4.430 Daylighting

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4.430 Light And Matter

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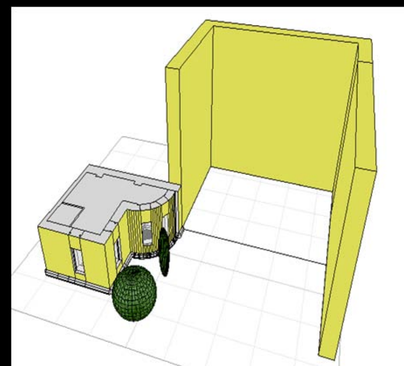
Building Technology Program

MISC

- ❑ Radiance workshops http://www.radiance.online.org /
- ❑ Lecture Note L09 and Assignment 4 are online.

Common Simulation Mistakes

How close do ‘simulation novices’ get?



Crit Room 102- Best Practice Model

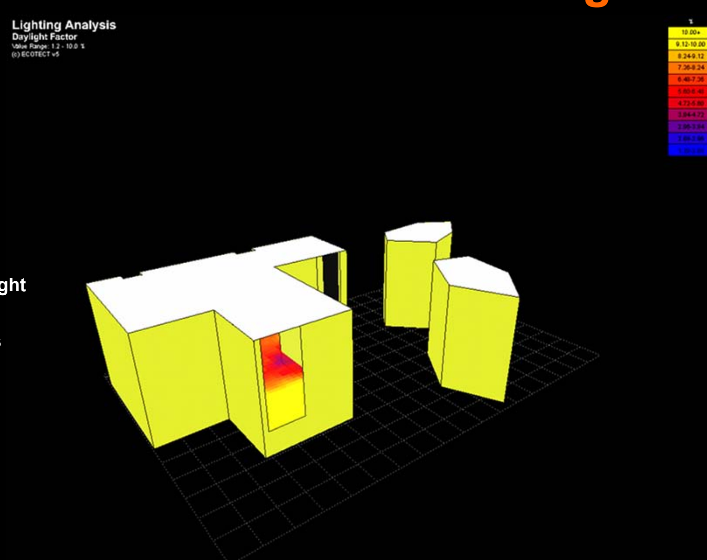
Courtesy of Diego Ibarra and Christoph Reinhart. Used with permission.

McGill = School of Architecture

error analysis of 69 student models of a sidelit space
comparison of simulation results using Ecotect Split Flux and Radiance

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

Error Sources: Geometric Modeling



Highest result

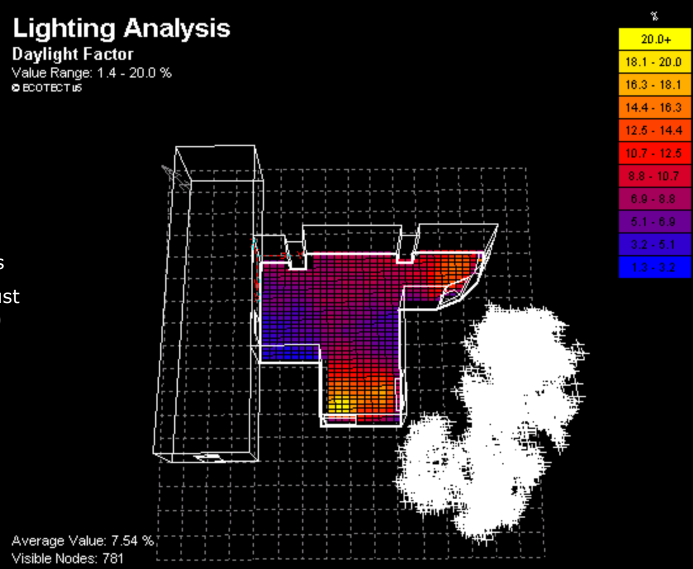
Mean DF = 10%

- **Window head height too high**
- **No wall thickness**

Error Sources: Software Interoperability

Mean DF = 7.5%

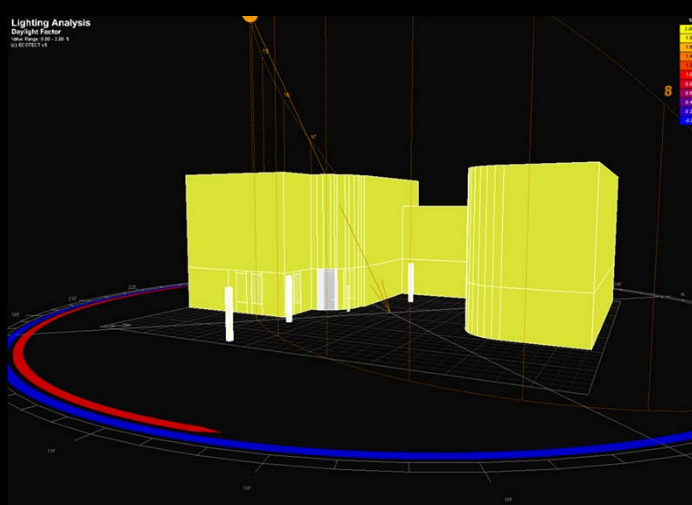
- No wall thickness
- No real trees (just construction lines)



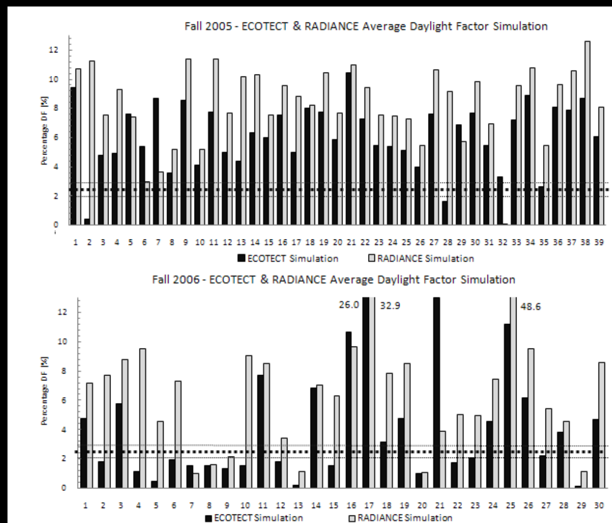
Error Sources: Material Properties

Mean DF = 1.5%

- **No wall thickness**
- **No glazings**

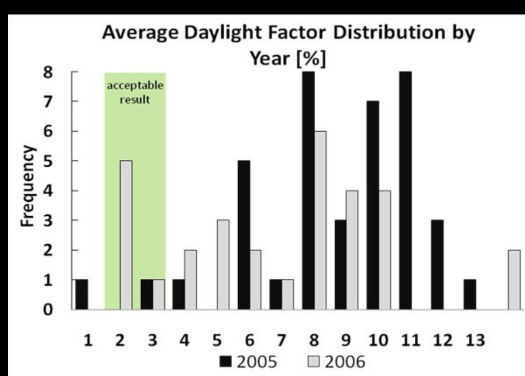


69 Student Models



- ❑ Ecotect results lie over and under Radiance results
- ❑ Enormous range of results.

Ecotect-Split-Flux vs. Radiance



- frequency distribution of mean daylight factor by year
- a closer analysis shows that none of the students built a 'correct' model
- the higher number of simulation results in the acceptable range indicate the effectiveness of 'simulation tips'

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 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 building and trees?
	• Did you model the ground plane?
	• Did you model wall thicknesses, interior partitions, hanging ceiling 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 surface whereas daylight 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 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).

Book Chapter: Reinhart C F, "Simulation-based Daylight Performance Predictions" in Building Performance Simulation for Design and Operation, Editors J Hensen and R Lamberts, Taylor Francis, to be published in January 2011

www.gsd.harvard.edu/research/gsdsquare/Publications/DaylightSimulationTips.pdf

High Museum of Art in Atlanta

Photo by gigi4791 on Flickr.

Project: High Museum of Art Expasions (1984 and 2005)
Architect: Richard Meier 1st Expansion, Renzo Piano 2nd Expansion
Lighting Design: ARUP Lighting

High Museum of Art in Atlanta

Photo by Matt Johnson on Flickr.

Photographs of the shading model of High Museum of Art removed due to copyright restrictions.

Project: High Museum of Art Expasions (1984 and 2005)
Architect: Richard Meier 1st Expansion, Renzo Piano 2nd Expansion

Repeated custom shading system to block direct sunlight.

High Museum of Art in Atlanta

Photographs of the light model and analysis of High Museum of Art removed due to copyright restrictions.

Performance analysis via repeated views from the position of the sun.

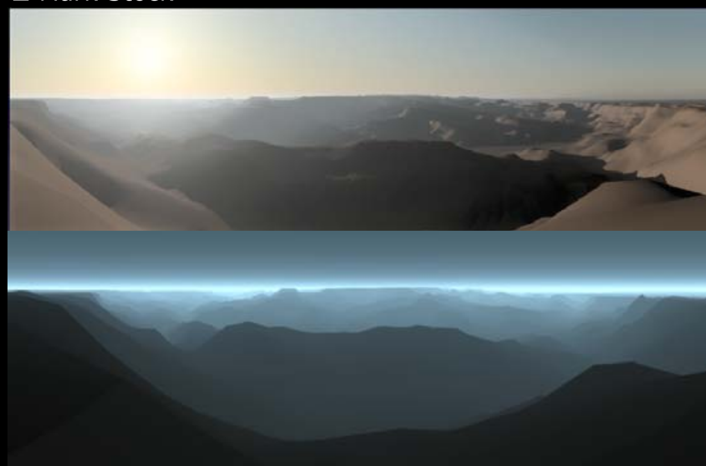
Material Properties

CIE sky in Radiance - sky.rad

```
# Sky definition.
!gensky 4 1 12.76 -c -a 45.500 -o -73.700 -m -75.000  -B 40.307263

skyfunc glow sky_mat
0 0 4 1 1 1 0

sky_mat source sky
0 0 4 0 0 1 180

skyfunc glow ground_glow
0 0 4 1 .8 .5 0

ground_glow source ground
0 0 4 0 0 -1 180
```

Modeling Skies

- Mark Stock



Modeling Materials

List of common material surface properties.

Table 10.1: Optical properties of common material surfaces.

Interior floor	20% diffuse reflectance*
Interior wall	50% diffuse reflectance*
Interior Ceiling	80% diffuse reflectance*
Interior Ceiling (high reflectance)	90% diffuse reflectance
Double Glazing	72% direct visual transmittance
Single Glazing	90% direct visual transmittance
Translucent Glazing	20% diffuse-diffuse hemispherical transmittance++
Exterior Building Surfaces	44% diffuse reflectance#
Exterior Ground	20% diffuse reflectance

*Taken from IESNA Handbook (Rea 2000)
++Taken from (Reinhart and Andersen 2006)
Taken from (Leder, Pereira and Moraes 2007)

- specular versus Lambertian reflectors
- significance of material libraries
- selecting meaningful material properties is your responsibility

Radiance Material 'Plastic'

```
void plastic TestMaterial
0
0
5   0.965 0.965 0.965  0.02 0
```

Red Green Blue Specularity Roughness

red, green, blue are reflectance   values greater than 0.9 are not usually realistic.
Specularity greater than 0.1 is usually not realistic.
Roughness varies from 0=perfectly smooth, to 0.5=perfectly rough.
Roughness greater than 0.4 (?) is usually not realistic.

- ❑Good Source for Radiance Materials: http://www.artifice.com/radiance/rad_materials.html

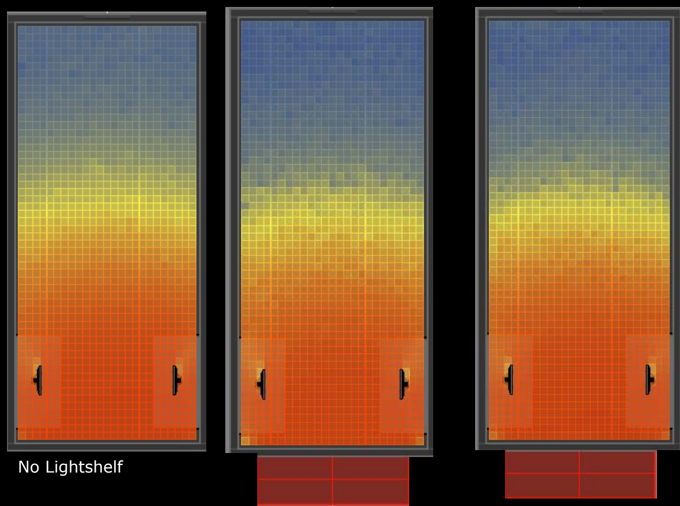
Radiance Material 'Metal'

```
    modifier metal id
         0    0
  5 red green blue specularityroughness
```

red, green, blue are reflectance – values greater than 0.9 are not usually realistic.
Specularity greater than 0.9 is typical.
Roughness varies from 0=perfectly smooth, to 0.5=perfectly rough.
Roughness greater than 0.2 is usually not realistic.

- ❑ Good Source for Radiance Materials: http://www.artifice.com/radiance/rad_materials.html

Daylight Autonomy

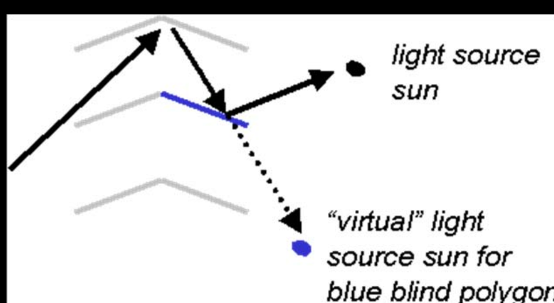


No Lightshelf

Lightshelf, 50% Lambertian reflector

Lightshelf, 80% reflectance, 90% specular

Mirror Material



Virtual light sources

Radiance Material ‘Mirror’

```
void mirror TestMaterial
0
0
3   0.965 0.965 0.965
```

Red Green Blue

Specularity is under 2% for most real materials.

Radiance Material ‘Glow’

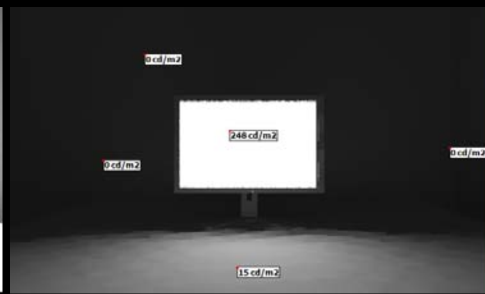
```
void glow TestMaterial
0
0
4   1.39  1.39  1.39    0
```

Red Green Blue Radius

- ❑ Measure luminance of a flat screen equals 250 cdm^{-2} equals 250 lumen/ster m^2
- ❑ 250 cdm^{-2} / 179 lumen/W = 1.39 W/ster m^2
- ❑ Note: The orientation of the surface matters.

Glare and Comfort Analysis

Sep 21 3PM



Sep 21 10PM

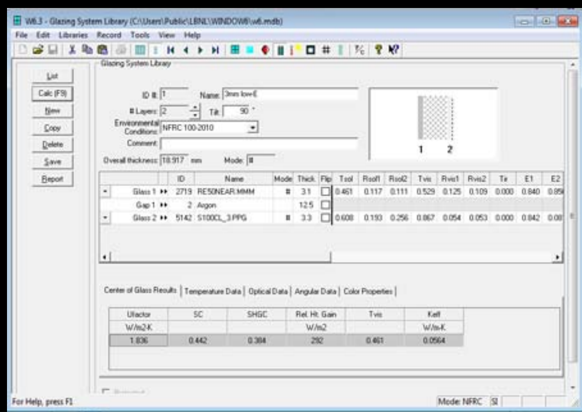
Material Glass

```
/*
 *  This definition of glass provides for a quick calculation
 *  using a single surface where two closely spaced parallel
 *  dielectric surfaces would otherwise be used.  The chief
 *  advantage to using this material is speed, since internal
 *  reflections are avoided.
 *
 *  The specification for glass is as follows:
 *
 *  modifier glass id
 *  0
 *  0
 *  3+ red grn blu [refractive_index]
 *
 *  The color is used for the transmission at normal incidence.
 *  To compute transmissivity (tn) from transmittance (Tn) use:
 *
 *  tn = (sqrt(.8402528435+.0072522239*Tn*Tn)-.9166530661)/.0036261119/Tn
 *
 *  The transmissivity of standard 88% transmittance glass is 0.96.
 *  A refractive index other than the default can be used by giving
 *  it as the fourth real argument.  The above formula no longer applies.
 *
 *  If we appear to hit the back side of the surface, then we
 *  turn the normal around.
 */
```

```
void glass ClearFloat_6mm_MF
0
0
3   0.661 0.742 0.742
```

Red: (227/255)*TN(0.88)

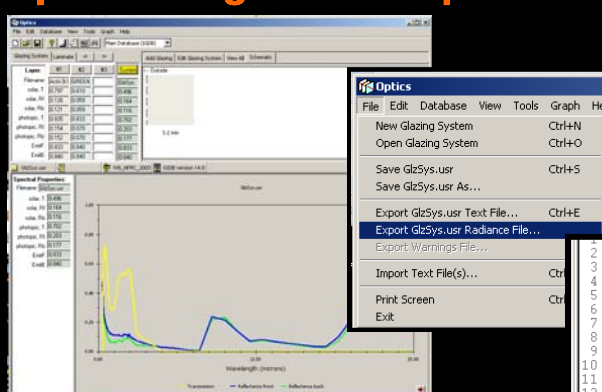
Window Program from LBNL



http://windows.lbl.gov/software/

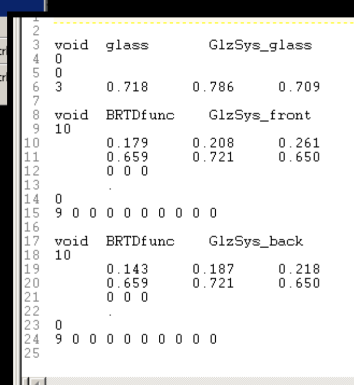
User can build a window unit (glazing plus frame using the National Fenestration Rating Council (NFRC) glazing database.

Optics Program - Export to Radiance



http://windows.lbl.gov/materials/optics5/

The user can then export glazing unit as glass and BRTDfunc Radiance materials. I recommend to use the former. The Export to Radiance has to my knowledge not been validated.



```
void  glass       GlzSys_glass
0
0
3     0.718    0.786    0.709

void  BRTDfunc    GlzSys_front
10
      0.179    0.208    0.261
      0.659    0.721    0.650
      0  0  0
      .
0
9  0  0  0  0  0  0  0  0  0

void  BRTDfunc    GlzSys_back
10
      0.143    0.187    0.218
      0.659    0.721    0.650
      0  0  0
      .
0
9  0  0  0  0  0  0  0  0  0
```

Fraunhofer ISE - Atrium

Photograph of glazing and photovoltaic panels in the atrium of Fraunhofer ISE removed due to copyright restrictions.

← South North →

Integration of Daylighting with Photovoltaics

Electrochromic Glazing – Physical Principle

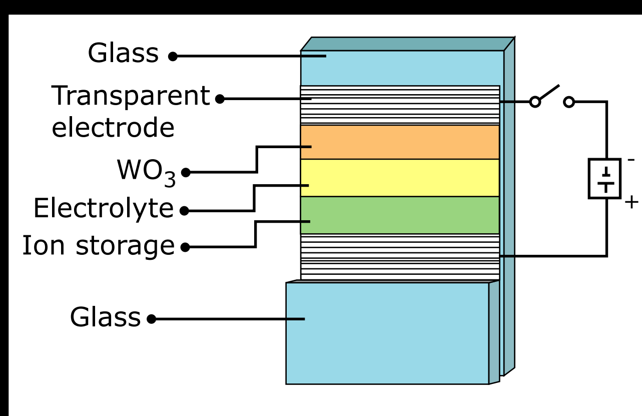


Image by MIT OpenCourseWare.

Source – Energy-Efficient Solar Buildings, "The future of Renewable Energies II", James & James (2002)

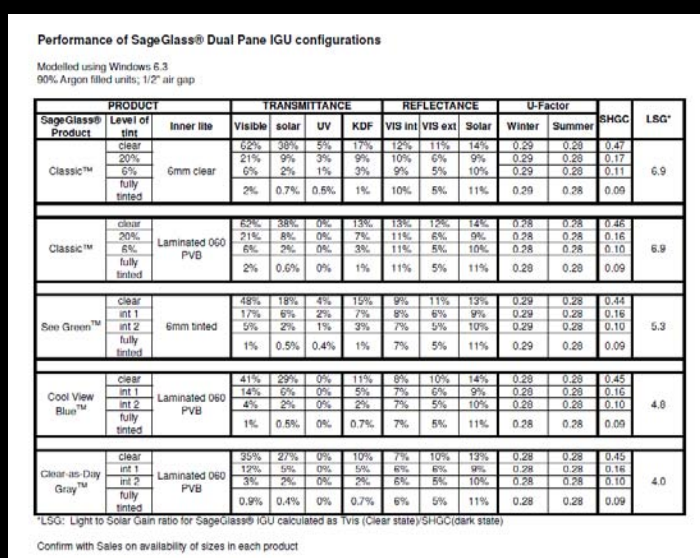
Stadtsparkasse Dresden $WULXP

Photo: Pilkington Flabeck

Project: Stadtsparkasse resden, Germany (1999)
Architects: Bauer & Keller, resden

First installation of an electrochromic glazing with continuous dimming in Europe.

How do you model this?



Performance of SageGlass® Dual Pane IGU configurations

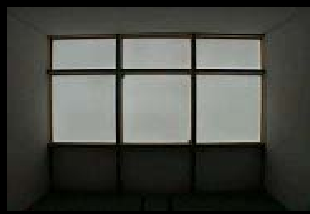
Modelled using Windows 6.3
90% Argon filled units; 1/2" air gap

PRODUCT			TRANSMITTANCE				REFLECTANCE			U-Factor		SHGC	LSG*
SageGlass® Product	Level of tint	Inner lite	Visible	solar	UV	KDF	VIS int	VIS ext	Solar	Winter	Summer		
Classic™	clear	6mm clear	62%	38%	5%	17%	12%	11%	14%	0.29	0.28	0.47	6.9
	20%		21%	9%	3%	9%	10%	6%	9%	0.29	0.28	0.17	
	6%		6%	2%	1%	3%	9%	5%	10%	0.29	0.28	0.11	
	fully tinted		2%	0.7%	0.5%	1%	10%	5%	11%	0.29	0.28	0.09	
Classic™	clear	Laminated 060 PVB	62%	38%	0%	13%	13%	12%	14%	0.28	0.28	0.46	6.9
	20%		21%	8%	0%	7%	11%	6%	9%	0.28	0.28	0.16	
	6%		6%	2%	0%	3%	11%	5%	10%	0.28	0.28	0.10	
	fully tinted		2%	0.6%	0%	1%	11%	5%	11%	0.28	0.28	0.09	
See Green™	clear	6mm tinted	48%	18%	4%	15%	9%	11%	13%	0.29	0.28	0.44	5.3
	int 1		17%	6%	2%	7%	8%	6%	9%	0.29	0.28	0.16	
	int 2		5%	2%	1%	3%	7%	5%	10%	0.29	0.28	0.10	
	fully tinted		1%	0.5%	0.4%	1%	7%	5%	11%	0.29	0.28	0.09	
Cool View Blue™	clear	Laminated 060 PVB	41%	29%	0%	11%	8%	10%	14%	0.28	0.28	0.45	4.8
	int 1		14%	6%	0%	5%	7%	6%	9%	0.28	0.28	0.16	
	int 2		4%	2%	0%	2%	7%	5%	10%	0.28	0.28	0.10	
	fully tinted		1%	0.5%	0%	0.7%	7%	5%	11%	0.28	0.28	0.09	
Clear-as-Day Gray™	clear	Laminated 060 PVB	35%	27%	0%	10%	7%	10%	13%	0.28	0.28	0.45	4.0
	int 1		12%	5%	0%	5%	6%	6%	9%	0.28	0.28	0.16	
	int 2		3%	2%	0%	2%	6%	5%	10%	0.28	0.28	0.10	
	fully tinted		0.9%	0.4%	0%	0.7%	6%	5%	11%	0.28	0.28	0.09	

*LSG: Light to Solar Gain ratio for SageGlass® IGU calculated as Tvis (Clear state)/SHGC(dark state)

Confirm with Sales on availability of sizes in each product

Study of Thermotropic Glazings



Courtesy of Helge Hartwig. Used with permission. Photos: Helge Hartwig, TU Munich

Project: research project at the Technical University of Munich (1999)
Project Manager: Helge Hartwig

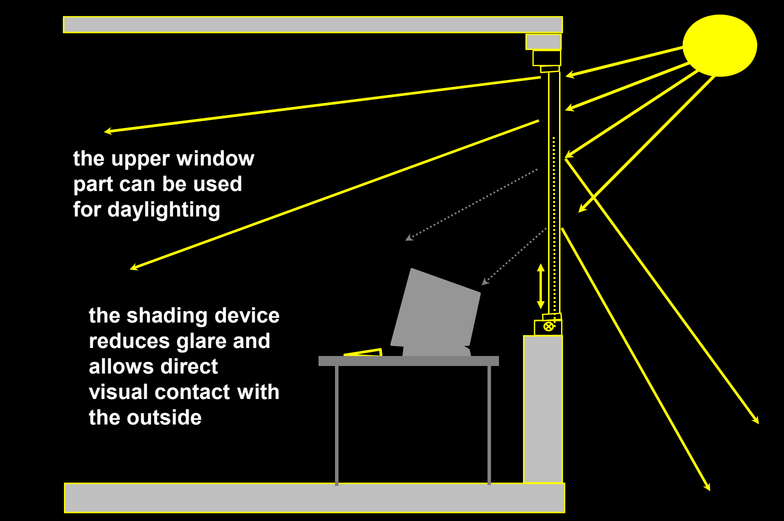
Split Blinds

Low end solution.

High end solution.

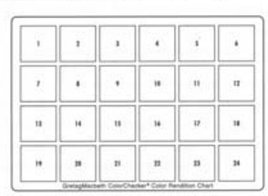
Building Design

- Façade Openings.



Macbeth ColorChecker

No.	Name	CIE (1931) x	y	Y	Munsell Notation Hue	Value/Chroma	ISCC/NBS Name
1.	dark skin	.400	.350	10.1	3 YR	3.7 / 3.2	moderate brown
2.	light skin	.377	.345	35.8	2.2 YR	6.47 / 4.1	light reddish brown
3.	blue sky	.247	.251	19.3	4.3 PB	4.95 / 5.5	moderate blue
4.	foliage	.337	.422	13.3	6.7 GY	4.2 / 4.1	moderate olive green
5.	blue flower	.265	.240	24.3	9.7 PB	5.47 / 6.7	light violet
6.	bluish green	.261	.343	43.1	2.5 BG	7 / 6	light bluish green
7.	orange	.506	.407	30.1	5 YR	6 / 11	strong orange
8.	purplish blue	.211	.175	12.0	7.5 PB	4 / 10.7	strong purplish blue
9.	moderate red	.453	.306	19.8	2.5 R	5 / 10	moderate red
10.	purple	.285	.202	6.6	5 P	3 / 7	deep purple
11.	yellow green	.380	.489	44.3	5 GY	7.1 / 9.1	strong yellow green
12.	orange yellow	.473	.438	43.1	10 YR	7 / 10.5	strong orange yellow
13.	blue	.187	.129	6.1	7.5 PB	2.9 / 12.7	vivid purplish blue
14.	green	.305	.478	23.4	0.25 G	5.4 / 8.65	strong yellowish green
15.	red	.539	.313	12.0	5 R	4 / 12	strong red
16.	yellow	.448	.470	59.1	5 Y	8 / 11.1	vivid yellow
17.	magenta	.364	.233	19.8	2.5 RP	5 / 12	strong reddish purple
18.	cyan	.196	.252	19.8	5 B	5 / 8	strong greenish blue
19.	white	.310	.316	90.0	N	9.5 /	white
20.	neutral 8	.310	.316	59.1	N	8 /	light gray
21.	neutral 6.5	.310	.316	36.2	N	6.5 /	light-medium gray
22.	neutral 5	.310	.316	19.8	N	5 /	medium gray
23.	neutral 3.5	.310	.316	9.0	N	3.5 /	dark gray
24.	black	.310	.316	3.1	N	2 /	black



A tool to measure and compare differences in color reproduction in various processes and under different light sources. An array of 24 colors represents natural objects such as human skin, foliage and blue sky. The square have the same color and reflective properties as their real world counterparts.

To use it compare the original color chart with a reproduced printout or photograph.

Advanced Radiance Visualizations I

Rendering through Radiance of the Louvre removed due to copyright restrictions.

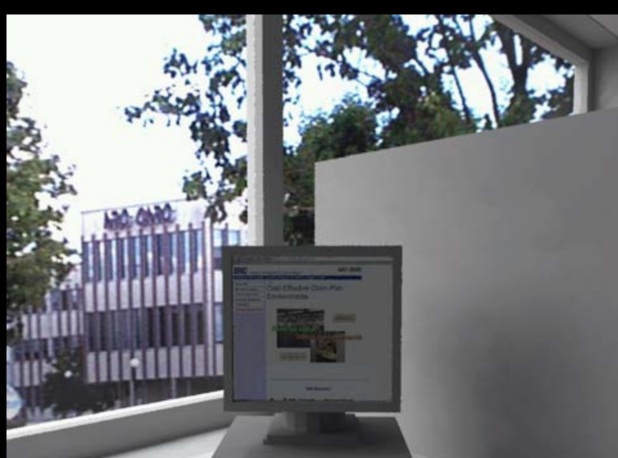
Advanced Radiance Visualizations II

Simulation: Peter Apian Bennewitz

Advanced Radiance Visualizations III

Rendering through Radiance of building interior removed due to copyright restrictions.

Advanced Radiance Visualizations IV



Simulation: Christoph Reinhart