

Integrated Solutions for Daylighting and Electric Lighting: IEA SHC Task 61/EBC Annex 77, Subtask D – Proposal and First Results

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ABSTRACT: The integration of daylight and electric lighting, considering user satisfaction and energy savings potentially can contribute significantly to reduce energy demand for lighting, that represents 18% of global energy demands. This paper presents the work and first results of IEA SHC Task 61/EBC Annex 77 “Integrated Solutions for Daylighting and Electric Lighting: From component to user centered system efficiency”, a joint project activity between the Solar Heating and Cooling (SHC) and Energy in Buildings and Communities (EBC). The project deals with the idea that an integrated design approach for the whole system, combining daylighting, electric lighting, the associated lighting controls and the users’ interaction, can achieve higher energy saving than the simple energy-efficient design of single components. First results show the main experience from three completed case studies.

KEYWORDS: Daylighting; Electric lighting; integration; case studies

1. INTRODUCTION

Lighting accounts today for approximately a fifth of the global electric energy use [1]. This demand can be significantly reduced by a better integration of daylighting and electric lighting solutions to the benefit of higher user satisfaction and energy savings. To this purpose, the International Energy Agency (IEA) launched, in February 2018, a collaborative project shared between the Solar Heating and Cooling (SHC) and the Energy in Buildings and Communities (EBC) programs, called IEA SHC Task 61/EBC Annex 77 “Integrated Solutions for Daylighting and Electric Lighting: From component to user-centered system efficiency” (<http://task61.iea-shc.org/>).

The project is founded on the idea that an integrated design approach combining daylighting and electric lighting, the associated lighting controls and the users’ interaction with them, can achieve higher energy savings than simple energy-efficient measures or the design of individual components. The Task is structured into four Subtasks aiming at: A) identifying user requirements in the design of lighting systems; B) providing an overview of existing technologies in daylighting and electric lighting; C) development of software and standards towards an integrated lighting design; and, D) increasing awareness among stakeholders by presenting exemplary integrated design solutions, with lab and field study performance tracking.

The Task in its entirety has a duration of three-and-a-half years, and it involves over 30 experts from 16 countries, representing industry, research institutes and universities. This paper reports on the activities and the current status of Subtask D, specifically focusing on the development of a Monitoring Protocol and the preliminary results from selected Case Studies.

2. SUBTASK D: OBJECTIVES AND STRUCTURE

The activities of Subtask D are structured into different project areas (Fig. 1) and supported by a dozen daylighting and lighting experts from different countries and institutions.

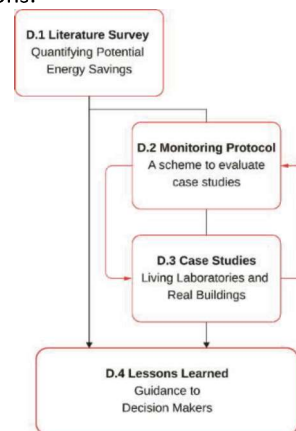


Figure 1: Project areas in IEA SHC Task 61 Subtask D

An initial literature survey (D.1) collect available scientific knowledge and experience on user-focused lighting systems leading to significant savings for lighting and related building energy use. Exemplary integrated design approaches are documented through the development of a monitoring protocol (D.2) and the on-site analysis of a number of case studies (D.3). The goal is to demonstrate and assess currently available, and typically applied, concepts for daylighting and electric lighting design and their integration, with a focus on energy savings and users' perspectives. The last step consists in summarizing the lessons learned (D.4), drawing relevant and generalizable conclusions from the case studies, cross-checked with information from the literature, so that they can be useful for façade and lighting designers, as well as for building owners and users, also communicated to a non-specialist audience.

2.1 Literature survey

The literature survey identified technical and non-technical opportunities and barriers to integrated design. Among other technical information, the survey confirmed the opportunities for energy savings that can be offered by integrated controls of shading and electric lighting, which can easily reach more than 60% savings with respect to traditional systems. On the non-technical side, the survey identified design strategies and methods that rely on the user in order to achieve energy savings ("user-driven strategies"). Such strategies show encouraging potential, although savings are context-dependent. Preliminary results are presented [2].

2.2 Monitoring Protocol

The monitoring protocol, inspired by the framework proposed in IEA-SHC Task 50 [3, 4], includes point-in-time and longitudinal technical and observer-based assessments. In principle, it should be possible to conduct basic field monitoring with relatively accessible instrumentation over two days. However, the protocol also provides methods and guidelines for more extensive monitoring. The protocol assesses four areas:

1. Energy use for lighting and associated controls;
2. Photometry, a characterization of the space via luminance maps, daylight factor, etc., or climate-based daylight modelling (CBDM) metrics;
3. Circadian potential (melanopic lux via the Lucas toolbox [5] or the Circadian Stimulus [6]), based on measured spectral power distribution at the eye or with vertical illuminance; the circadian potential can also be estimated via the data collected by wearable devices over a longer time frame;
4. User perspective, preferably via validated surveys and scales, or tailor-made evaluations and semi-structured interviews.

The monitoring protocol is conceived as an adaptable tool and it is constantly updated due to lessons learned

and data collection methods used in the different case studies. It will consist of a collection of methods for evaluations of real integrated design projects. Its flexibility allows to be tailored to the specific goal of the project. For example, in case studies on integrative lighting, the monitoring may look more in-depth at user perspectives in terms of alertness or perceptions, rather than at the energy performance of the lighting system.

2.3 Case studies

The case studies provide comprehensive information on exemplary projects, representing solutions, systems and strategies of integrated daylighting and electric lighting to inspire practitioners.

To date, 21 case studies have been selected from different countries and climates, including offices, schools, retail shops, healthcare facilities, listed buildings and living labs. The solutions monitored include integrative lighting applied to different typologies, traditional daylight harvesting systems thought for non-invasive large-scale retrofits, shade automation, or normative prompts as tools to educate users. The Monitoring Protocol has been devised in a way to be flexibly adjusted and accommodate the inherent specificities among the various buildings selected. Some case studies have already been monitored, including an office building in Brazil [7], a rehabilitation facility in Denmark, and a furniture shop in Germany [8].

2.4 Lessons learned

The lessons learned will include findings from the case studies and overarching recommendations based on the literature survey and case studies.

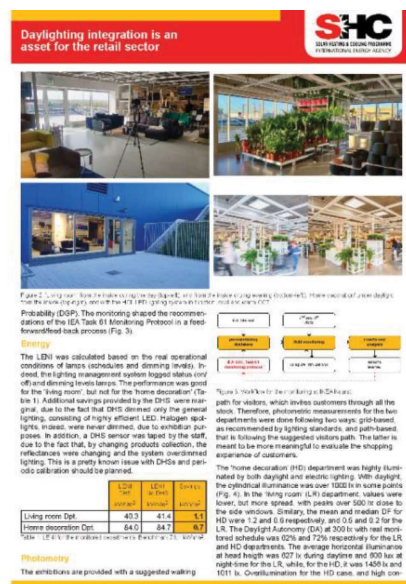


Figure 2: An example of factsheets for the lessons learned

The format is under discussion. It will most likely consist of a report including a short factsheet with

highlights for each case study (Fig. 2) and lessons learned. The target groups are architects, designers, and decision-makers, although scientists (and the general public) may also benefit from the findings.

3. PRELIMINARY RESULTS

Three case studies are presented here with similar structure. Each one has different characteristics, and the aim is to highlight original and positive aspects, as well as lessons learned about the integrated design project, and specific methodological aspects concerning the monitoring protocol and data collection procedures.

3.3.1. Office Building in Brasilia, Brazil

The building housing the Deans' offices for 'Research and Innovation' and 'Graduate Studies' on the campus of the University of Brasilia was chosen due to its bioclimatic and daylighting design, as well as its potential for lighting control use. The facades are North and South oriented, and the offices are distributed alongside them, with large windows shielded from direct solar radiation – external horizontal brise soleil in North façades, solar control films and curtains in South façades.

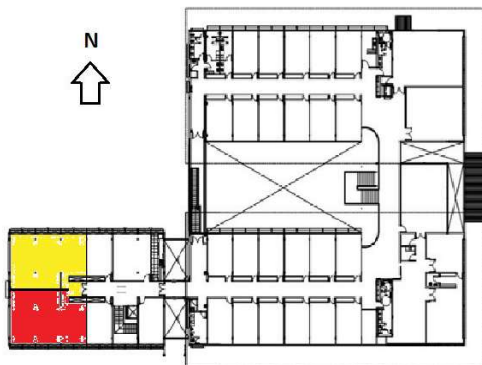


Figure 3: Building's plan, with monitored rooms in yellow (North) and red (South)



Figure 4: View of South façade

The aspects highlighted are quality of daylight and user satisfaction, monitoring photometry, circadian potential and user perspective. The building was monitored next to autumn equinox (march - cloud sky) and winter solstice (21 June, clear sky) of 2019 (only daylight, daylight and electric light, only electric light), according to the Monitoring Protocol.

Hand-held spot measurements

Photometric measurements were taken in selected occupied rooms, located along the North and South

facades (figure 3). The assessment included measurement of horizontal/vertical/cylindrical illuminance and external view quality. The measurement points were located on a grid, as suggested by the CEN standard [9]. External view quality was evaluated based on CEN criteria [10].

Afterwards, Equivalent Melanopic Lux (EML) values were calculated using the Lucas spreadsheet [5] and evaluated according to the Lighting for the Circadian System criterion of the WELL v2 building standard [11]. The WELL building standard is, to date, among the few certification schemes integrating criteria for assessing the circadian potential of lighting strategies and solutions. The credit requires verification of the EML value received at the eye of the occupant during specific times of occupation, awarding a number of credits.

Survey

A survey was administered based on a questionnaire adapted from IEA Task 61 (version November 2018). The survey with a total of 45 questions was structured in three sections: general data, social and physical climate, and user experience with lighting. It was distributed to 17 users who work in the monitored rooms.

Outcome

The results show adequate conditions of horizontal illuminance according to the CEN standard [9] that requires 500 lux on the task, ranging from 400 lux with daylight to around 900 lux with daylight and electric light. Regarding directionality of light, the values are above recommended limits (strong and moderately strong). Accentuated shadows are present on objects, especially in the South room. The circadian potential shows adequate conditions, satisfying the criteria in both the North and South rooms.

Regarding external view quality (Tab. 1), large windows along the entire extension of the South façade were rated as High. The North room has the same kind of windows, protected with external horizontal brise-soleil, and view quality rated as Minimum.

External view quality				
	South room		North room	
Parameters	Result	Rate	Result	Rate
Horizontal sight angle	100% > 54°	High	100% > 54°	High
Distance of view	> 50m	High	3 m	Minimum
Number of layers seen from 75 % of area	3	High	2	Medium
General view rate		High		Minimum

Table 1. External view quality results

The questionnaire showed the following results: Respondents were 42.3% men and 53.8% women, between 18 and 56 years old, working from 8am to 5pm, 5 days a week. The work is mostly computer-based tasks, the working environments are mostly organized in

shared open spaces or with low divisions. Regarding the workplace layout, 85.2% of occupants are located at a position less than 5 meters from the nearest window. 60% of occupants prefer working with daylight only, while 40% expressed a preference for a combination of daylighting and electric lighting. Most (75%) declare to be very satisfied with daylight, window size and view. But in South façade, 50% experience discomfort with daylight, due to reflections in the computer. Regarding controls, 76% declared to have medium or high control over daylighting and electric lighting, and 70.5% said that they have medium or high control of electric lighting.

Lessons learned

The integrated daylighting design in the building was relatively successful, both due to the orientation of the main facades (north/south) and the building form. Office rooms are not very deep and can take advantage of daylight during daytime and also from high quality external view, especially in South façade. Despite this, problems with reflections from daylight were detected, in South façade, that has no solar protection. The building could improve its energy performance regarding electric lighting consumption, if adequate daylight-linked controls were installed.

3.3.2. Rehabilitation Facility in Aarhus, Denmark

This study focused on surveying the electric lighting conditions in the patient rooms of a short-term rehabilitation facility in Aarhus, Denmark. The facility was equipped with two different electric lighting systems. Some of the rooms were lit by existing compact fluorescent lamps (CFL) and some by new integrative LED lighting, which was programmed to change intensity, color temperature and spectral distribution throughout the day. The purpose of the study was to measure the photometric characteristics of the two systems and investigate any possible correlation between the lighting settings and human response (such as sleep patterns and activity). The monitoring involved hand-held and automated measurements together with a questionnaire survey.

Hand-held spot measurements

As a first step, photometric measurements were taken in rooms equipped with the existing CFL lighting, as well as in rooms with the LED lighting. For the latter, five different lighting scenarios (light therapy, night care, calm, dynamic lighting at 9:00 and 21:00 o'clock) were assessed. Based on the assessment of horizontal/vertical/cylindrical illuminance, luminance maps and glare, a suggestion for improvement of the dynamic LED system was made. After the proposed changes were implemented by the facility, a new measurement sequence took place. In addition to the initial analysis, EML and circadian stimulus (CS), a metric developed by

the Lighting Research Center (LRC) to measure the effectiveness of a light source in providing circadian stimulation [12, 13], were calculated using the Lucas [5] and LRC spreadsheets [6].

Automated measurements

Automated measurement were set up in eight rooms (four with CFL and four with dynamic LED) for a period of two weeks involving eight patients and ten nurses. The participants were given two kinds of wearable dosimeters, one meant to be placed on the wrist and one on the shirt, in order to observe the lighting conditions to which they were exposed. The devices also logged the participants' activity. In addition, mobility monitors were located under the patients' beds to investigate their sleep quality. Camera-based sensors were placed on the ceiling of two of the rooms. The sensors, which consisted of Raspberry Pi computers with camera and fisheye lens, were used to continuously capture high dynamic range images for generating luminance maps [14, 15, 16].

Survey

The subjective sleep quality was assessed using a questionnaire based on the Pittsburgh Sleep Quality Index (PSQI) [17]. Additional questions covered personal information, such as smoking and coffee drinking habits, but also personal satisfaction with the lighting system.

Outcome

The photometric measurements showed that the dynamic LED system has the potential for a higher CS when a boost is needed (0.45 for light therapy setting), but also a lower CS for relaxation (0.04 for calm setting). CS for the existing CFL was only 0.08. For comparison, it is noted that a CS between 0.1 and 0.7 is considered corresponding to the range of effectiveness of light for the human circadian system, from threshold (0.1) to saturation (0.7) [18].

A positive effect of the dynamic lighting on people's behaviour could not be established. The PSQI results showed a better self-assessed sleep quality in the rooms with dynamic LED for patients and nurses, but the activity level recorded by the devices used in this study was lower there. All patients in the rooms with CFL answered that the light did not affect their mood, attention or energy, whereas in the rooms with dynamic LED some of the patients claimed to notice an effect to a small or large extent. Unfortunately, the small scale of this study did not allow for drawing more generalizable, and statistically robust, conclusions.

Lessons learned

As with any research involving people's subjective responses, many more participants and much more time would be needed to establish trustworthy correlations. However, this case study indicates that there might be potential benefits from installing dynamic lighting systems in healthcare facilities.

An interesting observation was that although the LEDs were dimmed down during the night, the TV or bathroom lights were frequently on while patients were sleeping, possibly negating any positive effect of the dynamic lighting system. It was also noticed that the patients probably found the controls too complex, since they often pressed several buttons within the same minute until they found the setting they wanted.

Trustworthy wearable sensors are essential for a case study like this, but not all might be suited for this type of research. Clarity in the survey questions is needed to avoid misinterpretation. The questionnaire used by the rehabilitation facility staff in this study proved to be somewhat problematic, since it could only assess if lighting conditions had an influence on people, but not whether this influence was positive or negative.

3.3.3. Furniture Shop in Kaarst, Germany

The monitoring focused on the first shop of a multinational furniture chain purposely designed for daylight penetration in the exhibition space. Daylighting was integrated with electric lighting via a daylight harvesting system in the 'living room' (LR) department (for saving energy) and an integrative lighting system with LED panels in the 'home decoration' (HD) department (for improving circadian potential). A full report of the monitoring is provided elsewhere [8].

Hand-held spot measurements

The monitoring included spot measurements illuminance, vertical spectral power distribution (SPD), as well as cylindrical illuminance. The measurement spots were located on a grid, as suggested by the CEN standard [9], and along the designed visitors' pathway; in both cases, the measurements were performed at eye level for a standing position (1.65 m). Luminance maps were produced for the detection of glare and light directionality. Models of the spaces were created and calibrated for further assessments, e.g. for climate-based daylight analysis. Online surveys were handed out to visitors and informal interviews were carried out with shop staff. The surveys aimed at evaluating the lighting perception and shopping experience. The site was first visited in February 2019 and later monitored for two weeks before the spring equinox (21 March).

Outcome

The decision of integrating daylight into the exhibition areas was successful. The majority of visitors reported a better atmosphere, especially in relation to lighting, with respect to other shops of the same chain. The surveyed people also declared that they would likely spend more time than planned in that shop, although no robust conclusions could be drawn about higher sales. The visitors claimed a 'home-feeling' with daylight. It was common to see visitors bringing and observing

goods under daylight when discussing a purchase. Luminance maps and simulations warned of the risk of intolerable glare from direct sunlight in some areas, but visitors had no complaints about that; rather they appreciated the fact. The staff members were also happy working in this new shop with daylight.

The penetration of daylight was such that most circulation spaces receiving some daylight had high melanopic illuminance, and the melanopic/photopic ratios were always high, close to one. High melanopic/photopic ratios indicate higher short-wavelength components in the light's SPDs [5].

The integrated design with daylight harvesting could have allowed for high energy savings, but inefficient lamps were installed for 'retail' purposes, reducing savings. The integrative lighting in the HR area was appreciated by the staff, but barely noticed by visitors. Even when the SPD was measured, the effect of integrative lighting could be barely noticed due to daylight abundance.

Lessons learned

This case study provided three main lessons: First, in terms of integrated design, daylighting can be an asset even for the retail sector. Since daylight is more challenging to control, retail lighting design has been traditionally relying on electric lighting. However, designers could plan for more daylight and get substantial benefits from this design choice. Second, installing advanced control systems does not necessarily secure energy savings. A careful, holistic approach should be taken. Third, in terms of methodological issues, some of the widely accepted methods and metrics have been developed for specific contexts, e.g. office-based tasks. In this case study, the use of a grid of points was not appropriate for spot measurements. Similarly, measured glare referred mostly to "pleasure" glare, since the task performed by shop visitors is very different and less focus-demanding than office work. This calls for a critical and thoughtful application of existing metrics during lighting design or monitoring.

4. CONCLUSION

This paper described some of the planned and ongoing activities of the IEA SHC Task 61/EBC Annex 77 "Integrated Solutions for Daylighting and Electric Lighting: From component to user-centered system efficiency", Subtask D: "Lab and Field Study Performance Tracking". The main experience from three completed case studies have been also illustrated. The first project area in Subtask D, consisting of a literature survey, provides a number of technical and non-technical solutions to exploit energy performance of integrated design. The report is expected in mid-2020, and it will be available for download at <http://task61.iea-shc.org/>.

Experiences from the case study monitoring are offering interesting lessons learned in terms of solutions for integrated design, as well as monitoring procedures. Several of the projects analysed seem to have primarily been prompted by objectives other than energy savings. For example, the three cases reported here aimed at increasing users' comfort and wellbeing (Brazil), regulating sleep and activity patterns of patients (Denmark), or improving the shopping experience (Germany). In all three cases, energy savings were or could be achieved. It can, therefore, be speculated that integrated design solutions should initially be promoted for aspects other than energy savings, because energy savings will very likely occur due to the integrated design process. Most of the case study monitoring was expected to be completed by spring 2020. The Covid-19 pandemic prevented continuation of monitoring in many cases, as most non-residential buildings have been unoccupied. A delay of a few months is expected, with a direct impact on the completion of final deliverables.

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