AN EVALUATION OF RADIANCE BASED SIMULATIONS OF ANNUAL INDOOR ILLUMINANCE DISTRIBUTIONS DUE TO DAYLIGHT

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ABSTRACT

This paper presents a new, accelerated method based on *daylight coefficients* according to Tregenza [1] to calculate cumulative annual indoor illuminance distributions. Simulation results are compared with five RADIANCE based daylight simulation methods including the daylight factor method [2], ADELINE 2.0 [3] and ESP-r version 9 series [4]. An explicit calculation of the indoor illuminances under all annual hourly mean sky luminance distributions serves as a reference case against which the other methods are tested. The analysis of the results reveals that the new method exhibits the highest accuracy and lowest simulation times for all considered building geometries. The quality of an annual daylight simulation is not necessarily coupled with the required simulation times but depends on the underlying sky luminous efficacy model and whether the method considers the hourly mean direct and diffuse illuminances for each time period explicitly.

INTRODUCTION

Daylighting is a component in the building design process that aims to maximize the annual daylight availability in a building according to the occupants' needs. The benefits of daylighting can be an enhanced visual comfort coupled with an improved occupant's working productivity and a reduced energy consumption if the artificial lighting is regulated in accordance with the available daylight.

To evaluate the performance of a given daylighting concept, simulation tools are necessary to calculate the daily and seasonal development of indoor illuminance levels due to daylight as well as artificial light. Based on this information it becomes possible to estimate the energy saving potential, visual comfort and future maintenance costs, providing a platform for architects and lighting engineers on which to decide of what type of lighting system meets their expectations and personal preferences for a particular building.

While the benefits are obvious, a daylight simulation tool also needs to fulfill certain requirements to become a suitable tool for the actual *day-to-day* building design process. It should

1. yield reliable results for complex building geometries and material surfaces
2. run under calculation times on the order of minutes to a few hours
3. be able to model short time step variances of the available daylight.

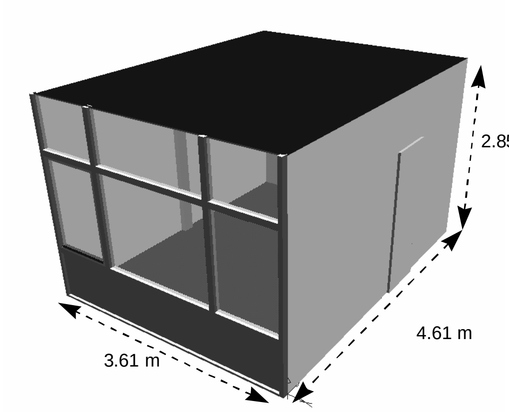
The last requirement is necessary to successfully model the performance of automated lighting concepts based on illuminance and occupancy sensors. The new method presented in this study meets all these conditions: excellent accuracy under convincing simulation times with the possibility of introducing shorter time steps. The method is compared to five other annual daylight simulations methods which have been proposed in the past to carry out annual daylight simulations, namely:

(1) complete year runs of all annual hourly mean sky luminance distributions (reference case)
(2) the daylight factor method
(3) ADELINE 2.0 [3], [5]
(4) classified weather data based on Herkel *et al.* [6]
(5) ESP-r version 9 series [4]

All these methods rely on the backward raytracer RADIANCE which is based on a mixed stochastic and deterministic raytracing approach [7] and whose results have been physically validated for a range of office geometries [8]. The advantage of a simulation based on raytracing compared to one based on radiosity is the ability to simulate specular and partly specular materials [9].

METHODOLOGY

Simulations based on the five above listed annual daylight simulation methods and the new method have been carried out for a single office and a more advanced five story office building as shown in Figure (1). Both facades are facing South. The office building has been added to discuss differences between ESP-r and the new method. Accordingly, only simulation results for ESP-r, the new method and the reference case are presented for the latter office building. All surfaces have been modeled as purely Lambertian except for the ceiling of the advanced office geometry which is partly specular. The external ground reflectance has been set to 20%. The diffuse and direct irradiance input data have been taken form the Test Reference Year (TRY) for Freiburg, Germany [10]. Using hourly illumination averages assumes that this data set yields the same cumulative distribution as all the instantaneous illuminations during the working year. The authors



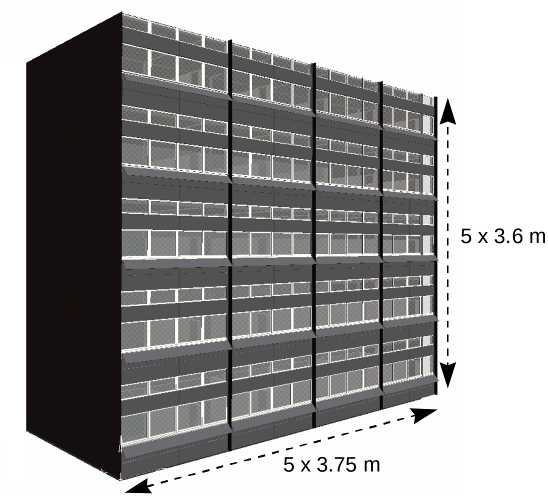


Figure 1: View of the single office and the advanced five story office building

are aware of the limitations of this model but the present paper merely concentrates on the comparison of different simulation approaches that yield mean hourly indoor illuminances data. No conclusions on the resulting artificial lighting consumption will be drawn here. For the hours of sunrise and sunset the sun position has been modeled for the middle of the time interval when the sun is above the horizon.

Since all simulations rely on RADIANCE, the same geometry and material files as well as the same set of simulation parameters could be used for all methods, i.e. differences in the cumulative illuminance distributions are exclusively due to how the respective method extracts the development of mean hourly illuminance levels form a chosen set of sky luminance distributions. The simulation results reveal how well new method approaches the reference case with respect to the other methods. Simulation errors intrinsic to the raytracing or due to geometry or material simplifications are common to all the methods including the reference case and are neglected. Errors introduced by modeling the continuously changing external daylight conditions as discrete hourly mean Perez sky luminance distributions are also discarded.

REVIEW OF SIMULATION METHODS

The following paragraph gives a short account of the underlying concepts of the methods compared in this study.

3.1 Complete year-runs

The highest amount of accuracy for annual daylight simulations is achieved by carrying out a series of raytracing runs for every daylight condition of the year. The necessary sky luminance distributions are modeled by the Perez model [11]. This time and hardware demanding method serves as the reference case in this study to quantify the accuracy of the other simulations. The underlying assumption, that this method produces the most reliable simulation results, seems to be justified to the authors since all the other methods are either based on the Perez model or the CIE skies, which are also covered by the Perez model.

Daylight Factor Method

The daylight factor, DF(x), is defined as the ratio of the indoor illuminance at point x in a building to the outdoor horizontal illuminance, under the overcast CIE sky which is rotationally invariant [12]. The annual indoor illuminance distributions follows from scaling the annual external illuminances with the daylight factor [2]. The weakness of this definition is that many TRYs provide direct and diffuse irradiances *not* illuminances. In this study the Perez luminous efficacy model has been used to get the diffuse illuminances from irradiances of the Freiburg TRY to ensure compatibility with the reference case. To overcome the rotational invariance of the daylight factor, linear correction factors have been proposed which consider the facade orientation of the investigated building [13]. For the single office an orientation factor of R_{of}=1.2 taken from [2] for a southern facade has been used. Accordingly, the illuminance, E(x) under a diffuse horizontal illuminance, $L^{diffuse}$, is given by:

$$E(x) = DF(x) \cdot R_{of} \cdot L^{diffuse} \quad (1)$$

ADELINE

The lighting simulation tool ADELINE has been developed within the Task 12 of the Solar Heating and Cooling program of the International Energy Agency [3] . The simulations are carried out in two steps. At first, the development of the indoor illuminance levels under the CIE overcast and clear skies with and without the sun are calculated for the 15th day of all months of the year with one hour time steps. In a second simulation step, hourly mean illuminance levels are approximated by mixing the corresponding clear and diffuse skies depending on the *effective sunshine probability* of the hour, according to Szerman [14].

Classified weather data

To reduce the over 4700 daylight situations, considered for a complete year-run, Herkel *et al.* have proposed a method to classify this ensemble into a set of some 450 classes [6]. In this method similar sets of daytime, sun position, direct and diffuse illuminances are grouped into classes which represent all appearing sky distributions during the course of a year. The mean global irradiances are left unaltered. This approach reduces the required calculation times by up to one order of magnitude with respect to the reference case.

Daylight Coefficients

The concept of daylight coefficients has been originally proposed by Tregenza in 1983 [1]. The daylight coefficient, $DC_{\alpha\gamma}(x)$, at a given point, x, for a sky element $\alpha\gamma$ is defined as:

$$DC_{\alpha\gamma} = \frac{\Delta E_{\alpha\gamma}(x)}{L^{total}_{\alpha\gamma}\,\Delta S_{\alpha\gamma}} \qquad (2)$$

where $\Delta E_{\alpha\gamma}(x)$ is the illuminance at x due to the sky element $\alpha\gamma$ with the total luminance $L^{total}_{\alpha\gamma}$. $\Delta S_{\alpha\gamma}$ is the angular size of $\alpha\gamma$. The decisive advantage of the daylight coefficient method over all formerly mentioned methods is that the daylight coefficients for a given point in a building merely depend on the building geometry, material characteristics and the division of the surrounding sky and ground into disjoint segments. The daylight coefficients are independent of any actual celestial sky luminance distribution. Hence, the building characteristics and the surrounding climatic conditions are separated. Once a complete set of daylight coefficients for a point in a building has been calculated, a linear superposition of the daylight coefficients with the $L^{total}_{\alpha\gamma}$ for a given sky condition yields the corresponding indoor illuminance at this point:

$$E(x) = \sum_{\gamma} DC_{\alpha\gamma}(x)\,L^{total}_{\alpha\gamma}\,\Delta S_{\alpha\gamma} \qquad (3)$$

Using Equation (3), annual daylight simulations can be carried out under simulation times in the order of minutes while still allowing to model short time step variances of the available daylight. The daylight coefficient approach resembles a higher order approximation of the daylight factor method only that $L^{total}_{\alpha\gamma}$ in Equation (3) denotes the total luminance of the sky element $\alpha\gamma$ while $L^{diffuse}$ in Equation (1) is the diffuse illuminance. The total indoor illuminance can be split into a direct and a diffuse contribution from the sun and the celestial hemisphere, respectively:

$$E(x) = DC_{sun}(x)L^{direct}_{\alpha\gamma}DS_{sun} + \sum_{\alpha\gamma} DC_{\alpha\gamma}(x)L^{diffuse}_{\alpha\gamma}DS_{\alpha\gamma} \qquad (4)$$

The following two paragraphs describe the routes followed by ESP-r and the new method to calculate a complete set of direct and diffuse daylight coefficients.

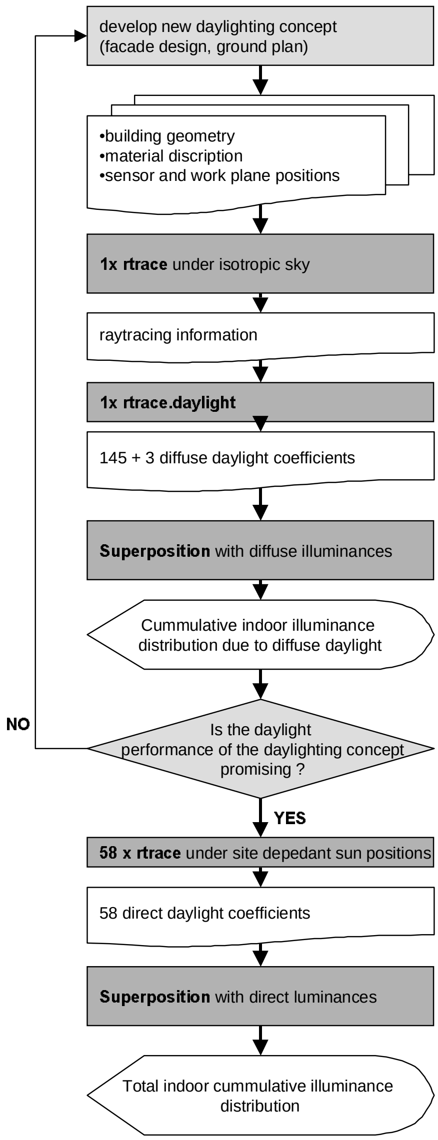


Figure 2: Flow Figure of the new method

Daylight coefficients in ESP-r

In ESP-r the RADIANCE input files are generated by a conversion of the thermal building model. The external ground is modeled by a circular ground plane of about the same size as the ground plan of the building. For the calculation of the daylight coefficients, the celestial hemisphere is split into 145 circular angular patches of equal angular size according to Tregenza [15]. The opening cone angle is set to 13.39 ^{o} to compensate for uncovered regions of the sky in between the circular patches, leading to an overlap and a double counting of several regions of the sky. Reflections from the external ground are only considered via rays that hit the aforementioned circular ground plane while over contributions due to external ground reflections are discarded. This can lead to significant errors especially for ceiling mounted sensors or regions that are mainly illuminated via reflections from the ceiling.

To calculate the 145 daylight coefficients, a new RADIANCE run is started for each sky segment in ESP-r, leading to a time consuming first simulation step. The same set of daylight coefficients is used for direct and diffuse light, i.e. the sun is modeled as an infinitely distant light source, 630 times its actual size, with a luminance reduced by a factor of 630.

Daylight coefficients in the new method

During an annual daylight simulation, RADIANCE basically repeats the same raytracing calculations a great number of times since only the sky luminance distribution changes with the investigated daylight condition. To avoid unnecessary calculations the new method calculates the diffuse daylight coefficients in a single raytracing run (Figure 2) Therefore, a RADIANCE run for given building variant is performed under an isotropic sky and all investigated rays are written into a file which serves as an input for the new C-program (*rtrace.daylight*) which in turn calculates the contributions of different sky segments to the diffuse indoor illuminance, i.e. the diffuse daylight coefficients.

The actual division of the celestial hemisphere into 145 disjoint segments used by this program is similar to the Tregenza division in ESP-r with the difference that no region of the sky is discarded since *rtrace.daylight* weighs all rays according to the direction under which they hit the sky. To include external ground reflections, three additional ground daylight coefficients have been introduced for zenith angles greater than 90^o. The three ground segments correspond to zenith angles from 90^o to 100^o, 100^o to 120^o and 120^o to 180^o.

A second C-program called *superposition* carries out the linear superposition of the hourly mean sky luminances with the diffuse daylight coefficients, i.e. the second term in Equation 4 is evaluated. For the 2428 daylight hours of the Freiburg TRY without direct sunlight, this yields the total indoor illuminances. For the remaining daylight hours, the contributions of the diffuse daylight provide a lower limit of the total illuminance levels reached. Based on this information a preliminary evaluation of the artificial lighting consumption for a given variant can be carried out. To also account for the direct sunlight - usually at a more advanced design stage - a second simulation step has to be carried out. Therefore, a second program has been written that calculates some 60 representative sun positions from all annual hourly mean sun positions for a given site. The direct daylight coefficients corresponding to these representative sun positions are calculated in distinct rtrace runs, yielding a complete set of 145 + 3 diffuse plus 60 direct daylight coefficients. The advantage of the new method is that the annual availability of diffuse daylight can be modeled under roughly the same calculation times as the daylight factor while yielding a more reliable lower limit of the daylight situation in a building. Hence, the time consuming but usually necessary, second simulation step for the direct sunlight can be reserved to a reduced number of building geometries.

The new method introduces two errors with respect to a complete year run: First, the continuous Perez sky luminance distribution is approximated by a discontinuous step function that is constant for each of the 145 sky segments. This inaccuracy can be neglected since the difference of the luminances between two neighboring sky segments is usually smaller than the absolute luminance errors caused by the underlying luminous efficacy model [11]. Second, an actual sun position is approximated by the nearest available sun position. This inaccuracy might lead to considerable errors, e.g. if a sensor point directly *sees* the sun position at the middle of a given time step while the approximated sun position is shaded or *vice versa*.

RESULTS

Simulation results for the single office are presented for seven simulation methods:

(1) complete year run (reference case)
(2) daylight factor method (DF)
(3) ADELINE
(4) classified weather data (*CLASSIFIED*)
(5) ESP-r
(6) new method considering direct and diffuse daylight coefficients (*DC total*)
(7) new method without direct daylight coefficients (*DC diffuse*)

General Features

This section explains how well the different methods simulate different weather situations.

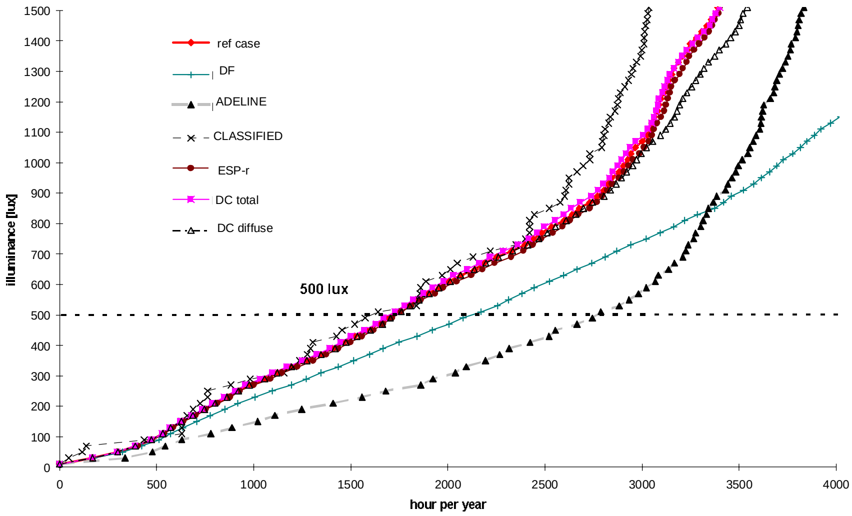


Figure 3: The annual cumulative distribution of indoor illuminance levels for a point 2.7 m away from the facade

daylight factor: The daylight factor method, DF, coincides with the reference case for the external illuminances while it constantly underestimates the internal illuminances. The first result is obvious, since an external DF is unity and since the same sky luminous efficacy model as for the reference case is used. The reason for the underestimation of the indoor illuminances on cloudy days is that the CIE overcast sky tends to underestimate horizontal sky luminances which in turn have a significant contribution to indoor illuminances at deeper room depths [1]. Under irradiance conditions with a direct component DF clearly underestimates the illuminance values since only the contribution of the diffuse daylight is considered (Eq.1).

ADELINE: On a cloudy day ADELINE constantly underestimates both indoor and outdoor illuminances. This clearly shows that ADELINE does not consider the given hourly mean diffuse illuminance values but always relies on the same CIE overcast sky of the corresponding month in the absence of direct sunlight. On the clear day, ADELINE approaches the reference case for external and internal illuminances since the Perez sky for a clear sky basically coincides with the clear CIE sky but for partly cloudy days the method tends to underestimate the diffuse illuminance distribution since a mixture of the two CIE skies fails to model bright overcast skies. In contrast to that, the Perez model is able to distinguish between bright and dark overcast skies.

CLASSIFIED: The classified data slightly overestimates the external illuminances while the internal illuminances are underestimated. The errors follow from the classification since every hourly mean illuminance condition is merely approximated by its nearest available weather class. The magnitude of the errors can be reduced by increasing the number of weather classes on the expense of longer calculation times. The results for ADELINE and *CLASSIFIED* show that a method only yields convincing simulation results if the diffuse and direct weather data is considered for each time step.

ESP-r and DC total: The results of ESP-r and *DC total* (the new method) lie very close together with the reference case. For a cloudy day the simulation results basically coincide with the reference case since the main error introduced by the daylight coefficients is that the continuous Perez sky luminous distribution is approximated by a discontinuous function. In the presence of direct sunlight, another error source is introduced since both methods approximate the hourly mean sun position by the nearest sun position for which a daylight coefficient is available. The relative root mean square errors (RMSE) for diffuse sky conditions alone are 6% (ESP-r) and 3% (*DC total*) for internal illuminances in the single office at a distance of 2.7 m from the facade. The RMSEs amount to 19% and 16% if the hours with direct sunlight are considered as well.

DC diffuse: DC diffuse and DF are the only two methods that merely consider diffuse daylight. The two diffuse methods perform equally well for the

Table 1: RMSE of the cumulative annual illuminance distribution for of all nonzero annual illuminances <1000 Lux and <500 Lux in the single office

	RMSE <1000Lux	RMSE < 500 Lux	simulation times
ref. case	-		12 days
DF	12 %	13 %	6 min
ADELINE	25 %	30 %	25 h
CLASSIFIED	25 %	30 %	20 h
ESP-r	5 %	5 %	3 h
DC total	2 %	2 %	1.5 h
DC diffuse	2 %	2 %	8 min

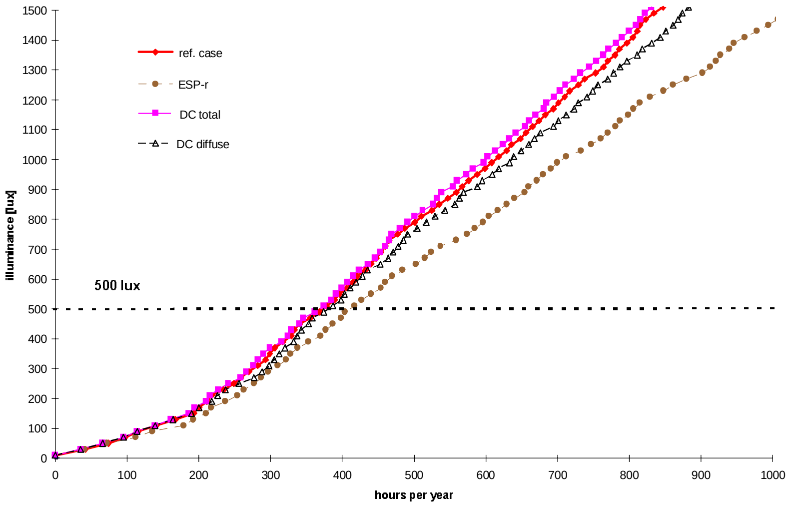


Figure 4: The annual cumulative distribution of indoor illuminance levels on the aisle behind the office on the 5 th floor of the office building

external illuminances, since they both rely on the Perez luminous efficacy model. On the contrary *DC diffuse* models the diffuse indoor illuminances more accurately than DF since it considers the luminance distribution of the celestial hemisphere while DF is merely based on the integral external illuminance. Since both methods roughly require the same simulation times, *DC diffuse* should be preferred over the DF method.

Simulation times

The last column in Table 1 shows the simulation times for all methods on a Pentium Pro 200 MHz Linux Workstation. The simulation times of 12 days for the reference case for the simple building geometry of the single office show that this method is unfit for *day-to-day* design proposes. ADELINE and *CLASSIFIED* have simulation times which are about an order of magnitude smaller than for the reference case. ESP-r requires roughly twice as long calculation times as *DC total* since only 59 instead of 145 rtrace runs have to be carried out. DF and *DC diffuse* have nearly the same calculation times for the necessary raytracing calculations. Only *rtrace.daylight* requires some extra time to extract the diffuse daylight coefficients from the raytracing results.

Cumulative annual illuminance distributions

A helpful number to judge the daylight availability in an office is how many hours per year a predefined minimum illuminance level cannot be maintained by daylight alone. This information can be drawn from the cumulative annual indoor illuminance distribution for a given point in a building. Figure 3 shows the cumulative indoor illuminance distribution for all seven methods for a point in the single office at 2.7 m distance form the facade. Table 1 presents the relative RMSEs with respect to the reference case for the cumulative illuminance distributions in Figure 3. The RMSEs are referring to annual hours with nonzero external illuminances at which the indoor illuminances lie below 1000 Lux and 500 Lux, respectively. The DF cumulative distribution lies below the reference case for all regions while *DC diffuse* basically coincides with the reference case up to illuminance values of 1000 Lux with an RMSE of only 2 % as opposed to 12 % for the daylight factor.

ADELINE constantly underestimates the cumulative distribution for illuminances up to 1500 Lux. Above this value the most of the simulated values are simulated under clear sky conditions which provide a much better approximation of the reference case than the CIE overcast sky.

CLASSIFIED approaches the reference case reasonably well up to about 1000 Lux. The plot approaches the reference case in steps, due to the bundling of the single hourly mean illuminances into classes. This causes high RMSEs around 25%. Above 1000 Lux the contributions from the direct daylight dominate the cumulative distribution.

Figure 3 further reveals that DC direct, ESP-r and the reference case basically coincide for all illuminance values. The RMSEs lie around 2% for *DC total* and 3% to 5% for ESP-r.

ESP-r and new method

Table 2: RMSE of the cumulative annual illuminance distribution for all nonzero annual illuminances <1000 Lux and <500 Lux in the office building

	RMSE < 1000 Lux	RMSE < 500 Lux	simulation times
ref. case	-	-	80 days
ESP-r	37 %	54 %	2 days
DC total	6 %	2 %	1 day
DC diffuse	8 %	6 %	1 h

The simulation results for the single office have clearly shown that the two daylight coefficient methods are the most efficient and accurate methods to predict hourly mean indoor illuminances and annual cumulative indoor illuminance distributions. Further simulations for the more advanced office building have been carried out to describe the differences between these two methods.

Figure 4 presents the cumulative indoor illuminance distribution for a point on the fifth floor of the building. The point is situated on the aisle north of the offices and all daylight enters the aisle via the offices, since the inner walls are glazed from 2 m to ceiling height (3.4m). Table 2 lists the relative RMSEs for the cumulative distributions in Figure 4 with respect to the reference case. The calculation time for the complete year run would have been 80 days on a single machine but the calculations have actually been carried out in parallel on a total of 15 UNIX and Linux workstations.

Figure 4 shows that ESP-r significantly underestimates the indoor illuminance levels on the aisle. The RMSE ranges from 37% to 54% as opposed to 1% and 6% for *DC total*. Comparing how often the illuminance levels in the aisle fall below 500 Lux the reference case predicts 420 hours as opposed to 475 hours by ESP-r and 428 hours by the new method. The reasons for this significant underestimation of the indoor illuminances of ESP-r can be concluded from an analysis of the single hourly mean illuminance levels. The relative underestimation of the ESP-r results compared to the reference case constantly lies around 25% for both direct as well as diffuse daylight. This indicates that the error is not linked to simulation of the sky luminances distribution but to the daylight coefficients in ESP-r. As mentioned above ESP-r does not consider any external ground daylight reflections that lie out of the circular ground plane inserted by ESP-r into the building geometry. Therefore, the majority of rays which would hit the ground is discarded in ESP-r. For a region in a building that is mainly illuminated indirectly via multireflected daylight, like the example point on the aisle or like a ceiling mounted sensor, this systematic underestimation can lead to the significant simulation errors shown above.

CONCLUSION

The results from the last section revealed several aspects that should be remembered when choosing a method to simulate the annual availability of daylight in a building:

Longer simulation times are not necessarily coupled with a higher accuracy of the simulation results.

The utilized external illuminance data decisively influences the simulation results. The comparison of the results for DF and *DC diffuse* shows that the integral illuminance of the sky has a stronger impact on the reliability on the indoor illuminance values than the sky luminance distribution, i.e. the difference of *DC diffuse* and DF is less pronounced than the difference between ADELINE and DF. Since usually only direct and diffuse irradiance data is available the utilized luminous efficacy model should be chosen with great care. Since the Perez luminous efficacy model is able to model overcast skies of varying brightness it should be given preference over the CIE model.

An annual simulation method should consider direct and diffuse illuminance values for each time step individually. The bundling of similar daylight situations into a few classes or the consideration of monthly mean daylight levels leads a smoothing of the actual short time step variances of the available daylight and hence to less reliable simulation results. On the contrary, an annual simulation tool should be able to predict the development of indoor illuminances in times steps of several minutes. The necessary input data can be either measured or generated from hourly data.

These findings harmonize well with the requirements for a simulation tool, fit for daily usage, formulated in the introduction and provide a basis on which the six compared simulation methods can be evaluated:

Complete year run: The simulation times between 12 and 80 days revealed that this method will probably be restricted to academic purposes at least in the near future. For weather input data with time steps below an hour the method is clearly apt to fail.

Daylight factor and DC diffuse: Concerning the required calculation times the daylight factor yields satisfying results for diffuse daylight and simple building geometries if coupled with reliable external illuminances. A major weakness of the daylight factor is the underlying CIE overcast sky. *DC diffuse* is a higher order approximation of the indoor illuminance values due to diffuse daylight and yields results that approximate the reference case for diffuse daylight conditions with a RMSE around 3 %. Since the simulation times of both methods are very similar, *DC diffuse* should be preferred over DF. A practical acceptance barrier for *DC diffuse* might be that a single percentage number is easier to communicate to *non-experts* than a set of 148 daylight coefficients. This difficulty can be overcome by providing an intuitive number instead, e.g. the number of hours per year that the artificial lighting needs to be turned on.

ADELINE: The relatively poor performance of ADELINE in this study can be attributed to the utilized luminous efficacy model and the smoothing of the weather data discussed under 2. and 3. The accuracy of the simulation results could be greatly enhanced by scaling the overcast sky with the actual diffuse illuminances for a given time step, comparable to the daylight factor method.

CLASSIFIED: The weakness of the classified data is also covered by point 3. The cumulative distribution of the classified data shown in Figure 3 has shown that the cumulative illuminance distribution generally approaches the reference case for illuminances below 1000 Lux. The high RMSEs are caused by the step-like shape of the plot due to the classification. As has been mentioned above, the accuracy of the simulation could be enhanced by increasing the simulation times, but since the necessary calculation times are already high - compared to the other methods- this procedure does not seem promising at this point.

ESP-r and DC total: All results in this study showed that the daylight coefficient approach exhibits the best results with respect to the reference case. The calculation times range from a few minutes to a day and the method allows for shorter time step variances of the available daylight at hardly any time expenses.

The two different methods perform equally well for a simple office geometry, but a set of ground daylight coefficients should be integrated into ESP-r to account for ground reflectances which can play a significant contribution in more advanced building geometries.

Concerning the design process of a building the new method features the advantage that the diffuse daylight can be modeled in an very efficient way. This way greater number of variants can be pre-screened at an early stage. The time demanding second simulation step can be postponed to a later stage. Nevertheless, the contribution of the direct sunlight are necessary for a thorough performance evaluation which covers the aspect of glare and the modeling of the manually controlled blind systems.

Finally, it should be stressed that all annual daylight situations can only perform as well as the facade elements and blind system of the investigated building can be modeled by RADIANCE for a single given sky condition. For a movable system like venetian blinds a set of daylight coefficients has to be calculated for several intermediate blind positions between which one has to interpolate. On the other hand, the daylight factor method is open to take advantage of any future improvements both of the raytracing algorithms in RADIANCE as well as the sky luminous distribution models.

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