EXPERIMENTAL VALIDATION OF 3DS MAX® DESIGN 2009 AND DAYSIM 3.0

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ABSTRACT

This paper compares daylight simulation results generated with two simulation programs, 3ds Max® Design 2009 and Daysim 3.0, to indoor illuminance measurements in a sidelit space. The sidelit space was in a single location, but was configured with five fenestration and glazing options, and operated under a variety of sky conditions. Both programs were given external direct and diffuse irradiances as simulation input, from which they had to predict indoor illuminances on a grid of upward facing work plane sensors and downward facing ceiling sensors. The comparison of both programs with measurements demonstrated that 3ds Max Design simulated indoor illuminances for the daylighting test cases with reliability comparable to Daysim. Most mean bias errors and root mean square errors were in the range of those reported in earlier validation studies. Both programs succeeded in reproducing measurements for a sidelit space with and without a lightshelf. While 3ds Max Design consistently underestimated the incoming light flux going through a translucent panel, Daysim results were lower than measurements for the internal venetian blind test case. The results suggest that the accuracy of both programs is sufficient for typical daylighting design investigations of spaces with complexity comparable to the five investigated daylighting test cases.

INTRODUCTION

The Radiance backward raytracer is a lighting simulation program that was initially developed by Greg Ward in the late eighties at Lawrence Berkeley National Laboratory (Ward and Rubinstein, 1988). The program generally enjoys the status of a ‘gold standard’ among daylight simulation programs as manifested e.g. in a 2006 survey of close to two hundred daylighting modelers from twenty-seven countries who expressed a strong bias towards Radiance. The survey participants named over forty different software packages that they frequently used but over 50% of all votes went to tools that are based on Radiance (Reinhart and Fitz, 2006). What are the reasons for Radiance’s reputation? Commonly quoted qualities of Radiance are its flexibility, the fact that it is ‘physically based’, and its capability to simulate complex geometries with various reflection and transmittance material properties. But, other raytracing programs offer comparable flexibility. So, one might conclude that Radiance’s reputation is partly founded on a series of independent validation studies that investigated how closely Radiance simulation predictions approach physical measurements under thousands of sky conditions in full-scale spaces with either a clear glazing and a lightshelf (Mardaljevic, 1995), venetian blinds (Reinhart and Walkenhorst, 2001), or a translucent glazing (Reinhart and Andersen, 2006). For a detailed discussion of these validation studies, the reader is referred to the Reinhart/Andersen study.

If validation studies based on measured data carry such weight among design practitioners interested in physically based simulation, it initially seems surprising that there are so few comparable validation studies for other simulation programs available. One could argue that measurement-based validations are expensive. However, the British Building Research Establishment (BRE) has offered a very rich data set of indoor illuminances in a full-scale test room for many years (Aizlewood, 1993). Surprisingly, to the authors’ knowledge, only one researcher has ever used the BRE data set extensively (Mardaljevic, 2000). Whatever might be the reasons for the limited use of the BRE data, a new data set has been recently collected in the Daylighting Laboratory of the National Research Council Canada (NRC) in Ottawa, Canada (45°N, 76°W). The data set consists of measured indoor and outdoor illuminances as well as direct and diffuse outdoor irradiances for five daylighting test cases of varying complexity. Thousands of measurements under a range of sunny and cloudy sky conditions were collected for each test case. The test cases, schematically shown in Figure 1, are a basic sidelit space with a standard double glazing (TC1), the same space with a diffuse lightshelf (TC2), translucent panels instead of clear glazings (TC3), an external venetian blind (TC4) and an internal venetian blind (TC5). The different elements are increasingly difficult to simulate so that the cases can be grouped into low, intermediate and high complexity.

The authors decided to generate this new data set instead of simply using the BRE data for a variety of reasons. The new data set expands the BRE data in the sense that a wider variety of test cases were investigated that are more challenging to model than a clear glazing and a diffuse lightshelf. A larger objective of this work is to promote the use of validation studies among software developers and having its own data set will allow the NRC to further distribute it to other parties. An acknowledged limitation of the new data set is that direct and diffuse irradiances were collected instead of the actual sky luminance distributions. The absence of measured sky luminances limits the evaluator's capability of differentiating between modeling errors introduced by the sky model versus the global illumination engine. On the other hand, this combined error is what a user has to deal with in practice. An extended discussion on the topic can be found in Reinhart and Andersen (2006).

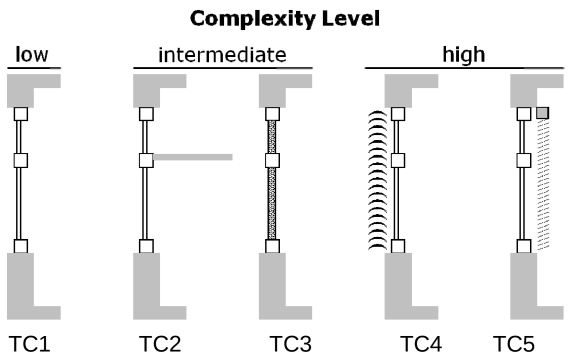

Figure 1 Façade sections of the five NRC daylighting test cases.

This paper summarizes results from a recent study in which the the NRC daylighting test cases were used to evaluate the simulation capabilities of two simulation programs, 3ds Max® Design 2009 (3ds Max Design) and Daysim 3.0 (Daysim). A detailed report of all study findings can be found under (Reinhart and Breton, 2009).

METHODOLOGY

NRC Daylighting Test Cases

All test case measurements were collected in the East room of the NRC Daylighting Laboratory. As shown in Figure 2, the laboratory consists of two identical sidelit spaces which are facing South-southeast (25.2º from due South). The East room (room on the right) is 2.85 m wide, 2.96 m high and 4.5 m deep and has a window-to-wall-area of 58%. There is a roughly 1.9 m high hedge in close vicinity to the two test rooms. The hedge was planted to visually separate the test rooms from the building surroundings, giving someone working in the test rooms an enhanced feeling of privacy. This measure was required since the test room is also used for human subject research. For the duration of the test case measurements, the hedge was covered with a black cloth to reduce simulation errors due to inaccurate reflectances off the hedge.

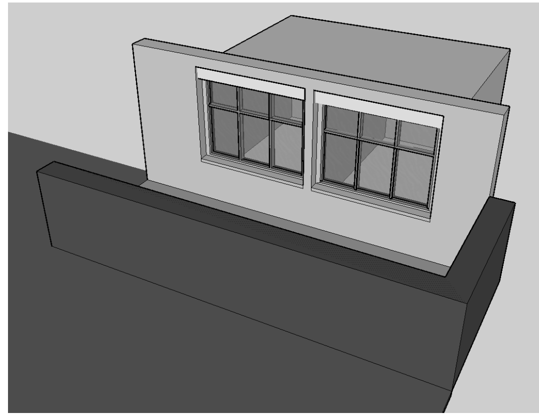

Figure 2: SketchUp model of TC1 (base case).

Interior illuminance measurements were taken with fifteen Licor illuminance sensors for TC1, TC2, TC4, and TC5 and five Licor illuminance sensors for TC3. All Licors were calibrated before and after the experiment and the measurement error of all sensors was determined to lie within a 5% band. Most outdoor direct and diffuse irradiances and illuminances were collected every 30 seconds using a Yankee rotating shadowband radiometer. For eight of the fourteen measurement days for test case TC1 a BF3 sensor was used to collect outside direct and diffuse irradiances as the Yankee had unexpectedly stopped running on these days.

For TC1, TC2, TC4 and TC5 interior illuminances were collected on a grid of twelve upward facing illuminance sensors at desk height (85cm above the ground). For TC3 only two work plane illuminances were collected on the central axis of the room at 1.5 m and 3.0 m distance from the façade. For all five test cases ceiling illuminances were collected at three locations along the central axis of the test space.

In order to model the space in various daylight simulation programs detailed SketchUp models of all five test cases were generated (SketchUp, last accessed December 2008). The estimated tolerance for modeling errors in the geometry is below 20 mm. Since previous simulation studies have shown that modeling the exterior ground is crucial, the hedge and the surrounding ground adjacent to the test space were geometrically modeled as well. Complementing the SketchUp files, the optical characteristics of all materials were carefully measured and documented along with the material descriptions that were used in Daysim and 3ds Max Design. Details can be found in (Reinhart and Breton, 2009).

For all test cases measurements were taken under a variety of sunny and cloudy sky conditions. While the original measurement interval was 30 seconds the data was averaged down to 15 minute time step intervals. The resulting number of sky conditions collected for each test case when the outside vertical façade illuminance was over 1000 lux ranged from 1751 for TC5 to 3107 for TC3.

Daysim Simulations

Daysim is a Radiance-based advanced daylighting analysis tools that uses a daylight coefficient approach combined with the Perez all-weather sky model (Perez, Seals and Michalsky, 1993) to predict hourly or sub-hourly time series of interior daylighting conditions based on direct and diffuse irradiances taken from a TMY file. Since Radiance in its original form ('Radiance Classic') simulates lighting conditions due to daylight under one sky condition at a time and since each calculation typically takes several minutes to hours, Daysim was developed to more efficiently calculate illuminance or luminance time series under varying sky conditions (Reinhart and Walkenhorst, 2001). A Daysim analysis typically extends over a whole calendar year and includes thousands of sky conditions. In order to process that many sky conditions within a reasonable time frame Daysim uses a daylight coefficient approach (Tregenza, 1983). Daysim results tend to be very similar to Radiance Classic results especially under overcast sky conditions. Under sunny sky conditions Daysim simulation results can somewhat diverge from Radiance since Daysim interpolates direct solar contributions for particular sky conditions from four neighboring, representative sky conditions. Daysim 3.0 uses the recently developed dynamic daylight simulation (DDS) daylight coefficient file format combined with direct shadow testing at each time step to get as close to Radiance Classic as possible (Bourgeois, Reinhart and Ward, 2008). Note though that the Daysim results reported in this study are not identical to those Radiance Classic would have generated.

In order to model the five test cases in Daysim a publicly available SketchUp plug-in, developed by Thomas Bleicher, was used that exports SketchUp scenes into Radiance format. All materials were modeled according to (Reinhart and Breton, 2009). Table 1 lists the simulation parameters that were used for all five test cases.

Table 1: Utilized Radiance simulation parameters.

ab	ad	as	aa	ar
7	1500	100	0.05	300

3ds Max Design Simulations

Lighting calculations using 3ds Max Design are based on Exposure technology. Exposure is a lighting analysis feature that includes a 'shader' of the Perez Sky Model. In other words when using the same input parameters 3ds Max Design uses the same sky luminance distribution as Daysim. For the global illumination calculation Exposure uses the mental ray raytracer. Global illumination is the simulation of all light inter-reflection effects in a scene. mental ray offers two fundamental approaches to compute global illumination which can be used together: Forward raytracing (photon mapping) and backward raytracing (final gathering) (mental-images, 2007). mental ray supports a variety of lighting phenomena including reflections, refractions, global illumination, and subsurface scattering. Similar to the ambient interpolation feature in Radiance full final gather tracing in mental ray is performed only on distinct and well-selected surface points (sensors). All other surface points interpolate the global illumination contribution from nearby final gather points. Discrete 3ds Max Design simulations were run for each measured sky condition individually. For each test case the required simulation time to calculate indoor illuminances under a single sky condition was in the order of 6 to 12 seconds on a 2 Quad Core Xeon Processor (2.66Ghz). A discussion of the required simulation times for 3ds Max Design and Daysim is presented in the discussion section.

Table 2 lists the mental ray simulation settings in 3ds Max Design that were used in this study. Since this is the first experimental validation study of 3ds Max Design, the simulation parameters were initially optimized based on the measurements from the five test cases. The optimization process included both simulation accuracy as well as simulation time. Once a set of simulation parameters had been selected, they were consistently used for all five test cases.

Table 2: Utilized 3ds Max Design simulation parameters.

3ds Max Render Dialog	Section	Parameter
Rendering Algorithms	Scanline	Enable: Off
Rendering Algorithms	Raytracing	Enable: On Max Trace Depth: 10 Max Trace Reflections: 10 Max Trace Refractions: 10
Shadows & Displacement	Shadows	Enable: On Mode: Simple
Final Gather	Basic	Enable Final Gather: On Multiplier: 1.0 Initial FG Point Density: 1.0 Rays per FG Point: 2500 Interpolate Over Num. FG Points: 5 Diffuse Bounces: 6 Weight: 1.0
Final Gather	Advanced	Noise Filtering: None Max Depth: 10 Max Reflections: 10 Max Refractions: 10 Use Falloff (Limit Ray Distance): Off
Final Gather	FG Point Interpolation	Use Radius Interpolation Method: Off
Caustics & Global Illumination	Caustics	Enable: Off
	Global Illumination	Enable: Off

RESULTS

In this section selected simulation results from 3ds Max Design and Daysim are compared to measured indoor and outdoor illuminances. More results can be found under (Reinhart and Breton, 2009).

Façade Illuminances

Figure 3 compares simulation results for 3ds Max Design and Daysim to measurements for the outside vertical facade sensor on a sunny day. In this and later figures the measured data is indicated by the line labeled "Benchmark". The figure shows that both simulation programs predict close to identical outside façade illuminances under sunny sky conditions. One would expect this finding as both programs are based on the same sky model. Under sunny sky conditions the simulations are within a 5 to 10% error band with respect to measurements. Under partly cloudy sky conditions (not shown here) the simulations also closely follow the up and down movements of the measurements and mostly lie within a 10 to 15% error band but - at times - simulations diverge by as much as 37% from the measurements. These findings reproduce those from earlier validation studies and show that the Perez model reaches its limits under partly cloudy sky conditions with quickly varying cloud cover (Reinhart and Walkenhorst, 2001).

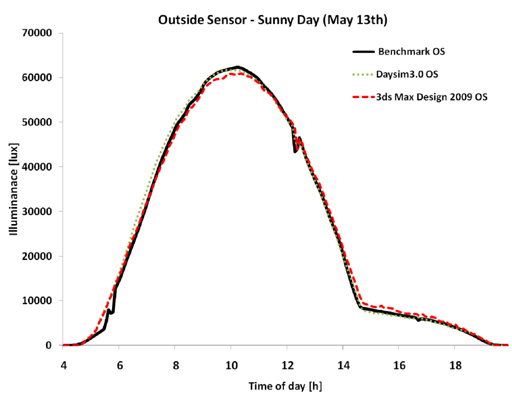

Figure 3: Measured and simulated vertical façade illuminances on the outside sensor on a sunny day.

Base Case (TC1) and Lightshelf (TC2)

Figure 4 shows measured and simulated indoor illuminances for an upward facing desktop sensor near the façade for the sunny day from Figure 3 for TC1. The pronounced variations in Figure 4 from over 40000 lux to below 7000 lux at about 9.45 a.m. and 10.45 a.m. were caused by the two vertical window mullions shading the sensor. Both simulation programs successfully model the effect. Note though that Daysim and the measurements only show a fifteen-minute peak at around noon whereas the 3ds Max Design peak is a bit wider. These differences are likely caused by slight difference of where 3ds Max Design and Daysim predict the sun to be located on the celestial hemisphere. Such differences can occur when a sensor is exposed to or shaded from direct sunlight for a brief time interval.

Figure 5 compares measured and simulated illuminances for a front work plane sensor for TC2 on a partly cloudy day. The figure shows that 3ds Max Design and Daysim simulations are very close under partly cloudy sky conditions and reproduce well the measurements. Similarly close results were obtained for all other work plane and ceiling sensors throughout the space for illuminances that ranged from under 100 lux to over 6000 lux covering the whole spectrum of illuminance conditions that are typically encountered in buildings.

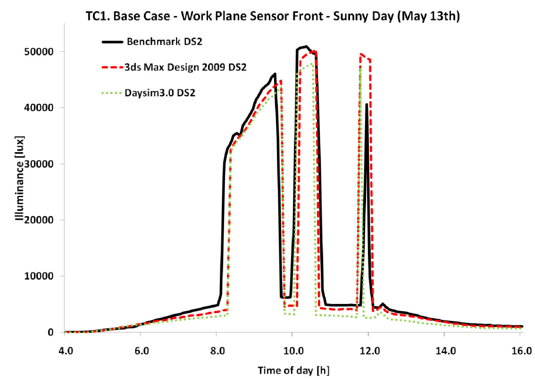

Figure 4: Measured and simulated illuminances for an upward facing work plane sensor close to the façade for TC1 (base case).

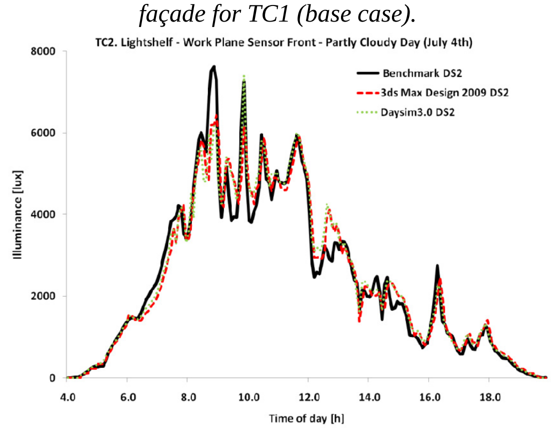

Figure 5: Measured and simulated illuminances for a front work plane sensors for TC2 on a cloudy day.

Translucent Glazing (TC3)

TC3 explores how the two simulation programs manage to simulate a 'non standard' material such a translucent panel. The panel was previously characterized using goniophotometer and integrating sphere measurements (Reinhart and Andersen, 2006). Daysim results are based on a transdata material modifier that models the angle dependant direct hemispherical transmittance of the panel according to integrating sphere measurements. In 3ds Max Design the panel was modeled as an ideal diffuser. According to the integrating sphere measurements the diffuse-diffuse hemispherical transmittance of the diffuser was set to 16%.

Figure 6 shows simulated and measured indoor illuminances under a sunny day for a front work plane. As shown before (Reinhart and Andersen, 2006), Daysim closely follows the measurements.

3ds Max Design reproduces the overall behavior of the measurements but there is a constant 'offset' between measurements and simulations suggesting that the diffuse transmittance specified for the translucent panel in mental ray is lower than the input value of 16%. According to Autodesk Media & Entertainment 'Autodesk is working with mental images [the makers of mental ray] to resolve this issue'.

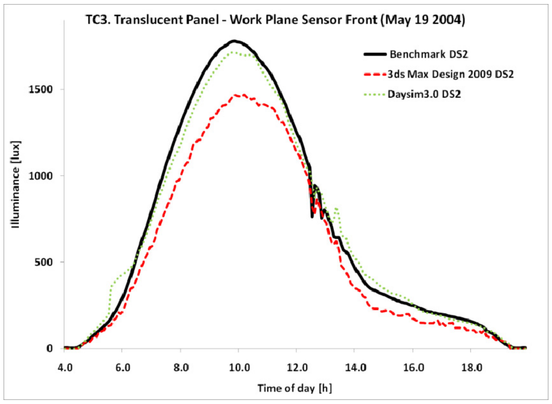

Figure 6: Measured and simulated illuminances for TC3 Translucent Panel.

Venetian Blinds (TC4 and TC5)

Test cases TC4 and TC5 evaluate how well a simulation program can model a complex fenestration system (CFS) such as external (TC4) or internal (TC5), downward-curved, venetian blinds. For both test cases the blinds were fully lowered. The external venetian blind system was a split blind system meaning that the upper third of the slats can be adjusted to be more open than the lower slats. The internal blinds (TC5) were a standard, manually adjusted system. For both systems the slats were set as close to horizontal as possible which proved to be somewhat of a challenge for the external blinds. Another modeling challenge for these test cases was that the curved blind slats had some specular component which was estimated to be 6% for the external venetian blinds and 2% for the internal venetian blinds using a Minolta CM2500d spectrophotometer. The curvature of the blinds was measured as accurately as possible for both venetian blind systems. Despite the importance of the blinds' curvature for the simulation results it is one of the simulation inputs that are most prone to errors due to measurement uncertainties and differences between individual slats. Figure 7 shows simulated and measured illuminances under partly cloudy sky conditions for a back ceiling sensor for TC5. Despite the aforementioned complexity involved in modeling venetian blinds, both simulations do a reasonably good job in reproducing the measured data under partly cloudy sky conditions. Daysim results lie very close to measurements except during about 10 a.m. to noon. During brighter periods of the day 3ds Max Design tends to lie 20% to 40% below the measurements.

Figure 8 shows simulation results for the external venetian blinds (TC4) under clear sky conditions for a ceiling sensor near the facade. Since most incoming direct sunlight was entering the space at an upward angle the front ceiling sensor gives a good indication of how well the light redirecting effect of the blinds was modeled on that day. 3ds Max Design overestimates the amount of sunlight being reflected off the slats whereas Daysim results are closer to the measurements except when the sun is roughly perpendicular to the façade (8 a.m. to noon). The differences between the measurements and simulations are reduced for both programs as the sun moves around the façade confirming that these simulation errors are caused by the programs' inability to correctly reproduce the sunlight's reflection off the blinds. These modeling uncertainties are not really surprising since specular components of curved surfaces are hard to measure with a handheld spectrometer and actual blind slat angles are hard to measure and might vary between slats.

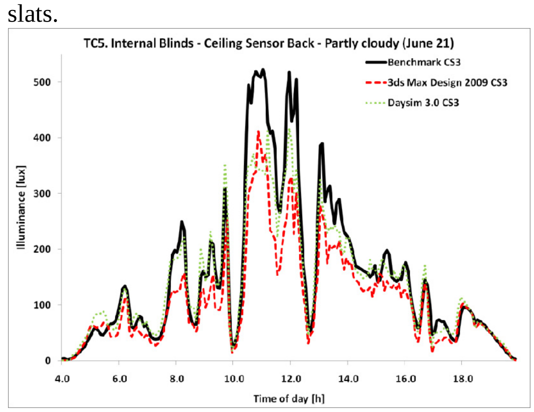

Figure 7: Measured and simulated illuminances for TC5 under partly cloudy sky conditions.

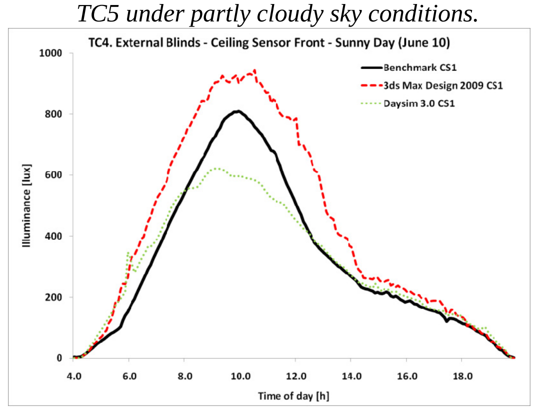

Figure 8: Measured and simulated illuminances for TC4 under sunny sky conditions.

Error Analysis

In order to provide a more holistic analysis of the differences between the simulation programs compared to the measurements, the relative mean bias error (MBE) and the relative root mean square error (RMSE) with respect to the measurements were calculated for all five test cases (Table 3).

Table 3: Mean Bias Errors and Root mean Bias Errors for all test cases. MBEs (RMSEs) smaller than -20% (-32%) or larger than 20% (32%) are marked in bold red.

Test Case		**MBE**				**RMSE**			
TC.0 Outside Sensor	3dsMax Daysim	9 7				17 14			
		Work Plane		**Ceiling**		**Work Plane**		**Ceiling**	
		Front	**Back**	**Front**	**Back**	**Front**	**Back**	**Front**	**Back**
TC.1 No Shading Device	3dsMax Daysim	11 -11	6 -4	-5 -16	18 -7	**110** (28) **73** (31)	29 24	28 **34**	28 22
TC.2 Lightshelf	3dsMax Daysim	2 -10	8 -2	13 1	**20** 0	24 26	28 21	21 21	28 20
TC.3 Translucent Panel	3dsMax Daysim	**-22** 4	**-28** 10	-18 8	**-39** 1	25 15	30 21	22 20	**40** 17
TC.4 External Blinds	3dsMax Daysim	**20** -6	18 -12	6 7	15 11	**41** 21	30 24	24 22	27 25
TC.5 Internal Blinds	3dsMax Daysim	-12 **-31**	2 -12	-12 **-27**	-16 -3	**49** 34	25 26	**32** **32**	28 25

Measurements were only considered for the error analysis if the measured outside façade illuminance was above 5000 lux. This selection criterion was used since the Perez sky model becomes sensitive to measurement uncertainties of input direct irradiances just after sunrise or before sunset. For test cases TC1, TC2, TC4 and TC5 errors for front and back work plane sensors are the mean of the three front row sensors and three back row sensors.

It is important to note that there currently does not exist a standard or common reference that suggests how high or low typical MBEs and/or RMSEs should be for a simulation to be considered 'reliable'. In a previous validation study of Daysim the largest MBE and RSME found were 20% and 32%, respectively (Reinhart and Walkenhorst, 2001). In order to help the reader interpret the results from Table 3, MBEs and RMSEs beyond ±20% and ±32% are therefore colored red bold in order to flag an 'unusually high' value.

One striking 'anomaly' for TC1 are the RMSE values for the front row of 110% for 3ds Max Design and 73% for Daysim. The reason for these large errors can be inferred from Figure 4. While the figure shows that both simulation programs succeed in reproducing the ups and downs of the front row sensor as it is moving in and out of direct sunlight, there are some small time shifts between the peaks. While it remains unclear what exactly caused these shifts, they result in some very large MBEs and RMSEs where the peaks do not fully overlap, i.e. according to the measurement the sensor is in direct sunlight but the simulation predicts otherwise and vice versa. For the MBEs these large errors average out but for the RMSEs they add up to the large values shown in Table 3. In order to demonstrate the magnitude of this 'shift effect' the numbers in brackets following the true RMSEs of the front work plane sensors for TC1 in Table 3 correspond to the RMSEs with the maximum relative error at each time step clipped to 100%. As one sees this brings the RMSEs for 3ds Max Design and Daysim down to more typical values of 28% and 31%, respectively.

Another series of large errors in Table 3 were caused by the earlier discussed underestimation of the 3ds Max Design simulations for the translucent panel. Finally, there are a few out-of-range errors for 3ds Max Design and Daysim for the venetian blind test cases.

DISCUSSION

Practical Considerations

The previous section presented how simulation results generated using two lighting simulation programs compare to measured data for five sidelit test cases. What are the implications of these results for a design practitioner? Under what circumstances can he or she now use these tools with confidence? An obvious but critical requirement for any simulation program to yield reliable results is that the user knows how to correctly use it, i.e. that he or she models a scene of interest in sufficient geometric detail, correctly specifies all scene materials and uses adequate simulation parameters. While a simple software can meaningfully support certain design decisions if the user understands its limitations, an advanced software may provide useless results if the user does not understand the software's underlying models. The following discussion assumes that all lighting simulations are done by a qualified user. Given this caveat, the results section has shown that 3ds Max Design and Daysim manage to approximate interior lighting levels in a variety of spaces based on direct and diffuse outside irradiances. How far can these results be generalized to other buildings, and are the observed modeling accuracies 'close enough'? This depends on what a user hopes to accomplish using simulations.

Most design practitioners currently use lighting simulation programs to visualize their designs for a qualitative analysis and client presentation purposes. Depending on the type of analysis it might or might not be important to the designer whether the simulated images are 'real' in terms of absolute luminance levels. The authors would argue that as a bare minimum for even the most rudimentary type of daylighting analysis the position of the sun in the sky has to be modeled accurately. Figure 4 shows that this is the case for 3ds Max Design and Daysim. Small differences such as the slight time shifts between measured and simulated peaks in Figure 4 have little or no impact on a visualization since they merely cause a slight shift of the shadow pattern within a scene. For a quantitative glare analysis or in order to develop a feeling of how bright a space is actually going to be, it becomes important that absolute luminances are correctly modeled as well. Figures 4 and 5 show that for spaces of low complexity both simulation programs correctly predict a large range of illuminances within a scene. Since the interior surfaces in the test space are mostly Lambertian, a visualization of the scene could be modeled with comparable accuracy as the illuminances, especially under cloudy sky conditions. Under sunny sky conditions and when more detailed curved specular surfaces - such as venetian blinds - are introduced into a scene, visualizations and point calculations become less accurate and the effect of potential glare sources might be harder to predict. The authors believe that for such complex scenes and design questions experimentation with real world objects becomes a necessary, complementary tool to 'validate' computer-based lighting simulations.

Practitioners are becoming increasingly interested in calculating absolute lighting levels at specific positions in a space in order to describe the daylight in terms of a 'performance metric'. This interest in metrics is largely triggered by required and voluntary standards such as the US Green Building Council's LEED 2.2 green building rating system (USGBC, 2006). Practitioners interested in using a lighting simulation to demonstrate compliance with the 8.1 LEED daylighting credit currently need to make sure that the simulation program they use supports the CIE clear and CIE overcast sky models. The clear sky is required for credit compliance under sunny sky conditions on an equinox day at noon, the CIE overcast sky is the reference sky for daylight factor calculations. The two CIE sky models are supported by 3ds Max Design and can be used in combination with Radiance using the gensky tool.

Clear and overcast CIE skies fall within the range of skies that can be modeled using the Perez sky model. The results from the results section for cloudy and clear sky conditions therefore approximate how well 3ds Max Design and Daysim manage to model daylight factors and illuminances under CIE clear sky conditions and suggest that both programs can be used for demonstrating credit compliance under LEED 8.1.

Finally, looking ahead there is currently a strong push towards replacing the aforementioned 'static' daylight performance metrics which are based on a single sky condition with climate-based metrics that look at a large number of different sky conditions for a site under the course of a year (Reinhart, Mardaljevic and Rogers, 2006). The results section has shown that both programs generally lend themselves for calculating these metrics since they are capable of simulating indoor illuminances under a range of sky conditions.

3ds Max Design and Daysim/Radiance

While the overall focus of this study is to compare both 3ds Max Design as well as Daysim simulations to measurements, a reader's natural tendency might be also to compare the performance of both programs and to judge 'which one is better'? This subsection aims to review the capabilities of both programs.

First of all, these results suggest that 3ds Max Design is a viable tool to base daylighting design decisions on. This is an important statement since Daysim and Radiance are really the only programs that have thus far been rigorously validated. This finding is actually not that surprising since both programs are based on very comparable models: They use the same sky model and a backward raytracer for the global illumination simulation. Considering the relative performance between 3ds Max Design and Daysim one should keep in mind that Daysim is a limited version of Radiance Classic since it does not support the full range of material modifiers within Radiance and it approximates direct solar contributions at any given time step via interpolation between neighboring daylight coefficients (Bourgeois et al., 2008). Daysim has been developed to be a practical tool to develop indoor illuminances under multiple sky conditions when Radiance Classic could not do it within a reasonable time frame. The question of simulation time is therefore closely related to what one wants to calculate. For a simulation under a single sky condition 3ds Max Design should be compared to Radiance Classic. Given that the observed simulation times for the daylighting test cases under a sunny sky were 0.6 to 4 hours for Radiance Classic compared 12 seconds for 3ds Max Design on a comparable computer it is fair to state that 3ds Max Design is significantly faster than Radiance Classic for daylight factor or CIE clear sky simulations. Annual Daysim simulations of the five test cases took between 3 and 15 hours independent of the time step used. For an annual daylight simulation in 3ds Max Design simulation times would actually take about the same time or longer as the tool would have to calculate indoor illuminances under all sky conditions individually (12 seconds per sky condition x 4380 daylit hours in a year = 14.6 hours). For a 5-minute-time-step annual calculation 3ds Max Design would take twelve times as long.

Other lighting programs

As previously mentioned there is a growing number of design practitioners who are looking for physically accurate results in their lighting simulation software. This paper has shown that 3ds Max Design and Daysim can be used to support daylighting related design decisions and that the new NRC daylighting test cases constitute a useful tool to benchmark lighting simulation software. The outcomes of such benchmarking exercises do not only provide useful guidance for software users but they can also help software developers to identify bugs and previously unknown weaknesses within their products. An example for this are the results for the translucent panel test case for 3ds Max Design.

It is the hope of the authors that more software developers will use the NRC daylighting test cases and other comparable data sets to validate their programs against and that over time such experimental validations will become a formal requirement for any software that is used to demonstrate credit compliance under LEED and other rating systems. ASHARE/ANSI Standard 140 already provides a similar set of requirements for building energy simulation software (ASHRAE, 2007).

CONCLUSION AND OUTLOOK

This study found that 3ds Max Design and Daysim could accurately model a sidelit space with a clear clear glazing with and without a lightshelf. 3ds Max Design simulations were lower than measurements for a translucent glazing. While both programs managed to accurately model indoor illuminances under overcast sky conditions for internal and external venetian blinds, the results were not as reliable under sunny sky conditions, probably due to challenges to generate accurate physical models of the partly specular blinds. Overall, these study findings suggest that both programs can be used to support daylighting related design decisions in scenes of comparable complexity as the five NRC daylighting test cases. This is good news for design teams interested in using physically based lighting simulations for further design analysis as they now have more than one simulation engine to choose from. Given the rising interest in physically accurate lighting simulations the authors expect that other simulation programs will soon go through comparable experimental validation exercises using either the NRC daylight test cases or other data sets. In order to facilitate this process the NRC daylight test cases (measurements and SketchUp files) will shortly be made publicly available.

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REFERENCES

Aizlewood M. E. 1993. Innovative daylighting systems: An experimental evaluation. Lighting Research & Tech. 25(4): 141-152.

ASHRAE 2007. ANSI/ASHRAE Standard 140-2007 Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs,

Bourgeois D., Reinhart C. F. and Ward G. 2008. A Standard Daylight Coefficient Model for Dynamic Daylighting Simulations. Building Research & Information 36(1): 68 - 82.

Mardaljevic J. 1995. Validation of a Lighting Simulation Program under Real Sky Conditions. Lighting Research & Tech. 27(4): 181-188.

Mardaljevic J. 2000. The BRE-IDMP dataset: a new benchmark for the validation of illuminance prediction techniques. Lighting Research & Tech. 33(2): 117-136.

mental-images. 2007. mental ray Functional Overview Version 1.5, Berlin.

Tregenza P R, Waters I M. 1983. Daylight Coefficients. Lighting Research & Tech. 15(2): 65-71.

Perez R, Seals R and Michalsky J. 1993. All-Weather Model for Sky Luminance Distribution - Preliminary Configuration and Validation. Solar Energy 50(3):235-245.

Reinhart C F, Breton P-F. 2009. Experimental Validation of Autodesk 3ds Max Design 2009 and Daysim 3.0, NRC-IRC report B3241.1, (www.autodesk.com/us/3dsmaxdesign/B3241.MentalRayValidation_v3.pdf).

Reinhart C F, Mardaljevic J and Rogers Z. 2006. Dynamic Daylight Performance Metrics for Sustainable Building Design. Leukos 3(1):1-20.

Reinhart C F and Andersen M. 2006. Development and validation of a Radiance model for a translucent panel. Energy & Buildings 38(7): 890-904.

Reinhart C F and Fitz A. 2006. Findings from a survey on the current use of daylight simulations in building design. Energy & Buildings 38(7): 824-835.

Reinhart C F and Walkenhorst O. 2001. Dynamic RADIANCE-based Daylight Simulations for a full-scale Test Office with outer Venetian Blinds. Energy & Buildings 33(7): 683-697.

SketchUp, G. (last accessed December 2008). SketchUp 7 http://sketchup.google.com/.

USGBC, 2006. LEED for New Construction Ver 2.2, US Green Building Council.

Ward, G and Rubinstein F. 1988. A New Technique for Computer Simulation of Illuminated Spaces. Journal of the IES 1: 80-91.