4.430 Daylighting

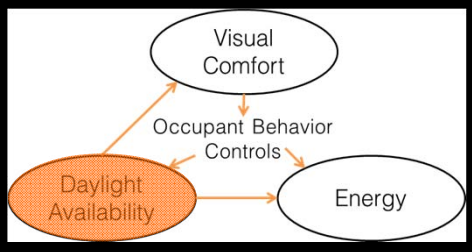
Christoph Reinhart

4.430 Massing Studies & Rules of Thumb

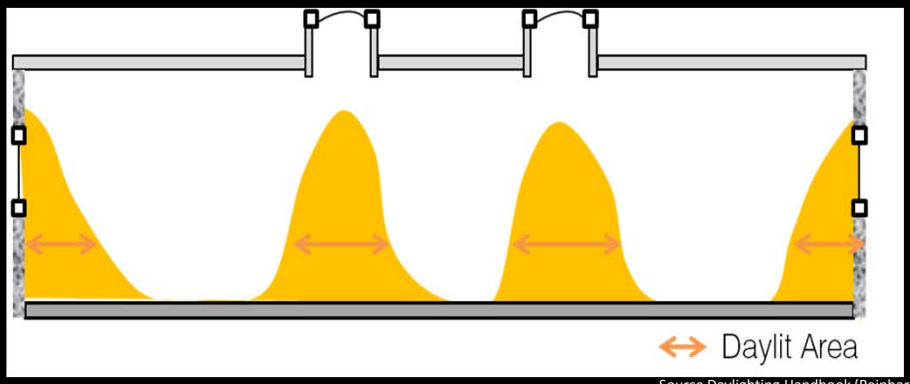
Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Massing Studies

What is the relationship between daylight availability and building massing, i.e. how much of a building can be daylit depending on its overall shape and surrounding context?



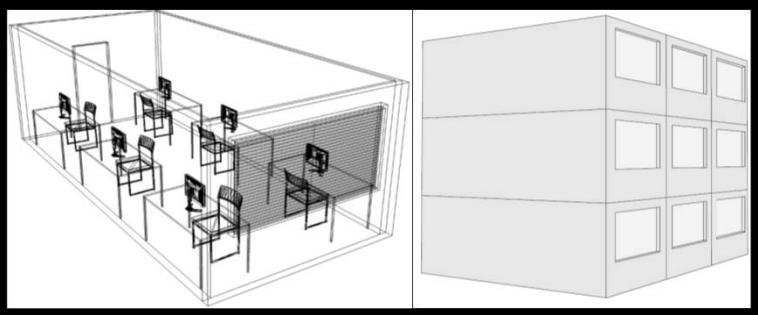
Daylight Availability and the Daylit Area



Source Daylighting Handbook (Reinhart)

- How can we determine the daylit area in a space?
- We will be looking at three related approaches.

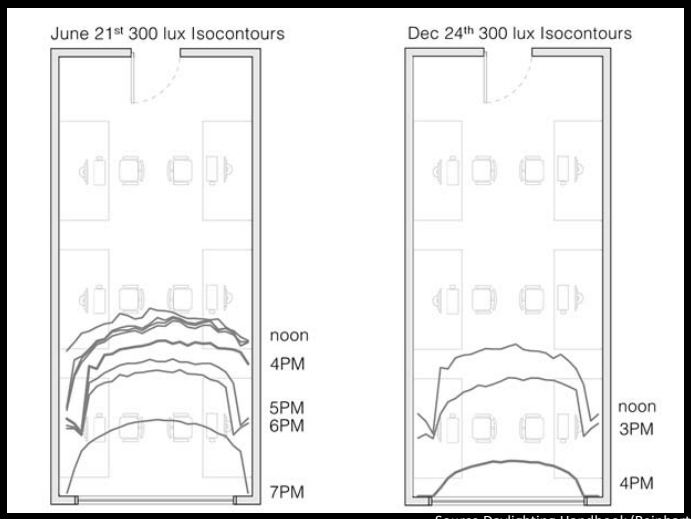
Reference Office



Source Daylighting Handbook (Reinhart)

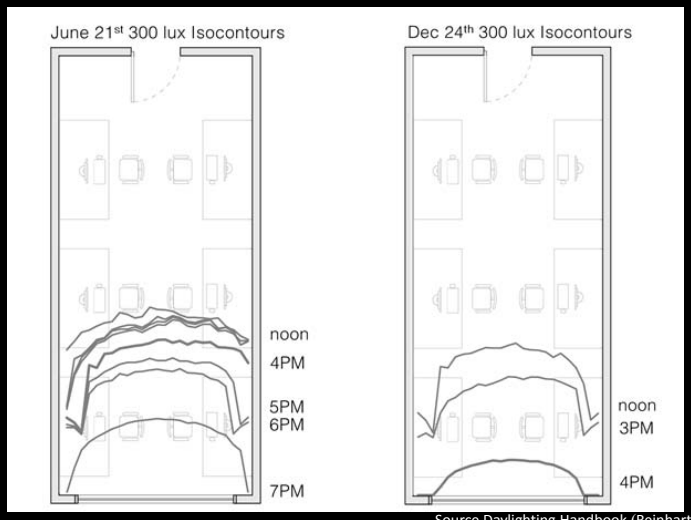
- The reference office is a test room that we will be using for various sensitivity studies throughout the term.

(1) Based on Daylight Autonomy



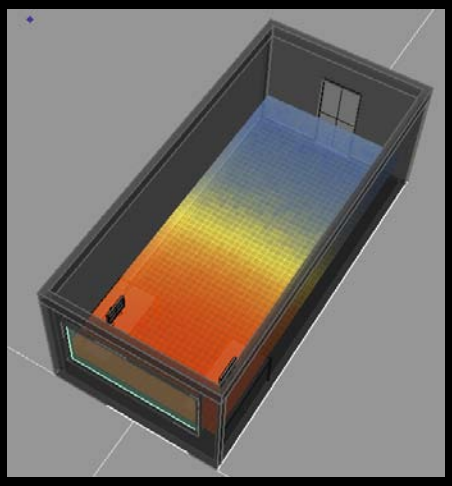
Source Daylighting Handbook (Reinhart)

(1) Based on Daylight Autonomy



Source Daylighting Handbook (Reinhart)

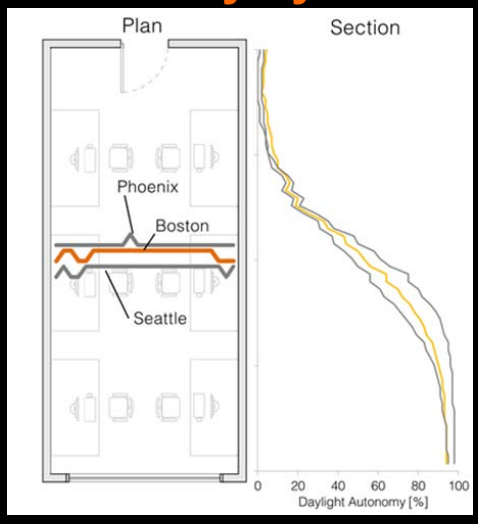
Daylight Autonomy



Source Daylighting Handbook (Reinhart)

- Daylight autonomy (DA) is a daylight availability metric that corresponds to the percentage of the occupied time when the target illuminance at a point in a space is met by daylight.

Daylight Autonomy by Climate



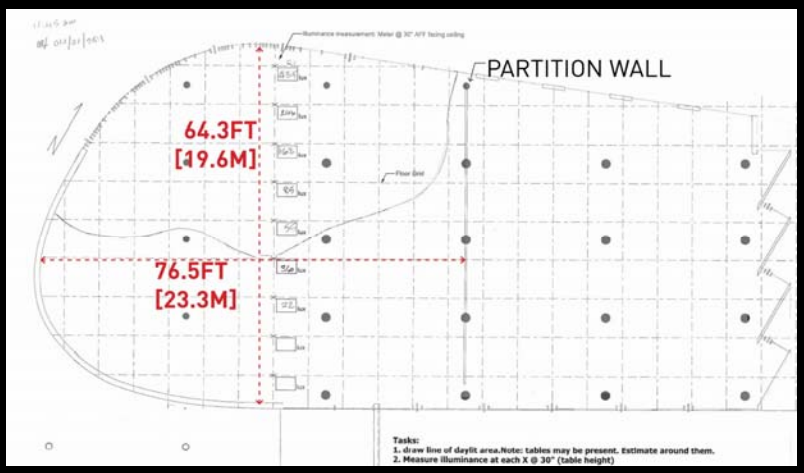
Source Daylighting Handbook (Reinhart)

- Daylight autonomy is climate dependent but not too much. With the endorsement of the IESNA, DA is likely to be implemented into LEED and other green building rating systems over the coming years.

Ok, that's what the computer tells us.
How well do daylight autonomy (and other daylight availability metrics) relate to occupant assessments of spaces

Carpenter Center Study

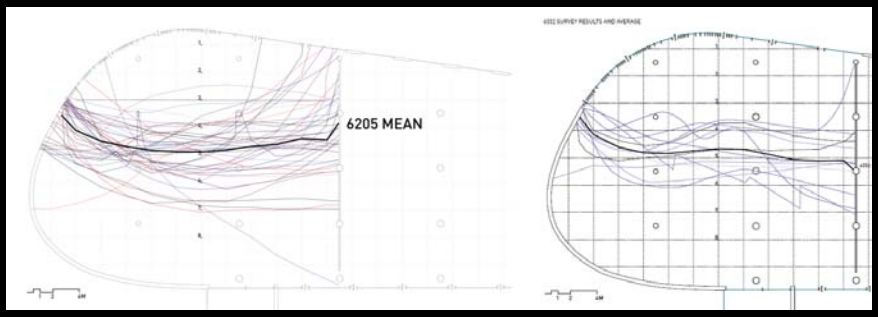
Carpenter Center Study



Courtesy of Elsevier. Used with permission.

C F Reinhart and D Weissman, "The Daylit Area Correlating architectural student assessments with current and emerging daylight availability metrics , Building and Environment, 50, pp. 155-162, 2012.

Carpenter Center Study

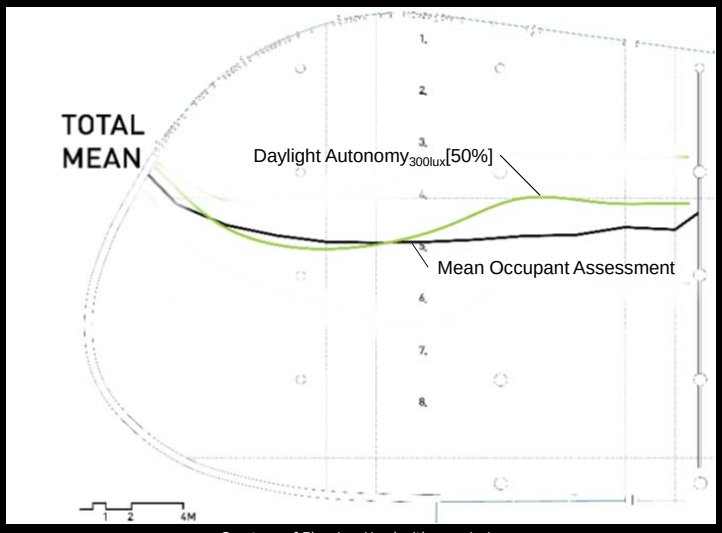


Courtesy of Elsevier. Used with permission.

Results for GSD 6205 and 6332

- Individual assessments obviously vary.
- The same is true for electric lighting preferences.

Daylight Autonomy Comparison



Courtesy of Elsevier. Used with permission.

- Comparison for this one space encouraging.
- We are now expanding the study with 21 universities.

Daylight Area Study II

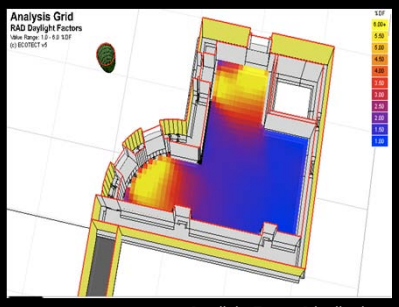
University
Miami University, Ohio, USA
Federal University of Santa Catarina, Brazil
University of Texas, USA
Technical University of Berlin
Loughborough University, UK
MIT
University of Southern California, USA
Univ. Of Washington Seattle
Victoria University Wellington, New Zealand
Technion, Israel
University of North Carolina – Charlotte, USA
Politecnico di Torino, Italy
Federal University of Paraíba – Centro de Tecnologia – João Pessoa - Brasil
Ecole Polytechnique Federale de Lausanne, Switzerland
PARSONS THE NEW SCHOOL FOR DESIGN, NY, USA
Boston Architectural College, MA, USA
University of Idaho – Boise
Cornell University
CEPT University, K.L.Campus, Navarangpura, Ahmedabad INDIA

Your first Daylight Simulation

Daylight Simulation

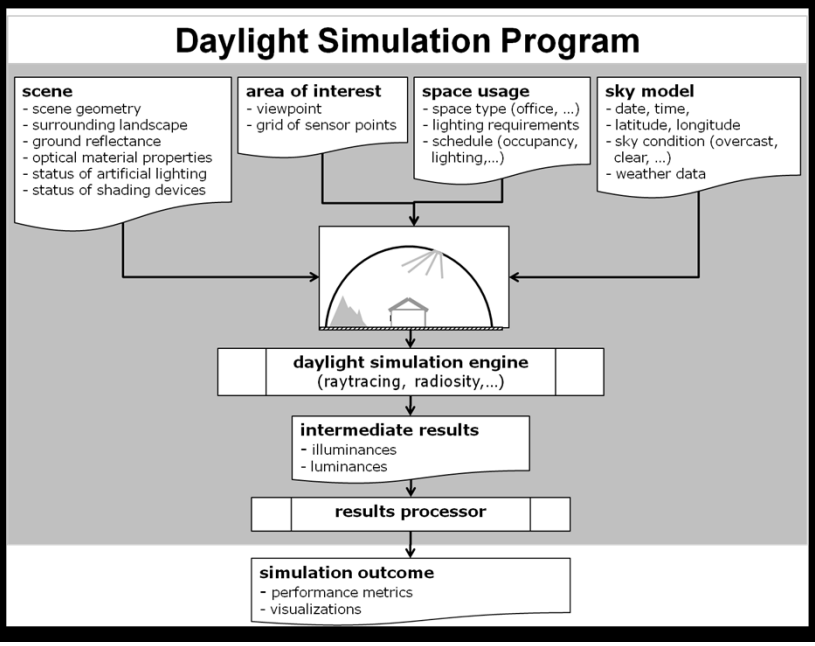
A computer-based calculation of the amount of daylight available inside or outside of a building under one or several sky conditions. Simulation outputs may be discrete numbers (illuminances and luminances) under selected sensor points within a scene or visualizations of a scene.

Visualization



Daylight Factor Distribution

Elements needed for a DL Simulation



Architectural vs. Daylight Models

- Generally both model types are very similar.
- To use an architectural model for daylighting analysis, different material types have to be organized by layers.
- You have to take care that material properties are assigned correctly and that all 'relevant objects in your scene, such as trees, neighboring buildings and wall thicknesses are included. Also pay attention to light leaks.

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).

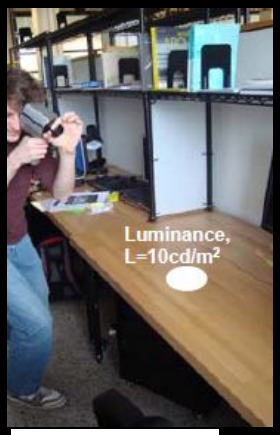
Image by MIT OpenCourseWare.

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

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

Modeling Basic Materials

Method 1



$$L = \frac{E\rho}{\pi}$$

1. Under diffuse lighting conditions take a luminance, L, and an illuminance, E, reading of a sample surface.
2. The estimated diffuse reflectance of the sample is

   $\rho = L\pi / E = 10\pi/55 = 57\%$

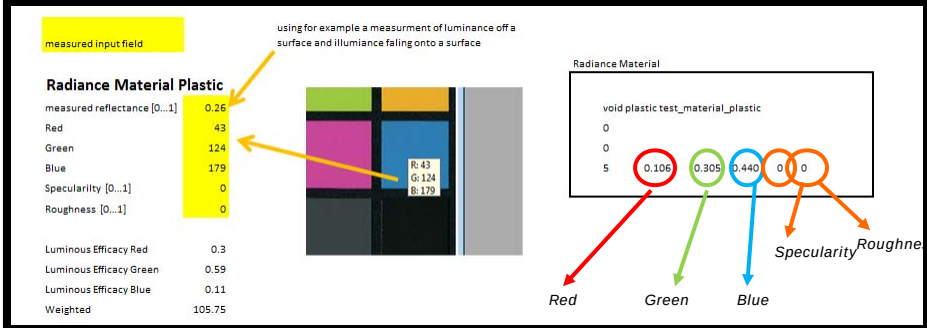
Method 2

Table of surface reflectance values

	Light source	A grey	B brown	C ochre	D olive	E red	F blue	G green	H yellow
Row 1	Incandescent	10	14	25	18	25	15	13	39
	Fluorescent 840	10	13	25	18	23	16	15	38
	Daylight D65	10	13	23	17	19	17	16	36
Row 2	Incandescent	15	18	31	25	31	24	21	47
	Fluorescent 840	15	18	31	25	29	25	23	47
	Daylight D65	15	17	30	24	25	26	24	45
Row 3	Incandescent	24	27	40	33	40	35	34	56
	Fluorescent 840	24	27	39	33	38	35	35	56
	Daylight D65	24	26	38	33	35	37	36	54
Row 4	Incandescent	36	41	50	47	53	49	47	64
	Fluorescent 840	36	41	50	47	52	50	48	64
	Daylight D65	36	40	48	46	49	51	50	63
Row 5	Incandescent	55	58	64	61	65	63	62	73
	Fluorescent 840	54	58	64	61	64	63	62	73
	Daylight D65	55	58	63	61	63	64	64	74
Row 6	Incandescent	74	77	79	77	77	78	78	81
	Fluorescent 840	73	76	79	77	76	78	78	81
	Daylight D65	74	77	79	77	76	79	78	81

1. Using a CIBSE reflectance chart pick the column with the closest color to the sample.
2. Identify the two rows in which the sample is brighter and darker than the reference squares.
3. Read of the reflectances of the closest reference square under the invesitgated lighting conditions.
4. The estimated diffuse reflectance of the sample is around ρ 54%

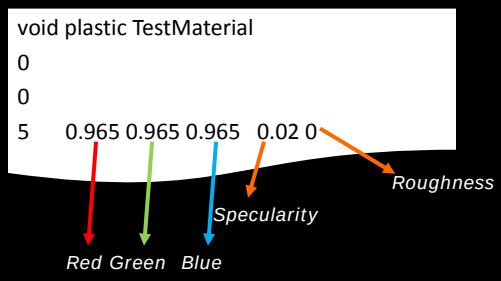
How to consider color?



1. Determine the diffuse reflectance of a sample surface.
2. Take a photograph of the sample and determine the RGB color.
3. Enter values into Excel spreadheet and copy the resulting radiance material into:

   DIVA 1.9 C:\DIVA\material.rad or DIVA2.0 C:\DIVA\Daylight\ material.rad

Radiance Material 'Plastic'



Typical reflectance values

- floors 30%
- wall 50%
- ceiling 70-90%

Typical specularity values:

- matt 0
- glossy 0.02

A good Source for Radiance Materials is
http://www.artifice.com/radiance/rad_materials.html

Radiance Material 'Glass'

measured input field

using for example a measurment of luminance off a surface and illumiance faling onto a surface

Radiance Material Glass

measured transmittance Red	0.72
measured transmittance Gre	0.72
measured transmittance Blue	0.72
refractive index	1.52 This usually stays the same.
Transmissivity Red	0.7846
Transmissivity Green	0.7846
Transmissivity Blue	0.7846

Radiance Material

```
void glass test_glazing
0
0
4       0.785       0.785   0.785   1.5
```

1. Determine the direct normal visual transmittance of a sample glazing.
2. Enter transmittance into Excel spreadheet and copy the resulting radiance material into:

   DIVA 1.9 C:\DIVA\material.rad or DIVA2.0 C:\DIVA\Daylight\ material.rad

Solar Radiation Data

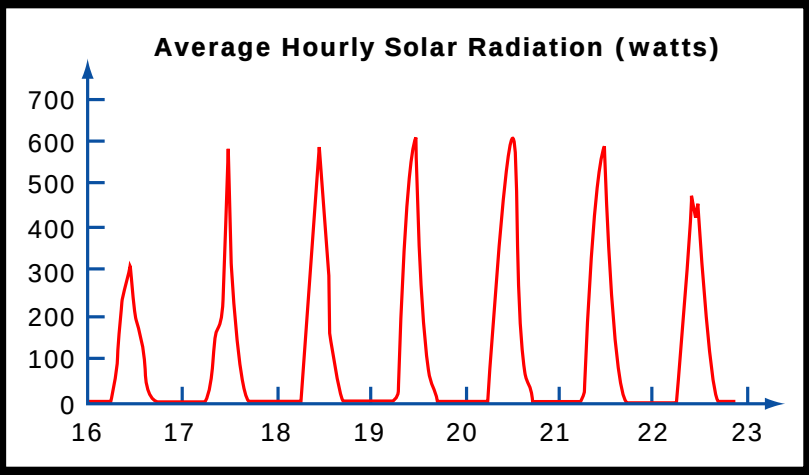


Image by MIT OpenCourseWare.

http://weather.keneli.org/Daily_Plus.htm

Solar Radiation Data

Solar Date and Time			Direct Horizontal Radiation [Wm^{-2}]	Diffuse Radiation [Wm^{-2}]
2	21	8.5	3	79
2	21	8.583	3	85
2	21	8.666	20	119
2	21	8.75	222	88
2	21	8.833	196	104
2	21	8.917	200	109
2	21	9	333	60
2	21	9.083	207	120
2	21	9.167	238	114
2	21	9.25	219	128
2	21	9.333	102	166
2	21	9.417	195	148
2	21	9.5	336	97
2	21	9.583	424	61
2	21	9.666	421	69
2	21	9.75	409	80
2	21	9.833	350	114
2	21	9.917	387	168
2	21	10	443	81
2	21	10.083	296	154
2	21	10.167	183	198
2	21	10.25	273	172
2	21	10.333	308	163
2	21	10.417	506	73
2	21	10.5	504	78

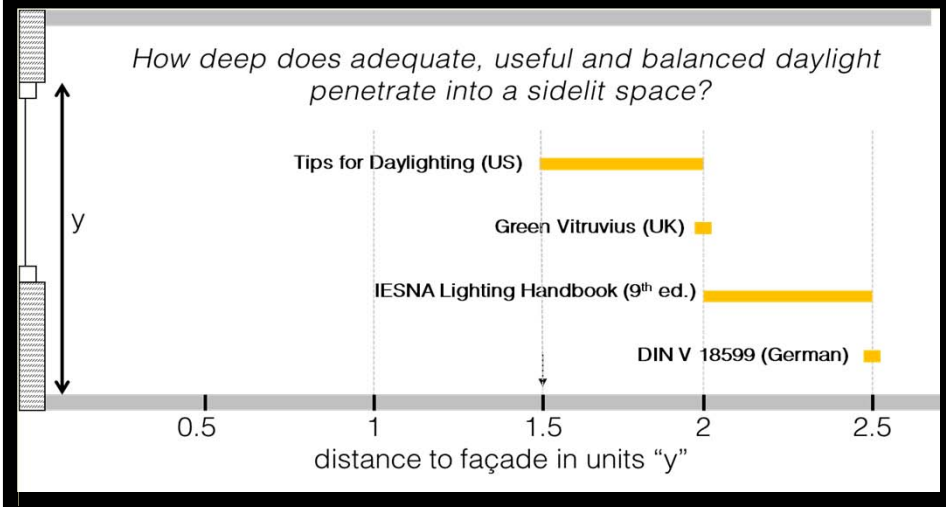
Time convention: 9.167 = 9h 0.167*60min = 9h 10 min = 9:10 AM

Rules of Thumb

Rule of Thumb

Definition: A useful principle having wide application but not intended to be strictly accurate or reliable in every situation (The American Heritage Dictionary of the English Language, 2004).

Window-Head-Height Rule of Thumb

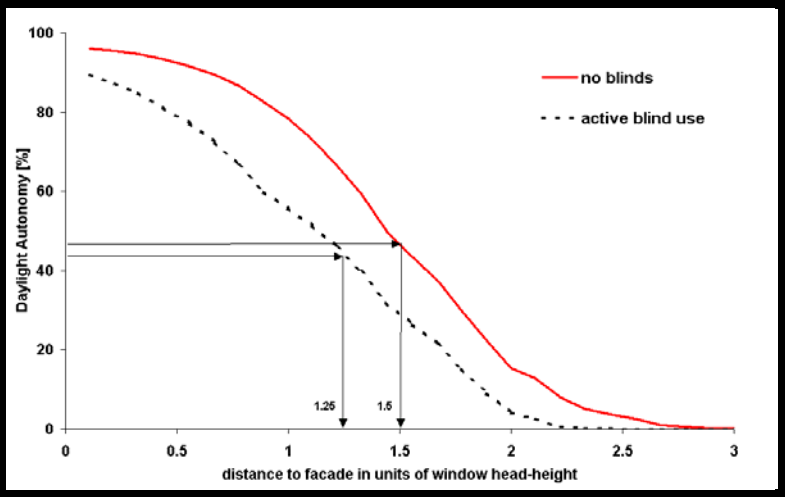


- Mantra in sustainable design
- Sole quantitative justification for room proportions/façade design
- An empirical rule

Daylighting Rule of Thumb (DRT)	reference
Daylighting within a building will only be **significant** within about twice the room height of a windowed facade.	A Green Vitruvius, p.72
The maximum depth of the **daylit area** corresponds to 2.5 times the difference of the window-head-height and the height of the work plane.	DIN V 18599 part 4
A standard window can produce **useful** illumination to a depth of about 1.5 times the height of the window. With lightshelves or other reflector systems this can be increased to 2.0 times.	US DOE – Building Toolbox
Keep depth of rooms within 1.5-2.0 times window head height for **adequate** illumination levels and balanced distribution.	Tips for Daylighting, p. 3-1
Room depths of 1.5 times the room's window head height will allow sunlight to provide **adequate** illumination levels and provide for balanced light distribution.	Daylighting Guide for Canadian Commercial Buildings, p.23
There is a direct relationship between the height of the window head and the depth of daylight penetration. Typically **adequate** daylight will penetrate 1.5 times the height of the window head.	Daylighting Guide for Buildings
To **avoid large ranges of in daylight illuminances** (greater than 25:1), the distance from the window wall to the inner wall should normally be limited to twice the window head height with clear glazings.	IESNA Lighting Handbook 8-24

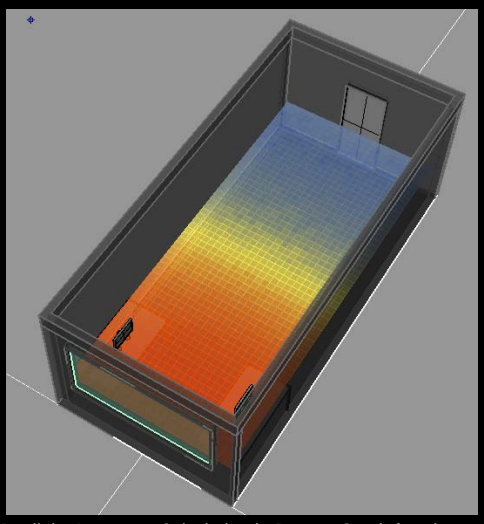
Adequate, useful & balanced daylight

adequate => above target illuminance level (daylight autonomy)
useful => include blind usage
balanced => comparable levels throughout the daylit area



Sidelit space in New York City, South façade (60% WWR, t_{vis}35%); occupied Mo Fr 8-5; Target illuminance 500 lux.

Daylit Area in DIVA-for-Rhino



Daylight Autonomy Calculation in Boston, South façade; occupied 8AM-6PM; Target illuminance 300 lux.

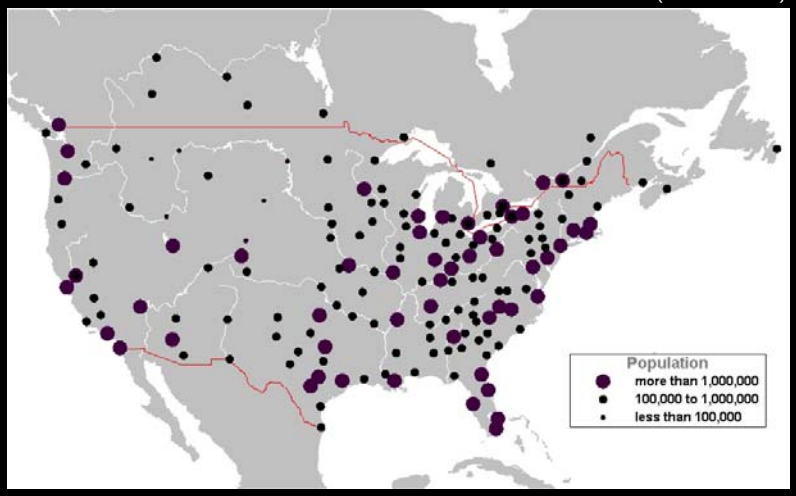
Parameter Study

Variable	Range				
climates centers	Daytona Beach, FL	L.A., CA	New York, NY	Vancouver, BC	Winnipeg, MB
facade orientation	North	South	West	East	
τ window [%]	35		75		
balustrade	yes		no		
sill	yes		no		
occupancy	office		classroom		
min ill. [lux]	300		500		

window head height identical in all 640 cases

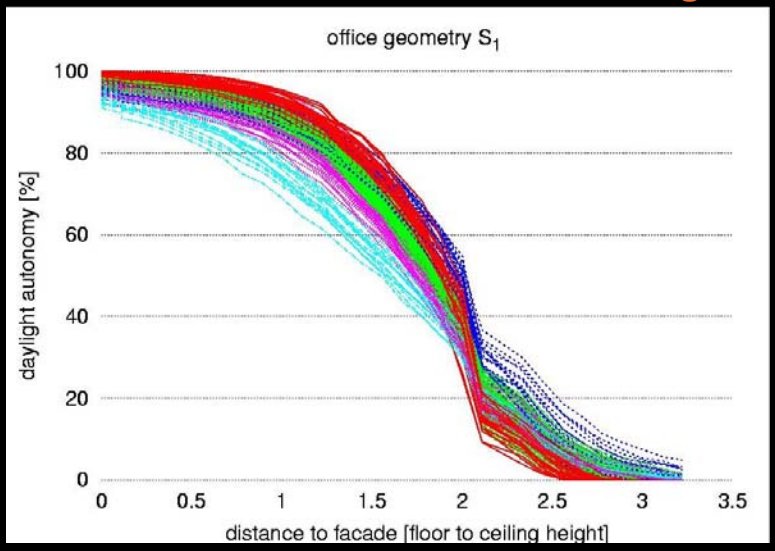
Varying Daylight Autonomy Distributions across 186 sites in North America

(Reinhart 2001)

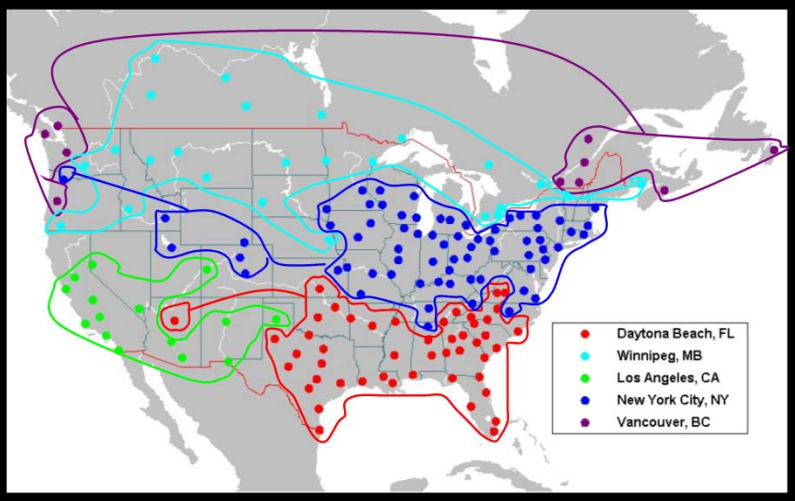


186 sites representing 74% of the US and 63% of the Canadian population.

Varying Daylight Autonomy Distributions across the 186 sites for a South facing Office

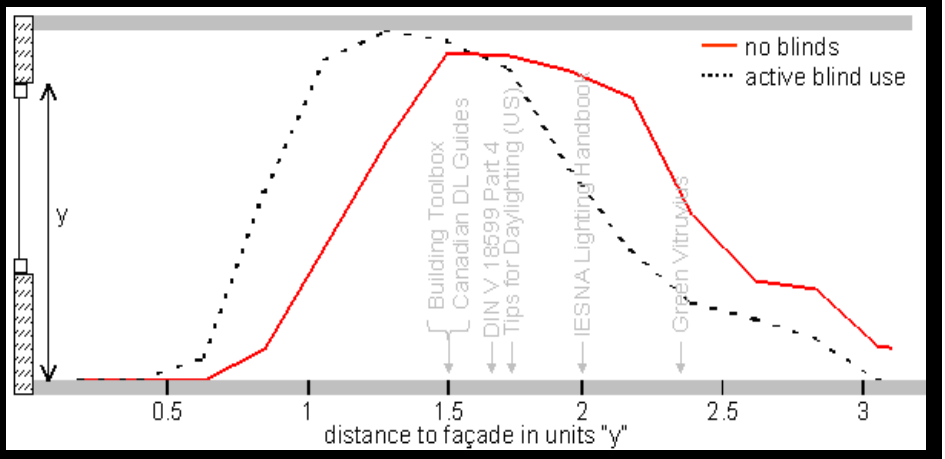


Five climatic regions for Canada and the US



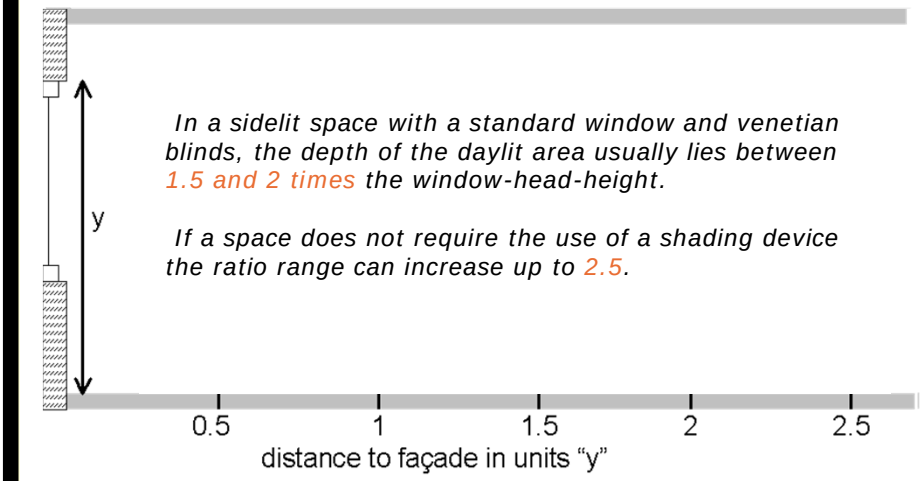
Paper: Reinhart C F, Effects of interior design on the daylight availability in open plan offices." Proceedings of the ACE3 2002 Summer Study on Energy Efficiency in Buildings, 14 pp., Pacific Grove, USA, August 2002.

Window-Head-Height Rule of Thumb



Frequency distribution of daylight penetration depths.

Window-Head-Height Rule of Thumb

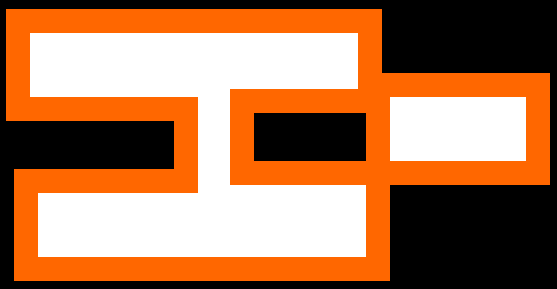


In a sidelit space with a standard window and venetian blinds, the depth of the daylit area usually lies between 1.5 and 2 times the window-head-height.

If a space does not require the use of a shading device the ratio range can increase up to 2.5.

Paper: Reinhart C F, A simulation based review of the ubiquitous window-head height to daylit zone depth rule of thumb , Buildings Simulation 2005, Montreal, Canada, August 15-18 2005.

Daylit Area (for Massing Studies)



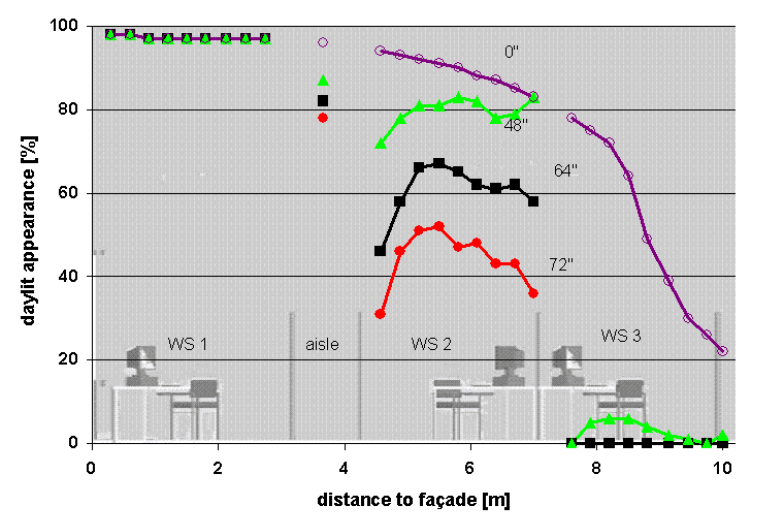
Daylit Area (2 times the window head height)

Non-Daylit Area

Student Work: McGill Art Building

www.arch.mcgill.ca/prof/reinhart/arch447/fall2005/StudentWork/14_NewArtsBuilding_Presentation.pdf

Significance of Furniture & Internal Partitions



Paper: Reinhart C F, Effects of interior design on the daylight availability in open plan offices. Proceedings of the ACE3 2002 Summer Study on Energy Efficiency in Buildings, 14 pp., Pacific Grove, USA, August 2002.

Neighboring Obstructions

Typical Spaces

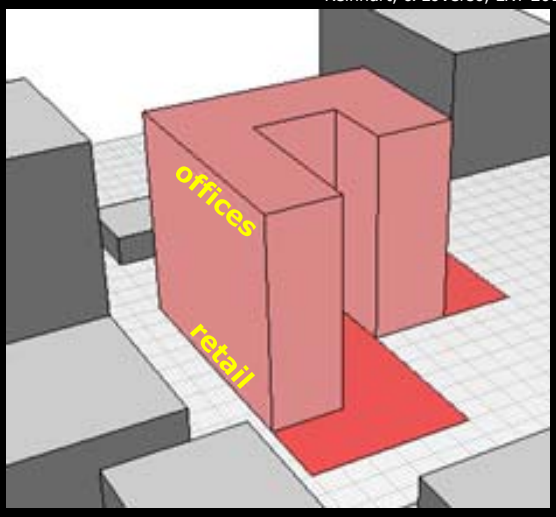
Renderings of building model removed due to copyright restrictions.
Source: Reinhart, C. F., and V. R. M. LoVerso. "A Rules of Thumb Based Design Sequence for Diffuse Daylight." Lighting Research and Technology 42, no. 1 (2010): 7–32.

- Parametric study to evaluate the effect of neighboring building on interior daylit availability. A total of 2304 spaces.

Paper: Reinhart C F and V R M LoVerso, "A Rules of Thumb Based Design Sequence for Diffuse Daylight", *Lighting Research and Technology*, 42:1, pp.7 32, 2010

Design Sequence for Diffuse Daylighting

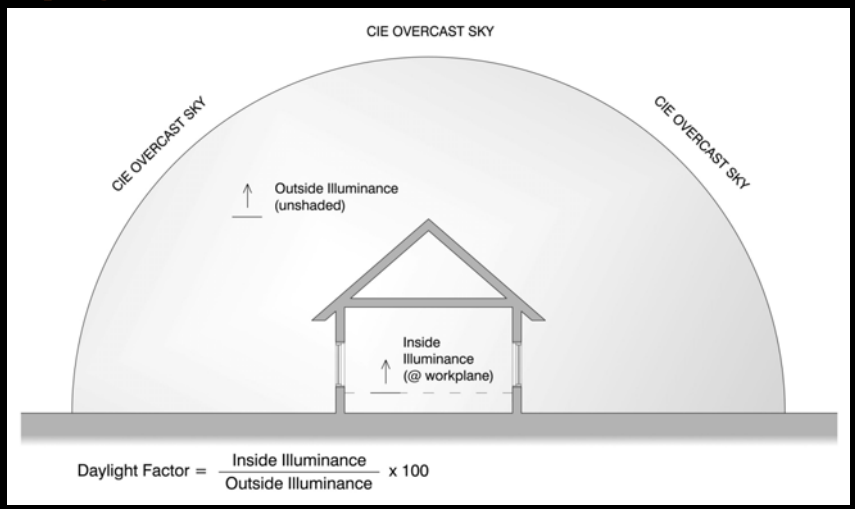
Reinhart, & LoVerso, LRT 2010



(1) Urban Project
(2) Come up with an initial Design Variant
(3) Divide Building into Zones
(4) Define Target DF =2%

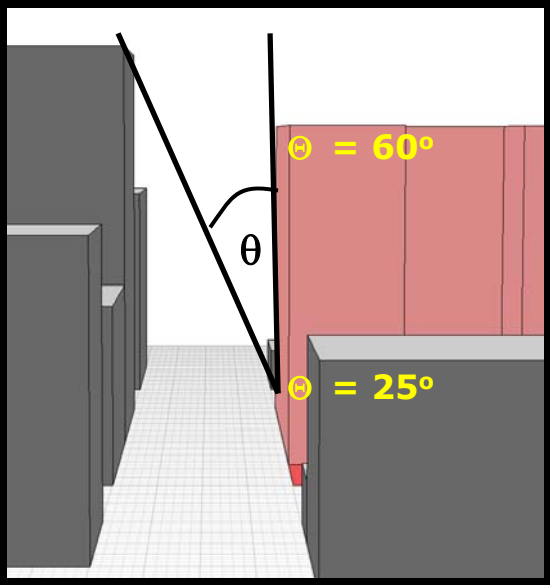
Paper: Reinhart C F and V R M LoVerso, "A Rules of Thumb Based Design Sequence for Diffuse Daylight", *Lighting Research and Technology*, 42:1, pp.7 32, 2010v

Daylight Factor Definition



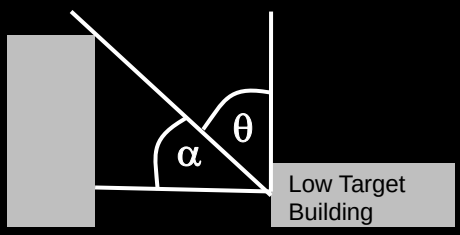
Target Levels: Standard daylit spaces (offices) 2%
Brightly daylit spaces (classrooms) 3%
Circulation Areas 1%.

Definition of Sky Angle



The reference point on the façade is the glazing center.

External Obstruction

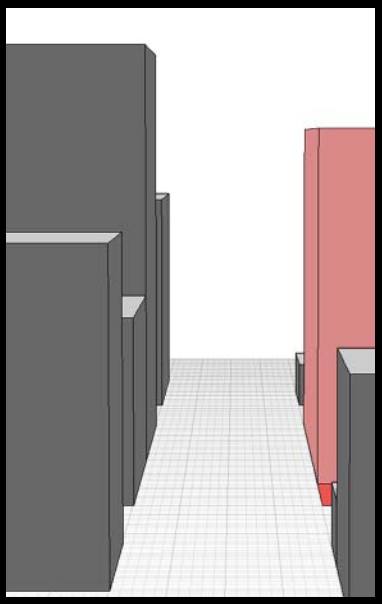


α = obstruction angle

θ = sky angle angle

The effect of neighboring building on a sidelit space in a one or two story building is low (and can even be positive for north facing facades) for obstruction angles smaller than 30°.

Daylight Feasibility Test

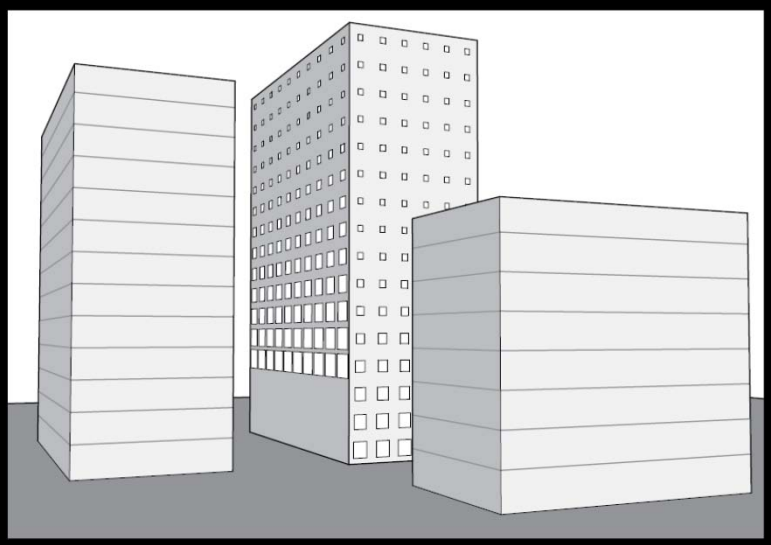


Carry out a daylight feasibility test for each zone. Cutoff level for the WWR is about 80% (fully glazed façade). Continue analysis for zones that pass the daylight feasibility test and revise you design/expectations accordingly.

$$WWR > \frac{DF}{10 \times \tau_{vis}} \frac{90^o}{\theta}$$

Note: At this point you should start to adapt your design.

Rules of Thumb as Formgivers



Courtesy of Jeff Niemasz. Used with permission.

Design: Jeff Niemasz

4.430 Daylighting
Spring 2012