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Vienna University of Technology

**MASTERARBEIT**

# Estimation of electrical lighting energy use in buildings: a method comparison

**ausgeführt zum Zwecke der Erlangung des akademischen Grades einer Diplom- Ingenieurin**

unter der leitung von

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# Abstract

To satisfy the requirements of users in buildings, the visual environment needs to meet certain conditions. Specifically, adequate illuminance levels must be maintained dependent on the rooms' function and usage. Toward this end, electrical lighting must be deployed in many instances. However, the use of electrical lighting and the associated electrical energy use can be reduced by appropriate utilization of daylight.

To estimate, in a convenient manner, the electrical energy use for lighting in buildings, there are a number of simplified procedures. An example of such a procedure involves the use of the indicator LENI (Lighting Energy Numeric Indicator). Using this indicator, area-related electrical energy use can be calculated on a room-by-room basis. However, such procedures involve a significant number of simplifications with regard to building geometry, properties of relevant building components (e.g., windows, shading), climatic context and occupancy.

In this context, the present master thesis has the purpose to explore the reliability of these procedures and calculation methods presented in the EN 15193 standard.

Toward this end, this study compares for a sample of rooms (e.g., lecture room, office space) the results obtained by simplified and detailed calculation methods with results obtained using measurements, in view of electrical energy demand for lighting in buildings. The research results are expected to further define the degree to which simplified calculation results could deviate from more detailed estimations or measurements.

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***This work is dedicated to my family, Camelia, Cristian and Alida Calistru***

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# Acronyms

| | |
|---|---|
| ***A*** | Total useful floor area of the building [$m^2$] |
| ***BMS*** | Building Management System |
| ***CEN*** | European Committee for Standardization |
| ***CIE*** | International Commission on Illumination |
| $D_C$ | Direct component of daylight factor |
| ***DF*** | Daylight factor |
| $E_m$ | Maintained illuminance |
| ***EN*** | European Normative |
| ***EPBD*** | Directive on Energy Performance of Buildings |
| ***EU*** | European Union |
| $F_A$ | Absence factor |
| $F_C$ | Constant illuminance factor |
| $F_D$ | Daylight dependency factor |
| $F_{DC}$ | Daylight dependent electric lighting control factor |
| $F_{DS}$ | Daylight supply factor |
| $F_O$ | Occupancy dependency factor |
| $F_{OC}$ | Occupancy dependent lighting control system factor |
| ***IEA*** | International Energy Agency |
| ***LENI*** | Lighting Energy Numeric Indicator [$kWh \cdot m^{-2} \cdot a^{-1}$] |

| | |
|---|---|
| ***lx*** | Lux |
| ***MF*** | Maintenance Factor |
| $P_{em}$ | Total installed charging power of emergency lighting luminaires in the room or zone [W] |
| $P_n$ | Total installed lighting power in the room or zone [W] |
| ***PN*** | Installed power density for electric lighting in the building [$W \cdot m^{-2}$] |
| $P_{pc}$ | Total installed parasitic power of the controls in the room or zone [W] |
| $R_a$ | Lower limit for the colour rendition index |
| $t_D$ | Daylight time usage [h] |
| $t_e$ | Emergency lighting charge time [h] |
| $t_N$ | Non-daylight time usage [h] |
| $t_O$ | Total annual operating time [h] |
| $t_y$ | Standard year time [h] (8760 h) |
| $UGR_L$ | Unified Glare Rate |
| ***W*** | Total annual energy used for lighting [$kWh \cdot a^{-1}$] |
| $W_L$ | Annual energy used for illumination [$kWh \cdot a^{-1}$] |
| $W_{L,t}$ | Total energy used for illumination [kWh] |
| $W_P$ | Annual parasitic lighting energy use [$kWh \cdot a^{-1}$] |
| $W_{P,t}$ | Total parasitic lighting energy use [kWh] |
| $W_t$ | Total estimated energy used for lighting [kWh] |

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# 1. Introduction

## 1.1. Objective

The main objective of this study is to explore the reliability of the simplified procedures given by the EN 15193 standard for calculating lighting demand in buildings, by comparing the results obtained using the calculation methods with results obtained during one year of measurements. For this purpose, two different rooms from Vienna University of Technology are used as case study.

This approach enables to compare both methods towards usability, deviation of results and possibly calibrate the methods as well as validate the standard methods towards their accuracy.

EN 15193 presents two methods of calculating the energy demand in a space: a quick method (using benchmark values) and a comprehensive method (using detailed calculations). The European normative EN 15193 calculates the energy required for artificial lighting taking into consideration certain parameters as: type of space, total installed lighting power in the room or zone, annual operating hours (during day and night), type of control (automatic or manual), occupancy and daylight availability. The last three parameters are presented in the standard as dependency factors.

## 1.2. Motivation

The fragile ecosystem of the Earth looses its stability while confronting with serious problems such as constant growing of the population worldwide, pollution and climate change.

The increasing transfer of the population into the urban areas, creates larger, more crowded and polluted cities. A constant increase of the population means a constant increase in consumption of natural resources and raw materials, higher energy requirements and increased waste in terms of materials and emissions, that ultimately make massive demands on the environment.

Greenhouse gases are progressively released into the atmosphere affecting the climate. Among these, carbon dioxide ($CO_2$) is the main responsible.

It is widely accepted that climate change is caused by burning fossil fuels and that the most catastrophic consequences can be avoided by reducing the emissions. Within the European Union, additional targets were set to reduce levels of carbon emissions by 20%, from 1990 to 2020 (Thorn 2009).

Requests for a significant reduction in energy consumption have been made around the world. Among these, the declarations of intent in the Kyoto Protocol (Kyoto Protocol 1997) and the following conference in Bali have established concrete targets and standards for countries to achieve in limiting or reducing emissions by increasing energy efficiency and using renewable energy sources. The International Energy Agency (IEA) estimates that lighting is responsible for 19 % of worldwide electricity consumption (Zumtobel 2013).

In Austria, lighting is responsible for a high percentage of the total energy consumption in buildings. In 2008, energy used for lighting was estimated to be 9.5% of the total consumption in all households, taking the fifth place on the chart of energy consumption (after heating, water heating, large domestic appliances, and fridges and freezers). In 2012, the energy used for lighting has the tendency to grow, rising to 10.7% of the total consumption in all households. The chart below presents a comparison between electricity consumption in Austria for different categories of consumption in 2008 and 2012 in all households (Statistics Austria 2013).

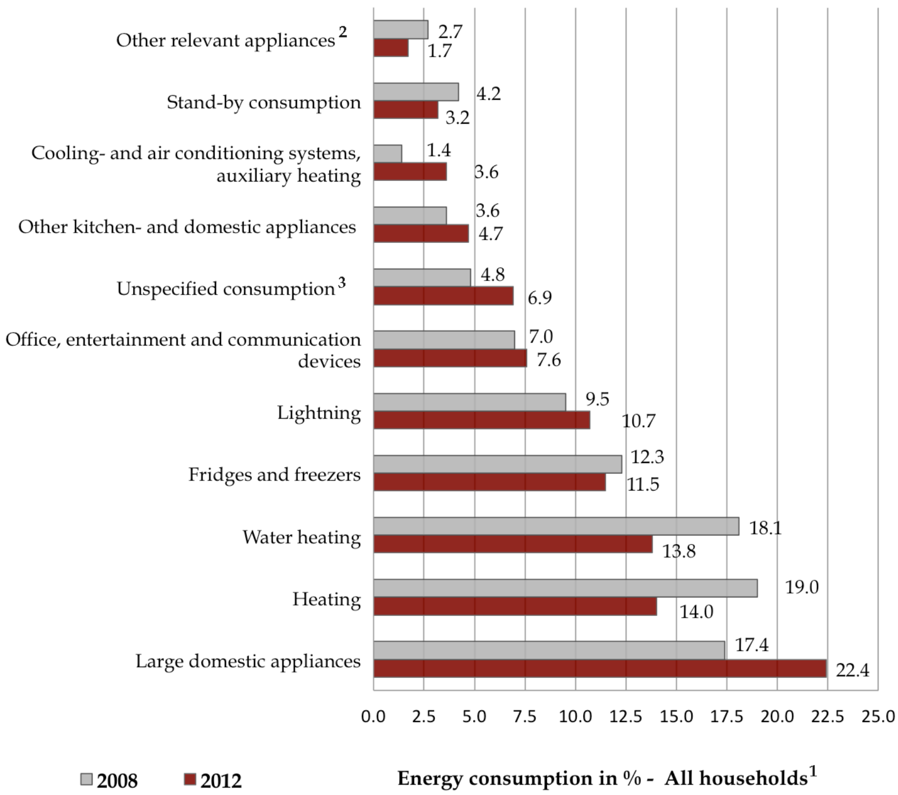


**Figure 1.1. Breakdown of electricity consumption by categories of consumption in Austria of 2008 and 2012** (Statistics Austria 2013)

[1] "All households" include all responding households, whether they had actual records in the according category or not

[2] including waterbeds, portable fountains, electric lawn mowers, etc

[3] Unspecified energy consumption: energy consumption, which is not classifiable as category of consumption

This could be improved most of all because of lighting's great energy saving potential. Better lighting products and better lighting schemes lead to rational energy use.

"Inadequate lighting increases the risk of accidents and causes loss of concentration, headaches and fatigue in many cases. Despite this, out-of-date lighting systems, which provide deficient lighting quality and poor light output ratios, are still in use. Apart from using effective technologies, it is above all lighting management which makes a significant contribution towards energy efficiency: by seamlessly integrating daylight and allowing automation using timers or presence detectors" (Zumtobel 2013).

Many measurements have been taken to regulate the energy efficiency of individual products like lamps and ballast, which employed into existing lighting schemes can offer an approximate 15% improvement in energy saving. Often they are put into service in poorly designed and operated lighting installations, resulting in bad lighting conditions and wasted energy. In the case of properly designed lighting schemes, the improved effectiveness of lighting – in terms of both quality and quantity – can reduce energy usage by up to 55% (Staudt et al. 2010).

Lighting has a significant energy saving potential, expected due to very fast technological development. Finding a balance between energy, environment and individual, by managing good lighting practices and efficient products, is done throughout lighting standards. Their role is to provide lighting schemes, which comply with good lighting practices: visual comfort, efficient energy consumption and sustainability (Thorn 2009).

## 1.3. Normative background: EN 15193, Energy Performance of Buildings - Energy Requirements for Lighting

Different attempts of implementing regulations have been made in the last years by the European Union. Among these, several directives aiming the reduction of greenhouse gases have already been published. European Parliament adopted the Directive on Energy Performance of Buildings (EPBD) in December 2002, with the goal of improving the energy efficiency of buildings. EU member countries were obliged to implement this important directive into national legislation by January 2006 (Gasparovsky et al. 2010).

In this context, to determine the electrical energy demand of electrical lighting in buildings, the European Standardization provides the European normative EN 15193: 2006 Energy performance of buildings – Energy requirements for lighting.

### 1.3.1. Overview

This chapter debates the European Normative EN 15193, which represents the headline of this master thesis. For a better understanding of the calculation methods that this standard offers, it is essential to describe the different variables required for determining the lighting energy use in buildings.

This chapter analyses and explains all parameters, as they are presented in EN 15193 standard. The last part of the section presents an overview on the application of the standard.

### 1.3.2. Scope of the normative

The purpose of this European standard is to establish conventions and procedures for the estimation of energy requirements of lighting in buildings and to specify a calculation methodology for evaluating the amount of energy used for indoor lighting. In seeking for a common methodology to estimate the energy performance of buildings, EN 15193 uses a simplified procedure, called LENI, the Lighting Energy Numeric Indicator. The indicator is used for certification purposes that offer guidance on establishment of notional limits for lighting energy derived from reference schemes.
The EN 15193 normative can be applied to a wide variety of buildings (offices, educational buildings, hospitals, hotels and restaurants, sport facilities, retail manufacture buildings), including both existing and new buildings, providing calculation methods as well as benchmark standard values. One consideration of this CEN standard is that it provides a framework outlining general aspects, but still leaves room for national variations and refinements.
Several alternative routes for determining the energy demand are presented in the European Normative EN 15193, Energy Performance of Buildings - Energy Requirements for Lighting (Figure 1.2):

i. The quick method
ii. The comprehensive method
iii. The metered method

For a better understanding of LENI, a profounder exploration of the standards' calculation methods is needed. The following scheme presents the alternative routes for calculating the energy demand.

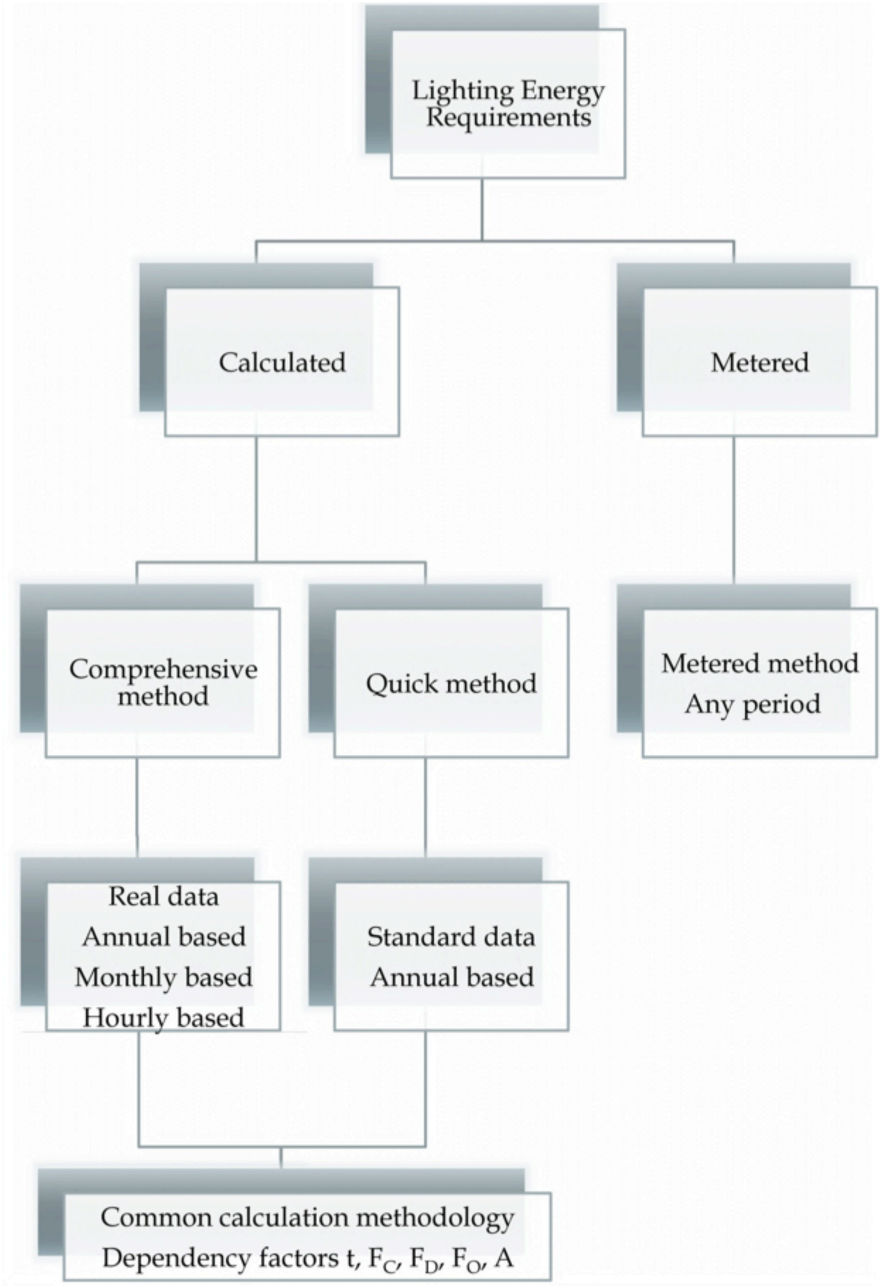


**Figure 1.2. Flow chart illustrating alternative routes to determine energy use** (EN 15193 2006)

### 1.3.3. Calculating energy used for lighting

There are two forms of installed power in buildings: the luminaire power (the provider power for functional illumination) and the parasitic power (that provides power for lighting control systems and for charging batteries for emergency lighting) (EN 15193 2006).

#### 1.3.3.1. Total estimated energy

The total estimated energy required for a period of time (hourly, monthly or annually) in a room or zone is given by the equation:

$$W_t = W_{L,t} + W_{P,t} \quad \text{[kWh]} \qquad \text{(Eq. 1.1)}$$

$W_{L,t}$ is the lighting energy required to fulfil the illumination function and purpose in the building. The standard uses the basic formula to measure and calculate the total lighting energy for a building ($W_{L,t}$):

$$W_{L,t} = \sum \{(P_n \times F_C) \times [(t_D \times F_O \times F_D) + (t_N \times F_O)]\} / 1000 \quad \text{[kWh]} \qquad \text{(Eq. 1.2)}$$

$W_{P,t}$ is the total parasitic energy required to provide charging energy for emergency lighting and standby energy for lighting controls in the building, given by the equation:

$$W_{P,t} = \sum \{\{P_{pc} \times [t_y - (t_D + t_N)]\} + (P_{em} \times t_e)\} / 1000 \quad \text{[kWh]} \qquad \text{(Eq. 1.3)}$$

Where the EN 15193: 2006, Energy Performance of Buildings - Energy Requirements for Lighting defines the parameters as:

- $P_n$ is the total installed lighting power, measured in watts [W];
- $P_{pc}$ is the total installed parasitic power, measured in watts [W];
- $P_{em}$ is the total installed charging power of the emergency lighting luminaires, measured in watts [W];
- $t_y$ is the standard year time, measured in hours [h]
- $t_e$ is the emergency lighting charge time, measured in hours [h];
- $t_D$ is the daylight time usage, measured in hours [h] ;
- $t_N$ is the non-daylight time usage, measured in hours [h] ;
- $F_C$ is the constant illuminance factor;
- $F_O$ is the occupancy dependency factor;
- $F_D$ is the daylight dependency factor.

### 1.3.3.2. Total annual energy used for lighting

To calculate the total annual energy used for lighting, the standard presents basically the same equation as for the total estimated energy, for a period of one year (EN 15193 2006).

$$\boldsymbol{W = W_L + W_P} \quad [\text{kWh} \cdot \text{a}^{-1}] \qquad \text{(Eq. 1.4)}$$

Where $W_L$ is the annual lighting energy required to fulfil the illumination function and purpose in the building and $W_P$ is the annual parasitic energy required to provide charging energy for emergency lighting and standby energy for lighting controls in the building. $W_L$ and $W_P$ are established by equations 1.2, respectively 1.3.

### 1.3.4. LENI - The Lighting Energy Numeric Indicator

The LENI indicator has been developed to confirm how much energy is needed each year to light up each square meter in a building so that illumination and specifications are fulfilled (EN 15193 2006). There are two means of determining the energy use: through calculations or measurements. For determining LENI, the normative provides the equation:

$$\textbf{\textit{LENI calculated}} = W / A \quad [\text{kWh} \cdot \text{m}^{-2} \cdot \text{a}^{-1}] \qquad \text{(Eq. 1.5)}$$

Where $W$ is the total annual energy used for lighting measured in [kWh · $a^{-1}$] with $W = W_L + W_P$ (Eq. 1.4), and $A$ is the total useful floor area of the building measured in [$m^2$]. This means:

$$LENI = \frac{W_L + W_P}{A} \quad [\text{kWh} \cdot \text{m}^{-2} \cdot \text{a}^{-1}] \qquad \text{(Eq. 1.6)}$$

That concludes to the resulting equation for calculating LENI:

$$LENI = \{[(P_n \, x \, F_C) \, x \, (t_D \, x \, F_O \, x \, F_D) + (t_N \, x \, F_O)] + [(P_{pc} \, x \, (t_y - t_D + t_N) + (P_{em} \, x \, t_e)]\} / 1000 \, x \, A \qquad \text{(Eq. 1.7)}$$

LENI measured in [kWh · $m^{-2}$ · $a^{-1}$]

If there is no parasitic power then the equation becomes:

$$LENI = \{\sum (P_n \, x \, F_C) \, x \; \{( t_D \, x \, F_O \, x \, F_D) + (t_N \, x \, F_O)\} / 1000 \, x \, A \qquad \text{(Eq. 1.8)}$$

LENI measured in [kWh · $m^{-2}$ · $a^{-1}$]

#### 1.3.4.1. Total installed lighting power ($P_n$)

$P_n$ is defined as the power of all luminaires in the room or zone, measured in watts (EN 15193 2006).

#### 1.3.4.2. Total installed parasitic power of controls ($P_{pc}$)

$P_{pc}$ is the input power of all control systems in luminaires in the room or zone, measured in watts (EN 15193 2006).

#### 1.3.4.3. Total installed charging power of emergency lighting luminaires ($P_{em}$)

$P_{em}$ is defined as the input charging power of all emergency lighting luminaires in the room or zone, measured in watts (EN 15193 2006).

#### 1.3.4.4. Standard year time ($t_y$)

The standard year time is defined as the number of hours during one standard year, measured in hours (EN 15193 2006).
The normative gives for $t_y$ the value 8760 h although there are exceptions in the case of leap years, when the number of hours increases to 8784 h (one additional day in the month of February).

#### 1.3.4.5. Emergency lighting charge time ($t_e$)

The emergency lighting charge time is the number of operating hours during which the emergency lighting batteries are being charged (EN 15193 2006).

#### 1.3.4.6. Daylight operating hours ($t_D$)

The EN 15193 standard defines the daylight operating hours ($t_D$), as the number of operating hours of the lamps and luminaires with the lamps ON in one year, during daylight time. The operating hours are not the occupancy hours, these being the number of hours when presence is detected in the room or space (EN 15193 2006).

#### 1.3.4.7. Non-daylight operating hours ($t_N$)

The Non-daylight operating hours are the number of operating hours of the lamps and luminaires with the lamps ON in one year, during the time without daylight availability (EN 15193 2006). Together with the $t_D$, these contribute to the total annual operating hours ($t_O$) of the lamps (Eq. 1.9). The European normative provides standard values for the operating hours in different types of spaces (Table 1.11).

$$t_O = t_D + t_N \quad [\mathrm{h}] \qquad \text{(Eq. 1.9)}$$

### 1.3.4.8. Constant illuminance factor ($F_C$)

The constant illuminance factor is the factor relating to the usage of the total installed power when constant illuminance control is in operation in the room or zone. When there is no system for controlling the constant illuminance in the space, then $F_C$ =1 (EN 15193 2006). In other case the standard offers the equation for calculating $F_C$:

$$F_C = (1+MF)/2 \qquad \text{(Eq. 1.10)}$$

Where *MF*, the maintenance factor (Table 1.1) is the ratio of the average illuminance on the working plane after a certain period of use of a lighting installation to the initial average illuminance obtained under the same conditions for the installation (EN 15193 2006).

The *MF* factor depends on several factors like the ageing of lamps, the failure of lamps, the soiling of luminaire and the soiling of room.

**Table 1.1. Environmental conditions and values for maintenance factor** (Zumtobel 2011)

| Ambient condition | Maintenance interval recommended | Working areas | *MF* |
|---|---|---|---|
| **Very clean** | 3 years | Clean-rooms, data centres | 0.80 |
| **Clean** | 3 years | Offices, schools | 0.67 |
| **Normal** | 2 years | Shops, laboratories, restaurants, warehouses, assembly bays | 0.57 |
| **Soiled** | 1 year | Steel works, chemical plants, welding shops, wood processing | 0.50 |

### 1.3.4.9. Occupancy dependency factor ($F_O$)

The normative defines the occupancy dependency factor ($F_O$) as the factor relating the usage of the total installed lighting power to the occupancy period in the room or zone. For the quick method the following values are provided.

**Table 1.2. Occupancy dependency factor ($F_O$) for buildings with different types of controls. Values used for the Quick Method** (EN 15193 2006)

| | Occupancy impact | |
|---|---|---|
| **Building type** | **Control type** | $F_O$ |
| Office<br>Education | Manu | 1.0 |
| | Automatic ≥ 60 % of the connected load | 0.9 |
| Retail, Manufacture, Sports and Restaurant | Manual | 1.0 |
| Hotel | Manual | 0.7 |
| Hospital | Manual (some automatic control) | 0.8 |

For the Comprehensive Method the following equation is used:

$$F_O = min \{1–[(1–F_{OC}) \times F_A /0.2] ; (F_{OC}+0.2–F_A); [7- (10 \times F_{OC})] \times (F_A– 1)\}$$

( Eq. 1.11)

Where $F_{OC}$ is the occupancy control factor and $F_A$ is the absence factor.

#### 1.3.4.9.1. Occupancy control factor ($F_{OC}$)

The occupancy control factor is fixed as a function of the lighting control system (Table 1.3). For both $F_{OC}$ and $F_A$ factors, the standard provides benchmark values depending on the type of control, respectively the type of building.

**Table 1.3. $F_{OC}$ values used for the Comprehensive Method** (EN 15193 2006)

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

#### 1.3.4.9.2. Absence factor ($F_A$)

The absence factor is the factor relating to the period of absence of occupants, corresponding to the fraction of the reference operating time ($t_D$ + $t_N$) that a building or room is not in use. In this case sleeping hours can usually be considered equivalent to absence (EN 15193 2006).

**Table 1.4. $F_A$ values used for the Comprehensive Method** (EN 15193 2006)

| Overall building calculation | | Room by room calculation | | |
|---|---|---|---|---|
| **Building type** | **$F_A$** | **Building type** | **Room type** | **$F_A$** |
| Offices | 0.20 | **Offices** | Cellular office 1 person. | 0,4 |
| | | | Cellular office 2-6 persons. | 0,3 |
| | | | Open plan office >6 persons sensing/30m² | 0 |
| | | | Open plan office > 6 persons sensing/10m² | 0,2 |
| | | | Corridor (dimmed) | 0,4 |
| | | | Entrance hall | 0 |
| | | | Showroom/Expo | 0,6 |
| | | | Bathroom | 0,9 |
| | | | Copying/ Server room | 0,5 |
| | | | Conference room | 0,5 |
| | | | Archives | 0,98 |
| Educational buildings | 0.20 | **Educational buildings** | Lecture hall | 0,4 |
| | | | Room for group activities | 0,3 |
| | | | Corridor (dimmed) | 0,6 |
| | | | Staff room | 0,4 |
| | | | Teachers' staff common room | 0,4 |

**Table 1.5. $F_O$ values as a function of $F_A$ for different control systems, used for the Comprehensive Method** (EN 15193 2006)

| $F_A$ | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Manual On/Off | 1.000 | 1.000 | 1.000 | 0.900 | 0.800 | 0.700 | 0.600 | 0.500 | 0.400 | 0.300 | 0.000 |
| Manual On/Off + additional automatic sweeping signal | 1.000 | 0.975 | 0.950 | 0.850 | 0.750 | 0.650 | 0.550 | 0.450 | 0.350 | 0.250 | 0.000 |
| Auto On/ Dimmed | 1.000 | 0.975 | 0.950 | 0.850 | 0.750 | 0.650 | 0.550 | 0.450 | 0.350 | 0.250 | 0.000 |
| Auto On/ Auto Off | 1.000 | 0.950 | 0.900 | 0.800 | 0.700 | 0.600 | 0.500 | 0.400 | 0.300 | 0.200 | 0.000 |
| Manual On/ Dimmed | 1.000 | 0.950 | 0.900 | 0.800 | 0.700 | 0.600 | 0.500 | 0.400 | 0.300 | 0.200 | 0.000 |
| Manual On/ Auto Off | 1.000 | 0.900 | 0.800 | 0.700 | 0.600 | 0.500 | 0.400 | 0.300 | 0.200 | 0.100 | 0.000 |

Observing Table 1.5, the value for $F_O$ can range from 0 to 1. When the building or the room would be permanently occupied during the reference time, $F_A$ would be 0.0 (Table 1.5). As a limit value, if a building or room would nearly never be entered into, $F_A$ would tend towards 1.0.

In this context, if absent 40% of working year and use Manual ON/OFF switch, then $F_O$ = 0.8 and the system will save 20% energy.

If absent 40% of working year and use Automatic ON/OFF switch, then $F_O$ = 0.7 and the system will save 30% energy.

#### 1.3.4.10. Daylight dependency factor ($F_D$)

$F_D$ is the factor relating the usage of the total installed lighting power to daylight availability in the room or zone. In case of no daylight availability, the standard assumes the value for $F_D$ = 1, same as in the case of manual control of the system (EN 15193 2006).

**Table 1.6. Daylight dependency factor ($F_D$) for buildings with different types of control and usage. Values used for the Quick Method** (EN 15193 2006)

| Building type | Control type | $F_D$ |
|---|---|---|
| Office, sports facilities, manufacturing | Manual | 1.0 |
| | Photo cell dimming – daylight sensing | 0.9 |
| Restaurant, wholesale and retail | Manual | 1.0 |
| Education buildings, Hospitals | Manual | 1.0 |
| | Photo cell dimming – daylight sensing | 0.8 |

For the Comprehensive Method, the daylight dependency factor $F_D$ is determined as a function of the daylight supply factor $F_{DS}$ and the daylight control factor $F_{DC}$:

$$F_D = 1 - (F_{DS} \times F_{DC}) \quad \text{(Eq. 1.12)}$$

#### 1.3.4.10.1. Daylight supply factor ($F_{DS}$)

The daylight supply factor $F_{DS}$ is a function of the daylight penetration and the maintained illuminance $E_m$. Also the location of the room is important, as the standard gives different values for different latitudes. For example, the northern is the location, the higher is the total lighting energy and implicit the LENI results.

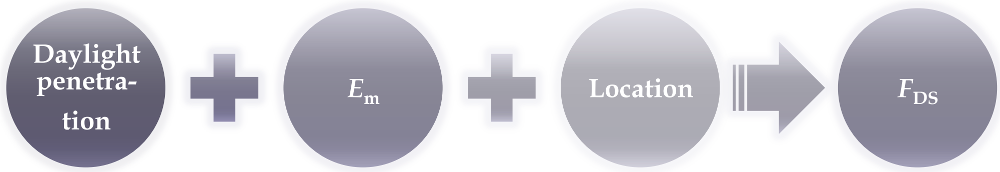


**Figure 1.3. Relation between daylight penetration, maintained illuminance ($E_m$), location and daylight supply factor ($F_{DS}$)**

The standard presents daylight penetration as being depended on the direct component $D_C$ (sky component) of the daylight factor ($DF$) (Table 1.7). The daylight factor provides information about the daylight quality in a room, described by the ratio of outside illuminance over inside illuminance, expressed in percent. The higher the *DF*, the more natural light is available in the room. The direct component is defined as the light from the patch of sky, visible at the analysis point in the room (New-Learn 2013).

**Table 1.7. Daylight penetration as function of the daylight factor** (EN 15193 2006)

| *Dc* | **Daylight Penetration (Access of the zone to daylight)** |
|---|---|
| *Dc* >=6% | Strong |
| 6%>*Dc* >=4% | Medium |
| 4%>*Dc* >=2% | Weak |
| *Dc* < 2 % | None |

For the maintained illuminance $E_m$, the European standards recommend various values depending on the type of the space and on the type of activity:

**Table 1.8. Illumination in educational and office spaces** (Zumtobel 2011)

| **Educational premises** | | | |
|---|---|---|---|
| **Type of activity** | $E_m$ | $UGR_L$ | $R_a$ |
| Classroom for evening classes and adults education | 500 | 19 | 80 |
| Lecture hall | 500 | 19 | 80 |
| **Offices** | | | |
| **Type of activity** | $E_m$ | $UGR_L$ | $R_a$ |
| Writing, typing, reading, data processing | 500 | 19 | 80 |
| CAD work station | 500 | 19 | 80 |
| Conference and meeting rooms | 500 | 19 | 80 |

Where $E_m$ is the illuminance maintenance, $UGR_L$ is the unified glare rate and $R_a$ is the lower limit for the colour rendition index. For the specific sample rooms (seminar room and office room), a maintained illuminance of 500 lx is preferable. Depending on the daylight penetration, on the maintained illuminance and on the location of the sample buildings, the EN 15193 normative offers the following values.

**Table 1.9. Daylight supply factor $F_{DS}$ for vertical facades as function of daylight penetration and maintained illuminance $E_m$ for different sites** (EN 15193 2006)

| Site | Latitude | Daylight Supply factor $F_{DS}$ ranges | | | | | |
|---|---|---|---|---|---|---|---|
| | | 500 lx | | | 750 lx | | |
| | [°] | weak | medium | strong | weak | medium | strong |
| Athens | 38 | 0.59 | 0.80 | 0.90 | 0.41 | 0.63 | 0.82 |
| Lyon | 46 | 0.51 | 0.70 | 0.82 | 0.36 | 0.55 | 0.72 |
| Bratislava | 48 | 0.49 | 0.68 | 0.79 | 0.35 | 0.54 | 0.70 |
| Frankfurt | 50 | 0.47 | 0.66 | 0.77 | 0.33 | 0.52 | 0.68 |
| Watford | 52 | 0.45 | 0.63 | 0.75 | 0.32 | 0.50 | 0.65 |

As Vienna is situated in the same geographical area and in close proximity to Bratislava, the standard ranges for the daylight supply factor ($F_{DS}$) are equivalent.

### 1.3.4.10.2. Daylight control factor ($F_{DC}$)

Daylight control factor $F_{DC}$ is depending on the daylight penetration and on the type of lighting control (manual or automatic, Table 1.10).


**Figure 1.4. Relation between daylight penetration, type of control and daylight control factor ($F_{DC}$)**

**Table 1.10. Daylight dependent artificial lighting control, $F_{DC}$** (EN 15193 2006)

| Control of artificial lighting system | $F_{DC}$ as function of daylight penetration | | |
|---|---|---|---|
| | **weak** | **medium** | **strong** |
| **Manual** | 0.2 | 0.3 | 0.4 |
| **Automatic, daylight depended** | 0.75 | 0.77 | 0.85 |

For example, a building in Vienna with a maintained illuminance $E_m$ of 500 lux and Strong daylight penetration, has a $F_D$ value of:

For Manual control $F_D = 1 – (0.79 \times 0.40) = 0.684$;

For Automatic control $F_D = 1 – (0.79 \times 0.85) = 0.3285$.

### 1.3.5. Calculation methods of lighting energy in buildings

There are two methods of performing LENI calculations: the quick method and comprehensive method.

#### 1.3.6.1. The quick method

This calculation method is used for estimating the building's total annual lighting energy usage and LENI indicator, in the design phase of the building. This method's estimations, do not consider the location of the building, nor the cardinal orientation, or daylight availability. In this case, the standard provides benchmark values (Table 1.11) for the parameters used in the equations. The table includes a number of default values for $t_D$, $t_N$, $F_C$, $F_D$, $F_O$ and parasitic energy. It is expected for the Quick method to generate higher LENI values than the Comprehensive method, because the values provided in the benchmark table are estimated values rather than actual values. This is why, for better and more accurate results, it is indicated to use the comprehensive method.

#### 1.3.6.2. The comprehensive method

Unlike the quick method, the comprehensive method can be used for all types of buildings considering all the other parameters that the quick method simplifies or neglects. The method offers more information about how to calculate the three factors ($F_C$, $F_O$, $F_D$) depending on the use of the building, its geometry, geographical position, outdoor obstructions, cardinal orientation, daylight penetration, maintained illuminance, occupancy, daylight availability and type of control (auto or manual). The method offers the possibility of calculating LENI for a selected period of time.

## 1.3.6. Benchmark of Lighting energy requirements

EN 15193 offers benchmark values for the parameters used in the quick calculation method (Table 1.11). The values are estimated numbers depending on the type of building and control of lighting system. They are based on meeting the necessary and desired lighting criteria applied to the building, being average for the building and varying substantially for different rooms or zones in the building (EN 15193 2006). They are typical values for existing installations and no target values for new lighting systems. The standard also offers limiting values for LENI, always reduced for automatic control than for manual, assuming that the lights are ON only when needed: presence of occupancy or low illuminance.

**Table 1.11. Benchmark values and lighting design criteria for different types of spaces** (EN 15193 2006)

| | | | | | | | | | | | | | No cte illuminance | | Cte illuminance | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Qual. class | $P_{em}$ | $P_{pc}$ | $P_N$ | $t_D$ | $t_N$ | $F_C$ | | $F_O$ | | $F_D$ | | LENI | LENI | LENI | LENI |
| | | kWh $m^{-2}$ $a^{-1}$ | kWh $m^{-2}$ $a^{-1}$ | W/$m^2$ | h | h | No cte ill | Cte ill | Manu | Auto | Manu | Auto | Limiting value | | | |
| | | | | | | | | | | | | | Manu | Auto | Manu | Auto |
| | | | | | | | | | | | | | kWh $m^{-2}$ $a^{-1}$ | | | |
| Office | * | 1 | 5 | 15 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 42.1 | 35.3 | 38.3 | 32.2 |
| | ** | 1 | 5 | 20 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 54.6 | 45.5 | 49.6 | 41.4 |
| | *** | 1 | 5 | 25 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 67.1 | 55.8 | 60.8 | 50.6 |
| Education | * | 1 | 5 | 15 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 34.9 | 27.0 | 31.9 | 24.8 |
| | ** | 1 | 5 | 20 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 44.9 | 34.4 | 40.9 | 31.4 |
| | *** | 1 | 5 | 25 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 54.9 | 41.8 | 49.9 | 38.1 |
| Hospital | * | 1 | 5 | 15 | 3000 | 2000 | 1 | 0.9 | 0.9 | 0.8 | 1 | 0.8 | 70.6 | 55.9 | 63.9 | 50.7 |
| | ** | 1 | 5 | 25 | 3000 | 2000 | 1 | 0.9 | 0.9 | 0.8 | 1 | 0.8 | 115.6 | 91.1 | 104.4 | 82.3 |
| | *** | 1 | 5 | 35 | 3000 | 2000 | 1 | 0.9 | 0.9 | 0.8 | 1 | 0.8 | 160.6 | 126.3 | 144.9 | 114.0 |
| Hotel | * | 1 | 5 | 10 | 3000 | 2000 | 1 | 0.9 | 0.7 | 0.7 | 1 | 1 | 38.1 | 38.1 | 34.6 | 34.6 |
| | ** | 1 | 5 | 20 | 3000 | 2000 | 1 | 0.9 | 0.7 | 0.7 | 1 | 1 | 72.1 | 72.1 | 65.1 | 65.1 |
| | *** | 1 | 5 | 30 | 3000 | 2000 | 1 | 0.9 | 0.7 | 0.7 | 1 | 1 | 108.1 | 108.1 | 97.6 | 97.6 |
| Restaurant | * | 1 | 5 | 10 | 1250 | 1250 | 1 | 0.9 | 1 | 1 | 1 | - | 29.6 | - | 27.1 | - |
| | ** | 1 | 5 | 25 | 1250 | 1250 | - | 0.9 | 1 | 1 | 1 | - | 67.1 | - | 60.8 | - |
| | *** | 1 | 5 | 35 | 1250 | 1250 | 1 | 0.9 | 1 | 1 | 1 | - | 92.1 | - | 83.3 | - |
| Sport | * | 1 | 5 | 10 | 2000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 43.7 | 41.7 | 39.7 | 37.9 |
| | ** | 1 | 5 | 20 | 2000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 83.7 | 79.7 | 75.7 | 72.1 |
| | *** | 1 | 5 | 30 | 2000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 123.7 | 117.7 | 117.7 | 106.3 |
| Retail | * | 1 | 5 | 15 | 3000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | - | 78.1 | - | 70.6 | - |
| | ** | 1 | 5 | 25 | 3000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | - | 128.1 | - | 115.6 | - |
| | *** | 1 | 5 | 35 | 3000 | 2000 | 1 | 0.9 | 1 | 1 | 1 | - | 178.1 | - | 160.6 | - |
| Manufact. | * | 1 | 5 | 10 | 2500 | 1500 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 43.7 | 41.2 | 39.7 | 37.5 |
| | ** | 1 | 5 | 20 | 2500 | 1500 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 83.7 | 78.7 | 75.7 | 71.2 |
| | *** | 1 | 5 | 30 | 2500 | 1500 | 1 | 0.9 | 1 | 1 | 1 | 0.9 | 123.7 | 116.2 | 111.7 | 105.0 |

Where: *PN* is the installed power density for electric lighting in the building with $PN=P_n/A$, *cte* is the constant illuminance control system, *Manu* is the manual control system, *Auto* is the automatic control system and *Qual. class* refers to the three quality classes of the system:

* Basic fulfilment of requirements;

** Good fulfilment of requirements;

*** Comprehensive fulfilment of requirements.

The classes are defined depending on the satisfaction of: maintained illuminance, avoidance of flicker, harsh shadows or too diffuse light, appropriate control of reflections, improved colour rendering, proper luminance distribution in the room and special attention to visual communication and health issues (EN 15193 2006).

### 1.3.7. Metering

For the Metered method, EN 15193 recommends several alternatives for measuring the energy consumption used for lighting:

i. Installing kWh meters on lighting circuits in the electrical distribution;

ii. Coupling or integrating local power meters in the lighting controllers of a lighting management system;

iii. Integrating a lighting management system that calculates the local consumed energy and makes this information available to a building management system (BMS);

iv. Integrating a lighting management system that calculates the consumed energy per building section and then makes this information available in an exportable format;

v. Integrating a lighting management system that records the running hours, the dimming level and relates this to its internal database on installed load (EN 15193 2006).

### 1.3.8. Application of CEN Standard EN 15193

In the past years, there were several occasions and attempts of promoting this standard and its content in different countries around Europe and not only.

Presentations and workshops were held in January 2009 in Germany and September 2009 in Istanbul, Turkey. The purpose of the presentations was to describe the standard and its methodology, to evaluate the results of different questionnaires and also to bring some additional information about the background of this standard. The participants showed a strong interest towards this project, although the questionnaires identified a low awareness of the standard. In contrast to the presentations, which were meant to inform the participants, the workshops focused on discussions and feedback (Staudt et al. 2010).

The development of this standard is considered to be a big step in the implementation of energy efficient lighting concepts. Its methods are considered to be applicable and useful, although critics were brought. Among these can be mentioned that some fragments of the standard were unclear, incomplete and not easy to understand, especially by someone that is not an expert in the field.

The results showed that in 11 out of 13 European countries, lighting requirements are considered in the energy rating of the buildings, but in only 5 countries the EN 15193 standard has completely or partly been put into force. Another alarming fact was that practitioners from nearly all countries that participated to the study are not completely informed about this standard. Furthermore, only half of the participants were aware of existing calculation software as “Dialux” or “Relux”. The participants agreed that there was a strong need for improvement, so further annexes were brought. Their goal was to cover those aspects that weren't sufficiently covered by the initial standard (Staudt et al. 2010).

The LENI subject was debated and discussed in many publications and several comments were brought along the years:
“Quick method is found unusable with normative benchmark values. As the standard excludes procedure for determination of daylight and non-daylight usage time of buildings, national methodology should be offered as a guideline […] Many of the default values offered in the standard should be revised in national level according to the national conditions of specific countries” (Gasparovsky et al. 2010).

“There had been defined a methodology integrated in the first draft of the standard EN 15193, but composed equations were non-functional, hence excluded from the final version of this standard. […] Lighting installation usage time $t_D$ and $t_N$ operation hours have critical influence to the resulting value (of consumption and thus for LENI as well) […] Instead, for the quick method standard values are provided. Factors $F_D$, $F_O$ and $F_C$ help to reduce the energy consumption for lighting assuming that if there is available daylight or if rooms are not occupied, eventually if a system compensating the *MF* is installed. It can be expected that influence of these factors is very critical. Using the comprehensive method, these factors are to be obtained by calculation”(Gasparovsky et al. 2011).

# 2. Methodology

## 2.1. Overview

This chapter presents the approach used in the present thesis. The first section provides information about the two sample rooms and the context in which these are found: location, cardinal orientation, etc. The following sections explore the calculation methods that the standard offers together with the measurements during a period of one year. In this manner, the methodology of the standard is verified on real sample rooms and with real measured values.

## 2.2. Description of simulated spaces

The two sample rooms used for this study are a part of the Building Physics Department of Vienna University of Technology (Figure 2.1 and Figure 2.2). They have different usage profiles offering a wider area for analysis:

**Room A** is used for teaching and as temporal working space for people in university context.

**Room B** is a typical single office in the same floor with Room A.

As it can be observed in the 3D model, the two sample rooms have the same cardinal orientation, and implicit the same sun exposure of the windows (Figure 2.3), the same types of building materials, the same type of luminaires and the same type of furniture (Figure 2.4).

Three luminaires correspond to each window, so when the sunlight is not sufficient or absent, daylight is replaced by electrical light. In the following pages, two tables describing Room A and Room B are presented. Information about usage, location, orientation, size, interior space and materials, lighting system, operating hours and lighting requirements for each sample room are necessary to be identified in order to perform energy calculations.


**Figure 2.1. General plan of Vienna University of Technology. Position and cardinal orientation of sample rooms** (TU Wien 2013)

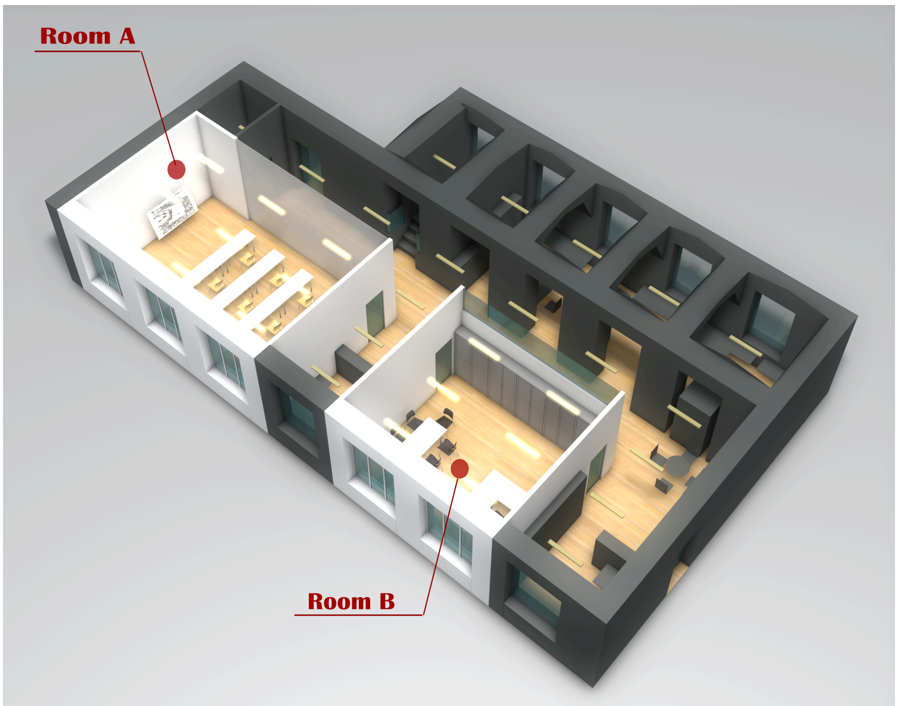


**Figure 2.2. 3D model of Building Physics Department including the sample rooms. Vienna University of Technology, North - East view**

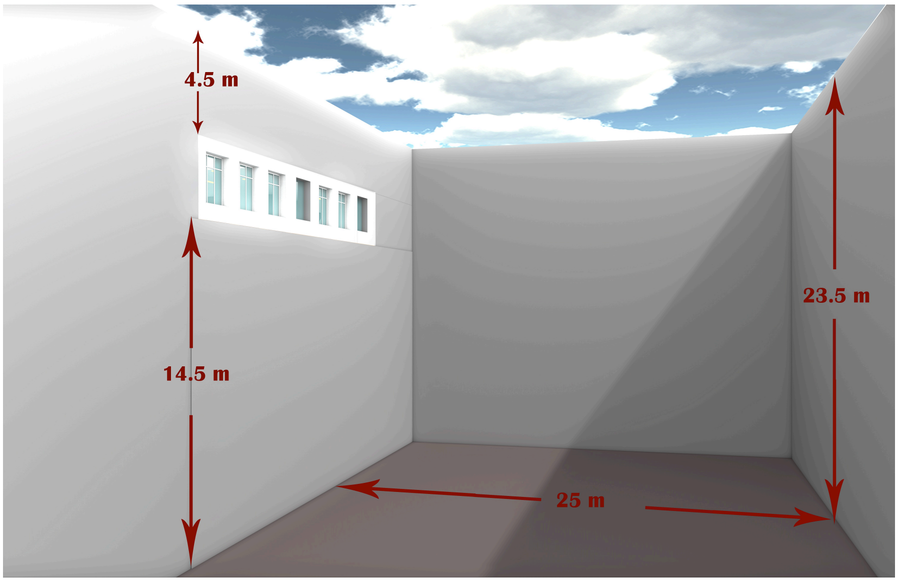


**Figure 2.3. Position of Building Physics Department in Vienna University of Technology, North - East view**

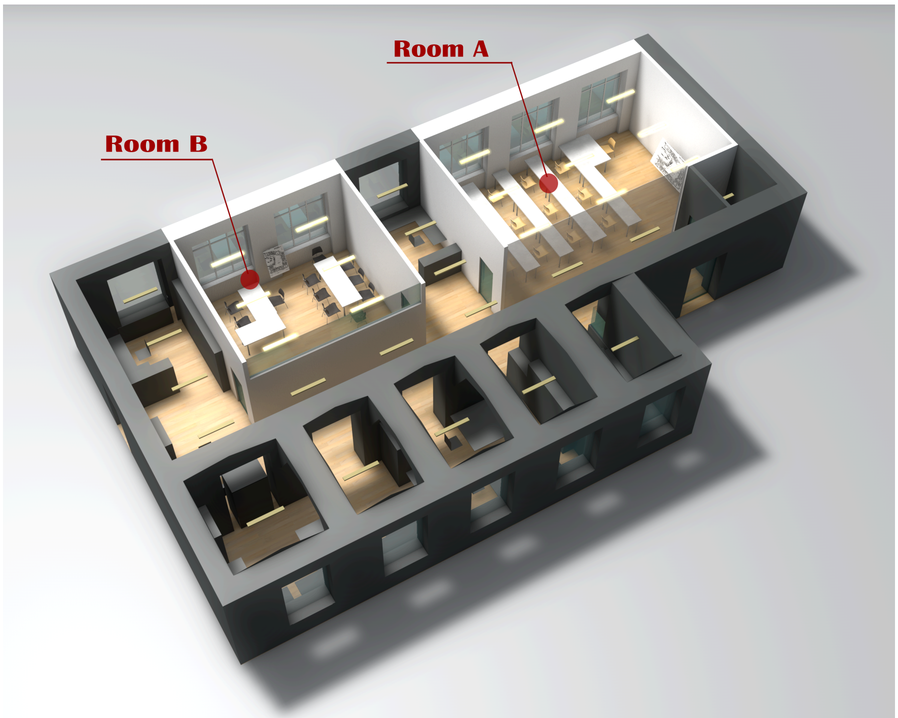


**Figure 2.4. 3D model of Building Physics Department including the sample rooms. Vienna University of Technology, South -West view**

**Table 2.1. Description of Room A**

| | |
|---|---|
| **Usage** | **Seminar classroom** |
| **Location** | Vienna, Austria, Karlsplatz 13, 1040<br>Longitude: 16.30°, Latitude: 48.20°<br>Department of Building Physics, Vienna University of Technology, 3 rd. floor |
| **Cardinal orientation** | North - East exposure of the windows |
| **Size** | Useful area = 56.25 m$^2$<br>Height = 4 m |
| **Description of the space** | Walls, ceiling – white plaster<br>3 windows on the exterior wall<br>One interior glass wall<br>Floor material - wooden laminated parquet |
| **Lighting solution** | 9 Trilux luminaires with 2 lamps each, organized in 3 control groups |
| **Lamps** | OSRAM LUMILUX HIGH EFFICIENCY FH 28W / 830 – tubular fluorescent lamps<br>9 X 2 X 28 W |
| **Mounting height** | 3 m |
| **Lighting control** | Manual: ON/OFF |
| **Operating hours** | 8 hours per day, 5 days per week, according to users<br>2000 hours/year (1800 daylight, 200 non-daylight), according to EN 15193 |
| **Lighting requirements** | Illuminance ($E_m$) = 500 lx on work plane<br>$UGR_L \leq 19$<br>$R_a = 80$ |

**Table 2.2. Description of Room B**

| | |
|---|---|
| **Usage** | **Office space** |
| **Location** | Vienna, Austria, Karlsplatz 13, 1040<br>Longitude: 16.30°, Latitude: 48.20°<br>Department of Building Physics, Vienna University of Technology, 3 rd. floor |
| **Cardinal orientation** | North - East exposure of the windows |
| **Size** | Useful area = 36.27 $m^2$<br>Height = 4 m |
| **Description of the space** | Walls, ceiling – white plaster<br>2 windows on the exterior wall<br>Glass surface on the upper part of interior wall<br>Floor material - wooden laminated parquet |
| **Lighting solution** | 6 Trilux luminaires with 2 lamps each, organized in 3 control groups |
| **Lamps** | OSRAM LUMILUX HIGH EFFICIENCY FH<br>28W / 830 – tubular fluorescent lamps<br>6 X 2 X 28 W |
| **Mounting height** | 3 m |
| **Lighting control** | Manual: ON/OFF |
| **Operating hours** | 8 -10 hours per day, 5 days per week, according to users<br>2500 hours/year (2250 daylight, 250 non-daylight), according to EN 15193 |
| **Lighting requirements** | Illuminance ($E_m$) = 500 lx on work plane<br>$UGR_L \leq 19$<br>$R_a$ = 80 |

## 2.3. The quick method

The quick method offers the possibility to estimate the total annual lighting energy usage and the LENI indicator in a space, in the design phase of the building. While exploring the Quick Method there are several options of calculating LENI:

i. Using the LENI equation that the standard offers and calculating manually with benchmark values (Table 2.3);
ii. Using Dialux lighting design software as calculation tool, which integrates the EN 15193 normative and calculates the lighting energy use, according to standard's equation.

For both methods the results are identical. This is why for the quick method is more practical to use the equation given by the EN 15193 standard for calculating LENI.

**Table 2.3. Benchmark values for office and education spaces**

| | | | | | | | | | | | | | No constant illumination | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $P_{em}$ | $P_{pc}$ | $P_N$ | $t_D$ | $t_N$ | $F_C$ | | $F_O$ | | $F_D$ | | LENI | LENI |
| | Qual Class | Parasitic Emergency kWh $m^{-2}$ $a^{-1}$ | Parasitic Control kWh $m^{-2}$ $a^{-1}$ | $W \cdot m^{-2}$ | h | h | No cte ill | Cte ill | Manu | Auto | Manu | Auto | Limiting value | |
| | | | | | | | | | | | | | Manu | Auto |
| | | | | | | | | | | | | | kWh $m^{-2}$ $a^{-1}$ | |
| **Office** | * | 1 | 5 | 15 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 42.1 | 35.3 |
| | ** | 1 | 5 | 20 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 54.6 | 45.5 |
| | *** | 1 | 5 | 25 | 2250 | 250 | 1 | 0.9 | 1 | 0.9 | 1 | 0.9 | 67.1 | 55.8 |
| **Education** | * | 1 | 5 | 15 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 34.9 | 27.0 |
| | ** | 1 | 5 | 20 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 44.9 | 34.4 |
| | *** | 1 | 5 | 25 | 1800 | 200 | 1 | 0.9 | 1 | 0.9 | 1 | 0.8 | 54.9 | 41.8 |

Where *No constant illumination* is the system where no dimmable lighting system is provided.

The values that are introduced in the equation are estimated values, that do not take into consideration: the location or cardinal orientation of the building, the geometry of the room (except the area) nor of the windows, the outside obstructions, the required maintained illuminance in the space. In this phase, important are only the type of building and the type of control, if automatic or manual. Taking into consideration the fact that these values were established in 2006, there is a high possibility of obtaining smaller results for the required installed power density (*PN* [W · $m^{-2}$]) and for the limiting values of LENI. The reason is the high efficiency of the lighting systems: fluorescent lamps with less consumption and better lighting.

For the usage hours, the standard estimates 2000 h for educational spaces and 2500 h for offices per year.

For educational spaces, the standard assumes that $t_O$ is 2000 h of which 1800 h would have daylight available and 200 h would not. Therefore, the standard states that $t_D$ is 1800 h and $t_N$ is 200 h, assuming an usage schedule from 08:00 to 16:00 for 250 working days per year.

For office spaces, out of a total annual usage hours of 2500 h, 2250 h would have daylight available and 250 h would not. Therefore the standard states that $t_D$ is 2250 h and $t_N$ is 250 h, assuming a working schedule from 08:00 to 18:00 for 250 working days per year.

When the system is controlled manually and no dimmable system is installed, the standard's benchmark values for the three factors are assumed to be 1 (Table 2.3 – No cte. ill. /Manu).

The following tables describe the values and methodology used in the standard equation (Table 2.4 and Table 2.5). Twenty steps are being presented for determining the total annual lighting energy usage and the LENI indicator.

**Table 2.4. Room A. Steps and values for the quick method**

| | | |
|---|---|---|
| **Parasitic power** | | |
| Total emergency charging power ($P_{em}$) | [1] | 0 W |
| Total lighting controls standby power ($P_{pc}$) | [2] | 0 W |
| **Luminaire data** | | |
| Total installed power ($P_n$) *56 W x 9* | [3] | 504 W |
| **Operating hours** | | |
| Daylight operating hours ($t_D$) | [4] | 1800 h |
| Non-daylight operating hours ($t_N$) | [5] | 200 h |
| Standard year time ($t_y$) | [6] | 8760 h |
| Emergency lighting charge time ($t_e$) | [7] | 0 h |
| **Factors** | | |
| Constant illuminance ($F_C$) | [8] | 1 |
| Occupancy dependency factor ($F_O$) | [9] | 1 |
| Daylight dependency factor ($F_D$) | [10] | 1 |
| **Parasitic energy** | | |
| Lighting controls parasitic power $P_{pc} \times (t_y - t_D + t_N)$<br>*(2) x [(6) - (4) + (5)]* | [11] | 0 |
| Emergency lighting parasitic factor $P_{em} \times t_e$<br>*(1) x (7)* | [12] | 0 |
| Total parasitic energy usage ($W_P$)<br>*[(11) + (12)] / 1000*<br>$W_P = [(P_{pc} \times (t_y - t_D + t_N) + (P_{em} \times t_e)] / 1000$ | [13] | 0 |
| **Illumination energy** | | |
| Energy usage without daylight/ occupancy control $P_n \times F_C$<br>*(3) x (8)* | [14] | 504 kWh · a$^{-1}$ |
| Daylight energy usage $t_D \times F_O \times F_D$<br>*(4) x (9) x (10)* | [15] | 1800 |
| Non - daylight energy usage $t_N \times F_O$<br>*(5) x (9)* | [16] | 200 |
| Total energy usage for illumination ($W_L$)<br>*{ (14) x [(15) + (16)] } / 1000*<br>$W_L = P_n \times F_C \times (t_D \times F_O \times F_D + t_N \times F_O) / 1000$ | [17] | 1008 kWh · a$^{-1}$ |
| Total annual energy usage $W = W_P + W_L$<br>*(13)+ (17)*<br>$\{[(P_{pc} \times (t_y - t_D + t_N) + (P_{em} \times t_e)] + P_n \times F_C \times (t_D \times F_O \times F_D + t_N \times F_O)\}/1000$ | [18] | 1008 kWh · a$^{-1}$ |
| Total useful floor area in m$^2$ ($A$) | [19] | 56.25 m$^2$ |
| Installed lighting power density load ($P_N$) $P_n / A$<br>*(3) / (19)* | [20] | **8.96** W · m$^{-2}$ |
| **Lighting energy numeric indicator (LENI)**<br>*(18) /(19)* | [21] | **17.92** kWh · m$^{-2}$ · a$^{-1}$ |

**Table 2.5. Room B. Steps and values for the quick method**

| | | | |
|---|---|---|---|
| **Parasitic power** | | | |
| Total emergency charging power ($P_{em}$) | | [1] | 0 W |
| Total lighting controls standby power ($P_{pc}$) | | [2] | 0 W |
| **Luminaire data** | | | |
| Total installed power ($P_n$) | *56 W x 6* | [3] | 336 W |
| **Operating hours** | | | |
| Daylight operating hours ($t_D$) | | [4] | 2250 h |
| Non-daylight operating hours ($t_N$) | | [5] | 250 h |
| Standard year time ($t_y$) | | [6] | 8760 h |
| Emergency lighting charge time ($t_e$) | | [7] | 0 h |
| **Factors** | | | |
| Constant illuminance ($F_C$) | | [8] | 1 |
| Occupancy dependency factor ($F_O$) | | [9] | 1 |
| Daylight dependency factor ($F_D$) | | [10] | 1 |
| **Parasitic energy** | | | |
| Lighting controls parasitic power<br>*(2) x [(6) - (4) + (5)]* | $P_{pc}$ x $(t_y - t_D + t_N)$ | [11] | 0 |
| Emergency lighting parasitic factor<br>*(1) x (7)* | $P_{em}$ x $t_e$ | [12] | 0 |
| Total parasitic energy usage ($W_P$)<br>*[(11) + (12)] / 1000*<br>$W_P$ = [($P_{pc}$ x ($t_y$ - $t_D$ + $t_N$) + ($P_{em}$ x $t_e$)] / 1000 | | [13] | 0 |
| **Illumination energy** | | | |
| Energy usage without daylight/ occupancy control<br>*(3) x (8)* | $P_n$ x $F_C$ | [14] | 336 kWh · $a^{-1}$ |
| Daylight energy usage<br>*(4) x (9) x (10)* | $t_D$ x $F_O$ x $F_D$ | [15] | 2250 |
| Non - daylight energy usage<br>(5) x (9) | $t_N$ x $F_O$ | [16] | 250 |
| Total energy usage for illumination ($W_L$)<br>*{ (14) x [(15) + (16)] } / 1000*<br>$W_L$ = $P_n$ x $F_C$ x ($t_D$ x $F_O$ x $F_D$+ $t_N$ x $F_O$) / 1000 | | [17] | 840 kWh · $a^{-1}$ |
| Total annual energy usage<br>*(13)+ (17)*<br>{[($P_{pc}$ x ($t_y$ - $t_D$ + $t_N$)+ ($P_{em}$ x $t_e$)] + $P_n$ x $F_C$ x ($t_D$ x $F_O$ x $F_D$+ $t_N$ x $F_O$)}/1000 | $W = W_P + W_L$ | [18] | 840 kWh · $a^{-1}$ |
| Total useful floor area in $m^2$ ($A$) | | [19] | 36.27 $m^2$ |
| Installed lighting power density load ($P_N$)<br>*(3) / (19)* | $P_n / A$ | [20] | **9.26** W · $m^{-2}$ |
| **Lighting energy numeric indicator (LENI)**<br>*(18) /(19)* | | [21] | **23.16** kWh · $m^{-2}$ · $a^{-1}$ |

## 2.4. The comprehensive method

The comprehensive method provides more accurate results for the total annual lighting energy use and LENI, in new or existing buildings on a room-by-room basis. The method accounts for all the other parameters that the quick method simplifies or neglects: location, obstructions (from surrounding buildings), orientation, daylight penetration, maintained illuminance, occupancy (depending on the type of space and how many users it serves) and also type of control (auto or manual).

The usage hours can be determined in different modalities: using the standard's benchmark values for $t_D$ and $t_N$, assuming the hours depending on the schedule of users, or adapting the building to national recommendations, if it is the case. The Austrian standards do not provide any additional recommendations to the EN 15193 for the usage time in buildings. Estimating the usage hours according to user's schedule, assuming that the electrical light is always used, results to similar values with the benchmarks (10hx250=2500h; 8hx250=2000h) for 250 days per year. In consequence, benchmark values are used.

When using the comprehensive method, the three dependency factors are to be obtained by calculation. For this reason it is indicated to use a calculation tool that gives more accurate results about the daylight penetration, because this has a very important role in defining the daylight dependency factor ($F_D$), as are the location and cardinal orientation. Dialux calculates the daylight penetration resulting from the geometry of the room and most of all from the geometry and size of the windows. Modelling the spaces correctly in Dialux is therefore very important.

Knowing the usage patterns of the space, can determine the absence factor $F_A$ and implicit the occupancy dependency factor $F_O$.

### 2.4.1. Modelling the spaces in Dialux

Dialux is a light-planning tool that offers the possibility to perform energy evaluations according to EN 15193's equation and methodology, asking for the user to input values for different parameters. These values are chosen from the benchmark tables or they are adjusted according to the situation. Using this simulation tool, more realistic results are obtained, by adapting the building (or the room) to the conditions and characteristics of the real space. The location, the cardinal orientation of the building, the size and geometry of the room and of the transparent area, the surrounding buildings, are responsible for the daylight penetration in the room and indirectly for the total annual lighting energy use and LENI.

**Figure 2.5. Room A (left) and Room B (right) modelled in Dialux**

**Table 2.6. Room A. Values for the comprehensive method**

| | | |
|---|---|---|
| **Power** | | |
| Total installed lighting power ($P_n$) | *56W x 9* | 504 W |
| Parasitic power of controls with lamps off ($P_{pc}$) | | 0 W |
| Emergency lighting charging power ($P_{em}$) | | 0 W |
| **Operating hours** | | |
| Daylight time usage ($t_D$) | | 1800 h |
| Non-daylight time usage ($t_N$) | | 200 h |
| Emergency lighting charge time ($t_e$) | | 0 h |
| **Control** | | |
| Constant illuminance factor ($F_C$) | | 1 (manual control) |
| Constant illuminance controllable | | / |
| **Occupancy** | | |
| Occupancy dependency factor ($F_O$) | $F_O = F_{OC} + 0.2 – F_A$ | 0.80 |
| Absence factor ($F_A$) | | 0.40 (Table 1.5) |
| Occupancy control factor ($F_{OC}$) | | 1.00 (Table 1.4) |
| **Daylight** | | |
| Daylight dependency factor ($F_D$) | $F_D = 1- (F_{DS} \times F_{DC})$ | 0.68 |
| Daylight supply factor ($F_{DS}$) | | 0.79 (Table 1.10) |
| Daylight control factor ($F_{DC}$) | | 0.40 (Table 1.11) |
| Control of artificial lighting system | | Manual |
| **Facades** | | |
| Classification of daylight penetration | | Good |
| Maintenance value of the illuminance ($E_m$) | | 500 lx |
| Latitude | | 48.20° |
| **Dialux outcome** | | |
| Total annual energy usage | $W = W_P + W_L$ | **576.54** $kWh \cdot a^{-1}$ |
| **Lighting energy numeric indicator (LENI)** | | **10.25** $kWh \cdot m^{-2} \cdot a^{-1}$ |

### Table 2.7. Room B. Values for the comprehensive method

| | | |
|---|---|---|
| **Power** | | |
| Total installed lighting power ($P_n$) | *56W x 6* | 336 W |
| Parasitic power of controls with lamps off ($P_{pc}$) | | 0 W |
| Emergency lighting charging power ($P_{em}$) | | 0 W |
| **Operating hours** | | |
| Daylight time usage ($t_D$) | | 2250 h |
| Non-daylight time usage ($t_N$) | | 250 h |
| Emergency lighting charge time ($t_e$) | | 0 h |
| **Control** | | |
| Constant illuminance factor ($F_C$) | | 1 (manual control) |
| Constant illuminance controllable | | / |
| **Occupancy** | | |
| Occupancy dependency factor ($F_O$) | $F_O = F_{OC} + 0.2 – F_A$ | 0.80 |
| Absence Factor ($F_A$) | | 0.40 (Table 1.5) |
| Occupancy control factor ($F_{OC}$) | | 1.00 (Table 1.4) |
| **Daylight** | | |
| Daylight dependency factor ($F_D$) | $F_D = 1- (F_{DS} \times F_{DC})$ | 0.80 |
| Daylight supply factor ($F_{DS}$) | | 0.68 (Table 1.10) |
| Daylight control factor ($F_{DC}$) | | 0.30 (Table 1.11) |
| Control of artificial lighting system | | Manual |
| **Facades** | | |
| Classification of daylight penetration | | Middle |
| Maintenance value of the illuminance ($E_m$) | | 500 lx |
| Latitude | | 48.20° |
| **Dialux outcome** | | |
| Total annual energy usage | $W = W_P + W_L$ | **548.88** kWh · $a^{-1}$ |
| **Lighting energy numeric indicator (LENI)** | | **15.13** kWh · $m^{-2}$ · $a^{-1}$ |

## 2.5. The metered method

For this method, local power meters were coupled to each control group, gathering during a period of one year, information and data about the usage of the installed lighting system (Table 2.8).

At the same time, occupancy sensors were determining the presence of occupants in the room (Table 2.8). The data is provided hourly during a total of 8784 hours (29 February, one additional day in 2012).

After gathering the entire data from the installed sensors, it is required to process the information for determining the total annual lighting energy usage (*W*) and LENI values. For the total annual energy usage it is necessary to analyse how many hours per year is the electrical energy in use for each control group and then multiply this number to the installed lighting power of the control group.

In the seminar room there are 3 control groups of 3 luminaires, each control group with a power of 168 W. The control groups were switched ON individually during one year for a cumulated number of 478 h (simultaneously or not), resulting in a total annual lighting energy use of 80.30 kWh per year (Table 2.9).

For the office room there are 3 control groups of 2 luminaires, with a power of 112 W per control group. The control groups were switched ON individually during one year for a cumulated number of 1274 h (simultaneously or not), resulting in a total annual lighting energy use of 142.69 kWh per year (Table 2.10).

The total annual lighting energy usage divided by the area of the room establishes the LENI indicator: 1,43 kWh $\cdot$ m$^{-2}$ per year for the seminar room and 3.80 kWh $\cdot$ m$^{-2}$ per year for the office room.

The next step is to find out the usage hours (daylight/non-daylight) for each space in order to compare what the standard recommends and what the measurements provide. With regards to the specific project, for more appropriate and accurate results of usage hours, it is necessary to analyse the weather file from the local meteorological station, for the specific location. This helps establish which are the hours considered to have daylight availability and which are not, during a period of one year in Vienna.

According to Lou Bedocs, lighting applications adviser at Thorn Lighting and member of the committee that drafted the normative, "EN 15193 does not specify certain daytime and night times on daily bases, but it assumes a particular annual occupancy period and estimates how many hours per year there would be useful amount daylight available for task illuminance. Good daylight availability would be the period when the horizontal illuminance outside the building is about 1000 lx. This with side windows creating 1% daylight factor, would yield about 10 lx indoors and contribute usefully about 2% light to the 500 lx needed for the office task lighting".

This concludes that the hours when the electrical system is turned ON during the time when the outside illuminance is higher than 1000 lx are considered $t_D$ and the rest of the hours are $t_N$.

**Table 2.8. Instrumentation for monitoring the occupancy and usage hours of the electrical lighting system**

| **Thermokon SR-MDS** | **Eltako FWZ61-16A** |
|---|---|
| Wireless Ceiling Multi Sensor<br>Occupancy detection 360° | Wireless electrical power meters coupled to each control group |
|   |   |

**Table 2.9. Room A. Values for the metered method**

| Parameter | | Value |
|---|---|---|
| Total installed lighting power ($P_n$) | *56W x 9* | 504 W |
| Installed lighting power per group | *56W x 3* | 168 W |
| Parasitic power of controls with lamps off ($P_{pc}$) | | 0 W |
| Emergency lighting charging power ($P_{em}$) | | 0 W |
| Cumulated usage hours for 3 control groups | | 478 h |
| Daylight time usage ($t_D$) | | 168 h |
| Non-daylight time usage ($t_N$) | | 71 h |
| Total usage hours ($t_O$) | $t_O = t_D + t_N$ | 239 h |
| Emergency lighting charge time ($t_e$) | | 0 h |
| Standard year time ($t_y$) | | 8784 h (+29.02.2012) |
| Daylight availability per year | | 4196 h |
| Hours of occupancy per year | | 2087 h |
| Total annual energy usage ($W$) | *478h x 168W* | **80.30** $kWh \cdot a^{-1}$ |
| Total area ($A$) | | 56.25 $m^2$ |
| Installed lighting power density load ($P_N$) | $P_n / A$ | 8.96 $W \cdot m^{-2}$ |
| **Lighting energy numeric indicator (LENI)** | *W/A* | **1.43** $kWh \cdot m^{-2} \cdot a^{-1}$ |

**Table 2.10. Room B. Values for the metered method**

| Parameter | | Value |
|---|---|---|
| Total installed lighting power ($P_n$) | *56W x 6* | 336 W |
| Installed lighting power per group | *56W x 2* | 112 W |
| Parasitic power of controls with lamps off ($P_{pc}$) | | 0 W |
| Emergency lighting charging power ($P_{em}$) | | 0 W |
| Cumulated usage hours for 3 control groups | | 1274 h |
| Daylight time usage ($t_D$) | | 395 h |
| Non-daylight time usage ($t_N$) | | 184 h |
| Total usage hours ($t_O$) | $t_O = t_D + t_N$ | 579 h |
| Emergency lighting charge time ($t_e$) | | 0 h |
| Standard year time ($t_y$) | | 8784 h (+29.02.2012) |
| Daylight availability per year | | 4196 h |
| Hours of occupancy per year | | 2380 h |
| Total annual energy usage ($W$) | *1274h x 112W* | **142.69** $kWh \cdot a^{-1}$ |
| Total area ($A$) | | 36.27 $m^2$ |
| Installed lighting power density load ($P_N$) | $P_n / A$ | 9.26 $W \cdot m^{-2}$ |
| **Lighting energy numeric indicator (LENI)** | *W/A* | **3.80** $kWh \cdot m^{-2} \cdot a^{-1}$ |

# 3. Results

## 3.1. Overview

This chapter summarizes the main results. Data collected from the sensors is analysed and compared with data obtained using the standard calculation methods. In this context, two cases are presented:

i. **The base case with standard input assumptions**

The first section illustrates the comparison of alternative calculation approaches (Quick and Comprehensive method) with measurements, with the purpose of observing better the results for each method and the differences between them.

ii. **The modified case with monitored hours input assumptions**

The second section, implements the daylight and non-daylight usage hours obtained during measurements, into the Quick and Comprehensive method. The diagrams evaluate the new results.

For each case there are several series of charts. The first presents the total annual lighting energy and the second, the LENI values per month, during a period of one year.

One more set of charts provided by the occupancy sensors and by the local power meters offer information about the occupancy hours and operating hours (daylight and non-daylight time usage).

As a conclusion, there is a third section that compares the annual results for the two cases: total annual lighting energy use and LENI results for the base case and modified case.

## 3.2. Room A

### 3.2.1. Base case with standard values input

For the base case, there are four types of charts presenting monthly results for: the total annual lighting energy, LENI, the occupancy hours and usage hours in the seminar room.

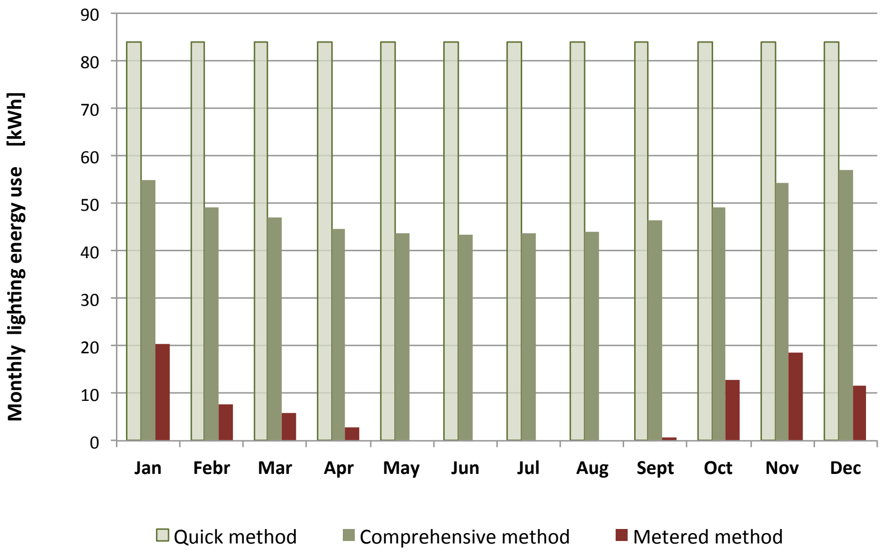


**Figure 3.1. Room A. Base case. Monthly lighting energy use**

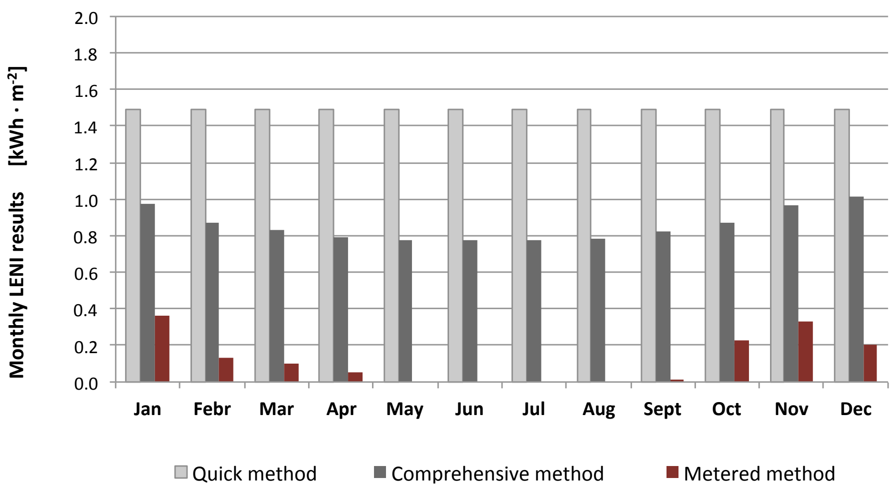


**Figure 3.2. Room A. Base case. Monthly LENI results**

Analysing the data from the occupancy sensors and from the local power meters, the following charts were completed. They offer information about the occupancy hours and operating hours (daylight and non-daylight time usage) in the seminar room.

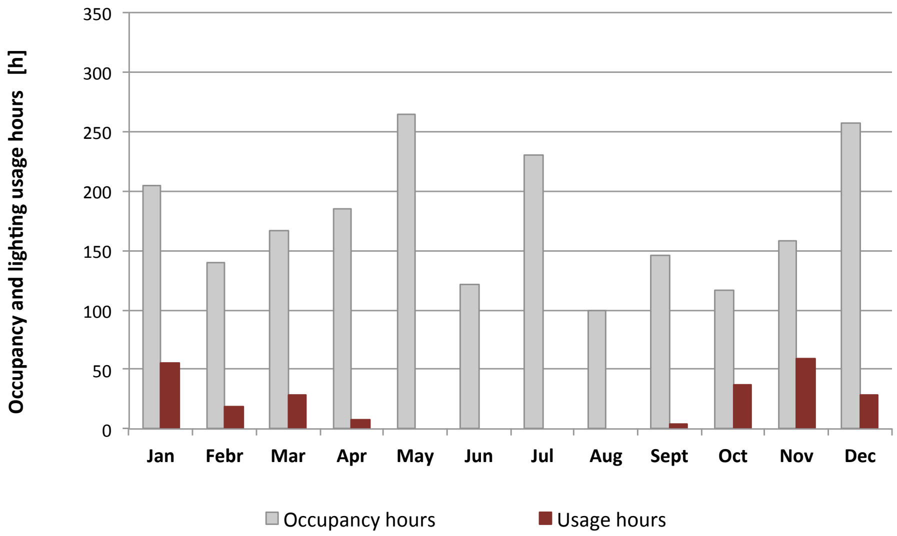


**Figure 3.3. Room A. Monthly occupancy and lighting usage hours**

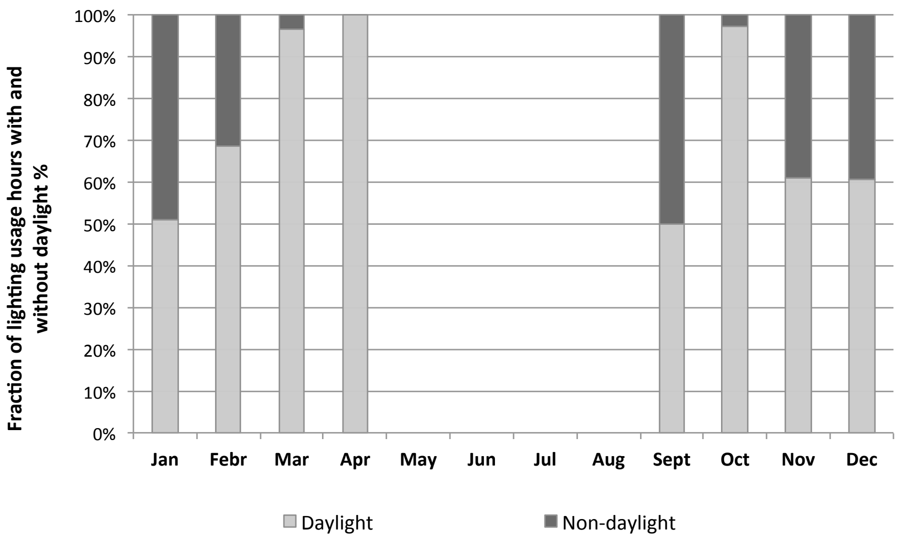


**Figure 3.4. Room A. Daylight and non-daylight time usage per month in %**

### 3.2.2. Modified case with monitored hours input

The modified case implements the daylight and non-daylight usage hours obtained during measurements, into the Quick and Comprehensive method. The two diagrams evaluate the new results for the total annual lighting energy and LENI.

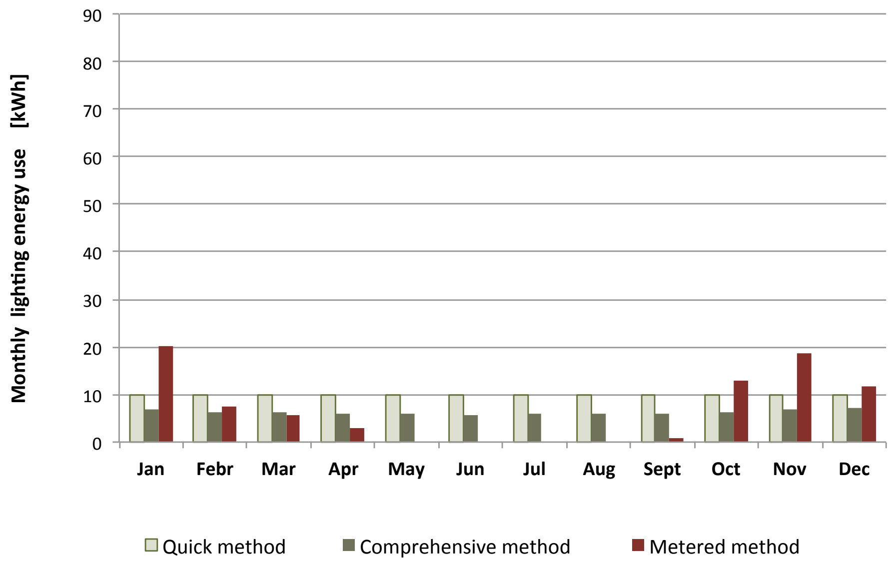


**Figure 3.5. Room A. Modified case. Monthly lighting energy use**

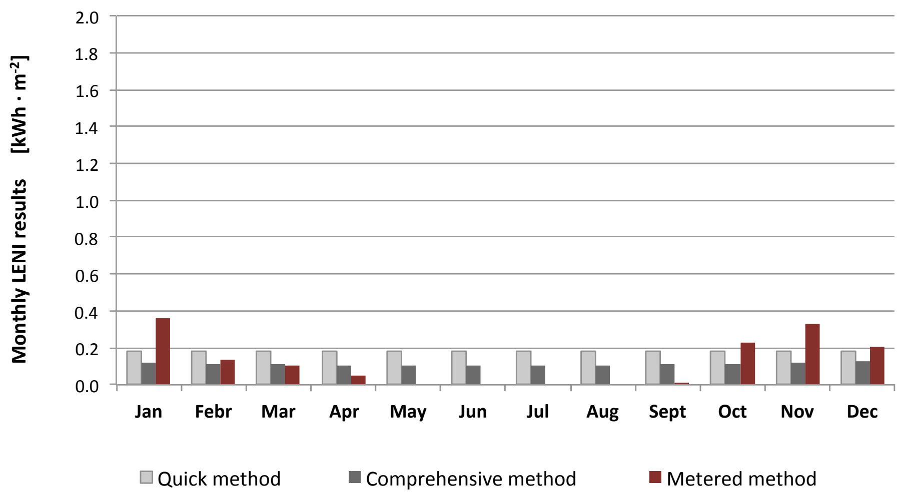


**Figure 3.6. Room A. Modified case. Monthly LENI results**

### 3.2.3. Total annual lighting energy use and LENI results for the two cases

The third section compares the annual results for the two cases: total annual lighting energy use and LENI results for the base case and modified case.

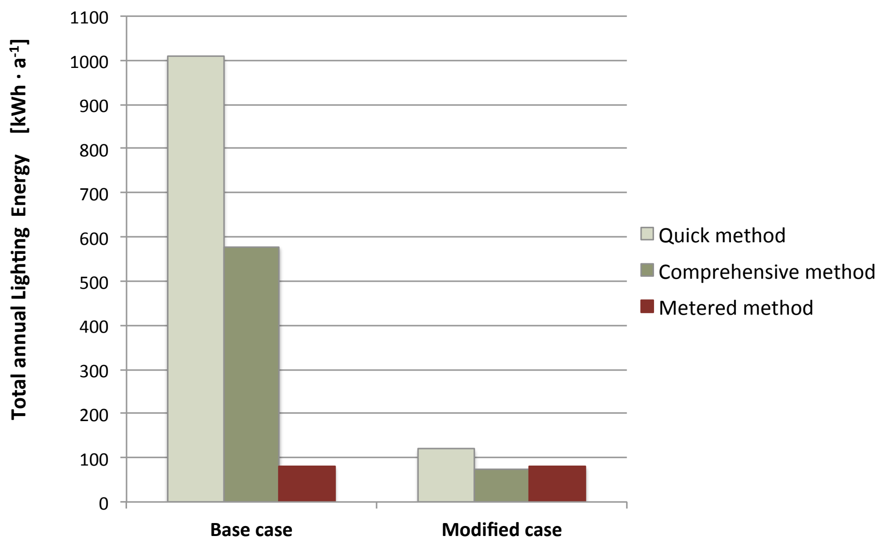


**Figure 3.7. Room A. Total annual lighting energy use for two cases**

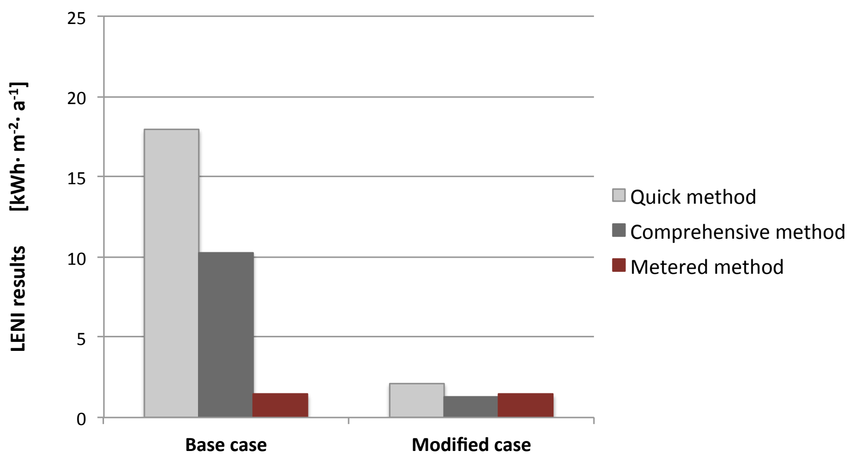


**Figure 3.8. Room A. LENI results for two cases**

## 3.3. Room B

### 3.3.1. Base case with standard values input

The base case presents monthly results for: the total annual lighting energy, LENI, the occupancy hours and usage hours in the office room.

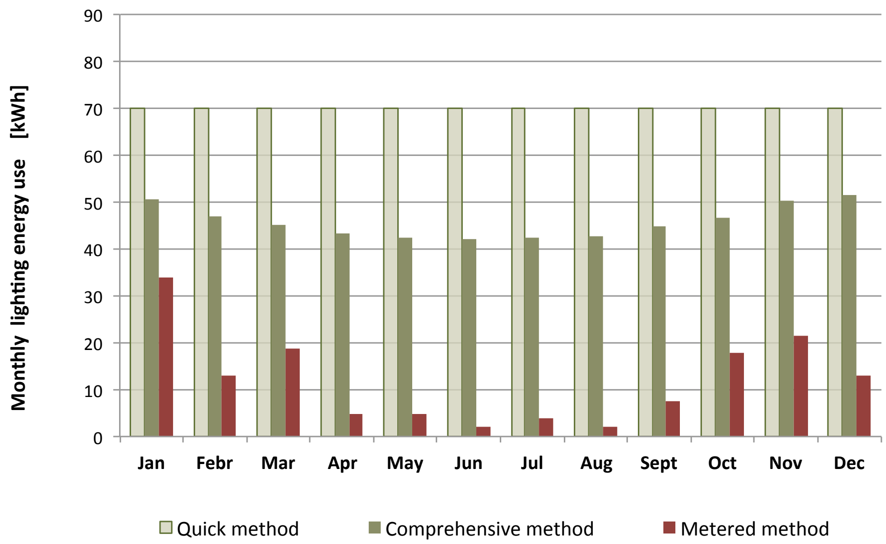


**Figure 3.9. Room B. Base case. Monthly lighting energy use**

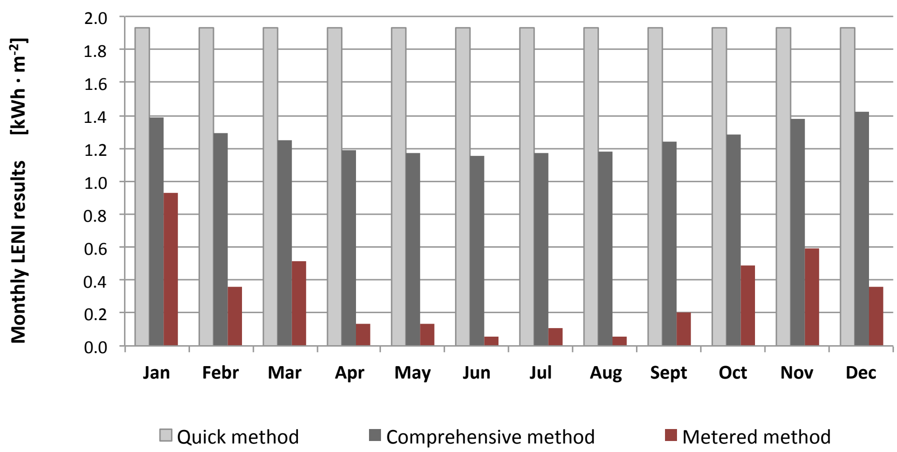


**Figure 3.10. Room B. Base case. Monthly LENI results**

Analysing the data from the occupancy sensors and from the local power meters, the following charts were completed. They offer information about the occupancy hours and operating hours (daylight and non-daylight time usage) in the seminar room during a period of one year.

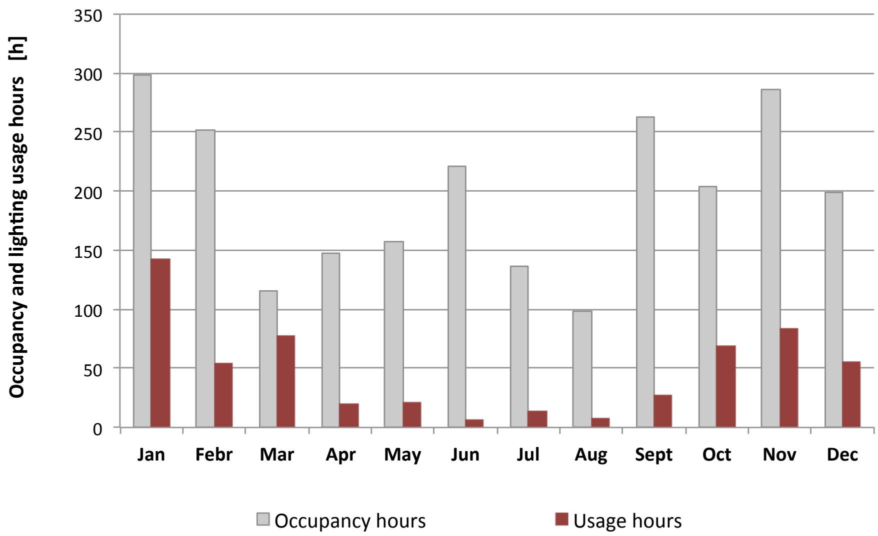


**Figure 3.11. Room B. Monthly occupancy and lighting usage hours**

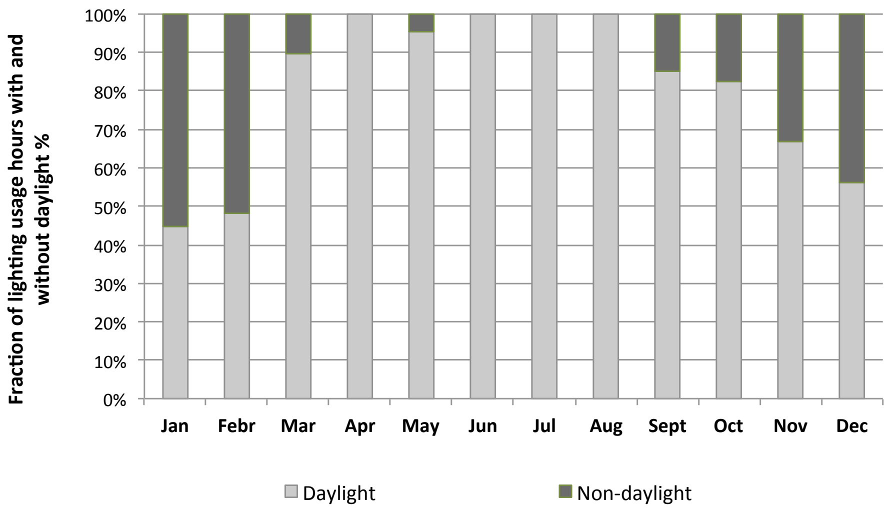


**Figure 3.12. Room B. Daylight and non-daylight time usage per month in %**

### 3.3.2. Modified case with monitored hours input

The modified case implements the values obtained during measurements, into the Quick and Comprehensive methods. The diagrams present the new results.

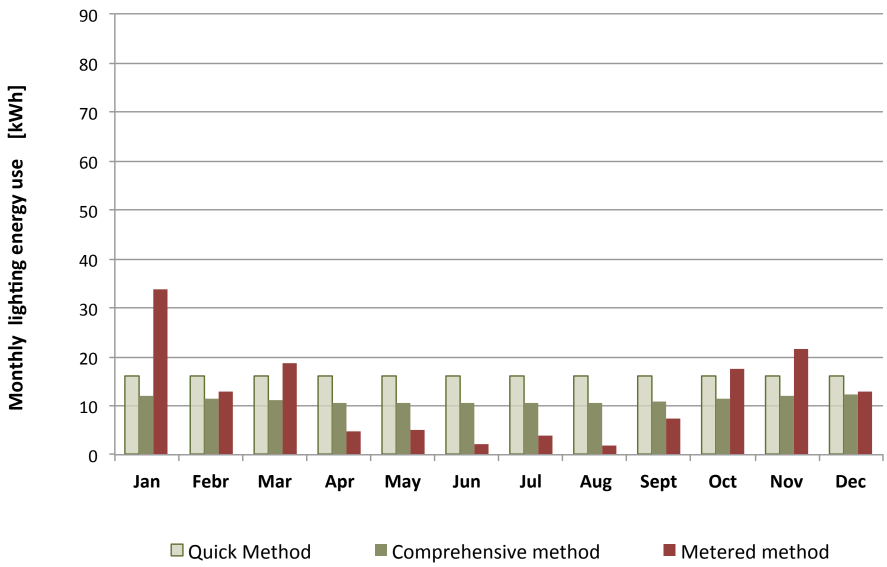


**Figure 3.13. Room B. Modified case. Monthly lighting energy use**

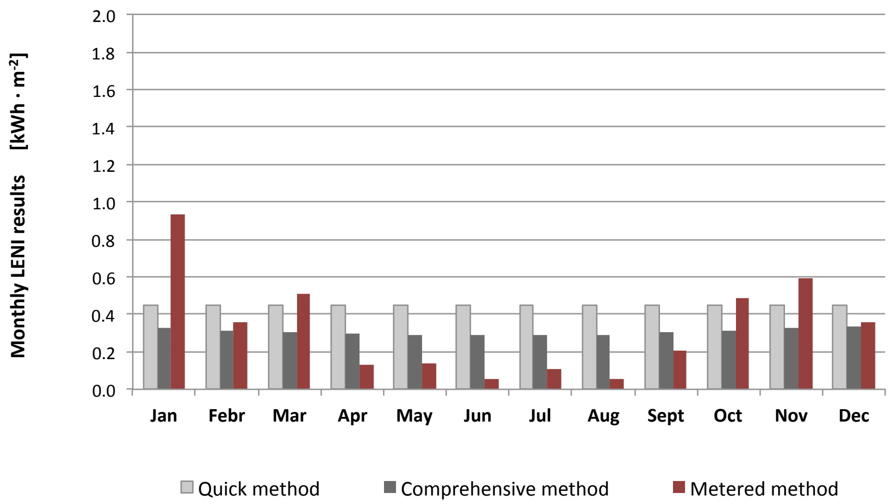


**Figure 3.14. Room B. Modified case. Monthly LENI results**

### 3.3.3. Total annual lighting energy use and LENI results for the two cases

This section compares the annual results for the base case with the results for the modified case in terms of annual lighting energy use and LENI.

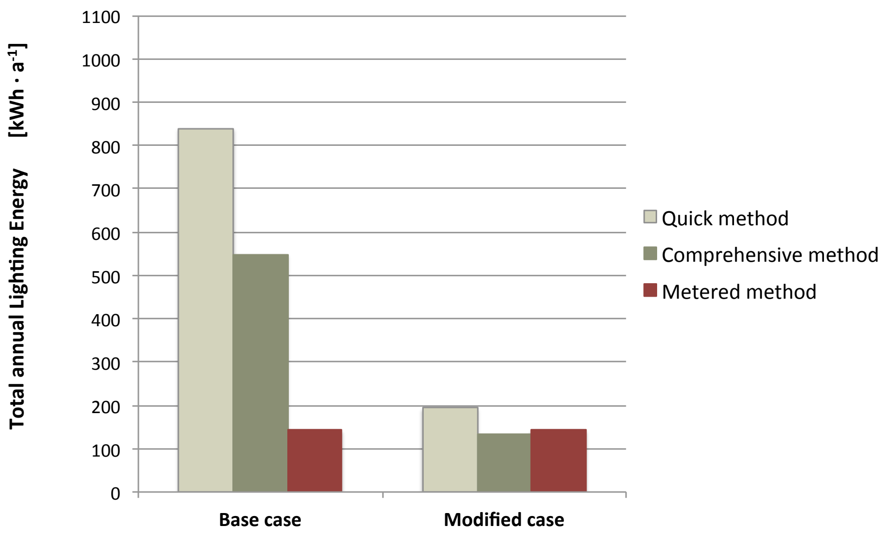


**Figure 3.15. Room B. Total annual lighting energy for two cases**

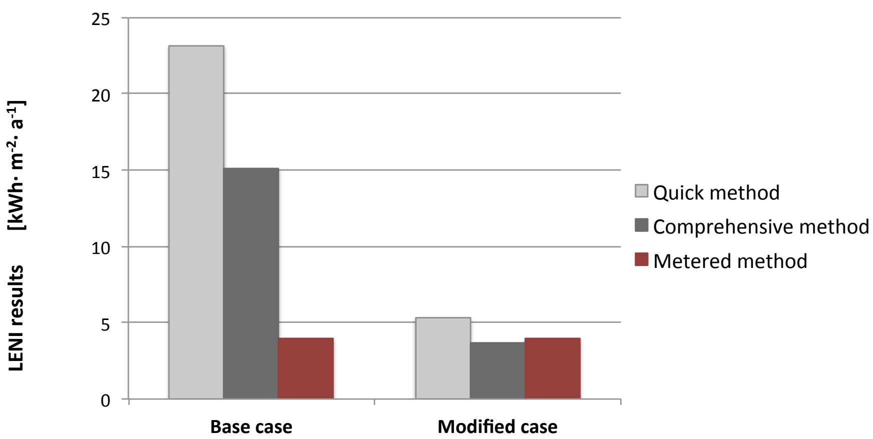


**Figure 3.16. Room B. LENI results for two cases**

# 4. Discussions

## 4.1. Overview

This chapter provides a summary discussion on the main results of the thesis for two cases: the base case with initial standard values input and the modified case with monitored hours input.

## 4.2. Base case

For this case, the first observation is that the Quick method provides considerable higher values than the other two methods. The reason is the fact that the Quick method is an estimation of the total annual lighting energy that does not account for several important factors (location, weather, daylight availability, etc.) and estimates a very high number of lighting usage hours for this type of spaces (2000 h for educational spaces and 2500 h for offices).

The results for the measured LENI are significantly smaller than the benchmark limiting values offered by EN 15193. The more the used data is accurate and specific for the project, the more the Calculated methods provide closer results to the Metered method.

The type of the space and its usage are directly reflected in the shape of the chart. There is an obvious reduction of electrical lighting usage between the months April and September. The occupancy sensors indicate that there is presence in these spaces during the whole year, but there are less operating hours of the electrical system between these specific months. The number of occupancy hours in the seminar room is 2087 h per year and in the office room, 2380 h.

The usage hours of the electrical lighting are 239 h per year in the seminar room and 579 h in the office room. At the same time, presence was detected in cases where the lights were OFF, this

meaning that the occupants did not use the artificial light because of good daylight availability. The reason is the increase of daylight intensity and daylight hours in the summer time, meaning less hours of electrical light usage and more use of the natural light.
Another reason is the fact that the spaces have the advantage of good daylight exposure, because of large window area and good positioning in the building (3 rd. floor, only one exiting floor above it). The obstruction effect due to surrounding buildings on daylight penetration is characterized as moderate.

## 4.3. Modified case

For the second case, the measured values given by the sensors are used in the Quick method and in the Comprehensive method. The daylight time usage and non-daylight time usage, calculated with the Metered method, are implemented into the Calculation methods.
For the seminar room, out of a total usage hours of 239 h per year, 168 h are daylight usage hours and 71 h are non-daylight, values considerably smaller than the standard recommends for the quick method ($t_D$=1800 h and $t_N$=200 h).
For the office room, out of a total usage hours of 579 h per year, 395 h are daylight usage hours and 168 h are non-daylight. The values are also, in this case, considerable smaller than the standard recommends ($t_D$=2000 h and $t_N$=250 h).
This substantial difference between the calculations and measurements observed in the Base case is adjusted in the second case. In consequence, the results for the Calculation methods and Metered method are very similar, comprehending what a significant influence the operating hours have, for achieving proper results.

# 5. Conclusions

Insufficient or improper lighting and energy waste are the reasons why lighting standards were initially required. Nevertheless, their calculation methods are not always perfect and they need further improvements. The architectural design of a building plays a very important role in achieving optimal illuminance in a space. The size and geometry of the transparent area, the size and geometry of the space, the cardinal orientation of the building, the use of shading devices, the type of construction materials used, are parameters that influence the intensity and quality of daylight. Exploiting rationally energy sources like daylight generates less energy use and cost effectiveness. When estimating the lighting demand of a building, daylight plays an important role, as does the number of usage hours, or the type of lamps and control. An automatic controlling system causes great amounts of energy savings, because the electrical light is used strictly when needed: presence of occupants and if the illuminance levels decrease under standard limits.

EN 15193 is a European normative and all default values inserted in the benchmark tables are average and realistic but do not provide accurate answers to specific places. In Europe, there are wide variations in climatic and local conditions as well as indoor requirements, that this CEN standard cannot cover accurately and therefore needs to be supplemented by local data.

The quick method offers the possibility to estimate the total annual lighting energy use and the LENI indicator in a space in the design phase of the building. The values that are introduced in the equation are estimated values that do not take into consideration the location or cardinal orientation of the building, daylight penetration, the geometry of the room (except the area) nor the required maintained illuminance. In this phase, only the type of space (usage) and the type of control is important, if automatic or manual.

The comprehensive method has the purpose to give more accurate results for the total annual energy use and LENI, considering all the other parameters that the quick method simplifies or neglects: location, cardinal orientation, daylight penetration, maintained illuminance, occupancy and type of control (auto or manual). For this step it is indicated to use a calculation tool as Dialux that presents more accurate results according to daylight penetration and $F_D$. Modelling the spaces correctly in Dialux is therefore, very important. The calculation of daylight penetration is resulted from the geometry of the room and most of all, from the geometry and size of the windows. To determine the occupancy factor $F_O$, it is necessary to have proper information about the presence of occupants in the space.

In this context, the comprehensive method is also an estimation of total annual lighting energy use and LENI, but with more accurate values, adapted to the conditions and characteristics of the space.

Having this in mind, the results for the comprehensive method should be more accurate than the quick method and closer to the metered method.

The measurements illustrate considerably smaller results than the two previous calculation methods. The reason is the usage hours, reduced in the present case because of good daylight penetration in the rooms, the artificial light being rarely used. Out of the total occupancy hours, only a certain percentage consists in usage hours of electrical light.

In the quick method, entering more precise data is possible, if these are known (e.g., the occupancy periods, control techniques). With these considerations, the quick and comprehensive calculations and the measured values derive closer together as the parameters are assigned properly.

The modern times offer advanced electrical systems that produce light with comparable quality and properties of natural light and with very low energy consumption. There are though, characteristics of daylight that still cannot be produced artificially. This refers to the role that sunlight plays on humans' health and harmonious development. Having this in mind, it is necessary to improve the buildings by combining the advantages of natural light (as much as daylight is available) with the need of artificial light.

## 5.1. Further research

Further improvements need to be done to extend the methodology of calculating LENI. EN 15193 is a new idea in terms of energy saving potential, but the continuous evolution of lighting technology and devices will always need an updated calculation methodology.

As a future study, it is essential that the standard defines a complete methodology on how to determine the daylight and non-daylight operating hours, depending on the location of the respective building or room. The usage hours have critical influence for the results as are the three dependency factors $F_D$, $F_C$, $F_O$.

The topic can be debated on another level and can generate interesting and useful results for standard users. One very interesting future study is to compare the energy demand and the LENI indicator for buildings in different locations and different climatic conditions, different cardinal orientation, or with various window sizes. The results will help understanding better how the daylight dependency factor ($F_D$) influences the results for LENI indicator.

Another attractive subject is to compare lighting systems that first use manual ON/OFF control and secondly an auto control with dimming lighting, depending on the needs of the user. The results will be clearly in favour of the second one, but determining how much energy can be saved using it, is an interesting topic.

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# 7. Appendix

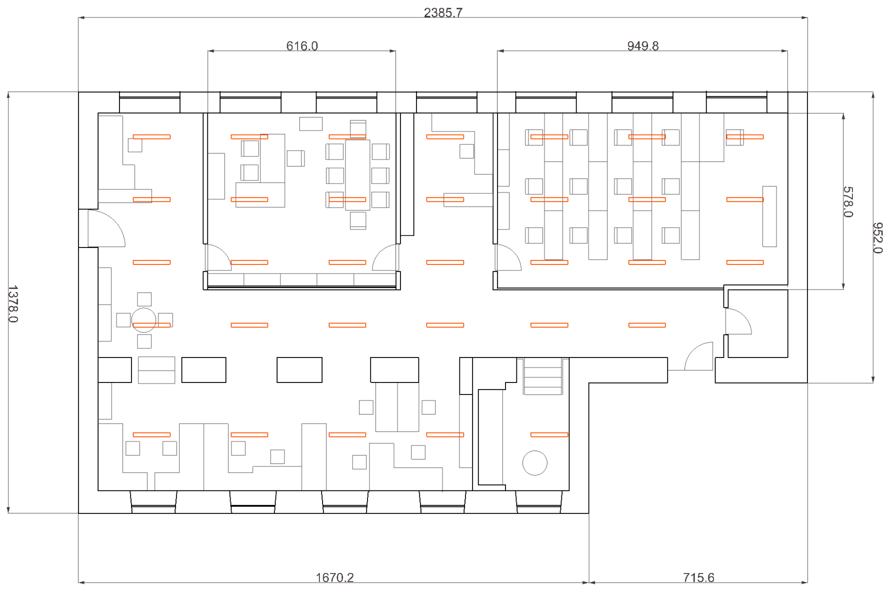


**Figure 7.1. Plan of sample rooms**

**Table 7.1. Surface reflection measurements for Dialux**

| Surface reflection measurements for Room A and Room B used in DIALux | | | | |
|---|---|---|---|---|
| **Surface** | **Texture** | **Reflectance** | **Transparency** | **Mirror Effect** |
| **Wall / Ceiling** | Plaster | 0,78 | - | - |
| **Glass wall** | Glass plate | 0,45 | 0,45 | 0,70 |
| **White board** | Furniture | 0,78 | - | - |
| **Floor** | Flooring | 0,36 | - | - |
| **Table** | Furniture | 0,54 | - | - |
| **Chairs** | Furniture | 0,63 | - | - |
| **Drawer wood** | Furniture | 0,30 | - | - |
| **Drawer door** | Furniture | 0,30 | - | - |
| **Door** | Door, plastic | 0,82 | - | - |
| **Window recess** | Plaster | 0,78 | - | - |
| **Windows** | Window Wood | 0,15 | 0,85 | 0,60 |

**Table 7.2. Room A. Monthly and yearly results**

| Monthly and yearly results \| Room A | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Parameters** | **January** | **February** | **March** | **April** | **May** | **June** | **July** | **August** | **Septemb** | **October** | **Novemb** | **Decemb** | **Yearly** | **Unit** |
| **Measurements** | Occupancy hours | 204.00 | 140.00 | 166.00 | 185.00 | 264.00 | 121.00 | 230.00 | 99.00 | 146.00 | 117.00 | 158.00 | 257.00 | 2087.00 | [h] |
| | Daylight usage hours (tD) | 28.00 | 13.00 | 28.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 36.00 | 36.00 | 17.00 | 168.00 | [h] |
| | Non-daylight usage hours (tN) | 27.00 | 6.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 1.00 | 23.00 | 11.00 | 71.00 | [h] |
| | Usage hours per month (tO) | 55.00 | 19.00 | 29.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 37.00 | 59.00 | 28.00 | 239.00 | [h] |
| | Total Energy Lighting | 20.33 | 7.56 | 5.71 | 2.86 | 0.00 | 0.00 | 0.00 | 0.00 | 0.67 | 12.94 | 18.65 | 11.59 | 80.30 | [kWh· a$^{-1}$] |
| | LENI | 0.36 | 0.13 | 0.10 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.23 | 0.33 | 0.21 | 1.43 | [kWh· m$^{-2}$· a$^{-1}$] |
| **Quick method 1** | Daylight usage hours (tD) | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 1800.00 | [h] |
| | Non-daylight usage hours (tN) | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 200.00 | [h] |
| | Usage hours per month (tO) | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 2000.00 | [h] |
| | Total Energy Lighting | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 84.00 | 1008.00 | [kWh· a$^{-1}$] |
| | LENI | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 1.49 | 17.92 | [kWh· m$^{-2}$· a$^{-1}$] |
| **Quick method 2** | Daylight usage hours (tD) | 28.00 | 13.00 | 28.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 36.00 | 36.00 | 17.00 | 168.00 | [h] |
| | Non-daylight usage hours (tN) | 27.00 | 6.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 1.00 | 23.00 | 11.00 | 71.00 | [h] |
| | Usage hours per month (tO) | 55.00 | 19.00 | 29.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 37.00 | 59.00 | 28.00 | 239.00 | [h] |
| | Total Energy Lighting | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 10.04 | 120.48 | [kWh· a$^{-1}$] |
| | LENI | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 2.14 | [kWh· m$^{-2}$· a$^{-1}$] |
| **Comprehensive method 1** | Daylight usage hours (tD) | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 150.00 | 1800.00 | [h] |
| | Non-daylight usage hours (tN) | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 16.66 | 200.00 | [h] |
| | Usage hours per month (tO) | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 166.66 | 2000.00 | [h] |
| | Total Energy Lighting | 54.75 | 49.19 | 46.90 | 44.60 | 43.64 | 43.45 | 43.64 | 44.02 | 46.51 | 49.00 | 54.37 | 56.86 | 576.93 | [kWh· a$^{-1}$] |
| | LENI | 0.97 | 0.87 | 0.83 | 0.79 | 0.78 | 0.77 | 0.78 | 0.78 | 0.83 | 0.87 | 0.97 | 1.01 | 10.26 | [kWh· m$^{-2}$· a$^{-1}$] |
| **Comprehensive method 2** | Daylight usage hours (tD) | 28.00 | 13.00 | 28.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 36.00 | 36.00 | 17.00 | 168.00 | [h] |
| | Non-daylight usage hours (tN) | 27.00 | 6.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.00 | 1.00 | 23.00 | 11.00 | 71.00 | [h] |
| | Usage hours per month (tO) | 55.00 | 19.00 | 29.00 | 8.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 37.00 | 59.00 | 28.00 | 239.00 | [h] |
| | Total Energy Lighting | 6.87 | 6.35 | 6.14 | 5.92 | 5.83 | 5.81 | 5.83 | 5.87 | 6.10 | 6.33 | 6.83 | 7.06 | 74.94 | [kWh· a$^{-1}$] |
| | LENI | 0.12 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | 0.13 | 1.33 | [kWh· m$^{-2}$· a$^{-1}$] |

**Table 7.3. Room B. Monthly and yearly results**

| Monthly and yearly results \| Room B | Parameters | January | February | March | April | May | June | July | August | Septemb | October | Novemb | Decemb | Yearly | Unit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Measurements | Occupancy hours | 298.00 | 252.00 | 116.00 | 148.00 | 157.00 | 221.00 | 137.00 | 99.00 | 263.00 | 204.00 | 286.00 | 199.00 | 2380.00 | [h] |
| | Daylight usage hours (tD) | 64.00 | 26.00 | 69.00 | 20.00 | 20.00 | 7.00 | 14.00 | 8.00 | 23.00 | 57.00 | 56.00 | 31.00 | 395.00 | [h] |
| | Non-daylight usage hours (tN) | 79.00 | 28.00 | 8.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 12.00 | 28.00 | 24.00 | 184.00 | [h] |
| | Usage hours per month (tO) | 143.00 | 54.00 | 77.00 | 20.00 | 21.00 | 7.00 | 14.00 | 8.00 | 27.00 | 69.00 | 84.00 | 55.00 | 579.00 | [h] |
| | Total Energy Lighting | 33.82 | 12.88 | 18.59 | 4.82 | 4.93 | 2.13 | 3.81 | 2.02 | 7.39 | 17.70 | 21.62 | 12.99 | 142.69 | $[kWh \cdot a^{-1}]$ |
| | LENI | 0.93 | 0.36 | 0.51 | 0.13 | 0.14 | 0.06 | 0.10 | 0.06 | 0.20 | 0.49 | 0.60 | 0.36 | 3.93 | $[kWh \cdot m^{-2} \cdot a^{-1}]$ |
| Quick method 1 | Daylight usage hours (tD) | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 2250.00 | [h] |
| | Non-daylight usage hours (tN) | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 250.00 | [h] |
| | Usage hours per month (tO) | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 2500.00 | [h] |
| | Total Energy Lighting | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 70.00 | 840.00 | $[kWh \cdot a^{-1}]$ |
| | LENI | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 1.93 | 23.16 | $[kWh \cdot m^{-2} \cdot a^{-1}]$ |
| Quick method 2 | Daylight usage hours (tD) | 64.00 | 26.00 | 69.00 | 20.00 | 20.00 | 7.00 | 14.00 | 8.00 | 23.00 | 57.00 | 56.00 | 31.00 | 395.00 | [h] |
| | Non-daylight usage hours (tN) | 79.00 | 28.00 | 8.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 12.00 | 28.00 | 24.00 | 184.00 | [h] |
| | Usage hours per month (tO) | 143.00 | 54.00 | 77.00 | 20.00 | 21.00 | 7.00 | 14.00 | 8.00 | 27.00 | 69.00 | 84.00 | 55.00 | 579.00 | [h] |
| | Total Energy Lighting | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 16.21 | 194.52 | $[kWh \cdot a^{-1}]$ |
| | LENI | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 5.36 | $[kWh \cdot m^{-2} \cdot a^{-1}]$ |
| Comprehensive method 1 | Daylight usage hours (tD) | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 187.50 | 2250.00 | [h] |
| | Non-daylight usage hours (tN) | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 20.83 | 250.00 | [h] |
| | Usage hours per month (tO) | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 208.33 | 2500.00 | [h] |
| | Total Energy Lighting | 50.46 | 46.97 | 45.23 | 43.18 | 42.46 | 41.94 | 42.46 | 42.76 | 44.92 | 46.66 | 50.15 | 51.59 | 548.78 | $[kWh \cdot a^{-1}]$ |
| | LENI | 1.39 | 1.30 | 1.25 | 1.19 | 1.17 | 1.16 | 1.17 | 1.18 | 1.24 | 1.29 | 1.38 | 1.42 | 15.13 | $[kWh \cdot m^{-2} \cdot a^{-1}]$ |
| Comprehensive method 2 | Daylight usage hours (tD) | 64.00 | 26.00 | 69.00 | 20.00 | 20.00 | 7.00 | 14.00 | 8.00 | 23.00 | 57.00 | 56.00 | 31.00 | 395.00 | [h] |
| | Non-daylight usage hours (tN) | 79.00 | 28.00 | 8.00 | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 4.00 | 12.00 | 28.00 | 24.00 | 184.00 | [h] |
| | Usage hours per month (tO) | 143.00 | 54.00 | 77.00 | 20.00 | 21.00 | 7.00 | 14.00 | 8.00 | 27.00 | 69.00 | 84.00 | 55.00 | 579.00 | [h] |
| | Total Energy Lighting | 12.00 | 11.38 | 11.08 | 10.72 | 10.59 | 10.50 | 10.59 | 10.65 | 11.02 | 11.33 | 11.94 | 12.20 | 134.00 | $[kWh \cdot a^{-1}]$ |
| | LENI | 0.33 | 0.31 | 0.31 | 0.30 | 0.29 | 0.29 | 0.29 | 0.29 | 0.30 | 0.31 | 0.33 | 0.34 | 3.69 | $[kWh \cdot m^{-2} \cdot a^{-1}]$ |

Seminar room_Energy Evaluation X 56W

DIALux

08.07.2013

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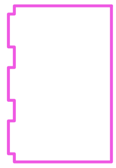
**Assessment Zone Daylight 1 / Parameter**

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Utilisation Zone 1
Accompanying Energy Evaluation Room: Room A (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 504 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 1800 |
| Non-Daylight Time Usage [h] | 200 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 1.00 |
| Occupancy dependency factor (Calculated Value) | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 1.00 |
| Daylight control factor | 0.00 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.00 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | None (DRb<2%) |
| Classification of daylight penetration (Calculated Value) | Good (DRb>=6%) |
| Middle daylight factor for windows (building shell opening) | 9.3 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

**Energy Evaluation / Summary**

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 1008.00 kWh/a
LENI: 17.92 kWh/(a · m²)

Total Energy Visual Task: 1008.00 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 56.25 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Feb | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Mar | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Apr | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| May | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Jun | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Jul | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Aug | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Sep | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Oct | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Nov | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |
| Dec | 84.00 | 1.49 | 84.00 | 1.49 | 0.00 | 0.00 |

**Figure 7.2. Room A. Base case. Dialux results for the Quick method**

**Seminar room_Energy Evaluation X 56W** DIALux

18.09.2013

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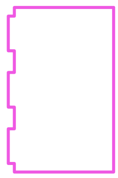
## Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Utilisation Zone 1
Accompanying Energy Evaluation Room: Room A (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 504 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 168 |
| Non-Daylight Time Usage [h] | 71 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 1.00 |
| Occupancy dependency factor (Calculated Value) | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 1.00 |
| Daylight control factor | 0.00 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.00 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | None (DRb<2%) |
| Classification of daylight penetration (Calculated Value) | Good (DRb>=6%) |
| Middle daylight factor for windows (building shell opening) | 9.3 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

## Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 120.46 kWh/a
LENI: 2.14 kWh/(a · m²)

Total Energy Visual Task: 120.46 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 56.25 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Feb | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Mar | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Apr | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| May | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Jun | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Jul | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Aug | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Sep | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Oct | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Nov | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |
| Dec | 10.04 | 0.18 | 10.04 | 0.18 | 0.00 | 0.00 |

**Figure 7.3. Room A. Modified case. Dialux results for the Quick method**

**Seminar room_Energy Evaluation X 56W** DIALux

01.07.2013

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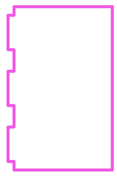
### Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Utilisation Zone 1
Accompanying Energy Evaluation Room: Room A (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 504 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 1800 |
| Non-Daylight Time Usage [h] | 200 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 0.68 |
| Daylight control factor | 0.40 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.79 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | Good (DRb>=6%) |
| Middle daylight factor for windows (building shell opening) | 9.3 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

### Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 576.54 kWh/a
LENI: 10.25 kWh/(a · m²)

Total Energy Visual Task: 576.54 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 56.25 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 54.75 | 0.97 | 54.75 | 0.97 | 0.00 | 0.00 |
| Feb | 49.19 | 0.87 | 49.19 | 0.87 | 0.00 | 0.00 |
| Mar | 46.90 | 0.83 | 46.90 | 0.83 | 0.00 | 0.00 |
| Apr | 44.60 | 0.79 | 44.60 | 0.79 | 0.00 | 0.00 |
| May | 43.64 | 0.78 | 43.64 | 0.78 | 0.00 | 0.00 |
| Jun | 43.45 | 0.77 | 43.45 | 0.77 | 0.00 | 0.00 |
| Jul | 43.64 | 0.78 | 43.64 | 0.78 | 0.00 | 0.00 |
| Aug | 44.02 | 0.78 | 44.02 | 0.78 | 0.00 | 0.00 |
| Sep | 46.51 | 0.83 | 46.51 | 0.83 | 0.00 | 0.00 |
| Oct | 49.00 | 0.87 | 49.00 | 0.87 | 0.00 | 0.00 |
| Nov | 54.37 | 0.97 | 54.37 | 0.97 | 0.00 | 0.00 |
| Dec | 56.86 | 1.01 | 56.86 | 1.01 | 0.00 | 0.00 |

**Figure 7.4. Room A. Base case. Dialux results for the Comprehensive method**

Seminar room_Energy Evaluation X 56W

DIALux

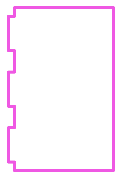
01.07.2013

Operator
Telephone
Fax
e-Mail

### Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Utilisation Zone 1
Accompanying Energy Evaluation Room: Room A (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 504 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 168 |
| Non-Daylight Time Usage [h] | 71 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 0.68 |
| Daylight control factor | 0.40 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.79 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | Good (DRb>=6%) |
| Middle daylight factor for windows (building shell opening) | 9.3 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

### Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 74.91 kWh/a
LENI: 1.33 kWh/(a · m²)

Total Energy Visual Task: 74.91 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 56.25 m²

**Monthly Results**

| Month | Lighting [kWh] | Lighting [kWh/m²] | Visual Task [kWh] | Visual Task [kWh/m²] | Parasitic [kWh] | Parasitic [kWh/m²] |
|---|---|---|---|---|---|---|
| Jan | 6.87 | 0.12 | 6.87 | 0.12 | 0.00 | 0.00 |
| Feb | 6.35 | 0.11 | 6.35 | 0.11 | 0.00 | 0.00 |
| Mar | 6.14 | 0.11 | 6.14 | 0.11 | 0.00 | 0.00 |
| Apr | 5.92 | 0.11 | 5.92 | 0.11 | 0.00 | 0.00 |
| May | 5.83 | 0.10 | 5.83 | 0.10 | 0.00 | 0.00 |
| Jun | 5.81 | 0.10 | 5.81 | 0.10 | 0.00 | 0.00 |
| Jul | 5.83 | 0.10 | 5.83 | 0.10 | 0.00 | 0.00 |
| Aug | 5.87 | 0.10 | 5.87 | 0.10 | 0.00 | 0.00 |
| Sep | 6.10 | 0.11 | 6.10 | 0.11 | 0.00 | 0.00 |
| Oct | 6.33 | 0.11 | 6.33 | 0.11 | 0.00 | 0.00 |
| Nov | 6.83 | 0.12 | 6.83 | 0.12 | 0.00 | 0.00 |
| Dec | 7.06 | 0.13 | 7.06 | 0.13 | 0.00 | 0.00 |

**Figure 7.5. Room A. Modified case. Dialux results for the Comprehensive method**

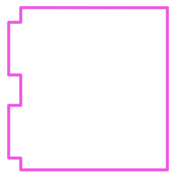
**Office Room_Energy Evaluation X 56W** DIALux
08.07.2013

Operator
Telephone
Fax
e-Mail

### Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Room B
Accompanying Energy Evaluation Room: Room B (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 336 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 2250 |
| Non-Daylight Time Usage [h] | 250 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 1.00 |
| Occupancy dependency factor (Calculated Value) | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 1.00 |
| Daylight control factor | 0.00 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.00 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | None (DRb<2%) |
| Classification of daylight penetration (Calculated Value) | Middle (6%>DRb>=4%) |
| Middle daylight factor for windows (building shell opening) | 4.0 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

### Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 840.00 kWh/a
LENI: 23.16 kWh/(a · m²)

Total Energy Visual Task: 840.00 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 36.27 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Feb | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Mar | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Apr | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| May | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Jun | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Jul | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Aug | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Sep | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Oct | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Nov | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |
| Dec | 70.00 | 1.93 | 70.00 | 1.93 | 0.00 | 0.00 |

**Figure 7.6. Room B. Base case. Dialux results for the Quick method**

Office Room_Energy Evaluation X 56W

DIALux

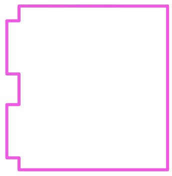
18.09.2013

Operator
Telephone
Fax
e-Mail

## Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Room B
Accompanying Energy Evaluation Room: Room B (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 336 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 395 |
| Non-Daylight Time Usage [h] | 184 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 1.00 |
| Occupancy dependency factor (Calculated Value) | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 1.00 |
| Daylight control factor | 0.00 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.00 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | None (DRb<2%) |
| Classification of daylight penetration (Calculated Value) | Middle (6%>DRb>=4%) |
| Middle daylight factor for windows (building shell opening) | 4.0 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

## Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 194.54 kWh/a
LENI: 5.36 kWh/(a · m²)

Total Energy Visual Task: 194.54 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 36.27 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Feb | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Mar | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Apr | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| May | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Jun | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Jul | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Aug | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Sep | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Oct | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Nov | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |
| Dec | 16.21 | 0.45 | 16.21 | 0.45 | 0.00 | 0.00 |

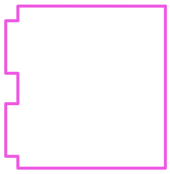
**Figure 7.7. Room B. Modified case. Dialux results for the Quick method**

Operator
Telephone
Fax
e-Mail

## Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Room B
Accompanying Energy Evaluation Room: Room B (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 336 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 2250 |
| Non-Daylight Time Usage [h] | 250 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 0.80 |
| Daylight control factor | 0.30 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.68 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | Middle (6%>DRb>=4%) |
| Middle daylight factor for windows (building shell opening) | 4.0 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

## Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 548.88 kWh/a
LENI: 15.13 kWh/(a · m²)

Total Energy Visual Task: 548.88 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 36.27 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 50.46 | 1.39 | 50.46 | 1.39 | 0.00 | 0.00 |
| Feb | 46.97 | 1.30 | 46.97 | 1.30 | 0.00 | 0.00 |
| Mar | 45.23 | 1.25 | 45.23 | 1.25 | 0.00 | 0.00 |
| Apr | 43.18 | 1.19 | 43.18 | 1.19 | 0.00 | 0.00 |
| May | 42.46 | 1.17 | 42.46 | 1.17 | 0.00 | 0.00 |
| Jun | 41.94 | 1.16 | 41.94 | 1.16 | 0.00 | 0.00 |
| Jul | 42.46 | 1.17 | 42.46 | 1.17 | 0.00 | 0.00 |
| Aug | 42.76 | 1.18 | 42.76 | 1.18 | 0.00 | 0.00 |
| Sep | 44.92 | 1.24 | 44.92 | 1.24 | 0.00 | 0.00 |
| Oct | 46.66 | 1.29 | 46.66 | 1.29 | 0.00 | 0.00 |
| Nov | 50.15 | 1.38 | 50.15 | 1.38 | 0.00 | 0.00 |
| Dec | 51.59 | 1.42 | 51.59 | 1.42 | 0.00 | 0.00 |

**Figure 7.8. Room B. Base case. Dialux results for the Comprehensive method**

**Office Room_Energy Evaluation X 56W** DIALux

01.07.2013

Operator
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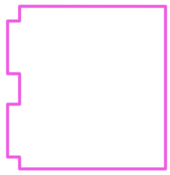
e-Mail

### Assessment Zone Daylight 1 / Parameter

Energy Evaluation According to Following Standard: EN 15193

Accompanying Project: Energy Evaluation
Accompanying Utilisation Zone: Room B
Accompanying Energy Evaluation Room: Room B (energy evaluation project)



| Parameter | Value |
|---|---|
| Total installed lighting power [W] | 336 |
| Parasitic power of controls with lamps off [W] | 0 |
| Emergency lighting charging power [W] | 0 |
| Daylight Time Usage [h] | 395 |
| Non-Daylight Time Usage [h] | 184 |
| Emergency lighting charge time [h] | 0 |
| Constant illuminance factor | 1.00 |
| Constant Illuminance Controllable | / |
| Maintenance factor | 0.67 |
| Occupancy dependency factor | 0.80 |
| Absence Factor | 0.40 |
| Occupancy control factor | 1.00 |
| Daylight Source | Window |
| Daylight dependency factor | 0.80 |
| Daylight control factor | 0.30 |
| Control of artificial lighting system | Manual |
| Daylight Supply Factor | 0.68 |
| Maintenance Value of the Illuminance [lx] | 500 |
| Maintenance Value of the Illuminance [lx] (Calculated Value) | 300 |
| Classification of daylight penetration | Middle (6%>DRb>=4%) |
| Middle daylight factor for windows (building shell opening) | 4.0 |
| Effective light transmission factor | 0.00 |
| Latitude [°] | 48.20 |

### Energy Evaluation / Summary

Energy Evaluation According to Following Standard: EN 15193
Location: Vienna, Longitude: 16.30°, Latitude: 48.20°

**Results**

Total Energy Lighting: 134.02 kWh/a
LENI: 3.70 kWh/(a · m²)

Total Energy Visual Task: 134.02 kWh/a
Total Energy Parasitic (Total): 0.00 kWh/a
Total Energy Parasitic (Standby): 0.00 kWh/a
Total Energy Parasitic (Loading the Emergency Lighting): 0.00 kWh/a
Total Area: 36.27 m²

**Monthly Results**

| Month | Lighting | | Visual Task | | Parasitic | |
|---|---|---|---|---|---|---|
| | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] | [kWh] | [kWh/m²] |
| Jan | 12.00 | 0.33 | 12.00 | 0.33 | 0.00 | 0.00 |
| Feb | 11.38 | 0.31 | 11.38 | 0.31 | 0.00 | 0.00 |
| Mar | 11.08 | 0.31 | 11.08 | 0.31 | 0.00 | 0.00 |
| Apr | 10.72 | 0.30 | 10.72 | 0.30 | 0.00 | 0.00 |
| May | 10.59 | 0.29 | 10.59 | 0.29 | 0.00 | 0.00 |
| Jun | 10.50 | 0.29 | 10.50 | 0.29 | 0.00 | 0.00 |
| Jul | 10.59 | 0.29 | 10.59 | 0.29 | 0.00 | 0.00 |
| Aug | 10.65 | 0.29 | 10.65 | 0.29 | 0.00 | 0.00 |
| Sep | 11.02 | 0.30 | 11.02 | 0.30 | 0.00 | 0.00 |
| Oct | 11.33 | 0.31 | 11.33 | 0.31 | 0.00 | 0.00 |
| Nov | 11.94 | 0.33 | 11.94 | 0.33 | 0.00 | 0.00 |
| Dec | 12.20 | 0.34 | 12.20 | 0.34 | 0.00 | 0.00 |

**Figure 7.9. Room B. Modified case. Dialux results for the Comprehensive method**