Artlight 2.0 – a runtime optimized algorithm for coupled thermal and daylight simulation with TRNSYS and RADIANCE

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Abstract

This paper presents a new modeling routine for an integral evaluation of complex fenestration systems (CFS) using the simulation tools TRNSYS and RADIANCE.

Artlight 2.0 adds the novel capability in TRNSYS to use the well-established three-phase method (3PM) from RADIANCE, which has been fully implemented in a new stand-alone TRNSYS-Type model (Type265). The improvement on existing state-of-the-art routines lies in a timestep-based communication between the thermal and daylight simulation throughout the simulation, while enabling an efficient runtime due to an improved implementation strategy.

This work describes the new model in detail and presents comparison results with other tools. Model setup and functionality are demonstrated by a simulation case study including different façade settings and blind systems.

Introduction

The role of CBDM in thermal building modeling

Model development to evaluate complex fenestration systems (CFS) within building energy simulation tools has increased significantly in recent years (Kirimtat et al. 2016). Although the number of tools is increasing, a satisfactory method including all aspects like high flexibility and an efficient runtime while preserving detailed results is still not available.

At the same time the utilization of daylight in buildings has gained a significant relevance in reducing the electrical energy demand for artificial lighting as well as optimizing the overall energy demand for heating and cooling (Ihm et al. 2009).

Although simplified rules of thumb-based planning tools are still widely used by practitioners due to their reduced complexity, climate-based daylight modeling (CBDM) including the local climate data is gaining higher relevance for planning and research purposes. Besides higher accuracy, it allows a deeper analysis of visual comfort aspects (glare) as well as related influence on the coupled energetic behaviour of a building.

Furthermore, established standards for dynamic daylight performance metrics like Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) (Nabil und Mardaljevic 2006) as well as their spatial considerations, Spatial Daylight Autonomy (SDA) and Annual Sunlight exposure (ASE) (IES LM-83-12) are based on hourly illuminance values.

Comparison with existing simulation tools

With the implementation of Artlight v1.0 (Hauer et al. 2011), a coupled thermal and daylight simulation, based on the RADIANCE three-phase method (3PM) was implemented in TRNSYS. While examining the thermal modeling of the CFS with simplified model approaches based on the bidirectional angular dependent g-values, the daylight simulation is linked to the annual simulation in TRNSYS by a Python-script calling external RADIANCE commands.

Though being a workaround in the implementation, this development showed successfully the capability of coupling both simulation tools. The methods used enable an accurate evaluation of daylight redirecting components in terms of daylighting potential and improved control as well as detailed performance analysis of visual and thermal comfort. Nevertheless, functionality and flexible use of this routine are limited and have to be improved for further use.

Meanwhile, several widely used building simulation tools have also extended their capabilities in allowing coupled daylight and thermal evaluation based on the 3PM (Karlsen et al. 2015; Guglielmetti 2015). Even though most of the methods claim to enable an integral approach to reduce overall efficiency concerning daylight and energetic aspects, none of them allow timestep-based feedback loops between the thermal and daylight simulation routine. However, this is crucial when developing improved control strategies and optimizing thermal and visual aspects of a complex façade in an integral manner.

OpenStudio precalculates annual illuminance schedules for each window group (windows, which are equally controlled). For the shading control a schedule is calculated, one for that group with the shades up, and another one for the shades down (NREL 2016). IDA ICE (version 4.7 and higher) allows the smplified calculation of daylight factors and illuminance values for several zones, user-defined sensor grids as well as different sky models. Nevertheless, a timestep-based coupling between thermal and daylight evaluation is not mentioned.

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With Type-DLT a model based on the Artlight (v1.0) idea was introduced for implementing the annual daylight modeling by the 3PM within the thermal building modeling in TRNSYS (Michele et al. 2014). Although this method also allows a timestep-based feedback loop between thermal and daylight simulation, the major obstacle concerning the inefficent simulation runtime with more than six hours for an annual simulation was not solved either.

Furthermore, the model structure is set up to analyze a common blind system for the whole façade without window subdivisions. In case of including additional daylight redirecting parts in the façade, several versions of Type DLT have to be included in the simulation. This makes the modeling process complicated and causes a multiplication of the runtime compared to a single shading system.

A major reason that most tools come up with a scheduled model input instead of instantaneous timestep coupling is due to time and data intensive simulation effort, as the three-phase Radiance workflow has to be executed at least once within each simulation timestep. The loss in flexibility by precalculated illuminance values and shading states is therefore accepted.

The novel model approach implemented in *Artlight 2.0* tackles these difficulties in allowing a sufficient runtime while providing highest flexibility in the coupling stategy and detailed result analysis. This leads to essential benefits over the state of the art especially for expert users in building model design.

Methods

Concept of Artlight 1.0

With Artlight 1.0, a first simulation routine was implemented within TRNSYS17, to run an annual simulation coupled in each timestep with a daylight simulation, as described in the previous section.

The development of Artlight 1.0 according to Figure 1 is based on two independent parts:

- *TRNSYS Type205:* Linker to Type56 building model and data wrapper for Artlight
- *Artlight:* script enabling climate-based daylight simulations with the RADIANCE 3PM, including different control strategies

In this first approach, *Type205* acts as timestep-based coupling routine between the daylight simulation in RADIANCE and the thermal building simulation in TRNSYS Type56. Based on the transferred climate data from TRNSYS in each timestep, Artlight calculates the corresponding sky vector (Reinhart subdivision with 2305 sky patches plus ground) and loads the needed flux matrices for executing the initial daylight calculations. After each calculation, the implemented control algorithms analyze the given threshold criteria regarding the minimum illuminance on the work plane and check for exceeding luminance requirement on the façade. Therefore, several iterative loops can occur within one timestep until all control criteria are achieved.

The used sky vector represents a Perez sky generated from global horizontal and direct normal irradiance data from the EnergyPlus weather data.

The precalculated flux matrices (view matrix VMX, transmission matrix BSDF (bidirectional scattering distribution function) and daylight matrix DMX) are loaded within each simulation timestep together with the generated sky vector. By executing the RADIANCE dctimestep routine within Artlight, a fast daylight calculation is done within each timestep.

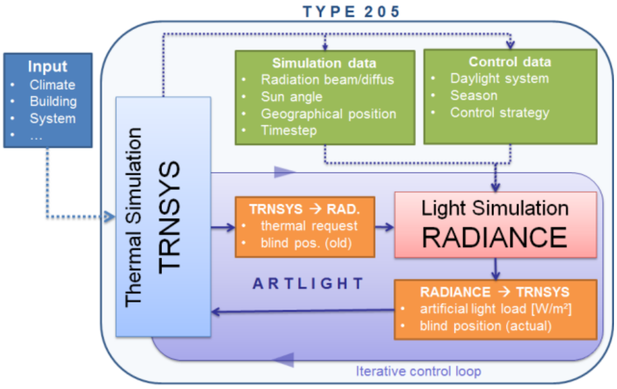


Figure 1: Scheme of simulation routine Artlight 1.0

Different implemented control strategies further allow running the coupled simulation either focussing on thermal optimization or daylight optimization of the situation in the room. While both strategies prevent glare at any time, the thermal control aims to reduce heating and cooling loads instead of optimizing illuminance levels. In an annual simulation of an office use, a combination of both strategies is obvious: daylight control during occupancy and thermal control during vacancy.

New model concept in Artlight 2.0

In contrast to Artlight 1.0, the complete part of the RADIANCE 3PM (parts within the violet marked area in Figure 1) is now implemented in the new Artlight routine (Artlight 2.0).

It is programmed as stand-alone model (Type265) and includes the following parts:

- Flux matrix creation
- Matrix loading and handling
- Flux matrix calculation
- Control strategies

Similar to the former version, Artlight 2.0 is linked with the radiation processor (Type15) for the environmental input data as well as with the multizone building model (Type56) for the coupled daylight and thermal modeling. The revised structure of Artlight 2.0 is shown in Figure 2.

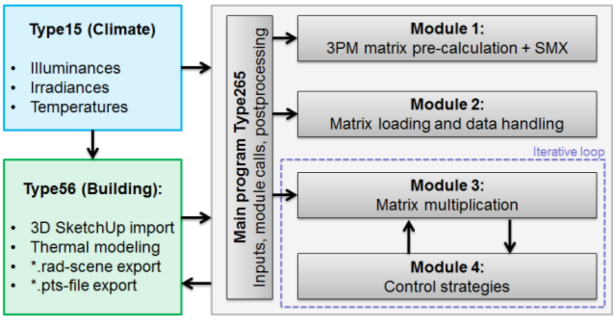


Figure 2: Artlight 2.0: model structure

The drawing of the building model is done in Sketchup and imported into Type56. In there, a newly available function (since TRNSYS18) allows exporting the RADIANCE-scene file (*.rad) corresponding to the thermal zone settings (geometries, material properties). This allows using the same Sketchup model for the thermal and daylight calculation and reduces modeling errors at the same time. Furthermore, an illuminance sensor grid with up to 10 sensors can be defined within the thermal model, which will be also included in the exported scene file. Artlight 2.0 is optimized to use an equal number of thermal and daylighting zones.

Module 1 can either use the exported files from Type56 or a manually created scene, to generate the view matrices and the daylight matrices. As a default, the daylight matrix is calculated using the Reinhart MF:4 subdivision of the Tregenza sky (2306 patches).

The view matrix has to be calculated separately for each window part and for each orientation. To fulfil the matrix-architecture in Artlight 2.0, all sensor points belonging to illuminance detection and all sensor points used for the luminance evaluation have to be defined in two separate sensor grid files (*.pts). Nevertheless, the number of sensor points is flexible and the hourly results for each sensor point are provided as data files at the end of a simulation run. They can be used for evaluations in external post processing tasks. In case of a simulation run with four defined orientations and four windows (without subdivision), the representative matrix structure shown in Figure 3.

Using RADIANCE tools, a user-provided *.epw-file can be converted via the *.wea-file format into a sky matrix (*.smx). The BSDF data for the transmission matrix has to be provided separately for each window subdivision and sets of blind positions by the user. They can be generated with external tools (WINDOW7, RADIANCE genBSDF…).

All function calls in Module 1 (which are rather time-consuming) only have to be done once after a new simulation is set up or if the model is changed. After generating all matrices once, the files are stored in a separate folder “Zone1”, which is copied in case of multiple thermal zones in one simulation.

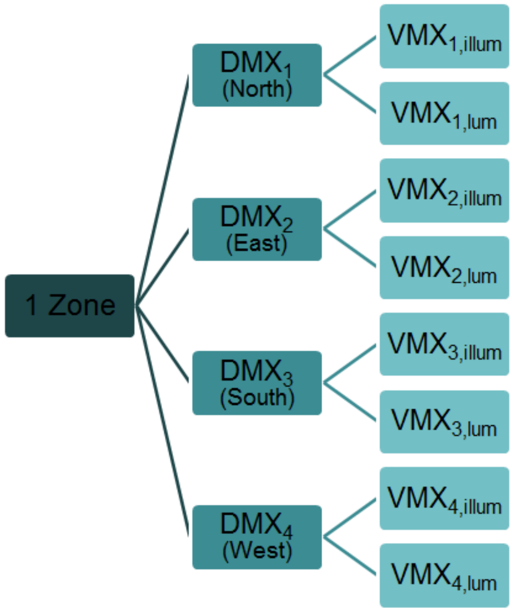


Figure 3: Flux matrix organisation in Artlight 2.0

To enable a fast calculation, all necessary matrix data to perform the daylight simulation has to be loaded into the RAM before the first simulation timestep. The data loading, caching and flexible storage (re-)allocation depending on the actual simulation setup is done in Module 2. Including modules beside the main program routine in FORTRAN allows storing loaded data in the cache memory during the entire simulation. Therefore, the time-consuming process of data reloading is reduced to one action in a preprocess before the first timestep.

$$Z = \begin{bmatrix} 1 \\ .. \\ 2306 \end{bmatrix}^T * \begin{bmatrix} 1 & 145 \\ .. & .. \\ 2306 & .. \end{bmatrix} * \begin{bmatrix} 1 & 145 \\ .. & .. \\ 145 & .. \end{bmatrix} * \begin{bmatrix} 1 & s \\ .. & .. \\ 145 & .. \end{bmatrix} \quad (1)$$

In Module 3, the whole 3PM matrix multiplication given in eq. (1) is processed in a repeating loop depending on the number of window (subdivisions) and façade orientations.

As a result, the timestep-based illuminance and luminance values are analysed, if they achieve the given threshold criteria shown in eq. (2) and eq. (3). Index number “s” represents the number of sensor points.

$$Illuminance\colon \left[\frac{\sum_{i=1}^{s} E_i}{s} \geq 500lx\right] \xrightarrow{then} true \quad (2)$$

$$Luminance\colon \left[\sum_{i=1}^{s} (L_{s,o} \leq 5000\,\frac{cd}{m^2})\right] \xrightarrow{then} true \quad (3)$$

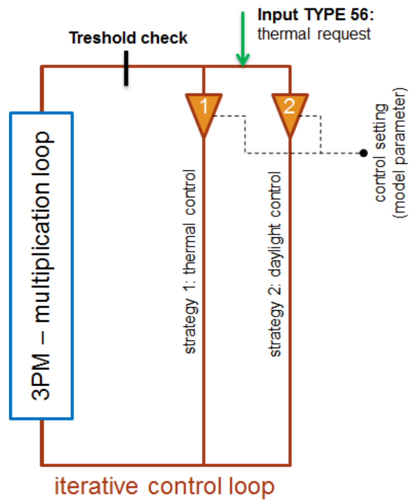


Figure 4: Iterative matrix multiplication loop

If the requirements are not fulfilled, the iterative control loop forces another calculation with an optimized blind position unless criteria match is given (Figure 4).

For the first calculation run within a timestep, Artlight uses the thermal request flag from the previous timestep to decide whether the blind should be fully closed (reduce cooling demand) or fully opened (reduce heating demand).
In case of the *thermal control strategy*, the blind remains fully open (decrease heating demand) or fully closed (decrease cooling demand), as long as no glare occurs. The optimization to reach the illuminance criteria of 500lx on the working plane is deactivated in case of the thermal control strategy.
In case of the *daylight control strategy*, the blind settings are optimized until a sufficient illuminance level and glare protection is guaranteed. In case the illuminance criteria cannot be reached by daylighting, artificial light is added. In case of a window subdivision, in a first step the upper (daylight-redirecting) part is optimized, in order to maximize daylighting from the top. In a second step, the lower part is optimized with the intention of taking over the shading part in order to avoid excessive solar gains.

In the postprocessing step, deallocation of the storage arrays, generating result outputs and writing result data files for hourly illuminance and luminance values are done. Artlight 2.0 comes up with some general outputs (mean work plane illuminance, artificial light demand, blind position) during the simulation run to check results online. Detailed result analysis may be done more efficiently in a postprocessing step by external tools (Excel, Matlab, etc.).

Runtime improvement

Major improvements implemented in Artlight 2.0 lead to a higher runtime efficiency and model flexibility within an annual simulation. As an overview, Table 1 highlights the contrasts between Artlight v1.0 and v2.0.

Table 1: Improvements in Artlight v2.0 over v1.0

Artlight 1.0	*Artlight 2.0*
timestep-based sky vector calculation	yearly-based sky matrix precalculation
timestep-based matrix reloading	matrix data caching in the very first timestep
RADIANCE dctimestep calculations	implemented flux-matrix calculation
single zone capability	multizone capability
single façade oriented daylight calculations	multioriented façade daylight calculations

The new matrix calculation algorithm allows now leaving out the time-consuming RADIANCE-routine “dctimestep”, which is normally called within each timestep to execute the 3PM matrix multiplication. Switching over to sky matrix calculation instead of using timestep sky vectors leads to an overall decrease in simulation time of a factor up to 20 (depending on model complexity).
Figure 5 shows a runtime comparison between both Artlight versions, including the influence of window subdivision with two independently controlled blinds and operation modes with sky vector and sky matrix.

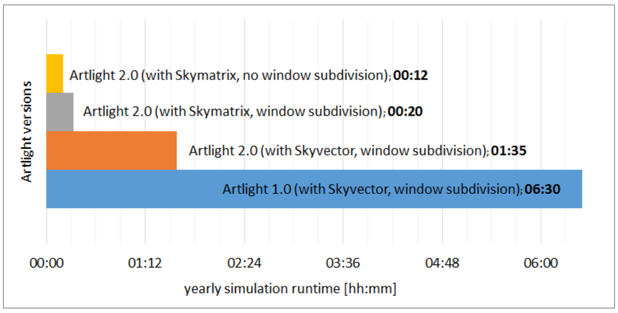


Figure 5: Runtime efficiency of Artlight implementation

Thermal modeling of CFS in TRNSYS

For the detailed thermal modeling of CFS within the multizone building model in TRNSYS, latest model implementations based on bidirectional scattering distribution functions (BSDF) are available (Hiller und Schöttl 2014). The standard window model in TRNSYS is based on one-dimensional angular dependent values for transmission, reflection and absorption. In contrast, the BSDF model enables a detailed modeling for the multiple scattered reflection and transmission, which is significant for blind systems, especially in case of specular daylighting systems.

The modeling is separated into shortwave radiation modeling by the precalculated BSDF data and the interrelated longwave radiation modeling according to algorithms defined in the ISO15099. This standard is currently still the most comprehensive and available modeling standard for complex glazing systems incorporating blinds (ISO 15099).

Several investigations in validation of this newly implemented model in TRNSYS Type56 against already established simulation tools, different simulation approaches and measured data are published (Hauer et al. 2015). For further details about the thermal BSDF-model in TRNSYS, the reader is referred to these publication.

Model comparison

Comparison of Artlight v2.0 against v2.0

To verify the validity of the new implementation, comparative simulations against the previous version of Artlight as well as other existing routines for coupled simulation were performed.

Figure 6 shows comparative results between both Artlight versions for simulated work plane illuminance. The simulated test scene consists of a simple shoebox room with a south-oriented façade. It describes the daily trend for the 2nd of July in Innsbruck. The red and green graph have a perfect match, while the results using the sky matrix differ slightly. The reason for this is the use of different algorithms to calculate sky vector and sky matrix in RADIANCE. Nevertheless, the new implemented algorithm in Artlight 2.0 shows a very good agreement.

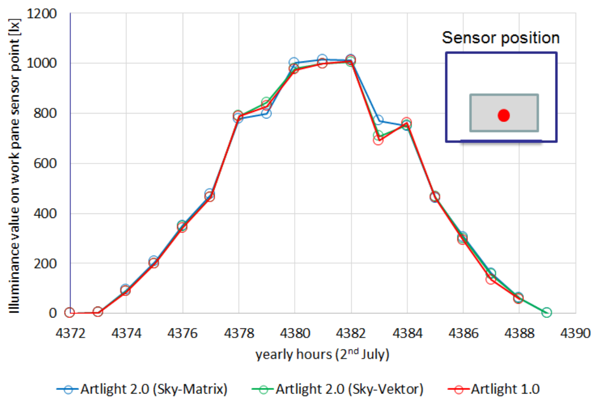


Figure 6: Comparison results: Artlight v1.0 and v2.0

Comparison of Artlight v2.0 against Type DLT

Figure 7 shows the result for a second comparison of the new Artlight algorithm against Type DLT (developed by EURAC Research). While also Type DLT enables coupled thermal and daylight simulation in TRNSYS, the calculation routine also includes the "dctimestep" method like Artlight 1.0. The comparison model includes nine illuminance sensors in the middle of the room evenly distributed along the whole room depth.

The values show an exact agreement. For this comparison, both programs used exactly the same matrices in order to eliminate deviations resulting from stochastic ray sampling during the flux matrices creation. More validation results about Artlight 2.0 can be found in (Hauer und Geisler-Moroder 2016)

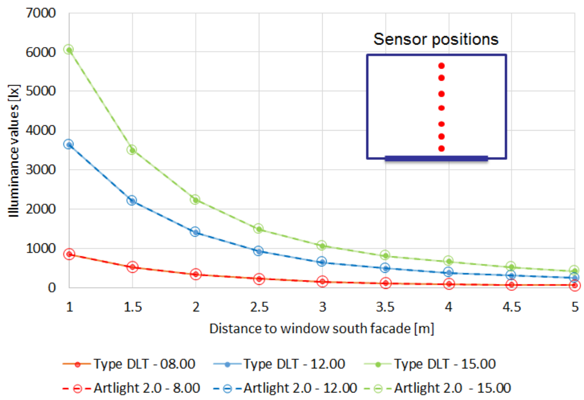


Figure 7: Validation results: Artlight 2.0 vs. Type DLT

Simulation and Model setup

Description of the reference room

For the validation of the developed simulation methods a standard design for the reference room according to a double office (Figure 8) is defined. By definition of an adiabatic envelope except the south-facing external façade it represents a single office out from a multistorey building.

The external wall has a thermal characteristic according to passive house standard; the inner walls are lightweight construction. The façade consists of an opaque parapet area and a fixed glazing area of 9m² and a window to wall ratio (WWR) of 0,6. The basic glazing is a highly insulated 3 pane multilayer glazing with argon gas filling and includes an 80mm air gap with a single pane impingement glazing on the outer side. Within the air gap the investigated shading or daylight redirecting system is mounted.

The glazing setup and calculation of the thermal properties are done in WINDOW7 by accessing the International Glazing Database (IGDB). The complex optical properties of the shading layer are treated by a BSDF, externally derived by the RADIANCE tool genBSDF based on a geometrical sketch. The thermal properties for the BSDF shading layer (infrared transparency, effective layer emissivity) are calculated according to the view factor method using the routine View3D. The effective openness factor according to ISO15099, which represents the convective behaviour of the blind stack, is varied linearly between 0.05 and 0.95 according to the slat angle.

After a full setup of the CFS, the BSDF report including the solar transmission matrix and the correspondent *.csv-file including the angular dependent layer absorptions are exported from WINDOW and compressed to a TRNSYS BSDF input file, which is then used by the complex glazing model in Type56. The exported *.xml file by WINDOW including the System BSDF (glazing + shade) is used by Artlight 2.0, which includes the necessary visual transmittance matrix for the daylight simulation.

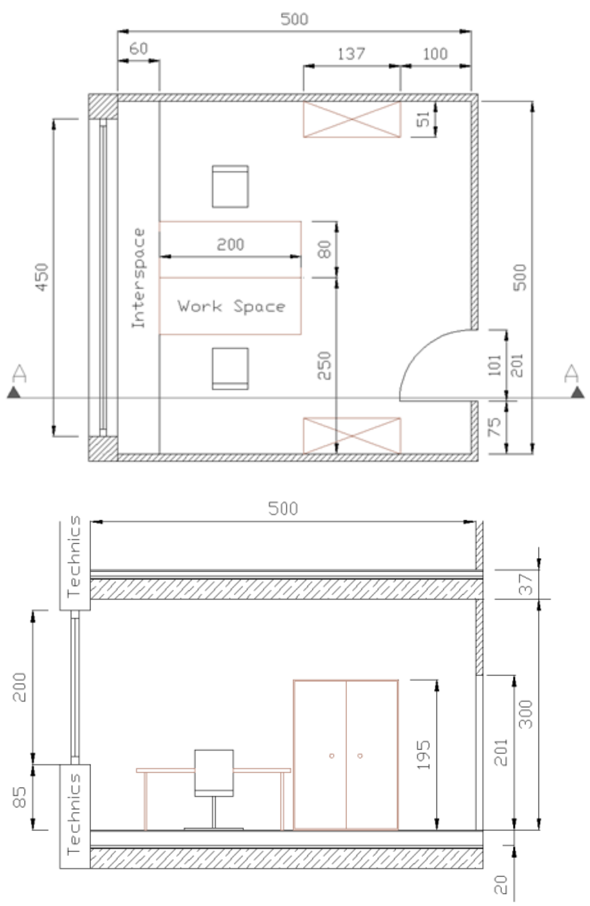


Figure 8: Geometrical reference room definitions

Internal gain definitions

According to SIA 2024 and its full load hours, the profiles for internal gains and humidity load are calculated and implemented in the room model of Type56. In Figure 9 the calculated weekly profiles of specific internal loads for persons and equipment are shown. These values include varying occupancy profile of two persons according to SIA2024. A separation into a radiative and convective part of the gains is done in Type56.

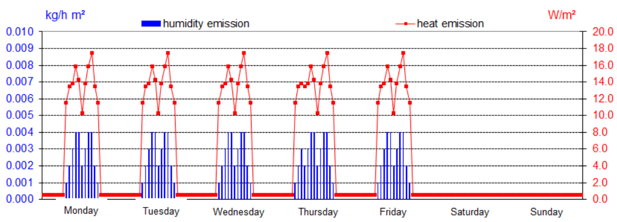


Figure 9: Calculated load profiles acc. to SIA 2024

Internal gains by means of artificial lighting are separated into 60% radiative gain and 40% convective gain in Type56 and use the hourly input from the Artlight simulation, which already implements the factors for luminous efficacy and the room utilization factor. Therefore, the effective efficiency of the artificial light in the thermal model is set to 70 lm/W. For this room a full artificial light load corresponds therefore to about 7.1 W/m² installed lighting power.

As the radiative heat exchanges within the thermal zone are solved by a detailed 3D-room modeling based on the Sketch-up geometry scene and calculated Gebhart-factors, the person gains were also accurately impressed to the model by defining two geo-positions, describing the sitting place of both occupants.

Thermal room model settings

The reference room definitions also include structural-physical aspects (wall mounting, U-Values...), lighting aspects (absorption coefficients, transmission values), user characteristics (attendant persons, internal loads, air change rates…) and typical interior as listed in Table 2.

Table 2: Thermal room parameters

Climate	Innsbruck
U-value façade wall (south-oriented)	0.15 W/m²K
U-value window glazing (no shade)	0.7 W/m²K
SHGC window glazing (no shade)	0.5
Window to wall ratio (WWR)	60 %
Sensible heat emissions*	70 W/pers.
Average moisture discharge*	80 g/h, pers.
Operating hours*	7am-6pm
Internal loads* (equipment)	9.6 W/m²
Heating threshold*	20 °C
Cooling threshold*	26 °C
Domestic ventilation - air change rate*	0.96/0.2 h^{-1}
Night ventilation – air change rate 3.00 h^{-1}	
Heat recovery rate	85 %
Infiltration rate	0.15 h^{-1}
Visual reflectance (ceiling/walls/floor)	80/ 50/ 30 %
Luminous efficacy of artificial light	70 lm/W
Room utilization factor artificial light*	70 %

*according to the SIA2024-standard (SIA 2024)

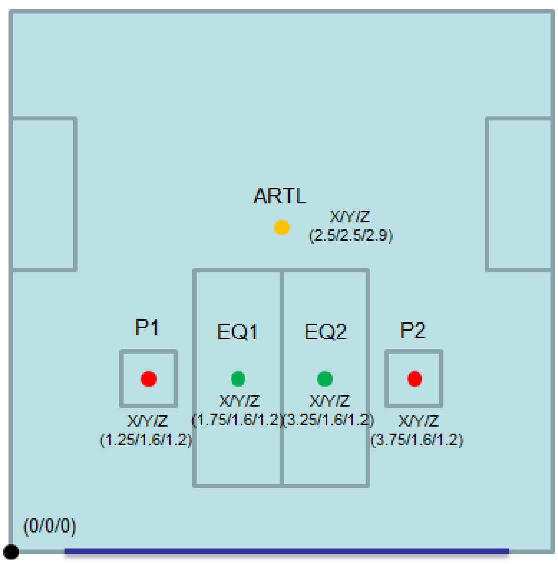


Figure 10: Geopositions of internal gains

The geopositions of P1 and P2 in Figure 10 are also used later on for the detailed evaluation of the thermal comfort according to PMV/PPD.

HVAC and Ventilation system modeling

The HVAC is modeled with an ideal heating system dissipating 40% as radiative power and a constant temperature threshold of 20°C as well as an ideal cooling system with a constant temperature threshold of 26°C.

The domestic ventilation system operates with 0.96 h^{-1} during occupancy and 0.2 h^{-1} during out of office hours. In the case of the room temperature exceeding 24°C at night and the outdoor temperature being at least 1K below that, the night ventilation with an air exchange rate of 3.0 h^{-1} is activated until a moderate room temperature of 21°C is reached. The heat recovery system with an efficiency rate of η=0,85 is always active, except when the ambient air exceeds the room temperature by more than 1K. In this case the summer bypass is active and compasses the heat recovery.

RADIANCE scene modeling

The Radiance scene is built up according to the ground floor plan in Figure 8 and is defined in four different versions according to the simulated façade subdivisions (Figure 13). A rendering of the Radiance-scene with façade subdivision 2 is shown in Figure 11.

In Figure 12, a schematic drawing describes the main positions of the sensors for illuminance detection (E-sensors) and luminance detection (L-sensors). For reaching a threshold of at least 500 lx on the work plane, 80 sensors are equally distributed over the whole work plane in a height of 0.85m above ground. Additionally, 10 sensors are equidistantly positioned, starting from the middle of the room towards the back wall. They are used to check the second illuminance criteria on reaching an average illuminance of 300lx above all 10 sensors.

Figure 11: Rendering of the Radiance-scene

At each occupant position, 112 viewer directions onto the façade are defined, which detects the luminance levels to achieve a maximum value for each individual subdivision between 1000 and 8000cd/m². Additionally, for each occupant point, a sensor for detecting the vertical illuminance in direction of the working position is defined. Although it is not evaluated in this study, it enables quantification of the melanopic impact as non-visual influence on the occupants.

Beside these sensors mainly for the façade control, an additional room grid including 529 illuminance sensor points (23 x 23) with equidistant sensor distribution of 0,2 x 0,2m is defined. It enables an evaluation of daylight metrics according to the standard (IES LM-83-12). The evaluation is done in a postprocessing step in MATLAB.

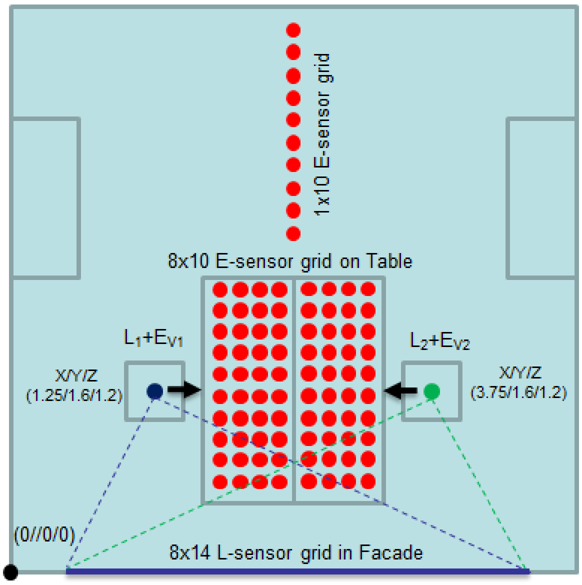


Figure 12: Sensor positions within the Radiance-scene

Simulation study

Based on the reference room setting and the different systems, a parametric simulation study is examined. The study is an example for how to setup and examine coupled simulations with the new Artlight tool. It highlights the capabilities and advantages of using this tool; it is less the objective to show the capabilities of the different daylighting systems in terms of their performance.

Investigated façade variants

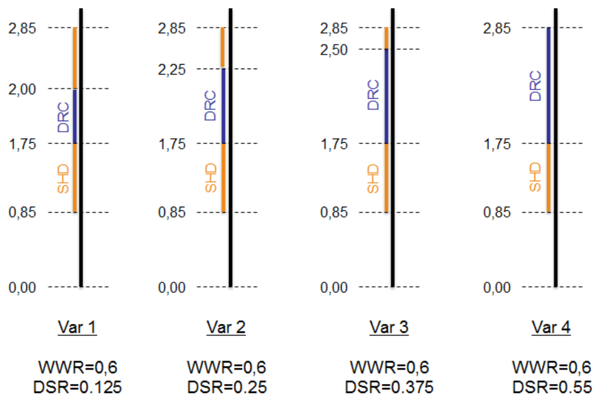


Figure 13: Variations in facade division

The simulation study includes four different façade divisions with varying area ratios between the daylight redirecting part and the shading lamella part (DSR = daylight to shading ratio). The window to wall ratio

(WWR) is constant for all simulations. Figure 13 shows the different façade variants. The abbreviation “SHD” describes the shading component and “DRC” the daylight redirecting component.

Investigated blind systems

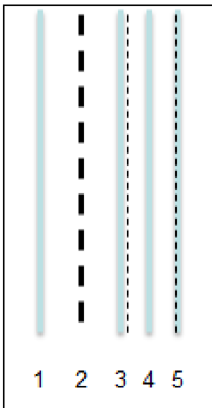
For the simulation study, three different blind systems are investigated: one diffuse Venetian blind system and two daylight redirecting blind systems. All systems are mounted between the glazing, protected by single pane impingement glazing to the outer environment.

In Table 3, position number for each layer are documented. In position 2 the blind systems according to Table 4 are implemented by a BSDF dataset, depending on the varying slat angle. The glazing without blind system has a U-value of 0.7 W/m²K and a g-value (SHGC) of 0.48 for perpendicular incidence.

According to the defined façade areas in Figure 13 for shading blinds (SHD) and daylight redirecting blinds (DRC), the investigated blind systems are combined to “system sets” in a way that it makes sense for daylighting purposes. The combinations are documented in Table 5.

Blind system 1 has a conventional, convex slat geometry, while system 2 and 3 are designed as concave slats for daylight redirecting purposes. The material used for blind 1 is uniformly diffuse reflective, while blind 2 and 3 have a highly specular surface coating (Miro3) on the upper side.

Table 3: Basic glazing setup in WINDOW7



Pos	ID	Name	mm
1	7199	Float glass	6.0
2	2	Air & System	80.0
3	7111	Float glass (with lowE)	6.0
	9	Argon/Air (90%/10%)	16.0
4	7199	Float glass	6.0
	9	Argon/Air (90%/10%)	16.0
5	7111	Float glass (with lowE)	6.0

Table 4: Specification of blind systems

	SHD 1	DRC 1	DRC 2
width	60mm	60mm	80mm
spacing	52mm	33.8mm	46mm
rise	4.6mm	6mm	11mm
ε_{front}	0.88	0.04	0.04
ε_{back}	0.88	0.88	0.8
$material_{front}$	RAL9016	Miro3	Miro3
$material_{back}$	RAL9016	RAL9016	RAL7030

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Table 5: Specification of system sets

	Lower part (SHD)	Upper part (DRC)
System set 1	SHD 1	SHD 1
System set 2	SHD 1	DRC1
System set 3	SHD 1	DRC2

Investigated simulation variants

On each façade variant and system setting (12 combinations), five different simulations variants with different parameter settings for the control strategy and the maximum luminance threshold for glare protection are examined.

Simulation variant 1 is evaluated with the thermal control strategy (“thermal”). Therefore, the blinds are adjusted in order to minimize the heating and cooling load in each timestep. Although this control strategy does not take into account the illuminance criteria, the maximum luminance criteria on the façade has to be achieved at any time to avoid visual discomfort. Artificial light is added in order to reach minimum 500 lx on each work plane sensor point.

Table 6: Varying simulation parameters

	Control	E_{table}	L_{max} - SHD	L_{max} - DRC
Var1	thermal	-	5000cd/m²	5000cd/m²
Var2	daylight	500lx	1000cd/m²	1000cd/m²
Var3	daylight	500lx	3000cd/m²	3000cd/m²
Var4	daylight	500lx	5000cd/m²	5000cd/m²
Var5	daylight	500lx	5000cd/m²	8000cd/m²

Simulation variants 2 to 5 are evaluated with the daylight control strategy (“daylight”). Therefore, a minimum level of 500 lx on the work pane has to be reached. First, by enhancing daylight utilization while reaching the luminance threshold for each façade part and second, by adding artificial light until a minimum illuminance of 500 lx on each work pane sensor point is guaranteed.

Simulation results and analysis

Several variations are included in the simulation study concerning different façade design, variation in blind systems used as well as different control strategies. The result analysis focuses firstly on the capability and functionality of the new Artlight tool. Secondly, the results will also give insight into the performance of daylight redirecting systems, which are evaluated by analyzing the overall energy balance.

The energetic plots show on the x-axis the different simulation variants and on the y-axis the end energy demand for heating, cooling and artificial light demand, calculated by the Artlight tool. The different analyzed façade variants (FA1-FA4) are marked by the graph colour as follows: red=FA1, green=FA2, blue=FA3, magenta=FA4.

The following graphs (Figure 14 to Figure 16) show the end energy demand for heating cooling and artificial light. For the evaluation of the end energy balance it is assumed to have heating and cooling provided by an air-to-air heat pump system. Therefore, the heating case is estimated with a COP of 3.5 and the cooling case with a COP of 2.5.

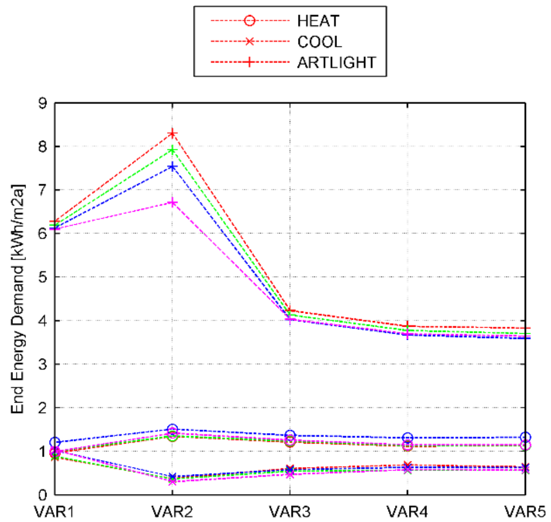

Figure 14: End energy demand, system set 1 (red=FA1, green=FA2, blue=FA3, magenta=FA4)

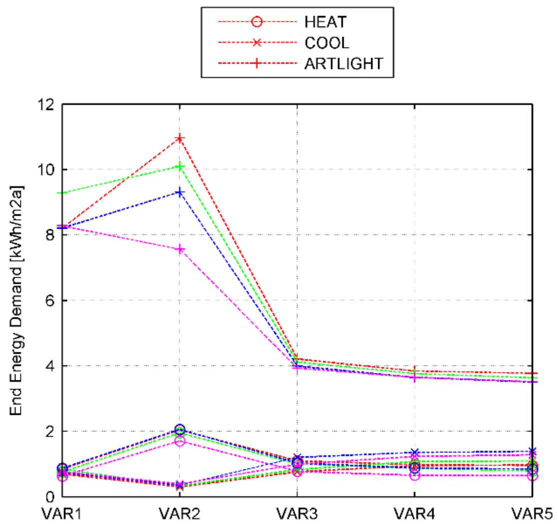

Figure 15: End energy demand, system set 2, (red=FA1, green=FA2, blue=FA3, magenta=FA4)

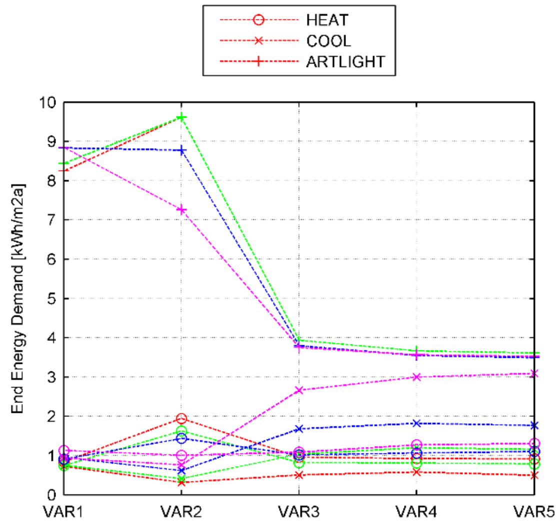

Figure 16: End energy demand, system set 3 (red=FA1, green=FA2, blue=FA3, magenta=FA4)

All three system sets show a similar behaviour. Heating and cooling demand are in general low according to the high building standard. Simulation variant 2 always shows the peak heating demand while cooling is always lowest. Due to the high building standard, the end energy demand for artificial lighting is highest in all cases.

The artificial light demand shows a high peak for simulation variant 2. Due to the strict luminance criteria of maximum 1000cd/m² on the façade, the blind has to be in the closed position more often, even for diffuse daylight situations. This raises the artificial light demand significantly. Starting from simulation variant 3 the artificial light demand goes down by more than 50%. This is due to higher diffuse light entry through the façade. A maximum luminance level of 3000cd/m² mostly allows keeping the blind open in case of diffuse illuminance from the sky (no direct sunlight), which makes the daylighting especially for work places near to the façade very efficient at overcast days.

For the same reason, there is no clear improvement recognizable by further increasing the luminance threshold up to 8000cd/m² in simulation variant 5. The result for system set 3 shows, that with higher luminance thresholds the cooling load can rise significantly although the artificial light demand remains almost stable. We see from the results that the remaining artificial light demand in this case is in the morning and evening hours, when there is less daylight available.

As a sum of heating and cooling demand, simulation variant 1 shows the lowest energy demand and variant 2 the highest demand. Nevertheless, looking at the overall energy balance including artificial light, simulation variant 1 shows the second highest. Due to more frequently closed or lowered blinds in summer to counter overheating, the artificial light demand rises at the same time. Therefore, thermal control strategy is more efficient for times without occupancy, e.g. weekends and holidays. In case of former analysis, the thermal control showed mostly minor energetic improvements during occupied hours due to higher artificial light gain caused by this strategy.

From the simulation results no optimum between the different façade divisions can be concluded. In the case of strict daylight criteria (simulation variant 2), an increasing area for the DRC-part shows advantage by less artificial light demand, but in the same way it tends also to raise the cooling demand in case of system set 3.

Conclusion

This paper shows concept, structure and validation of the newly developed Artlight 2.0 routine to enable coupled thermal and daylight simulation of complex fenestration systems within TRNSYS and RADIANCE. Through its practical use in a comprehensive simulation study including different façade variants and blind systems, the functionality of the tool has been shown. Furthermore, parameter variations on the simulation model and the influence of different control strategies are worked out. Both controls represent a situation over the state of the art in real building application. The model has been validated against other established tools and first results shows Artlight 2.0 to be a satisfactory method to analyse complex façade systems in terms of their energetic and daylighting performance. Especially detailed analysis of daylight redirecting systems is possible due to the implementation of BSDFs for both thermal and daylight modeling.

The behaviour of the system settings in the simulation is realistic and shows a comprehensible operation. As a noticeable outcome, all cases show very low artificial light demands, especially in summer, on the work plane and even in the back part of the room. At first glance also the good performance of the shading system compared to daylight redirecting systems is unexpected. To analyze this, simulation studies are planned to examine on room geometries with deeper space, where daylight redirecting systems are used in reality.

Nevertheless, it is not the aim of this study to evaluate the investigated systems on their thermal and daylighting performance, but the use of Artlight 2.0. In a next step, further investigations in simulation variants including more systems and locations are planned.

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