other main surfaces that may have a considerable impact on the lighting conditions of the room.

The floor plan, the photos and the 3D model of the room can be seen in Figure 19 below.

Figure 19: Home office 9: Translator- Floor plan (top left), 3D model (bottom left) and photos (right)

2.3 Lighting performance evaluation criteria

As noted earlier, each different task and activity has its own lighting requirements, and this was considered in the evaluation of all previously introduced home office areas. Each home office was first divided into different small areas considering the function of the area (working area or living area) and each of these small areas was assigned a special measuring grid. The division of these areas and the distribution of the measuring grids were performed in accordance with the previously introduced lighting standard TS EN 12464-1 (see sub-sections 1.3.8, 1.3.9 and 1.3.10).

Working areas

The criteria, which were relevant to this work and taken as basis in lighting performance evaluations are grouped according to job discipline of the occupants and they are presented below in Table 1, where E_m is minimum maintained illuminance on the reference task area, UGR_L is the maximum Unified Glare Rating limit, U_o is minimum illuminance uniformity on the task area and R_a is minimum color rendering index.

Table 1: Referenced lighting standard requirements on the task area, grouped by the profession in the home offices (Source: TSE 2013, p.23-47)

Professions (home office)	**Ref. no.**	**Type of areas, task or activity**	**E_m (lx)**	**UGR_L -**	**U_o -**	**R_a -**
Architect	5.26.4	CAD work stations	500	19	0.60	80
Book Editor Journalist Lawyer Translator	5.26.2	Writing, typing, reading, data processing	500	19	0.60	80
Fashion Designer Tailor	5.23.5	Sewing, fine knitting, stitching	750	22	0.70	80
Computer Technician	5.36.13	Computer room	300	19	0,60	80
Private Teacher	5.36.1	Classroom, tutorial room	300	19	0.60	80
Graphic Designer Industrial Designer	5.26.3	Technical drawing	750	16	0.70	80

As mentioned before, having a uniform lighting distribution in an area can prevent problems caused by sudden illuminance decrease such as fatigue, glare, strain, stress, etc. Hence, for

having a proper lighting performance on a task area, as well as its immediate surrounding must be taken into consideration. Table 2 shows minimum illuminance requirements that should be provided on task area and on its immediate surrounding.

Table 2: Required minimum illuminance levels on immediate surrounding areas based on task area illuminance (Source: TSE 2013, p.12)

Task area (E_{task}) (lx)	Immediate surrounding areas (lx)
≥750	500
500	300
300	200

Table 3 shows thresholds of average daylight factor for an efficient and uniform daylight distribution and their implications on appearance and thermal conditions in an indoor space.

Table 3: Rules of thumbs for daylight factor (Source: SLL 2012, CIBSE)

Average DF	Appearance and thermal energy implications
< 2%	Room looks gloomy. Electric lighting needed most of the day.
2% to 5%	Predominantly daylit appearance, but supplementary artificial lighting is needed. Good balance between lighting and thermal aspects.
>5%	Room is strongly daylit. Daytime electric is rarely needed but potential thermal problems (overheating in summer and heat losses in winter).

Also, it is emphasized in the lighting standard TS EN 12464-1 that:

- The illuminance uniformity in the immediate surrounding area shall be $U_o \geq 0.40$.
- The mean cylindrical illuminance of the areas, where visual communication quality is essential (offices, classrooms, etc.), should be minimum 150 lx and the uniformity shall be $U_o \geq 0.10$.
- The modelling between 0.3 and 0.6 at a point is a good indicator of uniform luminaire arrangement.

Living areas

Unlike workplaces, there are no standards or regulations for the lighting of residential areas, but only recommendations. The ones that are relevant and taken as reference in this work are presented below in Table 4, where E_m refers to minimum maintained illuminance, U_o is the minimum recommended illuminance uniformity and R_a is minimum color rendering index.

Table 4: Recommended lighting criteria for residential areas (Source: DiLaura et al. 2011)

Type of areas, task or activity	E_m (lx)	U_o -	R_a -
Living room	200	0.10	80
Bedroom	200		
Dining room	300		
Kitchen	300		

2.4 Measuring equipment

There is a wide selection of lighting measurement devices on the market. The below-mentioned instruments were used for this work.

Konica Minolta LS 100 Luminance meter

Konica Minolta LS 100 (Figure 20) is a spot luminance meter which is suitable for measuring not only instantaneous luminance, but also luminance ratio and peak luminance based on the previously measured and saved reference values in memory. It can be used for the measurement of broad range of light sources and reflective surfaces. The device has an automatic calibration and color correction options, but as well enables users to set their own on demand. The single reflex lens (SLR) of the device allows to measure target area precisely and irrespective of distance. The measured luminance values can be seen both in viewfinder and external display. Luminance unit can be chosen by user as cd/m^2 or fL. The measuring range is between 0.001 and 299.900 cd/m^2 (0.001 to 87.530 fL) with accuracy of ±2% ±1 digit of the displayed value (Konica 2013).

Within the scope of this work, this device was used for measuring the luminance values (cd/m^2) of the main room and furniture surfaces. These measured values applied later to the reflectance equation (Equation 3) with corresponding illuminance values.

Konica Minolta T-10A Illuminance meter

Konica Minolta T-10A (Figure 20) is a multi-functional digital illuminance meter with a silicon photocell receptor head. The device can measure illuminance, illuminance difference and ratio, average illuminance and integrated illuminance based on a reference integration time. The instrument automatically calibrates after turning on and enables user to input a color correlation factor (CCF). The user can perform both continuous and intermittent sources of light. Illuminance unit can be switched to lx or fcd. The measuring range is between 0.01 and 299.900 lx (0.01 to 29.990 fcd) with accuracy of ±2% ±1 digit of the displayed value. The measurement results can be read from the LCD screen of the device (Konica 2013).

Within the scope of this work, this instrument was used for measuring the outside horizontal illuminance (lx) and spot illuminance values (lx) inside of each home office space, based on previously assigned measuring grids. These measured values were later used for analysing daylight factor (Equation 2) and for performing the reflectance calculations of main room and furniture surfaces (Equation 3).

Figure 20: Konica Minolta LS 100 Luminance meter (left) and Konica Minolta T-10A Illuminance meter (right) (Source: Konica 2013)

2.5 Applied lighting simulation software

DIALux (DIALux 4.13 2016) is used as software for lighting performance simulations of this project. The software is a sophisticated lighting simulation tool, at the same time easy to use, effective and suitable for simulating indoor and outdoor scenes. It has a large catalogue of luminaires, which includes detailed technical and photometric information from various leading manufacturers. Through the luminaire search engine, namely LUMsearch (LUMsearch 2019), all luminaires in the catalogue are easily accessible and importable to DIALux. Furthermore, the DIALux supports the file formats DWG and DXF; therefore, the target simulation area can either be imported into DIALux after being drawn in a CAD tool or can be created from the beginning in DIALux (DIAL GmbH 2011).

In this work, 2D drawings of home office spaces were imported into DIALux. After modelling them in 3D, all previously recorded sky conditions, calculated reflectance values, measuring grids, day and time of measurements were defined into regarding file and simulations were performed

3 RESULTS

3.1 Overview

In this chapter, the results of on-site measurements and simulations will be shown. It consists of nine main chapters and in each chapter the analysis of one home office will be described. At the beginning of each chapter, floor plans with luminaire locations, technical data of luminaires and applied measuring grids will be shown. Subsequently, four sub-sections will be included in the chapters for presenting daytime results, evening results, overall analysis of all results and improvement scenarios based on all information, respectively.

3.2 Home office 1: Architect

Detailed information with photographs and 3D view can be found in the sub-section 2.2.1. The luminaire plan of the room is shown below in Figure 21. All given dimensions are in millimetres.

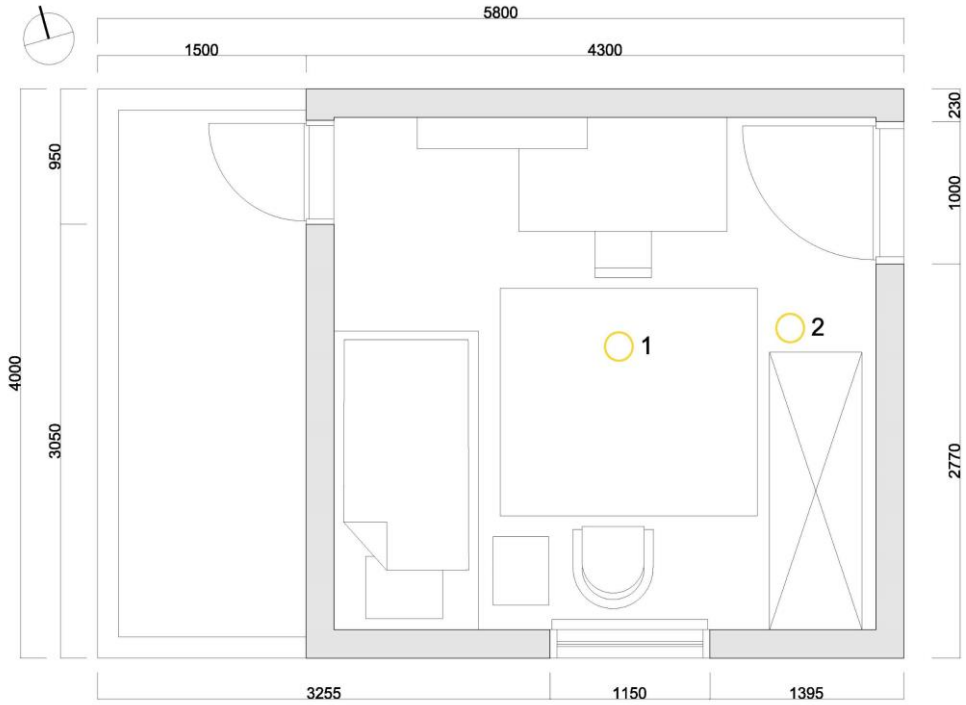

Figure 21: Home office 1- Floor plan with luminaires

The technical information of existing luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 21:

1) Pendant luminaire- 0,4 m suspension height- Sylvania Lynx-D 1800lm 26W 830

2) Standing luminaire- 1,85 m height- Osram Haloline Pro 64698 3500lm 150W 230V R7s

The grids that were used for illuminance measurement in this home office, which were created through the instructions of the lighting standard TS EN 12464-1 (see sub-sections 1.3.9 and 1.3.10) are shown in Figure 22. The measuring grid of the task area is represented in orange, immediate surrounding is in red and the living area is in green.

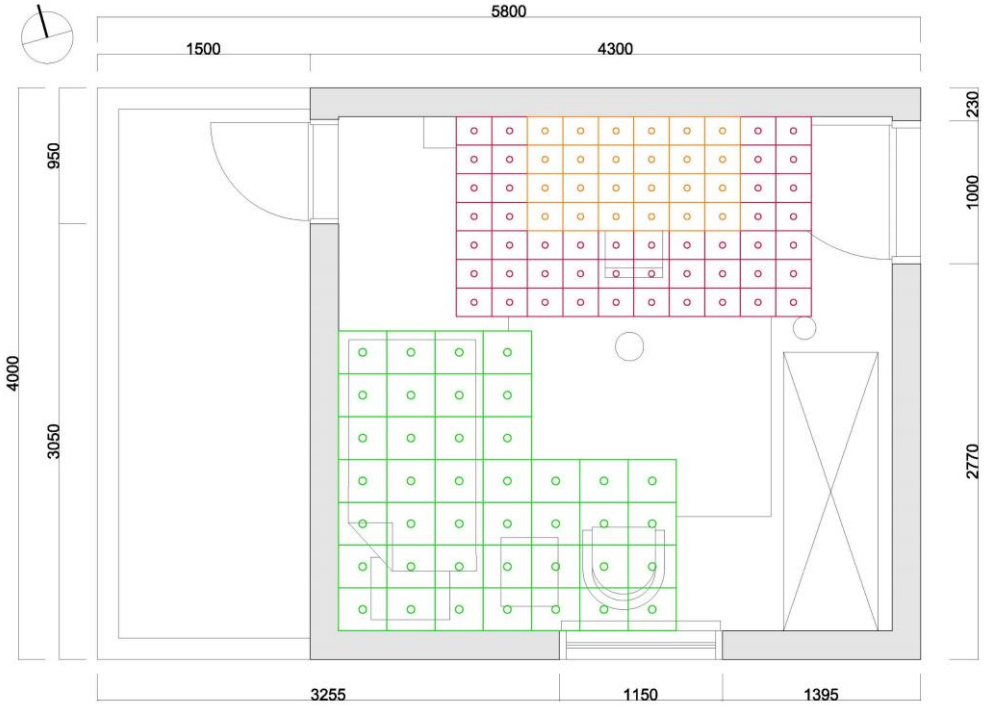

Figure 22: Home office 1- Floor plan with measuring grids

The information regarding to the assigned measuring grids is presented below in Table 5 and the grid cell labels are indicated in Figure 23. The grid codes that are given in the second column of Table 5 and the grid cell labels that are given in Figure 23 will be used identically in all following sub-chapters of the Chapter 3.2.

Table 5: Home office 1- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	Arch-Ta	250 x 200	24
Immediate Surrounding Area	Arch-Isa		46
Living Area	Arch-La	300 x 340	40

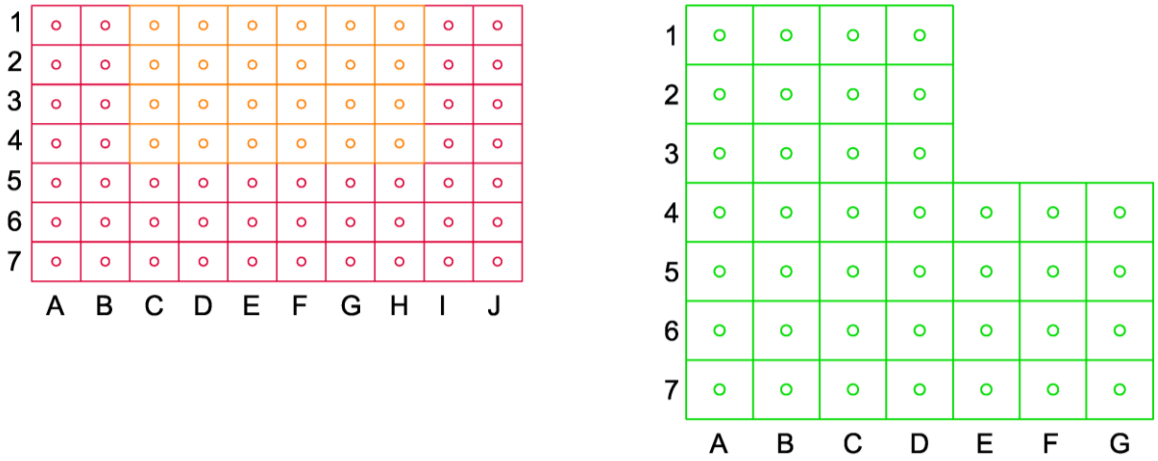

Figure 23: Home office 1- The measuring grid numbering of task area and immediate surrounding area (left) and living area (right)

3.2.1 Daytime measurement results

The daytime field measurement took place in the morning of 11.04.2017 from 10:15 to 10:55. The measurement was performed under clear sky with no direct sunlight and when all artificial lighting was turned off. The results of the task and immediate surrounding area are shown together below in Table 6 and the results of living area in Table 7. Both tables are also including obtained outside illuminance values in their last column.

Table 6: Home office 1- Field measurement results of the task and the immediate surrounding area (daytime)

Arch-Ta & Arch-Isa	A	B	C	D	E	F	G	H	I	J	E_{out}
1	490	427	351	301	277,5	249,7	214,3	197,4	186,4	182,3	61700
2	525	455	366	367	333	311	307	255,5	222,4	219,2	60360
3	590	460	395	371	349	334	312	267,5	251,4	247	59750
4	553	466	413	383	363	344	324	278,3	275	261,5	59540
5	537	480	435	442	409	376	332	312	310	284,3	60480
6	521	487	442	430	413	396	360	345	332	311	59520
7	513	495	463	450	422	410	388	370	347	323	58120

Table 7: Home office 1- Field measurement results of the living area (daytime)

Arch-La	A	B	C	D	E	F	G	E_{out}
1	410	449	562	590				58890
2	429	453	581	628				59100
3	441	482	610	655				58410
4	453	521	637	738	1014	1300	908	60520
5	391	496	671	812	1497	1958	1331	60274
6	358	409	709	974	1981	2671	2004	61360
7	302	368	581	1015	3681	4250	3892	62120

As a result of the measurements, the average outside illuminance was calculated 60010 lx. Considering previously measured point illuminance and luminance results, reflectance of the major surfaces in the room were derived by using Equation 3 and given in the Table 8.

Table 8: Home office 1- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	31
Carpet	12
Ceiling	72
Walls (grey)	52
Wall (black)	9
Working table	74
Wardrobe	5

Thereafter, the room was modelled with DIALux. Same measurement date and time, sky type and the above-mentioned reflectance values were defined in the software and the simulation was performed. The results can be seen from the Table 9 and Table 10.

Table 9: Home office 1- Simulation results of the task and the immediate surrounding area (daytime)

Arch-Ta & Arch-Isa	A	B	C	D	E	F	G	H	I	J
1	333	263	250	199	185	194	194	170	137	119
2	388	313	306	243	223	211	211	184	159	134
3	438	330	322	264	232	221	215	184	174	147
4	427	335	314	272	245	233	216	184	168	148
5	396	336	307	307	263	237	218	218	193	167
6	380	350	311	311	268	238	212	212	187	167
7	373	354	328	328	302	272	240	240	201	163

Table 10: Home office 1- Simulation results of the living area (daytime)

Arch-La	A	B	C	D	E	F	G
1	206	243	265	275			
2	220	245	285	318			
3	225	260	320	373			
4	236	288	370	469	598	612	558
5	200	268	402	695	1105	1169	1034
6	149	212	413	784	1738	1961	1799
7	104	136	203	518	2635	3446	3260

Since it is not possible to manually enter an outside illuminance value in DIALux, for being able to find the outside illuminance that was used by the simulation software during calculations, exterior scenario of the room was identically modelled and then the simulation was performed. As a result, the average outside illuminance was found 35740 lx and this result later used for the analysis of daylight factor (DF).

3.2.2 Evening measurement results

The evening field measurements took place in 11.04.2017 from 20:00 to 20:45. The measurement was performed with no daylight and 25 minutes after all lights were switched on. The results of the task and immediate surrounding area are shown together in Table 11 and the results of living area are presented in Table 12.

Table 11: Home office 1- Field measurement results of the task and the immediate surrounding area (evening)

Arch-Ta & Arch-Isa	A	B	C	D	E	F	G	H	I	J
1	45,6	51,3	56,7	85,2	106,5	127,9	157,9	165,5	150,4	111,2
2	50,7	58,9	70,4	103,1	128,2	163,5	187,1	200,5	180,7	140,8
3	54,9	74,3	82,9	110,2	133	170,6	196,8	204	195,4	175,6
4	65,8	95,2	101,1	137,5	163	203,5	205,7	209,5	219,9	199,4
5	88	106,9	168,4	210,6	245,8	276,4	266,9	254,8	259,7	240,9
6	95,8	132,5	220,1	259,1	299,8	323	301	285,4	278,3	261,8
7	109,6	140,7	245,8	280,3	321	385	336	315	297,6	270,8

Table 12: Home office 1- Field measurement results of the living area (evening)

Arch-La	A	B	C	D	E	F	G
1	45,2	57,1	75,9	146,8			
2	44,6	56,7	73	106,9			
3	40,9	48,5	67,6	94,7			
4	39	45,9	60,8	75,3	85,5	115,6	123,9
5	35,6	40,9	48,7	56	60,5	74	76,3
6	30,1	36,2	42,4	48,5	52,6	52,7	54,4
7	27,6	31,4	39,3	42,3	45,7	48,2	48,8

Afterwards, photometric data and the product description of the existing luminaires were found from luminaire search engine and were added on the previously created 3D model with DIALux. Same measurement conditions, date and time were precisely defined in the software and afterwards the simulation was performed. The results obtained through this simulation are shown in Table 13 and Table 14.

Table 13: Home office 1- Simulation results of the task and the immediate surrounding area (evening)

Arch-Ta & Arch-Isa	A	B	C	D	E	F	G	H	I	J
1	58	74	88	106	115	138	147	152	132	124
2	68	87	105	129	142	160	168	172	156	147
3	81	106	120	148	160	178	183	190	188	178
4	91	122	144	179	195	212	215	219	214	204
5	109	146	200	229	258	274	274	256	252	246
6	123	169	240	283	318	330	319	289	274	265
7	132	185	269	323	363	370	348	309	284	273

Table 14: Home office 1- Simulation results of the living area (evening)

Arch-La	A	B	C	D	E	F	G
1	44	57	99	176			
2	42	54	92	157			
3	39	49	75	117			
4	35	43	61	86	134	174	177
5	30	35	44	57	76	89	90
6	26	29	35	41	49	52	52
7	24	26	31	35	37	36	36

3.2.3 Analysis of results

The average illuminance (E_{avg}) and uniformity (U_o) values that have been obtained through field measurements and simulations are shown below in Table 15 together with the recommended values in the standards. Detailed information about the relevant standard and requirements can be seen in Chapter 2.3.

Table 15: Home office 1- Overview of base case results and minimum standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	319	228	145	157	500
	U_o	0,62	0,75	0,39	0,56	0,60
Immediate Sur. Area	E_{avg}	390	263	199	212	300
	U_o	0,47	0,45	0,23	0,27	0,40
Living Area	E_{avg}	1055	715	60	66	200
	U_o	0,29	0,15	0,46	0,36	0,10

As can be observed from the data shown above, simulation and field measurement E_{avg} results of the task area were found considerably less than minimum standard requirements both in daytime and evening. Additionally, E_{avg} values of the immediate surrounding area were measured higher than the E_{avg} of the task area, which is normally recommended to be less.

Also, E_{avg} results of the living area are notably more than adequate in daytime, but to the contrary, they are less in evening. Moreover, while living area U_o results are generally satisfactory, this is valid only for daytime results of the task and immediate surrounding area.

Besides, the daylight factor of each scenario was calculated, considering that it could provide an explanation to the above-mentioned result differences. The daylight factor analysis results are shown in Figure 24 below.

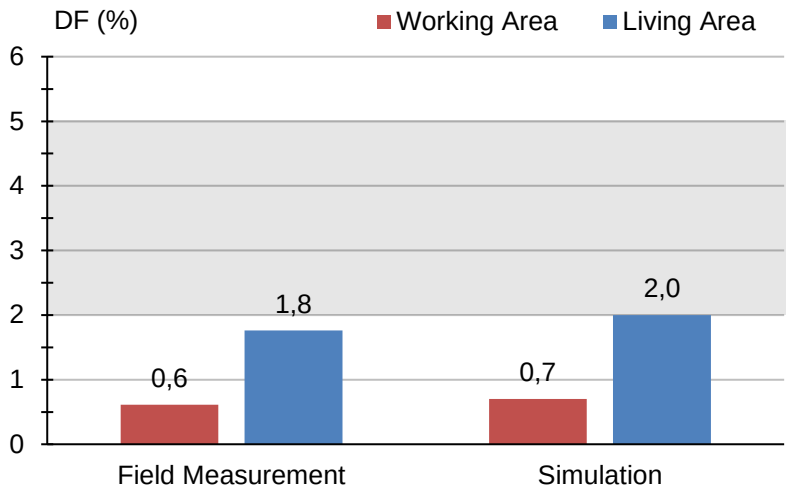

Figure 24: Home office 1- Daylight factor analysis results

Based on the similarity between the daylight factor results, it can be mentioned that the incoherence between daytime results are mainly caused by the difference between the measured outside illuminance (60010 lx) and the one that DIALux used for performing the simulations (35740 lx). Besides, considering that the gray zone in the graph indicates the recommended daylight factor range, it can be interpreted that the working area (task area + immediate surrounding) and living area have overall insufficient daylight amount.

Furthermore, the maximum Unified Glare Rating (UGR), mean cylindrical illuminance ($\bar{E}_z$) and modelling of the working area were evaluated with for evening only under artificial lighting. The results are as follows:

- UGR_{max} = <10
- $\bar{E}_z$ = 131 lx
- Modelling = 0,43

Considering the given standard criteria in the Chapter 2.3, the UGR_{max} is in accordance with the recommendations. On the other hand, even though the modelling is numerically following the standards, since the $\bar{E}_z$ is below the required value, both $\bar{E}_z$ and modelling should not be considered appropriate and should be subjected to improvement.

3.2.4 Improvement proposal

By taking all above-mentioned observations and findings into consideration, an improvement scenario was developed for artificial lighting performance. Firstly, more accurate luminaires were chosen, which can better and effectively meet the requirements of the environment. The locations of these luminaires were then determined by the field arrangement option of the DIALux. The new luminaire arrangement is shown through the plan in Figure 25.

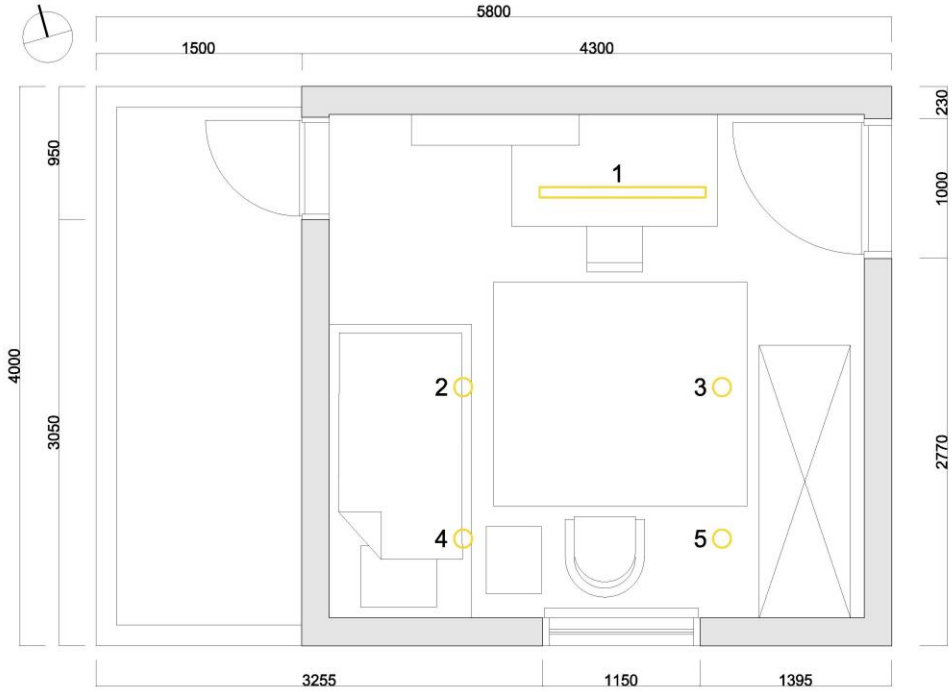

Figure 25: Home office 1- Improvement proposal

The technical information of new luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 25:

1) Pendant luminaire- 0,35 m suspension height - Philips TPS680 TL5 4850lm 50W

From 2 to 5) Ceiling recessed LED spotlights - Philips RS140B 650lm 11W 840

Task and immediate surrounding area simulation results of the improvement proposal are presented in Table 16.

Table 16: Home office 1- Results of the task and the immediate surrounding area (improvement proposal)

Arch-Ta & Arch-Isa	A	B	C	D	E	F	G	H	I	J
1	184	259	375	466	511	549	532	443	291	204
2	233	326	423	528	583	608	583	488	332	232
3	260	358	444	551	603	623	595	501	360	257
4	268	364	452	554	606	620	591	501	365	265
5	276	360	472	536	576	581	544	480	359	267
6	273	341	432	481	513	518	493	440	338	258
7	272	327	399	437	460	470	452	410	325	251

According to the results given above, E_{avg} of the task area is 530 lx and the U_o is 0,70. Also E_{avg} of the immediate surrounding area is 367 lx and U_o is 0,50. Hence, now they comply with standard requirements (Table 15). The other evaluated and improved indicators of the working area are as follows:

- UGR_{max}= <10
- $\bar{E}_z$ = 215 lx
- Modelling = 0,33

Furthermore, living area simulation results are shown below in Table 17. Since the E_{avg} was found 227 lx and the U_o was found 0,51, this area as well is in accordance with the minimum standard recommendations.

Table 17: Home office 1- Results of the living area (improvement proposal)

Arch-La	A	B	C	D	E	F	G
1	125	200	270	278			
2	146	239	329	319			
3	154	252	336	323			
4	153	255	329	319	234	184	225
5	152	250	337	319	224	176	212
6	140	229	311	295	202	157	188
7	115	184	238	228	162	122	146

3.3 Home office 2: Book editor & Graphic designer

Detailed information with photographs and 3D view can be found in the sub-section 2.2.2. The luminaire plan of the room is shown in Figure 26. The dimensions are in millimetres.

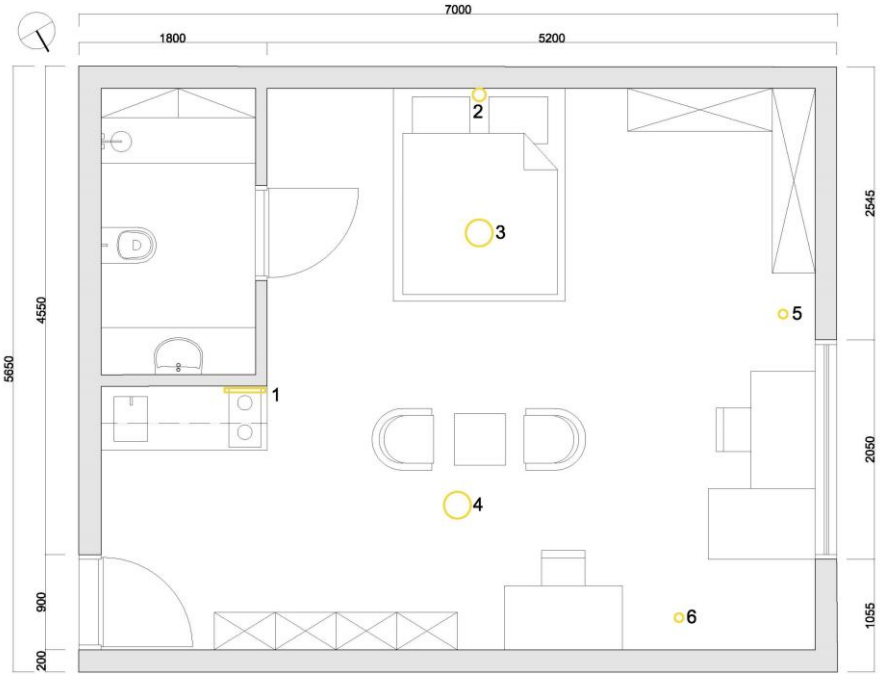

Figure 26: Home office 2- Floor plan with luminaires

The technical information of existing luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 26:

1) Cooker hood lamp- 1,5 m height- Sylvania Tubular E14 CL 415lm 40W 230V

2) Wall surface mounted luminaire- 1,6 m mounting height- Philips Master LED Bulb D12 345lm 4,5W 230V

3 and 4) Ceiling mounted luminaire- 0,1 m luminaire height- RZB Home502 LED white 2500lm 30W 840

5 and 6) Table luminaires- IKEA Table LED-Lamp Vintage E27 190612 120lm 1,4W 2500K

Figure 27 shows the measuring grids that were applied to this home office, which were created by taking the instructions of the lighting standard TS EN 12464-1 into consideration (see sub-sections 1.3.9 and 1.3.10). The measuring grid of the task area is shown in orange, immediate surrounding is in red, the living area is in green and lastly the kitchenette is shown in blue.

Figure 27: Home office 2- Floor plan with measuring grids

The detailed information about grids that were used for measuring illuminance in this home office are presented below in Table 18. Apart from that, labelling of the grid cells is presented in Figure 28. Both grid codes that are given in the second column of Table 18 and the labelling of the grid cells that are given in Figure 28 will be used in all following sub-chapters of the Chapter 3.3 identically.

Table 18: Home office 2- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Book Editor- Task area	Be-Ta	200 x 220	15
Book Editor- Immediate Surrounding Area	Be-Isa		39
Graphic Designer- Task Area	Gd-Ta	200 x 220	30
Graphic Designer- Immediate Surrounding Area	Gd-Isa		42
Living Area	BG-La	450 x 400	40
Kitchen	BG-K	200 x 250	28

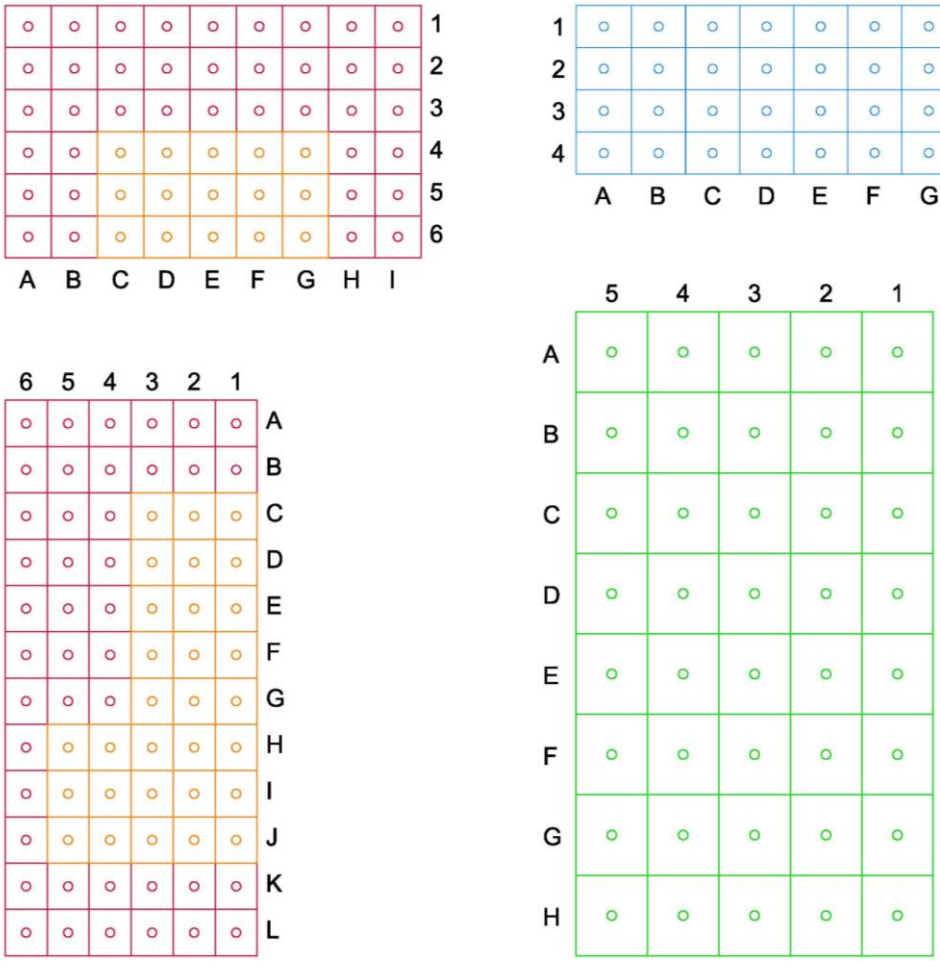

Figure 28: Home office 2- The measuring grid numbering of task area and immediate surrounding area of book editor (top left), kitchen (top right), task area and immediate surrounding area graphic designer (bottom left) and living area (bottom right)

3.3.1 Daytime measurement results

The daytime field measurement took place in the morning of 09.04.2017 from 09:50 to 11:05. The measurement was performed under clear sky with no direct sunlight and no artificial lighting. The illuminance results of all areas that were obtained by daytime field measurement can be seen below from Table 19 to Table 22 with simultaneously measured outside illuminance values in their last column.

Table 19: Home office 2- Field measurement results of the task and the immediate surrounding area of the book editor (daytime)

Be-Ta & Be-Isa	A	B	C	D	E	F	G	H	I	E_{out}
1	499	436	426	406	395	369	335	322	319	60120
2	535	481	439	413	406	371	345	342	331	60030
3	561	503	458	435	418	385	354	352	344	61860
4	599	528	507	469	442	423	399	364	373	61350
5	613	555	515	480	455	426	416	386	387	62870
6	635	588	532	491	465	442	430	418	399	62630

Table 20: Home office 2- Field measurement results of the task and the immediate surrounding area of the graphic designer (daytime)

Gd-Ta & Isa	A	B	C	D	E	F	G	H	I	J	K	L	E_{out}
1	1423	2076	2355	2673	2874	3148	3258	3458	2708	2418	2219	924	65920
2	1366	1653	1940	2078	2128	2431	2578	2756	2441	1928	2107	913	64650
3	1257	1447	1678	1754	1900	1992	2118	2440	1951	1568	1959	904	62710
4	1156	1311	1418	1554	1598	1783	1888	1986	1657	1450	1220	887	63520
5	992	1165	1242	1332	1377	1583	1677	1605	1511	1313	1080	824	62780
6	956	1084	1109	1164	1247	1289	1403	1480	1289	1093	990	790	62320

Table 21: Home office 2- Field measurement results of the living area (daytime)

BG-La	A	B	C	D	E	F	G	H	E_{out}
1	209,9	222	234,3	255,6	300	318	339	354	62890
2	199,3	206,8	217,2	232,7	268,4	294,8	305	320	62610
3	183,6	187,5	206,6	221,9	247,8	277,6	298,4	311	61820
4	168,2	174,6	183	204,9	218	238,6	267,1	274,3	61550
5	144,3	148,8	172,5	181,6	188	210,8	216,7	236,6	60120

Table 22: Home office 2- Field measurement results of the kitchen (daytime)

BG-K	A	B	C	D	E	F	G	E_{out}
1	123,6	126,9	131,4	136,4	140	146,8	152,5	63730
2	115	123,6	124,9	138,5	145,3	145,5	156,3	62550
3	111,2	120	123,6	138,7	142,3	148,6	159,1	62680
4	100	112,1	123,4	144,2	148,3	153,4	161,5	60960

Based on performed measurements, the average outside illuminance value was calculated 62480 lx. Also, reflectance of some major surfaces in the room were found by applying measured point illuminance and luminance values to the Equation 3 and given in Table 23.

Table 23: Home office 2- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	57
Ceiling	70
Walls (grey)	56
Wall (concrete)	41
Working tables	60
Wardrobes and Shelves	58
Kitchen counter	59

Afterwards, the room was modelled one-to-one in 3D with DIALux. Same measurement date, time, sky type and the reflectance values were introduced to the software and simulated. The results obtained through this lighting performance simulation are shown from Table 24 to Table 26 below.

Table 24: Home office 2- Simulation results of the task and the immediate surrounding area of the book editor (daytime)

Be-Ta & Be-Isa	A	B	C	D	E	F	G	H	I
1	335	305	303	275	262	236	228	211	262
2	377	343	315	293	276	241	218	214	236
3	394	371	335	297	284	249	229	210	194
4	444	386	329	310	263	263	239	207	191
5	462	398	354	314	269	269	247	216	196
6	514	448	373	329	285	285	252	217	196

Table 25: Home office 2- Simulation results of the task and the immediate surrounding area of the graphic designer (daytime)

Gd-Ta & Gd-Isa	A	B	C	D	E	F	G	H	I	J	K	L
1	613	1729	1807	1859	1823	1838	1983	2015	1969	1610	919	208
2	777	1185	1356	1460	1548	1591	1590	1522	1403	1131	854	482
3	727	1031	1189	1307	1373	1428	1419	1344	1224	1001	802	482
4	670	902	996	1070	1163	1155	1148	1050	951	811	743	521
5	625	809	885	954	1015	1026	988	856	787	681	673	503
6	520	647	697	733	778	798	783	767	675	629	583	470

Table 26: Home office 2- Simulation results of the living area (left) and the kitchen (right)(daytime)

BG-La	A	B	C	D	E	F	G	H
1	119	127	156	184	212	245	275	293
2	117	121	137	157	175	198	220	224
3	112	113	127	144	157	173	186	191
4	106	103	112	125	128	141	144	148
5	98	97	102	111	113	124	124	125

BG-K	A	B	C	D	E	F	G
1	116	107	104	101	97	93	105
2	110	107	103	96	94	90	91
3	109	99	95	86	87	85	88
4	99	90	84	76	78	80	83

Due to the fact that it is not possible to manually introduce an outside illuminance value to DIALux, for being able to find the outside illuminance value that was used by the software during simulations, an exterior scenario of the room was modelled identically and simulated. As a result, the average outside illuminance was found 36180 lx and this result later used for analyzing the daylight factor (DF).

3.3.2 Evening measurement results

The evening field measurements were performed in 09.04.2017 from 20:30 to 22:00 with no daylight and 40 minutes after all lights were switched on. The results of both working areas can be found in Table 27 and Table 28 below.

Table 27: Home office 2- Field measurement results of the task and the immediate surrounding area of the book editor (evening)

Be-Ta & Be-Isa	A	B	C	D	E	F	G	H	I
1	244,8	235,6	182,4	146,4	136,5	123,5	120,8	98,3	94,2
2	305,6	250,3	193,4	168	151,6	127,9	122,6	114,6	118,3
3	276,9	235,8	174	157,6	147	130,9	124,6	135,4	138,6
4	189,6	165,3	153,7	149,1	155,3	160,9	171,9	179,7	186,3
5	100,4	116,3	128,4	146,2	163,4	178,3	186,4	198,6	214,9
6	90,6	95,6	104,6	139,3	170,5	181,4	195,4	204,7	220,6

Table 28: Home office 2- Field measurement results of the task and the immediate surrounding area of the graphic designer (evening)

Gd-Ta & Gd-Isa	A	B	C	D	E	F	G	H	I	J	K	L
1	242,6	189,6	105,3	80	71,5	63,4	51,6	49,1	46,6	42,2	36,3	34,1
2	253,4	229	122	89,4	82,6	71	53,4	50	47	43,7	39,1	38,6
3	222,9	175,3	103,5	84,6	78,1	64,3	58,1	52,1	49,8	44,2	42,2	40
4	147,4	136,5	91,3	80,2	78,6	66,6	58,9	54,8	50,4	48,6	45,1	41,2
5	131,6	121,2	84,6	79	76,3	68,2	62	55	51,6	51,1	49,5	43,9
6	125,3	110,6	80	76,6	74,3	73,6	65,3	58,3	55,5	54,2	51,2	49,9

Furthermore, the results of the living area and the kitchen obtained by field measurements are given below in Table 29 and Table 30, respectively.

Table 29: Home office 2- Field measurement results of the living area (evening)

BG-La	A	B	C	D	E	F	G	H
1	138,3	158,6	176,9	193	161,5	138,9	133,1	153,5
2	175,9	206,3	258	271,4	212,6	172,0	164,4	192,4
3	237,8	254,1	282,6	289,6	234,7	190,2	212,0	229,6
4	193,9	218,6	253,4	274,1	216,8	182,5	206,0	237,0
5	140,5	159,8	188,5	180,3	169,3	154,5	166,3	188,6

Table 30: Home office 2- Field measurement results of the kitchen (daytime)

BG-K	A	B	C	D	E	F	G
1	64,5	76,5	81,6	136,7	371	887	210,4
2	56,7	66,4	84,7	114,8	284,1	776	196,3
3	46,5	59,8	63	87,1	107,4	182,6	105
4	40,2	44,6	51,2	58,4	69,3	74,1	86,5

Afterwards, except the luminaire 5 and 6, same of the existing luminaires were found in the luminaire search engine and were imported to the DIALux model. Since the luminaires 5 and 6 was not available in catalogues, alternative equivalent luminaires used for simulations. The exact measurement day, time and conditions were defined in the software and the 3D model was simulated. The illuminance results of simulations are shown from Table 31 to Table 33 below.

Table 31: Home office 2- Simulation results of the task and the immediate surrounding area of the book editor (evening)

Be-Ta & Be-Isa	A	B	C	D	E	F	G	H	I
1	250	250	164	121	102	96	96	98	96
2	349	297	188	135	114	108	110	113	116
3	173	213	154	124	110	112	117	120	120
4	79	115	122	117	119	120	128	136	139
5	63	79	97	108	120	123	135	144	148
6	62	71	87	102	121	128	143	157	161

Table 32: Home office 2- Simulation results of the task and the immediate surrounding area of the graphic designer (evening)

Gd-Ta & Gd-Isa	A	B	C	D	E	F	G	H	I	J	K	L
1	230	208	120	75	52	42	36	32	30	29	30	30
2	331	263	149	89	60	46	40	35	33	32	31	31
3	159	187	117	77	55	45	40	36	34	32	32	32
4	67	94	90	71	56	50	44	40	39	37	35	35
5	51	61	65	61	54	50	45	44	42	40	37	36
6	54	54	56	57	54	53	50	48	46	44	42	42

Table 33: Home office 2- Simulation results of the living area (left) and the kitchen(right)(evening)

BG-La	A	B	C	D	E	F	G	H
1	121	144	163	157	140	120	113	121
2	173	195	220	209	182	150	144	164
3	223	226	251	236	204	167	166	199
4	182	206	231	222	195	166	170	205
5	133	161	183	178	162	145	151	176

BG-K	A	B	C	D	E	F	G
1	19	21	25	41	309	1286	166
2	20	22	25	40	266	851	142
3	22	24	28	43	64	110	75
4	22	24	30	44	51	61	70

3.3.3 Analysis of results

The average illuminance (E_{avg}) and uniformity (U_o) values that have been obtained as a result of field measurements and simulations are shown below in Table 34 together with the minimum illuminance recommendations that are provided by the lighting standard TS EN 12464-1. Further information on the standard can be seen in Chapter 2.3.

Table 34: Home office 2- Overview of base case results and minimum standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Book Editor-Task Area	E_{avg}	397	269	147	123	500
	U_o	0,84	0,80	0,82	0,78	0,60
Book Editor-Immediate Sur. Area	E_{avg}	455	300	169	136	300
	U_o	0,70	0,64	0,54	0,46	0,40
Graphic Designer-Task Area	E_{avg}	2203	1398	64	53	750
	U_o	0,60	0,49	0,66	0,56	0,70
Graphic Designer-Immediate Sur. Area	E_{avg}	1339	803	92	75	500
	U_o	0,59	0,26	0,37	0,40	0,40
Living Area	E_{avg}	236	152	199	176	200
	U_o	0,61	0,64	0,67	0,65	0,10
Kitchen	E_{avg}	135	95	160	139	300
	U_o	0,74	0,80	0,25	0,14	0,10

As can be observed on Table 34, task area E_{avg} of the book editor was found both in daytime and evening less than minimum requirements, on the other hand, U_o results are overall satisfactory. Also, immediate surrounding area of the book editor has higher E_{avg} than the task area, which normally should be less. In addition, both task and immediate surrounding E_{avg} results of the graphic designer were measured considerably higher than necessary in daytime, but to the contrary, significantly less in the evening.

Within the scope of the living area, inferences of the field measurement results differ from the simulation results. While E_{avg} and U_o that were obtained through field measurement are following the requirements, according to the simulation, only U_o results are in accordance

with the standards and an improvement for E_{avg} should be considered. Besides, E_{avg} results of the kitchen area are less than recommended, but contrary to this, all U_o results are as required.

The difference between the field measurement and simulation E_{avg} results cannot be considered as negligible for both daytime and evening, so the reason behind should be determined. For this purpose, daylight factors were calculated and shown in Figure 29.

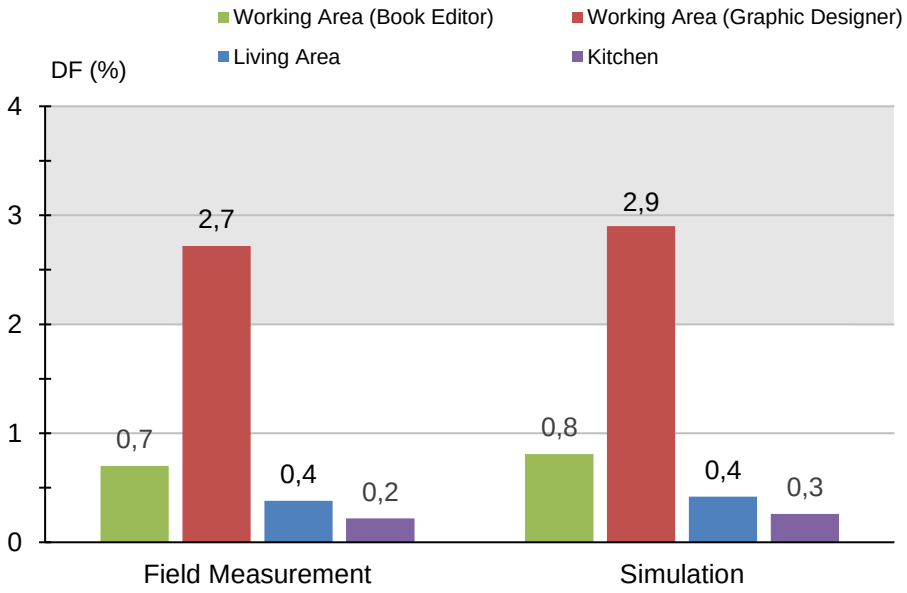

Figure 29: Home office 2- Daylight factor analysis results

As can be seen from Figure 29, the average daylight factors that were derived based on field measurement results and simulation results are similar, which indicates that the big difference between E_{avg} values are because of having very different outside illuminance in reality (62480 lx) and in simulation (36180 lx). Additionally, since the gray zone in the Figure 29 represents the ideal daylight factor range (see Chapter 2.3), it can be observed that all areas except the working area of the graphic designer have insufficient daylight amount.

Moreover, Unified Glare Rating (UGR), mean cylindrical illuminance ($\bar{E}_z$) and modelling of both working areas were evaluated in the evening under only artificial lighting. The results, which do not comply with the recommendations (see Chapter 2.3) can be seen in Table 35.

Table 35: Home office 2- UGR, $\bar{E}_z$ and modelling results (base case)

Working Area / Indicator	UGR_{max}	$\bar{E}_z$ (lx)	Modelling
Book Editor	>30	78	0,80
Graphic Designer	>30	53	1,76

Briefly, all above-mentioned assessments regarding the lighting conditions of the home office shows that all evaluated areas must be subjected to improvement.

3.3.4 Improvement proposal

Based on all above observations and findings, an improvement scenario was developed for the artificial lighting performance of the home office. Firstly, considering the environment and its requirements, more accurate and effective luminaires were selected and placed by DIALux with its field arrangement option. The new luminaire plan can be seen in Figure 30.

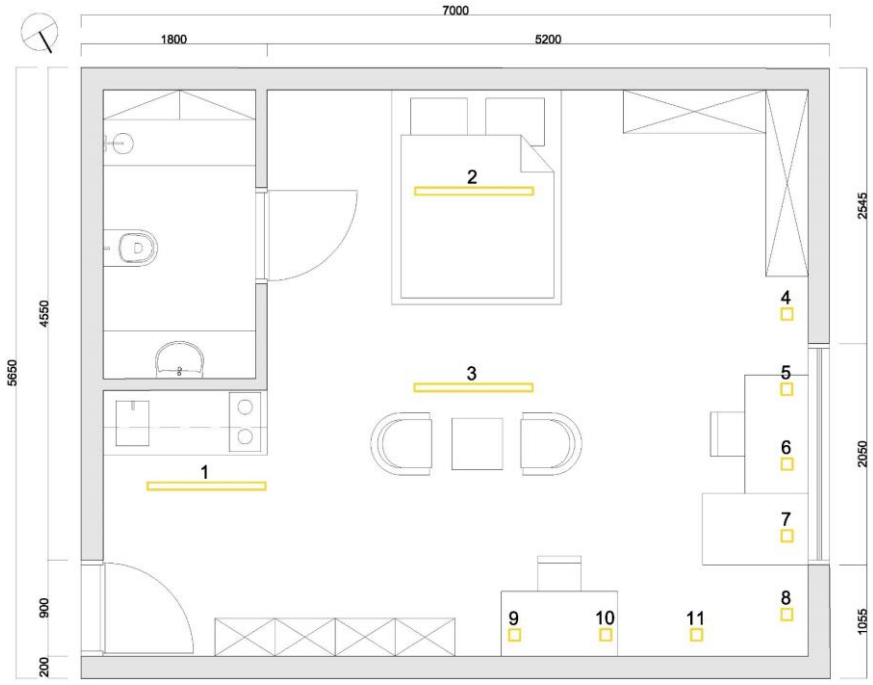

Figure 30: Home office 2- Improvement proposal

The technical information of new luminaires and lamps, which are indicated with the same reference numbers in the Figure 30, are as follows:

From 1 to 3) Pendant luminaire- 0,25 m suspension height - LTS ML-A 070 2480lm 27W

From 4 to 11) Ceiling recessed LED spotlights - MODULAR mini multiple GE alu-black 792lm 9.2W 4000K

Detailed illuminance results of both working areas are presented below in Table 36 and in Table 37. Afterwards, overview of the results and findings that were obtained from these tables can be seen in Table 38.

Table 36: Home office 2- Results of the task and the immediate surrounding area of the book editor (improvement proposal)

Be-Ta & Be-Isa	A	B	C	D	E	F	G	H	I
1	668	659	642	619	598	569	530	446	327
2	669	657	636	609	584	559	529	452	338
3	589	573	557	525	495	479	459	391	295
4	491	470	455	424	385	380	361	320	261
5	424	394	374	345	315	305	295	272	234
6	372	340	321	289	268	265	261	246	227

Table 37: Home office 2- Results of the task and the immediate surrounding area of the graphic designer (improvement proposal)

Gd-Ta & Gd-Isa	A	B	C	D	E	F	G	H	I	J	K	L
1	705	716	735	753	760	767	769	767	761	749	754	743
2	787	812	811	833	854	849	867	882	867	863	869	861
3	739	769	778	796	812	816	844	859	850	856	873	884
4	608	637	657	667	678	692	720	737	753	760	791	845
5	469	491	512	521	526	539	566	577	611	627	683	773
6	355	370	384	394	397	401	426	455	484	512	570	684

Table 38: Home office 2- Overview of the improvement proposal results for task area and immediate surrounding area

Area / Indicator	Task area		Immediate sur. area		Working Area (Task + Immediate Sur. area)		
	E_{avg} (lx)	U_o	E_{avg} (lx)	U_o	UGR_{max}	$\bar{E}_z$ (lx)	Modelling
Book Editor	559	0,82	388	0,58	<10	172	0,46
Graphic Designer	785	0,74	627	0,57	<10	232	0,34

According to the illuminance results of the improvement proposal that were mentioned in Table 36, Table 37 and Table 38, both working areas ensure their users a visually comfortable environment and compliance with standards, considering the information in Table 34. Also as mentioned before, the UGR, $\bar{E}_z$ and modelling of both areas were found very different than recommended values and needed to be improved. Eventually, it can be stated that improvement results of both working areas conforming to the standard in these respects as well.

In addition to all, the living area and kitchen were evaluated. The results of those areas can be seen below in Table 39.

Table 39: Home office 2- Results of the living area and the kitchen (improvement proposal)

BG -La	A	B	C	D	E	F	G	H
1	246	324	336	293	293	336	348	273
2	316	444	452	371	365	441	468	345
3	350	502	509	407	400	495	530	383
4	313	441	448	369	363	444	473	352
5	239	319	329	288	287	338	361	291

BG -K	A	B	C	D	E	F	G
1	187	217	245	266	263	258	253
2	225	262	295	317	316	307	284
3	247	291	329	354	354	335	307
4	282	335	379	410	405	377	337

Since the U_o and the E_{avg} of the living area were found respectively 0,64 and 372 lx and the kitchen were found respectively 0,62 and 301 lx, these areas are as well adequate to the minimum standard recommendations

3.4 Home office 3: Computer technician

Detailed information with photographs and 3D view can be found in the sub-section 2.2.3. The luminaire plan of the room can be seen in Figure 31. The dimensions are in millimetres.

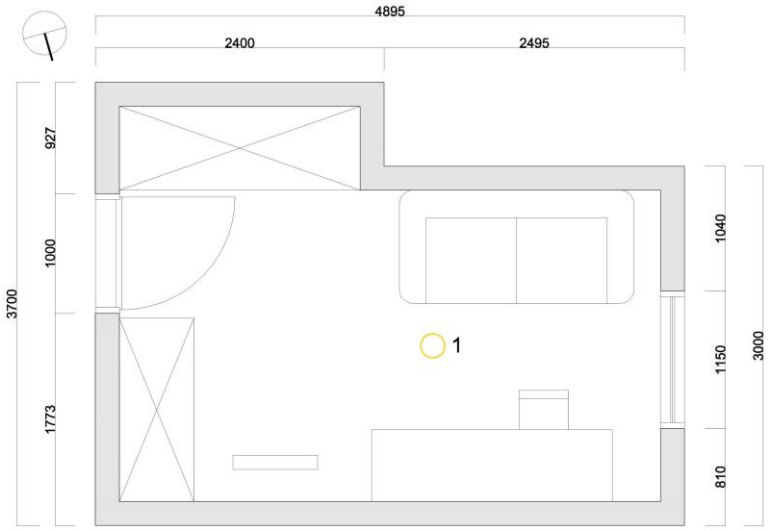

Figure 31: Home office 3- Floor plan with luminaires

The technical information of existing luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 31:

1) Pendant luminaire- 0,20 m suspension height - OSRAM Classic 2600lm 100W 220-240V

The measuring grids that were used for the field measurement, which were applied according to the instructions of TS EN 12464-1 are shown in Figure 32 (see sub-sections 1.3.9 and 1.3.10). The grid of the task area is represented in orange, immediate surrounding is in red and the living area is in green.

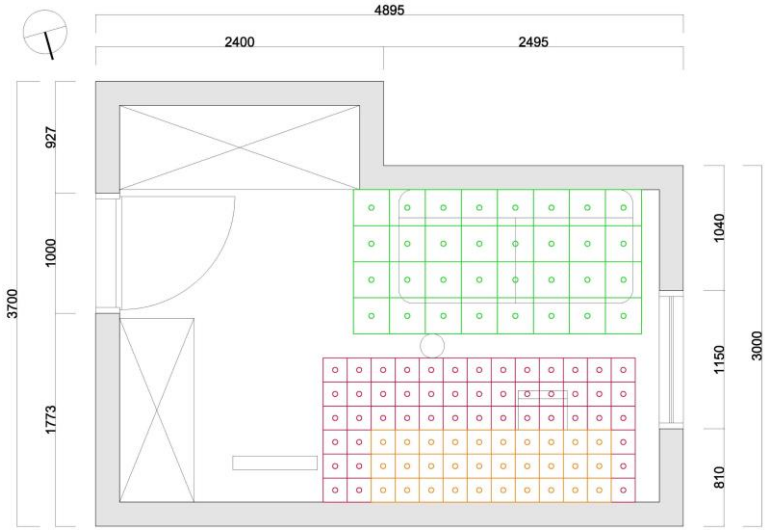

Figure 32: Home office 3- Floor plan with measuring grids

The detailed information about the measuring grids that were used in this home office are presented below in Table 40. Also, the applied labelling to grid cells are shown in Figure 33.

The grid codes that are given in the second column of Table 40 and the labelling of the grid cells that were given in Figure 33 will be identical in all sub-chapters of the Chapter 3.4

Table 40: Home office 3- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	Ct-Ta	200 x 200	30
Immediate Surrounding Area	Ct-Isa		48
Living Area	Ct-La	300 x 300	32

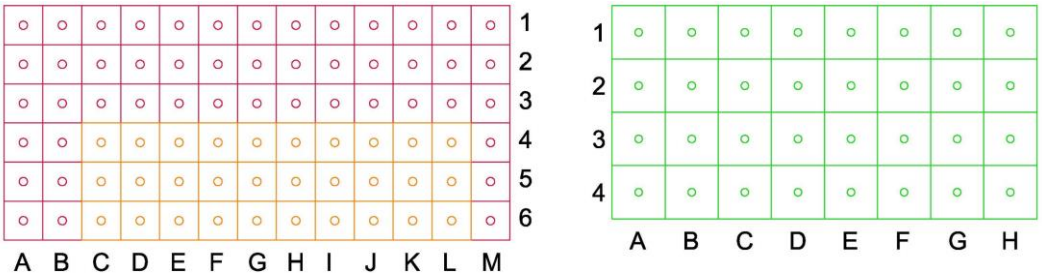

Figure 33: Home office 3- The measuring grid numbering of task area and immediate surrounding area (left) and living area (right)

3.4.1 Daytime measurement results

The daytime field measurement was performed in the morning of 18.04.2017 from 10:35 to 11:05, under overcast sky and when all artificial lighting was turned off. The results of the working area and the living area are shown respectively in Table 41 and Table 42, including the measured outside illuminances in their last column.

Table 41: Home office 3- Field measurement results of the task and the immediate surrounding area (daytime)

Ct-Ta &Isa	A	B	C	D	E	F	G	H	I	J	K	L	M	E_{out}
1	443	509	544	495	438	412	345	340	322	306	289,1	209,5	187,4	13880
2	784	840	742	538	494	438	407	377	333	312	296,5	259,4	193,6	13920
3	1232	1348	830	660	620	525	478	429	390	330	303,4	277,6	203,5	14060
4	2017	1691	1259	923	707	599	507	461	416	363	324	290,4	215,6	14460
5	2373	1874	1454	1168	976	804	716	522	431	377	341	297,7	220,4	15390
6	2821	2234	1650	1247	1087	963	821	553	477	383	350	318	223,9	15120

Table 42: Home office 3- Field measurement results of the living area (daytime)

Ct-La	A	B	C	D	E	F	G	H	E_{out}
1	143,7	183,2	211	228,6	263,6	281,3	303	341	14925
2	149,3	203,4	238,5	263,5	292,1	314	437	524	13840
3	187,3	241,5	278	300	323	349	519	765	13510
4	205,1	261,4	295	334	387	521	921	1685	14900

According to the performed outside measurements, the average illuminance value was found 14370 lx. Also, reflectance values of some major surfaces were calculated (Equation 3) and the results can be seen in Table 43.

Table 43: Home office 3- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	57
Ceiling	70
Walls	56
Working table	60
Wardrobes	58
Sofa	59

Later on, the room was completely modelled in 3D and the same measurement date, time, sky type and the reflectance values were introduced to the software for the simulation. The illuminance results obtained through this simulation are given in Table 44 and Table 45 below.

Table 44: Home office 3- Simulation results of the task and the immediate surrounding area (daytime)

Ct-Ta & Ct-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	334	393	408	360	353	298	242	203	203	156	121	98	90
2	723	749	633	475	475	362	288	230	230	178	137	109	98
3	1170	995	775	573	573	421	299	238	238	182	138	111	99
4	1725	1420	902	720	567	467	374	250	213	184	149	113	102
5	2182	1695	1040	796	638	521	385	274	229	190	153	119	104
6	2521	1999	1169	882	692	561	414	281	241	198	157	119	107

Table 45: Home office 3- Simulation results of the living area (daytime)

Ct-La	A	B	C	D	E	F	G	H
1	65	84	108	136	157	193	216	192
2	70	90	122	164	198	275	379	441
3	72	96	130	182	224	335	519	733
4	79	102	147	221	281	453	804	1511

Furthermore, an exterior scenario of the room was modelled for finding the outside illuminance that was used by DIALux during calculations, since it is not possible to manually introduce an outside illuminance. As a result of this simulation, average outside illuminance was found 9910 lx and this result later used for analyzing the daylight factor (DF).

3.4.2 Evening measurement results

The evening field measurements were performed in 18.04.2017 between 20:00 and 20:50, without daylight and 30 minutes after all lights were switched on. The results of the working area (Table 46) and the living area (Table 47) are presented below.

Table 46: Home office 3- Field measurement results of the task and the immediate surrounding area (evening)

Ct-Ta & Ct-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	33,7	36,9	40,5	51,1	54,3	58,5	62,6	67,6	71,6	73,6	70,6	66,2	61,5
2	35,9	40,8	46,1	56,2	60,6	71,5	76,1	82,8	89,2	94,7	80,9	76	70,3
3	40,5	46,4	50,8	60	68,7	83,7	90,3	103,4	105,7	112,3	96,2	91,2	82,3
4	46,4	50	55,9	68,4	78,2	90,6	104,2	109,8	110	115,7	99,2	85,4	69,3
5	49,5	53,1	58,6	70,8	85,4	98,2	117	119,5	119,1	121,9	100,1	90,2	75,6
6	53,9	60,1	67,2	79,3	91,5	105,6	127,8	131,4	130,8	135,4	119,6	99,6	83,6

Table 47: Home office 3- Field measurement results of the living area (evening)

Ct-La	A	B	C	D	E	F	G	H
1	80,3	98,3	95,9	82,1	78,1	56,2	46,6	35,2
2	95,2	126,8	119,9	96,7	101,2	67,7	56,9	40,2
3	156,3	201,4	191,7	111,6	124,7	80,9	65,5	52,1
4	200,7	252,9	223,7	167	142,2	91,3	70,1	58,2

Afterwards, same of the existing luminaires, the exact measurement day, time and conditions were defined in the software and the 3D model was simulated. The results of this simulation are presented in Table 48 and Table 49.

Table 48: Home office 3- Simulation results of the task and the immediate surrounding area (evening)

Ct-Ta & Ct-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	41	46	52	60	63	70	74	77	78	77	73	67	62
2	47	53	61	71	75	83	89	93	94	93	88	80	73
3	48	56	64	75	81	90	98	103	105	103	97	87	78
4	53	57	69	81	90	102	109	117	119	117	110	98	88
5	54	59	72	84	95	109	117	127	130	127	119	105	93
6	56	61	75	89	101	116	126	138	140	138	128	112	99

Table 49: Home office 3- Simulation results of the living area (evening)

Ct-La	A	B	C	D	E	F	G	H
1	90	100	101	93	83	70	58	48
2	116	134	135	121	104	83	65	53
3	148	178	182	155	126	95	72	56
4	186	240	247	199	150	107	78	58

3.4.3 Analysis of results

The overview of the results that were found through field measurements and simulations can be seen in Table 50 below together with the relevant standard recommendations. Further information on the lighting standard and requirements can be seen in Chapter 2.3.

Table 50: Home office 3- Overview of base case results and minimum standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	490	364	70	78	300
	U_o	0,59	0,33	0,53	0,59	0,60
Immediate Sur. Area	E_{avg}	797	577	85	93	200
	U_o	0,23	0,16	0,40	0,44	0,4
Living Area	E_{avg}	373	274	108	117	200
	U_o	0,38	0,24	0,32	0,41	0,1

The above-mentioned data shows that all E_{avg} results in daytime are in accordance with the standard requirements. However, as mentioned before, just having a sufficient E_{avg} is solely not enough to determine whether an area is following the standards or not. Since both in field measurement and simulation, the E_{avg} of the immediate surrounding area was measured higher than the task area, also, the U_o of the whole working area were found less than minimum requirements, it can be mentioned that the lighting performance is overall not efficient in daytime. Likewise, all evening results indicate that the artificial lighting in the room is as well inefficient and improvement is essential. Due to having a big difference in daytime results, the daylight factor was analyzed and presented in Figure 34.

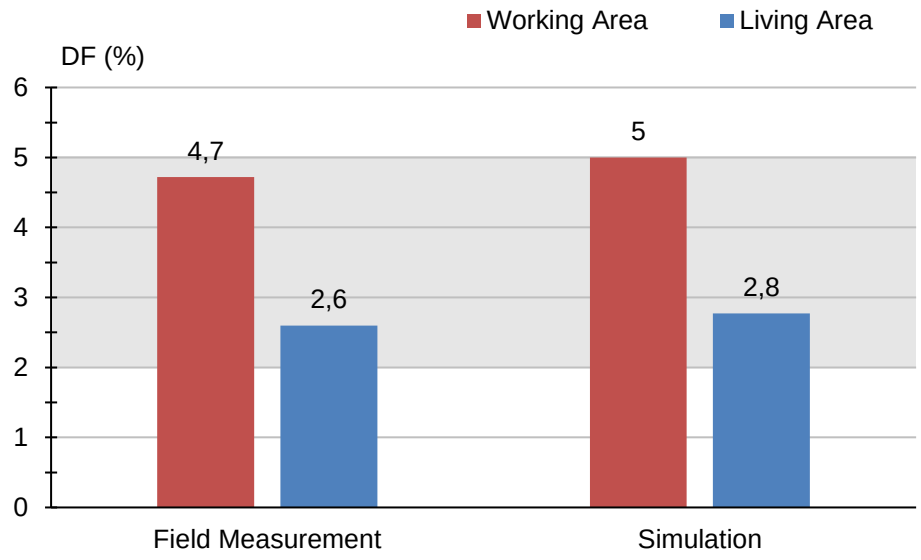

Figure 34: Home office 3- Daylight factor analysis results

The similarity between the daylight factor results show that, the incoherence between daytime E_{avg} results is mainly caused by the difference between the measured outside illuminance (14370 lx) and the one that DIALux used for performing the simulations (9910 lx). On the other hand, since the gray area in the graph refers to the recommended daylight factor range, it can be inferred that the daylight utilization is effective and balanced in the home office space.

Other indicators that were evaluated only for the working area, in the evening with only artificial lighting and are as follows:

- UGR_{max} = <10
- $\bar{E}_z$ = 44 lx
- Modelling = 0,52

According to the standard criteria in the Chapter 2.3, the UGR_{max} is in accordance with the recommendations. However, even though the modelling value is numerically following the standards, since the $\bar{E}_z$ is below the required value, both $\bar{E}_z$ and modelling should not be considered adequate.

3.4.4 Improvement proposal

After all observations and inferences, an improvement scenario was created for the artificial lighting performance. Within the scope of the improvement proposal, new luminaires were chosen and located with the field arrangement option of the DIALux. The new luminaire plan can be seen in Figure 35.

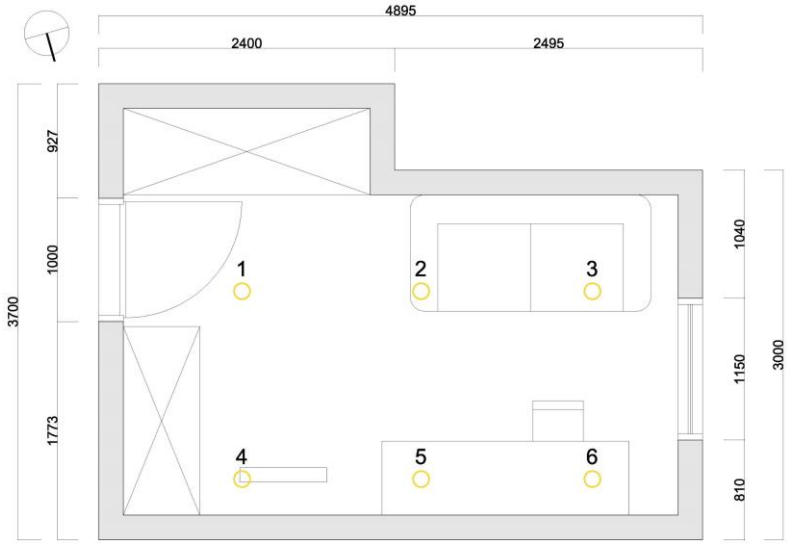

Figure 35: Home office 3- Improvement proposal:

The technical information of new luminaires and lamps, which are indicated with the same numbers that were given in Figure 35, are as follows:

From 1 to 6) Ceiling recessed LED spotlights – Philips RS141B-LED6-32 650lm 11W 830
Detailed illuminance results of the task area and immediate surrounding area that were obtained after improvement proposal are presented in Table 51.

Table 51: Home office 3- Results of the task and the immediate surrounding area (improvement proposal)

Ct-Ta & Ct-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	215	331	385	347	266	208	202	250	332	397	371	275	207
2	247	385	445	402	304	232	224	284	384	459	429	315	229
3	228	347	403	365	281	222	215	265	350	416	390	291	221
4	181	249	291	275	225	192	186	217	269	305	287	232	192
5	147	187	212	207	183	167	166	182	208	225	217	189	167
6	136	167	187	186	169	156	155	169	189	200	194	175	157

According to the results in Table 51, E_{avg} of the task area is 330 lx and the U_o is 0,61. Also E_{avg} of the immediate surrounding area is 209 lx and U_o is 0,65. Consequently, as a result of the applied improvement proposal, the home office now fulfills all the given recommendations by the lighting standard (Table 50). Other assessed and improved indicators of the working area and their results are:

- UGR_{max}= <10
- $\bar{E}_z$ = 168 lx
- Modelling = 0,34

In addition, the results of the living area simulation are shown in Table 52.

Table 52: Home office 3- Results of the living area (improvement proposal)

Ct-La	A	B	C	D	E	F	G	H
1	131	151	116	86	97	137	141	94
2	321	427	251	146	184	357	398	198
3	523	738	375	185	247	603	688	287
4	352	471	272	158	199	392	437	212

Since the E_{avg} value of the living area is measured as 293 lx and the U_o as 0,29, this area is now compatible with the standard criteria that was given in Table 50.

3.5 Home office 4: Industrial designer

Detailed information with photographs and 3D view can be found in the sub-section 2.2.4. The existing luminaire layout is shown below on floor plan in Figure 36. All the dimensions are in millimetres.

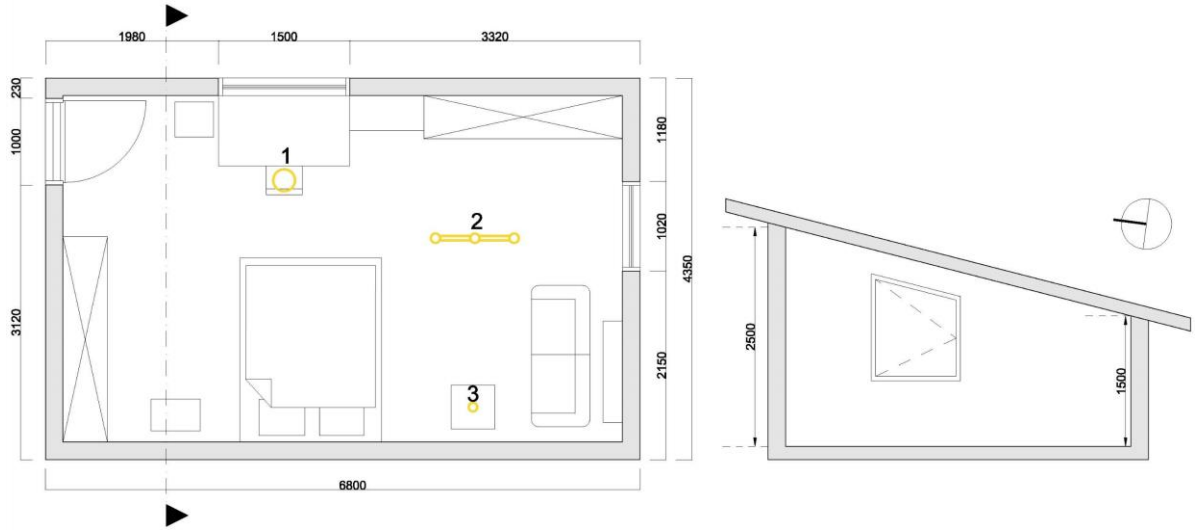

Figure 36: Home office 4- Floor plan with luminaires

The existing luminaires and lamps in the room, which indicated with the same reference numbers in the Figure 36, are as follows:

1) Pendant luminaire- 0,4 m suspension height - Philips Economy Energy Saver 660lm 11W 220-240V 2700K 50-60Hz

2) Ceiling surface mounted luminaire- 3 x Philips Tornado T2 741lm 12W E27 220-240V

3) Table luminaire- Osram Classic Eco B E14 405lm 30W 230V 2700K Ra=100

The grids that were used for illuminance measurement in this home office are shown in Figure 37, which were applied in accordance with the instructions of the lighting standard TS EN 12464-1 (see sub-sections 1.3.9 and 1.3.10). The task area measuring grid is shown in orange, immediate surrounding is in red and the living area is in green.

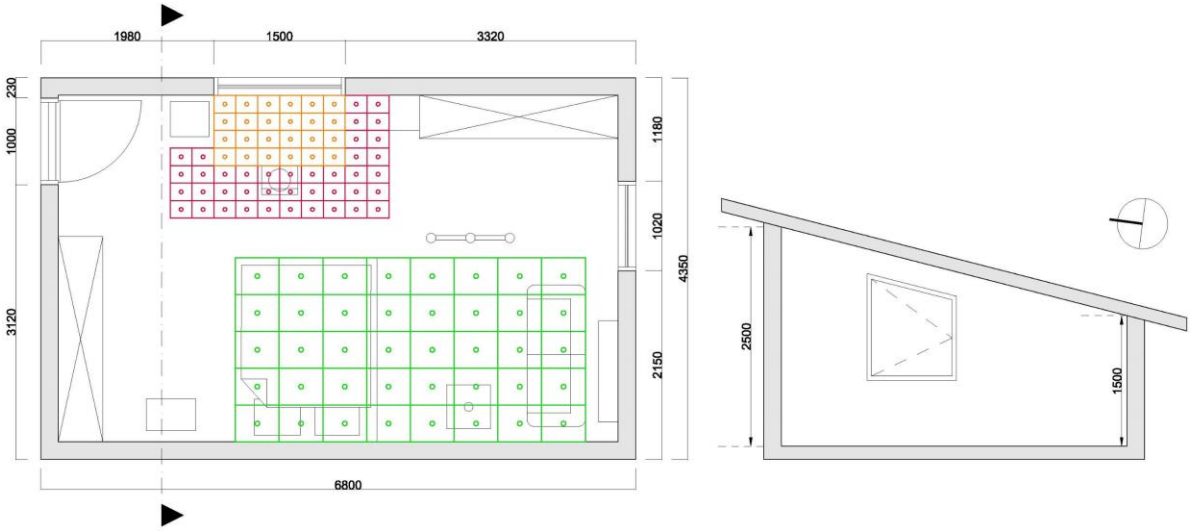

Figure 37: Home office 4- Floor plan with measuring grids

Detailed information on measuring grids can be found in Table 53 below. In addition, Figure 38 illustrates grid cell labelling. The grid codes given in Table 53 and the grid cell labels in Figure 38 will be used in the same way in all sub-chapters of the Chapter 3.5.

Table 53: Home office 4- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	Id-Ta	200 x 250	24
Immediate Surrounding Area	Id-Isa		40
Living Area	Id-La	420 x 500	40

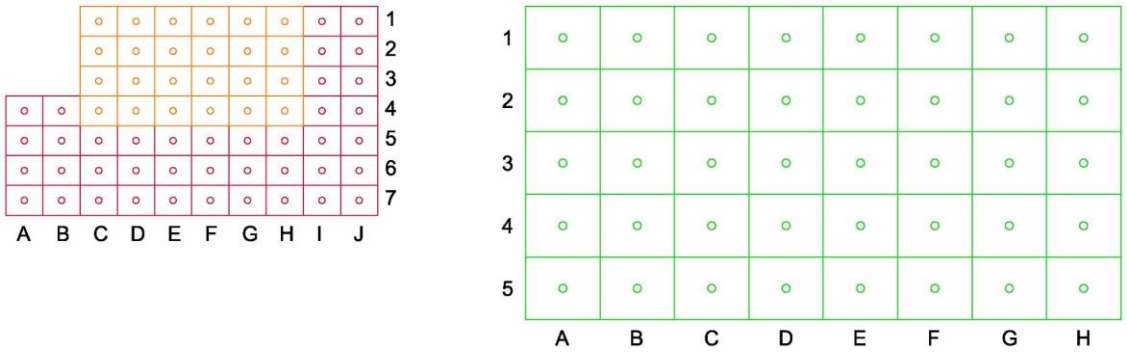

Figure 38: Home office 4- The measuring grid numbering of task area and immediate surrounding area (left) and living area (right)

3.5.1 Daytime measurement results

The daytime field measurement was performed in the morning of 13.04.2017 from 10:30 to 10:55, under overcast sky and when all artificial lighting was turned off. The results of the working area are shown hereinafter in Table 54 and the results of living area in Table 55. Both tables also include measured outside illuminance values in their last column.

Table 54: Home office 4- Field measurement results of the task and the immediate surrounding area (daytime)

Id-Ta&Id-Isa	A	B	C	D	E	F	G	H	I	J	E_{out}
1			979	1186	1214	1203	1149	896	562	361	12540
2			1465	1865	1932	1903	1747	1353	1083	711	13230
3			1389	1752	1832	1814	1650	1342	978	697	14590
4	467	802	1239	1534	1611	1594	1544	1159	905	657	14030
5	502	784	993	1074	1178	1378	1158	997	806	594	13850
6	477	654	754	807	1060	1274	1016	904	710	578	13860
7	455	487	596	696	751	761	744	709	624	530	13450

Table 55: Home office 4- Field measurement results of living area (daytime)

Id-La	A	B	C	D	E	F	G	H	E_{out}
1	285,7	286,4	298,3	299,3	312	324	381	685	14400
2	201,5	222,6	253,4	275,9	292,6	303	312	382	14310
3	180,2	189,3	204,1	202,4	201,3	196,4	193,6	197,6	13790
4	171	173,4	176,9	175,4	174,9	171,4	165	160,2	13610
5	164,3	169,5	175,6	170,6	167,5	165,4	159,6	150,3	13220

Based on the performed measurements, the average outside illuminance was measured as 13740 lx. Also, reflectance values of some major surfaces were derived by using Equation 3 and the results are shown in Table 56.

Table 56: Home office 4- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	40
Ceiling	80
Walls	90
Working table	78
Wardrobes	45
Sofa	47

After modelling the home office with DIALux, the same measurement date, time, sky type, reflectance values and all properties of the existing room were defined to the simulation software. The simulation results are shown in Table 57 and Table 58.

Table 57: Home office 4- Simulation results of the task and the immediate surrounding area (daytime)

Id-Ta& Id-Isa	A	B	C	D	E	F	G	H	I	J
1			637	797	804	791	768	572	391	204
2			1092	1403	1454	1432	1389	1005	791	403
3			1033	1315	1377	1363	1313	996	873	506
4	317	654	839	1068	1127	1114	1076	854	695	495
5	344	570	725	725	788	791	728	728	580	464
6	325	462	581	581	639	640	589	589	506	416
7	308	410	495	495	537	537	505	505	438	366

Table 58: Home office 4- Simulation results of living area (daytime)

Id-La	A	B	C	D	E	F	G	H
1	218	224	201	185	174	195	277	525
2	167	176	168	160	156	172	204	275
3	139	144	146	143	141	138	142	138
4	134	141	142	140	132	128	124	105
5	137	146	145	141	140	125	117	100

Besides all these, an exterior scenario of the room was modelled and simulated for finding the outside illuminance that was taken by DIALux during calculations, since it is not possible to manually introduce an illuminance value to the software. As a result, average outside illuminance was found 9540 lx and this result later used for analyzing the daylight factor (DF).

3.5.2 Evening measurement results

The evening field measurements were performed in 13.04.2017, from 21:00 to 21:35, without daylight and 45 minutes after all lights were turned on. The task and immediate surrounding area results are shown together in Table 59 and the living area results are in Table 60.

Table 59: Home office 4- Field measurement results of the task and the immediate surrounding area (evening)

Id-Ta& Id-Isa	A	B	C	D	E	F	G	H	I	J
1			65,6	92,7	123,4	130,5	109	105,3	88,6	72,6
2			74,2	105,3	139,7	152,9	137,1	126,1	92	75,3
3			83,4	120,1	151	167,3	149,8	139,4	96,8	89,1
4	36,9	52,3	90,6	128,2	158,2	198,5	161,3	141,8	117,4	103,6
5	33,1	51	106,7	117,5	145,3	184,6	153,5	149,8	121,5	136
6	27,88	43,9	100,3	111,9	121,8	159,7	144	141,6	147,6	156,4
7	23,11	39,6	82,5	98,6	110,4	141,5	140,7	137,5	152,8	195,5

Table 60: Home office 4- Field measurement results of living area (evening)

Id-La	A	B	C	D	E	F	G	H
1	88,6	91,3	112,2	242,5	220,9	205,7	144,9	52,7
2	65,8	85,7	101,7	120,2	96,9	82,2	64,6	27,96
3	44,7	63,3	84,9	92,6	78,5	62,1	41,3	26,45
4	35,8	58,6	60,7	91	65,3	59,1	38,9	24,90
5	23,23	36,1	45,8	88	62,8	53,5	31,5	21,77

Moreover, all measurement conditions were defined exactly in DIALux and then the 3D model simulated. The working area results (Table 61) and living area simulation results (Table 62) are shown below.

Table 61: Home office 4- Simulation results of the task and the immediate surrounding area (evening)

Id-Ta& Id-Isa	A	B	C	D	E	F	G	H	I	J
1			81	109	130	144	141	122	98	79
2			86	117	144	164	159	133	102	81
3			90	128	162	187	180	147	115	92
4	44	63	93	138	181	211	203	162	125	103
5	44	63	101	138	184	214	206	171	129	118
6	43	60	93	124	161	187	182	155	130	146
7	41	56	83	108	136	155	154	137	132	189

Table 62: Home office 4- Simulation results of living area (evening)

Id-La	A	B	C	D	E	F	G	H
1	47	56	61	126	444	521	377	79
2	36	44	51	64	81	89	76	54
3	30	37	46	56	62	67	60	49
4	29	36	45	57	68	75	65	48
5	25	31	40	54	71	90	67	44

3.5.3 Analysis of results

The overview of the results that were found through field measurements and simulations can be seen in Table 63 together with the relevant standard recommendations. More information on the regarding lighting standard and requirements can be seen in Chapter 2.3.

Table 63: Home office 4- Overview of base case results and minimum standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	1473	1067	127	142	750
	U_o	0,60	0,54	0,52	0,57	0,70
Immediate Sur. Area	E_{avg}	782	542	108	119	500
	U_o	0,46	0,38	0,22	0,35	0,40
Living Area	E_{avg}	234	168	77	86	200
	U_o	0,64	0,60	0,29	0,29	0,1

According to the data given in Table 63, the average illumination value of both the task area and the immediate surrounding is above the minimum required value in daytime. Even if this seems numerically appropriate to the standards, it is very potential to have thermal problems because the daylight in the work area is too much above the minimum requirement. In addition, the uniformity value of the task area does not comply with the standard recommendations. In case of evening results, except for the uniformity of the living area, all E_{avg} and U_o results are completely out of recommendations. Therefore, in order to follow the standards, it is inevitable that the lighting conditions of the room should be improved. Due to having a big difference in daytime results, the daylight factor was analyzed and presented in Figure 39.

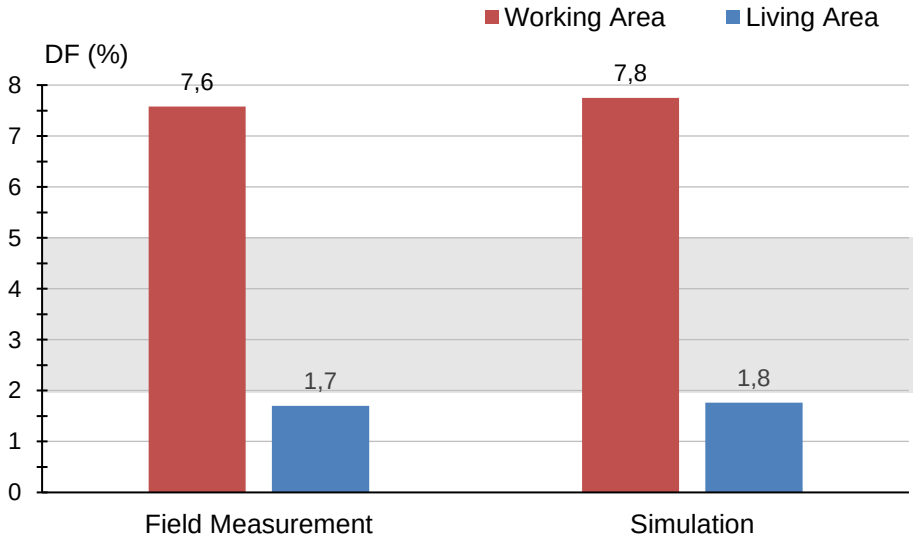

Figure 39: Home office 4- Daylight factor analysis results

Since the results of daylight factor are very similar, it can be said that the incoherence between E_{avg} results during the day is mainly due to the difference between the measured outside illuminance (13740 lx) and the one DIALux uses for performing simulations (9540 lx). Moreover, the gray area of the graph in Figure 39 represents the recommended daylight factor range. Therefore, as can be seen in the graph, while the use of daylight in the living area is less than recommended, there is high exposure to daylight in the working area as already expected after the obtained E_{avg} results.

Other indicators evaluated only for the working area, in the evening with only artificial lighting are as follows:

- UGR_{max} = <10
- $\bar{E}_z$ = 84 lx
- Modelling = 0,20

As can be seen from the given standard criteria in the Chapter 2.3, none of the above-mentioned indicators are adequate and they need to be improved.

3.5.4 Improvement proposal

By taking all analysis into consideration, an improvement scenario was done for the artificial lighting. New luminaires were chosen which meet the needs of the environment better and they were located with the field arrangement option of DIALux. The new luminaire plan can be observed in Figure 40.

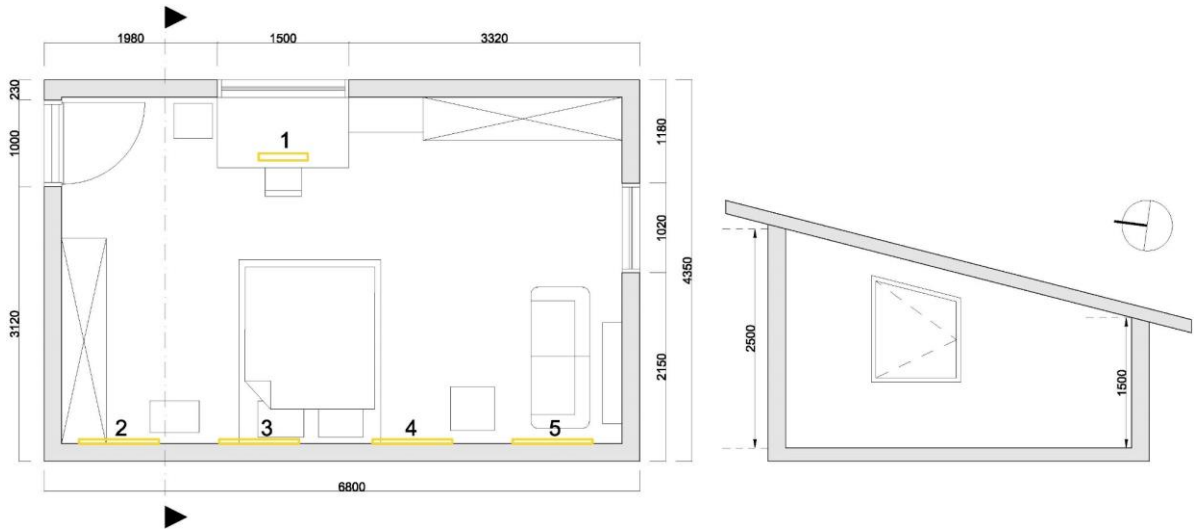

Figure 40: Home office 4- Improvement proposal

The technical information of new luminaires and lamps, which are indicated with the same numbers that were given in Figure 40, are as follows:

1) Pendant luminaire- 0,4 m suspension height- Halla 08-50 Lina-80 B (Type-1) 5000lm 40,3W 830

2 to 5) Wall surface mounted luminaire- 1,2 m mounting height- RZB LED Modul 1150lm 22W 830

Detailed illuminance results of the working area which were obtained by the improvement proposal simulation are presented in Table 64.

Table 64: Home office 4- Results of the task and the immediate surrounding area (improvement proposal)

Id-Ta& Id-Isa	A	B	C	D	E	F	G	H	I	J
1			598	777	867	870	778	594	420	305
2			607	799	898	901	809	611	440	311
3			634	847	953	957	855	643	460	324
4	308	441	632	860	973	978	875	652	457	323
5	302	427	634	799	922	924	809	644	441	314
6	288	399	574	712	812	814	721	584	407	296
7	271	361	504	614	698	699	621	512	368	275

According to the results in Table 64, E_{avg} of the task area is 790 lx and the U_o is 0,75. Also E_{avg} of the immediate surrounding area is 513 lx and U_o is 0,53. Consequently, as a result of the applied improvement proposal, the home office now fulfills all the given recommendations by the lighting standard (Table 63). Other indicators of the working area that have been evaluated and improved with their results are as follows:

- UGR_{max}= <10
- $\bar{E}_z$ = 384 lx
- Modelling = 0,31

Additionally, the results of the living area simulation are shown in Table 65.

Table 65: Home office 4- Results of the living area (improvement proposal)

Id-La	A	B	C	D	E	F	G	H
1	265	260	206	160	139	116	98	86
2	216	211	191	170	158	141	129	121
3	248	234	221	223	215	195	194	190
4	385	318	299	360	349	285	313	334
5	591	380	332	555	539	323	473	549

Since the E_{avg} of the living area was calculated as 269 lx and the U_o was found as 0,32, eventually, both the working area and the living area have become fully compliant with the lighting standards as a result of the improvement scenario.

3.6 Home office 5: Journalist

Detailed information with photographs and 3D view can be found in the sub-section 2.2.5. The luminaire plan of the room can be seen in Figure 41. The dimensions are in millimetres.

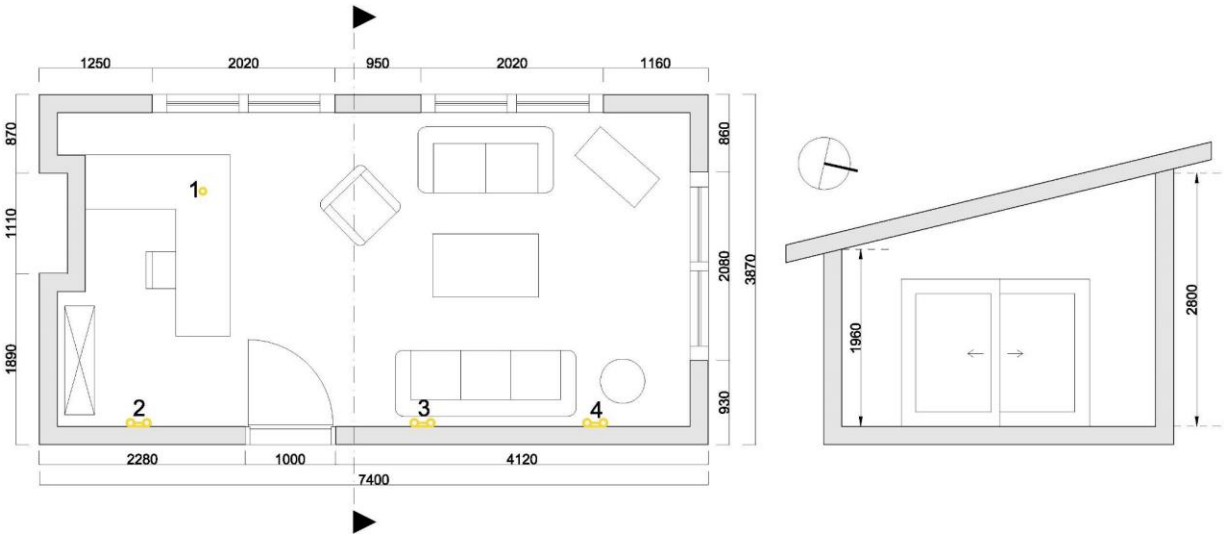

Figure 41: Home office 5- Floor plan with luminaires

The existing luminaires and lamps in the room, which indicated with the same reference numbers in the Figure 41, are as follows:

1) Table luminaire- Philips Eco Candle B39 E14 370lm 8W 220-240V 2700K

2 to 4) Wall surface mounted luminaire- 2,2 m mounting height- 2 x Philips LED E14 Small Edison Screw Candle 470lm 40W 240V 830

The grids that were used for illuminance measurement in this home office are shown in Figure 42, which were applied in accordance with the instructions of the lighting standard TS EN 12464-1 (see sub-sections 1.3.9 and 1.3.10). The task area measuring grid is shown in orange, immediate surrounding is in red and the living area is in green.

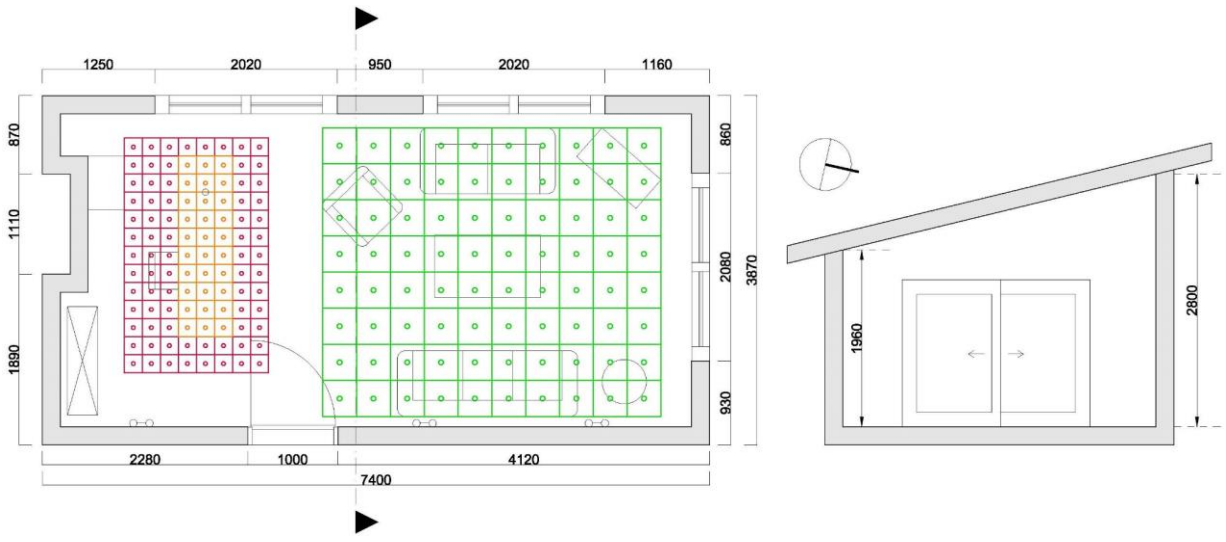

Figure 42: Home office 5- Floor plan with measuring grids

The detailed information on measuring grids is presented in Table 66 and the grid cell labelling are in Figure 43. The grid codes given in Table 66 and grid cell labels in Figure 43 will be used in the same way in all sub-chapters of the Chapter 3.6.

Table 66: Home office 5- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	J-Ta	200 x 200	30
Immediate Surrounding Area	J-Isa		74
Living Area	J-La	400 x 375	80

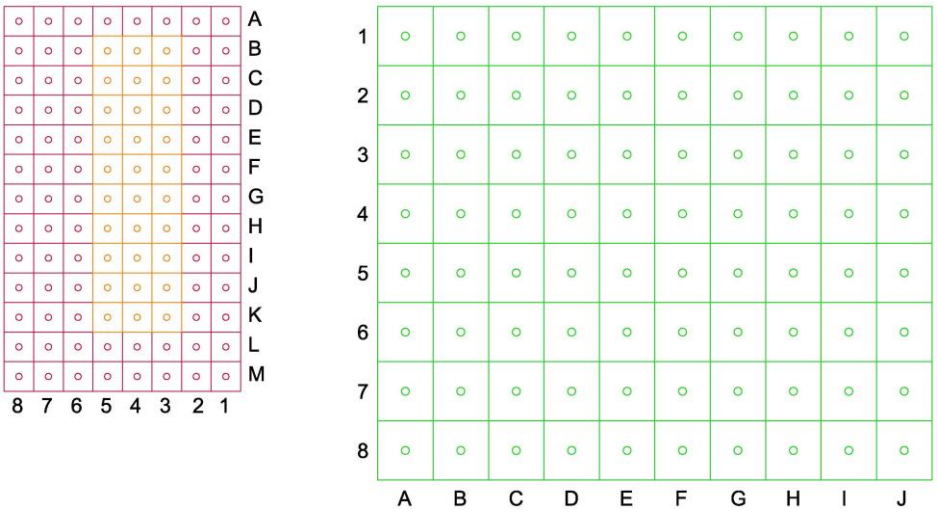

Figure 43: Home office 5- The measuring grid numbering of task area and immediate surrounding area (left) and living area (right)

3.6.1 Daytime measurement results

The daytime field measurement took place in the morning of 15.04.2017 from 10:25 to 11:20. The measurement was performed under clear sky with no direct sunlight and no artificial lighting. The results of the working area and living area are shown respectively in Table 67 and Table 68, including simultaneously measured outside illuminances in their last column.

Table 67: Home office 5- Field measurement results of the task and the immediate surrounding area (daytime)

J-Ta& J-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M	E_{out}
1	2107	1893	1490	1098	949	798	708	643	607	586	528	443	440	64620
2	2081	1795	1362	1056	856	740	685	619	586	566	506	432	429	63130
3	1976	1489	1116	910	792	700	618	595	556	525	486	419	409	63780
4	1881	1409	991	816	751	663	611	552	539	513	472	404	397	63530
5	1756	1317	955	779	671	621	584	539	531	496	443	399	383	62150
6	1514	1230	925	744	644	596	557	511	490	474	436	394	379	62830
7	1226	1092	877	711	619	571	531	483	472	453	415	386	368	62610
8	889	830	805	684	583	532	505	466	443	427	388	380	364	62430

Table 68: Home office 5- Field measurement results of the living area (daytime)

J-La	A	B	C	D	E	F	G	H	I	J	E_{out}
1	949	702	861	1179	1291	1360	1423	1524	1057	903	62520
2	610	530	589	643	766	902	956	1018	993	1056	63070
3	451	488	499	513	605	784	807	870	941	1277	63430
4	366	351	403	424	488	644	664	794	893	1357	63510
5	308	346	384	393	459	594	605	721	842	1267	63100
6	292,7	301	365	372	433	559	569	678	812	1233	64910
7	258,2	266,8	334	341	399	493	521	559	723	930	65510
8	243,3	252,6	297	306	366	450	490	533	586	681	66630

Based on the performed measurements, the average outside illuminance was measured as 63590 lx. Also, reflectance values of some major surfaces were derived by using Equation 3 and the results are shown in Table 69.

Table 69: Home office 5- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	28
Ceiling	22
Walls	80
Working table	25
Table (living area)	2
Sofa	15

Thereafter, the room was modelled with DIALux. Same measurement date and time, sky type and the above-mentioned reflectance values were defined in the software and the simulation was performed. Simulation results of the working area and the living area are shown respectively hereinafter in Table 70 and in Table 71.

Table 70: Home office 5- Simulation results of the task area and the immediate surrounding area (daytime)

J-Ta&J-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1518	1518	944	626	626	455	455	356	287	287	229	206	206
2	1499	1499	934	622	622	443	443	337	273	273	227	198	198
3	1450	1122	801	607	607	463	371	292	292	249	218	196	196
4	1348	1014	715	554	554	423	340	277	277	241	213	190	190
5	1207	905	657	508	508	407	328	260	260	227	200	182	182
6	977	977	646	464	464	353	353	273	229	229	191	173	173
7	705	705	541	419	419	335	335	272	228	228	187	164	164
8	460	465	460	368	354	311	311	257	207	207	167	151	151

Table 71: Home office 5- Simulation results of the living area (daytime)

J-La	A	B	C	D	E	F	G	H	I	J
1	735	400	531	932	1160	1236	1252	1174	788	543
2	427	364	396	503	587	642	668	653	643	795
3	288	267	291	329	368	407	440	475	621	929
4	208	203	220	239	263	297	335	396	594	942
5	174	178	190	209	224	256	293	365	566	921
6	138	139	156	166	186	214	253	312	490	823
7	117	127	135	147	164	194	227	272	391	586
8	112	127	140	151	168	186	216	237	292	340

Since it is not possible to manually enter an outside illuminance value in DIALux, for being able to find the outside illuminance that was used by the simulation software, exterior scenario of the room was identically modelled and then simulated. As a result, the average outside illuminance was found 35110 lx and later used for the daylight factor (DF) analysis.

3.6.2 Evening measurement results

The evening field measurements were performed in 15.04.2017 from 20:30 to 21:25 with no daylight and 30 minutes after all lights were turned on. The field measurement results can be found in Table 72 and Table 73 below.

Table 72: Home office 5- Field measurement results of the task and the immediate surrounding area (evening)

J-Ta& J-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	21,45	33,5	44,1	46,8	40,2	37,2	33,5	32,9	32,6	31,9	31,7	30,9	30,1
2	23,55	49,8	76,9	71,4	52,6	43,2	37,8	34,9	34,3	33,6	32,8	32,4	31,7
3	24,12	64,1	113,4	296,3	256,4	159,8	84,5	74,6	65,8	59,1	56,4	35,9	34,1
4	26,66	65,8	119,2	389	344	182,7	87,6	80,5	68,7	60,2	58,6	36,8	34,6
5	23,7	65,2	113,5	333	264,5	158,4	86,1	76,5	66	59,6	57,4	39,8	34,8
6	22,62	44,9	75,6	81,6	54,8	45,9	39,8	38,4	37,6	37,2	36,9	36,8	35,5
7	20,1	39,4	47,5	49,8	43,7	39,8	38,4	38,2	37,7	37,5	37	36,9	36
8	19,56	25,68	36,9	35,4	34,7	33,1	33	32,8	32,4	32,1	31,5	31,3	30,8

Table 73: Home office 5- Field measurement results of the living area (evening)

J-La	A	B	C	D	E	F	G	H	I	J
1	14,3	14,36	14,98	14,6	13,65	13,21	12,52	13,63	14,86	15,56
2	15,65	16,1	16,74	16,58	15,84	15,62	15,31	14,9	14,73	14,21
3	17,5	20,32	21,56	21,12	20,61	20,43	20,05	19,65	19,05	18,63
4	23,57	24,56	26,6	26,14	25,94	25,59	25,16	25,03	24,83	24,55
5	29,85	30,8	32,8	34,4	33,8	33,3	33,1	32,6	32,2	31,8
6	34,5	36,4	36,8	37	37,4	37,8	38,5	38,9	39,6	40,2
7	38,6	44,8	45	46,3	46,8	47,6	48,1	47,4	47,8	50,8
8	28,62	32,5	33,6	33,9	36,1	36,8	37,1	38,6	41,7	44,6

Afterwards, except the luminaire 1, all existing luminaires in the room were found in the luminaire search engine and were added on the DIALux model. Since luminaire 1 was not available in catalogues, considering its photometric data and the product description, an alternative equivalent was found and used in simulations. Same measurement conditions, date and time were precisely defined in the software and afterwards the simulation was performed. The simulation results of the working area and the living area are shown in Table 74 and Table 75, respectively.

Table 74: Home office 5- Simulation results of the task and the immediate surrounding area (evening)

J-Ta&J-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	12	15	24	39	42	34	29	28	25	23	25	25	25
2	13	22	60	109	91	57	40	32	27	25	25	25	25
3	14	43	196	288	173	88	50	35	29	27	26	27	27
4	14	64	353	463	235	105	54	37	29	28	27	28	27
5	14	42	187	273	169	87	49	35	29	27	27	29	28
6	13	20	53	87	75	52	37	32	28	26	28	28	28
7	13	15	22	32	34	32	27	28	27	25	28	28	27
8	13	13	14	20	21	23	22	25	25	24	27	27	26

Table 75: Home office 5- Simulation results of the living area (evening)

J-La	A	B	C	D	E	F	G	H	I	J
1	11	11	11	11	10	9,96	10	10	11	12
2	11	12	12	12	12	12	12	12	11	12
3	14	15	16	16	17	16	16	16	16	15
4	17	19	20	21	21	21	22	22	21	19
5	22	25	27	28	29	28	29	29	28	25
6	27	32	37	37	37	37	39	39	38	34
7	31	39	45	45	45	45	47	47	48	43
8	28	35	34	33	34	36	36	39	43	43

3.6.3 Analysis of results

The overview of the results that were found by all field measurements and simulations can be seen in Table 76 together with the relevant standard recommendations.

Table 76: Home office 5- Overview of base case results and standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	735	463	132	109	500
	U_o	0,60	0,43	0,42	0,24	0,60
Immediate Sur. Area	E_{avg}	762	466	38	30	300
	U_o	0,48	0,32	0,52	0,40	0,40
Living Area	E_{avg}	669	414	28	25	200
	U_o	0,37	0,27	0,43	0,40	0,10

The data given in Table 76 shows that, in evening both field measurement and simulation results are considerably below what is required, so the artificial lighting performance of the room must be improved. In the daytime there is a great difference between the field measurement and simulation results. For the task area, while the field measurement E_{avg} is far more than what is required and it is very potential to have thermal problems there, on the other hand, simulation results are not even fulfilling the minimum requirements.

Besides, daylight factors of the living area and the working area were analyzed and presented in Figure 44 below.

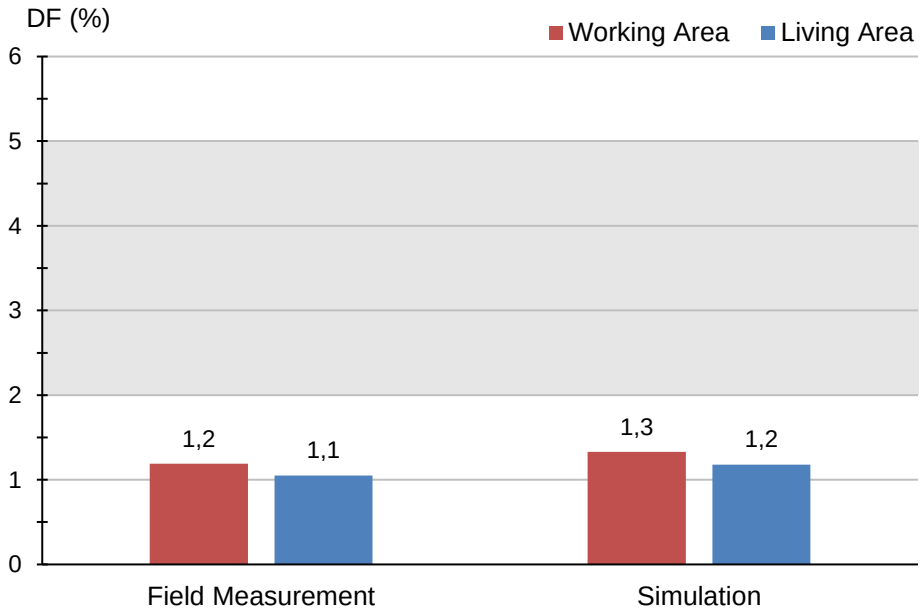

Figure 44: Home office 5- Daylight factor analysis results

Hence the daylight factor results are showing similarity, it can be said that the incoherence between E_{avg} results during the day is caused by the difference between the measured outside illuminance (63590 lx) and the one DIALux uses for performing simulations (35110 lx). Moreover, the gray area of the graph in Figure 44 represents the recommended daylight factor range. So, it can be mentioned that both the working area and the living area have insufficient daylight amount.

Other indicators evaluated only for the working area, in the evening with only artificial lighting are as follows:

- UGR_{max} = >30
- $\bar{E}_z$ = 16 lx
- Modelling = 0,84

As can be seen from the given standard criteria in the Chapter 2.3, all indicators that have been mentioned above are inadequate and they need to be improved.

3.6.4 Improvement proposal

Considering all findings, an improvement scenario was developed for the artificial lighting of the home office. Considering the requirements of the environment, new luminaires were selected which can be more accurate and effective and they located with the field arrangement option of DIALux. The new luminaire plan can be seen in Figure 45.

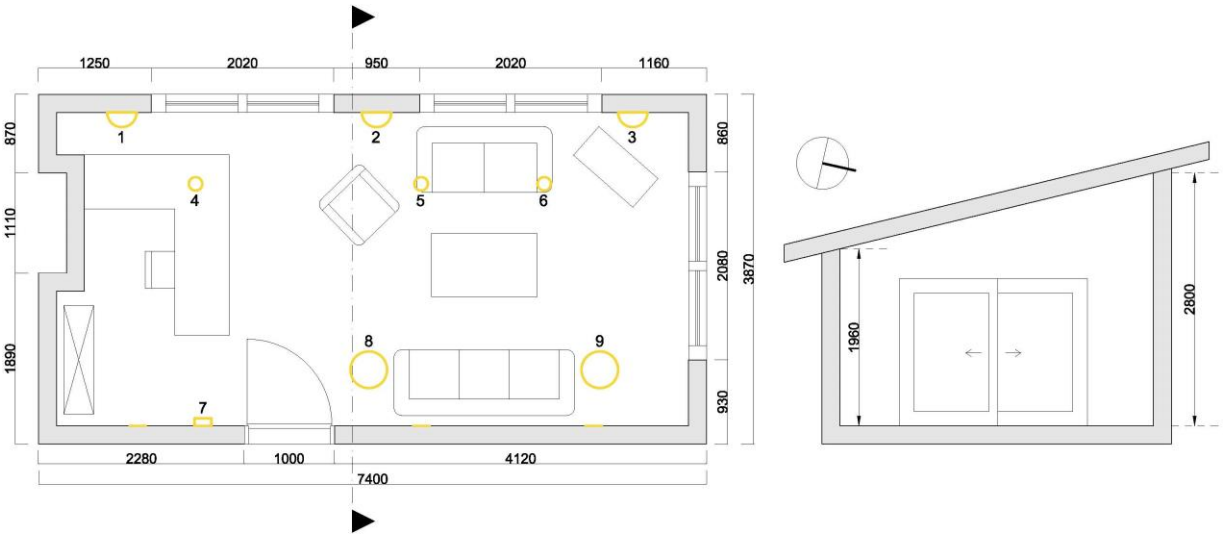

Figure 45: Home office 5- Improvement proposal

The technical information of new luminaires and lamps, which are indicated with the same numbers that were given in Figure 45, are as follows:

1 to 3) Wall surface mounted luminaire- 1,4 m mounting height- FLOS Nord 2500lm 75W
4 to 6) Linea light group- 1,95 m mounting height-LLG_8443_One_Light 1100lm 11W 3000K
7) Wall surface mounted luminaire- 1,3 m mounting height- Artemide Aria Mini 1909lm 21W
8 and 9) Standing luminaire- 1,6 m height- Halolux 64480IM 4210lm 230W
Detailed illuminance results of the working area are presented in Table 77 below.

Table 77: Home office 5- Results of the task and the immediate surrounding area (improvement proposal)

J-Ta& J-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	148	201	254	277	282	262	250	247	273	318	382	455	494
2	197	292	401	456	433	366	318	291	312	375	484	649	838
3	265	440	620	688	627	500	368	324	340	407	535	791	1191
4	314	565	802	864	768	598	409	346	355	420	554	816	1281
5	342	578	805	860	766	594	408	340	346	407	533	787	1201
6	353	498	655	707	642	495	393	317	319	374	478	650	854
7	351	419	465	485	454	375	322	274	377	312	365	431	477
8	341	360	334	316	303	275	253	221	219	240	260	272	232

According to the results in Table 77, E_{avg} of the task area is 539 lx and the U_o is 0,60. Also E_{avg} of the immediate surrounding area is 427 lx and U_o is 0,38. Consequently, the working

area now fulfills all the given recommendations of the lighting standard (Table 76). Other improved indicators of the working area and their results are as follows:

- UGR_{max}= 18
- $\bar{E}_z$ = 186 lx
- Modelling = 0,58

Additionally, the results of the living area simulation are shown in Table 78.

Table 78: Home office 5- Results of the living area (improvement proposal)

J-La	A	B	C	D	E	F	G	H	I	J
1	332	451	276	193	89	99	190	179	324	464
2	155	331	1244	1199	254	386	1505	816	223	172
3	103	266	989	972	268	386	1165	705	177	98
4	80	126	212	211	129	149	221	186	98	73
5	79	92	92	87	77	78	91	95	88	73
6	211	348	157	79	67	70	97	232	327	144
7	967	1972	576	103	66	72	175	1112	1822	496
8	686	1510	435	90	59	66	148	789	1402	395

3.7 Home office 6: Lawyer

Existing luminaire plan of the room is shown in Figure 46. The dimensions are in millimetres. Detailed information with photographs and 3D view can be found in the sub-section 2.2.6.

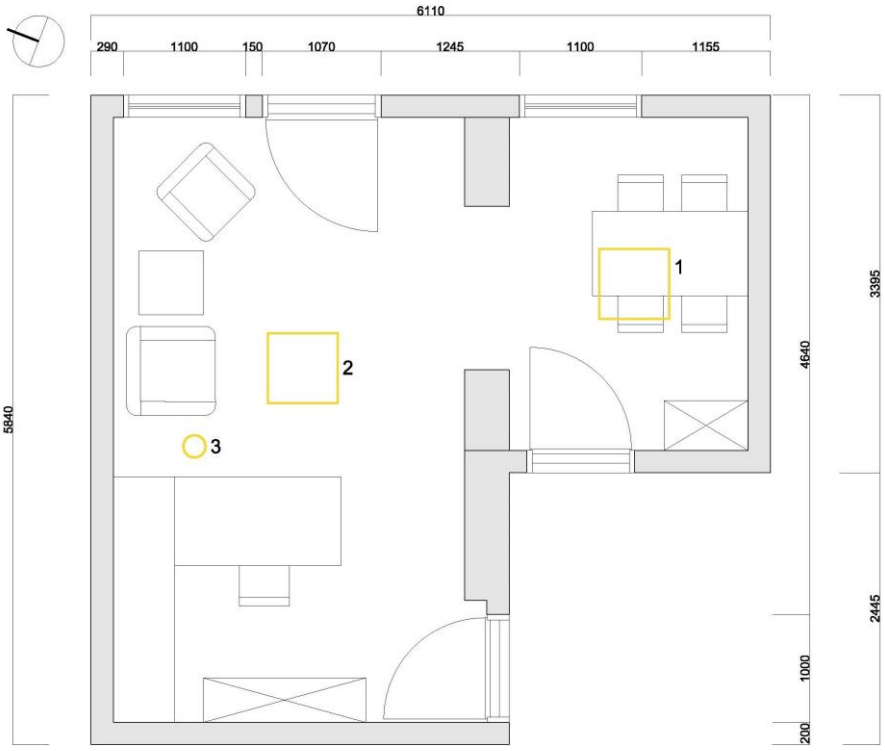

Figure 46: Home office 6- Floor plan with luminaires

The existing luminaires and lamps in the room, which indicated with the same reference numbers in the Figure 46, are as follows:

1 and 2) Ceiling mounted luminaire- 0,1 m luminaire height- Philips MASTER TL-D-80 5400lm 18W 840

3) Standing luminaire- 0,9 m height- Philips E27 1000lm 13W 220-240V 2700K 50-60Hz

The grids that were used for illuminance measurement are can be found in Figure 47, which were applied by taking the instructions of lighting standard TS EN 12464-1 into consideration (see sub-sections 1.3.9 and 1.3.10). The task area measuring grid is shown in orange, immediate surrounding is in red, living area is in green and dining area is in purple.

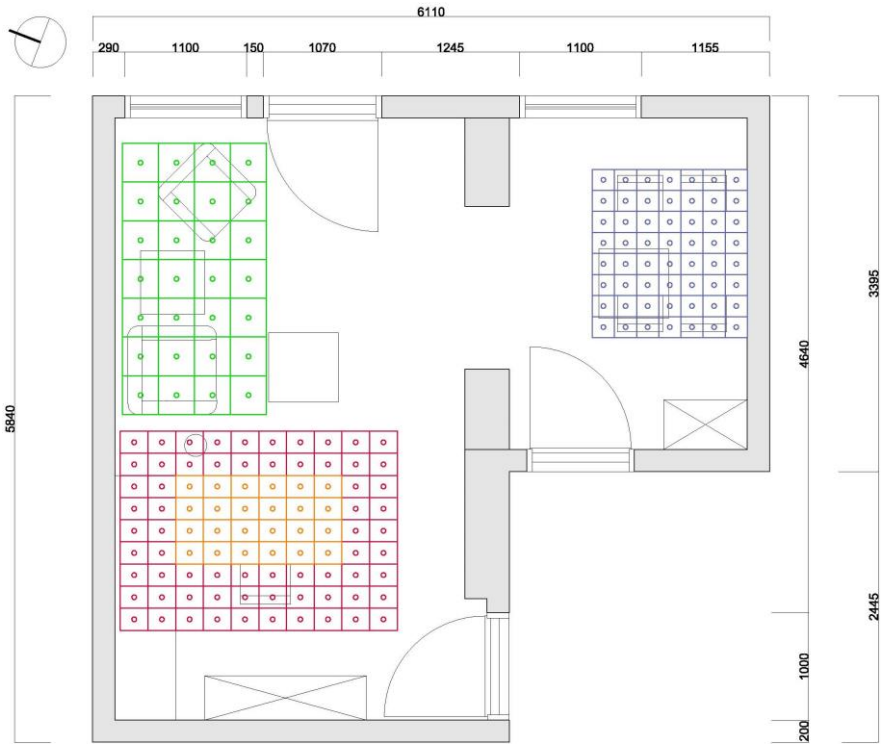

Figure 47: Home office 6- Floor plan with measuring grids

The detailed information on measuring grids is presented in Table 79 and the grid cell labelling are in Figure 48. The grid codes given in Table 79 and grid cell labels in Figure 48 will be used in the same way in all sub-chapters of the Chapter 3.7.

Table 79: Home office 6- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	L-Ta	200 x 250	24
Immediate Surrounding Area	L-Isa		66
Living Area	L-La	350 x 325	28
Dining Area	L-Da	190 x 200	56

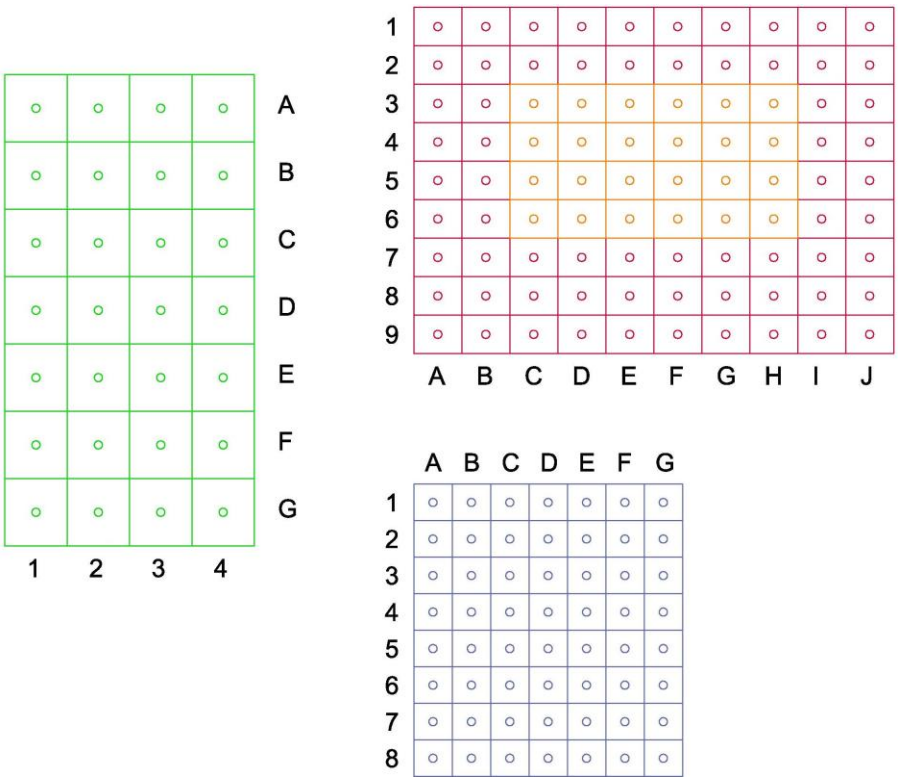

Figure 48: Home office 6- The measuring grid numbering of living area (left), task area and immediate surrounding area (top right), dining area (bottom right)

3.7.1 Daytime measurement results

The daytime field measurement was performed in the morning of 17.04.2017 from 10:30 to 11:25, under overcast sky and without artificial lighting. The in-situ measurement results of all areas are presented below from Table 80 to Table 82 below.

Table 80: Home office 6- Field measurement results of the task and the immediate surrounding area (daytime)

L-Ta&L-Isa	A	B	C	D	E	F	G	H	I	J	E_{out}
1	191,7	192,5	198,7	199,6	202,3	210,3	193,2	190,2	188	184,2	16080
2	174,9	175,7	181,3	182,1	184,5	191,8	176,3	173,5	171,5	168,1	16140
3	150,1	150,8	158,6	162	163,9	169,7	158,2	152	151,3	144,2	15580
4	135,4	139,2	146,5	149,6	157	160,8	149,1	133,9	131	130,2	15840
5	120,5	122,6	125,5	128,9	131,4	135,4	126	124,6	122,4	121,3	16190
6	112,3	115	121,5	123,8	125,6	129	119,4	118,1	117,3	114,3	16430
7	111,9	114,8	121	123,3	125,1	128,5	119	117,6	116,8	113,8	14850
8	111	113,6	118,9	121,6	124	127	114,8	116,2	113,5	116	15290
9	107,4	110,4	114,2	117,9	119,6	122,7	112,3	113	110,3	104,6	14520

Table 81: Home office 6- Field measurement results of the living area (daytime)

L-La	A	B	C	D	E	F	G	E_{out}
1	1596	1116	788	609	521	456	333	13130
2	2197	1372	1029	778	533	462	339	14220
3	2398	1626	1197	832	563	489	361	15460
4	2035	1207	952	772	548	471	346	15450

Table 82: Home office 6- Field measurement results of the dining area (daytime)

L-Da	A	B	C	D	E	F	G	E_{out}
1	1812	1651	1529	978	806	793	701	15460
2	1518	1365	1276	927	832	806	690	15040
3	1128	1078	996	770	681	642	565	14330
4	920	880	817	682	623	558	503	13850
5	727	713	684	597	548	537	487	14520
6	615	624	598	555	513	491	459	13810
7	598	502	493	452	438	421	414	14490
8	512	467	443	412	401	388	383	13260

According to the performed outside measurements, the average illuminance value was found 14950 lx. In addition, reflectance values the major surfaces of the home office were calculated (Equation 3). The results can be observed in Table 83.

Table 83: Home office 6- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	40
Ceiling	85
Walls	70
Wood coating (arch)	9
Working table	7
Dining table	4

Afterwards, the room was modelled one-to-one in 3D with DIALux. Same measurement date, time, sky type and the reflectance values were introduced to the software and simulated. The daytime simulation results of the working area are shown below in Table 84. Additionally, illuminance results of the dining and living area can be seen together in Table 85.

Table 84: Home office 6- Simulation results of the task and the immediate surrounding area (daytime)

L-Ta& L-Isa	A	B	C	D	E	F	G	H	I	J
1	139	140	145	148	144	142	137	140	137	133
2	131	130	136	134	137	129	133	133	127	128
3	101	101	109	112	113	116	112	112	112	112
4	93	96	104	106	105	108	106	102	105	98
5	90	92	88	90	93	94	96	95	103	94
6	71	74	85	86	88	93	91	90	85	78
7	68	71	77	79	81	83	81	83	80	74
8	56	58	64	66	67	70	70	71	69	65
9	55	58	63	64	66	69	69	67	65	60

Table 85: Home office 6- Simulation results of the dining area and living area (daytime)

L-Da	A	B	C	D	E	F	G
1	1610	1452	1215	669	489	396	344
2	1237	1083	974	618	490	385	341
3	921	864	762	531	444	398	326
4	721	676	623	483	416	349	309
5	576	554	497	408	354	330	295
6	456	458	417	369	322	294	267
7	384	363	359	313	297	272	255
8	330	318	311	278	262	241	236

L-La	A	B	C	D	E	F	G
1	1399	877	588	400	254	199	167
2	1870	1081	690	455	281	203	174
3	1947	1141	720	478	282	207	170
4	1788	1065	697	452	277	208	167

Since it is not possible to manually define an outside illuminance value in DIALux, for being able to find the outside illuminance that was used by the software during calculations, an identical exterior scenario of the room was modelled and simulated. As a result, the average outside illuminance was found 9980 lx and later used for the daylight factor (DF) analysis.

3.7.2 Evening measurement results

The evening field measurements were performed in 17.04.2017 from 21:15 to 22:10 with no daylight and 25 minutes after all lights were turned on. The illuminance results of all areas that were obtained by evening field measurement can be observed from Table 86 to Table 88 below.

Table 86: Home office 6- Field measurement results of the task and the immediate surrounding area (evening)

L-Ta&L-Isa	A	B	C	D	E	F	G	H	I	J
1	259,8	402	686	594	481	369	315	304	270,9	225,1
2	191,4	296,4	503	496	366	270,8	246,9	230,8	230,8	209,9
3	155,3	200,3	280,9	273,1	217,3	201,6	190,3	180,7	176,9	171,6
4	99,4	129,8	160,8	152,4	150,6	144,9	146,2	141,9	135,4	130,7
5	89,2	109,8	131,3	130,4	128,7	126,5	125,4	121,3	118,6	115
6	84,9	94,1	110,6	103,7	100,4	98,2	95,4	93,1	92,4	90,3
7	71,2	75,3	87,6	86,1	85,7	84,4	84	81,5	80,9	80,2
8	56,9	58,2	68,7	68	66,6	65,1	63,3	62,7	59,7	58,9
9	46,1	50,7	60,1	58,6	57,8	56	54,6	53,7	52,1	49,5

Table 87: Home office 6- Field measurement results of the dining area (evening)

L-Da	A	B	C	D	E	F	G
1	228,9	254,6	249,7	242,2	228,9	215,4	204,3
2	266,4	273	270,1	269,3	264,1	258,4	244,6
3	298,5	307	303	296,8	287,1	276,4	267,9
4	323	336	329	322	314	295,7	271,9
5	348	366	356	344	327	310	285,6
6	354	368	361	351	334	317	293,7
7	363	371	365	358	339	323	302
8	342	360	354	340	319	308	294,6

Table 88: Home office 6- Field measurement results of the living area (evening)

L-La	A	B	C	D	E	F	G
1	76,9	115,4	180,3	264,2	345	394	370
2	73,2	105,5	159,8	222,8	285,4	324	301
3	61,7	92,3	137,9	189,6	245,1	279	253,7
4	55,7	75,4	113,6	139,8	181,6	200,4	191,7

Afterwards, same of the existing luminaires were found in the luminaire search engine and were imported to DIALux. The measurement day, time and conditions were defined in the software and the simulation was performed. The working area results are presented in Table 89. In addition, results of the dining area and living area are together shown in Table 90 below.

Table 89: Home office 6- Simulation results of the task and the immediate surrounding area (evening)

L-Ta&L-Isa	A	B	C	D	E	F	G	H	I	J
1	219	385	869	907	427	317	302	294	267	236
2	192	229	667	715	359	269	254	246	227	206
3	159	180	296	299	233	207	200	191	188	174
4	123	147	176	184	174	167	164	159	154	145
5	111	125	141	149	150	148	147	143	140	133
6	89	97	112	118	120	121	120	118	112	107
7	72	76	88	90	92	94	94	93	91	88
8	58	60	68	70	72	73	73	72	72	70
9	48	49	56	57	59	60	60	60	59	58

Table 90: Home office 6- Simulation results of the dining and living area (evening)

L-Da	A	B	C	D	E	F	G
1	250	252	260	257	253	241	230
2	287	290	297	290	283	271	257
3	326	329	334	325	316	299	280
4	357	361	366	355	343	325	302
5	372	377	381	367	355	336	310
6	385	391	395	381	368	347	321
7	383	388	393	379	366	345	321
8	366	369	373	360	349	330	308

L-La	A	B	C	D	E	F	G
1	87	121	192	269	379	446	426
2	82	112	170	230	314	362	348
3	75	101	149	196	260	296	286
4	65	84	118	150	193	217	212

3.7.3 Analysis of results

The average illuminance (E_{avg}) and uniformity (U_o) values that have been obtained through field measurements and simulations are shown below in Table 91 together with the recommended values in the standards. Further information about the relevant standard and requirements can be observed in Chapter 2.3.

Table 91: Home office 6- Overview of base case results and standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	140	100	150	168	500
	U_o	0,84	0,85	0,61	0,67	0,60
Immediate Sur. Area	E_{avg}	141	95	166	180	300
	U_o	0,74	0,58	0,28	0,27	0,40
Living Area	E_{avg}	926	651	194	212	200
	U_o	0,35	0,25	0,29	0,30	0,10
Dining Area	E_{avg}	732	517	306	330	300
	U_o	0,52	0,46	0,67	0,70	0,10

The data given in Table 91 shows that, in daytime while task area and immediate surrounding E_{avg} results were found considerably less than minimum standard requirements, on the contrary, living and dining area E_{avg} results are far above than required. On the other hand, U_o results of all areas are following the standard recommendations. In the evening, both E_{avg} and U_o results of the living and the dining area were found satisfactory. In case of the task area and the immediate surrounding area, while E_{avg} of both areas were measured far below than recommended, U_o was adequate only in task area. Therefore, for following the standards, the home office should be subjected to improvement.

Due to having a big difference in daytime results, the daylight factor was analyzed and presented in Figure 49.

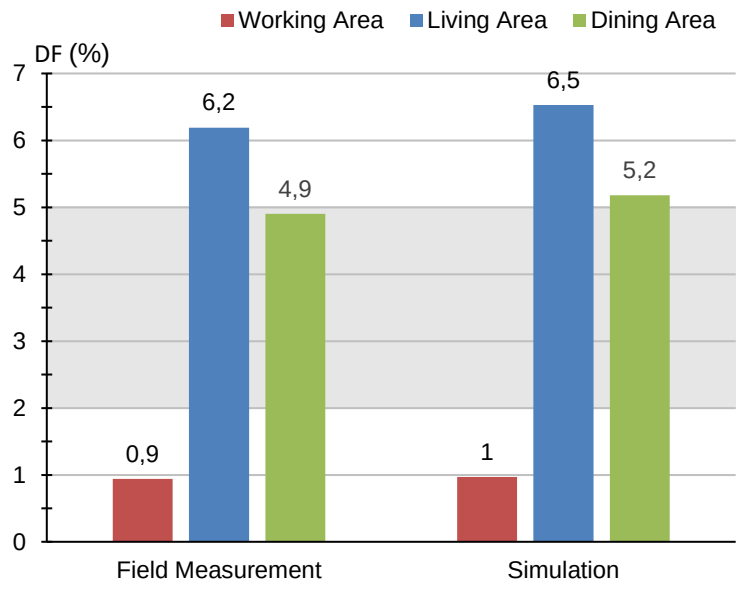

Figure 49: Home office 6- Daylight factor analysis results

Since the daylight factor results are very similar to each other, it can be mentioned that the incoherence between daytime E_{avg} results is mainly because of the difference between the

measured outside illuminance (14950 lx) and the one DIALux uses for performing simulations (9980 lx). Also, considering that the gray zone in the graph indicates the recommended daylight factor range, as expected after daytime E_{avg} results, while the working area has insufficient daylight amount, the living area and dining area is under high exposure to daylight and it is very potential to have thermal problems in those areas.

The other indicators evaluated just for the working area, in the evening with only artificial lighting are as follows:

- UGR_{max} = 26
- $\bar{E}_z$ = 49 lx
- Modelling = 0,63

As can be seen from the given standard criteria in the Chapter 2.3, none of the indicators that have been mentioned above are satisfactory.

3.7.4 Improvement proposal

After all findings, an improvement scenario was created for the artificial lighting. Considering the requirements of the environment, new luminaires were selected which can be more accurate and effective and they located with the field arrangement option of DIALux. The new luminaire plan can be seen in Figure 50.

Figure 50: Home office 6- Improvement proposal

The technical information of new luminaires and lamps, which are indicated with the same numbers that were given in Figure 50, are as follows:

1 and 2) Pendant luminaire- 0,15 m suspension height- ATELJELYKTAN 201576 Megalo E27 4434lm 100W 3000K

3 to 11) Ceiling recessed LED spotlights – Luxor PSM3390 965lm 8W 3000K

The illuminance results of the working area that were obtained after improvement proposal can be seen in Table 92.

Table 92: Home office 6- Results of the task and the immediate surrounding area (improvement proposal)

L-Ta&L-Isa	A	B	C	D	E	F	G	H	I	J
1	384	468	529	556	559	576	573	579	548	534
2	368	486	563	546	540	597	605	569	533	549
3	353	474	555	540	539	590	616	559	525	545
4	354	466	534	562	565	585	588	581	546	556
5	363	456	511	560	562	567	566	578	570	547
6	340	451	515	544	545	568	571	566	535	546
7	320	445	530	504	501	561	576	532	501	524
8	306	430	507	490	483	540	549	513	487	506
9	306	397	458	483	483	501	499	504	485	480

According to the results in Table 92, E_{avg} of the task area is 561 lx and the U_o is 0,91. Also E_{avg} of the immediate surrounding area is 495 lx and U_o is 0,62. As a result, both task area and immediate surrounding area now fulfills recommendations of the lighting standard (Table 91). Other improved indicators of the working area and their results are as follows:

- UGR_{max}= 14
- $\bar{E}_z$ = 150 lx
- Modelling = 0,45

Also, improvement proposal results of the dining and the living area are presented together in Table 93.

Table 93: Home office 6- Results of the dining and the living area (improvement proposal)

L-Da	A	B	C	D	E	F	G
1	237	255	280	293	292	273	250
2	259	281	310	323	321	300	272
3	282	308	335	349	345	319	288
4	293	321	350	364	359	332	297
5	295	324	353	366	359	332	297
6	287	312	340	352	348	320	289
7	269	292	315	324	320	298	272
8	248	266	286	291	289	268	248

L-La	A	B	C	D	E	F	G
1	374	242	203	204	200	180	153
2	548	311	257	263	257	227	188
3	504	329	284	302	297	258	208
4	477	354	337	380	375	315	245

The E_{avg} and U_o of the dining area was measured respectively 304 lx and 0,78. Also, the E_{avg} of the living area was calculated as 296 lx and the U_o was found as 0,52. So, as a result of the improvement scenario both areas are adequate according to the standards.

3.8 Home office 7: Private teacher

Detailed information, photographs and 3D view were shown in the sub-section 2.2.7. The existing luminaires of the room can be seen in Figure 51. The dimensions are in millimetres.

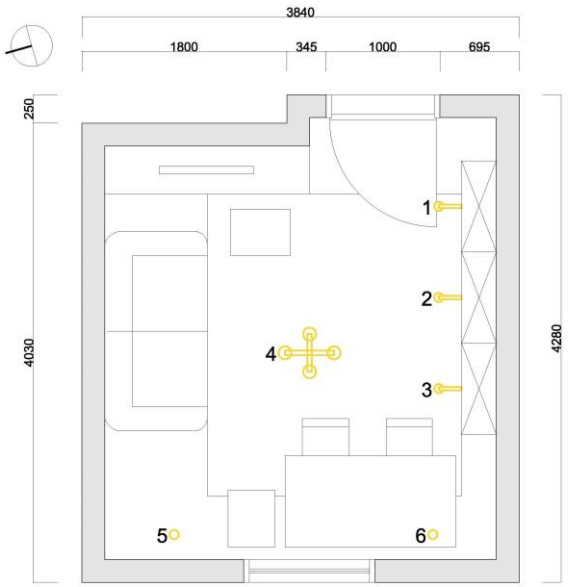

Figure 51: Home office 7- Floor plan with luminaires

The technical information of existing luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 51:

1 to 3) Bookshelf lights- 2,50 m mounting height- SLV 146452 FILI 80lm 2W 2800K

4) Pendant luminaire- 0,25 m suspension height – ARCLUCE Demo230 710lm 60W 3000K

5 and 6) Ceiling recessed LED spotlights – ARCLUCE Quantum Black 270lm 30W 4000K

All applied measuring grids that were created with the instructions of TS EN 12464-1 (see sub-sections 1.3.9 and 1.3.10) are shown in Figure 52. The grid of task area is shown in orange, immediate surrounding is in red and the living area is in green.

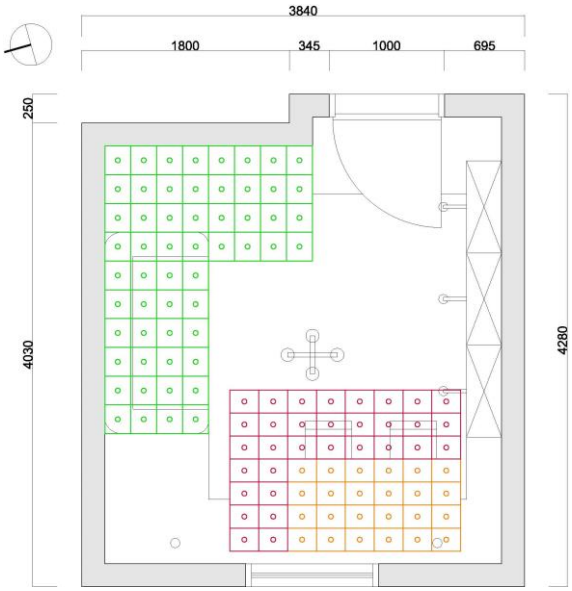

Figure 52: Home office 7- Floor plan with measuring grids

The detailed information about the measuring grids that were used in this home office are presented below in Table 94. Also, labelling of the grid cells is shown in Figure 53. The grid codes that are given in the second column of Table 94 and the labelling of the grid cells that were given in Figure 53 will be identical in all sub-chapters of the Chapter 3.8.

Table 94: Home office 7- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	Pt-Ta	200 x 250	24
Immediate Surrounding Area	Pt-Isa		32
Living Area	Pt-La	250 x 225	56

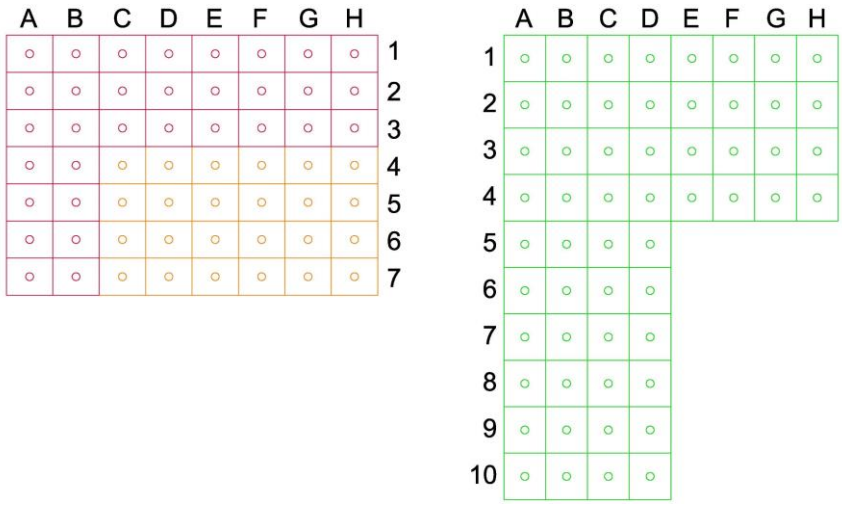

Figure 53: Home office 7- The measuring grid numbering of task area and immediate surrounding area (left) and living area (right)

3.8.1 Daytime measurement results

The daytime field measurement took place in the morning of 19.04.2017 from 10:30 to 11:10. The measurement was performed under overcast sky with no direct sunlight and without artificial lighting. The working area and living area results are shown respectively in Table 95 and Table 96, including simultaneously measured outside illuminances in their last column.

Table 95: Home office 7- Field measurement results of the task and the immediate surrounding area (daytime)

Pt-Ta&Pt-Isa	A	B	C	D	E	F	G	H	E_{out}
1	689	732	811	779	755	628	660	534	12420
2	858	921	998	915	774	717	648	557	13020
3	1014	1063	1170	1103	1002	874	731	705	12450
4	1214	1405	1726	1566	1417	1322	1123	839	13780
5	1401	1608	1840	1676	1563	1393	1124	822	14870
6	1614	2192	2478	2210	1991	1642	1228	784	14800
7	1882	2667	2855	2687	2542	2198	1494	681	14960

Table 96: Home office 7- Field measurement results of the living area (daytime)

Pt-La	A	B	C	D	E	F	G	H	E_{out}
1	145	152,2	156,7	159	162,2	164,3	167,7	172,2	12050
2	152,3	156	164,9	168,5	173,3	178,4	183,3	185,6	13120
3	155,1	155,7	173,5	177,6	182,3	187,3	189	190,7	13580
4	157,6	158,6	179,2	181,7	190,6	191,3	192,2	194,5	13900
5	159	161,9	183,3	195,1					14120
6	163,5	167	189	203,2					14470
7	167,4	181,6	205,7	213					14900
8	175,7	187,2	219,1	248,3					15350
9	182	207,7	240,4	275,6					14120
10	202,3	221,2	272,9	337					15580

Based on the measurements, the average outside illuminance value was found 13970 lx. Additionally, reflectance values the major surfaces in the home office were calculated by applying Equation 3 and the results are presented below in Table 97.

Table 97: Home office 7- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	34
Carpet	39
Ceiling	90
Walls	71
Working table, Shelves	78
Sofas	30

Afterwards, the room was modelled one-to-one in 3D with DIALux. Same measurement date, time, sky type and the reflectance values were introduced to the software and simulated. The daytime simulation results are shown hereinafter in Table 98 and Table 99.

Table 98: Home office 7- Simulation results of the task and the immediate surrounding area (daytime)

Pt-Ta&Pt-Isa	A	B	C	D	E	F	G	H
1	431	475	491	500	462	393	339	284
2	520	585	619	610	560	486	388	313
3	651	748	807	810	726	604	496	401
4	773	943	1142	1113	988	833	662	448
5	1182	1583	1583	1517	1315	1053	769	431
6	1391	2009	2162	2054	1728	1287	827	408
7	1486	2398	2653	2522	2108	1350	693	299

Table 99: Home office 7- Simulation results of the living area (daytime)

Pt-La	A	B	C	D	E	F	G	H
1	117	117	122	126	125	127	129	123
2	95	95	98	102	101	103	103	103
3	98	103	110	114	110	113	113	112
4	102	109	115	121	115	119	120	121
5	119	115	126	133				
6	126	126	140	149				
7	147	148	167	169				
8	155	153	176	183				
9	169	188	204	233				
10	183	207	256	308				

Besides, an exterior scenario of the room was modelled and simulated for finding the outside illuminance that was taken by DIALux during calculations, since it is not possible to manually introduce an illuminance value to the software. As a result, average outside illuminance was found 9780 lx and this result later used for analyzing the daylight factor (DF).

3.8.2 Evening measurement results

The evening field measurements were performed in 19.04.2017 from 20:30 to 21:15 with no daylight and 40 minutes after all lights were turned on. The detailed in-situ illuminance results can be found in Table 100 and Table 101.

Table 100: Home office 7- Field measurement results of the task and the immediate surrounding area (evening)

Pt-Ta&Pt-Isa	A	B	C	D	E	F	G	H
1	447	546	588	478	457	360	297,6	232,7
2	342	376	430	370	348	308	258,4	200,8
3	246,8	295,3	318	274,4	259,4	220,6	155,5	136,3
4	157,7	180,9	200,6	161,5	153,8	140,7	137,8	128,4
5	129,8	150,4	169,8	142,6	136,4	127,5	126,4	132,9
6	117,4	128,6	97	102,4	108,8	112,6	116,4	126,5
7	113,7	104,6	75,7	84,6	101,8	109,1	112	124,6

Table 101: Home office 7- Field measurement results of the living area (evening)

Pt-La	A	B	C	D	E	F	G	H
1	27,84	34,6	42,3	49,1	52,3	54,7	56,9	60,3
2	29,63	38,7	43,6	55,9	60,3	68,7	74,9	82,3
3	34,7	45,4	54,3	81,3	91,1	101,4	133,5	147,5
4	36,6	49,2	61,3	110,8	127,6	193,5	283,4	322
5	42,8	56,9	66,4	122,6				
6	48,7	60,3	76,3	142,4				
7	50,8	63,4	80,7	174,3				
8	53,1	66,2	84,4	190,9				
9	58,4	67,6	86,3	220,5				
10	55,9	58,2	70,2	121,4				

Moreover, all measurement conditions were defined exactly in DIALux model and simulated. The simulation results of the working area and living area are shown respectively in Table 102 and Table 103.

Table 102: Home office 7-Simulation results of the task and the immediate surrounding area (evening)

Pt-Ta&Pt-Isa	A	B	C	D	E	F	G	H
1	461	572	620	603	531	415	316	219
2	355	446	488	473	409	320	238	174
3	260	313	331	327	296	236	181	146
4	189	212	196	201	190	170	151	135
5	146	145	127	140	145	143	141	137
6	123	111	97	113	127	133	138	139
7	115	100	83	99	115	126	136	139

Table 103: Home office 7- Simulation results of the living area (evening)

Pt-La	A	B	C	D	E	F	G	H
1	35	38	42	45	47	51	54	57
2	39	42	46	51	56	64	71	76
3	44	48	57	70	83	112	145	165
4	46	53	68	95	141	223	323	385
5	50	60	85	145				
6	54	68	110	217				
7	57	72	123	257				
8	56	70	116	234				
9	54	65	94	166				
10	53	60	77	113				

3.8.3 Analysis of results

The result overview that was obtained by all field measurements and simulations can be observed in Table 104 together with the related standard recommendations.

Table 104: Home office 7- Overview of base case results and standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	1633	1248	126	138	300
	U_o	0,42	0,24	0,60	0,60	0,60
Immediate Sur. Area	E_{avg}	1051	765	282	308	200
	U_o	0,51	0,37	0,37	0,32	0,40
Living Area	E_{avg}	187	137	86	95	100
	U_o	0,78	0,69	0,32	0,37	0,10

As can be seen from the Table 104, in the morning, while E_{avg} results of the living area are following the standards, in the task and the immediate surrounding they are considerably

higher than minimum requirements. On the other hand, in terms of U_o results, again only the living area showed satisfactory results. In the evening, in contrast to the daytime results, all areas have less E_{avg} than recommended. Also, except the U_o of immediate surrounding area, none of the U_o values are following the standards. Based on all above-mentioned reasons, it can be mentioned that the lighting performance of the room should definitely be improved.

Due to having a big difference in daytime results, the daylight factor was analyzed and presented in Figure 54.

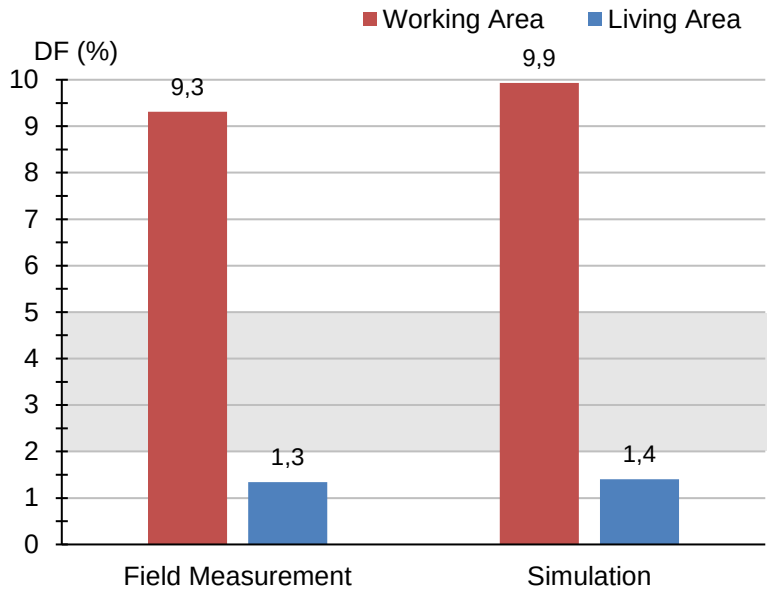

Figure 54: Home office 7- Daylight factor analysis results

Based on the similarity between the daylight factor results, it can be mentioned that the incoherence between daytime results are mainly caused by the difference between the measured outside illuminance (13970 lx) and the one that DIALux used for performing the simulations (9780 lx). Besides, considering that the gray zone in the graph indicates the recommended daylight factor range, while the working area is under high exposure to daylight and it is very potential to have thermal problems there, on the contrary, living area has insufficient daylight amount and artificial lighting may be necessary during all day.

The other indicators that was evaluated in the evening with only artificial lighting and just for the working area, are as follows:

- UGR_{max} = 15
- $\bar{E}_z$ = 71 lx
- Modelling = 0,65

Considering the given standard criteria in the Chapter 2.3, it can be stated that none of the above-mentioned indicators are following the standards and an improvement is necessary.

3.8.4 Improvement proposal

Based on all above observations and findings, an improvement scenario was developed for the artificial lighting. Firstly, considering the environment and its requirements, more accurate and effective luminaires were selected and placed by the field arrangement option of the DIALux. The new luminaire plan can be seen in Figure 55.

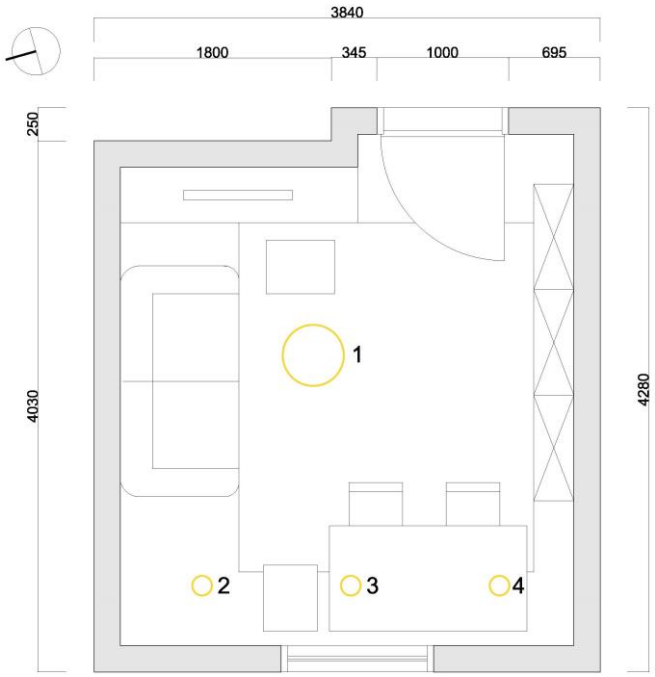

Figure 55: Home office 7- Improvement proposal

The technical information of new luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 55:

1) Pendant luminaire- 0,20 m suspension height – MODULAR 11810662 3288lm 31W

From 2 to 4) Ceiling recessed LED spotlights - Performance in Lighting 1243lm 12W

The improvement proposal simulation results of the task and immediate surrounding area can be observed below in Table 105.

Table 105: Home office 7- Results of the task and the immediate surrounding area (improvement proposal)

Pt-Ta&Pt-Isa	A	B	C	D	E	F	G	H
1	413	419	407	387	365	336	297	260
2	411	416	408	392	376	355	321	292
3	419	424	416	407	397	381	356	338
4	426	430	423	417	414	395	390	382
5	425	428	424	422	423	411	409	402
6	416	415	414	414	418	411	412	405
7	398	396	396	397	402	406	407	397

According to the results in Table 105, E_{avg} of the task area is 408lx and the U_o is 0,94. In addition E_{avg} of the immediate surrounding area is 385 lx and U_o is 0,67. As a result, the

working area now fulfills recommendations of the lighting standard (Table 104). Other analyzed indicators of the working area and their improved results are as follows:

- UGR_{max}= 14
- $\bar{E}_z$ = 201 lx
- Modelling = 0,48

Additionally, the results of the living area are shown in Table 106. Since the E_{avg} was found 262 lx and the U_o was found 0,45, after the improvement proposal this area is in accordance with the minimum standard recommendations as well.

Table 106: Home office 7- Results of the living area (improvement proposal)

Pt-La	A	B	C	D	E	F	G	H
1	119	131	147	161	169	180	183	178
2	133	147	166	186	201	217	222	214
3	158	174	208	247	278	313	327	315
4	174	198	246	305	356	416	444	424
5	194	224	283	364				
6	211	246	314	406				
7	226	261	328	416				
8	237	268	326	397				
9	260	289	333	380				
10	287	317	358	392				

3.9 Home office 8: Tailor & Fashion designer

Existing luminaire plan of the room is shown in Figure 56. The dimensions are in millimetres.

Figure 56: Home office 8- Improvement proposal

Further information, photographs and 3D view were given in sub-section 2.2.8. The technical information of existing luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 56:

1) Pendant luminaire- 0,36 m suspension height – HOROZ E27 2620lm 65W 220-240V 6400K

2 and 3) Ceiling mounted luminaire- 0,1 m luminaire height- Philips MASTER TL-D-80 5400lm 18W 840

All applied measuring grids that were created with the instructions of TS EN 12464-1 (see sub-sections 1.3.9 and 1.3.10) can be seen below in Figure 57. The grids of all task areas are shown in orange and immediate surroundings are in red. Also, the living area measuring grid is presented in green and the kitchen is in blue.

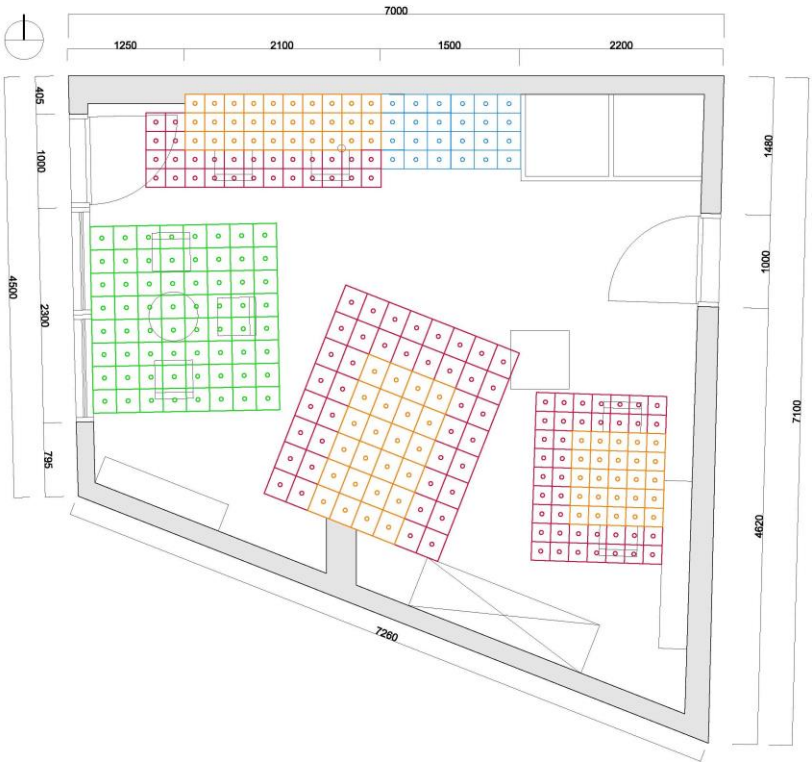

Figure 57: Home office 8- Floor plan with measuring grids

The detailed information about the grids that were given in Figure 57, which were used for measuring illuminance in this home office are presented below in Table 107. Also, labelling of the grid cells can be observed in Figure 58. The grid codes that are given in the second column of Table 107 and the labelling of the grid cells that are given in Figure 58 will be used identically in all following sub-chapters of the Chapter 3.9.

In addition, the numbering of the working areas that can be seen in Table 107 and Figure 58 is made from left to right, considering their position in the floor plan.

Table 107: Home office 8- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area 1	TF-Ta1	200 x 210	30
Immediate Surrounding Area 1	TF-Isa1		28
Task area 2	TF-Ta2	300 x 250	24
Immediate Surrounding Area 2	TF-Isa2		40
Task area 3	TF-Ta3	200 x 200	25
Immediate Surrounding Area 3	TF-Isa3		38
Living Area	TF-La	250 x 250	64
Kitchen	TF-K	200 x 250	24

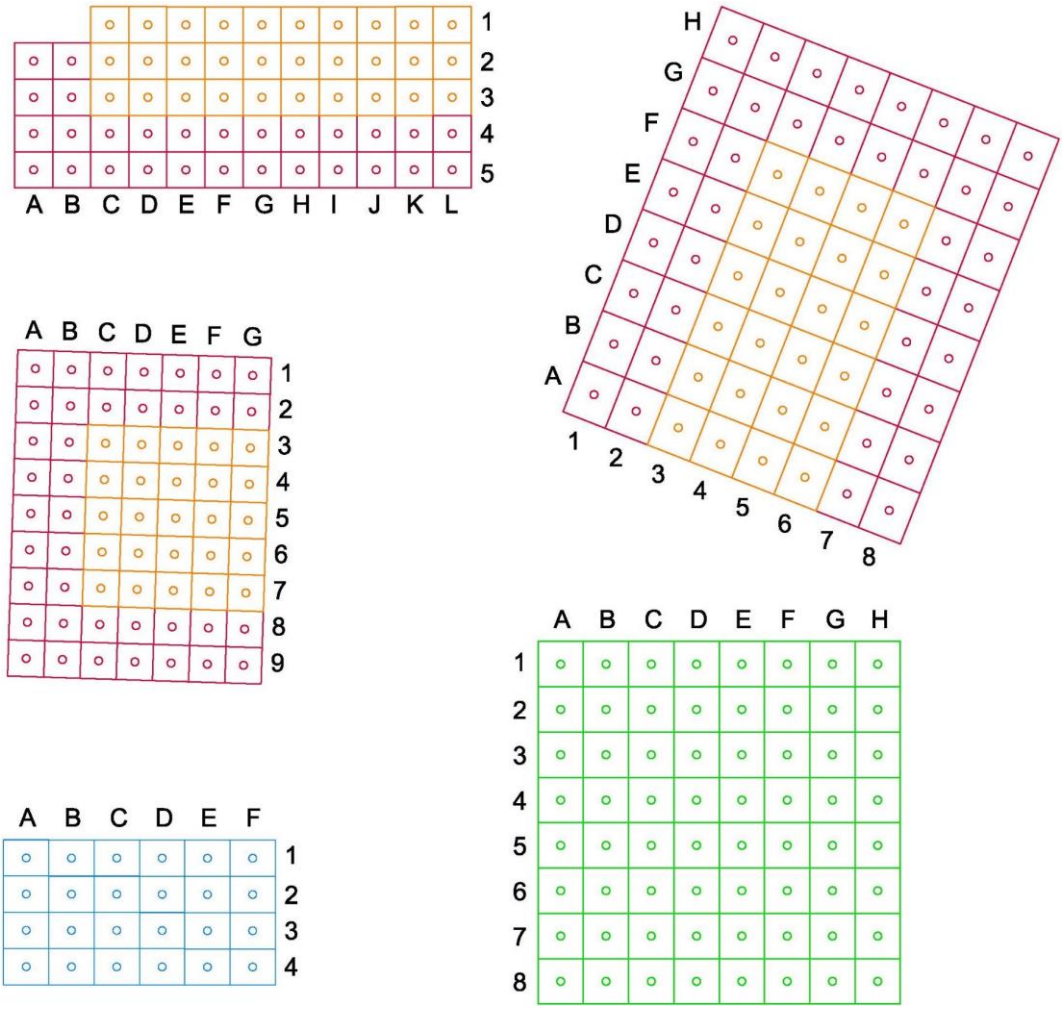

Figure 58: Home office 8- The measuring grid numbering of working area 1 (top left), working area 2 (top right), working area 3 (middle left), kitchen (bottom left) and living area (bottom right)

3.9.1 Daytime measurement results

The daytime field measurement was performed in the morning of 20.04.2017 from 10:00 to 11:35, under clear sky and when all artificial lighting was turned off. The results of all working areas are shown in their numerical order below, from Table 108 to Table 110. Also, they include measured outside illuminance values in their last column.

Table 108: Home office 8- Field measurement results of the task area 1 and the immediate surrounding area 1 (daytime)

TF-Ta1& TF-Isa1	A	B	C	D	E	F	G	H	I	J	K	L	E_{out}
1			1100	1021	997	941	873	807	671	667	574	531	65310
2	1834	1770	1253	1141	1018	1010	908	881	693	690	577	532	64540
3	1878	1806	1363	1255	1143	1043	919	879	700	695	598	545	64310
4	1924	1735	1528	1360	1219	1147	1045	974	742	708	612	570	63840
5	1969	1771	1583	1388	1240	1166	1154	983	837	754	618	601	63730

Table 109: Home office 8- Field measurement results of the task area 2 and the immediate surrounding area 2 (daytime)

TF-Ta2&TF-Isa2	A	B	C	D	E	F	G	H	E_{out}
1	412	436	457	468	480	483	485	486	62650
2	379	396	442	454	457	462	466	475	63020
3	306	330	346	351	355	357	374	410	62410
4	281,4	306	312	325	331	340	355	369	61710
5	270,4	282,4	295,8	304	308	315	323	330	62230
6	253,6	278,9	280,4	290,9	302	304	315	322	61240
7	229,7	245,7	248,7	254,6	265,5	268,3	280,5	285,2	61020
8	213,4	216,3	228,2	234,2	252,1	247,6	249,4	256,8	61430

Table 110: Home office 8- Field measurement results of the task area 3 and the immediate surrounding area 3 (daytime)

TF-Ta3&TF-Isa3	A	B	C	D	E	F	G	E_{out}
1	180,9	177,1	173,4	169,8	166,3	162,3	146,6	61390
2	178,1	174,6	172,2	167,9	163,7	157,9	138,4	61190
3	175	172,3	167,7	166,1	160,4	152,1	126,4	60670
4	162,3	159,4	157	154,1	142,1	141,5	114,9	60490
5	158,9	157,3	115,8	149	120,9	104,8	99,4	60220
6	149,2	143,3	141,6	124,9	105,2	92,5	79,5	59690
7	144	140,4	116,4	95,4	89,9	81,2	76,7	59560
8	141,8	136,2	112,8	92,7	82,5	77,6	74	59500
9	137,9	132,2	112	88,3	80,2	75,5	73,6	59060

Additionally, illuminance measurement results of the living area can be seen in Table 111 and the kitchen is in Table 112. Both tables are including simultaneously measured outside illuminance values in their last column.

Table 111: Home office 8- Field measurement results of living area (daytime)

TF-La	A	B	C	D	E	F	G	H	E_{out}
1	2619	2316	1847	1572	1430	1252	1034	921	66560
2	2648	2325	1910	1579	1436	1262	1047	949	65560
3	2749	2406	1930	1638	1459	1196	1058	1014	65140
4	2842	2425	1948	1681	1492	1220	1092	1026	65090
5	2710	2285	1800	1537	1366	1142	991	868	64720
6	2667	2185	1705	1447	1292	1100	956	838	64280
7	2565	2001	1635	1335	1193	1012	893	795	64100
8	2230	1726	1462	1194	1083	928	833	748	63420

Table 112: Home office 8- Field measurement results of kitchen (daytime)

TF-K	A	B	C	D	E	F	E_{out}
1	382	307	290,7	249,3	236,1	230,2	62910
2	384	310	298,6	253,5	240,5	231,7	62240
3	398	322	301	261	246,3	233,7	61370
4	404	331	314	271,3	255,1	236,1	61410

Based on the measurements, the average outside illuminance value was found 62530 lx. In addition, reflectance values the major surfaces in the home office were calculated by applying Equation 3 and the results are presented below in Table 113.

Table 113: Home office 8- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	66
Walls (white)	80
Walls (red)	30
Ceiling	73
Working table 1	58
Working table 2	17
Working table 3	58
Wardrobes	17
Kitchen counter	40

Thereafter, the home office was modelled with DIALux. Same measurement date and time, sky type and the above-mentioned reflectance values were defined in the software and the simulation was performed. The illuminance results obtained through the simulation are presented from Table 114 to Table 116 below.

Table 114: Home office 8- Simulation results of the working area 1 (daytime)

TF-Ta1& TF-Isa1	A	B	C	D	E	F	G	H	I	J	K	L
1			677	724	665	653	575	505	442	439	380	377
2	1314	1089	891	751	670	665	598	514	461	454	394	406
3	1369	1073	963	826	687	687	605	513	456	456	378	402
4	1410	1120	986	878	722	673	610	577	479	418	395	342
5	1468	1143	1022	896	736	688	616	570	476	422	399	343

Table 115: Home office 8- Simulation results of the working area 2 (left) and working area 3 (right)(daytime)

TF-Ta2& Isa2	A	B	C	D	E	F	G	H
1	271	287	328	335	351	357	353	340
2	249	260	291	299	313	314	315	307
3	214	230	241	253	255	262	264	258
4	197	214	218	231	231	237	237	240
5	176	184	193	199	201	206	212	208
6	158	175	176	183	191	192	194	189
7	142	146	150	156	166	165	168	168
8	134	133	141	145	157	154	157	156

TF-Ta3& Isa3	A	B	C	D	E	F	G
1	113	114	115	102	99	109	109
2	111	111	112	102	98	107	107
3	103	103	97	95	93	90	98
4	100	102	96	92	89	87	85
5	89	89	95	93	88	87	86
6	89	89	88	84	79	77	74
7	89	87	84	81	76	75	70
8	90	89	83	71	69	69	67
9	88	85	83	71	69	69	67

Table 116: Home office 8- Simulation results of the living area (left) and kitchen (right)(daytime)

TF-La	A	B	C	D	E	F	G	H
1	2092	1614	1273	1020	938	763	644	544
2	2120	1617	1285	1032	928	774	640	545
3	2093	1607	1265	999	912	742	624	520
4	2083	1552	1215	978	880	727	608	517
5	2046	1531	1185	934	848	691	576	488
6	2012	1468	1120	876	792	662	554	465
7	1874	1349	1005	800	728	600	509	433
8	1655	1144	888	703	653	539	470	397

TF-K	A	B	C	D	E	F
1	275	226	214	185	174	158
2	272	220	205	178	168	157
3	261	210	198	170	161	159
4	262	212	203	173	164	161

Due to the fact that it is not possible to manually introduce an outside illuminance value to DIALux, for being able to find the outside illuminance value that was used by the software during simulations, an exterior scenario of the room was modelled identically and then the simulation was performed. As a result, the average outside illuminance was found 36790 lx and this result later used for analyzing the daylight factor (DF).

3.9.2 Evening measurement results

The evening field measurements were performed in 20.04.2017 from 20:30 to 22:00 with no daylight and 40 minutes after all lights were turned on. The evening in-situ measurement results can be seen hereinafter from Table 117 to Table 119.

Table 117: Home office 8- Field measurement results of the working area 1 (evening)

TF-Ta1& TF-Isa1	A	B	C	D	E	F	G	H	I	J	K	L
1			152	179	202	216	250	253	261	266	236	220
2	126	148	160	183	220	222	257	261	269	272	269	227
3	139	159	176	197	229	240	259	267	272	297	276	234
4	150	171	183	208	240	251	261	271	276	300	282	263
5	169	190	204	227	259	267	269	274	270	294	275	269

Table 118: Home office 8- Field measurement results of the working area 2 (left) and working area 3 (right)(evening)

TF-Ta2& Isa2	A	B	C	D	E	F	G	H
1	119	145	172	229	232	281	311	315
2	118	140	167	201	231	270	294	303
3	116	139	156	191	227	256	276	292
4	112	136	155	181	218	249	274	294
5	105	130	150	176	207	234	272	292
6	103	125	148	173	201	241	282	307
7	101	122	148	170	197	246	294	321
8	96	121	146	169	195	248	301	333

TF-Ta3& Isa3	A	B	C	D	E	F	G
1	281	272	263	242	222	206	185
2	257	249	240	221	202	180	158
3	219	216	222	208	190	174	152
4	193	188	186	172	150	133	122
5	148	134	158	145	130	126	102
6	128	127	121	108	95	90	85
7	109	103	100	97	90	85	75
8	88	85	80	74	71	65	64
9	77	71	70	61	60	55	50

Table 119: Home office 8- Field measurement results of the living area (left) and kitchen (right)(evening)

TF-La	A	B	C	D	E	F	G	H
1	155	199	218	285	304	325	354	367
2	181	212	295	329	362	374	396	382
3	203	256	326	375	395	426	445	430
4	215	281	335	382	409	475	469	458
5	212	274	330	378	402	462	483	451
6	201	251	316	371	391	419	428	412
7	192	217	272	320	341	368	373	365
8	170	196	220	252	275	297	302	296

TF-K	A	B	C	D	E	F
1	246	123	99	82	76	67
2	270	212	158	135	110	78
3	285	228	187	141	121	89
4	296	239	189	148	127	106

Afterwards, existing luminaires were found in the luminaire search engine and were imported to DIALux. The exact measurement day, time and conditions were defined in the software

and the simulation was performed. The simulation results of the all areas can be seen in the below from Table 120 to Table 122.

Table 120: Home office 8- Simulation results of the working area 1 (evening)

TF-Ta1& TF-Isa1	A	B	C	D	E	F	G	H	I	J	K	L
1			160	175	202	223	251	280	303	315	310	277
2	127	149	164	181	213	234	263	294	319	332	325	299
3	140	160	176	197	230	250	279	311	335	346	340	323
4	151	172	183	209	236	257	288	312	337	349	353	332
5	171	193	205	229	252	270	295	312	330	341	344	322

Table 121: Home office 8-Simulation results of the working area 2 (left) and working area 3 (right)(evening)

TF-Ta2& Isa2	A	B	C	D	E	F	G	H
1	122	157	203	246	272	308	333	337
2	117	149	191	231	256	292	317	325
3	113	146	171	215	243	283	307	315
4	112	142	166	209	238	279	304	316
5	111	139	164	206	235	278	303	315
6	106	136	160	203	234	280	309	327
7	106	131	165	204	229	275	317	342
8	101	126	159	199	225	275	325	359

TF-Ta3& Isa3	A	B	C	D	E	F	G
1	304	294	281	253	235	217	200
2	273	265	254	229	214	199	186
3	236	229	238	219	197	186	169
4	200	195	196	182	164	156	141
5	164	160	177	165	150	143	127
6	150	146	139	131	119	114	102
7	124	121	111	106	96	93	85
8	105	102	98	89	86	79	77
9	90	88	84	75	73	68	66

Table 122: Home office 8- Simulation results of the living area (left) and kitchen (right)(evening)

TF-La	A	B	C	D	E	F	G	H
1	168	213	259	297	323	353	376	384
2	194	249	308	358	388	424	445	438
3	215	279	348	410	444	488	506	488
4	225	294	369	438	474	524	542	517
5	222	292	366	434	469	518	534	508
6	209	273	340	401	432	475	489	467
7	184	237	292	340	363	395	407	391
8	158	200	239	273	289	311	320	311

TF-K	A	B	C	D	E	F
1	269	135	116	99	88	67
2	293	223	184	149	125	90
3	308	241	201	163	139	107
4	313	248	209	172	148	121

3.9.3 Analysis of results

The overview of the results that were found through field measurements and simulations can be seen in Table 123 together with the relevant standard recommendations. Further information on the lighting standard and requirements can be seen in Chapter 2.3.

Table 123: Home office 8- Overview of base case results and standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area 1	E_{avg}	868	574	234	264	750
	U_o	0,61	0,66	0,65	0,60	0,70
Immediate Sur. Area 1	E_{avg}	1247	794	228	251	500
	U_o	0,46	0,43	0,55	0,50	0,40
Task Area 2	E_{avg}	309	209	172	190	750
	U_o	0,81	0,75	0,80	0,56	0,70
Immediate Sur. Area 2	E_{avg}	350	230	226	247	500
	U_o	0,60	0,58	0,43	0,41	0,40
Task Area 3	E_{avg}	123	86	133	148	750
	U_o	0,62	0,81	0,57	0,57	0,70
Immediate Sur. Area 3	E_{avg}	140	93	150	166	500
	U_o	0,53	0,72	0,33	0,40	0,40
Living Area	E_{avg}	1560	1018	326	357	200
	U_o	0,48	0,39	0,48	0,44	0,10
Kitchen	E_{avg}	291	198	159	175	300
	U_o	0,80	0,80	0,42	0,38	0,10

Based on the data given in Table 123, it can be said that there is a big difference between daytime field measurement and simulation results. For example, while the E_{avg} result of task area 1 that was obtained from the field measurement follows the standards, the simulation result is much lower than recommended. For all other areas, there is also a large difference between field measurement and simulation, but in the end none of the results show compliance with standards. In addition, while in general it is recommended to have less E_{avg} in immediate surrounding areas than task areas, in all cases immediate surrounding E_{avg} was found more. For daytime U_o results, it can be stated that except the result of the task area 3, all are within recommended limits. In the evenings, except for the living area, neither E_{avg} nor U_o is not fulfilling the standard recommendations on any area. Therefore, in order to follow the standards, it is inevitable that the lighting conditions of the room should be improved.

Due to having a big difference in daytime results, the daylight factor was analyzed and presented in Figure 59 below.

Figure 59: Home office 8- Daylight factor analysis results

As can be seen from Figure 59, the average daylight factors that were derived based on field measurement results and simulation results are similar, which indicates that the incoherence between E_{avg} values are because of having very different outside illuminance in reality (62530 lx) and in simulation (36790 lx). Additionally, since the gray zone in the Figure 59 represents the ideal daylight factor range (see Chapter 2.3), it can be observed that all areas except the living area have insufficient daylight amount and improvement is necessary.

The other indicators evaluated just for the working area, in the evening with only artificial lighting can be observed below in Table 124.

Table 124: Home office 8- UGR, $\bar{E}_z$ and modelling results (base case)

Working Area / Indicator	UGR_{max}	$\bar{E}_z$ (lx)	Modelling
Working area 1	<10	151	0,39
Working area 2	29	103	0,65
Working area 3	30	54	0,69

The results of the UGR, $\bar{E}_z$ and modelling analysis given in Table 124 shows working area 1 showed successful results in the mentioned indicators. On the other hand, both working area 2 and working area 3 results were unsatisfactory according to the standard criteria and they need to be improved.

3.9.4 Improvement proposal

By taking all analysis into consideration, an improvement scenario was created for the artificial lighting. New luminaires which meet the needs of the environment better were

chosen and they were located with the field arrangement option of DIALux. The new luminaire plan can be observed in Figure 60.

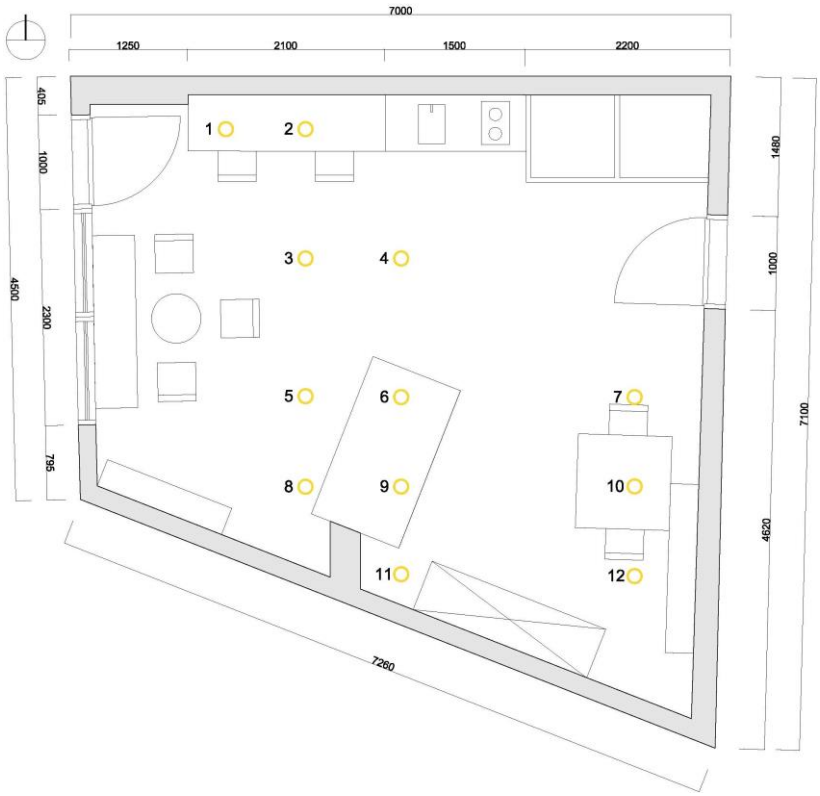

Figure 60: Home office 8- Improvement proposal

The technical information of new luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 60:

From 1 to 12) Ceiling recessed LED spotlights – MODULAR SMART160 LED 2020lm 16W

The improvement proposal simulation results of the working area 1 can be observed below in Table 105. Also, results of the working area 2 and working area 3 are given together in Table 126. Afterwards, the result overview and findings that were obtained from both tables can be seen in Table 127.

Table 125: Home office 8- Results of the working area 1 (improvement proposal)

TF-Ta1& TF-Isa1	A	B	C	D	E	F	G	H	I	J	K	L
1			711	793	862	885	898	889	845	810	721	623
2	477	617	698	801	878	899	914	905	865	832	741	657
3	495	622	699	801	881	903	928	921	884	859	770	717
4	492	613	671	772	848	880	913	918	897	845	812	739
5	450	561	611	703	778	814	857	872	871	843	825	769

Table 126: Home office 8- Results of the working area 2 (left) and working area 3 (right) (improvement proposal)

TF-Ta2& Isa2	A	B	C	D	E	F	G	H
1	423	746	797	806	812	803	807	825
2	637	798	839	842	841	824	814	815
3	722	832	853	860	844	817	797	783
4	744	824	842	847	827	792	766	730
5	746	805	821	819	796	759	709	617
6	719	767	776	770	708	615	581	529
7	685	707	659	607	582	556	534	508
8	576	566	555	555	555	547	530	506

TF-Ta3& Isa3	A	B	C	D	E	F	G
1	600	636	675	711	720	708	679
2	621	662	704	744	754	742	715
3	631	674	755	801	827	814	780
4	631	675	758	804	827	815	775
5	613	655	749	795	818	807	760
6	603	644	710	752	771	761	717
7	577	614	670	709	722	714	676
8	542	574	603	628	637	620	597
9	502	529	552	571	579	562	542

Table 127: Home office 8- Overview of the improvement proposal results for all working areas

Area / Indicator	Task area		Immediate sur. area		Working Area (Task + Immediate Sur. area)		
	E_{avg} (lx)	U_o	E_{avg} (lx)	U_o	UGR_{max}	$\bar{E}_z$ (lx)	Modelling
Working area 1	820	0,76	734	0,61	<10	370	0,33
Working area 2	788	0,78	679	0,62	21	257	0,42
Working area 3	764	0,88	632	0,80	22	263	0,32

According to the above-mentioned illuminance results, all working areas ensure their users a visually comfortable environment and compliance with standards thanks to the improvement proposal (Table 123). Also, it can be stated that the new UGR_{max}, $\bar{E}_z$ and Modelling values of all three working area now as recommended. Additionally, the results of the living area and kitchen are shown in Table 128.

Table 128: Home office 8- Results of the living area (left) and kitchen (right)(improvement proposal)

TF-La	A	B	C	D	E	F	G	H
1	209	255	328	398	470	577	719	823
2	191	230	292	350	416	519	660	768
3	174	208	260	312	370	471	603	707
4	163	193	242	289	347	448	575	675
5	152	180	228	273	330	431	558	659
6	147	174	221	270	328	435	570	679
7	137	163	214	263	325	437	587	708
8	137	165	213	267	334	452	613	742

TF-K	A	B	C	D	E	F
1	538	308	247	181	164	124
2	576	354	268	211	189	137
3	603	397	300	240	220	170
4	636	438	337	270	245	195

Since the U_o and the E_{avg} of the living area were found respectively 0,35 and 385lx and the kitchen were found respectively 0,41 and 306 lx, these areas are as well adequate to the minimum standard recommendations.

3.10 Home Office 9: Translator

Detailed information, photographs and 3D view were shown in the sub-section 2.2.9. The existing luminaires of the room can be seen in Figure 61. The dimensions are in millimetres.

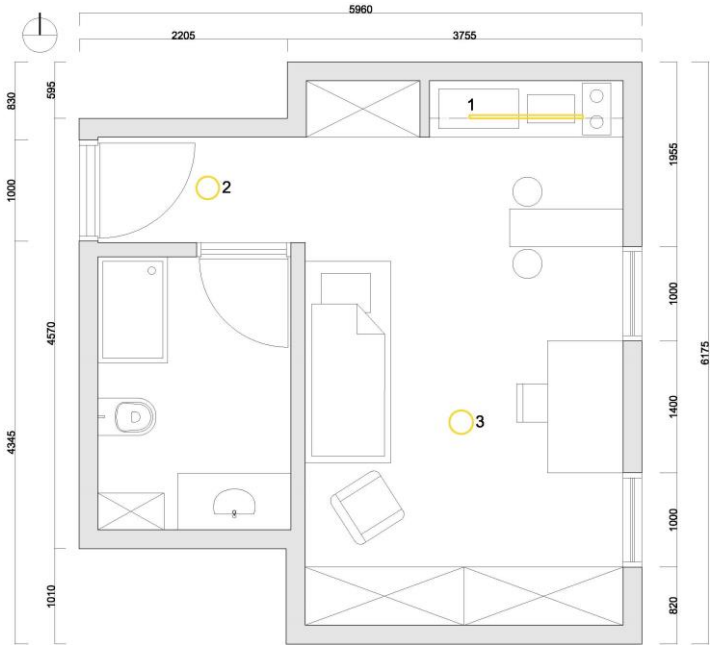

Figure 61: Home office 9- Floor plan with luminaires

The existing luminaires and lamps in the room, which indicated with the same reference numbers in the Figure 61, are as follows:

1) Cooker hood lamp / fluorescent lamp- OSRAM Basic 2850lm 36W/640 103V 4000K

2) Ceiling recessed light- Radium Ralux Duo 1200lm 18W/830 230V 3000K

3) Ceiling recessed light- VERBATIM LED 1800lm 18W 3000K

The grids that were used for illuminance measurement are can be found below in Figure 62.

Figure 62: Home office 9- Floor plan with measuring grid

The measuring grids shown in Figure 62 were applied by taking the instructions of lighting standard TS EN 12464-1 into consideration (see sub-sections 1.3.9 and 1.3.10). The task area measuring grid is shown in orange, immediate surrounding is in red, living area is in green, dining area is in purple and the kitchen in blue.

The detailed information about the measuring grids that were used in this home office are presented below in Table 129 and after the labelling of grid cells are shown in Figure 63. The grid codes that are given in the second column of Table 129 and the labelling of the grid cells that were given in Figure 63 will be identical in all sub-chapters of the Chapter 3.10.

Table 129: Home office 9- Measuring grid information

Grid name	Grid code	Grid cell size (mm)	Grid cell amount
Task area	Tr-Ta	200 x 200	28
Immediate Surrounding Area	Tr-Isa		63
Living Area	Tr-La	250 x 220	60
Dining Area	Tr-Da	200 x 200	36
Kitchen	Tr-K	200 x 205	40

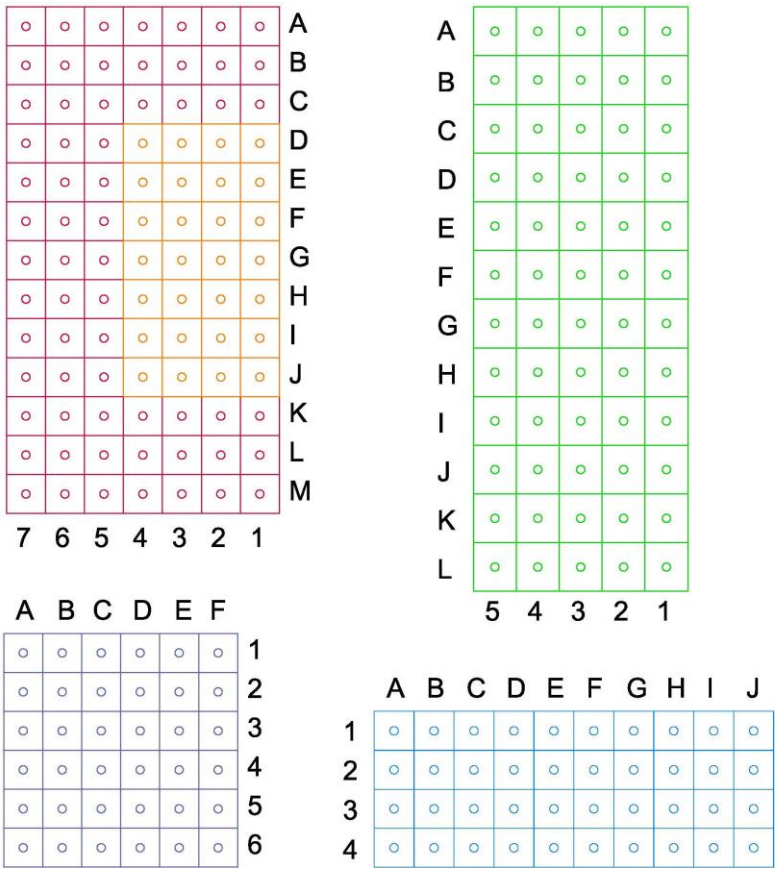

Figure 63: Home office 9- The measuring grid numbering of the task and immediate surrounding area(top left), living area (top right), dining area (bottom left) and kitchen (bottom right)

3.10.1 Daytime measurement results

The daytime field measurement was performed in the morning of 08.04.2017 from 10:30 to 11:30, under clear sky without any direct sunlight and when all artificial lighting was turned off. The illuminance results of all areas that were obtained by daytime field measurement can be seen below from Table 130 to Table 133 below with simultaneously measured outside illuminance values in their last column.

Table 130: Home office 9- Field measurement results of the task and the immediate surrounding area (daytime)

Tr-Ta &Isa	A	B	C	D	E	F	G	H	I	J	K	L	M	E_{out}
1	6036	6076	4051	972	959	554	492	717	2299	2496	6030	7564	7519	62500
2	5894	5114	2497	1401	1375	942	903	1281	3090	3201	5373	6153	5885	62390
3	4467	3873	2213	1533	1512	1282	1182	1938	3102	3214	4625	4872	4392	62100
4	3472	2920	1911	1565	1544	1359	1314	2067	3193	3352	3699	3786	3312	61520
5	2155	1987	1643	1549	1523	1368	1834	1968	2192	2387	2525	2413	2251	61340
6	1684	1635	1484	1440	1393	1338	1634	1737	1879	2031	2070	1946	1815	60930
7	1448	1428	1403	1357	1335	1297	1333	1521	1541	1724	1611	1536	1505	60540

Table 131: Home office 9- Field measurement results of the living area (daytime)

Tr-La	A	B	C	D	E	F	G	H	I	J	K	L	E_{out}
1	526	532	540	545	550	553	542	534	529	511	487	480	62260
2	514	523	534	538	542	552	545	527	517	492	479	466	62070
3	497	514	530	535	541	544	538	517	514	484	478	448	61810
4	495	509	522	526	533	536	531	513	507	478	460	450	60450
5	486	501	510	518	521	532	526	516	501	489	449	436	60420

Table 132: Home office 9- Field measurement results of the dining area (daytime)

Tr-Da	A	B	C	D	E	F	E_{out}
1	899	966	1004	841	685	293	61740
2	1154	1486	1738	1782	1629	474	61890
3	1336	1788	2158	2416	2457	781	63120
4	1408	2056	2564	3238	3521	3452	62560
5	1478	2212	2805	3533	4380	5064	63000
6	1505	2282	2864	3747	5873	5528	63160

Table 133: Home office 9- Field measurement results of the kitchen (daytime)

Tr-K	A	B	C	D	E	F	G	H	I	J	E_{out}
1	517	528	531	534	537	479	422	395	322	290,6	62920
2	523	544	551	545	549	499	435	403	334	292,3	62330
3	539	553	554	557	568	519	470	450	361	306	61660
4	559	564	574	576	585	583	533	495	376	311	61090

Based on the above-mentioned outside measurement illuminance values, the average outside illuminance was found 61900 lx. Additionally, reflectance values the major surfaces in the home office were calculated by applying Equation 3 and the results are presented below in Table 134.

Table 134: Home office 9- Reflectance values of major surfaces

Surface	Reflectance (%)
Floor	30
Walls	80
Ceiling	88
Working table	45
Dining table	63
Wardrobes	65
Kitchen counter	45

Afterwards, the room was modelled in 3D with DIALux. Same measurement date, time, sky type and the reflectance values were introduced to the software and the simulation was performed. From Table 135 to Table 138, the results of all areas that were obtained through this lighting performance simulation were provided.

Table 135: Home office 9- Simulation results of the task and the immediate surrounding area (daytime)

Tr-Ta& Tr-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	5114	4870	2136	642	647	307	315	444	1652	1644	4077	5201	5103
2	4074	3564	1629	927	927	603	603	927	2418	2418	3645	4175	3993
3	3043	2634	1499	1041	1041	864	864	1323	2372	2372	3069	3305	2979
4	2361	2006	1294	1062	1062	988	988	1414	2062	2062	2508	2499	2245
5	1439	1352	1089	1009	939	972	1221	1311	1464	1596	1622	1546	1436
6	1113	1084	956	911	943	928	1075	1145	1241	1276	1296	1217	1130
7	967	959	867	889	836	863	954	1015	1029	1085	1076	1013	949

Table 136: Home office 9- Simulation results of the living area (daytime)

Tr-La	A	B	C	D	E	F	G	H	I	J	K	L
1	374	394	380	387	409	386	394	380	375	357	334	327
2	360	370	364	381	374	368	371	363	353	338	325	313
3	343	355	343	365	353	357	362	353	340	314	307	295
4	341	351	366	375	365	377	356	349	342	314	306	283
5	372	392	414	403	393	406	381	373	376	355	326	297

Table 137: Home office 9- Simulation results of the dining area (daytime)

Tr-Da	A	B	C	D	E	F
1	609	681	655	569	462	193
2	784	1012	1185	1215	1110	317
3	909	1219	1473	1650	1678	528
4	958	1403	1752	2077	2409	1332
5	1006	1510	1917	2417	2998	3948
6	1025	1558	1958	2564	3337	5159

Table 138: Home office 9- Simulation results of the kitchen (daytime)

Tr-K	A	B	C	D	E	F	G	H	I	J
1	414	394	387	386	366	339	293	256	174	152
2	436	395	406	407	397	359	306	258	196	150
3	442	408	409	418	399	379	340	311	223	154
4	378	419	429	437	446	442	403	355	237	173

Due to the fact that it is not possible to manually introduce an outside illuminance value to DIALux, for being able to find the outside illuminance value that was used by the software during simulations, an exterior scenario of the room was modelled identically and then the simulation was performed. As a result, the average outside illuminance was found 36970 lx and this result later used for analyzing the daylight factor (DF).

3.10.2 Evening measurement results

The evening field measurements were performed in 08.04.2017 from 20:45 to 21:45 with no daylight and 30 minutes after all lights were turned on. The illuminance results that were obtained by evening field measurement can be observed from Table 139 to Table 141 below.

Table 139: Home office 9- Field measurement results of the task and the immediate surrounding area (evening)

Tr-Ta& Tr-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	52,3	59,6	63	75,3	84,9	90,3	94,8	79,5	73,6	72,5	70,3	61,4	50,7
2	55,2	64,1	68	79,6	88,6	92,6	98,3	87,3	81,2	79,3	74,3	67,3	55,1
3	60,7	70,8	74,2	88,1	92,4	96,4	100,5	92	89,5	86,2	82	77,1	62,5
4	64,8	76,5	81,5	90,3	100,6	115,6	119,4	110,4	106,4	98,7	94,6	84,2	77,6
5	75,6	90,3	98,6	100,6	113,6	125,7	140,5	131,6	121,4	114,6	103	91,5	83,1
6	84,3	100,2	115,4	118,6	123	132,5	147,1	139,5	130,4	124,6	113	108,5	99,6
7	93,3	105,6	120,3	129,8	134,9	145,6	160,4	152,7	141,7	135,9	121,4	114	105,3

Table 140: Home office 9- Field measurement results of the living area (evening)

Tr-La	A	B	C	D	E	F	G	H	I	J	K	L
1	96,1	109,6	124,7	140,2	165,4	174,3	185,9	168,4	146,7	128	115,5	105,8
2	83,8	96,5	100,2	111,4	129,8	144,9	152,3	145,7	121,6	103,6	102,7	98,9
3	70,4	82,4	90,2	93,6	105	111,7	129,4	113,6	96,4	88,2	79,4	70,6
4	61,2	64,1	71,1	76,8	84,7	87,9	96,1	89,4	75,4	73,5	69,7	54,8
5	56,3	62,3	65,9	71,3	75,5	80,2	90,5	81,4	65,3	63,9	59,4	50,3

Table 141: Home office 9- Field measurement results of the dining area (left) and the kitchen (right) (evening)

Tr-Da	A	B	C	D	E	F
1	201	201	192	170	147	134
2	132	131	125	116	106	106
3	114	111	107	102	95	89
4	94	89	86	80	79	75
5	89	85	82	76	71	67
6	85	81	77	69	64	59

Tr-K	A	B	C	D	E	F	G	H	I	J
1	355	418	539	620	677	695	630	533	428	320
2	299	402	625	695	706	751	684	650	435	305
3	271	366	451	545	593	660	557	484	394	285
4	199	304	352	426	449	502	494	431	345	246

Afterwards, the existing luminaires were found in the luminaire search engine and were imported to DIALux. The exact measurement day, time and conditions were defined in the software and the lighting performance simulation was performed. The results of this simulation are presented hereinafter from Table 142 to Table 144.

Table 142: Home office 9- Simulation results of the task and the immediate surrounding area (evening)

Tr-Ta& Tr-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	58	60	69	80	88	97	99	97	92	84	72	61	58
2	63	67	78	85	92	102	104	102	96	92	82	69	64
3	72	77	87	93	99	110	112	110	104	101	92	80	76
4	76	83	93	101	108	119	121	121	115	111	100	88	83
5	85	92	106	116	129	138	140	140	137	129	118	105	98
6	97	104	117	125	139	148	152	152	148	140	129	114	105
7	107	114	126	135	149	158	163	164	160	150	138	121	111

Table 143: Home office 9- Simulation results of the task and the living area (evening)

Tr-La	A	B	C	D	E	F	G	H	I	J	K	L
1	95	104	120	149	177	193	200	193	169	136	117	95
2	88	95	108	130	150	161	166	161	143	118	104	87
3	76	87	96	112	126	134	136	133	120	102	92	78
4	69	77	84	94	103	108	109	106	98	86	79	68
5	65	71	76	86	92	95	94	93	87	76	71	60

Table 144: Home office 9- Simulation results of the dining area (left) and the kitchen (right) (evening)

Tr-Da	A	B	C	D	E	F
1	211	209	201	175	160	141
2	137	136	132	120	116	113
3	119	117	114	105	103	102
4	100	98	95	87	87	85
5	96	93	91	83	81	69
6	96	92	87	78	74	60

Tr-K	A	B	C	D	E	F	G	H	I	J
1	326	447	634	748	807	808	748	635	444	317
2	307	423	615	723	783	786	731	626	438	308
3	288	394	561	657	712	715	665	572	412	298
4	216	311	426	492	531	535	501	439	334	256

3.10.3 Analysis of results

The overview of the results that were found by all field measurements and simulations can be seen below in Table 145 together with the relevant standard recommendations. More detailed information about the related lighting standard can be found in Chapter 2.3.

Table 145: Home office 9- Overview of base case results and standard recommendations

Base Case		Daytime		Evening		Min. Standard Rec.
		Field meas.	Simulation	Field meas.	Simulation	
Task Area	E_{avg}	1744	1214	92	101	500
	U_o	0,28	0,25	0,79	0,79	0,60
Immediate Sur. Area	E_{avg}	2836	1918	99	108	300
	U_o	0,46	0,44	0,51	0,54	0,40
Living Area	E_{avg}	512	358	98	110	200
	U_o	0,85	0,79	0,51	0,55	0,10
Dining Area	E_{avg}	2261	1544	105	113	300
	U_o	0,13	0,13	0,56	0,53	0,10
Kitchen	E_{avg}	482	342	478	524	300
	U_o	0,60	0,44	0,41	0,41	0,10

The data given in Table 145 shows that, in evening, except the kitchen, both field measurement and simulation E_{avg} results are considerably below what is required, so the artificial lighting performance of the room must be improved. On the other hand, all U_o values are following the standards. In the daytime, it can be observed that there is great difference between the field measurement and simulation results. Furthermore, in contrast to evening measurements, all areas except the kitchen have E_{avg} values that are far above what is required. As a result, the lighting performance of the room should definitely be improved.

While in the evening the deviation of simulation and the field measurement for the E_{avg} results was found 9,7%, for the daytime results this difference was found 30,7%. Due to the big deviation in all results, the daylight factors were analyzed and presented in Figure 64.

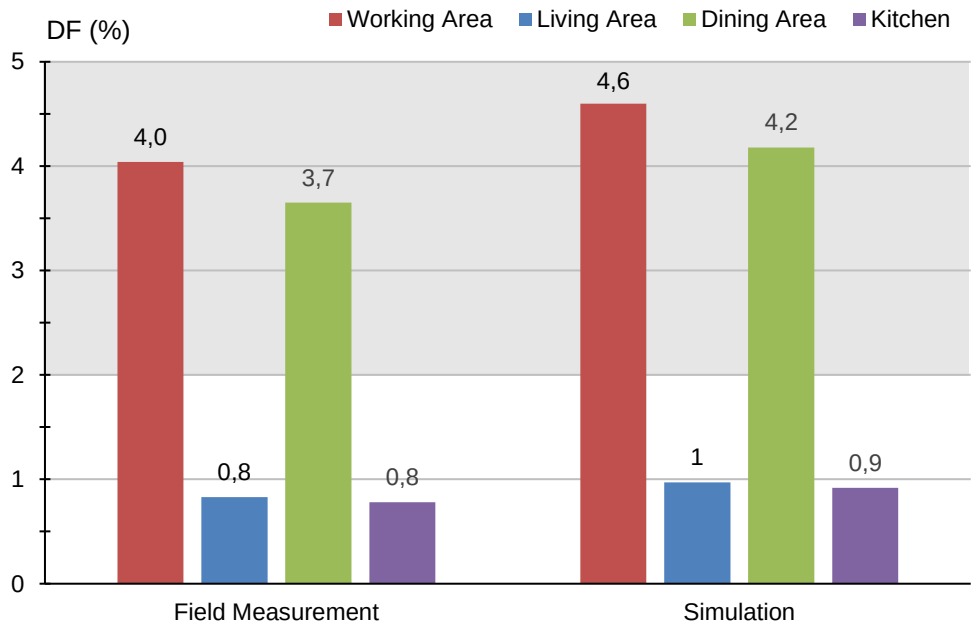

Figure 64: Home office 9- Daylight factor analysis results

Hence the daylight factor results are showing similarity, it can be said that the deviation of E_{avg} results during the day is caused by the difference between the measured outside illuminance (61900 lx) and the one DIALux uses (36970 lx). Besides, the gray area of the graph in Figure 64 represents the recommended daylight factor range. So, it can be stated that only working area and the dining area has adequate daylight amount.

Other indicators evaluated only for the working area, in the evening with only artificial lighting are as follows:

- UGR_{max} = <10
- $\bar{E}_z$ = 72 lx
- Modelling = 0,42

According to the standard criteria in the Chapter 2.3, the UGR_{max} is in accordance with the recommendations. However, even though the modelling value is numerically following the standards, since the $\bar{E}_z$ is below the required value, both $\bar{E}_z$ and modelling should not be considered adequate.

3.10.4 Improvement proposal

Considering all above-mentioned observations and findings, an improvement scenario was developed for artificial lighting performance. Firstly, more accurate luminaires were chosen, which can better and effectively meet the requirements of the environment. The locations of these luminaires were then determined by the field arrangement option of the DIALux. The new luminaire arrangement is shown below in Figure 65.

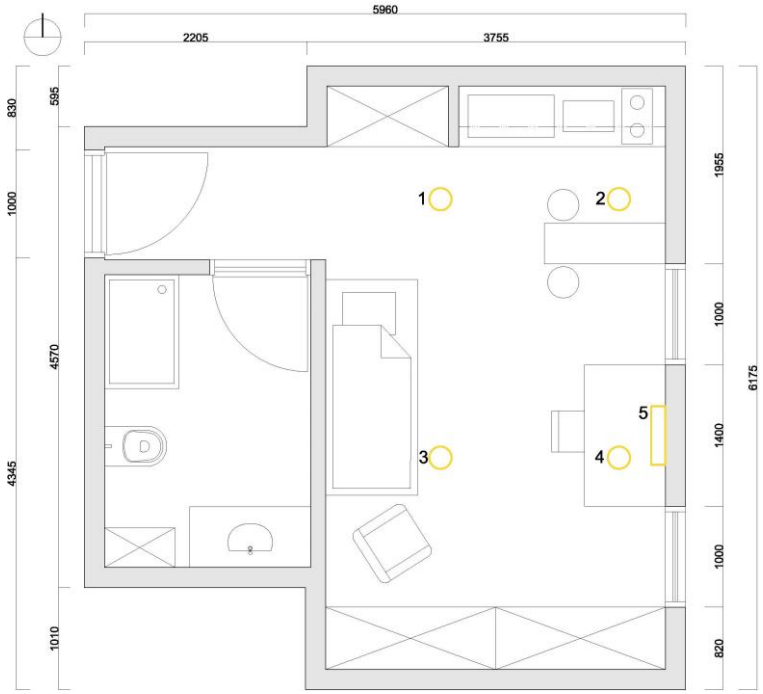

Figure 65: Home office 9- Improvement proposal

The technical information of new luminaires and lamps in the room are as follows, which are indicated with the same reference numbers in the Figure 65:

From 1 to 4) Ceiling recessed LED spotlights – REGIOLUX-2200 830 2164lm 24,7W

5) Wall surface mounted luminaire- 1,93 m mounting height- ARTEMIDE Parete 1210lm 16W

The illuminance results of the working area, which were obtained after the improvement proposal simulation can be observed below in Table 146.

Table 146: Home office 9- Results of the task and the immediate surrounding area (improvement proposal)

Tr-Ta& Tr-Isa	A	B	C	D	E	F	G	H	I	J	K	L	M
1	313	327	384	467	534	590	624	624	585	518	409	309	259
2	336	350	412	480	541	600	636	636	595	536	443	335	279
3	362	373	427	492	545	603	637	638	600	549	459	356	301
4	350	375	422	480	526	576	607	609	576	532	450	356	304
5	305	370	411	452	499	536	561	562	539	490	428	351	308
6	321	365	395	429	468	498	518	519	500	458	405	338	301
7	356	359	387	416	450	478	494	495	478	441	392	332	296

According to the results in Table 146, E_{avg} of the task area is 569 lx and the U_o is 0,82. In addition E_{avg} of the immediate surrounding area is 403 lx and U_o is 0,64. As a result, the working area now fulfills all the criteria of the lighting standard (Table 145).

Other improved indicators of the working area and their results are as follows:

- UGR_{max}= <10
- $\bar{E}_z$ = 253 lx
- Modelling = 0,37

The improvement proposal illuminance results of the living are presented in Table 147.

Table 147: Home office 9- Results of the living area (improvement proposal)

Tr-La	A	B	C	D	E	F	G	H	I	J	K	L
1	135	171	196	237	271	278	271	253	225	206	200	203
2	153	194	229	284	331	341	327	297	255	228	219	222
3	174	226	280	370	451	469	436	378	304	261	247	256
4	186	252	324	449	569	596	542	452	345	286	266	282
5	199	273	360	512	662	694	626	511	377	307	284	303

The results in Table 147 shows that the E_{avg} and the U_o of the living area are respectively 321 lx and 0,42. The living area is fully suitable for standard recommendations given in Table 145, after the improvement proposal has been applied.

Lastly, the illuminance simulation results of the dining area and the kitchen can be observed from Table 148.

Table 148: Home office 9- Results of the dining area (left) and the kitchen (right) (improvement proposal)

Tr-Da	A	B	C	D	E	F
1	519	605	669	698	694	618
2	511	590	650	677	674	608
3	481	546	595	616	612	563
4	431	475	508	517	513	468
5	390	419	439	437	431	372
6	348	362	371	361	352	301

Tr-K	A	B	C	D	E	F	G	H	I	J
1	161	282	278	277	279	283	287	286	269	251
2	264	330	318	315	321	331	343	345	334	309
3	403	378	360	357	367	385	407	412	398	362
4	455	432	411	405	423	453	487	497	483	433

Based on Table 148, E_{avg} of the dining area is 512 lx and the U_o is 0,58. In addition E_{avg} of the kitchen is 354 lx and U_o is 0,45. As a result, according to the information given in Table 145, both areas now follow all the recommendations of the lighting standard.

3.11 General analysis of results

Daytime results

According to the field measurement and simulation results of all home offices, in the daytime, indoor illumination was found generally unsatisfactory and none of the places could properly meet the expectations of the lighting standard TS EN 12464-1. For example, Figure 66 presents the average illuminance results of all task areas in each home office, together with the relevant minimum standard requirement.

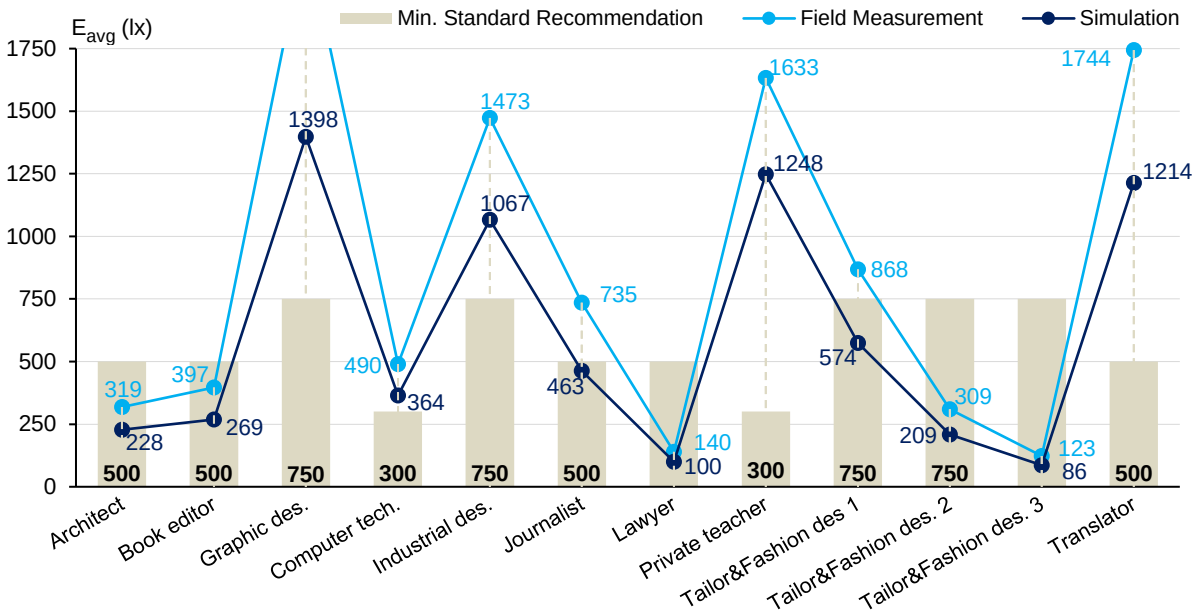

Figure 66: Overview of E_{avg} results obtained by field measurements and simulations, together with minimum standard requirements, for all task areas (daytime)

As can be seen from the Figure 66, natural lighting in the home offices were either too less or significantly greater than recommended. Therefore, it can be stated that to comply with the standards, an improvement is essential for all home offices. Although having much higher illuminance than the minimum requirement in an area does not seem to be a problem numerically, it can cause daylight glare, improper modelling index (unbalance between direct and diffused light), potential thermal problems, etc. In other words, excessive amount of daylight does not cause problems in daylight availability, but in the quality of daylighting.

Additionally, field measurement and simulation results of all task areas were compared with each other and the deviations were calculated. Eventually, the calculated deviations were varying between 23,6% and 37%, which were higher than expected. Also, the deviation between the outside illuminance values were calculated to determine whether there is a specific pattern. The results are presented in Figure 67 below.

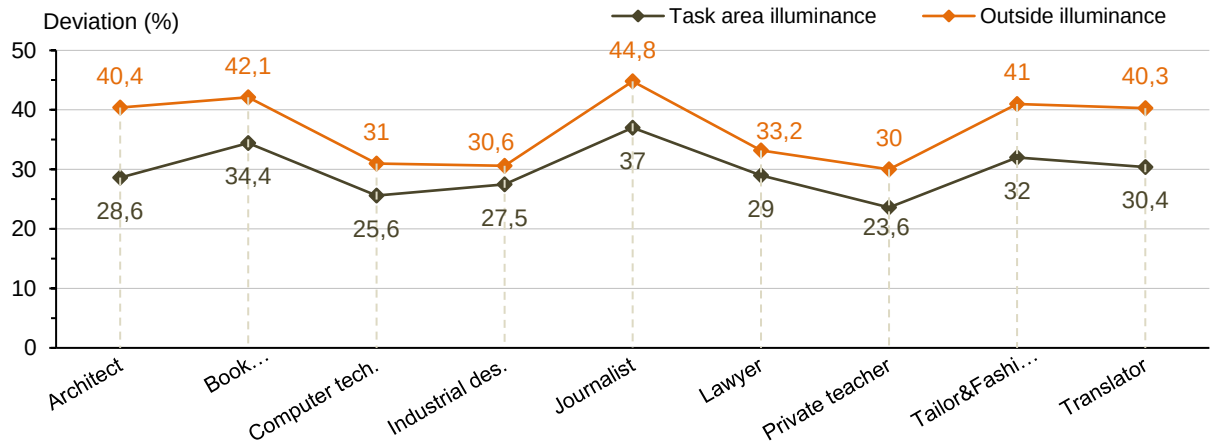

Figure 67: Percentage deviations between E_{avg} results obtained from field measurements and simulations in daytime: task areas (brown) and outside illuminance values (orange)

As can be seen in Figure 67, there is a clear similarity in the deviation pattern of task area illuminance results and outdoor illuminance results. In addition, Figure 68 shows a comparison of the outside illuminance values obtained by field measurements and used by DIALux during simulations. The home offices marked with blue were evaluated under clear sky and the others under overcast sky.

Home Office/ Outside Illuminance (lx)	Field Meas.	Simulation
Architect	60010	35740
Book editor & Graphic designer	62480	36180
Computer tech.	14370	9910
Industrial des.	13740	9540
Journalist	63590	35110
Lawyer	14950	9980
Private teacher	13970	9780
Tailor & Fashion designer	62530	36790
Translator	61900	36970

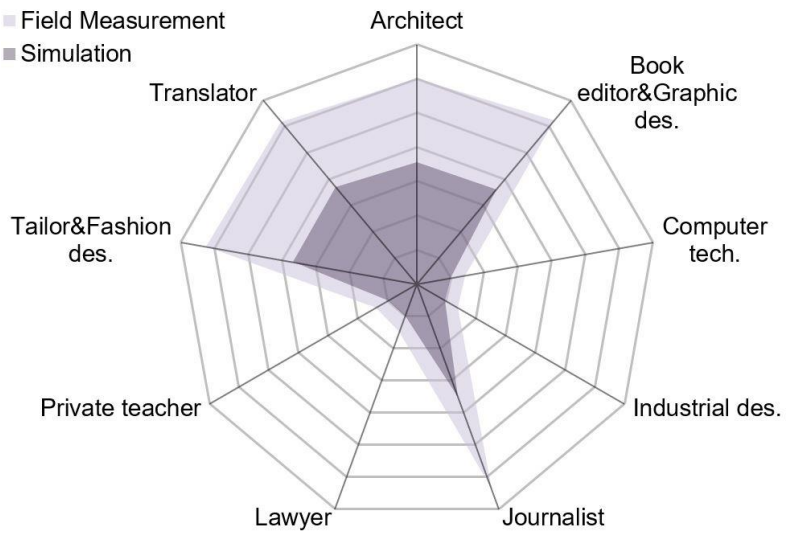

Figure 68: Comparison of the outside illuminance values obtained by field measurements and used by DIALux during simulation.

As a result, considering the table in Figure 68, it can be said that the main reason of the deviations (Figure 67) is: the lighting performance evaluations of home offices were carried out with significantly different outside illuminance values. Therefore, under these conditions, a similarity between the results could not be expected. On the other hand, the visible patterns that are shown by the graphs in Figure 67 and Figure 68 reveals that different calibration settings can minimize the resulting deviations.

Evening results

The field measurement and simulation results of average illuminances show that in the evening, the indoor illumination was insufficient in all home offices and none of them could satisfy the minimum recommendations of the lighting standard TS EN 12464-1. For example, Figure 69 shows the average illuminance results of all task areas in each home office, together with the relevant minimum standard requirement.

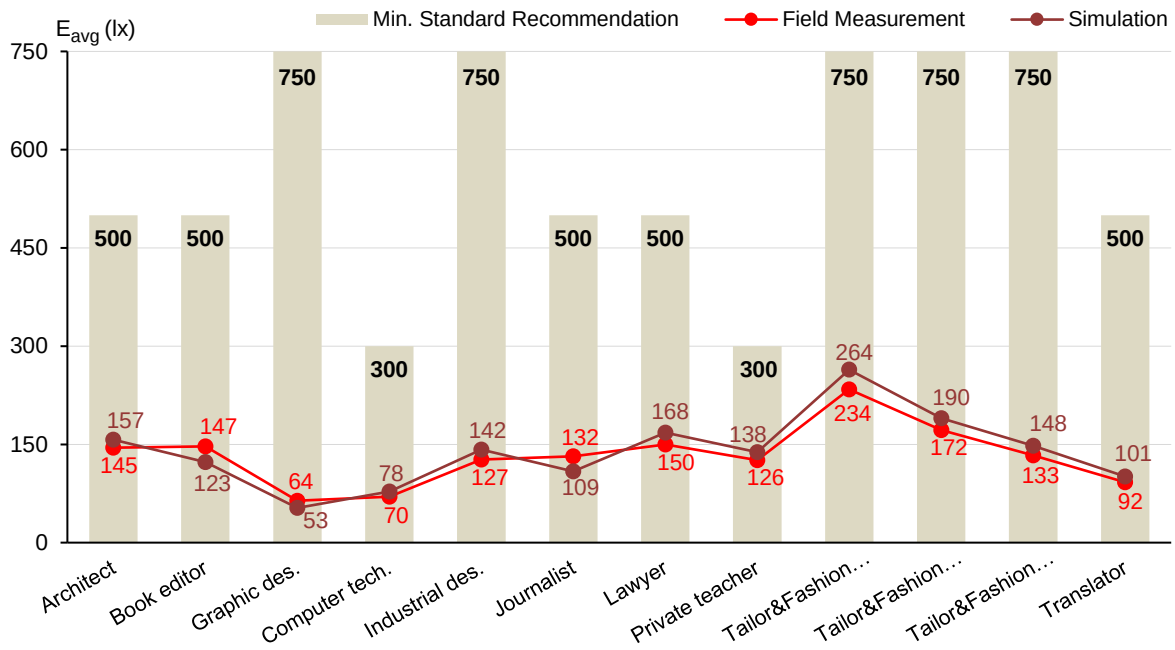

Figure 69: Overview of E_{avg} results obtained by field measurements and simulations, together with minimum standard requirements, for all task areas (evening)

As can be observed from Figure 69, in the evening, neither the on-site measurement results nor the simulation results of average illuminance could not satisfy even half of the minimum standard recommendations in any task area. Therefore, all areas should be subjected to improvement.

Also, in each home office the field measurement and simulation results of all areas were compared with each other and the deviations were calculated. As a result of this, the deviations were found between 8,4% and 16,5%, which are presented in Figure 70 below.

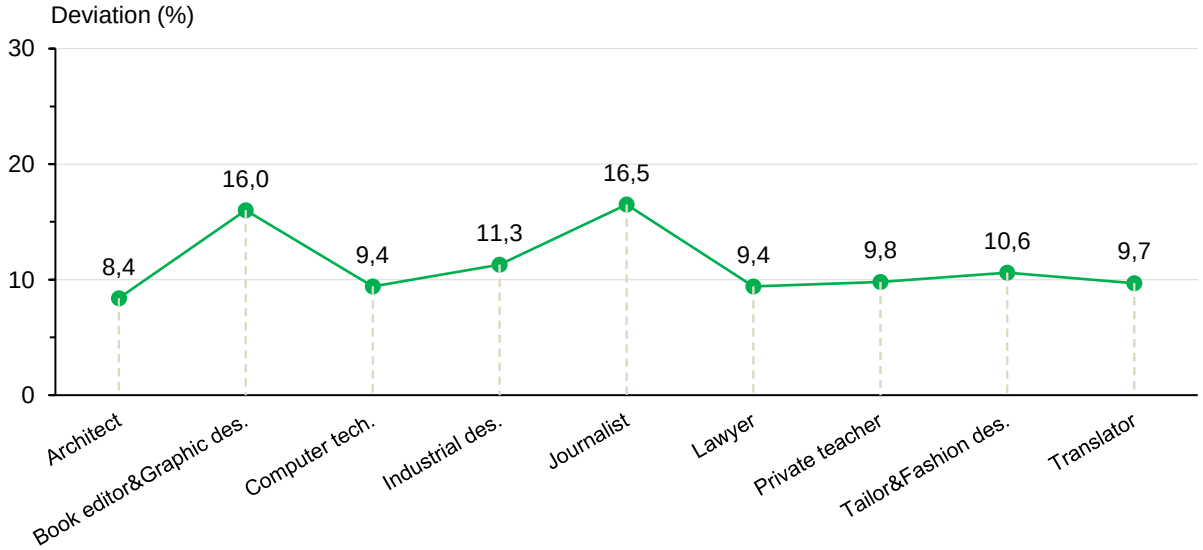

Figure 70: Percentage deviation between E_{avg} results obtained from field measurements and simulations in evening (E_{avg} of all areas)

Figure 70 shows that the deviations between the field measurement and simulation results are noticeably less in the evening compared to the daytime. Also, by taking all shortcomings and limitations into account, the result deviations of all home offices, except the home office 2 (Book editor& Graphic designer) and home office 5 (Journalist), can be considered as acceptable. As stated previously in the relevant chapters, some of the existing luminaires in the above-mentioned two home offices were not available in LUMsearch (LUMsearch 2019), so their simulations had to be performed with alternative equivalent luminaires. Therefore, this can be considered as one of the main causes for having less accuracy in simulation and higher deviation between the results of these two home offices was not unexpected.

Improvement proposal results

Considering all above-mentioned observations and findings, an improvement scenario was developed for the artificial lighting of each home office.

As noted earlier, these scenarios were created with the "field arrangement" feature of the DIALux and interferences to these software arrangements were kept to a minimum. In detail, except the home office 4 (Industrial designer), home office 5 (Journalist) and the home office 8 (Tailor & Fashion designer), no changes applied to the luminaire arrangement suggestion of DIALux. The changes that were applied to above-mentioned home offices and the reasons are as follows:

- **Home office 4 and 5**: The areas that will be provided an improvement proposal using the "field arrangement" option of DIALux must have a flat ceiling. The option does not work on any other ceiling types and both home offices have shed roof (see sub-sections 2.2.4 and 2.2.5). Therefore, the suggestion of the software was manually adapted to the slope of the ceiling.

- **Home office 8:** The "field arrangement" option suggests new luminaire locations only for a specified height and on a single plane. For this reason, it was observed that the software placed some of the luminaires into the beam passing through the middle of the home office. Therefore, the proposal was made suitable for the existing conditions.

After the application of improvement scenarios, both E_{avg} and U_o values of all task areas significantly improved and satisfied the minimum recommendations of the lighting standard TS EN 12464-1. The new E_{avg} and U_o results of all task areas, together with the relevant minimum standard requirement are shown in Figure 71 and Figure 72 below, respectively.

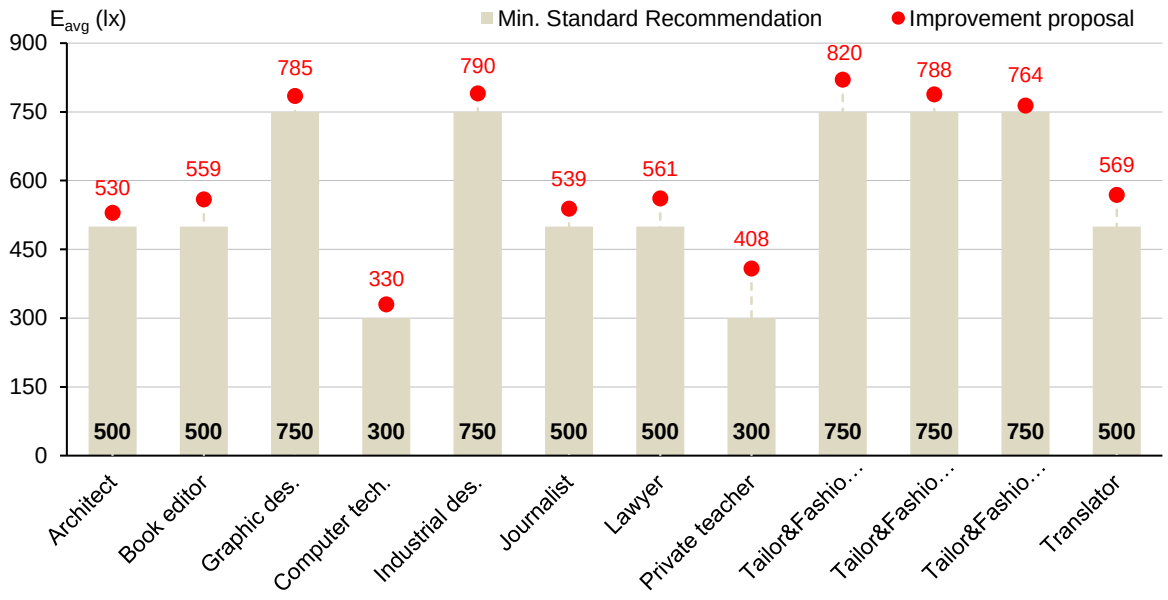

Figure 71: Overview of E_{avg} results obtained by improvement proposals with simulation, together with minimum standard requirements, for all task areas

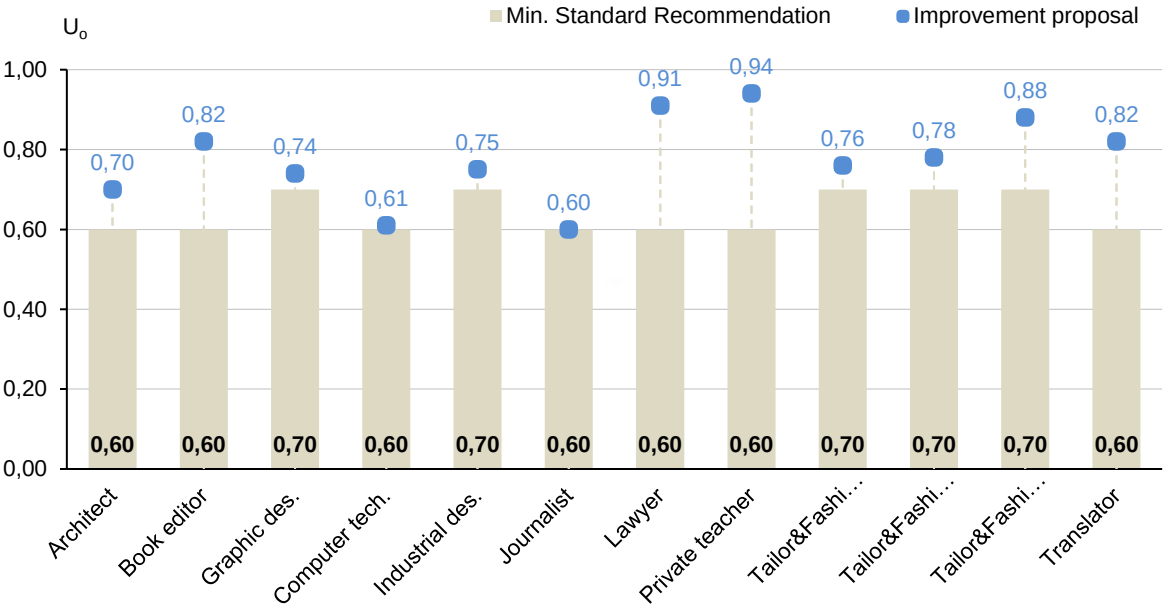

Figure 72: Overview of E_{avg} results and U_o results obtained by improvement proposals with simulation, together with minimum standard requirements, for all task areas

Consequently, it can be stated that the field arrangement option of DIALux serves the purpose with a few exceptions.

4 CONCLUSION

Briefly, this master thesis focuses on evaluating current lighting levels of the home office spaces, considering the information provided by on-site measurements and simulations. These processes were carried out once in the morning with only natural lighting, and once in the evening with only artificial lighting. The evaluations consist of not only the illuminance analysis, but also different indicators such as uniformity, daylight factor, unified glare rating. The effectiveness of the existing lighting conditions was decided based on the lighting standard TS EN 12464-1. In addition to comparing with the standard recommendations, the results were also compared with each other, with the aim of detecting similarities, differences and specific patterns between the results that may be the explanation of differences. Lastly, an improvement scenario was provided to each home office with the "field arrangement" feature of the DIALux, with minimum interference to the software decisions. The goal was to test the properness and advisability of the improvement suggestions of the software.

According to the results, none of the home offices are satisfying standard recommendations neither in daytime nor in the evening. In the daytime, some areas were measured less than minimum requirements, while some were considerably higher. However, in the evening, without exception, all home offices had less illumination than the recommended. Since very little is known about the lighting performance of home office spaces and the usability of the lighting standards in small-scale places, this result was expected.

Besides, when the results of on-site measurements and simulations were compared with each other, it is observed that in daytime, the deviation between results is considerably higher compared to the evening. For the daytime results, additionally, the deviation between the outside illuminance values was calculated and an obvious pattern was observed between outdoor and indoor illuminance deviation graphics. Therefore, it can be mentioned that the difference can be significantly reduced with more proper calibration settings. In the evening, in general the deviations were smaller. Only in two home offices higher deviation was observed than the others and this was mainly caused by the unavailability of the luminaire in the catalogues in LUMsearch.

Lastly, as observed during the implementation of improvement scenarios, field arrangement option of DIALux serves the purpose and the desired illuminances can be achieved just with small changes in the suggestion of the software. However, the area that is under improvement process should have a flat ceiling because the field arrangement option does not work on any other ceiling type, such as shed roof or gable roof.

The field measurement processes contain several shortcomings. For example, during measurements except for artificial lighting, all other electronic devices (television, computer,

etc.) were turned off. It can be said that, although all these conditions provided to get more accurate results within the scope of this master thesis, on the other hand, they are quite unrealistic especially in these days when the technology is rapidly developing and nearly every job is carried out on the computer.

Additionally, in order to avoid shadows on inspection equipment for having maximum possible accuracy, the only person in the room during measurements was the performer. However, calibration setting errors that may have occurred during measurements should always be considered. As a result of this possibility, to apply these obtained luminance and illuminance values to the reflection formula may cause to have incorrect surface reflectance values. Also, since these values will be introduced to DIALux for the lighting simulation of the area in question, this may cause to have misleading simulation results overall. Therefore, neither the on-site measurement, nor the simulation results should not be accepted as 100 percent precise and an error margin should always be taken into consideration.

As well as on-site measurements, the simulation process and the used lighting simulation software have their own limits. One important limitation is that the DIALux does not support complex shapes, although many CAD-based 2D and 3D drawings can be imported to the software. For example, the software allows having doors and windows that are only square or rectangular. Also, it enables user to have windows only on the walls, so, it is not possible to have a skylight in the 3D model. Thus, it can be expected to have less accuracy in the simulation results of areas with such building elements, especially when the effect of daylight is not excluded.

As another important limitation of DIALux, it can be said that the user cannot define the external conditions of an interior simulation area. As a result, external interventions that may play an important role in illuminance of an area, for instance a neighbor building and/or a tree in front of the window, cannot be modeled and this can lead to very different results than actual. Similarly, the user is not able to manually enter an outside illuminance value. The software offers only three different types of sky, including overcast sky, clear sky and mixed sky. As stated in the previous chapters, besides the interior simulations, the exterior conditions of each home office were separately modeled and simulated to determine the outside illuminance values that were used by the software during simulations. When results of these simulations and the in-situ measured outside illuminances were compared, it was found that they are considerably different than each other.

Also, it was observed that the deviation was more for the home offices that were evaluated under clear sky. Therefore, it is strongly recommended to perform lighting performance measurements under an overcast sky. However, this may not always be possible and make the measuring process even more challenging in places such Izmir/Turkey, where

dominantly has clear sky. Furthermore, it can be mentioned that although the DIALux enables user to define many other detailed information regarding to the simulation area (latitude and longitude, time zone, city, day, time, alignment, obstruction, etc.), their effect on results were quite insufficient.

In addition, DIALux takes a snapshot from time and simulates only for this moment, while field measurements last minimum 30 minutes for each home office and the sky was not stable during this time period. Briefly stated, due to the fact that DIALux accepts sky as uniform and since this is not reflecting the reality, differences can be observed between field measurement results and simulation results of the same home office.

DIALux provides great advantage and convenience in artificial lighting performance simulations due to having luminaire catalogues with their detailed technical data and from various manufacturers. On the other hand, the simulation of an area where artificial lighting is included may have some problems if the existing luminaires are not available in catalogues. In such a case, since it is not possible to manually create a luminaire in the simulation software, it is recommended to find an equivalent of the existing from the catalogue and perform the simulation.

The cooperation between the architect, civil engineer and lighting designer starting from the early design stages is recommended for being able to choose luminaires that are meeting the needs of the environment effectively and for providing a better visual comfort.

In spite of having numerous lighting measurement and simulation methods, a universal solution is not developed yet. Hence, future research efforts may include the evaluation of other home office spaces from different regions and different job disciplines. Furthermore, all improvement scenarios in this master thesis were developed with the aim of having more effective lighting and visual comfort, considering the lighting standard recommendations. As a step forward, it is also possible to search for scenarios that will be more economical besides all aforesaid aims. Another further research may be about how satisfactory the standard recommendations are in terms of fulfilling the needs and wishes of home office users. In principle, the standards are aiming to provide an average satisfaction among people, therefore, in public places such as professional offices, schools, etc., it is necessary to comply with average expectancies. However, satisfactoriness of these standards may be discussed for home office areas, which have more private function than public.

As a very advanced level of progress, development of a smart phone app may be considered, which can offer advices for interior planning and can guide the user of small-scale areas considering the existing luminaires and availability of daylight. Such an app may help the user to utilize both natural and artificial lighting efficiently, without any need of a professional consultancy.

5 INDEX

5.1 List of Figures

5.2 List of Tables

5.3 List of Equations

6 REFERENCES

CEN, 2019. *European Committee for Standardization. CEN Members.* http://standards.cen.eu/dyn/www/f?p=CENWEB:5. Accessed 11.02.2019.

Crosbie, T. and Moore, J., 2004. *Work-Life Balance and Working from Home*. Social Policy and Society 3(3). pp. 223-233. DOI: 10.1017/S1474746404001733.

Dave, S.H., 2012. *Comprehensive Performance Metrics for Complex Fenestration Systems Using a Relative Approach.* Master Thesis: Massachusetts Institute of Technology.

DIN, 2014. *Turkey host to CEN and CENELEC*. The Deutsches Institut für Normung Press Post, 13 June. https://www.din.de/en/din-and-our-partners/ press/press-releases/turkey-host-to-cen-and-cenelec-97720. Accessed 11.02.2019.

DIAL GmbH, 2011. *DIALux Version 4.9 User Manual: The Software Standard for Calculating Lighting Layouts.* 16th ed. Lüdenscheid: DIAL GmbH.

DIALux 4.13., 2016. *Computer Software.* DIAL GmbH. https://www.dial.de/en/ dialux-desktop.

DiLaura, D., Houser, W., Mistrick, G. and Steffy, R., 2011. *IES The Lighting Handbook.* 10TH ed. New York: Illuminating Engineering Society.

Duff, J.T., 2012. *The 2012 SLL Code for Lighting: the Impact on Design and Commissioning.* SDAR Journal of Sustainable Design & Applied Research 1 (2), Article 4. DOI: 10.21427/D7FJ0R

Duff, J.T., Kelly, K., 2013. *In-field measurement of cylindrical illuminance and the impact of room surface reflectances on the visual environment.* In: Proceedings of the SLL International Lighting Conference, 12-13 April 2013, Dublin. pp. 1-11. Dublin: SLL.

Esseci, 2019. *Technical Lighting Notions: Illuminance Grids.* https://www.esse-ci.com/en/category_utility/technical-lighting-notions. Accessed 14.02.2019.

Eurostat, 2018. *Working from home in the EU.* Luxembourg: European Comission Post, 20 June. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20180620-1. Accessed 10.02.2019.

Herve, D., Ramos, C.E., 2011. *Architectural lighting: designing with light and space. 1st ed.* New York, NY : Princeton Architectural Press.

Ganslandt, R. and Hofmann, H., 1992. *Handbook of Lighting Design.* 1st ed. Lüdenscheid: ERCO.

Google Maps, 2018. *Google Maps*. https://www.google.com/maps. Accessed 27.02.2019.

Gordon, G., 2015. *Interior lighting for designers. 5th ed.* Hoboken, NJ: Wiley

IPUMS (Integrated Public Use Microdata Series), 2017. University of Minnesota, Minneapolis, MN: IPUMS. https://international.ipums.org/international/index.shtml. Accessed 27.02.2019.

Kittler, R., Kocifaj, M., and Darula, S., 2012. *Daylight science and daylighting technology.* New York, NY: Springer.

Konica Minolta Sensing Inc., 2013. *Illuminance Meter T-10A & T-10MA Instruction Manual.* https://www.konicaminolta.com/instruments/download/instruction_manual/light/pdf/t-10a_instruction_eng.pdf. Accessed 08.02.2019.

Konica Minolta Sensing Inc., 2013. Luminance meter LS-100 & LS-110 Instruction Manual. http://www.konicaminolta.com/instruments/download/instruction_manual/light/pdf/ls-100-110_instruction_eng.pdf. Accessed 08.02.2019.

Kruisselbrink, T., Dangol, R. and Rosemann, A., 2018. *Photometric measurements of lighting quality: An overview.* Building and Environment 138. pp. 42–52. DOI: 10.1016/j.buildenv.2018.04.028

Laughton, M.A., Warne, D.J. (Eds.), 2003. *Electrical Engineer's Reference Book*. 16th ed. Oxford: Newnes. pp. 21/3 – 21/31.

LUMsearch, 2019. *Luminaire search engine,* DIAL GmbH. https://www.lumsearch.com. Accessed 28.05.2019.

Nag, P. K., 2019. *Office Buildings Health, Safety and Environment.* Design Science. and Innovation. pp. 183-209. Singapore: Springer Nature Singapore.

OMS, 2015. *Lighting Quality Standard.* http://lqs.omslighting.com/wp-content/uploads/2015/03/lqs_book.pdf. Accessed 11.02.2019.

Preto, S. and Gomes C.C. 2019. *Lighting in the Workplace: Recommended Illuminance (lux) at Workplace Environs*. In: Di Bucchianico G. (Ed.). Advances in Design for Inclusion: Proceedings of the AHFE 2018 International Conference on Design for Inclusion, July 21–25, 2018, Loews Sapphire Falls Resort at Universal Studios, Orlando, Florida, USA. Advances in Intelligent Systems and Computing 776. Cham: Springer, pp. 180-191.

Rea, M. S. (Ed.), 2000. *The IESNA Lighting Handbook: Reference & Application.* New York, NY: Illuminating Engineering Society of North America.

SLL (Society of Light and Lighting), 2012. *The SLL Code for Lighting.* CIBSE. Page Bros: Norwich

Tai, N.C., 2013. *Application of Luminance Contrast in Architectural Design*. Computer Aided Design and Applications 10 (6). pp. 953-963. DOI: 10.3722/cadaps.2013.953-963.

The Lighting Research Center, 2000. *Illumination fundamentals.* New York: Optical Research Associates.

TRILUX, 2018. *Beleuchtungspraxis.* http://www.trilux.com/de/beleuchtungspraxis. Accessed 15.02.2019.

TSE, 2011. *Turkish Standard TS EN 12665. Light and lighting – Basic terms and criteria for specifying lighting requirements.*

TSE, 2013. *Turkish Standard TS EN 12464-1. Light and lighting – Lighting of work places – Part 1: Indoor work places.*

TSE, 2019. *The Establishment of TSE.* http://en.tse.org.tr/Hakkimizda. Accessed 11.02.2019.

Zumtobel Lighting GmbH, 2018. *The Lighting Handbook.* 6th ed. http://www.zumtobel.com/PDB/teaser/EN/lichthandbuch.pdf. Accessed 06.02.2019.