How close do “beginners” get?

The impact of simulation novices in the accuracy of simulation results

Diego Ibarra and Christoph Reinhart

Previous research

- ✓ Bradley, Kummert and McDowell (2004), compared the difference in simulation results when three expert users applied ANSI/ ASHRAE Std 140-2001 to the TRNSYS simulation program.
- ✓ Users were categorized as a developer, a user/developer, and an expert user.
- ✓ The study concluded that, "there is great leeway within a given software package to make widely varying assumptions and yet still fall well within the range of acceptably accurate results".

✓ Context: The "user" as a key variable in daylight simulation results

Previous research

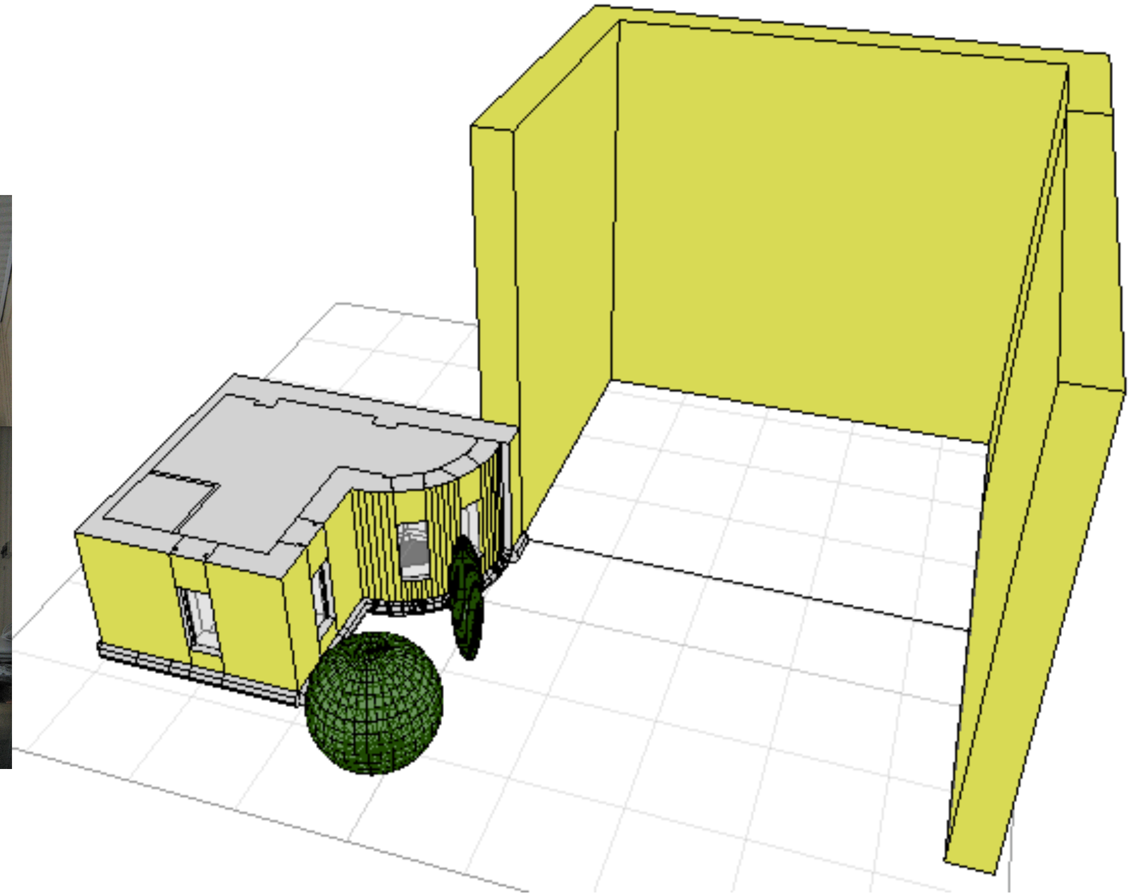
✓ The "user" as a key variable for obtaining accurate simulation results

- ✓ Bradley, Kummert and McDowell (2004), compared the difference in simulation results when three expert users applied ANSI/ ASHRAE Std 140-2001 to the TRNSYS simulation program.
- ✓ Users were categorized as a developer, a user/developer, and an expert user.
- ✓ The study also concluded that "…knowledgeable users can still be confident that their results will not vary dramatically from those of other expert users".

✓ Context: The "user" as a key variable in daylight simulation results

Simulation Case Analyzed

McGill – School of Architecture



Ceiling	Diffuse reflectance 80%
Wall	Diffuse reflectance 80%
Floor	Diffuse reflectance 8%
Windows	Visual transmittance 65%

DF simulation of a 65m2 (700sqft) space.
Model sample: ***80 models*** *(ARC 424 – Fall 05 & 06)*

ab	ad	as	aa	ar
6	1500	100	0.05	300

✓ Research objectives & methodology

Objectives

To determine how accurate one can actually expect simulation novices to simulate daylight metrics.

✓ **Analyze the impact of using** RADIANCE backward ray-tracing algorithm Vs ECOTECT's built-in Split flux algorithm.

✓ **Identify common mistakes** simulation novices make and their impact in the accuracy of their simulation results

✓ **Provide a simple set of modeling guidelines** for novice users to successfully implement daylight simulations, and suggestions for software developers on how to further improve simulation workflows.

✓ Research objectives & methodology

Comparing simulation engines

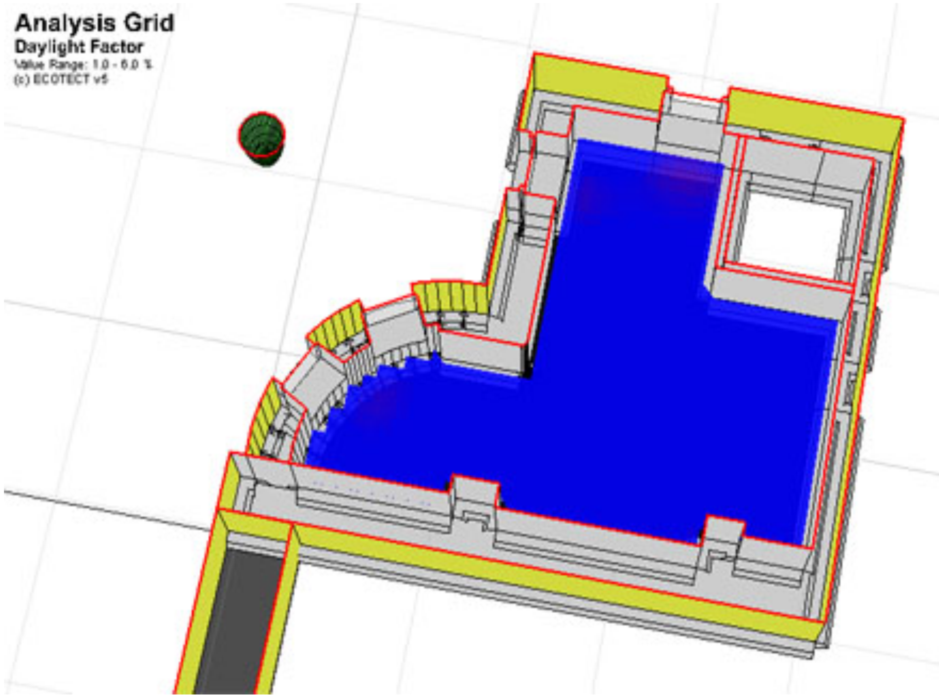


Figure 1. ECOTECT Best Practice Model

Mean DF	0.55%	-79% (x5)
Area above 2% DF	0.00%	-100%

ECOTECT completely unreliable results

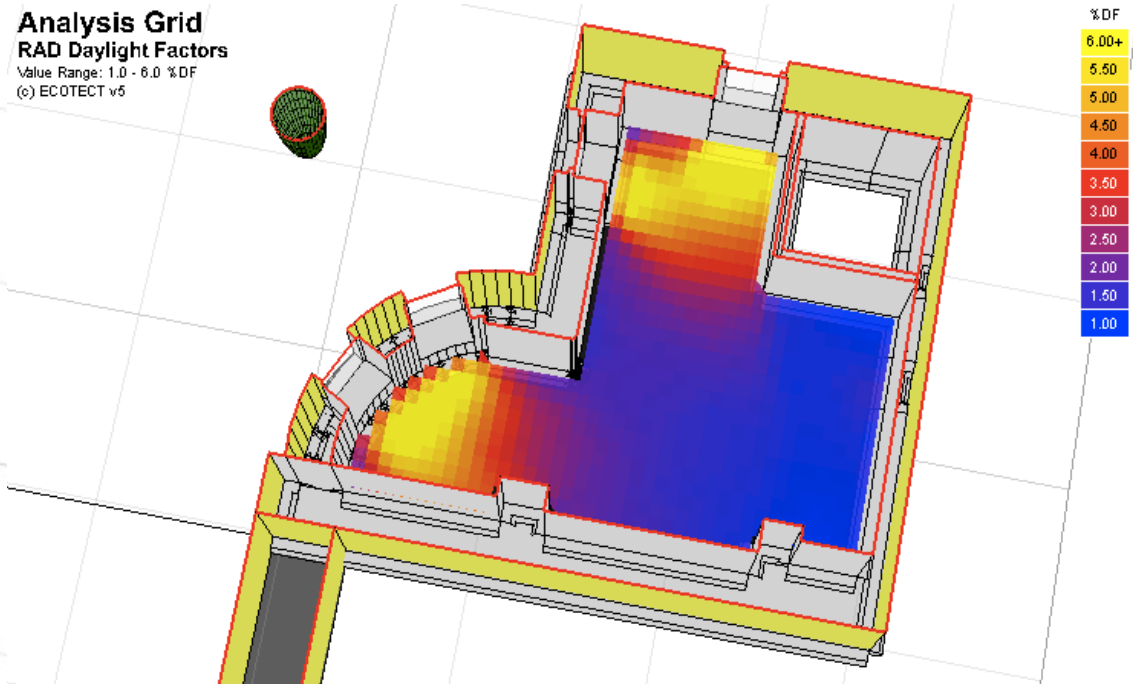
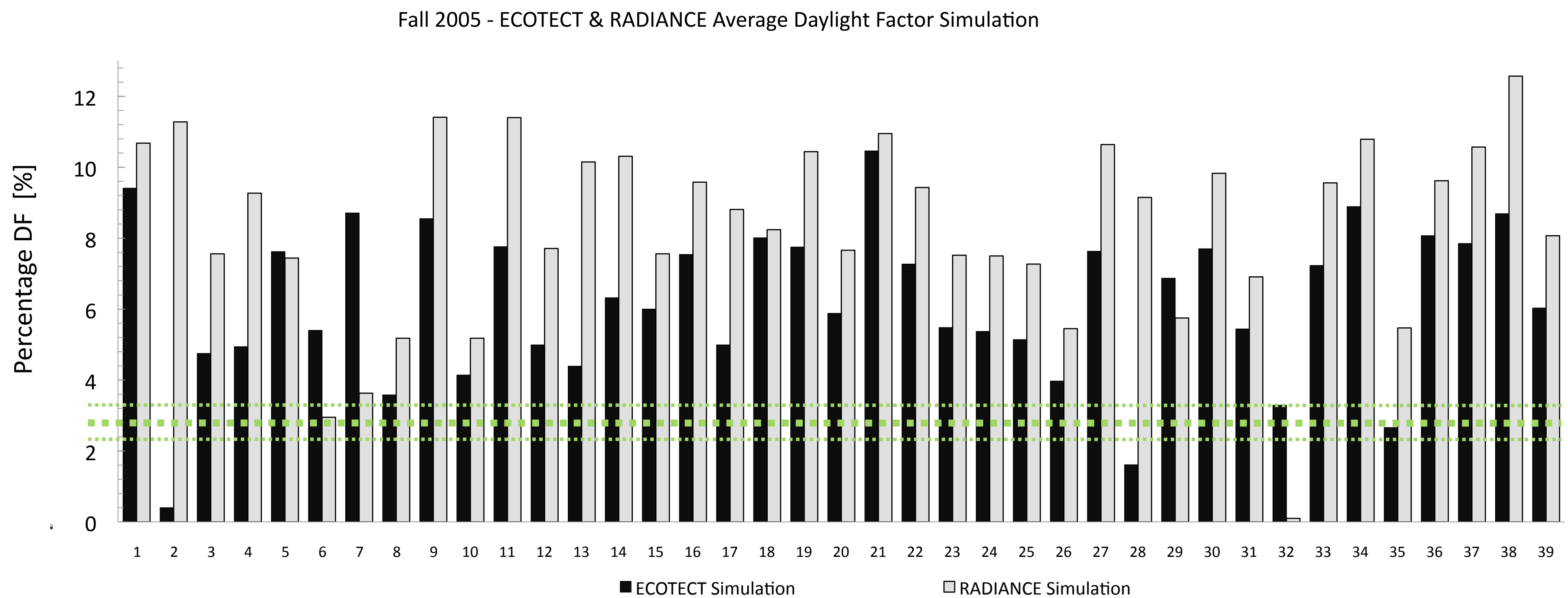


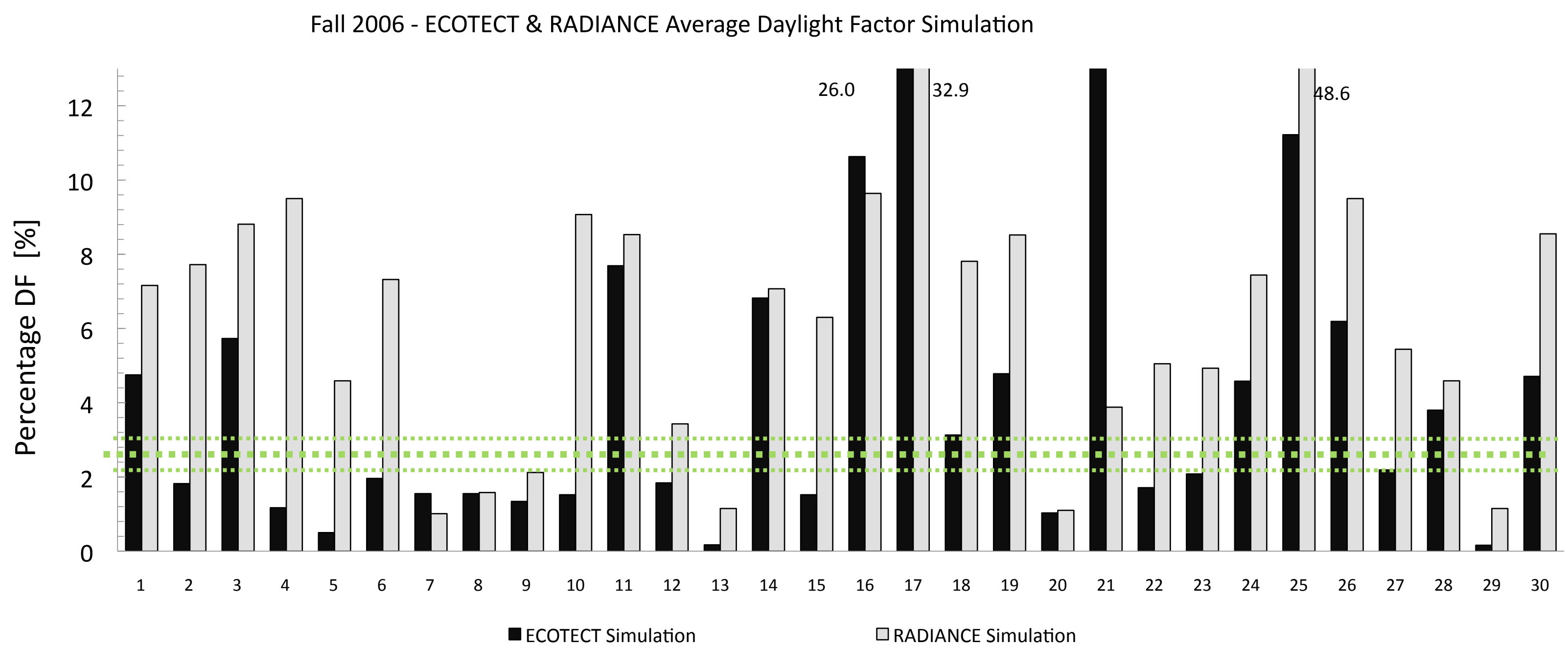
Figure 2. RADIANCE Best Practice Model

Mean DF	2.59%	100%
Area above 2% DF	41.54%	100%

ab	ad	as	aa	ar
6	1500	100	0.05	300

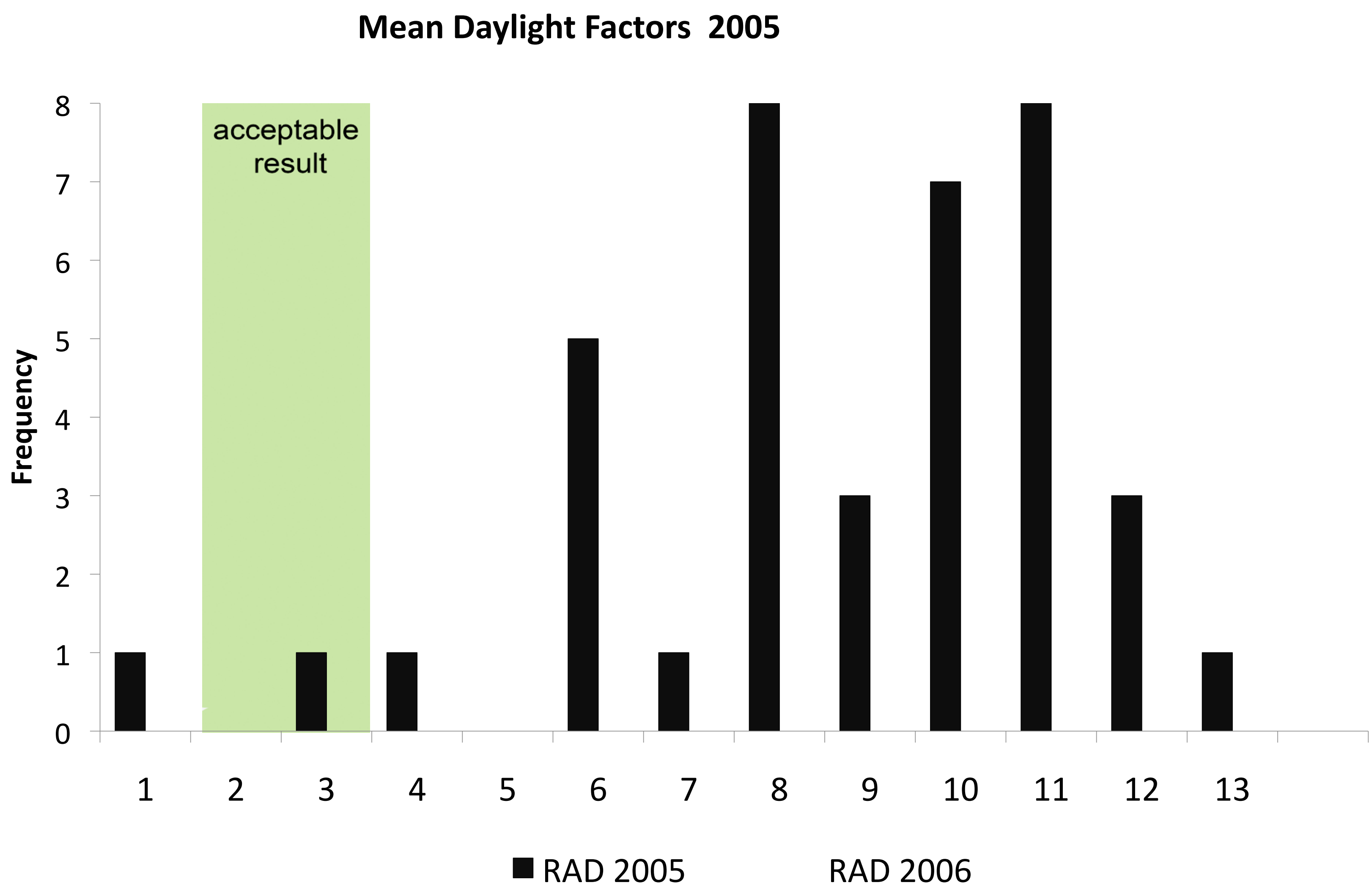
✓ Best practice model results





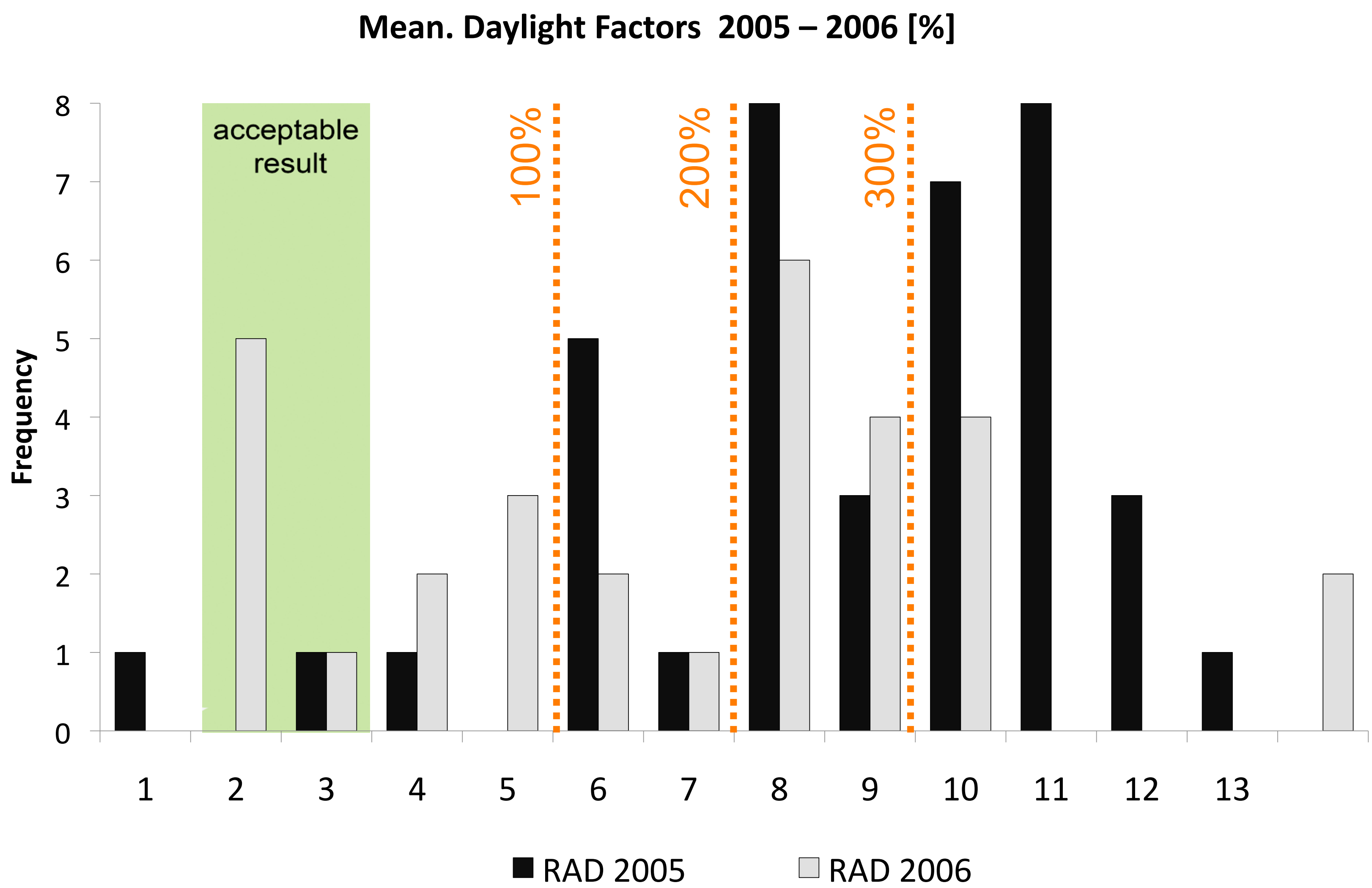
✓ Model sample results: quantitative analysis

Efficacy of providing simulation tips

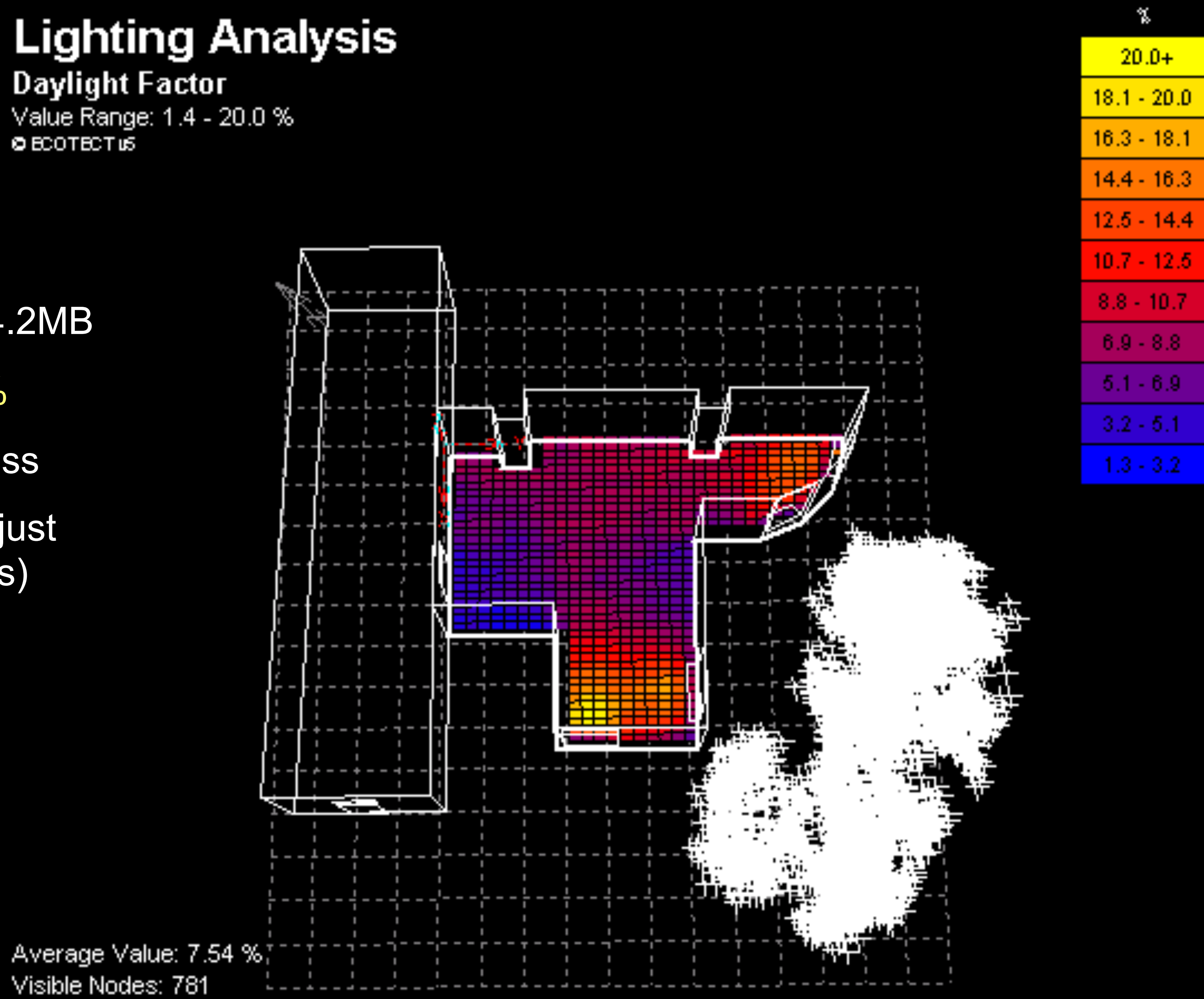


✓ **Model sample results: quantitative analysis**

Efficacy of providing simulation tips



✓ Model sample results: quantitative analysis



Largest model: 4.2MB

Mean DF = 7.5%

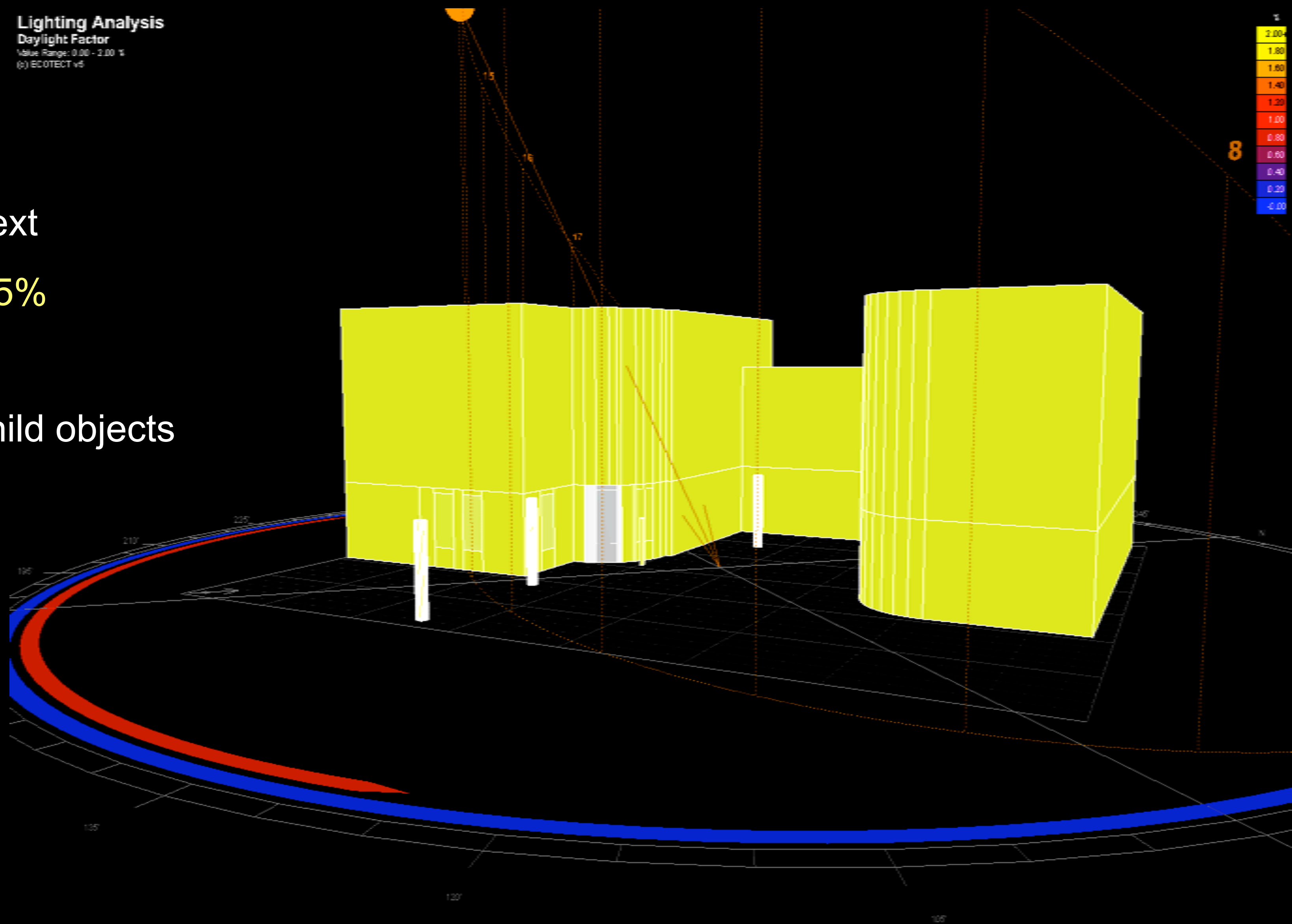
- No wall thickness
- No real trees (just construction lines)

✓ Model sample: notable models

Building Context

Mean DF = 1.5%

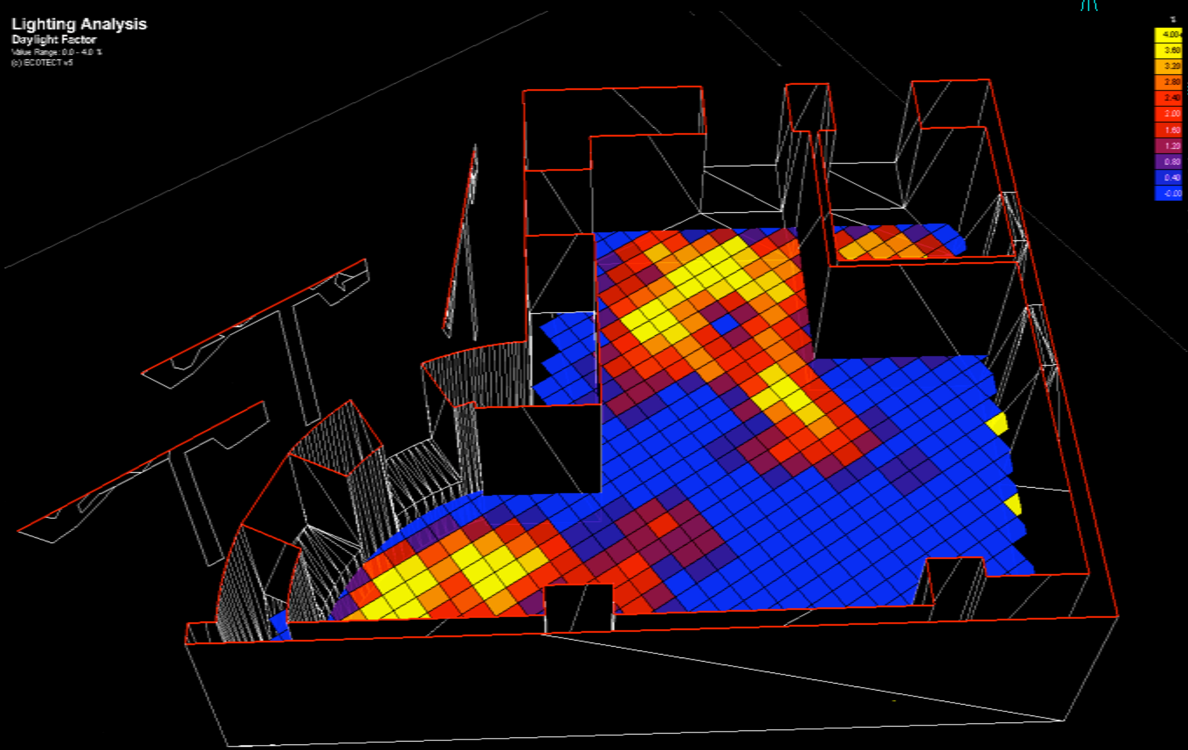
- No windows
- Not set as child objects



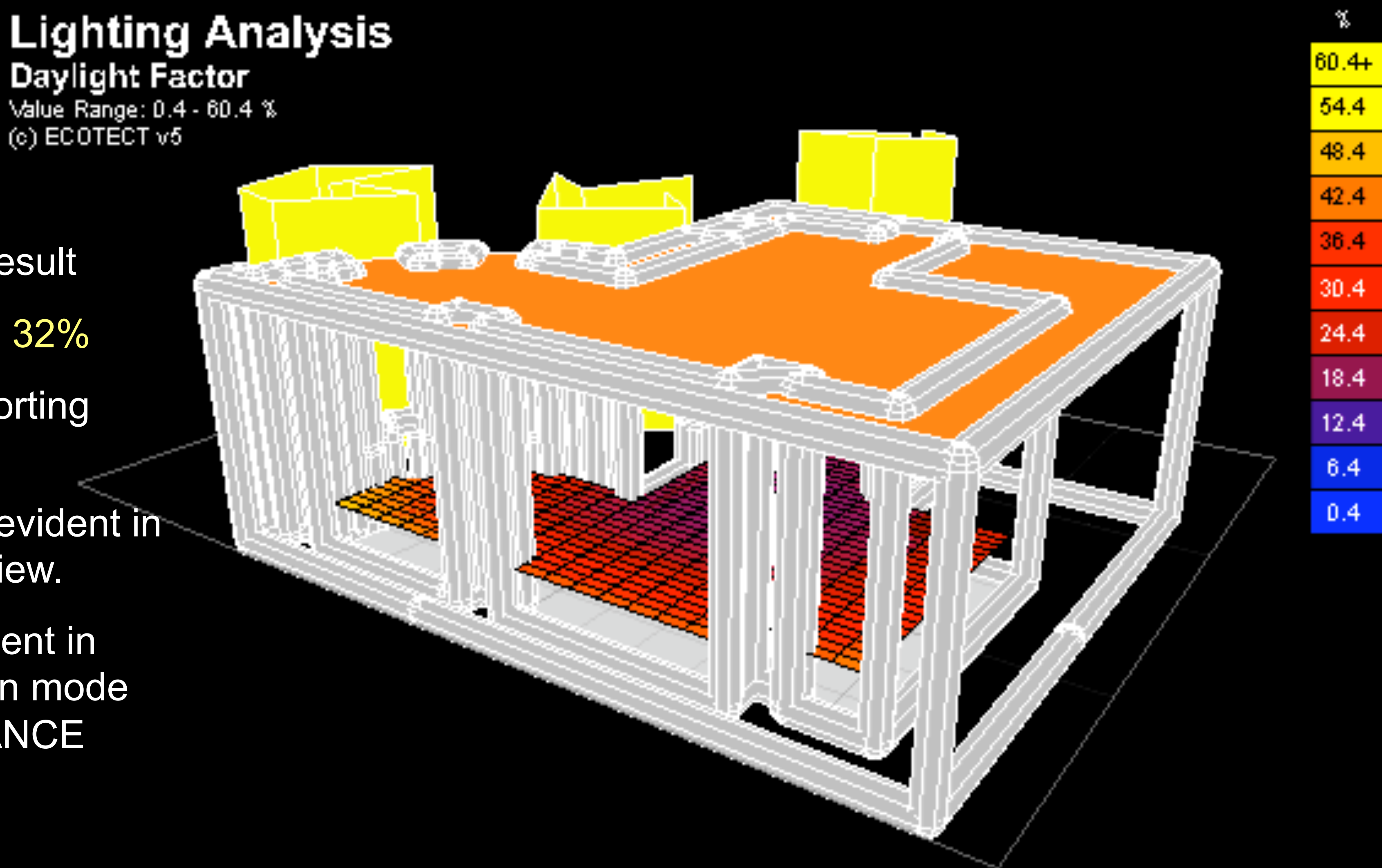
✓ Model sample: notable models

Mean DF = 1.0%

- Imported detailed .DXF geometry, including perforated colored trees
- No windows and no internal reflectances (0%)



✓ Model sample: notable models



Very high result

Mean DF = 32%

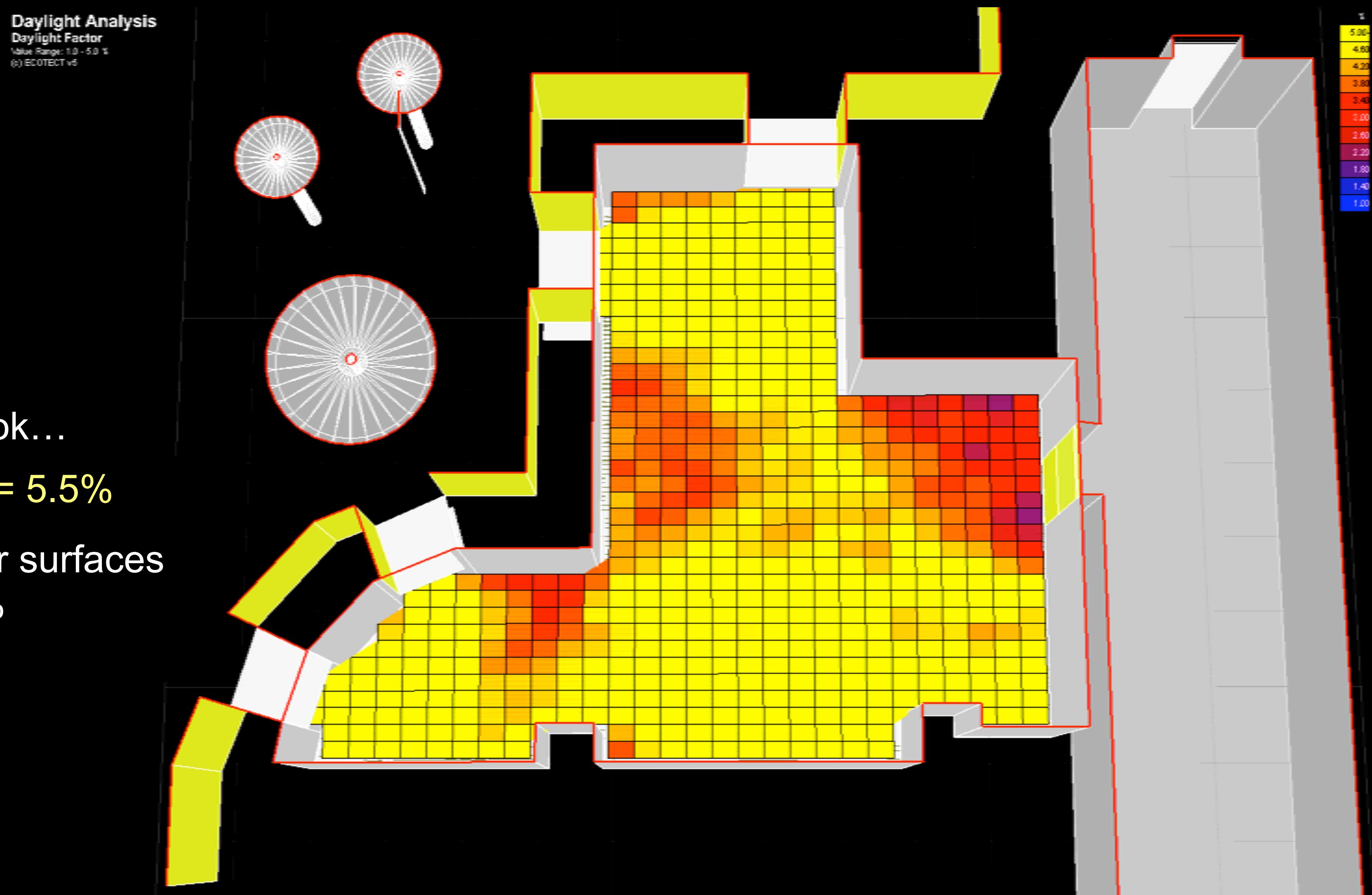
- Error importing model
- Error not evident in 3D editor view.
- Error evident in visualization mode and RADIANCE rendering

✓ Model sample: notable models

Closer Look…

Mean DF = 5.5%

- All interior surfaces set to 99% reflectivity



✓ Model sample: notable models

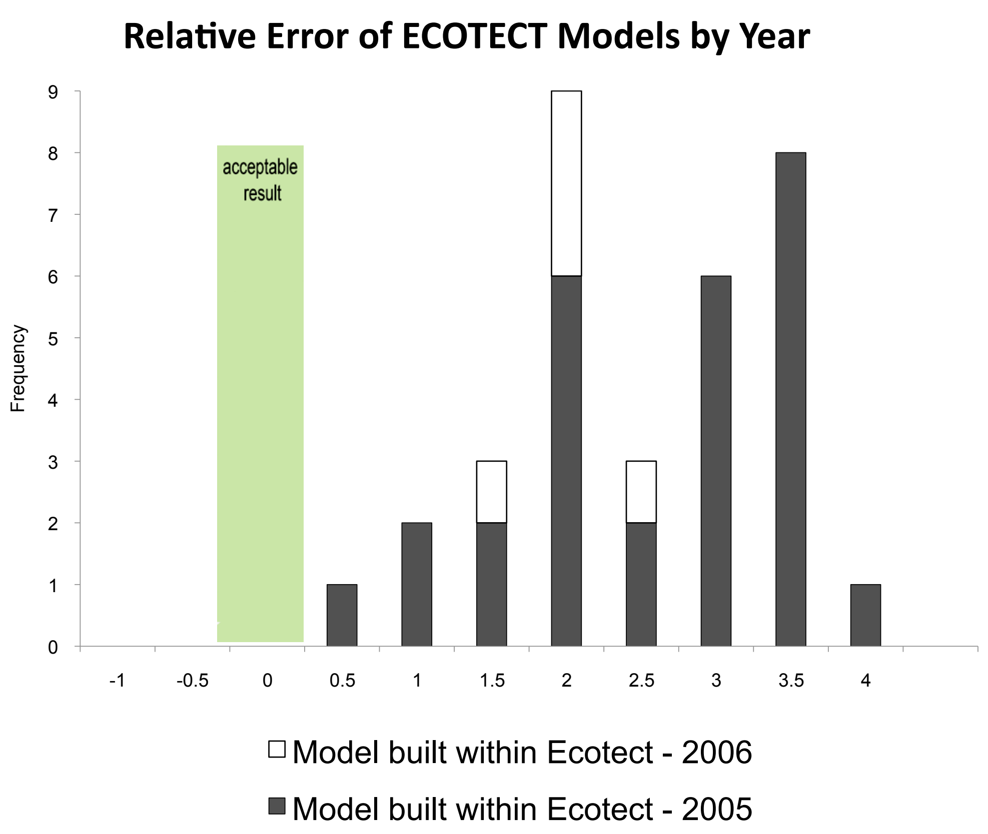
Qualitative analysis

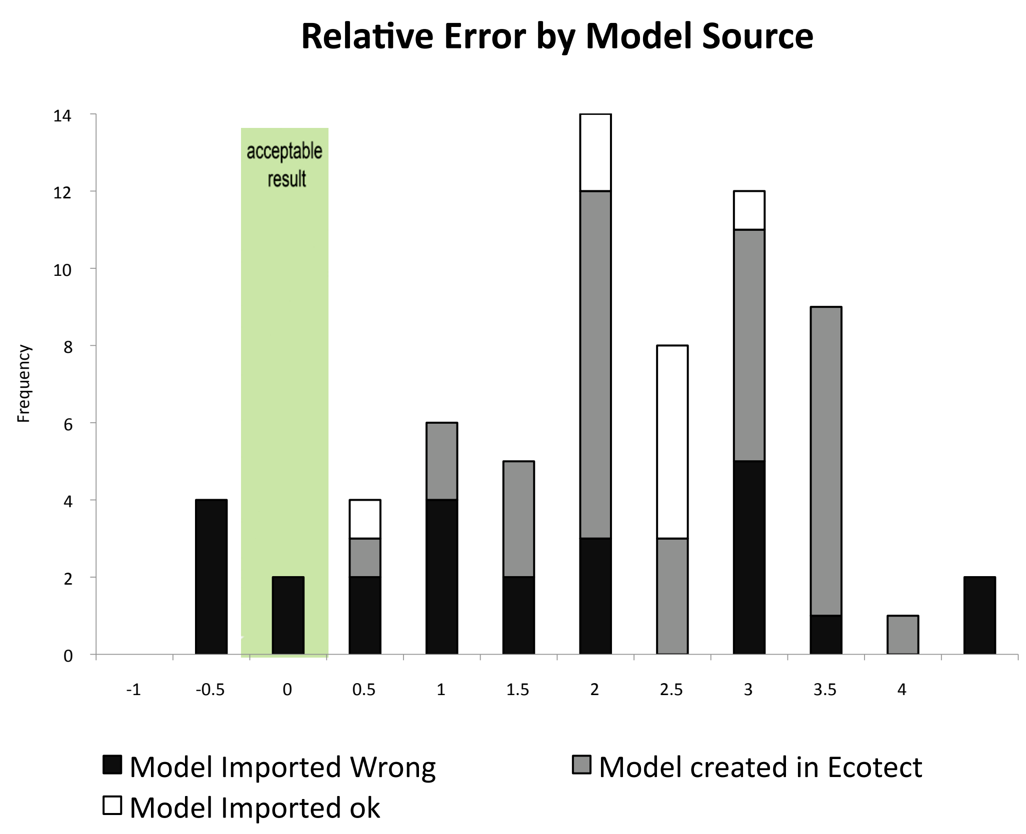
Table 3. List of model inputs that were used to characterize the 69 student models.

Category	Question	Possible Answers	Error Frequency
General	Q1: In which semester was the model built?	Fall 05 / Fall 06	2005 - 2006
Geometry	Q2: Was the model built within Ecotect? Imported from a third party unsuccessfully (i.e. not exploded or incomplete envelope)? Or Imported successfully (i.e. with glazing or added in Ecotect)?	0= Imported unsuccessfully | 1= Built within ECOTECT | 2= Imported Successfully	26
	Q3: Are interior room dimensions modeled accurately?	0=Yes | 1=wrong depth | 3=wrong height | 4=wrong depth and height	44
	Q4: Are the window dimensions (size and position of window openings) modeled accurately?	1= Yes 0= No	30
	Q5: At what thickness are the walls modeled?	Thickness in mm [target value 980mm]	13
	Q6: Are neighboring buildings modeled?	0= Yes | 1= No	16
	Q7: Are adjacent trees modeled?	0= Yes | 1= No	24
Materials	Q8: Did the model use the customized NRC material library (as opposed to the Ecotect default library; Fall 06 only)?	0= Yes | 1= No	67
	Q9: What was the modeled glazing transmittance?	visual transmittance in % [target value 65%]	69
	Q10: What was the modeled ceiling reflectance?	reflectance in % [target value 80%]	55
	Q11: What was the modeled wall reflectance?	reflectance in % [target value 80%]	69
	Q12: What was the modeled floor reflectance?	reflectance in % [target value 8%]	69
Simulation Settings	Q13: Were the sensor positions correctly (correct sensor height)?	grid height in mm.[target 800mm]	18
	Q14: Were the sensor modeled correctly (grid sufficiently fine and inside envelope boundary)?	0= Yes | 0= No	14
	Q15: What was the selected simulation precision in ECOTECT:	1= lo | 2= medium | 3= high | 4=very high | 5=full	

* Thanachareonkit, A. 2008. "Comparing Physical and Virtual Methods for Daylight Performance Modeling Including Complex Fenestration Systems."

✓ Model sample analysis





✓ Model sample results: preliminary analysis

Make sense of the multivariate regression analysis with the collaboration of Jennifer Veitch and Navaneethan Siva (NRC-Canada).

Table X1. Descriptive statistics for the dependent variable and four predictors.

		Full Sample, N=67		2005, N=39		2006, N=28	
	Category	M	SD	M	SD	M	SD
Relative Error (%)		1.92	.96	2.25	0.90	1.45	0.85
Ecotect (0=no, 1=yes)		.51	.50	0.74	0.44	0.18	0.39
Wall dimension error	Geometry	.61	.43	0.93	0.22	0.16	0.19
Average materials error	Materials	2.07	.76	1.96	0.76	2.24	0.73
Grid height error	Simulation	.10	.22	0.15	0.27	0.02	0.08

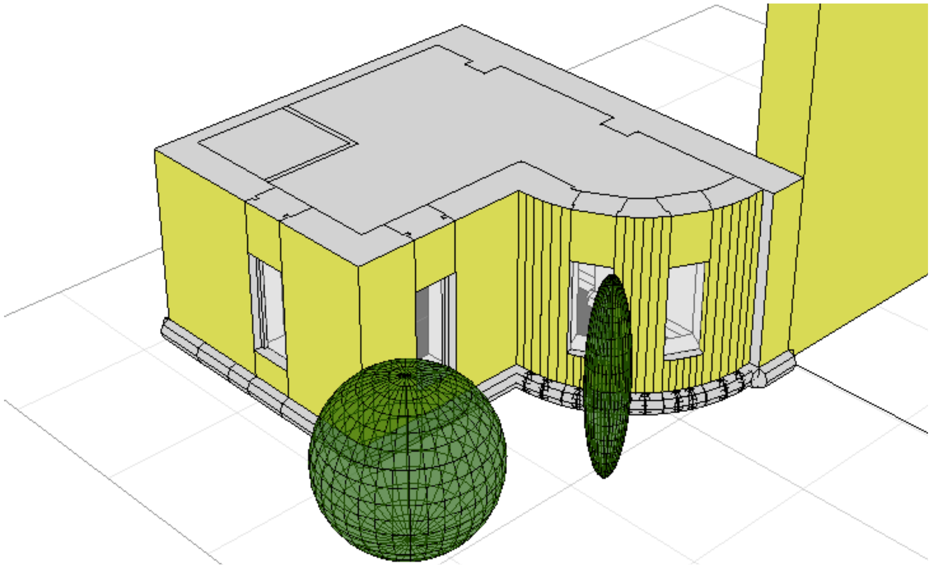
Table X2. *Summary table for regressions of relative error in daylight factor prediction for the full sample and split by class year.*

	Full sample	2005	2006
	β	β	β
Ecotect model (0=no, 1=yes)	.30*	.43*	.23
Wall dimension error	.29*	-.22	.43*
Average materials error	.34**	.37*	.27
Grid height error	.080	.01	.16
df	4, 62	4, 34	4, 23
Total R^2	.34***	.25*	.40*
Adjusted R^2	.30***	.26*	.29*

~ 30% of the variance in the relative error of students' models can be explained by three variables: the absolute error in the **wall dimension**, the absolute error in **the floor reflectance**, and whether or not they made their original **model in Ecotect**.

✓ Multivariate regression analysis

Discussion



User inputted parameters

1. One can argue that the simulation case analyzed was too complicated.
2. Question the Daylight Factor as a meaningful daylighting metric, compared to climate-based daylight simulations such as Daylight Autonomy and Useful Daylight Illuminance
3. The relevance of analyzing student models to derived meaningful conclusion to introduce daylight simulations into practice.

✓ **Discussion**

Conclusions

✓ The "user" as a key variable for obtaining accurate simulation results

1. **Dramatically different simulation results** reported by ECOTECT and RADIANCE. 79% lower Mean DF and a reduction in the Area above>2% DF from 41% to a 0%. **ECOTECT built-in algorithm not reliable**.
2. Novice's Model Quality: a total of **14 parameters** were identified **as repetitive errors**.
3. **Most critical errors** due to **unsuccessful geometry imports**, **no wall thickness** and assigning **material optical** properties.
4. Offering simple **simulation tips** considerable improves the accuracy of simulation results.
5. It is necessary to address the whole simulation workflow in **smaller steps** to improve the accuracy of results. Created Simple Modeling Guidelines.

✓ Conclusions

Table: Daylight Simulation Checklist for ECOTECT (Ibarra, Reinhart).

GEOMETRY

- ✓ Prioritize creating the geometry within ECOTECT.
- ✓ Model the space dimensions accurately (within +/- 5 cm).
- ✓ Model the window dimensions and positions accurately (within +/- 5 cm).
- ✓ Model wall thicknesses and other façade elements that will affect light distribution within the space. (i.e. window frames, shading devices, etc.).
- ✓ Model surrounding elements (trees, adjacent buildings, ground, etc.).

IMPORTING GEOMETRY

If importing geometry from another 3D modeling tool:

- ✓ Make sure you simplify the model as much as possible before importing. (Only import geometric features that will have a relevant impact on the light distribution within the space).
- ✓ Make sure you import using the same dimension scale as the current scene.
- ✓ Make sure window surfaces are imported correctly (avoid having more than one surface per window glazing).
- ✓ Make sure surfaces are ungrouped to be able later to assign optical material properties by surfaces.

MATERIALS

- ✓ Prioritize using RADIANCE material libraries (i.e. NRC library)
- ✓ Assign interior wall reflectances (i.e. 50% reflectance)
- ✓ Assign ceiling reflectances (i.e. 80% reflectance)
- ✓ Assign interior floor reflectances (i.e. 20% reflectance)
- ✓ Assign exterior wall reflectances (i.e. 40% reflectance)
- ✓ Assign exterior ground reflectance (i.e. 20% reflectance)
- ✓ Assign window visual transmittance (i.e. 85% single, 72% double)

SIMULATION SETTINGS

- ✓ Position the sensor grid above the work plane height (i.e. 0.75 m -0.95 m)
- ✓ Make sensor grid resolution at least 0.8 m x 0.8 m
- ✓ Verify that the grid does not extend through the exterior walls.
- ✓ Before running the simulation, check the 3D model in the "Visualization" mode (verify windows, material assignments, surrounding elements, etc.).
- ✓ Export the model scene to RADIANCE using the following rtrace settings for the Radiance simulations: AB=5; AD =1500; AR=100, AS=20; AV=0 0 0; (medium complexity scene).
- ✓ Make sure you select the right sky luminance distribution model for the daylight simulation type you are running (i.e. CIE Overcast Sky for a Daylight Factor Simulation or a Clear or Sunny sky for an Illuminance Simulation).
- ✓ When running climate-based simulations, make sure to load the correct weather file and project geographic coordinates.
- ✓ Verify simulation results according to the following parameters:
  - Daylight Factor: range 0-100%; typically DF_{mean} < 5% (indoor space).
  - Illuminance Analysis: range 0-100.000 lux; typically Avg. < 5000 lux. (sunny)
  - Daylight Autonomy: range 0-100%; typically 20-80% (indoor space)

Iteratively test and validate the workflow proposed by the modeling guidelines.

Example of a platform dependent daylight simulation checklist for ECOTECT/RADIANCE

✓ Simulation Guidelines (checklist)

Example of a platform independent daylight simulation checklist

Table: Daylight Simulation Checklist (Reinhart, Ibarra).

Before you start	Did you decide which daylighting performance metrics to simulate and how to interpret the results?	❑
	Do you have a general idea of what the results should look like? E.g. a mean daylight factor in a standard sidelit space should lie between 2% and 5%; interior illuminance should lie between 100 lux and 3000 lux and daylight autonomies should range from 20% to 90% throughout the space.	❑
	Have you verified that the simulation program that you intend to use has been validated for the purpose that you intend to use it for, i.e. that the simulation engine produces reliable results and that the program supports the sky models related to your performance metric of choice? (An example would be the old CIE overcast sky for daylight factor calculations.)	❑
	Have you secured credible climate data for your building site? (This is only required for certain daylighting performance metrics.)	❑
Scene	Did you model all significant neighboring obstructions such as adjacent buildings and trees?	❑
	Did you model the ground plane?	❑
	Did you model wall thicknesses, interior partitions, hanging ceilings and larger pieces of furniture (if applicable)? Try to model all space dimensions within a 5cm tolerance.	❑
	Did you consider window frames and mullions by either modeling them geometrically or by using reduced visual transmittances for windows and skylights?	❑
	Did you check that all window glazings only consist of one surface? Several CAD tools model double/triple glazings as two/three parallel surfaces whereas daylighting programs tend to assign the optical properties of multiple glazings to a single surface.	❑
	Did you assign meaningful material properties to all scene components (see Table 10.1)?	❑
	Did you model any movable shading devices such as venetian blinds? (The choice to model movable elements is related to the performance metric that you intend to use.)	❑
Simulation setup	Make sure that you set up your project files correctly. This may involve:	
	- Checking that your project directory and file names do not contain any blanks (" ").	❑
	- Verifying that all sensors have the correct orientation, i.e. work plane sensors are facing up and ceiling sensors are facing down.	❑
	- Setting the resolution of the work plane to 0.5m x 0.5m or 1ft x 1ft and placing it around 0.85m above the floor.	❑
	- Selecting simulation parameters that correspond to the 'scene complexity'. To do so you should consult the technical manual of your simulation program *.	❑
	- Selecting the correct sky model (CIE, Perez).	❑

✓ Simulation Guidelines (checklist)

Questions?

The full paper may be downloaded from the conference proceedings of Building Simulation 2009:

http://www.ibpsa.org/proceedings/BS2009/BS09_0196_203.pdf

Be careful with what you wish for…

Now we have more than 100 models to analyze…