
This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Dubois, Marie-Claude; Gentile, Niko; David Amorim, Claudia Naves; Osterhaus, Werner; Stoffer, Sophie; Jakobiak, Roman; Geisler-Moroder, David; Matusiak, Barbara; Onarheim, Fredrik Martens; Tetri, Eino

Performance Evaluation of Lighting and Daylighting Retrofits: Results from IEA SHC Task 50

Published in:

SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry

DOI:

[10.1016/j.egypro.2016.06.259](https://doi.org/10.1016/j.egypro.2016.06.259)

Published: 01/01/2015

Document Version

Publisher's PDF, also known as Version of record

Published under the following license:

CC BY-NC-ND

Please cite the original version:

Dubois, M.-C., Gentile, N., David Amorim, C. N., Osterhaus, W., Stoffer, S., Jakobiak, R., Geisler-Moroder, D., Matusiak, B., Onarheim, F. M., & Tetri, E. (2015). Performance Evaluation of Lighting and Daylighting Retrofits: Results from IEA SHC Task 50. In *SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry* (pp. 926-937). (Energy Procedia; Vol. 91). Elsevier.
<https://doi.org/10.1016/j.egypro.2016.06.259>

This material is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.

SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry

Performance evaluation of lighting and daylighting retrofits: results from IEA SHC task 50

Marie-Claude Dubois^{a*}, Niko Gentile^a, Claudia Naves David Amorim^b, Werner Osterhaus^c, Sophie Stoffer^c, Roman Jakobiak^d, David Geisler-Moroder^e, Barbara Matusiak^f, Fredrik Martens Onarheim^f, Eino Tetri^g

^aDivision of Energy and Building Design, Institute for Architecture and the Built Environment, Lund University, Box 118, S-22100 Lund, Sweden

^bFaculty of Architecture and Urbanism, University of Brasilia, Campus Universitario Darcy Ribeiro, Brasilia, DF, CEP 70.910-900, Brazil

^cLighting Research Design Laboratory, Department of Engineering, Aarhus University, Dalgas Avenue 2, DK-8000 Aarhus C, Denmark

^ddaylighting.de, Helmholtzstrasse 13-14, D-10587 Berlin, Germany

^eBartenbach GmbH, Rinner Strasse 14, A-6071 Aldrans, Austria

^fFaculty of Architecture, NTNU Norwegian University of Science and Technology, Alfred Getz vei 3, N-7491 Trondheim, Norway

^gLighting Unit, Aalto University, Otakaari 7, FI-02150 Espoo, Finland

Abstract

This article presents some results from a large monitoring campaign performed in 22 buildings around the world as part of International Energy Agency (IEA) Task 50 “Advanced lighting solutions for retrofitting buildings”. This article mainly addresses the work of Subtask D, which aims to demonstrate sound lighting retrofit solutions in a selection of representative, typical Case Studies. In order to evaluate the Case Studies, a monitoring protocol was developed to assess the overall lighting performance taking into consideration: 1) Energy use, 2) Retrofit costs, 3) Photometric assessment, and 4) User assessment. The monitoring was carried out from June 2014 to December 2015 in 22 non-residential buildings in ten countries. This article presents results from selected Case Studies, drawing conclusions regarding retrofit solutions as well as reflecting on methodological procedures for the measurements and data collection. Measured data as well as key conclusions from Subtask D will be summarized in an electronic web and portable sourcebook at the end of the IEA Task 50 (December 2015), which will be freely available through the Internet.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review by the scientific conference committee of SHC 2015 under responsibility of PSE AG

* Corresponding author. Tel.: Tel.: +46-(0)46-222-7629.

E-mail address: marie-claude.dubois@ebd.lth.se

Keywords: Daylighting; electric lighting; monitoring protocol; measurements; procedures; retrofit; energy use; energy savings; light quality; user assessment; retrofit costs; field studies; light fixtures; lamps; controls; sensors; dimming.

1. Introduction

Electric lighting accounts for approximately one fifth of the global electricity consumption. Without drastic changes in policies and practical implementations, the world's electric lighting demand is expected to grow dramatically despite the increased energy-efficiency brought by solid-state lighting, lighting control and daylight harvesting technologies. This increase in electric lighting consumption will generate a significant increase in greenhouse gas emissions justifying the need to urgently promote energy savings in the lighting sector.

Nomenclature

IVS	Initial Visit Survey
LED	Light Emitting Diodes
LRA	Lighting Retrofit Advisor
SHC	Solar Heating and Cooling

Major lighting energy savings can only be realized by retrofitting the existing building stock, which still relies on inefficient lighting technology for the majority of buildings. In this context, the International Energy Agency launched in 2013 Task 50 entitled 'Advanced Lighting Solutions for Retrofitting Buildings' under the umbrella of the Solar Heating and Cooling (SHC) Programme. IEA Task 50, which will be completed at the end of 2015 and involves 14 participating countries, pursues the goal to accelerate retrofitting of daylighting and electric lighting in the non-residential sector using cost-effective, best practice approaches applicable to a wide range of typical existing buildings. Task 50 is divided into four subtasks: A - market and policy, B - daylighting and electric lighting solutions, C - methods and tools and D - case studies. An additional joint working group called "Lighting Retrofit Adviser" (LRA) aims to collect and harmonize the subtasks' outcomes. More information can be found online at <http://task50.iea-shc.org>.

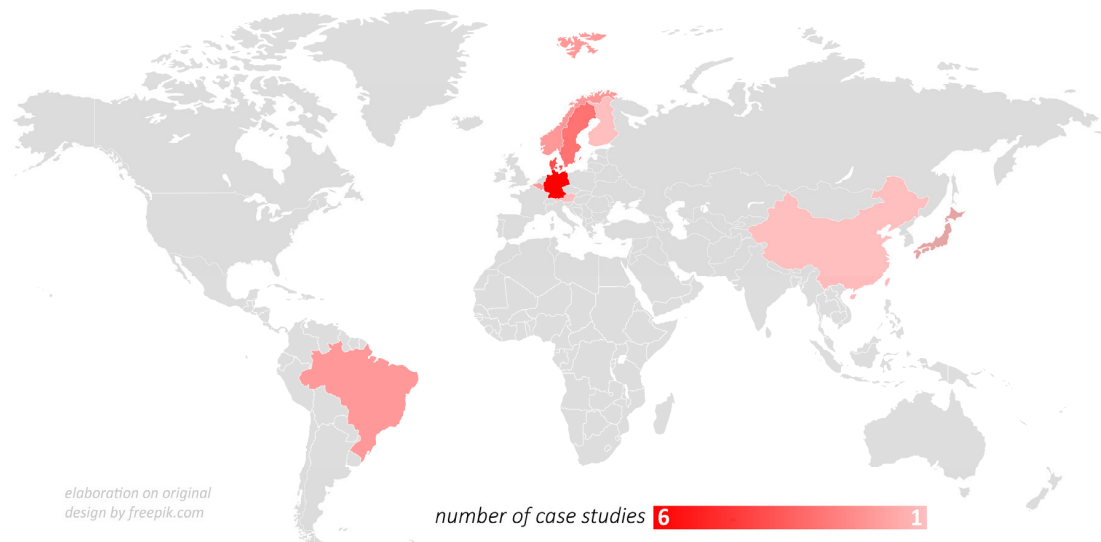


Fig. 1. Distribution of case studies around the world.

This article presents results from the work package on Case Studies called ‘Subtask D’, which aimed to demonstrate sound lighting retrofit solutions in a selection of representative, typical Case Studies spread around the world, see Fig. 1. In order to fulfill this goal, experts involved in Subtask D developed a monitoring protocol applicable to non-residential buildings retrofitted with electric lighting and/or daylighting technologies. The protocol is basically a common framework for monitoring and analysis of case study buildings. This protocol was subsequently tested by monitoring a total of 22 non-residential buildings in ten countries (see table 1). This article first outlines the main features of the monitoring protocol and then some of the lessons learned from the monitoring process are discussed. A few Case Studies are also presented and discussed.

2. Monitoring protocol

The access to monitored data is crucial to assess whether daylighting or electric lighting systems deliver the anticipated performance in terms of energy efficiency, cost-effectiveness, and lighting quality. The monitoring protocol [1] developed as part of Subtask D is a toolbox for professionals including a five-phase procedure for preparing and conducting the lighting retrofit assessment. After a general introduction, five phases are covered in separate chapters in the monitoring protocol document, which measures four fundamental aspects of a lighting retrofit project (Energy use, Retrofit costs, Photometric assessment, User assessment), as outlined in Fig. 2.

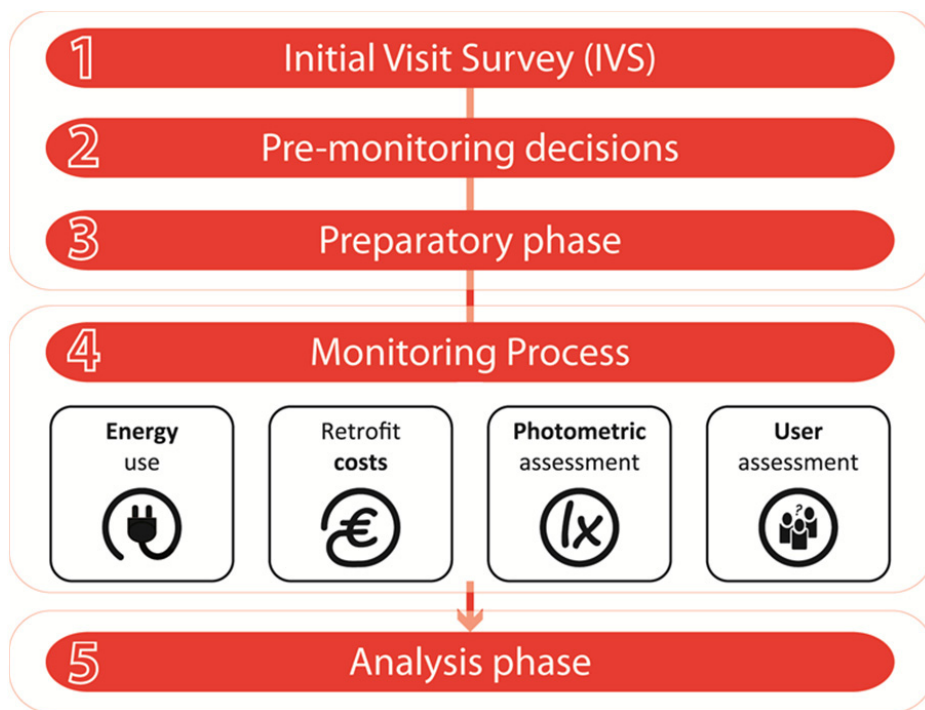


Fig. 2. Structure of the monitoring protocol.

The section about energy use and retrofit costs basically involve the collection of information on costs, the description of daylight/electric lighting systems and, when possible, the measurements of energy consumption. The photometric assessment, which is the most developed part of the protocol, involves measurements of seven key photometric quantities that allow describing lighting conditions and quality, see [2] for details. Finally, the fourth aspect of the protocol called ‘User assessment’ involves subjective assessments via questionnaires and/or interviews with the building occupants.

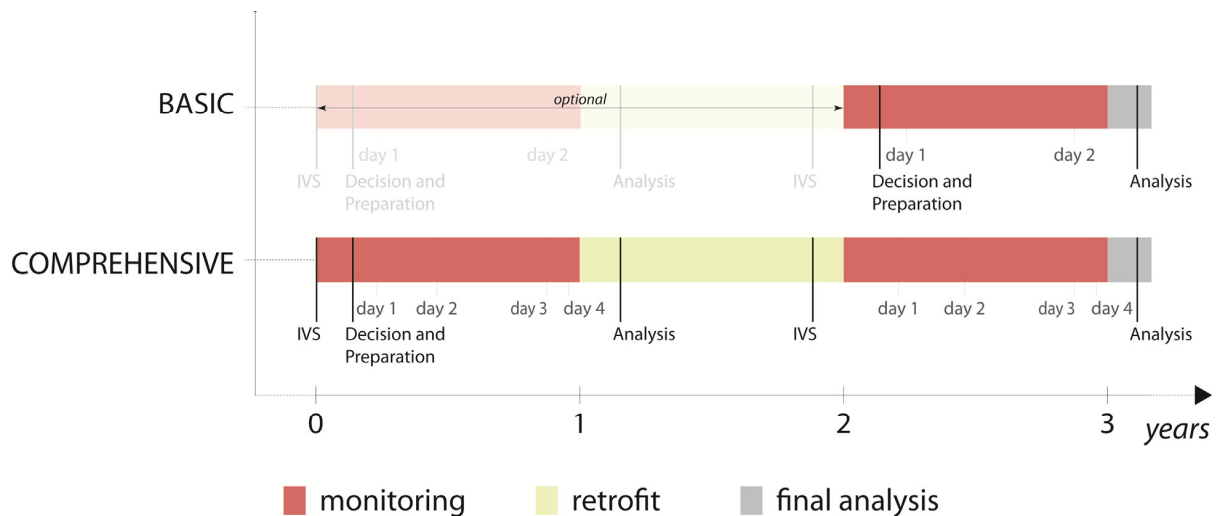


Fig. 3. Timeline for the evaluation for the two different levels of monitoring.

The protocol offers two monitoring levels: 1) a ‘basic’ and 2) a ‘comprehensive’ level. The choice depends on the purpose of monitoring and on practical constraints like the access to the building and the availability of resources. The protocol is developed so that a comprehensive picture of the electric lighting/daylighting performance can be obtained for the conditions before and after renovation (referred to as pre- and post-retrofit in the monitoring protocol document). However, it is possible to use segments of the protocol. For example, in some cases, it is not possible to access the pre-retrofit situation as the building has already been retrofitted. In this case, it is possible to perform the post-retrofit evaluation only and compare the results obtained with typical (benchmark) values for similar types of spaces.

The ‘basic’ level requires a) more limited instrumentation, b) access to the spaces at least in their post-retrofit condition, c) an overcast sky day and clear sky day (close to an equinox) over a one-year period for the actual monitoring, d) approximately one year for the whole evaluation process (Fig. 3). On the other hand, the ‘comprehensive’ level requires a) advanced instrumentation, b) access to the spaces both before and after the retrofit, c) four days per year over a period of two years for the actual monitoring (overcast day, clear skies for an equinox and each solstice), d) approximately three years for the whole evaluation process. Note also that it is possible to mix elements of the basic and comprehensive monitoring procedure to suit the specific needs of the building or monitoring team.

3. Lessons learned

3.1. Lessons learned from the monitoring process

3.1.1. Timing and weather conditions

The measurements related to daylight were difficult to achieve in practice since on the planned monitoring day, the weather conditions were not as expected. For example the daylight factor can only be measured under overcast skies. This was especially problematic when the monitored building was very remote from the work place of the monitoring team. Last minute cancellations and travel costs were significant in this case. One way to go around this problem is to plan several measuring days in advance and make sure that there is measuring staff available in the city where the building is located. In any case, this issue should be addressed with the building manager at the beginning of the monitoring process, preferably already during the IVS, to allow for some flexibility in the monitoring schedules.

Table 1. List of case studies listed by country.

Austria	Belgium	Belgium	Brazil	Brazil	China
	N/A	N/A			N/A
Bartenbach R&D Office, Aldrans	Belgian Building Research Institute, Limelette (Wavre)	Belgian Building Research Institute, Sint-Stevens-Woluwe	Tribunal of Justice, Brasilia	Ministry of Energy and Environment, Brasilia	The People's Hall, Beijing
Retrofit of daylighting and electric lighting systems				T12 to T8 lamps w/electronic ballasts	
Denmark	Denmark	Denmark	Denmark	Finland	
					
Horsens Town Hall, Horsens	Alfa Laval Factory Building, Kolding	Aarhus University Dental School Clinic, Aarhus	Indoor Pool and Spa "Spanien" Aarhus	Aalto University School of Electrical Engineering, Espoo	
Fluorescent (2700K) to LED panels and tubes (6000K)	T12 to T8/T5 lamps to increase illuminance, visibility and visual comfort	T8 (3000K) to T5 (4000K) lamps with Daylight-linked dimming	Historical preservation, retrofit with LED and fluorescent lamps	T8 to LED luminaires	
Germany	Germany	Germany	Germany	Germany	Japan
					N/A
Friedrich Fröbel School, Olbersdorf	Dietrich Bonhoeffer Vocational College, Detmold	DIY Market, Coburg	Apartment Building, Berlin	Student Housing, Berlin	T Corporation, Yokohama
Advanced daylighting systems, innovative controls	Renovation of facades to a high level of insulation	HID to LED	Listed building, renovation of facades, replacement lamps.	Listed building, renovation of facades, replacement lamps.	
Norway	Norway	Sweden	Sweden	Sweden	
					
NTNU Campus, Architecture Studio, Trondheim	Powerhouse Kjørbo, Oslo	Lund Univ. School of Architecture, Lund	WSP Consulting Engineering Office, Stockholm	School, Helsingborg	
Retrofit of skylights and electric lighting	Total building retrofit to zero emission building	Total building retrofit	Total building retrofit, pre- and post-retrofit information available	Fluorescent to LED with dimming	

Colour Key for Building Types

Industry	Retail	Office	Housing	Assembly	Sport/Recreation	Education
----------	--------	--------	---------	----------	------------------	-----------

3.1.2. Privacy issues

In general, the IEA T50 experts found that some of the measurements were slightly intrusive for the building occupants. Since the monitored buildings are typically occupied, it is necessary to have a close collaboration with the building manager for gaining access to the environment and have occupants feel at ease and as little disturbed as possible on the monitoring day. Monitoring procedures can also interfere with expectations of confidentiality for both building owners and users. Such concerns should be discussed when initiating a monitoring process and an agreement about how to treat potentially sensitive data should be made.

3.1.3. Measurement techniques

The authors found that some measurements were very time consuming and required a significant familiarity with instrumentation and the monitoring process. For example, measuring directionality was found to be difficult, and it was discarded by many experts during the monitoring process. In addition, the measurement of energy use was often problematic since electric lighting circuits are not provided with a separate electricity meter in most buildings. In these cases, energy use had to be estimated based on information about lighting fixtures and occupancy patterns.

3.2. Lessons learned from the monitored buildings

3.2.1. Austria

3.2.1.1. Bartenbach research and development (R&D) office, Aldrans

The Bartenbach R&D office is an example of a comprehensive lighting retrofit of an office building (Figs. 4 and 5). Here the daylight solution, the electrical lighting, the lighting control and the interior design of the room have been retrofitted.

- The daylight solution consists of exterior louvers with varying distances between the single slats optimized for the geographical location. An additional screen has been added for luminance control and glare protection. With this combination, the visual link to the exterior is maximized even for sunny conditions.
- The architecture integrated electric lighting solution is an efficient tunable white LED downlight system where the color temperature can vary from 2,200 to 5,000K for dynamic scenarios. The dimmable system provides up to 1250lx in every light color at the work plane to also allow biologically activating light. Independent of the selected light colour, the energy consumption at 500lx workplane illuminance is below 6 W/m².
- In this project, an integrated control for the daylight solution, the electric lighting system, the heating and the ventilation system have also been installed. Occupancy sensors, workplane as well as exterior illuminance sensors, wind speed sensors and temperature sensors feed this holistic control system.



Fig. 4. Pre-retrofit view of Bartenbach R&D Office.

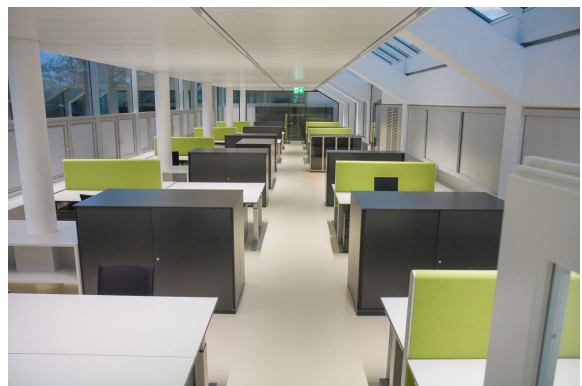


Fig. 5. Post-retrofit view of Bartenbach R&D Office.

The installed daylighting solution provides a highly daylit building with hardly any need for additional electric lighting during daytime hours. The variable combination of louvers and screens also allows for good solar and glare protection. For the morning and evening hours, the highly flexible electric lighting solution produces dynamic scenarios in an attempt to support the human circadian rhythm at highest energy efficiency. The integrated control reacts to exterior and interior conditions to intelligently combine the daylight and electric lighting solution and provide a pleasant lighting experience.

3.2.2. Brazil

3.2.2.1. Tribunal of justice of federal district and territories (TJDF-T), Brasília

The results of the monitoring in the TJDF-T building shows that despite the fact that this is a building with high daylighting potential (good orientation with North-South facades, bilateral daylight entry, windows with solar protection), daylight utilization is not as good as expected. The solar protection is not always effective, causing glare in some conditions and the user to close the curtains. Glare typically occurs when the user is facing the windows. The solar protection system can then increase perceived glare due to its light surface colour and resulting high reflectance. The electric lighting controls are not linked with daylighting, which has consequences in terms of energy efficiency. Even directionality is not adequate in this building, especially in the center of spaces, far from windows.

3.2.2.2. Ministry of energy and environment (MMA), Brasília

The results show good performance for the post-retrofit situation, especially regarding quality of the electric lighting and controls. Original T12 fluorescent lamps were replaced by T8 lamps with electronic ballasts, enhancing illuminance for all working areas. The system now allows control of each room separately, which was not possible before. Regarding daylighting strategies, the building could not have external devices due to the fact that it is an architectural heritage building. Therefore a solar film-coating was added to the windows. Glare occurs when the user is facing the windows, especially on East-facing facades. On West-facing facades that are equipped with external solar protection (brise soleil) the devices are always closed, obstructing external view and daylighting. However, monitoring showed that directionality of the lighting was appropriate in this building.

The user surveys indicate satisfaction with aspects like electric lighting and its controls, but the appearance of the spaces is considered “cold” after the retrofit. The users were unsatisfied with window size and the transparency of the solar protection after the retrofit, indicating that these aspects could be the object of future interventions. The results indicate some difficulties in finding the right strategies and technologies for daylighting improvement in heritage protected buildings. Problems like glare and overheating due to sun exposure were not properly solved, causing lower than predicted daylighting use and significantly reduced or completely eliminated views to the exterior for many of the building inhabitants.

3.2.3. Denmark

3.2.3.1. Horsens town hall and dentistry school clinic, Aarhus University

Horsens Town Hall is an example of a basic lighting retrofit where only the electric lighting installation was retrofitted while the daylighting design and lighting controls remained unchanged. Before the final installation with LED panels, an attempt was made to replace the T8 fluorescent lamps and magnetic ballasts in the original luminaires with LED tubes. These lamp replacements reduced energy use by about 55 percent compared to previous levels, but also reduced the illuminance by about the same amount, providing an illumination level below the required 200lx (in Denmark). Furthermore, this created a significantly altered lighting distribution pattern due to the directionality of the LED tubes.

For the final retrofit in offices and meeting rooms, LED panels with a colour temperature of 5,500 to 6,000K were installed. The new LED panels provided an even illumination and maintained the required illuminance above 200lx for all working areas. The electric lighting is manually controlled via on/off switches installed at the wall near the entrance to each room. To reduce the energy use for the electric lighting system, manual switches are generally provided for each of two luminaire rows parallel to the windows, so the row closer to the window can be turned off

when sufficient daylight is present. Despite the quite high correlated colour temperature of the LED panels, the vast majority of users rated the lighting systems as an improvement over the old fluorescent luminaires.

The daylight illumination in the spaces at Horsens Town Hall is quite limited, even on south-facing facades, due to a window construction with low height and large frames. Venetian blinds are integrated between the window panes to prevent possible glare from direct sunlight at the computer workstations. While the blinds are well maintained and effective regarding glare control, it seems like the blind positions were very rarely adjusted, since most of the blinds were found to be in the same position during all monitoring visits.

The small windows and low daylight levels seem to result in user behaviour with little interaction with the shading system. As a consequence, the electric lighting was on most of the time to maintain a sufficient illuminance level.

A solution to reduce the use of electric lighting could be to install a daylight-linked dimming and shading control, where Venetian blinds are adjusted to provide more daylight once glare is deemed to be no longer present, and the electric lighting is still turned on manually but adjusted or switched off relative to the available daylight illuminance in the spaces. This will, however, only have the desired effects if the sensors for the dimming controls are appropriately positioned and calibrated. Otherwise this can create conditions where the users overrule the system.

The latter effect can be observed in the case study for the Dentistry School Clinic at Aarhus University, where the installed sensors and their set points adjusted the illuminance level far too often and thereby caused discomfort and annoyance for the occupants. As repeated attempts by the electrical company supplying the system failed to correct the problems, it ultimately resulted in the sensor illuminance set-point being adjusted to its highest level, so that no dimming occurs. Because of this, projected energy savings cannot be achieved.

3.2.4. Finland

3.2.4.1. School of electrical engineering, Aalto University, Espoo

In Finland, the monitored retrofitted project at Aalto University consists of six office spaces. The original lighting system of each space consisted of four T8 fluorescent luminaires. During the past years, lamps have been substituted many times and also the reflectors have been substituted once. All other parts of the luminaires (including ballasts) were original. In two of the rooms, the old luminaires were replaced with new LED luminaires. In two similar rooms, LED luminaires with active dimming were installed. The new luminaires were installed in the same position as the old ones. The active dimming solution used in two of the six rooms consisted of stand-alone built-in dimming solutions for LED luminaires with a photosensor and a presence detection sensor. The installation procedure for the luminaires with active dimming control was exactly the same as for the LED luminaires without a control system. Since the active dimming control system is embedded in the luminaire, there was no need to install extra wires for control. The existing electrical installation in the rooms was retained. Following the installation of the new luminaires, an automatic learning period was started. This resulted in energy savings through optimized absence detection for different situations, light level compensation over the entire life cycle, and automatic daylight harvesting.

After the retrofit, two energy meters have been installed in two rooms to measure the energy consumption of the new lighting systems. The energy consumption before the retrofit was evaluated by measuring the power of the old luminaires and estimating the hours of operation of the luminaires. The luminous environment was assessed by measurements and also simulated with DIALux for both pre- and post-retrofit conditions. User satisfaction was evaluated with questionnaires.

Pre-retrofit lighting conditions did not meet the standard requirements in every room in terms of average illuminance, or in terms of uniformity, or both, depending on the room. After the retrofit, minimum values required by the standards were met. Before the retrofit, the average illuminance was between 180 and 350lx, and after the retrofit it was between 520 and 580lx. Illuminance uniformity increased from 0.5 to 0.8, and the colour rendering index remained almost the same: 84 before and 83 after retrofitting. The Unified Glare Rating (UGR) increased from less than 10 to between 16 and 18, indicating a higher likelihood of experiencing discomfort glare from the new luminaires. Energy savings due to the new luminaires without dimming were 38 percent of the pre-retrofit power consumption, while the new luminaires with active dimming resulted in 68 percent savings.

The change in users' satisfaction due to the retrofit was evaluated by comparing the mean ratings of different questions from the pre- and post-retrofit questionnaires. Users evaluated the appearance of the lighting system, of the room, and of the lighting environment, the amount of light, colour naturalness, visibility and visual performance. The results showed that users were more satisfied with the lighting environment after retrofitting.

3.2.5. Germany

In Germany five cases were studied. In these buildings, the building skin and electric lighting system were retrofitted. In three of the buildings, the retrofit only concerned the electric lighting system. The vocational school in Detmold was selected for presentation, because it was renovated to the efficiency level of a passive-house school and hence can serve as an example of how the improvement of the U-value of the facades impacts daylighting.

3.2.5.1. Dietrich Bonhoeffer vocational college Lippe-Detmold

The vocational college in Detmold consists of four classroom buildings and two gymnasiums. A classroom in Building 1 and the small gymnasium were selected for monitoring. In the sports hall, the lower part of the glazed facade, which had been masked by a baffle wall, was reopened. This was possible because the gymnasium will only be used for gymnastics after renovation, but no longer for ball games. After renovation, the gymnasium provides a view and the window-to-floor area ratio was increased by 20 percent. Since the new frames are thinner in relation to the old frames, the glazing-to-floor area ratio increased by 38 percent. However, since the sports hall had single glazing before renovation and is glazed after renovation with triple glazing with a significant area of light diffusing glass (Figs. 6 and 7), the visual transmittance of the glass was reduced by 43 percent. In total the efficient window-to-floor area ratio decreased by 22 percent. After renovation, the daylight factor in the centre of the floor space accounted for 2.4 percent. New LED-lighting replaces the fluorescent lighting installed before renovation.



Fig. 6. Small gymnasium before renovation.

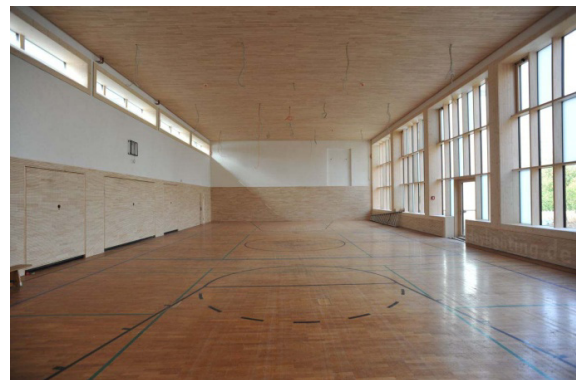


Fig. 7. Small gymnasium after renovation.

3.2.6. Sweden

3.2.6.1. School of architecture building, Lund University

In Sweden, the employee's lunch room of the School of Architecture at Lund University's Campus was monitored. This room provides a good example of a well daylit room where electric light is not needed for most of the day. In this case, the retrofit of the building involved window replacement from an ordinary double-glazing combination with white venetian blinds between panes to a more energy-efficient triple-glazing assembly with low-e coating and an interior rolling screen. The new window has a slightly lower visual transmittance than the original. Apart from a total retrofit of the electric lighting in this room, the renovation also involved a change of interior reflectance of walls to very high values ($> 90\%$) and the addition of glazed sections in doors and side walls in the room above head-height that contribute to transmitting daylight between spaces. All these design aspects contributed

to good daylighting and minimized the reliance on electric lighting. Lessons learned from monitoring this room can be summarized below:

- The glazing-to-floor area ratio was reasonable (12% of floor area and 20% of the room's exterior wall area measured on the interior side) and still provided very good daylight conditions given this high-latitude location.
- Windows were placed high up next to the ceiling in order to maximize the daylight penetration.
- The room depth (5 m) was exactly twice the window-head-height (2.5 m), which means that sufficient daylight could reach the wall opposite the window.
- The inner walls and floor had a high reflectance, which maximised inter-reflections and minimized the need for electric lighting.

3.2.6.2. WSP office building, Stockholm

The other building monitored in Sweden was the WSP Consulting Engineering Office in Stockholm. The space interior was completely refurbished. In particular, some small cellular meeting rooms were removed. This provided space for new workstations and, at the same time, eliminated some daylight obstructions. In addition, the reflectance of surfaces was improved. For example, a dark red/black wall (24% reflectance) was repainted white (91% reflectance). These measures brought the daylight factor to values higher than 2 percent in the post-retrofit situation. The use of electric lighting during the day was sporadic, even for the working station far from windows. Despite the improved daylight penetration, no major glare issues were reported thanks to automated shading screens installed on the North-East façade. However, employees complained about the noise made by the motors operating the screen.

Unfortunately, the expected energy savings were not quite achieved because of the lack of proper implementation of the lighting control system. In this building, an important lesson was learned regarding the control type and strategy for task lighting at individual workstations. Personal ceiling mounted pendant luminaires were fitted with a built-in occupancy sensor. Two main problems were identified: 1) The installer left the setting on 'presence' detection (automatic on-off switch) and set a 15 minute time-delay for the off-function. 2) The sensors' field of view was too wide, so any person passing by triggered the switch-on mode of several fixtures. This was very annoying and the employees did not know how to change it. In general, the authors noted that absence detection and a more limited field of view for the sensors would have been preferable in this landscape office context.

In addition, dimmable T5 pendant luminaires controlled through a switch cord (single pull = on/off switch, cord continuously pulled = dimming) were installed. It was found that none of the employees understood how the system worked. The light fixtures were frequently not meeting the required light levels since many employees dimmed by mistake and did not know how to get back to the original setting.

4. Summary of the lessons learned from the monitoring activities

A monitoring protocol was developed as part of IEA-SHC Task 50 on 'Advanced Lighting Solutions for Retrofitting Buildings'. The protocol was tested in 22 case studies in ten countries. The case studies will be presented with monitored data and key conclusions in a 'Light Retrofit Advisor' (freely available on Internet and portable devices) once the analysis process has been fully completed. A few key lessons learned from the monitoring process are summarized below:

- Reducing energy use attributed to electric lighting was the main driver for the majority of the lighting retrofits monitored in this study.
- All retrofits monitored achieved improvements in either energy efficiency or lighting quality or both.
- The best overall results could be achieved when the focus was on an effective integration of energy performance, daylight and electric lighting.
- When the building design allows for good daylighting before the start of an electric lighting retrofit, it seems more likely that a retrofit can achieve good results with respect to user satisfaction and reduced lighting energy consumption due to effective integration with daylighting. However, as electric lighting is required for shorter periods in well-daylit spaces, lighting retrofits are less likely to be cost-effective as installation costs can easily outweigh the projected energy savings.
- When openings in the building envelope do not provide good views to the outdoors or effective daylighting in a space (e.g. because of the effective aperture being too small), building users might interact significantly less with

available shading devices to regulate daylight and sunlight penetration into the space, typically resulting in even lower illumination from daylight. They might position the shading devices to avoid direct glare at specific times, but then forget to adjust the shading devices again to increase the daylight contribution later on. This could be observed before and after lighting retrofits. However, installing an integrated control system for shading and lighting to allow better daylight utilization could likely provide further energy savings potential in such a case.

- Replacing older fluorescent with appropriate LED lighting systems can lead to substantial energy savings for electric lighting. Lighting quality and user satisfaction can also be improved at the same time by providing better visual conditions in the spaces. It is, however, not recommended to just replace fluorescent tubes with LED tubes in existing luminaires other than those with diffusing panels, as it can lead to inappropriate light distribution patterns and significantly lower illuminance levels at the work plane.
- Heritage buildings present a special case, especially for daylighting and solar shading solutions, but sometimes also for electric lighting solutions, as there are typical limitations regarding alterations to exterior and/or interior building design features (depending on protection class and protected features). In the “Spanien” Public Pool and Spa in Aarhus, Denmark, the visual appearance of key luminaires had to be maintained as they are considered a part of the design heritage. Nevertheless, switching from fluorescent to dimmable LED lamps with flexible colour control inside existing luminaires resulted in a reduction in energy use and allows for the possibility to manually adjust illuminance levels and light colour depending on available daylight or other requirements.
- Upgrading older fluorescent lighting systems to newer ones can also provide benefits for both energy use and lighting quality.
- Control systems for electric lighting or solar shading devices, are frequently found to be poorly implemented, calibrated or commissioned, or perhaps too complex, resulting in reduced energy savings, annoyance of users or even in complete deactivation of the control system. This highlights the need for better guidance on the installation, commissioning and operation of lighting control systems.
- It is suggested that building owners implementing a lighting retrofit strongly consider monitoring appropriate performance metrics (see monitoring protocol) before and after such a retrofit to gauge the potential for the retrofit and later assess the success of the retrofit.

The monitoring is still on-going in some of the participating countries. Many more lessons learned will be summarized in a stand-alone report (‘D5 Lessons Learned’) to be available on the IEA-SHC website for this research task upon completion of all case studies.

Acknowledgements

The authors thank Johan Röklander from WSP Environmental for his generous support with access to the WSP Building in Stockholm. The authors also thank their respective funding agencies for supporting their work:

- Swedish Energy Agency (Statens Energimyndighet), Sweden;
- Danish Energy Agency (Energystyrelsen), Energy Technology Development and Demonstration Program, Denmark
- Research Council of Norway (Forkningsrådet), Norway;
- Federal Ministry for Economy and Technology (Bundesministerium für Wirtschaft und Technologie), Germany;
- Austrian Ministry for Transport, Innovation and Technology (Bundesministerium für Verkehr, Innovation und Technologie and Austrian Research Promotion Agency (Österreichische Forschungsförderungsgesellschaft), Austria;
- Foundation of Research Support of the Federal District (Fundação de Apoio à Pesquisa do Distrito Federal) and National Council of Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico), Brazil;
- Finnish Agency for Funding Research (TEKES) and Strategic Center for Science, technology and Innovation (RYM Ltd.), Indoor Environment Research Program, Finland.

References

- [1] N.Gentile, M.-C. Dubois, W. Osterhaus, S. Stoffer, C. Amorim , D. Geisler-Moroder, A. Hoier, R. Jakobiak, Monitoring protocol to assess the overall performance of lighting and daylighting retrofit projects, 6th International Building Physics Conference, IBPC 2015 (Turin), also in Energy Procedia, vol. 78, pp. 2681-2686.
- [2] N. Gentile, M.-C. Dubois, W. Osterhaus, S. Stoffer, C. Amorim, D. Geisler-Moroder, R. Jakobiak, A toolbox to evaluate non-residential lighting and daylighting retrofit in practice, Energy and Buildings, accepted and under final review; 2015.