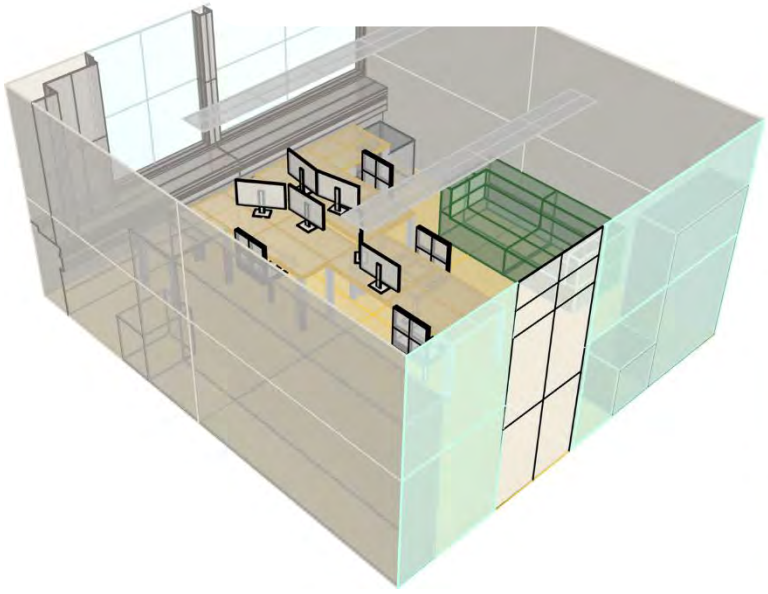
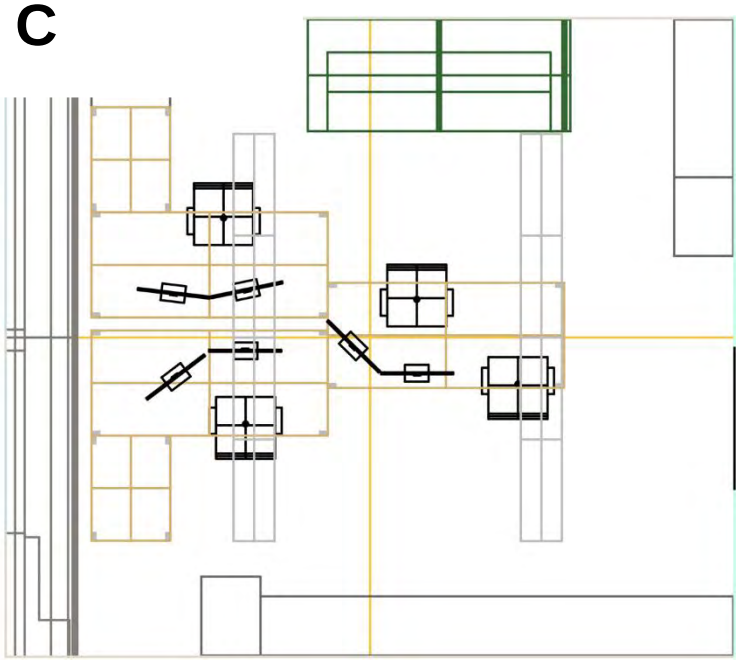
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Reference rooms for simulating low carbon, high comfort integrated lighting solutions

T70.C.4.2 – A Technical Report of Subtask C





IEA SHC TASK 70 | EBC Annex 90: LOW CARBON, HIGH COMFORT INTEGRATED LIGHTING

Technology Collaboration Programme
by iea

Solar Heating & 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.

Our focus areas, with the associated Tasks in parenthesis, include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54, 69)
- 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, 68)
- 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)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42, 58, 67)

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SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Reference rooms for simulating low carbon, high comfort integrated lighting solutions

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KEYWORDS

Reference model; Spectral lighting simulation; Non-visual effects of light; Integrative lighting; Office; Factory hall; Daylighting; Electric lighting.

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PREFACE

Lighting accounts for 15% of the global electrical energy consumption and 5% of global CO_2 emissions. Thus, widening the rating perspective of lighting solutions to a more holistic view of its impact on CO_2 emissions, encompassing the whole life cycle chain also in the context of regional energy markets aspects, interaction with other building trades, etc. is urgently deemed necessary. This goes far beyond the pure LED lamp-driven energy efficiency gains.

The aim of IEA SHC Task 70 / EBC Annex 90 “Low Carbon, high comfort integrated lighting” is to identify and support implementing the potentials of lighting (electric, façade: daylighting and passive solar) in the decarbonization on a global perspective while aligning the new integrative understanding of humans’ light needs with digitized lighting on a building and a building related urban scale. This includes the following activities:

- Actively support broadening the view on lighting solutions as a whole in the context of decarbonization. Help bridge the gap between a component view (manufacturer’s focus) and design-oriented system approaches. Support the transition from a rather pure energy focused view so far to a life cycle assessment (LCA) perspective. On this basis, identify key impact factors, and develop the most effective strategies and roadmaps while including regional specifics.
- Contextualize this with the fast-developing digitization of buildings/lighting installations on the technology, design and operational side. Add to selected open points in the digital chain like better design processes.
- Align this with the still growing understanding of user needs; here specially build upon results from earlier IEA projects (e.g., IEA SHC Task 61 / EBC Annex 77).
- Integrate competencies: Bring the different involved players (electric lighting, façade, industry, controls) so far not connected on low carbon solutions together in workshops and specific projects. Create added value also by transferring into standardization, regulations and building certificates.
- Foster the broad implementation of low carbon solutions, also and especially in developing countries, by promoting tailored “Low Tech – High Impact Solutions” through demonstration, design guidelines, and workshops.

To accomplish these objectives, the work plan of IEA SHC Task 70 / EBC Annex 90 is organized according to the following four main subtasks.

Subtask A: Low Carbon Lighting and Passive Solar: Scenarios, Strategies, Roadmaps.

Subtask B: Visual and non-visual User Requirements.

Subtask C: Digitalized Lighting Solutions (Technology & Design Tools / Process).

Subtask D: Application and Case Studies.

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1 Executive Summary

Lighting simulation software is increasingly expected to support integrated assessments of daylight, electric lighting, lighting controls, visual comfort, energy performance, and non-image-forming effects of light. Recent developments in spectral simulation now make it possible to account for the spectrally-resolved (per wavelength) distributions of light and to evaluate α-opic metrics related to human health, colour-related aspects, energy impacts, and inputs for life-cycle assessment workflows. However, there are few examples of simulation methods and datasets available to industry, leaving a gap for broader, reproducible evaluations of integrative lighting design solutions.

This report addresses that gap by presenting full-spectral reference simulation models for two example application areas of non-residential lighting design: an office room and a factory hall. Developed collaboratively by internationally recognized experts, the reference models are intended to support global harmonization of methods with the goal of increasing model transparency, reducing model inconsistencies, ensuring physical accuracy, and providing authoritative benchmark frameworks for simulation methods. Reference models save practitioners time and effort by providing systematic information on best practices, enabling knowledge transfer and supporting education through detailed examples of use. The field of modelling non-visual effects of lighting is relatively immature. Provision of reference models is expected to foster communication between experts and the development of common terminology and standardized procedures in this burgeoning field.

The models provide the necessary input data for full-spectrum lighting and daylight simulations and are intended to support the development, implementation, comparison, and validation of spectral simulation workflows. The associated dataset is publicly available on Zenodo (https://doi.org/10.5281/zenodo.18836176) and includes complete 3D geometry, spectral material properties, luminaire data, bidirectional scattering distribution functions (BSDFs), and links to weather files. The dataset also includes example implementations for Radiance and OWL to improve reproducibility and facilitate adoption by software developers, researchers, and practitioners.

The report is organized into detailed descriptions of the two reference spaces – first the office, then the factory hall – and finally presents a template for reporting the results.

The reference office is based on the UIBK Living Lab Room 518, an actual three-person office located at the University of Innsbruck in Austria. It is modelled as a west-facing, side-lit room with two windows, detailed geometry, measured or database-derived spectral material data, reconstructed glazing and venetian blind systems, and daylight-dependent electric lighting control. The shading system is automatically controlled according to façade irradiance, while the luminaires are dimmed based on occupancy and brightness sensing to maintain an average illuminance of 500 lx at the workplaces with a maintenance factor of 0.8.

The reference factory hall is defined according to CEN/TR 15193-2 and represents a new manufacturing building (“factory hall”) located in Stuttgart, Germany. It includes a 28 m × 26 m × 5 m hall geometry, north-oriented rooflights, no external shading, spectrally defined opaque and transparent materials, a diffusing rooflight system, and daylight-dependent control of high-bay LED luminaires. The hall lighting is designed for a maintained illuminance of 500 lx during weekday working hours, with all luminaires controlled simultaneously.

To support consistent reporting and comparison between tools, the report further provides a template for documenting simulation settings, user assumptions, deviations from the template, runtime, hardware, and results. The proposed outputs include daylight factors, annual daylight metrics, glare indicators, circadian lighting metrics, electric lighting energy use, HVAC-related energy values, and graphical or tabular spatial results. Overall, the reference rooms establish a transparent and reproducible basis for evaluating lighting simulation software in the context of low-carbon, high-comfort integrated lighting design.

2 Introduction

Lighting uses about 15% of the world's electricity and causes roughly 5% of global CO_2 emissions. Good building design that makes effective use of daylight can cut the need for electric lighting by more than half [1]. Research in the early 2000s also showed that light affects more than just what we see: special cells in the eye (intrinsically photosensitive retinal ganglion cells, ipRGCs) link light to processes that influence health and well-being [2]. Because of this, architects and lighting designers increasingly need to consider these "non-visual" (or non-image-forming, NIF) effects alongside visual comfort.

To support this, several lighting simulation tools have recently been improved or newly developed to perform spectral simulations. These calculations account for the wavelength distribution of light, so that NIF effects can be assessed accurately [3]. Pierson et al. [4] compared different approaches and showed that they vary in complexity, accuracy, and computation time. Beyond NIF effects, the full-spectrum capability also makes it possible to simulate sunlight across a wider wavelength range, also including UV and infrared radiation. As a result, modern lighting simulation software can now be used for more than traditional lighting tasks, including analyses of colour appearance [5], energy-related impacts, and α-opic metrics (α-opic metrics describe how strongly optical radiation stimulates all five types of photoreceptors in the eye: rods, three types of cones, and ipRGCs) [6, 7]. The energy performance results produced by these simulations can also be used as input for life-cycle assessments (LCA) of lighting systems.

A wide range of lighting simulation programs are available today, from commercial to free and open-source options. To help architects and planners choose appropriate tools for specific applications, experts within the IEA SHC Task 70 / EBC Annex 90 developed a framework for comparing simulation software. The framework includes three elements:

(1) a table summarising each tool’s features across key areas (intended users, design phase, algorithms/engines, electric lighting, daylighting, control systems, visual and non-visual effects, and LCA support);
(2) a short description of each tool; and
(3) two reference simulation models that allow tools to be compared in terms of usability, capabilities, and output.

The technical report covering elements (1) and (2) has been published in parallel with this report and is available on the Task's website, i.e., Report T70.C.4.1 [8].

This report summarizes the results for element (3): it presents the two full-spectral reference simulation models in detail. Prior work introduced reference models for other specific purposes. For example, an office model for energy simulations was developed in IEA SHC Task 56 [9], and the “MIT Reference Office” was designed for evaluating façade and electric lighting strategies [10]. However, these models are limited to office scenarios and each mainly targets a single type of assessment based on photometric, visual metrics. They do not cover the broader requirements of integrative lighting design including NIF effects. To address this gap, we developed two spectral reference models representing the two main application areas – offices and factories – and provide the necessary input data for full-spectrum simulations, along with a template for reporting results.

The reference models are publicly available on Zenodo [11] and are described in detail in a journal article in “Data in Brief” [12]. The dataset provides complete 3D geometry, spectral material properties, luminaire data, BSDFs, and links to weather files. To facilitate use of the models, example workflow implementations in two software systems – Radiance and OWL – are provided[1]. This enables reproducible hyperspectral lighting simulations and facilitates the development and validation of spectral simulation workflows. Example simulation results for three software systems – Radiance, DALEC, and GBSWARE – were presented in [13].

[1] Cf. subfolders on Zenodo [11]: See “office/_office_step00_all.sh” or “hall/_hall_step00_all.sh” in “./Implementation_Radiance/”, and “DiB_OWL_Office.gh” or “DiB_OWL_Hall.gh” in “./Implementation_OWL”.

3 Reference Office Space: UIBK Living Lab

Within the *OptiFas* project at the University of Innsbruck (UIBK), an innovative concept for workplace-specific daylight and electric lighting control was implemented in a real office setting. This work served as a foundation and has been further developed in recent years by researchers from the Unit of Energy Efficient Building in various research projects. For the experimental setup of the integrated daylight and electric lighting environment, a three-person office within the premises of the Department of Structural Engineering and Material Sciences on the fifth floor of the Faculty of Engineering Sciences was selected and transformed into a living lab (see Figure 1).



Figure 1: Office building of the Faculty of Engineering Sciences of the University of Innsbruck, Austria, with location of Room 518 marked with red circle (left; source original image: Universität Innsbruck/Birgit Pichler) and interior of the UIBK "Living Lab 518" three-person office (right).

In the implementation, in parallel to the real-life testing and evaluation of control concepts, the aim was also to create the most cost-effective solution possible using as much existing hardware as possible in order to demonstrate effective retrofitting in existing buildings.

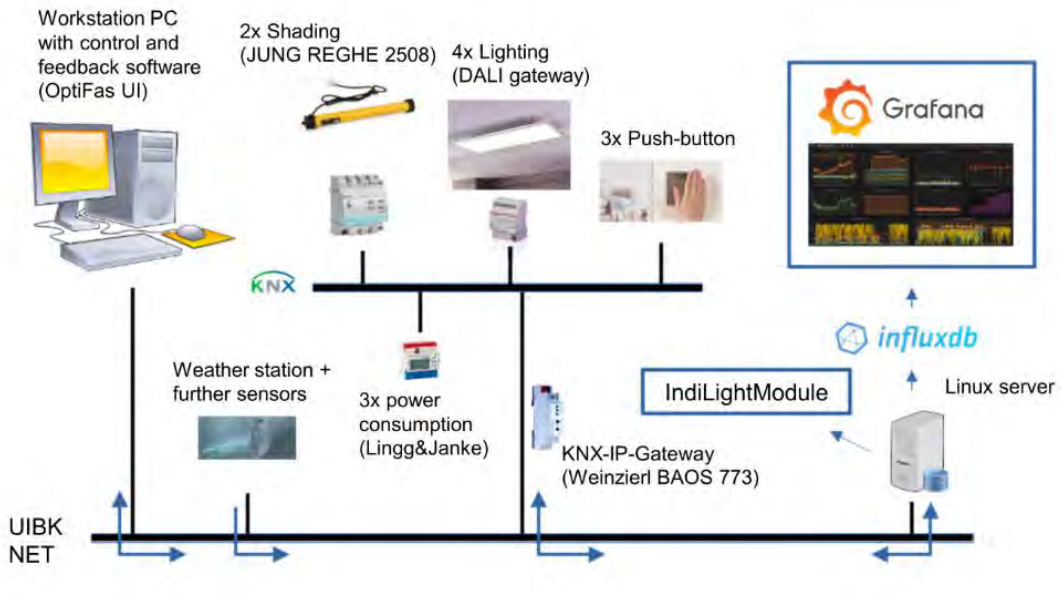


Figure 2: Control scheme implemented in the UIBK Living Lab 518.



Figure 3: Outdoor and indoor sensors and measurement equipment for control and long-term monitoring.

3.1 Location

- Location: Innsbruck, Austria, 47.2640926° N, 11.3428399° E (https://maps.app.goo.gl/tTSLDgKHeKrPP16Y7).
- Climate: *AUT_Innsbruck.111200_IWEC.epw*, distance of weather station “Innsbruck airport” from site of the campus where the office is located: 0.8 km.
- The EPW weather data file can be downloaded from https://energyplus.net/weather-location/europe_wmo_region_6/AUT/AUT_Innsbruck.111200_IWEC.

3.2 Room description

3.2.1 Geometry

- 3D model: *t70_reference_office_lab518.3dm*
- 5.55 m x 4.86 m x 2.69 m side-lit office with two windows (2.34 m x 1.66 m and 1.39 m x 1.66 m)
- Facade orientation: West (270.8°)
- Shading lines: far and near shading[2] specified as elevation angle per azimuth angle: *lab518_shading_lines.txt*

The data files (3D model and shading lines) are provided in the subfolder *T70_Office/geometry/* in *the dataset on* Zenodo [11].

The geometry was modelled using Rhinoceros 3D according to 2D plans as well as measurements in the real building. To increase generality as a representative model for an office room, the concrete column in the southwest corner of the room, which can be seen in photos of the interior (see Figure 1 and Figure 3), was removed in the model.

[2] Available on: https://www.tirol.gv.at/statistik-budget/tiris/tiris-anwendungen/solarpotenziale-tirol/, shading lines retrieved on 17 September 2024.

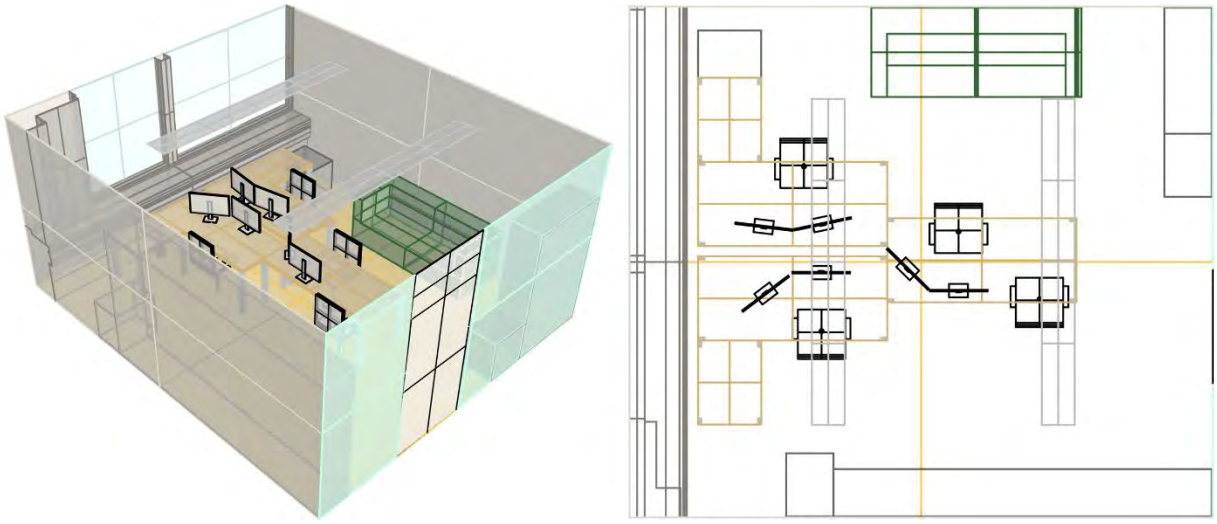


Figure 4: View and plan of the 3D model of the UIBK Living Lab 518.

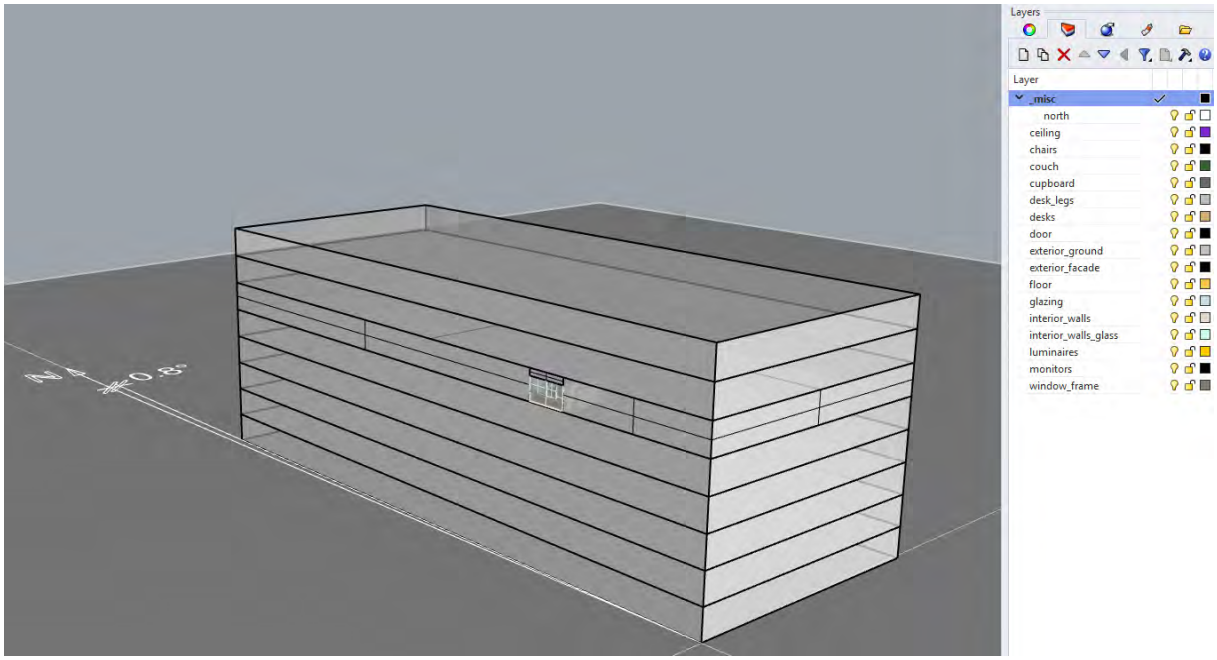


Figure 5: 3D model of the university building showing location of the UIBK Living Lab 518 on the west facade.

3.2.2 Photometric characteristics

3.2.2.1 Materials

Interior opaque materials were measured with a handheld spectrometer (model: Gretag MacBeth Spectrolino) in the Living Lab office. Suitable spectral data for the façade cladding (layer “exterior_facade”) and the exterior ground (layer “exterior_ground”) matching the visual appearance of the real surfaces were selected from the Spectral Materials Database[3].

The transparent materials were generated using LBNL’s Optics[4] software based on spectral data from the IGDB[5].

[3] https://spectraldb.com/

[4] https://windows.lbl.gov/optics-downloads

[5] https://windows.lbl.gov/igdb-downloads

The geometry in the 3D model is divided into individual layers based on the different materials. The layer names are given in Table 1 and Table 2.

The spectra are provided in CSV format in the subfolder *T70_Office/spectra/.*

Table 1: Photometric characteristics of transparent materials in UIBK Living Lab.

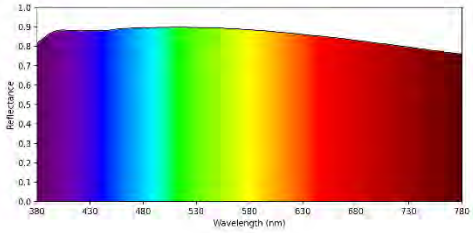
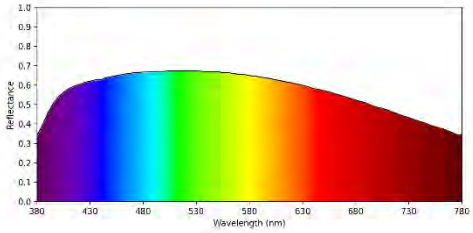
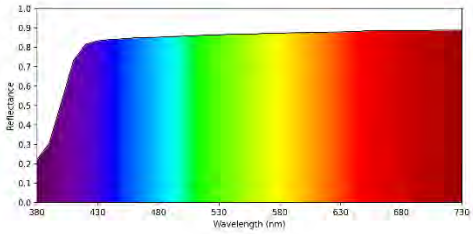
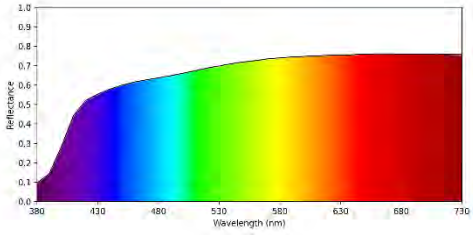
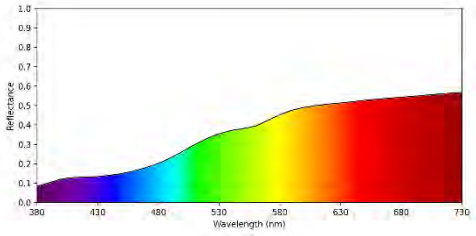
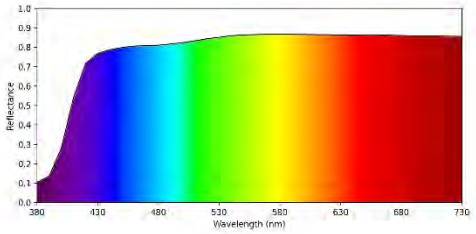
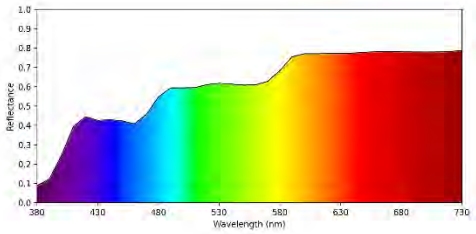
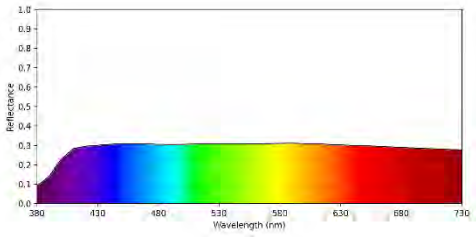
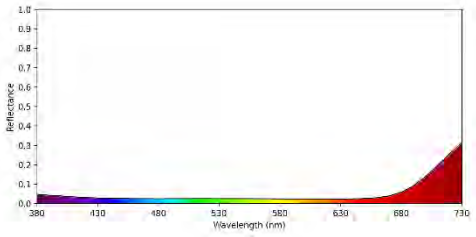
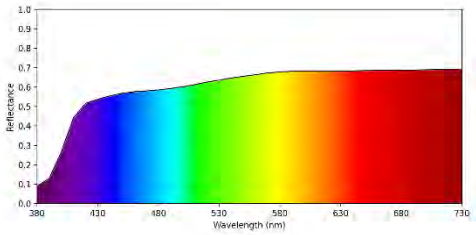
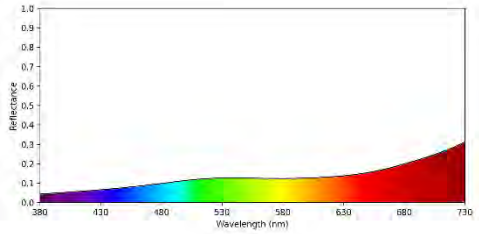
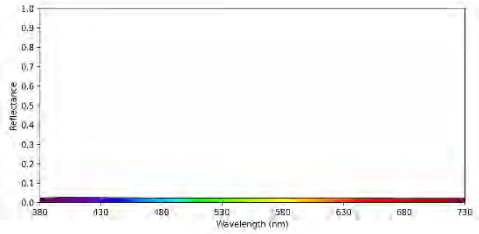
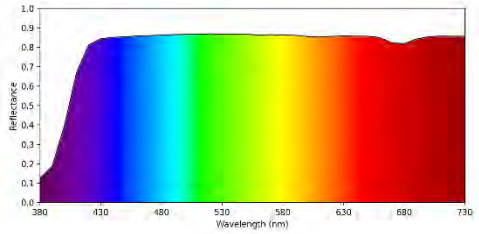
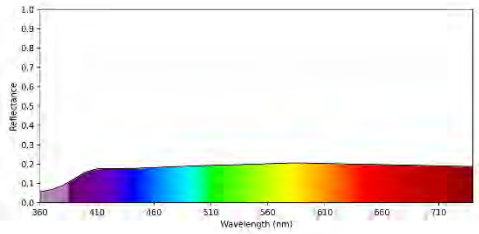
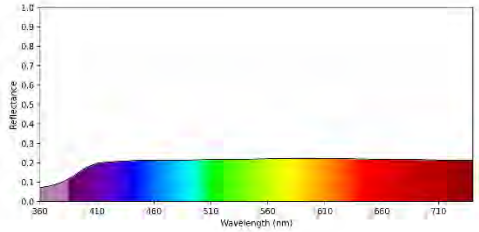
Geometry (layer name)	**Colour**	**Transmittance**			
		V(λ)	**V(λ),D65**	**M(λ)**	**Spectral data file**
Glass wall (interior_walls _glass)	Trans-parent	88.68%	88.77%	89.32%	InterPane_Float_6mm.usr / InterPane_Float_6mm_t_vis.csv 
Glazing (glazing)	Trans-parent	65.23%	65.42%	66.16%	BauIng_518_Window.usr / BauIng_518_Window_t_vis.csv 

Table 2: Photometric characteristics of opaque materials in UIBK Living Lab.

Geometry (layer name)	**Colour**	**Reflectance**			
		V(λ)	**V(λ),D65**	**M(λ)**	**Spectral data file**
Walls (interior_walls)	White	86.88%	86.82%	85.25%	T70_office_walls.csv 
Ceiling (ceiling)	White	71.84%	71.60%	64.62%	T70_office_ceiling.csv 

Floor (floor)	Yellow	40.08%	39.42%	24.32%	T70_office_floor.csv 
Door (door)	White	85.66%	85.57%	81.73%	T70_office_door.csv 
Desks (desks)	Wood	65.58%	64.98%	53.85%	T70_office_desk.csv 
Desk legs (desk_legs)	Aluminium	30.78%	30.78%	30.62%	T70_office_desk_legs.csv 
Chairs (chairs)	Black	2.60%	2.60%	2.67%	T70_office_chairs.csv 
Cupboard (cupboard)	Light grey	65.55%	65.33%	59.60%	T70_office_cupboard.csv 

Couch (couch)	Olive green	12.58%	12.52%	10.38%	T70_office_couch.csv 
Monitors (monitors)	Black	2.35%	2.35%	2.47%	T70_office_monitors.csv 
Window frame and sill (window_frame)	White, specular finish	86.31%	86.34%	86.00%	T70_office_frame.csv 
Facade cladding (exterior_facade)	Grey (Grey Aluminium Facade Cladding)	20.01%	19.98%	18.94%	00027_spectral.csv / 00027_spectral_sci.csv  (Source: https://spectraldb.com/)
Exterior ground (exterior_ground)	Grey (Exterior Concrete Floor)	22.02%	22.00%	21.54%	00769_spectral.csv / 00769_spectral_sci.csv  (Source: https://spectraldb.com/)

3.2.2.2 Luminaires



Figure 6: Luminaire specification and product image (source: LUDWIG Leuchten).

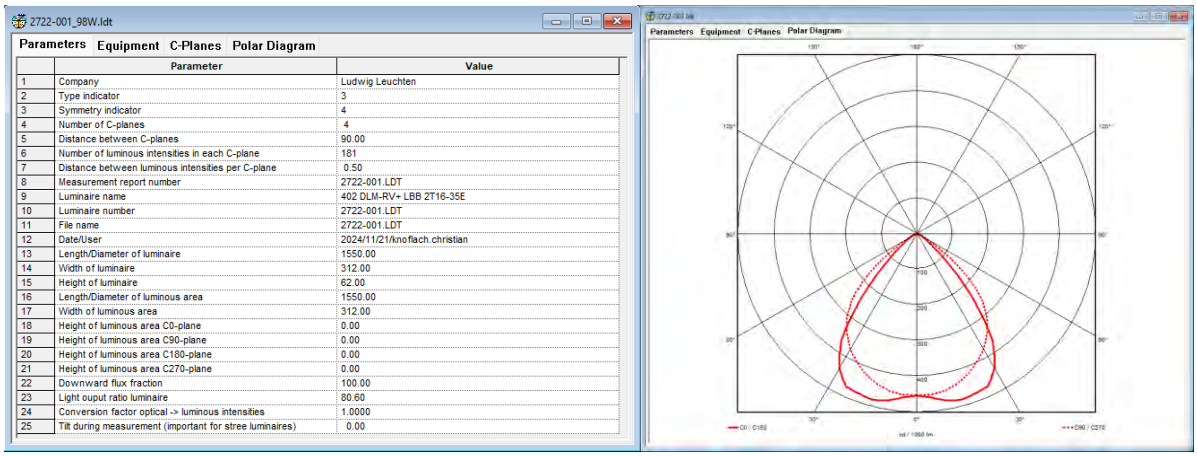
The luminous intensity distribution was modelled by Christian Knoflach (Bartenbach GmbH) in the two sections from the original data sheet and the full spatial distribution was determined by interpolation.

Contrary to the original specification, each of the four luminaires is currently equipped with two high output T5 lamps of type 840 with 49W each. The system thus has 98W with a total luminous flux of 8.620 lm.

- 98 W (2 x 49 W)
- 8.620 lm (2 x 4.310 lm)
- Luminaire efficiency: 80.6%
- Lower hemisphere: 100%
- 4000 K
- Ra 80
- LDT file: *2722-001_98W.ldt*
- Relative SPD: *Fluorescent_840.csv*

The luminous intensity distribution file for the luminaire equipped with 98W as installed in the office is provided in the subfolder *T70_Office/luminaire/.*

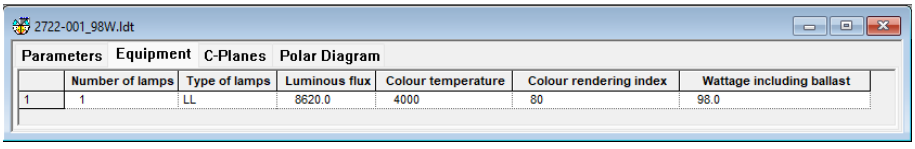
The relative SPD for a typical 840 fluorescent lamp is provided in CSV format in the folder *T70_Office/spectra/.*


2722-001_98W.ldt

Parameters | Equipment | C-Planes | Polar Diagram

	Parameter	Value
1	Company	Ludwig Leuchten
2	Type indicator	3
3	Symmetry indicator	4
4	Number of C-planes	4
5	Distance between C-planes	90.00
6	Number of luminous intensities in each C-plane	181
7	Distance between luminous intensities per C-plane	0.50
8	Measurement report number	2722-001.LDT
9	Luminaire name	402 DLM-RV+ LBB 2T16-35E
10	Luminaire number	2722-001.LDT
11	File name	2722-001.LDT
12	Date/User	2024/11/21/knoflach.christian
13	Length/Diameter of luminaire	1550.00
14	Width of luminaire	312.00
15	Height of luminaire	62.00
16	Length/Diameter of luminous area	1550.00
17	Width of luminous area	312.00
18	Height of luminous area C0-plane	0.00
19	Height of luminous area C90-plane	0.00
20	Height of luminous area C180-plane	0.00
21	Height of luminous area C270-plane	0.00
22	Downward flux fraction	100.00
23	Light ouput ratio luminaire	80.60
24	Conversion factor optical -> luminous intensities	1.0000
25	Tilt during measurement (important for stree luminaires)	0.00

Figure 7: Luminaire parameters (left) and polar diagram of LID (right) as provided with modelled EULUMDAT file.


2722-001_98W.ldt

Parameters | Equipment | C-Planes | Polar Diagram

	Number of lamps	Type of lamps	Luminous flux	Colour temperature	Colour rendering index	Wattage including ballast
1	1	LL	8620.0	4000	80	98.0

Figure 8: Luminaire equipment specified in modelled EULUMDAT file.

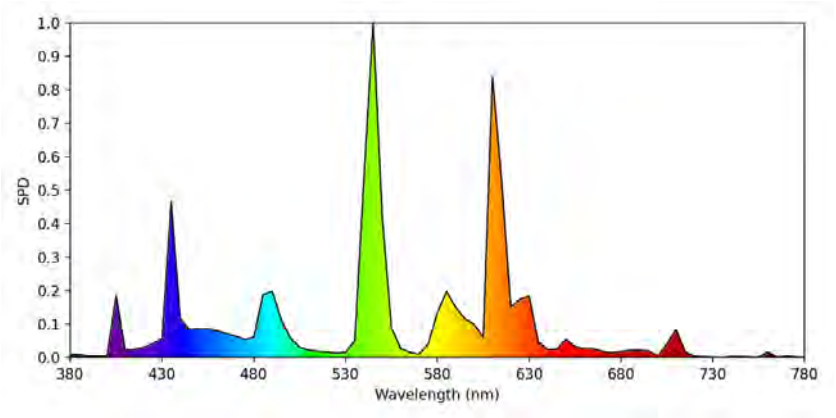


*Figure 9: Relative spectral power distribution of fluorescent lamps installed in the reference office space UIBK lab 518 (*Fluorescent_840.csv*).*

3.2.2.3 Window system (glazing and shading)

The transparent part of the west façade is equipped with two closed cavity windows, each of which consists of an internal triple pane thermal insulation glazing, a louvre system in the cavity and an external single-pane glass. The glazing system was reconstructed in LBNL's WINDOW[6] software and the performance data was determined.

```
BERKELEY LAB WINDOW v7.7.16.0 Glazing System Thermal and Optical Properties 01/16/25 14:00:32


ID       : 440
Name     : Bauing_ILM_Lamelle_+00
Tilt     : 90.0
Glazings: 5
KEFF     : 0.042 [W/m-K]
Width    : 103.000 [mm]
Uvalue   : 0.550 [W/m2-K]
SHGCc    : 0.416
SCc      : 0.478
Tvis     : 0.610
RHG      : 305.817 [W/m2]
```

Figure 10: Extract from the report from the WINDOW software.

The venetian blind system is built in WINDOW in the shading layer library. Figure 11 shows the specification of the base material as well as the definition of the geometry of the venetian blind system in the UIBK reference office space.

The full specification of the transparent façade is provided through the following output from the WINDOW software. With focus on lighting simulation, the modelling includes the glazing setup without frame, i.e., reports the centre of glass results, but omits thermal modelling of the overall closed cavity window. All data are provided for glazing layers only and for glazing layers plus venetian blind system in tilt angles from -85° to +85° in steps of 5° (placeholder ??? in the data filenames below: "XXX" for glazing only (no venetian blinds), "+00" for horizontal blinds, "+05" to "+85" for positive blind tilt angles, and "-05" to "-85" for negative blind tilt angles). The orientation of positive and negative tilt angles is shown in Figure 12. The data files are provided in the subfolder *T70_Office/window/.*

- **2D-SHGC:** This directory contains the CSV files with the angular data output from WINDOW for each Klems incident direction including main performance indicators like SHGC, transmission front/back and solar/visible, or absorption per layer.
  Data files: *Bauing_ILM_Lamelle_???_0_AngularData.csv*

- **BSDF:** This directory contains all XML files with the BSDFs for full Klems resolution generated for the glazing only (XXX) or for the respective tilt angle of the venetian blind system.
  Data files: *Bauing_ILM_Lamelle_???.xml*

- **CSV:** This directory contains all corresponding CSV files with the plain BSDF data for full Klems resolution as exported from WINDOW.
  Data files: *Bauing_ILM_Lamelle_???.csv*

[6] https://windows.lbl.gov/window-software-downloads

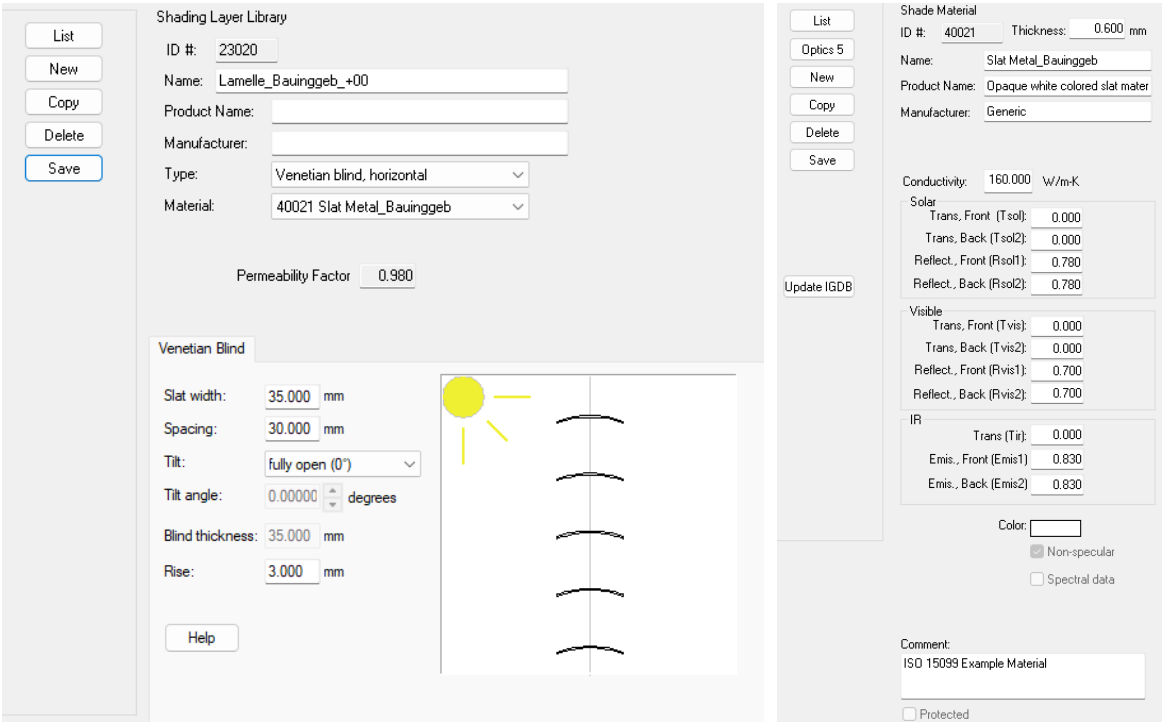


Figure 11: Specification of the venetian blind system in the UIBK reference office space (left) and its base material specification (right) in the WINDOW software.

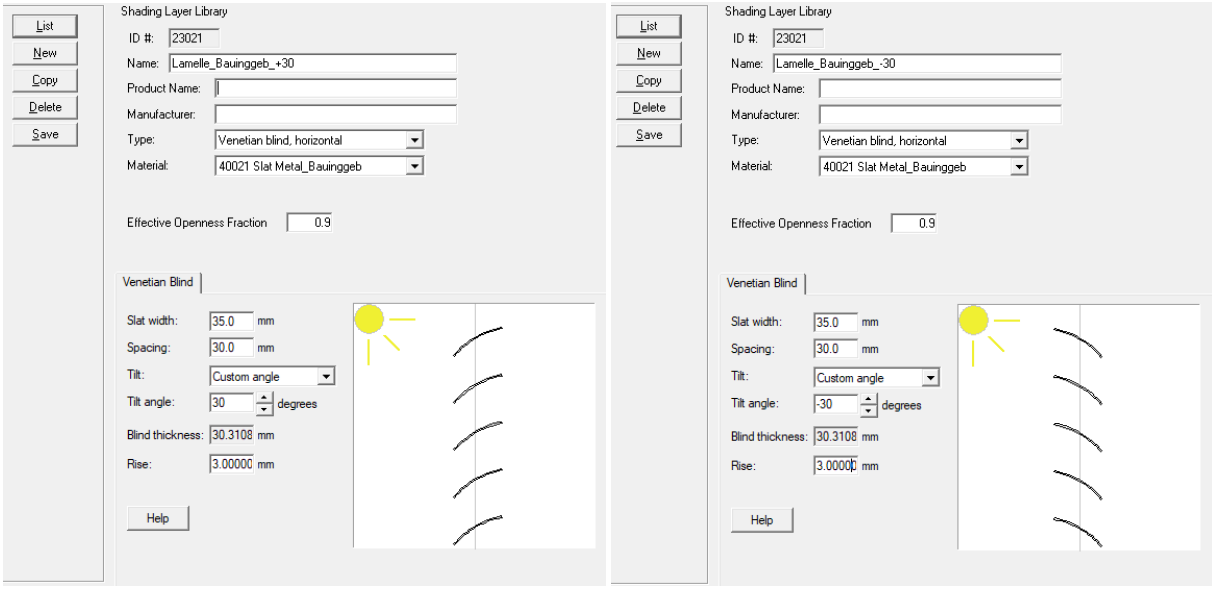


Figure 12: Example specification of the venetian blind system in the UIBK reference office space for non-horizontal settings. Tilt angle +30° (left) and tilt angle -30° (right).

3.2.3 Control

3.2.3.1 Shading system

The venetian blinds are controlled via the building management system to provide solar shading. When the global vertical irradiance at the façade is greater than 120 W/m^2, the blinds are fully lowered and put into an almost closed position (75° tilt angle).

The blinds in both windows are always controlled together and simultaneously.

3.2.3.2 Electric lighting

The luminaires follow a daylight dependent control based on one combined PIR occupancy and look-down brightness sensor located centred on the ceiling. When someone is present in the office, the light is dimmed to an average of 500 lux at the three workplaces. The maintenance factor is 0.8.

All four luminaires are always controlled simultaneously and at the same dimming levels.

3.2.3.3 Manual intervention

While manual intervention by the users is additionally possible at any time via a button next to the door for both the shading system (up/down and tilting) as well as the luminaires (on/off, dimming), we do not include it in the specification of the reference office setup.

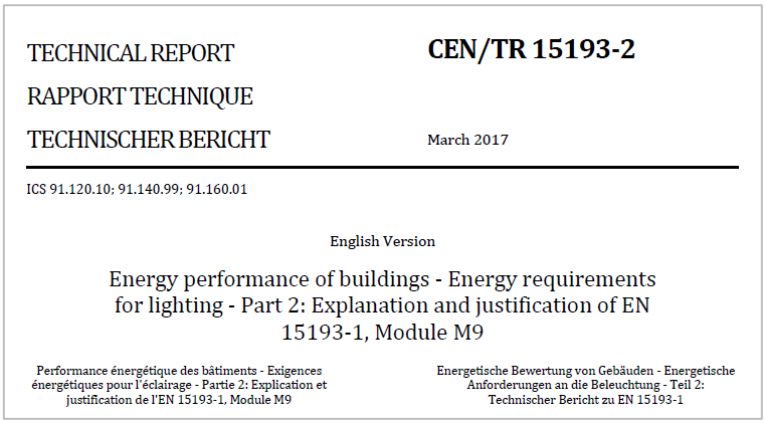
3.2.4 Additional background information for the reference office room

Table 3: Additional parameters for the reference office UIBK living lab 518.

Parameter			**Value**
Space	**Geometry** acc. to UIBK lab 518 (3D geometry file: t70_reference_office_lab518.3dm)	Width b_R [m]	4.86
		Depth a_R [m]	5.55
		Height h_R [m]	2.69
		Area [m²]	26.97
		Volume [m³]	72.56
	Thermal parameters	U-value, outside walls [W/(m²K)]	0.12
		Thickness, outside walls [m]	0.44
HVAC	**Heating**	Local district heating (Natural gas-based)	
		Passive house (suppl. radiator-based heating system)	
	Ventilation	Controlled ventilation unit with heat recovery	
	Cooling	Groundwater cooling (via ventilated air)	
	Building automation	Night ventilation	
Usage		As long as no other usage profile is available, the usage profile according to SIA 2024:2006 is proposed.	Single/group office 3.1

4 Reference Hall

The technical report CEN/TR 15193-2 [14] accompanies the lighting standard EN 15193-1:2017 and provides explanation and examples for implementing the standard. In Annex J the report provides calculation examples for various building types. We define a reference factory hall according to “Example 1 – New design manufacturing building” specified in Section J.1.1.



TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 15193-2

March 2017

ICS 91.120.10; 91.140.99; 91.160.01

English Version

Energy performance of buildings - Energy requirements for lighting - Part 2: Explanation and justification of EN 15193-1, Module M9

Performance énergétique des bâtiments - Exigences énergétiques pour l'éclairage - Partie 2: Explication et justification de l'EN 15193-1, Module M9

Energetische Bewertung von Gebäuden - Energetische Anforderungen an die Beleuchtung - Teil 2: Technischer Bericht zu EN 15193-1

Figure 13: Reference factory hall definition background: Technical Report CEN/TR 15193-2.

4.1 Building description

Location: Stuttgart, Germany

Climate: DEU_Stuttgart.107380_IWEC.epw[7].

The EPW weather data file can be downloaded from https://energyplus.net/weather-location/europe_wmo_region_6/DEU/DEU_Stuttgart.107380_IWEC and is placed in the subfolder *T70_Hall/weatherdata/.*

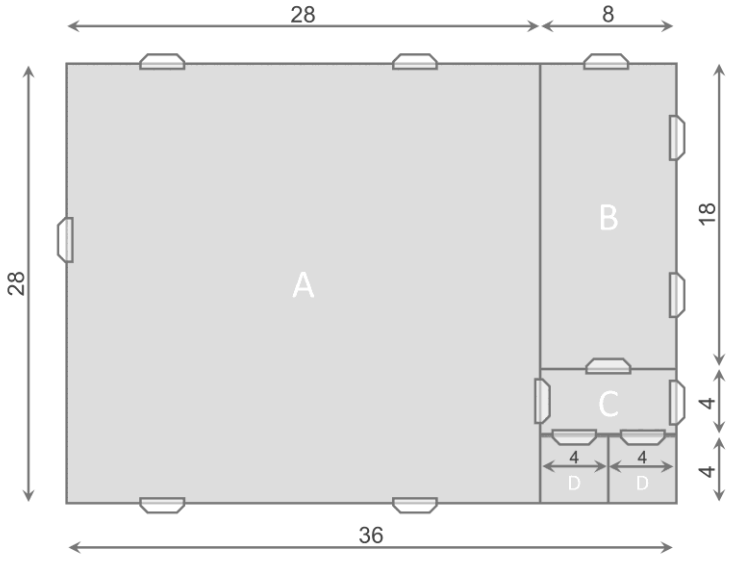


Figure 14: Plan of reference factory hall. True north is to the left.

[7] EPW weather data downloaded from https://energyplus.net/weather-location/europe_wmo_region_6/DEU/DEU_Stuttgart.107380_IWEC on February 13, 2025.

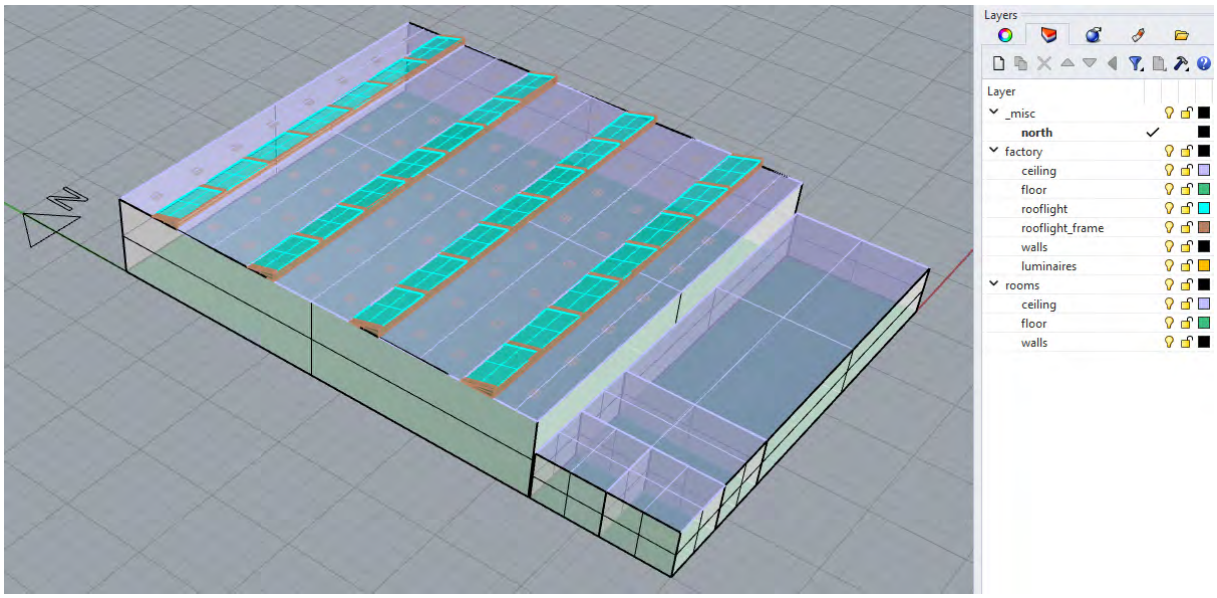


Figure 15: 3D model of reference factory hall.

4.2 Hall description

4.2.1 Geometry

The geometry was modelled using Rhinoceros 3D according to the specification in CEN/TR 15193-2.

- 3D model: *t70_reference_hall.3dm*
- 28 m x 26 m x 5 m overall dimensions of the hall
- Rooflight orientation: North
- External shading: none

The data file of the 3D model is provided in the subfolder *T70_Hall/geometry/.*

4.2.2 Photometric characteristics

4.2.2.1 Materials

The surface reflectances are specified in CEN/TR 15193-2 with 70 % for the ceiling, 50 % for the walls, and 20 % for the floor, respectively. Colour neutral opaque materials were selected from the Spectral Materials Database[8] to approximately match these reflectances.

The transparent materials were generated using LBNL's Optics[9] software based on spectral data from the IGDB[10].

The geometry in the 3D model is divided into individual layers based on the different materials. The layer names are given in Table 4 and Table 5.

The spectra are provided in CSV format in the subfolder *T70_Hall/spectra/.*

[8] https://spectraldb.com/

[9] https://windows.lbl.gov/optics-downloads

[10] https://windows.lbl.gov/igdb-downloads

Table 4: Photometric characteristics of transmitting materials in the reference factory hall.

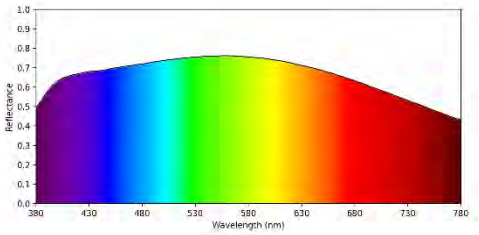
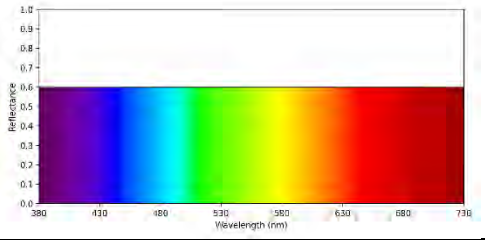
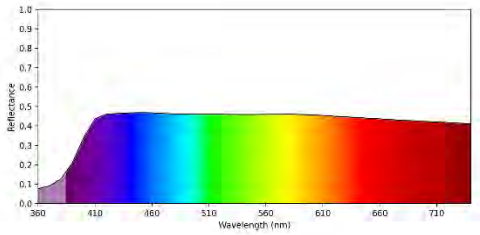
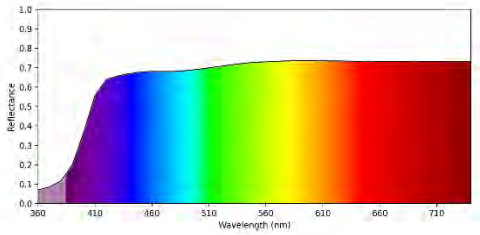
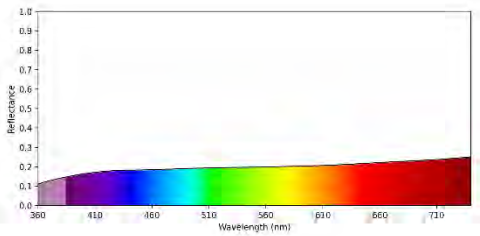
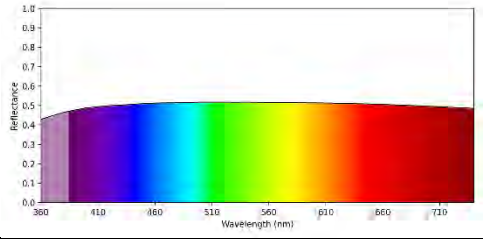
Geometry (layer name)	**Colour**	**V(λ) transmittance**	**M(λ) transmittance**	**Spectral data**
Rooflight glass (factory_rooflight)	Transparent	74.65%	72.54%	Guardian_ClimaGuard_doublePane.usr / Guardian_ClimaGuard_doublePane_t_vis.csv 
Rooflight diffusing layer (factory_rooflight)	Translucent (diffuse polycarbonate)	60.00%	60.00%	diffusing_shade_generic_60.csv (diffusing shade material, adapted from CGDB ID 31002, no spectral data, assumed spectrally neutral) 

Table 5: Photometric characteristics of opaque materials in the reference factory hall (Source of spectral data: https://spectraldb.com/).

Geometry (layer name)	**Colour**	**V(λ) reflectance**	**M(λ) reflectance**	**Spectral data**
Walls (factory_walls)	Neutral, 50%	45.83%	46.30%	00552_spectral.csv / 00552_spectral_sci.csv 
Ceiling (factory_ceiling)	Neutral, 70%	72.33%	69.03%	00995_spectral.csv / 00995_spectral_sci.csv 
Floor (factory_floor)	Neutral, 20%	20.06%	19.10%	00002_spectral.csv / 00002_spectral_sci.csv 

Rooflight frame (factory_rooflight_frame)	Aluminium	51.54%	51.52%	00677_spectral.csv / 00677_spectral_sci.csv 

4.2.2.2 Luminaires

CEN/TR 15193-2 specifies a daylight dependent dimmable LED luminaire for the factory hall. We did online research and selected a typical high-bay luminaire as representative example for the reference hall definition.

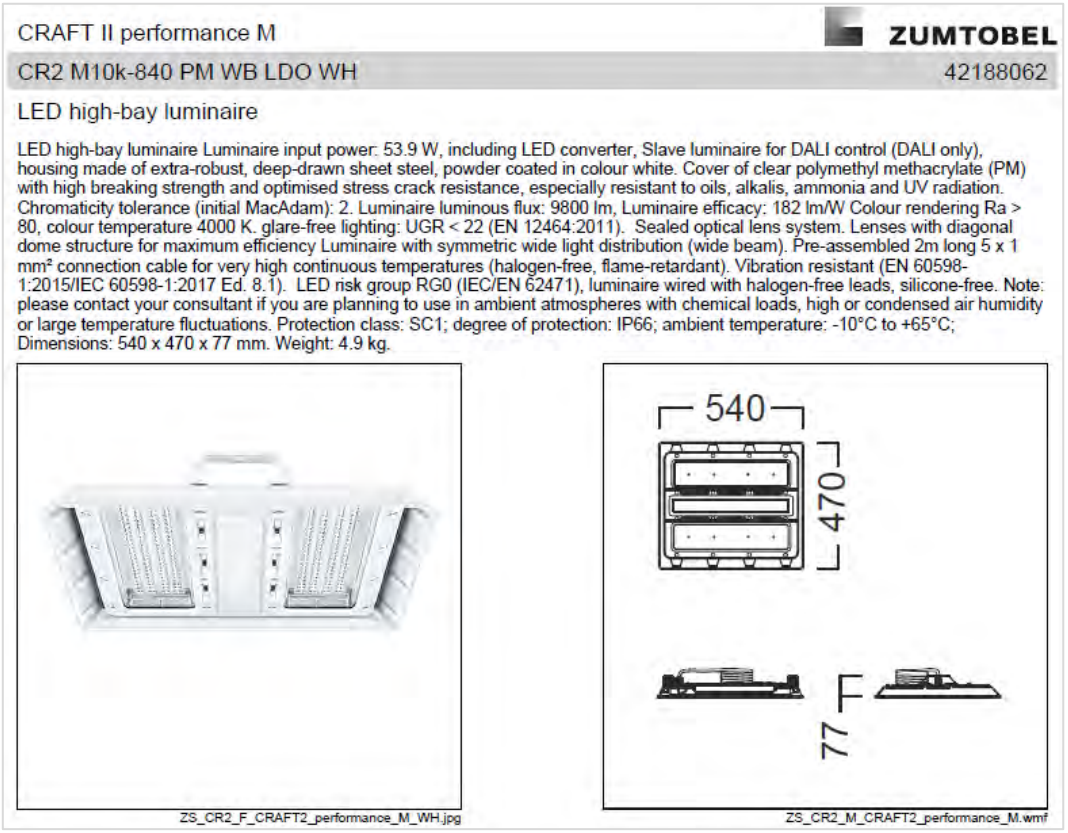


Figure 16: Luminaire specification and product image from datasheet (source: Zumtobel Lighting[11]).

The luminous intensity distribution and the product datasheet were downloaded from the manufacturer's website on 13 February 2025.

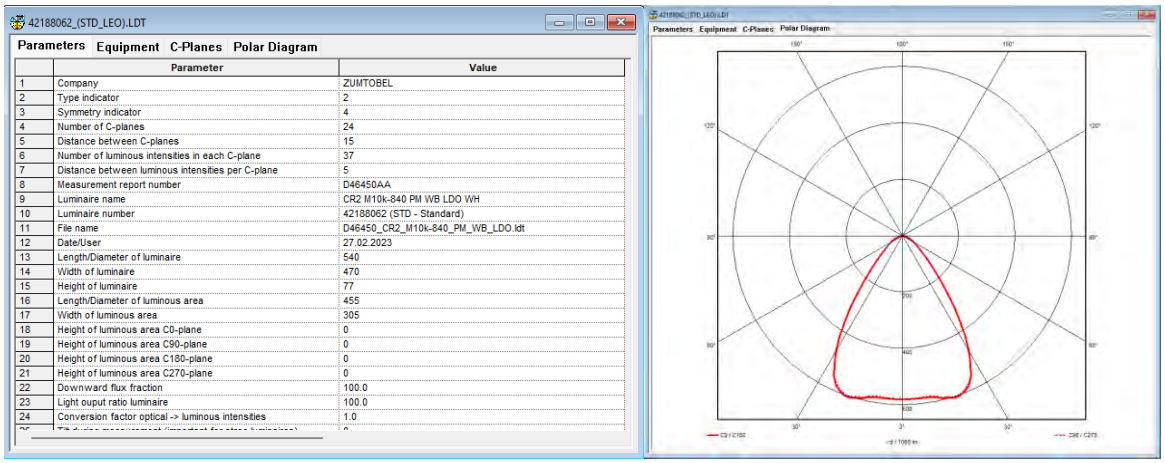
The main specifications are:

- Luminaire input power: 53.9 W Power factor = 0.94
- Luminaire luminous flux: 9800 lm
- Luminaire efficacy: 182 lm/W
- Colour Rendering Index min.: 80
- Correlated colour temperature: 4000 K

[11] Downloaded from https://www.zumtobel.com/at-de/produkte/craft2.html?&GUID=CF451334-7D66-4469-ADCD-1F7EAE946F44#CRAFT%20II%20performance%20M%20PM%20Acryl on February 13, 2025.

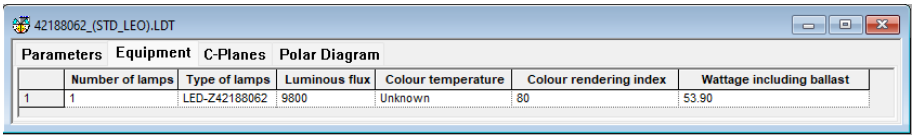
A typical spectrum of a 4000K LED lamp is assumed. The spectral data for the CIE typical LED lamp 03[12] with 4103K and Ra 85 is provided (*CIE_illum_LEDs_03_norm.csv*).

The luminous intensity distribution data file in EULUMDAT format (*42188062_(STD_LEO).LDT*) and IES format (*42188062_(STD_LEO).IES*) as well as the datasheet are provided in the subfolder *T70_Hall/luminaire/.*



	Parameter	Value
1	Company	ZUMTOBEL
2	Type indicator	2
3	Symmetry indicator	4
4	Number of C-planes	24
5	Distance between C-planes	15
6	Number of luminous intensities in each C-plane	37
7	Distance between luminous intensities per C-plane	5
8	Measurement report number	D46450AA
9	Luminaire name	CR2 M10k-840 PM WB LDO WH
10	Luminaire number	42188062 (STD - Standard)
11	File name	D46450_CR2_M10k-840_PM_WB_LDO.ldt
12	Date/User	27.02.2023
13	Length/Diameter of luminaire	540
14	Width of luminaire	470
15	Height of luminaire	77
16	Length/Diameter of luminous area	455
17	Width of luminous area	305
18	Height of luminous area C0-plane	0
19	Height of luminous area C90-plane	0
20	Height of luminous area C180-plane	0
21	Height of luminous area C270-plane	0
22	Downward flux fraction	100.0
23	Light ouput ratio luminaire	100.0
24	Conversion factor optical -> luminous intensities	1.0

Figure 17: Luminaire parameters (left) and polar diagram (right) as provided in the EULUMDAT file.



	Number of lamps	Type of lamps	Luminous flux	Colour temperature	Colour rendering index	Wattage including ballast
1	1	LED-Z42188062	9800	Unknown	80	53.90

Figure 18: Luminaire equipment specified in the EULUMDAT file.

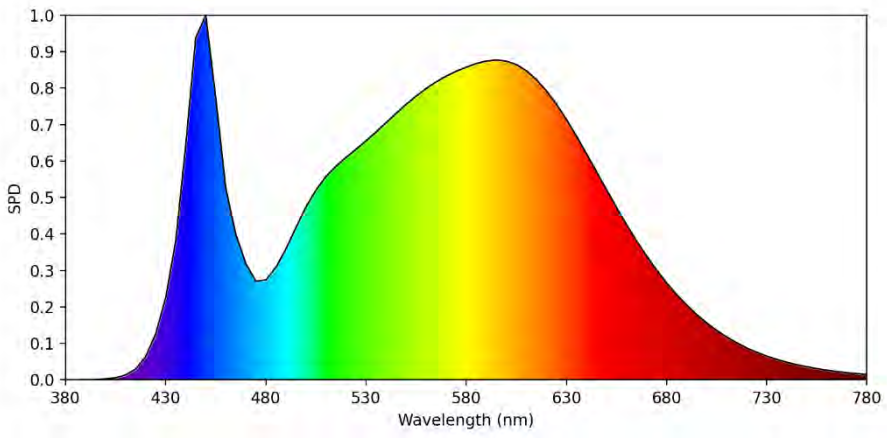


*Figure 19: Relative spectral power distribution of typical 4000K LED (CIE LED lamp 03, 4103K, Ra 85 (*CIE_illum_LEDs_03_norm.csv*).*

With this luminaire we specified 8 rows with 8 luminaires each. Two rows of luminaires are mounted between the rooflight bands each, and one additional row each between the rooflight and the wall.

4.2.2.3 Rooflight

The rooflight is assumed to be a double pane insulation glazing with an additional third diffusing pane on the exterior. The overall system was modelled in LBNL's WINDOW software and the performance data was determined (Figure 20).

[12] Downloaded from https://cie.co.at/datatable/relative-spectral-power-distributions-illuminants-representing-typical-led-lamps, on December 17, 2025.

```
BERKELEY LAB WINDOW v8.0.33.0 Glazing System Thermal and Optical Properties 01/27/25 16:21:04


ID       : 1
Name     : T70_Reference_Hall_Skylight
Tilt     : 90.0
Glazings: 3
KEFF     : 0.058 [W/m-K]
Width    : 49.684 [mm]
Uvalue   : 0.980 [W/m2-K]
SHGCc    : 0.349
SCc      : 0.401
Tvis     : 0.393
RHG      : 260.026 [W/m2]
```

Figure 20: Extract from the report from the WINDOW software.

The diffusing pane was adapted from the CGDB entry ID 31002 and defined as a diffusing material with assumed spectrally neutral behaviour (cf. Figure 21).

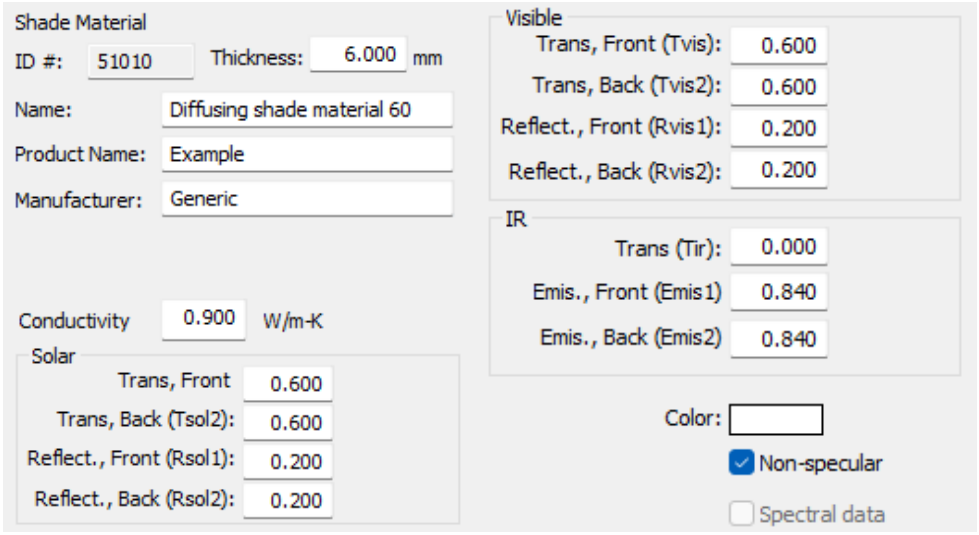


Figure 21: Specification of the diffusing pane characteristics in the WINDOW software.

The full window made of insulating glazing and diffusing pane was modelled in WINDOW. The specification is provided through the following output from the software.

- BSDF file for the window system: *T70_Reference_Hall_Skylight.xml*
- CSV file with the plain BSDF data for full Klems resolution and integral values for transmittance and reflectance: *T70_Reference_Hall_Skylight.csv*

The data files are provided in the subfolder *T70_Hall/rooflight/*.

4.2.3 Control

The luminaires follow a daylight dependent control based on look-down brightness sensors located between the rooflight bands. All luminaires are always controlled simultaneously and at the same dimming levels.

The maintained illuminance in the factory is 500 lx, with a maintenance factor of 0.8. The working hours in the factory hall are 8 am to 5 pm, Monday through Friday, with no shut down for holidays.

The rooflight has no dynamic parts, so no control is needed.

5 Online Resources

Links to online resources that were used for the definition of the reference models:

- EPW weather data file for Innsbruck, Austria: https://energyplus.net/weather-location/europe_wmo_region_6/AUT/AUT_Innsbruck.111200_IWEC
- EPW weather data file for Stuttgart, Germany: https://energyplus.net/weather-location/europe_wmo_region_6/DEU/DEU_Stuttgart.107380_IWEC
- Shading lines for Tyrol, Austria: https://www.tirol.gv.at/statistik-budget/tiris/tiris-anwendungen/solarpotenziale-tirol/
- Spectral Materials Database [15,16]: https://spectraldb.com/
- OPTICS: https://windows.lbl.gov/optics-downloads
- IGDB: https://windows.lbl.gov/igdb-downloads
- WINDOW: https://windows.lbl.gov/window-software-downloads
- Zumtobel luminaire specification: https://www.zumtobel.com/at-de/produkte/craft2.html?&GUID=CF451334-7D66-4469-ADCD-1F7EAE946F44#CRAFT%20II%20performance%20M%20PM%20Acryl
- Relative spectral power distributions of illuminants representing typical LED lamps [17]: https://files.cie.co.at/CIE_illum_LEDs.csv

6 References

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Appendix: Template for Reporting Results

Example Software XYZ

Edit all information and results for your simulation settings and results. All placeholder text in green should be edited.

Simulation run by:

- Jane Doe, June 1, 2025

Software and hardware:

- Example Software XYZ, version 1.234
- Timestep calculations: 1) backwards raytracing, 2) forwards raytracing, 3) three-phase matrix, 4) five-phase matrix, 5) Other (describe), 6) Unknown, Information not provided by the user interface
- Simulation settings
  - If not configurable by the end user: Default settings
  - If configurable by the end user:
    - Settings for raytracing calculation [provide values for key settings; e.g., number of reflections, ambient bounces, etc.]
    - Settings for renderings [key settings]
    - Specify the phase of the project the software was run for, e.g., simulations were intended for 1) early conceptual phase, 2) design development or 3) final specifications phase. [assuming the simulator will configure settings per desired level of accuracy]
- Sky model: 1) default (information on sky model, atmospheric data, etc. not provided as a configurable setting by the software tool), 2) Perez with MF:4 subdivisions for sun disk, etc.
- Spectral: 1) not available, 2) 3-channel, 3) 9-channel, 4) Other – specify number of channels.
- Total run time for annual simulation, general hardware description: 1hrs 23min, on Computer 2025, 8 core CPU (4 performance, 4 efficiency cores), 16 GB RAM
- Any other important parameters?
- …

General comments on the simulation, deviations from the templates, other:

- E.g.
- Software does not report $UDI_{100\text{-}3000}$, the result was calculated manually from the annual illuminance values
- Software does not support spectral simulations, all surfaces were modelled spectrally neutral with RGB values all set to V(l) value
- …

Description of alternative context for office: Context “myContext”

- Location, weather data file,
- Orientation (window facing direction)
- Alternative façade system?
- Alternative electric lighting system?
- Alternative control?
- Air-air heat pump instead of natural gas heating
- …

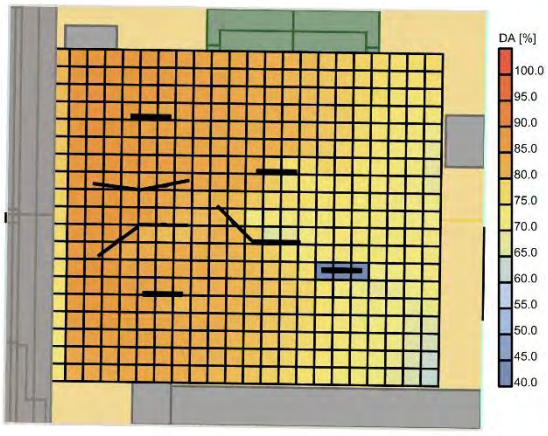
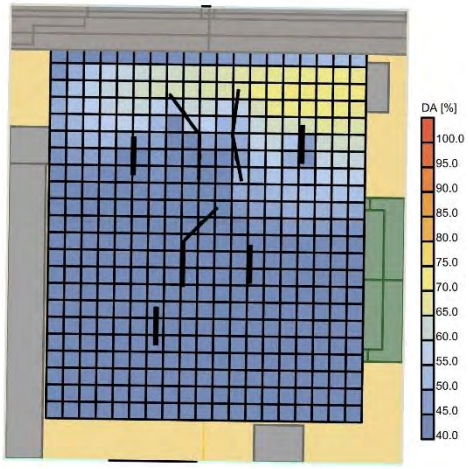
Description of alternative context for factory hall: Context “myContext”

- Location, weather data file,
- Orientation (skylight facing direction)
- Alternative skylight: the diffuse skylight was replaced with a solar protection glazing with t_{vis} = xx.yy%
- Alternative electric lighting system?
- Alternative control?
- …

Results for reference case “Office”

	Metric	Reference case	Context myContext
Daylight Factor (CIE overcast sky)	DF min	x.xx %	x.xx %
	DF mx	x.xx %	x.xx %
	DF avg	x.xx %	x.xx %
	% area with at least 2% DF	x.xx %	x.xx %
Daylight metrics based on annual results	$sDA_{300,50\%}$	xx.x %	xx.x %
	$ASE_{1000,250h}$	xx.x %	xx.x %
	% area with at least 50% $UDI_{100\text{-}3000}$	xx.x %	xx.x %
	$F_{DGP=0.40,exceed}$ for view 1	x.xx %	x.xx %
	$F_{DGP=0.40,exceed}$ for view 2	x.xx %	x.xx %
Circadian lighting	mEDI	xxx.x lx	xxx.x lx
Electric lighting	Annual electricity use for electric lighting	xxx.x kWh / yr	xxx.x kWh / yr
	Operating hours	xxxx h	xxxx h
Annual electricity use for HVAC (zonal level)	Heating	xx.x kWh / yr (type of heating / no heating)	xx.x kWh / yr (type of heating / no heating)
	Cooling	xx.x kWh / yr (type of cooling / no cooling)	xx.x kWh / yr (type of cooling / no cooling)
	Ventilation	xx.x kWh / yr (type of ventilation / no ventilation)	xx.x kWh / yr (type of ventilation / no ventilation)
Annual energy use for HVAC (zonal level, specify fuel – e.g., natural gas for heating)	Heating	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)
	Cooling	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)
	Ventilation	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)

Example graphical output: e.g., spatial daylight distribution (DA or DF distribution)
(provide also tabular results (text files) for the sensor grid behind the figures and high-resolution image files)

Reference case	Context myContext
	
Spatial distribution of Daylight Autonomy (DA [%]) for the reference office (window is on the left side, West)	Spatial distribution of Daylight Autonomy (DA [%]) for the office in context myContext (window is on the top, North)

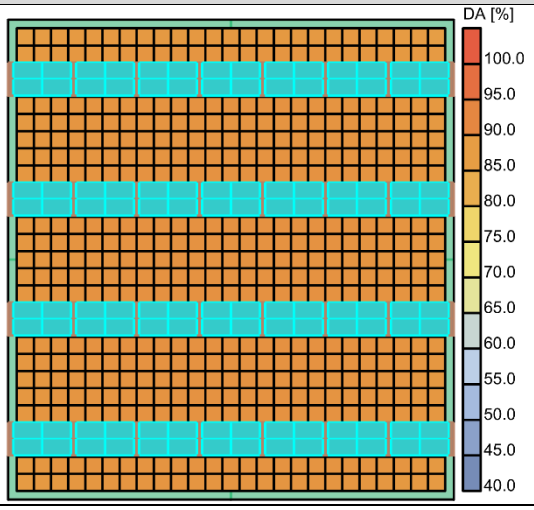
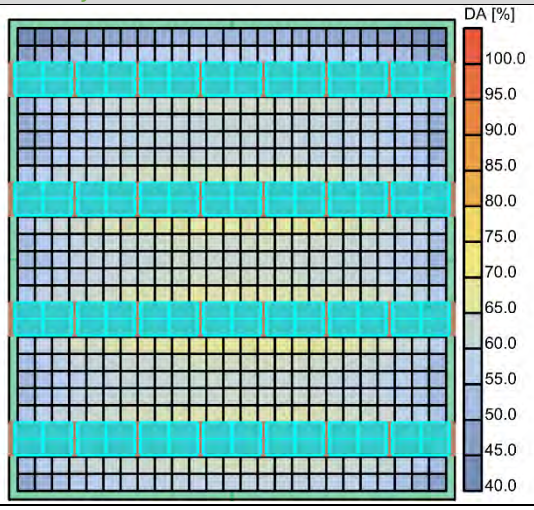
Specific comments on the simulation for the reference case “office”:

- Example comments:
- Shading lines were modelled as geometry in 1000m distance
- Software XYZ can only report glare for a single view point. The simulation was run two times.
- Additional relevant output, specific to software? (Images, data, …)
- assumptions for the HVAC calc:
    - HVAC setpoints and schedule
    - COP
    - etc.
- …

Results for reference case “Hall”

	Metric	Reference case	Context myContext
Daylight Factor (CIE overcast sky)	DF min	x.xx %	x.xx %
	DF mx	x.xx %	x.xx %
	DF avg	x.xx %	x.xx %
	% area with at least 2% DF	x.xx %	x.xx %
Daylight metrics based on annual results	$sDA_{300,50\%}$	xx.x %	xx.x %
	$ASE_{1000,250h}$	xx.x %	xx.x %
	% area with at least 50% $UDI_{100\text{-}3000}$	xx.x %	xx.x %
	$F_{DGP=0.40,exceed}$, view 1	x.xx %	x.xx %
	$F_{DGP=0.40,exceed}$, view 2	x.xx %	x.xx %
	$F_{DGP=0.40,exceed}$, view 3	x.xx %	x.xx %
	$F_{DGP=0.40,exceed}$, view 4	x.xx %	x.xx %
Circadian lighting	mEDI	xxx.x lx	xxx.x lx
Electric lighting	Annual energy demand for electric lighting	xxx.x kWh / yr	xxx.x kWh / yr
	Operating hours	xxxx h	xxxx h
Annual electricity use for HVAC (zonal level)	Heating	xx.x kWh / yr (type of heating / no heating)	xx.x kWh / yr (type of heating / no heating)
	Cooling	xx.x kWh / yr (type of cooling / no cooling)	xx.x kWh / yr (type of cooling / no cooling)
	Ventilation	xx.x kWh / yr (type of ventilation / no ventilation)	xx.x kWh / yr (type of ventilation / no ventilation)
Annual energy use for HVAC (zonal level, specify fuel – e.g., natural gas for heating)	Heating	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)
	Cooling	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)
	Ventilation	xx.x kWh / year (energy source)	xx.x kWh / year (energy source)

Example graphical output: e.g., spatial daylight distribution (DA or DF distribution)
(provide also tabular results (text files) for the sensor grid behind the figures and high-resolution image files)

Reference case	Context myContext
	
Spatial distribution of Daylight Autonomy (DA [%]) for the reference hall (skylights facing North)	Spatial distribution of Daylight Autonomy (DA [%]) for the hall in context myContext (skylights facing North, solar protection glazing)

Specific comments on the simulation for the reference case “hall”:

- Example comments:
- Software XYZ can only report glare for a single view point. The simulation was run four times.
- Additional relevant output, specific to software? (Images, data, …)
- assumptions for the HVAC calc:
    - HVAC setpoints and schedule
    - COP
    - etc.
- …