SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Review of new systems and trends

IEA SHC Task 61 / EBC Annex 77: Integrated Solutions for Daylighting and Electric Lighting

Solar Heating and Cooling Technology Collaboration Programme (IEA SHC)

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency.

Our mission is *"Through multi-disciplinary international collaborative research and knowledge exchange, as well as market and policy recommendations, the IEA SHC will work to increase the deployment rate of solar heating and cooling systems by breaking down the technical and non-technical barriers."*

IEA SHC members carry out cooperative research, development, demonstrations, and exchanges of information through Tasks (projects) on solar heating and cooling components and systems and their application to advance the deployment and research and development activities in the field of solar heating and cooling.

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- Solar Cooling (Tasks 25, 38, 48, 53, 65)
- Solar Heat for Industrial and Agricultural Processes (Tasks 29, 33, 49, 62, 64)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56, 59, 63, 66)
- Solar Thermal & PV (Tasks 16, 35, 60)
- Daylighting/Lighting (Tasks 21, 31, 50, 61)
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- SHC Solar Academy
- *Solar Heat Worldwide*, annual statistics report
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PREFACE

Lighting accounts for approximately 15 % of the global electric energy consumption and 5 % of greenhouse gas emissions. Growing economies, higher user demands for quality lighting and rebound effects as a result of low priced and more versatile electric lighting continuously still lead to an absolute increase of lighting energy consumption. More light is used, often less consciously.

Especially the electric lighting market but as well the façade, daylighting und building automation sectors have seen significant technological developments in the past decade. However these sectors still act mainly independent of each other, leaving out big potentials lying in a better technology and market integration. This integration is on the one hand beneficial to providing better user-centred lighting of indoor spaces. On the other hand it can contribute significantly to the reduction of worldwide electricity consumptions and C02-emissions, which is in line with several different governmental energy efficiency and sustainability targets.

IEA SHC Task 61 / EBC Annex 77 “Integrated Solutions for daylighting and electric lighting – From Component to system efficiency” therefore pursues the goal to support and foster the better integration of electric lighting and daylighting systems including lighting controls with a main focus on the non-residential sector. This includes the following activities:

- Review relation between user perspective (needs/acceptance) and energy in the emerging age of “smart and connected lighting” for a relevant repertory of buildings.
- Consolidate findings in use cases and “personas” reflecting the behaviour of typical users.
- Based on a review of specifications concerning lighting quality, non-visual effects as well as ease of design, installation and use, provision of recommendations for energy regulations and building performance certificates.
- Assess and increase robustness of integrated daylight and electric lighting approaches technically, ecologically and economically.
- Demonstrate and verify or reject concepts in lab studies and real use cases based on performance validation protocols.
- Develop integral photometric, user comfort and energy rating models (spectral, hourly) as pre-normative work linked to relevant bodies: CIE, CEN, ISO. Initialize standardization.
- Provide decision and design guidelines incorporating virtual reality sessions. Integrate approaches into wide spread lighting design software.
- Combine competencies: Bring companies from electric lighting and façade together in workshops and specific projects. Hereby support allocation of added value of integrated solutions in the market.

To achieve this goal, the work plan of IEA SHC Task 61 / EBC Annex 77 is organized according to the following four main subtasks, which are interconnected by a joint working group:

- Subtask A: User perspective and requirements
- Subtask B: Integration and optimization of daylight and electric lighting
- Subtask C: Design support for practitioners (Tools, Standards, Guidelines)
- Subtask D: Lab and field study performance tracking
- Joint Working Group: Evaluation tool & VR Decision Guide

Subtask B focuses on the evolution of the technologies and identifies new opportunities offered by control systems for lighting and daylighting systems, with the objective to improve energy performance as well as improving operation by occupants and facility managers.

EXECUTIVE SUMMARY

Innovative and integrative lighting solutions are a rapidly developing trend among BMS manufacturers. They are being implemented in various systems from industry-leading firms, however they are met with a challenge of finding the best possible compromise between occupant expectations and optimization of building operation.

This report describes relation between new trends and systems, the challenges associated with them, and the value creation that follows these innovative solutions.

The general discussion is followed by examples of 3 innovative systems from leading European brands and experts. Presented solutions are showing different possible directions in the development of new integrated solutions – integration of electric lighting and daylight-blocking blinds, integration of electric-lighting and blinds with the best possible solar gains and glare prevention at the workplaces, and innovative approach to implementing a glare prevention and human-centric lighting in the building's lighting system. Each of the three shown innovative systems is analysed with its' advantages and challenges.

Contents

1 Introduction

Innovative solutions are met with the challenge of finding the best possible compromise between occupant expectations and optimization of building operation (low cost, low energy use, etc.)

The survey and the assessment of lighting control technologies presented in report B.1 identified key criteria of successful solutions:

a. Reliability (low maintenance)
b. Efficiency (for energy purpose)
c. Friendliness (user acceptance, simple interface)
d. Flexibility (allowing to adjust to evolution on needs)
e. Easy commissioning and re-commissioning
f. Future proof (system which could adapt to evolutions of technology over time)
g. Interoperability (linked to other control systems and services, simplifies management, data, etc.)

A clear distinction was made between the residential sector and the industrial and commercial buildings.

In homes, occupants control rather freely their light according to the various needs. Automatic controls concern mostly roller shades used for *heat protection and security*. Lighting controls have limited interest in living areas. However, they are currently used in common areas such as corridors and car parks in multistory apartment buildings.

On the other hand, in non-residential buildings, the key issues deal with energy performance, operation constraints, occupancy, and indoor light quality.

2 New value proposition associated to lighting control systems.

Controls with occupancy and daylight sensors can lead to around 30-60% savings in lighting's power consumption depending of the type of spaces. However, when energy efficient lighting is deployed (luminous efficacy of luminaires higher than 100 lm/W), the associated annual financial gains are not that significant. This reduces the motivation for investing in control systems solely for reduction of the energy bill.

Electric Lighting Power density (W/m^2)	Occupation of building Hours per year	Savings related to lighting controls (for instance)	Hours per year of effective lighting	Cost of Lighting electricity per year @0,15 €/KWh
4	3000	50 %	1500	0,9 €/m^2.yr
8	3000	50%	1500	1,8 €/m^2.yr

Table: Savings associated to lighting controls in annual lighting electricity costs in non-residential buildings.

The table above shows that with modern lighting installations, savings due to lighting controls are high in proportion, but rather low in costs (around 1-1,5 €/m^2.yr). Note: the values above do not take into account possible gains in cooling loads, which are related to the reduction of the heat generated by the lighting installation.

This aspect shows that success of lighting controls is less related to energy performance (item b) from chapter 1 above) than all other criteria (a) to g)). Lighting controls can generate problems, but most of all can contribute to the value proposition of lighting, in relations to the list above.

In terms of value proposition associated to lighting controls, lighting controls can be seen as a technology which is a "Pain Reliever" (or problem solver), as well as a source of "Value Creation" (offering new business opportunities)

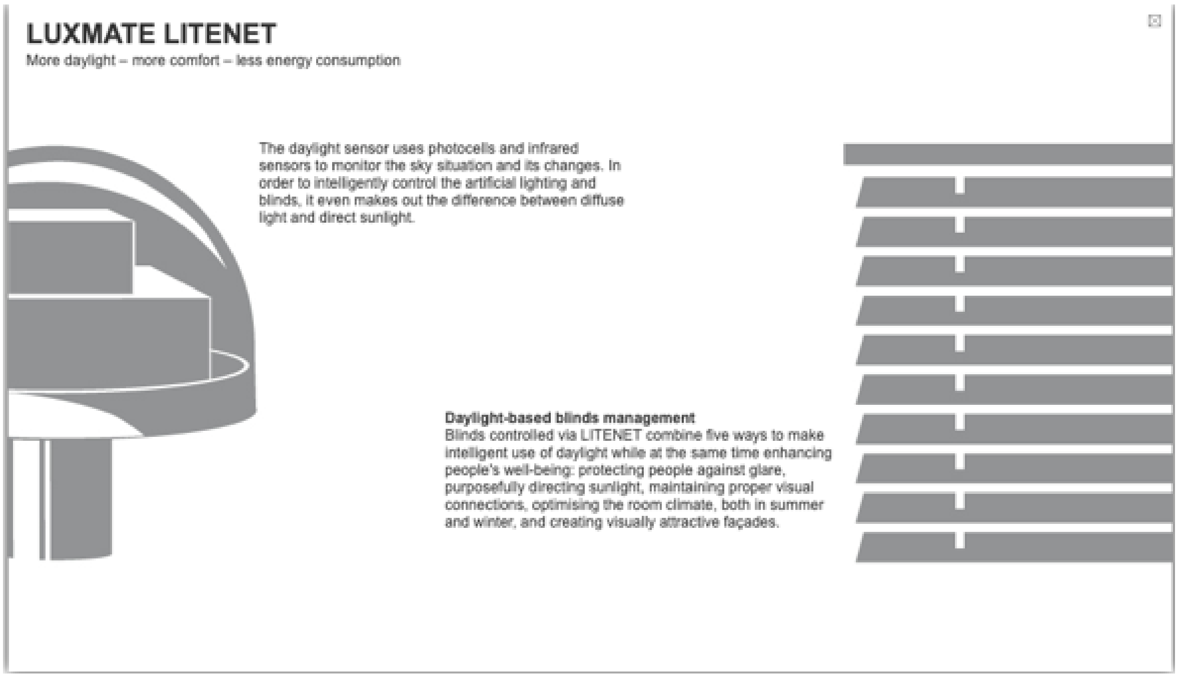
Lighting control as a source of "Value Creation" (offering new business opportunities)
Control of specific lamps (wall washers, task, et.)
New sensors and sensor location - Open loop / closed loop
User-friendly, simple and attractive interface
Full flexible module for control, beyond lighting (communication, displays, etc.)
Glocalization 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.)
Making a house warmer during cold sunny days (intelligent shading controls)
Making 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-proofing: update of systems
Possibility to re-program the controls

Table: Analysis of lighting controls in relation with possible Value Proposition.

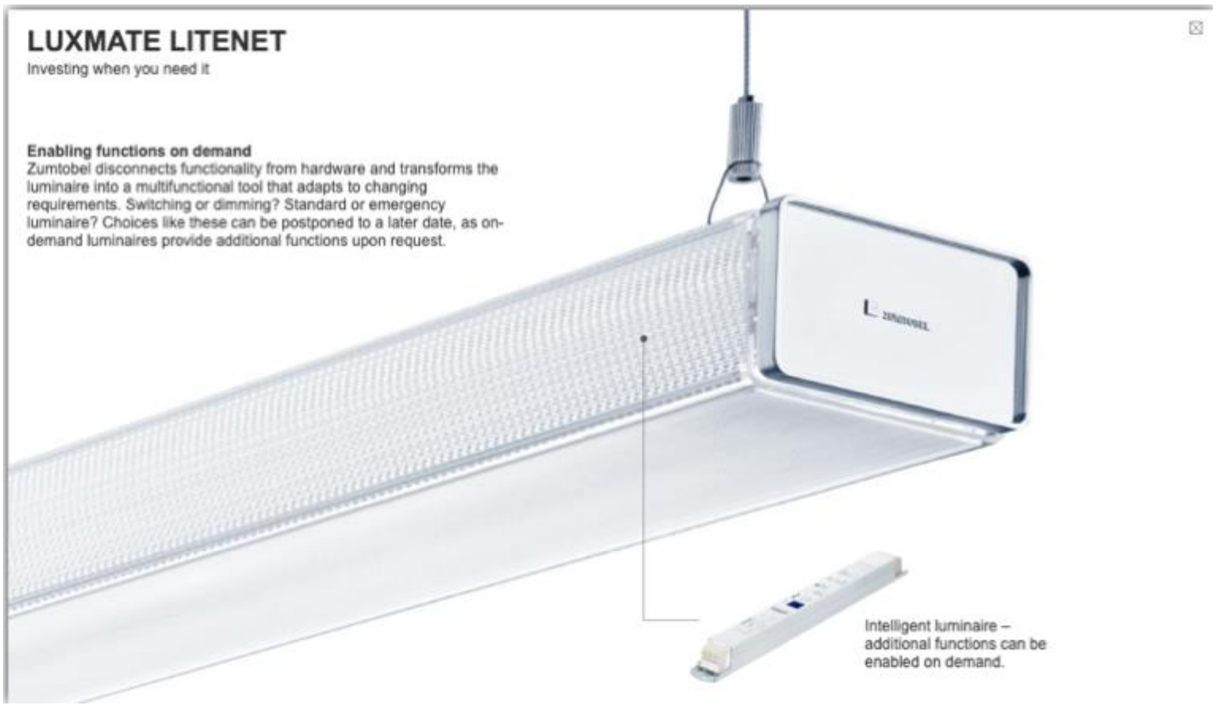
This business oriented approach explains a number of directions of innovative lighting controls systems. We present three of them below.

3 Example 1: LUXMATE by Zumtobel

The company Zumtobel has developed a system called: LUXMATE LITENET / PROFESSIONAL . It is a high-end room management system with lighting and blinds control, for an entire building. The product is characterized by the specific features described below:

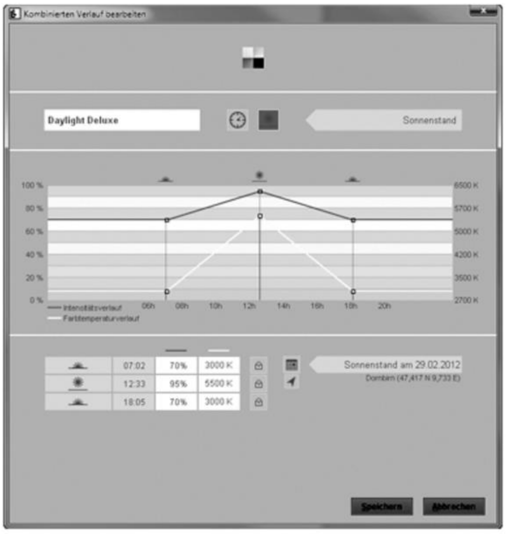


The outdoor sophisticated sensor tracks the power and the directionality of available daylight, and 5 options of blind positions are proposed to make the facades more homogeneous.



The same system is used to operate electric lighting upon a wide variety of options.

LUXMATE LITENET
with TUNABLE WHITE



The LUXMATE LITENET Lighting Management System controls small building units as reliably as large-scale building complexes. Maximum energy efficiency can be achieved by intelligent integration of daylight sensors, presence detectors and time sensors. With the latest generation of the lighting management system, control of Tunable White luminaires has been smoothly integrated into the system.

What's special about it is that the luminaires' intensity and colour temperature can be set entirely independently and intuitively, on the basis of graphically displayed timelines. The lighting control system is supplied with the basic features of a beneficial lighting concept, including predefined sequences over the course of the day for offices, production facilities, healthcare facilities and retirement homes, based on the latest scientific findings. As these scenarios can be individually adjusted, and existing LITENET installations can be updated, energy-efficient lighting solutions with dynamic colour temperatures and luminous intensity levels can be implemented easily.

The LUXMATE system offers complete control over intensity and color temperature of all the compatible fixtures in the system. Moreover, there are predefined scenarios for different types of room use.

This example shows the feasibility of the system, but also the high sophistication needed to meet the performance criteria (human comfort, and energy performance). Is it worth developing a standard for describing such family of solutions? We can identify some issues: control protocol, performance and interfaces.

Attributes of the LUXMATE system:

Component / strategy	Description
Daylight sensor	Outdoor, located on roof, provide data to all facades Reading of illuminances (lx)
Motor of shading system	any
Indoor sensor type	Illuminance sensor in ceiling, looking downward, presence detectors for workstations
Number of indoor sensors	Dependent on the size of the project and number of rooms and their size – the system can operate in small offices with up to 500 luminaries (output addresses), all the way up to large multi-story office buildings with up to 10000 output addresses.

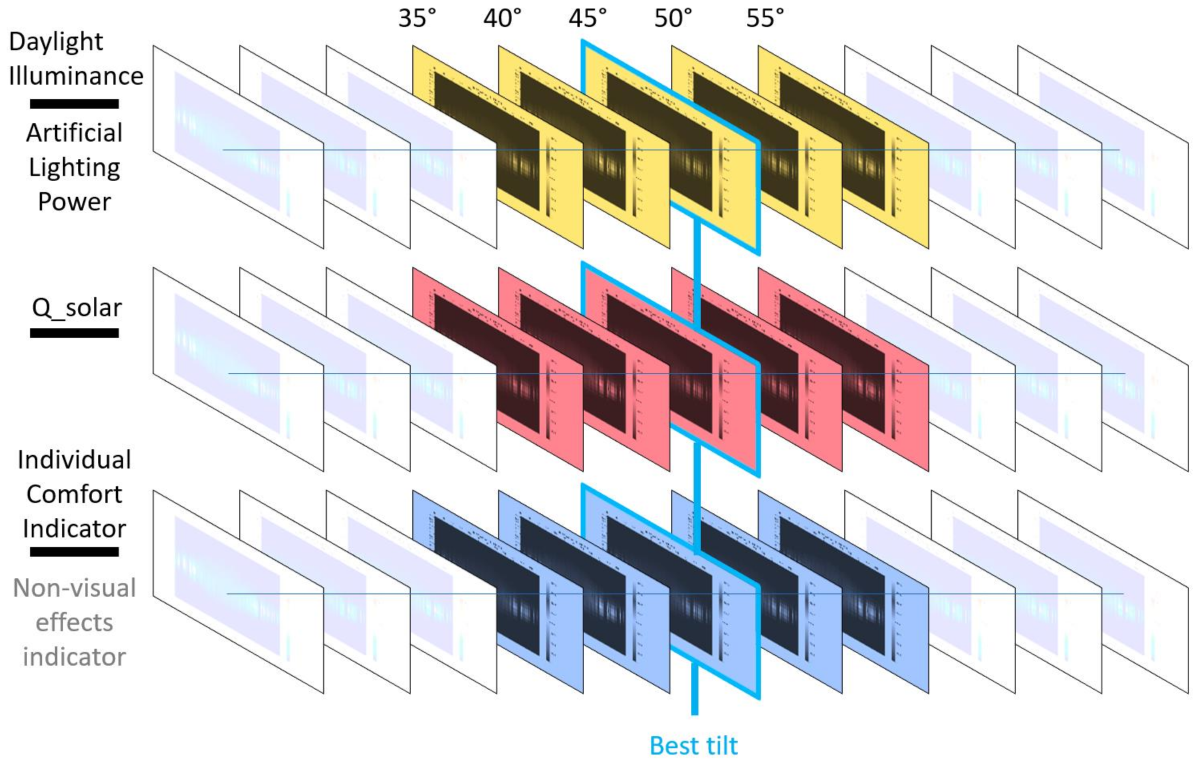
4 Example 2 HELLA BIM2INDILIGHT

In a research cooperation between solar shading and solar automation company HELLA, the University of Innsbruck, Unit of Energy Efficient Buildings, Bartenbach and ATP, a novel approach for a simulation-based open loop control named "IndiLight" was investigated. The model predictive control requires a model of the building structure (utilizing BIM datasets), a detailed façade specification for each state (BSDFs and angular dependent SHGCs), room interiors including illuminance reference points and view directions for each user, and the detection of the outdoor environment in terms of modelling (terrain and shadowing) and sensing (incident radiation).

The IndiLight control calculates the required artificial light to complement the existing daylight illuminance to the required illuminance levels for all possible states of the daylighting device (I.e. in case of a venetian blind tilt angle and percentage of extension) based on a pre-calculated database. A time-efficient calculation algorithm weighs the indicators daylight, artificial lighting energy, solar gains, comfort and non-visual effects according to predefined target functions in order to optimize the façade configuration for the actual weather- and indoor situation. The result per tilt angle is a pointwise illuminance level and the setpoint for the luminaires for an individual timestep.

An equivalent approach leads to tilt-wise solar gains per window, the tilt-wise glare indicator and non-visual indicator per predefined viewpoint.

Daylight Illuminance	Artificial Lighting $\text{Power}_{\text{luminaire}}(\text{tilt})$	Solar $\text{Gains}_{\text{room}}(\text{tilt})$	$\text{DGP}_{\text{viewpoint}}(\text{tilt})$*	Non-Visual $\text{Stimulus}_{\text{viewpoint}}(\text{tilt})$
[lx]	[W]	[W]	[-]	[-]
at reference points	for each luminaire	per window	from viewpoints	from viewpoints
per tilt angle	per tilt angle	per tilt angle	per tilt angle	per tilt angle



The system analyses existing conditions and pre-calculated scenarios, and chooses the best tilt setting considering all the relevant factors.

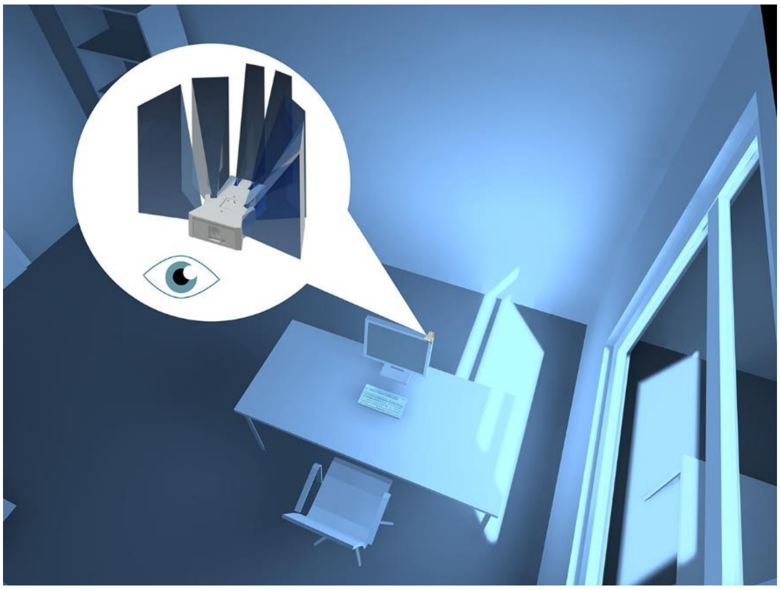
Component / strategy	Description
Daylight sensor	Irradiance outdoor located on roof, provide data to all facades Reading of illuminances (lx)
Motor of shading system	any
Indoor sensor type	Presence detection
Number of indoor sensor	0
Time step	15’
Modelling	High detailing required in modelling

5 Example 3 HCL-CON (Human Centric Lighting – Control)

Conventional lighting control systems currently do not detect and control the relevant parameters, but only horizontal illuminance levels, e.g. on the floor or table surface. However, the human eye (when standing or sitting) detects mainly in the horizontal range, so the vertical field of vision is decisive for user comfort. Determining factors are the luminance ratios, i.e. contrasts in the environment, on the screen and glare from the façade. A study (C. Moosmann, 2015) shows that glare control systems are mainly used to regulate daylight and hardly at all to regulate the indoor temperature, which has disastrous consequences in terms of energy. Human Centric Lighting Control "HCL-Con" addresses this issue with a new approach.

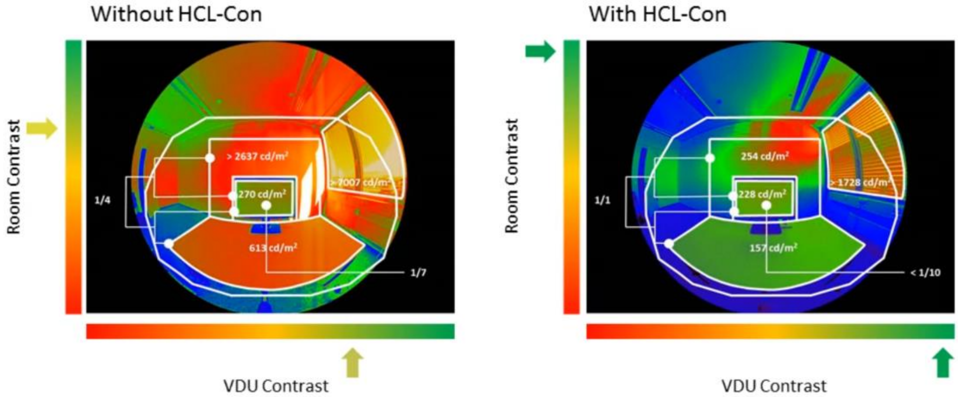
Conventional lighting controls detect and regulate horizontal illuminance levels (left), but the user comfort is predominantly in the vertical field of vision(right). © Fraunhofer IBP

The use of HCL-Con is intended to create ideal lighting conditions at the modern VDU workplace. In terms of functional, economic and visual aspects, added value is generated compared to solutions available on the market.



Concept of the HCL-Con sensor for the detection of vertical illuminance levels. © Fraunhofer IBP

The lighting environment at the VDU workstation changes in the course of the working day: daylight enters the room; the shading is lowered; artificial light is activated; the VDU switches off because no more input is made, etc. For the user, all these individual activities give a resulting lighting impression and an overall experience associated with it. Behind this, however, are control systems with several sensor locations and different limit values. In the current office situation, various deficits are to be solved by HCL-Con. These include, for example, the lack of acceptance of façade and screen control, the non-existent control of setpoints or the limit values that are not oriented towards user perception.



Lighting scenes with the same basic parameters were compared in pairs of images, each with conventional (inadequate) lighting control and with optimised HCL-Con lighting control. © Fraunhofer IBP

The concept has been validated by a proband study. Tests with self-developed prototypes in the Fraunhofer IBP laboratories show a significant increase in user comfort with higher energy efficiency. A patent for the process has been filed and talks are being held with interested parties from industry. The focus at Fraunhofer IBP is on the specification of the input variables and the development of the software, i.e., the algorithms for the ideal control of the various parameters. The concept can be implemented as an independent component, but also as an integral solution, i.e.., in screens or table lamps.

Component / strategy	Description
Daylight sensor	Indoor, located on Screen, horizontal, provide data from 7 direction, all Reading of illuminances (lx)
Motor of shading system	KNX, BAK
Indoor sensor type	Located on Screen, horizontal, provide data from 7 direction, all Reading of illuminances (lx), vertical sensor measuring cct.
Number of indoor sensors	1 device with 6 horizontal and one vertical sensors, Number of devices is variable, depending on the number of Screens.

6 Issues about attributes

The presentation of the three innovative lighting – daylighting solutions shows directions and challenges that these systems are tackled with:

Topic	Challenges
Outside Sensor (open loop)	Reliability, design, PV powered, shading,
Indoor sensor (closed loop)	Location, number
Electric motor	Reliability, noise, steps, AC-DC, SMI
Time step for actions (lighting / daylighting)	Performance vs user satisfaction
Predictive mode	Anticipation of weather changes
PV powered shading system	Autonomy level
Tolerance issues	Acceptability by occupants
Slat angle	Precision // tolerance of sun shading
Commissioning	Tuning of system