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MASTERARBEIT

Evaluation of Lighting Quality in Informal Workplaces via Measurements and Simulation: A Case Study

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ABSTRACT

People in Europe spend about 90% of their lifetime indoors. As such, a high quality of illumination can be considered to be one main aim of building planning. In workplaces, appropriate lighting levels are of special importance, as these directly influence the well-being and productivity of occupants. This might be one main reason, why building planning processes of large office buildings regularly encompass the consultancy of illumination specialists. Such specialists design tailor-made illumination solutions that consider both user needs and aspects of energy efficiency. User needs regularly encompass sufficient lighting levels on workplaces, sufficient contrast and color reproduction for specific tasks, aspects of comfort and control, and avoidance of glare.

While large scale building projects thus are carefully designed regarding lighting aspects, this, however, is not certainly true for small-scale office spaces. Such spaces regularly are designed by the company owners and/or future employees by themselves. Such designs are often based on available luminaries and cost efficiency, rather than on in-depth consideration of user needs. Moreover, little is known about these individual office space setups in terms of user satisfaction and compliance to recommended minimum thresholds of different lighting performance key indicators.

This contribution literally sheds light onto the illumination quality in a specific type of small-scale offices, namely architectural practices. To get an overview, a two-fold approach was deployed in this master thesis: For a number of small scale architecture practices, in-situ lighting level measurements of both daylight availability and artificial illumination were conducted. Parallelly, a simulation engine was utilized to model and simulate these offices and potential improvements (this has been conducted rudimentary in this work). These efforts allow for looking at the following research questions:

(i) What lighting levels can be found in typical (Austrian/Viennese) small-scale architecture offices? During daytime, can a sufficient availability of daylight be found? Are the artificial luminaries capable of providing sufficient lighting conditions on workplaces?

(ii) Do simulations provide sufficient accuracy in comparison to measurements to support optimization of lighting conditions?

The measurements in the offices have been conducted in seven distinct offices with different sizes in various locations in Vienna in February 2017.

KEYWORDS

Office lighting, Artificial Lighting,Daylight, Visual Comfort,illuminance, Optimization, Light simulation.

KURZFASSUNG

Menschen verbringen (in Europa, aber auch weiten Teilen der Welt) einen Großteil Ihrer Lebenszeit in Innenräumen. Aus diesem Grund ist eine gute Ausleuchtung, bzw. eine gute Qualität an Beleuchtung dieser Innenräume von großer Wichtigkeit. Dies trifft ganz besonders auf Arbeitsplätze zu, da die Beleuchtung hier nicht nur das Wohlbefinden und gesundheitliche Aspekte berührt, sondern auch eine Grundvorraussetzung für Produktivität ist. Aus diesem Grund ist bei Großprojekten (im Bürobau) so gut wie immer eine Konsulent für Lichtplanung involviert. Solche Spezialisten befassen sich mit auf die jeweilige Situation maßgeschneiderten Beleuchtungslösungen, welche nicht nur Energieeiffzienz sondern auch im Detail die Anforderungen der jeweiligen Nutzung und der zukünftigen Gebäudenutzer berücksichtigen. Nutzerbedürfnisse im Beleuchtungsbereich umfassen in der Regel nicht nur eine aureichende Beleuchtungsstärke auf Arbeitsplätzen und im gesamten Umfeld, sondern auch ausreichende Kontrastwerte und Farbwiedergabe, sowie Aspekte der individuellen Steuerung und damit einstellbaren Komfort, sowie die Vermeidung von Blendungserscheinungen.

Während in großvolumigen Bauvorhaben die Lichtplanung fast immer in professionellen Händen liegt, ist das nicht unbedingt der Fall, wenn man sich sehr viel kleinere und oftmals individuell realisierte Planungsprozesse ansieht. Kleine Büros werden sehr oft von den (späteren) Nutzern (bzw. manchmal auch Eigentümern) gestaltet und dabei wird die Lichtplanung oftmals weniger an den normativen / arbeitsplatzspezifischen Nutzererfordernissen sondern vielmehr an verfügbaren Beleuchtungskörpern und (geringen) Kosten festgemacht. Es gibt nur sehr wenig Information über die Beleuchtungsqualitäten in solchen, individuell eingerichteten Büroräumlichkeiten bekannt. Es existieren auch nur wenige Studien über Nutzerzufriedenheit und Einhaltung von normativen Anforderungen für solche Arbeitsplätze.

Diese Arbeit beleuchtet – im wahrsten Sinne des Wortes – die Beleuchtungsqualität in Klein-Büros. Dabei wurde eine spezifische Branche – nämlich die Architekturbranche – ausgewählt. Für eine Reihe von Büros wurden Bemühungen zur Erfassung der Beleuchtungszustände durchgeführt: Um einen umfassenden Überblick über die Beleuchtungsqualitäten in (kleinen) Architekturbüros zu erhalten wurden sowohl in-situ Messungen in den Büros durchgeführt, wie auch mit Simulationswerkzeugen die jeweiligen Situationen nachmodelliert und simuliert. Die Simulation kann bei entsprechender Übereinstimmung mit den Messdaten des Status Quo für das Studium potentieller Verbesserungsmaßnahmen herangezogen werden, dies wurde in dieser Arbeit auch

rudimentär durchgeführt. Die folgenden Forschungsfragen können anhand der beschriebenen Bemühungen bearbeitet werden:

(i) Welche Qualitäten können in typischen (Wiener) Klein-Architekturbüros betreffend Tages- und Kunstlicht angetroffen werden? Besteht eine ausreichende Versorgung mit Tageslicht, bzw. können mit den vorhandenen Lampen ausreichend gute Beleuchtungssituationen generiert werden?

(ii) Können Simulationsmodelle in ausreichender Genauigkeit die Realität nachbilden, so dass die Simulationswerkzeuge für das Studium von Optimierungsmaßnahmen herangezogen werden können?

Die Messungen in den Büros fanden im Februar 2017 statt.

KEYWORDS

Tageslicht, Künstliche Beleuchtung, Büroausleuchtung, Visueller Komfort, Optimierung, Beleuchtungsstärke, Lichtsimulation.

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LIST OF ABBREVIATION

E_{max}	Illuminance maximum level
E_{min}	Illuminance minimum level
E_i	Indoor Illuminance
E_o	Outdoor Illuminance
DF%	Daylight Factor
L	Luminance of light source (cd/m^2)
L_b	Background Luminance (cd/m^2)
ω	Size of the luminous area (sr)
P	Position of the light source
Kr	Room index
L	Length of room [m]
W	Width of room [m]
H	Height above the working plane
φ	Lamp lumen per luminaire (lm)
A	Area of the room (m^2)
CU	Cofficient of utilisation
MF	Maintaince factor

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1. Introduction

1.1 Overview

Without a doubt, light plays a fundamental role in architecture. Architects and engineers involved in the building planning and delivery process, therefore, should consider the generation of appropriate illumination of indoor (and outdoor) spaces. “Illumination not only supports the visual perception and therefore the information brokerage, but also is signified by psychic-emotional and psychic-biological effects”. Depending on the function of specific spaces, different guidelines and regulations stipulate minimum requirements. For instance, the Management of Health and Safety at Work Regulations (MHSW) require ”employers to provide health and safety measures at the workplace. This, above all, includes lighting, which needs to be suitable and adequate to meet the requirements of the Workplace “(Health, Safety and Welfare Regulations 1992).

Therefore, optimizing the illumination of and allocating appropriate luminaries within office workplaces is an important part of the planning process in the planning and refurbishment of office buildings. This is due to the fact that visual discomfort of occupants will result in issues regarding their well-being and health, as well as decreased productivity. While planning processes of large office spaces in close to all cases include special consultants for artificial and natural lighting, this is not necessarily true for small scale offices. Such small offices often are not subjected to a specific lighting/luminaire planning, but rather equipped with the at the moment available luminaries and furniture. Moreover, the fast availability of the workspace and low cost are often prioritized in comparison to careful designing the illumination situation. Needless to say, improvement measures for workspaces with shortcomings in illumination often just encompass the addition of table lamps. Such improvement measures are often implemented by the employees themselves, and often are interventions which neither can be considered in terms of lighting design, nor in terms of energy- and cost efficiency.

This contribution examines the illumination situations in small-scale Viennese architects offices by measurement and simulation to enrich the level of knowledge about the illumination quality of such workspaces.

1.2 Motivation

During the recent years, unprecedented changes in the way people work (or are required to work) could be witnessed. "For most - if not all – workers the need to create a remarkable client experience has led to the intensification of work and the need to cope with continually changing work requirements and a faster pace of work. In this context, the challenge for employers and researchers is to design work environments that can best meet the needs of 21st-century workers' and ensure maximum levels of wellbeing and performance" (Silvester and Konstantinou 2010). Depending on the field of economy office employees are working in, the majority of their everyday work routine can range from collaboration and communication with colleagues to specific computer-supported office tasks. In the case of architectural offices, a major part of the time is invested in drafting and modeling of computer models, accompanied by other activities, such as model-building, hand-drawing, and different other activities to designing, evaluating, promoting, or reviewing parts of the building planning and delivery process.

So, employees need to work in a comfortable and healthy environment. An appropriate lighting design might help to conserve the eye health, enhances working performance, and provides visual comfort by (at least) fulfilling minimum requirements. Furthermore, properly designed illumination can have beneficial effects in terms of energy-saving measures (electricity consumption, but also mitigation of overheating tendencies). Needless to say, artificial illumination has a big influence on electricity and thus energy consumption of a building. Architects and lighting consultants thus regularly face partly conflicting targets: On the one hand, lighting design addresses a high level of user satisfaction and tailor-made solutions for the lighting design of indoor spaces. On the other hand, the energy consumption of the building caused by artificial illumination should be decreased as good as possible, due to environmental and cost reasons. Good lighting design thus often severely incorporates daylight, which not only offers a good level of illumination if properly deployed, but by nature is an energy-conserving measure. In addition to the already mentioned aspects of lighting planning, the avoidance of glare and the provision of good contrast levels and a high degree of color reproduction are important in many cases.

The (most-)basic criterion for the illumination situation is the illuminance level on a workplace. The requirements toward this criterion highly depend on features of the corresponding visual task. The illuminance is regularly influenced by (reflecting) room surfaces, the photometric data of the lighting sources and their positioning in relation to the so-called task area (the area where a specific work is done). Many guidelines and studies recommend to consider certain illuminance uniformity values for workplaces. One criterion to determine the uniformity is the light distribution curve of the luminaire, which is unique for each of them. The light distribution curves of the luminaire are influenced by the power of light source, by its geometry and design, and by the different angles a workplace can show in relation to the light source. The illuminance on a surface can be determined based on the characteristics of the room and the location and characteristics of light sources/luminaries within a room.

For planners, it is necessary to determine which luminaries (based on their lighting distribution curves, their light colour, etc.) should be chosen and positioned to provide optimal illuminances for task areas at acceptable energy consumption. Typical questions, which influence the design of any lighting system for office spaces are:

- How does the geometry of offices, windows and roof lights look like?
- Which tasks (and thus minimum requirements) are most likely to be performed at the workplace?
- Does the (already existing) illuminance situation match with visual needs of employees?
- Do employes have a desktop lamp at their workplace or should everything being illuminated just by ceiling/wall mounted luminaries?
- Is the illuminance distributed uniformly at the work place?
- Does reflectance of the room surface or the positioning of luminaries / windows cause glare? Have employees experienced a glare reflection on their desk or unpleasant light in their room?
- Is there a necessity to often manually adjust/change the illuminance level at workplaces?

1.3 Background

Previous researches on lighting evaluation at workplaces with a focus on minimizing energy consumption of lighting as well as increasing lighting quality has been so far conducted.(Uygun et al. 2015), having studied “Optimization of Energy Efficient Luminaire Layout Design” at Workplace, have proposed a mathematical model to find optimum position for luminaires by providing visual comfort requirements. Two different scenarios for a selected case were conducted to obtain sufficient illuminance level, using different number of luminaires. To minimize the differences between the calculation points and the average illuminance level, they attempted to achieve maximum uniformity of light distribution. The research done by (Wang and Tan 2013) developed a solution for overall illumination control of a LED system based on neural network mapping model. They presented an accurate model to simulate the relationship between luminaire dimming levels and table illuminance of the test bed. Based on this model, the illumination optimization approach adjusted the dimming levels of luminaires to achieve energy conservation and to satisfy users. They used the simulation just to give readers an overall control effect and they also showed different scenarios to verify the performance of the solution. (Al-Tamimi et al. 2009) “ investigated about improving illumination levels and energy savings by uplamping technology for office buildings and they introduced a simple solution with support of lighting simulation tool (DIALUX) ”. Lux meter is used as a method instrument to calculate the lighting electrical load for further analysis, then the following solutions in four distinct scenarios are suggested:

- Replace the existing luminaires with direct photometric down hung mirror finished louvered type luminaire.
- Replace the existing lamps by efficient lamps
- Replace the existing electromagnetic capper ballast by electronic ballast EB series
- Mounting height of the luminaire from workplace should be 2.6 m

It is concluded that by applying the solutions, we would be able to reduce energy consumption to less than 35-42% with fluorescent lamps, and to 65-75% with incandescent lamps and as a result Lux level reinforce could increase the quality of the light up to 30%. Studies on lighting at workplace have consistently shown that sunlight has positive effects on workers' subjective well-being; and that employees prefer to work near windows or at workplaces with natural lighting (Leather et al. 1998) , (Oldham and Fried 1987) , (Wang and Boubekri 2009), (Yildirim et al. 2007). However, in contemporary workplaces the access of employees to natural lighting is not always possible. 24/7 working, shift-work, office work and different geographical latitudes mean that most employees work in environments, where there is a need for artificial lighting for some or all of their work period. This emphasizes a need to understand how the use of artificial lighting impacts directly or indirectly on workers' well-being and performance. Lighting at workplace may influence employees' performance in several ways. It may, for example, affect eye-strain and visual comfort (Van Bommel and Van Beld 2004), (Boyce 2003). "Lighting may also affect cognitive performance and problem-solving ability by interfering with physiological factors like circadian rhythms" (Juslen and Tenner 2005). Lighting can also impact on mood and interpersonal relationships at work and therefore job satisfaction" (Boyce 2003). Studies have also found that the colour of lighting would similarly have an impact on persons' mood and work performance (Küller et al. 2006). One experimental study regarding the influence of lighting, age and gender on mood and cognitive performance, found that younger females, compared to males, experience essentially longer positive and negative mood. Older adults showed a negative mood in cool bluish lighting, whilst younger adults showed a more negative mood in warm, reddish light (Knez and Kers 2000).

Researchers have been able to document consistent effects in relation to the impact of lighting on visual performance and health. Poor lighting can result in eye strain, fatigue and aching, which in turn is likely to lead to deterioration in performance, particularly if work relies on visual acuity such as computer-based (VDT) job roles (Parsons 2000), (Nave 1984). As this type of work, the importance of lighting for visual health and performance at work is likely to become increasingly important. However, relationships between lighting, well-being and performance are unlikely to be simple, and employees' preference for particular types of lighting may not necessarily impact their performance. For example, whilst employees clearly prefer indirect-to- direct lighting (Veitch 2001), there is little evidence of a direct impact on health, well-being, or cognitive performance of office workers (Fostervold & Nersveen 2008). To be more precise, many studies have documented significant effects in areas such as visual performance and well-being.(Hedge et al. 1995) found that office workers prefer ceiling suspended, lensed-indirect up-lighting to a parabolic down lighting system, and experience fewer problems of screen glare and tired eyes. (Juslen 2007) has also found that when horizontal luminance is alternated per workshift (between 800 and 1200 Lux), the swiftness of workers in a factory, assembling electronic devices under 1200 Lux condition, increases significantly; an effect that holds for morning and evening shifts in the winter, and during the evening shift in the summer.

1.3.1 Office lighting standards and Recommendations

As our world becomes increasingly service-oriented, people tend more to work in offices or workstation environments. In most office situations, productivity and efficiency are of high-priority goals but there is also a trend in increasing employees satisfaction in most workplaces (Bejan et al. 2008). To evaluate the quality of office lighting, the following criteria should be measured and analyzed:

1.3.1.1 Daylight Factor

Daylight factor (DF) is the ratio between the available interior illuminance to the available exterior illuminance under overcast sky conditions. It is then multiplied with a factor of 100 in order to get the daylight factor in percent.The daylight factor in a room could be calculated for a specific point or over a surface, also can be measured in existing buildings using with a lux meter.The illuminance levels need to be measured simultaneously inside the room in a specific point and outside under an unobstructed diffuse sky.

$$DF = E_i / E_o \times 100\% \qquad [1]$$

Where:

E_i is the illuminance at the selected point inside the room [Lux]

E_o is the illuminance from the unobstructed diffuse sky [Lux]

When a mean daylight factor is calculated,a typical value for a room that be considered as brightly lit is over 5% (Baker & Steemers 2002), whereas a room with a value of 2% is required to consider a supplementary artificial lighting (Aschehoug & Arnesen 1998) when a room with a value of about 1% is considered as a dark space so artificial illumination unavoidable.

1.3.1.2 Luminance Ratio

Specifications for lighting in occupational settings are based on the well-established visual effects of light, with aspects such as illuminance, glare restriction, and the color-rendering index being taken into account. High luminance ratio is necessary to provide good visibility, stimulation and attraction. However, extremely high luminance ratio will cause glare, because human visual system will have difficulties to adapt a high and a low luminance level at the same time. To maintain good lighting quality without producing discomforting glare, the luminance ratios should not exceed 3:1 or 1:3 between a paper task and an adjacent VDT screen or between a task and the immediately adjacent surroundings, and 10:1 or 1:10 between a task and remote surfaces (IES 2004 - 2011).

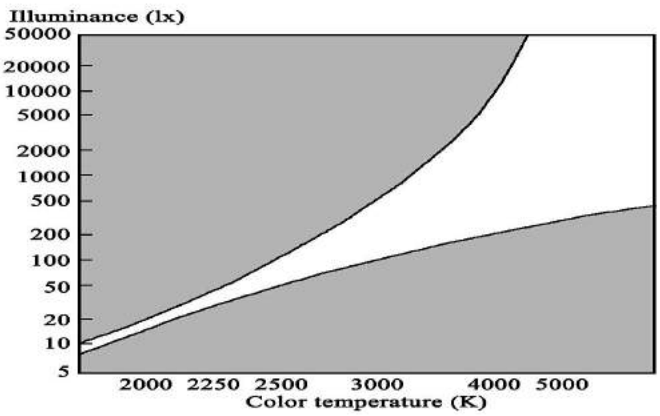


Figure 1 : The Kruithof curve (source: Boyce 2003)

To maintain visual comfort, the luminance ratios should not exceed 1:40 between a task and luminaires, and 1:20 between a light-source-adjacent surface and a light source. To minimize VDT glare/veiling reflections, the luminance ratios between a brighter ceiling and/or wall zone and a dimmer ceiling and/or wall zone should not exceed: 4:1 in a critical situation, and 8:1 in a normal situation (IES 2011).

1.3.1.3 Correlated Color Temperature (CCT)

A correlated color temperature (CCT) is often employed to evaluate the chromatic features of light sources. CCT describes the color appearance of the light sources. Higher CCT makes the light look cooler and lower CCT makes it look warmer. However, CCT is also related to individual preferences. generally, a CCT lower than 3000K gives a warm perception. CCT between 3000K and 3500K gives a neutral white perception, a CCT higher than 4100K gives a cold white perception and appears harsh and institutional in dark conditions (IES 2011). Currently, there is a lack of detailed guidance or recommendation by IES on the determination of CCT, besides the conventional Kruithof curve (Figure 1), which determines the ideal color temperature of electric lighting installations in an interior space. The white area represents the preferred combinations of the color temperature of a light source and illuminance. Color temperature/ illuminance combinations in the lower-shaded area are claimed to produce cold, drab environments, while it is believed that those in the upper-shaded area produce overly colorful and unnatural environments (Boyce 2003).

1.3.1.4 Color Rendering Index (CRI)

CRI describes the ability of a light source to reproduce color appearances of various colored objects compared to natural sunlight (IES 2004). The highest value of CRI is 100. The importance of CRI depends on the extent to which color distinction is critical to the visual tasks. In general, a CRI of 70 or higher is needed to achieve visual comfort. If color-critical tasks are performed, the CRI of light sources should be 85 or higher (IES 2004, 2011).CRI is understood to be a measure of how well light sources render the colors of objects, materials, and skin tones. How is the CRI number actually calculated? The test procedure involves comparing the appearance of eight color samples (see upper right for an approximation) under the light in question and a reference light source. The average differences measured are subtracted from 100 to get the CRI. So small average differences will result in a higher score, while larger differences give a lower number. Of all the colors possible, only these eight are measured. Further, the samples used are pastels, not saturated colors. CRI is calculated by measuring the discrepancy between the lamp in question and a reference lamp in terms of how they render the eight color samples. If the lamp being tested has a correlated color temperature (CCT) of less than 5000 Kelvin (K), the reference source is a black body radiator approximately like an incandescent lamp. For higher CCT sources, the reference is a specifically defined spectrum of daylight. Therefore, light sources that mimic incandescent light or daylight for the eight color samples are, by definition, the ones that will score highest on the CRI(Sedat 2008).

1.3.1.5 Direct and Indirect Glare

Direct glare occurs when the light source is visible to an occupant's eyes. Indirect glare, which is also known as reflected glare or veiling reflection, takes place when light is reflected from a polished surface, like a visual display terminal (VDT) screen and glossy materials, and goes into the occupant's eyes (IES 2004) (Occupational Health Clinics for Ontario Workers Inc. 2008). Both direct and indirect glare will reduce the visibility and cause discomfort. Direct and indirect glare can be reduced by blocking the visible light source using indirect lighting systems, or covering overhead luminaires with diffusers and lenses or dimming the general lighting with supplemental task lighting, avoiding glossy surfaces in view field the office workers, and using anti-glare screens on computers (IES 2004, 2011) , (Occupational Health Clinics for Ontario Workers Inc. 2008) , (Knoll 2006).


(2)

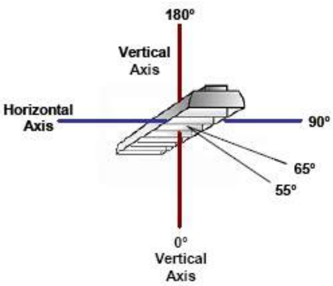
(3)


Figure 2 **:** Reflected glare on computer screen from ceiling luminaires (Source: from IES 2004, 2011)

Figure 3: Direct glare from windows and luminaires (Source: from IES 2004, 2011)

1.3.1.6 Luminous Intensity Distribution Curve

Luminous intensity distribution curves are typically represented in polar plots because this format allows us to visualize both the orientation and the light distribution of the light fixture. The candlepower distribution of a light fixture depends upon reflector design, shielding type, and lamp-ballast selection. It is assumed that the light fixture position is at the crossing of two axes (horizontal and vertical), and that 0° (nadir) is beneath the light fixture.



(4)

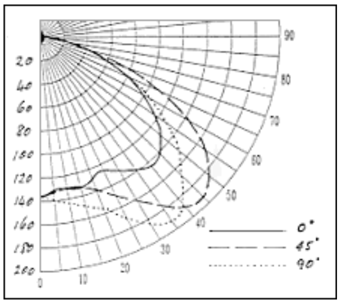
(5)


Figure 4 : Horizontal and vertical axes fluorescent (Source: from IES 2004, 2011)

Figure 5: Vertical plane through light fixture (source: from IES 2004, 2011)

Other angles, which represent the various placements of a photocell as it moves in a circular pattern around the light fixture, are marked on the graph as well (IESNA 2004, 2011). If the distribution of light is not symmetrical in all directions around the vertical axis such as for a 2ft. x 4ft. light fixture, candlepower values may be taken in a number of vertical planes through the light fixture (Figure 4). The planes shown in photometric reports are 0°, 22.5°, 45°, 67.5°, and 90°. The planes most commonly used in lighting practice are 0° or parallel to the lamp axes, 90° or perpendicular to the lamp axes, and at an angle 45° to the lamp axes.

1.3.1.7 Uniformity

Uniformity is generally described as the ratio between highest- and lowest illuminance values at the given room or space. Uniformity is described in terms of illuminance even If visual perception depends on the luminance of surfaces because general practice is to use a surface with similar reflectance within the task area. Acceptable reflectance values are also provided in many lighting standards. For example, the European standard (DIN EN 12464-1) proposes the following reflectance factors for the main room surfaces:

- Ceiling: 60-90%
- Walls: 30-80%
- Floor: 10-50%
- Work surface: 20-60%

A complete uniform visual field is undesirable since it is perceived as not interesting and not stimulating, but also too much non-uniformity is undesirable since it creates a distraction (IEA 2012). Studies about people's reactions to various lighting patterns show that the preferred lighting form is having a uniform illuminance over an area of about 1m2, where the task has to be accomplished and less illuminance in the surrounding area if the task deals with 2-D work. If the tasks deal with present 3D surfaces (industry works, prototypes) then less uniformity is needed in order to perceive the shape and texture of the object (Boyce, Peter R. 2003). In workplaces with video screens, the luminance of the display should be also taken into account, when planning the lighting in order to provide such a level of illumination that does not create abrupt changes in luminance between screen and the rest of the room.

$$\text{Uniformity} = E_{max} \,/\, E_{min} \qquad [2]$$

Where:
Emax: is maximum illuminance inside the room [Lux]
Emin: is minimum illuminance inside the room [Lux]

1.3.1.8 Maximum UGR

The unified glare rating value (UGR) is a method to measure the probability of psychological glare. UGR calculates the luminance size of the light source, the luminance of the background, size of the source in angle and the position of the glare source. UGR is defined as:

$$\mathbf{UGR = 8.\log\ (\frac{0.25}{L_b}).\sum(\frac{L^2.\omega}{P^2})} \quad [3]$$

L: Luminance of light source (cd.m^2)

L_b: Background Luminance (cd.m^2)

ω: Size of the luminous area (sr)

P: Position of the light source

(BS EN 12464-1:2011. DIN 5035 – 6, IES 2004,2011)

The new European standard sets UGR = 19 as the maximum permissible value for offices which is equivalent to the luminance limiting curve for 500 Lux.

1.3.1.9 Flicker

The flicker of light sources can cause headaches. Electromagnetic ballasts of fluorescent luminaires often produce flicker, together with an audible hum. Most high-frequency electronic ballasts can eliminate flicker and humming noise (IES 2004, 2011).

1.4 Objective Of This Contribution

"Understanding the illumination situation within small scale architecture offices by deploying measurements and simulation efforts. While the simulation shall act as basis for future optimization efforts pertaining to the illumination conditions in these offices, measurements are accompanied by subjective evaluation of the workplace quality via conducting surveys."

1.4.1 Research Question

This research study, in turn, attempts to address the following performance inquires:

Q1) How is the quality of illumination (daylight and artificial lighting) in the existing condition of workplaces, compared with corresponding standards (DIN EN 12464-1)?

Q2) Can it be said that the simulation provides similar results as the measurements? Can thus be said that the simulation can be used for the study of potential improvements?

Q3) Which suggestions could be proposed for the improvement of the lighting conditions in the case studies?

2. Methodology

2.1 Principal Workflow

For this research, some small-scale architectural offices in Vienna were chosen as case study objects. In this objects, the lighting conditions were examined, both via measurement, and via modeling and simulation in a state-of-the-art light simulation tool (chosen for this study: Dialux). The efforts pertained to both daylight availability and artificial light. Namely, the measurements were conducted during daytime and during evening/nighttime. Moreover, the employees of the offices were asked to fill a survey about their satisfaction regarding the lighting conditions of their workplace. The survey included questions about their impression of availability of sufficient lighting levels, and the visual performance of their workplaces.

After conducting in-site measurements in the offices, corresponding simulation models were generated (considering the standards at workplaces as illustrated in DIN EN 12464-1). These models – after analyzing the status quo - have been used to determine optimization potentials for the offices spaces. Thereby, different luminaire positions were tested simulationwise, as well as other luminaries. The target values aimed at by these principal improvement steps are based on the corresponding minimum requirements for illumation of workplaces.
In short words, the workflow was as follows:

- Selection of case study offices, selection of spaces in the case study offices.
- Setting up a measurement grid for each of the case study spaces ("Defining position of the measurement points.").
- Measuring the illumination levels in the offices both during daytime (daytime availability, artificial luminaries turned off) and during nighttime (just artificial luminaries). The illumination during daytime was conducted at different weather conditions to better approximate with sky model settings in later simulation efforts
- Generation of a simulation model in a lighting design software (Dialux). Thereby, all required input data has been set /modelled as exact as possible (location, geometry and orientation of the offices, reflectances of surfaces, used luminaries, size and location, as well as properties, of the windows, etc.).
- Simulation of the Status Quo in the lighting simulation tool for daylight and artificial lighting
- Comparison of the measurements with the simulation results.

- Simulation of improved situation of the offices (following minimum requirements according to DIN EN 12464-1 / IESNA 2004 – 2011), using other luminaries, and other luminarie setups).

The outside obstructions have been modelled in the simulation tool. Their properties (reflectances) have been set as close as determinable after in-situ-visits. Figure 6 illustrates the principal workflow in steps:

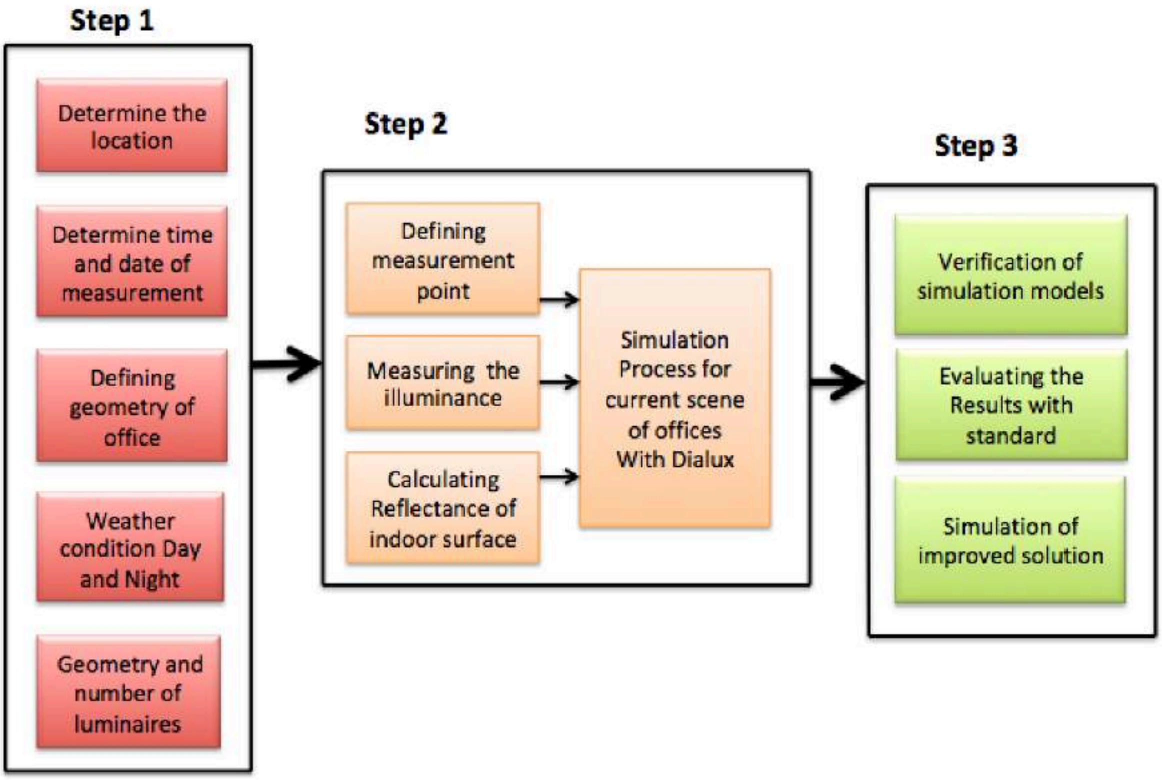


Figure 6 : Illustration of measuring and simulating process

2.2 Case Study Buildings

These case studies are conducted for seven offices in different locations in Vienna. Further details and information of the studies are mentioned hereunder:

2.2.1 Case Study 1 - Argentinierstrasse 35

The first case study is in Argentinierstrasse 35 (Figure 7). For the purpose measurement, a technical drawing room in an architectural office was selected. The L-shaped plan of the first case study had (4.28(m) W * 5.36(m) L * 3.67(m) H) dimensions. The examined room had south-west geographical direction and its southern wall had two windows with dimensions of (1.4(m) W * 2.4(m) H). Figures 7 and 8 provide some illustrations about the case study 1.

Figure 7 : (Left) the technical drawing windows, from outside, Argentinierstrasse 35.
(Right) the location of architectural office, top view, Argentinierstrasse 35.

Figure 8 : (Right) The technical drawing Plan, Argentinierstrasse 35
(Upper Left) Obstruction applied, 3d Model, (Lower Left) Technical drawing, interior view.

The floor was made from bench wood. The wall and ceiling were had a plaster surface. There were two drawers, four tables and some plastic chairs inside the room. The Figure 9, below, shows a more transparent situation of the office.

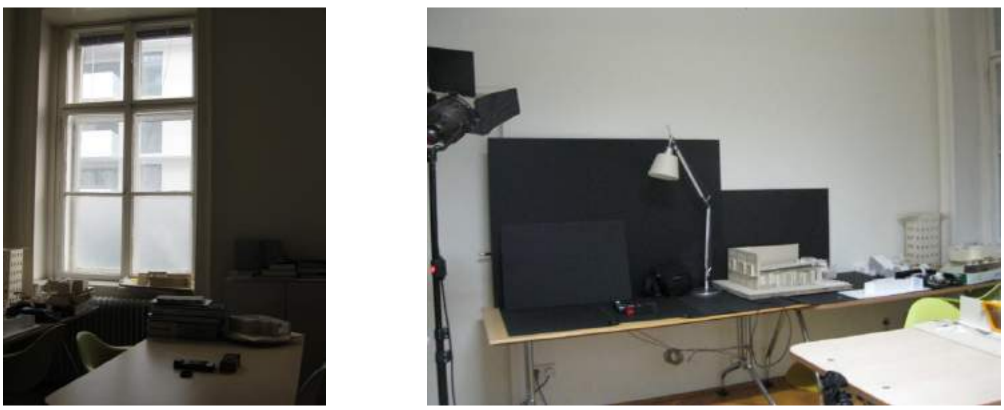


Figure 9 : (Right) Technical drawing room during night measurement
(Left) Technical drawing room during daylight measurement

2.2.2 Case Study 2 – Mariahilferstrasse 101

The technical drawing room (Figure 10) for the second case study is located in Mariahilferstrasse. The plan of the study was square with dimensions of (14.43(m)W *15.17(m) L *3.7(m) H). The room was entered from its south; the southern and northern walls had three windows with dimensions of (1.5(m) W * 2.46(m) H). Figures 10 and 11 provide some illustrations about the case study 2.

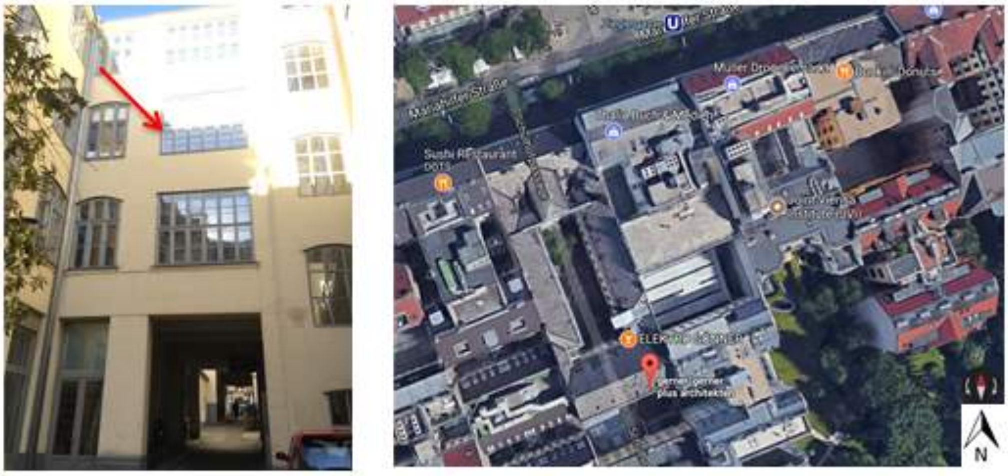


Figure 10 : (Left) Technical drawing windows, from outside, Mariahilferstrasse101.
(Right) The location of architectural office, top view, Mariahilferstrasse101.

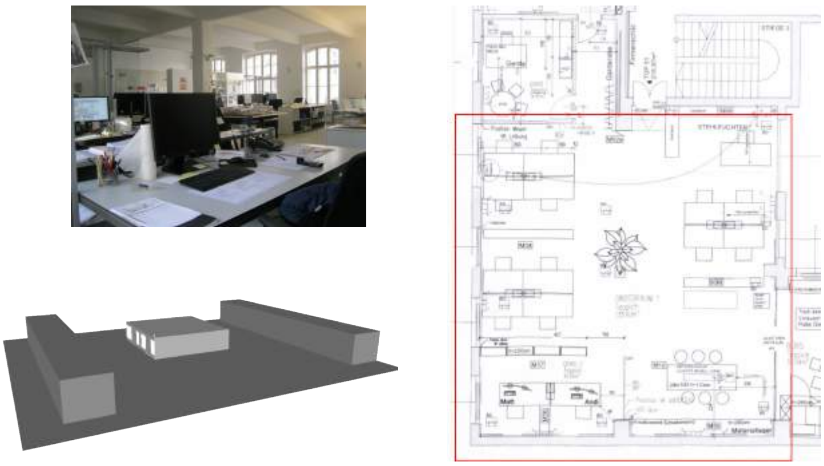


Figure 11 : (Right) Technical drawing Plan, Mariahilferstrasse101.
(Upper Left) Technical drawing, interior view, (lower left) Obstruction applied, 3d Model.

The floor was covered with a carpet and the wall and ceiling had a thin layer of plaster surface. There were some drawers, thirteen tables and some plastic chairs in the room. Figures 12 shows the office more clearly.

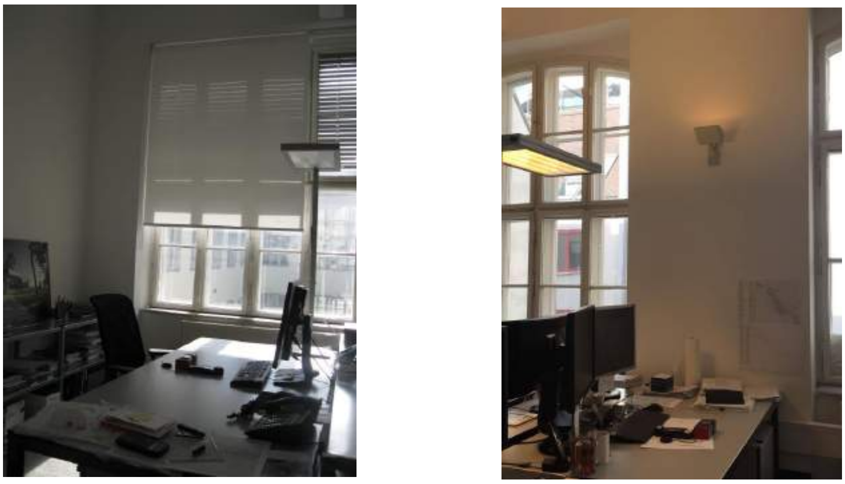


Figure 12 : (Left) Technical drawing room during daylight measurement.
(Right) Technical drawing room during artificial light and daylight measurement.

2.2.3 Case Study 3 – Neustiftgasse 32

I have selected my next technical drawing room for the third case study in Neustiftgasse (Figure 13). The plan of this study was rectangle with dimensions of (9.60(m) W * 14.20(m) L * 3.6(m) H). The room was entered from its south, and the southern wall had five windows with dimensions of (2(m) W * 2(m) H). Figures 13 and 14 illustrate the outside view of the building together with the location of the office.

Figure 13 : (Left) Technical drawing windows, from outside, Neustiftgasse 32.
(Right) The location of architectural office, top view, Neustiftgasse 32.

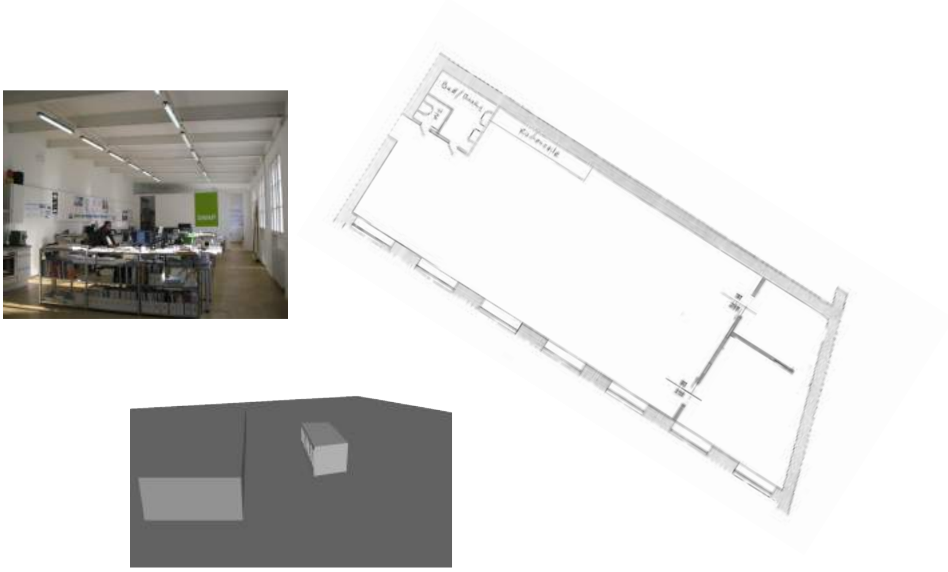


Figure 14 : (Right) Technical drawing Plan, Neustiftgasse 32.
(Upper Left) Technical drawing, interior view, (lower left) Obstruction applied, 3d Model.

The floor was made of wood; the wall and ceiling have a layer of plaster surface. Two tables and some plastic chairs were in that room. There were three PCs on each table. Please see Figure 15 for exact situation of the office.

Figure 15 : (Left) Technical drawing room during daylight measurement
(Right) Technical drawing room during evening measurement

2.2.4 Case Study 4 – Zieglergasse 29

The fourth case study was in Zieglergasse 29 (Figure 16), and the plan of my technical drawing room was rectangle with dimensions of (5.5 (m) W * 10.5(m) L * 3.5(m) H) .The pathway to the room was from east to west; eastern wall had four windowsand western wall two windows with dimensions of (1.4(m) W * 2.4(m) H). Figures 16 and 17 provide some illustrations about this case study.

Figure 16 : (Left) The technical drawing windows, from outside, Zieglergasse 29.
(Right) The location of architectural office, top view, Zieglergasse 29.

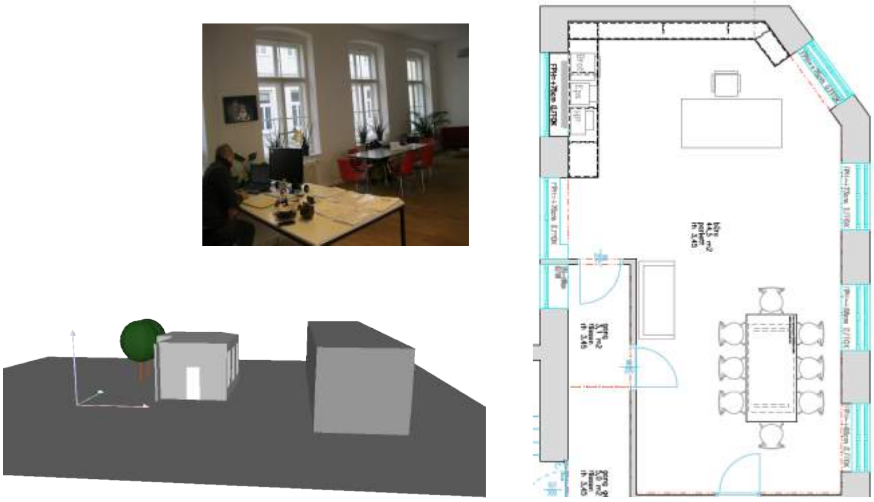


Figure 17 : (Right) The technical drawing Plan, Zieglergasse 29.
(Upper Left) Technical drawing, interior view, (lower left) 3d Model, Obstruction applied.

The floor was made of bench wood; the wall and ceiling have a layer of plaster. There were three drawers, two tables and some plastic chairs in the room (Please see Figure 18).

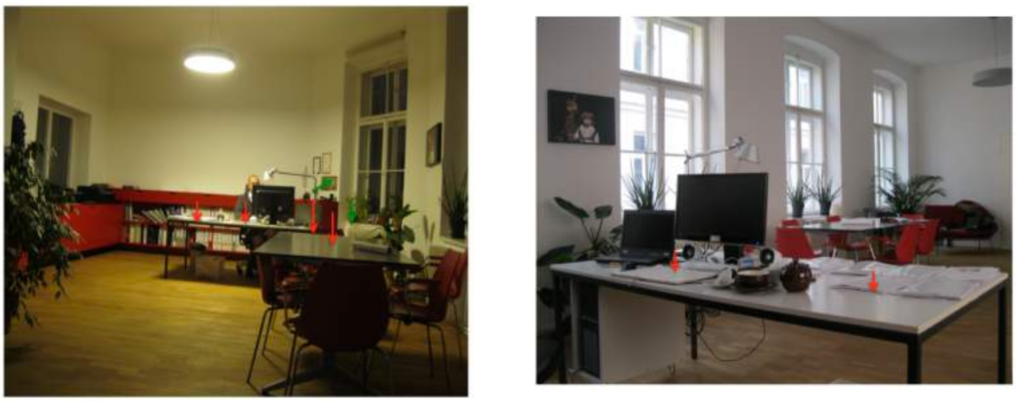


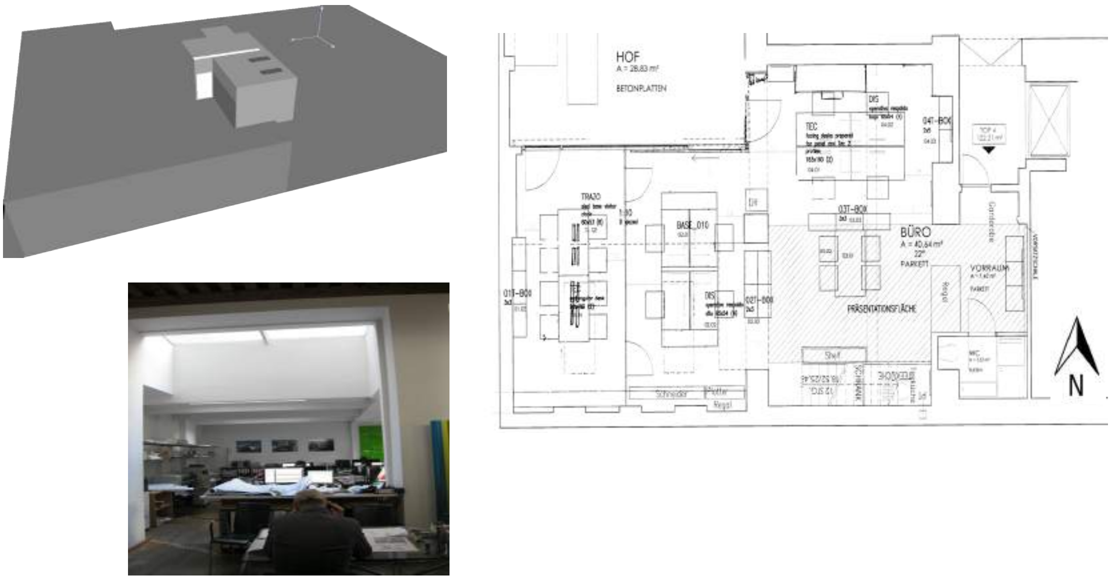
Figure 18 : (Left) Technical drawing room during night measurement.
(Right) Technical drawing room during daylight measurement.

2.2.5 Case Study 5 – Westbahnstrasse 26

The fifth case study was in Westbahnstrasse 26, (Figure 19). My selected technical drawing room was L- Shape with dimensions of (8(m) W * 15.26(m) L * 4.7(m) H). The pathway to the room was from east to west; the eastern wall had several wide windows with dimensions of (6.6(m) W * 4.7(m) H). Please see Figures 19 and 20 to get a better image from the outside view of the building as well as the location of the office.

Figure 19 : (Left) The technical drawing windows, from outside, Westbahnstrasse 26.

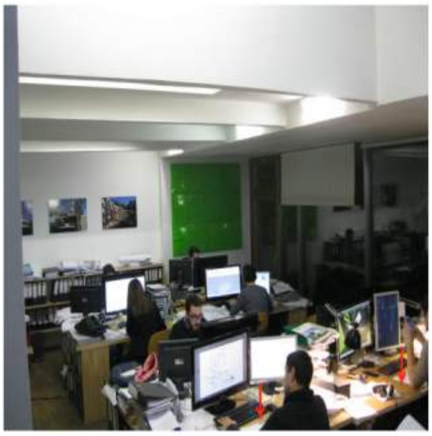
(Right) The location of architectural office, top view, Westbahnstrasse 26.



20 : (Right) The technical drawing Plan, Westbahnstrasse 26.

(Lower Left) the Technical drawing, interior view, (Upper left) 3d Model, Obstruction applied.

The floor was made of wood; the wall and ceiling had a plaster surface. There were two bookshelves, eight tables and some plastic chairs in the given room. Please see Figure 21.



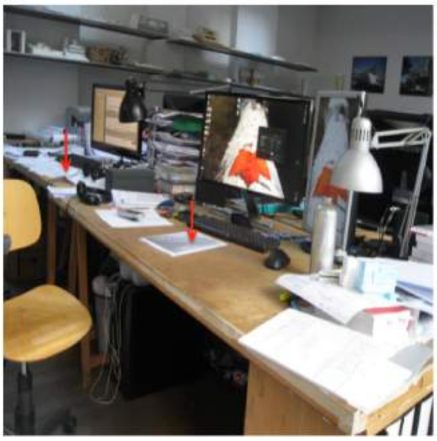


Figure 21 : (Left) Technical drawing room during night measurement

(Right) Technical drawing room during daylight measurement

2.2.6 Case Study 6 – Burggasse 94a

The sixth case study was in Burggasse, (Figure 22) and my chosen technical drawing room was rectangle with dimensions of (5.10(m) W * 23.30(m) L * 3.6(m) H). The room was entered from its South, and the southern wall had five windows with dimensions of (2(m) W * 2(m) H). Figures 22 and 23 well illustrate the outside view as well as the location of the office.

Figure 22 : (Left) The technical drawing windows, from outside, Burggasse 94a.

(Right) The location of architectural office, top view, Burggasse 94a.

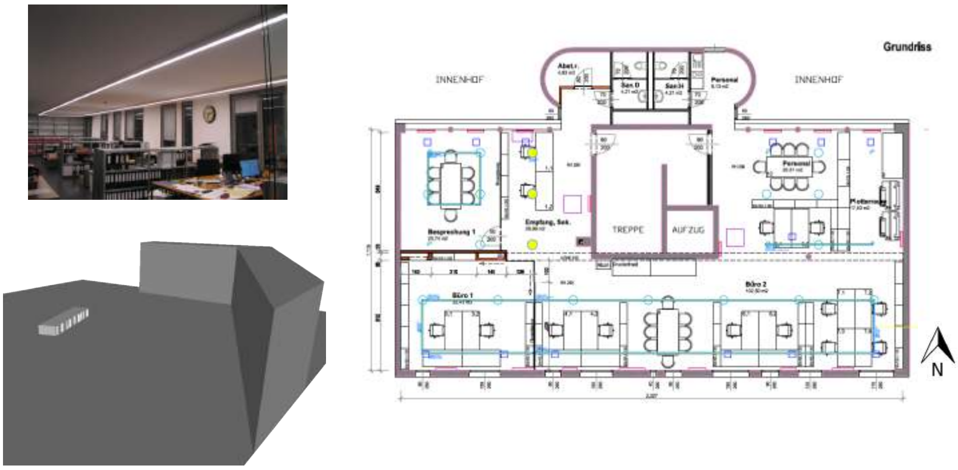


Figure 23 : (Right) The technical drawing Plan, Burggasse 94a.

(Upper Left) the Technical drawing, interior view, (Lower left) 3d Model, Obstruction applied.

The floor surface was made from epoxy; the walls and ceiling had a thin layer of plaster. Four tables and some plastic chairs were in the room. On each table, there were two or three CAD Workstations (including PCs and some space for papers and plans).

Figure 24 : (Left) Technical drawing room during daylight measurement

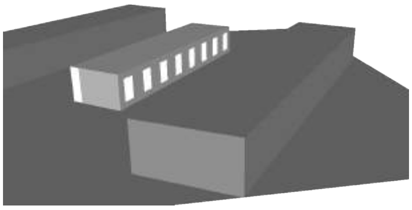
(Right) Technical drawing room during evening time measurement

2.2.7 Case Study 7 – Capistrangasse 5

The seventh case study was in Capistrangasse, (Figure 25) and this time my three interconnected technical drawing rooms were rectangle with dimensions of (6.0(m) W * 16.40(m) L * 3.6(m) H). The pathway to the room was entered from east to west and the eastern wall had several windows with dimensions of (2(m) W * 2(m) H). Please see Figures 25 and 26.

Figure 25 : (Left) The technical drawing windows, from outside, Capistrangasse 5.

(Right) The location of architectural office, top view, Capistrangasse 5.



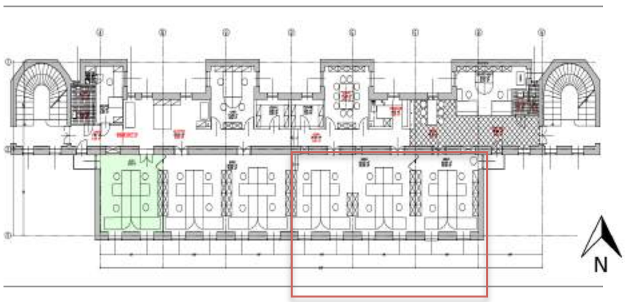


Figure 26 : (Right) The technical drawing Plan, Capistrangasse 5.

(Upper Left) the Technical drawing, interior view, (Lower Left) 3d Model, Obstruction applied.

The floor was made of wood, and the walls and ceiling had a plaster layer. Six tables and some plastic chairs were in the room. On each table, there were two or three PCs. The office is well depicted in Figure 27.

Figure 27 : (Left) Technical drawing room during daylight measurement.

(Right) Technical drawing room during evening time measurement.

2.3 Assumed Office Material Surface Properties

To simulate and evaluate office illumination using Dialux, the luminance of the selected surface properties were required to be measured due to achieved reflectivity of assumed material during simulation.The type of surface material as well as their reflectivity are mentioned in Table 1.

Table 1: Reflectivity of Material was measured in chosen office.

Assumed Matrial Surface	Actual surface Material	Roughness	Reflectivity (%)
Workplace	Wood furniture surface	0.08	0.51
Wall	Paint (Matt)	0.08	0.88
Floor	Wood (Polished)	0.43	0.43
Window Frame	Aluminum Board (Painted)	0.02	0.85
Entrance Door	Sunmica (Stain finish)	0.08	0.81

For estimating the reflectance of interior surfaces, illuminance (Lux) and Luminance ($cd.m^2$) at a specific point of each surface were measured with Mintola Luminance Meter LS100. The illuminance was measured, having used a Mintola T10 a illuminance meter. Under the right circumstance, the luminance L of surface must be related to illuminance E and reflection ρ (Hiscocks 2011).

$$\mathbf{L} = \frac{\mathbf{E}\,\boldsymbol{\rho}}{\boldsymbol{\pi}} \quad (\mathbf{cd.m^2}) \qquad [4]$$

Where,

L : Luminance of light source ($cd.m^2$)

E : Luminance of light source (Lux)

ρ : Reflectance of the white painted interior of the sphere

Roughness values were based on literature (Jacobs 2015).

2.4 Measurements

In fact, the grid point requires to determine average illuminance on workplace. Uniformity is also dependant on the size and shape of the reference surface. Reference surfaces typically embrace a workplace together with the surrounding and back spaces, and working or inner areas.Due consideration needs to be given to the geometry of the lighting installation, the luminous intensity distribution of the luminaires, the degree of precision required and the photometric quantities to be evaluated. The arrangement of luminaires and the arrangement of measurement points should not be identical.The spacing between measurement points needs to be less than the mounting height.

Table 2: Measuring points recommended (source: base on DIN EN 12464-1)

	Longest dimension of area or room	Grid size
Task area	Approx. 1 m	0.2 m
Small rooms	Approx. 5 m	0.6 m
Medium rooms	Approx. 10 m	1 m
Large rooms	Approx. 50 m	3 m

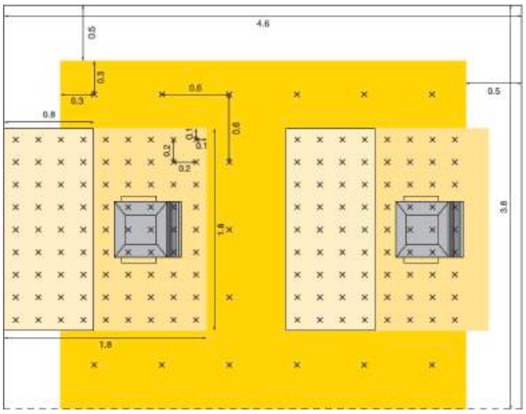


Figure 28: calculation points and surrounding area (based on DIN EN 12464-1)

Measurement of required additional information,such as outdoor illuminance during the indoor measurement in the offices was conducted via the weather station on top of TU Wien.

2.5 Measurement Equipment

2.5.1 Konica Minolta T-10

This device is used to measure illuminance of a specific location and is capable of measuring average value of illumination, to be viewed on the LCD screen. This Device is calibrating automatically after powering up and has the ability to measure intermittent and continuous light source. It also has the features of a very large measurement range of 0.01 to 299,900 Lux. The device is similarly capable of measuring flickering light and therefore users have the possibility to use setting colour correction factors for specific light sources. Figure 29 illustrates the instrument.

The technical details are described below:

- The Instrument has the ability to measure illuminance (Lux), average illuminance (Lux), over a measurement time period (Lux).
- This Lux meter has a vast measurement range (0.01 to 299,900Lux) along with an automatic range switching
- It has an accuracy of ±2% ±1digit of displayed value (based on Konica Minolta standard).
- The measurement instrument can be operated between -10 and 40 $^{\circ C}$, and relative humidities of 85% and below.
- User calibration function: CCF (color correction factor) setting function
- Dimension of: 69x174x 35 mm
- Power source of: 2AA-Size batteries / AC adapter (optional)
  (Konica Minolta T10, 2008)

Figure 29 : Konica Minolta T10

2.5.2 Konica Minolta LS 100 luminance meter

This device provides the users with the most advanced light measuring technology. The spot illuminance meter is small, compact, light and portable. This device system is optical with single lens reflex (SLR) technology that allows an accurate measurement, even at very short distances and small area and down to 0.4 mm in diameter. The LCD screen shows the values of luminance measurements, being visible in viewfinder. Color correction and calibration functions are included in device and users are able to choose standard luminance. The instrument itself automatically corrects differences from specific light sources and owns an ability to set values. Please see Figure 30.

The technical details are listed below:

- The ability to measure: illuminance (Lux), illuminance ratio (%) or peak luminance ($cd.m^2$) instantaneous luminance.
- This Lux meter has a vast measurement range fast: (0.001 to 299,900 $cd.m^2$), Slow: (0.001 to 49.990 $cd.m^2$)
- It has Accuracy of 0.001 to 0.999 $cd.m^2$, ±2% ±2 digit of displayed value 1.000 $cd.m^2$ or greater: ±2% ±1 digit of displayed value (based on Konica Minolta standard).
- The measurement instrument can be operated between -10 and 40 $^{\circ C}$, and relative humidities of 85% and below.
- Luminance units: $cd.m^2$ or fL (switchable)
- Focusing distance: 1014 mm to infinity
- Measuring angel : 1^o
- Dimensions: 79 x 208 x 105 mm
- Power: 9V battery (x1)

(Konica Minolta LS 100, 2013)

Figure 30 : Konica Minolta LS 100

2.6 Simulation

The program, which has been used for this project is Dialux software (Dial 2017). This is a free-to-use lighting simulation software,using radiosity method for computing light distribution. That can be used for indoor and outdoor light designing.The tool allows for import and export of a variety of models from and to other tools but also can be used as stand alone modelling and simulation tool Dialux can be used both for derivation of lighting performance indicators such as daylight factor, illuminance and luminance values of any surface in the model and energy indicators such as the Lighting energy numeric indicator. Moreover, Dialux features a large database of luminaries, including photometric data and technical information. Many luminarie manufacturers offer individual data files in ULD or EULUMDAT formats, which can be direclty used to create virtual lighting scenes in Dialux.

This tools could be also used for day-lighting factors calculations according to EN15193-1 (EN15193-1, 2017) and also simulate both pre and post situations of the interior scene for studying the illuminance levels and distribution in workeplace. In this research, modeling the office scenes has been conducted based on corresponding building plans and in-situ measurements. Moreover, the urban surroundings, which form daylight obstructions, have been included in the simulation models. As such, the quality of results for daylight simulations could be improved.

2.7 Deriving Workplace Illumination

There are some fundamental methods, which are common for calculating average illuminance. The method, which has been used in this work plane, is the lumen method. The average lumens reaching at working surface area directly from luminaires and indirectly from other reflective surfaces can be calculated with this method. The results depend on room geometry and reflectance, luminous intensity distribution of luminaires and geometry of the room. (BS: IES 2004, 2011).

Procedure of calculation:

Determining the utilization factor from the table of photometric data:

Establish reflectance values for ceiling, walls, and floor from the table of photometric data to calculating room index K_r using the formula below:

$$K_r = \frac{LW}{h(L+W)} \qquad [5]$$

K_r = room index

L = a length of room [m]

W = width of room [m]

h = height above the working plane [m]

based on the value of the room index the CU value derived from the utilization factor table in luminaire data sheet. typical LED utilization factor datasheet as Figure 31:

Utilisation factor table

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80 0.50 0.30	0.80 0.50 0.10	0.70 0.50 0.30	0.70 0.50 0.20	0.70 0.50 0.10	0.70 0.30 0.10	0.50 0.30 0.10	0.50 0.10 0.10	0.30 0.30 0.10	0.30 0.10 0.10	0.00 0.00 0.00
0.60	0.76	0.73	0.76	0.74	0.72	0.68	0.68	0.65	0.67	0.65	0.64
0.80	0.84	0.79	0.83	0.81	0.79	0.75	0.74	0.71	0.73	0.71	0.70
1.00	0.91	0.85	0.90	0.87	0.84	0.80	0.80	0.77	0.79	0.77	0.75
1.25	0.97	0.89	0.96	0.92	0.89	0.85	0.84	0.82	0.83	0.81	0.80
1.50	1.02	0.92	1.00	0.96	0.92	0.88	0.88	0.85	0.87	0.85	0.83
2.00	1.09	0.97	1.07	1.01	0.97	0.94	0.93	0.91	0.92	0.90	0.88
2.50	1.14	1.00	1.11	1.05	0.99	0.97	0.96	0.95	0.95	0.94	0.92
3.00	1.17	1.02	1.14	1.07	1.01	1.00	0.98	0.97	0.97	0.96	0.94
4.00	1.21	1.04	1.17	1.10	1.03	1.02	1.01	1.00	0.99	0.99	0.96
5.00	1.23	1.05	1.19	1.11	1.05	1.04	1.02	1.01	1.00	1.00	0.98

Figure 31 : Typical LED utilisation factor datasheet

for instance, the value of Kr for Case study 1 in Artificial mode in 0.67, which is the closest value in the table for the value of 0.60 , and on the other hand the reflectance coffient for roof, wall and floor is $\rho_f = 0.10, \rho_w = 0.50, \rho_c = 0.80$ the according to the utilisation factor table the CU value is 0.73, since the lumen method is average luminance on the working surface, the following equation calculate E_{ave}.

$$E_{ave} = \frac{\varphi}{A}(CU)(MF) \qquad [6]$$

Where:

$\varphi =$ lamp lumen per luminaire (lm)

$A =$ Area (m^2)

CU = Cofficient of utilisation

MF = Maintaince factor

3. RESULTS

In the following section, the results of measurements, calculations and simulations of the case studies are described (This is in more details described under the methodology).

3.1 Case study 1

The first case study is Argentinierstrasse 35, this room has a single direct lighting system.

3.1.1 Measurement plan for case study 1

In this room, as shown in Figure 32. Point 1 to 4 were selected on workplace surface for measurement. The place of the sample points are shown in the following Figure.

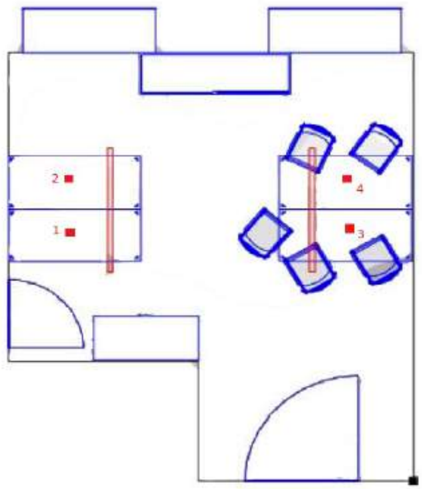


Figure 32 : The Points of measurements in the technical drawing room in Argentinierstrasse 35

3.1.2 Daytime Measurement

The measurement was done during 11:00 and 12:00 AM on 24.02.2017. The sky was overcast, and it was 9^{oC}. The tables 3 provide the measured data during that day. To calculate daylight factor on the mentioned surfaces, the mean horizontal outdoor illuminance level (20024 Lux) was measured.

Table 3 : Only daylight measurements in the technical drawing room, Argentinierstrasse 35

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight Only	1	210	1
	2	310	1.5
	3	257	1.3
	4	298	1.5
	Outside	Mean Horizontal	20024

The measured data as shown in Table 3 (illumination levels on measurement points) shows that during daytime the highest illumination is close to the windows in the room. Despite the per-se acceptable illumination levels at the different points, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 4 : Comparison of only daylight measurements with standard, Argentinierstrasse 35

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	210	-22	-72
2	310	15	-59
3	257	-4	-66
4	298	11	-60
Average	269	Standard	750

Table 4, compares the illuminance average (Lux), only daylight with required standard and, its deviation from average. it is possible to observe big failure compare to standard.

Table 5 : Comparison of daylight and artificial lighting measurments (Lux) with standard, Argentinierstrasse 35

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	255	-56	-66
2	781	33	-4
3	686	17	-9
4	621	6	-17
Average	586	Standard	750

Table 5, it is clearly shown that comparison of the illuminance average (Lux), daylight and artificial light on the tables in a technical drawing room with standard and, its deviation from average, it is possible to see a shortage in compare to standard.

3.1.3 Simulation of Existing situation with Dialux

The Figure 33 shows the measured data from current situation, using Dialux.

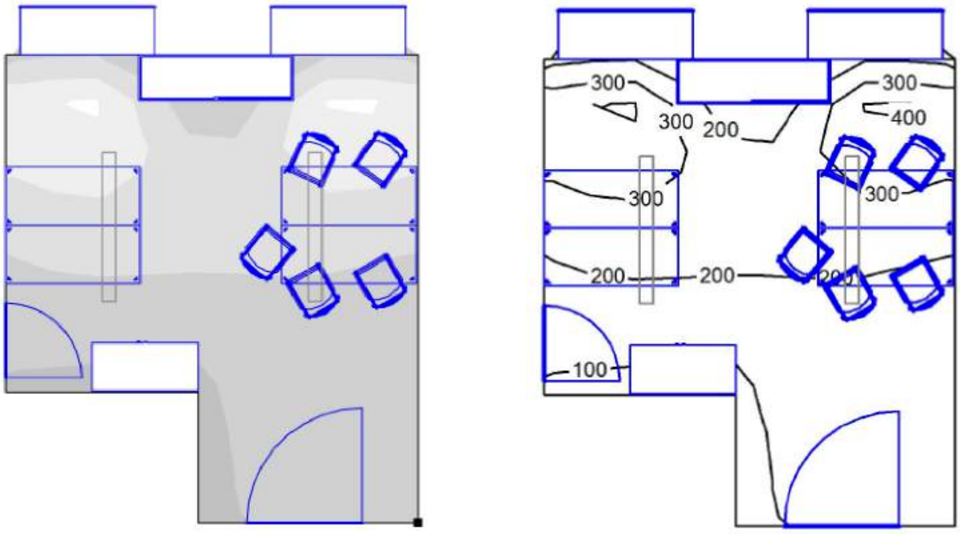


Figure 33 : (Left) grayscale, current situation, only daylight, based on Dialux
(Right) isoline, current situation, only daylight, based on Dialux

The simulated illuminances with Dialux illustrate nearly the same deficiencies as measured data showed. The horizontal illumination in the technical drawing room is lower than desirable. The average illuminance of the room was (E_{ave} = 220 Lux) after obstruction was applied during simulation, while it should be minimum of 750 Lux in this case.

Table 6 : Comparison of only daylight measurments (Lux) with simulation (Lux), Argentinierstrasse 35

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	210	200
2	310	300
3	257	300
4	298	300
Average	269	275

Table 6 represents, the comparing of the daylight measurements (Lux) with current situation simulation in the technical drawing room. According to table 6, the discrepancy between the simulated and measured illuminances shows little differences.

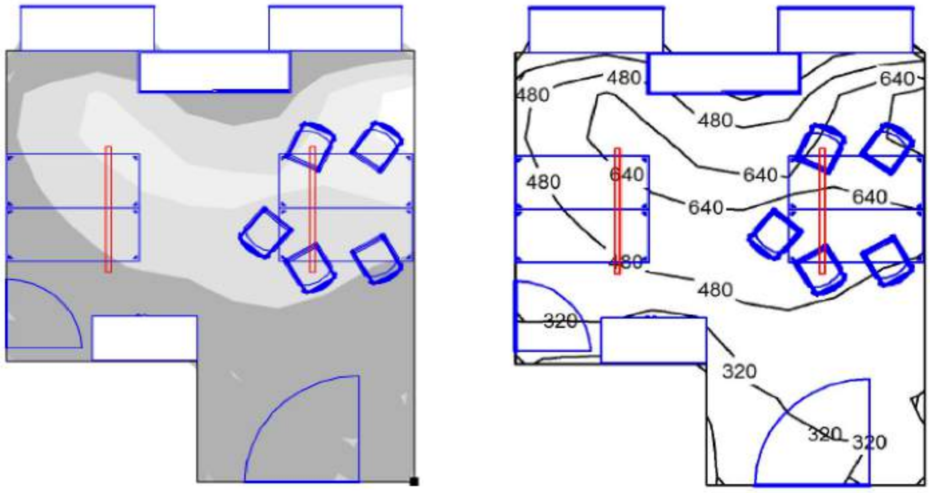


Figure 34 : (Left) grayscale, current situation, daylight and artificial light
(Right) isoline, current situation, daylight and artificial light

As shown in the Figure 34, the average illuminance E_{ave} = 500 Lux.The uniformity is (U_o=0.2), while required to be minimum (U_o=0.7) in this case. similar luminaire were chosen form dialux catalogue for this situation were Philips SM 530 C ,due to the unknown luminaire of the mentioned office.

Table 7 : Comparison of daylight and artificial lighting measurments (Lux)
with simulation (Lux), Argentinierstrasse 35

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	255	480
2	781	480
3	686	640
4	621	640
Average	586	560

Table 7, compared the accuracy of daylight and artificial lighting measurement with that of the current situation simulation. hereupon, the discrepancy between the simulation and measrement are proved to be significant and that could be due to unknown manufacturer of luminaire.

3.1.4 Evening Time Measurement (Artificial lighting)

The evening measurement to evaluate the condition of luminaire was done from 6 to 7 PM on the same date under similar weather conditions as observed in that morning. That to be described in table 8.

Table 8 : Comparison of only artificial lighting with standard, Argentinierstrasse 35

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	55	-42	-93
2	46	-51	-94
3	152	61	-80
4	124	32	-83
Average	94	Standard	750

Table 8 illustrates of the illuminance average (Lux), artificial light only with standard and its deviation from average. And I possible to observe large difference between my result. similar luminaire were chosen form dialux catalogue for this situation due to unknown manufacturer of luminaire, the Figure 35 shows the simulation result for this situation.

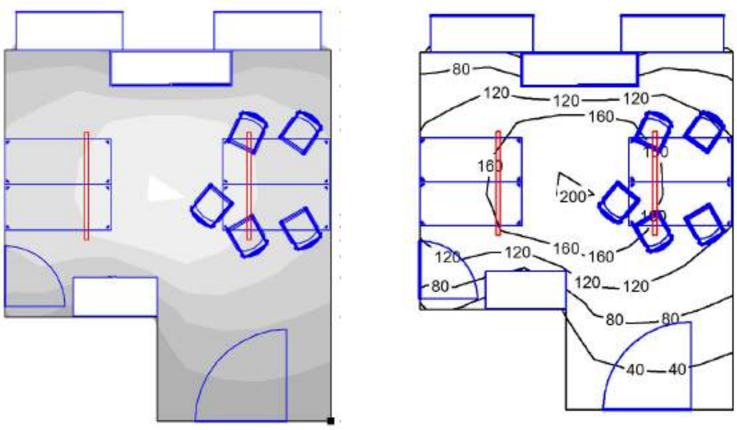
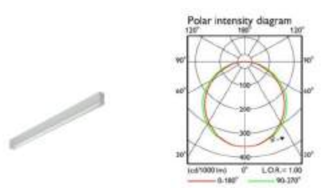


Figure 35 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



PHILIPS SM530C /830 OC

Luminous fLux: 1900 lm

Luminaire efficacy: 101 lm / W

Correlated color temperature: 3000 Kelvin

Figure 36 : The illumination characteristic and distribution curve (source: illustration by the author)

Table 9 : Comparison of only artificial lighting measurments (Lux) with simulation (Lux), Argentinierstrasse 35

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	55	137
2	46	133
3	152	135
4	124	124
Average	94	132

Table 9 compares measured with simulated illuminances for only artificial situation. The persisting deviations can potentially be caused by the luminaries selected for the simulation, which seems to be not fully compatible with existing luminares. Moreover, simplifications pertaining to glazing parameters, outside obstructions and surface reflectances might be casual for the deviations.

3.1.5 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires were used in the simulation similar to the standard recommendation to achieved (E_{ave} = 720 Lux). The selected luminaires for this case study are Zumtobel T16 VAERO-HA 2/80 W, dimensions: 1,608 m x 0.318 m x 0.062 m. Given direct light component and defined glare-free pattern at 60^o / 65^o as well as unique glare reduction for horizontal display, therefore uniformity increased up to (U_o= 0.7). In Figure 37 can be seen the simulated data according to the standard based on Dialux.

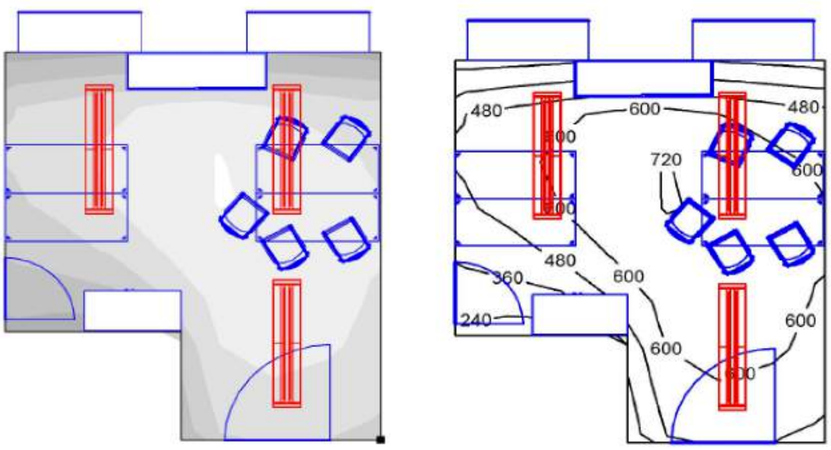
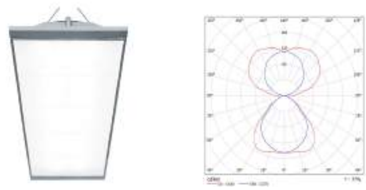


Figure 37 : (Left) grayscale, standard, improved case
(Right) isoline, standard, improved case



Zumtobel Vareo –HA 2/80 w L840.

Luminous fLux: 12300 lm

Luminaire efficacy: 107 lm / W

Correlated color temperature: 4000 Kelvin

Figure 38 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 10 : Deriving average Workplace Illumination

Case Study 1	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	19.48	221
Daylight + Artificial	---	---	---	19.48	502
Standard	0.60	0.73	28376	19.48	720

Table 10, it is shown that Deriving of average Workplace illumination in the technical drawing room.

3.2 Case study 2

The second case study was in Mariahilferstrasse; this room has free standing and direct lighting system.

3.2.1 Measurement plan for case study 2

In this room, as shown in Figure 39, points were carefully selected.points 1 to 13 were chosen carefully, which are 0.8 meter above the ground, were between the office employers sitting behind the desk and their Personal computer. The locations of the sample points are shown in the Figure below.

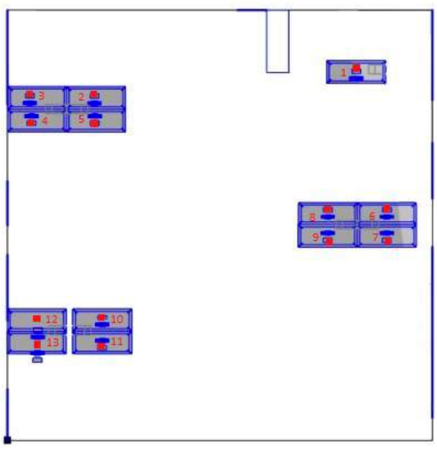


Figure 39 : The Points of measurements in the technical drawing room, Mariahilferstrasse 101

3.2.1 Daytime Measurement

The measurement was performed between 11:00 and 12:00 AM on 27.02.2017. The sky on that day was clear and it was 14^{oC}. Table 11 shows the measured data, using illuminance meter, throughout that day. To calculate the daylight factor on the mentioned surfaces, the mean horizontal outdoor illuminance level (52618 Lux) has been measured.

Table 11 : Only daylight measurements in the technical drawing room, Mariahilferstrasse101

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight Only	1	543	1
	2	452	0.85
	3	817	1.5
	4	454	0.86
	5	437	0.83
	6	920	1.74
	7	917	1.74
	8	635	1.2
	9	560	1.1
	10	330	0.6
	11	770	1.5
	12	935	1.7
	13	352	0.7
	Outside	Mean Horizontal	52618

The measured data as shown in Table 11, (illumination levels on measurement points) shows that during daytime the highest illumination is close to the windows in the room. Despite the per-se acceptable illumination levels at the different points, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 12 : Comparison of only daylight measurements with standard, Mariahilferstrasse101

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	543	-13	-28
2	452	-28	-40
3	817	31	9
4	454	-27	-39
5	437	-30	-42
6	920	47	23
7	917	47	22
8	635	2	-15
9	560	-10	-25
10	330	-47	-56
11	770	23	3
12	935	50	25
13	352	-44	-53
Average	625	Standard	750

Table 12 compares the illuminance average (Lux), only daylight with their standard. It also shows comparatively the light abundance versus its standards. This abundance of Lux on horizontal desks causes harsh direct glare for employees.

Table 13 : Comparison of daylight and artificial lighting measurements with standard, Mariahilferstrasse101

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	1168	10	56
2	802	-25	7
3	1590	49	112
4	761	-28	1
5	686	-36	-9
6	1050	-1	40
7	1082	2	44
8	840	-21	12
9	610	-43	-19
10	950	-11	27
11	990	-7	32
12	1602	51	114
13	1700	60	127
Average	1064	Standard	750

Table 13, it is clearly shown the comparison of the illuminance average (Lux),daylight and artificial light in the technical drawing room with standard and it is possible to observe large abundance of Lux on horizontal workplace that causing direct glare for employee.

3.2.1 Simulation of existing situation with Dialux

The Figure 40 shows the measured data of the existing situation, using Dialux.

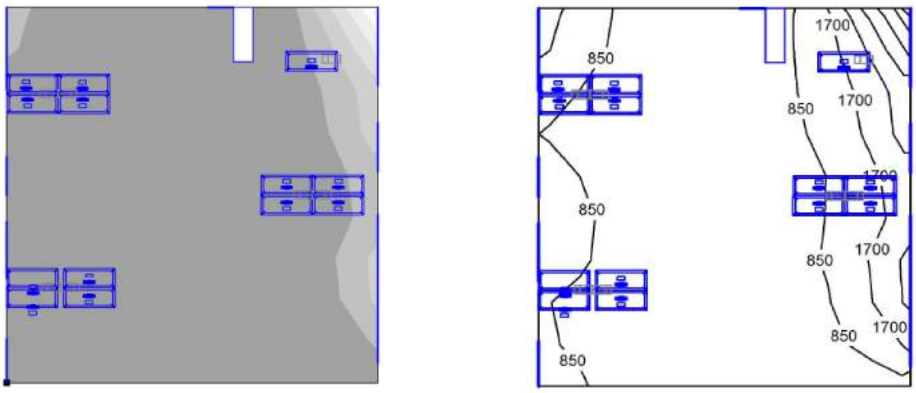


Figure 40 : (Left) grayscale, cuttent situation, daylight, based on Dialux
(Right) isoline , current situation , daylight, based on Dialux

The simulated illuminances with Dialux shows almost the result similar to that of the measured illuminances. The horizontal illuminance on some desks in the technical drawing room is surprisingly higher than what has been already expected. Illuminance distribution and uniformity also spread unequally; near the windows, for example, the Lux values are higher than the middle row of the office. The (E_{ave} = 850 Lux) should be minimum 750 Lux in this case.

Table 14: Comparison of only daylight measurments (Lux) with simulation (Lux), Mariahilferstrasse101

Measurement Point	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	543	850
2	452	850
3	817	850
4	454	850
5	437	850
6	920	1700
7	917	1700
8	635	850
9	560	850
10	330	850
11	770	850
12	935	850
13	352	850
Average	625	981

Table 14 compares the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room. According to the above table, the discrepancy between the simulated and measured illuminances are significant.

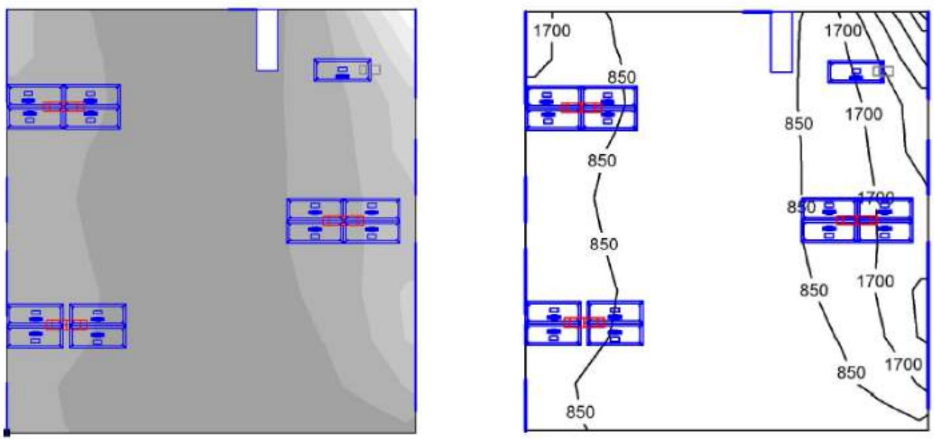


Figure 41 : (Left) grayscale, current situation, 100% of lamp with daylight
(Right) isoline, current situation, 100% of lamp with daylight

As shown in the Figure 41, the average illuminance or so-called E_{ave} is 1025 Lux. The spread of illuminance is not equal, and near the window has higher Lux values than in the center.The uniformity is shown (U_o= 0.4), while this should have been at least 0.7 in this case. Luminaries used at this room for measuring current situation were 3FFILIPPI Fly2 Piantana GR 2x55.

Table 15 : Comparison of daylight and artificial lighting measurments (Lux) withsimulation (Lux), Mariahilferstrasse101

Measurement Point	Measured Illuminances (Lux)	Simulated Illuminances (Lux)
1	1168	1127
2	802	712
3	1590	1751
4	761	965
5	686	665
6	1050	1321
7	1082	1321
8	840	949
9	610	1247
10	950	1274
11	990	1274
12	1602	1274
13	1700	1274
Average	1064	1166

Table 15 compares the accuracy of daylight as well as artificial lighting measurements (Lux) condition with that of the current situation simulation. Accordingly, the discrepancy between the simulated and measured illuminances are proved to be significant and this could be due to an unknown manufacturer of the luminaire.

3.2.2 Evening time Measurement (Artificial Lighting)

The evening measurement to evaluate the condition of luminaire was made from 6 PM to 7 PM of the same date under similar weather conditions as observed in that morning. This is to be described as follows.

Table 16 : Comparison of only artificial lighting measurements with standard in the technical drawing room, Mariahilferstasse 101

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	543	-39	-28
2	980	11	31
3	654	-26	-13
4	620	-30	-17
5	1100	24	47
6	814	-8	9
7	900	2	20
8	505	-43	-33
9	436	-51	-42
10	1292	46	72
11	1200	35	60
12	1295	46	73
13	1180	33	57
Average	886	Standard	750

Table 16 compares of the illuminance average (Lux) of only artificial light with its standard level and surprisingly I noticed a large difference in my results. The Figure 42 shows illumination condition at the relevant office.

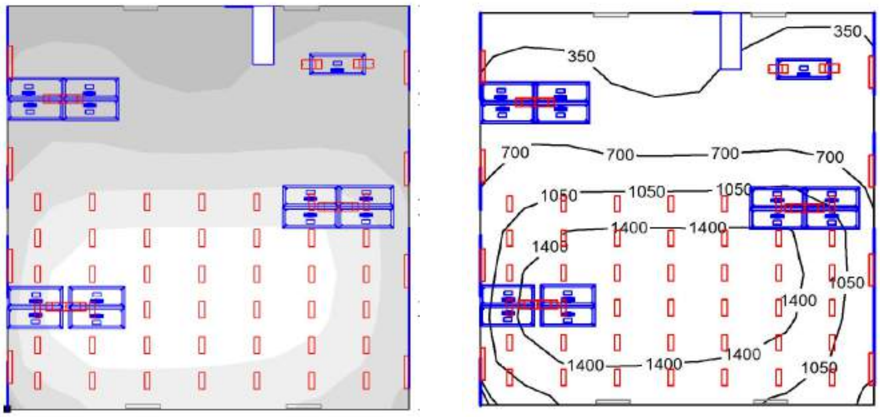
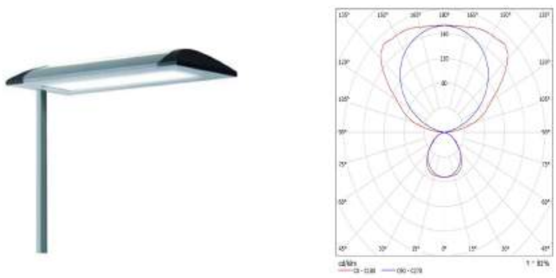


Figure 42 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



3FFILIPI FLY 2 Piantana

Luminous fLux: 7741 lm

Luminaire efficacy: 118 lm / W

Correlated color temperature: 4000 Kelvin

Figure 43 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 17 : Comparison of only artificial lighting measurments (Lux) with simulation (Lux), Mariahilferstrasse101

Measurement Point	Measured Illuminances (Lux)	Simulated Illuminances (Lux)
1	543	585
2	583	980
3	654	583
4	620	604
5	1100	1020
6	814	938
7	900	938
8	505	602
9	436	425
10	1292	1221
11	1200	1243
12	1295	1227
13	1180	1282
Average	886	865

Table 17 compares measured with simulated illuminances for the case of only artificial light. A rather high degree of correspondence can be seen. The persisting deviations can potentially be caused by the luminaries selected for the simulation, which do not fully correspond to the existing luminaries. Moreover, simplifications pertaining to glazing parameters, outside obstructions and surface reflectances might be causal for the deviations.

3.2.3 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires used enabled us to reach the standard (E_{ave}=719 Lux). The selected luminaires for this case study are PHILIPS RC310B L600 2 xLED20S/830. Given the direct light component and defined glare-free pattern at 55^0 / 65^0 as well as its special glare reduction feature for horizontal display, the uniformity has increased to (U_o= 0.67). Figure 44 shows the simulated data according to standard, using Dialux.

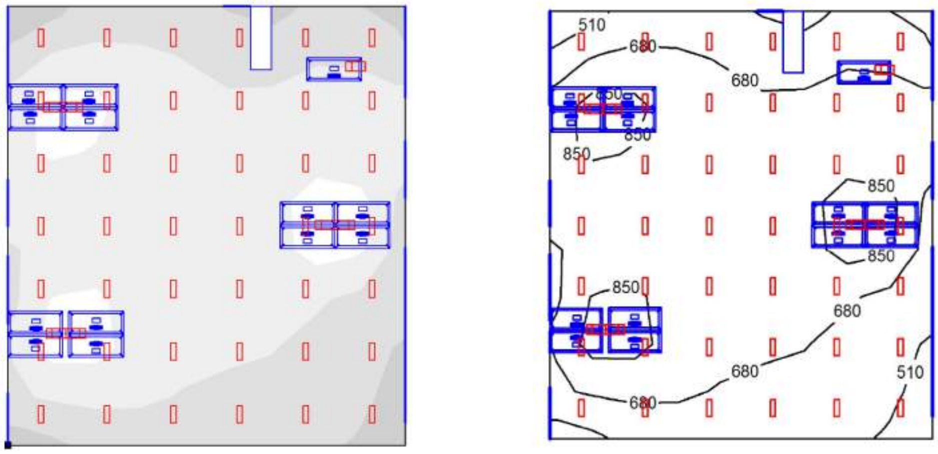
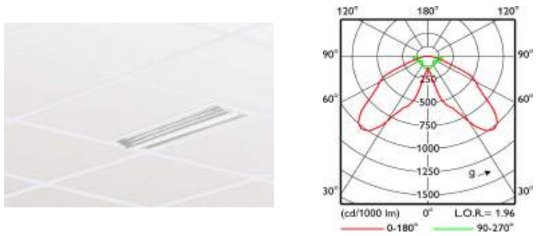


Figure 44 : (Left) grayscale, standard, improved case
(Right) isoline, standard, improved case



PHILIPS RC310B L600 2 LED20S/830 P65

Luminous fLux: 4600 lm

Luminaire efficacy: 112 lm / W

Correlated color temperature: 3000 Kelvin

Figure 45 : The illumination characteristic and distribution curve (source: illustration by the author)

Table 18 : Deriving average Workplace illumination

Case Study 2	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	219.28	970
Daylight + Artificial	---	---	---	219.28	1025
Standard	2.50	1	247387	219.28	720

Table 18, it is shown that Deriving of average Workplace illumination in the technical drawing room.

3.3 Case study 3

The third case study took place in Neustiftgasse. The room has single, direct lighting system.

3.3.1 Measurement plan for case study 3

In this place, as noted in Figure 46, between 1 to 6 points were carefully selected in front of each desk, which was close to office employees. The height of each table was 0.8 meter. The sample points are shown in the following Figure.

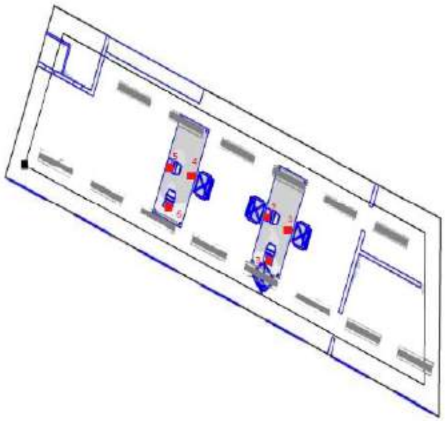


Figure 46 : The Points of measurements in the technical drawing room in Neustiftgasse 32

3.3.2 Daytime Measurement

The measurement was done between 10:00 to 11:00 AM on 10.02.2017. It was cloudy on the same day with almost 2^{oC}. Table 19 presents the measured data during the mentioned day. To calculate daylight factor on the mentioned desk surfaces, the mean horizontal outdoor illuminance level (22918 Lux) has been measured.

Table 19 : Only daylight measurements in the technical drawing room ,Neustiftgasse 32

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight only	1	124	0.5
	2	114	0.5
	3	170	0.7
	4	121	0.5
	5	144	0.6
	6	186	0.8
	Outside	Mean Horizontal	22918

The measured data as shown in table 19, (illumination levels on measurement points) shows during the daylight measurement, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 20 : Comparison of only daylight measurements with standard,Neustiftgasse 32

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from standard (%)
1	124	-13	-83
2	114	-20	-85
3	170	19	-77
4	121	-15	-84
5	144	1	-81
6	186	30	-75
Average	143	Standard	750

Table 20, described the comparison between the illuminance average (Lux), only daylight with required standard and it is a comparatively large deficiency in comparison to standard.

Table 21 : Comparison of daylight and artificial lighting measurements with standard, Neustiftgasse 32

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	280	15	-63
2	253	4	-66
3	200	-18	-73
4	260	6	-65
5	268	10	-64
6	205	-16	-73
Average	244	Standard	750

Table 21, illustrates the comparison of the illuminance average (Lux),daylight and artificial light in the technical drawing room with standard and it is possible to observe large deficiency of Lux on horizontal workplace.

3.3.3 Simulation of existing situation with Dialux

In the Figure 47 shows the measured data from current situation simulated, using Dialux.

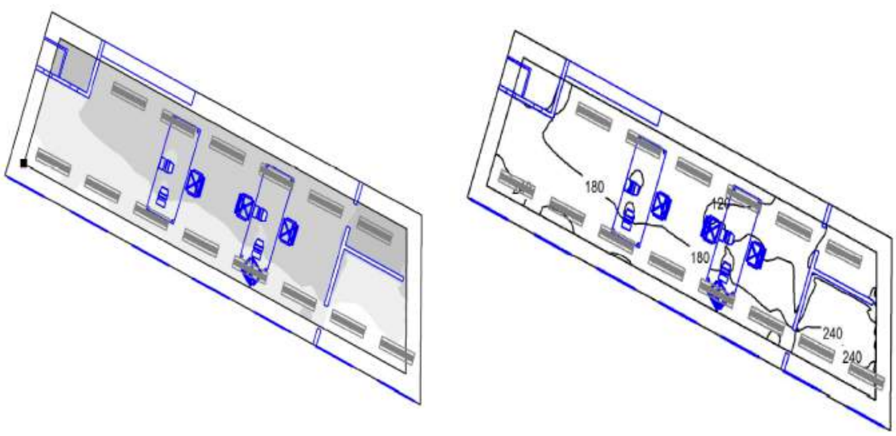


Figure 47 : (Left) grayscale, current situation, daylight, based on Dialux
(Right) isoline, current situation, daylight, based on Dialux

The simulated illuminances with Dialux shows almost same deficiency as measured illuminances. The horizontal illumination on some Workplace was lower than desirable, illumination distribution spread unequally and uniformity levels was below the minimum recommendation. The Lux values are (E_{ave} = 137 Lux) which should be a minimum of 750 Lux in this case.

Table 22: Comparison of only daylight measurments (Lux) with simulation (Lux), Neustiftgasse 32

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	124	125
2	114	115
3	170	179
4	121	129
5	144	155
6	186	188
Average	143	149

Table 22, evaluate the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room. According to the above table, the discrepancy between the simulated and measured Insignificant.

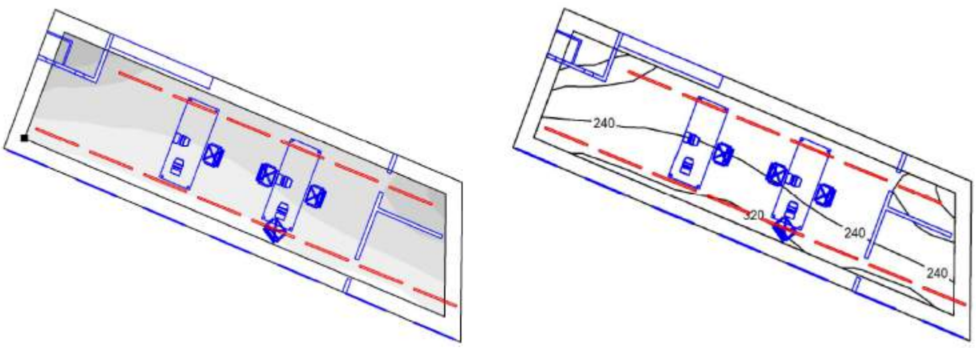


Figure 48 : (Left) grayscale, current situation, 100% of lamp with daylight
(Right) isoline, current situation, daylight, 100% of lamp with daylight

As shown in the Figure 48, the average illuminance or so-called E_{ave} is 232 Lux. distribution of illuminance are not equal also near the window has higher Lux values than middle of the room. The uniformity is (U_o= 0.3), which should be minimum (U_o= 0.7) in this case. Luminaire has used in this room for measuring current situation Philips SM 531 C LED 19S/840.

Table 23: Comparison of daylight and artificial lighting measurments (Lux) with simulation (Lux), Neustiftgasse 32

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	280	220
2	253	276
3	200	276
4	260	277
5	268	237
6	205	268
Average	244	259

Table 23, compares the accuracy of the daylight and artificial lighting measurements (Lux) with simulated illuminance in same situation. therefore, The evaluation of result from simulation corresponds with measurements seem insignificant.

3.3.1 Evening time Measurement (Artificial lighting)

The evening measurement to evaluate the condition of luminaire was perform 6 to 7 P.M of same date under similar weather conditions as observed in that morning, This is to be described as follows.

Table 24 : Comparison of only artificial lighting with standard in the technical drawing room, Neustiftgasse 32

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	115	-9	-85
2	138	9	-82
3	113	-10	-85
4	131	4	-83
5	136	8	-82
6	124	-2	-83
Average	126	standard	750

Table 24, compares of the illuminance average (Lux), only artificial light in the technical drawing room with the relevant standard and it is noticed a large deficiency in my result.

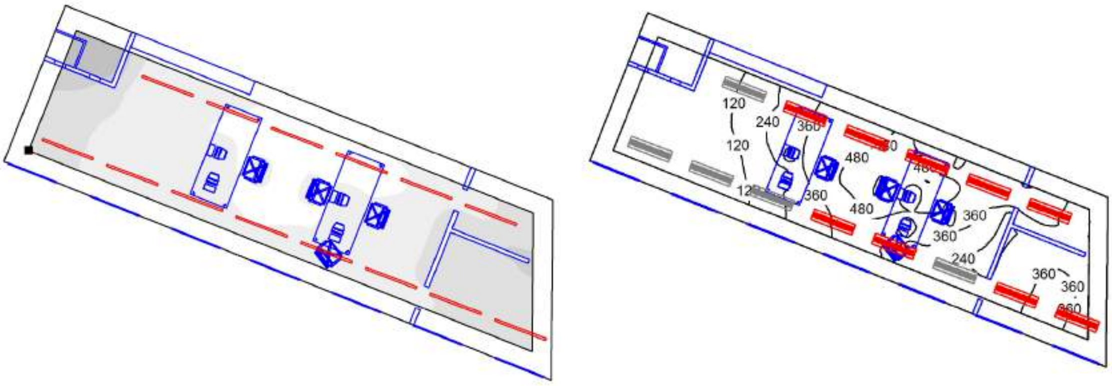
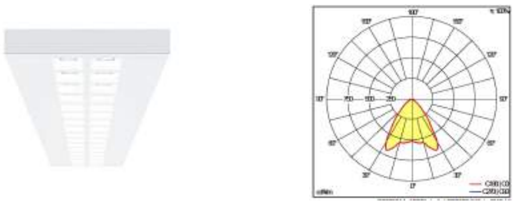


Figure 49 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



Zumtobel - MIREL-L A LED3800-840 L1200 EVG

Luminous fLux: 3740 lm

Luminaire efficacy: 134 lm / W

Correlated color temperature: 4000 Kelvin

Figure 50 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 25: Comparison of only artificial lighting measurments (Lux) with simulation (Lux), Neustiftgasse 32

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	115	161
2	138	164
3	113	154
4	131	163
5	136	157
6	124	153
Average	126	159

Table 25, compares measured with simulated illuminances for the case of only artificial light. A rather lower degree of correspondence can be seen. The deviations can probably be caused by the luminaries was chosen for the simulation, which does not fully correspond to the existing luminaries in the room. Moreover, simplifications pertaining to glazing parameters, outside obstructions, and surface reflectances might be causal for the deviations.

3.3.2 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and amount of luminaire were considered in the simulation according to the standard recommendation that minimum requested illuminance has been reached (E_{ave} =800 Lux).The selected luminaires for this case study are Zumtobel VAERO LED 840. With direct / indirect light component and defined glare-free pattern at 45^0 / 55^0 besides special glare reduction for horizontal display, therefore uniformity increased up to (U_o= 0.4). In the Figure below shown the simulated data according to standard based on Dialux.

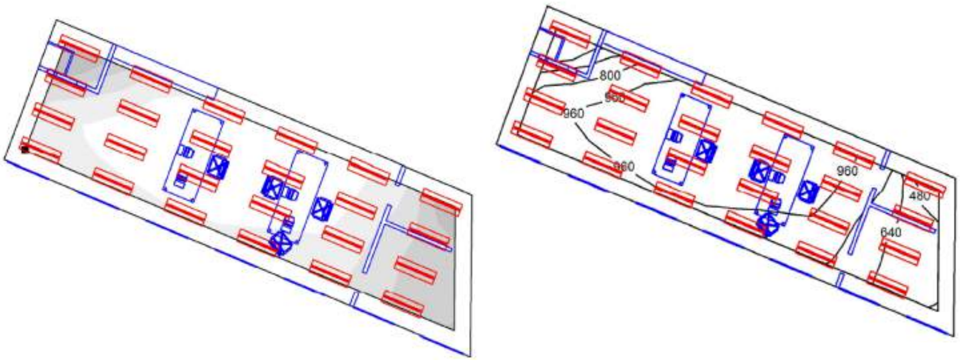
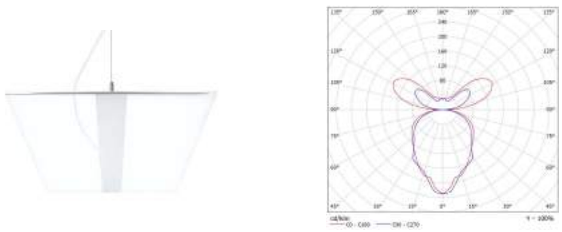


Figure 51 : (Left) grayscale, standard, improved case

(Right) isoline, standard, improved case



VAERO LED5000-840 LDE ASQ1 WH

Luminous fLux: 5000 lm

Luminaire efficacy: 107 lm / W

Correlated color temperature: 4000 Kelvin

Figure 52 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 26 : Deriving average Workplace illumination

Case Study 3	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	62.27	139
Daylight + Artificial	---	---	---	62.27	232
Standard	1.25	0.7	120000	62.27	800

Table 26, it is shown that Deriving of average Workplace illumination in the technical drawing room.

3.4 Case study 4

The fourth case study was in Zieglergasse, this room has single, direct lighting system.

3.4.1 Measurement plan for case study 4

In this room as shown in the Figure 53 points were carefully selected. The locations of the sample points are shown in Figure below.

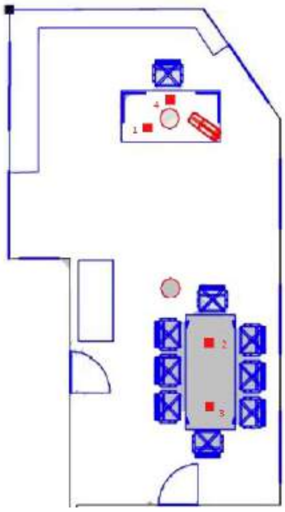


Figure 53 : The Points of measurements in the technical drawing room in Zieglergasse 29

3.4.2 Daytime Measurement

The measurement was performed between 10:00 to 11:00 AM on 13.02.2017. The sky on that day was clear and it was 3^{oC}. Table 27 shows the measured, using illuminance meter, throughout that day. To calculate the daylight factor on the mentioned Surfaces, the mean horizontal outdoor illuminance level (43344 Lux) thas been measured.

Table 27: Only daylight measurements in the technical drawing room, Zieglergasse 29

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight only	1	200	0.5
	2	291	0.7
	3	266	0.6
	4	210	0.5
	Outside	Mean Horizontal	43344

The measured data as shown in table 27, (illumination levels on measurement points) shows during the daylight measurement, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 28 : Comparison of only daylight measurements with standard, Zieglergasse 29

Measurement Points	Illuminance (Lux)	Deviation From Average (%)	Deviation From Standard (%)
1	200	-17	-73
2	291	20	-61
3	266	10	-65
4	210	-13	-72
Average	242	Standard	750

In table 28, compares the illuminance average (Lux), only daylight in the room with their standard. It observes comparatively large deficiency in vis-à-vis standard.

Table 29 : Comparison of daylight and artificial lighting measurements with standard , Zieglergasse 29

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	490	14	-35
2	365	-15	-51
3	315	-26	-58
4	543	27	-28
Average	428	Standard	750

Table 29, it is clearly shown the comparison of the illuminance average (Lux), daylight and artificial light in the technical drawing room with their standard. It also observes the deficiency of illumination on the horizontal surface of the Workplace.

3.4.3 Simulation of existing situation with Dialux

The Figure 54 illustrate the measured data from current situation simulated base on Dialux.

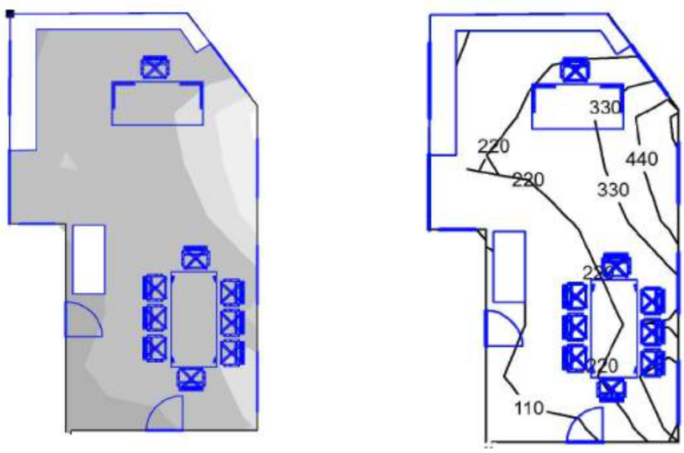


Figure 54 : (Left) grayscale, current situation, daylight, based on Dialux
(Right) isoline, current situation, daylight, based on Dialux

The simulated illuminances with Dialux shows almost the result similar to that of the measured illuminances.The horizontal illuminance on some workplace in technical drawing room is lower than expected, illuminance distribution and uniformity also spreaded unequally; near the windows, for example, the Lux values higher than the middle row of the office. The (E_{ave} = 220 Lux) should be minimum 750 Lux in this case.

Table 30: Comparison of only daylight measurments (Lux) with simulation (Lux), Zieglergasse 29

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	200	220
2	291	330
3	266	220
4	210	220
Average	242	248

Table 30 compares the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room. According to the above table, the discrepancy between the simulated and measured illuminance is seems insignificant.

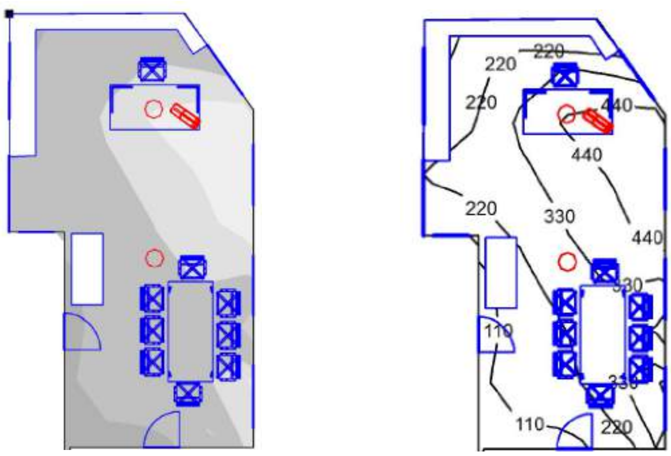


Figure 55 : (Left) grayscale, current situation, 100% of lamp with daylight
(Right) value chart, current situation, 100% of lamp with daylight

As shown in the Figure 55, the average illuminance E_{ave} is 330 Lux. The spread of illuminance is not equal, and near the window has higher Lux values than center. The uniformity is shown (U_o= 0.3), while this should have been at least (U_o= 0.7). Luminares used at this room for measuring current situation were PHILIPS FS484F 1xLED45S/840 MLO for Desk lamp and PHILIPS PT570P 1xLED19S/ROSE WB ceiling luminaire.

Table 31: Comparison of daylight and artificial lighting measurments (Lux) with Simulation, Zieglergasse 29

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	490	440
2	365	330
3	315	330
4	543	440
Average	428	385

Table 31 compares the accuracy of daylight as well as artificial lighting measurements (Lux) condition with that of the current situation simulation. therefore, the discrepancy between the simulated and measured illuminances are proved to be insignificant.

3.4.4 Evening time Measurement (Artificial Lighting)

The evening measurement to evaluate the condition of luminaire was made from 6 to 7 P.M of the same date under similar weather conditions as observed in that morning. This is to be described as follows.

Table 32 : Comparison of only artificial lighting with standard in the technical drawing room, Zieglergasse 29

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	540	111	-28
2	100	-61	-87
3	56	-78	-93
4	330	29	-56
Average	257	Standard	750

Table 32 compares of the illuminance average (Lux) of only artificial light with its standard level and surprisingly I noticed a large difference in my results. The Figure 56 shows illumination condition at the relevant office.

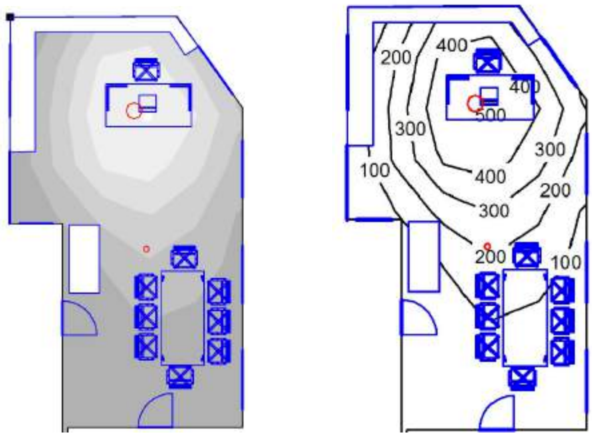
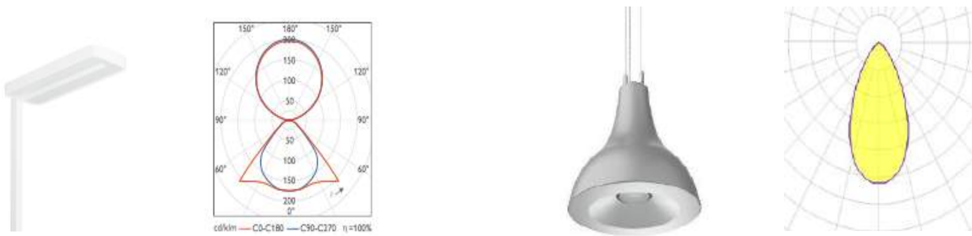


Figure 56 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



PHILIPS FS484F 1xLED45S/840 MLO

Luminous fLux: 4500 lm

Luminous efficacy: 112 lm / W

Corelated colour temprature: 3000 Kelvin

PHILIPS PT570P 1xLED19S/ROSE WB

Luminous fLux: 1900 lm

Luminous efficacy: 61 lm / W

Corelated colour temprature: 3000 Kelvin

Figure 57 : The Illumination characteristic and distribution curve luminaire (source: illustration by the author)

Table 33: Comparison of only artificial lighting measurments (Lux) with Simulation, Zieglergasse 29

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	540	505
2	100	146
3	56	67
4	330	429
Average	257	287

Table 33 compares measured with simulated illuminances for the case of only artificial light. A rather low degree of correspondence can be seen. The deviations can probably be caused by the luminaries was chosen for the simulation, which does not fully correspond to the existing luminaries in the room. Moreover, simplifications pertaining to glazing parameters, outside obstructions, and surface reflectances might be causal for the deviations.

3.4.5 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires used enabled us to reach the standard (E_{ave} =720 Lux).The selected luminaires for this case study are Zumtobel TECON B BASIC LED5200-840. Given the direct light component and defined glare-free pattern at 55^0 / 45^0 besides special glare reduction for horizontal display, the uniformity has increased to (U_o= 0.6). Figure 58 shows the simulated data according to standard, using Dialux.

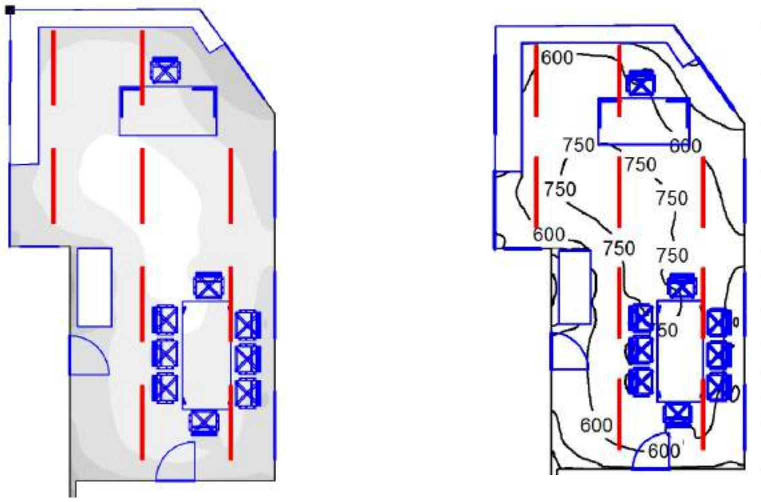
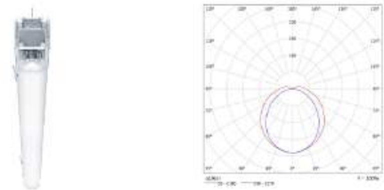


Figure 58 : (Left) grayscale, standard, improved case
(Right) isoline, standard, improved case



Zumtobel TECON B BASIC LED5200-840
Luminous fLux: 5260 lm
Luminous efficacy: 146 lm / W
Coulor temperature: 4000 Kelvin

Figure 59 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 34 : Deriving average Workplace illumination

Case Study 4	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	45.09	220
Daylight + Artificial	---	---	---	45.09	330
Standard	1	0.9	83200	45.09	720

Table 34, it is shown that Deriving of average Workplace illumination in the technical drawing room.

3.5 Case study 5

the fifth case study was in Westbahnstrasse 26, this room has single, direct lighting system.

3.5.1 Measurement plan for case study 5

In this room, as shown in the Figure 60 points were carefully selected. Points 1 to 9, which are 0.8 meter above ground, were between the office employers sitting at the desk and their personal computer. The locations of the sample points are shown in the figure below.

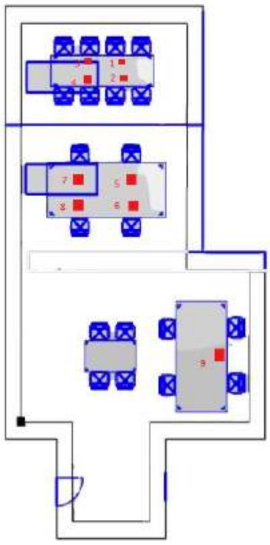


Figure 60 : The Points of measurements in the technical drawing room in Westbahnstrasse 26

3.5.2 Daytime Measurement

The measurement was performed between 10:00 and 11:00 AM on 15.02.2017. The sky on that day was clear and it was 7^{oC}. The table 35 provide the measured data thoroughout that day. To calculate daylight factor on the mentioned Surfaces, the mean horizontal outdoor illuminance level (46323 Lux) has been measured.

Table 35 : Only daylight measurements in technical drawing room, Westbahnstrasse 26

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight only	1	244	0.1
	2	273	0.2
	3	240	0.1
	4	180	0.4
	5	350	0.8
	6	275	0.6
	7	192	0.4
	8	210	0.5
	9	170	0.4
	Outside	Mean Horizontal	46323

The measured data as shown in table 35, (illumination levels on measurement points) shows during the daylight measurement, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 36 : Comparison of only daylight measurements with standard, Westbahnstrasse 26

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	244	3	-67
2	273	15	-64
3	240	1	-68
4	180	-24	-76
5	350	48	-53
6	275	16	-63
7	192	-19	-74
8	210	-11	-72
9	170	-28	-77
Average	237	Standard	750

Table 36, compares the illuminance average (Lux), only daylight in the technical drawing room with their standard. It also shows comparatively large deficiency in some points vis-à-vis standards. In the mentioned office Due to lack of direct lighting, an employee used a desk lamp to lighten up the workplaces. Consequently, daylight and artificial lighting measurement did not perform.

3.5.3 Simulation of existing situation with Dialux

The Figure 61 shows the measured data of the existing situation, using Dialux.

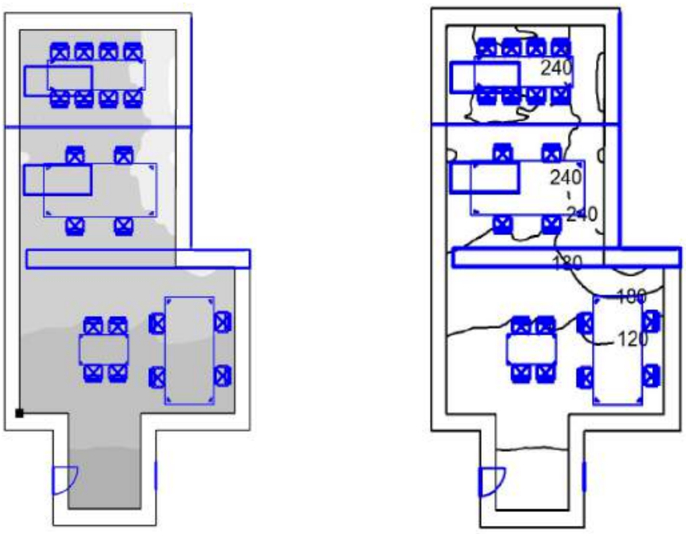


Figure 61 : (Left) grayscale, current situation, only daylight, based on Dialux
(Right) isoline, current situation, only daylight, based on Dialux

The simulated illuminances with Dialux shows almost the result similar to that of the measured illuminances. The horizontal illuminance on some Workplace in the whole room is lower than expected, illumination distribution and uniformity levels was below the minimum recommendation; near the windows, for example, the Lux values are higher than the middle row of the office. The average of illuminance is (E_{ave} = 240 Lux) which should be minimum 750 Lux in this case.

Table 37 : Comparison of only daylight measurments (Lux) with simulation (Lux), Westbahnstrasse 26

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	244	225
2	273	239
3	240	219
4	180	218
5	350	218
6	275	216
7	192	203
8	210	203
9	170	140
Average	237	209

Table 37, compares the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room. According to the above table, the discrepancy between the simulated and measured illuminances are insignificant.

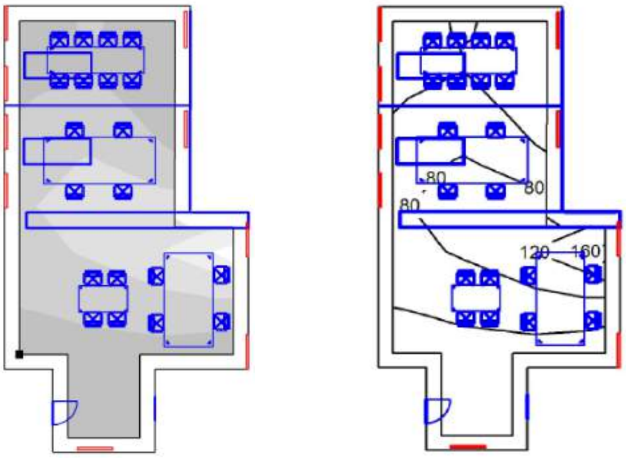


Figure 62 : (Left) grayscale, current situation, 100% of lamp with daylight
(Right) value chart, current situation, 100% of lamp with daylight

as shown in the Figures 62, the average illuminance E_{ave} is 260 Lux. The spread of illuminance is not equal. The uniformity is shown (U_o = 0.3), while this should have been at least 0.7 in this case. Luminares used at this room for measuring current situation were PHILIPS RC533B PSD W8L117 1 xLED15S/830 NOC.

3.5.4 Evening time Measurement (Artificial Lighting)

The evening measurement to evaluate the condition of luminaire was made from 6 to 7 P.M of the same date under similar weather conditions as observed in that morning. This is to be described as follows.

Table 38 : Comparison of only artificial lighting with standard in the technical drawing room, Westbahnstrasse 26

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	105	-47	-86
2	106	-46	-86
3	176	-11	-77
4	175	-11	-77
5	75	-62	-90
6	120	-39	-84
7	192	-3	-74
8	197	0	-74
9	631	220	-16
Average	197	Standard	750

Table 38, compares of the illuminance average (Lux) of artificial light with its standard level its standard level and surprisingly a large difference in my results. The Figure 63 shows the illumination condition at the relevant office.

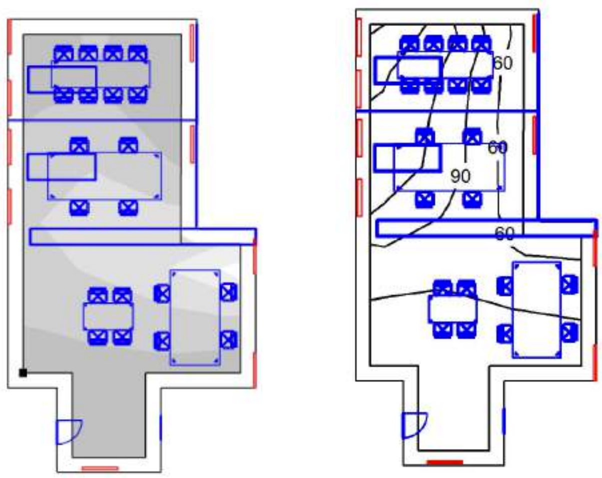
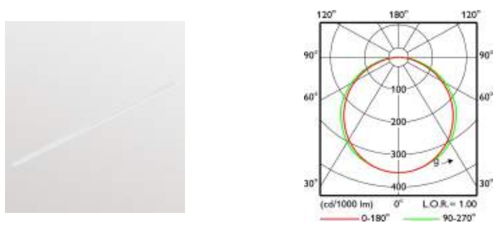


Figure 63 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



PHILIPS RC533B PSD W8L117 1 xLED15S/830 NOC.

Luminous fLux: 1500 lm

Luminaire efficacy: 103 lm / W

Correlated color temperature: 4000 Kelvin

Figure 64 : The Illumination characteristic and distribution curve luminaire (source: illustration by the author)

Table 39: Comparison of only artificial lighting measurments (Lux) with Simulation, Westbahnstrasse 26

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	105	108
2	106	115
3	176	150
4	175	134
5	75	101
6	120	86
7	192	134
8	197	121
9	631	665
Average	197	179

Table 39, compares measured with simulated illuminances for the case of only artificial light. A rather lower degree of correspondence can be seen. The deviations can probably be caused by the luminaries was chosen for the simulation, which does not fully correspond to the existing luminaries in the room. Moreover, simplifications pertaining to glazing parameters, outside obstructions, and surface reflectances might be causal for the deviations.

3.5.5 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires used enabled us to reach the standard (E_{ave} = 720 Lux). The selected luminaires for this case study are Zumtobel AERO LED11000-840. Given direct light component and defined glare-free pattern at 55^0 / 45^0 as well as its special glare reduction for horizontal display, the uniformity has increased to (U_0 = 0.7). In the Figure 65 shows the simulated data according to a standard, using Dialux.

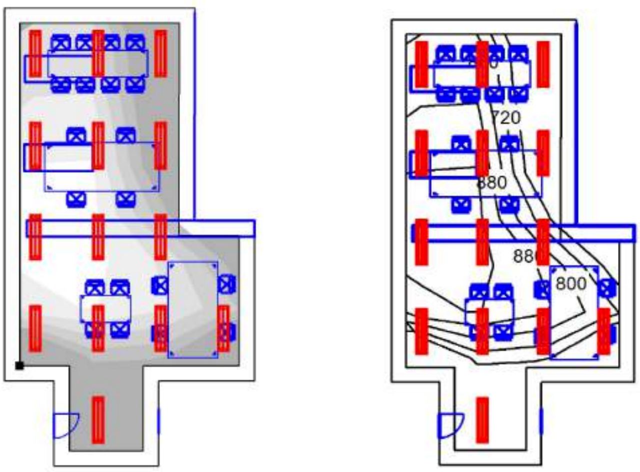
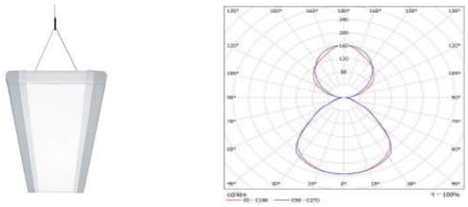


Figure 65 : (Left) grayscale, standard, improved case

(Right) isoline, standard, improved case



Zumtobel AERO LED11000-840

Luminous fLux: 10400 lm

Luminaire efficacy: 109 lm / W

Correlated color temperature: 4000 Kelvin

Figure 66 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 40 : Deriving average Workplace illumination

Case Study 5	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Artificial	1	0.91	15500	96.1	260
Daylight	---	---	---	96.1	240
Standard	1	1.2	145600	96.1	720

Table 40, it is shown that Deriving of average Workplace illumination in the technical drawing room.

3.6 Case study 6

The sixth case study was in Burggasse 94a, this room has single, direct lighting system.

3.6.1 Measurement plan for case study 6

In this room, as shown in the Figure 67, Points 1 to 7 were carefully selected, which are 0.8 meter above ground, were between the office employers sitting at the desk and their personal computer. The locations of the sample points are shown in the Figure below.

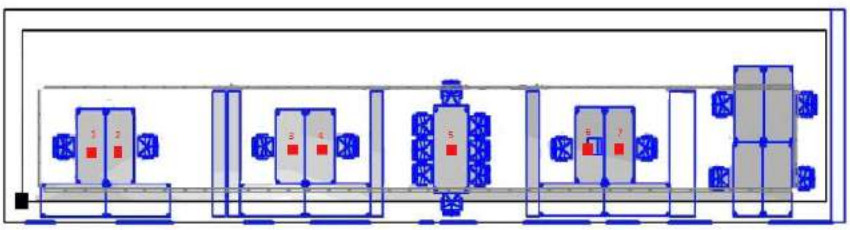


Figure 67 : The Points of measurements in the technical drawing room in Burggasse 94a .

3.6.2 Daytime Measurement

The measurement was performed between 11:00 and 12:00 AM on 20.02.2017. The sky on that day was clear and it was 2^{oC}. The table 41 shows the measured data using illuminance meter, throughout that day. To calculate the daylight factor on the mentioned Surfaces, the mean horizontal outdoor illuminance level (33020 Lux) has been measured.

Table 41 : Only daylight measurements in the technical drawing room, Burggasse 94a

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight Only	1	397	1.2
	2	280	0.8
	3	508	1.5
	4	205	0.6
	5	229	0.7
	6	574	1.7
	7	423	1.3
	Outside	Mean Horizontal	33020

The measured data as shown in Table 41 (illumination levels on measurement points) shows that during daytime the highest illumination is close to the windows in the room. Despite the per-se acceptable illumination levels at the different points, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 42 : Comparison of only daylight measurements with standard, Burggasse 94a

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	397	6	-47
2	280	-25	-63
3	508	36	-32
4	205	-45	-73
5	229	-39	-69
6	574	54	-23
7	423	13	-44
Average	374	Standard	750

In table 42, compares the illuminance average (Lux), only daylight in the technical drawing room with their standard. It also shows a comparatively large deficiency in versus its standard.

Table 43 : Comparison of daylight and artificial lighting measurements with standard, Burggasse 94a

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	1266	5	69
2	1030	-14	37
3	990	-18	32
4	1078	-10	44
5	1765	47	135
6	1250	4	67
7	1022	-15	36
Average	1200	Standard	750

Table 43, it is clearly shown the comparison of the illuminance average (Lux), daylight and artificial light in the technical drawing room with thier standard. It is possible to observe large abundance of Lux on the horizontal Workplace that causing harsh glare for employee.

3.6.3 Simulation of existing situation with Dialux

The Figure 68 shows the measured data of the current situation, using Dialux.

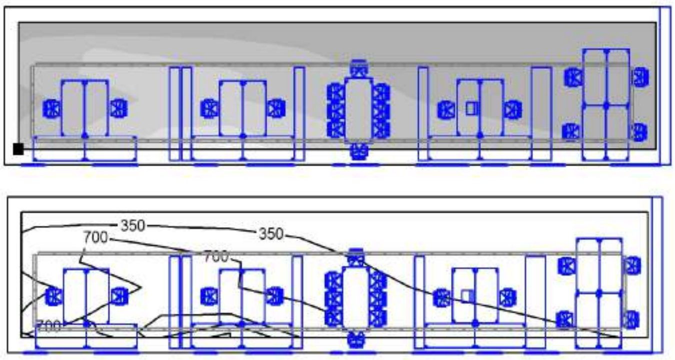


Figure 68 : (Above) grayscale, current situation, only daylight, based on Dialux
(Below) isoline, current situation, only daylight, based on Dialux

The simulated illuminances with Dialux shows almost the result similar to that of the measured illuminances. the horizontal illuminance on some workplace is lower than expected, illuminance distribution and uniformity also spread unequally. The (E_{ave} = 448 Lux) should be minimum 750 Lux in this case.

Table 44 : Comparison of only daylight measurments (Lux) with simulation (Lux), Burggasse 94a

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	397	341
2	280	340
3	508	665
4	205	302
5	229	195
6	574	639
7	423	278
Average	374	394

Table 44, compares the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room.according to the above table, the discrepancy between the simulated and measured illuminances are insignificant.

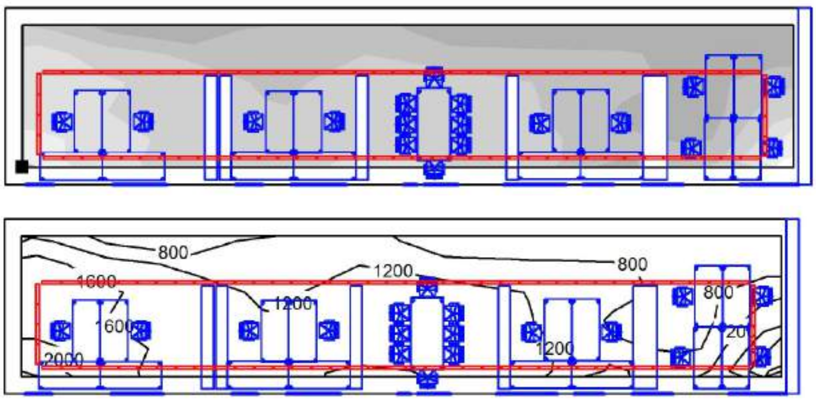


Figure 69 : (Above) grayscale, current situation, 100% of lamp with daylight
(Below) value chart, current situation, 100% of lamp with daylight

As shown in the Figures 69, the average illuminance Eave is 1268 Lux. The spread of illuminance is not equal, and near the window has higher Lux values than in the middle row of office. The uniformity is shown (U_o = 0.4), while this should have been at least (U_o = 0.7) in this case. the abundance of Lux on the horizontal workplace that results in unpleasant glare for an employee during a day. Luminaire has used this room for measuring current situation were PHILIPS RC415B G2 PSD W15L125.

Table 45 : Comparison of daylight and artificial lighting measurments (Lux) with simulation (Lux), Burggasse 94a

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	1266	1325
2	1030	1406
3	990	863
4	1078	1162
5	1765	1988
6	1250	1182
7	1022	1112
Average	1200	1291

Table 45, compares the accuracy of daylight as well as artificial lighting measurements (Lux) condition with that of the current situation simulation. therefore, the discrepancy between the simulated and measured illuminances are proved to be insignificant.

3.6.4 Evening time Measurement (Artificial Lighting)

The evening measurement evaluate the condition of luminaires that was made from 6 to 7 P.M of the same date under similar weather conditions as observed in that morning. This is to be described as follows.

Table 46 : Comparison of only artificial simulation with standard, Burggasse 94a

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	1024	27	37
2	832	3	11
3	693	-14	-8
4	757	-6	1
5	692	-14	-8
6	833	3	11
7	828	2	10
Average	808	Standard	750

Table 46, compares of the illuminance average (Lux) of only artificial light with its standard level and surprisingly I noticed a large difference in my results. The Figure 70 shows illumination condition at the relevant office.

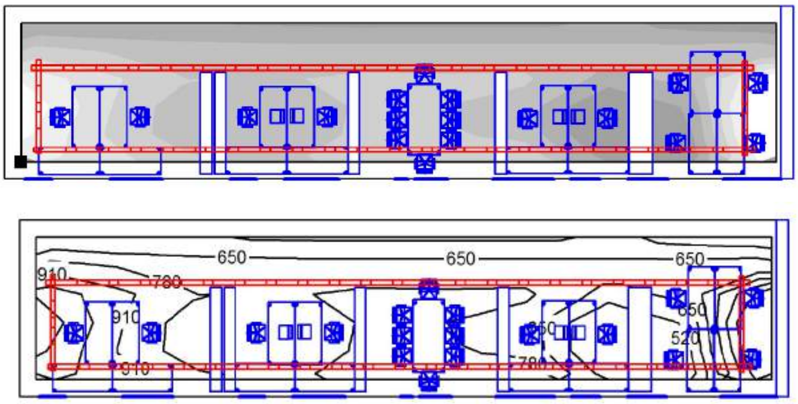
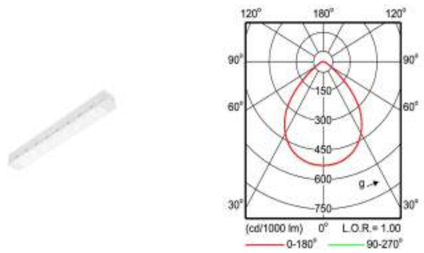


Figure 70 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



PHILIPS RC415B G2 PSD W15L125

Luminous fLux: 2000 lm

Luminaire efficacy: 121 lm / W

Correlated color temperature: 4000 Kelvin

Figure 71 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 47 : Comparison of only artificial lighting measurments (Lux) with simulation (Lux), Burggasse 94a

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	1024	1053
2	832	843
3	693	687
4	757	811
5	692	688
6	833	816
7	828	823
Average	808	817

Table 47 compares measured with simulated illuminances for the only artificial lighting measurements. A rather high degree of correspondence can be seen. The persisting deviations can potentially be caused by the luminaries selected for the simulation, which do not fully correspond to the existing luminaries. Moreover, simplifications pertaining to glazing parameters, outside obstructions and surface reflectances might be causal for the deviations.

3.6.5 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires used enabled us to reach near to standard (E_{ave} =828 Lux). The selected luminaires for this case study are Zumtobel SLOIN LED10000-840. Given the direct light component and defined glare-free pattern at 55^0 / 45^0 as well as special glare reduction for horizontal display, the uniformity increased up to (U_o= 0.6). In the Figure 72 shows the simulated data according to the standard, using Dialux.

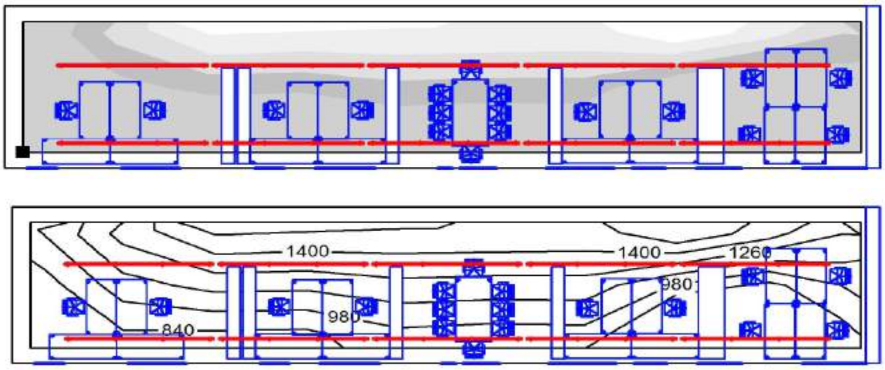
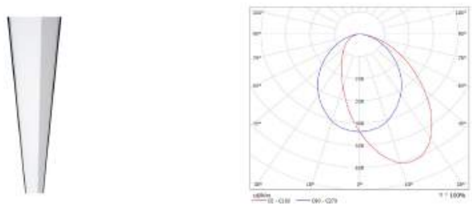


Figure 72 : (Above) grayscale, standard, improved case
(Below) isoline, standard, improved case



Zumtobel SLOIN LED10000-840

Luminous fLux: 10390 lm

Luminaire efficacy: 85 lm / W

Correlated color temperature :4000 Kelvin

Figure 73 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 48 : Deriving average Workplace illumination

Case Study 6	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	118.68	448
Daylight + Artificial	---	---	---	118.68	1268
Standard	2.5	1.36	145600	118.68	828

Table 48, it is shown that Deriving of average Workplace Illumination in the technical drawing room.

3.7 Case study 7

The seventh case study was in Capistrangasse, this room has stand indirect lighting system.

3.7.1 Measurement plan for case study 7

In this room, as shown in the Figure 74 points 1 to 7 were carefully selected on the workplace surface. The locations of the sample points are shown in Figure below.

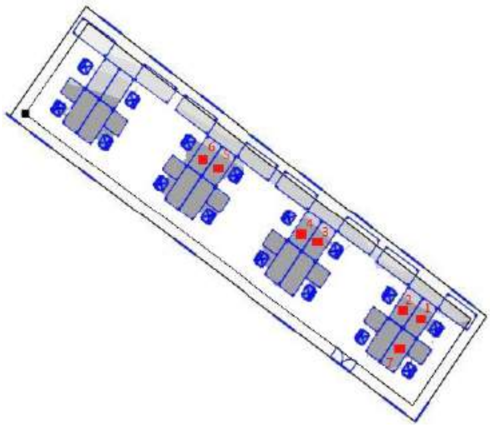


Figure 74 : The Points of measurements in the technical drawing room in Capistrangasse 5

3.7.2 Daytime Measurement

The measurement was performed between 11:00 and 12:00 AM on 22.02.2017. The sky on that day was overcast and it was 4 $^{o\,C}$. The table 49 provide the measured data, throughout that day. To calculate the daylight factor on the mentioned Surfaces, the mean horizontal outdoor illuminance level (31460 Lux) has been measured.

Table 49 : Only daylight measurements in technical drawing room, Capistrangasse 5

	Measurement Points	Illuminance (Lux)	Daylight factor (df%)
Daylight Only	1	210	0.7
	2	253	0.8
	3	263	0.8
	4	141	0.4
	5	144	0.4
	6	236	0.7
	7	100	0.3
	Outside	Mean Horizontal	31460

The measured data as shown in Table 49 (illumination levels on measurement points) shows that during daytime the highest illumination is close to the windows in the room. Despite the per-se acceptable illumination levels at the different points, the calculation of the corresponding daylight levels is below the minimum recommendation of 2% at all points and in average.

Table 50: Comparison of only daylight measurements with standard, Capistrangasse 5

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	210	9	-72
2	253	31	-66
3	263	37	-65
4	141	-27	-81
5	144	-25	-81
6	236	23	-69
7	100	-48	-87
Average	192	Standard	750

In table 50, compares the illuminance average (Lux), only daylight in the technical drawing room, with their standard. It also shows comparatively large deficiency in vis-à-vis standard.

Table 51 : Comparison of daylight and artificial lighting measurements with standard, Capistrangasse 5

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	296	16	-61
2	465	83	-38
3	263	3	-65
4	141	-45	-81
5	144	-43	-81
6	236	-7	-69
7	238	-7	-68
Average	255	Standard	750

Table 51, it is clearly shown the comparison of the illuminance average (Lux), daylight and artificial light in the technical drawing room with their standard and it is possible to observe deficiency of Lux on the horizontal workplace surfaces.

3.7.3 Simulation of existing situation with Dialux

The Figure 75 shows the measured data of current situation,using Dialux.

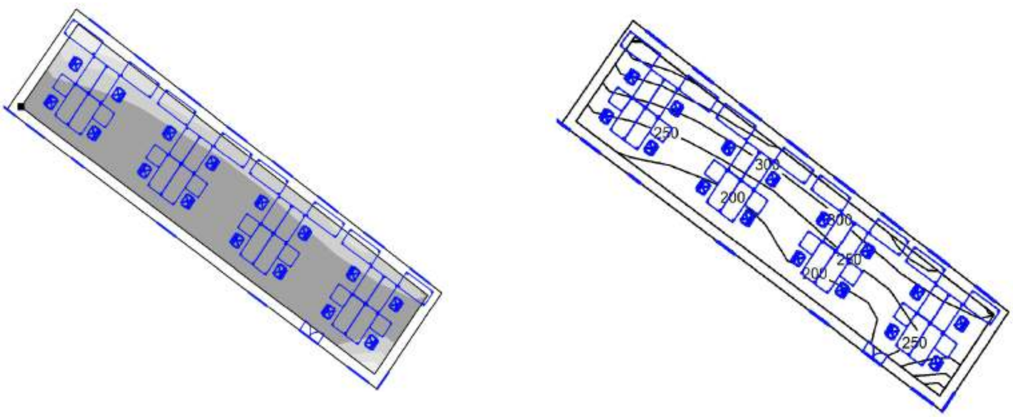


Figure 75 : (Left) grayscale, current situation, daylight, based on Dialux
(Right) isoline, current situation, daylight, based on Dialux

The simulated illuminances with Dialux shows almost the result similar to that of the measured illuminances. The horizontal illumination on some Workplace surfaces in the technical drawing room is lower than desirable, illuminance distribution spread unequally and uniformity levels was below the minimum recommendation. The Lux (E_{ave} = 257 Lux) should be minimum 750 Lux in this case.

Table 52 : Comparison of only daylight measurments (Lux) with simulation (Lux), Capistrangasse 5

Measurement Points	Measured illuminances (Lux)	Simulated illuminances (Lux)
1	210	286
2	253	212
3	263	223
4	141	224
5	144	198
6	236	220
7	100	164
Average	192	218

Table 52 compares the accuracy of only daylight measurements (Lux) with existing situation simulation in the technical drawing room. According to the above table, the discrepancy between the simulated and measured illuminances are insignificant.

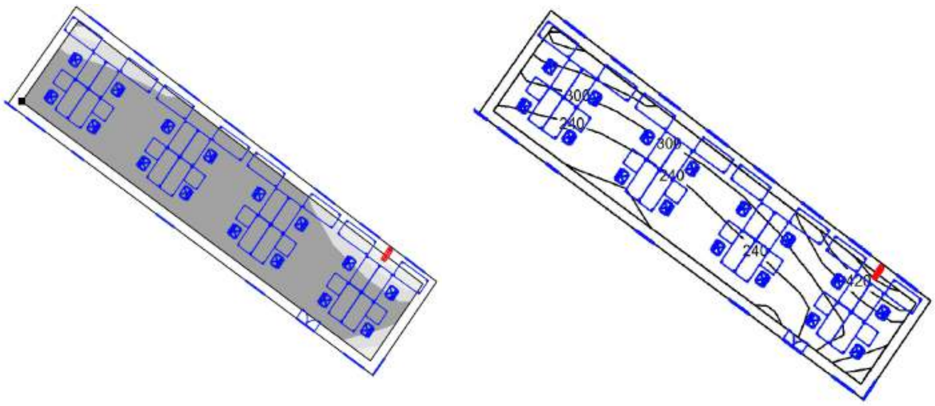


Figure 76 : (Left) grayscale, current situation, 100% of lamp with daylight
(Right) value chart, current situation, 100% of lamp with daylight

As shown in the Figures 76, the average illuminance E_{ave} is 300 Lux. The spread of illuminance and uniformity are not equal, and near the window has higher Lux values than the middle row of office. The uniformity is shown (U_o= 0.3), while this should be minimum (U_o= 0.7) in this case. The luminaires used at this room for measuring current situation were PHILIPS FS484F1xLED45S/840 MLO.

Table 53 : Comparison of daylight and artificial lighting measurments (Lux) with simulation (Lux), Capistrangasse 5

Measurement Points	Measured illuminance (Lux)	Simulated illuminance (Lux)
1	296	271
2	465	418
3	263	341
4	141	201
5	144	179
6	236	242
7	238	249
Average	255	272

Table 53 compares the accuracy of daylight as well as artificial lighting measurements (Lux) condition with that of the current situation simulation. therefore, the discrepancy between the simulated and measured illuminances are proved to be insignificant.

3.7.4 Evening time Measurement (Artificial Lighting)

The evening measurement to evaluate the condition of luminaires was made from 5 to 6 P.M of the same date under similar weather conditions as observed in that morning. This is to be described as follows.

Table 54 : Comparison of only artificial lighting measurement with standard, Capistrangasse 5

Measurement Points	Illuminance (Lux)	Deviation from Average (%)	Deviation from Standard (%)
1	261	20	-65
2	240	10	-68
3	232	7	-69
4	155	-29	-79
5	134	-38	-82
6	236	9	-69
7	264	21	-65
Average	217	Standard	750

Table 54 compares of the illuminance average (Lux) of only artificial light with thier standard level and their deviation from average. and surprisingly, I noticed a large difference in my result. The Figure 77 shows illumination condition at the relevant office.

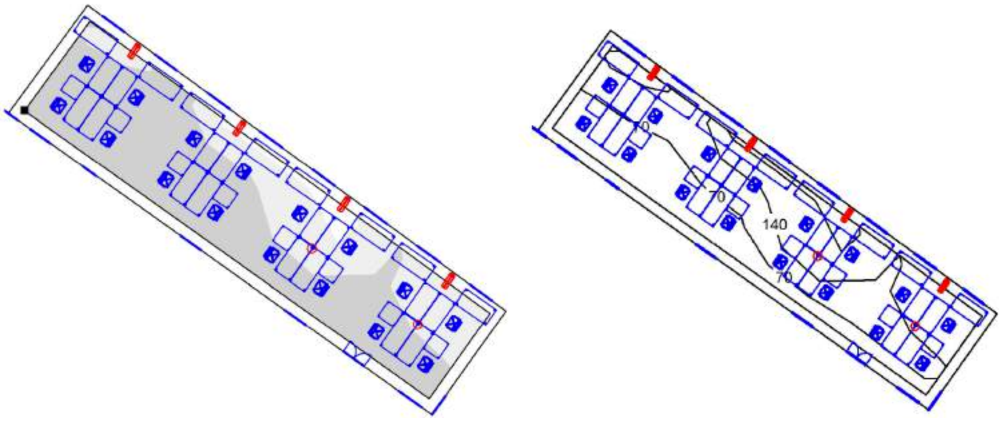
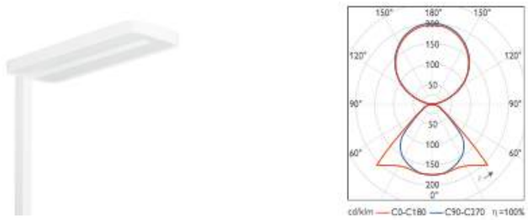


Figure 77 : (Left) grayscale, current situation, artificial light, based on Dialux
(Right) isoline, current situation, artificial light, based on Dialux



PHILIPS FS484F 1xLED45S/840 MLO

Luminous fLux: 4500 lm

Luminous efficacy: 112 lm / W

Corelated colour temprature: 3000 Kelvin

Figure 78 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 55 : Comparison of only artificial lighting measurments (Lux) with simulation (Lux), Capistrangasse 5

Measurement Points	Measured illuminance (Lux)	Simulated illuminance (Lux)
1	261	280
2	240	255
3	232	247
4	155	255
5	134	145
6	236	250
7	264	283
Average	217	245

Table 55 compares measured with simulated illuminances for the only artificial lighting measurements. A rather high degree of correspondence can be seen. The persisting deviations can potentially be caused by the luminaries selected for the simulation, which do not fully correspond to the existing luminaries. Moreover, simplifications pertaining to glazing parameters, outside obstructions and surface reflectances might be causal for the deviations.

3.7.5 Simulation (luminaire setup addressing the standard-stipulated minimum requirements)

In this case, the arrangement and number of luminaires used enabled us to reach the standard (E_{ave}= 800 Lux).The selected luminaires for this case study are Zumtobel AERO LED-840. Given direct light component and defined glare-free pattern at 55^0 / 45^0 besides special glare reduction feature for horizontal display, therefore uniformity increased to (U_o= 0.7). Figure 79 shows the simulated data according to the standard,using Dialux.

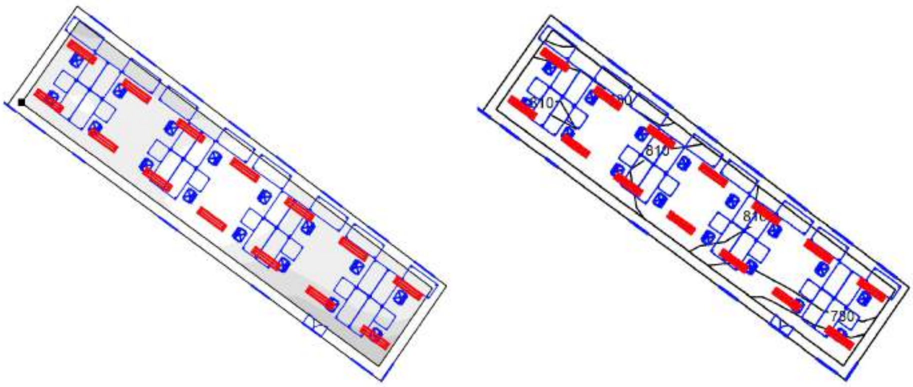
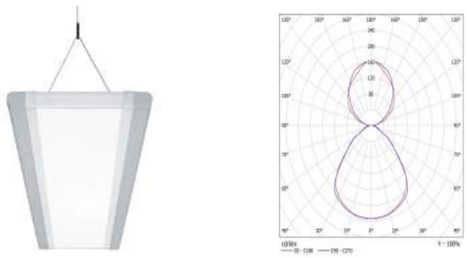


Figure 79 : (Left) grayscale, standard, improved case
(Right) isoline, standard, improved case



Zumtobel AERO LED11000-840
Luminous fLux: 10400 lm
Luminaire efficacy: 109 lm / W
Correlated color temperature: 4000 Kelvin

Figure 80 : The Illumination characteristic and distribution curve (source: illustration by the author)

Table 56 : Deriving average Workplace illumination

Case Study 7	K_r	CU	φ (lm)	A (m^2)	E_{ave} (Lux)
Daylight	---	---	---	126.3	257
Daylight + Artificial	---	---	---	126.3	300
Standard	1.50	1	149800	126.3	800

Table 56, it is shown that Deriving of average Workplace Illumination in the technical drawing room.

3.8 Summry of results

Table 57, clearly shown the summary of results for all case studies,in most of these offices it is practically visible to observe the shortage of illuminance on the workplace, unless one or two of the mention offices suffered from aboundance of illumination.

Table 57 : Summary of results, all Case studies

Case Studies	Situation	Average Measured Illuminance (lux)	Average Simulated Illuminance (lux)
Case Study 1	Only Daylight	269	275
	Daylight+Artificial Lighting	586	560
	Only Artificial Lighting	94	132
Case Study 2	Only Daylight	625	981
	Daylight+Artificial Lighting	1064	1166
	Only Artificial Lighting	886	865
Case Study 3	Only Daylight	143	149
	Daylight+Artificial Lighting	244	259
	Only Artificial Lighting	126	159
Case Study 4	Only Daylight	242	248
	Daylight+Artificial Lighting	428	385
	Only Artificial Lighting	257	287
Case Study 5	Only Daylight	237	209
	Daylight+Artificial Lighting	225	260
	Only Artificial Lighting	197	179
Case Study 6	Only Daylight	374	394
	Daylight+Artificial Lighting	1200	1291
	Only Artificial Lighting	808	817
Case Study 7	Only Daylight	192	218
	Daylight+Artificial Lighting	255	272
	Only Artificial Lighting	217	245

4. Survey Analysis

This survey was intended to examin certain issues such as the appearance of the lighting system, appearance of the room and its lighting environment, the amount of light, colour naturalness, visibility, and visual performance. This has enabled me to test my hypothesis. It is of significatly important to note that data analysis alone would not be sufficient for finding decent answers to my research questions, although their interpretation seems essentilly vital.

4.1 User satisfaction

4.1.1 Occupants

Altogether 33 room occupants participated in a general questionnaire, 24 of whom were male and another 9 were female. 15 occupants were above 30, 14 occupants aged between 30 and 39, and another 4 occupants were between 40 and 49. All of the respondents have willingly participated in my survey.

4.1.2 Surveys

In this questionnaire, the appearance of the lighting system, appearance of the room and its lighting in the office environment, amount of light, colour naturalness, visibility, and visual performance have been evaluated. Full text of the survey can be found in Appendix 2.

Lighting parameters have been graded from 1 to 7 where, 1 indicates, “completely dissatisfied ” and 7 indicates, “completely satisfied”. Answers to these questions are achievable in Table 58.

Table 58 : User surveys results

	1	2	3	4	5	6	7
User satisfaction	Completely dissatisfied	dissatisfied	Fairly dissatisfied	Neither satisfied nor dissatisfied	Fairly satisfied	satisfied	Completely satisfied
Appearance of illumination							
Illumination at the workplace	0	3	4	2	15	9	0
illumination in the room general	0	0	0	3	4	17	9
illumination in the front PC	6	4	0	0	18	2	3
Feeling unpleasent glare	0	2	8	5	4	5	9
Use the desk lamp in workplaces	11	12	2	8	0	0	0
Manually adjust light	0	14	4	5	2	3	5
Visual scene							
Sufficient illuminance for completing the task	0	19	0	0	0	0	14
Artificial light Causing strong glare	0	5	8	4	2	7	7
Sense about light visually	0	0	0	0	6	22	5
Lighting system match with visual needs	0	0	0	0	0	24	9
Lighting preference	0	5	8	4	2	7	7

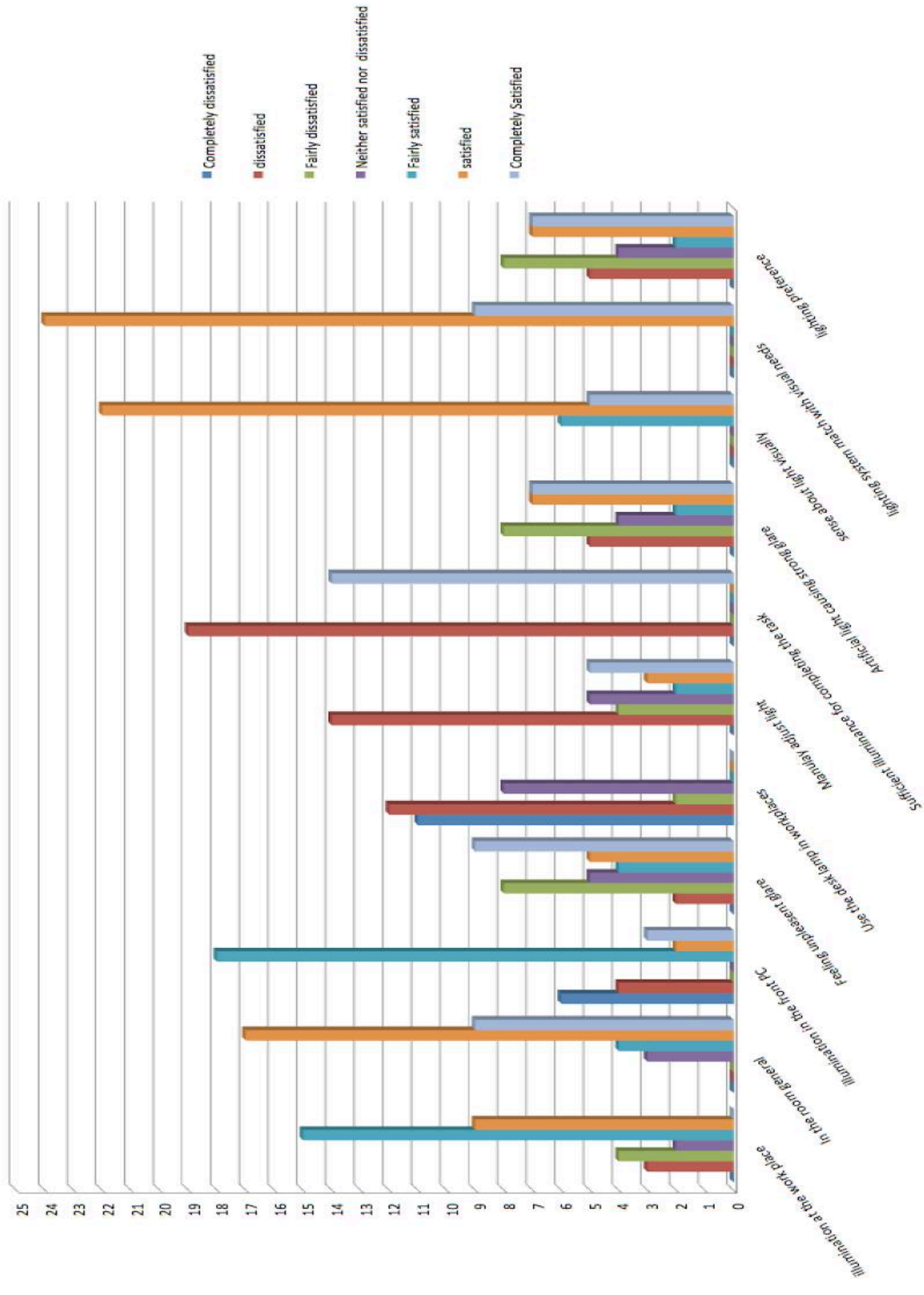


Figure 81: Employee feedback on each question

5. Conclusion, Limitations, and Future Research

This contribution concentrated on lighting levels in small scale offices, namely architecture offices in Vienna, Austria. Thereby, both measurements were conducted, as well as simulation models were generated and used for evaluation. These efforts were conducted to find answers to three research questions (see section "Research questions"):

Q1) How is the quality of illumination (daylight and artificial lighting) in the existing condition of workplaces, compared with corresponding standards (DIN EN 12464-1)?

Results of both measurements and simulations show that illumination levels, in general, can be considered as too low in comparison with normative recommendations. In the case of artificial lighting, in some cases the performance on the work planes was in the range of or at least close to minimum requirements, in others there could a severe shortfall of the measured values in comparison to the minimum requirements be observed. Regarding daylight-only measurements, the performance of the different workplaces is of course strongly dependent on orientation and positioning in relation to the windows. However, even in "well-positioned" places, only a few case studies showed acceptable daylight factor values and illuminances (thus reached the minimum requirements).

To sum up, it can be stated that the majority of workplaces would benefit from a reshaping of artificial lighting, and in some cases, positioning in relation to the windows should be considered.

Q2) Can it be said that the simulation provides similar results as the measurements? Can thus be said that the simulation can be used for the study of potential improvements?

In most cases, the simulation showed only small deviations from measurements, while in others the deviations could found to be larger. Regularly rather good accordance of measured and simulated values could be observed in the daylight simulation cases, even if Dialux does not consider the real-condition sky models, but rather artificial approximations of different sky conditions (clear sky, mixed sky, overcast sky). Regarding the cases "evening" (artificial lighting) and artificial plus daylight, simulations and measurements also provide rather acceptable accordance. As such the question can be answered with a Yes.

Q3) Which suggestions could be proposed for the improvement of the lighting conditions in the case studies?

The preliminary optimizations conducted in the framework of this work showed that the replacement of luminaries with better-suited ones (for the specific case) or adding of additional luminaries can help to improve the illuminance performance in most of the offices. Regarding daylight availability, the changing of glazing parameters, the relocation of some of the workplaces, and the change of the reflectance values of room surfaces might help to improve values.

The present research has to be looked upon under consideration of a set of limitations: First of all, only a very limited number of sample rooms could be examined. Future efforts should enlarge the examined sample. Secondly, especially regarding the improvement suggestions, these have been selected based on the standard values, and not so much onto what is possible in the corresponding spaces. For real improvement, in-depth lighting design should be conducted, which – however – could be based on the conducted measurements and simulation runs of this thesis. The deviations between simulations and measurements can have a number of reasons: First of all, a certain uncertainty/inaccuracy in measuring cannot be excluded, no matter how detailed and how careful measurements are conducted. Secondly, even if luminance values and illuminance value of different surfaces were used to arrive at reflection values, inaccuracies regarding these values can influence the simulation results. Furthermore, regarding the daylight case, it has to be stated that "measured" daylight factors are derived at indoor measurements in the corresponding offices and outdoor measurements from a weather station some kilometers away from the corresponding office. Thus, it might be that the daylight factors resulting from this procedure do not consider local changes in the outdoor illuminance. Moreover, the simulation tool Dialux offers only standardized outdoor illuminance patterns, which do show a large deviation from the measured values. Even, if daylight factors are "normalized" in their calculation, there might be found a certain deviation based on these sky models in comparison to reality.

Future efforts should include energy evaluation of the examined spaces and a comparison between status quo and optimization cases that target the utilization of highly-efficient LED technology.

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Appendix 1 :

Checklist	
1	Determination of the locations
2	Date and time of the measurements
3	Ascertain Geometry of offices
4	Ascertain amount, size and place of windows
5	Determine the existing fixed objects in the office like curtain
6	Distinguish Material of objects, walls, floor and ceiling
7	Reflectance of the office surfaces
8	Type and number of lamps, ballasts, dimmers and technical data
9	Age and number of burning hours of the luminaires
10	Determine the arrangement and geometry of luminaires
11	Identify the luminaires which are not operating correctly during measurements
12	Identify the measuring grid and / or position of the measurement points
13	Measuring the illuminance values of the existing offices during day time and night time
14	Determine the measurement equipment, Manufacturer, serial number, class, calibration
15	Doing users' surveys to evaluate the employee opinion and satisfaction
16	Simulating the current situation with lighting design tool (Dialux)
17	Applying the lumen method to determine level of light and UGR (unified glare rating) to determine visual comfort
18	Simulating a lighting scene for the same place regarding to the national and international standards with (Dialux)
19	Evaluating the results to define the deficiencies
20	Continuing of two previous steps till achieving the optimum result

Appendix 2 :

LIGHTING CONDITION SURVEY

The main purpose of this questionnaire is to asset the opinion of room occupants on the present amount and quality of light.

1. Gender

   -Female -Male

2. Age

   -Under 30
   -30 to 39
   -40 to 49
   - 50 to 59
   - 60 and over

3. In general how much time do you spend in office or work area?

   - All the time (7-8 hours a day)
   - Most of the time (4-6 hours a day)
   - Very little (less than 4 hours a day)
   - Others (please specify)………

4. Which of the following tasks are most common part of your job activity?

   - Using PC
   - Reading
   - Writing by hand
   - Making Drawing

5. Do you prefer working in natural light, artificial light or combination of natural and artificial?

   -Prefer natural
   -Prefer artificial
   -Prefer combination

6. In general how do you rate the light level, artificial and natural combined?

   a. At the work place
   Too much light 1 – 2 – 3 – 4 – 5 – 6 – 7 Too little light

b. In the room in general
Too much light 1 – 2 – 3 – 4 – 5 – 6 – 7 Too little light

c. In front of PC

Too much light 1 – 2 – 3 – 4 – 5 – 6 – 7 Too little light

7. From your present location, do you experience any unpleasant gloomy (dark) area in the room?

   Very much 1 – 2 – 3 – 4 – 5 – 6 – 7 Not at all

8. From your present location, do you experience any unpleasant bright (glare) area in the room?

   Very much 1 – 2 – 3 – 4 – 5 – 6 – 7 Not at all

9. Do you have a desktop lamp or similar at your workplace?

   - Yes
   - No

If yes, do you use it

- Always
- Often
- Seldom
- Never

If No: Do you think that a desktop lamp would improve your working conditions?

- Yes
- No

10. Do you often feel the need to manually adjust the light level in your workplace?

    Often 1- 2 -3 - 4 - 5 - 6 - 7 Never

11. The luminaires in your room:

    - Are all grouped together (they are all controlled by the same switch)
    - Are dived into independent groups (every group is controlled by a different switch)

12. Is the light level in your room adequate for you to complete all the tasks?

    - Yes, always
    - Yes, but sometimes I need to manually adjust the light level to be able to work (dimming, turning on the desk lamp, etc.)
    - No, sometimes I need to change workplace to complete the task

13. Does the artificial light ever cause glare strong enough to bother you?

    a. At the work place

    Often 1 – 2 – 3 – 4 – 5 – 6 – 7 Never

b. At the VDU (Visual Display Unit)

Often 1 – 2 – 3 – 4 – 5 – 6 – 7 Never

14. How do you feel about the lighting in your room?

    - Very unpleased 1- 2- 3- 4 -5 – 6- 7 Very pleased

    -Visually uncomfortable 1- 2- 3- 4 -5 -6 -7 Visually comfortable

15. Does the lighting system match your visual needs?

    - Not at all 1- 2- 3- 4 -5 – 6- 7 Yes, absolutely

Thank you very much for your time that you spend for cooperation.

Appendix 3 :

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80 0.50 0.30	0.80 0.50 0.10	0.70 0.50 0.30	0.70 0.50 0.20	0.70 0.50 0.10	0.70 0.30 0.10	0.50 0.30 0.10	0.50 0.10 0.10	0.30 0.30 0.10	0.30 0.10 0.10	0.00 0.00 0.00
0.60	0.76	0.73	0.76	0.74	0.72	0.68	0.68	0.65	0.67	0.65	0.64
0.80	0.84	0.79	0.83	0.81	0.79	0.75	0.74	0.71	0.73	0.71	0.70
1.00	0.91	0.85	0.90	0.87	0.84	0.80	0.80	0.77	0.79	0.77	0.75
1.25	0.97	0.89	0.96	0.92	0.89	0.85	0.84	0.82	0.83	0.81	0.80
1.50	1.02	0.92	1.00	0.96	0.92	0.88	0.88	0.85	0.87	0.85	0.83
2.00	1.09	0.97	1.07	1.01	0.97	0.94	0.93	0.91	0.92	0.90	0.88
2.50	1.14	1.00	1.11	1.05	0.99	0.97	0.96	0.95	0.95	0.94	0.92
3.00	1.17	1.02	1.14	1.07	1.01	1.00	0.98	0.97	0.97	0.96	0.94
4.00	1.21	1.04	1.17	1.10	1.03	1.02	1.01	1.00	0.99	0.99	0.96
5.00	1.23	1.05	1.19	1.11	1.05	1.04	1.02	1.01	1.00	1.00	0.98

Case Study 1 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80 0.50 0.30	0.80 0.50 0.10	0.70 0.50 0.30	0.70 0.50 0.20	0.70 0.50 0.10	0.70 0.30 0.10	0.50 0.30 0.10	0.50 0.10 0.10	0.30 0.30 0.10	0.30 0.10 0.10	0.00 0.00 0.00
0.60	0.70	0.67	0.70	0.68	0.67	0.62	0.61	0.58	0.61	0.58	0.56
0.80	0.79	0.74	0.78	0.76	0.73	0.68	0.68	0.65	0.67	0.64	0.63
1.00	0.86	0.80	0.85	0.82	0.79	0.75	0.74	0.71	0.73	0.70	0.69
1.25	0.93	0.85	0.91	0.87	0.84	0.80	0.79	0.76	0.78	0.75	0.74
1.50	0.97	0.88	0.95	0.91	0.88	0.84	0.83	0.80	0.82	0.79	0.77
2.00	1.05	0.94	1.03	0.98	0.93	0.90	0.89	0.86	0.87	0.85	0.83
2.50	1.10	0.97	1.07	1.01	0.96	0.94	0.92	0.90	0.91	0.89	0.87
3.00	1.14	0.99	1.11	1.04	0.99	0.96	0.95	0.93	0.94	0.92	0.90
4.00	1.18	1.02	1.14	1.07	1.01	0.99	0.98	0.96	0.96	0.95	0.93
5.00	1.20	1.03	1.17	1.09	1.02	1.01	0.99	0.98	0.98	0.97	0.94

Case Study 2 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80 0.50 0.30	0.80 0.50 0.10	0.70 0.50 0.30	0.70 0.50 0.20	0.70 0.50 0.10	0.70 0.30 0.10	0.50 0.30 0.10	0.50 0.10 0.10	0.30 0.30 0.10	0.30 0.10 0.10	0.00 0.00 0.00
0.60	0.48	0.46	0.47	0.46	0.45	0.38	0.37	0.32	0.37	0.32	0.30
0.80	0.59	0.55	0.58	0.56	0.55	0.47	0.46	0.41	0.46	0.41	0.39
1.00	0.68	0.63	0.66	0.64	0.62	0.55	0.54	0.49	0.53	0.49	0.46
1.25	0.77	0.70	0.75	0.72	0.69	0.62	0.61	0.56	0.60	0.56	0.54
1.50	0.83	0.75	0.81	0.78	0.74	0.68	0.67	0.62	0.66	0.62	0.59
2.00	0.93	0.83	0.91	0.86	0.82	0.77	0.75	0.71	0.74	0.71	0.68
2.50	1.00	0.88	0.97	0.92	0.87	0.82	0.81	0.77	0.80	0.76	0.74
3.00	1.05	0.92	1.02	0.96	0.90	0.86	0.85	0.82	0.83	0.81	0.78
4.00	1.11	0.96	1.07	1.01	0.95	0.91	0.90	0.87	0.88	0.86	0.83
5.00	1.14	0.98	1.11	1.04	0.97	0.94	0.93	0.90	0.91	0.89	0.86

Case Study 3 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80	0.80	0.70	0.70	0.70	0.70	0.50	0.50	0.30	0.30	0.00
	0.50	0.50	0.50	0.50	0.50	0.30	0.30	0.10	0.30	0.10	0.00
	0.30	0.10	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.00
0.60	0.62	0.59	0.61	0.60	0.59	0.53	0.52	0.49	0.52	0.48	0.47
0.80	0.73	0.68	0.71	0.69	0.68	0.62	0.61	0.57	0.61	0.57	0.55
1.00	0.81	0.75	0.80	0.77	0.74	0.69	0.68	0.65	0.68	0.64	0.62
1.25	0.89	0.81	0.87	0.84	0.81	0.76	0.75	0.71	0.74	0.71	0.69
1.50	0.94	0.86	0.92	0.88	0.85	0.80	0.79	0.76	0.78	0.75	0.74
2.00	1.03	0.92	1.00	0.95	0.91	0.87	0.86	0.83	0.85	0.83	0.81
2.50	1.08	0.96	1.05	1.00	0.95	0.92	0.90	0.88	0.89	0.87	0.85
3.00	1.12	0.98	1.09	1.03	0.97	0.95	0.93	0.91	0.92	0.90	0.88
4.00	1.16	1.01	1.13	1.06	1.00	0.98	0.96	0.94	0.95	0.93	0.91
5.00	1.19	1.02	1.15	1.08	1.01	0.99	0.98	0.96	0.96	0.95	0.93

Case Study 4 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80	0.80	0.70	0.70	0.70	0.70	0.50	0.50	0.30	0.30	0.00
	0.50	0.50	0.50	0.50	0.50	0.30	0.30	0.10	0.30	0.10	0.00
	0.30	0.10	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.00
0.60	0.61	0.58	0.60	0.59	0.58	0.52	0.51	0.47	0.51	0.47	0.46
0.80	0.72	0.67	0.71	0.69	0.67	0.61	0.60	0.56	0.60	0.56	0.55
1.00	0.81	0.75	0.79	0.77	0.74	0.69	0.68	0.64	0.67	0.64	0.62
1.25	0.89	0.81	0.87	0.83	0.80	0.75	0.75	0.71	0.74	0.71	0.69
1.50	0.94	0.86	0.92	0.88	0.85	0.80	0.79	0.76	0.78	0.75	0.73
2.00	1.03	0.92	1.00	0.95	0.91	0.87	0.86	0.83	0.85	0.83	0.81
2.50	1.08	0.95	1.05	1.00	0.95	0.91	0.90	0.88	0.89	0.87	0.85
3.00	1.12	0.98	1.09	1.03	0.97	0.94	0.93	0.91	0.92	0.90	0.88
4.00	1.16	1.01	1.13	1.06	1.00	0.97	0.96	0.94	0.94	0.93	0.91
5.00	1.19	1.02	1.15	1.08	1.01	0.99	0.97	0.96	0.96	0.95	0.92

Case Study 5 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80	0.80	0.70	0.70	0.70	0.70	0.50	0.50	0.30	0.30	0.00
	0.50	0.50	0.50	0.50	0.50	0.30	0.30	0.10	0.30	0.10	0.00
	0.30	0.10	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.00
0.60	0.76	0.73	0.76	0.74	0.72	0.68	0.68	0.65	0.67	0.65	0.64
0.80	0.84	0.79	0.83	0.81	0.79	0.75	0.74	0.71	0.73	0.71	0.70
1.00	0.91	0.85	0.90	0.87	0.84	0.80	0.80	0.77	0.79	0.77	0.75
1.25	0.97	0.89	0.96	0.92	0.89	0.85	0.84	0.82	0.83	0.81	0.80
1.50	1.02	0.92	1.00	0.96	0.92	0.88	0.88	0.85	0.87	0.85	0.83
2.00	1.09	0.97	1.07	1.01	0.97	0.94	0.93	0.91	0.92	0.90	0.88
2.50	1.14	1.00	1.11	1.05	0.99	0.97	0.96	0.95	0.95	0.94	0.92
3.00	1.17	1.02	1.14	1.07	1.01	1.00	0.98	0.97	0.97	0.96	0.94
4.00	1.21	1.04	1.17	1.10	1.03	1.02	1.01	1.00	0.99	0.99	0.96
5.00	1.23	1.05	1.19	1.11	1.05	1.04	1.02	1.01	1.00	1.00	0.98

Case Study 6 Luminaire data sheet

Room Index k	Reflectances for ceiling, walls and working plane (CIE)										
	0.80	0.80	0.70	0.70	0.70	0.70	0.50	0.50	0.30	0.30	0.00
	0.50	0.50	0.50	0.50	0.50	0.30	0.30	0.10	0.30	0.10	0.00
	0.30	0.10	0.30	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.00
0.60	0.61	0.58	0.60	0.59	0.58	0.52	0.51	0.47	0.51	0.47	0.46
0.80	0.72	0.67	0.71	0.69	0.67	0.61	0.60	0.56	0.60	0.56	0.55
1.00	0.81	0.75	0.79	0.77	0.74	0.69	0.68	0.64	0.67	0.64	0.62
1.25	0.89	0.81	0.87	0.83	0.80	0.75	0.75	0.71	0.74	0.71	0.69
1.50	0.94	0.86	0.92	0.88	0.85	0.80	0.79	0.76	0.78	0.75	0.73
2.00	1.03	0.92	1.00	0.95	0.91	0.87	0.86	0.83	0.85	0.83	0.81
2.50	1.08	0.95	1.05	1.00	0.95	0.91	0.90	0.88	0.89	0.87	0.85
3.00	1.12	0.98	1.09	1.03	0.97	0.94	0.93	0.91	0.92	0.90	0.88
4.00	1.16	1.01	1.13	1.06	1.00	0.97	0.96	0.94	0.94	0.93	0.91
5.00	1.19	1.02	1.15	1.08	1.01	0.99	0.97	0.96	0.96	0.95	0.92

Case Study 7 Luminaire data sheet