4.430 Daylighting

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4.430 Daylight Simulations

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MISC

- Google DIVA forum , onebuilding.org, radianceonline.org
- Most of the concepts discussed in this lecture are covered in

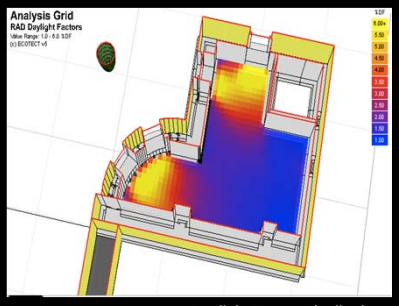
Reinhart C F, "Simulation-based Daylight Performance Predictions", in Building Performance Simulation for Design and Operation, Editors J Hensen and R Lamberts, Taylor & Francis, 2011

Daylight Simulations

Daylight Simulation

A computer-based calculation of the amount of daylight available inside or outside of a building under one or several sky conditions. Simulation outputs may be discrete numbers (illuminances and luminances) under selected sensor points within a scene or visualizations of a scene.

Visualization



Daylight Factor Distribution

Who should 'do' daylight simulations?

Architects!

Better interfaces. Faster computers.

To interactively improve your design at the schematic design stage.

To be able to engage in a dialogue with the HVAC engineer.

Competitive edge: high demand for simulationists

Opportunity to work on more interesting projects.

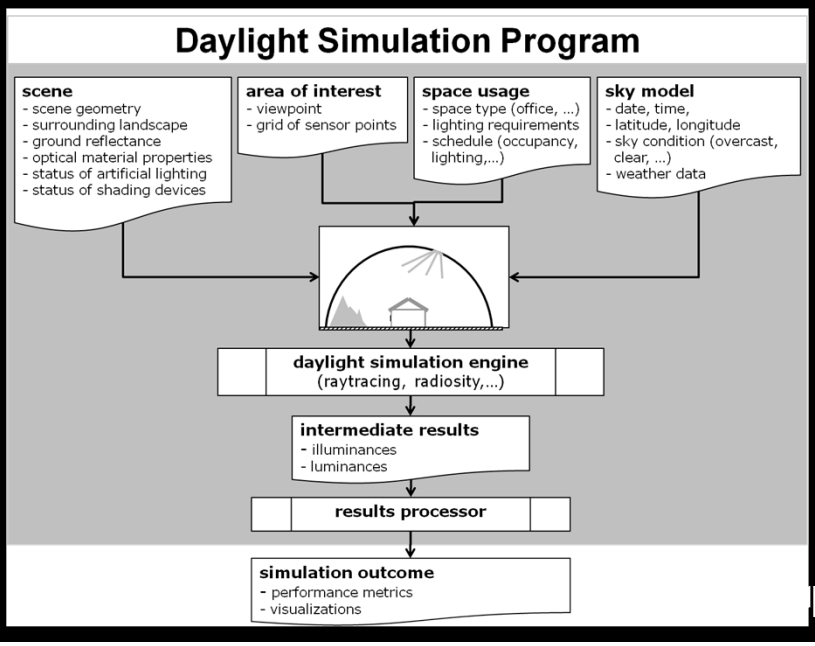
Questions to ask when choosing a daylight simulation program

What do you want to calculate?

Has the software been validated?

How easy is it to learn?

Elements needed for a DL Simulation



Daylight Factor Calculation Methods

Average Daylight Factor (Lynes formula see rules of thumb)

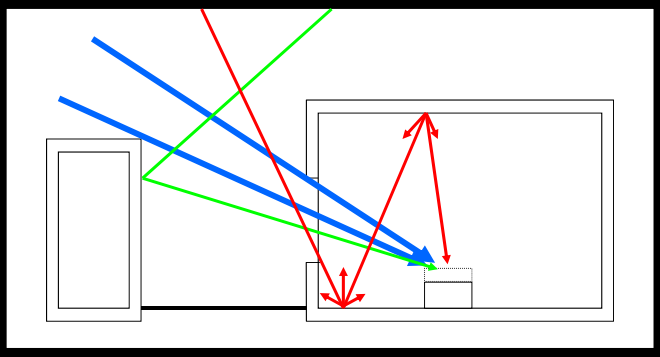
Original Split Flux Method (Daylight Factor Protractors)

Split Flux Method in Ecotect

Raytracing/Radiosity

Split Flux Method (Daylight Facotr)

UK Building Research Establishment (BRE)



SC = direct component

ERC = externally reflected component

IRC = internally reflected component

DF= SC + ERC + IRC

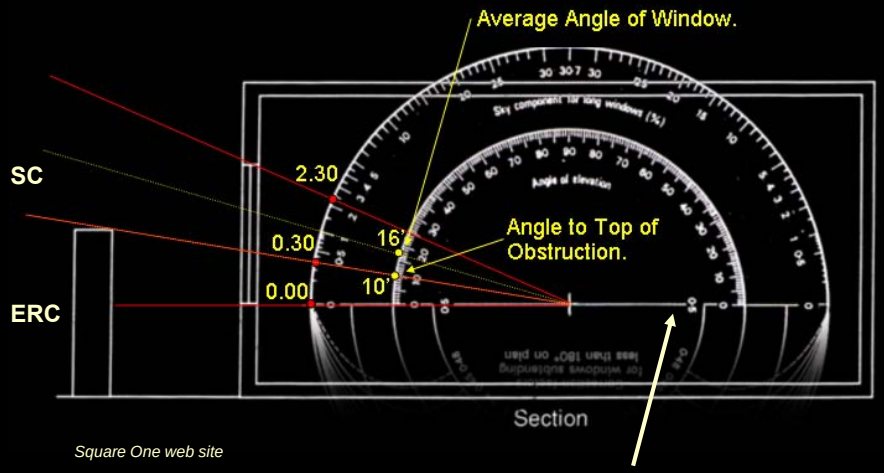
Design Sky Values

Design Sky values represent a horizontal illuminance level that is exceeded 85% of the time between the hours of 9am and 5pm throughout the working year. Thus they also represent a worst case scenario that you can design to and be sure your building will meet the desired light levels at least 85% of the time.

Diagrams of raytracing and the split flux method removed due to copyright restrictions.

Limitation in Ecotect: Climate files are not used by lighting simulation.

Protractor Method I



Square One web site

Daylight Factor Protractors

Protractor Method II

Then the bottom side in plan view:

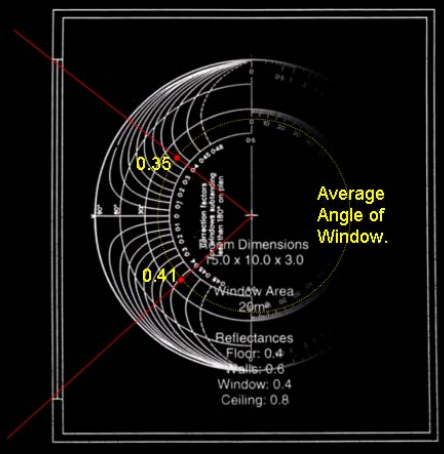
SC = 2.3 – 0.3
= 2.0

ERC = (0.3 – 0.0) x 0.2
= 0.06

Applying correction:

SC = 2.0 x 0.76
= 1.52

ERC = 0.06 x 0.76
= 0.0456



Plan

Square One web site

Protractor Method III

Next find the Internally Reflected Component:

$$IRC = \frac{0.85\ W}{A\ (1 - \rho_1)} \times (Cp2 + 5p3)$$

Where:

W = Window area (m^2),
A = Total internal surface area, wall, floors ceilings and windows (m^2),
ρ_1 = Area weighted average reflectance of area A, (use 0.1 as reflectance for glass).
ρ_2 = Average reflectance of surfaces below working plane,
ρ_3 = Average reflectance of surfaces above working plane,
C = Coefficient of external obstruction.

Protractor Method IV

DF = SC + ERC + IRC

= 1.52 % + 0.0456 % + 1.7586 %

= 3.324 %

In Boston:

Design sky = 7566 Lux (Tregenza formula)

Light Level = 7566 Lux x 3.324 %

= 251 Lux

Split Flux Method in Ecotect

A geometric version of the Split Flux Method (BRE)

Raytracing: each ray represents an approximately equal solid angle of sky

Diagrams of raytracing and the split flux method removed due to copyright restrictions.

Split Flux Method in Ecotect

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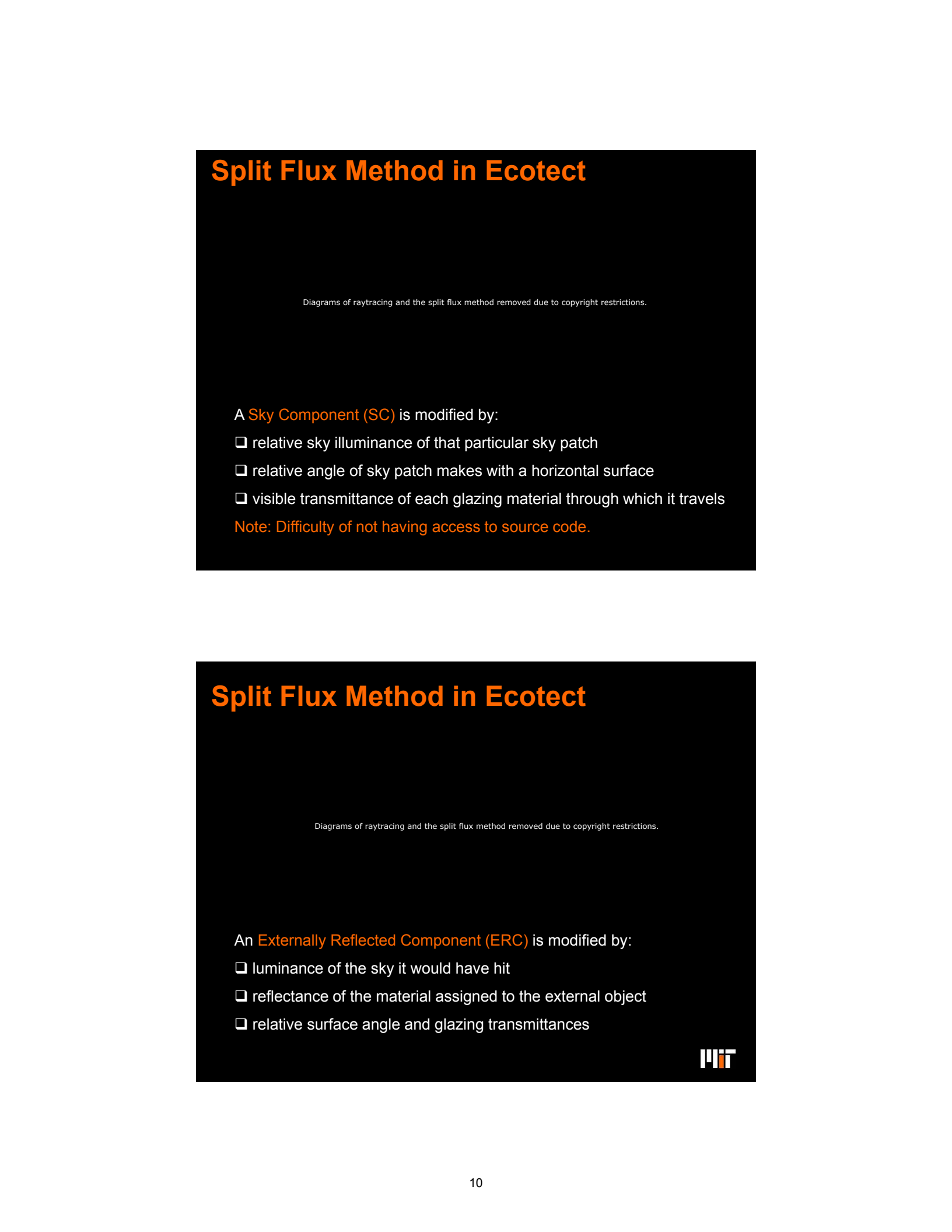
Split Flux Method in Ecotect



A Sky Component (SC) is modified by:

- ❑ relative sky illuminance of that particular sky patch
- ❑ relative angle of sky patch makes with a horizontal surface
- ❑ visible transmittance of each glazing material through which it travels

Note: Difficulty of not having access to source code.

Split Flux Method in Ecotect

An Externally Reflected Component (ERC) is modified by:

- ❑ luminance of the sky it would have hit
- ❑ reflectance of the material assigned to the external object
- ❑ relative surface angle and glazing transmittances

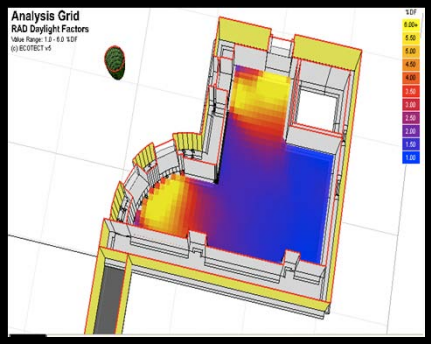
Split Flux Method in Ecotect

Diagrams of raytracing and the split flux method removed due to copyright restrictions.

An Internally Reflected Component (IRC) is modified by:

- ❑ store internal surface reflectance of the object
- ❑ altitude angle of the ray is used to determine which parts of the IRC formula the ray contributes to.

How accurate is Ecotect? Comparison of a Best Practice Model using Ecotect-Split-Flux vs. Radiance



Courtesy of Diego Ibarra and Christoph Reinhart. Used with permission.

Best Practice Model Ecotect
Mean Daylight Factor = 0.55%
Percentage of floor area >2% = 0%

Best Practice Model Radiance
Mean Daylight Factor = 2.59%
Percentage of floor area >2% = 42%

- dramatic difference between both engines due to wall thickness

Paper: Ibarra D, Reinhart C F, "Daylight factor simulations How close do simulation beginners really get?", Proceedings Building Simulation 2009, www.ibpsa.org/proceedings/BS2009/BS09_0196_203.pdf

Radiance

Survey on the Use of Daylight Simulations

Survey on the use of daylight simulation tools — National Research Council Canada

Dear colleague,

This is your opportunity to influence future developments of daylight simulation tools.

You are invited to participate in an online survey on the current use of daylight simulation tools during building design. The survey is carried out as part of an international research project of the International Energy Agency's Task 31, *Daylighting Buildings in the 21st Century*. The survey is administered by the National Research Council Canada. The outcome of the survey will be used to:

- **identify existing weaknesses of daylighting design software packages**
- **better understand design practitioners' needs**
- **tailor the output of tools accordingly**

We would like you to fill out the following online questionnaire according to your daylighting design experience. Please respond to all of the items as openly and honestly as possible. There are no right or wrong answers; it is only your opinion that is important. All of the information that we obtain from you through this survey will be kept confidential. Your participation in this research is voluntary. Should you decide to participate in the survey, you still reserve the right to end your participation at any time and for any reason, without prejudice. To end your participation, just close your browser. There are no foreseeable risks or costs to you from participating in this research. There is no direct benefit to you, however we hope that the result from this research will help us to assist software developers to improve their tools.
Should you have any concerns, questions or suggestions, please contact Dr. Christoph Reinhart at christoph.reinhart@nrc-cnrc.gc.ca or +1(613)993 9703.

Completing the survey should take about 5 minutes of your time.

I have read the above information and freely agree to participate in this online survey.

You can print a copy of this agreement for future reference. The results of this survey will be published on this web site by April 2004.

Please note: The survey has been approved by the Ottawa Research Ethics Board of the National Research Council Canada as Protocol 2003-31. For any further going questions or concerns, please contact the secretary of the Ottawa Research Ethics Board, at Paula.Desjardins@nrc-cnrc.gc.ca or +1 (613) 993-4234.

- 185 participants from 27 countries (40% Canada & US)
- validation seems less of an issue
- out of 40 tools mentioned, >50% of votes for RADIANCE based tools

Paper: CF Reinhart and A Fitz, "Findings from a survey on the current use of daylight simulations during building design", Energy and Buildings 38:7 pp. 824-835, 2006.

Radiance Validation Studies

Light. Res. & Technology
Mardaljevic, 1995

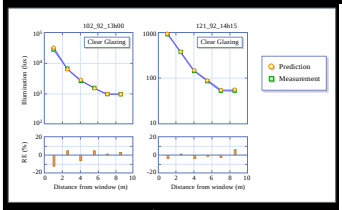
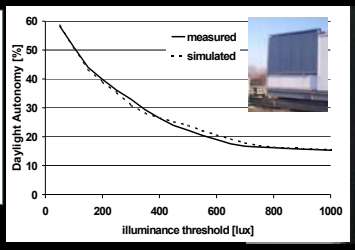


Image by MIT OpenCourseWare.

Energy & Buildings
Reinhart, Walkenhorst 2001



Energy & Buildings
Reinhart, Andersen 2006

Conclusion: Radiance combined with daylight coefficients and Perez sky model can efficiently and reliably model annual illuminance time series with a mean relative error of 20%.

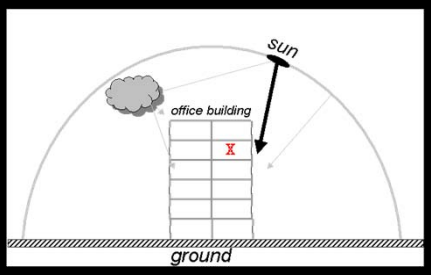
Some Facts on Radiance

Physically based backward raytracer - no fudge factors.

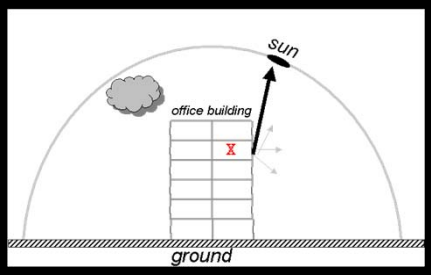
A wide variety of material properties and sky models.

Longish learning curve. ("Magic" lies in simulation parameters.)

Backward vs. Forward Raytracing

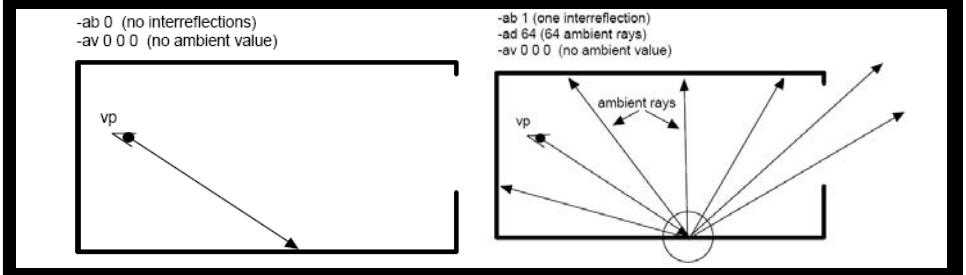


forward raytracer



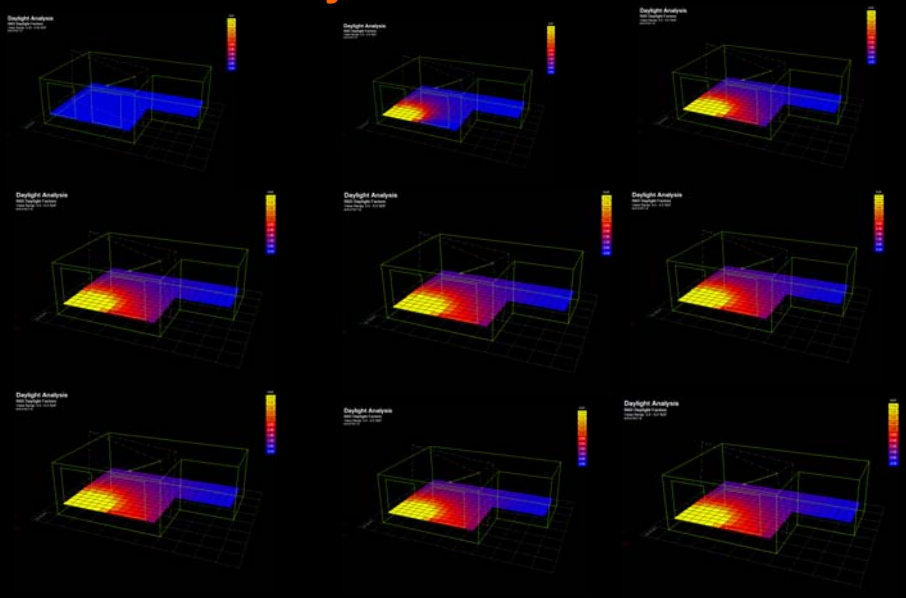
backward raytracer (Radiance)

Demo: Visualization

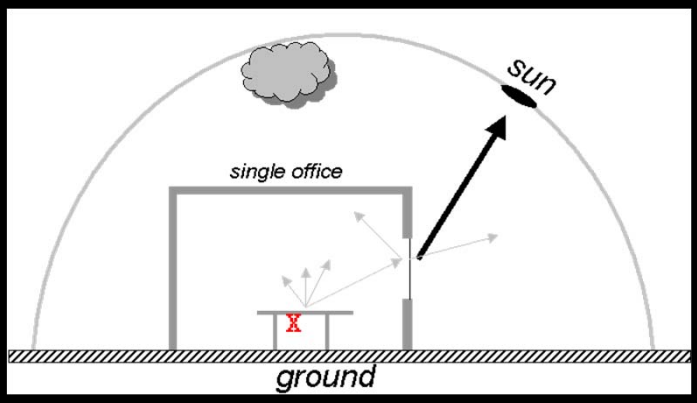


Source: R Compagnon

Parameter Study Radiance: ab 0 to ab 8



Radiance Scene Complexity I



ambient bounces	ambient division	ambient sampling	ambient accuracy	ambient resolution	direct threshold	direct sampling
5	1000	20	0.1	300	0	0

recommended Radiance simulation parameters

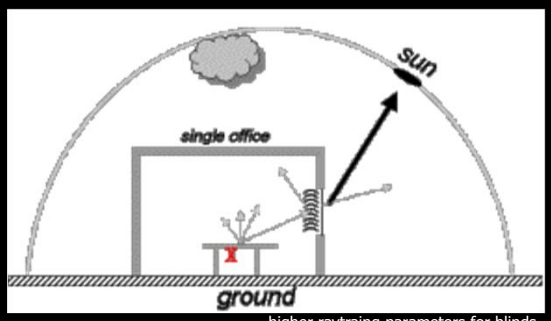
Radiance Simulation Parameters I

ambient bounces	ambient division	ambient sampling	ambient accuracy	ambient resolution	direct threshold	direct sampling
5	1000	20	0.1	300	0	0

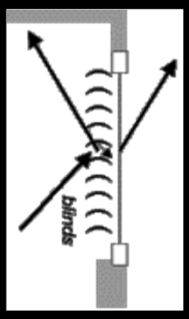
$$\text{simulation resolution} = \frac{\text{max scene dimensions x ambient accuracy}}{\text{ambient resolution}}$$

Example: $\frac{\text{100m x 0.1}}{\text{300}}$ **~ 3cm (window mullion)**

Radiance Scene Complexity II



higher raytraing parameters for blinds



raytracing detail

ambient bounces	ambient division	ambient sampling	ambient accuracy	ambient resolution	direct threshold	direct sampling
7	1500	100	0.1	300	0	0

recommended Radiance simulation parameters

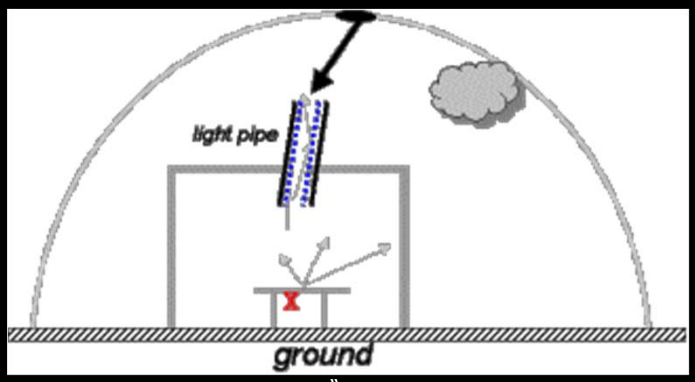
USDA Consolidation Laboratories Ames, Iowa - AEC

Courtesy of Zack Rogers, PE, President, Daylighting Innovations. LLC. Used with permission.

simulation: AEC

Balance of daylight distribution in adjacent office and laboratory spaces.
Rules of Thumb do not apply any more.

Limitations of Radiance



Radiance will not necessarily „find" the sun.

Mention Photon Mapping.

Daylighting Test Cases

Daylight Simulation Test Cases

Facade section drawings of the daylighting test cases removed due to copyright restrictions.

Photograph of NRC Daylighting Laboratory removed due to copyright restrictions.

Paper: Reinhart C F, Breton PF, "Experimental Validation of 3ds Max® Design 2009 and Daysim 3.0", LEUKIOS 6:1 2009. (www.autodesk.com/us/3dsmaxdesign/B3241.MentalRayValidation_v3.pdf)

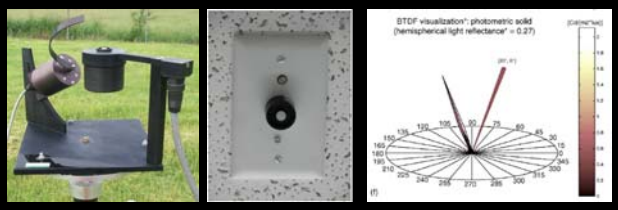
3ds Max Design 2009

- Based on Exposure™ technology.
- Exposure™ includes a shader of the Perez Sky Model (same model as Daysim).
- For the global illumination calculation Exposure uses the mental ray raytracer which supports forward (photon mapping) and backward raytracing (final gathering).
- Same as in Radiance final gather tracing in mental ray is performed only on discrete points (sensors).
- Light sensors in 3ds Max Design are specified using the Light Meter object.

Screenshot of rendered interior using Autodesk 3ds Max Design 2009 removed due to copyright restrictions.

Tutorial: http://images.autodesk.com/adsk/files/3dsmax_started.pdf

Validation Work Flow



SketchUp Model (geometry) | Outside Irradiances | Illuminances | Material Properties

Simulation Program:
- 3ds Max Design 2009
- Daysim3.0
- …

Simulated Illuminances

Outside Façade Illuminances

Graph of illuminance (outdoor sensor on a sunny day) removed due to copyright restrictions.

Graph of illuminance (outdoor sensor on a partly cloudy day) removed due to copyright restrictions.

- ❑ Nearly identical simulation results for outside sensors.
- ❑ Differences mainly from how ground reflectances are being treated.

Test Case 1 – No Shading

Graph of illuminance (base case) removed due to copyright restrictions.

Image of SketchUp model of the East Room for the test cases removed due to copyright restrictions.

- ❑ Very close agreement over a large illuminance range.
- ❑ Slight offset probably due to geometry modeling errors and time lacks.

Test Case 2 – Lightshelf

Graphs of illuminance (lightshelf) removed due to copyright restrictions.

- ❑ Very close agreement from 50lux to 8000lux (covers total range typically encountered in buildings.

Test Case 5 – Internal Venetian Blinds – Sunny Day

Graphs of illuminance (external blinds on a sunny day) removed due to copyright restrictions.

Image of SketchUp model of Venetian blinds removed due to copyright restrictions.

- Systematic error under sunny sky conditions for both programs.
- Modeling challenges: Setting the slat angles evenly; measuring optical properties of blind slats (specular component); light spilling through cord holes.

Main Study Findings

- 3ds Max Design and Radiance/Daysim can be used to support daylighting related design decisions in scenes of comparable complexity as the five daylighting test cases.
- This finding constitutes a certain paradigm shift as there are suddenly more than one lighting simulation engine that has been extensively validated based on physical measurements.
- It is expected that other programs will soon also undergo comparable simulation procedures.

4.430 Daylighting

Spring 2012