# MODELING CLIMATE, SITE & PLACE ASSESSMENT TO SELECT WHERE AND HOW TO BUILD SUSTAINABLE ARCHITECTURES

Prof. Arch. Giuseppe Ridolfi, PhD

ASSESSING the PLACE a mix of interrelated aspects

CLIMATE/SITE/CULTURE

***the Context of intervention or, in short, the Place as the mix of environmental aspects such as socio-economic, cultural, regulatory, and physical.***

***The architect's task is to gather these information, evaluate different aspects and alternatives and compose them in early design ideas***

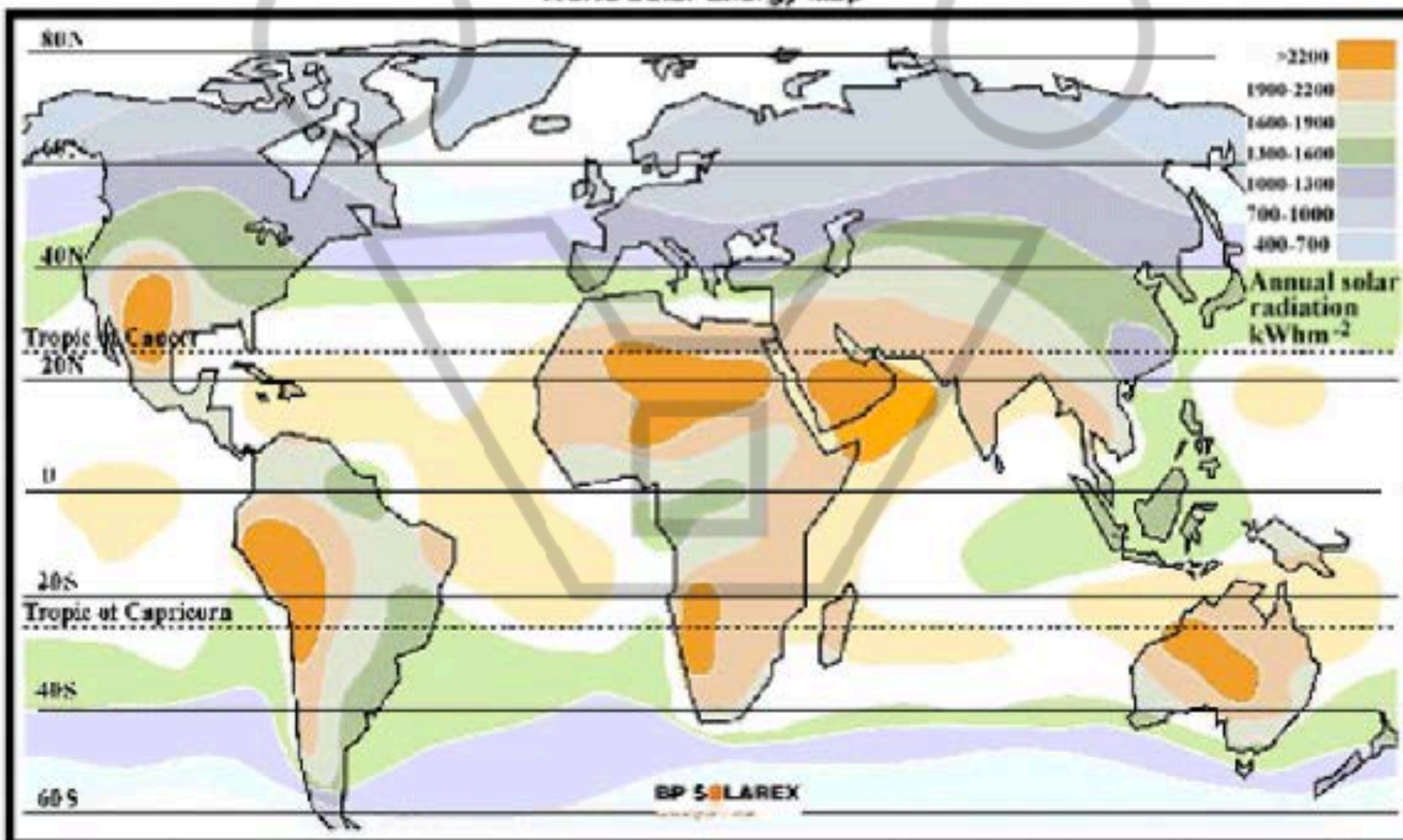
# 1. CLIMATE

# CLIMATE: **affects physical, socio-cultural, and technological aspects**


# The influence of the site: GEOGRAPHICAL POSITION

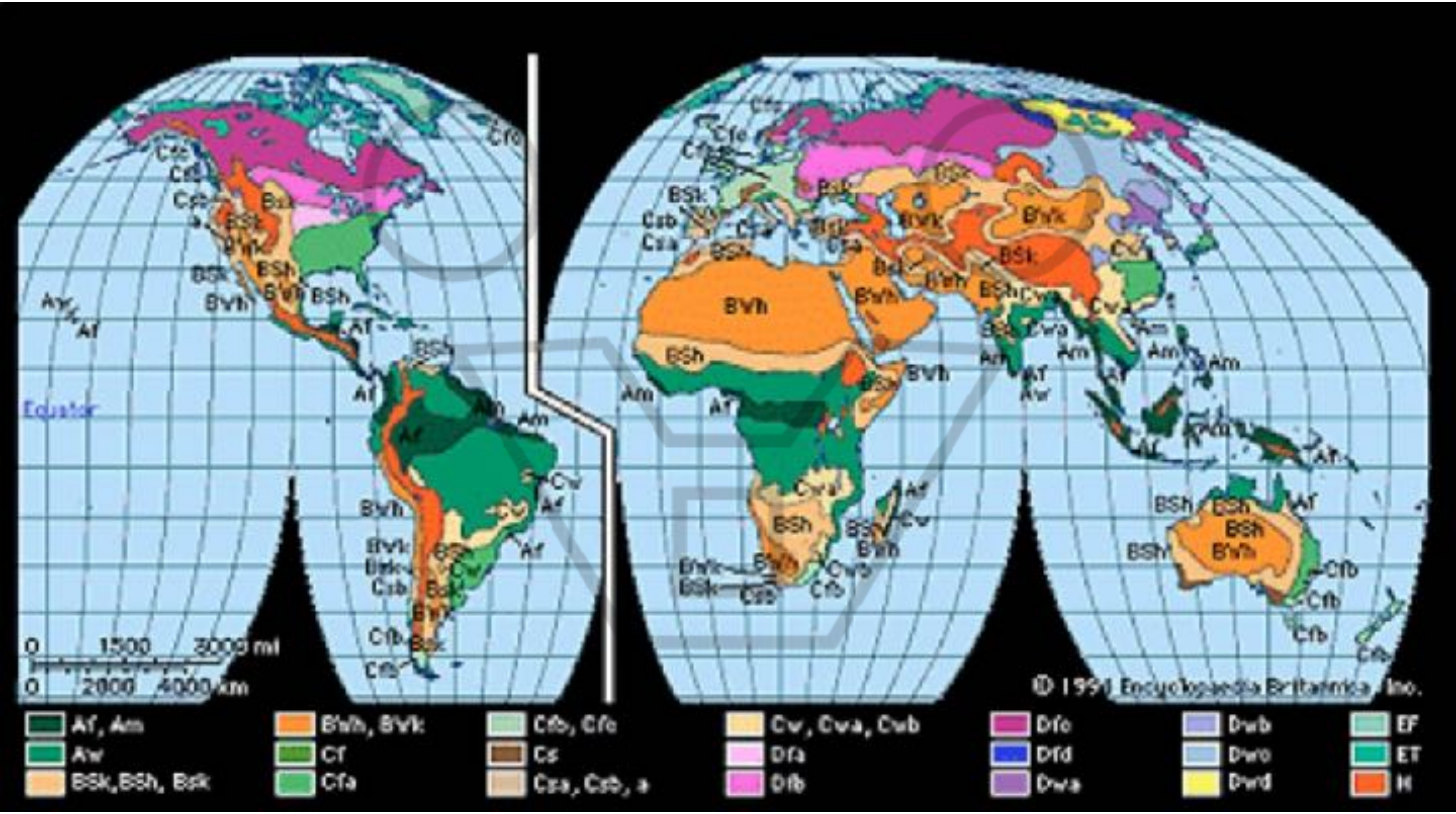
Insolation is the sun's energy on a surface
Sun's energy depends on angle, sky conditions, volume and surfaces around.
Weather files give the total amount of *direct energy* along a year measured perpendicularly to the sun direction
And *diffuse energy* measured getting all the energy and subtracting the direct energy capted,

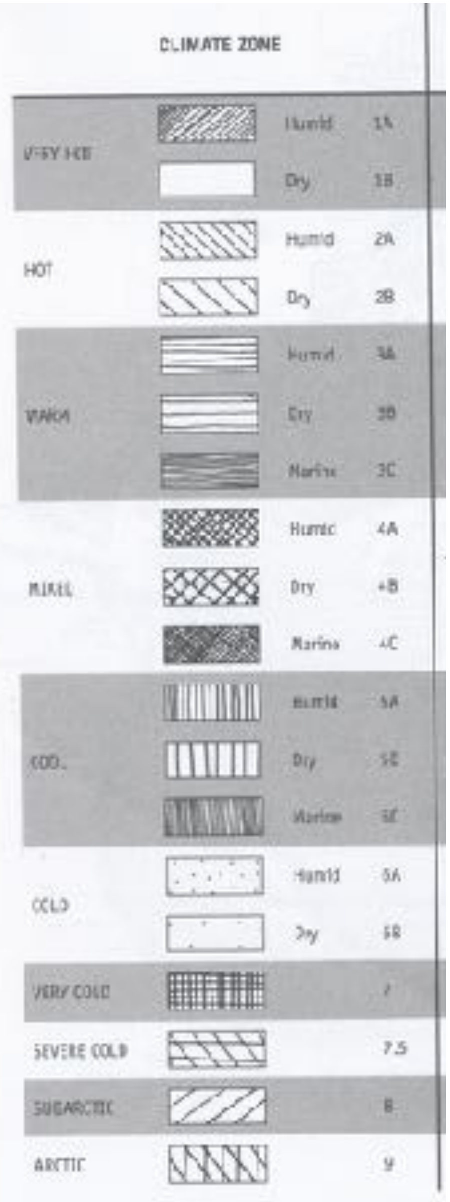
World Solar Energy Map



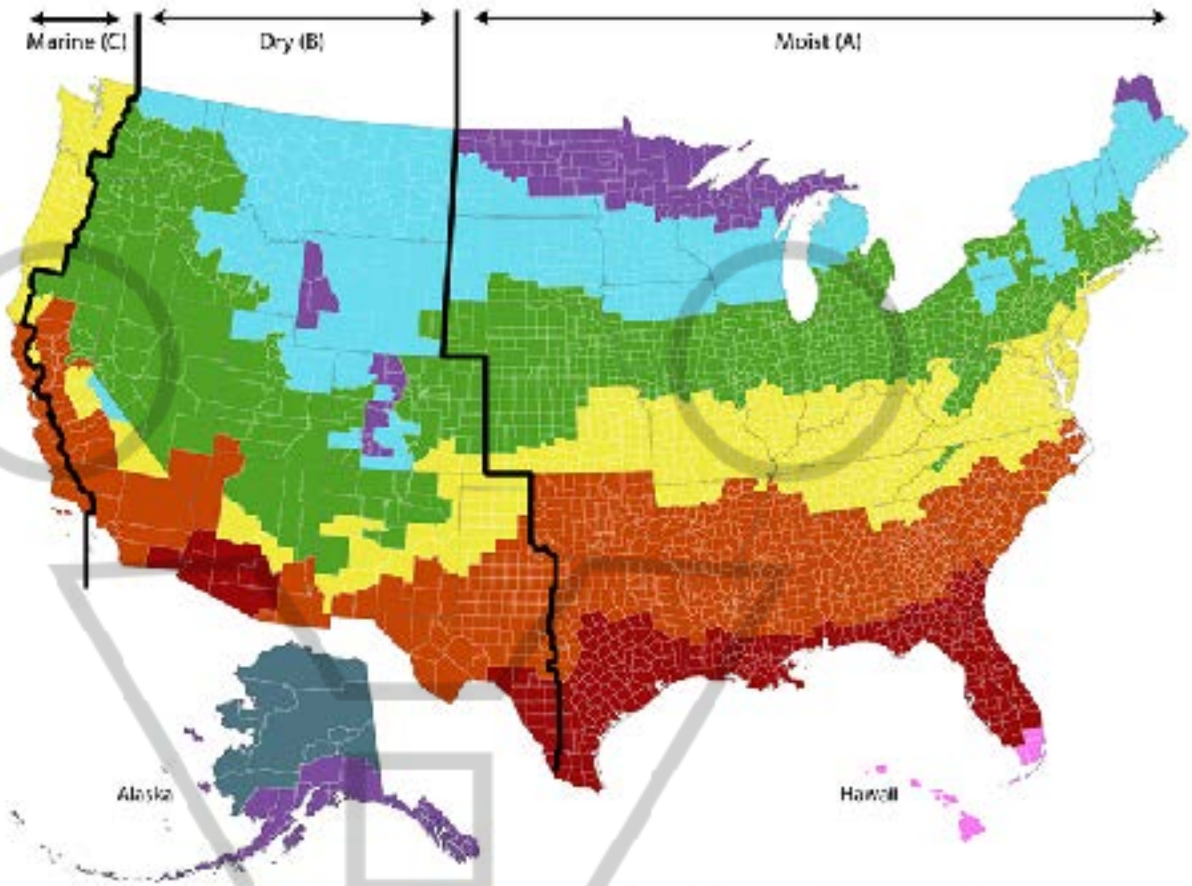

www.solarpartners.org

1- Find your climate zone






International climate zones, definitions



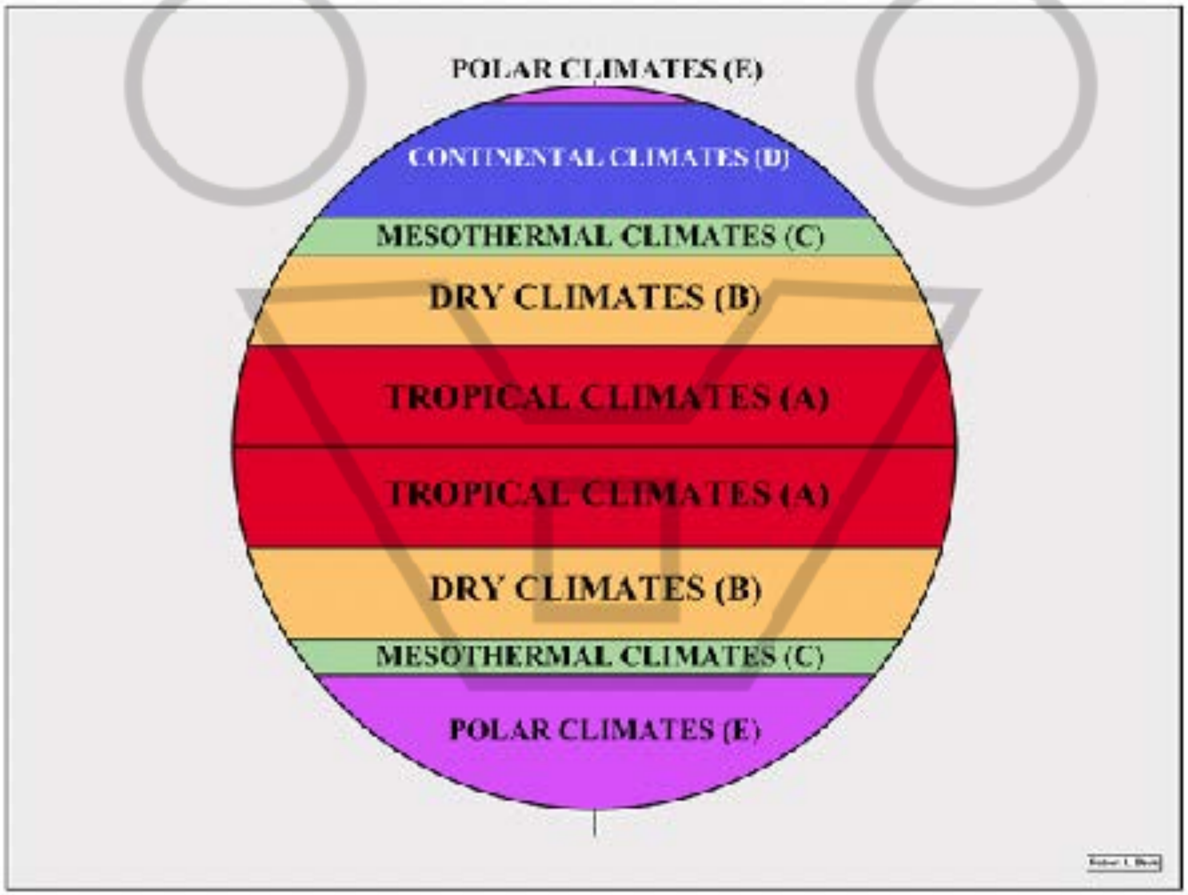

| Climate Zone | Representative City |
|---|---|
| 1A | Miami, Florida |
| 2A | Houston, Texas |
| 2B | Phoenix, Arizona |
| 3A | Atlanta, Georgia |
| 3B CA | Los Angeles, California |
| 3B Other | Las Vegas, Nevada |
| 3C | San Francisco, California |
| 4A | Baltimore, Maryland |
| 4B | Albuquerque, New Mexico |
| 4C | Seattle, Washington |

| Climate Zone | Representative City |
|---|---|
| 5A | Chicago, Illinois |
| 5B | Boulder, Colorado |
| 6A | Minneapolis, Minnesota |
| 6B | Helena, Montana |
| 7 | Duluth, Minnesota |
| 8 | Fairbanks, Alaska |

ASHRAE climate classification

# Köppen's climate classificationc

**Latitudinal Model of the Köppen Climate Groups**



# Köppen's climate classification

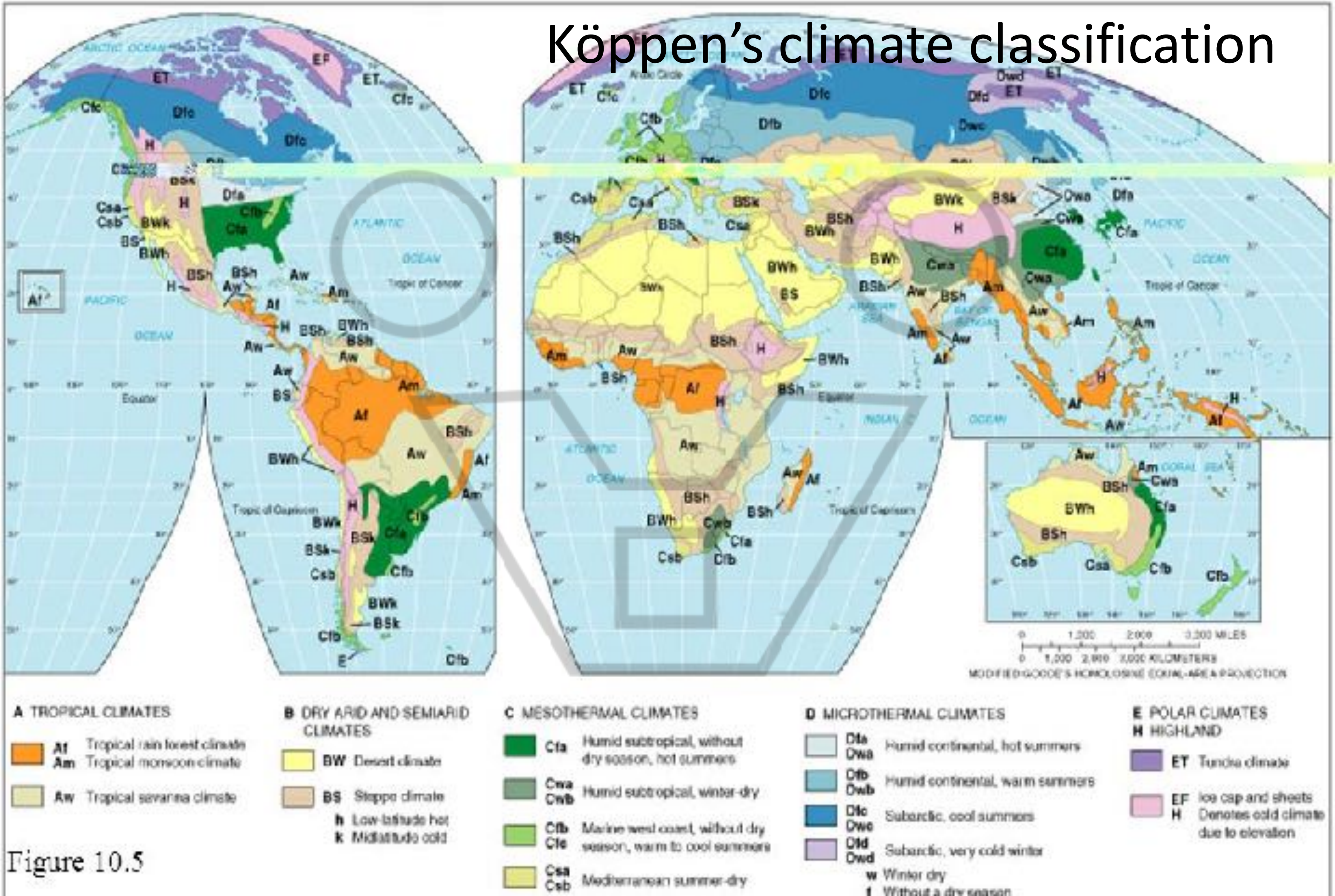


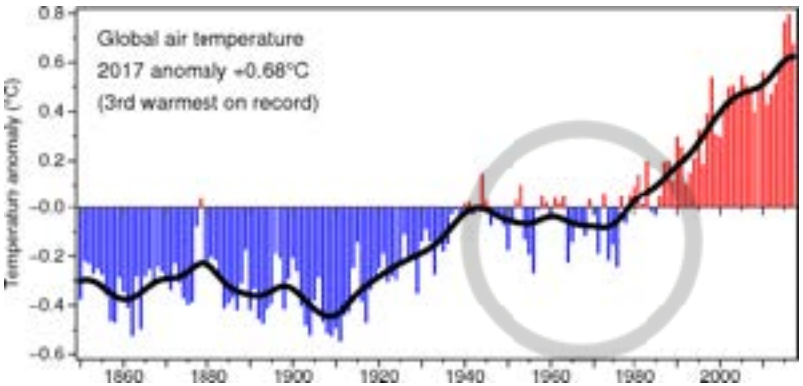

Figure 10.5

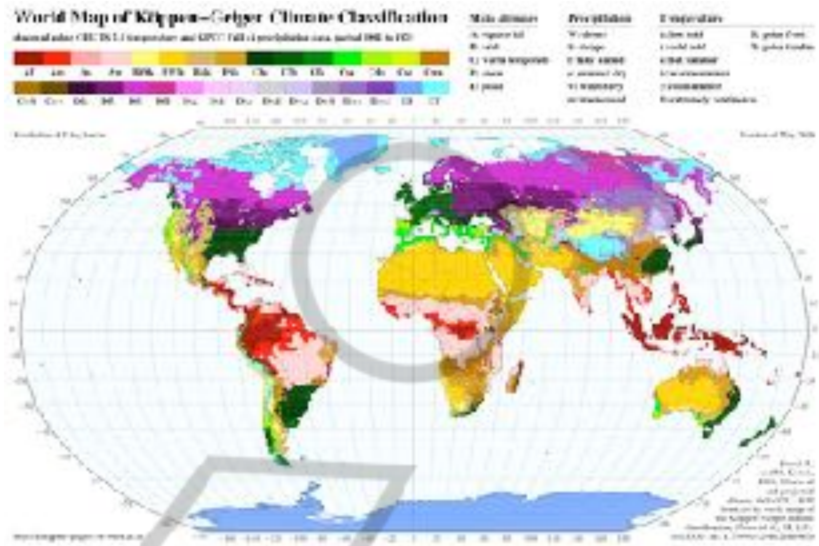
2- Tune-Up your climate conditions and zones considering the best appropriate wheather data

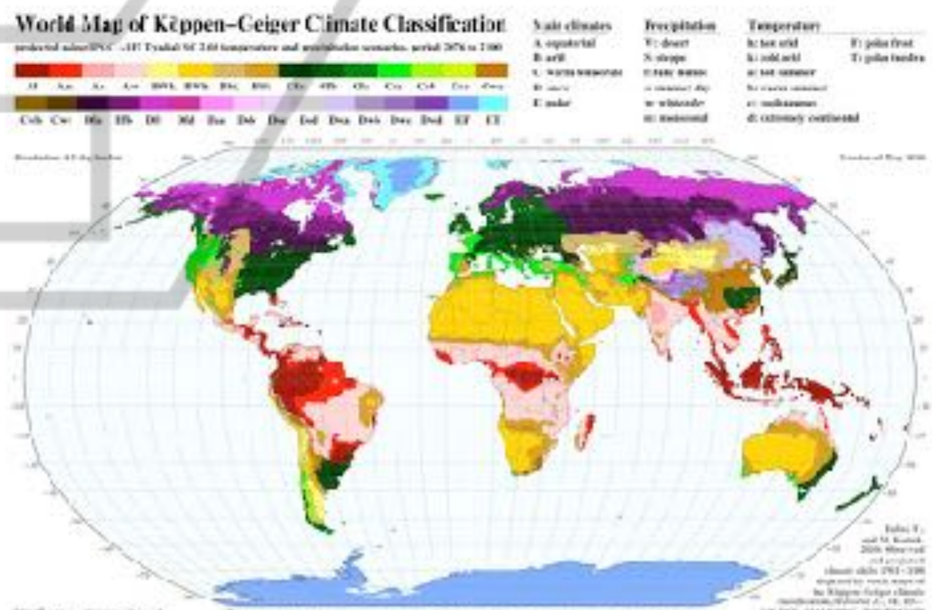
-find detailed statistical data of your site

-consider climate condition of similar sites
In terms of:
•altitude,
•locations (by the sea, hill, urban,...)
•type of soils
•terrain morphology,
•winds exposition,

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

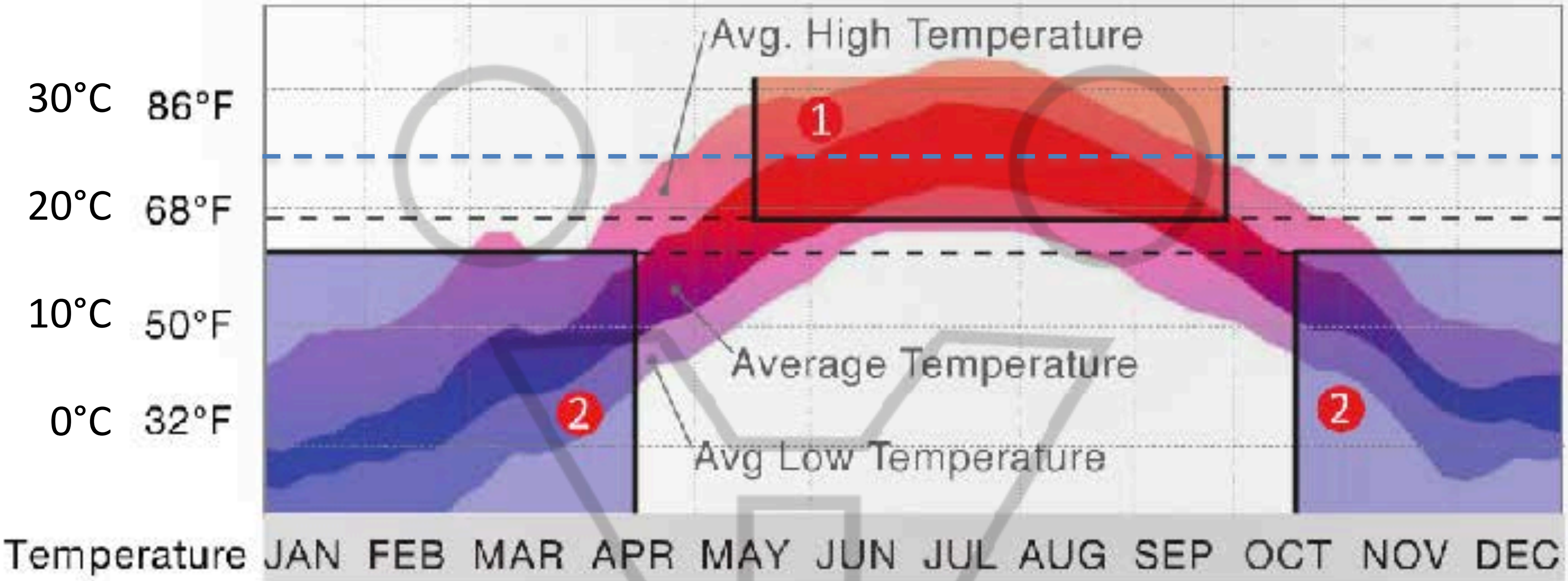


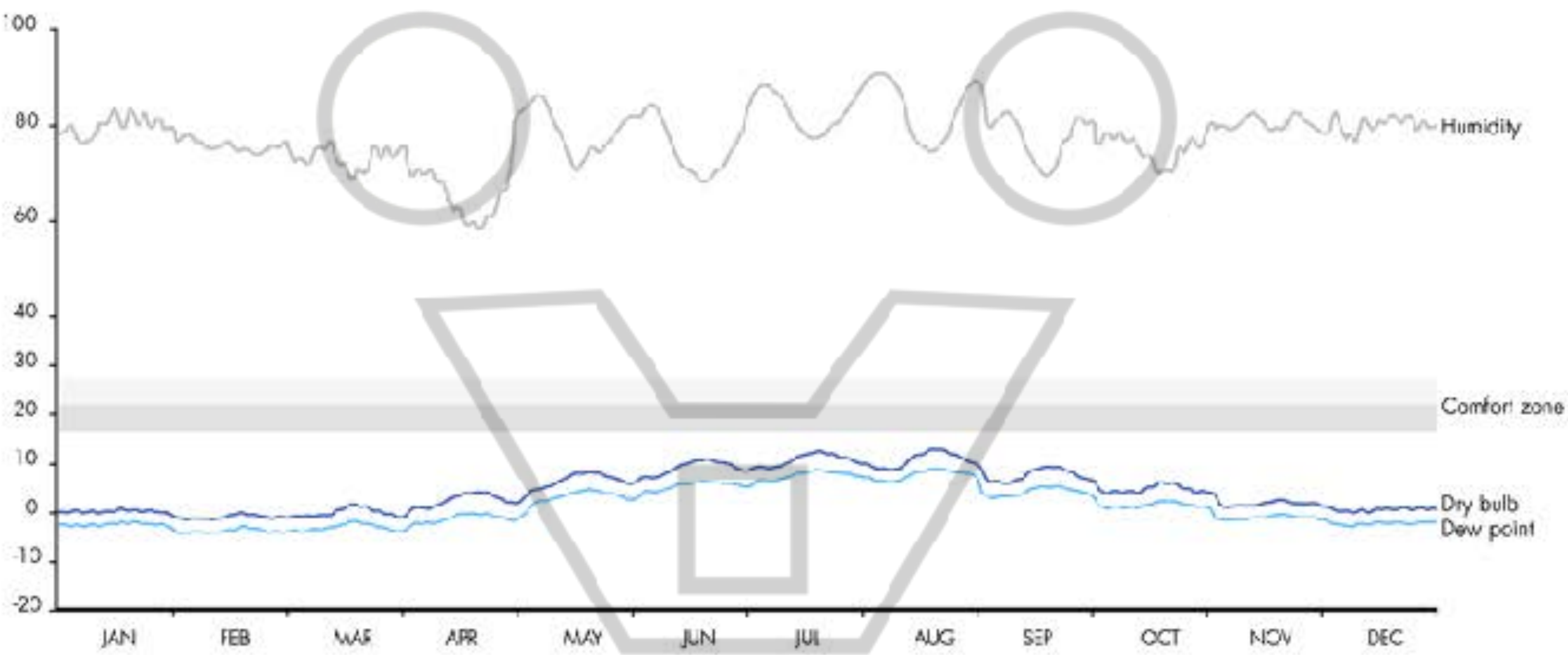
2. Confirm the main energy behaviour using Annual Temperature Profile

**COOLING VS HEATING: A GENERAL ESTIMATIONwith ANNUAL TEMPERATURE METHOD**

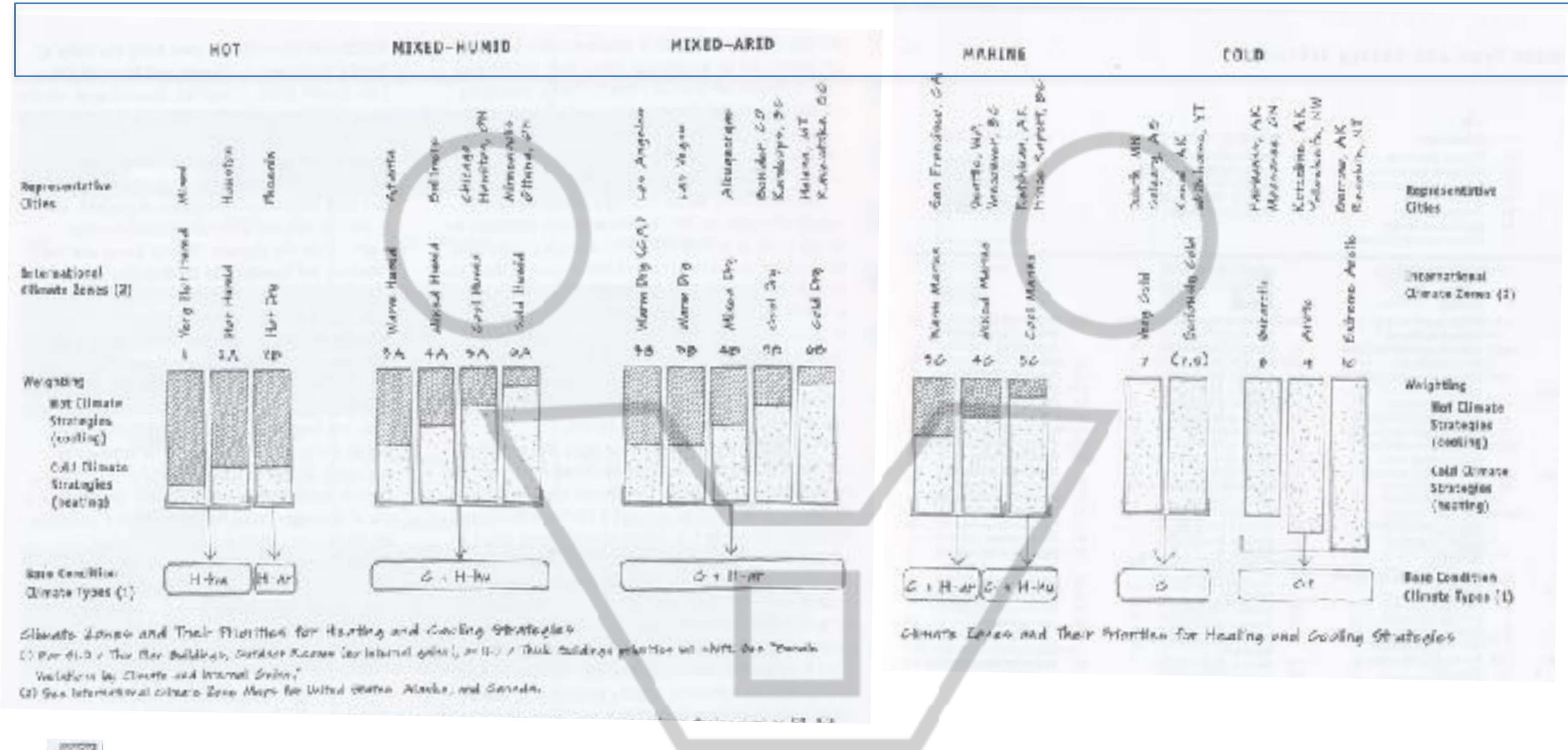



7.3 Temperature Method.
Annual temperature profile, with estimated heating and cooling seasons highlighted.

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


100
80
60
40
30
20
10
0
-10
-20
Humidity
Comfort zone
Dry bulb
Dew point
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

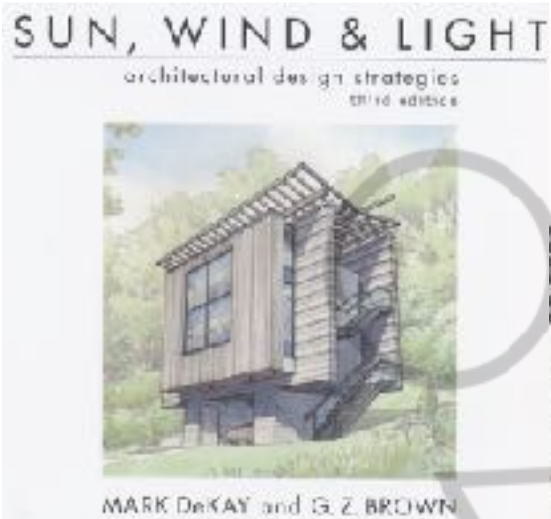
# 3. Analize thermal condition in order to establish design priorities **heating/cooling**

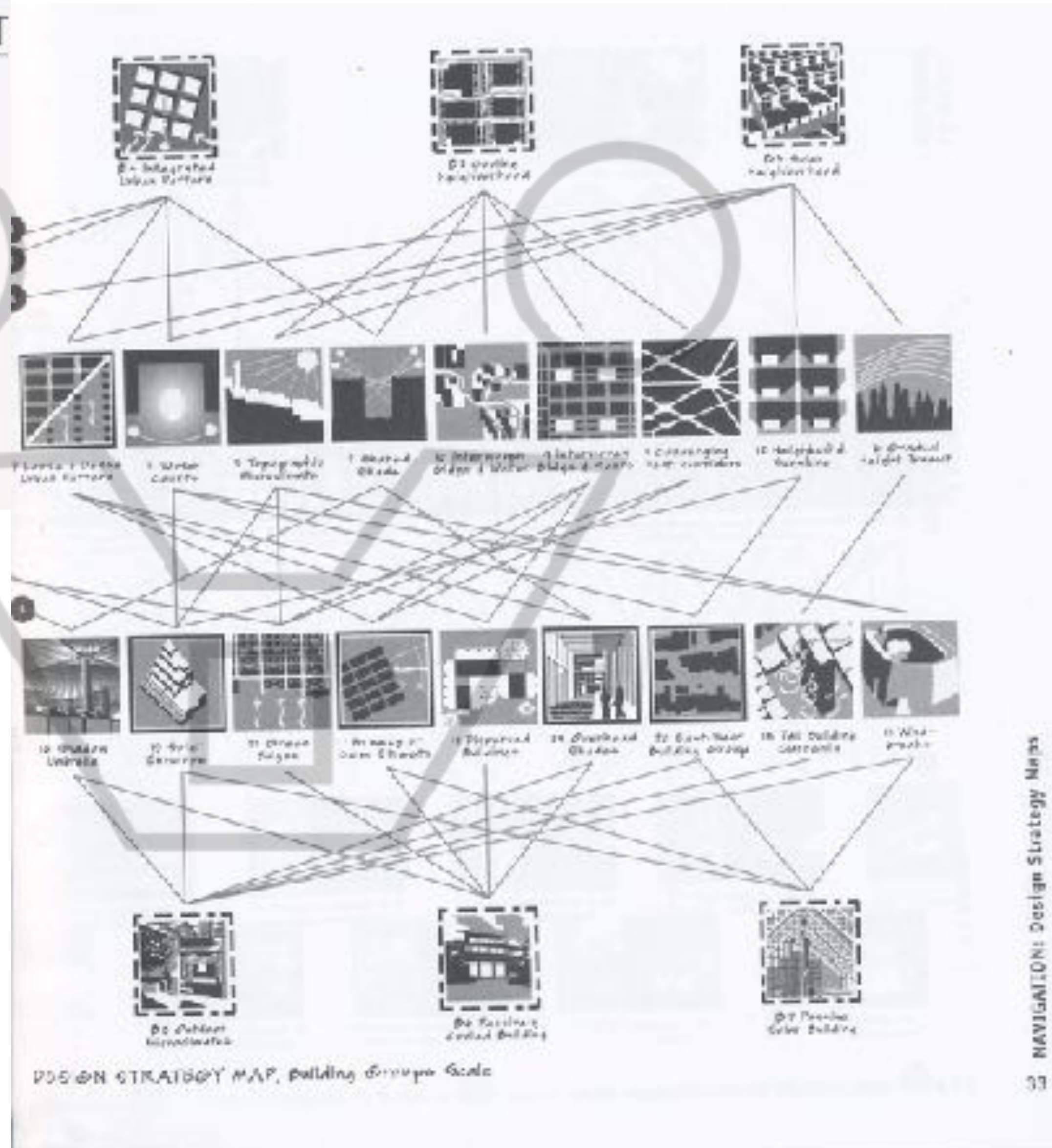



To be cooled

To be heated

# 4. Find & define appropriate design criteria & recommendations

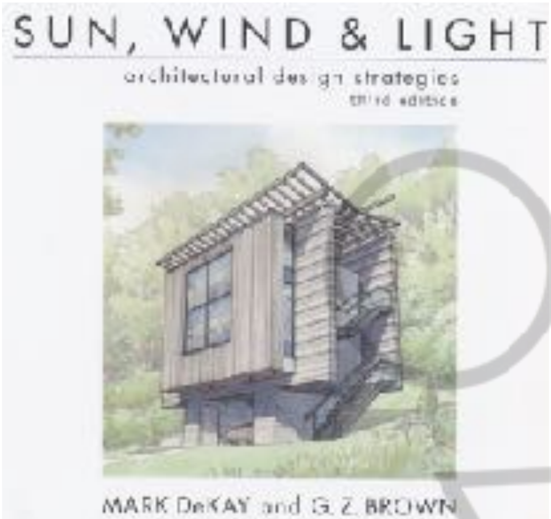



USING RULES OF THUMBS

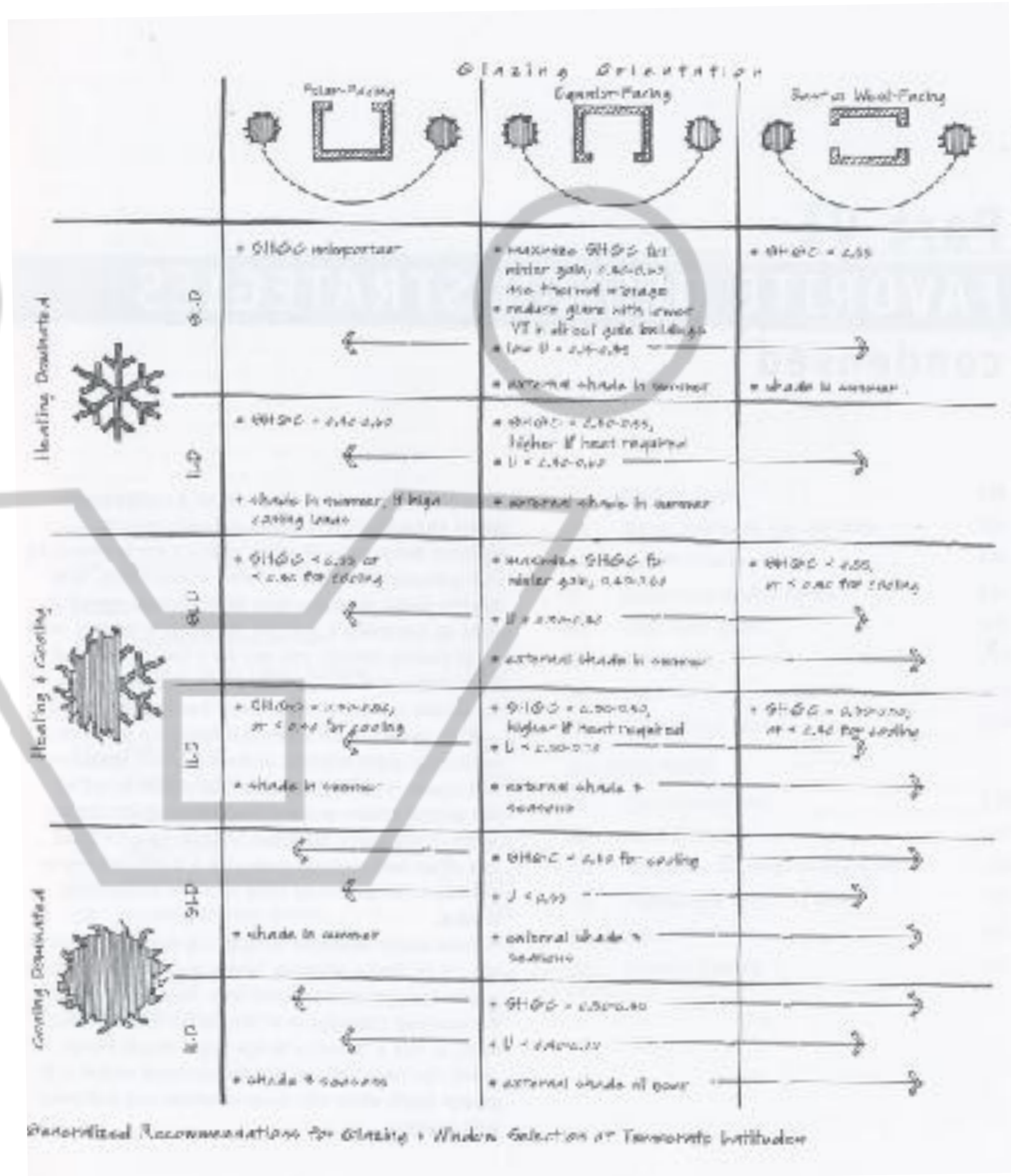
Example of general recommendations for urban integration

# 4. Find & define appropriate design criteria & recommendations




USING RULES OF THUMBS

Example of general recommendations for glazing types and orientation



# MODELING CLIMATE, SITE & PLACE ASSESSMENT TO SELECT WHERE AND HOW TO BUILD SUSTAINABLE ARCHITECTURES

USING COMPUTATIONAL APPROACH

# 1. CLIMATE

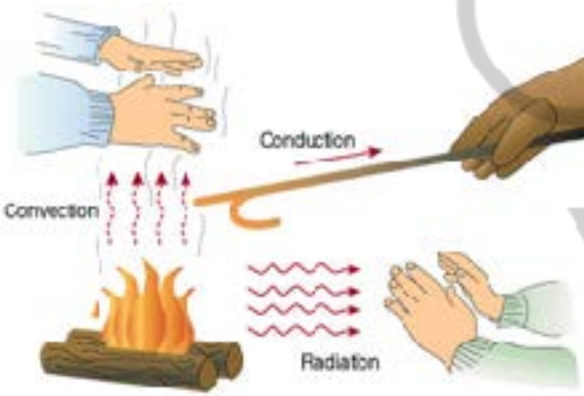
Temperature
Humidity
WInds

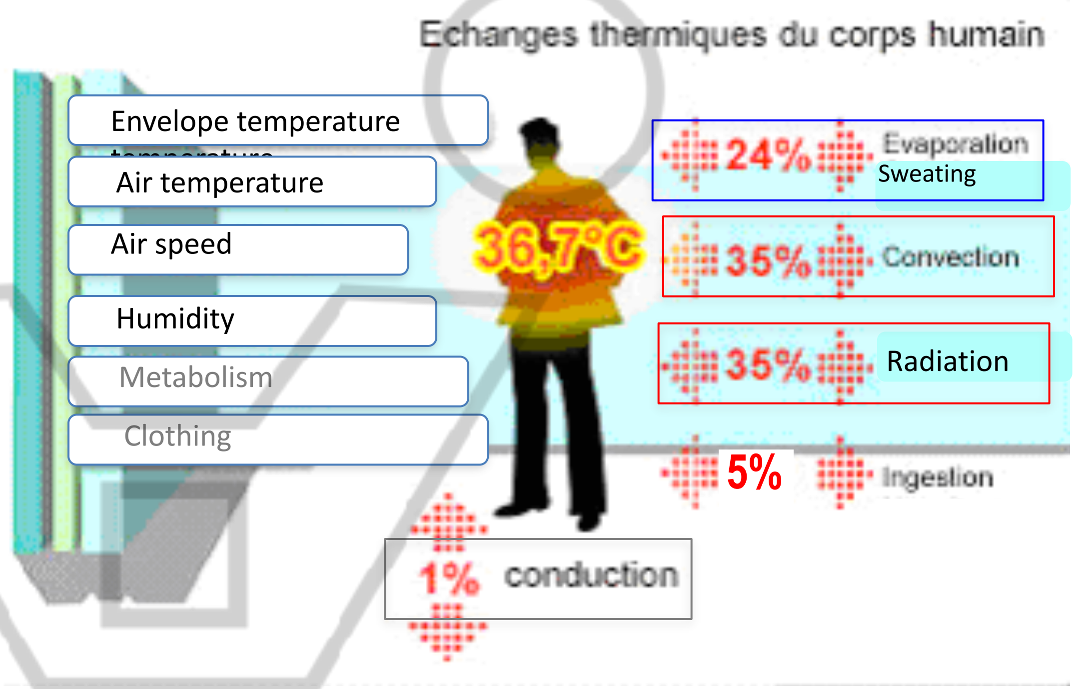
# 1. CLIMATE

## TEMPERATURES & HUMIDITY

# THERMAL COMFORT

## Parameters affecting thermal comfort

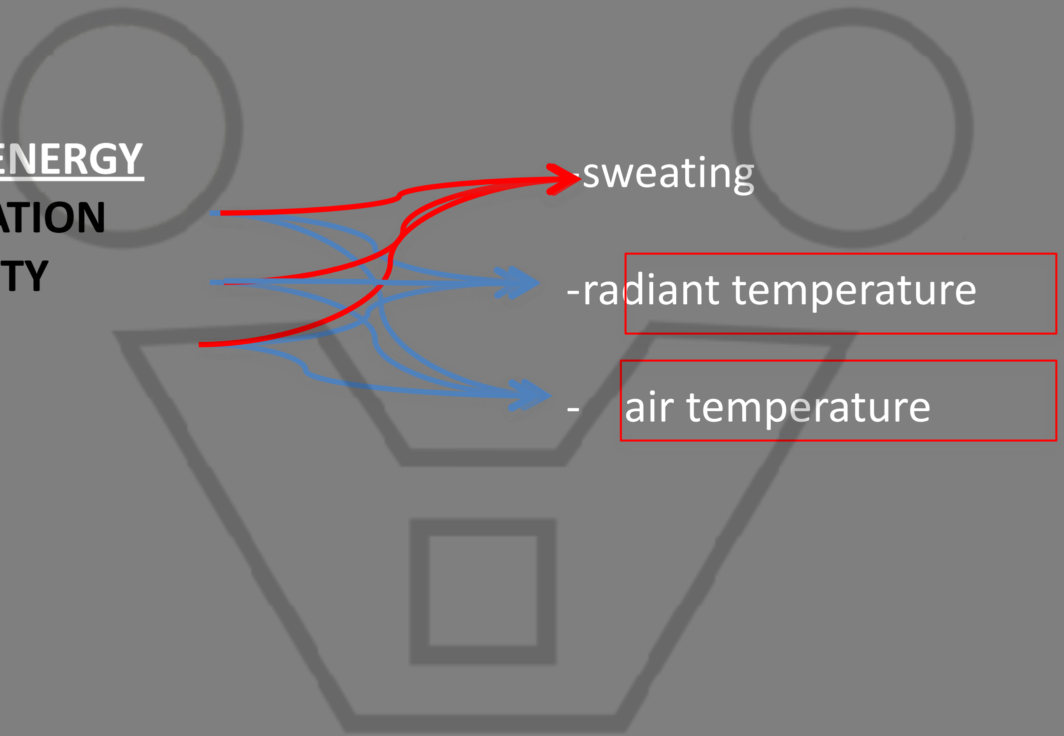


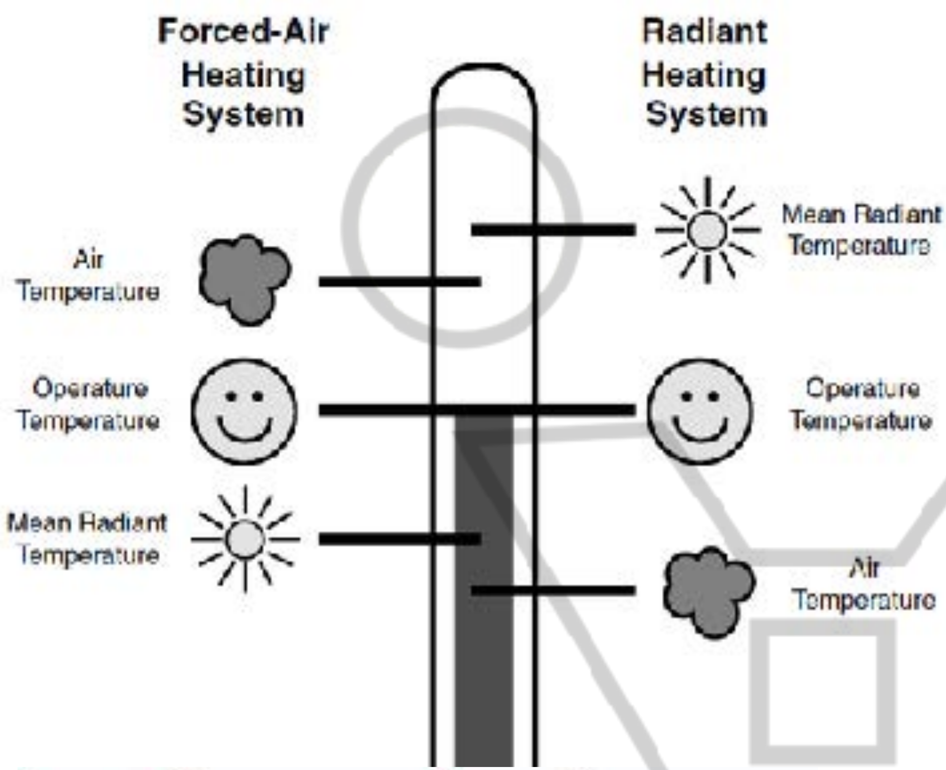

RADIANT TEMPERATURE+AIR TEMPERATURE

**Environmental Parameters affecting thermal comfort:**

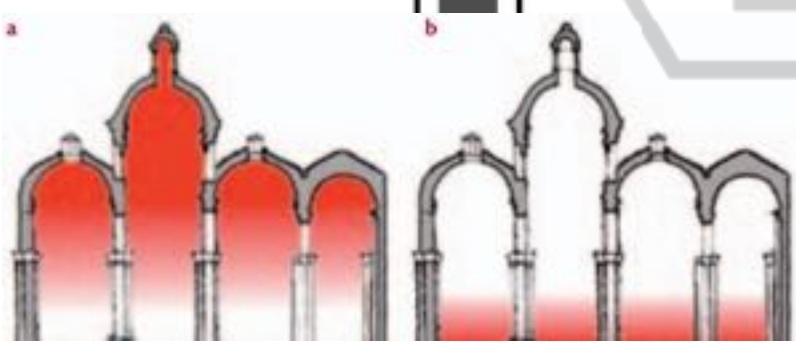
- <u>**SOLAR ENERGY**</u>
- **VENTILATION**
- **HUMIDITY**



# OPERATIVE TEMPERATURE




Radiant heating systems compensate a lower air temperature with a higher radiant temperature, while air heating systems compensate a lower radiant temperature with a higher air temperature. The operative temperature -- a weighted average of both -- can be the same. Source: *Radiant Heating & Cooling Handbook*, Richard Watson, 2008.



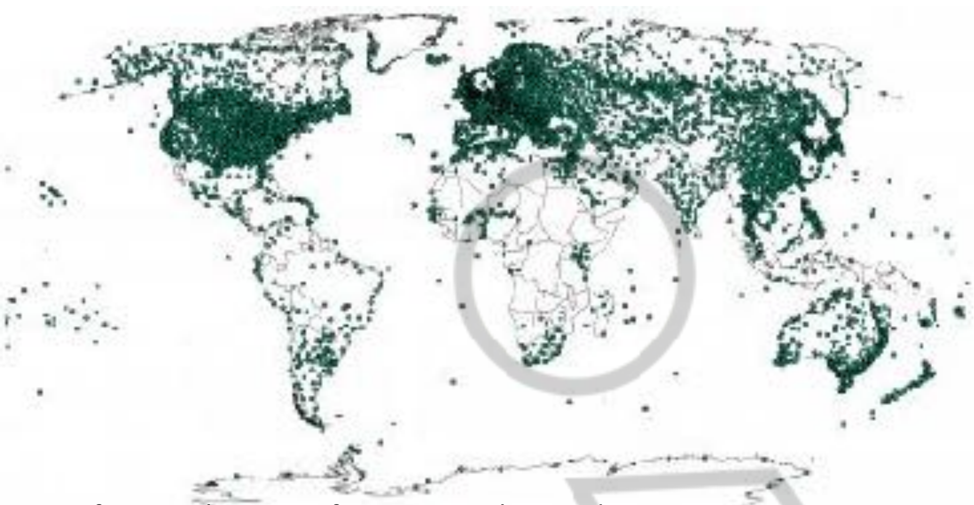

Air heating (left) versus radiant heating (right) in a church building. Source: Fabric-friendly heating, Dario Camuffo.

TEMPERATURE

$f$ (altitude, context, sun radiation, wind, humidity, sky)

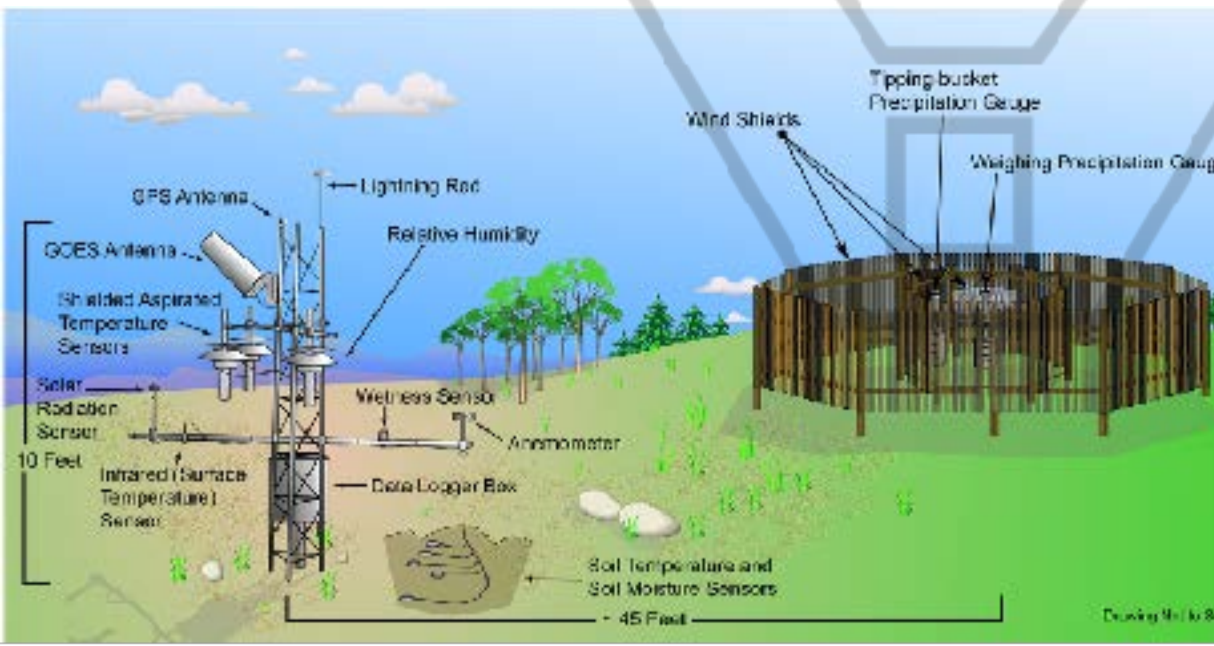
Climate data

# HOW TO COLLECT CLIMATE DATA: WEATHER STATIONS

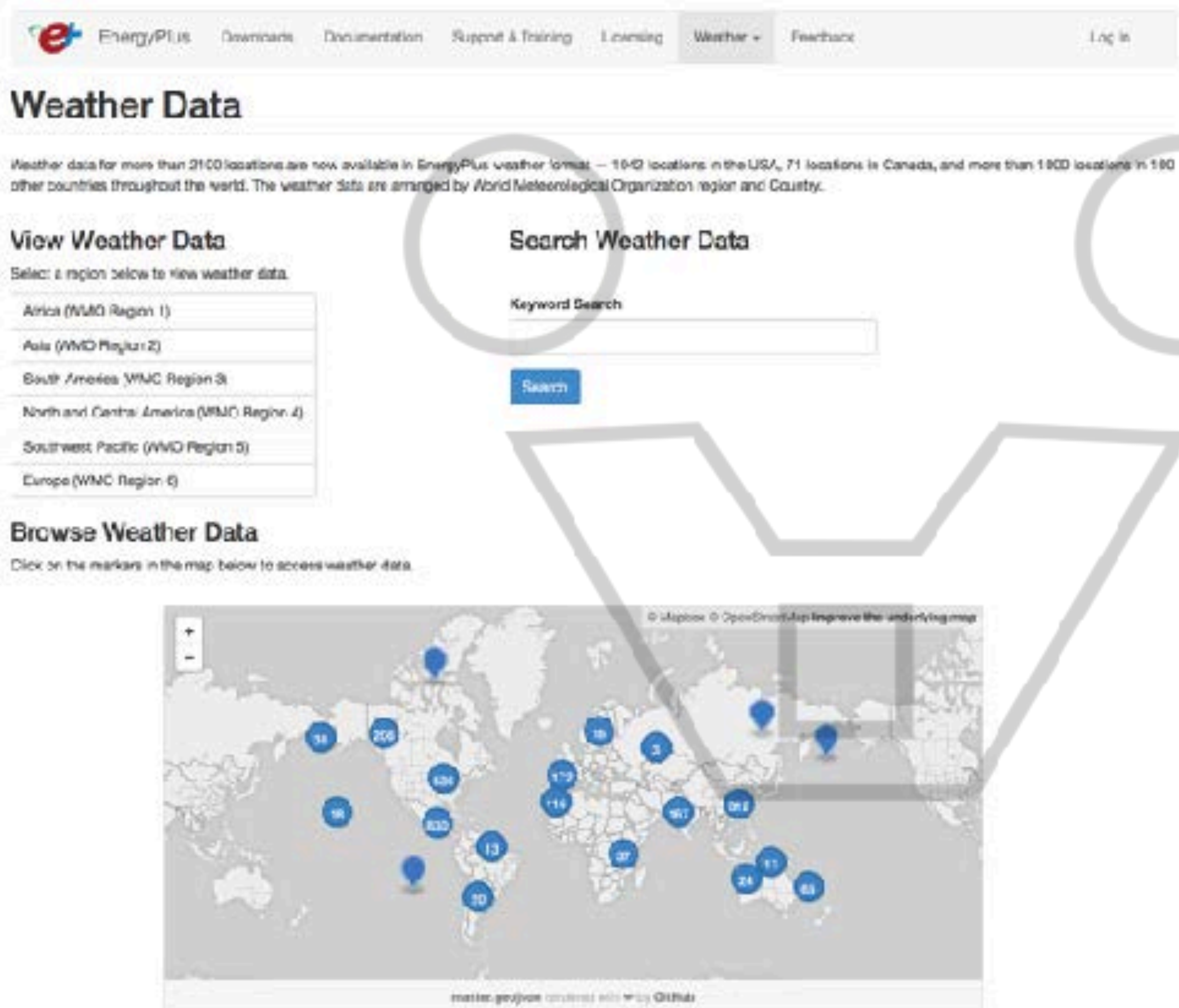


Map of station locations for ASHRAE climate data

Wheather data includes:
- geographical coordinates
- 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




https://energyplus.net/weather




.ddy
.stat
.epw

## Environmental parameters affecting thermal comfort: SOLAR ENERGY

Site Inventory: Physical Attributes 121

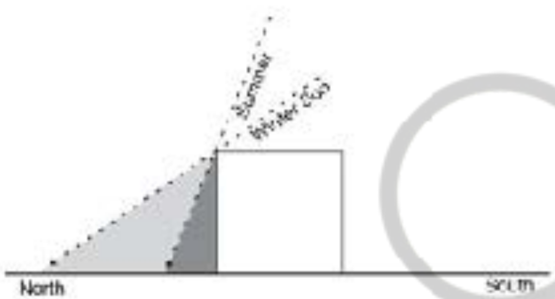
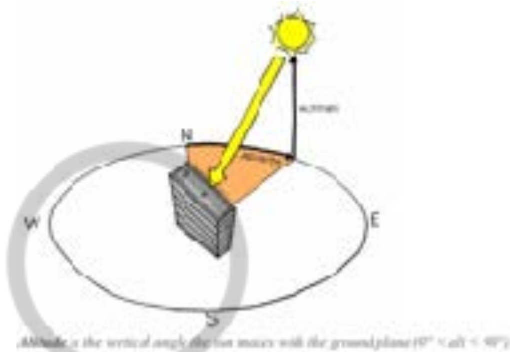
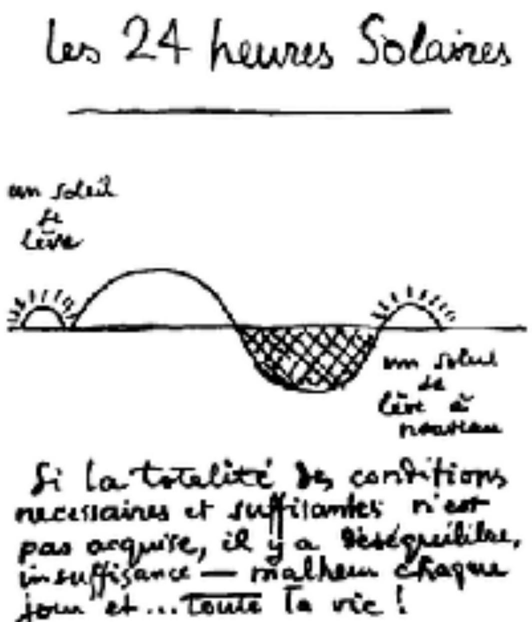



**Figure 5-15** Schematic diagram of the seasonal variation in shade cast by a building in the northern Hemisphere. Solar exposure in outdoor spaces near a building varies not only with weather conditions but also with time of day, day of year, and location of the space in relation to both the building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

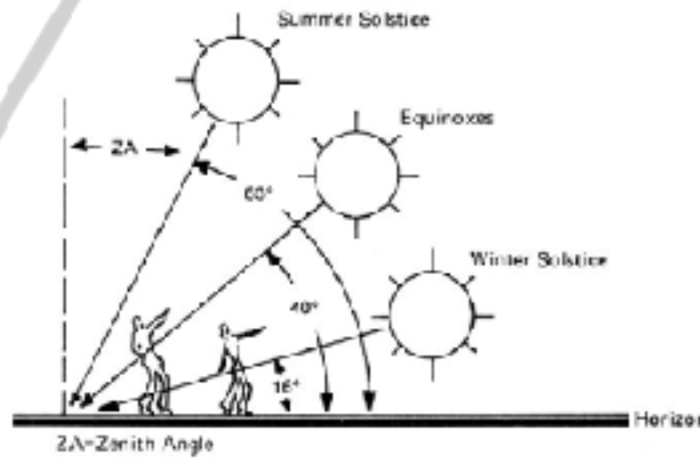



# SOLAR ENERGY




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



**HOW TO MEASURE SOLAR ENERGY ?**

RADIATION=W/m2

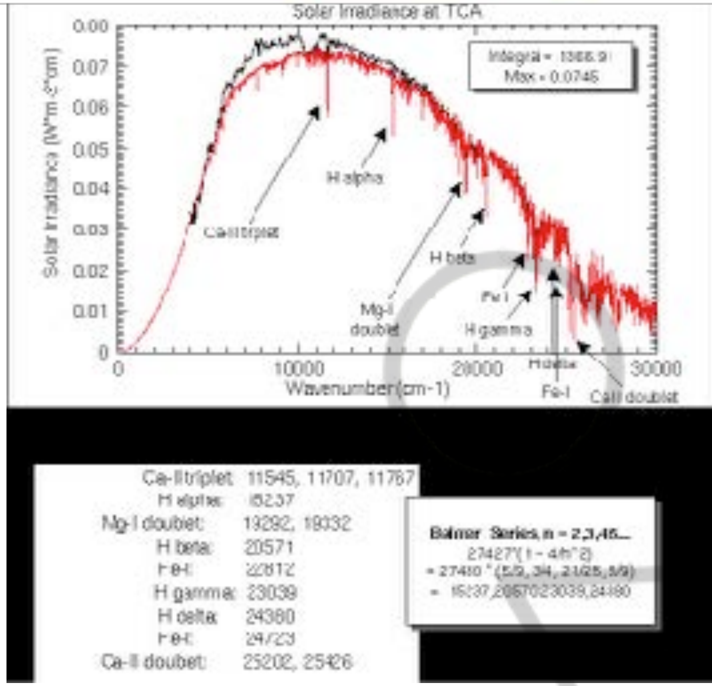
BTU vs KW

Ft2 > m2

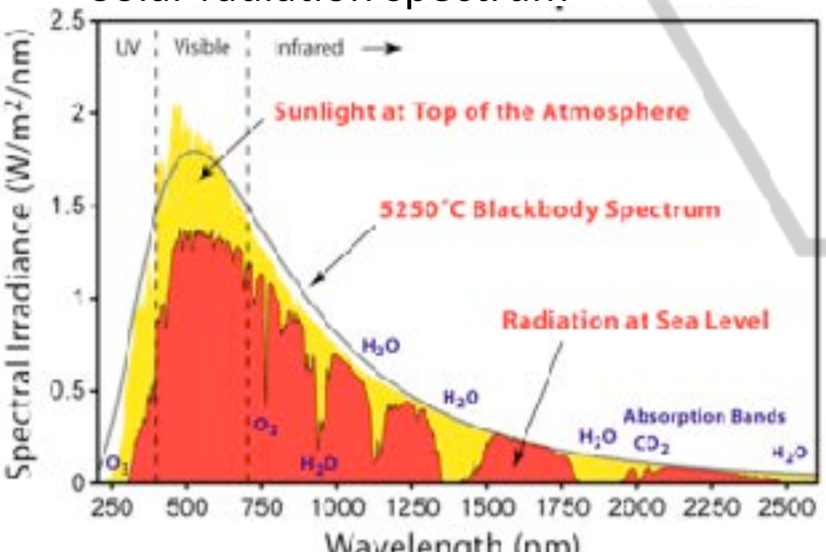
1 Btu=0,293071 W/h

1 ft2=0,092903 m2

# Environmental parameters affecting thermal comfort: SOLAR ENERGY




Solar radiation spectrum




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.

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

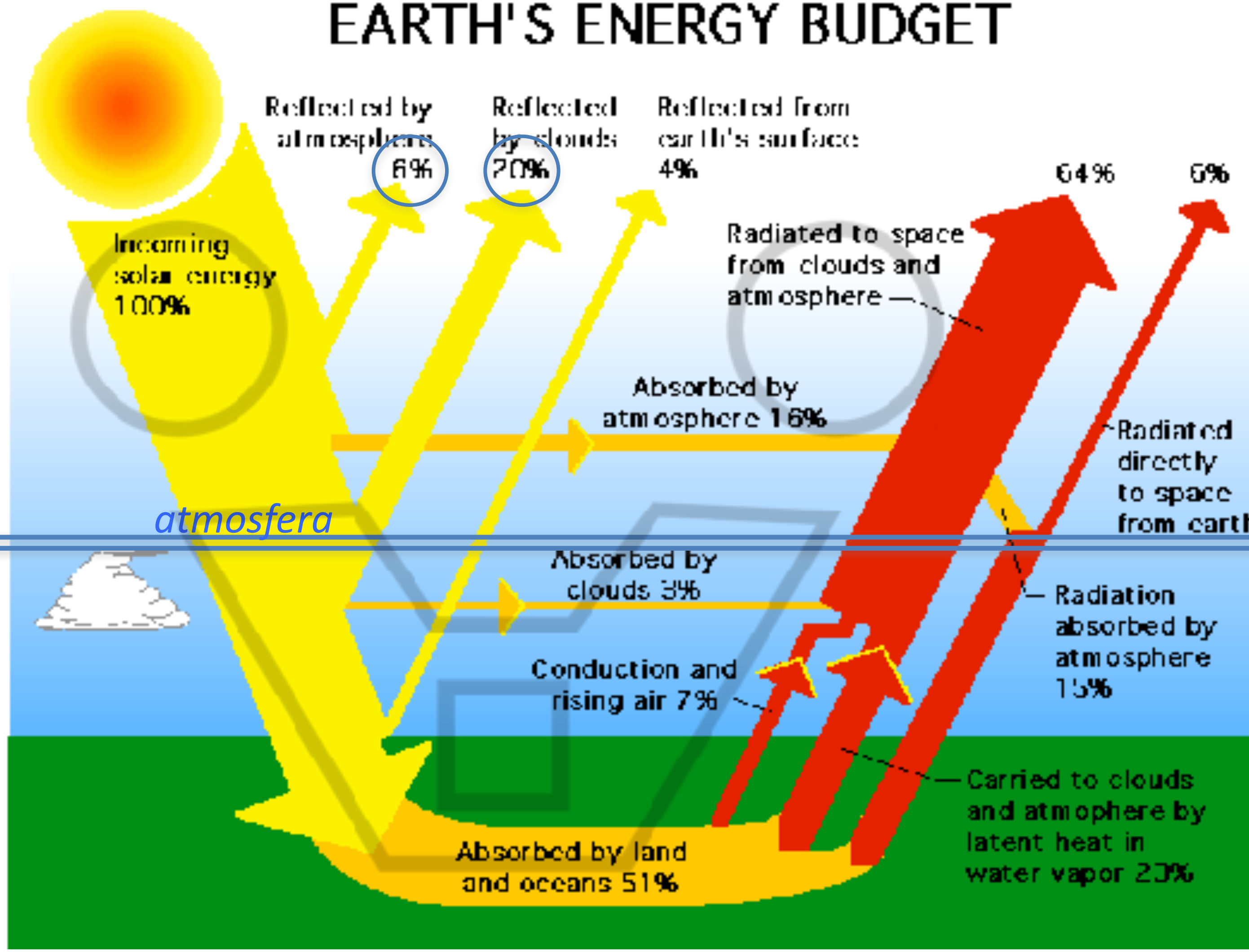
# EARTH'S ENERGY BUDGET

100%=1.366 W/m2
-costante solare-

26%= 356 W/m2

74% =1010 W/m2

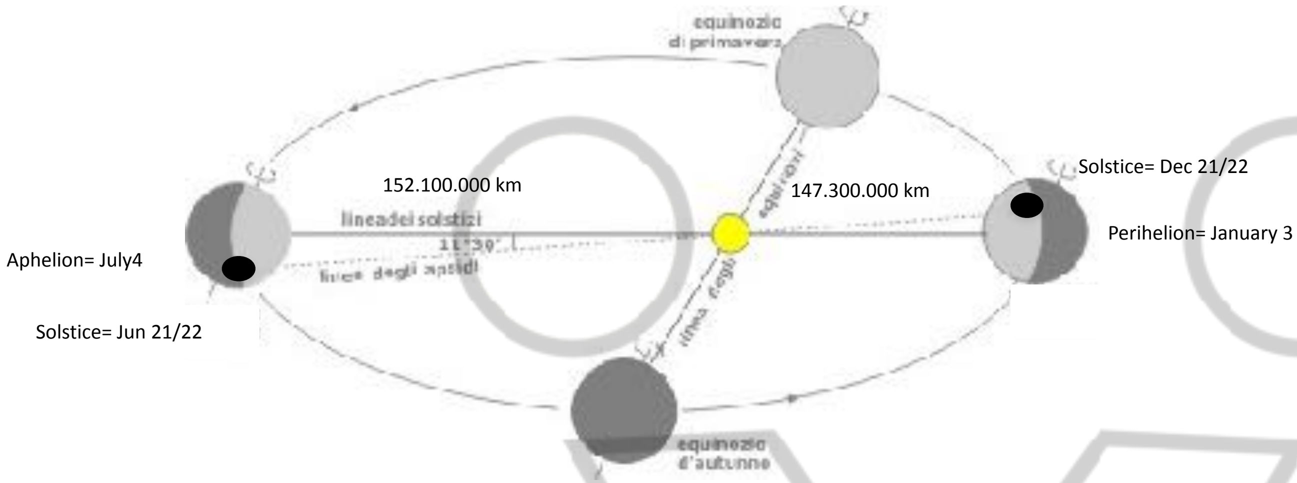
1.000 W/m2




**Radiazione assorbita**

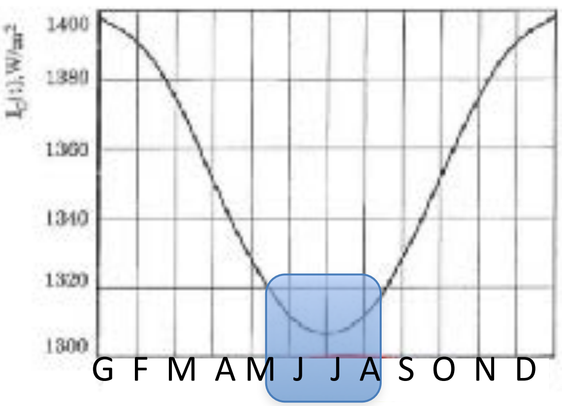
Detratte tutte le perdite per riflessione e retrodiffusione da parte di atmosfera e superficie terrestre, l'energia incidente che rimane è assorbita dalla superficie terrestre e contribuisce così al suo riscaldamento, in maniera <u>variabile a seconda della latitudine e del tipo di superficie</u>

# VARIATION OF SOLAR RADIATION DUE TO ANNUAL PERIOD AND LATITUDE

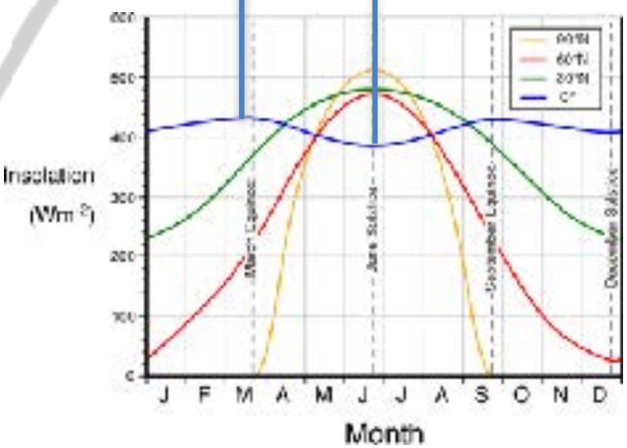



EQUINOX


SOLSTICE

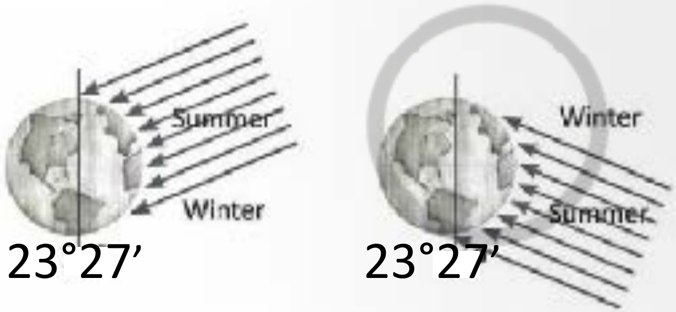



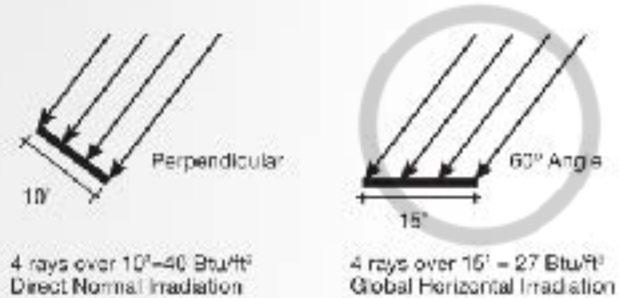

Variation of solar radiation caused by the distance of the Earth

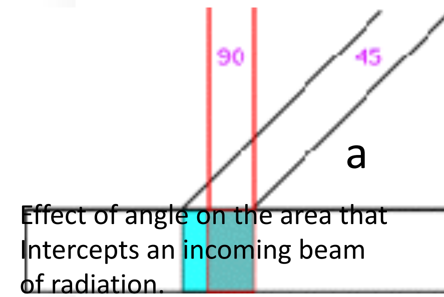



Monthly values of available insolation in $Wm^{-2}$ for the equator, 30, 60, and 90° North

# The influence of the site: GEOGRAPHICAL POSITION



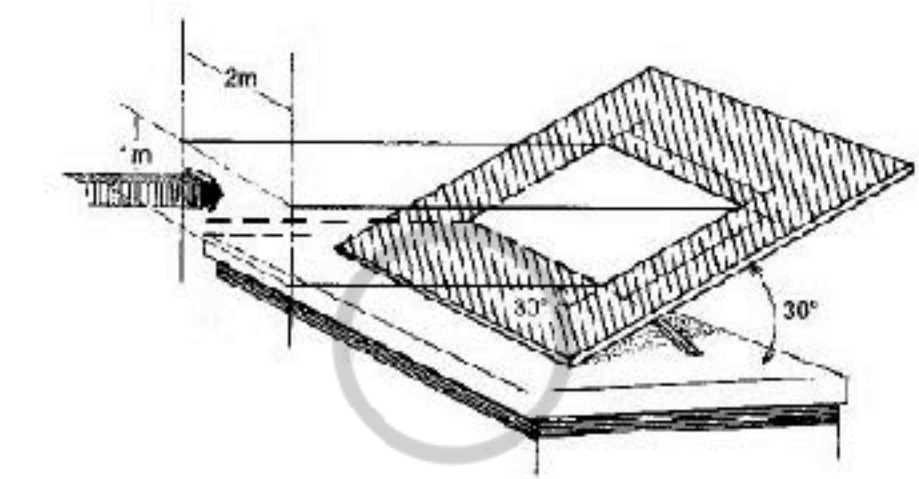



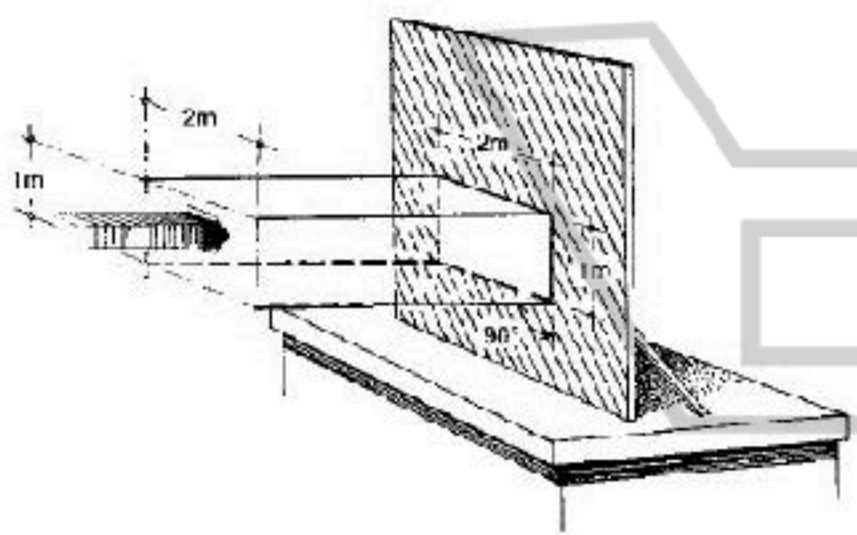



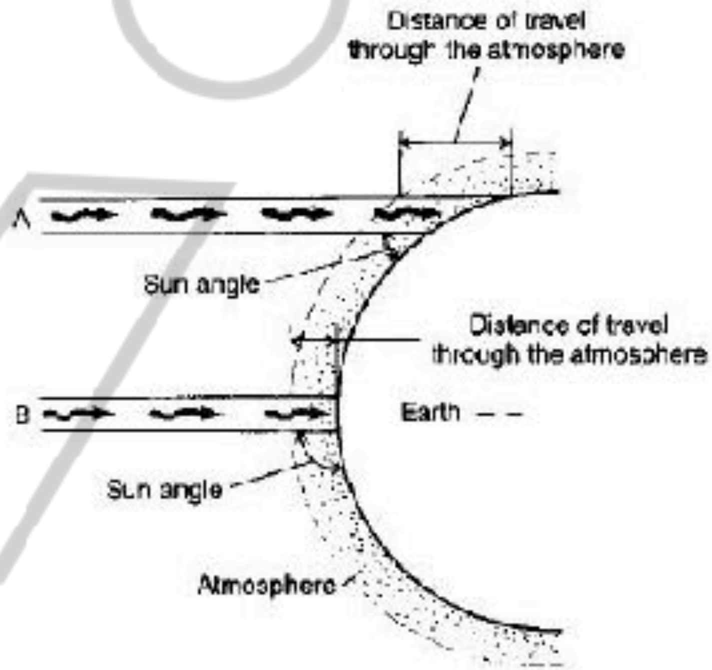

Effect of angle on the area that intercepts an incoming beam of radiation.

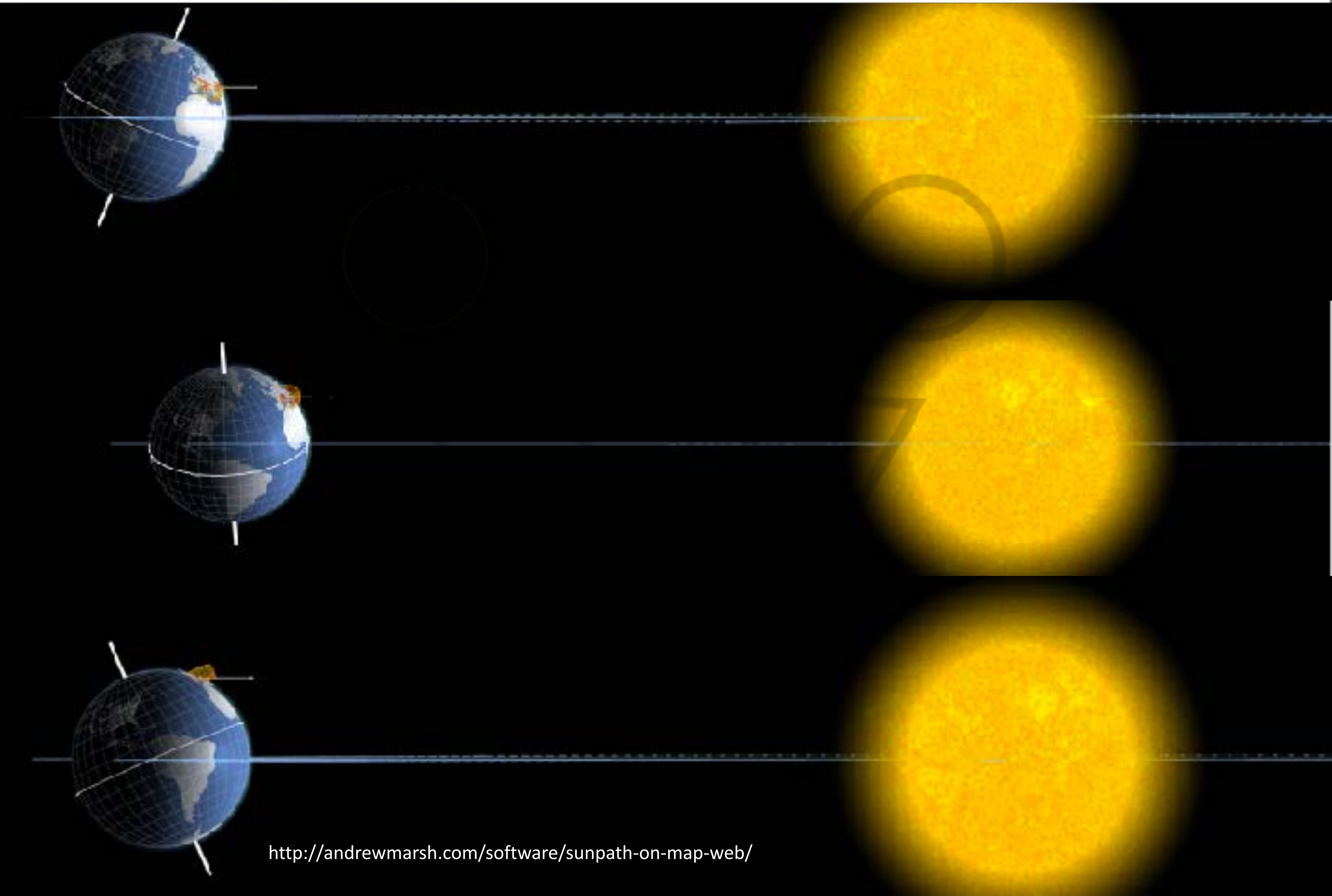
**Intensity = SIN (a)**

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

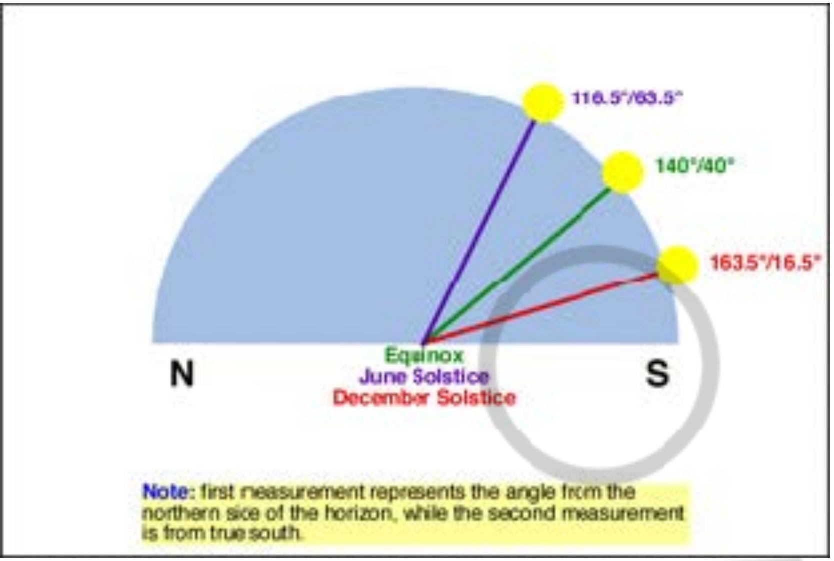

2m
1m
30°
30°


2m
1m
2m
1m
90°

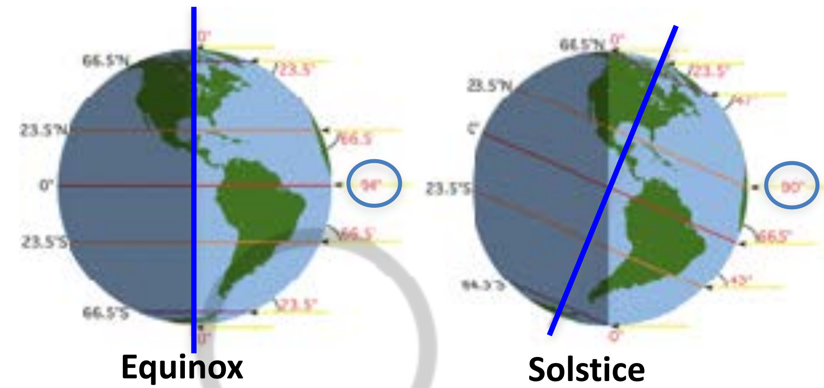

Distance of travel through the atmosphere
A
Sun angle
Distance of travel through the atmosphere
B
Earth
Sun angle
Atmosphere



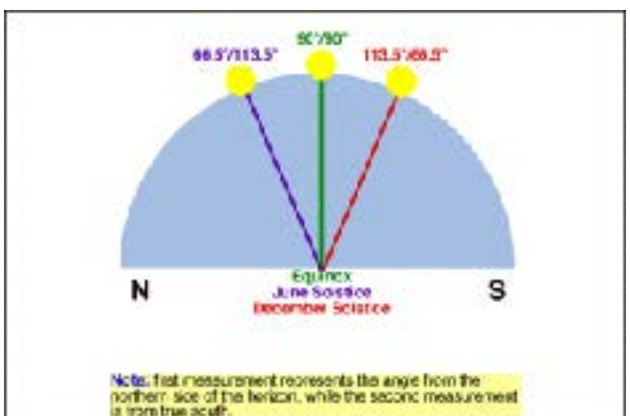
http://andrewmarsh.com/software/sunpath-on-map-web/



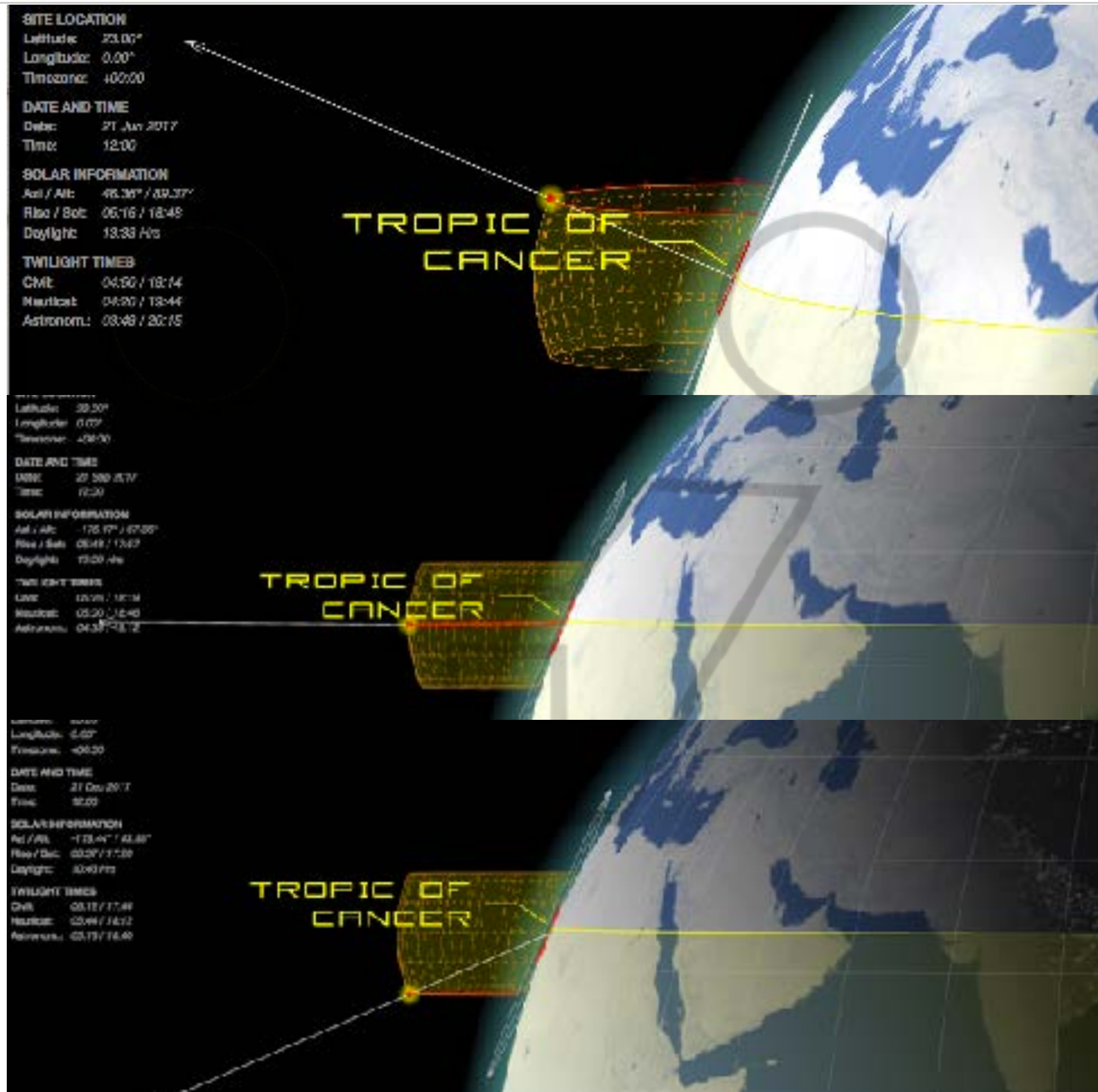

**solar noon for 50 degrees North during the June solstice, equinox, and December solstice.**

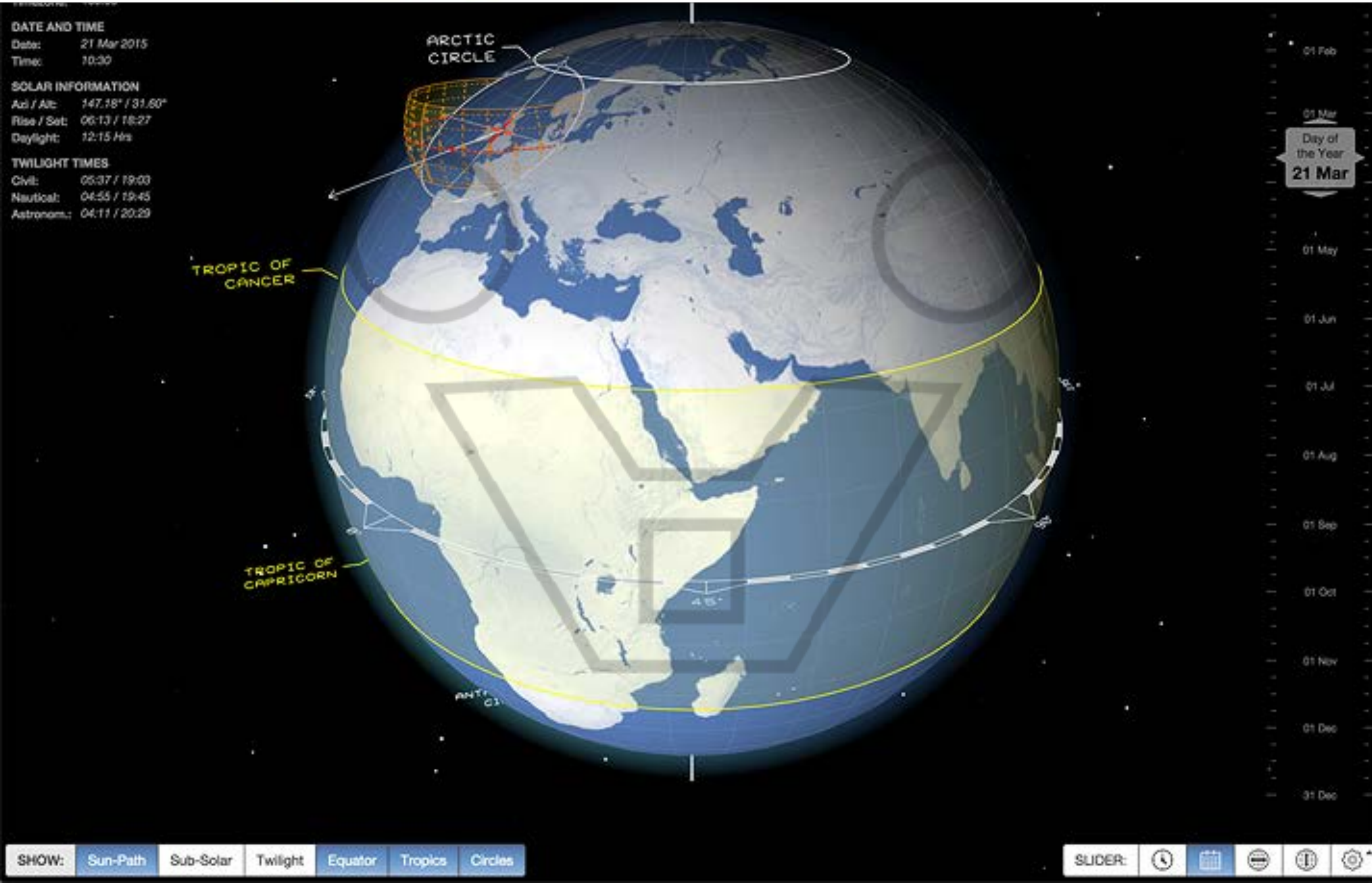



Relationship of maximum Sun height to latitude for the equinox (left) and June solstice (right). The red values on the right of the globes are maximum solar altitudes at **solar noon. Black numbers on the left indicate the location of the Equator, Tropic of Cancer (23.5 degrees N), Tropic of Capricorn (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.**



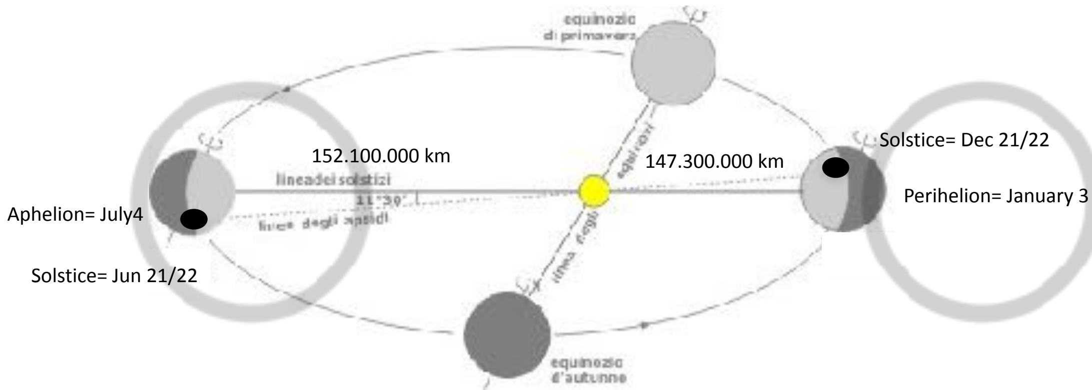

Variations in solar altitude at **solar noon for the equator during the June solstice, equinox, and December solstice**

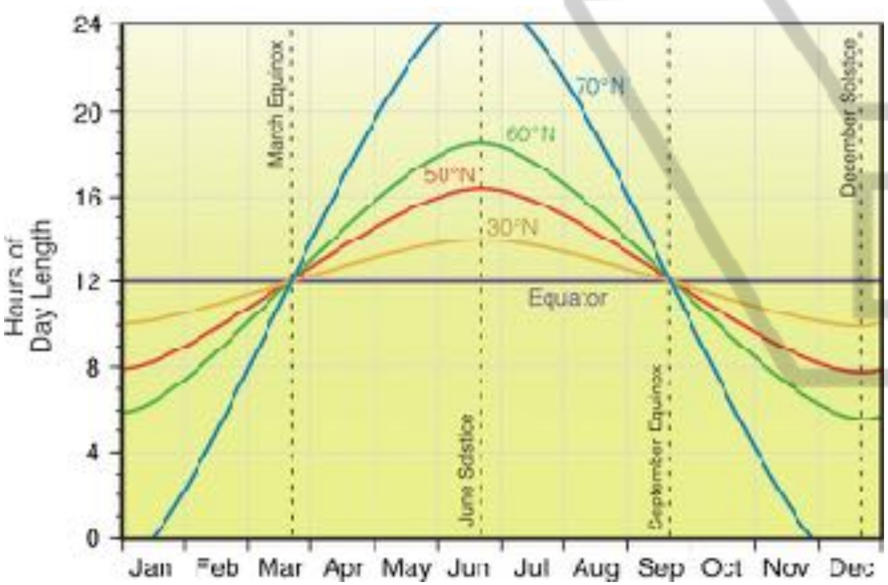

SITE LOCATION
Latitude: 23.00°
Longitude: 0.00°
Timezone: +00:00
DATE AND TIME
Date: 21 Jun 2017
Time: 12:00
SOLAR INFORMATION
Azi / Alt:
Rise / Set: 05:16 / 18:49
Daylight: 13:33 Hrs
TWILIGHT TIMES
Civil: 04:50 / 19:14
Nautical: 04:20 / 19:44
Astronom.: 03:48 / 20:15
TROPIC OF CANCER
DATE AND TIME
SOLAR INFORMATION
TROPIC OF CANCER
DATE AND TIME
SOLAR INFORMATION
TWILIGHT TIMES
TROPIC OF CANCER



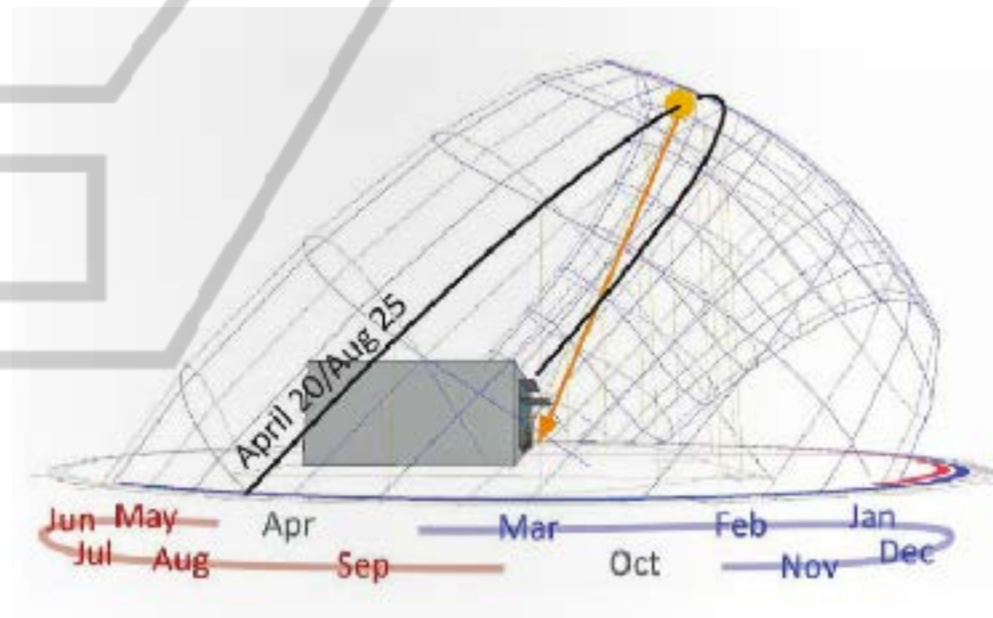

http://andrewmarsh.com/apps/staging/earthsun.html

# VARIATION OF SOLAR RADIATION DUE TO ANNUAL PERIOD AND LATITUDE



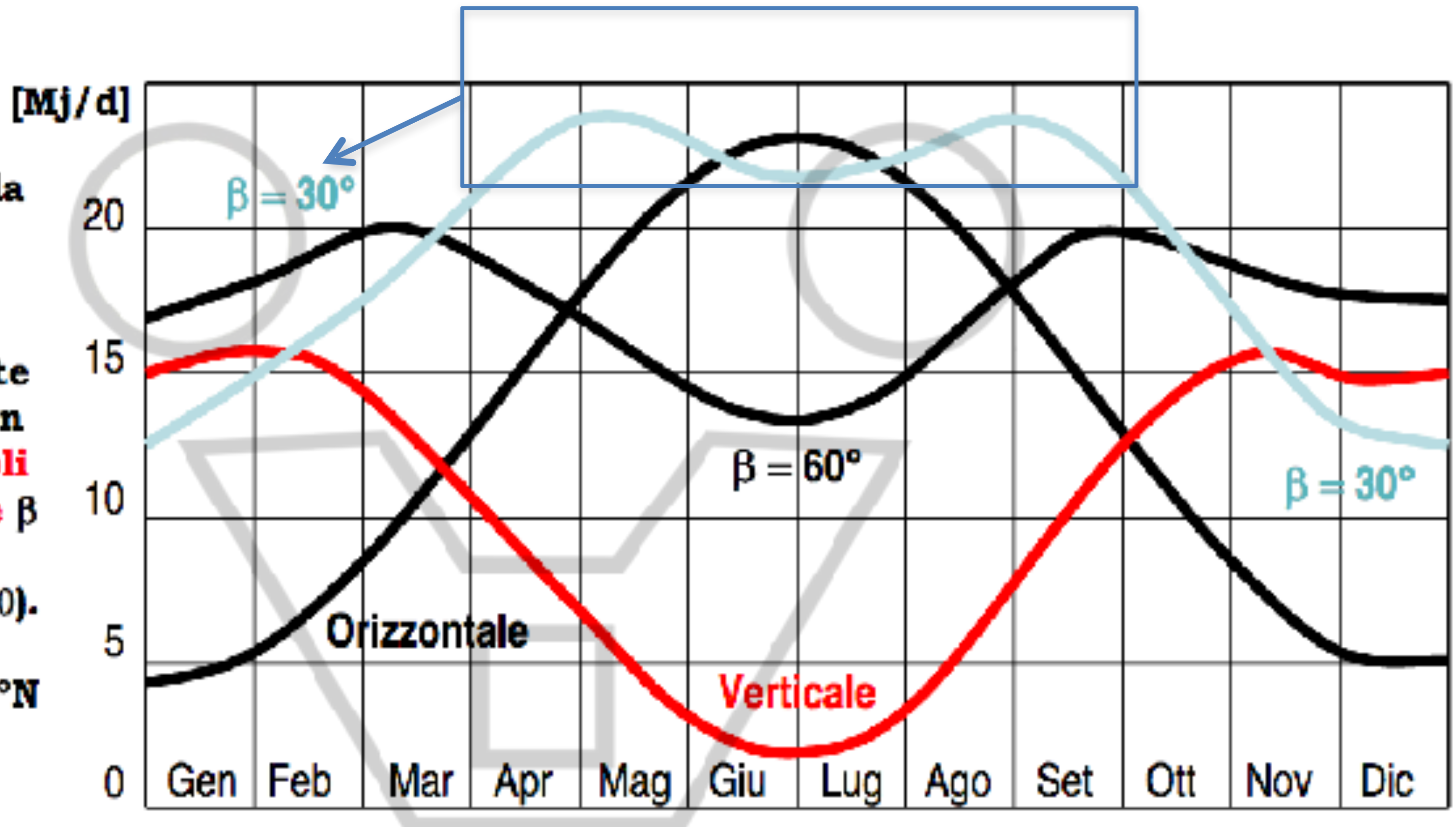




Annual variations in day length for locations at the equator, 30, 50, 60, and 70° N



# The influence of the site: GEOMETRY

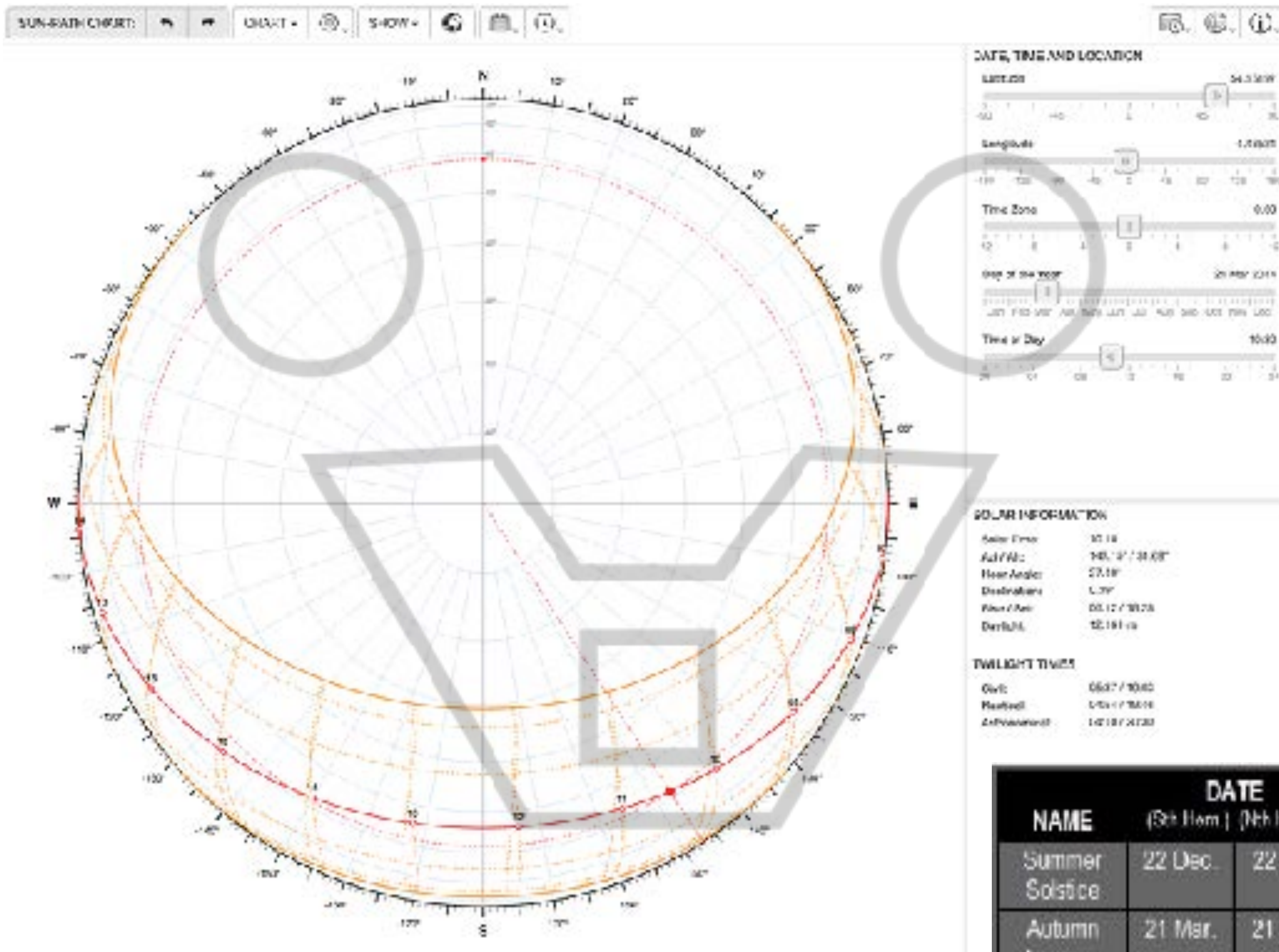
**Confronto fra la radiazione solare giornaliera media incidente su superfici con differenti angoli di inclinazione β ed orientate a Sud (azimut γ=0). Località con latitudine φ=40°N (Nuoro) e cielo sereno**



## The influence of the site: GEOGRAPHICAL POSITION

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

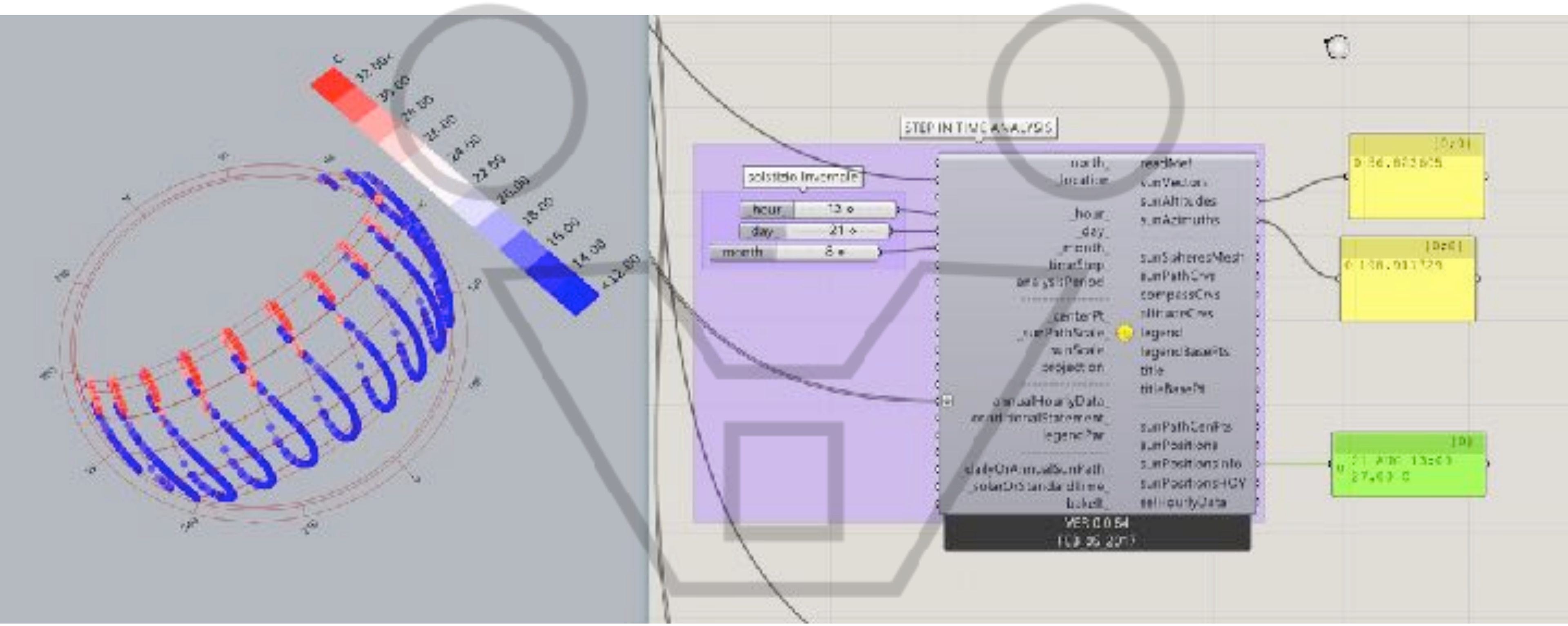
# The influence of the site: GEOGRAPHICAL POSITION




| 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
http://andrewmarsh.com/apps/releases/sunpath2d.html

SOLAR GEOMETRY WITH LADYBUG

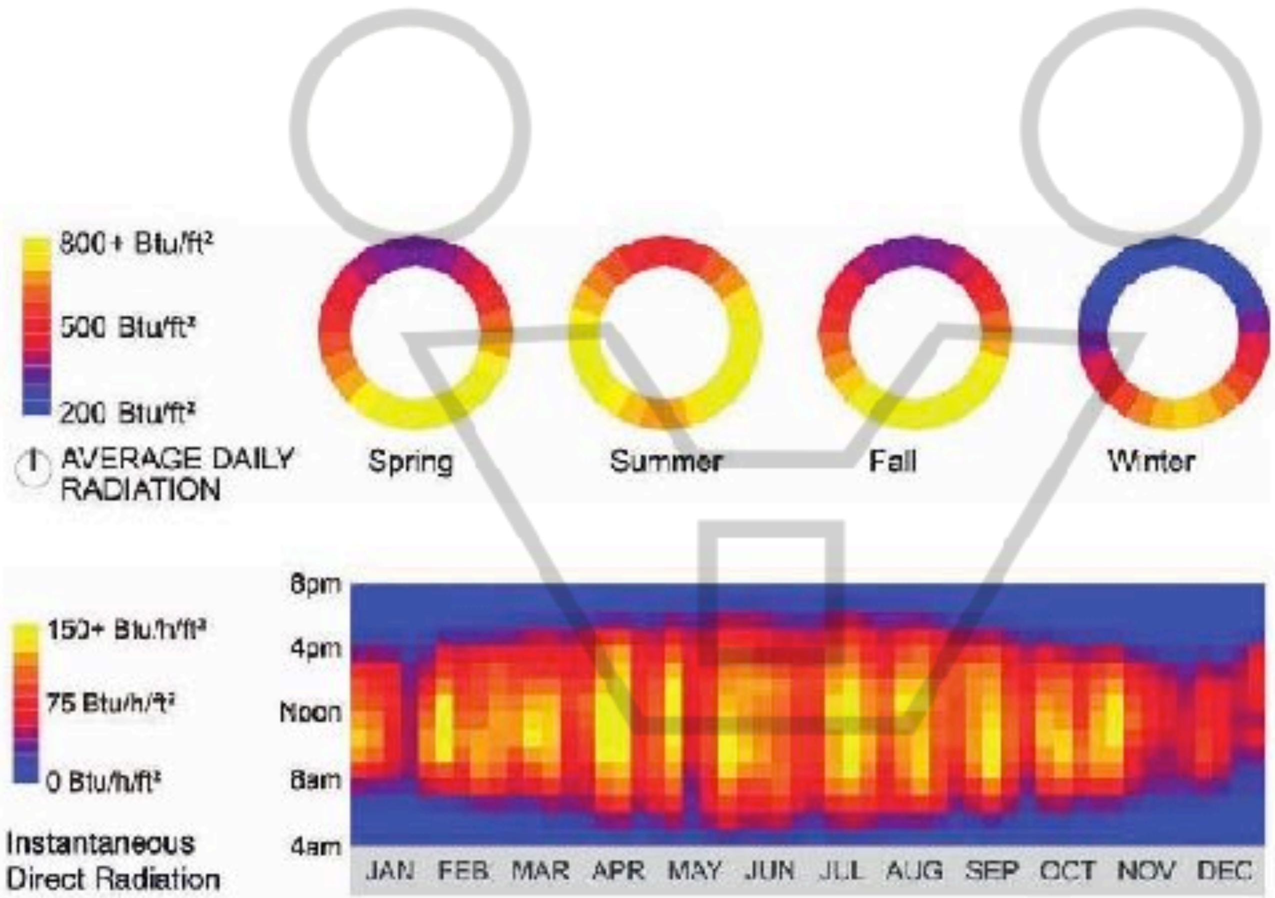



# PATCHES FOR GRASSHOPPER

HYDRA WEB PLATFORM https://hydrashare.github.io/hydra/index.html?keywords=LBExampleFiles

MAILAB http://www.mailab.biz/category/environmental-design/

# AVERAGE DAILY RADIATION



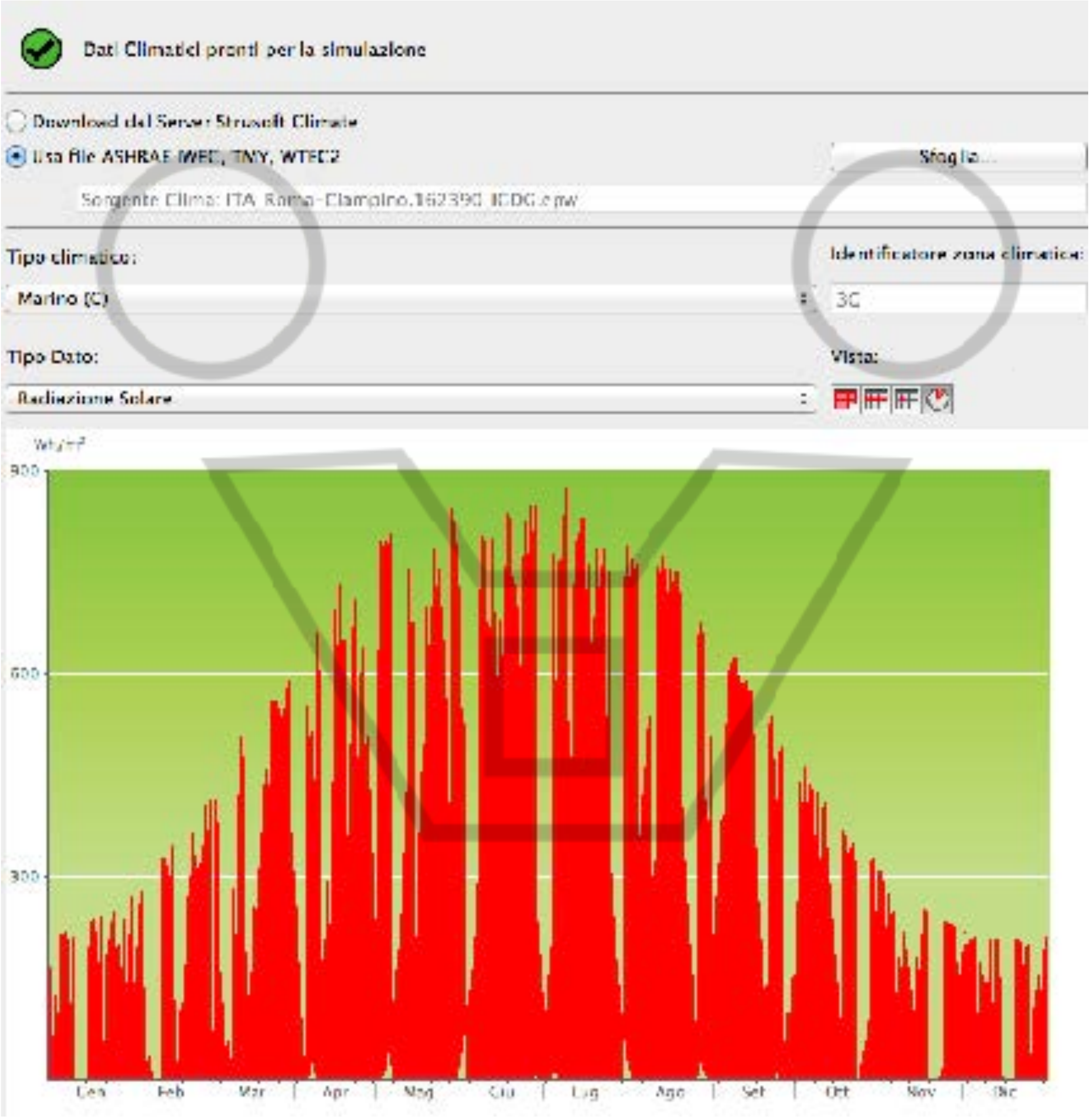

4: CLIMATE ANALYSIS

**4.10 and 4.11**

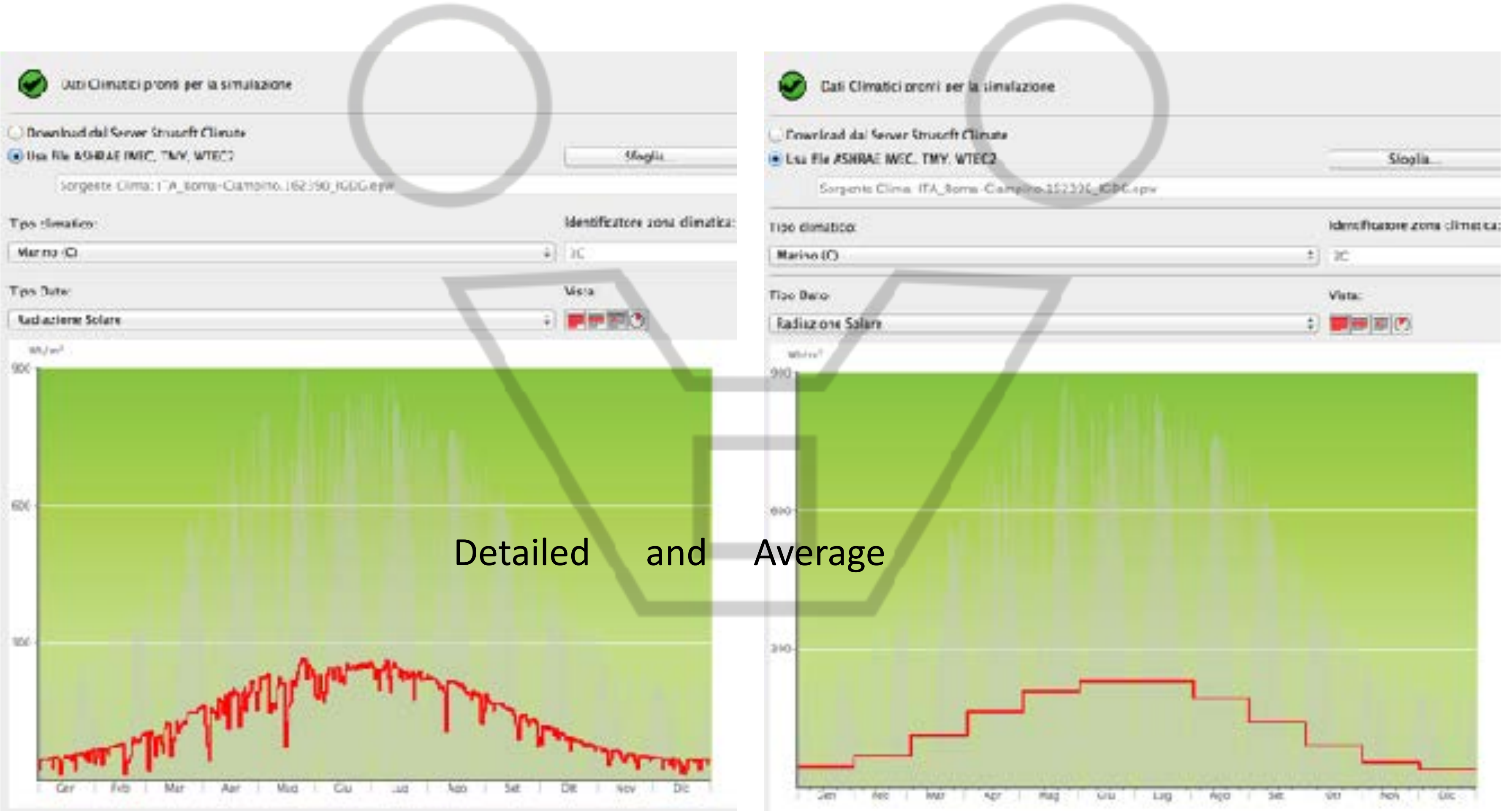
Solar roses from Central Park in New York City show the average daily amount of solar energy on each vertical segment of a cylinder. Since solar angles are symmetrical about the solstices, each season was centered on an equinox or solstice. The lower images show radiation on a horizontal surface for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

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

# Visualization of sun energy radiation

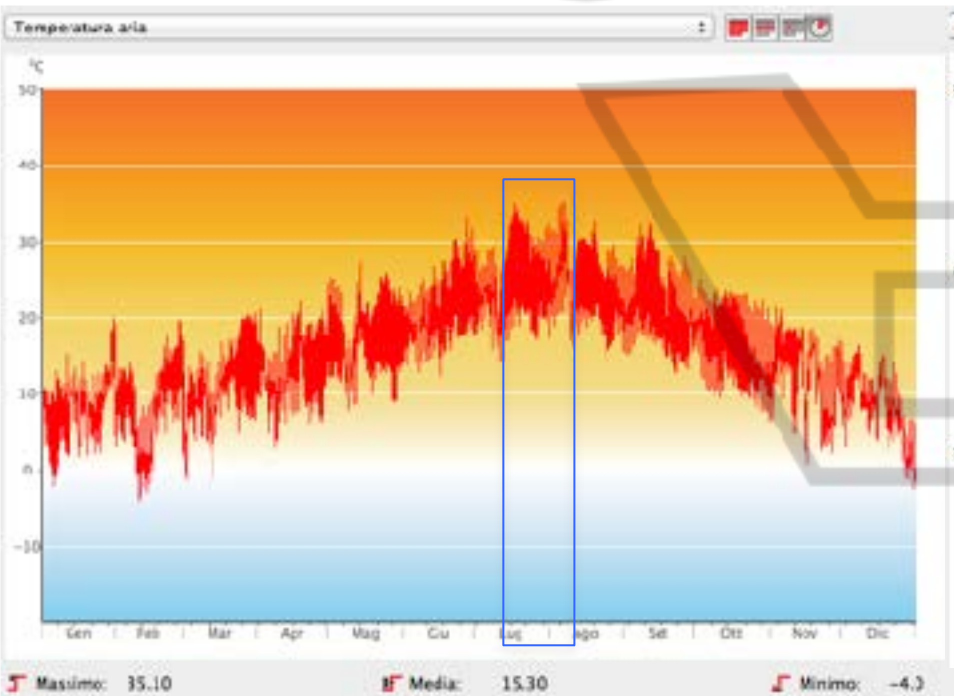


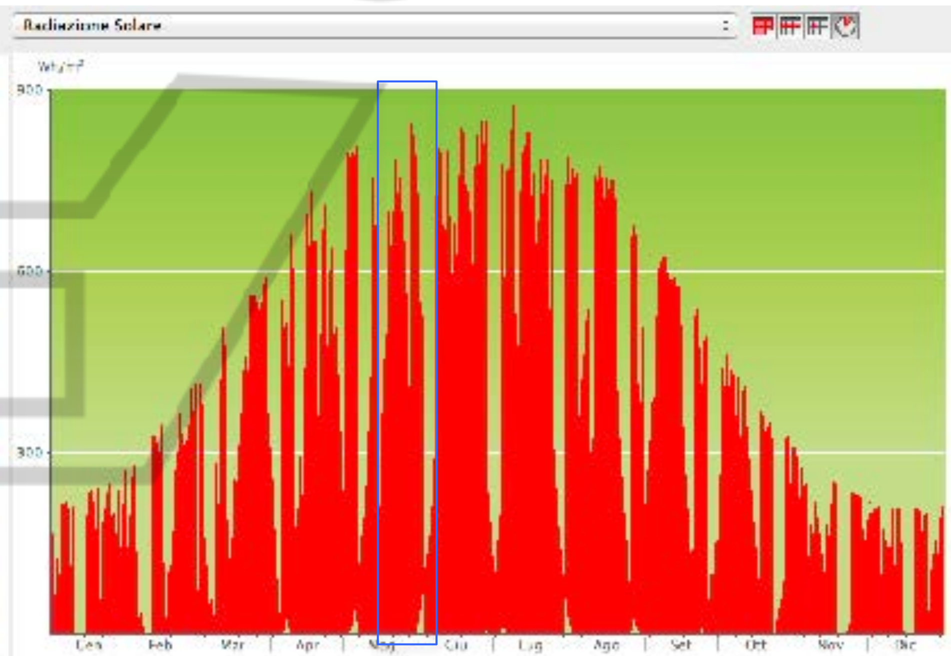
# Visualization of sun energy radiation



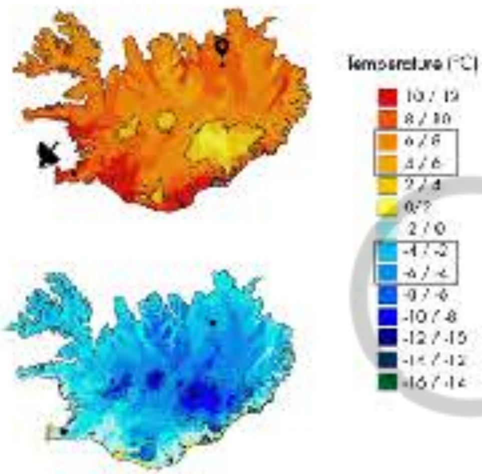

Detailed and Average

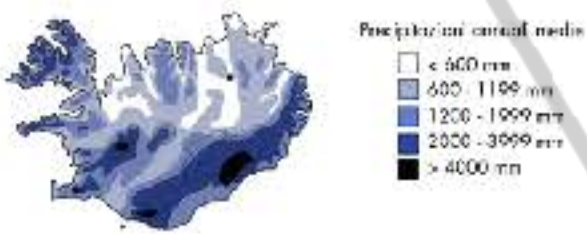
# Visualization of air temperature in relation with solar radiation

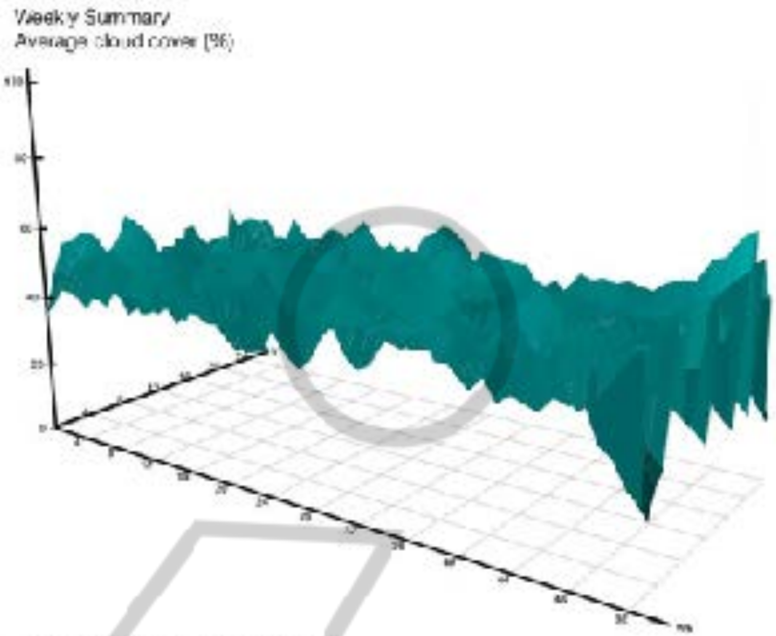


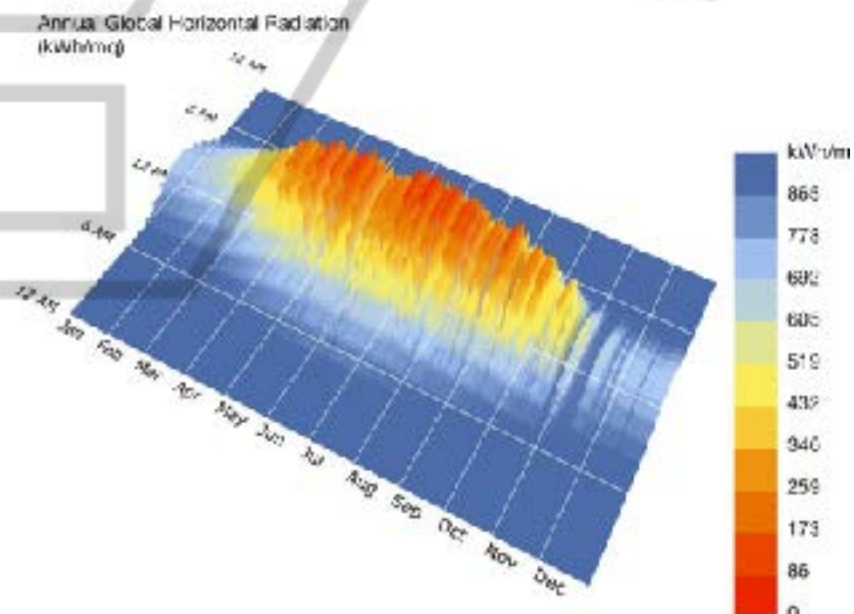




from archicad

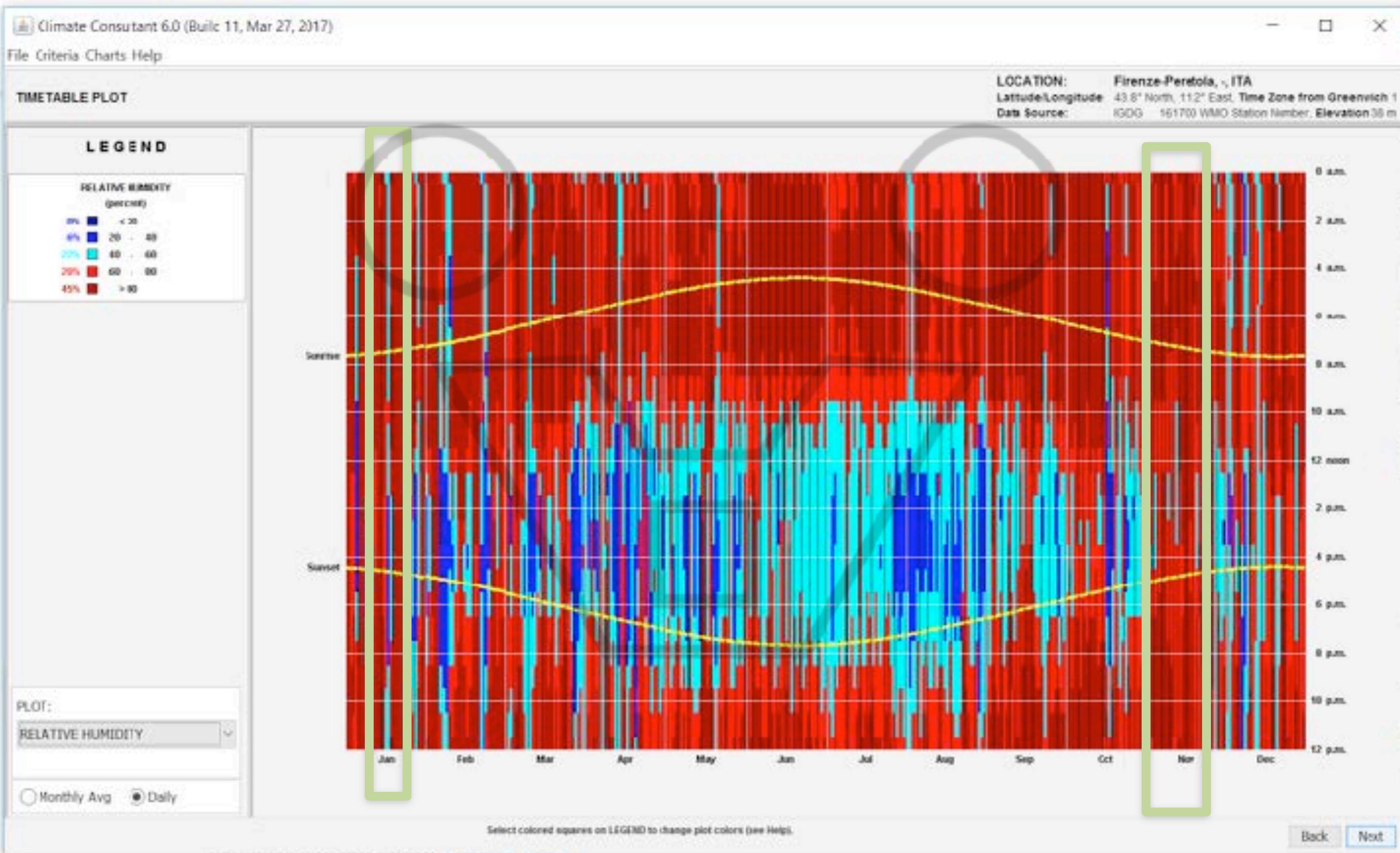

Temperature (°C)


Precipitazioni annuali medie
< 600 mm
600 - 1199 mm
1200 - 1999 mm
2000 - 3999 mm
> 4000 mm

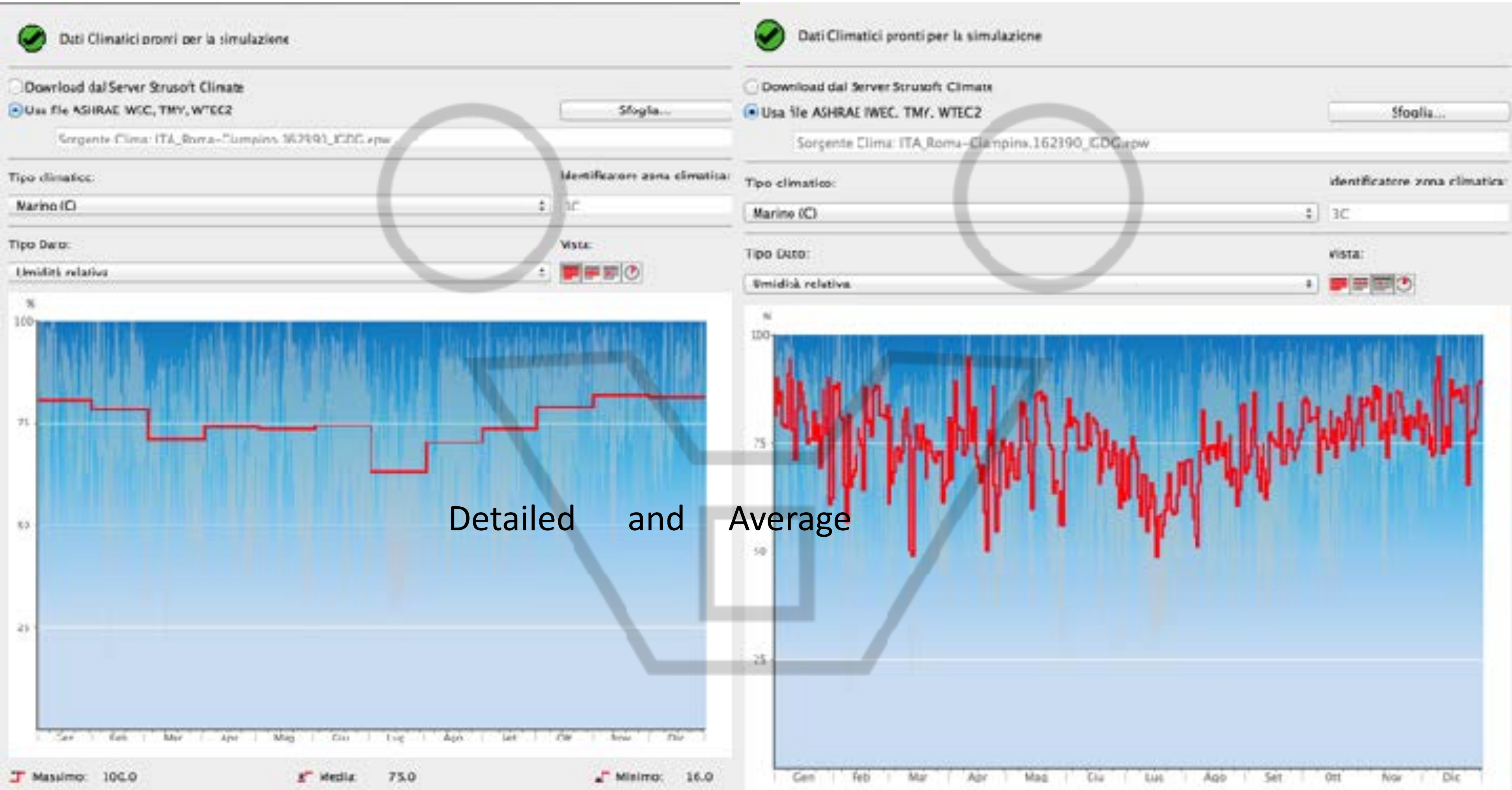

Weekly Summary
Average cloud cover (%)


Annual Global Horizontal Radiation
(kWh/mq)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
866
778
692
605
519
432
346
259
173
86
0

# Perché UR è maggiore di notte?



# Visualization of Relative Humidity




Detailed and Average

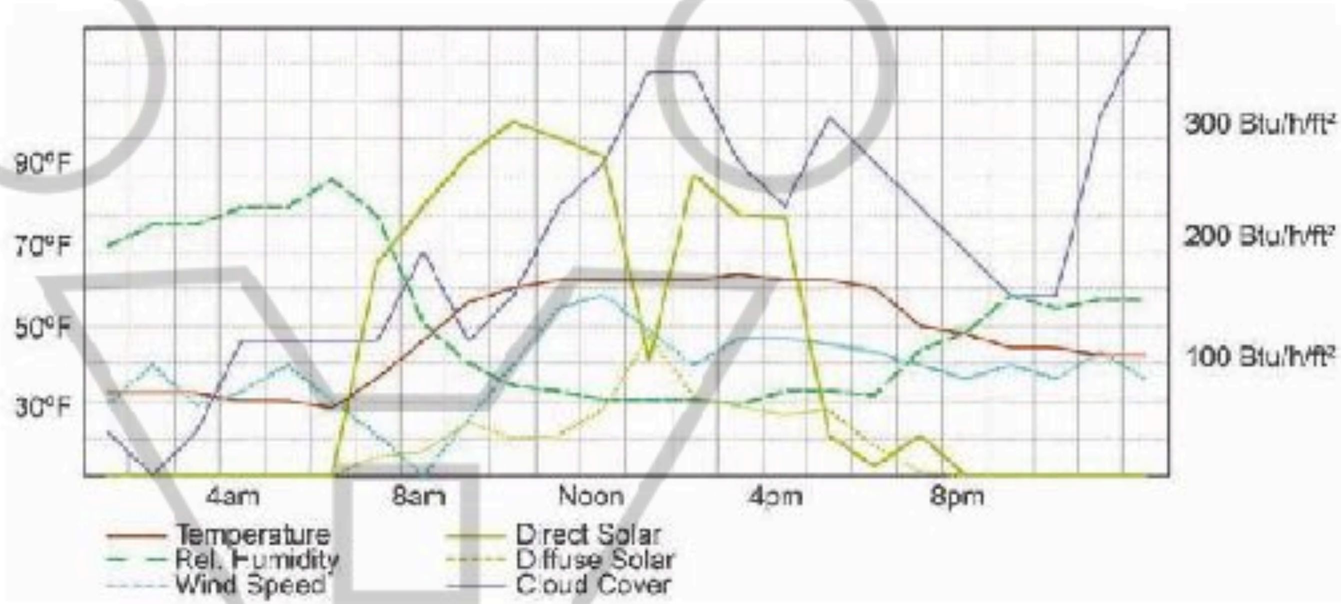
from archicad

# 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.*



## 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.

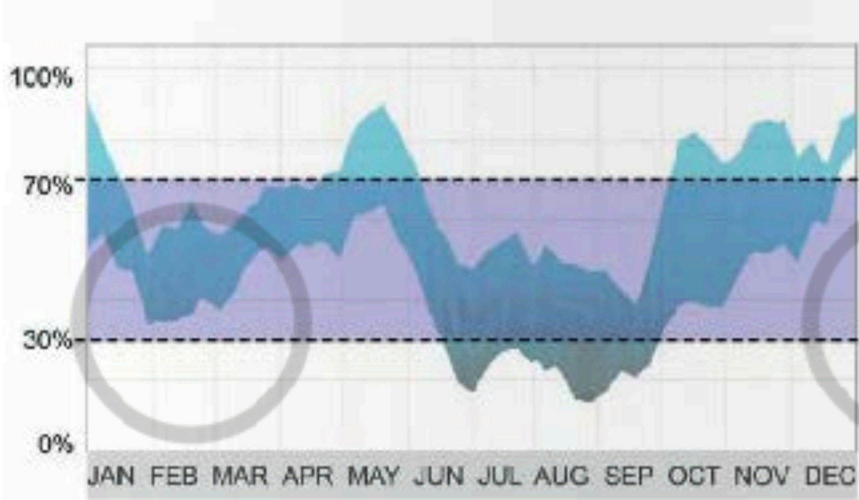

| | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42° | 48 | 50 | 52 | 55 | 57 | 59 | 62 | 64 | 66 | 68 | 71 | 73 | 75 | 77 | 80 | 82 |
| 41° | 46 | 48 | 51 | 53 | 55 | 57 | 59 | 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 |

| | |
|---|---|
| [illegible] 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 |
| [illegible] | Pericolo di morte: colpo di calore imminente |

# The influence of the weather : SKY CONDITIONS

*clear sky*

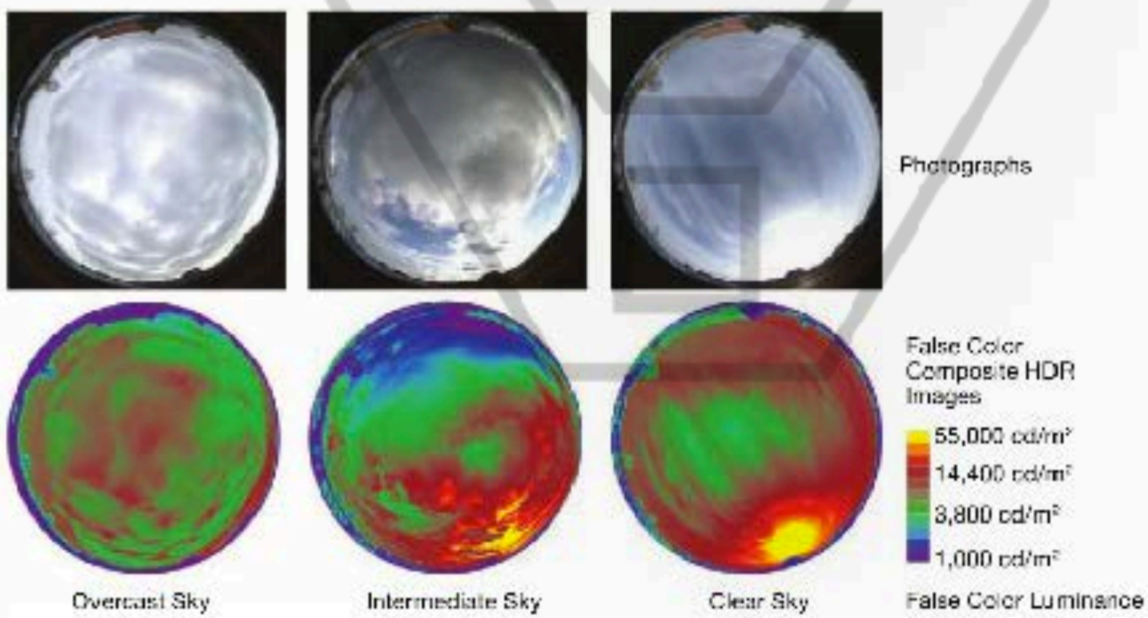
*overcast sky*




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 Carlson.*



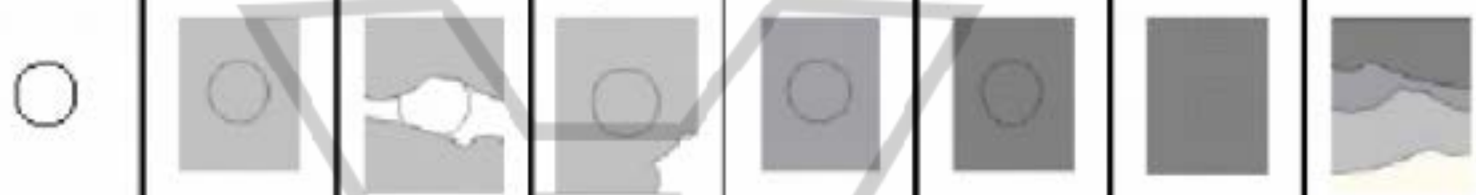

8.3

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% |

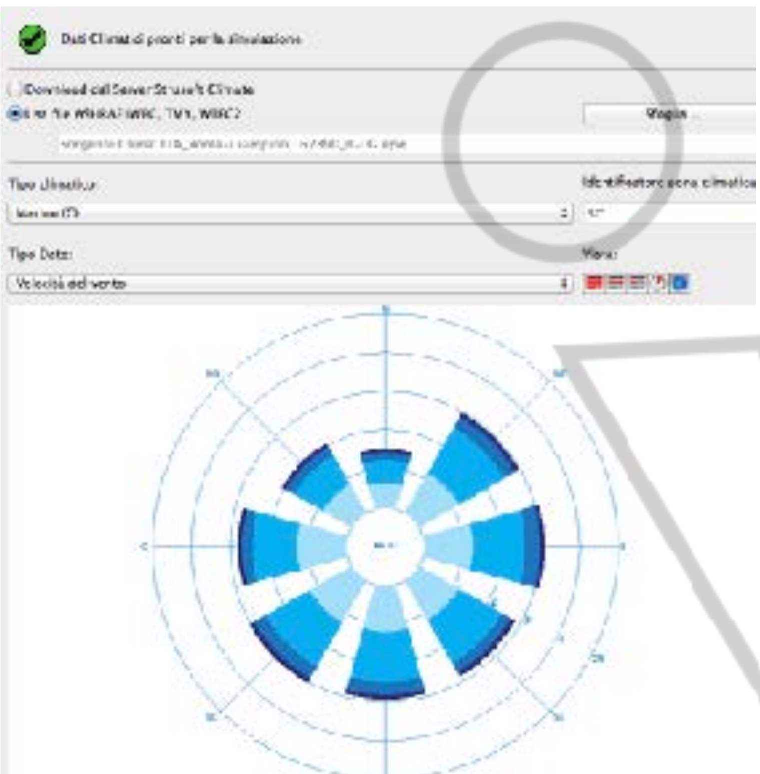
http://www.sunsim.it/

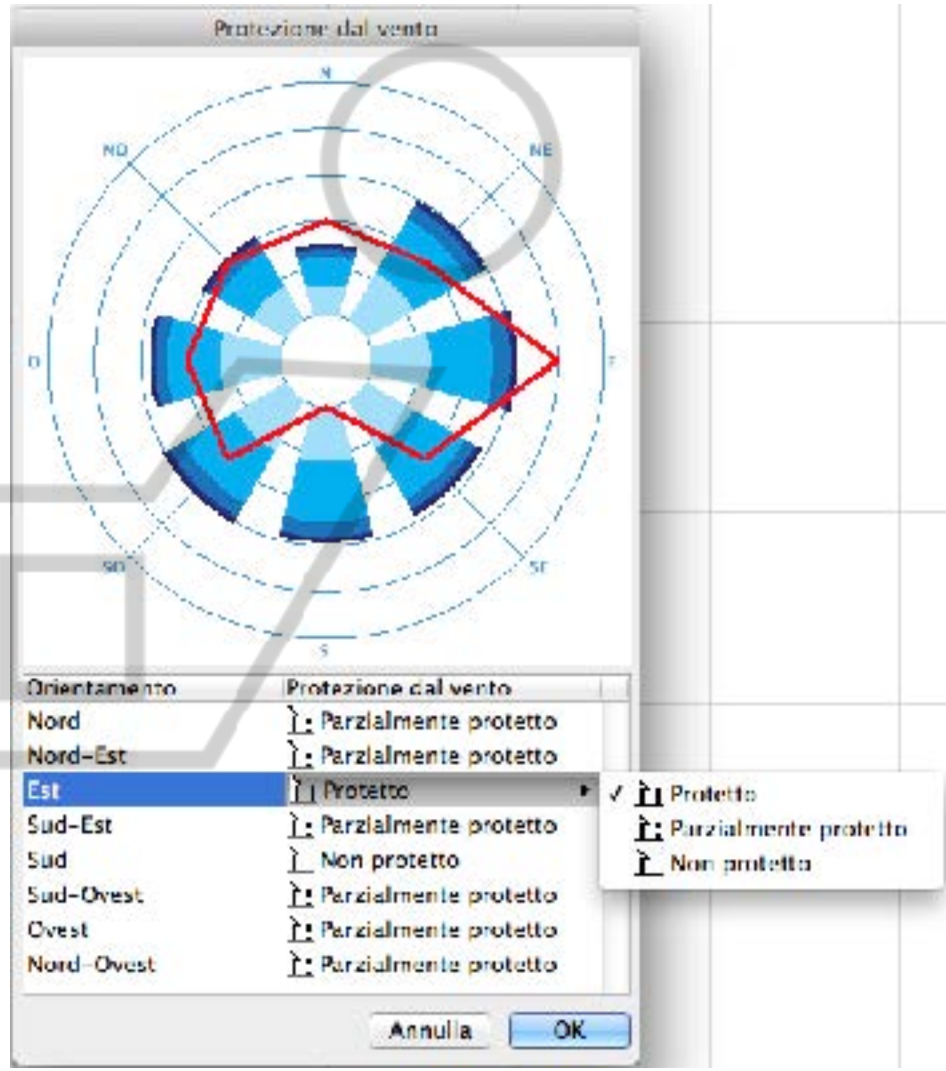
# 1. CLIMATE

## WINDS

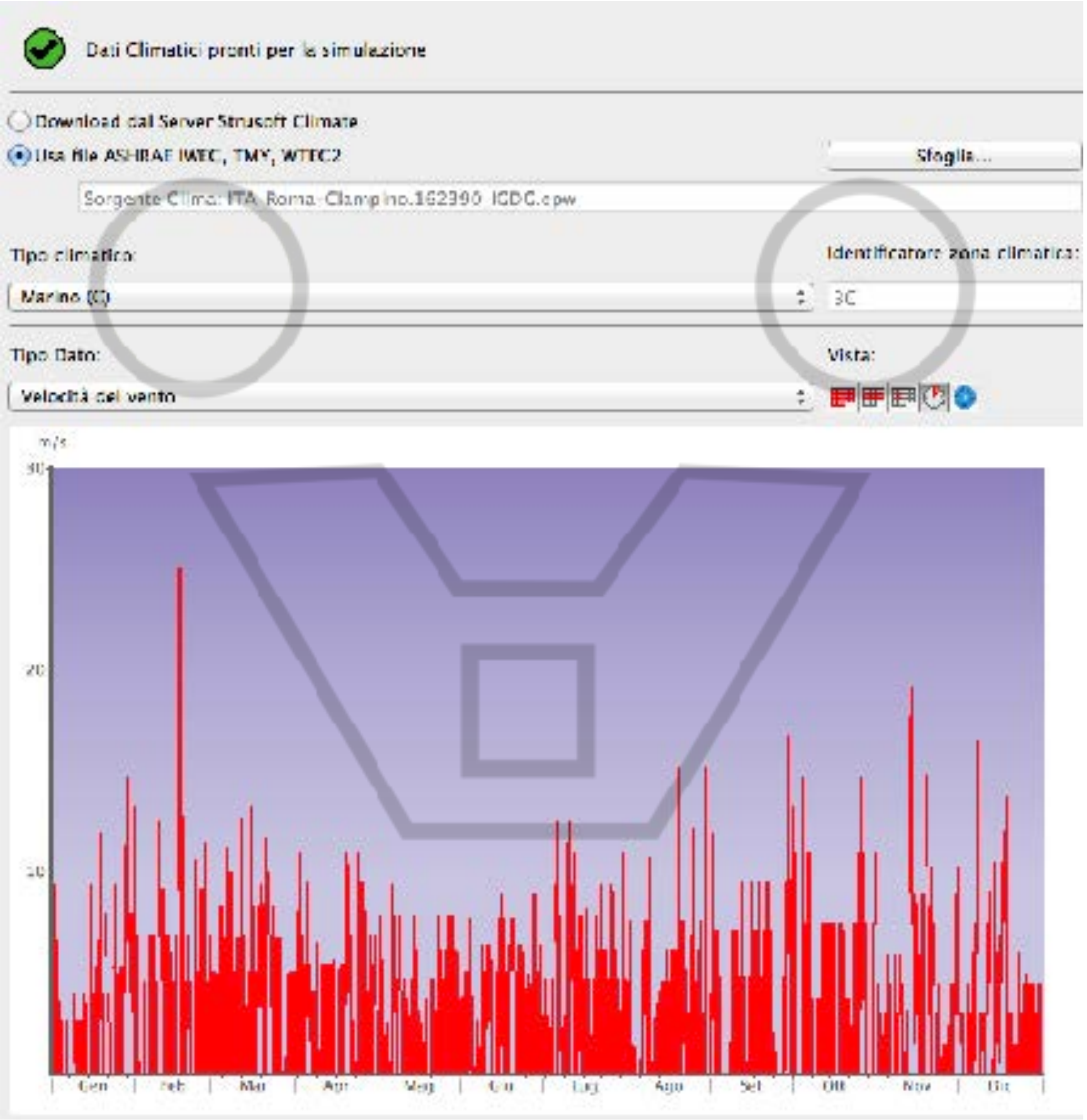
# Air movement: WIND ANALYSIS

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

# 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 | [illegible] | 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 | [illegible] | -7 | -6 | -5 | -4 | -2 | -1 | 0 | [illegible] | 2 | [illegible] | 4 | 6 | 7 | [illegible] | [illegible] | 10 | [illegible] | 13 | 14 | 15 | 17 | 18 | 19 | 21 |
| 6 | 9 | [illegible] | 7 | 6 | 5 | 4 | [illegible] | 2 | [illegible] | [illegible] | 2 | 3 | 4 | 5 | 6 | 8 | [illegible] | 10 | [illegible] | 12 | 14 | 15 | 16 | 18 | 19 | 20 |
| 8 | -10 | [illegible] | -8 | -7 | -6 | [illegible] | [illegible] | [illegible] | [illegible] | 0 | 1 | 2 | 4 | 5 | 6 | 7 | [illegible] | 10 | [illegible] | 12 | 13 | 15 | 16 | 17 | 19 | 20 |
| 10 | -10 | [illegible] | -8 | [illegible] | -6 | -5 | -4 | -2 | [illegible] | 0 | 1 | 2 | [illegible] | 4 | 6 | [illegible] | [illegible] | 9 | 10 | 12 | 13 | 14 | 16 | [illegible] | 18 | 20 |
| 12 | -11 | [illegible] | [illegible] | -7 | -6 | -5 | -4 | [illegible] | -2 | [illegible] | 1 | 2 | [illegible] | 4 | 5 | [illegible] | [illegible] | 9 | 10 | 11 | 13 | 14 | 15 | 16 | 10 | 19 |
| 14 | 11 | 12 | [illegible] | 8 | 7 | 5 | 4 | 3 | 2 | [illegible] | 0 | 1 | 2 | 4 | 5 | 3 | 7 | 8 | 10 | 11 | 12 | 13 | 15 | 16 | 17 | 10 |
| 16 | -11 | -12 | -8 | -8 | -7 | -3 | -5 | -1 | -3 | [illegible] | 0 | 1 | 2 | 3 | 4 | 3 | 7 | 8 | 9 | 11 | 12 | 13 | 14 | 16 | 17 | 18 |
| 18 | -12 | -11 | -10 | -8 | [illegible] | [illegible] | [illegible] | -4 | -3 | -2 | -1 | 1 | 2 | 3 | 4 | [illegible] | [illegible] | 8 | 9 | 10 | 11 | 12 | 14 | 15 | 17 | 18 |
| 20 | -12 | -11 | -10 | -9 | -10 | -7 | [illegible] | -4 | -3 | -2 | -1 | [illegible] | 1 | 2 | 4 | 5 | [illegible] | 7 | 9 | 10 | 11 | 12 | 14 | 15 | 16 | 17 |
| 22 | 13 | 11 | 10 | 9 | 8 | 7 | [illegible] | [illegible] | 4 | 3 | 1 | [illegible] | 1 | 2 | 3 | [illegible] | [illegible] | 7 | 8 | 9 | 11 | 12 | 13 | 15 | 16 | 17 |
| 24 | -13 | -12 | -11 | -10 | -9 | -7 | [illegible] | [illegible] | -4 | -3 | -2 | -1 | 1 | 2 | 3 | [illegible] | 5 | 6 | 8 | 9 | 10 | 12 | 13 | 14 | 15 | 17 |
| 26 | -13 | -12 | -11 | -10 | -9 | -8 | -7 | [illegible] | -4 | -3 | -2 | -1 | 0 | [illegible] | 2 | 2 | [illegible] | 6 | [illegible] | 9 | 10 | 11 | 12 | 14 | 15 | 16 |
| 28 | -14 | [illegible] | -12 | -10 | -9 | [illegible] | -7 | -6 | -5 | -4 | [illegible] | -1 | 0 | [illegible] | 2 | [illegible] | [illegible] | 6 | 7 | 0 | 9 | 11 | 12 | 13 | 15 | 15 |
| 30 | 14 | 13 | 12 | [illegible] | 10 | [illegible] | 7 | 6 | 5 | 4 | 3 | 2 | 1 | [illegible] | 2 | 3 | 4 | 5 | 7 | 8 | [illegible] | 12 | 12 | 13 | 14 | 16 |
| 32 | -14 | -13 | -13 | [illegible] | -10 | -9 | [illegible] | -7 | -6 | -4 | -3 | -2 | -1 | 0 | [illegible] | 3 | 4 | 5 | 6 | 7 | 9 | 12 | 11 | 13 | 14 | 15 |
| 34 | -15 | -14 | -13 | -12 | -10 | -9 | [illegible] | [illegible] | -6 | -5 | -4 | [illegible] | -1 | 0 | [illegible] | 2 | [illegible] | 5 | 6 | 7 | 8 | 10 | 11 | 12 | 13 | 15 |
| 36 | -15 | -14 | -12 | [illegible] | [illegible] | -10 | [illegible] | [illegible] | -6 | -5 | -4 | [illegible] | -2 | [illegible] | [illegible] | 2 | [illegible] | 4 | 5 | 7 | [illegible] | [illegible] | 10 | [illegible] | 13 | 14 |
| 38 | 16 | 15 | 13 | [illegible] | [illegible] | 11 | [illegible] | [illegible] | 7 | 6 | 5 | [illegible] | [illegible] | [illegible] | 0 | 1 | [illegible] | 4 | 5 | 6 | 8 | [illegible] | 10 | [illegible] | 13 | 14 |
| 40 | -16 | -15 | -14 | -13 | -12 | -11 | [illegible] | -8 | -7 | -6 | -5 | -4 | -3 | [illegible] | 0 | 1 | 2 | 3 | 5 | 6 | 7 | [illegible] | 10 | [illegible] | 12 | 14 |
| 42 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | [illegible] | -8 | -6 | -5 | -4 | [illegible] | -2 | [illegible] | 1 | 2 | 3 | 4 | 5 | [illegible] | [illegible] | 9 | [illegible] | 12 | 13 |
| 44 | -17 | -15 | -15 | -14 | [illegible] | -11 | -11 | [illegible] | -10 | -7 | -5 | [illegible] | [illegible] | -2 | [illegible] | 1 | 1 | 3 | 4 | 5 | 5 | [illegible] | 9 | 10 | 12 | 13 |
| 46 | 17 | 15 | 16 | 14 | 13 | 12 | 11 | [illegible] | 8 | 7 | [illegible] | [illegible] | 4 | 3 | [illegible] | 1 | 1 | 2 | 3 | 5 | 5 | 7 | 9 | 10 | 11 | 13 |
| 48 | -18 | -15 | -16 | -14 | -13 | -12 | -11 | -10 | -9 | -8 | -6 | -5 | -4 | -3 | -2 | -1 | 1 | 2 | 3 | [illegible] | 3 | 7 | 8 | 9 | 11 | 12 |
| 50 | -18 | -17 | -16 | -15 | -14 | -12 | -11 | -10 | -9 | -8 | [illegible] | [illegible] | [illegible] | -3 | -2 | -1 | [illegible] | 1 | 3 | 4 | 5 | [illegible] | 8 | 9 | 10 | 12 |
| 52 | -10 | -17 | -16 | -15 | -14 | -13 | -12 | -11 | -10 | -10 | -7 | -5 | -5 | -4 | -3 | -1 | [illegible] | 1 | 2 | 4 | 5 | [illegible] | 7 | 9 | 10 | 11 |
| 54 | 10 | 15 | 17 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | [illegible] | [illegible] | 4 | 3 | 2 | 1 | 1 | [illegible] | 3 | [illegible] | [illegible] | 7 | 8 | 10 | 11 |
| 56 | -19 | -18 | -17 | -16 | -15 | -14 | -13 | -11 | -10 | -9 | -8 | -7 | -6 | -5 | -3 | -2 | -1 | 0 | 2 | 3 | [illegible] | 5 | 7 | 8 | 9 | 11 |
| 58 | -20 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | [illegible] | -10 | -8 | -7 | -6 | -5 | -4 | -3 | -1 | 0 | [illegible] | 2 | 2 | [illegible] | 6 | 8 | 9 | 10 |
| 60 | -20 | -18 | -16 | -17 | -16 | -14 | -13 | -12 | [illegible] | -10 | -9 | [illegible] | -6 | -5 | -4 | -3 | -2 | -1 | [illegible] | 2 | 3 | [illegible] | 6 | 7 | 0 | 10 |
| 62 | 20 | 17 | 18 | 17 | 16 | 15 | 14 | 13 | [illegible] | 10 | [illegible] | [illegible] | 7 | 6 | 5 | 3 | 2 | 1 | 0 | 2 | 3 | 4 | 5 | 7 | 8 | [illegible] |
| 64 | -21 | -20 | -18 | -17 | -16 | -15 | -14 | -13 | -12 | [illegible] | -10 | -9 | -7 | -6 | -5 | [illegible] | -2 | -1 | 0 | 1 | 2 | 4 | 5 | 6 | 8 | 9 |
| 66 | -21 | [illegible] | -19 | -18 | [illegible] | -16 | -14 | -13 | -12 | [illegible] | -10 | [illegible] | -8 | -6 | -5 | [illegible] | [illegible] | -2 | 0 | 1 | 2 | [illegible] | 5 | 6 | [illegible] | 9 |
| 68 | -21 | [illegible] | -19 | -20 | [illegible] | -16 | -15 | -14 | -13 | [illegible] | -10 | [illegible] | -6 | [illegible] | -6 | [illegible] | [illegible] | -2 | [illegible] | 0 | 2 | [illegible] | 4 | 6 | [illegible] | [illegible] |
| 70 | 22 | 21 | 20 | 19 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 8 | 7 | 6 | 5 | 4 | 2 | [illegible] | 0 | 1 | [illegible] | 4 | 5 | 6 | 8 |
| 72 | -22 | -21 | -20 | -19 | -18 | -17 | -16 | -15 | -13 | -12 | -11 | -10 | -8 | -8 | -6 | -5 | -4 | -3 | -2 | 0 | 1 | 2 | 3 | 5 | 6 | 7 |
| 74 | -23 | [illegible] | -20 | -19 | -18 | -17 | -15 | -15 | -14 | -13 | -12 | -11 | -8 | -8 | [illegible] | [illegible] | -4 | -3 | -2 | -1 | 1 | [illegible] | 3 | 4 | 6 | [illegible] |
| 76 | -23 | [illegible] | -21 | -20 | -19 | -19 | -18 | -15 | -14 | -13 | -12 | -11 | -10 | -9 | [illegible] | [illegible] | [illegible] | -4 | -2 | -1 | 0 | 1 | 3 | 4 | 5 | [illegible] |
| 78 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 13 | 12 | 11 | 10 | 9 | 8 | [illegible] | [illegible] | 4 | 3 | 2 | 1 | 1 | 2 | 4 | 5 | [illegible] |
| 80 | -24 | -23 | -23 | -21 | -19 | -13 | -17 | -16 | -15 | -14 | -13 | -12 | -10 | -9 | -8 | -7 | [illegible] | -1 | -3 | -2 | -1 | 1 | 2 | 3 | 5 | 6 |

Apparent temperature with no [illegible] and relative humidity fixed at 70%
Formula from "Norms of apparent temperature in Australia", **Aust. Met. Mag.** Vol 43, 1994, 1-16.