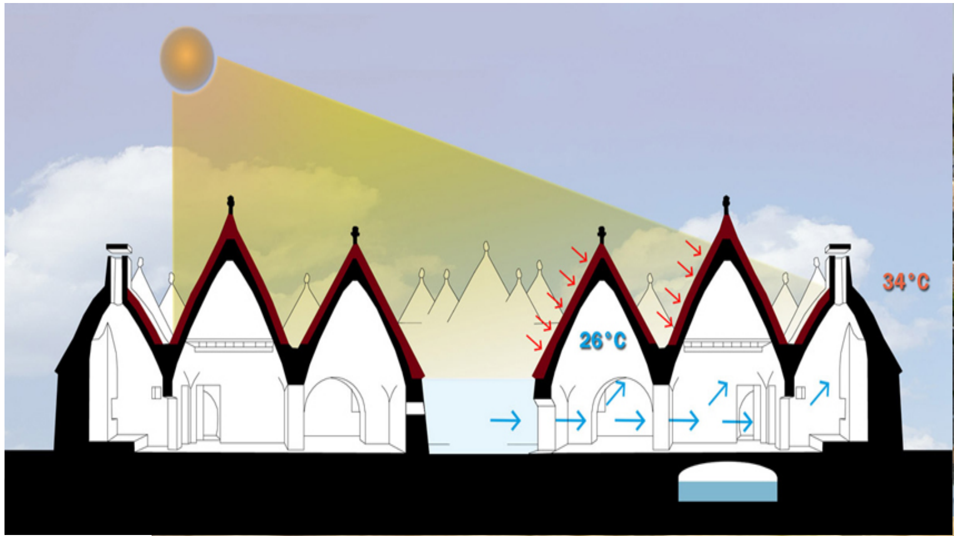
UNIVERSITÀ
DEGLI STUDI
FIRENZE
Scuola di
Architettura

MODELING CLIMATE, SUN GEOMETRY, WIND AND GREEN METRICS

Prof. Arch. Giuseppe Ridolfi, PhD

CLIMATE
a physical, socio-cultural, and technological determinant





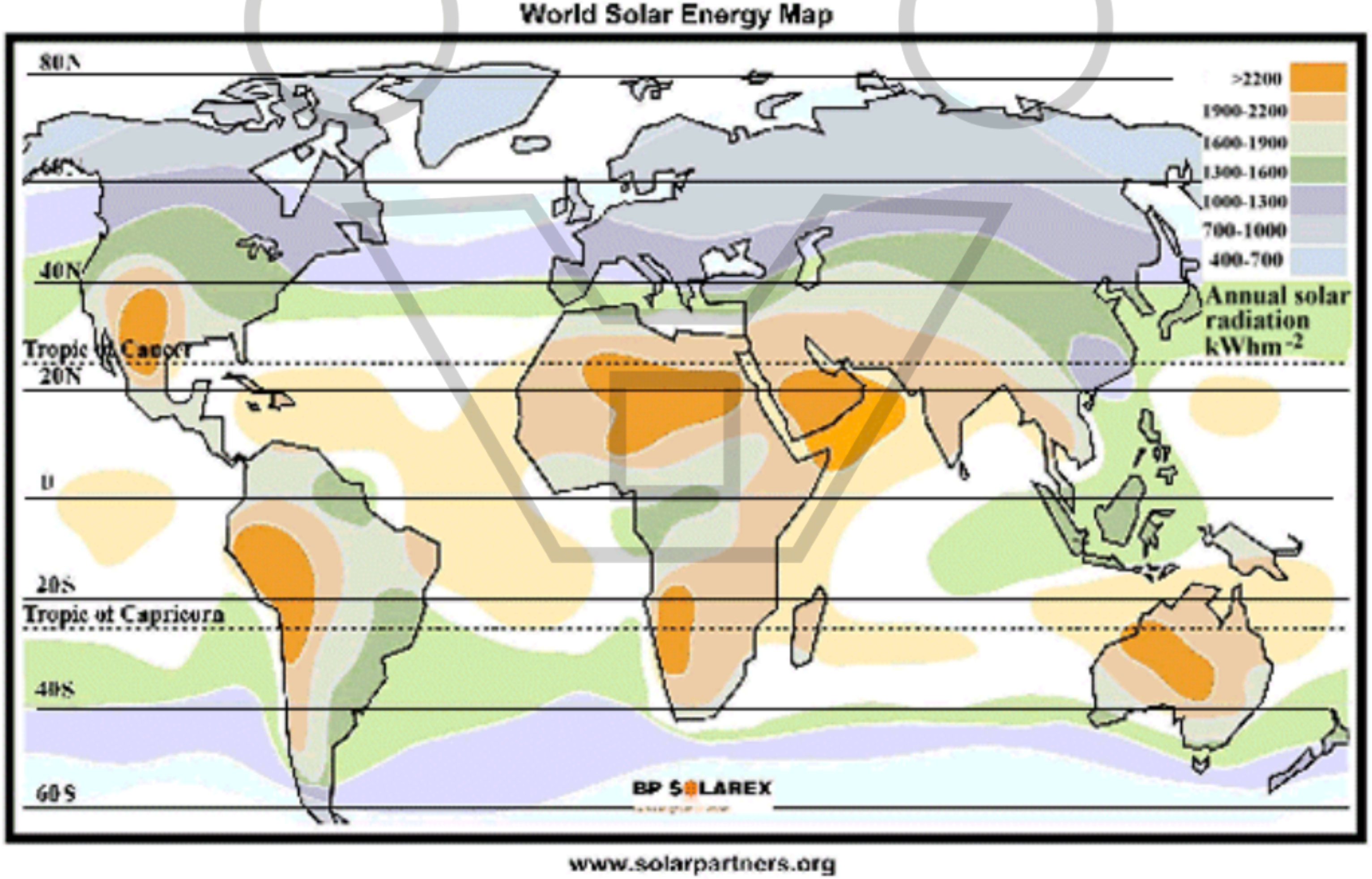
The influence of the site: GEOGRAPHICAL POSITION

Insolation is the sun's energy on a surface

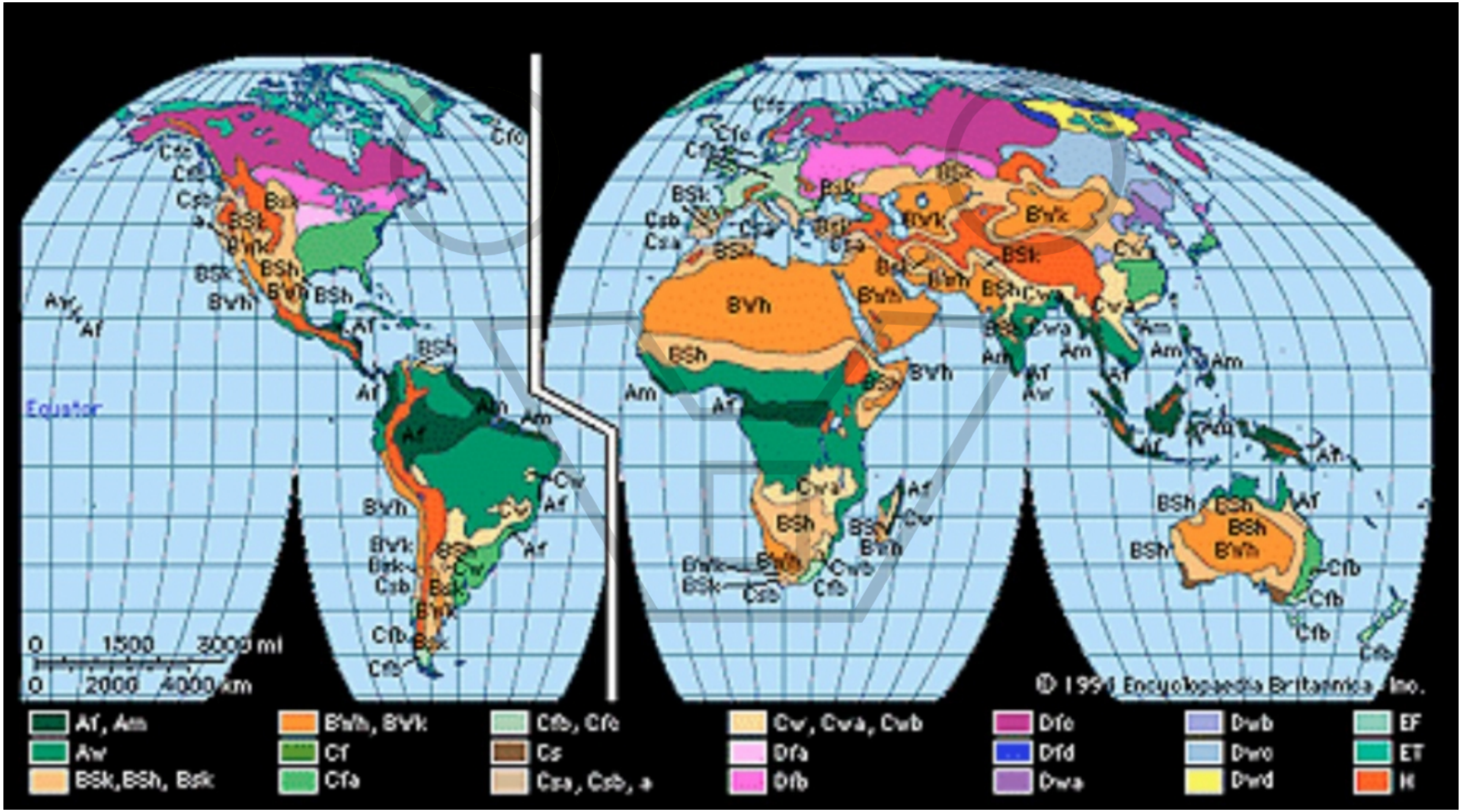
Sun's energy depends on angle, sky conditions, volume and surfaces around.

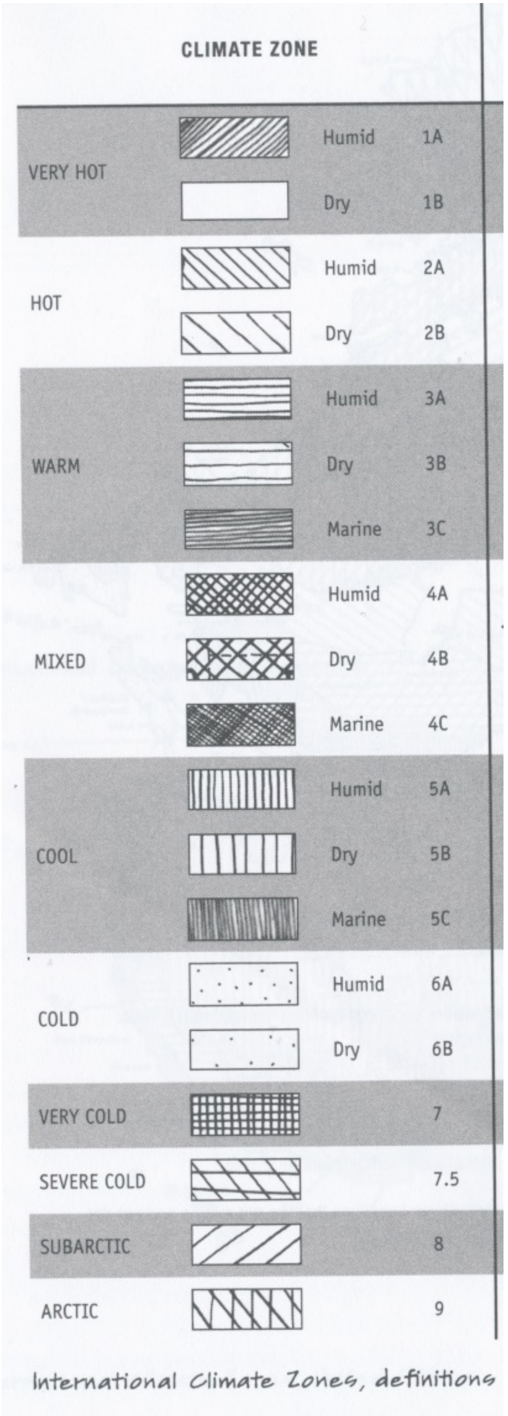
Weather files give the total amount of *direct energy* along a year measured perpendicularly to the sun direction

And *diffuse energy* measured getting all the energy and subtracting the direct energy capted,

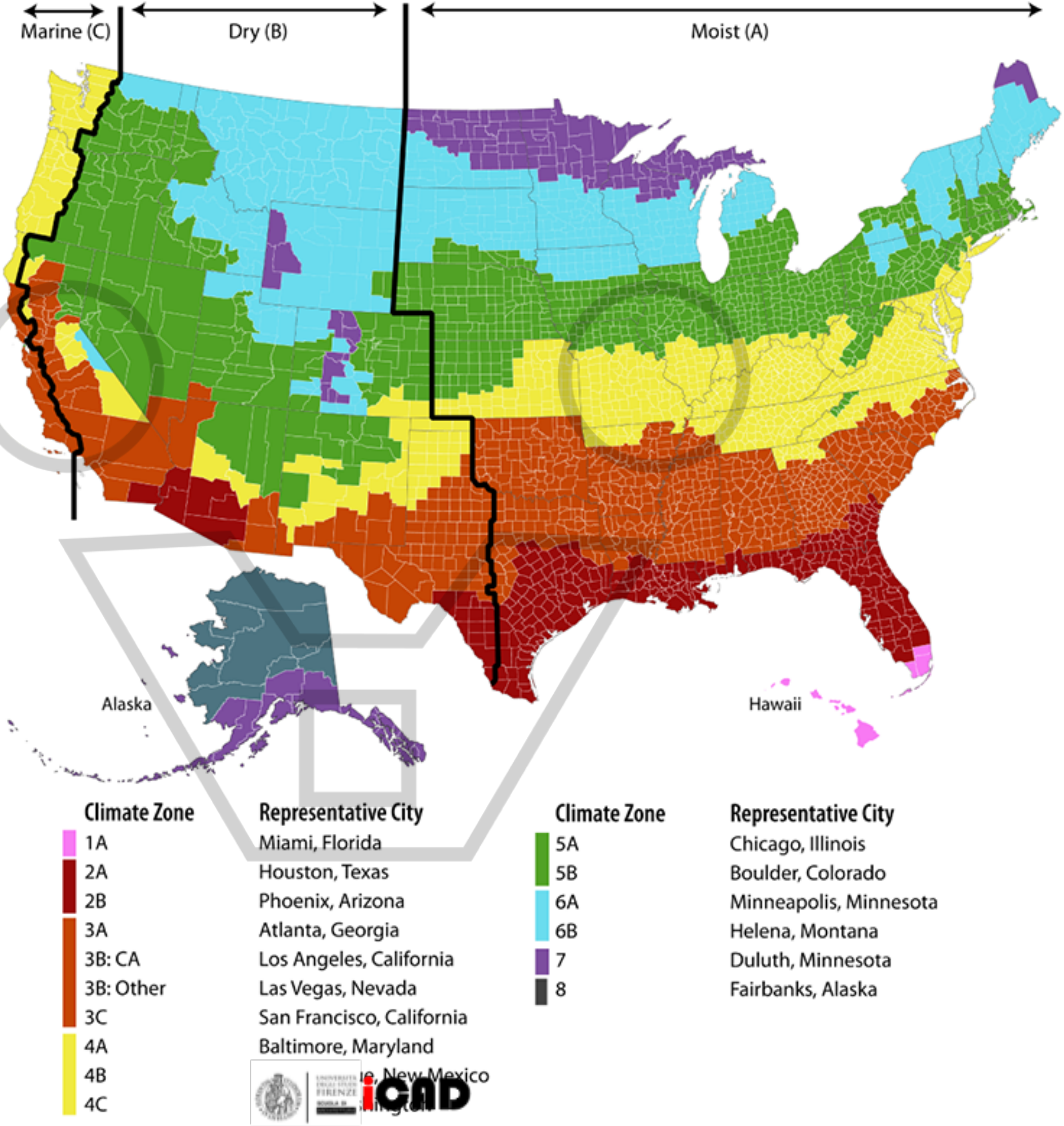


1- Find your climate zone



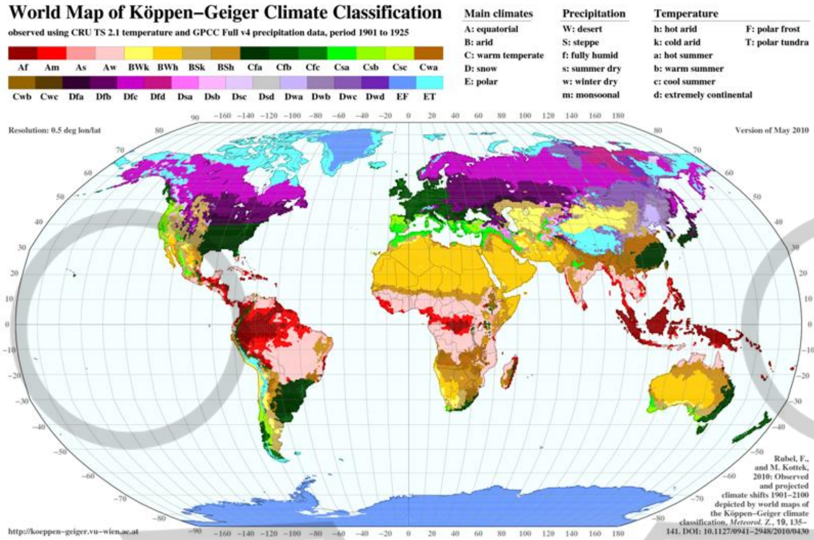


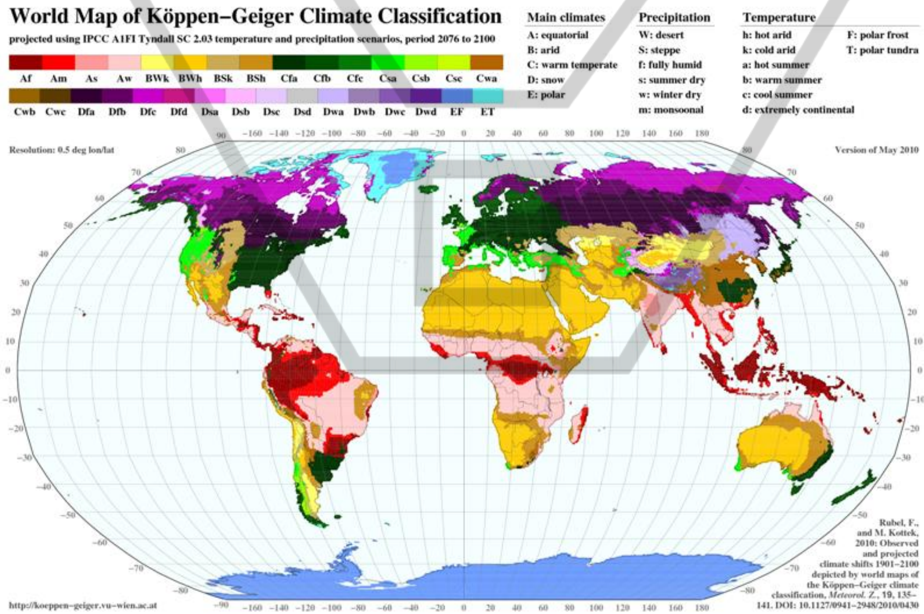
CLIMATE ZONE
VERY HOT
Humid 1A
Dry 1B
HOT
Humid 2A
Dry 2B
WARM
Humid 3A
Dry 3B
Marine 3C
MIXED
Humid 4A
Dry 4B
Marine 4C
COOL
Humid 5A
Dry 5B
Marine 5C
COLD
Humid 6A
Dry 6B
VERY COLD 7
SEVERE COLD 7.5
SUBARCTIC 8
ARCTIC 9
International Climate Zones, definitions



Marine (C)
Dry (B)
Moist (A)
Alaska
Hawaii
Climate Zone
Representative City
1A Miami, Florida
2A Houston, Texas
2B Phoenix, Arizona
3A Atlanta, Georgia
3B: CA Los Angeles, California
3B: Other Las Vegas, Nevada
3C San Francisco, California
4A Baltimore, Maryland
4B e, New Mexico
4C
Climate Zone
Representative City
5A Chicago, Illinois
5B Boulder, Colorado
6A Minneapolis, Minnesota
6B Helena, Montana
7 Duluth, Minnesota
8 Fairbanks, Alaska

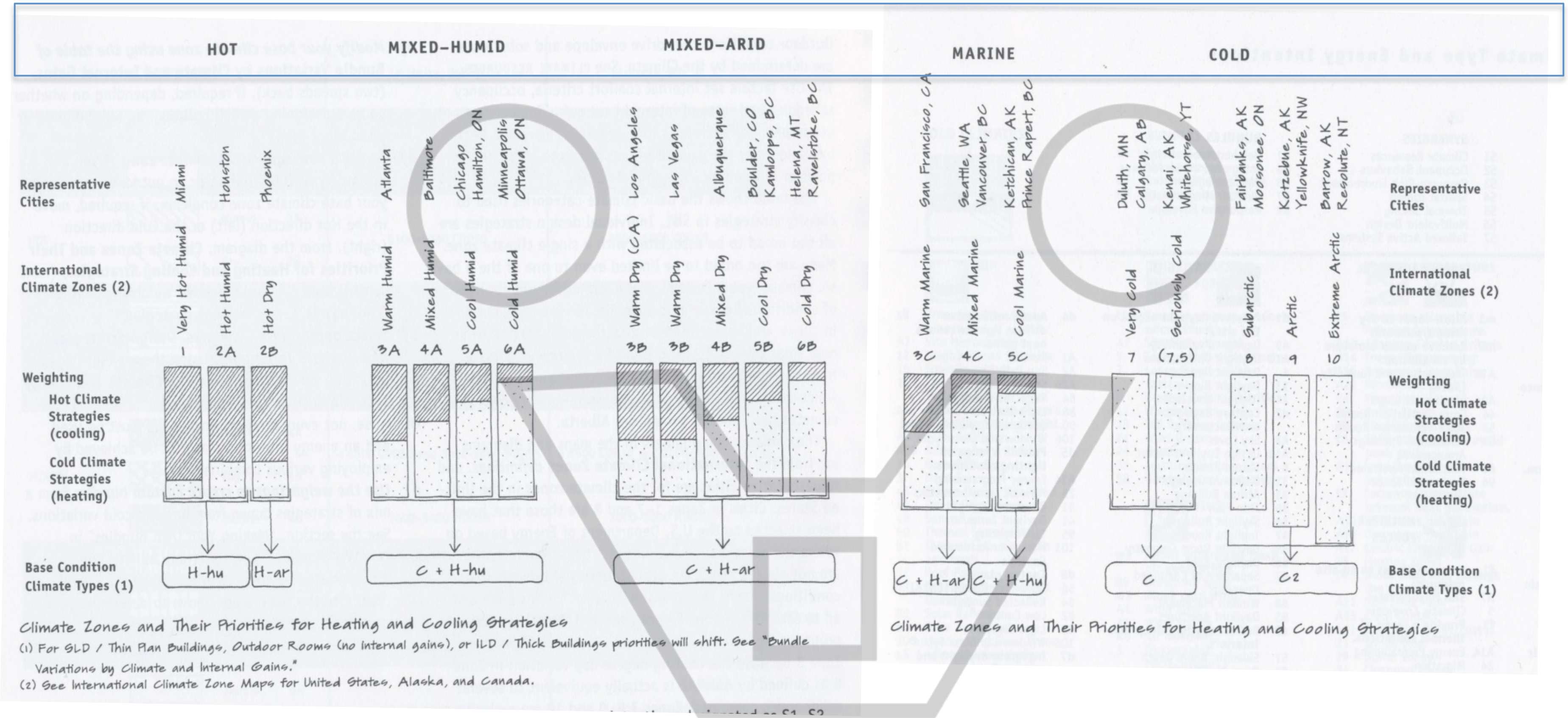
2- Tune-Up your climate zone considering the climate evolution and site





Prof. Giuseppe Ridolfi, PhD

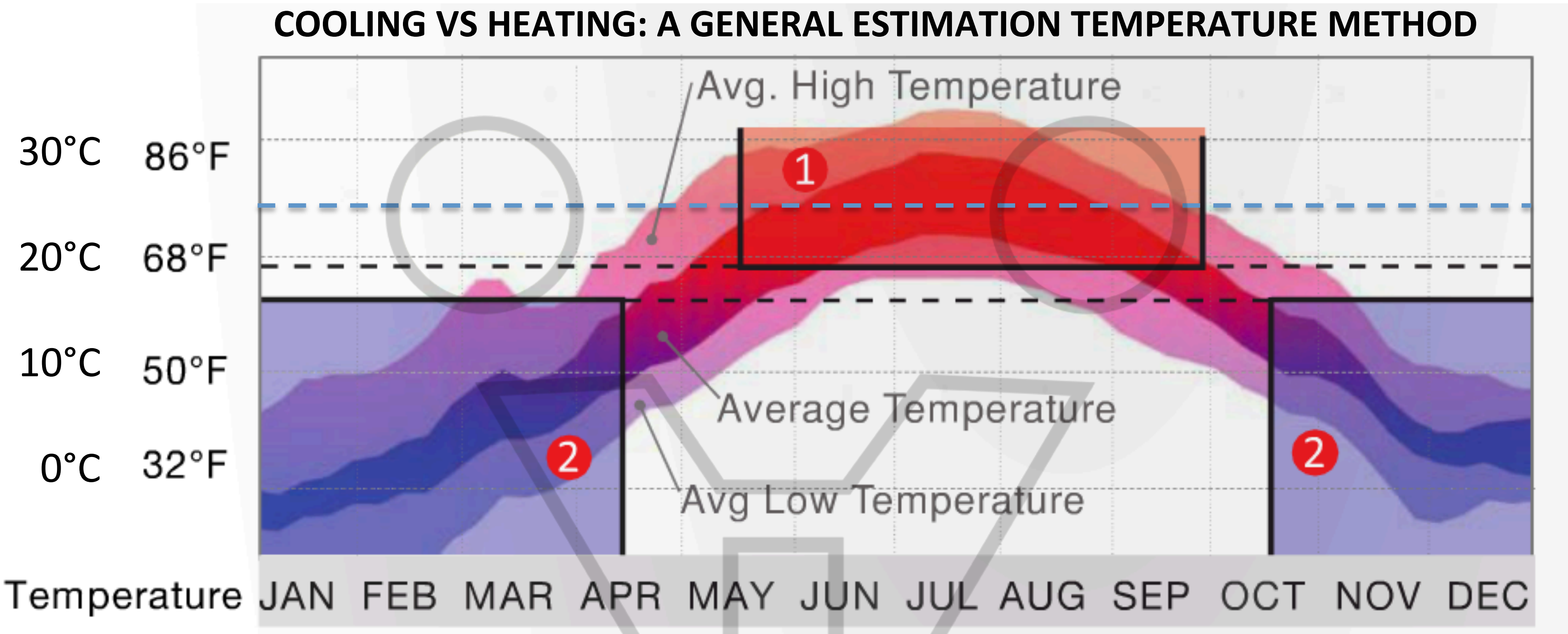
Climate zones and their priorities for heating/cooling



To be cooled

To be heated

4. Confirm the main energy behaviour with conceptual energy analysis



7.3 Temperature Method. Annual temperature profile, with estimated heating and cooling seasons highlighted.

Source: Ecotect outputs of annual weather data from Central Park in New York City.

Environmental parameters affecting thermal comfort:

- **SOLAR ENERGY**
- **VENTILATION**
- **HUMIDITY**

- radiant temperature
- air temperature

HOW TO MEASURE SOLAR ENERGY ?

RADIATION=W/m2

BTU vs KW

Ft2 > m2

1 Btu=0,293071 W/h

1 ft2=0,092903 m2

CLIMATE DATA We collect data near airports and other stations

Wheather data includes:

- Annual weather files (8760 hours of the year) used to compute Energy Use Intensity (EUI)
- TMY (Typical metereological year) that is encapsulated in the .epw files mantained by *Energy Efficiency and Renewable Energy (EERE)*
- Peak condition files used to dimension mechanical

Wheather data also includes:

- geographical coordinates

Environmental parameters affecting thermal comfort: SOLAR ENERGY

Site Inventory: Physical Attributes **121**

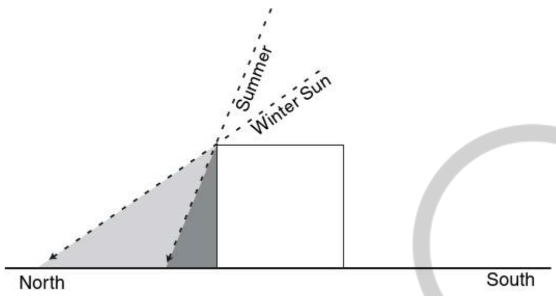
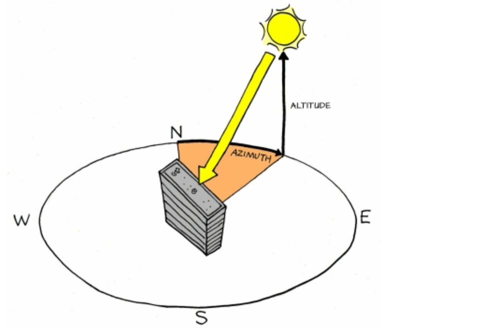
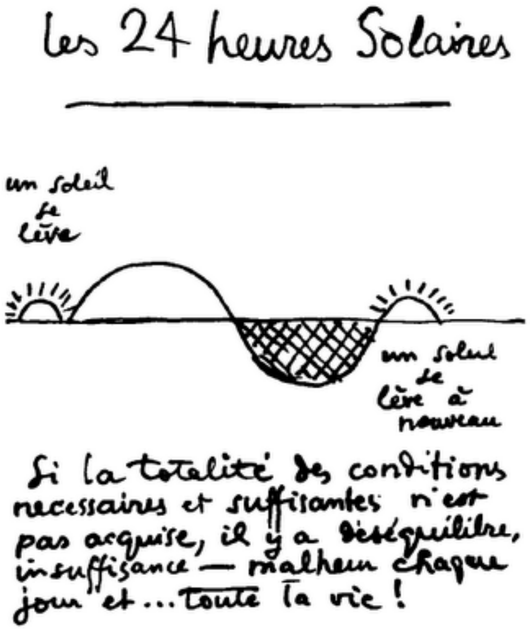


Figure 5-15 Schematic diagram of the seasonal variation in shade cast by a building in the northern hemisphere. Solar exposure in outdoor spaces near a building varies not only with weather conditions but also with time of day, day of year, and location of the space in relation to both the building and the sun.



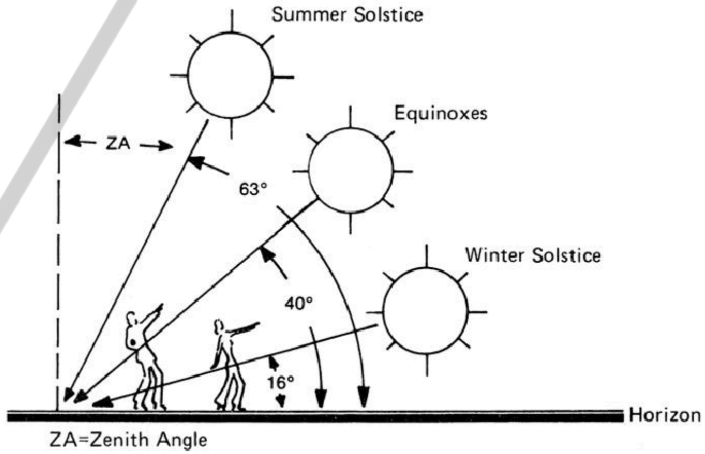
Altitude is the vertical angle the sun makes with the ground plane (0° < alt < 90°).

SOLAR ENERGY



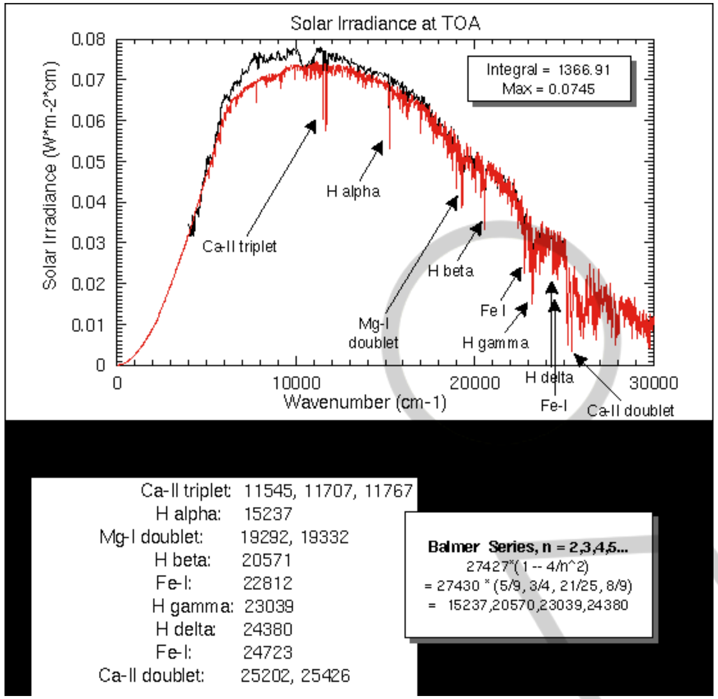
120 Site Analysis

Figure 5-14 Diagram of seasonal changes in the maximum daily sun angle for a mid-latitude location in the Northern Hemisphere. Source: Marsh, *Landscape Planning*, Third Ed., copyright © 1998, p. 290, Figure 15.3. Reprinted by permission of John



Environmental parameters affecting thermal comfort: SOLAR ENERGY

Solar radiation* at the top of the atmosphere.

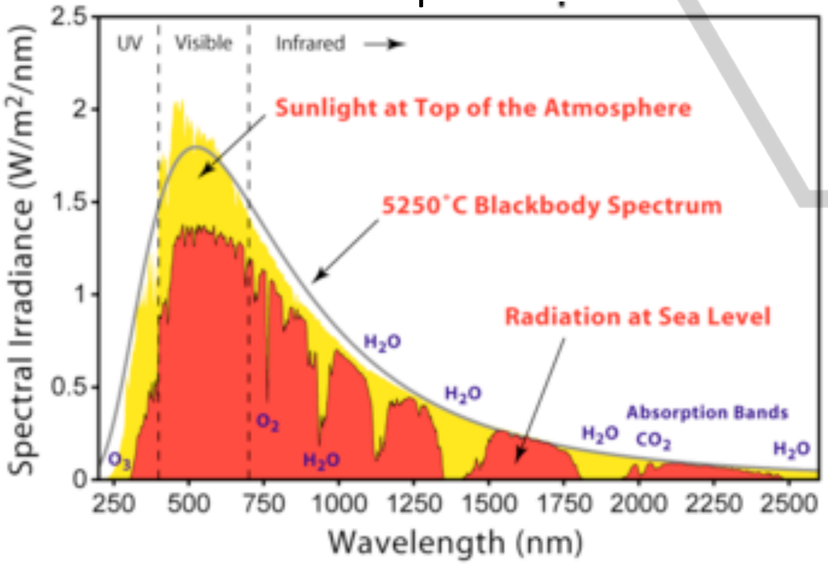


*) *Radiation* occurs when an object emits electro magnetic energy.
Irradiation is the energy absorbed by an object/surface

1366 W/m² (solar costant)

1 W = 3,416 Btu.

Solar radiation spectrum



Considering the earth surface,
the total solar energy is= 174 PW
Peta= million of billions

Ricordiamo che: 1 Kcal = 4.186 J = 1,16 x 10-3 kWh = 1×10-7 TEP

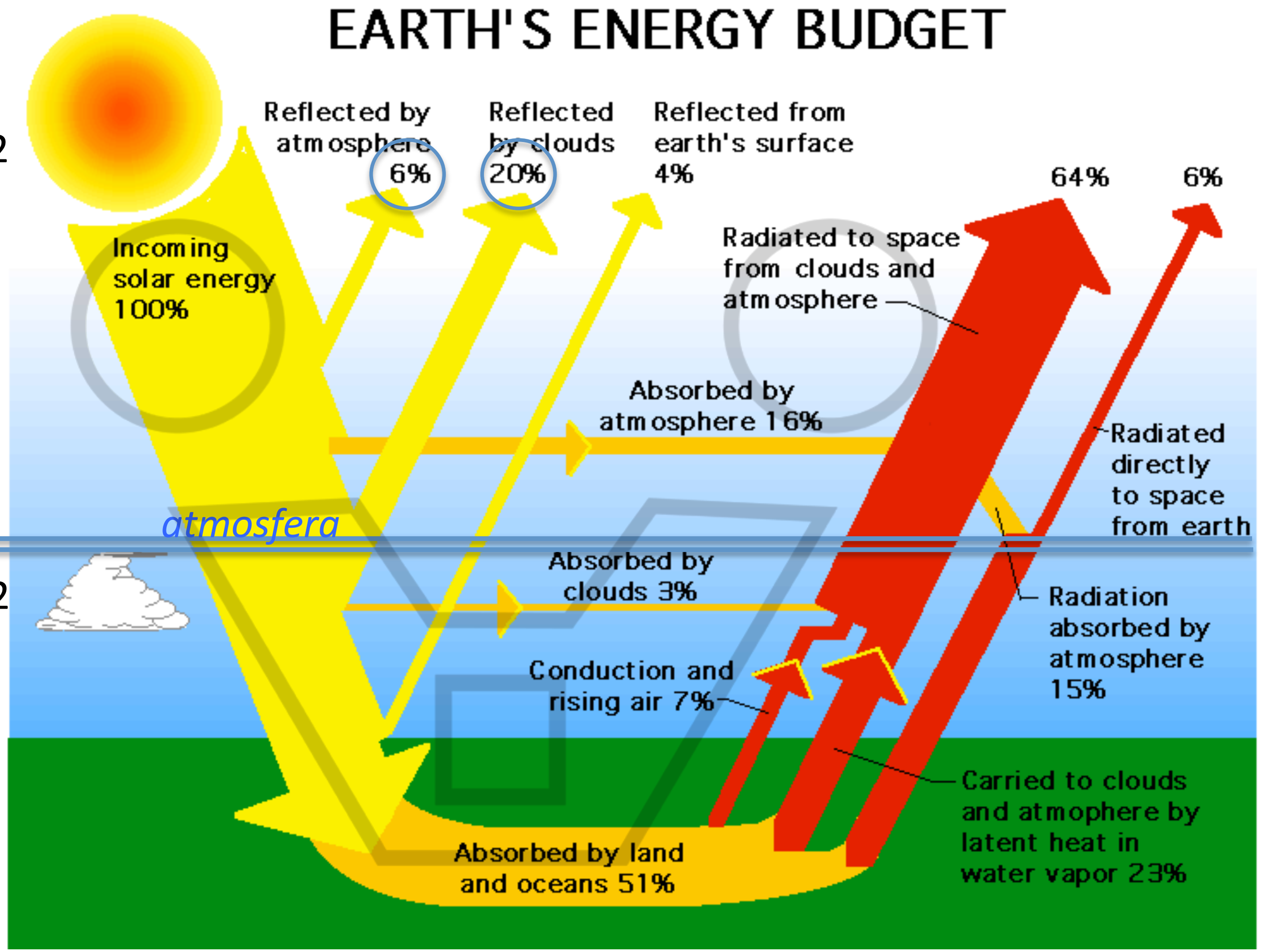
1joule=1 Nm=0.000278Wh=0,0009478 Btu

100%=1.366 W/m2
-costante solare-

26%= 356 W/m2

74% =1010 W/m2

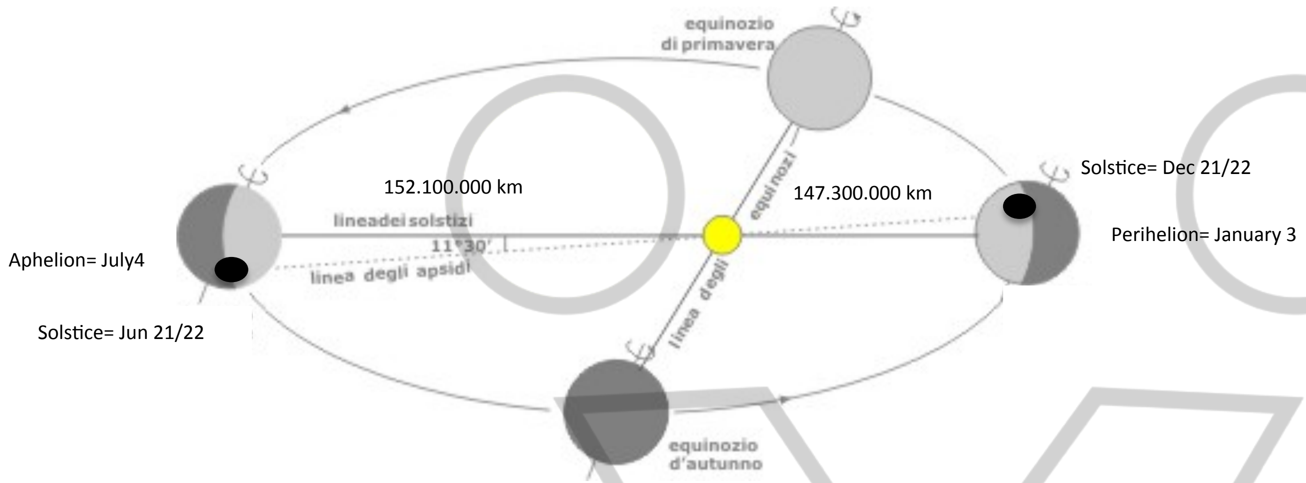
1.000 W/m2

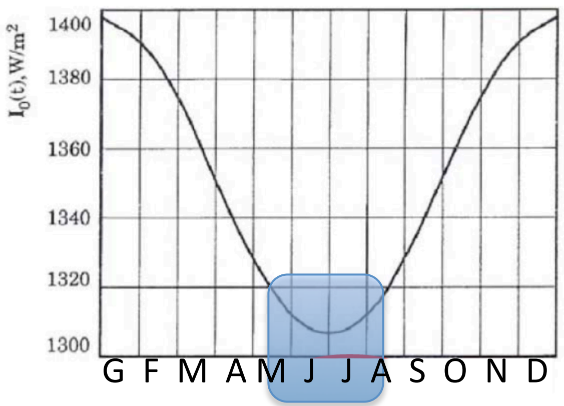


Radiazione assorbita

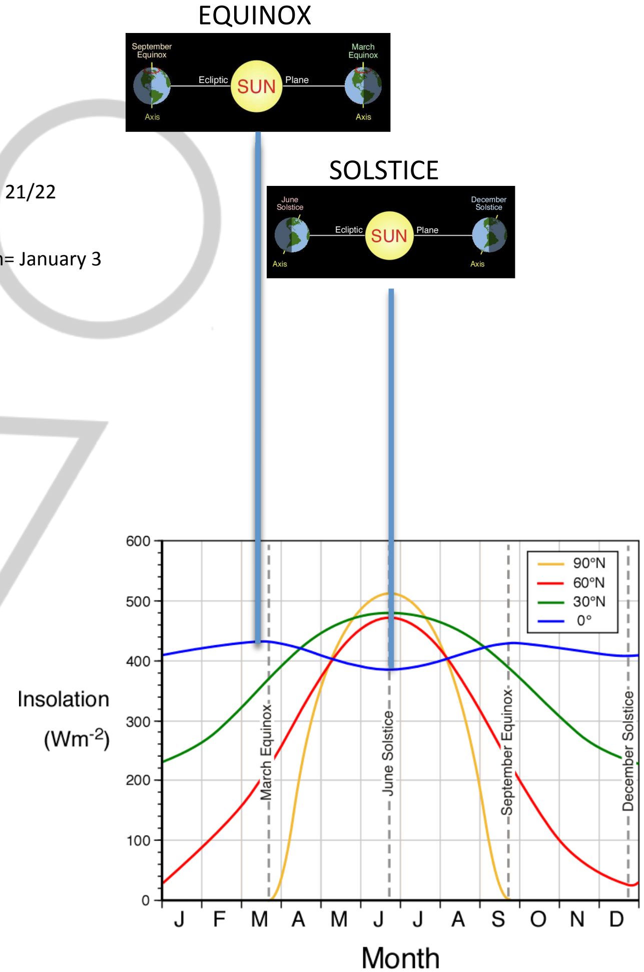
Detratte tutte le perdite per riflessione e retrodiffusione da parte di atmosfera e superficie terrestre, l'energia incidente che rimane è assorbita dalla superficie terrestre e contribuisce così al suo riscaldamento, in maniera variabile a seconda della latitudine e del tipo di superficie

VARIATION OF SOLAR RADIATION DUE TO ANNUAL PERIOD AND LATITUDE



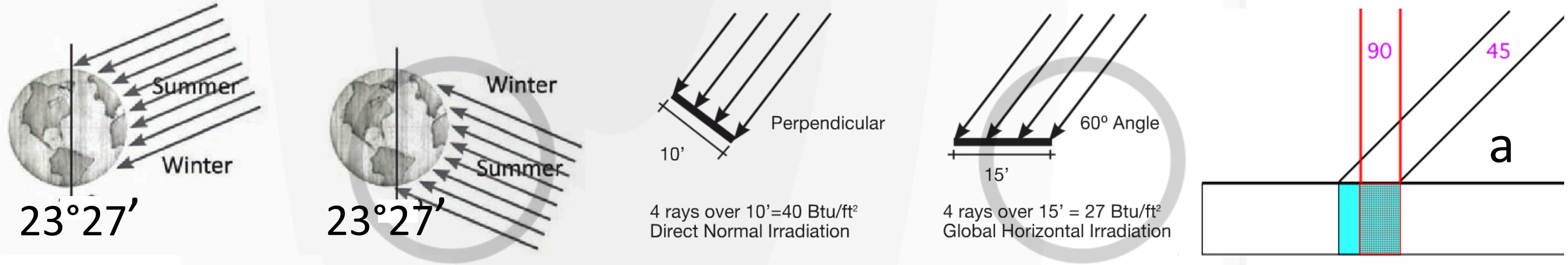


Variation of solar radiation caused by the distance of the Earth



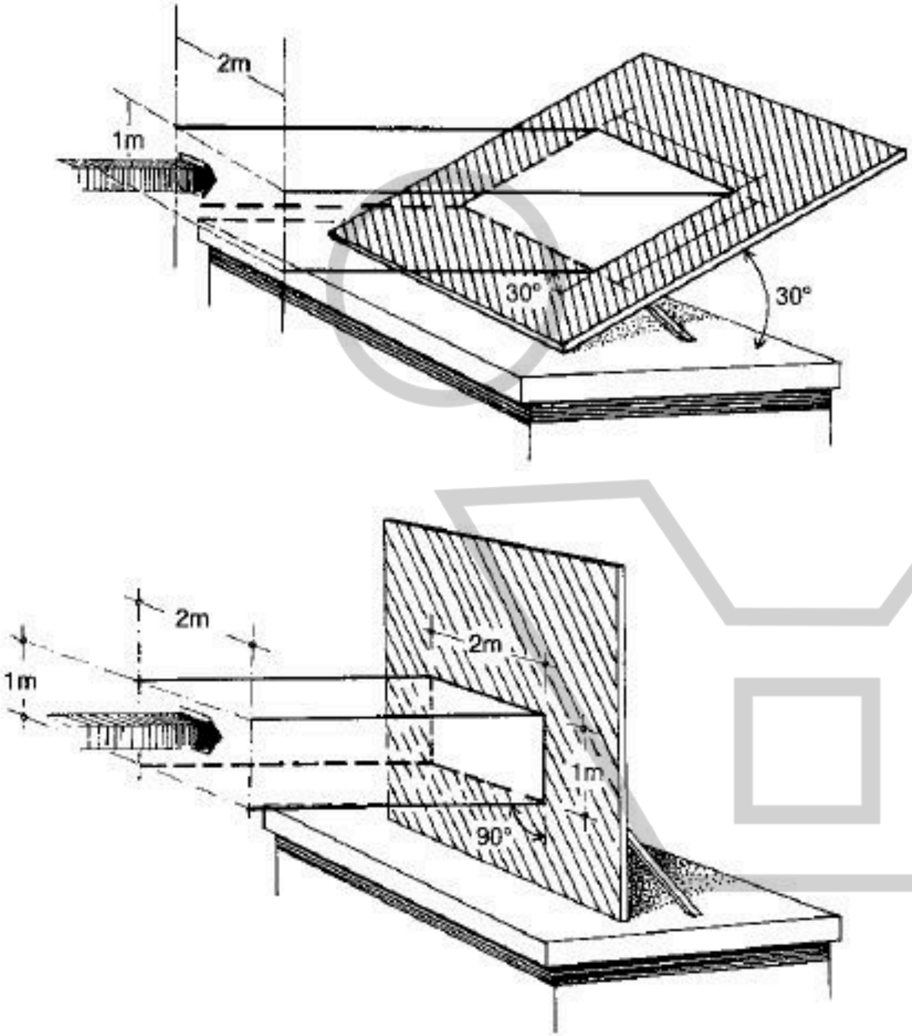
Monthly values of available insolation in Wm^{-2} for the equator, 30, 60, and 90° North

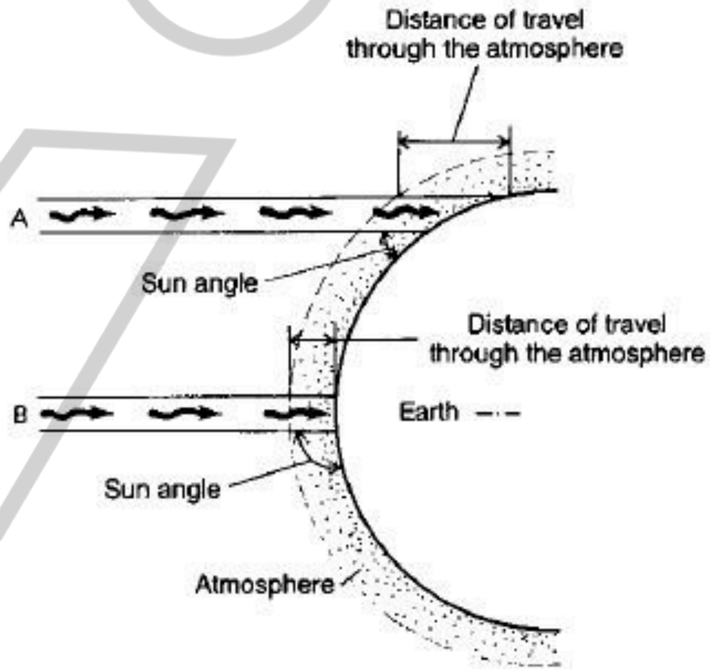
The influence of the site: GEOGRAPHICAL POSITION

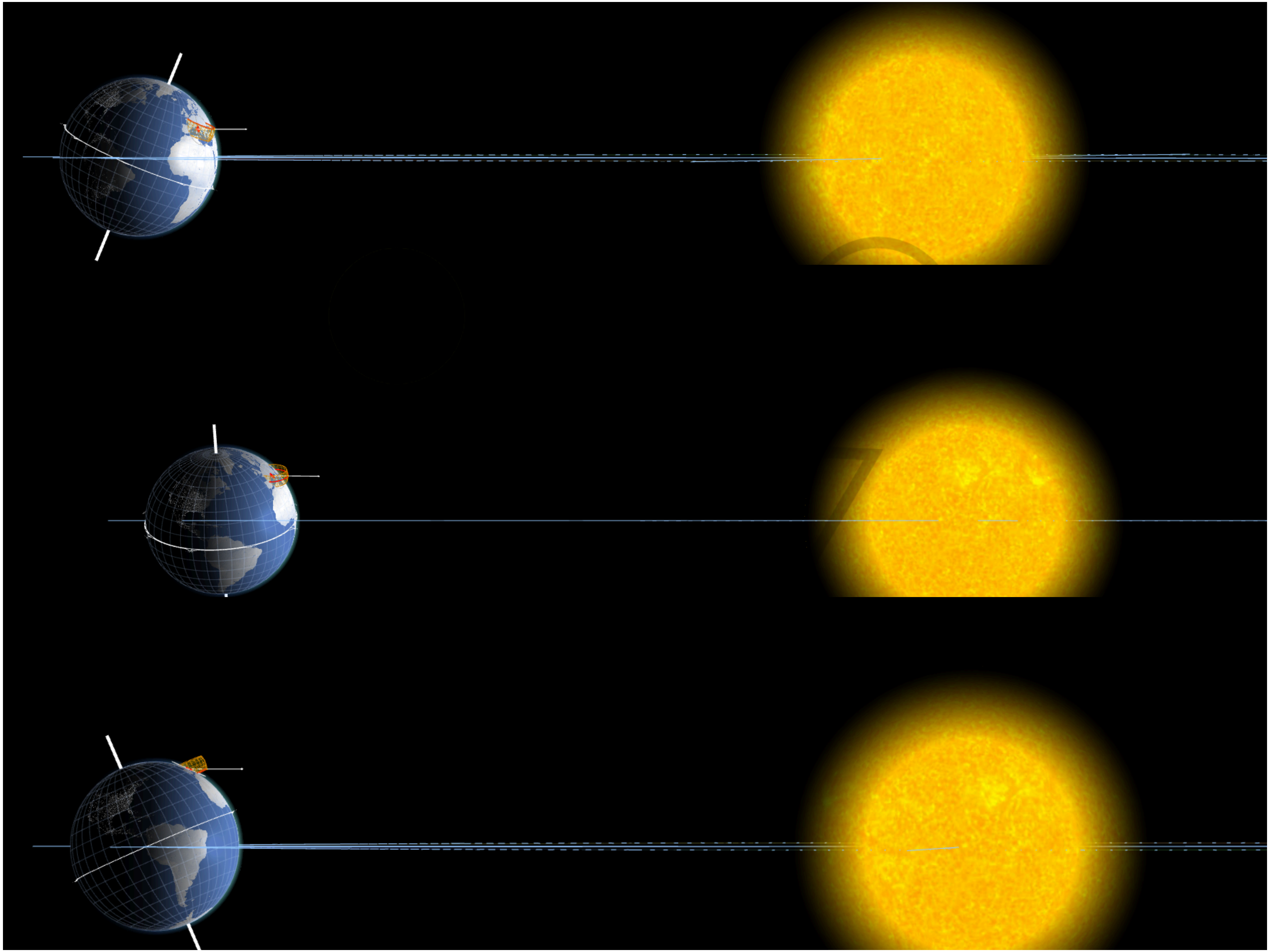


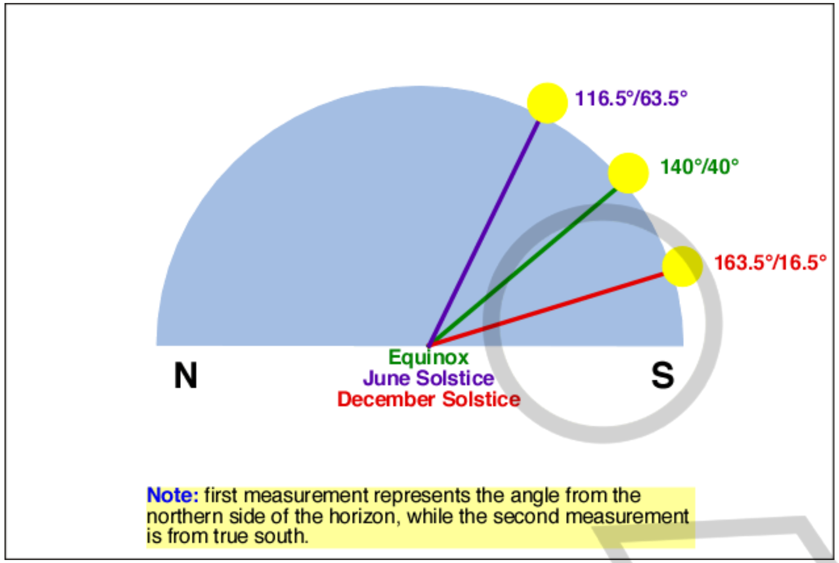
Effect of angle on the area that Intercepts an incoming beam of radiation.

Intensity = SIN (a)

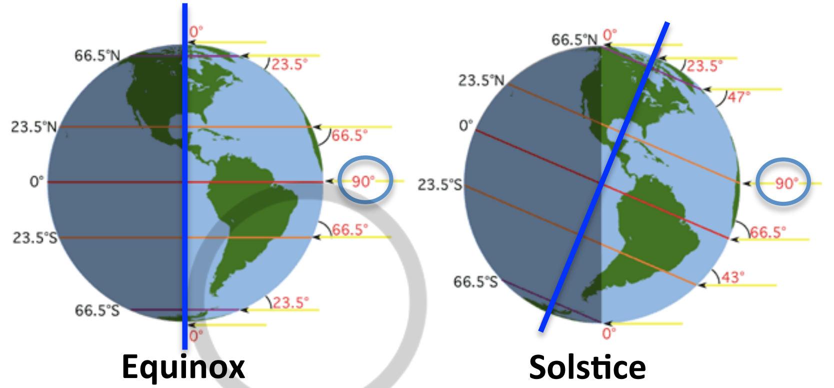

2m
1m
30°
30°
2m
1m
2m
1m
90°


Distance of travel
through the atmosphere
A
Sun angle
Distance of travel
through the atmosphere
B
Earth
Sun angle
Atmosphere

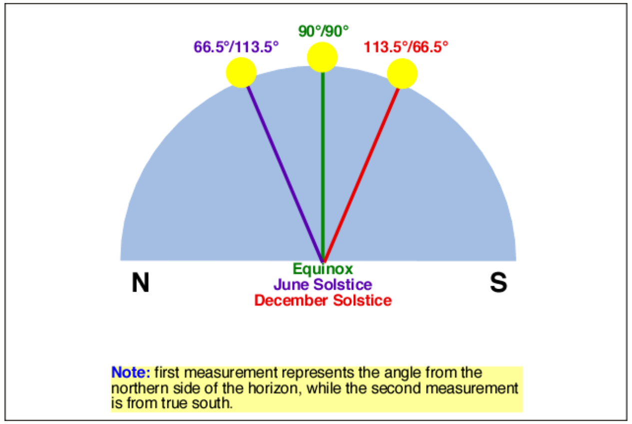




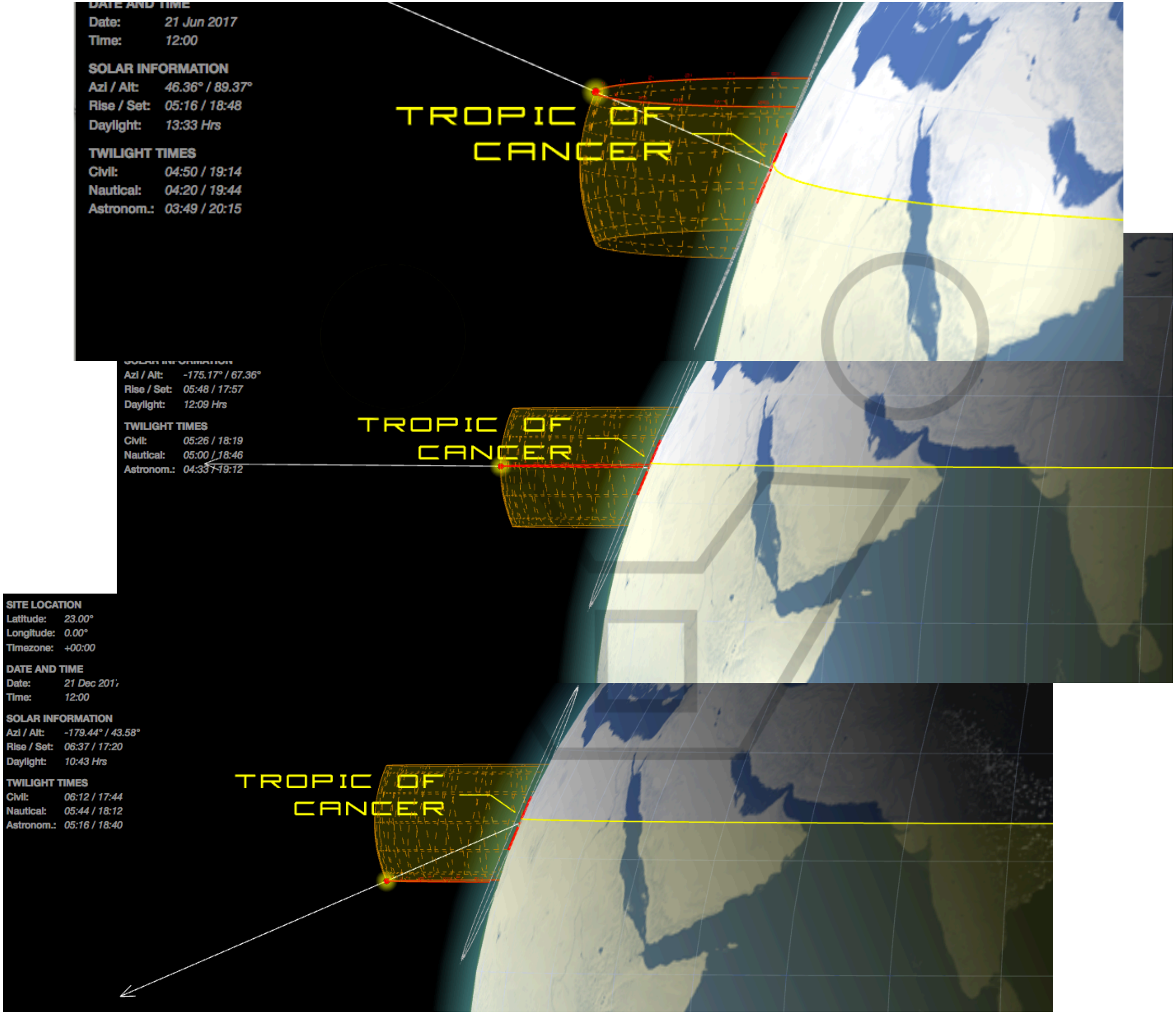
solar noon for 50 degrees North during the June solstice, equinox, and December solstice.



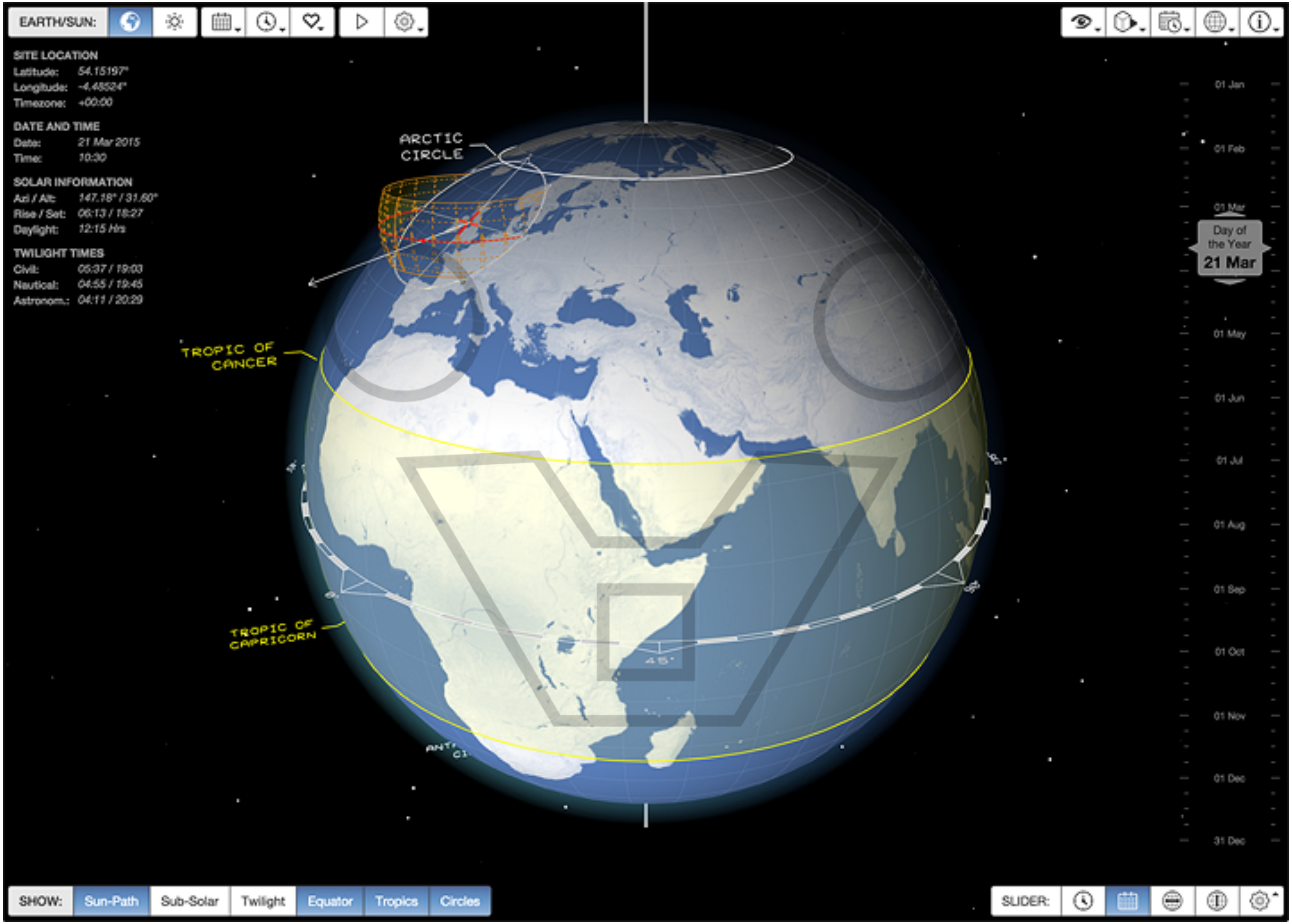
Relationship of maximum Sun height to latitude for the equinox (left) and June solstice (right). The red values on the right of the globes are maximum solar altitudes at **solar noon. Black numbers on the left indicate the location of the Equator, Tropic of Cancer (23.5 degrees N), Tropic of Capricorn (23.5 degrees S), Arctic Circle (66.5 degrees N), and the Antarctic Circle (66.5 degrees S). The location of the North and South Poles are also identified. During the equinox, the equator is the location on the Earth with a Sun angle of 90 degrees for solar noon. Note how maximum Sun height declines with latitude as you move away from the Equator. For each degree of latitude traveled maximum Sun height decreases by the same amount. At equinox, you can also calculate the noon angle by subtracting the location's latitude from 90. During the summer solstice, the Sun is now directly overhead at the Tropic of Cancer. All locations above this location have maximum Sun heights that are 23.5 degrees higher from the equinox situation. Places above the Arctic Circle are in 24 hours of daylight. Below the Tropic of Cancer the noon angle of the Sun drops one degree in height for each degree of latitude traveled. At the Antarctic Circle, maximum Sun height becomes 0 degrees and locations south of this point on the Earth are in 24 hours of darkness.**



Variations in solar altitude at **solar noon for the equator during the June solstice, equinox, and December solstice**



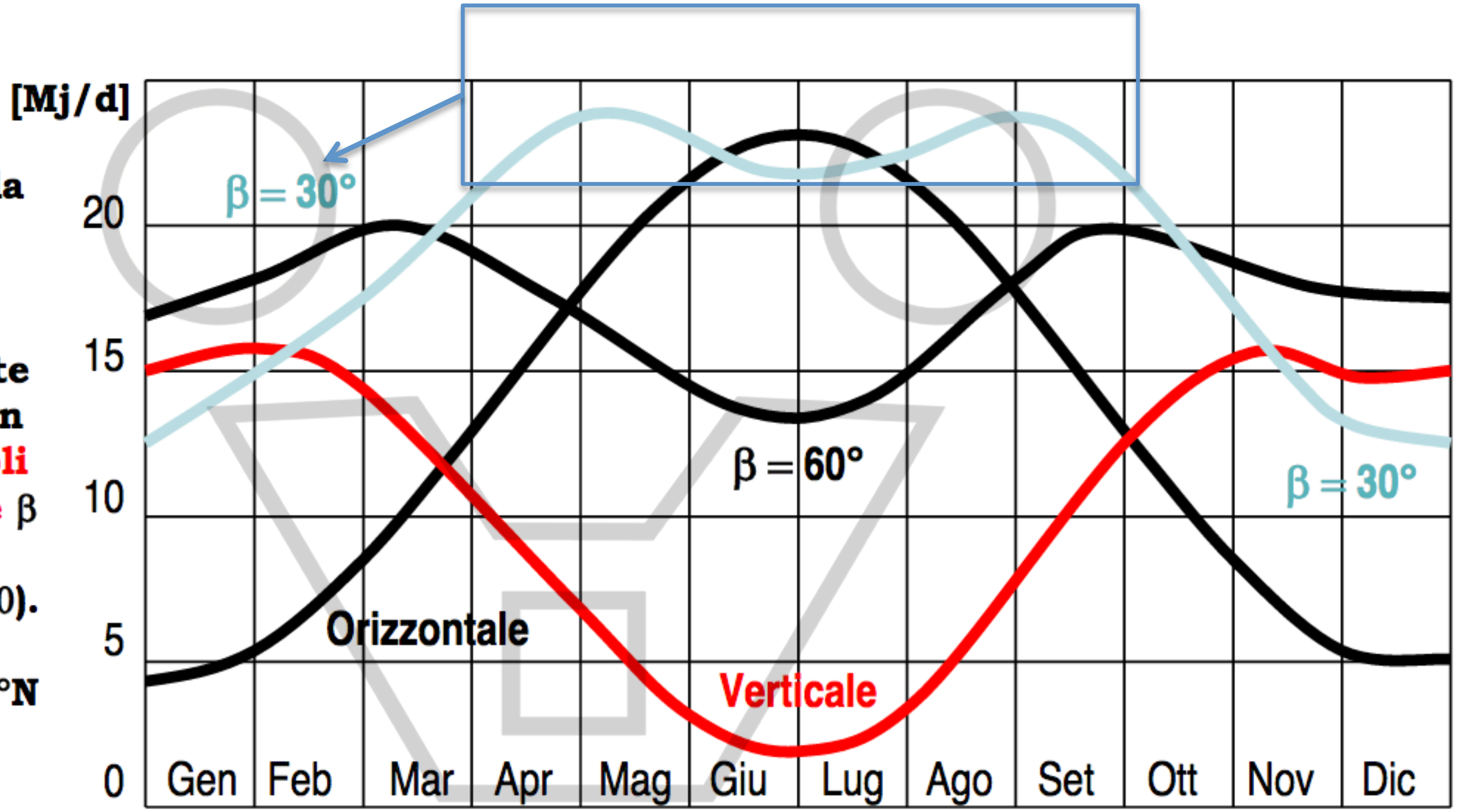
Date: 21 Jun 2017
Time: 12:00
SOLAR INFORMATION
Azi / Alt: 46.36° / 89.37°
Rise / Set: 05:16 / 18:48
Daylight: 13:33 Hrs
TWILIGHT TIMES
Civil: 04:50 / 19:14
Nautical: 04:20 / 19:44
Astronom.: 03:49 / 20:15
TROPIC OF CANCER
Azi / Alt: -175.17° / 67.36°
Rise / Set: 05:48 / 17:57
Daylight: 12:09 Hrs
TWILIGHT TIMES
Civil: 05:26 / 18:19
Nautical: 05:00 / 18:46
Astronom.: 04:33 / 19:12
TROPIC OF CANCER
SITE LOCATION
Latitude: 23.00°
Longitude: 0.00°
Timezone: +00:00
DATE AND TIME
Date: 21 Dec 2017
Time: 12:00
SOLAR INFORMATION
Azi / Alt: -179.44° / 43.58°
Rise / Set: 06:37 / 17:20
Daylight: 10:43 Hrs
TWILIGHT TIMES
Civil: 06:12 / 17:44
Nautical: 05:44 / 18:12
Astronom.: 05:16 / 18:40
TROPIC OF CANCER



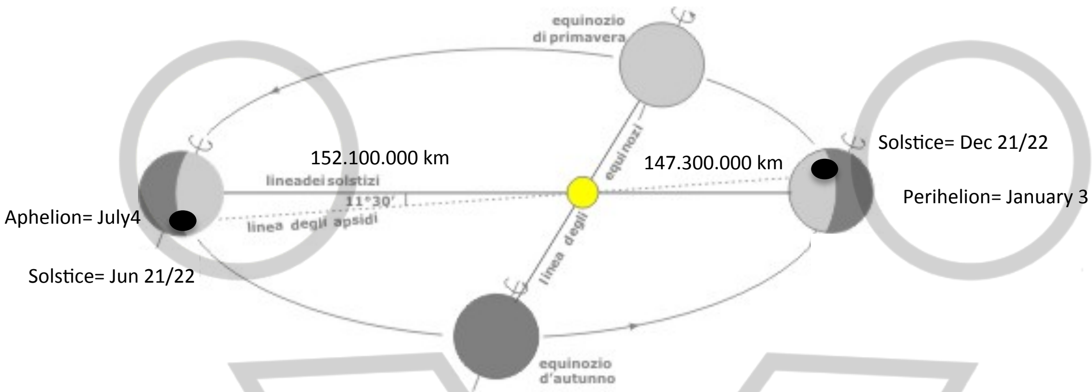
http://andrewmarsh.com/apps/staging/earthsun.html

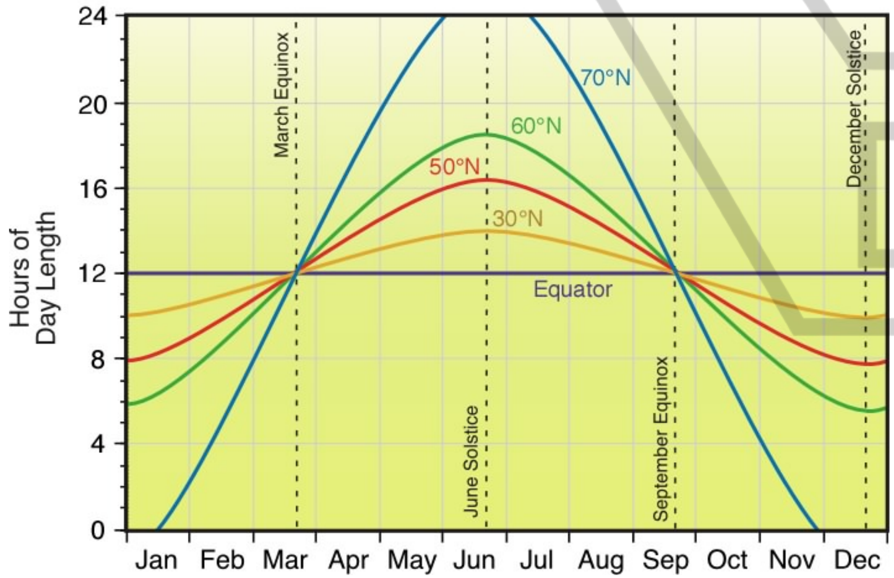
The influence of the site: GEOMETRY

Confronto fra la radiazione solare giornaliera media incidente su superfici con differenti angoli di inclinazione β ed orientate a Sud (azimut γ=0). Località con latitudine ϕ=40°N (Nuoro) e cielo sereno

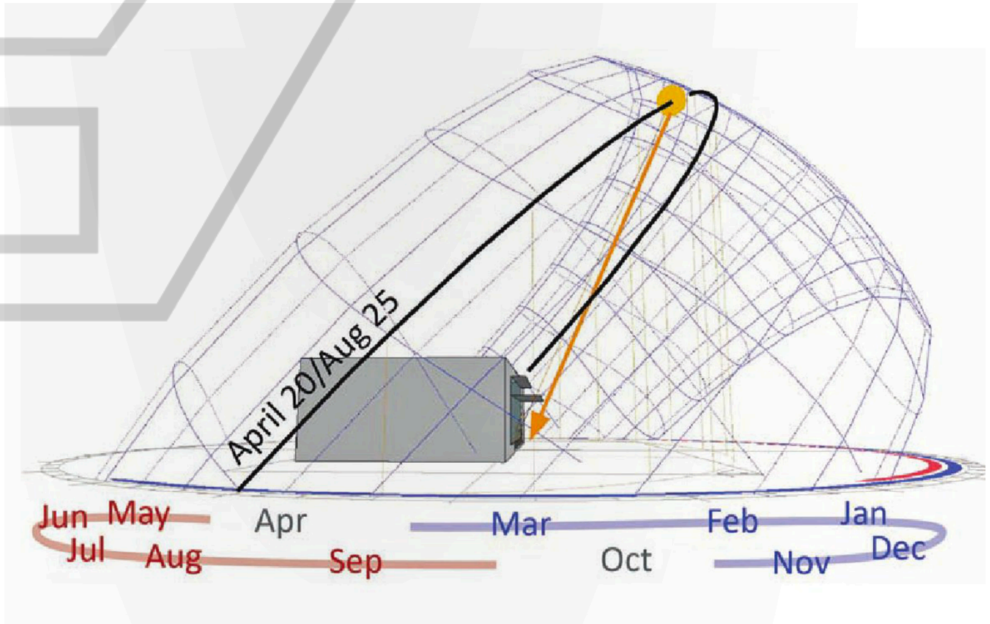


VARIATION OF SOLAR RADIATION DUE TO ANNUAL PERIOD AND LATITUDE





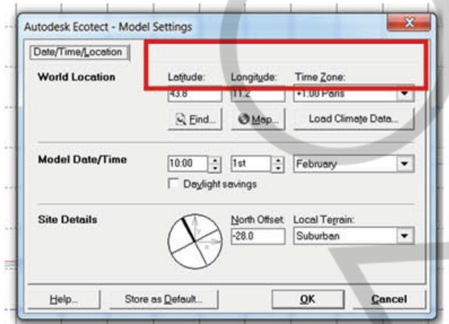
Annual variations in day length for locations
at the equator, 30, 50, 60, and 70° N



SOLAR ENERGY= **f** (power, angle of incidence, sky conditions)= **World Location**

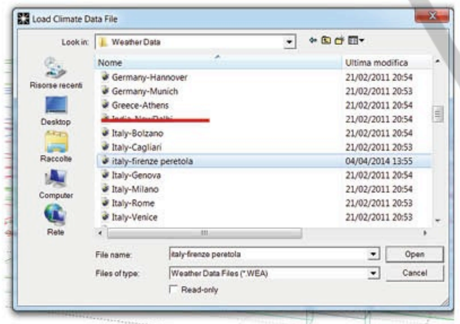
ECOTECT APPROACH

Autodesk® Ecotect® Analysis sustainable design analysis software is a comprehensive concept-to-detail sustainable building design tool. Ecotect Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. Online energy, water, and carbon-emission analysis capabilities integrate with tools that enable you to visualize and simulate a building's performance within the context of its environment.



Coordinates

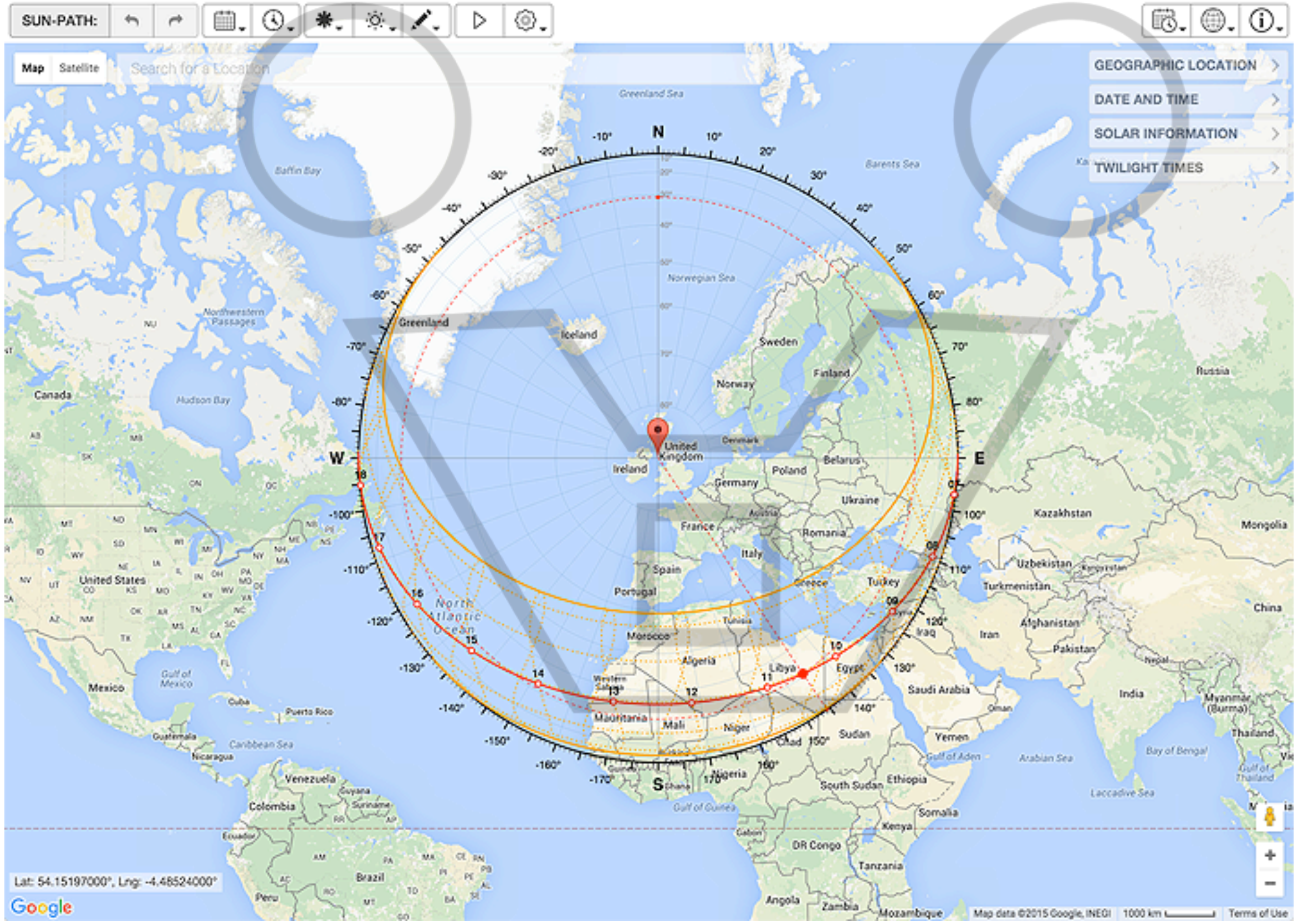
Type of terrain



Weather data

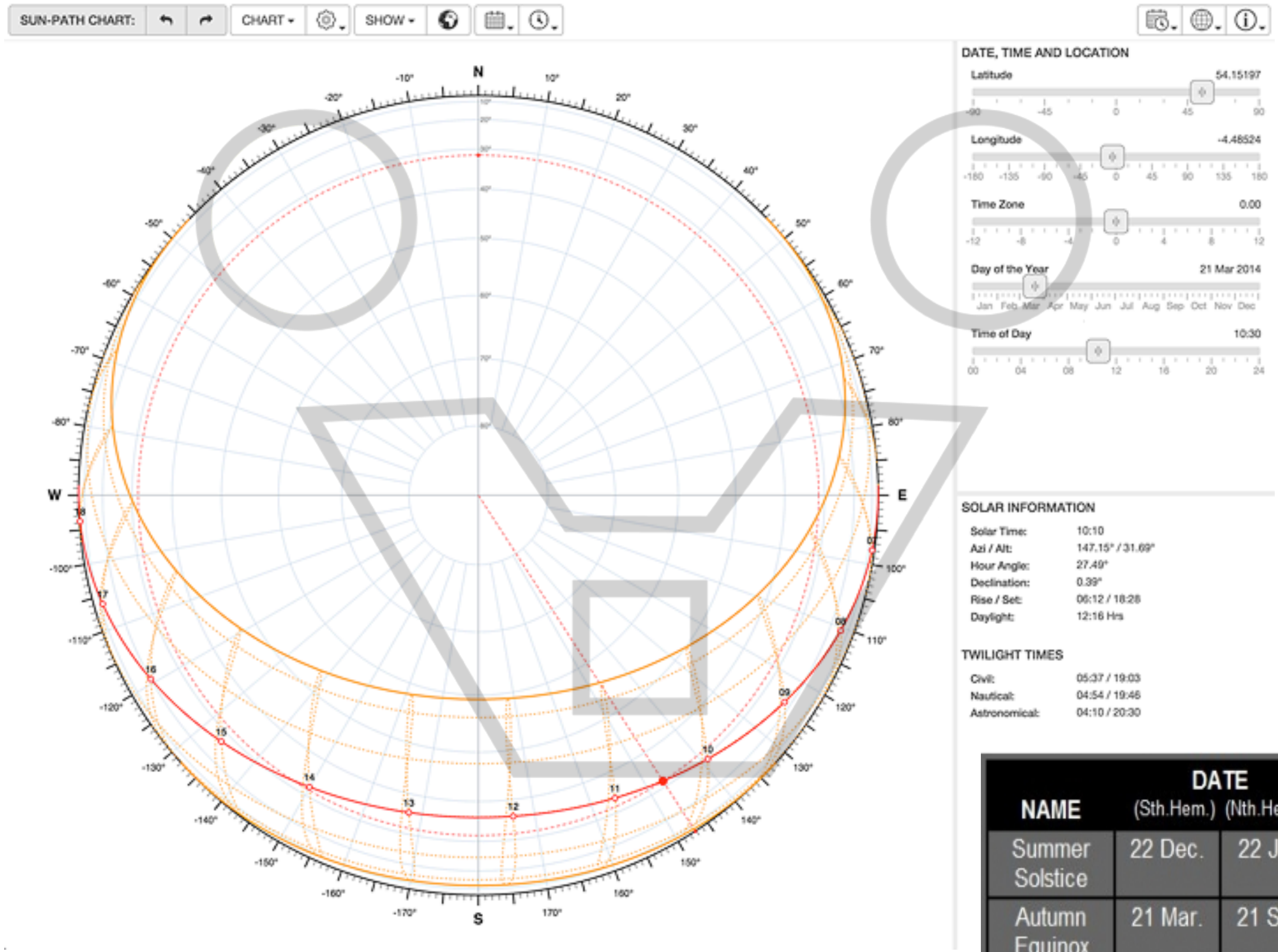
The school

The influence of the site: GEOGRAPHICAL POSITION



SOLAR GEOMETRY
http://andrewmarsh.com/software/sunpath-on-map-web/

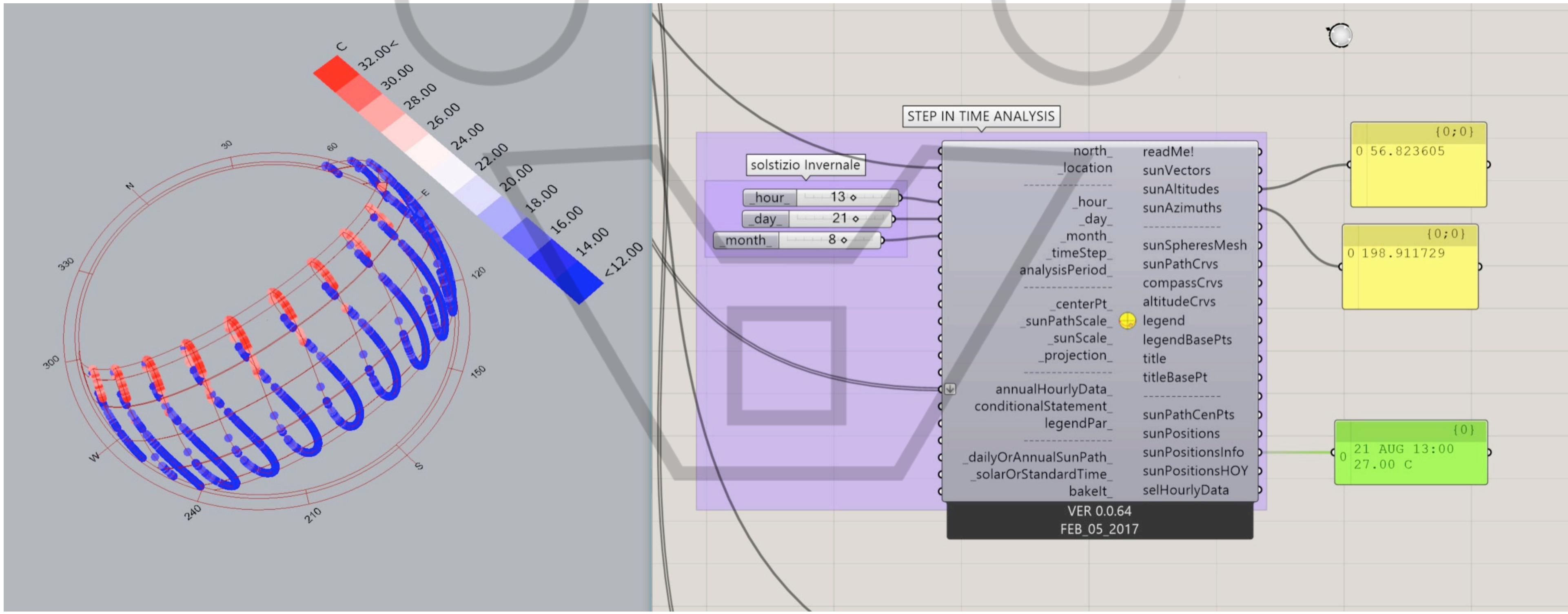
The influence of the site: GEOGRAPHICAL POSITION



SOLAR GEOMETRY
http://andrewmarsh.com/apps/releases/sunpath2d.html

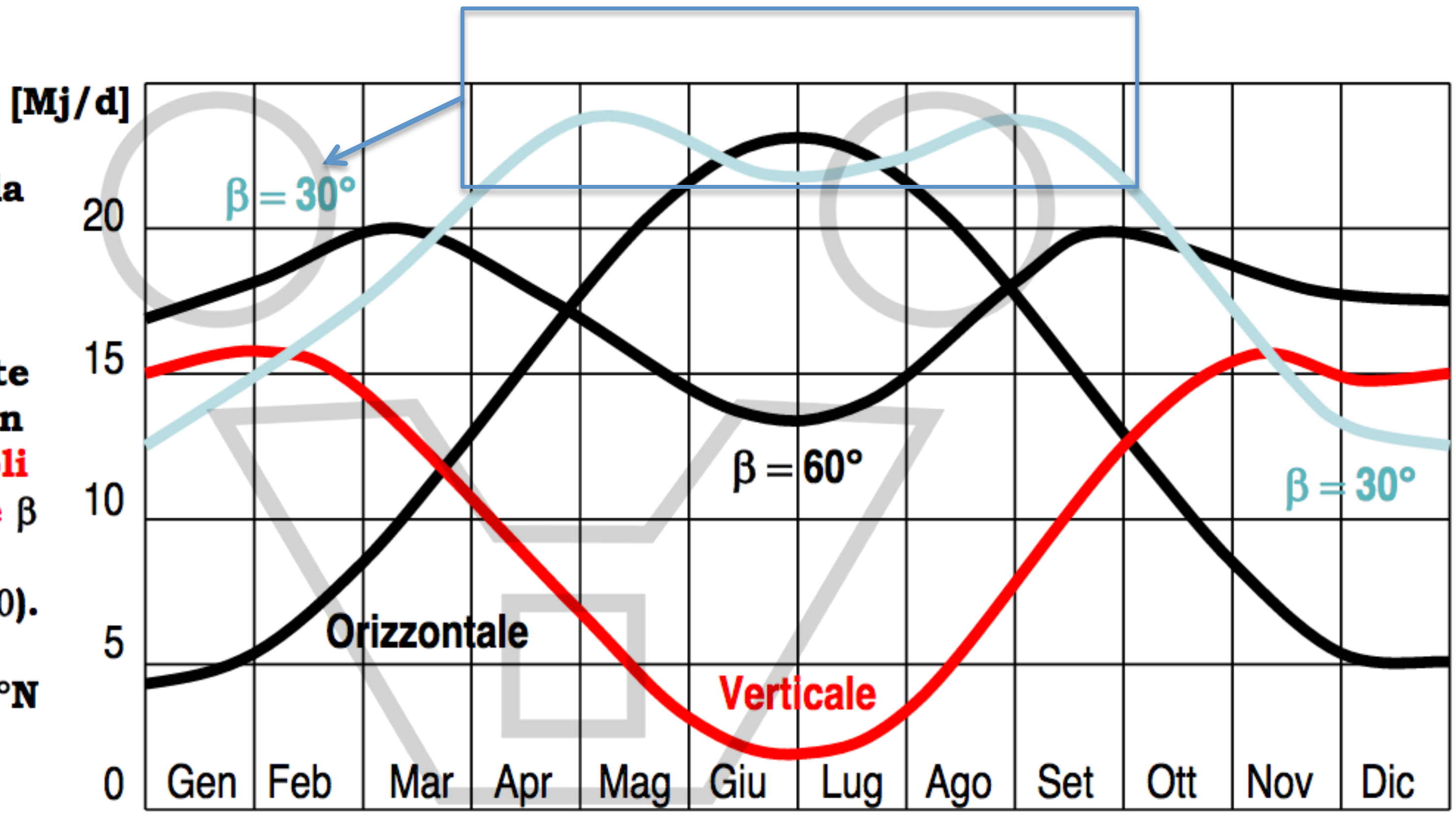
NAME	DATE (Sth.Hem.)	(Nth.Hem.)	DESCRIPTION
Summer Solstice	22 Dec.	22 Jun.	Sun at its highest noon altitude
Autumn Equinox	21 Mar.	21 Sep.	Sun rises due east, sets due west
Winter Solstice	21 Jun.	21 Dec.	Sun at its lowest noon altitude
Spring Equinox	21 Sep.	21 Mar.	Sun rises due east, sets due west

SOLAR GEOMETRY WITH LADYBUG

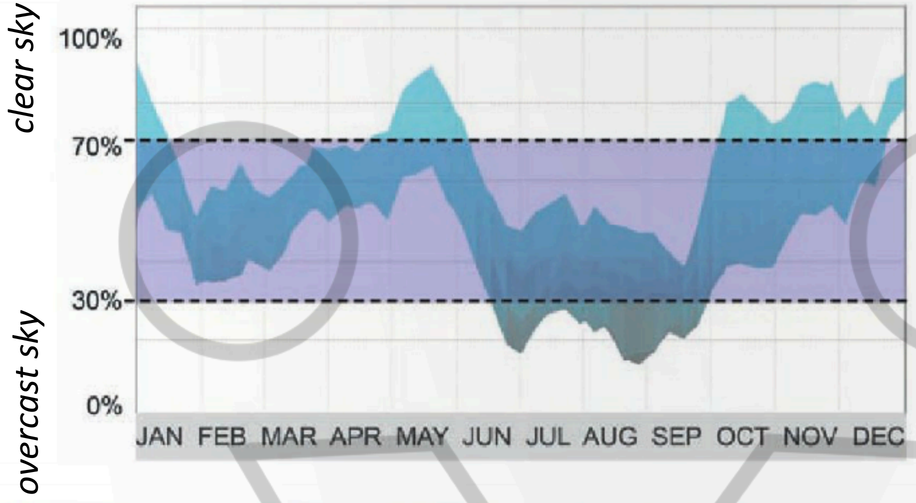


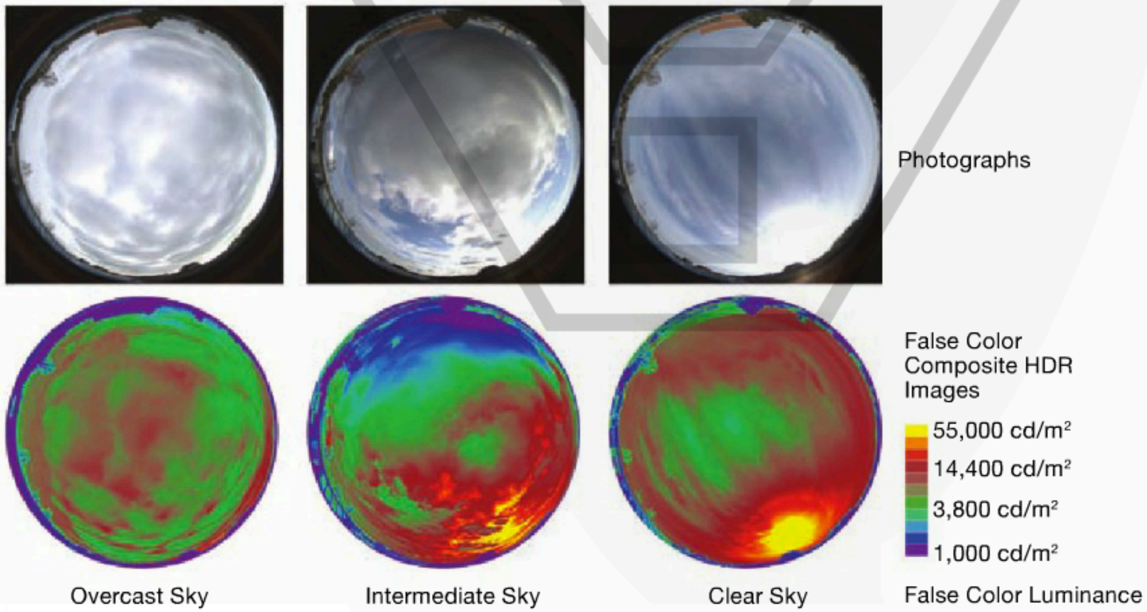
The influence of the site: GEOMETRY

Confronto fra la radiazione solare giornaliera media incidente su superfici con differenti angoli di inclinazione β ed orientate a Sud (azimut γ=0). Località con latitudine ϕ=40°N (Nuoro) e cielo sereno



The influence of the weather : SKY CONDITIONS





8.2

Cloud cover in Allen, Texas, varies from intermediate and overcast in winter, to intermediate and clear in summer. The CIE defines clear skies as >70% cloud cover, overcast skies as <30% cloud cover, and other skies as intermediate.

Source: Modified output from Autodesk Ecotect Suite. Courtesy of Callison.

8.3

Actual sky conditions that correspond to overcast, intermediate, and clear skies are shown using high dynamic range (HDR) fish-eye photographs and false color images. While most daylight simulation uses synthetic, averaged sky conditions, actual sky conditions vary by the minute. HDR skies can be used in daylighting simulations, see Case Study 8.6.

Source: Inanici (2010). Images © Illuminating Engineering Society, www.ies.org.

Cloud coverage is measured as a percentage of total sky

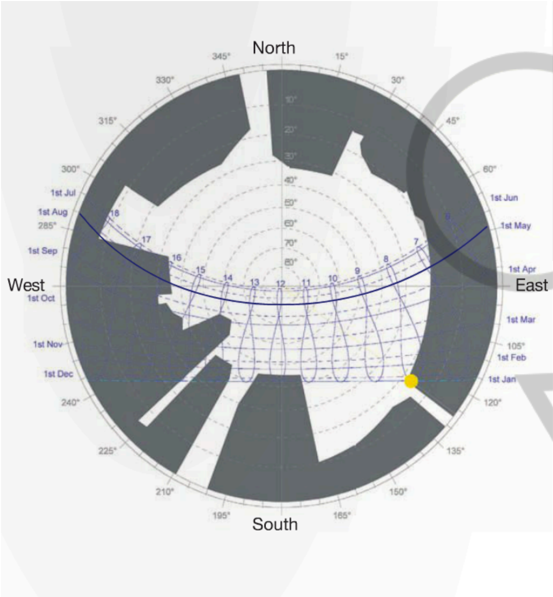
The influence of the weather : SKY CONDITIONS

Radiazione solare	Condizioni atmosferiche							
	Cielo sereno	Nebbia	Nuvoloso	Disco solare giallo	Disco solare bianco	Sole appena percettibile	Nebbia fitta	Cielo coperto
globale	1000 W/m²	600 W/m²	500 W/m²	400 W/m²	300 W/m²	200 W/m²	100 W/m²	50 W/m²
diretta	90%	50%	70%	50%	40%	0%	0%	0%
diffusa	10%	50%	30%	50%	60%	100%	100%	100%

http://www.sunsim.it/

The influence of the site: Shading Mass

The calculation of the solar energy that can be received by a certain point of the site throughout the year is an analysis that is currently used for the correct installation of photovoltaic panels. In addition to the use of software it is possible to carry out this analysis directly on-site with the use of appropriate equipments more or less sophisticated. These tools can also be used to check the view shed of a given point in the area.



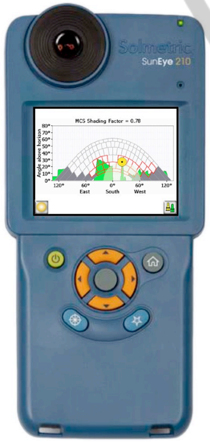
Fish-eye image showing annual solar path and adjacent buildings that shade a location within an urban context. Afternoon hours in the summer are mostly shaded, while the first two hours of each day are also shaded. The peak summer cooling date is highlighted, showing full shade after 4 p.m.

Source: Modified Autodesk Ecotect output. Courtesy of Callison.

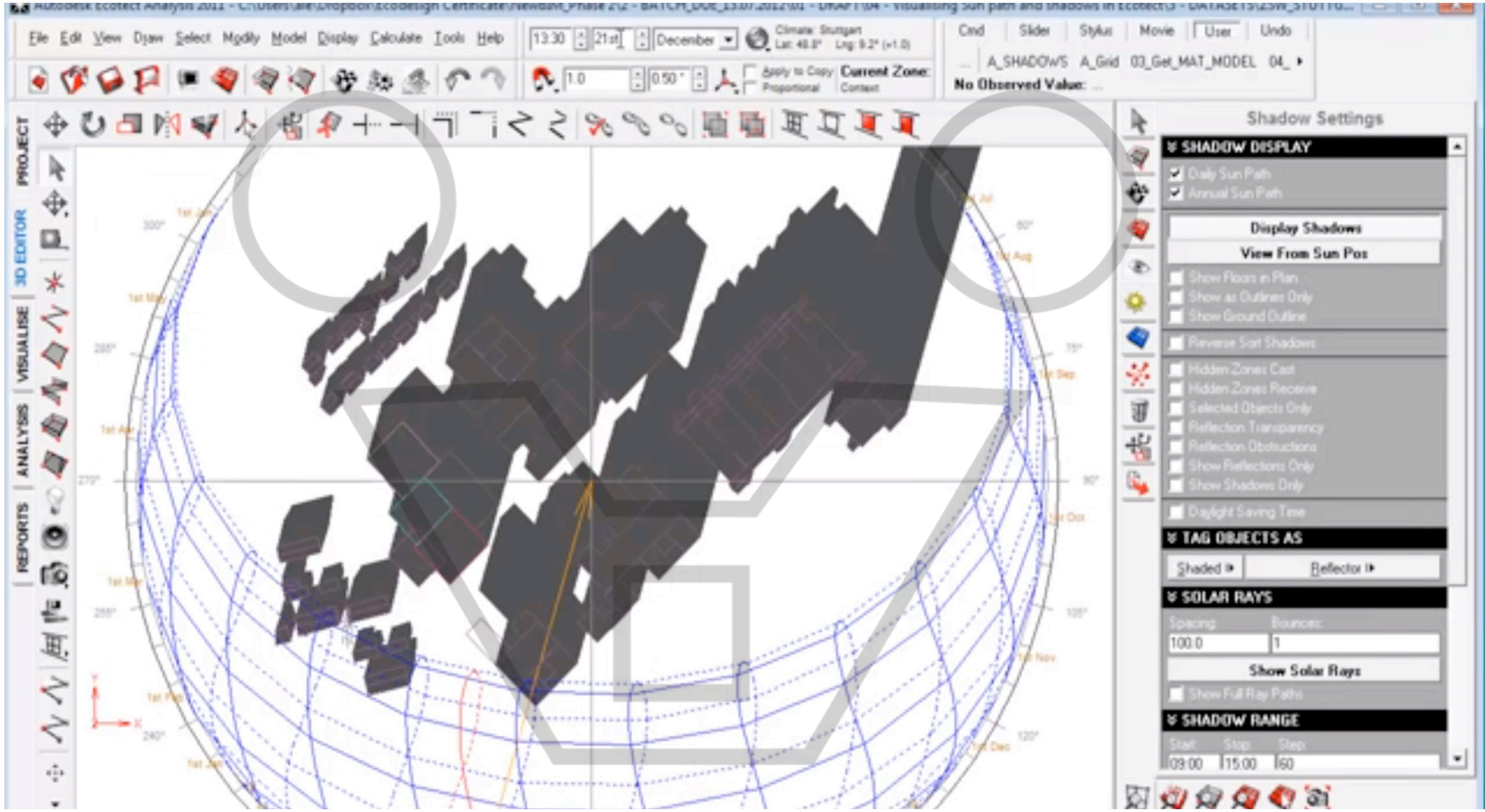
Solar Pathfinder - The Solar Pathfinder has been the standard in the solar industry for solar site analysis for decades. Its panoramic reflection of the site instantly provides a full year of accurate solar/shade data, making it the instrument of choice.

Fish eye Camera

SunEye™ - The Solmetric SunEye™ is a hand held electronic device that allows users to instantly assess total potential solar energy given the shading of a particular site. Identifying the shading pattern early in the process reduces the expense of system and home design and improves the efficiency of the final system or house.

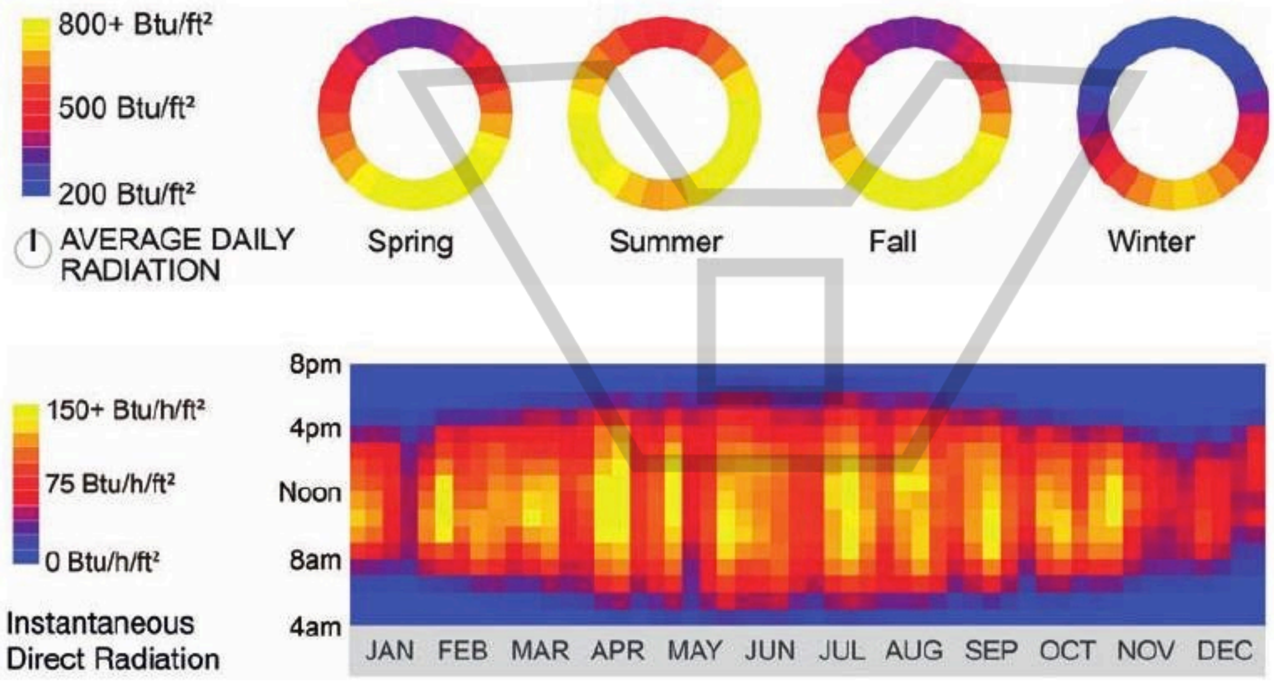


Solmetric iPV - is an iPhone® based site evaluation tool, providing full solar site analysis in an affordable hand held package.


File Edit View Draw Select Modify Model Display Calculate Tools Help
13:30
21st
December
Climate: Stuttgart
Cmd
Slider
Stylus
Movie
User
Undo
A_SHADOWS
A_Grid
03_Get_MAT_MODEL
04_
Apply to Copy
Proportional
Current Zone:
No Observed Value:
PROJECT
3D EDITOR
VISUALISE
ANALYSIS
REPORTS
Shadow Settings
SHADOW DISPLAY
Daily Sun Path
Annual Sun Path
Display Shadows
View From Sun Pos
Show Floors in Plan
Show as Outlines Only
Show Ground Outline
Reverse Sort Shadows
Hidden Zones Cast
Hidden Zones Receive
Selected Objects Only
Reflection Transparency
Reflection Obstructions
Show Reflections Only
Show Shadows Only
Daylight Saving Time
TAG OBJECTS AS
Shaded
Reflector
SOLAR RAYS
Spacing:
Bounces:
100.0
1
Show Solar Rays
Show Full Ray Paths
SHADOW RANGE
Start:
Stop:
Step:
09:00
15:00
60

The influence of the site: GEOGRAPHICAL POSITION

AVERAGE DAILY RADIATION

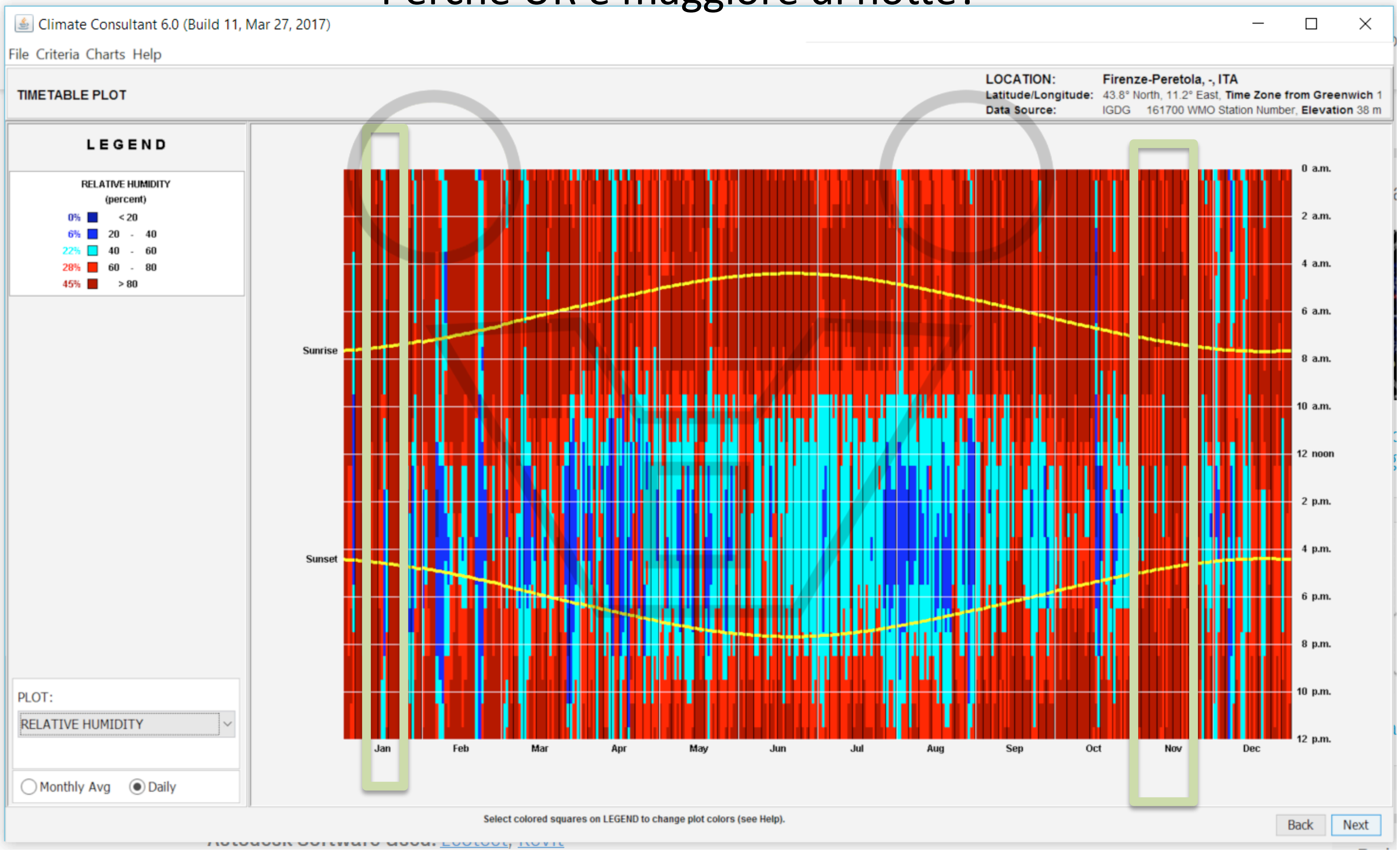


4.10 and 4.11

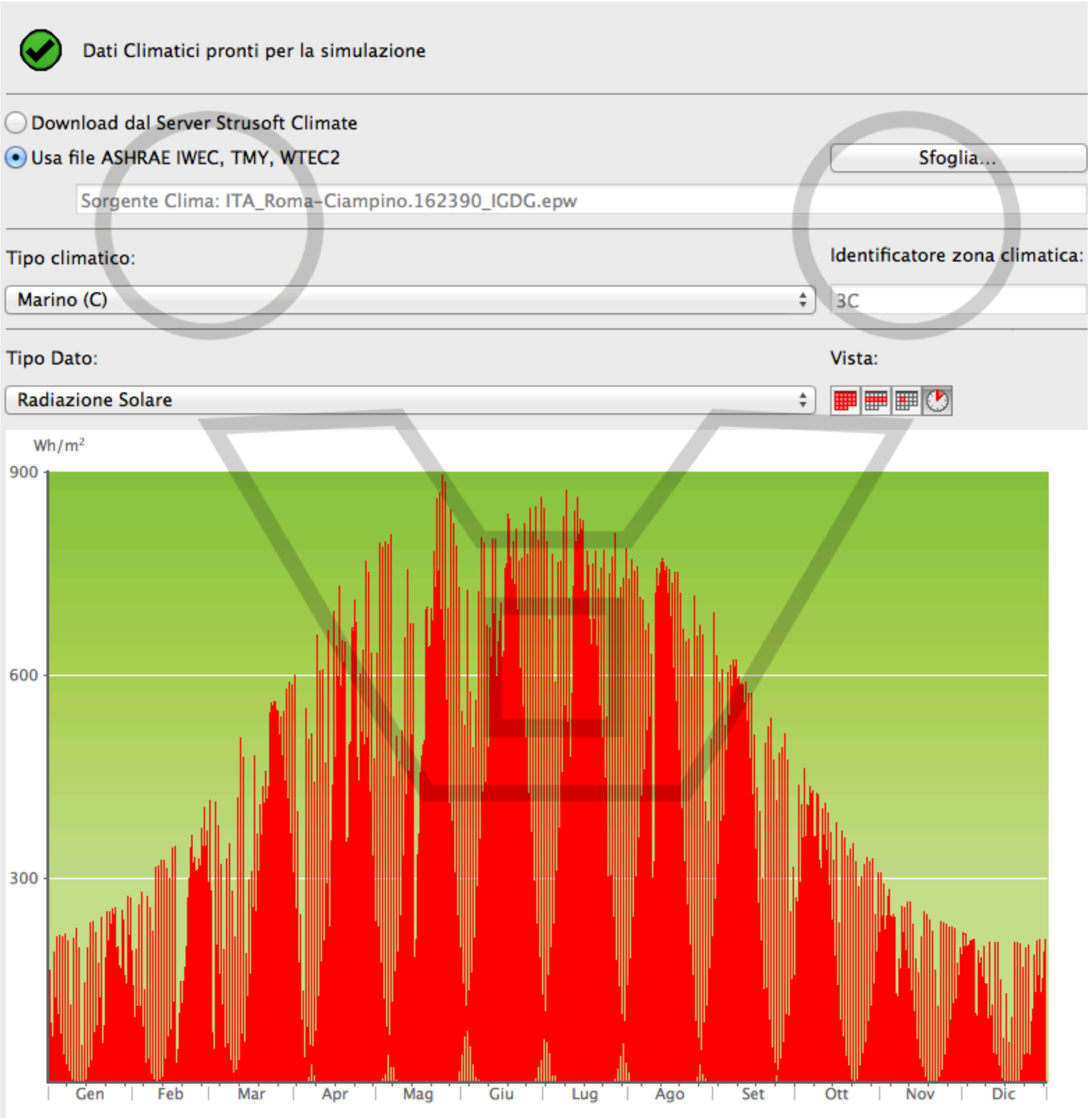
Solar roses from Central Park in New York City show the average daily amount of solar energy on each vertical segment of a cylinder. Since solar angles are symmetrical about the solstices, each season was centered on an equinox or solstice. The lower images show radiation on a horizontal surface for each hour and day of the year from the same weather file.

Source: Autodesk's Ecotect output. Courtesy of Callison.

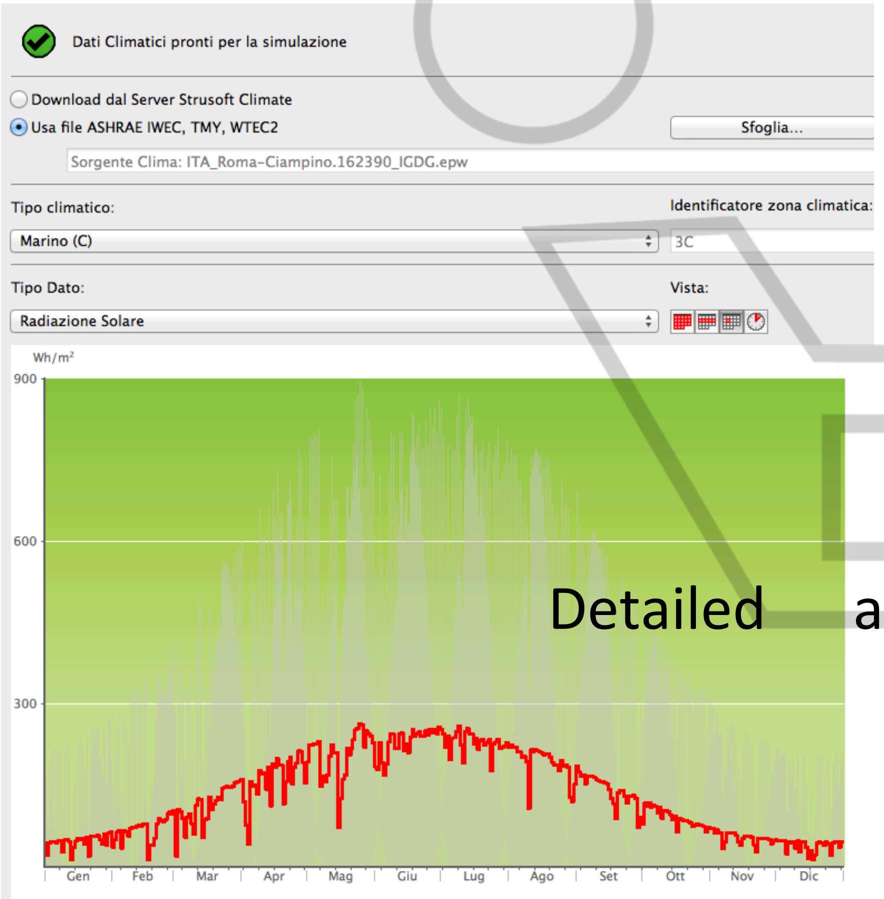
Perché UR è maggiore di notte?

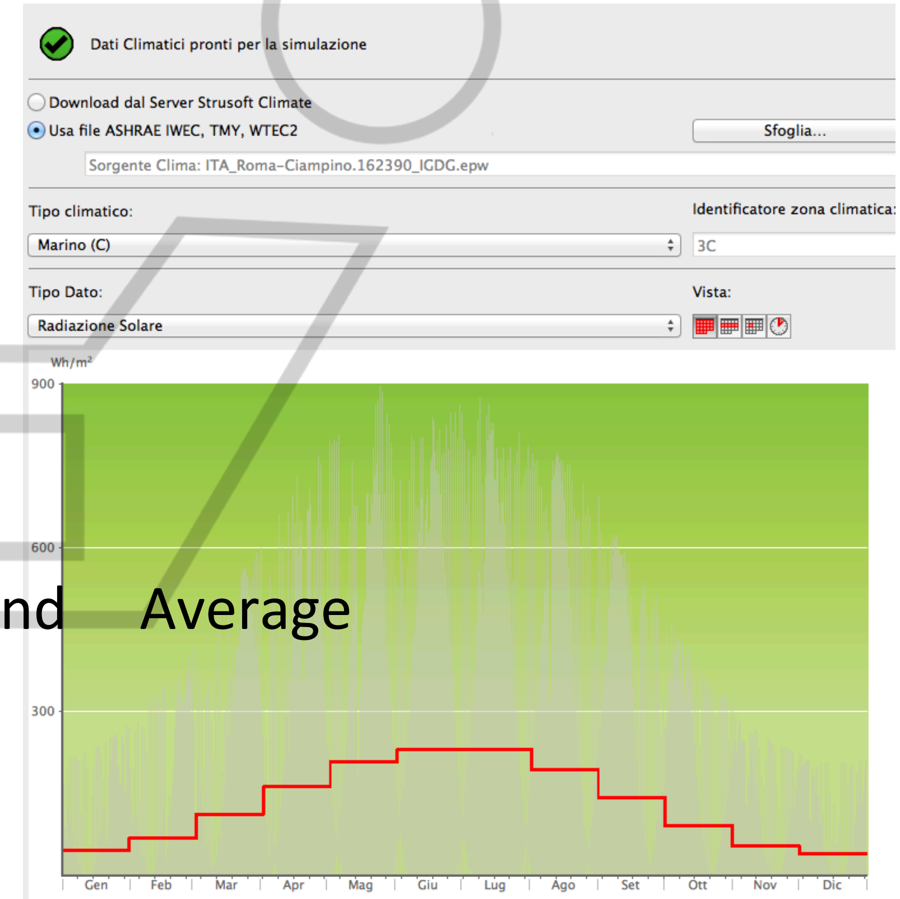


Visualization of sun energy radiation



Visualization of sun energy radiation





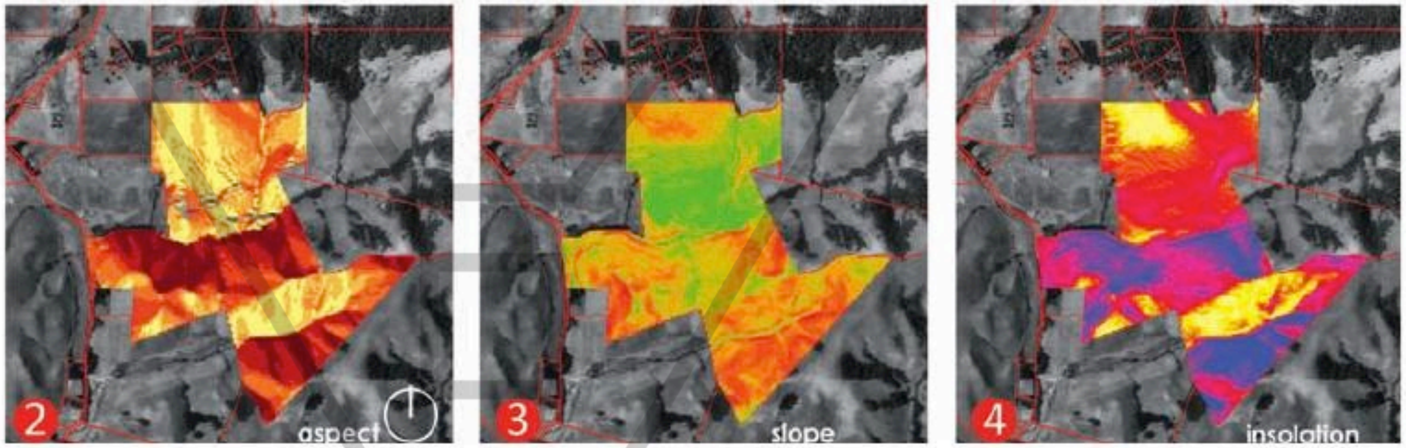
Detailed and Average

Visualization of sun energy radiation

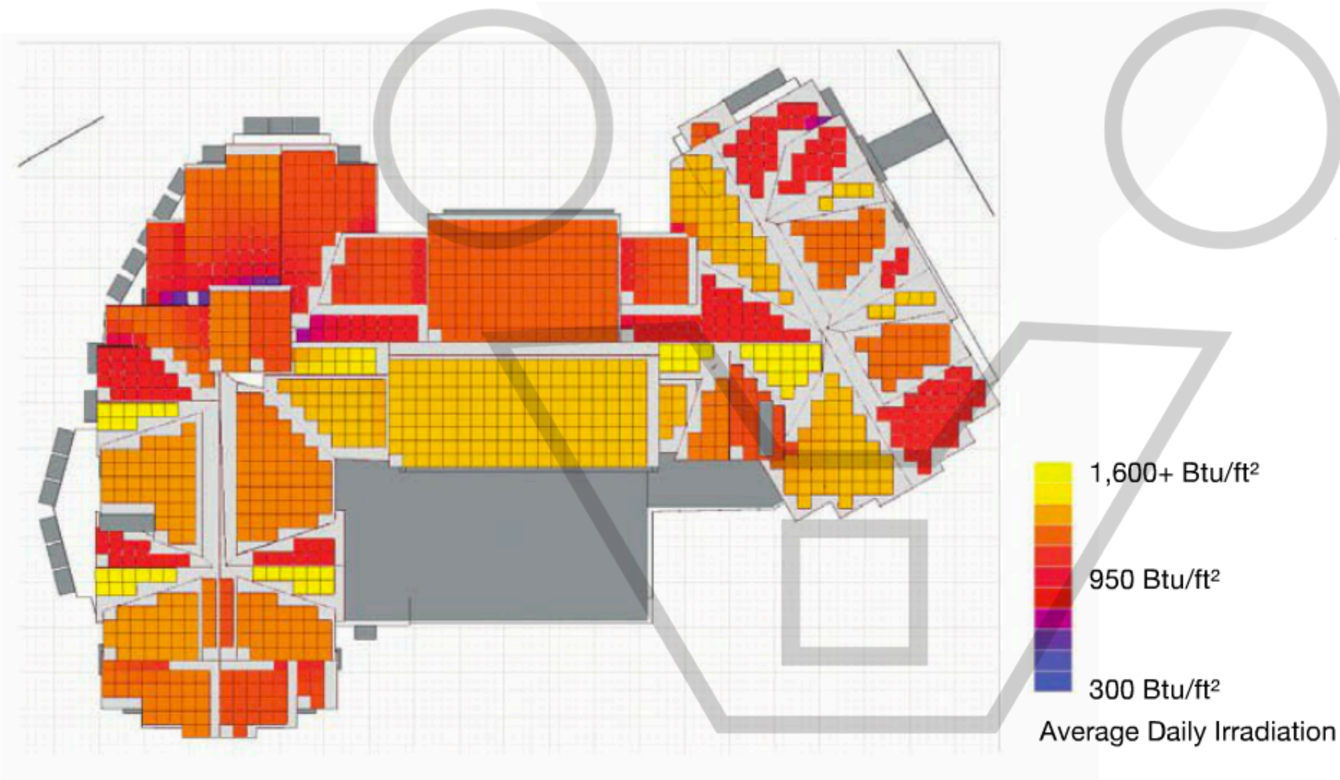
Terrain solar exposure and solar access to evaluate the best location

5.16

View Desirability, Slope Desirability, Solar Desirability.



Irradiation analysis

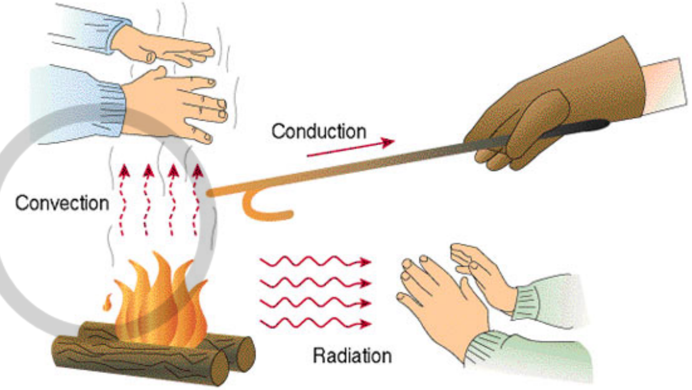


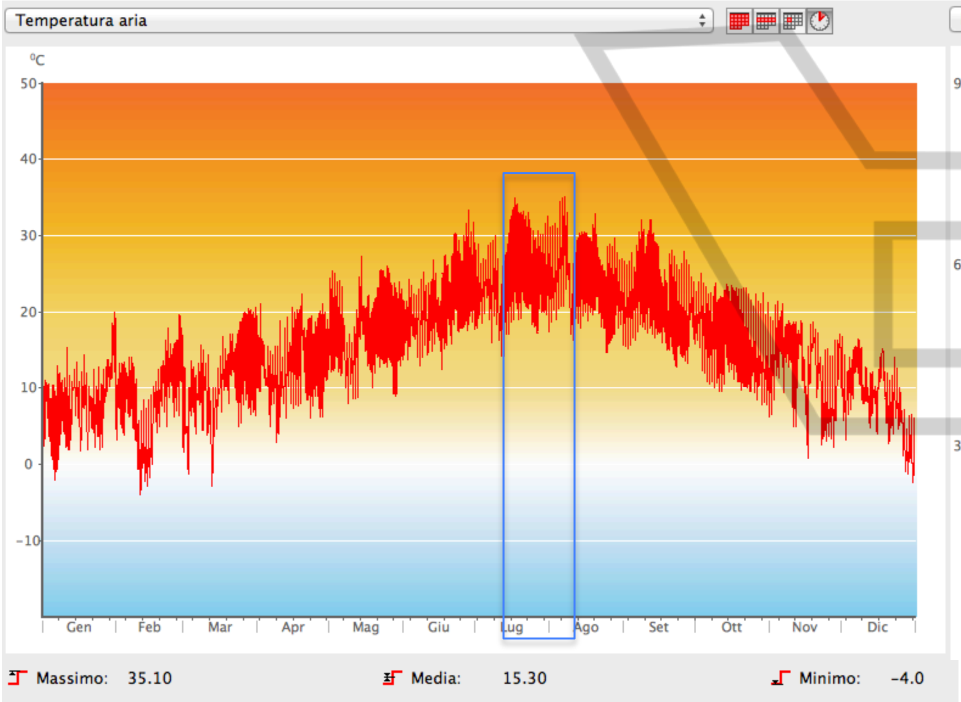
7.8

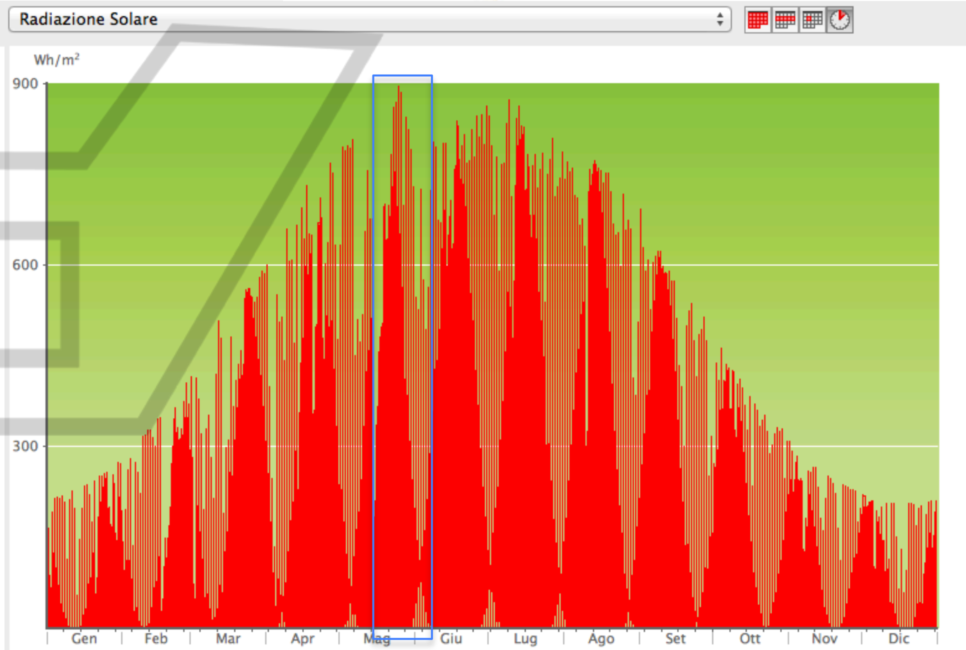
Roof plan with annual solar irradiation analysis to show ideal orientations and roof forms for renewable energy collection using Autodesk Ecotect.

Source: Courtesy of Callison.

Visualization of air temperature in relation with solar radiation







from archicad

Visualization of Relative Humidity

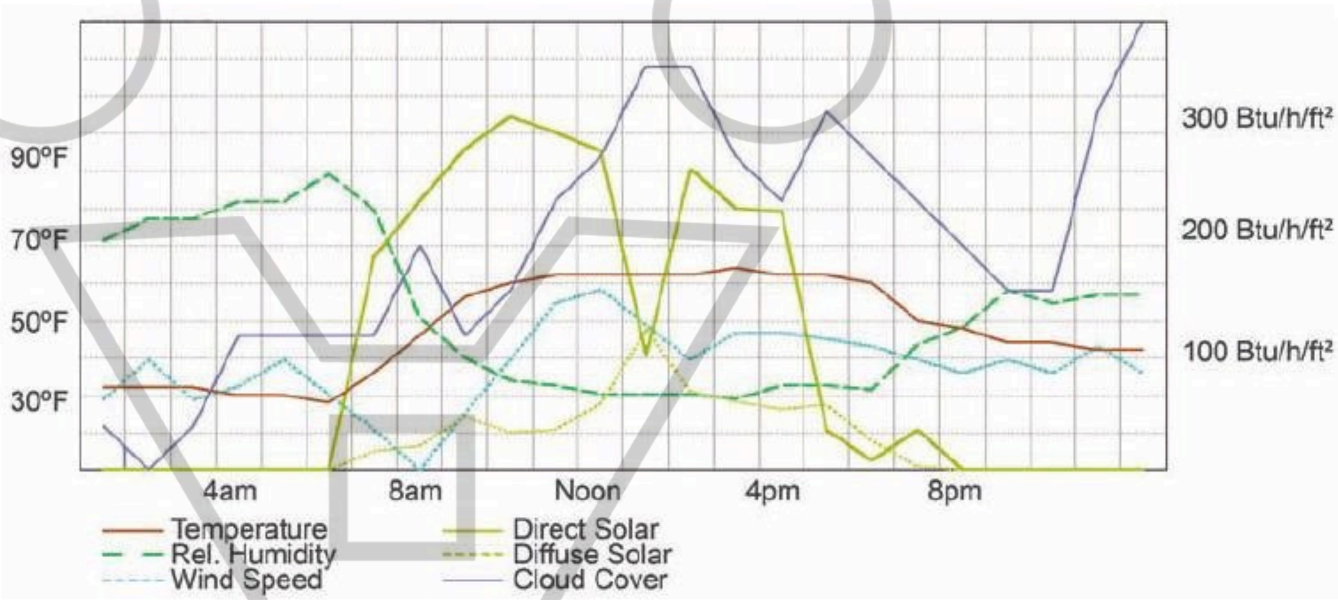
from archicad

Inverse relationship between Temperature and Humidity

4.5

A 24-hour period set of data from a weather file shows the interaction of the dry bulb temperature, the relative humidity, the direct solar, diffuse solar, wind speed and cloud cover. Note the inverse relationship of temperature and humidity; direct and diffuse solar irradiation; and the inconsistent relationship between cloud cover and direct solar.

Source: Autodesk Ecotect Suite output of EnergyPlus weather data. Courtesy of Callison.

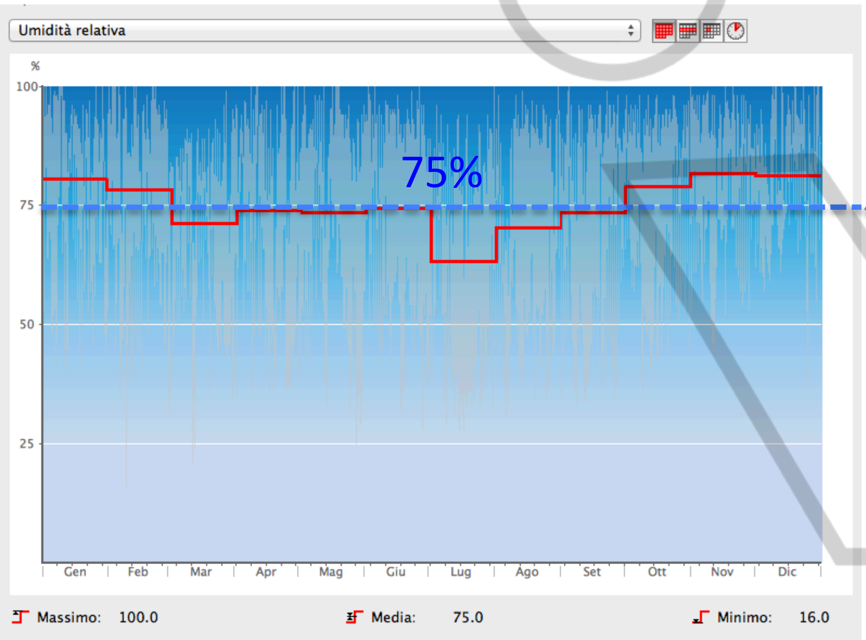


Environmental parameters affecting thermal comfort: HUMIDITY

Apparent Temperature (AT)

The **AT** is defined as the temperature, at the reference humidity level, producing the same amount of discomfort as that experienced under the current ambient temperature and humidity.

Basically the **AT** is an adjustment to the *ambient temperature* (**T**) based on the level of humidity.



	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
42°	48	50	52	55	57	59	62	64	66	68	71	73	75	77	80	82
41°	46	48	51	53	55	57	59	61	64	66	68	70	72	74	76	79
40°	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75
39°	43	45	47	49	51	53	55	57	59	61	63	65	66	68	70	72
38°	42	44	45	47	49	51	53	55	56	58	60	62	64	66	67	69
37°	40	42	44	45	47	49	51	52	54	56	58	59	61	63	65	66
36°	39	40	42	44	45	47	49	50	52	54	55	57	59	60	62	63
35°	37	39	40	42	44	45	47	48	50	51	53	54	56	58	59	61
34°	36	37	39	40	42	43	45	46	48	49	51	52	54	55	57	58
33°	34	36	37	38	40	41	43	44	46	47	48	50	51	53	54	55
32°	33	34	36	37	38	40	41	42	44	45	46	48	49	50	52	53
31°	32	33	34	35	37	38	39	40	42	43	44	45	47	48	49	50
30°	30	32	33	34	35	36	37	39	40	41	42	43	45	46	47	48
29°	29	30	31	32	33	35	36	37	38	39	40	41	42	43	45	46
28°	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
27°	27	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
26°	26	26	27	28	29	30	31	32	33	34	34	35	36	37	38	39
25°	25	25	26	27	27	28	29	30	31	32	33	34	34	35	36	37
24°	24	24	24	25	26	27	28	28	29	30	31	32	33	33	34	35
23°	23	23	23	24	25	25	26	27	28	28	29	30	31	32	32	33
22°	22	22	22	22	23	24	25	25	26	27	27	28	29	30	30	31

Fino a 29 C°	Nessun disagio
Da 30 a 34 C°	Sensazione di disagio
Da 35 a 39 C°	Intenso disagio. Prudenza: limitare le attività fisiche più pesanti
Da 40 a 45 C°	Forte sensazione di malessere. Pericolo: evitare gli sforzi
Da 46 a 53 C°	Pericolo grave: interrompere tutte le attività fisiche
Oltre 54 C°	Pericolo di morte: colpo di calore imminente

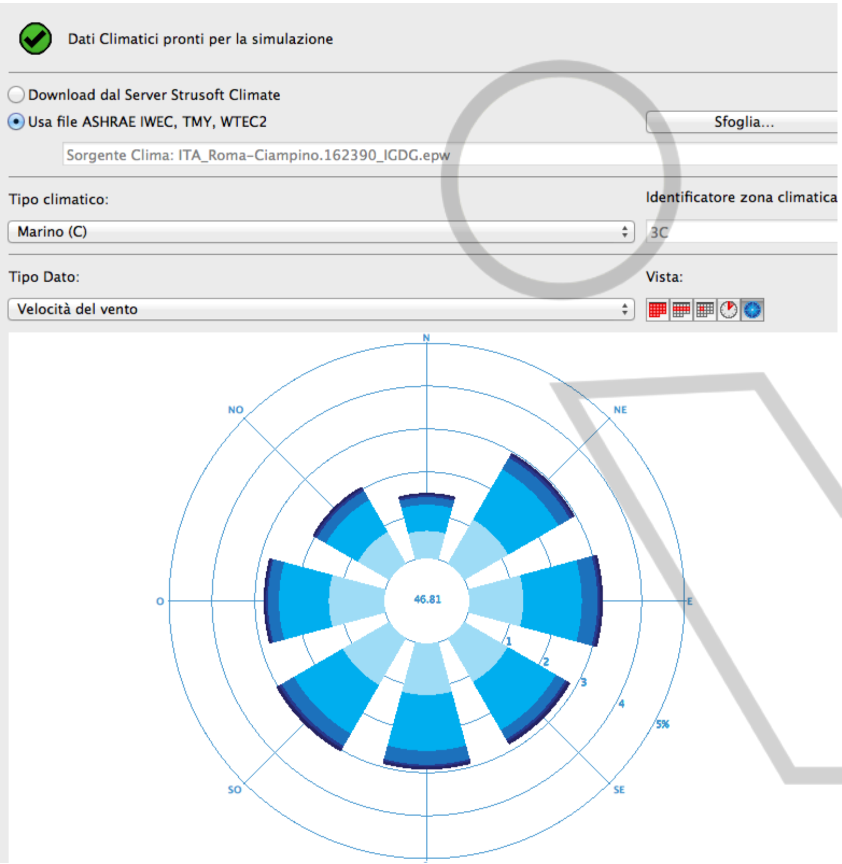
MODELING WIND

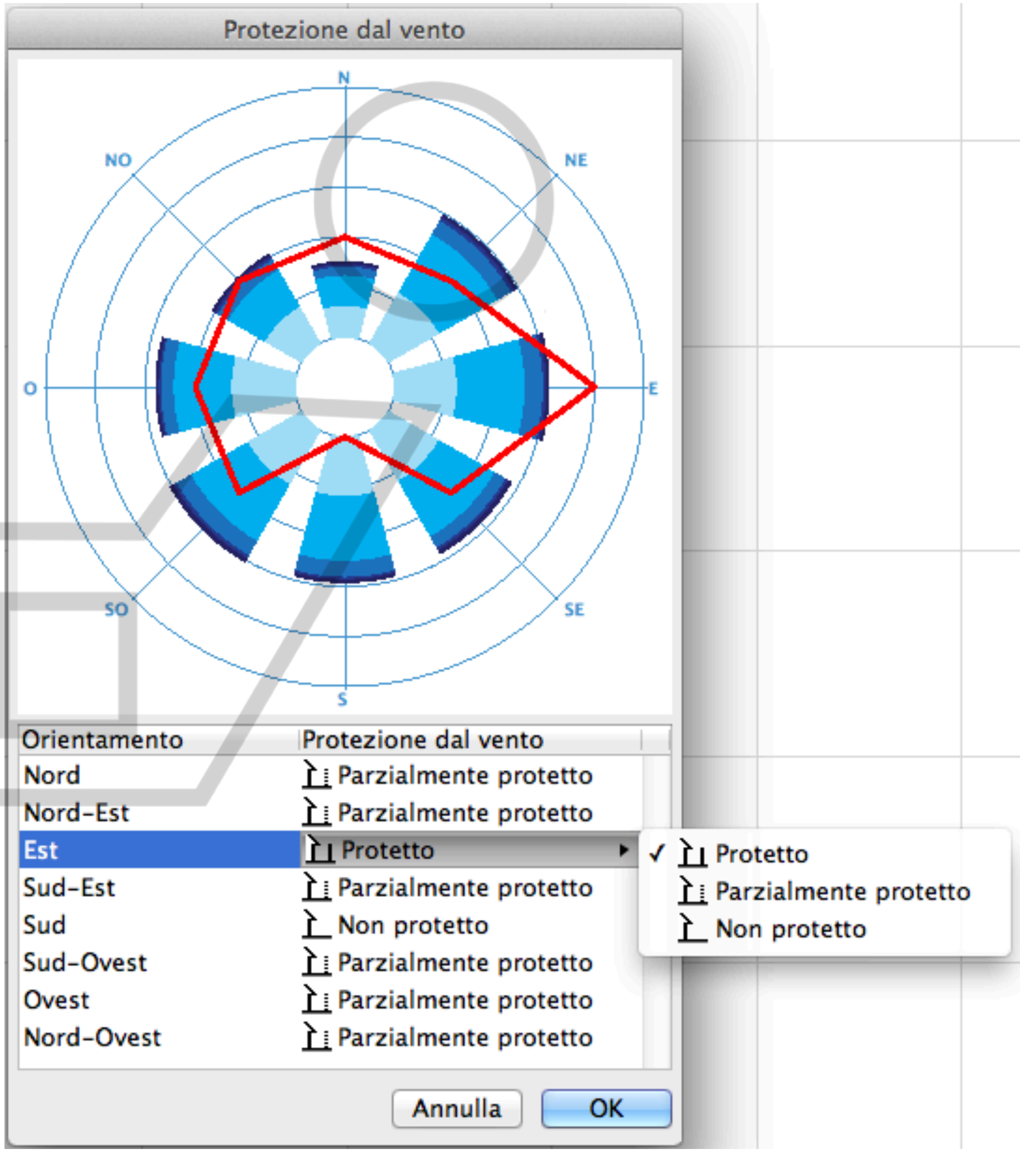
Summer Sunset
Monsoon Sunset
Winter Sunset
Summer Sunrise
Monsoon Sunrise
Winter Sunrise
Prevailing Wind

Wind and Ventilation

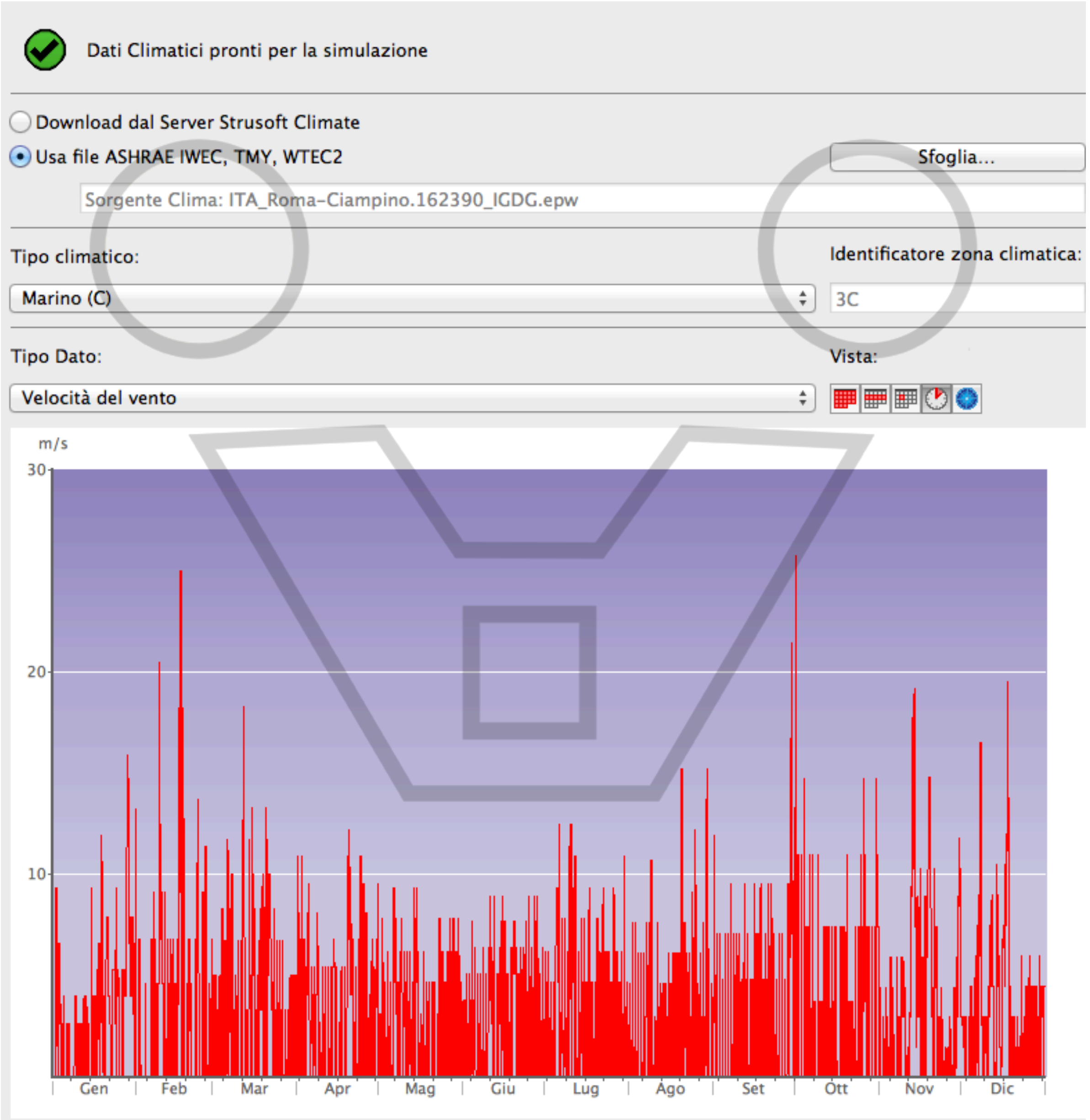
Air movement: WIND ANALYSIS

1- determine the coldest and the hottest seasonal period and hours
2- for that periods find the most frequent wind directions





Wind Velocity

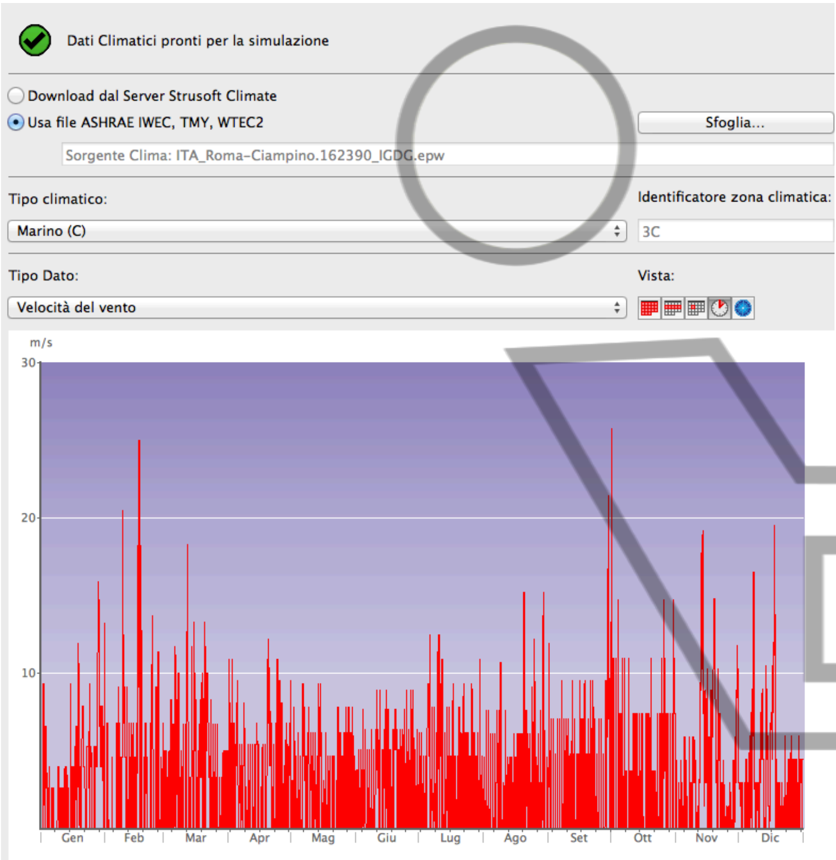


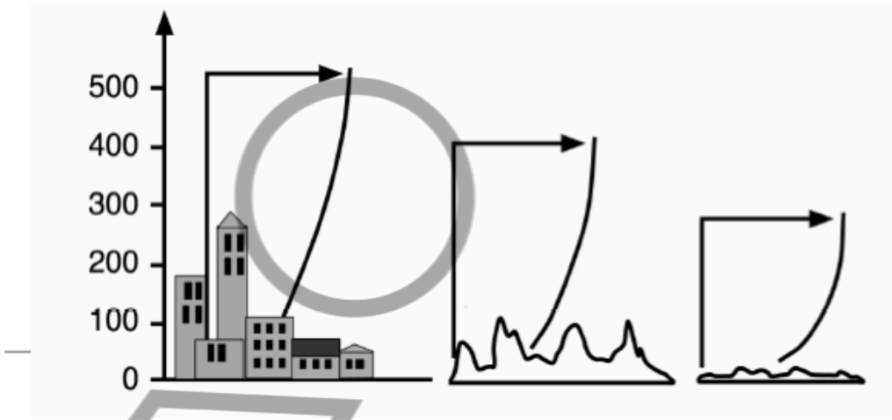
from archicad

Air movement: WIND ANALYSIS

3- define wind speed for the hottest and coldest periods

4- reduce the speed according to altitude and roughness of the site





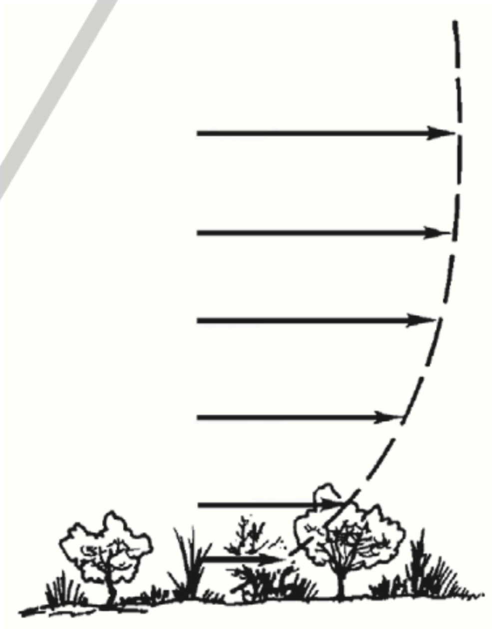


Figure 1—General wind velocity profile near surface (from Rothermel 1983).

Environmental parameters affecting thermal comfort: HUMIDITY

Effect of Wind on Temperature

Apparent temperature (AT) as a Wind Chill - after Steadman 1994

Temperature (°C)

Wind Speed (km/h)	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	17	19	20	21
2	-9	-8	-6	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	18	20	21
4	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	15	17	18	19	21
6	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	12	14	15	16	18	19	20
8	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19	20
10	-10	-9	-8	-7	-6	-5	-4	-2	-1	0	1	2	3	4	6	7	8	9	10	12	13	14	16	17	18	20
12	-11	-9	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	16	18	19
14	-11	-10	-9	-8	-7	-5	-4	-3	-2	-1	0	1	2	4	5	6	7	8	10	11	12	13	15	16	17	19
16	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	14	16	17	18
18	-12	-11	-10	-8	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	11	13	14	15	17	18
20	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16	18
22	-13	-11	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	4	6	7	8	9	11	12	13	15	16	17
24	-13	-12	-11	-10	-9	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	6	8	9	10	12	13	14	15	17
26	-13	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	2	4	5	6	7	9	10	11	12	14	15	16
28	-14	-13	-12	-10	-9	-8	-7	-6	-5	-4	-3	-1	0	1	2	3	5	6	7	8	9	11	12	13	15	16
30	-14	-13	-12	-11	-10	-9	-7	-6	-5	-4	-3	-2	-1	1	2	3	4	5	7	8	9	10	12	13	14	16
32	-14	-13	-12	-11	-10	-9	-8	-7	-6	-4	-3	-2	-1	0	1	3	4	5	6	7	9	10	11	13	14	15
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74	-23	-22	-20	-19	-18	-17	-16	-15	-14	-13	-12	-10	-9	-8	-7	-6	-4	-3	-2	-1	1	2	3	4	6	7
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78	-23	-22	-21	-20	-19	-18	-17	-16	-15	-13	-12	-11	-10	-9	-8	-6	-5	-4	-3	-2	0	1	2	4	5	6
80	-24	-23	-22	-21	-19	-18	-17	-16	-15	-14	-13	-12	-10	-9	-8	-7	-6	-4	-3	-2	-1	1	2	3	5	6

Apparent temperature with no rad[illegible]tive humidity fixed at 70%

Formula from *Norms of apparent tempe*[illegible]*stralia*, **Aust. Met. Mag**, Vol 43, 1994, 1-16.

Air movement: WIND ANALYSIS

HOW TO VISUALIZE WINDS – Airflow Modeling

Understanding the air flow and distribution patterns for buildings.

The building form and shape can affect how air flows through the building and across neighboring developments into the building.

This is an important consideration for natural ventilation and can significantly reduce costs of air-conditioning provisions.

There are Computational Fluid Dynamics (CFD) tools available that can help simulate the air-flow patterns within built-spaces as well as for whole building estates

Basic software tool:

Flow Design http://www.autodesk.com/education/free-software/flow-design (student version available)

Other popular software tools:

Fluent by Ansys: http://www.ansys.com/. (student version available)

FloVent from Mentor Graphics: http://www.mentor.com/.

Comsol Multiphysics modeling software: https://www.comsol.com/.

References

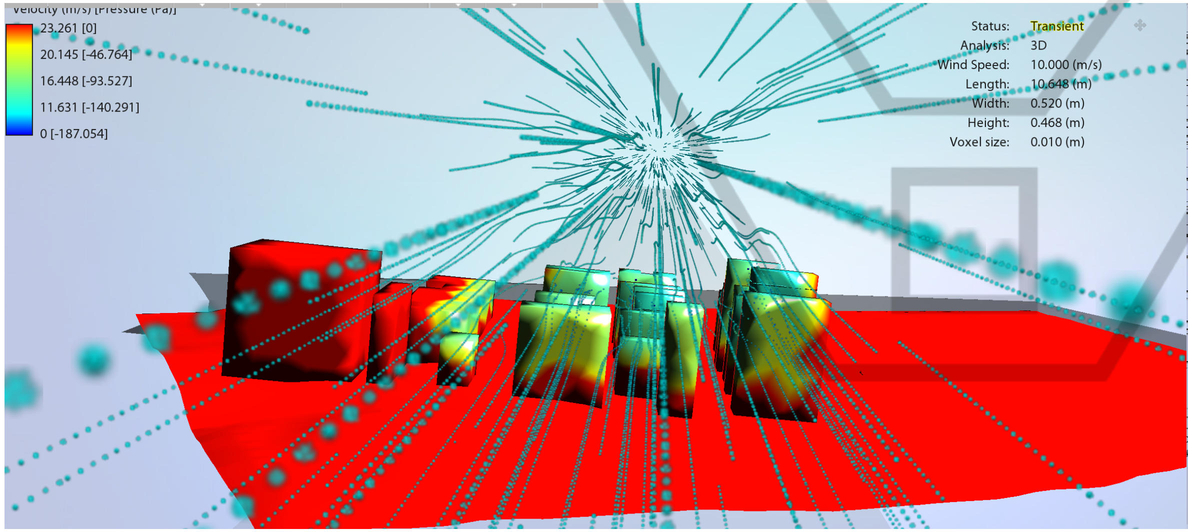
AIA (The American Institute of Architects) (2012) An Architect's guide to integrating energy modeling in the design process

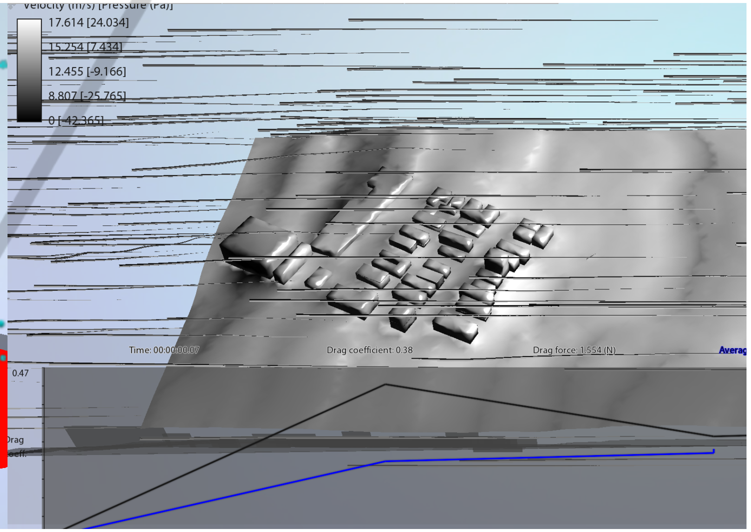
ERI@N (Energy Research Institute @ NTU) (2013) Nanyang Technological University (NTU), Singapore

NREL (2009) A handbook for planning and conducting charrettes for high-performance projects, National Renewable Energy Laboratory (NREL), Sept 2009

Air movement: WIND ANALYSIS

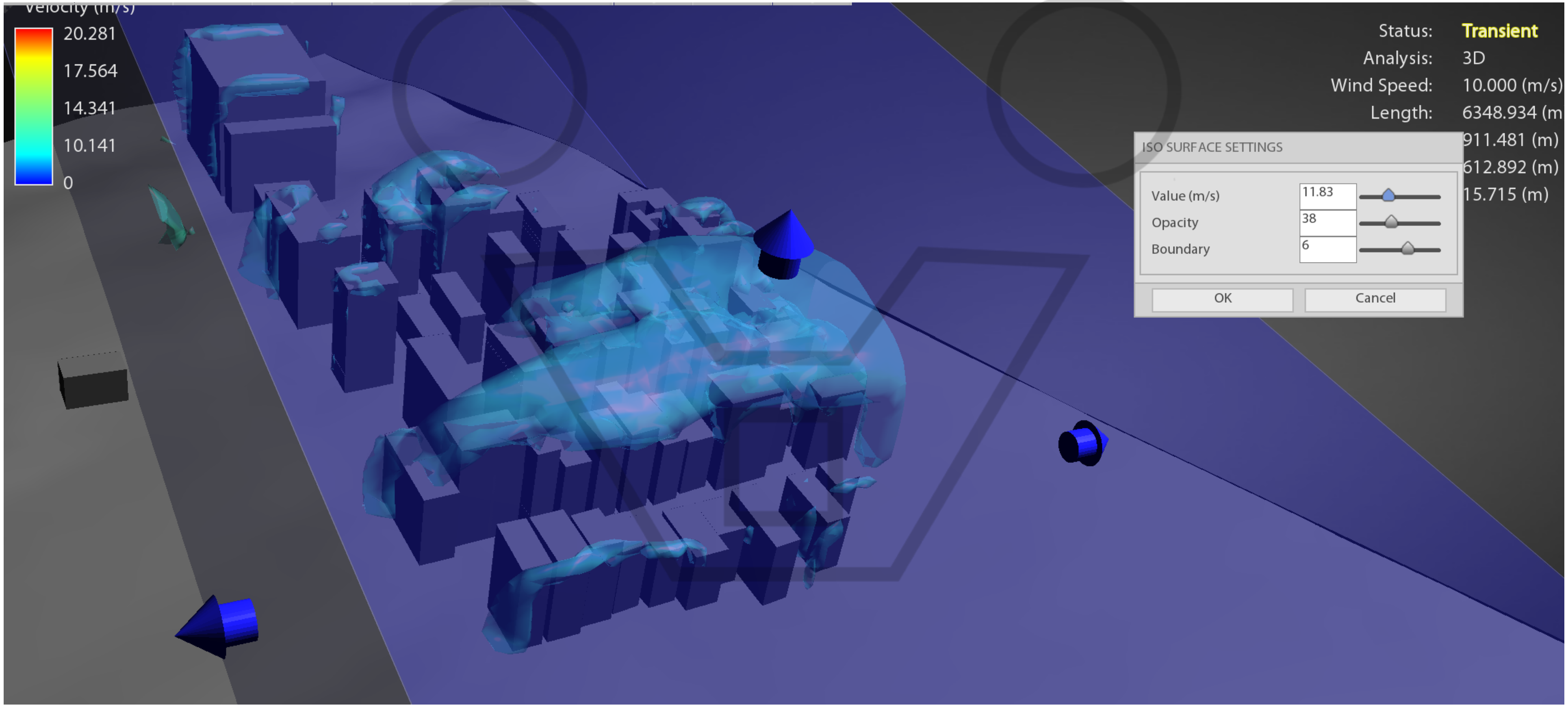
5- Orient the model according to the wind direction



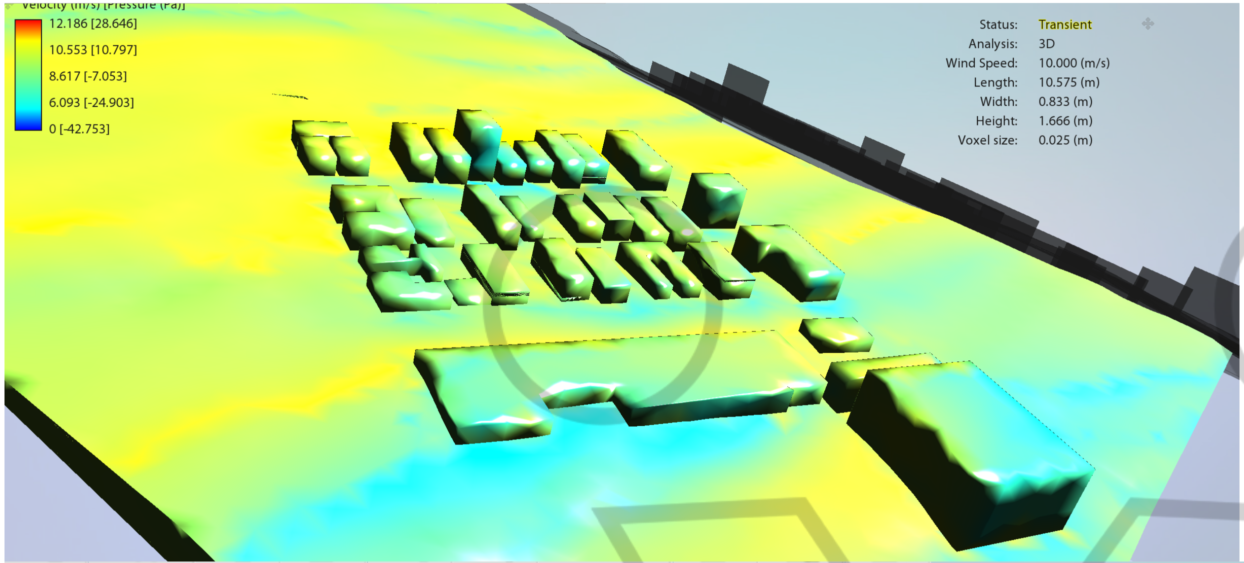


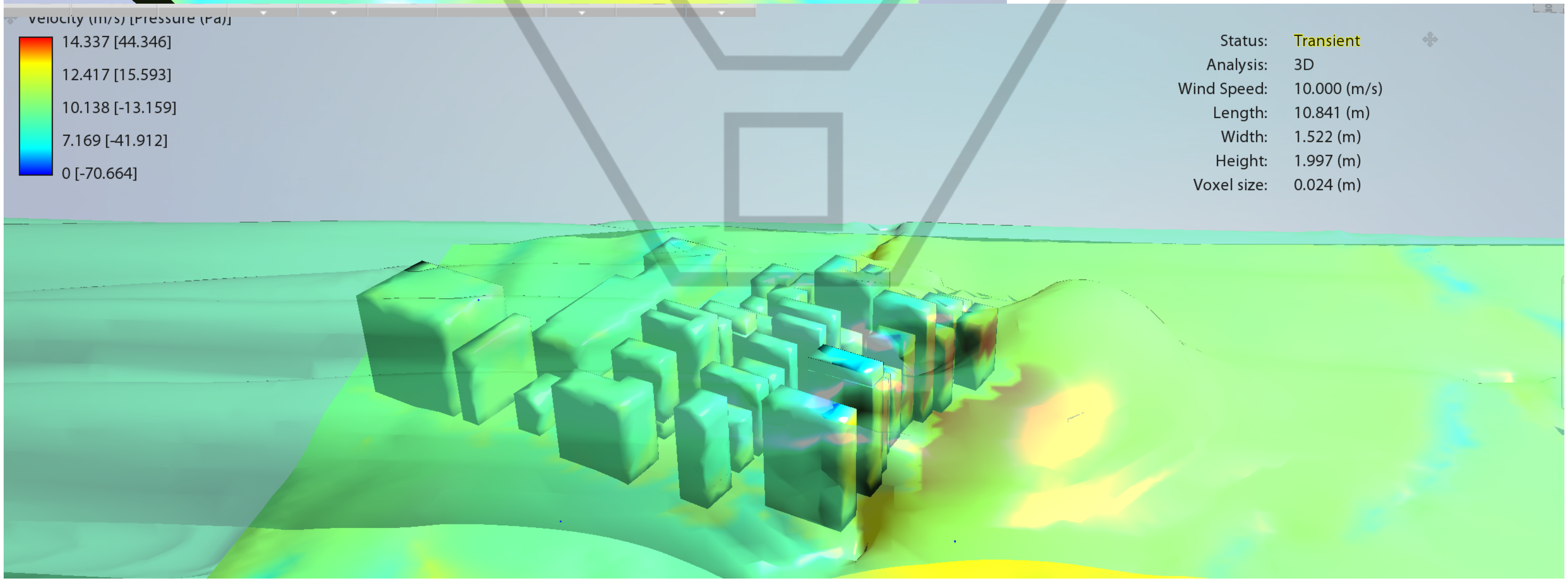
Air movement: WIND ANALYSIS

6- Set the wind velocity & analyze results (low, high pressure zones)



Air movement: WIND ANALYSIS





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http://www.energy-design-tools.aud.ucla.edu/