ESTIMATION OF ELECTRICAL LIGHTING ENERGY USE IN BUILDINGS: A METHOD COMPARISON

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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 exist a number of simplified procedures. An example of such a procedure involves the use of the indicator LENI (Lighting Energy Numeric Indicator). Using such indicators, 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 use patterns. In this context, the present paper explores the reliability of such procedures as compared to the results that can obtained using more detailed (simulation) methods. Toward this end, we compare for a sample of rooms (e.g., lecture room, office space) the results obtained by simplified and detailed methods 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 of daylight availability in architectural spaces the corresponding implications for electrical lighting usage.

INTRODUCTION

Satisfactory lighting levels are crucial for well-being, comfort and productivity in indoor spaces. Therefore a sufficient provision via daylight and artificial lighting is an important aspect of building design and operation. Taking the environmental protection and reduction of energy consumption and CO_2-emissions into consideration, artificial lighting should provide (i) sufficient lighting levels (ii) at a high efficiency, (iii) whenever daylight is not sufficiently available. (Dehoff 2010) To estimate the amount of energy necessary for accomodating these requirements, different standard approaches have been developed. For instance, the European Standard EN15193 offers two calculation schemes, a quick method and a detailed calculation. The indicator suggested for evaluation of the energy usage of luminaires by this standard is called LENI (Lighting Energy Numeric Indicator). Obviously the energy used for artificial lighting is influenced by a set of parameters (Beu 2011, Domke and Brebbia 2011, Staudt et al. 2010, Gasparovsky et al. 2010, 2011). These include the usage of the examined room, zone or building, the total installed lighting power, annual operating hours during daytime and nighttime, the type of control of the luminaries (automatic or manual), occupancy and daylight availability. The simple method does only include some of the parameters (and defaults others). In contrast the detailed method allows a more sophisticated evaluation of the required lighting energy.

In this contribution two sample rooms were used for a comparison of calculated and real energy consumption by electrical lighting. The objective is to explore and proof the reliability of the standard procedures. Therefore, the LENI calculations were conducted for these rooms, as well as a long-term-monitoring of the lighting energy use inside these rooms.

METHODOLOGY

Sample rooms

The two sample rooms used in this contribution are spaces within the Department of Building Physics and Building Ecology of the Vienna University of Technology (VTU). 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. Both rooms share the same cardinal direction of their windows and thus feature very similar daylight penetration. Moreover, both spaces feature the same type of luminaires and are similar in interior design, surface color and reflectance of constituting building elements and furniture. Three luminares correspond with each window, therefore room A (3 window axis) features 9 luminares, while room B (2 windows) features 6 luminares. An illustration of the rooms within the department's office is provided in Figure 1. Figure 2 shows the position if the two spaces within the façade and illustrates the surrounding obstructions (both rooms face a large courtyard), Figure 3 show bird's eye views of both rooms. Key information about both spaces, including size, number and type of luminaries, and usage hours is offered in Table 1.

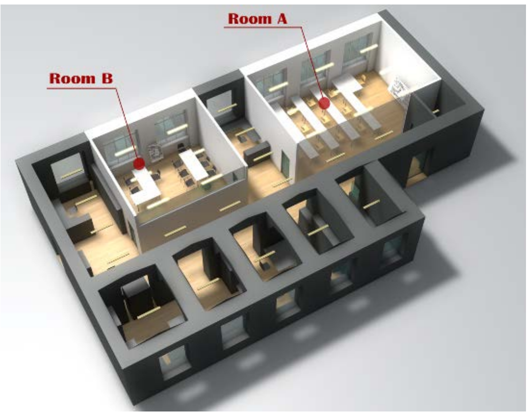

Figure 1: Room A (teaching and temporal working space) and room B (single office) within the Department of Building Physics and Building Ecology's offices.

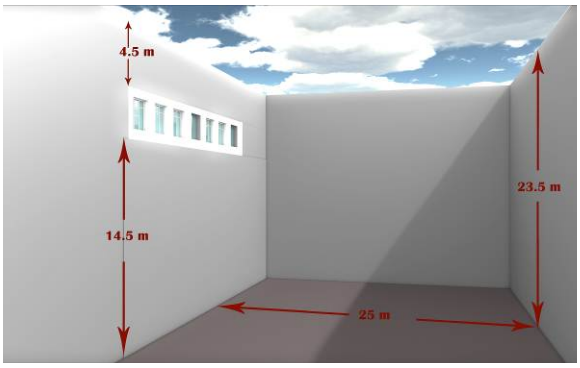

Figure 2: Position of the windows within the building structure and obstructions due to courtyard-perimeter.

Figure 3: Bird's eye view of room A (left) and B (right).

Table 1: Key information about rooms A and B

	Room A	Room B
Use	Teaching/Working Space	Single Office
Location	Vienna, Austria Longitude: 16.30°, Latitude: 48.20° 3rd Floor, Vienna University of Technology	
Cardinal Orientation	North-East exposure of windows	
Size	Area: 56.25m² Height: 4m	Area: 36.27 m² Height: 4 m
Perimeter description	Walls, ceiling – white plaster Floor material - wooden laminated parquet	
No of windows	3, additionally Glass-Wall to connected floor.	2
Lighting Solution	9 pendant luminaires	6 pendant luminaires
Lamps	OSRAM LUMILUX HIGH EFF. FH 28W / 830 – tubular fluorescent lamps	
Total installed power	9 x 56 W = 504 W	6 x 56 W = 336 W
Mounting height	3m	
Lighting control	Manual on/off	
Control groups	3 (rows)	2 (rows)
Operation hours (based on user description)	8 hours a day, 5 days a week	8-10 hours a day, 5 days a week
Operation hours (based on EN 15193)	2000 (1800 daylight + 200 non-daylight)	2500 (2250 daylight + 250 non-daylight)
Lighting requirments (workplane)	Illuminance (E_m) = 500 lx on work plane UGRL ≤ 19 Ra = 80	

Used Methods for estimation of lighting energy demand

The aforementioned European Standard EN 15193 offers a set of estimation schemes for lighting energy use. Figure 4 shows a flow chart of suggested derivation methods for lighting energy use as published in the standard. Two calculation approaches (quick and comprehensive) are suggested, alternatively the use of metered data is suggested as metered method. While the quick and comprehensive method can obviously be applied to any building (existing, or yet to be build), the metered method can only be applied to existing buildings equipped with appropriate metering equipment. All three approaches for determination of electrical power use by the artificial lighting were conducted for both spaces.

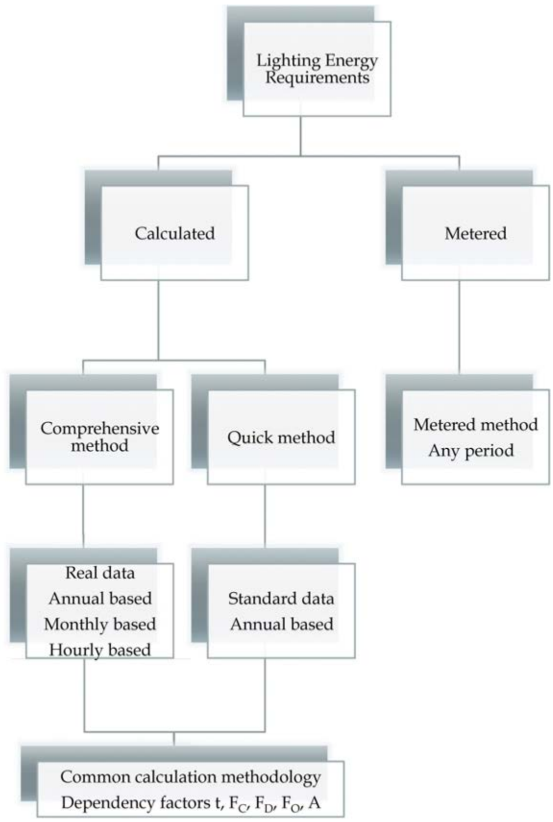

Figure 4: Flow chart illustrating alternative routes to determine lighting energy use (EN 15193 2006)

(i) Quick Method: The quick method is based on a simplified set of input parameters and can be calculated manually or with proper software tools (e.g. Dialux). The quick method does not take into consideration the building's location, the cardinal orientation or the daylight avaibility. Some of the necessary input variables are extracted from default value tables provided by EN 15193. In general the results of the quick method are generally assumed to show higher values than those of the comprehensive method, as default values are dimensioned rather high to have a safety factor in the estimation.

(ii) Comprehensive Method: Unlike the quick method, the comprehensive method offeres a improved calculation model. This method takes into consideration location, obstructions, orientation, daylight penetration, maintained illuminance, occupancy and the type of control. Therefore it is considered to offer more accurate results than the quick method. However, the calculation method typically is feeded with estimated values for the spaces operation. This is especially true, when the method is used for planning of non realized buildings, where no information about actual operation times is available. Although all equations are detailly documented within EN 15193, the semi-automated caluculation with software tools allow for faster results. Therefore, the application of the comprehensive method was performed with the software Dialux (Figure 3 is based on screenshots extracted from the software).

(iii) Metered Method: For derivation of the energy consumed by artificial lighting within the two spaces, local power meters were coupled to each control group. This monitoring was pursued for a period of more than one year. Additionally, occupancy sensors were installed in the two rooms, to get an overview about the real number of operation hours. As the year of monitoring was a leap year (2012), the data offers 8784 hours of information. Sensors used were Thermokon SR-MDS (Occupancy) and Eltako FWZ61-16A (electrical power meter).

Calculation scenarios

The occupancy within the evaluated spaces has acrucial impact on the results of the calculations. Depending if an evaluation is performed for a building yet to be eracted or an existing space, it might be or might not be possible to hearken on real operation hour data. To consider this aspect, two scenarios were assumed.

(i) In the *base case*, the operation hours of the spaces were taken from the suggested values of EN15193. Table 2 illustrates the operation hours for educational (assumed for Room A) and office spaces (assumed for Room B). Thereby, t_D stands for the operation hours during day, t_N for the operation hours during night (non-daylight) and t_O for the sum of t_D and t_N (overall orperation hours). The usage time of luminaires during these operation times are either seen as identical (quick method) or calculated based on a set of factors (comprehensive method) determined by standard values and/or the geometrical representation of the spaces in the used software tool (in this case dialux, DIALUX 2014). These factors adress for instance the daylight availability.

Table 2: Operation hours for educational and office spaces

Usage time	**Room A (teaching)**	**Room B (office)**
t_D	1800	2250
t_N	200	250
t_O	2000	2500

(ii) As real operation hours of the spaces and usage times of the artifical lighting system tend to deviate from standard values, monitored data of the occupancy was used to derive the operation hours for the *modified case*. Figure 5 illustrates the monthly hours with monitored occupancy and the hours with use of the electrical lighting system (usage hours) for room A, Figure 6 shows the corresponding

information for room B. Therby, the usage hours are defined as hours with at least one control group of the luminaires the coresponding room turned on. The measured annual occupancy time for room A is 2087 h, and for room B 2380 h, while the usage time of artificial lighting in room A was 239 h and in room B was 579 h. Table 3 offers an overview about the cumulated measurments of the monitoring period. Note that there is no exact specification in EN 15193, which times of the day are considered to be "daytime" and "non-daytime" operation of the spaces. Therefore – based on an interview with one of the committeemembers of EN 15193 (Thorn 2009) – it was decided to consider times with an average outside illuminance of 1000 lx or higher as daytime and times with an average outdoor illuminance less then 1000 lx as non-daylight time. The distinction between "daytime" and "non-daytime" has an influence on the calculation and results of the comprehensive method. The seperation of the monitored usage time into daytime and non-daytime was conducted via analysis of measured outdoor illuminace data of the monitoring period. This data was taken from a near-by weatherstation, mounted on the rooftop of the VTU main building.

Table 3: Occupancy hours and usage hours (t_D+t_N = t_O) of electric luminaires as measured in

	Room A (teaching)	**Room B (office)**
Occupancy time	2087	2380
t_D	168	395
t_N	71	184
t_O	239	579

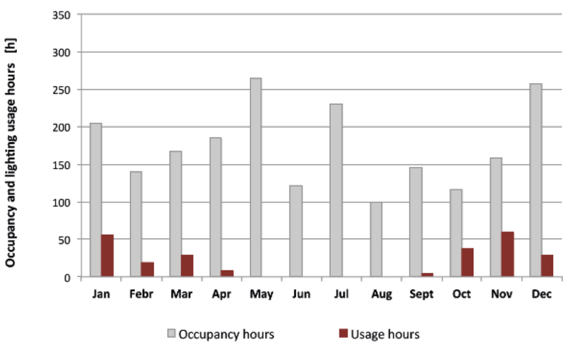

Figure 5: Monitored monthly occupancy and usage hours in room A.

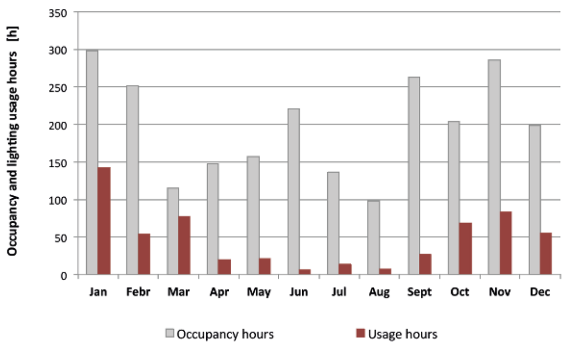

Figure 6: Monitored monthly occupancy and usage hours in room B.

RESULTS & DISCUSSION

Base Case:

Results in this section show the quick and the comprehensive method feeded with the normative assumptions toward operation and usage hours. Table 4 offers the annual results of the LENI-indicator for quick method, comprehensive method and metered method for rooms A and B. Figure 7 documents the derived monthly results of LENI for room A, while Figure 8 offers the derived monthly results of LENI for room B. Both the quick and the comprehensive method show values that strongly overestimate the electrical lighting demand in both rooms. The overestimation is stronger for room A. It can be clearly seen that the quick method does not take into consideration seasonal changes, while the comprehensive method shows slightly lower energy demands in the months with longer daylight availability.

Table 4: Results comparison for Base Case

LENI based on [kWh.m^{-2}.a^{-1}]	**Room A**	**Room B**
Metered Method	1.43 *[100%]*	3.80 *[100%]*
Quick method	17.92 *[1253%]*	23.16 *[609%]*
Comprehensive method	10.25 *[717%]*	15.13 *[398%]*

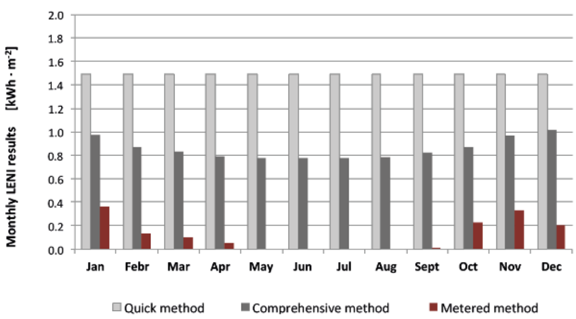

Figure 7: Comparison of the LENI derived from quick method, comprehensive method (base case conditions) and metered method for room A

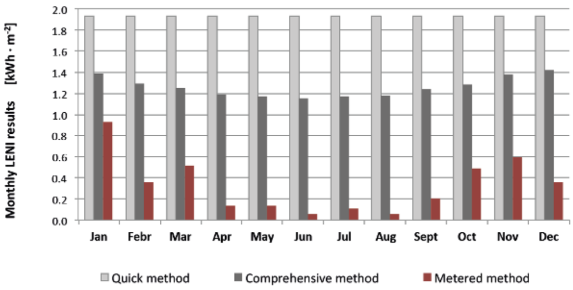

Figure 8: Comparison of the LENI derived from quick method, comprehensive method (base case conditions) and metered method for room B

Modified Case:

Results in this section show the quick and the comprehensive method feeded with the monitored data concerning operation and usage hours. Figure 9 and 10 show the derived monthly results of LENI for room A and B. Table 5 offers the annual results for quick method, comprehensive method and metered method for rooms A and B. Both the quick and the comprehensive method show closer results to the metered values as in the base case comparison. The monthly evaluation even shows months were both methods underestimate the measured energy demand. However, looking at the annual values, the quick method still overestimates the real energy demand, while the comprehensive method slightly underestimates the energy requirements.

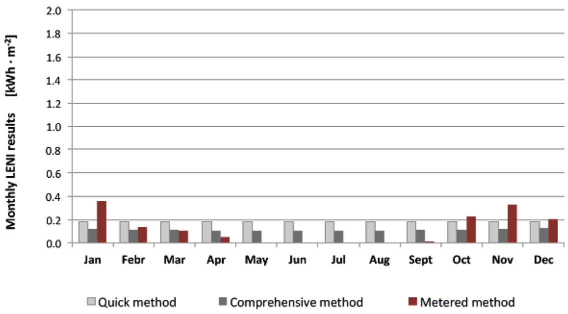

Figure 9: Comparison of the LENI derived from quick method, comprehensive method (modified case conditions) and metered method for room A

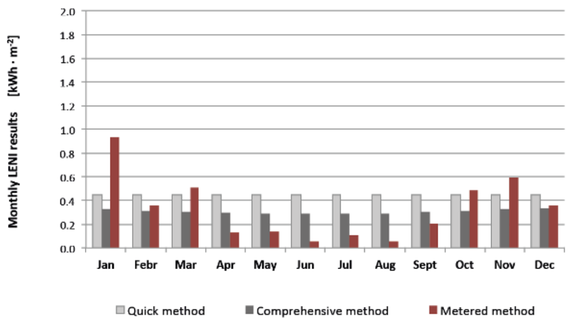

Figure 10: Comparison of the LENI derived from quick method, comprehensive method (modified case conditions) and metered method for room B

Table 5: Results comparison for Modified Case

LENI based on	[kWh.m^{-2}.a^{-1}]	Room A	Room B
Metered Method		1.43 *[100%]*	3.80 *[100%]*
Quick method		2.14 *[150%]*	5.36 *[141%]*
Comprehensive method		1.33 *[93%]*	15.13 *[97%]*

Comparison of Base Case and Modified Case

Figure 11 and 12 compare the LENI results for room A and B for both cases.

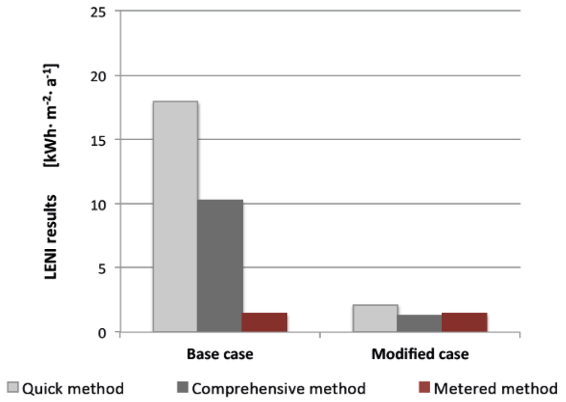

Figure 11: Comparison of LENI-results for Room A for base case and modified case.

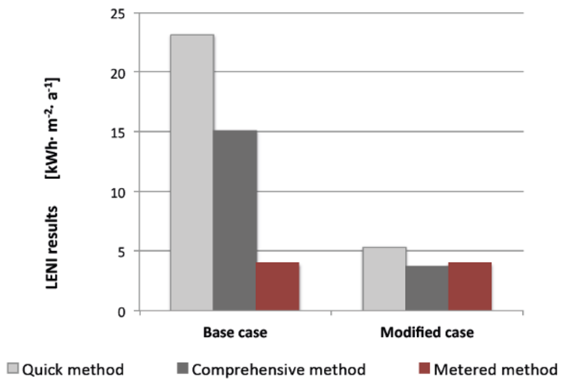

Figure 12: Comparison of LENI-results for Room B for base case and modified case.

CONCLUSION & FUTURE RESERACH

This contribution utilized three methods suggested by the European Standard EN 15193 for estimation of the energy demand for lighting and compared their results. These methods can on the one hand be used for lighting energy planning of new buildings or retrofits, on the other hand should allow a benchmark for existing buildings and their artificial lighting systems. The comparison of two typically occupied university spaces, however, showed that for a realistic comparison of calculated and measured values the knowledge of operation and usage times is necessary. The base case results that were pillowed on standard assumptions showed very large deviations to the real energy requirementes, although the occupancy hours of the two spaces were not to far from the standard assumptions. On the contrary, given the simplifications in the quick method, and the semi-automated derivation of artificial-light-use-influencing factors in the comprehensive method, the modified case with adapted operation hours offered a rather good approximation of the real energy use. As a consequence, a detailled monitoring of existing spaces, and exact requirement analysis for future spaces is strongly recommendable for generation of input data for estimation of performance indicators for lighting energy use.

However, the presented contribution used only a limited number of examined spaces, and therefore might not be able to offer information about deviation in calculation of spaces with other usages or changed input data concerning occupancy profiles, daylight supply and different lighting systems. Therefore, it seems appropriate to further investigate in this specific field with a two sided approach: On the one hand, the comparison should be extented with further example spaces of different usages and a wide field of varied input parameters. On the other hand, specific analysis of the factorization of input variables both in the quick and the comprehensive standard method should be performed to identify ways for better approximation of the key performance indicators concerning lighting energy use.

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