IEA SHC Task 61 / EBC Annex 77 Integrated solutions for daylighting and electric lighting - Subtask D: lab and field study performance tracking

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Abstract

The recently launched IEA SHC Task 61 aims at fostering the integration of daylighting and electric lighting solutions for the benefit of higher user satisfaction and energy savings at the same time. In order to drastically reduce the energy use of buildings daylighting, electric lighting and associated controls must be integrated, and the role of the user should be considered in the integration process. An effective means for promoting good examples of integration is reporting on successful case studies. In this perspective, a part of the IEA SHC Task 61, Subtask D, investigates existing knowledge for integrated solutions, proposes a monitoring protocol to evaluate integrated projects and, finally, presents exemplary case studies of integrated design. In this paper, we describe the structure and current status of IEA SHC Task 61 Subtask D.

Keywords: daylighting; electric lighting; controls; integration; human centric lighting; circadian lighting; energy savings; case study; IEA SHC; TEA; OBEA.

1. Introduction

In February 2018, the International Energy Agency (IEA) launched a joint project activity between the Solar Heating and Cooling (SHC) and 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 overall objective of the activity is to foster the integration of daylighting and electric lighting solutions for the benefit of higher user satisfaction and energy savings simultaneously. The project's hypothesis is that an integrated design approach for the whole system, combining daylighting, electric lighting, the associated lighting controls and the users' interaction with them, can achieve higher energy saving than the simple energy-efficient design of single components. Such approach entails a close collaboration between façade and lighting design professionals at the early stages of the building design process. It also requires that the designers incorporate new professional competences from the domain of social science. In order to facilitate this process, IEA SHC Task 61/EBC Annex 77 operates with four Subtasks aiming at:

- identifying user requirements in the design (Subtask A),
- providing an overview of existing technologies in the two domains of daylighting and electric lighting (Subtask B),
- supporting the development of software tools and standards supporting an integrated lighting design approach (Subtask C), and
- inspiring and increasing awareness among stakeholders by presenting exemplary integrated design solutions (Subtask D).

This paper reports on the activities and the current status of Subtask (ST) D (Figure 1).

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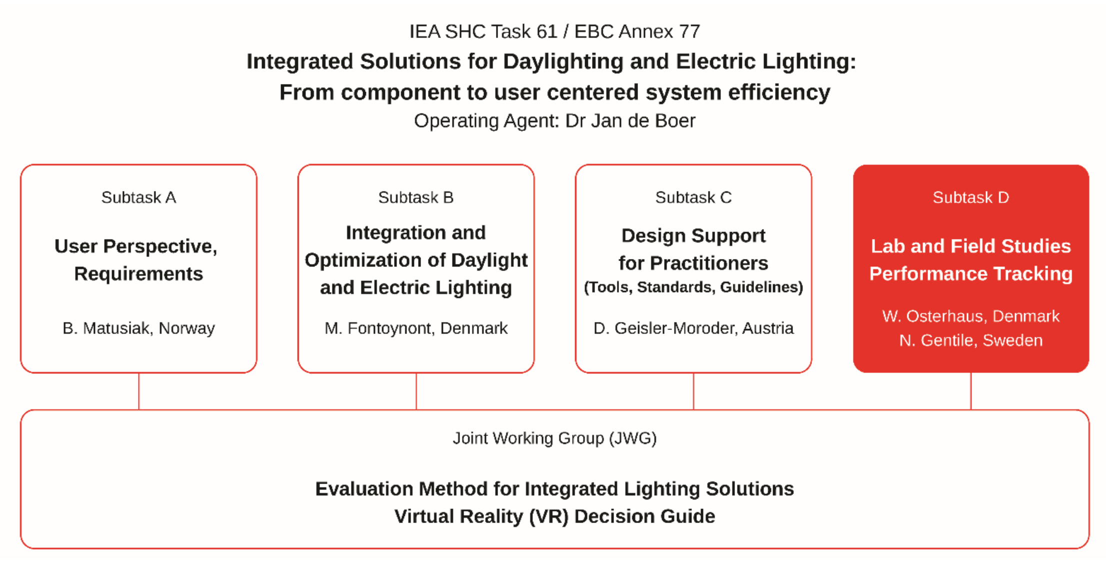

Fig. 1: Structure of IEA SHC Task 61/EBC Annex 77 with Subtask D as the focus for this paper

The Task in its entirety has a duration of three-and-a-half years, and it involves about 30 experts from 16 countries. Roughly a quarter of the experts represents industry, a quarter represents research institutes, and the remaining half represents universities.

2. IEA SHC Task 61 EBC Annex 77 Subtask D: Structure and content

As mentioned, Subtask D wishes to inspire and increase awareness among stakeholders by presenting exemplary integrated design approaches through monitoring of a number of case studies. The monitoring should help 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' acceptance. The activities of Subtask D comprise four project areas (Figure 2), which are explored in more detail later in this paper. About ten daylighting and lighting experts are actively supporting different project areas of Subtask D. Other experts are contributing to the Subtask by conducting case studies in their respective countries.

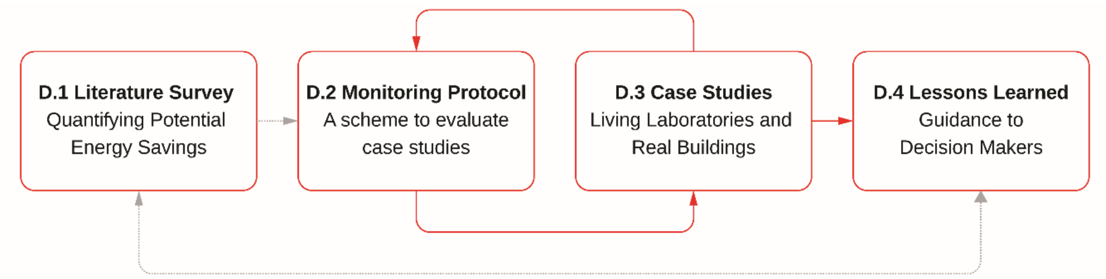

Fig. 2: Project areas in Subtask D and their interconnections

2.1. D.1. Literature Survey: Quantifying Potential Energy Savings

D.1 collects available scientific knowledge and experience on user-focused lighting systems leading to significant savings for lighting and related building energy use. In practice, D.1 shows *what we know* about integration, as well as the threats and opportunities relevant for the user and energy system choice. The literature survey is conducted using scientific databases only (e.g. Scopus, Web of Science, Xplore) and it predominantly includes peer-reviewed journal articles from recent publications (since 2010). Over 400 papers have been thoroughly scrutinized, but not all of them will be deemed eligible for inclusion in the survey. Other relevant papers from previous periods have been reviewed and included in the draft of the document.

The fundamental concept on which the literature survey is based assumes that the energy savings may vary, and ideally increasing, when lighting components and systems are integrated, even when components and systems for daylighting, electric lighting, and related controls may have an intrinsic energy-efficiency (Figure 3). Therefore, the literature survey first investigates systems (daylighting, electric lighting, and associated controls), and then analyzes opportunities and threats of various strategies for their integration. Finally, it reports on how such integration is already included in existing sustainability and energy rating or certification schemes.

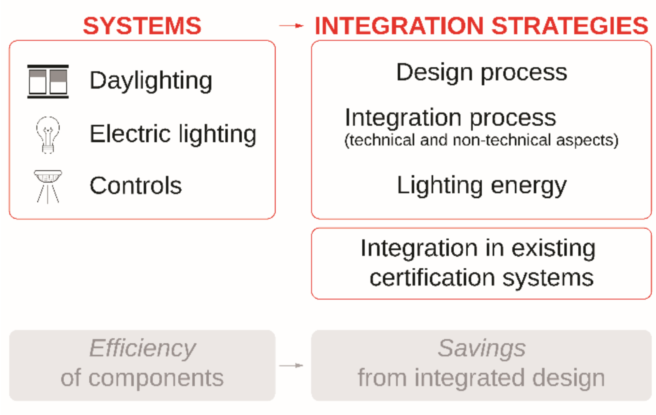

Fig. 3: Outline of the document in preparation for D.1. Literature Survey

D.1 is already at an advanced stage and a freely available report is expected in 2020. The report will be available for download at http://task61.iea-shc.org/.

Two main results are expected from the survey:

1) Most importantly, the survey identifies design strategies and methods that rely on the user, rather than the system, in order to achieve energy savings. We classified such methods as "user-driven strategies". Some of the strategies that mostly rely on user interaction are feedback in controls, for example by displaying individual energy consumption on monitors near the work place (Meerbeek et al., 2016), the design of manual switch interfaces (Dugar et al., 2011; Maleetipwan-Mattsson et al., 2017; Sadeghi et al., 2016), persuasive games (Orland et al., 2014), or information strategies (Carrico and Riemer, 2011). Most of these and similar strategies can be successfully applied in integrated lighting design, for example, the use of co-located tangible manual switch interfaces for electric lighting and shading results in more frequent operation of the controls, leading to a more appropriate visual environment. More information on these and other aspects are provided in Gentile et al. (2019). Important conclusions on user-driven strategies are that they are insufficiently explored in terms of energy savings, and that current knowledge relies on too few scientific studies. Therefore, it is difficult to generalize findings and savings potential. It seems that some studies, generally from the engineering domain, are particularly detailed in illustrating measured savings, but they may lack robust theoretical framework at the study design level. Other studies, predominantly from the social science domain, have a robust theoretical framework for the study design, but they do not provide quantifiable energy savings. This suggests a need for more interdisciplinary research on the topic of user-driven strategies.

2) On the technical side, the survey confirms the savings opportunities offered by integrated controls of shading and electric lighting, which can easily reach more than 60 per cent savings for electric lighting with respect to traditional systems. Based on recent papers published on controls, we speculate that rapid development in Visible Lighting Communication and Li-Fi, i.e. data communication via visible light modulation (Haas et al., 2016), may foster the use of integrated controls. Electric lighting shifts from being a mere building service to be controlled to being a control mechanism itself (Haas et al., 2017). Therefore, electric lighting will become a central factor in smart building design and, as controller, will be intrinsically integrated with other building services. However, the level of automation of integrated controls should be defined carefully, as users tend to dislike or even sabotage systems without user override functions. It then becomes a threat to the predicted energy savings.

Additionally, there is a growing concern with regards to the energy use of the control system devices themselves. This is a result of booming controls in smart buildings and the increased efficacy of electric light sources. A report published by the IEA found that the energy use for keeping connectivity in certain LED smart lamps can exceed the energy used for functional illumination (IEA 4E SSL Annex Task 7, 2016). A recent simulation study based on actual occupancy data projected that savings from controls become marginal – or they may even be offset – when adequate daylighting is provided, electric lighting is efficient, and occupancy rates are low (Gentile and Dubois, 2017). To address this concern, it has been demonstrated that it is technically and economically feasible to aim for zero standby use for many of these devices (Meier, 2019).

2.2. D.2. Monitoring Protocol

IEA SHC Task 61 deals with system efficiency, and systems include a number of components and aspects that should be evaluated holistically rather than individually. A thorough evaluation scheme, i.e. a monitoring protocol looking at the manifold facets of integrated system should be established. This is the purpose of D.2. D.2 tries to summarize *what we should know* of integration projects and *how this knowledge should be gathered and evaluated*. The protocol should collect and make available a large amount of information, and be able to summarize this information in an immediate and accessible way.

The monitoring protocol combines scientifically sound technical environmental assessments (TEAs) as well as observer-based environmental assessments (OBEAs) (Craik and Feimer, 1987). The protocol requires point-in-time field measurements carried out during a couple of days of monitoring, preferably close to solar equinoxes, conducted with relatively inexpensive and accessible photometric instrumentation. The protocol welcomes longitudinal investigations for longer periods, if resources are available. The current monitoring protocol is based on an existing protocol implemented in IEA-SHC Task 50 (Dubois et al., 2016; Gentile et al., 2016). Additional inspiration is provided by TEAs and OBEAs from different sources, e.g. the European standards for daylight (CEN/SIS, 2018), the work on circadian potential by Lucas et al. (2014), or validated OBEAs like the post-occupancy evaluation of daylight in buildings developed by IEA SHC Task 21 (IEA SHC Task 21/ECBCS Annex 29, 1999).

At the moment, the content of the protocol is dynamic, and it is continuously updated in a feed-forward and feed-back process alongside the monitoring processes occurring in D.3 Case Studies (Figure 2). This because D.3 Case Studies includes projects of different nature, and some of the assessments may be irrelevant in some cases, while other, an perhaps new, assessment methods might be required for other exemplary aspects of a specific integrated lighting project. If such new assessment methods are being used, they will later be documented in D.2 Monitoring Protocol.

Despite its dynamic nature, the monitoring protocol always covers the following four macro-areas of investigation: 1) energy use for lighting, 2) photometry, 3) circadian potential, and 4) user perspective (Figure 4).

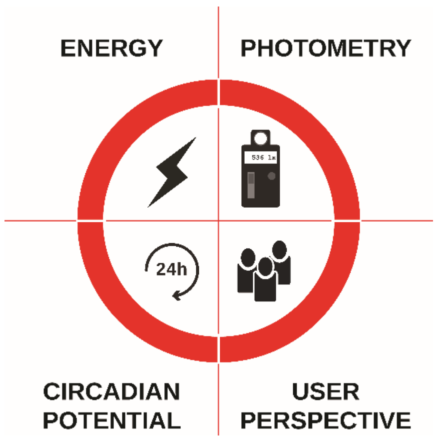

Fig. 4: Macro-areas investigated by D.2. Monitoring Protocol

The area 'energy' provides information on the energy use for lighting and its associated controls for each case study. Considerations on solar gains, or cooling and heating loads from daylighting are also included, although these might be displayed in rather basic form for some case studies (e.g. simple listing of g-value for the fenestration system).

The area ‘photometry’ characterizes daylighting and electric lighting via TEAs (or *objective* assessments), i.e. metrics measured with technical instrumentation. The simplest example is the Daylight Factor, but other suitable TEAs are also provided, depending on the case study. When possible, the ‘photometry’ is assessed largely by using High-Dynamic Range (HDR) imaging, as luminance distribution seems to be an excellent descriptor for the luminous environment (Kruisselbrink et al., 2018).

The area ‘circadian potential’ gives an indication of the spectral power composition of the light sources at two extreme points in the space, typically with low and high prevalence of daylight. The circadian stimuli are assessed via point-in-time-and-space measurements of melanopic lux levels. The melanopic lux levels are derived from Lucas’ toolbox by entering the measured spectral power distribution at eye level. In most of the case studies, the latter is measured with a spectro-radiometer in the two conditions of electric lighting only, and daylight mixed with electric lighting.

Finally, the area “user perspective” includes surveys involving the actual user of the space, e.g. employees in an office, and interviews with a person responsible for the technical building systems, like the building manager. Contents of survey and interviews differ based on the characteristics of each case study. For example, the surveys might focus on the visual environment if an automatic glare control system is being evaluated, or they might focus more on the acceptance of technology, if the case study introduces a new control system with some kind of innovative user interface.

Table 1 provides more details about the current assessments required for each macro-area. Please note that Table 1 serves a purely illustrative purpose and shows just a few of the assessment methods that have been used for early case study monitoring in D.3.

Tab. 1: Example of the assessments used in the monitoring protocol

Macro-area	Assessment	Details
Energy	Measured energy for lighting and associated controls	Breakdown energy for illumination and standby
	Evaluation of solar gains	Brief description of fenestration system (g-value, etc.) and qualitative comment
	…	…
Photometry	Daylight factor	Basic characterization of daylighting
	Grid-based illuminance (horizontal or vertical)	Measured for mixed daylighting and electric lighting
	Discomfort glare	Derived by HDR images for critical positions
	Directionality	HDR picture of purely diffusive sphere
	View out	According to EN17037:2018
	Solar exposure	According to EN17037:2018
Circadian potential	Equivalent Melanopic Lux	Measured for two extreme task positions with predominantly daylighting and electric lighting. Derivation based on Lucas et al. (2014)
User perspective	Questionnaire for actual users	Modular questionnaires addressing topic of interests for the specific case study
	Interview with building management staff	Informal or semi-structured

Early monitoring suggests that the mixed use of TEAs and OBEAs is fundamental for a robust project evaluation. In fact, some aspects are difficult or impossible to evaluate exclusively with point-in-time assessments. This maybe the case for system malfunctioning under specific conditions or for discomfort glare experiences which might only occur at specific times. In such circumstances, the information can be retrieved only by surveying those continuously occupying the space. Even in the event of a system working as planned, post occupancy evaluations are important to identify room for improvements.

2.3. D.3. Case Studies: Living Laboratories and Real Buildings

The case studies are the core of this Subtask. They will demonstrate exemplary projects, representing *what we think will inspire lighting practitioners.* To date, there are 17 worldwide case studies selected, although this number may change during the Task. The current list of case studies includes offices, schools, retail spaces, listed buildings and living labs and cover a wide range of climates (Table 2). A precondition for a case study to be included is that the spaces are occupied.

Some case studies are already being monitored, for example, an integration project in a large furniture retail space is presented at this conference (Campama Pizarro and Gentile, 2019). Many of the case studies include some kind of advanced lighting controls, often steering both daylighting and electric lighting. Some case studies are particularly interesting for the daylighting part, while those having advanced solutions for electric lighting rely frequently on automatic tuning of the correlated color temperature (CCT). The latter technology – also named *human centric lighting* or *circadian lighting* (among other names) – seems to gain increasing popularity in more recent buildings or freshly retrofitted spaces. The vast majority of daylighting and electric lighting controls included in the selected case studies aim at improving visual comfort (e.g. glare control for daylighting and contrast control for electric lighting) *while* saving energy. Type and intent of controls suggest that the scope of integrated lighting designs is supporting more and more human aspects in addition to energy savings. More generally, the initial monitoring of case studies shows that many integrated projects are intentionally planned and designed for aspects beyond energy savings, such as improving the shopping experience in retail spaces (Campama Pizarro and Gentile, 2019), or increasing the well-being and productivity of employees. This is important to be highlighted, as it is self-apparent that the building owners' or commissioners' decision to opt for an integrated design is clearly supported by these extra arguments, which may be economically more relevant for them.

Interestingly enough, even in some cases, where the only scope is to save energy, like for the preschool in Dalby, Sweden, the human component is central. In that case study, for example, simple manual on-off switches are installed and the energy saving is achieved by training young children to recognize the importance of switching off lighting when leaving a room or when daylight provides adequate illumination.

Tab. 2: List of case studies currently included in the monitoring of IEA SHC Task 61/EBC Annex 77- Subtask D

City, Country	Space use	Distinctive feature	Primary goals for the design
Aldrans, Austria	Living lab – office type	Advanced lighting controls	Energy savings, visual comfort, improve daylighting
Boa Vista, Brazil	Offices	Advanced daylight architecture	Maximizing daylighting while providing adequate visual comfort
Boa Vista, Brazil	Offices	Advanced daylight architecture	Maximizing daylighting while providing adequate visual comfort
Brasilia, Brazil	Offices	Advanced lighting controls	Energy savings, visual comfort
Beijing, China	Educational / meeting room	Daylighting tubes integrated with electric lighting controls	Energy savings, visual comfort, improving daylighting

Beijing, China	Offices	Daylight-linked control for electric lighting	Energy savings, visual comfort
Shekou, China	Offices	Integrated daylighting and electric lighting	Energy savings improve daylighting
Aarhus and Copernhagen, Denmark	Offices, classrooms, health-care facilities	Daylight-linked control for electric lighting, integrated daylight and electric lighting, circadian lighting	Energy savings, visual comfort, shading, health benefits
Kaarst, Germany	Furniture retail facility	Daylighting even in showrooms, daylight control for electric lighting and blinds, human centric lighting	Improve shopping experience, energy savings
Stuttgart, Germany	Living lab – office type	Advanced day-/electric lighting control based on contrast in the field of view	Energy savings, visual comfort
Stuttgart, Germany	Living lab – office type	Façade Integrated Day- and LED-Lighting Based on Micro-Optical Components	Energy savings, improving daylighting
Lüdenscheid, Germany	Offices	Daylighting and electric lighting controls	Energy savings, visual comfort, improve daylighting
Aversa, Italy	Cellular office	Integration of daylight-linked control for electric lighting in a listed building	Energy savings, visual comfort, minimization of invasive installations
Sandvika, Norway	Offices (cellular and landscape)	Several types of advanced daylight controls	Energy savings, visual comfort
Lund, Sweden	Preschool	Training of children in the use of manual switch on-off	Maximizing energy savings with low-tech solutions
Fribourg, Switzerland	Living lab – office type	Advanced controls for electric lighting with innovative with tuneable CCT	Energy savings, visual comfort

2.4. D.4. Lessons Learned – Guidance to Decision Makers

The final step in Subtask D is to summarize and present the information collected in the previous project areas as "lessons learned".

The lessons learned aim at drawing relevant and generalizable conclusions from the case studies, in a way that they can be useful for façade and lighting designers, and related professional groups, as well as building owners and users engaged in the design process. Given these target groups, the lessons learned should also be easily understood by a non-specialist audience. The lessons learned are mainly drawn from the case studies, but findings from the monitoring are cross-checked with information retrieved by the literature review (Figure 2).

This document is expected to be available at the very end of the project and its format is currently being discussed by the experts.

3. Project timeline and concluding remarks

This paper described the content and current status of IEA-SHC Task 61/EBC Annex 77 "Integrated Solutions for Daylighting and Electric Lighting - Subtask D: Lab and field study performance tracking. The project will end in June 2021, i.e. about 24 months from the time of writing. At the moment, some early case studies have been monitored, while others are expected to be monitored around the next two equinoxes (September 2019 and March 2020). New case studies will be accepted until the second half of 2020, while 2021 will be dedicated to the collection of findings and the writing of D.4. Lessons Learned.

The first deliverable, which is the D.1. Literature Survey, is on schedule at the time of writing. The final document is planned for publication in the first half of 2020. The document should be available shortly afterwards on the Task website. As mentioned in the paper, the progression of D.2 and D.3 is interdependent and they are expected to be completed by the end of 2020, and published at the end of the task. The final deliverable D.4 will be available at the end of the Task, after June 2021.

Few early remarks can be drawn from the experience gained so far. On the literature side, it seems that a more extensive and carefully considered use of integrated controls will foster the adoption of integrated lighting design. This will raise the need for appropriate design software. Its characteristics are preliminary discussed elsewhere in this Task (Subtask C). Despite integrated controls playing a central role in future planning, the literature shows that the human component is just as fundamental as the technical one; in particular, a better understanding of user cognition, perception and behavior may unleash unexpected energy savings.

On the case studies side, it seems that the energy aspect is often just one of the aspects driving integrated lighting design. On one hand, it is important for designers to provide energy-efficient integrated design, so that societal challenges are addressed. On the other hand, designers should be ready to support the design with other arguments addressing the building owners' and users' needs.

4. Acknowledgments

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