Final report

1. Project details

Project title	**Title: Integrated Solutions for Daylight and Electric Lighting**
File no.	**Journal nr.: 64017-05110**
Name of the funding scheme	**EUDP17-II**
Project managing company / institution	SBI-AAU now BUILD-AAU
CVR number (central business register)	
Project partners	Aalborg University, Aarhus University, Dansk Center for Lys, VELUX, LightCare, Bygherreforeningen
Submission date	30 September 2022

2. Summary

This project deals with the participation of Danish stakeholders in the IEA SHC Task 61 / IEA-EBC Annex 77: ”Integrated Solutions for Daylighting and Electric Lighting”. The tasks gathered strategic information through 4 key subtasks:

1) on human needs (WP2 of our contract) literature review on physiological and psychological needs, survey) Contribution from our consortium was limited, but the IEA SHC Task 61 experts delivered very important literature reviews, explored new needs related to home-office, proposed approach of demand associated to personas to adapt to categories of occupants. These documents are quite extensive and will help Danish stakeholders in their Human Centric approach, giving directions for developments and providing strategic evidence of benefits.
2) on technology (WP3 and WP4 of our contract, international management by AAU). We published 5 major reports. A survey in 10 countries gave an overview of the expectations for integrated lighting and daylighting control. We conducted and extensive review on available solutions, we analysed the 3 promising leading new solutions, identified the potential offered by new User Interfaces and proposed standards to develop to increase the confidence of the various stakeholders.
3) on design support (there was no contribution of our consortium on this task). The IEA SHC Task 61 experts made a number of proposals to improve tools by architects and engineers in

the domain of integrated lighting and daylighting controls. They published 4 reports on methods, standardization of BDRF characteristics of window components (shades), supplied spectral sky models for software and ways to rate performances.

4) on case studies (WP5 of our contract). The task conducted dealt with conducting a literature review on case studies and findings. We proposed comprehensive monitoring protocols that can be adapted depending on the framework and objectives of the respective case studies, coordinated 25 case studies conducted in 12 countries and published results in individual fact sheets for each case study and a summary document on "Lessons Learned".

DANISH:

Projektet omhandler deltagelse af en række danske interessenter i IEA SHC task 61 / IEA-EBC Anneks 77: "Integrated Solutions for Daylighting and Electric Lighting" (Oversat: Integrerede løsninger for dagslys og elektrisk belysning). Projektet indsamlede strategisk information gennem fire delopgaver, omhandlende:

1) Menneskers behov (WP2 ej i vores kontrakt) herunder litteraturstudie og undersøgelser om fysiologiske og psykologiske behov. Bidrag fra vores konsortium var begrænset, men IEA61Task-eksperter foretog herunder vigtig litteratur gennemgang, udforskede nye behov i relation til hjemmekontorer, samt foreslog tilgang til efterspørgsler forbundet med persona for at tilpasse sig kategorier af beboere. Disse omfattende dokumenter vil hjælpe danske interessenter i deres menneskelig-centrerede (Human Centric) belysningsstrategi, ved at fungere som retningslinjer til udviklingen, samt levere strategisk bevis for fordele.
2) Teknologi (WP3 og WP4 i vores kontrakt, international ledelse af BUILD AAU). Vi har publiceret 5 store rapporter. En undersøgelse i 10 lande gav indblik i forventninger til integreret belysning- og dagslysstyring.
   Vi afviklede en omfattende gennemgang af tilgængelige løsninger, og analyserede tre lovende nye løsninger. Vi identificerede potentialer ved nye brugergrænseflader (UI) og foreslog udvikling af standarder, for at øge tilliden hos de forskellige interessenter.
3) Design support (intet bidrag fra vores konsortium til denne opgave). Men IEA61Task-eksperter fremsatte en række forslag til forbedring af værktøjer for arkitekter og ingeniører inden for integreret belysning- og dagslysstyring.
   Her offentliggjorde IEA61Task-eksperter 4 rapporter om henholdsvis metoder, standardisering af BDRF-karakteristika for vindueskomponenter (solafskærmning), spektrale sky-modeller til software, samt metoder til at bedømme præstationer/ydeevne.
4) Casestudier (WP5 i vores kontrakt). I opgaven gennemførte vi en litteraturgennemgang af casestudier og fund. Vi foreslog testprotokoller, samt koordinerede 25 casestudier udført i 12 lande og publicerede resultater som følge heraf.

3. Project objectives

The objective of the project was to explore the various challenges associated to integrated daylighting and lighting controls in buildings and deliver a number of reports aimed at Energy Agencies, and professionals. As well as online tools to help the various stakeholders. Indeed, in 2021, electric lighting has become quite efficient and electric lighting power density is now in a range of 2-6 W/m^2 (for most buildings, except shops and supermarkets) leading to an annual consumption for electric lighting in the range of 3 KWh/m^2.year to 18 KWh/m^2.year, depending on duration of use. The major way to move these figures downward is through controls: lighting controls to further reduce consumption of electric lightingand solar shading, to reduce heat gains as well as improve comfort of occupants.

The objective of the project was to identify opportunities of integrated to controls, to:

- Further reduce energy consumption (turning off or dimming electric lights whenever possible)
- To control daylight (and sunlight) penetrations in the best possible way for the occupants, to maximize daylight use, reduce glare, maintain view out, reduce overheating of the space This means to contribute to occupant well being

We focused on various technologies and identified the potential of new wireless solutions, which could reduce installation costs, facilitate commissioning (and re-commissioning), allow easy control with user-friendly interfaces. For shading systems, we focused on solutions allowing not only to reduced sunlight penetrations, but to propose optical control to improve daylight contribution and reduce glare.
For communication with professionals, the initial plan was to develop an interactive software. The scope has been adjusted to put more focus on a web-based tool (as opposed to individual, stationary Virtual Reality sessions), acting as a supplement for communication of design solutions integrating electric lighting and daylight – all accessible on a web platform. BUILD-AAU developed a fully digital and interactive simulation tool for one of the case studies (with a possibility of implementing Virtual Reality gear such as Oculus Rift), with results that influenced the design decisions in that project (used case study in Gdynia, Poland. Provided by one of project partners – Gdansk University of Technology), and therefore showing a successful implementation of the new design tool.
A challenge in the development was the collection of the data from participants (technical and photographic inputs from case studies), that was significantly limited after the pandemic outbreak. Another challenge was limited access to the powerful computers. In the fully-digital module, an important aspect was realism of the sunlight visualisation over time. Simulating it accurately in a form of animation requires powerful computing mechanisms. Therefore, a decision was made to obtain new machines capable of executing such tasks and extra training in the industry-leading 3D software UNITY3D. Due to the COVID-19 limitations, the delivery of the machines, as well as access to the office premises have also posed some challenges, however it was tackled by obtaining special permissions and remote access to the machines.

4. Project implementation

Overall, the project could proceed close to actual plans and tasks could be completed close to the original time plan. Nevertheless, the project period has been impacted by the 2020-2021 Covid-19 crisis. This concerns mostly the campaign of case studies, where access to buildings for instrumentation and testing was rejected due to Covid-19 restrictions. In Denmark, two case studies to be conducted by BUILD-AAU had to be cancelled: the university library at DTU and a retirement home in the Copenhagen area. AU conducted three planned case studies at Slagelse Psychiatric Hospital, Vikærgaarden Rehabilitation Centre in Aarhus, and at Navitas in Aarhus. While the first two of these focussed on the integration of circadian lighting (døgnrytmebelysning), the Navitas case study assessed the energy impact of lighting control (automated) and shading control (manual) implementations. Due to significantly reduced access for the first two completed case studies and long periods of lockdown for the Navitas case study, data sets were more limited than planned, but nevertheless sufficient to achieve results.

For the rest, the major impact was the transfer of all communication and meetings to a digital mode, which reduced involvement of companies in the programme and made informal exchange between members of the international team more difficult.

For the subtasks A, B, and C, the impact of the crisis was limited and milestones only delayed by few months. All planned deliverables have been produced, but some of them behind schedule (1 year). For subtask D, delivery of the final reports is expected for the end of September/early October 2021.

Development of the on-line interactive tool was also challenged with setback due to delay in reception by BUILD-AAU of the data supplied by the various groups in their case study program. Most of the final developments and uploads were conducted in Q1-Q2 of 2021. The results were two types of developed modules for the application. First one is utilizing images (in a form of photographs taken with specific DSLR camera settings - as described in the created manual in Appendix B), which are later processed in the app to create an interactive simulation where user can adjust levels of lighting, its colour temperature, and daylight intensity. The second type was a fully digital simulation of provided case study using 3D modelling and lighting calculation software. The workflow was documented with a goal of describing the procedure and expertise of creating similar simulations for future case studies (Appendix C). The first module can be implemented on any web-platform in a form of JS/HTML code and source files (images). The second module is a stand-alone application that can be ran locally on a Windows-operating PC.

5. Project results

The original scope of the program was (reference document of the IEA SHC Task 61 to integrate

- daylight utilization by enhanced facade technologies and other architectural solutions,
- electric lighting schemes addressing technology and design strategies,
- lighting control systems and strategies with special emphasis on visual and non-visual user needs and with special emphasis on the interface of day- and electric lighting.

The technological results were mostly the identification of promising solutions, allowing more advanced integration of the systems. Three systems were clearly identified: by Zumtobel, Hella and IPP. On the side of tools, various new tools were proposed, for decision-making (coordinated by IBP Stuttgart), for improvement of simulations (coordinated by Bartenbach Lichtplanung in Austria), and for online demonstration of systems (developed by BUILD-AAU)

Target groups are: lighting manufacturers, engineers and architects, installers, facility managers. Industrial workshops were organized at every meetings (every six months).

In Denmark, Dansk Center for Lys and Bygherreforeningen organized 3 events to present results toward building and lighting professionals, with a total attendance of 200 participants. In Denmark, progress was presented in LYS, presented on the website: https://task61.iea-shc.org/ and highlights presented in the following document: https://task61.iea-shc.org/highlights

The module developed by AAU to be played online targets designers and engineers, wanting to showcase their solutions (or examples of case studies) to the clients. The module is easy to operate and interact with, and gives an instant visualisation of the dynamic controls of light and shading devices. Through implementation on the web, it is also a powerful communication tool that can reach large audiences.

Dissemination activities and publications (including expected) of Danish participants:

Osterhaus, W., Gentile, N., Nielsen, K.G., Gkaintatzi-Masouti, M. et al. Energy saving potential of user-centered integrated lighting solutions: A literature review. Research Report from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021.

Gentile, N., Osterhaus, W., Nielsen, K.G., Gkaintatzi-Masouti, M. et al. A monitoring protocol to evaluate user-centred integrated lighting solutions: A procedure to post-occupancy evaluation of daylight and electric lighting integrated projects. Report from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021.

Gentile, N., Osterhaus, W., Nielsen, K.G., Gkaintatzi-Masouti, M. et al. Lessons learned: Case Studies. Report from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021.

Osterhaus, W., Nielsen, K.G., Gkaintatzi-Masouti, M and Dobos, F. Navitas Education and Office Building in Aarhus. Case Study Fact Sheet from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021 (4 pages).

Osterhaus, W., Nielsen, K.G., Gkaintatzi-Masouti, M and Dobos, F. Vikaergaarden Rehabilitation Center in Aarhus. Case Study Fact Sheet from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021 (4 pages).

Osterhaus, W., Nielsen, K.G., Gkaintatzi-Masouti, M and Dobos, F. Slagelse Psychiatric Hospital. Case Study Fact Sheet from Subtask D of IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting: From Component to User-Centered System Efficiency. October 2021 (4 pages).

Osterhaus, W., Gkaintatzi-Masouti, M., Baumann, T. Assessing luminous environments through luminance maps from HDR images captured by a Raspberry Pi computer. Presented at Licht 2020, Bamberg, Germany, 22-24 March 2021. https://youtu.be/2k2B7oNe1-I

Erhardtsen, I., Osterhaus W., Støttrup, K.F., Derengowski, N, Gkaintatzi-Masouti, M., Nielsen, K.G., Markvart, J., Dobos, F., Stoffer, S., Reinholt, P., Schauer, J., Pedersen, A. Energievaluering af dynamisk døgnrytmelys. *Lysets Dag, Annual Conference of the Danish Center for Lighting, Online, 26 October 2020*. https://www.youtube.com/watch?v=QPqsiQ8RYaM&feature=youtu.be

Osterhaus, W., Gkaintatzi-Masouti, M. and Gentile, N. Wearable Light Sensors in Case Study Evaluations. *Webinar of the International Solar Energy Society (ISES) and the International Energy Agency (IEA) SHC Task 61 – Integrated Solutions for Daylighting and Electric Lighting, 24 September 2020.* https://www.ises.org/news/webinar-invitation-iea-shc-solar-academy-integrated-solutions-daylighting-and-electric-lighting

Naves David Amorim, C, Gentile, N., Osterhaus, W., Altomonte, S. Integrated solutions for daylighting and electric lighting: IEA SHC Task 61/EBC Annex 77, Subtask D – proposal and first results. *Proceedings of 35th PLEA Conference on Sustainable Architecture and Urban Design: Planning Post Carbon Cities, A Coruña, Spain, 1-3 September 2020.*

Gentile, N., Osterhaus, W., Altomonte, S., Naves David Armorim, C. IEA SHC Task 61 / EBC Annex 77 Integrated Solutions for Daylighting and Electric Lighting - Subtask D: Lab and Field Study Performance Tracking. *Proceedings of ISES Solar World Congress, Santiago de Chile, 2-4 November 2019.*

Gentile, N., Osterhaus, W., Altomonte, S., Garcia Alvarez, M., Naves David Amorim, C., Garcia-Hansen, V., Obradovic, B. Energy-Saving Potential for Integrated Daylighting and Lighting Design via User-Driven Solutions: A Literature Review. *Proceedings of the 29th Quadrennial Session of the International Commission on Illumination, CIE 2019 – Connecting the World in Light, Washington, DC, 14-22 June 2019.*

Osterhaus, W., Erhardtsen, I. and Stoffer, S. Døgnrytmelys og energibesparelser. Presented at ”Hvad ved vi egentlig? – Temadag om døgnrytmebelysning, lyststyring og dagslys”, 14 May 2019, Aalborg University, Copenhagen.

Osterhaus, W. and Stoffer, S. Lys og produktivitet i kontormiljøer. Presented at ”Hvad ved vi egentlig? – Temadag om døgnrytmebelysning, lyststyring og dagslys”, 14 May 2019, Aalborg University, Copenhagen.

Nielsen, E.L., Dokumentation og beregningsmetoder. Presented at ”Hvad ved vi egentlig? – Temadag om døgnrytmebelysning, lyststyring og dagslys”, 14 May 2019, Aalborg University, Copenhagen.

Fontoynont, M. Lysstyring: Trends og nye muligheder. Presented at ”Hvad ved vi egentlig? – Temadag om døgnrytmebelysning, lyststyring og dagslys”, 14 May 2019, Aalborg University, Copenhagen.

Erhardtsen, I. Status og perspektiver på lysstyring. Presented at ”Hvad ved vi egentlig? – Temadag om døgnrytmebelysning, lyststyring og dagslys”, 14 May 2019, Aalborg University, Copenhagen.

6. Utilisation of project results

The results of subtask A are essential evidence to help manufacturers to adapt their products to improve human well-being together with energy efficient solutions. The information is expected to be used by product specifiers to develop sound global solutions.

The result of subtask B is mainly a critical analysis of the supply, expected to help clients, engineers, to select the best control solutions.

Results of subtask C target engineers and architects with expertise in electric light and daylight simulations, allowing them to optimize solution and present performance to their clients.

Results of subtask D (case studies) are for all stakeholders (final clients, specifiers, installers, manufacturers and scientists). They document solutions and gather results from field experimentation The online tool which has been developed will be used by designers and manufacturers as a communication tool, helping to visualise modern lighting control systems and their integration with daylight. Selected case studies showcase different contexts and can be used as examples for designers and architects.

Fraunhofer-IBP in Stuttgart has developed the general website containing results. It should be open to the public late July 2021.

7. Project conclusion and perspective

The project allowed to maintain collaboration between various international research organizations and private firms. The technology of integrated daylighting and lighting controls seems to be quite advanced in Europe, and China, in comparison with other countries. In addition, it is a concern for occupant well-being, too. Development of innovative interfaces is however a worldwide concern; with the US, in particular, trying to bridge the solutions between lighting and non-lighting options. There are various key conclusions that can be stated:

Human needs

- Requirements for light depend on human groups, and ageing of the population is a major issue
- Glare is not well understood by professionals, it is the major comfort issue
- The best CCT of light is a cultural issue, with major differences between East and West, North and South

- Windows are essential for well-being, with minimum window area being a topic to be addressed by building regulations
- Difficulty to mimic perfectly daylights leads to the necessity to use daylight as often as possible, to meet human needs. For example to compensate visual fatigue when working on computer screens.
- A number of recommendations have been formulated to provide sufficient amounts of daylight and electric light for a number of typical activities

Personas have been proposed to illustrate typical users of buildings with the following characteristics:

Age • Gender • Vision (glasses? vision damage? diagnoses?) • Light preferences (light lover or hater) • Glare sensitivity • Education (basic, high school, university) • Living conditions (large town, small town, countryside…) • Occupation (teacher, student, nurse, cook, chairwoman…etc.) • Role in the institution (leader, coworker in group activities, work individually) • Type of visual tasks (colour discrimination? fine details or coarse?) • Psychological profile (dominates, accepts passively or flexible) • Chrono-biological profile? (wake up early/late in the morning?)

Technology

The survey conducted toward more than 100 stakeholders in 9 countries led to the following classification of expectations toward lighting controls:

In Denmark, an easy commissioning is found very important while the robustness of systems, low failure rate and warranty of the system are found more important in China and Poland. In Austria and Sweden, both an easy commissioning, robustness and low failure rate are found to be of high importance. Future-proof concepts and standardization issues are found to be of high important in China and Austria. In Poland, both initial and ongoing cost issues are found important in relation to building managers/facility managers while only the initial cost issues are found important in Norway. In Italy, a future proof concept and initial cost issues are rated as to be most of importance.

In relation to occupant controls, most of the countries find that simplicity of operation is very important. However, it is found less important in Norway and Poland (in Poland only half of participants find it important). All countries find the adjustments of illuminance important. Belgium and Norway find it most important to be able to control the illuminance manually, while Denmark and Poland find it most important with automatic adjustment of illuminance. None of the countries finds it of particular importance to be able to control the spectrum of light. In Sweden, a manual switching together with the capacity to override the control system is rated as important, while automatic lighting control related to occupancy and daylighting are rated as important in Italy together with automatic and manual lighting control pr. zone.

In relation to new technology opportunities available, all countries find it important that the lighting systems have compatibility with other systems (BMS, HVAC, etc.). Poland and Austria find it of high importance with wireless capabilities and internet connection (grid connected systems) of the lighting systems, while an open source protocol is rated as important in Denmark and Italy. Additionally, an automatic combined control of daylight and electric light is rated as important in Denmark and Italy, whereas Poland finds it of importance that the control system has a combined light and heat control of shading. Both automatic combined control of daylight and electric and combined light and heat control are found important in Austria.

In general, the conducted survey suggest that following aspects are rated to be of highest importance in relation to lighting control systems:

- Potential to reduce energy consumption from the electric light
- Possibility to adjust the illuminance level
- Possibility to reduce unwanted heat gain
- Possibility to reduce glare from windows
- Possibility to open and close shading systems manually
- Simplicity of the control system
- Possibility for the occupants to manually override the control system
- Well-being of the occupants
- Easy commissioning
- Future proof and flexibility of the system over long term

The principle of our task was to identify the best possible approach to deploy successful lighting and daylighting strategies, meaning strategies leading to A) reduction of energy use and B) improve satisfaction of building occupants.
Objective A) is achieved mostly in allowing the system to operate in a smart way, providing electric light only when needed, and in the appropriate quantities
Objective B) is broader, since it suggests that controls should help to reduce discomfort (glare from windows, inappropriate exposure to entering sunlight), improve physiological well-being (adjust spectra of light according the time of the day and the needs), contribute to security (incl. cybersecurity, intrusion).
We have identified other benefits associated with new control systems: flexibility (adaptability of changes in the use of buildings), simplification of installation, easier commissioning and simplified maintenance.
We have also identified needs for improvement: more standardization to compensate for the extreme diversity of systems. For example, the frequency bands of wireless protocols. One issue among others: differences in frequency bands (MHz) that are country specific.

Clearly, reduction of costs of systems is needed, since costs are often judged in excess in relation to the financial benefits during operation. Bust some costs are diminishing with mass production (for instance electric motors for shading). Control is often an option brought late in the design process, and then abandoned for reasons of costs. In residential buildings, the market of automatic control for shading is booming: high gains in relation to costs, added value when selling the house / apartment.

This suggests that energy conservation cannot be the only objective for the promotion of lighting and daylighting controls. The energy benefits should be associated with other benefits in operation, to make the supply more attractive.

We have also shown that state of the art is quite different in residential and non-residential buildings with respect to the fact that occupants expect to possibly override the system when necessary. Commissioning task should not be underestimated, since the success of a control system is judged through its ability to provide light quantities and spectra in accordance to needs.

Robustness has been described: increasing sophistication of control could lead to increasing the potential failures. Solutions are proposed, with regular checks integrated in the software.

Acceptance by building occupants is an important aspect, suggesting to inform / communicate or even provide training. Hence the interest on a good user interface.

Lighting Control User Interfaces are under significant development, and progressing both in quality and in functionality

- Remote control - data and control feed through the internet is becoming more and more popular option added to the user interface of lighting control systems. The system away from home, if it is connected to a router and internet – such options already exists as for example IKEA TRADFRI interface.

- Development by the users - In the digital era and accessibility to coding knowledge, many users decide to develop applications on their own. Such practice was noticed by manufacturers, for example Philips, who made a special platform for such user-based development (https://developers.meethue.com). Such an online community exchanging apps and codes is an excellent source of ideas for further development of the official product. It can also show the versatility of the product in different settings and scenarios. In example browsing through user-developed apps one can find lighting control through hand gestures through infrared sensors, weather based light control (through online-received data), color matching videos or other themes etc. For different application, users also develop their own interface systems, most efficient for the exact functionality that is needed.

- Personalization of the systems – on top of adjusting the lighting in forms of scenes, there also comes personalization of the UI itself. Digital displays offer options of changing the appearance of the device making it more fitting to the user, or designated space. On the other hand, manufacturers (f.eg. Niko Servodan) offer material selection for the finishes of the analog controls, which can amplify the character of the interior design of spaces.

- Synchronization with smart home systems – in the age of IOT with systems such as Amazon Alexa, Google Play Assistance or Apple HomeKit just to name a few, lighting is becoming an integrated element of Smart Home systems.

- Suggestive scenes from producers – to showcase the possibilities, and make it easy and readily-accessible, producers pre-define number of scenes and make it accessible right after initializing the system. Some lighting scenes are marketed as backed by research – f.ex. energizing light with peaks in blue spectrum, or on the other side of spectrum – evening light with reduced blue wavelengths for better sleep. In the future, we should expect more and more such solutions being available in the systems in forms of presets downloaded with updates.

- Shading control: interfaces are more user friendly and cost effective. They become gradually a standard, especially with motorized shading systems. They are significant elements to manage solar protection and shutters according to outdoor climatic conditions, leading to benefits, both in energy use and comfort.

- One key trend of the future is to improve feedback to the system user, suggesting actions or informing on consequences of actions.

Another aspect is to address the real value proposition of control systems: it clearly goes beyond energy savings: the challenge for Danish manufacturers of lighting controls is to propose a number of functionalities that have been identified:

Control specific lamps (wall washers, task, et.)
New sensors and sensor location Open loop / closed loop
Propose a user-friendly, simple and attractive interface
Propose a full flexible module for control, beyond lighting (communication, displays, etc.)
Propose geo-localization services with lighting (LiFi)
Easy commissioning and re-commissioning
Future proof (system which could adapt to evolutions of technology over time) : Updating through the internet: new software
Interoperability (linked to other control systems and services, simplifies management, data, etc.)
Make a house warmer during cold sunny days
Make house cooler during warm sunny days
Remote control from outside the building (facility management, user comfort)
Anticipation of overheating: shading controls need to be more predictive and smarter (more data to collect)
Flexibility can be related to future proof : update of systems
Possibility to re-program the controls

Concerning standardization issues, we have identified a number of key domains where standardization activities are needed:

Topic	Detail	Challenges
Sensors	Outside Sensor (open loop) and indoor sensor (closed loop)	Reliability, accuracy, design (multiple sensors?)
Motor	DC / AC / SMI	Reliability, noise, steps
Operation	Performance	Precision of blind control / type steps
Accuracy of blind controls	Time step for actions (lighting / daylighting)	Performance vs user satisfaction, tolerance issues
Commissioning procedure	On site during installation and during maintenance	Tuning of systems
PV powered solutions	Sizing issue	Autonomy level

Results from Case Studies

As stated earlier, there have been 25 completed case studies that were conducted in 12 countries (Australia, Austria, Belgium, Brazil, China, Denmark, Germany, Italy, Norway, Spain, Sweden, and the USA). Case studies included spaces in already operated buildings, in living laboratories, as well

as in full-scale mock-ups. Building types included private and public office buildings, commercial retail spaces, educational buildings, hospitals and other health facilities, as well as retirement homes. Some of the case studies were listed as particularly sustainable designs, others focused on specific technologies, such as circadian (integrative) lighting, electrochromic glazing, novel shading devices, light-directing devices, highly complex building system integration allowing for detailed performance monitoring, or even low-budget lighting controls.
Case studies followed a common reporting template covering a description of the case study space or building, the design goals, the undertaken monitoring tasks, measured or calculated energy use data, photometric daylighting and electric lighting performance data, circadian potential and user perspectives.

Details on each case study can be found later in the fact sheets to be published online and the "lessons learned" report associated with these case studies on the IEA Task 61 website: *https://task61.iea-shc.org/publications*

As part of this report, we wish to highlight a number of aspects that appear important:

Appropriate and integrated design tools for all stages of the project
At present, there is still a lack of integrated design tools that can address all aspects of the goals for integrated design of daylighting and electric lighting. This is particularly true for assessing circadian potential and the performance of highly complex fenestration systems with adjustable or switching properties for dynamic climate-based daylight simulations. However, some advances were made in Subtask C of the IEA SHC Task 61. However, it will take some time before these new tools are ready for the market and available for implementation in all projects. Funding support for such work would be a very welcome initiative.

Technology integration for daylight, electric lighting, shading design and related factors affecting user well-being and comfort from the start of and throughout the project and even after occupancy
Daylight control to reduce lighting energy use has been characterized historically as unreliable: providing too little or too much light, causing occupant complaints, and failing to reduce energy use. Fortunately, digitalization has vastly improved performance despite the increased complexity of high-resolution lighting controls. The "lessons-learned" from the case studies document rather clearly that those projects that paid particular attention to integration and fine-tuning of systems throughout the whole design and construction process, were especially successful. Achieving high-performance goals requires follow-through during the later stages of procurement, construction, and commissioning in the final building. Monitored verification under real-world conditions can help identify critical issues well before procurement and occupancy. This is particularly relevant for integrated, innovative shading and lighting systems where balancing trade-offs between competing performance criteria (e.g. glare protection, view and high daylighting performance) is required. The case studies also underscored the importance of integrated design and control of dynamic building facades with respect to climate, occupant requirements, and facility management goals.

Integration of circadian lighting systems with daylighting design
Four of the projects specifically looked at the impact of specific electric lighting to support the circadian rhythm of building occupants. The two Danish case studies undertaken lacked appropriate consideration of daylight contributions in affecting circadian rhythms of occupants and energy consumption of the installed systems, as the electric lighting was not linked with daylight availability.

The energy use was thus significantly higher than that of a standard reference lighting design with daylight-linked control and occupancy sensors. Energy calculations for the installed circadian system with daylight-linked controls and occupancy sensors indicated that adding these controls could have saved a third of the energy when compared to the installed system without these controls.

Testing and calibration (fine-tuning) period (commissioning) prior to occupancy
While proper commissioning procedures should really be standard routines, it appears that this is not always the case.
During the case studies, various instances with obvious shortcomings were encountered. Light sensors were incorrectly placed or oriented, circuits for daylight-linked lighting control zones incorrectly wired, illuminance set-points for electric lighting too high, or daylight-linked controls not even present, even though there were part of the initially proposed design scheme. Cost savings and time pressure seem to be some of the factors here. Others appear to be a lack of training of facility management staff. Such issues can in many cases easily be addressed and corrected.
As some case studies have also demonstrated, unique self-commissioning features that enable determination of source contributions to each photo sensor can be used, for example:

1) contribution of up- and downward output per fixture to the photo sensor signal,
2) photo sensor signal versus source power level over the full dimming range, and
3) daylight work plane illuminance versus photo sensor signal.

Monitored data can be used to evaluate control performance, followed by adjustments to default settings for minimum dimming and light levels to improve energy efficiency, changes to grouping of sources to improve luminance uniformity, and then re-evaluations of dimming performance.

Appropriate and simple user interfaces as well as user training about the key features of the building/space
It is critical that users can operate the respective systems, especially those directly affecting their comfort and well-being. This requires some basic understanding of the key performance features of the occupied space(s) and/or the building. Training occupants on the advanced features of a building is very effective. User interfaces should be kept as simple as possible to support user needs. Unnecessarily complex user interfaces that are not fully understood by users and unexpected or undesired operation of systems can lead to disabling of certain features or control mechanisms.

Post-occupancy evaluation (POE) to address specific user needs and behaviour
It is highly recommended that POE studies be conducted for all buildings involving complex integrated building systems, including lighting systems. User feedback from such studies is valuable for understanding if systems work as intended and whether users are satisfied with their operation, or whether user might have personal preferences or requirements that would enhance their well-being and work performance. Some case studies included highly detailed occupant surveys and used these for effective improvements of the system.

Energy monitoring and feedback to users
It appears prudent to ensure that building users get feedback on actual energy use in the spaces they occupy and how their behaviour affects energy use. It is suggested to illustrate to users the consequences of their choices (e.g. keeping shading devices closed when no longer required) on the resulting energy use from electric lighting. The user remains a key player in energy use and needs to be supported in making better-informed decisions. Dashboard-like displays of key performance figures or similar measures can perhaps support such goals and encourage users to be more sustainable.

Operation and maintenance guidelines
Once a building has been occupied and is in operation, regular checks of the systems are necessary. This should include checks of proper operation of all components and achievement of the stated performance targets. Specific instructions should be provided with respect to when and how to check/replace particular components, for example lamps or luminaires, or sensors for various control functions. The appropriate specifications for all components should be clearly stated.

Next Steps

The next steps in technology are related to cost reductions. These can be achieved by using as much as possible solutions available for other applications, through global digitalization:

- Lighting through Power over Ethernet (PoE - use data system to supply and control lighting)
- Lighting through DC (48V or other) allowing migration from the automotive world to buildings, and allowing better use of DC networks associated with solar power.
- Bluetooth communication (communication with consumer electronics, using smartphone interfaces)
- Next generation smartphone-based interfaces
- Internet of Things (IoT) / 5G external – internal control
- Standard Motor Interface (SMI) for motors operating shading devices

The IEA SHC Task 61 project showed that fully integrated daylighting and lighting control is achievable, and will become a standard.

However, fully integrated daylighting and lighting control is today:

- Often too expensive in relation to gains
- Not always well tested and checked (commissioning) before being turned over to the users, resulting in some cases in unnecessary energy use and user dissatisfaction
- Sometimes lacking appropriate maintenance procedures to ensure effective long-term operation
- Not user friendly (complex interfaces requiring training)
- Rarely supplied by one consortium, resulting in compatibility problems
- Not future proof enough

This shows directions for future developments, which will likely be conducted by manufacturers of motorized façade shading systems and complex daylighting systems. They have most of the capabilities needed and can adapt to existing lighting control solutions, with added focus on sensor design (location, closed or open loop) and communication protocols (especially with electric lighting systems).

Based on the results from the international case studies conducted during this project, it can be expected that the integration of daylighting and electric lighting and their controls will gain further momentum in architecture and consulting engineering practices and be extended to other areas affecting occupant comfort. Without such integration from the start of a project, the full potential will be difficult to achieve.

This, in turn, will require the development of more advanced algorithms (especially addressing complex daylighting and shading devices) for design and analysis tools that will be able to assist designers in their tasks. A white paper outlining generation procedures for bi-directional scattering distribution functions (BSDF) of complex daylighting systems has been produced by this project. Supporting the development of such design tools would seem to be an important task for funding agencies.

Appendices

8. Appendix A: Annual reports that were published in the project report

Semi-annual status reports are only available for the IEA members with server access under this link:
https://dms-prext.fraunhofer.de/livelink/livelink.exe?func=ll&objId=17112859&objAction=browse&viewType=1

The publicly available reports are under this link: https://task61.iea-shc.org/publications

- *Add link to other relevant documents, publications, home pages etc.*

9. Appendix B: Manual for taking photographs for JWG module

This will be a separate file.

10. Appendix C: Procedure of creating content for the standalone digital JWG module and quality assurance

This will be a separate file.

11. Appendix D: List of meetings and participants

11.1 Task Meeting 1 - February 28 – March 2 2018 in Lund, Sweden

Meeting Participants

Sergio Altomonte, Belgium
Jens Christoffersen, Denmark
Stanislav Darula, Slovakia
Jan de Boer, Germany
Aicha Diakite, Germany
Marc Fontoynont, Denmark
Peter Fuhrmann, The Netherlands
Maria Garcia Alvarez, Denmark
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Carolin Hubschneider, Germany
Jerome Kaempf, Switzerland
Michael G. Kent, UK
Yasuko Koga, Japan
Thorbjörn Laike, Sweden
Eleanor Lee, U.S.A.
Marios Liaros, Sweden
Tao Luo, China
Barbara Szybinska Matusiak, Norway
Ali Motamed, Switzerland
Biljana Obradovic, Norway
Werner Osterhaus, Denmark
Harris Poirazis, Sweden
Alexander Rosemann, The Netherlands
Victoria Eugenia Soto Magan, Switzerland
Forrest Webler, Switzerland
Jan Wienold, Switzerland
Yujie Wu, Switzerland
Asta Logadottir, Denmark

11.2 Task Meeting 2 - September 5-7 2018 in Lausanne, Switzerland

Meeting Participants

Sergio Altomonte, Belgium
Bruno Bueno, Germany
Ayana Dantas de Medeiros, Brazil
Stanislav Darula, Slovakia
Jan de Boer, Germany
Bertrand Deroisy, Belgium
Aicha Diakite, Germany
Marc Fontoynont, Denmark
Maria Garcia Alvarez, Denmark
Veronica Garcia-Hansen, Australia
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Alstan Jakubiec, Singapore
Jerome Kaempf, Switzerland
Eleanor Lee, U.S.A.
Tao Luo, China
Eik Lykke Nielsen, Denmark
Christophe Marty, France
Justyna Martyniuk-Peczek, Poland
Barbara Szybinska Matusiak, Norway
Claudia Naves David Amorim, Brazil
Julien Nembrini, Switzerland
Daniel Neves Pimenta, Germany
Biljana Obradovic, Norway
Werner Osterhaus, Denmark
Bernard Paule, Switzerland
Harris Poirazis, Sweden
Jan Remund, Switzerland
Natalia Sokol, Poland
Greg Ward, U. S. A.
Robert Weitlaner, Austria
Jan Wienold, Switzerland
Daniel Witzel, Germany
Yujie Wu, Switzerland

11.3 Task Meeting 3 - March 28-29 2019 in Beijing, China

Meeting Participants

Daniel Chen, China
Giovanni Ciampi, Italy
Jan de Boer, Germany
Ruben Delvaeye, Belgium
Yachun Gao, China
Veronica Garcia-Hansen, Australia
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Yunfei Han, China
Yuan Li, China
Peng Lin, China
Tao Luo, China
Daniel Neves Pimenta, Germany
Michelangelo Scorpio, Italy
Anne Sophie Louise Stoffer, Denmark
Robert Weitlaner, Austria
Shao-Yu Wu, Germany
Peng Xue, China
Bin Zhang, China
Tian Zhen, China

11.4 Task Meeting 4 - September 16-18 2019 in Gdansk, Poland

Meeting Participants

Sergio Altomonte, Belgium
Adam Bladowski, Poland
Bruno Bueno, Germany
Cláudia Naves David Amorim, Brazil
Jens Christoffersen, Denmark
Robert Weitlaner, Austria
Yasuko Koga, Japan
Julia Kurek, Poland
Thorbjörn Laike, Sweden
Marios Liaros, Sweden

Stanislav Darula, Slovakia
Jan de Boer, Germany
Ruben Delvaeye, Belgium
Aicha Diakite, Germany
Marc Fontoynont, Denmark
Nikodem Derengowski, Denmark
Veronica Garcia-Hansen, Australia
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Sergo Sibilio, Italy
Anne Sophie Louise Stoffer, Denmark
Tao Luo, China
Justyna Martyniuk-Peczek, Poland
Barbara Szybinska Matusiak, Norway
Daniel Neves Pimenta, Germany
Biljana Obradovic, Norway
Werner Osterhaus, Denmark
Kieu Pham, Australia
Harris Poirazis, Sweden
Katarzyna Russek, Poland
Michelangelo Scorpio, Italy
Natalia Sokol, Poland

11.5 Task Meeting 5 - March 16-18 2020 via Web

Meeting Participants

Sergio Altomonte, Belgium
Priji Balakrishnan, Singapore
Marie Boucher
Bruno Bueno, Germany
Cláudia Naves David Amorim, Brazil
Jens Christoffersen, Denmark
Giovanni Ciampi, Italy
Nikodem Derengowski, Denmark
Aicha Diakite, Germany
Jan de Boer, Germany
Bertrand Deroisy
Ruben Delvaeye, Belgium
Aicha Diakite, Germany
Kasper Fromberg Støttrup, Denmark
Marc Fontoynont, Denmark
Peter Fuhrmann, Netherlands
Veronica Garcia-Hansen, Australia
Alstan Jakubiec, Canada
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Myrta Gkaintatzi-Masouti, Denmark
Martine Knoop, Germany
Yasuko Koga, Japan
Thorbjörn Laike, Sweden
Eleanor Lee, USA
Marios Liaros, Sweden
Tao Luo, China
Justyna Martyniuk-Peczek, Poland
Barbara Szybinska Matusiak, Norway
Ayana Medeiros, Brasil
Marzieh Nazari, Norway
Julien Nembrini
Daniel Neves Pimenta, Germany
Biljana Obradovic, Norway
Werner Osterhaus, Denmark
Kieu Pham, Australia
Harris Poirazis, Sweden
Michelangelo Scorpio, Italy
Gunther Seckmeyer, Germany
Sergo Sibilio, Italy
Natalia Sokol, Poland
Anne Sophie Louise Stoffer, Denmark
Taoning Wang, USA
Marta Waczynska
Greg Ward, USA
Robert Weitlaner, Austria
Simon Wössner, Germany

11.6 Task Meeting 6 – September 28-29 2020 via Web

Meeting Participants

Sergio Altomonte, Belgium
Cláudia Naves David Amorim, Brazil
Bruno Bueno, Germany
Donatienne Carmon, Belgium
Giovanni Ciampi, Italy
Jan de Boer, Germany
Nikodem Derengowski, Denmark
Bertrand Deroisy, Belgium
Kasper Fromberg Støttrup, Denmark
Marc Fontoynont, Denmark
David Geisler-Moroder, Austria
Niko Gentile, Sweden
Myrta Gkaintatzi-Masouti, Denmark
Lars Oliver Grobe, Switzerland
Alstan Jakubiec, Canada
Julia Resende Kanno, Brazil
Yasuko Koga, Japan
Julia Kurek, Poland
Flavia de Lacerda Bukzem, Brazil
Thorbjörn Laike, Sweden
Eleanor Lee, USA
Gerald Lukasser, Austria
Justyna Martyniuk-Peczek, Poland
Barbara Szybinska Matusiak, Norway
Marzieh Nazari, Norway
Biljana Obradovic, Norway
Werner Osterhaus, Denmark
Kieu Pham, Australia
Per Reinholdt, Denmark
Michelangelo Scorpio, Italy
Sergo Sibilio, Italy
Natalia Sokol, Poland
Taoning Wang, USA
Marta Waczynska
Greg Ward, USA
Robert Weitlaner, Austria
Jan Wienold, Germany
Helen Rose Wilson, Germany
Daniel Witzel, Germany
Yujie Wu, Switzerland

11.7 Task Meeting 7 – November 23-24 2020 via Web

No participant list was recorded.

11.8 Task Meeting 8 – March 18-19 2021 via Web

No participant list was recorded.

11.9 Task Meeting 9 – May 10-11 2021 via Web

No participant list was recorded.