UNIVERSITÀ DEGLI STUDI FIRENZE
Scuola di Architettura

MULTIMEDIA | ARCHITECTURE | INTERACTION

DAYLIGHT.
A CONFLICTUAL RELATIONSHIP BETWEEN THERMAL AND VISUAL COMFORT

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TOPICS & ELEMENTS FOR ARCHITECTURAL DESIGNING

- **INTRO**
  TYPES OF ELECTROMAGNETIC RADIATION
- **QUALITY OF LIGHT**
  RADIATION FREQUENCIES & COLOUR TEMPERATURE
- **ILLUMINATION vs THERMAL COMFORT**
- **GREENHOUSE EFFECT**
- **GLAZING, GLARING, SHADING**

>CHOSING LAMPS

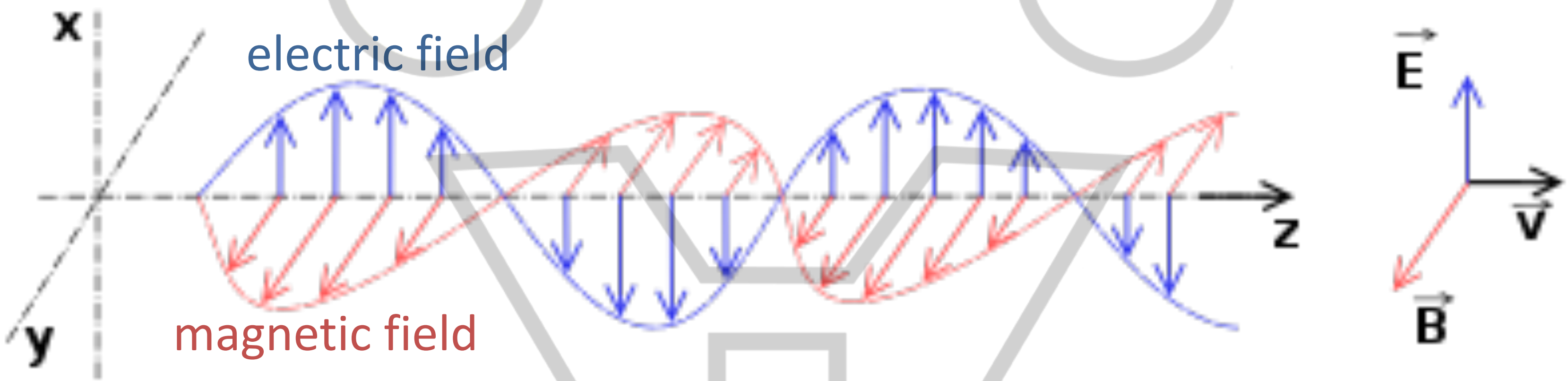
>CHOSING GLAZING

>CHOSING SHADING

>DAYLIGHT ANALYSIS

Electromagnetic radiation

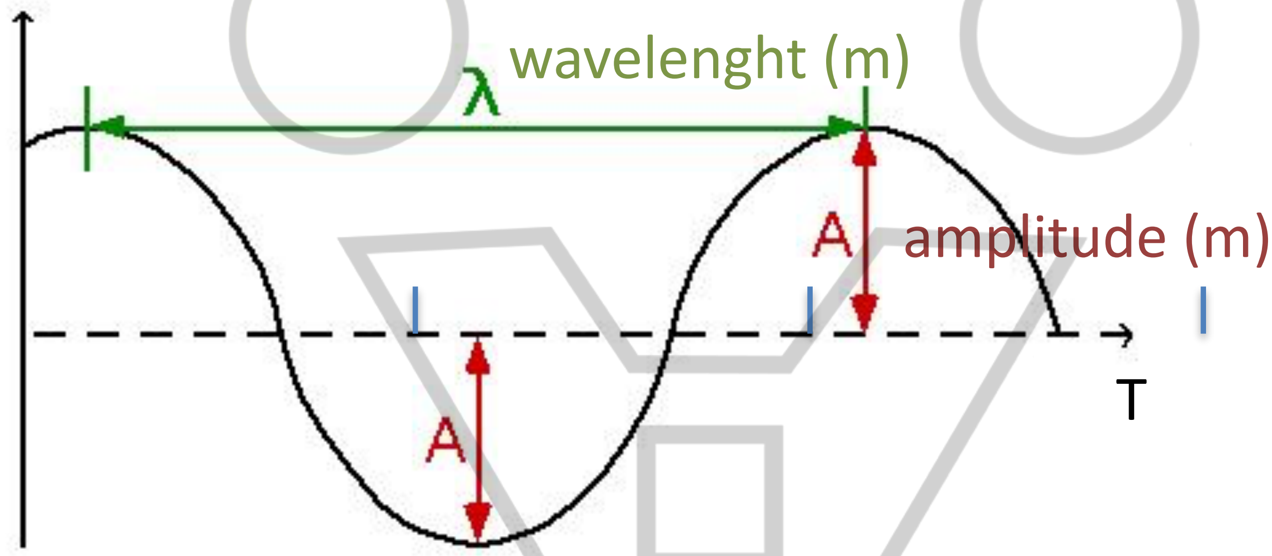
electric fields & magnetic fields



A linearly polarized sinusoidal electromagnetic wave, propagating in the direction +**z** through a homogeneous, isotropic, dissipationless medium, such as vacuum. The electric field (blue arrows) oscillates in the ±**x**-direction, and the orthogonal magnetic field (red arrows) oscillates in phase with the electric field, but in the ±**y**-direction.

Electromagnetic radiation

ELECTRIC WAVES VARIABLES

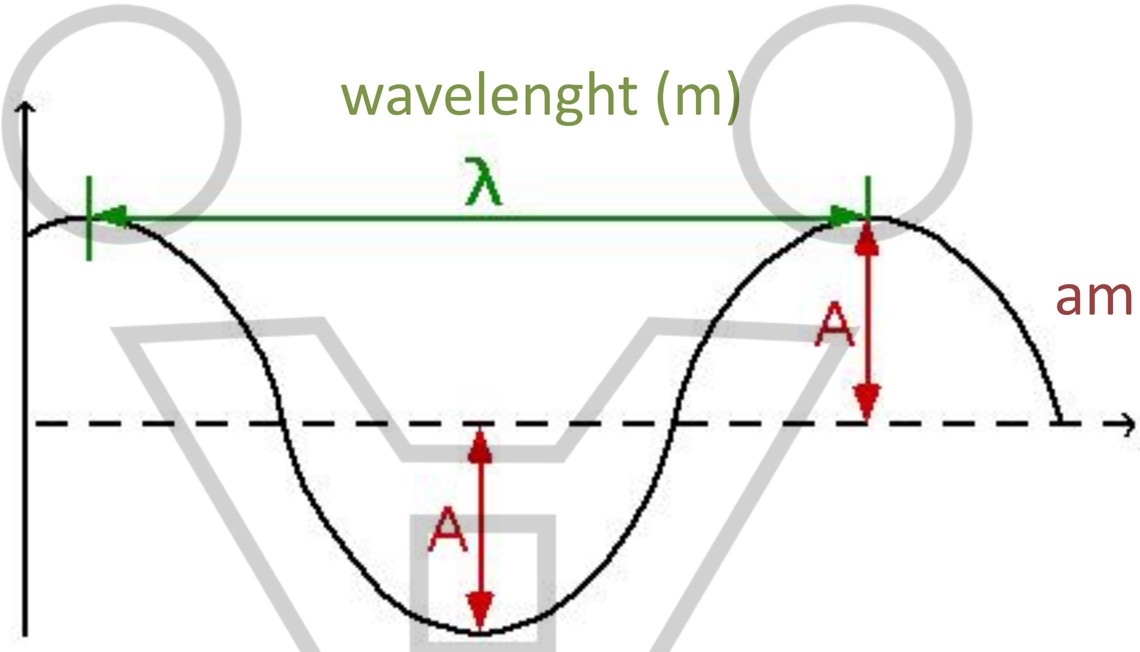


frequence (**Hz**) = number of oscillations in a unit of time (sec)

frequence= f(wavelenght, amplitude, time)

Electromagnetic radiation

ELECTRIC WAVES CARRYING ENERGY



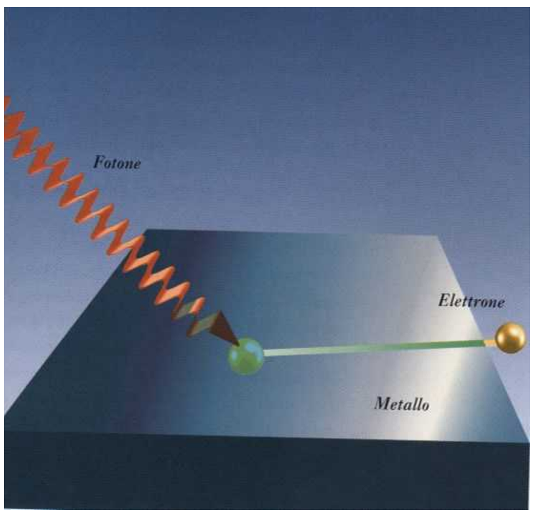
frequence (**Hz**) = number of oscillations in a unit of time (sec)

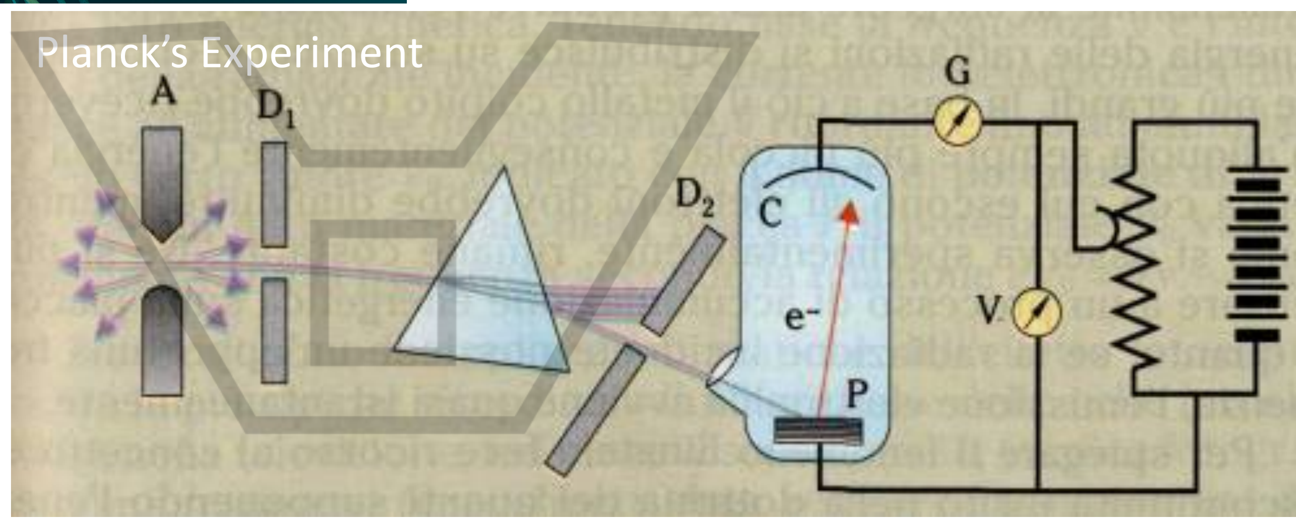
Each wave brings different quantity of energy!

shorter is its length, <u>higher is its frequency, and its energy</u>

Electromagnetic radiation

ELECTRIC WAVES CARRYING ENERGY

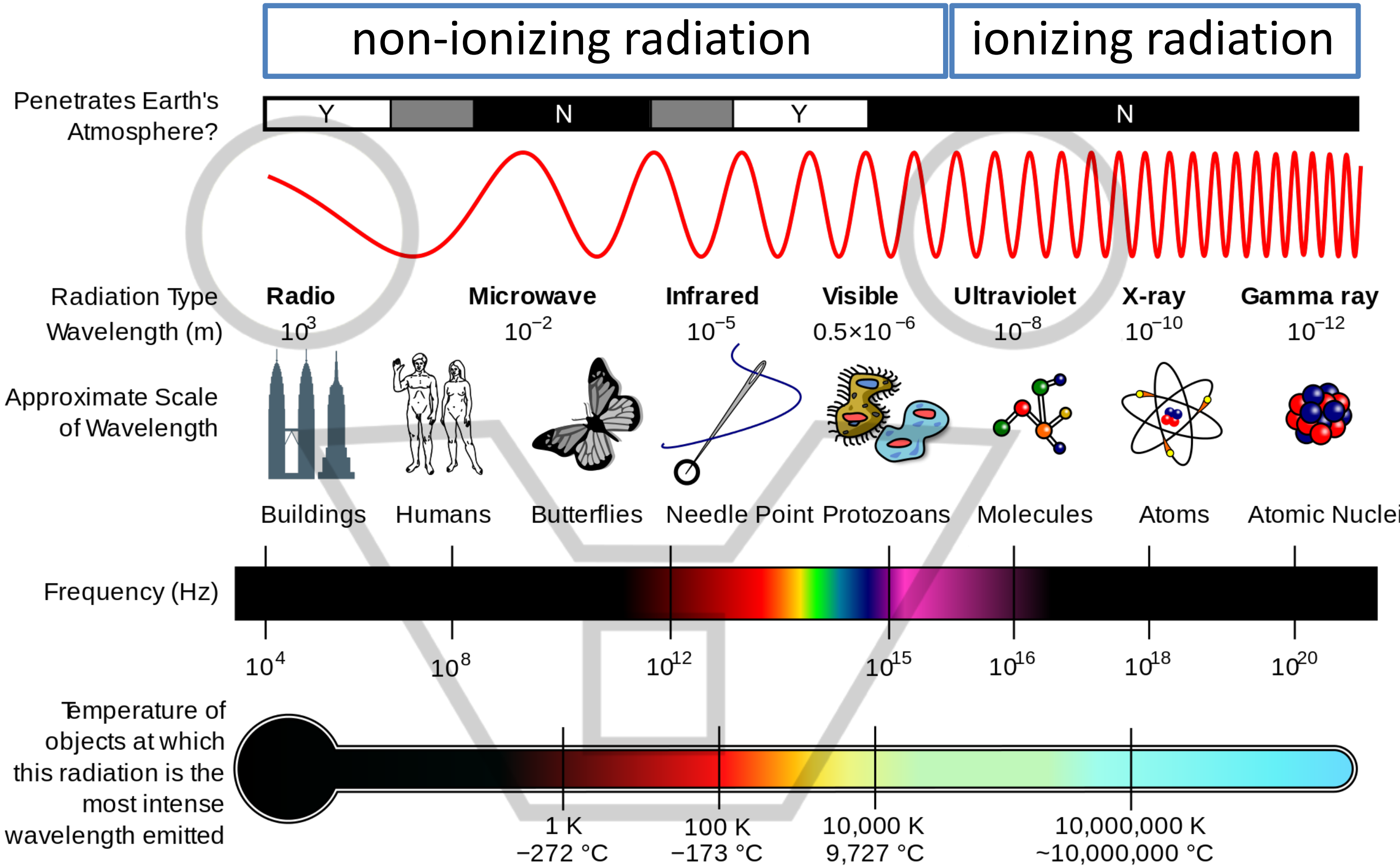




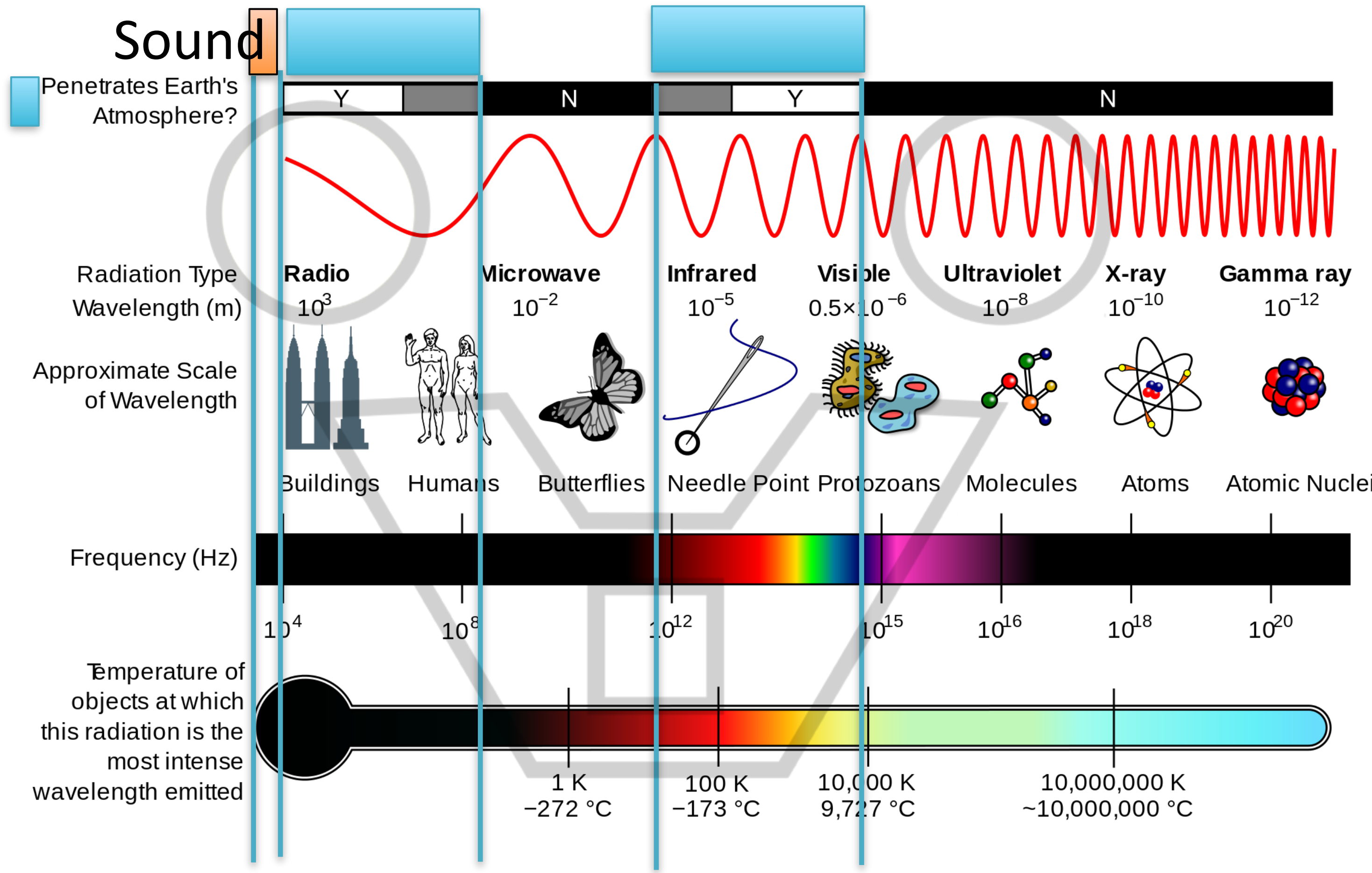
RADIATION (light, heat, ..)

expresses the transfer of kinetic energy of the particles (photons) hittting the matter

DIFFERENT TYPES OF RADIATIONS: IONIZING EFFECT



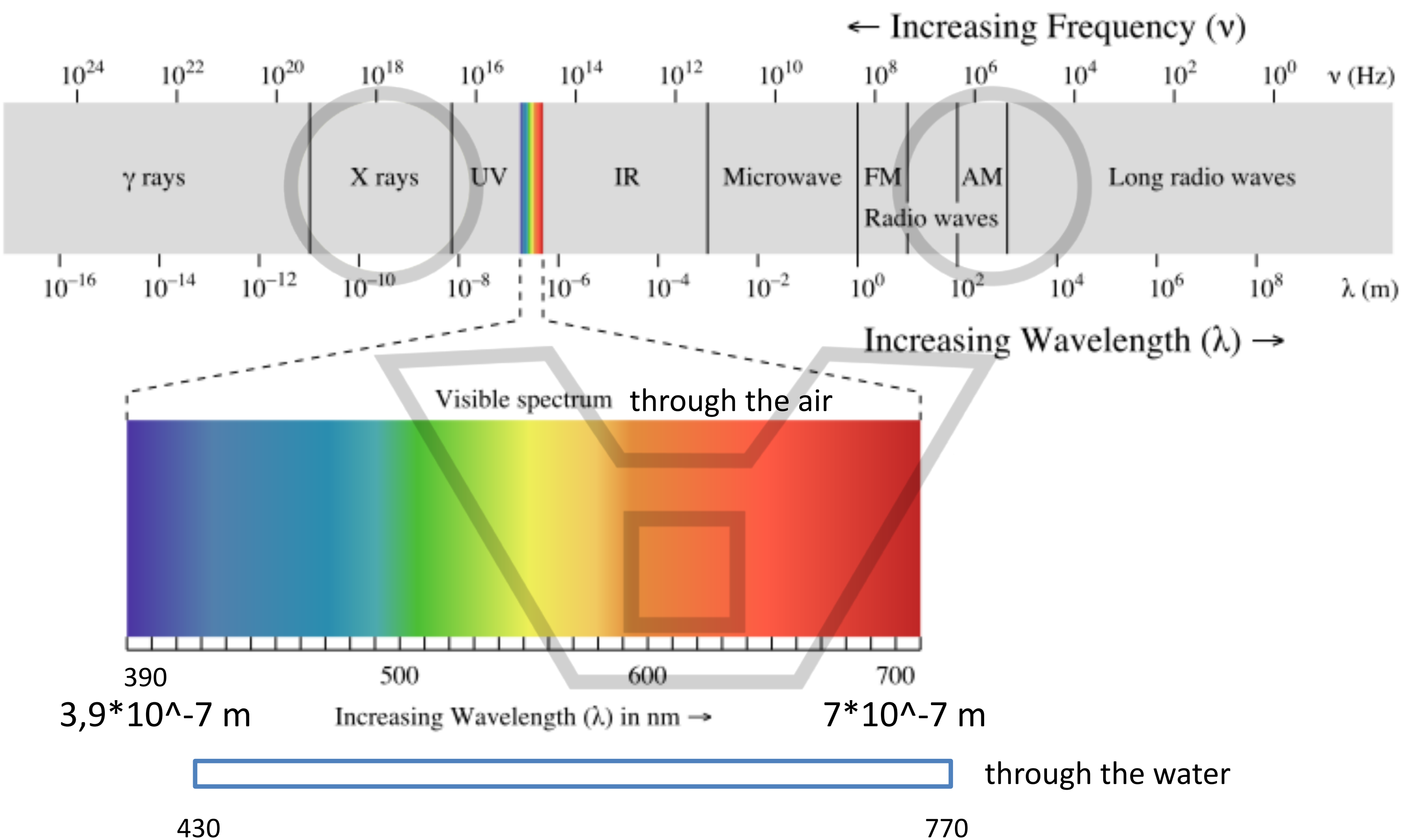
DIFFERENT TYPES OF RADIATIONS: ATMOSPHERE PENETRATION



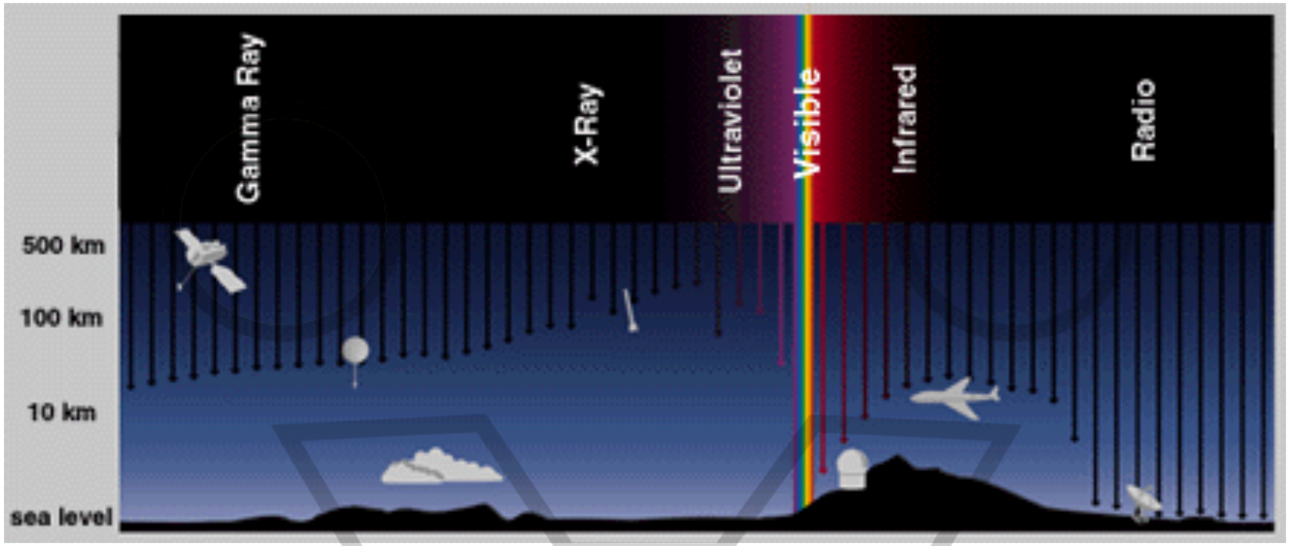
Soundwaves (t 20 Hz to about 20 kHz) are not electromagnetic radiation.

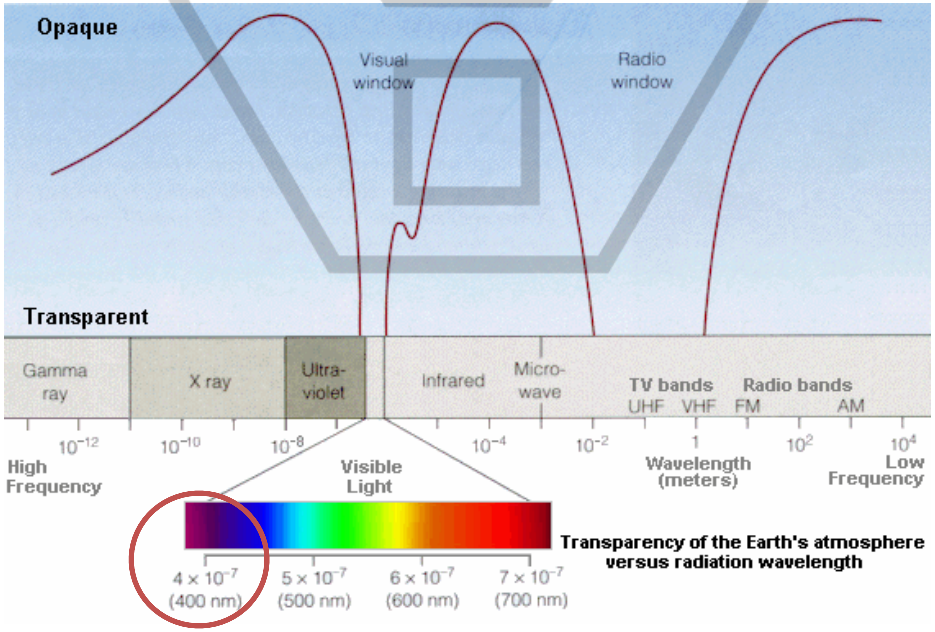
They are the result of molecules compression induced by electromagnetic waves

VISIBLE SPECTRUM



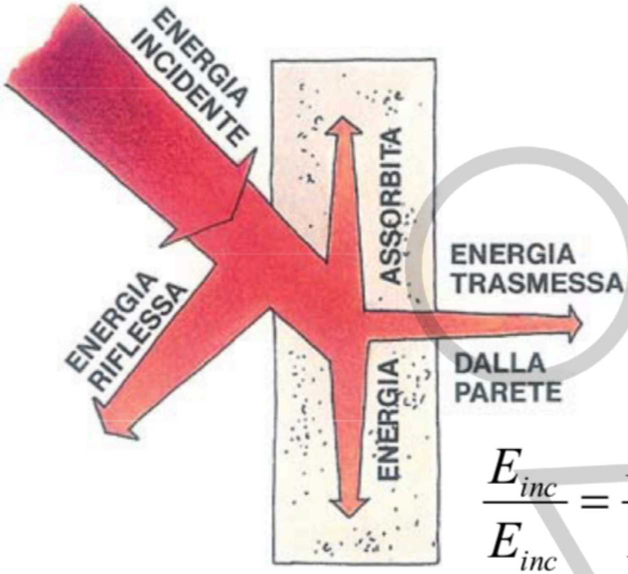
ATMOSPHERE PENETRATION: UV CHARACTERISTICS





Transparency of the Earth's atmosphere versus radiation wavelength

QUALITY OF LIGHT
RADIATION FREQUENCIES
& COLOUR TEMPERATURE



$$\frac{E_{inc}}{E_{inc}} = \frac{E}{E}$$

$$E_{inc} = E_{rifl} + E_{ass} + E_{trasm}$$

$$\frac{E_{inc}}{E_{inc}} = \frac{E_{rifl}}{E_{inc}} + \frac{E_{ass}}{E_{inc}} + \frac{E_{trasm}}{E_{inc}}$$

Every material, above the 0°K **emits** energy in form of **radiation**
-273,15 °C

Every **irradiated** material **absorb** some kind of energy

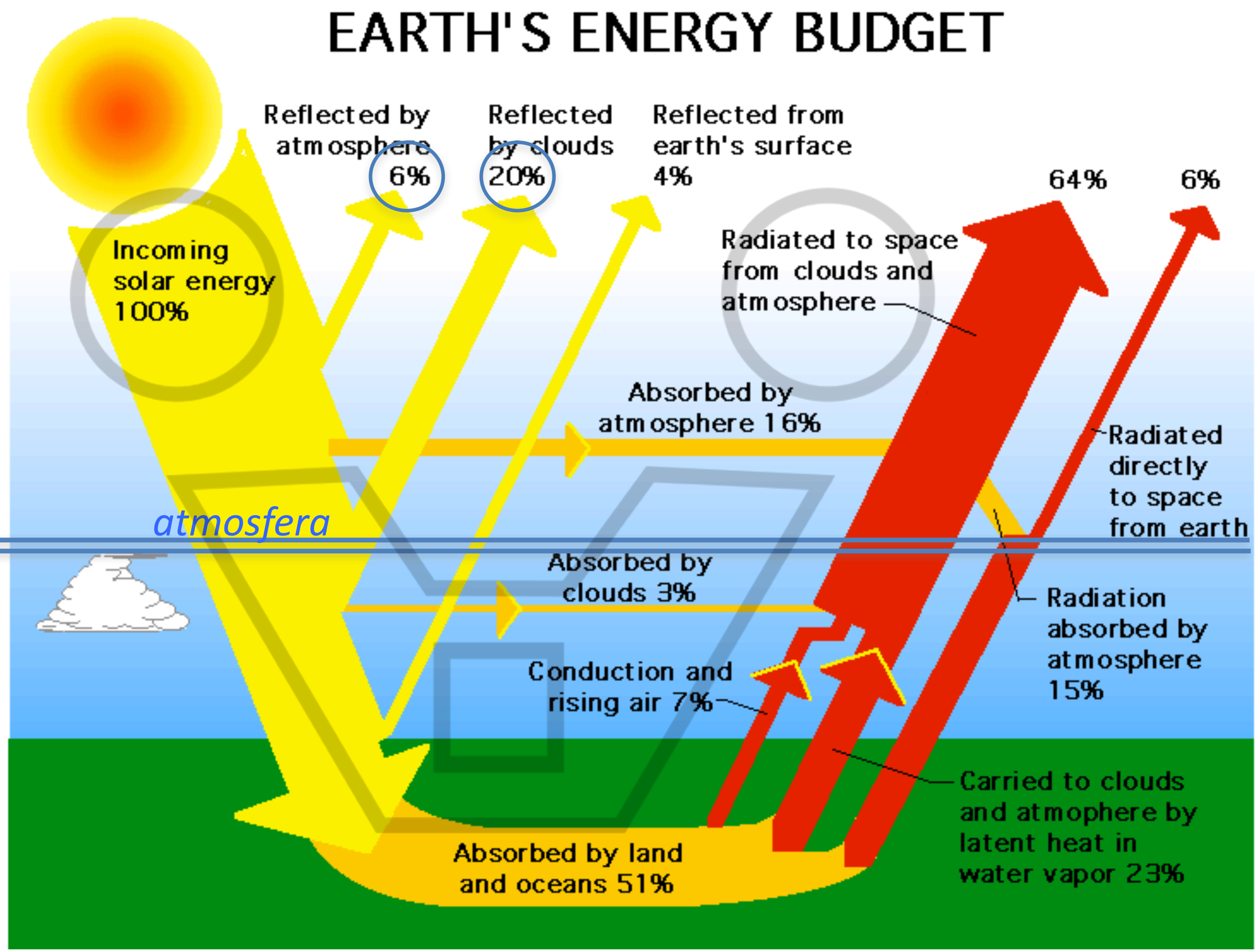
Every **irradiated** material **reflects** some amount of energy

100%=1.366 W/m2
-costante solare-

26%= 356 W/m2

74% =1010 W/m2

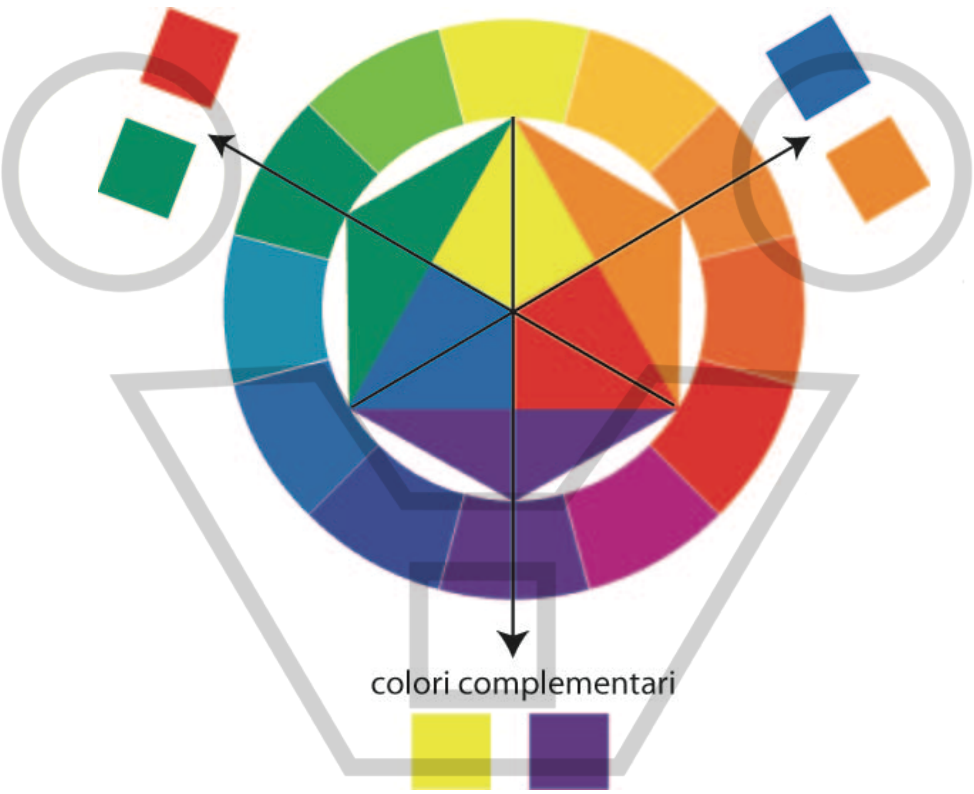
1.000 W/m2



Radiazione assorbita

Detratte tutte le perdite per riflessione e retrodiffusione da parte di atmosfera e superficie terrestre, l'energia incidente che rimane è assorbita dalla superficie terrestre e contribuisce così al suo riscaldamento, in maniera variabile a seconda della latitudine e del tipo di superficie

SPECTRUM ANALYSIS REVEALING MATERIAL COMPOSITION

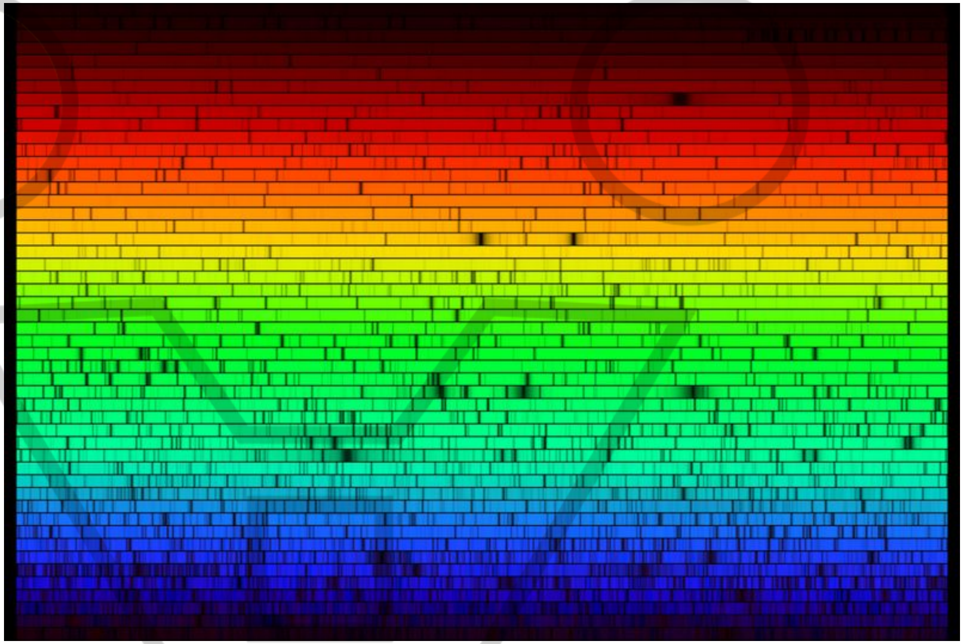


Every **irradiated** material **absorb** some kind of energy

Every **irradiated** material **reflects** some amount of energy

SPECTRUM ANALYSIS REVEALING MATERIAL COMPOSITION

Se attraverso un gas si fa passare la luce emessa da un corpo che presenta uno spettro continuo, si otterrà uno spettro sul cui continuo appaiono delle righe oscure (righe di assorbimento o righe di Fraunhofer) esattamente a quelle stesse lunghezze d'onda alle quali il gas, alle opportune condizioni di eccitazione, presenterebbe delle righe di emissione .



every material has its specific absorption frequency

Le linee di Fraunhofer dello spettro solare. Le linee scure sono dovute all'assorbimento da parte degli elementi presenti negli strati più esterni del Sole.

SPECTRUM ANALYSIS REVEALS MATERIAL COMPOSITION

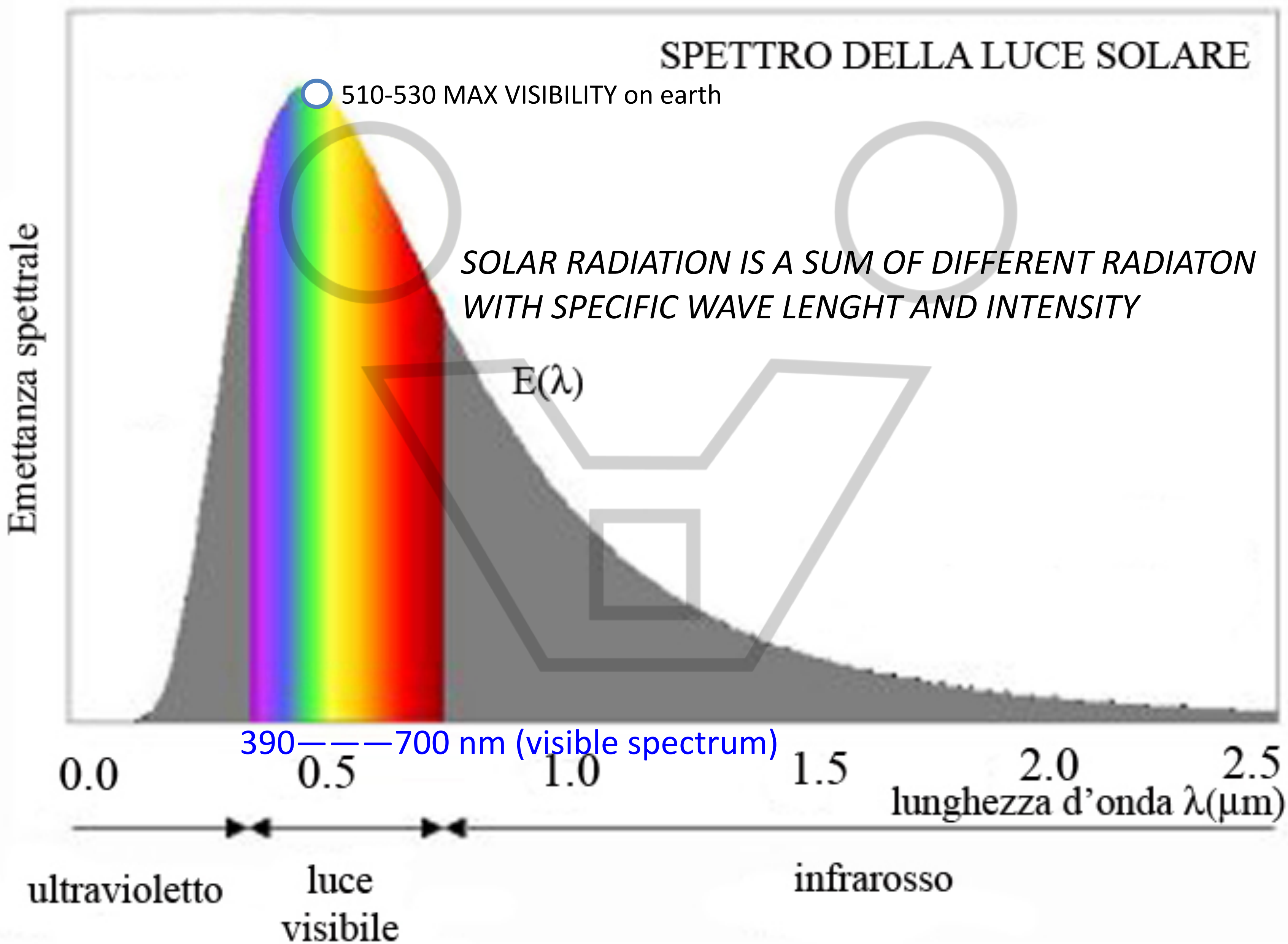
I gas luminosi, a bassa pressione e bassa temperatura, presentano alcune luminose righe di emissione ; ogni elemento chimico presenta righe in emissione che gli sono caratteristiche, cosicchè dallo spettro in emissione dei gas è possibile dedurre la loro composizione chimica .

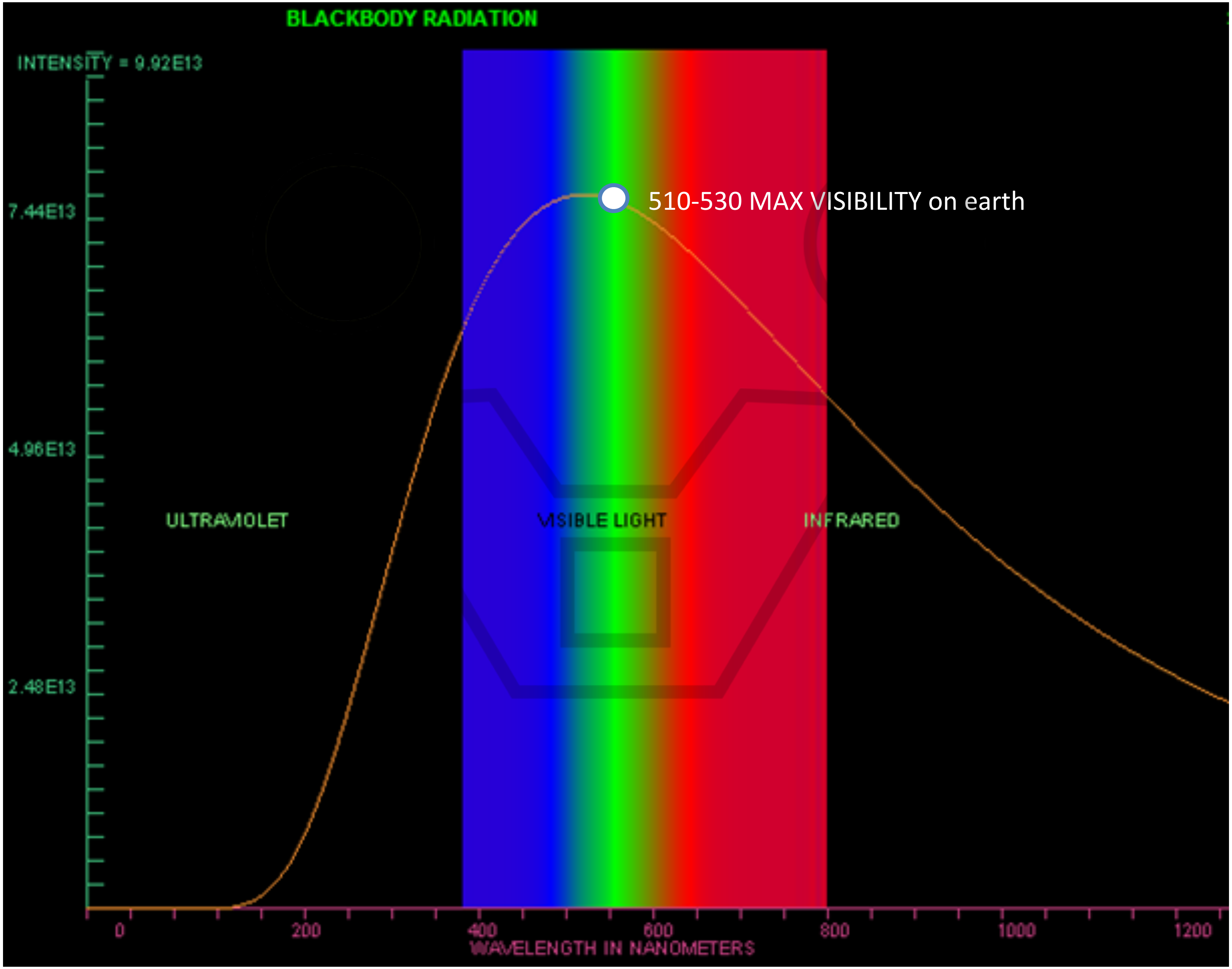
Bunsen & Kirchhoff's Experiments (1850)

Flames emissions happened only at some specific wave length

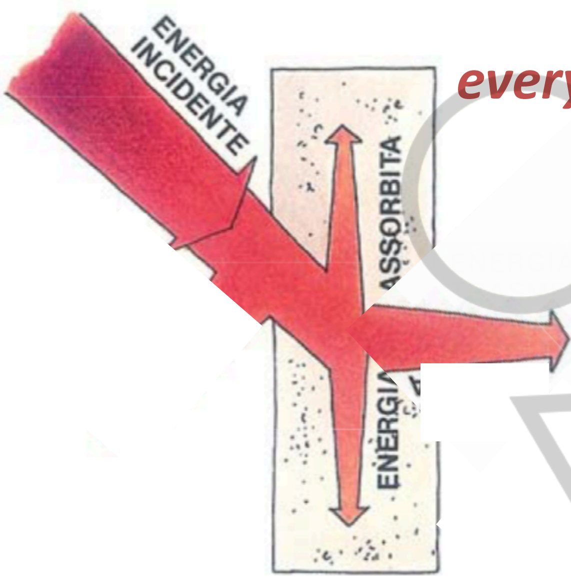
every material has its specific emission frequency

COLOURS OF VISIBLE LIGHT




BLACKBODY RADIATION
INTENSITY = 9.92E13
7.44E13
4.96E13
2.48E13
510-530 MAX VISIBILITY on earth
ULTRAVIOLET
VISIBLE LIGHT
INFRARED
0
200
400
600
800
1000
1200
WAVELENGTH IN NANOMETERS

The BLACKBODY



every material change its emission frequency and colour in relation to its temperature

Black body is a perfect absorber and emitter without reflections

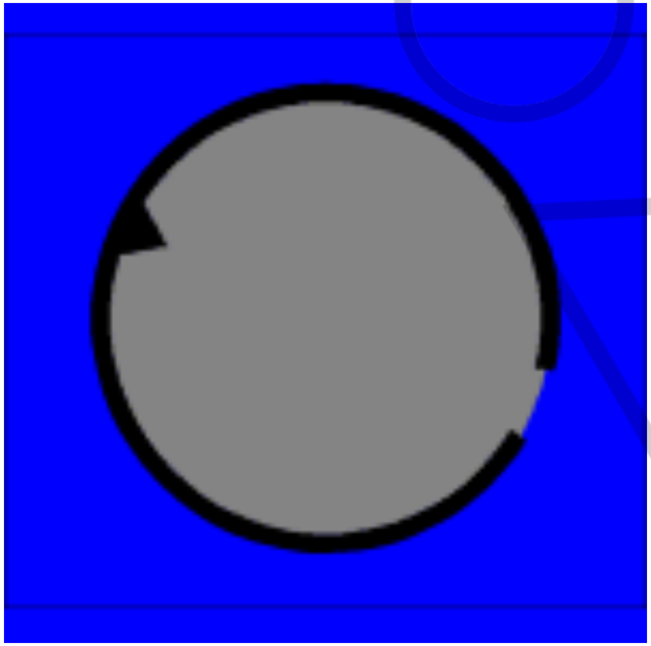
in real world each body has a balance between absorption and emission

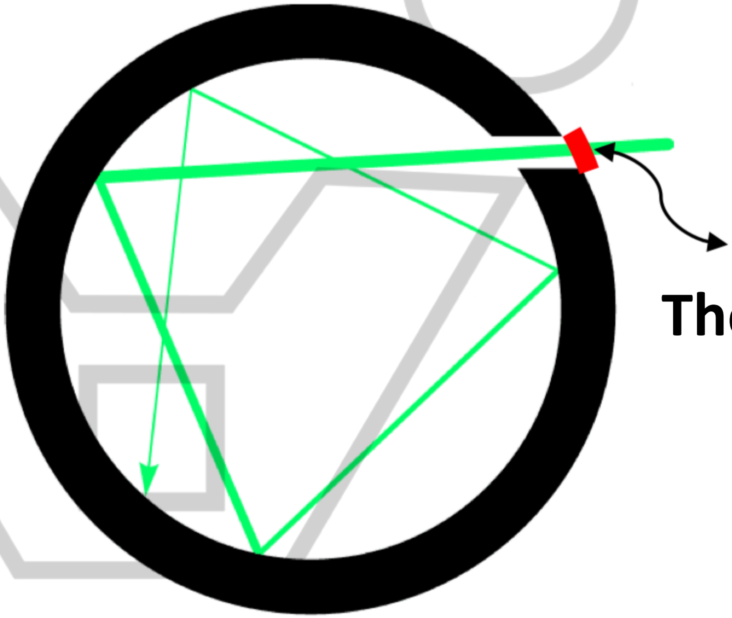
Tutti i corpi emettono ad ogni temperatura, ma solo radiazione infrarossa (non rivelata dai nostri occhi) viene prodotta a temperatura ambiente (T ≈ 293° K),ciò genera la falsa idea che i corpi emettano radiazione solo quando diventano incandescenti.

ENERGY, WAVELENGHTS AND TEMPERATURE OF A BLACK BODY

Black body is a perfect absorber and emitter without reflection

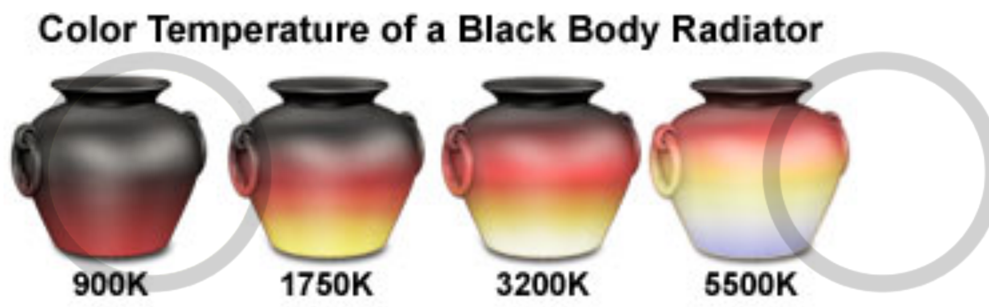
in real world each body has a balance between absorption and emission

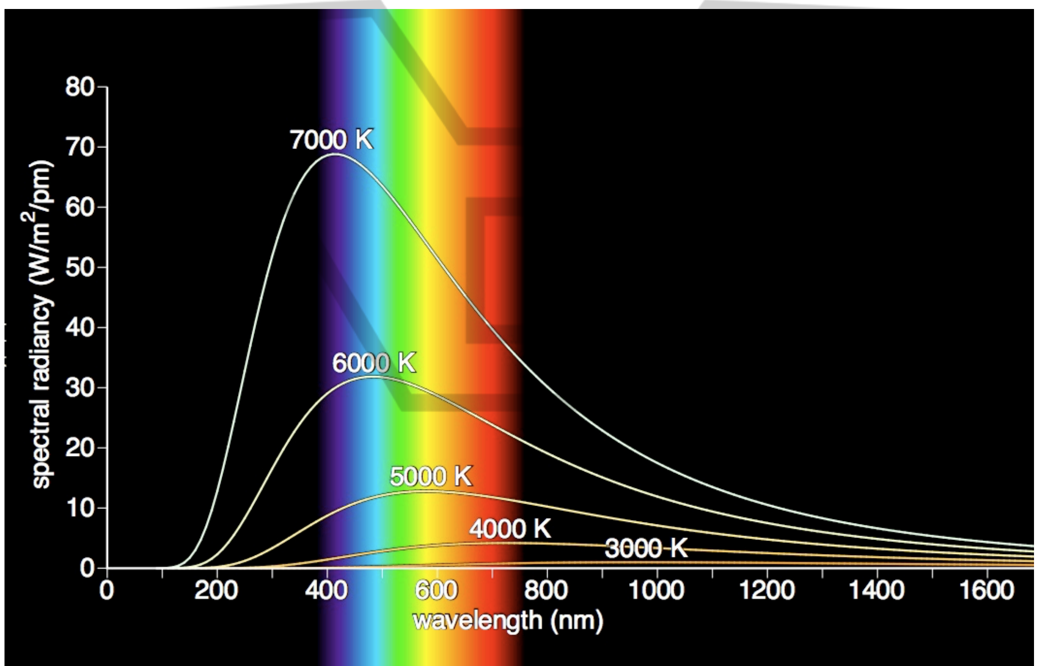




La particolarità più importante del corpo nero è che l'energia riemessa, chiamata radiazione di corpo nero, dipende solo dalla sua temperatura ed è indipendente dalla forma o dal materiale di cui è costituito.

ENERGY, WAVELENGHTS AND TEMPERATURE OF A BLACK BODY





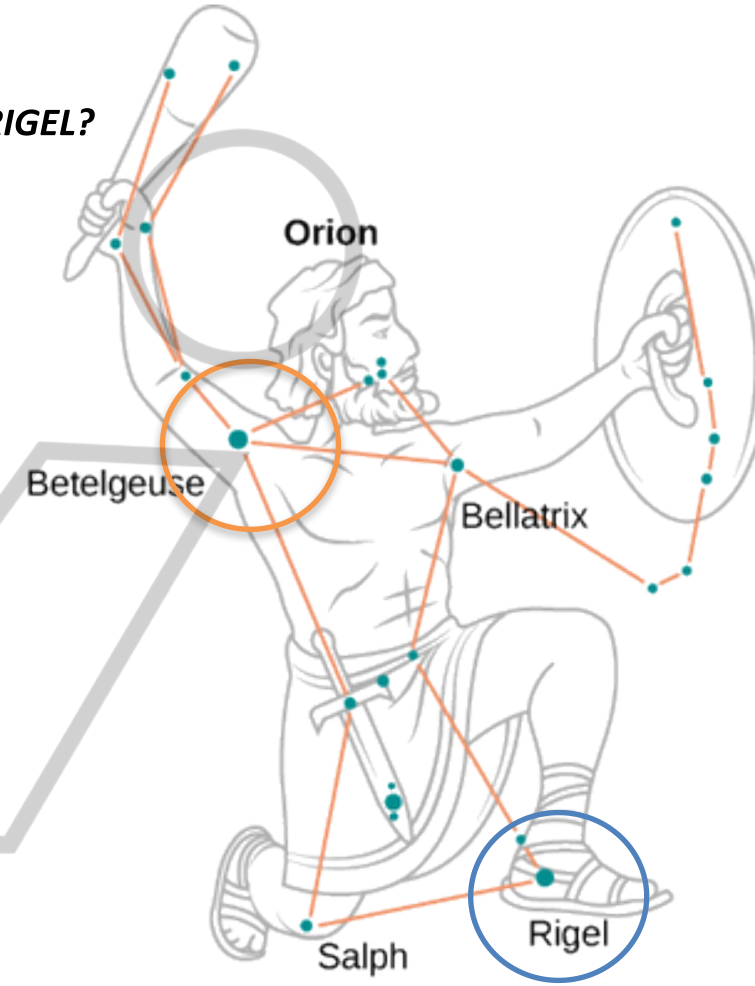
STEFAN_BOLTZMAN'S LAW

WIEN'S LAW (1893-)

PLANK'S LAW

ENERGY, WAVELENGHTS AND TEMPERATURE OF A BLACK BODY

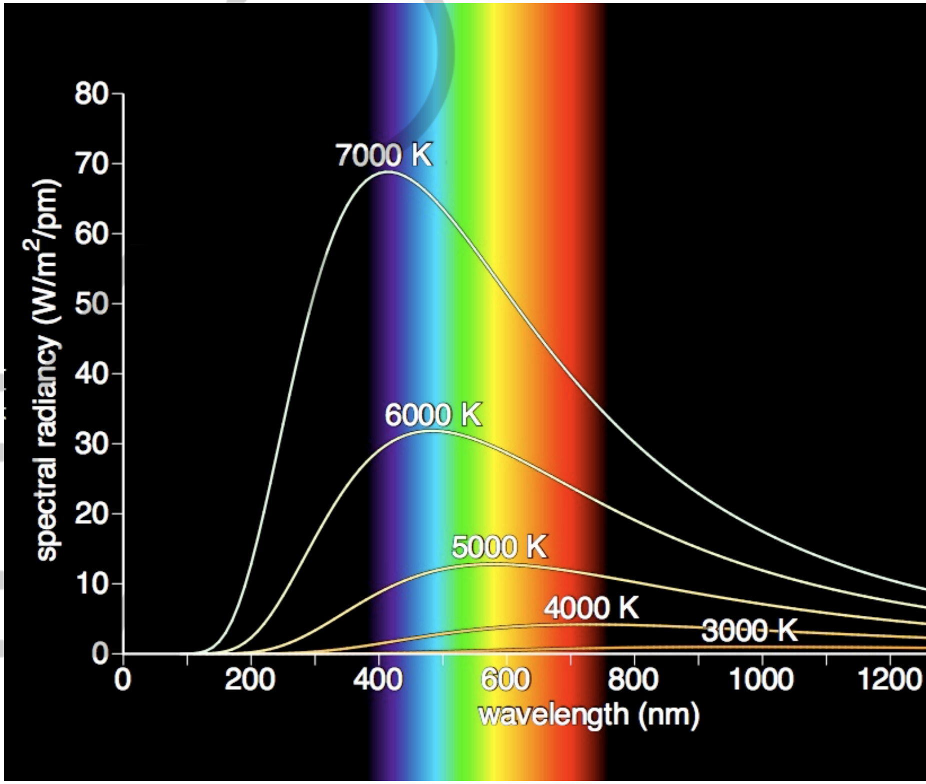
WHERE IS THE HIGEST TEMPERATURE? IN BETELGEUSE OR IN RIGEL?



ENERGY, WAVELENGHTS AND TEMPERATURE OF A BLACK BODY

BETELGEUSE

RIGEL

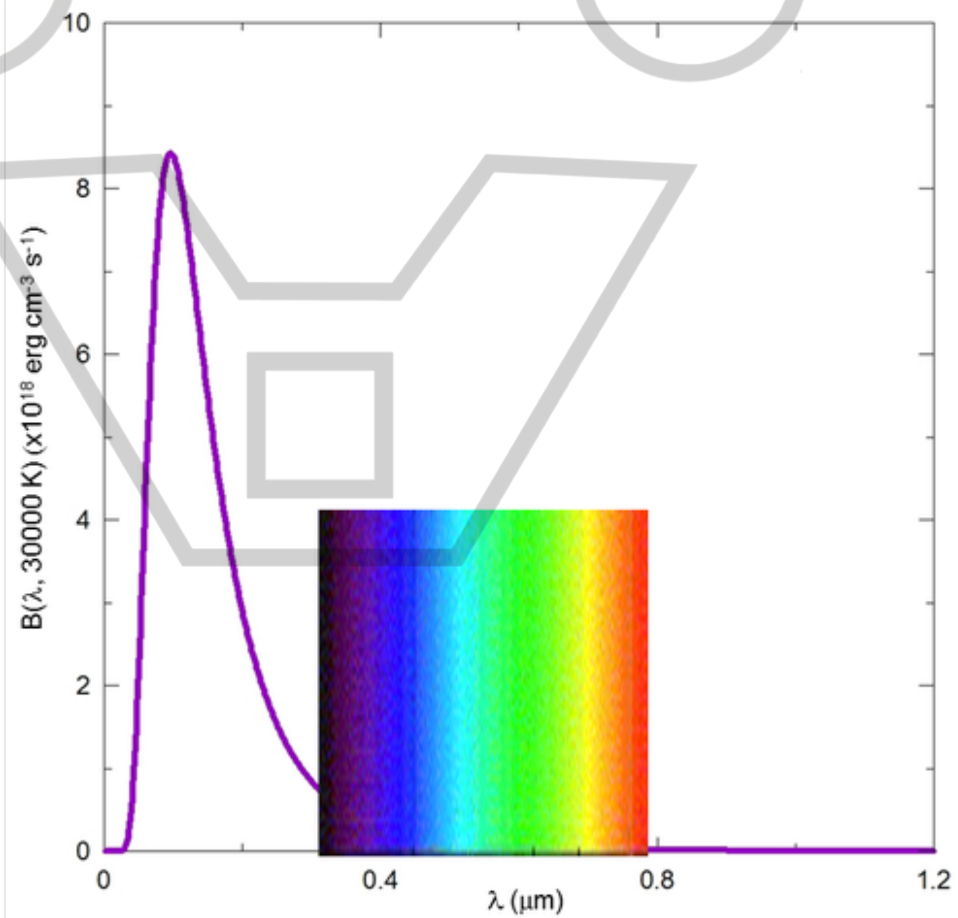


A STAR SPECTRUM AND ITS VISIBLE FREQUENCIES

stella

$T \approx 30\,000$ K

$\lambda_{max} \approx 1000\ \mu$

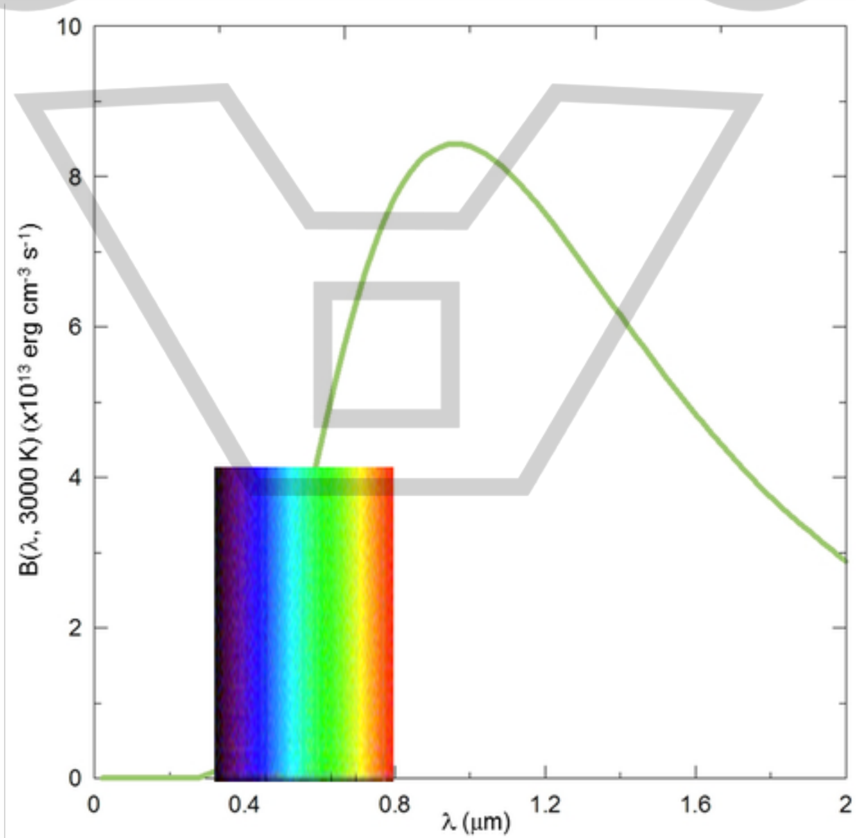


A LIGHT BULB SPECTRUM AND ITS VISIBLE FREQUENCIES

lampada a incandescenza

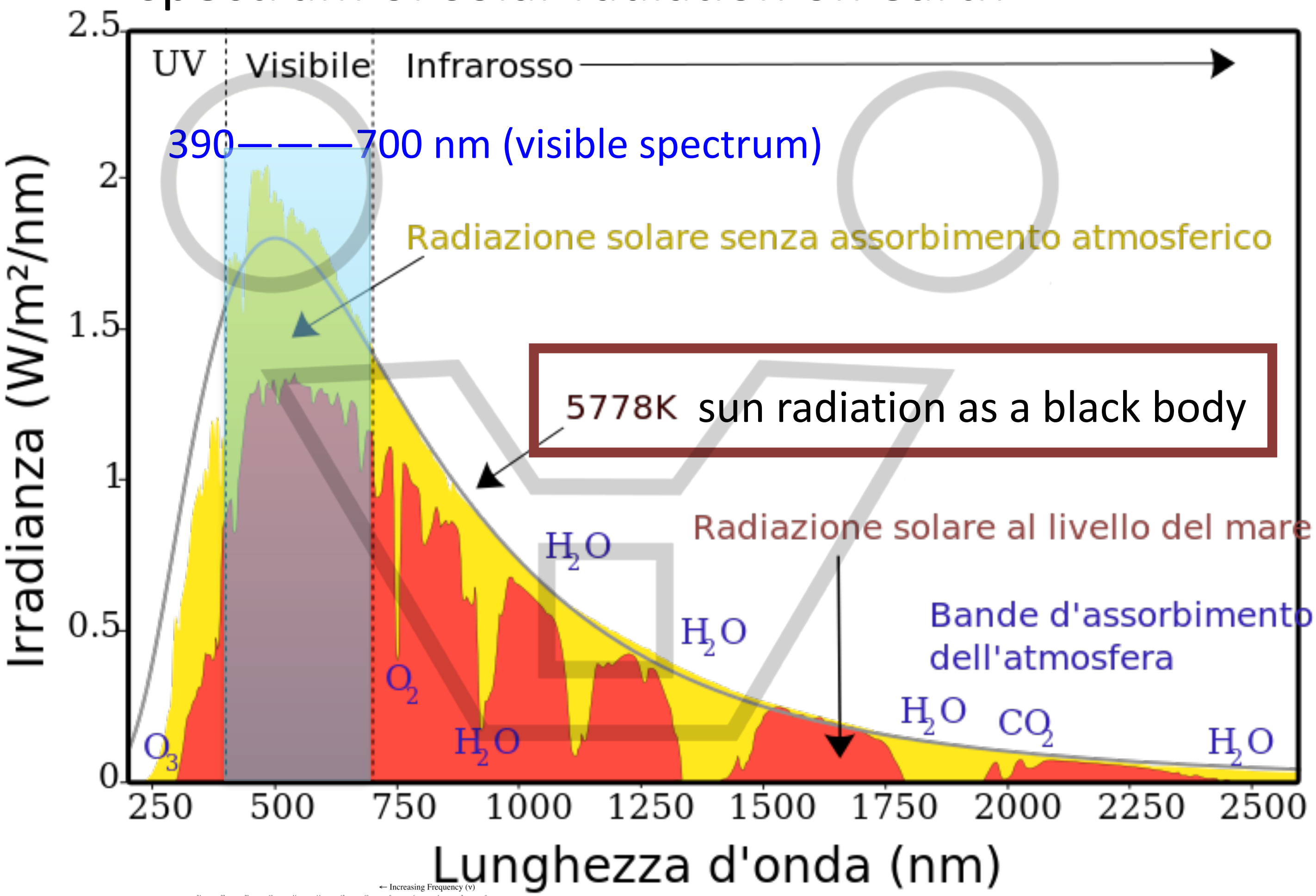
$T \approx 3\,000$ K

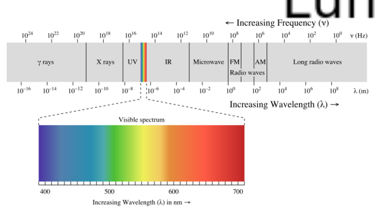
$\lambda_{max} \approx 1\ \mu$



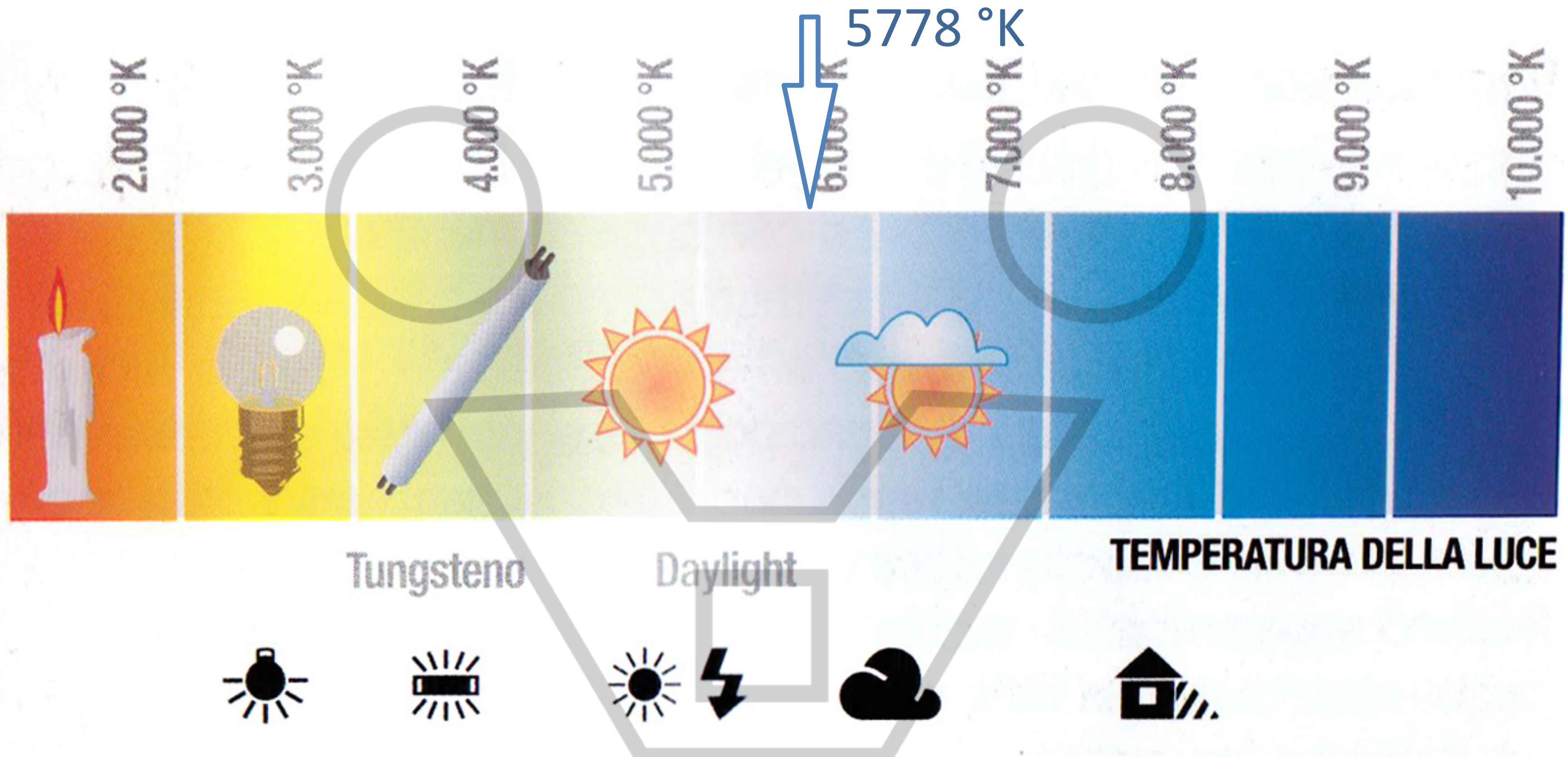
ENERGY IN THE VISIBLE SPECTRUM

spectrum of solar radiation on earth

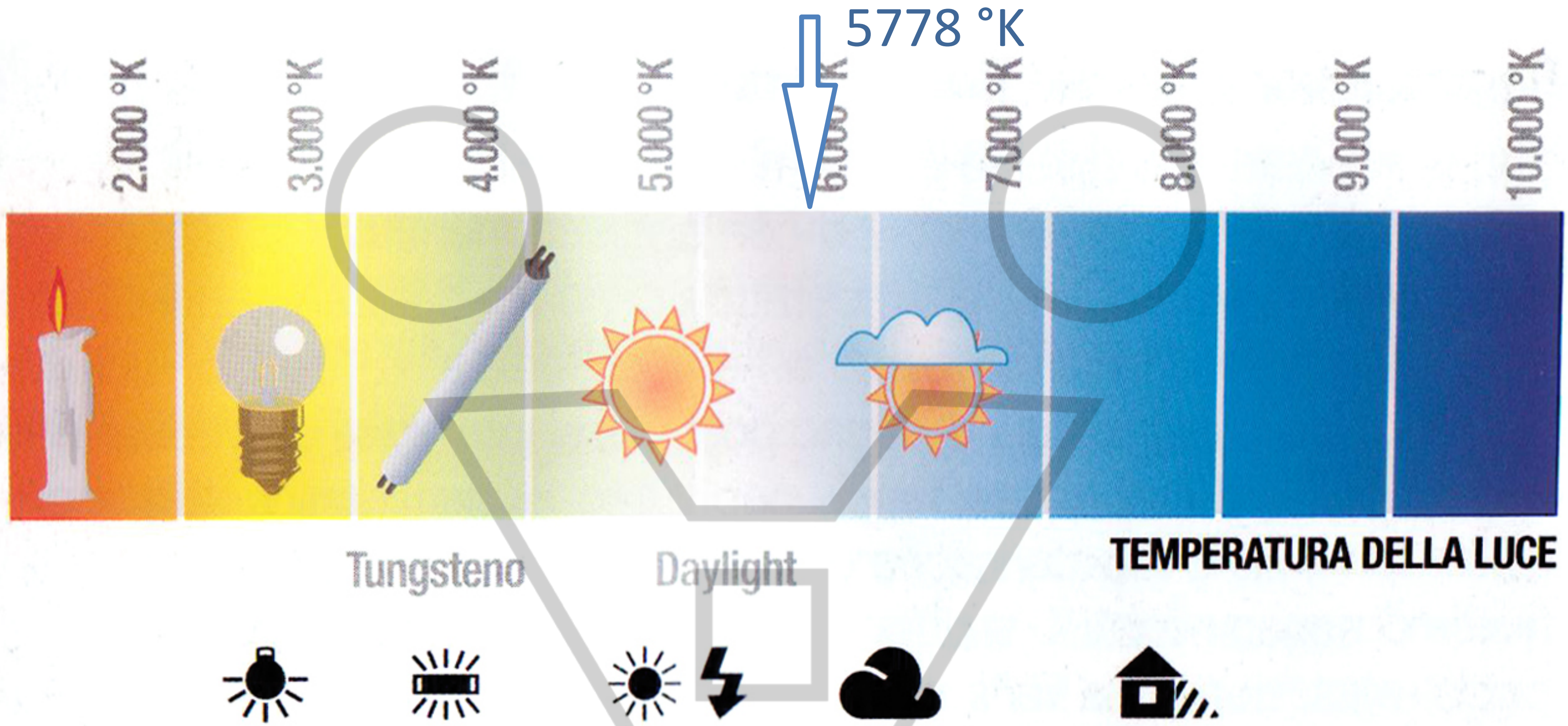


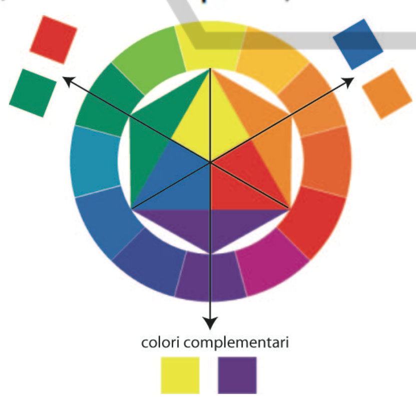


VISIBLE LIGHT TEMPERATURE



COMPLEMENTARY COLORS

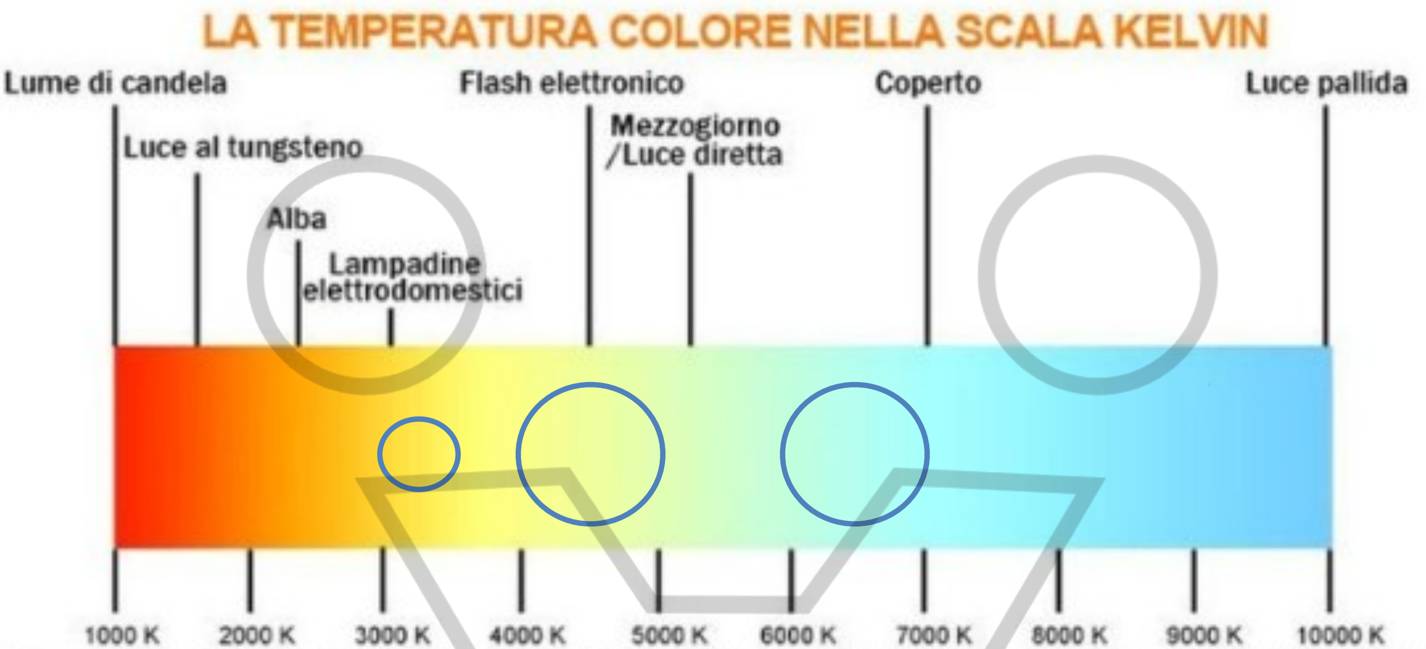




Se in una giornata di sole impostate l'opzione "cloud" si otterrà una immagine calda rosata come all'alba

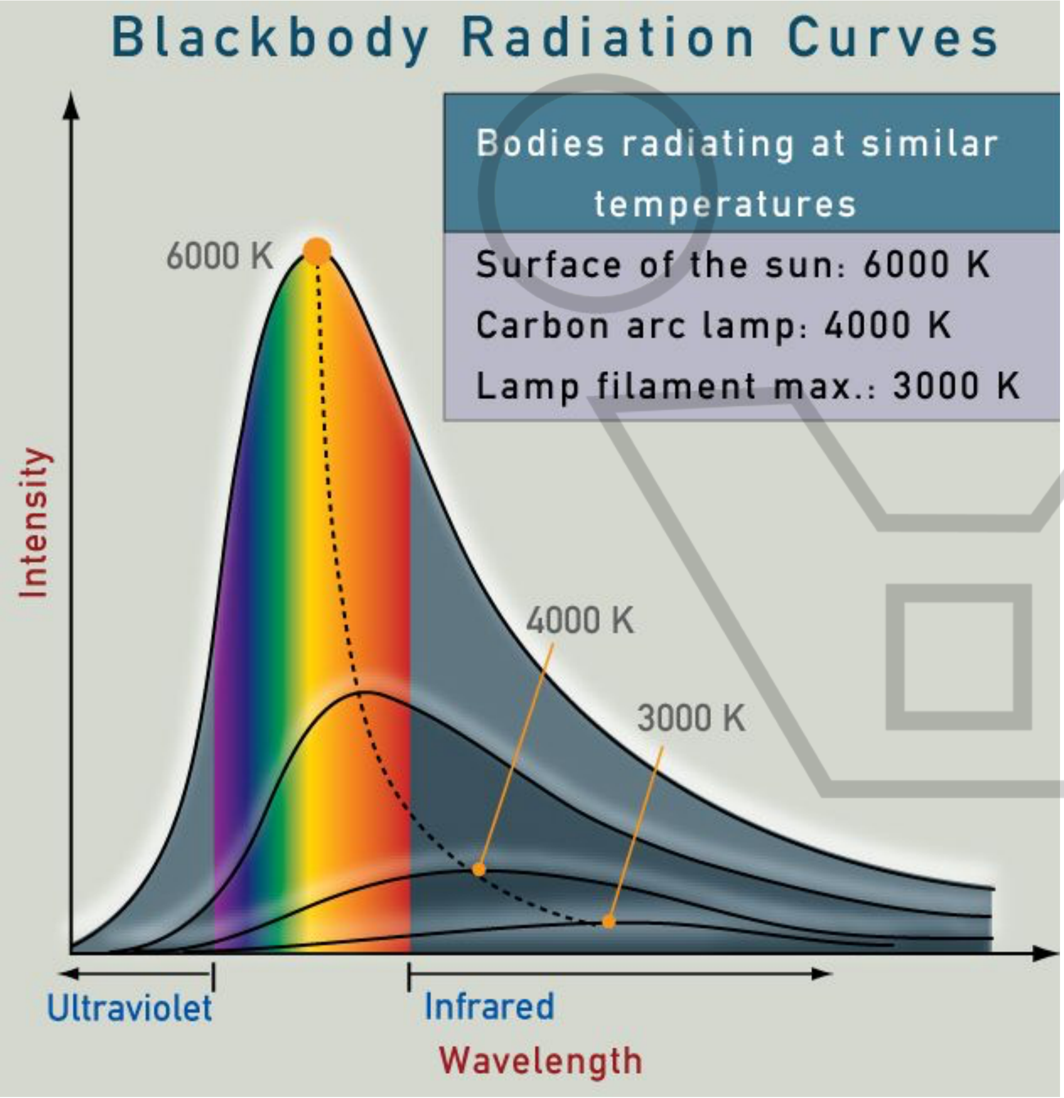
PHOTOS SHOOTED IN DAYLIGHT CONDITION.
WHICH FILTER (analogue) °K (Digital) YOU NEED TO SET?

LAMPS TEMPERATURES & LIGHT COLOURS



Se si confrontano le fonti di luce artificiale con la luce del giorno, possiamo concludere che le luci LED rappresentano la scelta più vicina alla luce naturale.

QUALITY OF LIGHT: ENERGY, WAVELENGHTS AND TEMPERATURE



Color Temperatures of Common Light Sources

Daylight Sources	Color Temperature (K)
Skylight	12000 to 18000
Overcast Sky	7000
Noon Sun/Clear Summer Sky	5000 to 7000
Noon Sun/Clear Winter Sky	5500 to 6000
Photographic Daylight	5500
Noon Sunlight (Date Dependent)	4900 to 5800
Average Noon Sunlight (Northern Hemisphere)	5400
Sunlight at 30-Degree Altitude	4500
Sunlight at 20-Degree Altitude	4000
Sunlight at 10-Degree Altitude	3500
Sunrise and Sunset	3000
Artificial Sources	**Color Temperature (K)**
White LED	6500 to 9500
Electronic Flash	5500 to 6500
Xenon Burner	6000
White Flame Carbon Arc	5000
Warm White Fluorescent Tubes	4000
Aluminum-Filled Flash Bulbs (M2, 5, & 25)	3800
500-Watt 3400 K Photoflood	3400
12 Volt/100 Watt Tungsten-Halogen @ 9 Volts	3200
12 Volt/50 Watt Tungsten-Halogen @ 9 Volts	3200
100-Watt Household Lamp	2900
40-Watt Household Lamp	2650
Gaslight	2000 to 2200
Candlelight (British Standard)	2900

ILLUMINATION vs THERMAL COMFORT

LIGHT & THERMAL SIDE EFFECTS

CHOOSING LAMPS

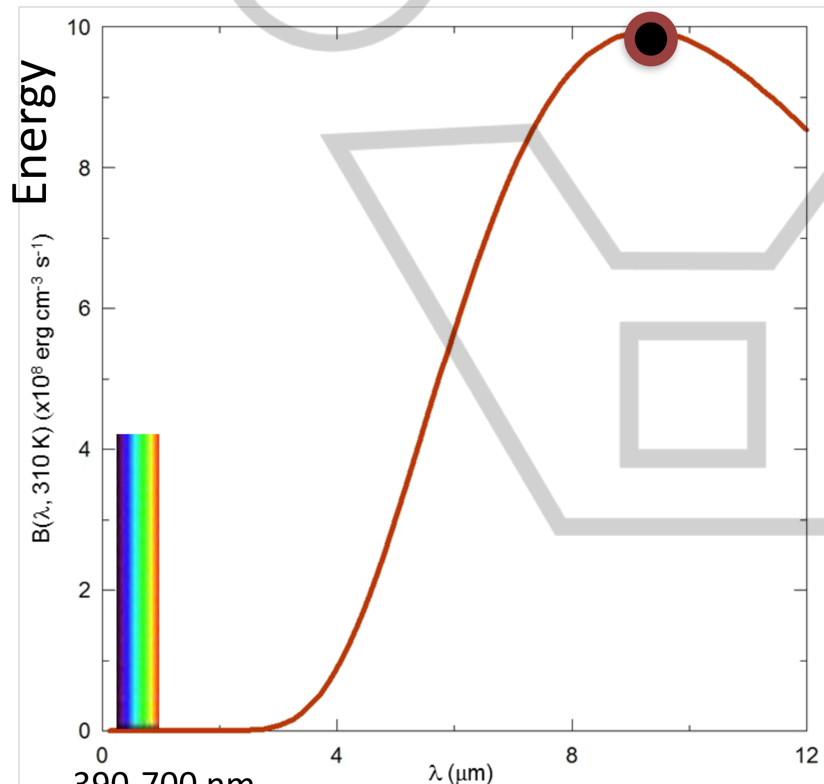
MATERIAL INVISIBLE LOW RADIATION EMISSION: INFRARED

Every material, above the 0°K **emits** energy in form of **radiation**

human body

T = 37° C = 310 K

$\lambda_{max} \approx 9\ \mu$ micron (nm= 9000 =9*10^3)

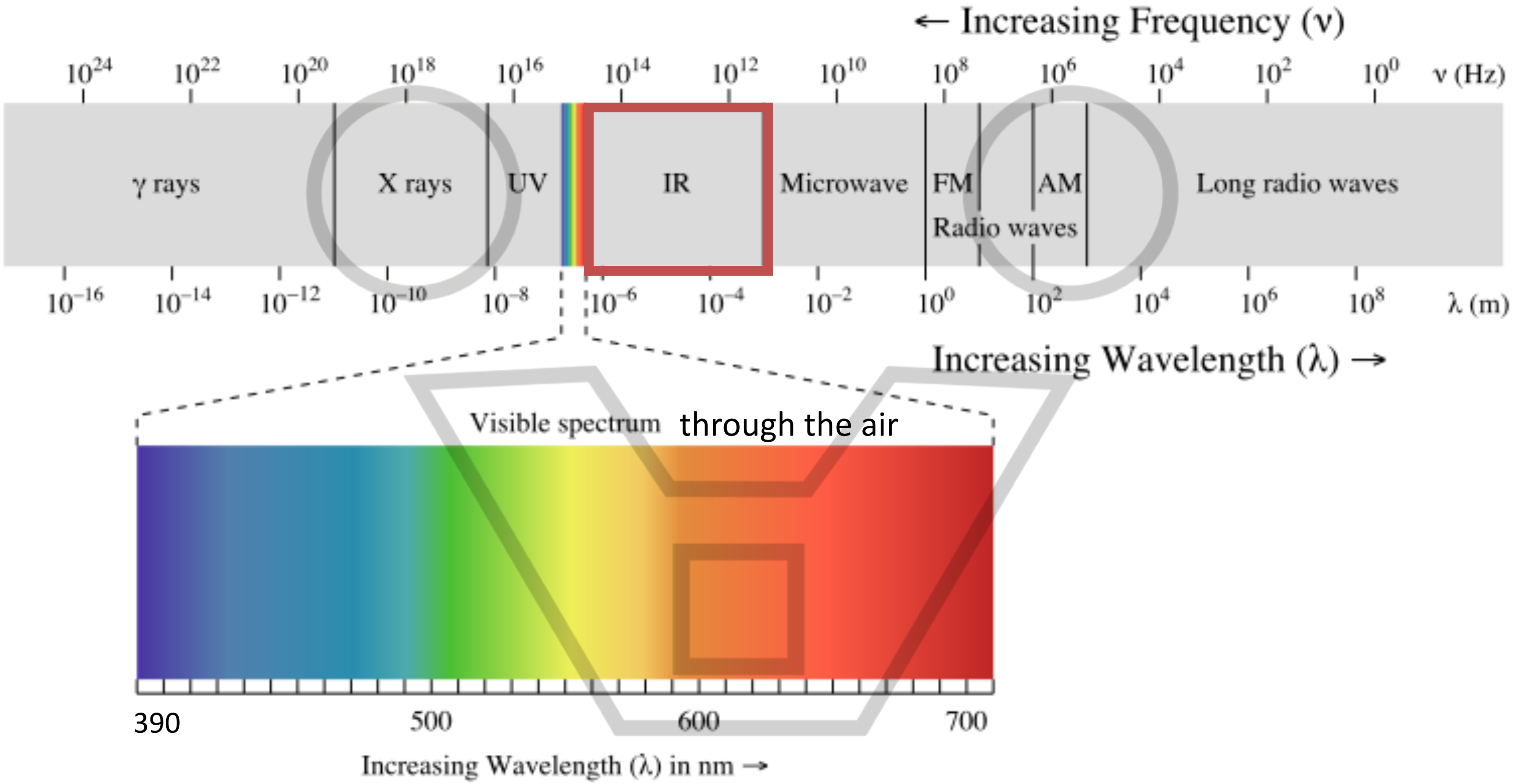


Frequency

Why a human body is invisible in the dark ?

390-700 nm
0.39-0.7 micron
3,9-7*10^-7 metri

INFRARED



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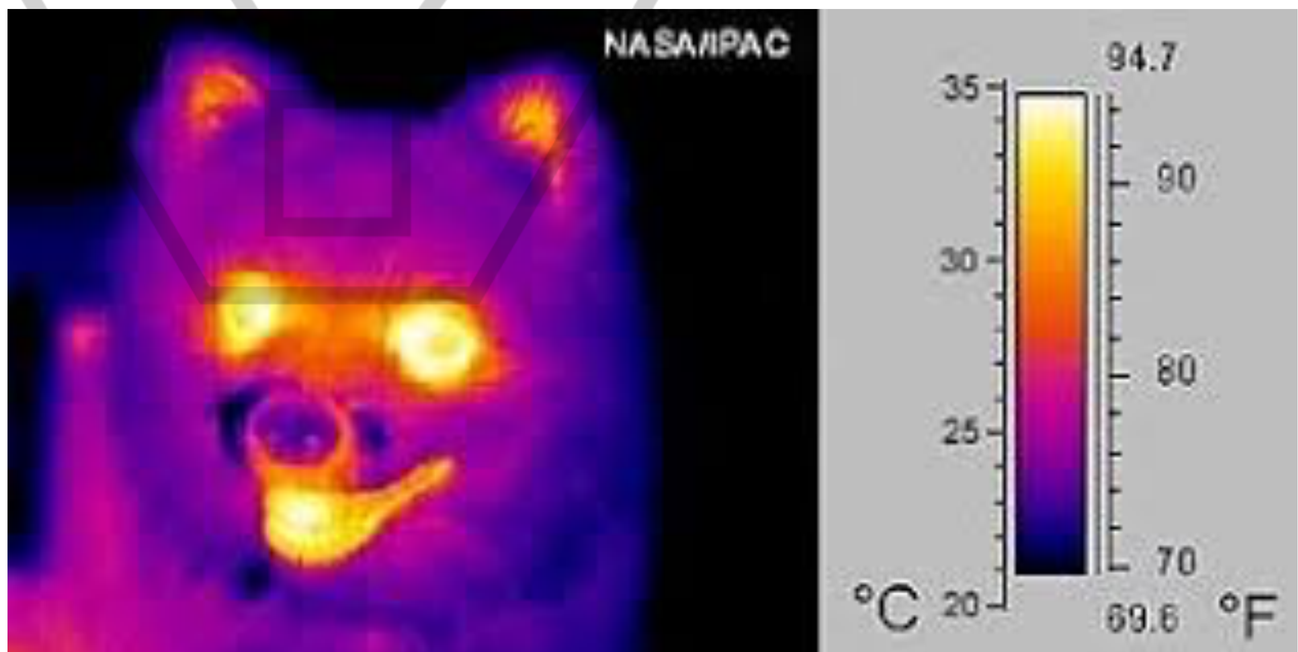
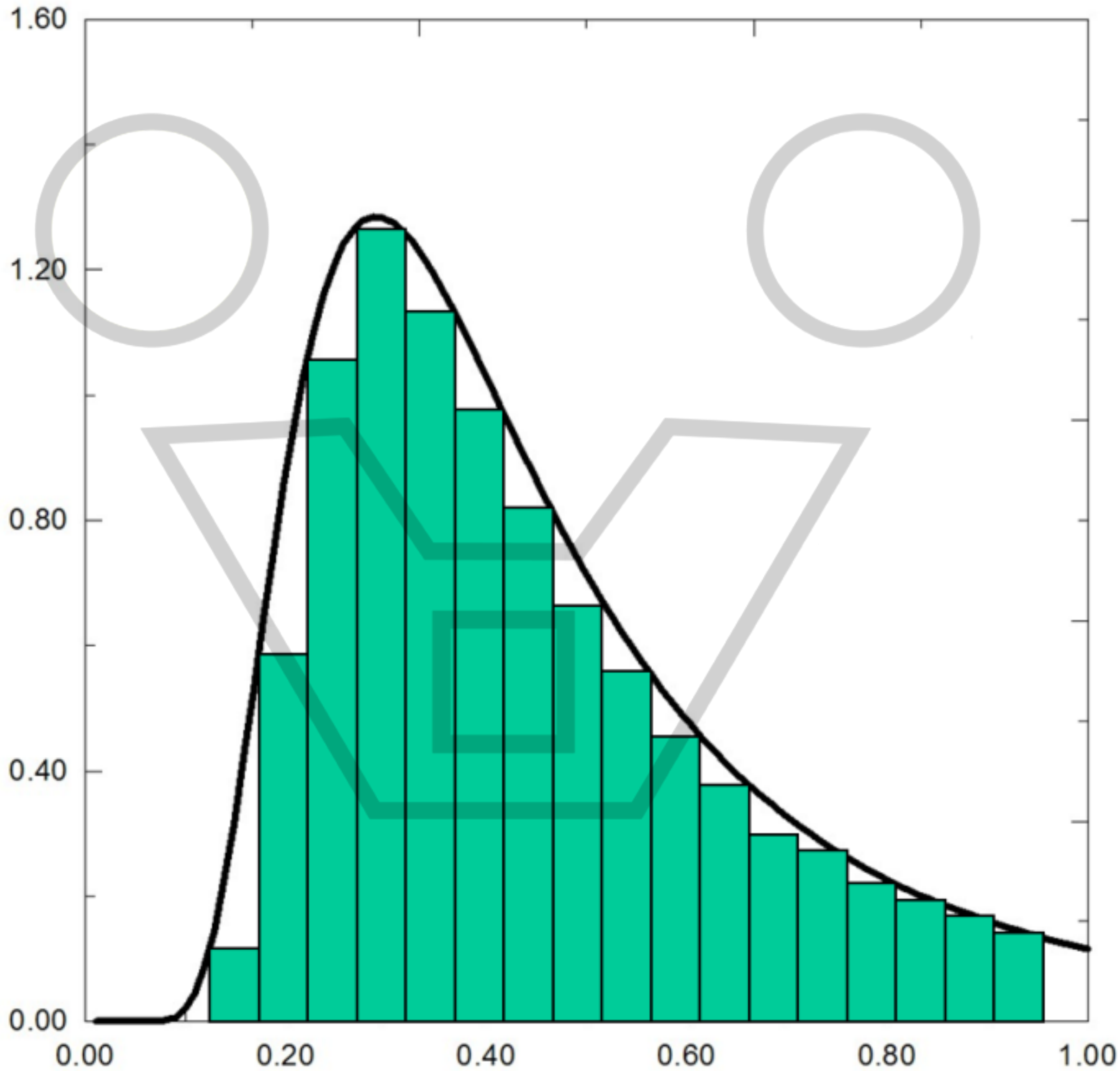
MATERIAL INVISIBLE LOW RADIATION EMISSION: INFRARED

thermography to see in the dark and to read body temperature



AMOUNT OF ENERGY ASSOCIATED WITH RADIATION



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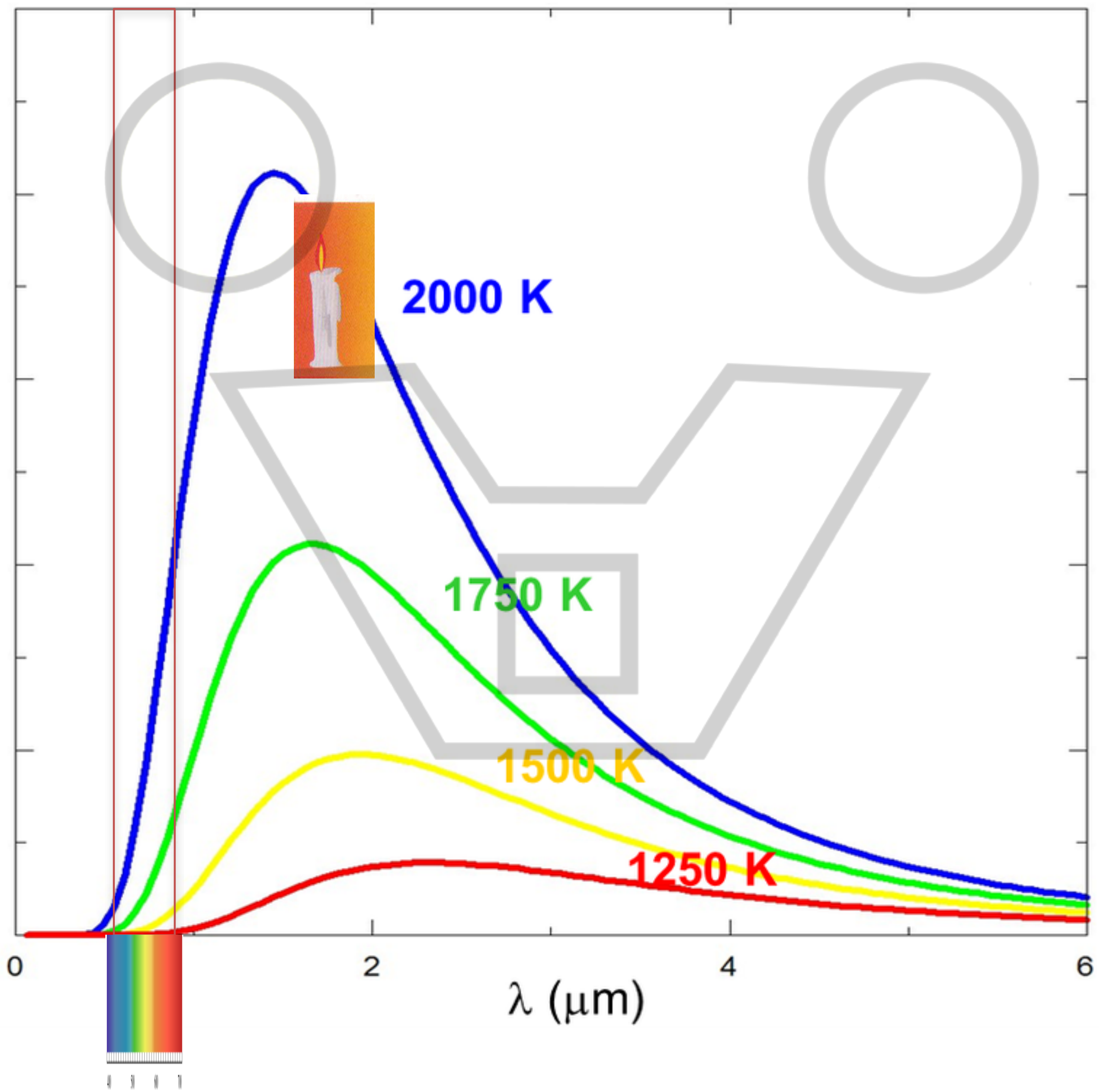
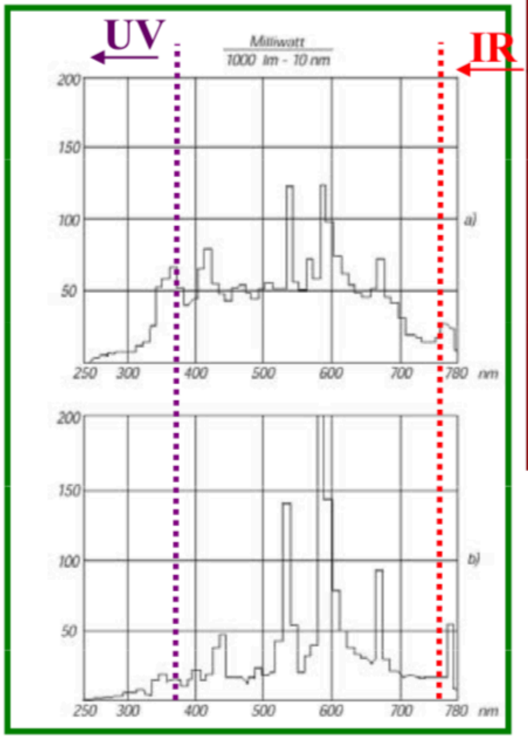
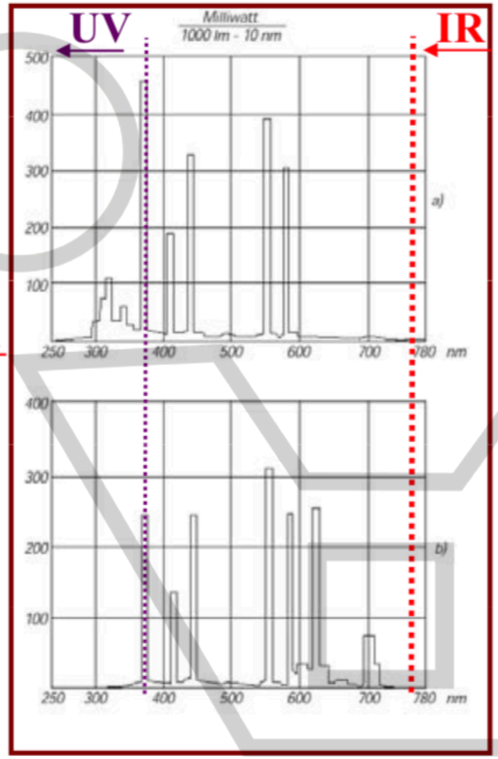


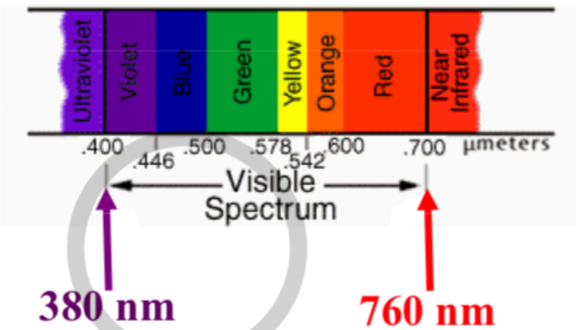
TYPES OF LAMPS: ENERGY, WAVELENGHTS & TEMPERATURE COLOR

halogen incandescent lamps

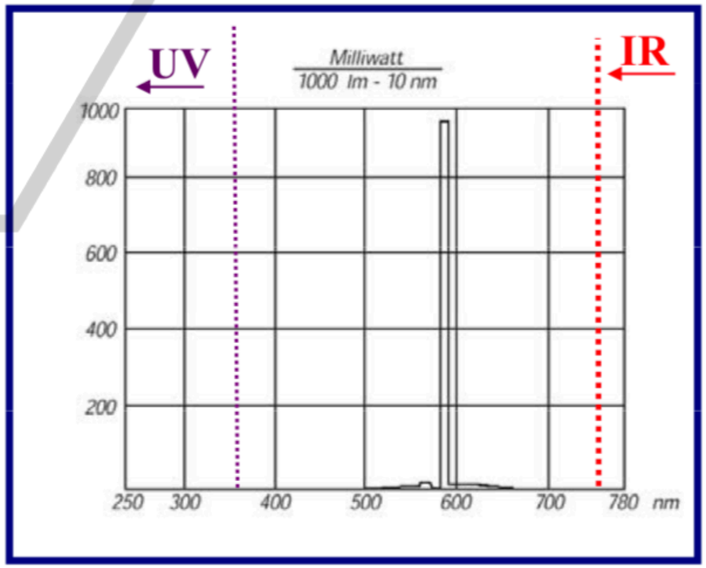




gas discharge tubes



Low Pressure Sodium Vapor (LPSV) Lamps

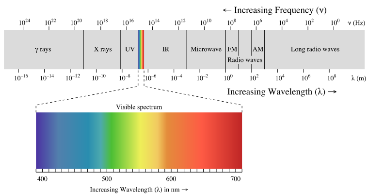


ILLUMINATION vs THERMAL COMFORT

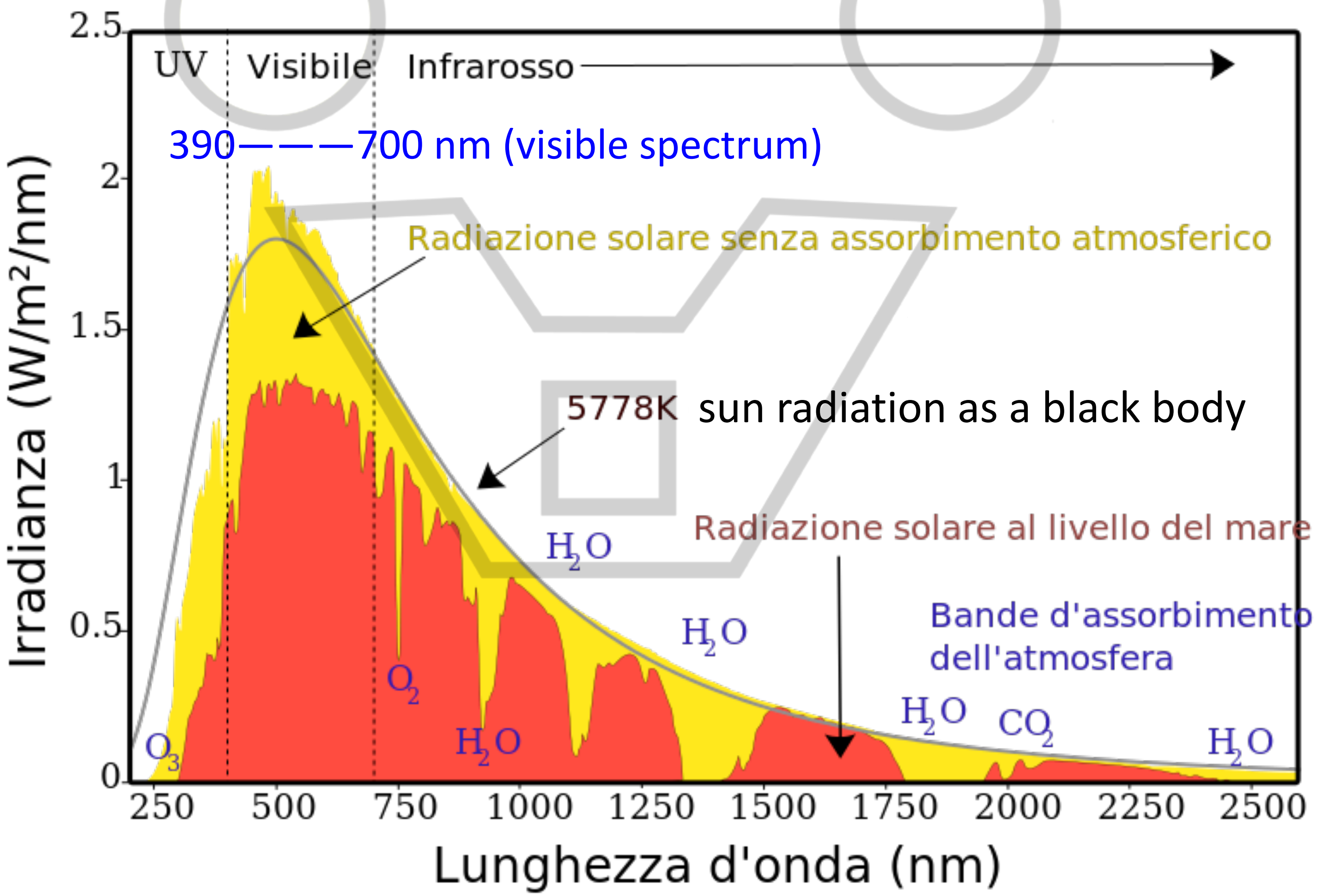
LIGHT & THERMAL SIDE EFFECTS

CHOOSING GLAZING

ENERGY IN THE VISIBLE SPECTRUM



spectrum of solar radiation on earth



ENERGY IN THE VISIBLE SPECTRUM & IN GLASS SPECTRUM

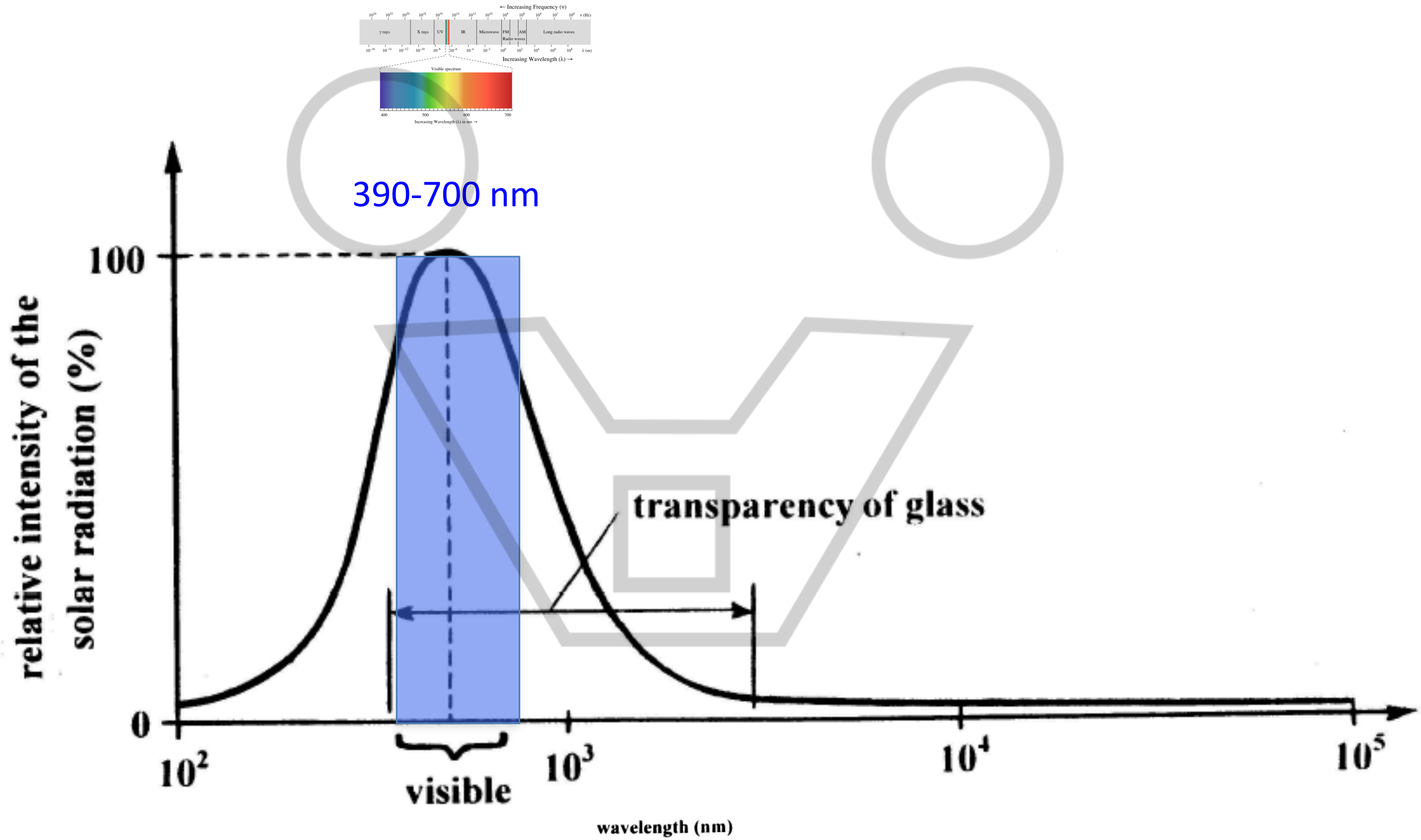


Fig. 7. Range di trasparenza del vetro rappresentato sullo spettro della radiazione solare.
Un confronto con la figura precedente mostra che il vetro non è trasparente nel range di emissione dei corpi a temperatura ambiente o di poco superiore.

TRASPARENCY OF GLASS & RADIATIONS PASSING THROUGH GLASS

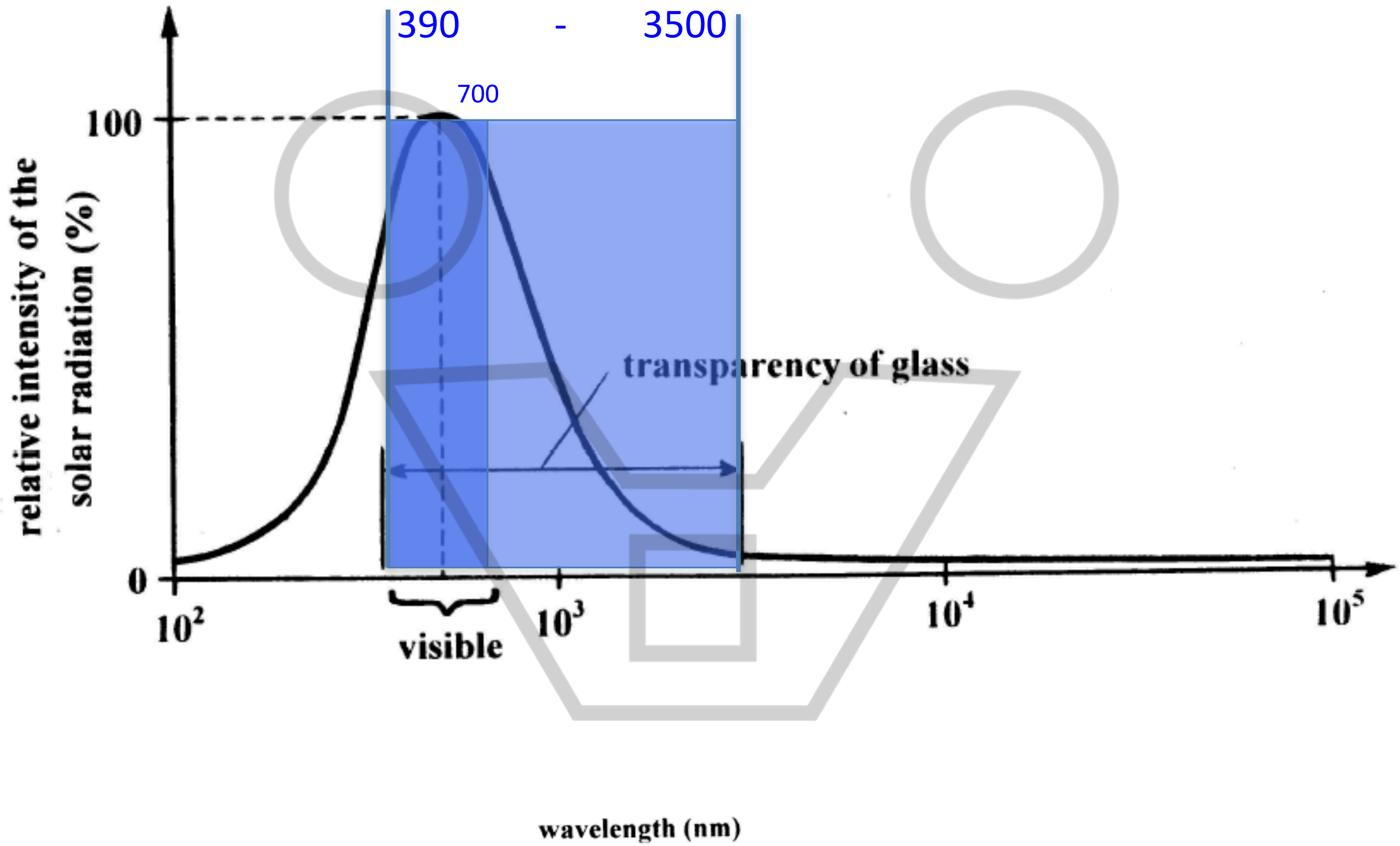


Fig. 6. Spettro della radiazione solare.

Sull'asse orizzontale è indicato il range di emissione relativo ad un corpo a 300 K. Lo spettro di emissione di questo corpo non è rappresentato e sarebbe interamente sotto la curva dello spettro solare.

GLAZING TYPE: Spectrally selective coating

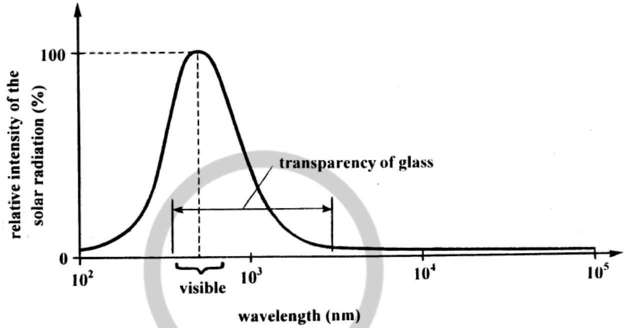
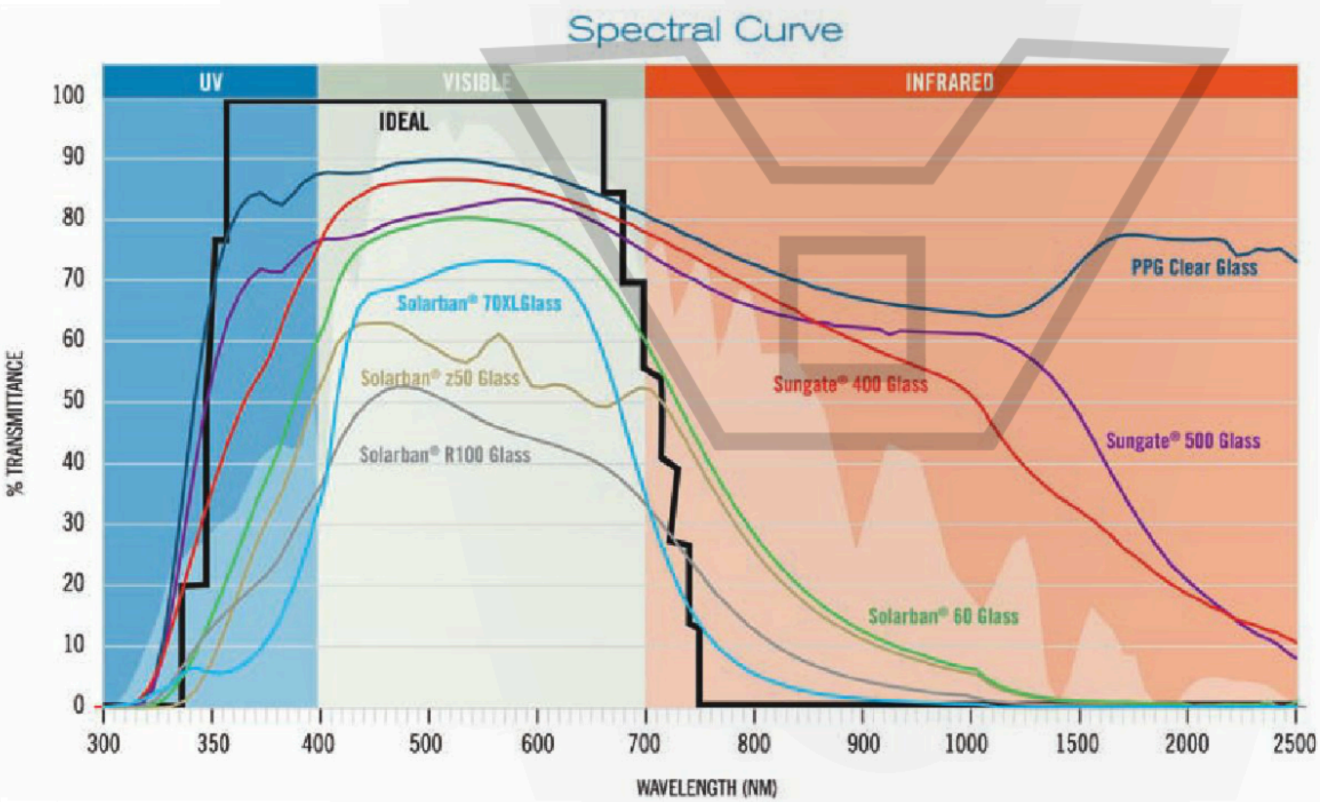


Fig. 7. Range di trasparenza del vetro rappresentato sullo spettro della radiazione solare. Un confronto con la figura precedente mostra che il vetro non è trasparente nel range di emissione dei corpi a temperatura ambiente o di poco superiore.



6.5

Spectrally selective coatings allow glazing products to reflect solar irradiation outside the visible spectrum without significantly reducing visible light transmittance. This allows low-SHGC products with high Tvis.

Source: Courtesy of PPG Industries.

GLAZING PROPERTIES: insulation vs daylight

(TVis) Visible Trasmittance for daylighting

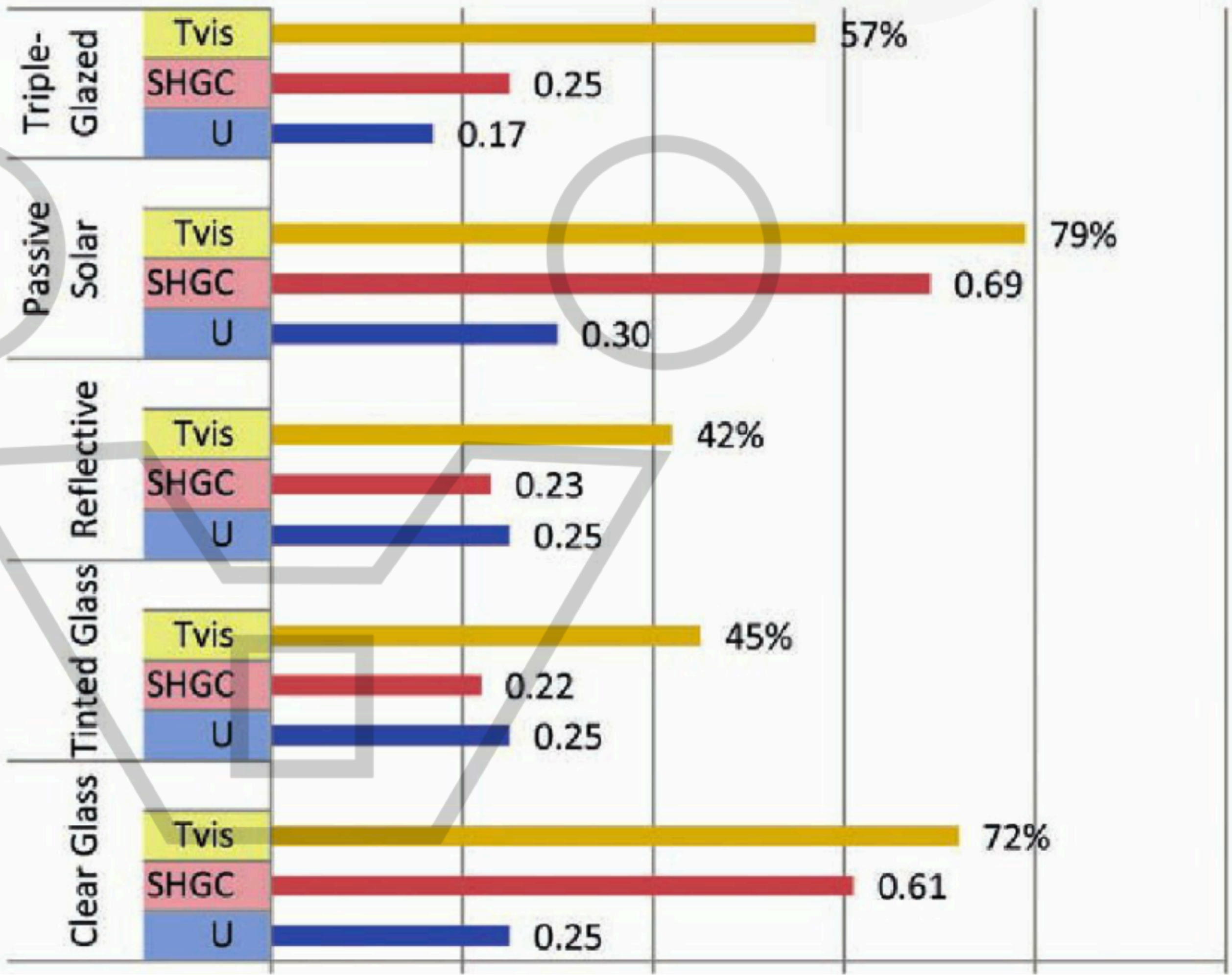
Visible transmittance is the amount of light in the visible portion of the spectrum that passes through a glazing material.

(SHGC) Solar Heat Gain Coefficient

is the fraction of the incident solar radiation transmitted through a windows plus the portion absorbed and subsequently released inward

U-value ability to transmit heat

it is expressed in units of W/m²·K. The lower the U-value, the better insulated the building element.



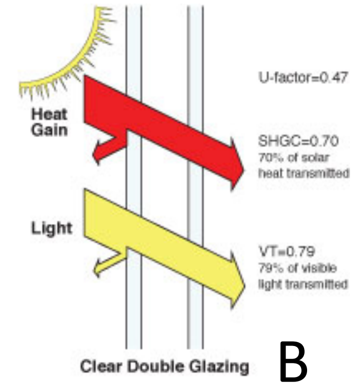
6.4

Glazing properties from some widely manufactured insulated glazing units (IGUs).

Source: Courtesy of Callison. Chart based on ©ASHRAE Handbook of Fundamentals (2005), 31.20.

GLAZING PROPERTIES: Light-to-Solar-Gain Ratio

Light-to-Solar-Gain Ratio
In the past, windows that reduced solar gain (with tints and coatings) also reduced visible transmittance. However, new high-performance tinted glass and low-solar-gain low-E coatings have made it possible to reduce solar heat gain with little reduction in visible transmittance. Because the concept of separating solar gain control and light control is so important, measures have been developed to reflect this. The **LSG ratio** is defined as a ratio between **visible transmittance (VT)** and **solar heat gain coefficient (SHGC).**

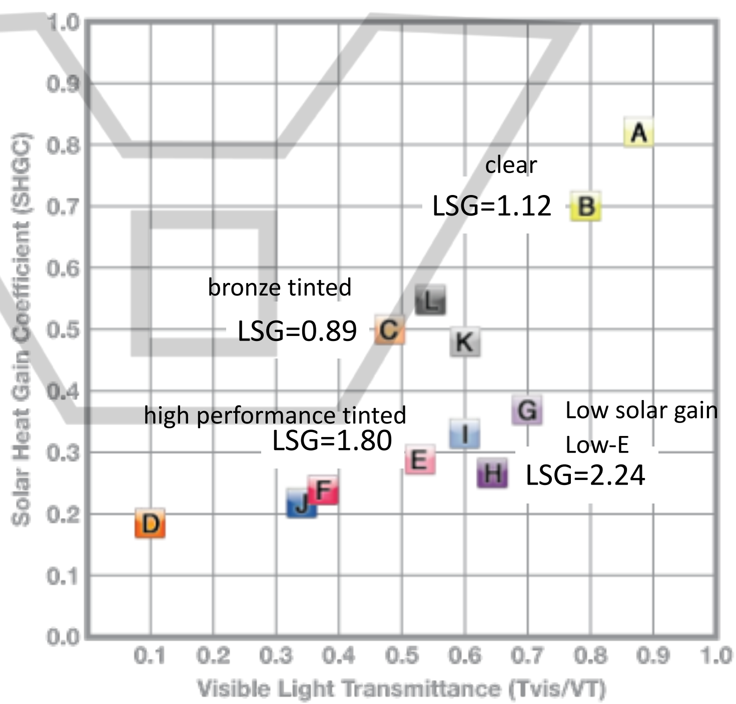


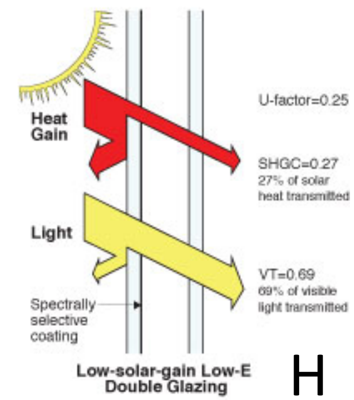
B

LSG ratio= VT/SHGC

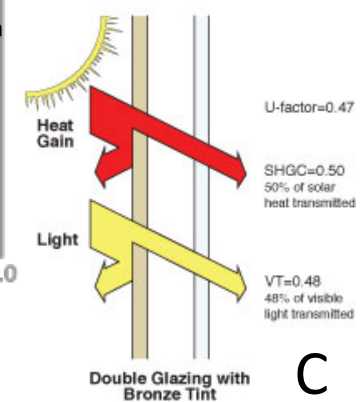
*The image illustrates the center-of-glass properties for the options used in the Facade Design Tool. A double-glazed unit with clear glass (**B**) has a visible transmittance (VT) of 0.79 and a solar heat gain coefficient (SHGC) of 0.70, so the LSG is VT/SHGC = 1.12. Bronze-tinted glass in a double-glazed unit (**C**) has a visible transmittance of 0.45 and a solar heat gain coefficient of 0.50, which results in an LSG ratio of 0.89. This illustrates that while the bronze tint lowers the SHGC, it lowers the VT even more compared to clear glass. The double-glazed unit with a high-performance tint (**E**) has a relatively high VT of 0.52 but a lower SHGC of 0.29, resulting in an LSG of 1.80—significantly better than the bronze tint. A clear double-glazed unit with a low-solar-gain low-E coating (**H**) reduces the SHGC significantly, to 0.27, but retains a relatively high VT of 0.64, producing an LSG ratio of 2.4—far superior to those for clear or tinted glass.*

DOUBLE GLAZE SOLUTION





H



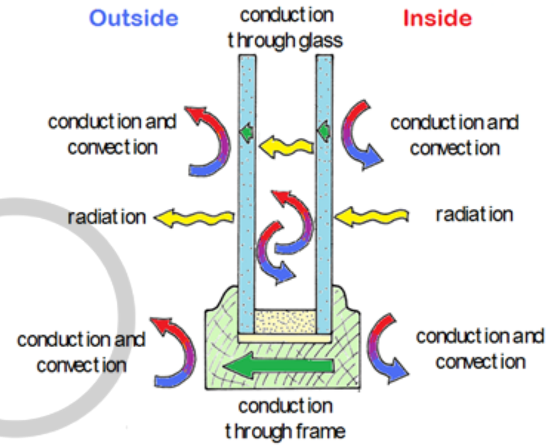
C

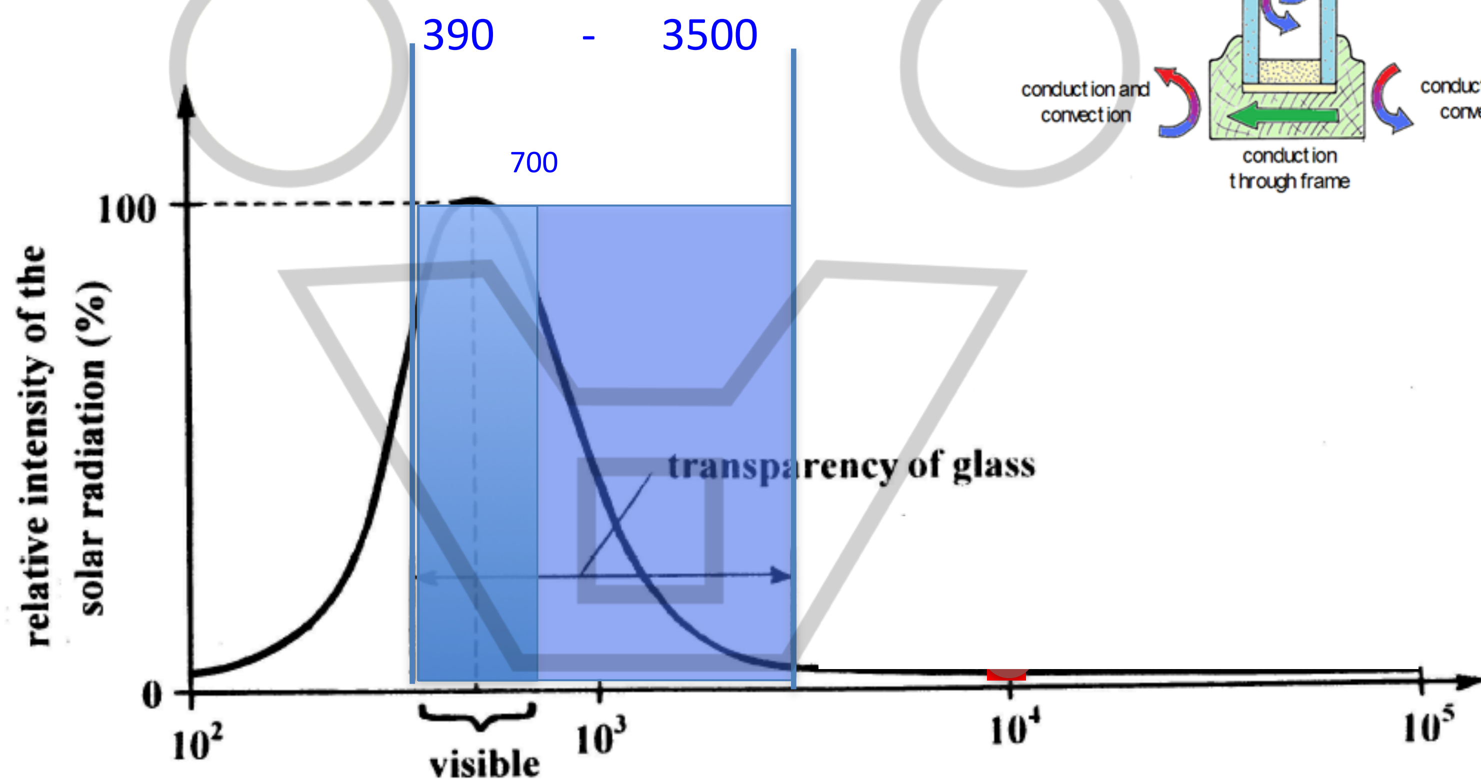
ILLUMINATION vs THERMAL COMFORT

LIGHT & THERMAL SIDE EFFECTS

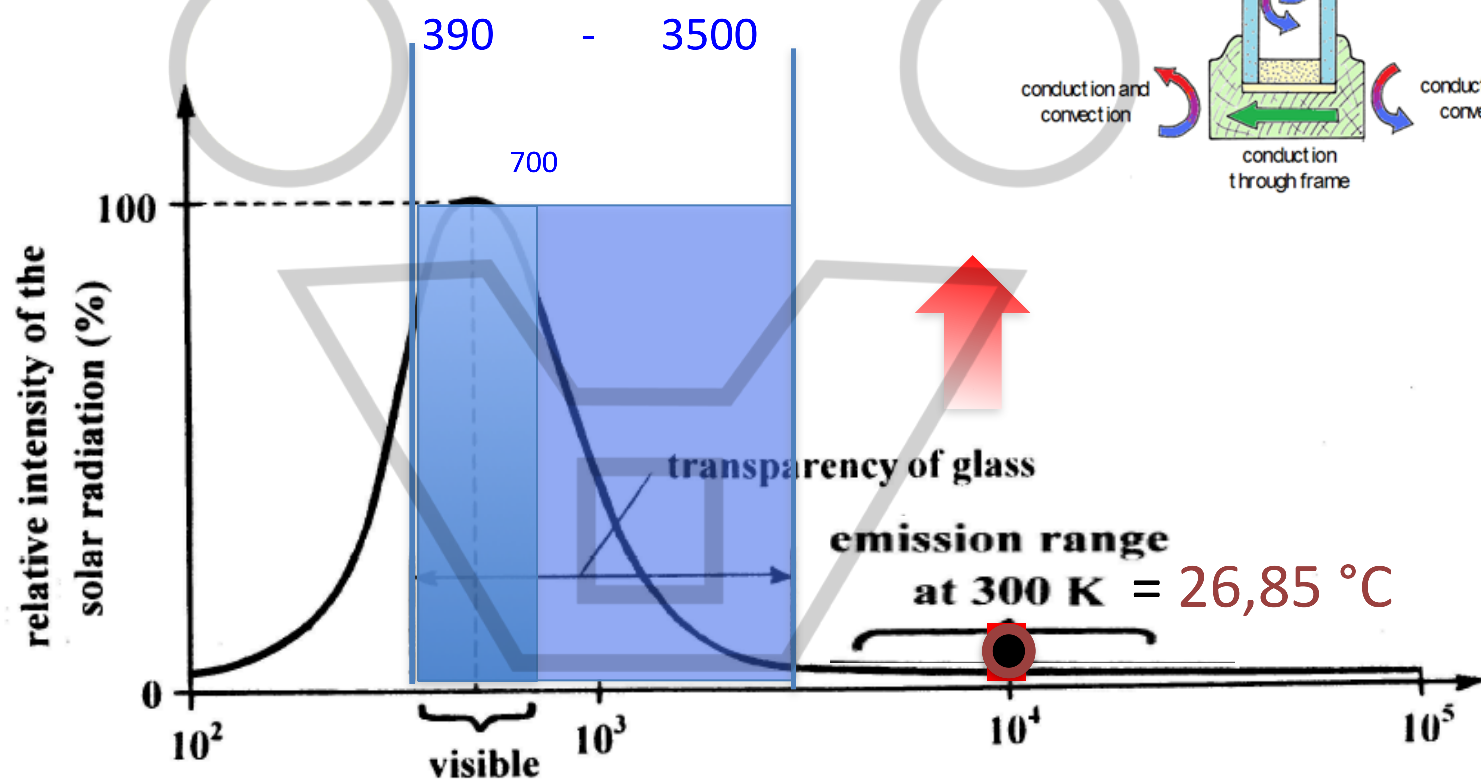
THE GREENHOUSE EFFECT

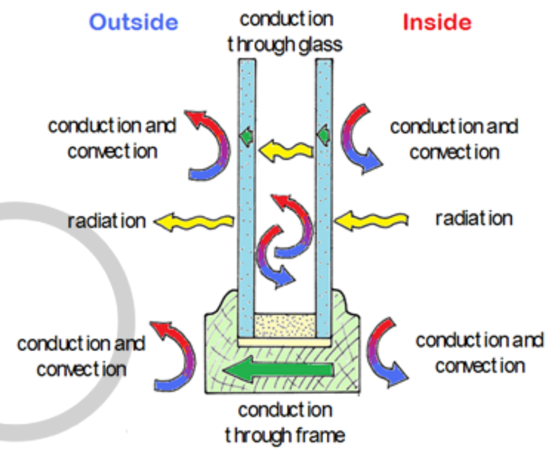
THE GREEN HOUSE EFFECT





THE GREEN HOUSE EFFECT





ILLUMINATION vs THERMAL COMFORT

LIGHT & THERMAL SIDE EFFECTS

QUANTITATIVE & QUALITATIVE DAYLIGHT ANALISYS

DAYLIGHT

Daylighting is the controlled admission of natural light "direct sunlight and diffuse skylight" into a building to reduce electric lighting and saving energy. *By providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as one-third of total building energy costs.*

The science of daylighting design is not just how to provide enough daylight to an occupied space, but how to do so without any undesirable side effects

ILLUMINATION. LEVELS AND CALCULATION

Calculating Illumination

Illumination can be calculated as

I = Ll Cu LLF / Al (1)

where

I = illumination (lux, lumen/m2)
Ll = lumens per lamp (lumen)
Cu = coefficient of utilization
LLF = light loss factor
Al = area per lamp (m2)

ILLUMINANCE - RECOMMENDED LIGHT LEVELS

Light Level or Illuminance, is the total luminous flux incident on a surface, per unit area. The work plane is where the most important tasks in the room or space are performed.
Measuring Units Light Level - Illuminance
Illumenance is measured in foot candles (ftcd, fc, fcd) (or lux in the metric SI system). A foot candle is actually one lumen of light density per square foot, one lux is one lumen per square meter.

1 lux = 1 lumen / sq meter = 0.0001 phot = 0.0929 foot candle (ftcd, fcd)

1 phot = 1 lumen / sq centimeter = 10000 lumens / sq meter = 10000 lux

1 foot candle (ftcd, fcd) = 1 lumen / sq ft = 10.752 lux

COMMON AND RECOMMENDED LIGHT LEVELS INDOOR

The outdoor light level is approximately 10,000 lux on a clear day. In the building, in the area closest to windows, the light level may be reduced to approximately 1,000 lux. In the middle area its may be as low as 25 - 50 lux. Additional lighting equipment is often necessary to compensate the low levels.
Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux.

Condition	Illumination	
	(ftcd)	*(lux)*
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

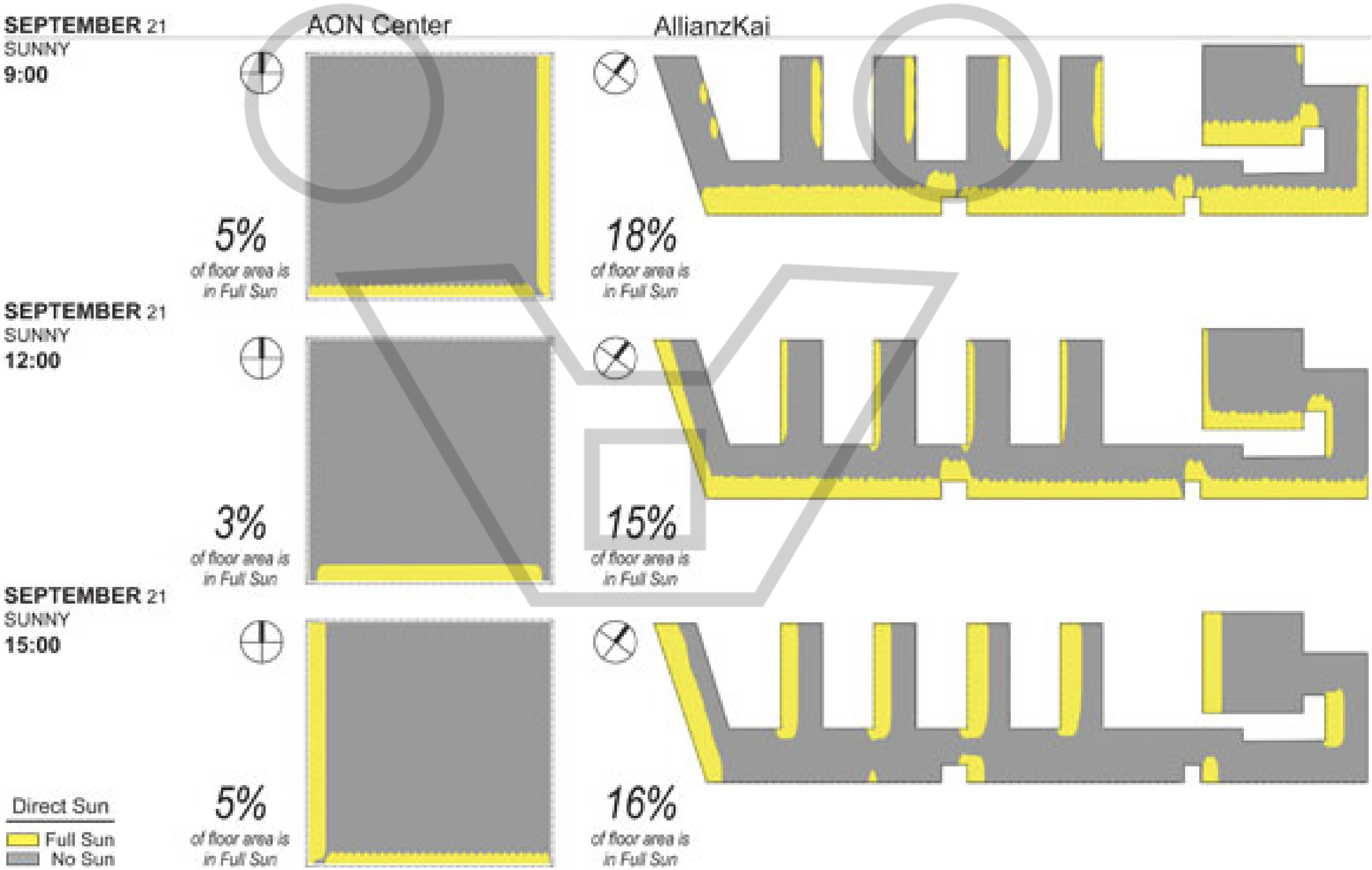
Common light levels outdoor at day and night

Activity	Illumination *(lux, lumen/m^2)*
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	500
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Guidance for recommended light level in different work spaces

DAYLIGHT ASSESSMENT: DIRECT SUN PERCENTAGE

These graphs are used to illustrate direct sun penetration only at various times of the day on September 21st. This is a simple analysis but can be very useful to consider the potential impact of sun at any time of the year with regards to glare or solar heat gain. Iterative analysis might investigate the incremental benefit of alternate building geometries or fixed architectural shading elements such as overhangs. Areas shaded with yellow represent Illumination values above 3,000 lux (~300 footcandles), generally considered as direct sun. [23]

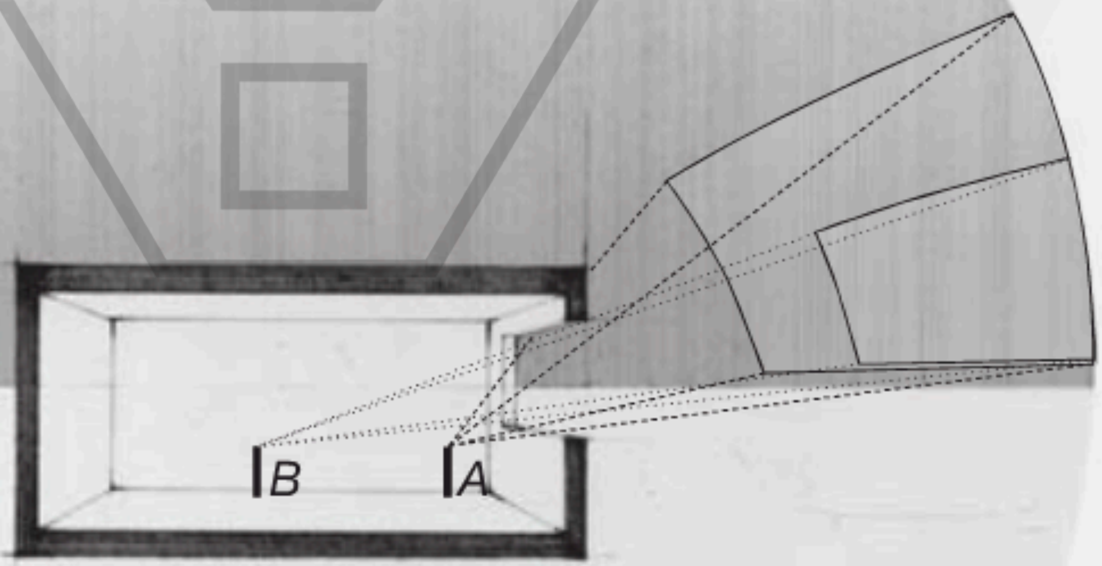


DAYLIGHT ASSESSMENT: DF-DAYLIGHT FACTOR

Daylight factor is a ratio that represents the amount of illumination available indoors relative to the illumination present outdoors at the same time under overcast skies

Daylight factor is based on the amount of indoor light as a percentage of outdoor light levels. Using a CIE overcast sky, it reports the percentage of outdoor light that arrives at a given point. Point A has access to significantly more sky than point B, with a proportionally higher daylight factor.

Source: Illustration by Amal Kissoondyal.



DAYLIGHT ASSESSMENT: DF-DAYLIGHT FACTOR

Daylight Metrics

Metric	Notation	Units	Description
Illuminance	E	lux, fc	Illuminance at each point for each date/time sample.
Basic Daylight Autonomy	DA	%	Fraction of occupied hours per year where the illuminance at a point is greater than or equal to a target threshold value.
Continuous Daylight Autonomy	cDA	%	Fraction of occupied hours per year where the illuminance at a point is greater than or equal to a target threshold value and where partial credit is given where the illuminance is less than the threshold value.
Maximum Daylight Autonomy	mDA (maxDA)	%	Fraction of occupied hours per year where the illuminance at a point is greater than a maximum threshold value.
Minimum Daylight Autonomy	minDA	%	Fraction of occupied hours per year where the illuminance at a point is less than a minimum threshold value.
Spatial Daylight Autonomy	sDA	%	Fraction of area where Daylight Autonomy is greater than or equal to a threshold value. May apply to any of the daylight autonomy metrics (DA, cDA, UDI, etc).
Useful Daylight Illuminance (Acceptable)	UDI (UDI-a)	%	Fraction of occupied hours per year where the illuminance at a point is (inclusive) between minimum and maximum threshold values.
Useful Daylight Illuminance (Supplementary)	UDI (UDI-s)	%	Fraction of occupied hours per year where the illuminance at a point is below the minimum threshold value.
Useful Daylight Illuminance (Excessive)	UDI (UDI-e)	%	Fraction of occupied hours per year where the illuminance at a point is above the maximum threshold value.
Annual Daylight Exposure	ADE	lx-hours/year fc-hours/year	The cumulative amount of visible light incident on a point per year.
Annual Sunlight Exposure	ASE	hours/year	Number of hours per year a point receives direct sunlight greater than a threshold value.
Spatial Annual Sunlight Exposure	sASE	%	Fraction of area where Annual Sunlight Exposure is greater than a threshold value.

http://www.licaso.com/docs/2017/Content/B_Feature%20Topics/Daylight%20Metrics.htm

DAYLIGHT ASSESSMENT: DAYLIGHTING METRICS

Daylighting Metric Definitions

Metric	Calculation Method Parameters*	Scale Description	Criteria	Path	Program
Single Point in Time	Max to Min Illuminance Ratio and SPT, sunny equinox at noon	Emax: Emin Prerequisite Area%	≤ 8 : 1 Area % point thresholds here Eavg [fc] ≥ 25fc	1	CHPS-CA
Daylight Saturation Percentage	Continuous DA with 40fc and Incremental DA with 400fc	[(DSP40 - 2 x DSP400) [%]]avg	Area weighted average DSP point thresholds	2	CHPS-CA
Daylight Factor	DF, cloudy climate	Area %	Area % point thresholds where DFavg[%] ≥ 2%	3	CHPS-CA
Daylight Autonomy Ratio	Continuous DA using design illuminance	Area %	75% area must have ≥ 40% DAR, pass/fail	1	CHPS-NY
Glazing Factor	DF variation	Area %	75% area must have ≥ 2% Glazing Factor, pass/fail	1	LEED-NC
Single Point in Time	SPT, sunny equinox at noon, modeling or measurement	Area %	75% area must have ≥ 25fc, pass/fail	2	LEED-NC
SPOT Daylight Autonomy	Continuous DA and MaxDA using design illuminance	MaxDA %, binned prerequisite DA %, binned	≤ 5% area › 1% MaxDa 60% area compared to stacked %DA bins	-	None
Useful Daylight Illuminances	Annual hour binning for various saturation levels	UDI hours %, binned	Undetermined	-	None

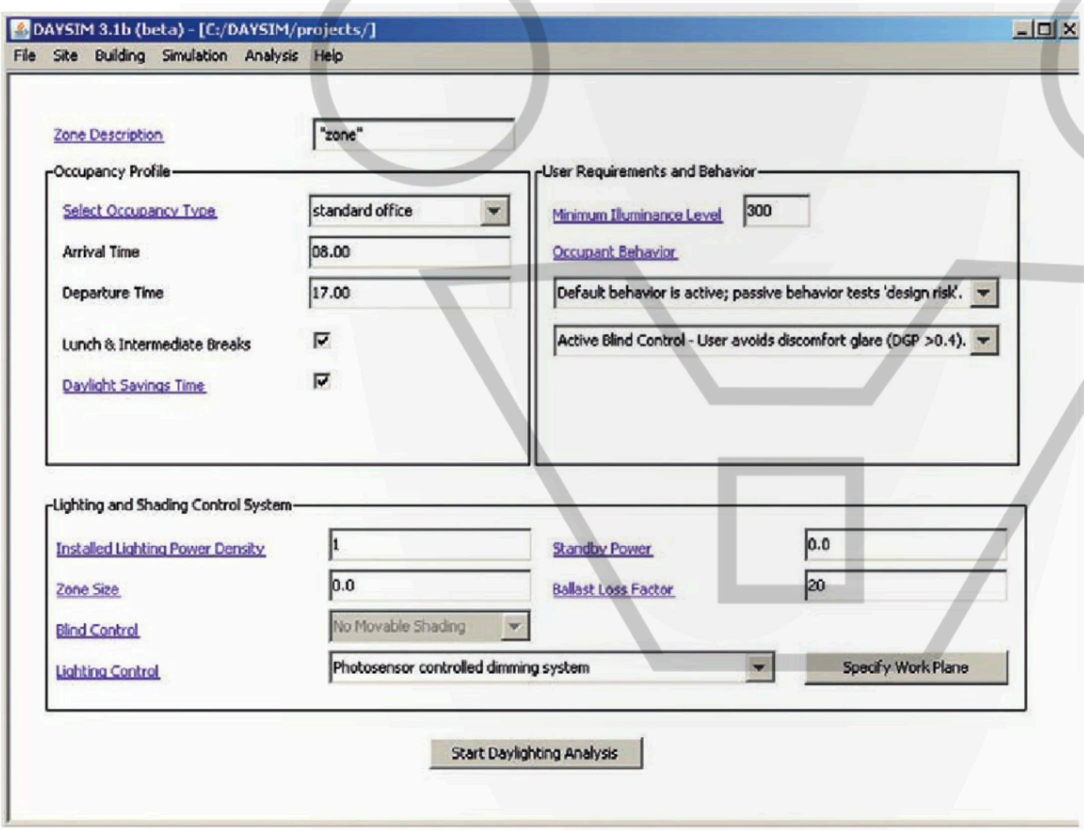
**Other prerequisites exist but those listed are critical to the calculation method.*

Source: Architectural Energy Corporation

https://energydesignresources.com/media/1702/edr_designbriefs_daylightmetrics.pdf?tracked=true

DAYLIGHT ASSESSMENT: DF - SOFTWARE TOOLS

DAYLIGHT ASSESSMENT SOFTWARE



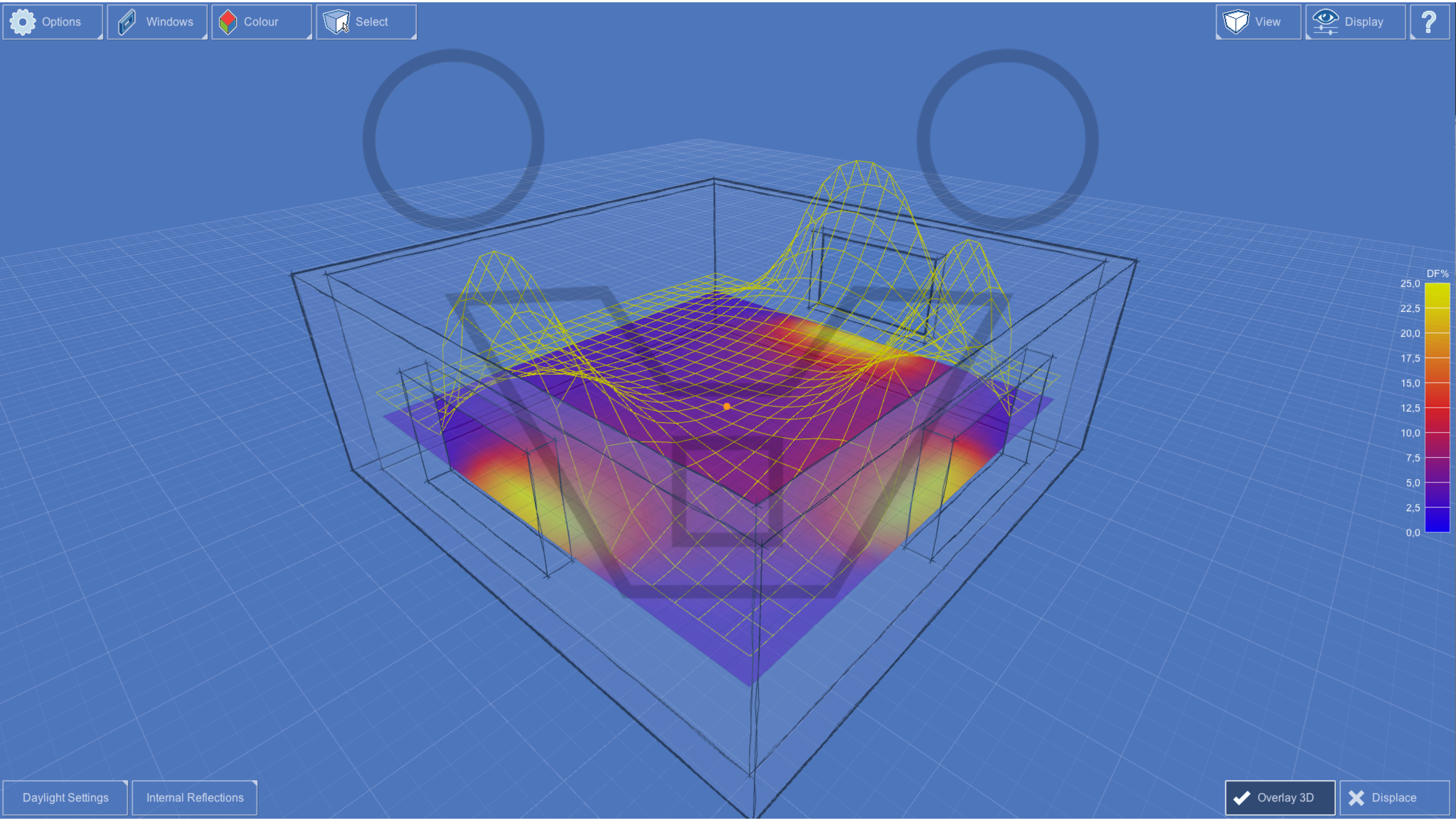
8.10

Daysim software, that estimates daylight autonomy, has a user-inputted minimum lighting threshold, generally the illuminance level recommended for electric lighting. The characteristics of the occupants, the hours of operation, and other information are necessary to accurately estimate when electric lights may be dimmed or off on an annual basis.

A given sensor that reports a DA of 75% means that electric lights would not be necessary at the sensor during 75% of the occupied hours each year. DA presents a best case scenario for lights to be dimmed or off, since glare may cause blinds to be deployed, reducing light levels at the sensor. DA software requires the input of various assumptions about the building or users' operations of blinds as

DAYLIGHT ASSESSMENT: DF - SOFTWARE TOOLS

Daylight Factor Shoe box Analysis using computational tools



http://andrewmarsh.com/apps/staging/daylight-box.html

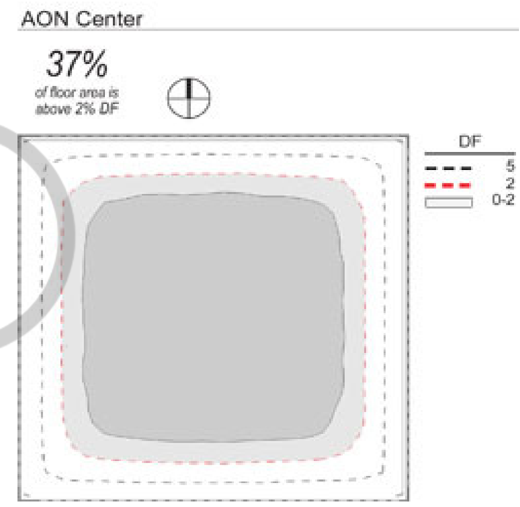
DAYLIGHT ASSESSMENT: DF - Examples

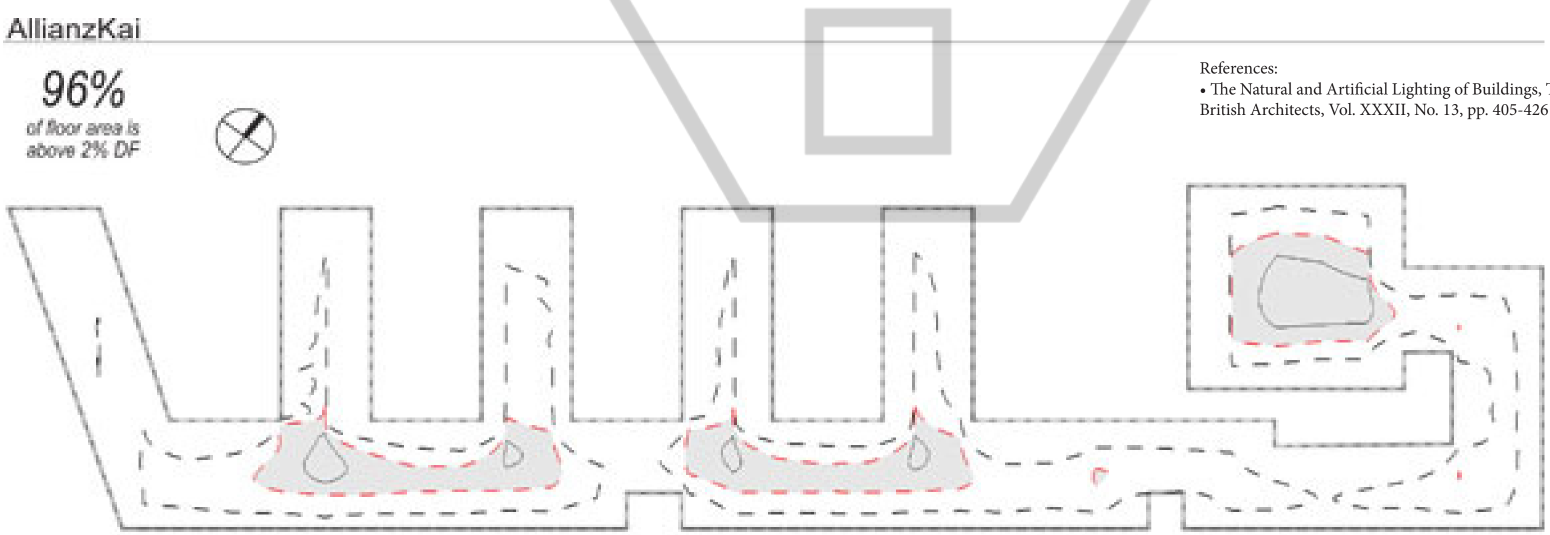
Daylight Factor is typically calculated by dividing the horizontal work plane illumination indoors by the horizontal illumination on the roof of the building being tested and then multiplying by 100. For example, if there were 20,000 lux available outdoors and 400 lux available at any given point indoors, then the DF for that point would be calculated as follows DF = 400/20,000 *100 or DF=2.

Daylight Factor is to be used under overcast sky conditions only. Daylight factor is the most common metric used when studying physical models to test daylighting designs in 'overcast sky simulators'. It is reasonably easy to calculate in real buildings or physical models with illumination meters. It is possible to calculate DF with digital models but care should be taken to understand the 'sky model' that is referenced and interpret the data accordingly.

Daylight Factor outputs are helpful in making quick comparisons of relative daylight penetration under overcast sky conditions and is arguably less useful in climates with a great deal of sun. However, most climates across the United States have substantial periods of overcast skies and DF is a useful metric to inform design decisions for these periods.

Daylight Factor can be reported with static or dynamic measures, however it is most commonly considered statically (at a single point in time) as shown above. In fact, the stability of DF regardless of the time of day and year (assuming an overcast sky) is one of the benefits of the metric. [25] http://patternguide.advancedbuildings.net/using-this-guide/analysis-methods





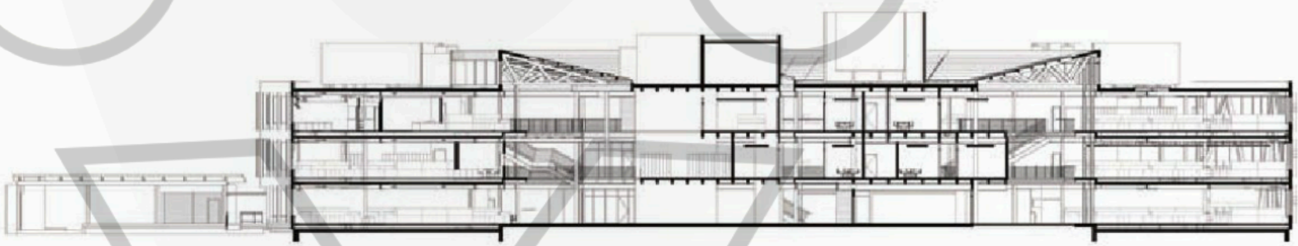
References:
• The Natural and Artificial Lighting of Buildings, The Journal of the Royal Institute of British Architects, Vol. XXXII, No. 13, pp. 405-426 and 441-446).

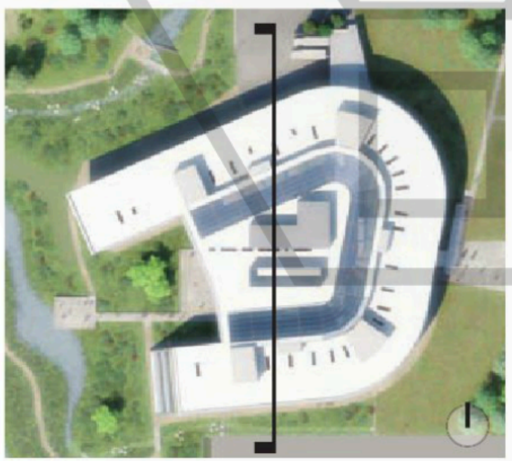
DAYLIGHT ASSESSMENT: DF - FALSE COLOR

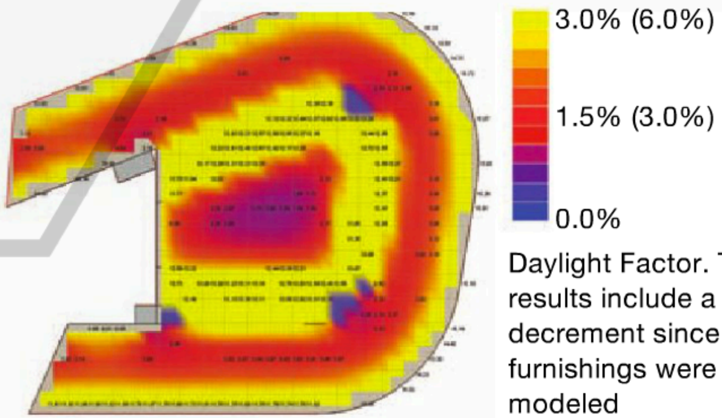
Daylight Factor Analysis in false color

Federal Center South, Building 1202, is a 60'-wide office plate in the form of a U-shape around a daylit atrium. The false color results of a daylight factor simulation on the ground floor show good daylight based on sectional properties, including: office plate width, skylight geometry and glazing properties.

Source: Courtesy of ZGF Architects LLP.







Daylight Factor. The results include a 50% decrement since interior furnishings were not modeled

a **daylight factor** (DF)is the ratio of the light level inside a structure to the light level outside the structure.

It is defined as:
DF = (Ei / Eo) x 100%

where,

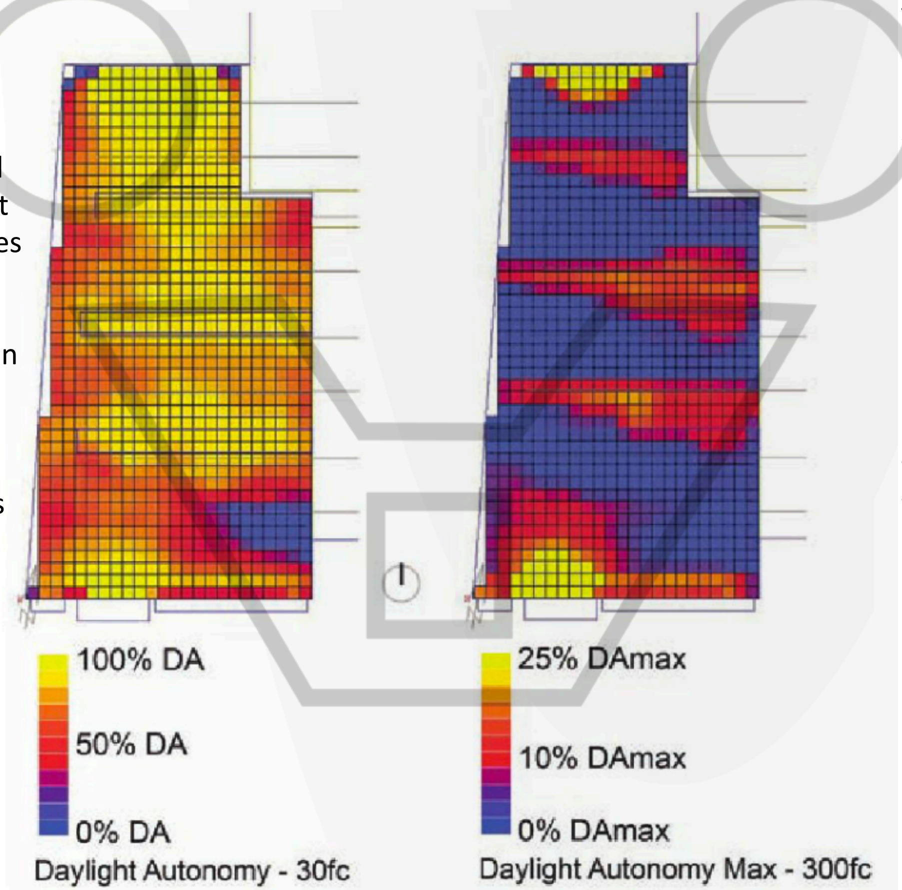
Ei = illuminance due to daylight at a point on the indoors working plane,

Eo = simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

DAYLIGHT ASSESSMENT: DIFFERENT DF METHODOLOGIES

DIGITAL SIMULATION TO EVALUATE DAYLIGHT AUTONOMY vs DAYLIGHT AUTONOMY MAX

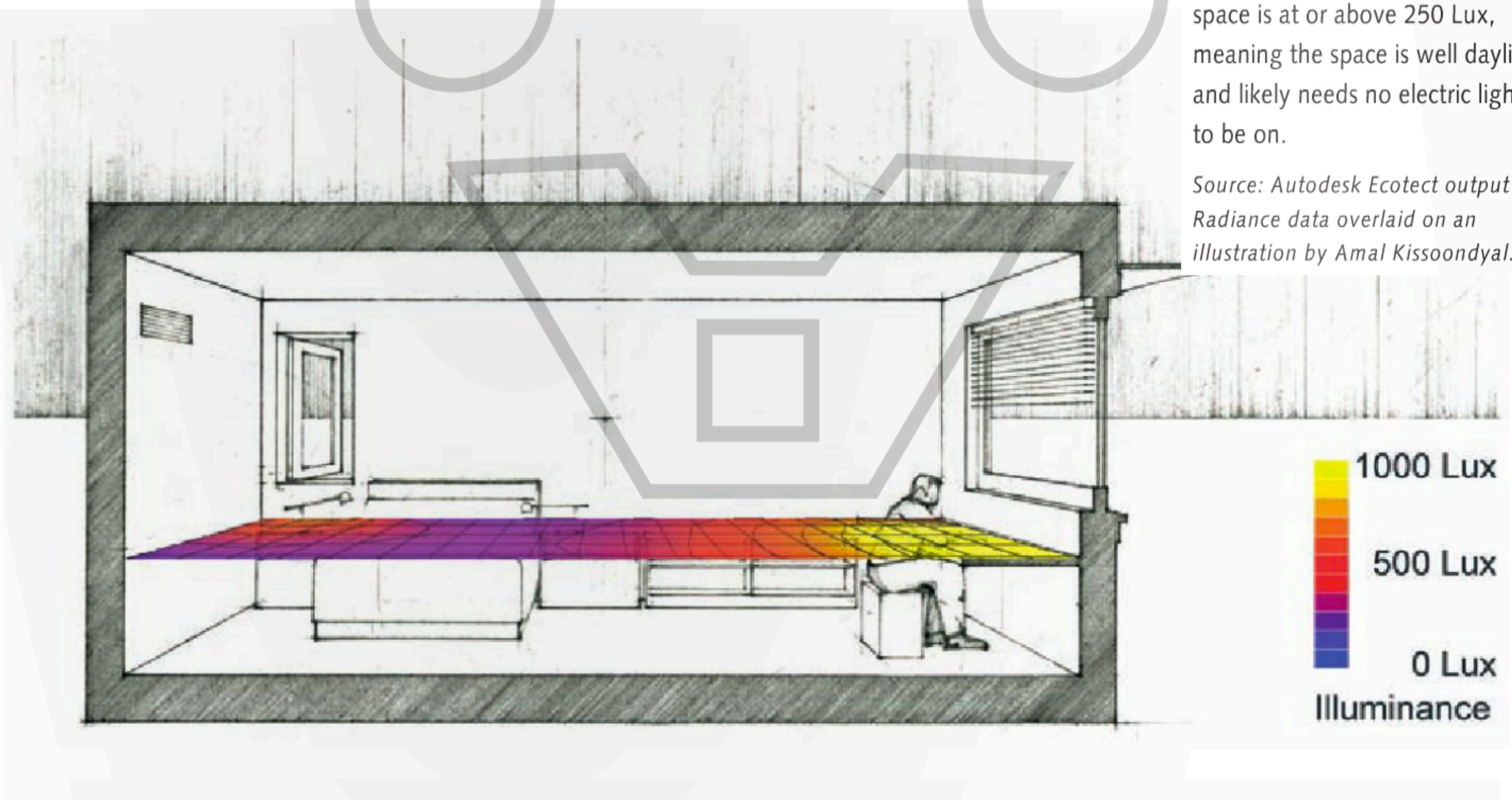
Daylight Autonomy (DA) at a specified workplane location is defined as the percentage of year when a minimum illuminance requirement is met by daylight alone. The exact method for sky and time simulation over a typical year is not defined, but the fact that it requires an annual simulation classifies this calculation method as dynamic. The minimum illuminance is typically the IESNA recommendation for a given task type. The use of the DA metric dates back to a Swiss standard, circa 1989.4 Variations of the original DA have been developed and Continuous DA methods such as incremental summing and continuous summing may more closely predict daylight performance.



Maximum Daylight Autonomy
To be used in conjunction with the continuous summing method, Rogers also defined Maximum Daylight Autonomy (MaxDA).6 MaxDA is an incremental summing method that uses a maximum illuminance bound instead of a minimum. Times of the occupied schedule are counted if the given point has an exceedingly high illuminance, which is used as an indicator of glare or unwanted heat gains. The threshold typically is ten times the illuminance criterion,7 though this value is not grounded in a specific glare or heat gain study.

DAYLIGHT ASSESSMENT: ILLUMINANCE LEVELS

Illuminance Levels Analysis in False Color



False color illuminance levels for 2 p.m. on March 21 at a work plane height of 30" above floor level show that the majority of the space is at or above 250 Lux, meaning the space is well daylit and likely needs no electric lights to be on.

Source: Autodesk Ecotect output of Radiance data overlaid on an illustration by Amal Kissoondyal.

DAYLIGHT ASSESSMENT: ILLUMINANCE LEVELS

Benchmarks & measurement methodology under LEED NS standard

Metric Path and Criteria Definitions – LEED NC Version 2.2

OPTION 1 — CALCULATION BASIC METHOD based on windows ratio

Achieve a minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas. The glazing factor is calculated as follows:

Glazing = Window Area [SF]/Floor Area [SF] x
Window Geometry Factor x
Actual Tvis/Minimum Tvis Factor x
Window Height Factor

OR

OPTION 2 — SIMULATION COMPUTATIONAL METHOD based on illuminance 10-foot grid

Demonstrate, through computer simulation, that a minimum daylight illumination level of 25 footcandles has been achieved in a minimum of 75% of all regularly occupied areas. Modeling must demonstrate 25 horizontal footcandles under clear sky conditions, at noon, on the equinox, at 30 inches above the floor.

OR

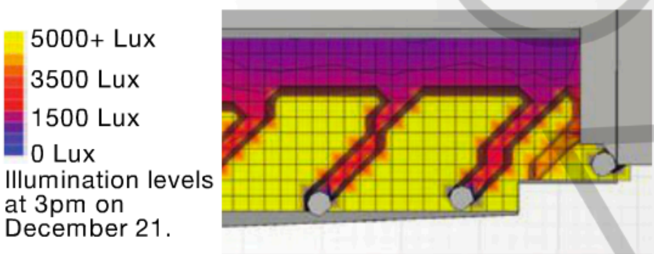
OPTION 3 — MEASUREMENT

Demonstrate, through records of indoor light measurements, that a minimum daylight illumination level of 25 footcandles has been achieved in at least 75% of all regularly occupied areas. Measurements must be taken on a 10-foot grid for all occupied spaces and must be recorded on building floor plans. In all cases, only the square footage associated with the portions of rooms or spaces meeting the minimum illumination requirements can be applied towards the 75% of total area calculation required to qualify for this credit. In all cases, provide daylight redirection and/or glare control devices to avoid high-contrast situations that could impede visual tasks. Exceptions for areas where tasks would be hindered by the use of daylight will be considered on their merits.

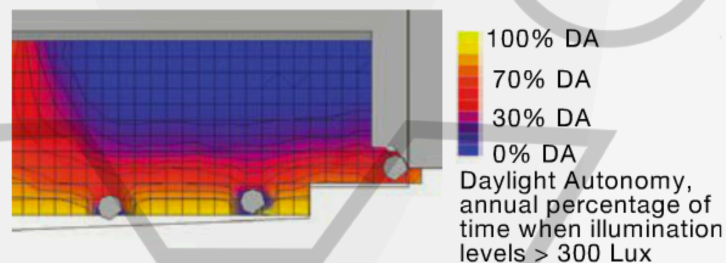
Source: USGBC, www.usgbc.org/

DAYLIGHT ASSESSMENT. ILLUMINANCE vs DAYLIGHT AUTONOMY

POIN-IN-TIME (Illuminance analysis) vs ANNUAL ANALYSIS (Daylight Autonomy)



Illuminance
– Point-in-time –

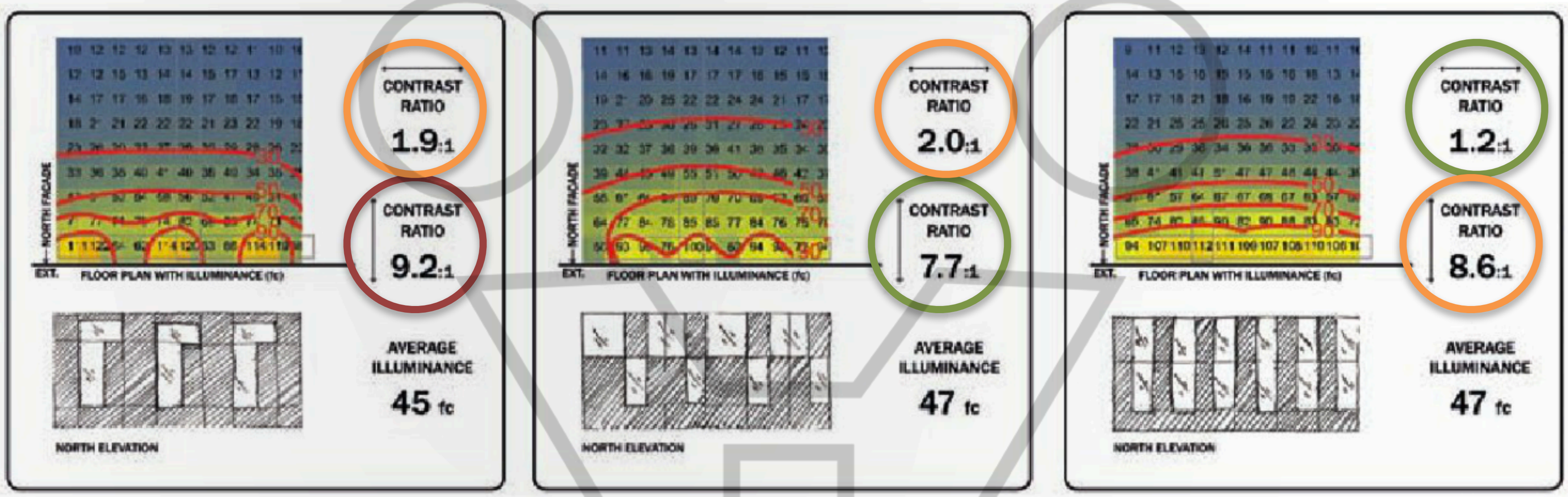


Daylight Autonomy
– Annual analysis –

2.6

Plan view of an open office space, showing a façade with columns at the bottom. A point-in-time (PIT) analysis (left) provides information about daylight levels and potential for glare at 3:00 p.m. on the winter solstice, for example. An annual daylight autonomy analysis (right) shows areas that are successfully daylit for a certain percentage of the year. Both use false colors to illustrate lighting levels; they are Autodesk Ecotect outputs of Radiance and Daysim analyses, respectively.

DAYLIGHT ASSESSMENT: CONTRAST RATIO



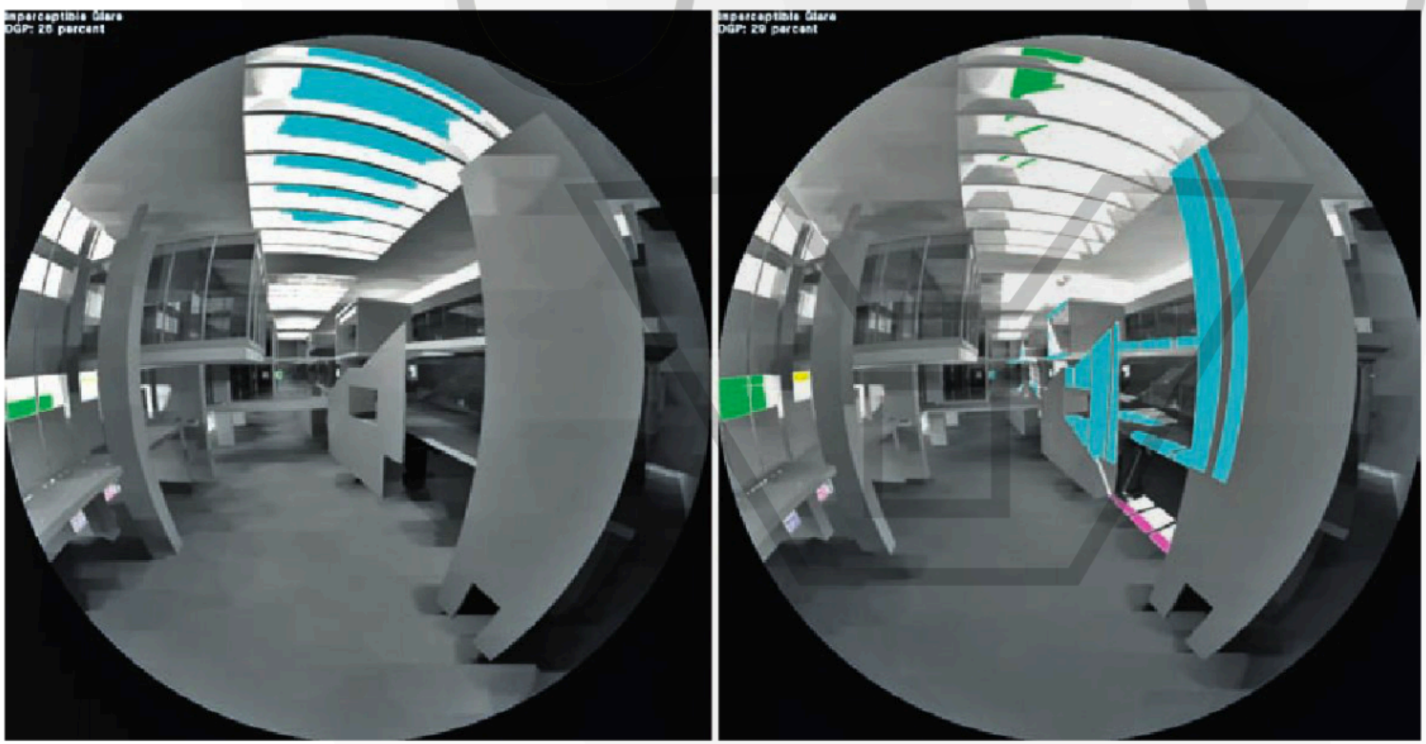
Plan-view studies showing illuminance levels for three window options on a north façade under overcast skies. The room's contrast ratios across width and depth are also shown, with lower contrast being preferable, but difficult to achieve, with side-lighting. Lighting designers typically include a room's contrast ratio in their studies to ensure even lighting throughout a space.

Source: Courtesy SERA Architects.

windows on north facade

DAYLIGHT ASSESSMENT: DAYLIGHT GLARE

Computational simulation using DIVA software



8.12

Daylight glare probability studies of atrium skylight options using DIVA software shows .26 and .29, both considered imperceptible glare. Each area within a field of view that contributes to glare is assigned a random color to show its location.

Source: Courtesy of SERA Architects.

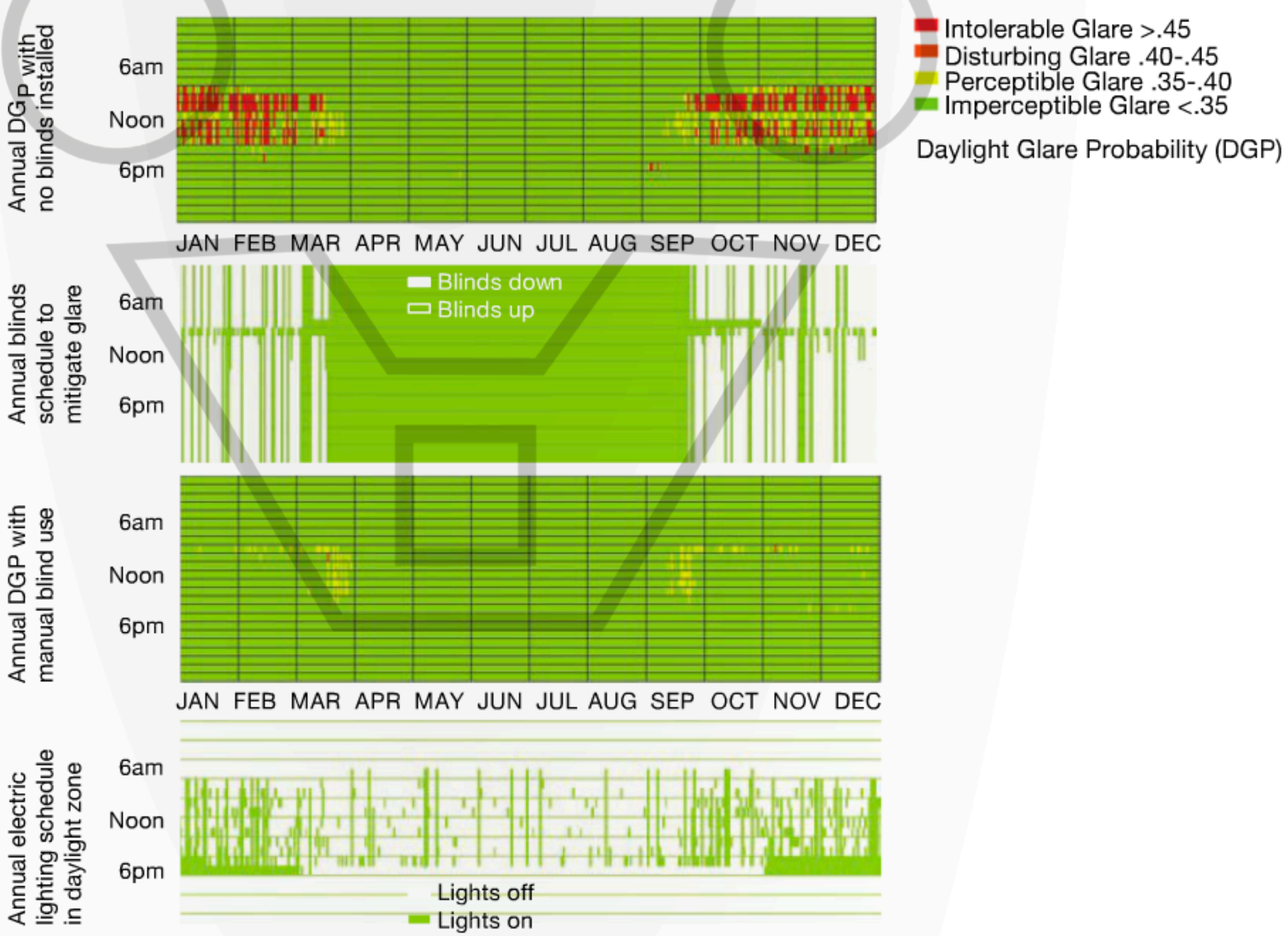
DAYLIGHT ASSESSMENT: DAYLIGHT GLARE

DGP - DAYLIGHT GLARE PROBABILITY

8.13

An east-facing viewpoint within a south-facing office space experiences glare primarily during times with low-angle sun in the Fall and Winter. Diva for Rhino software creates a blinds schedule to minimize glare, based on research of building occupants' tendency to lower them based on glare but raise them infrequently, per the Lightswitch model (Reinhart, 2002). The blind schedule helps create a lighting usage schedule that can estimate lighting energy use savings to compare design options.

Source: Courtesy of Jeff Niemasz.

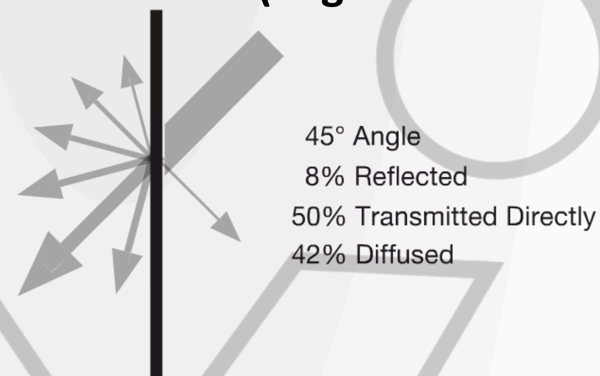


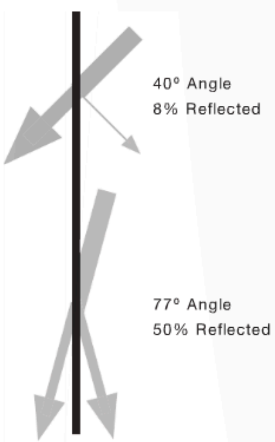
DAYLIGHT DIFFUSION USING GLAZE INCLINATION

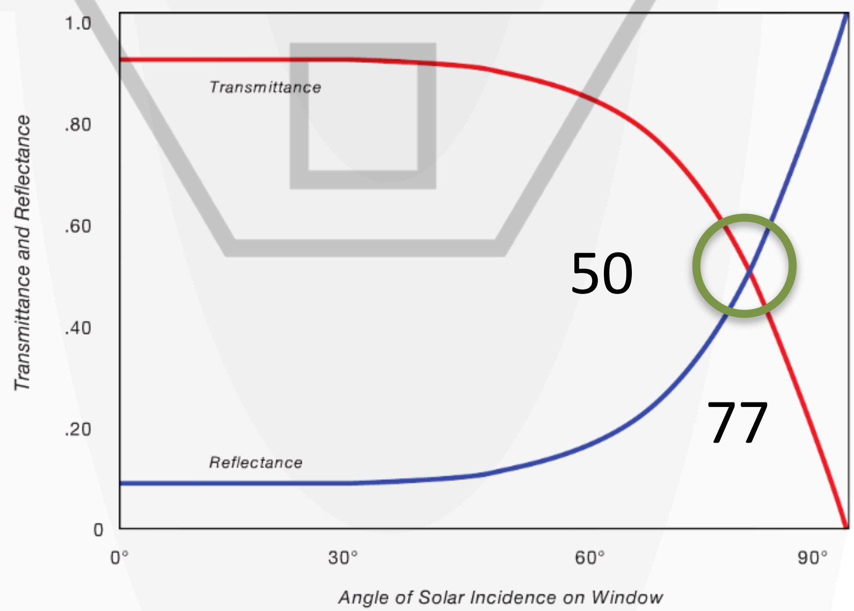
Reflectance & Transmittance f(angle of incidence)

6.6

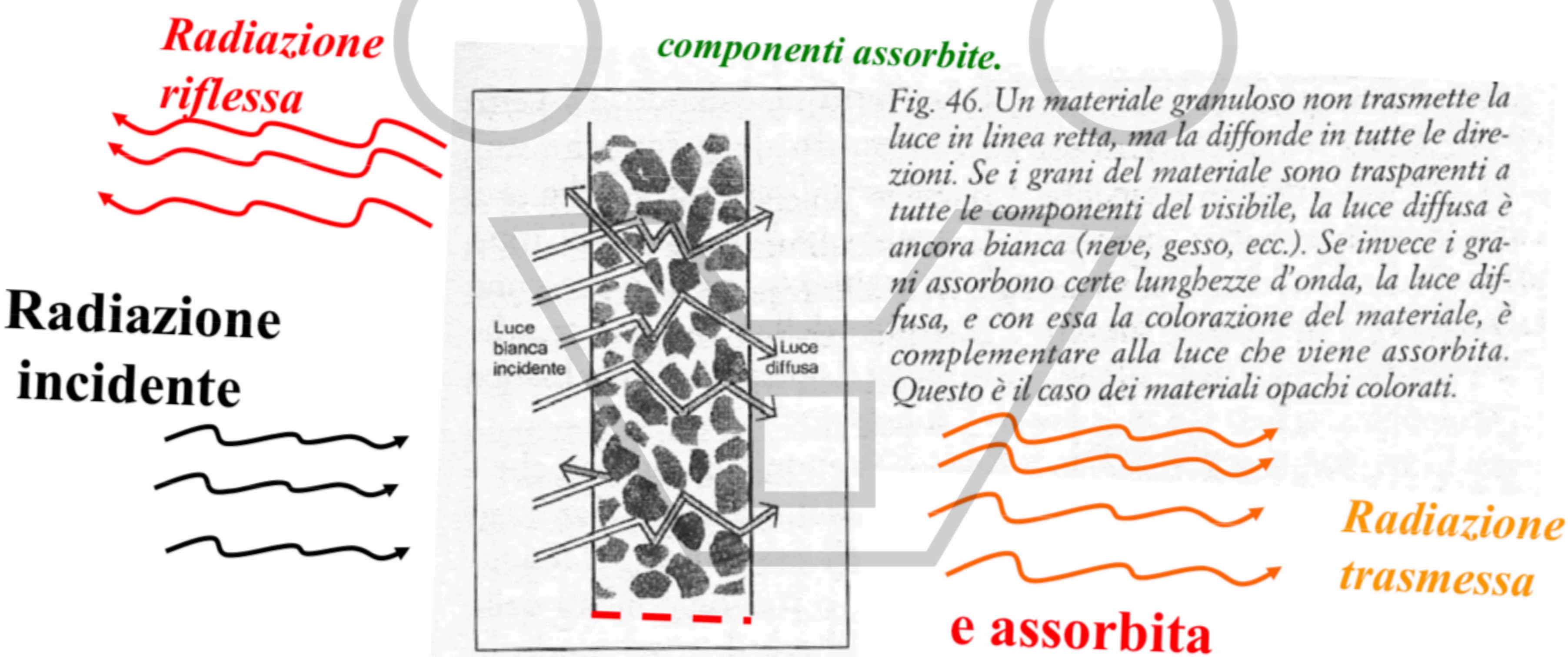
Translucent materials transmit some light and heat directly, and diffuse the rest of the transmitted light. In most cases, the diffused light is more concentrated around the directly transmitted light.







DAYLIGHT DIFFUSION USING DIFFUSIVE GLAZE



(granular material)

DAYLIGHT DIFFUSION. SURFACE PROPERTIES

Table 2: Model Surface Properties for a standard classroom

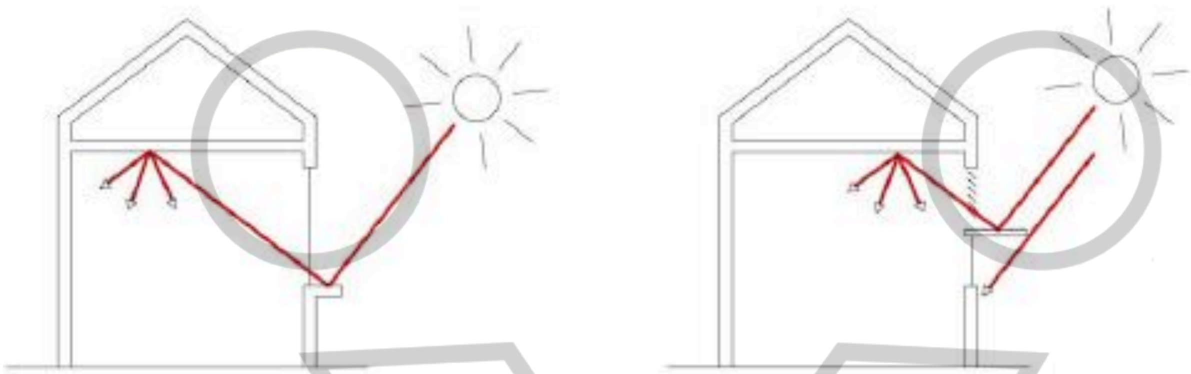
Model Element	Characteristic
Floor Reflectance	20%
Wall Reflectance	60%
Ceiling Reflectance	75%
Ground Reflectance	25%
Mullion Reflectance	50%
Lightshelf Reflectance	50%
Overhang Reflectance	50%
View Window Transmittance	36%
Daylight Window Transmittance	50%

Source: Architectural Energy Corporation

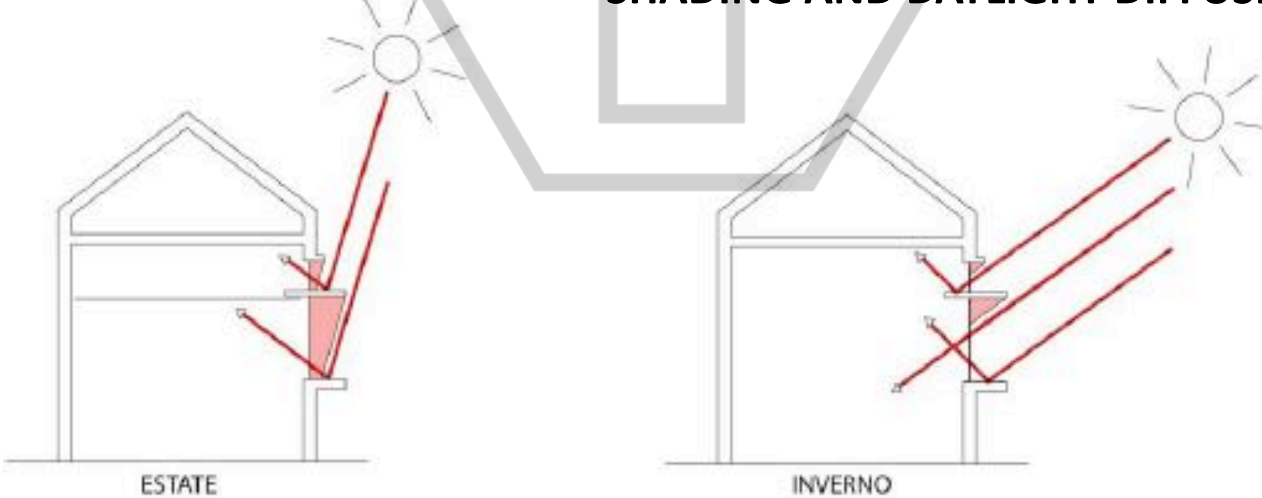
https://energydesignresources.com/media/1702/edr_designbriefs_daylightmetrics.pdf?tracked=true

DAYLIGHT DIFFUSION USING BRISE SOLEIL

Systems for daylight diffusion



SHADING AND DAYLIGHT DIFFUSION

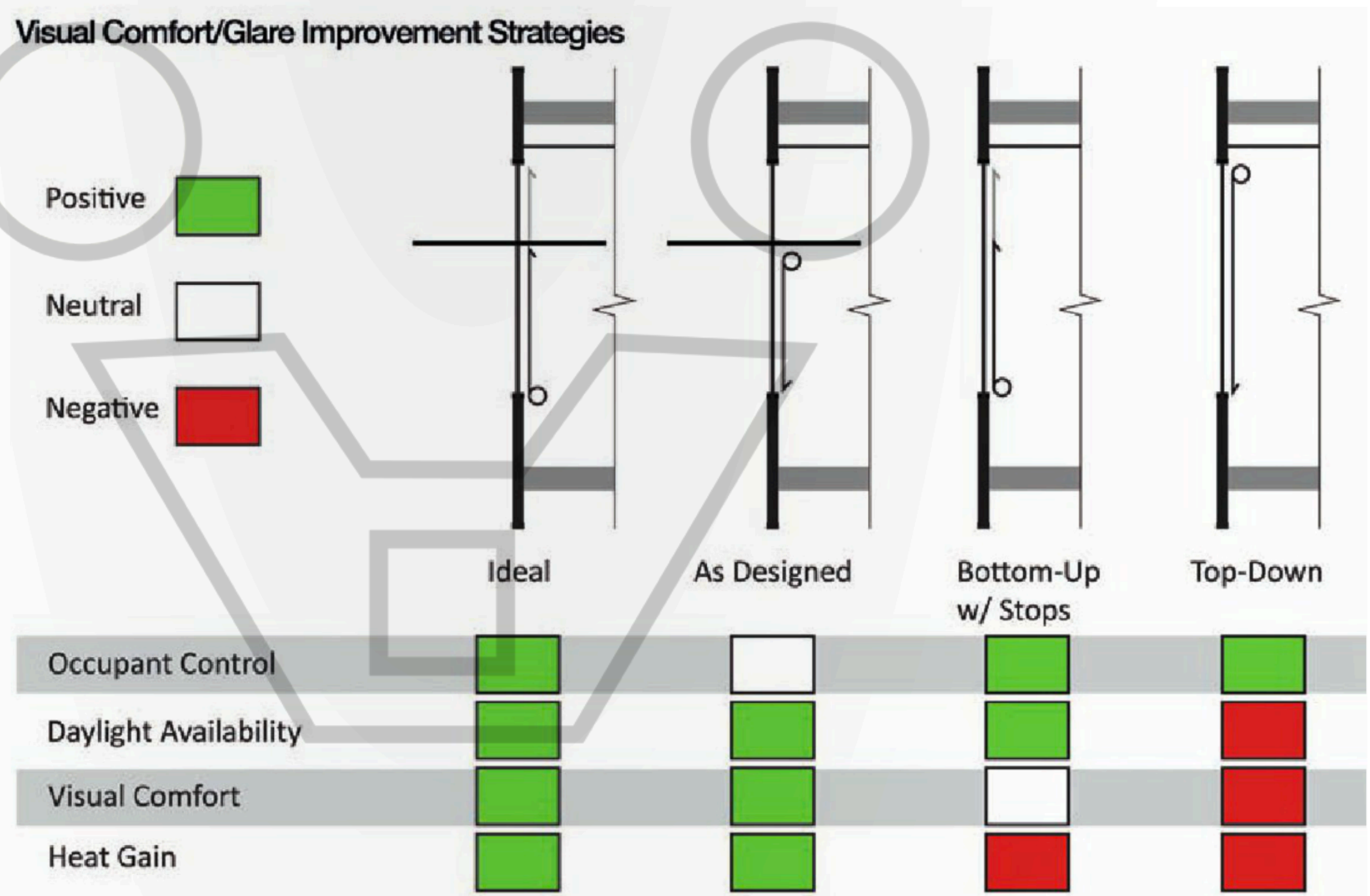


VISUAL COMFORT. GLARE IMPROVEMENT STRATEGIES

3.6

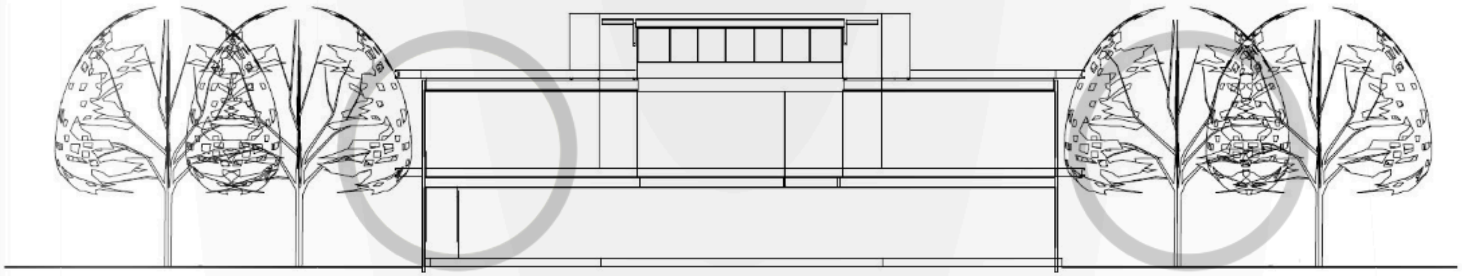
A study prepared for Iowa State University by ZGF Architects LLP rates four window options for user controllability, daylight availability, visual comfort, and heat gain. While simulations predict lighting energy savings due to the use of daylight, these savings are only realized when the system successfully blocks glare or allows users to block glare without blocking daylight.

Source: Courtesy of ZGF Architects LLP.



VISUAL COMFORT. MODELING CONTEXTUAL SHADER

HOW TO MODEL TREES



8.53

Sectional line drawing looking south, showing trees at two potential distances from the façade.

Courtesy of Skidmore, Ownings & Merrill, Chicago.

8.54

Creation of digital tree geometry.

Courtesy of Skidmore, Ownings & Merrill, Chicago.

Simulation

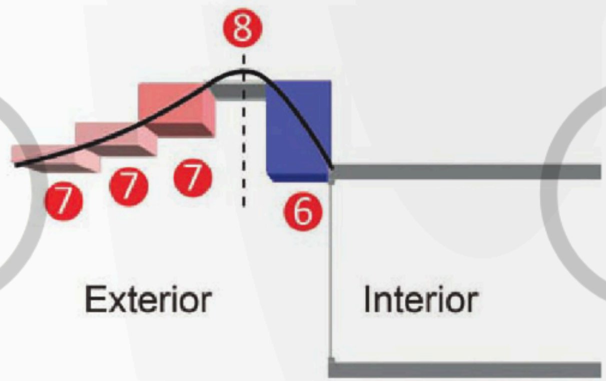
This simulation was performed by SOM's Design Performance Group, which specializes in early design simulations. The Revit-based model was imported and re-built in Rhino for this tree canopy study in the design development phase.

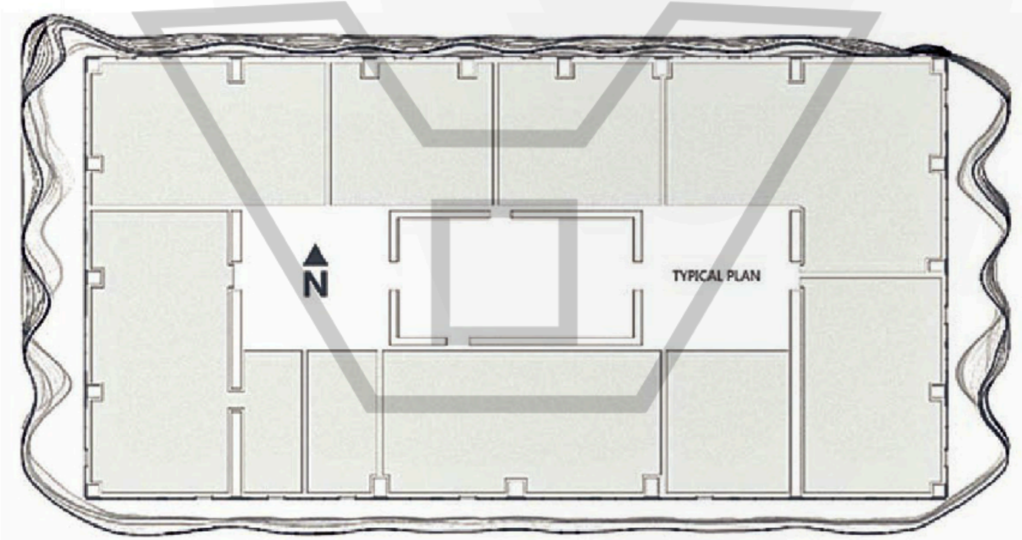
Research was conducted into modeling and defining the optics and seasonal behavior of a Thornless Honeylocust to create a simulated tree. A vector outline (1) of the species was projected onto two sides of a 3D volume. The canopy openness was approximated in the Rhino model (2) to allow direct, dappled light from various directions and a variation of light passing through and reflecting off leaves. This approach reduced meshed surfaces and simulation time.

Research and guidance from Christopher Meek at the University of Washington Integrated Design Lab (IDL) into the optical properties (3) of the leaves were used to create a Radiance material (4) for the leaves using Optics 6 Software. The tree leaves were scheduled to be present in the model between May 15th and October 15th to simulate deciduous vegetation.

GLARE & DAYLIGHT ANALYSIS

LIGHTING vs GLARING: Shaping windows and shading



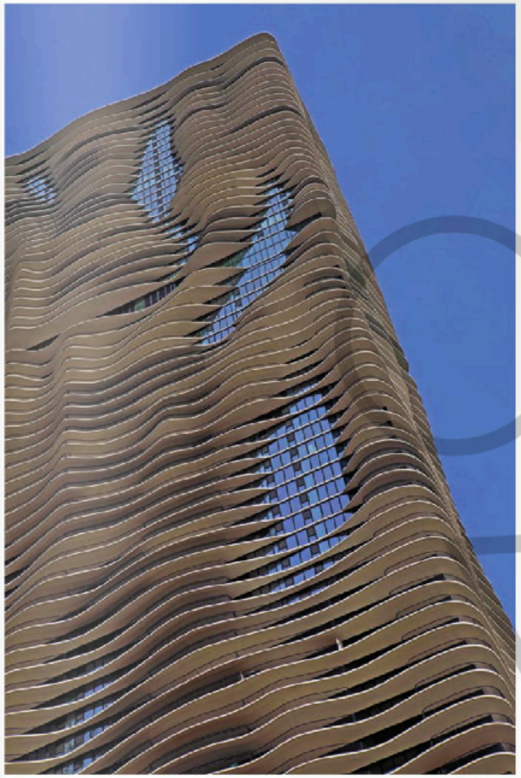


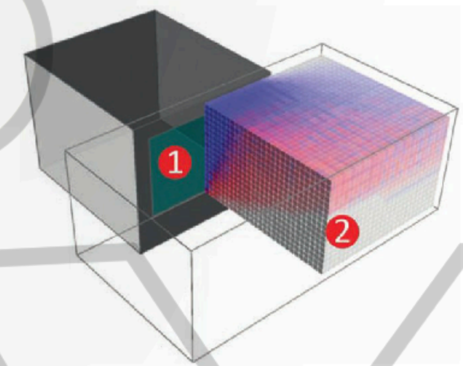
The Shaderade approach, which advanced earlier work by Eran Kaftan and Dr. Andrew Marsh, involves mapping the annual energy consequences of each position where a shade could affect energy transmission through a window (1) in two or three dimensions (2).

The method begins by running a single simulation of a building shaded only by context, which yields hourly information about thermal loads and heat gains transmitted through the windows from

GLARE & DAYLIGHT ANALYSIS

Parametric shading morphogensys





7.30

The Aqua Tower. The parametric aesthetic of the Aqua Tower was investigated using the Shaderade method of shading design.

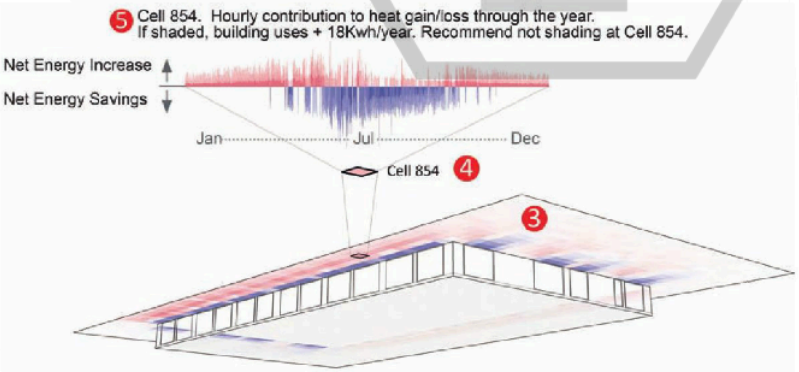
Source: Photo by Jeff Niemasz.

7.31

Shaderade Boston cube. Each colored cell shows net higher (red) or lower (blue) energy use if a shading device occupied its area.

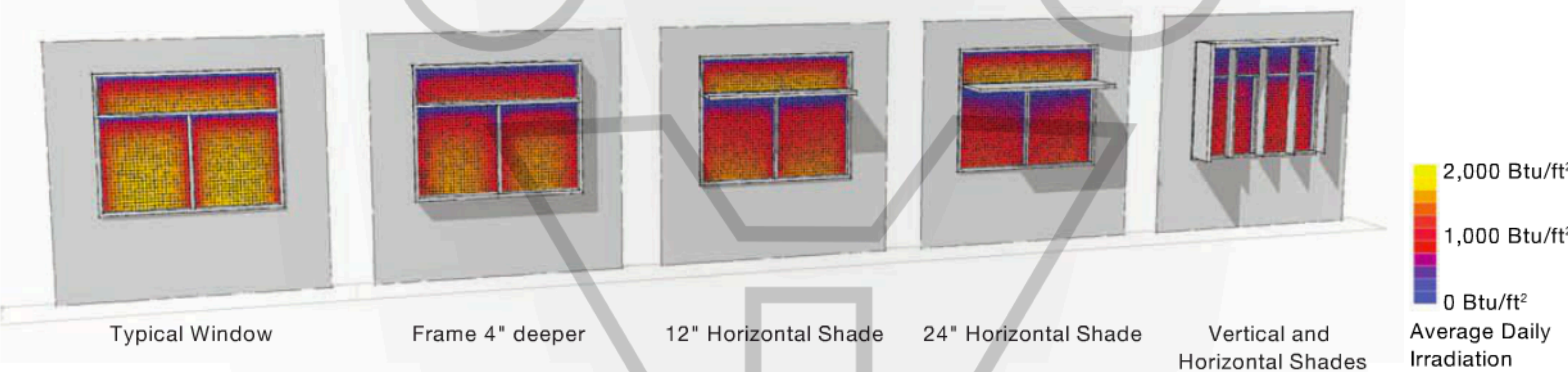
7.32

Section through a typical window, showing ideal shading device depth at the inflection point of higher and lower energy use.



SIMULATION OF SHADING EFFECT for DAYLIGHT ASSESSMENT

daily Irradiation on windows



DAYLIGHT ASSESSMENT USING ANALOGIC TECHNIQUES

The Eliodon

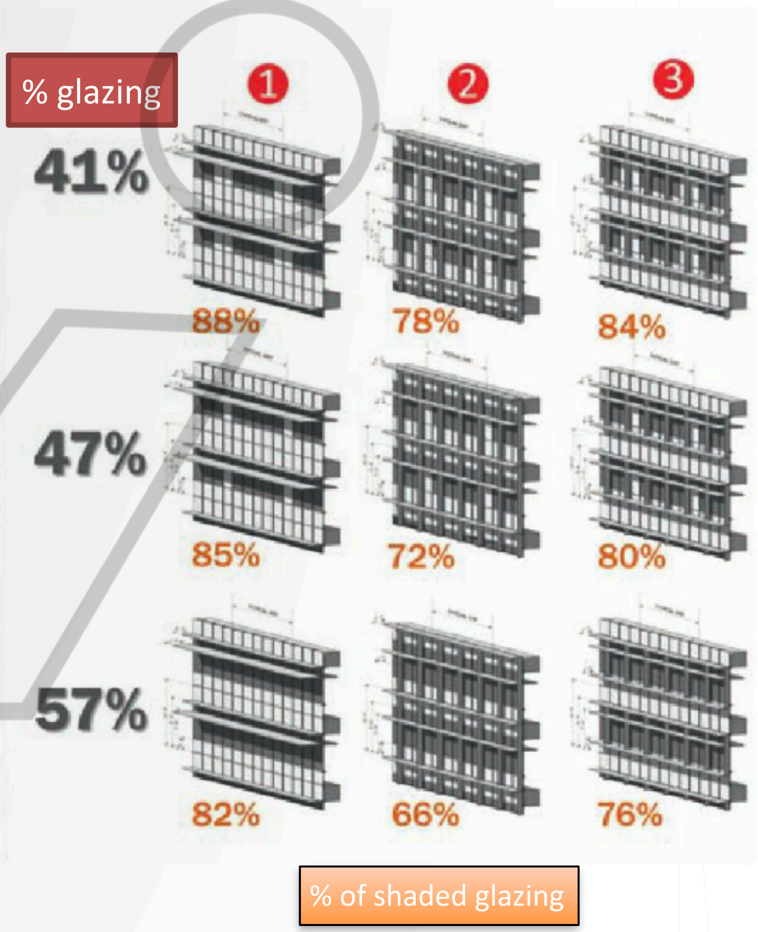
Physical scale model to evaluate daylight and glare

DAYLIGHT ASSESSMENT USING ANALOGIC TECHNIQUES

Physical scale model to evaluate daylight and glare

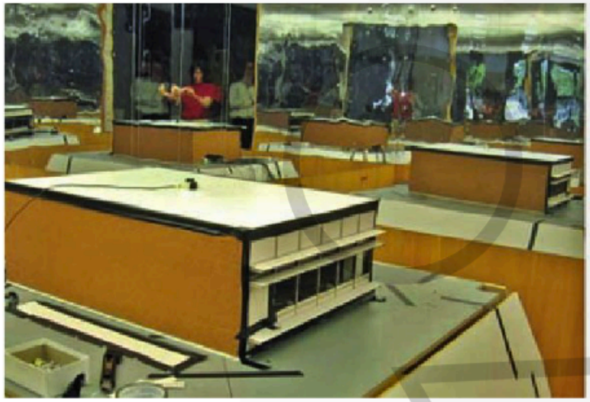
7.17

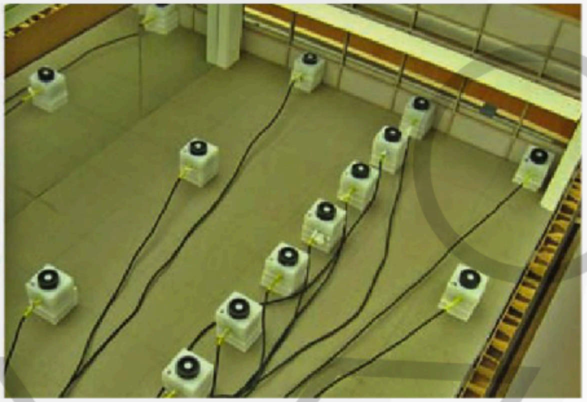
Façade shading studies testing options with (1) horizontal shade only, (2) vertical and horizontal fins with the horizontal element as a light shelf, and (3) vertical and horizontal fins with the horizontal as sill reflector. Each option was tested with 3 glazing percentage options (4). The orange number shows the percentage of the glazing that is shaded in each option.



DAYLIGHT ASSESSMENT USING ANALOGIC TECHNIQUES

Physical scale model in Heliodon to evaluate daylight and glare in overcast sky





8.14

A physical daylighting model showing use of light meters to calculate the daylight factor. An overcast sky is simulated by the light box, which has highly reflective ceiling and walls to create uniform light levels.

Source: Courtesy of SERA Architects.

And a physical daylighting model showing use of a heliodon at the Energy Studies in Buildings Laboratory in Portland, Oregon, to predict daylighting levels under sunny sky conditions. The large wheels rotate the model through specific solar angles in relation to a bright electric light.

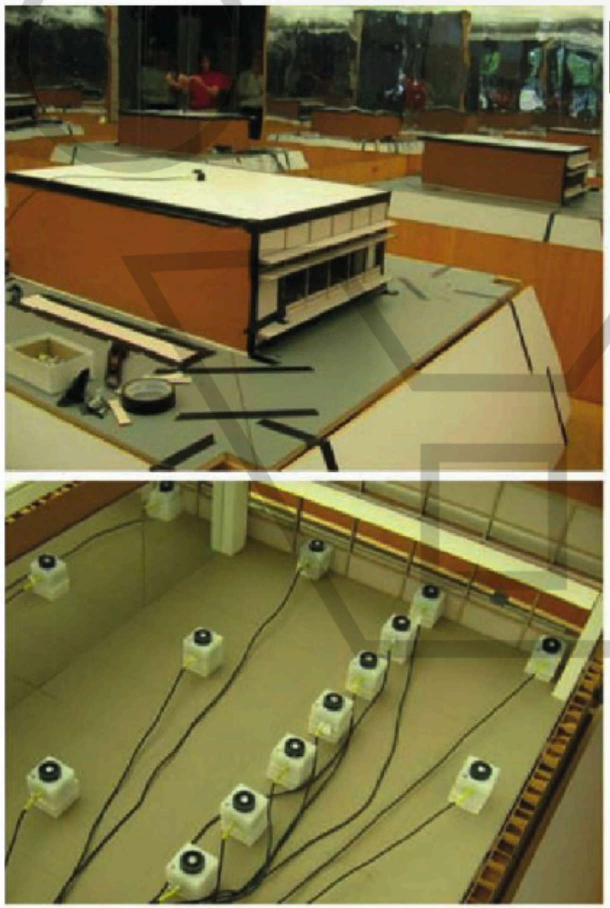
Source: Courtesy of SERA Architects.

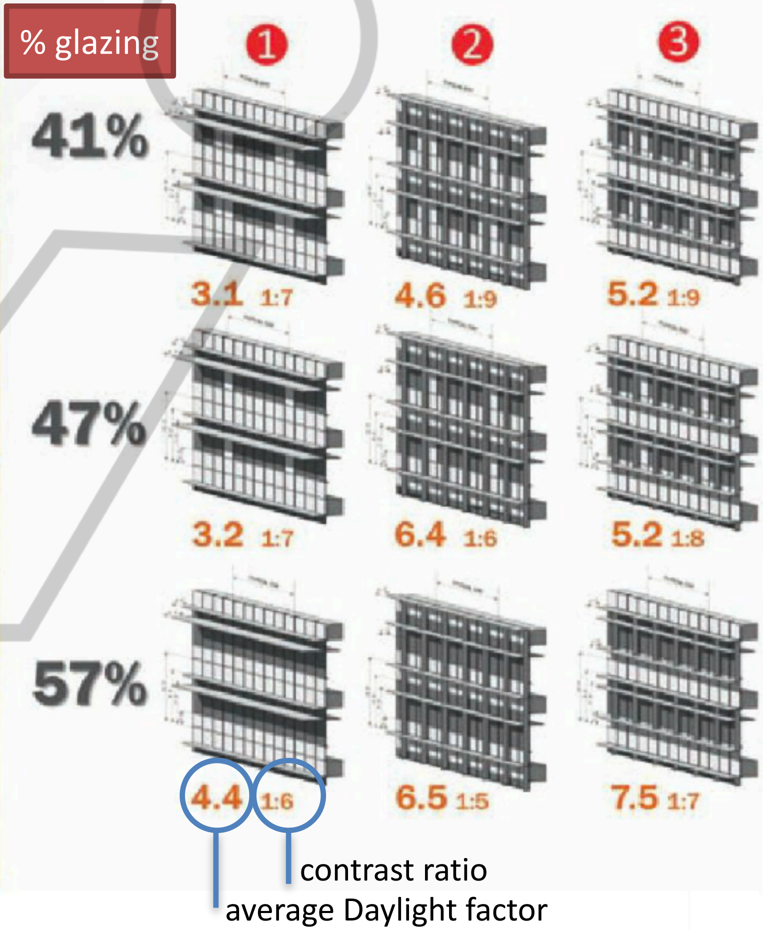
DAYLIGHT ASSESSMENT USING ANALOGIC TECHNIQUES

Physical scale model to evaluate daylight and glare

7.18

Daylighting studies testing the same 9 shading options as 7.17. The large orange number shows the average daylight factor in the 16′ perimeter zone, and the small number shows the contrast ratio across this area.





RESOURCES

READINGS

> Kjell Anderson, **Design Energy and Simulation for Architects (textbook)**
https://www.mailab.biz/wp-content/uploads/TEXTBOOKS/Design_energy_simulation_for_architect_guide.pdf

- Chapter #06. Glazing Properties
- Chapter #07. Solar irradiation and Thermal Storage
- Chapter #08. Daylight and Glare

> Advanced Buildings-Energy Performance Solutions from NBI, **Daylighting Pattern Guide**
https://patternguide.advancedbuildings.net

> Energy Design Resources, **Design brief. Understanding Daylight metrics.**
https://energydesignresources.com/media/1702/edr_designbriefs_daylightmetrics.pdf?tracked=true

>Velux, **Daylight, Energy and Indoor Climate Basic Book**
http://www.velux.com/~/media/com/articles/pdf/deic_basic_book_ver%203-0.pdf

- Chapter 01 Daylight

COMPUTATIONAL TOOLS

> Andrew Marsh, **Daylight room** (online tool)
http://andrewmarsh.com/apps/staging/daylight-room.html

> Mailab, **Daylight Factor Analysis on Grasshopper**
https://www.mailab.biz/daylightpatch/

VIDEO TUTORIALS

> Autodesk, **Daylight analysis using Revit-Insight**
https://www.youtube.com/watch?v=y0PKoF2As44
https://www.youtube.com/watch?v=vbUeY-BHjW0

> Alejandro Pacheco, Maha Shalaby, **Parametric Daylight Facade Optimization Methodology**
https://www.youtube.com/watch?v=hsg_zDMXB68