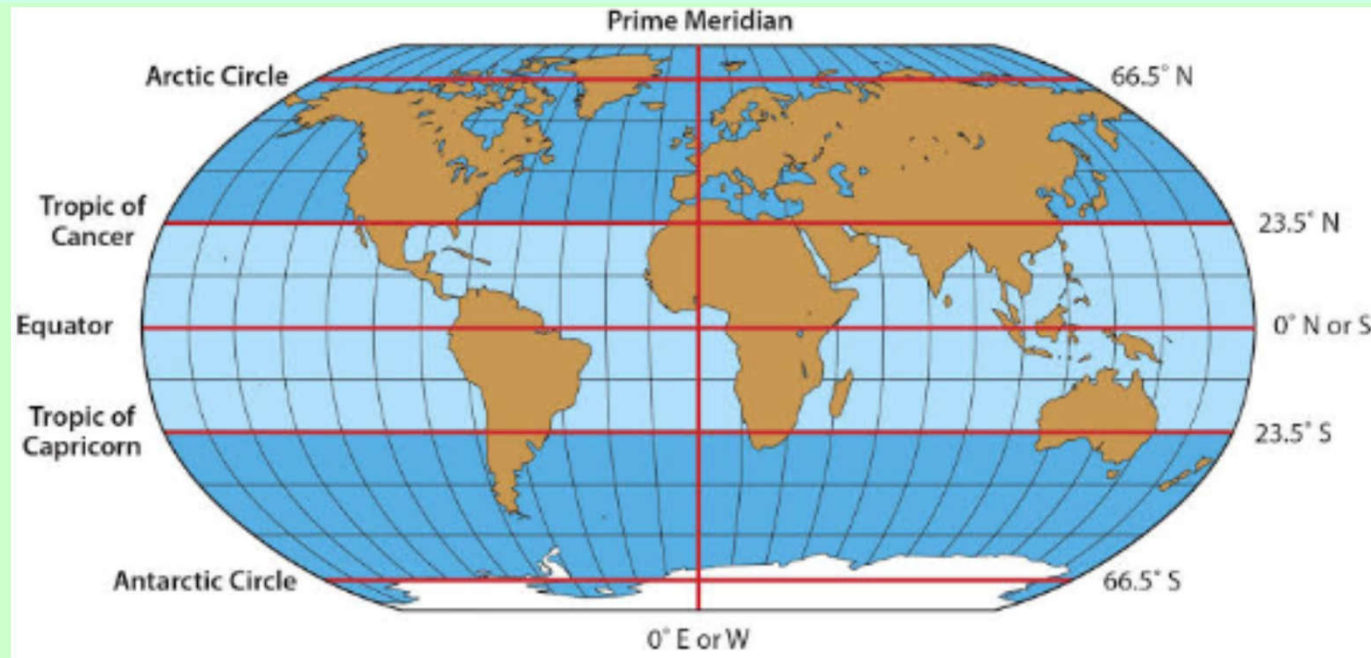


MEBS6004 Built Environment

<http://ibse.hk/MEBS6004/>



Climatology and climatic factors



Ir Dr. Sam C. M. Hui

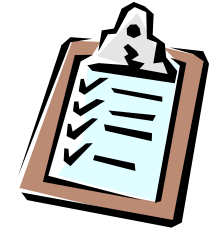
Department of Mechanical Engineering

The University of Hong Kong

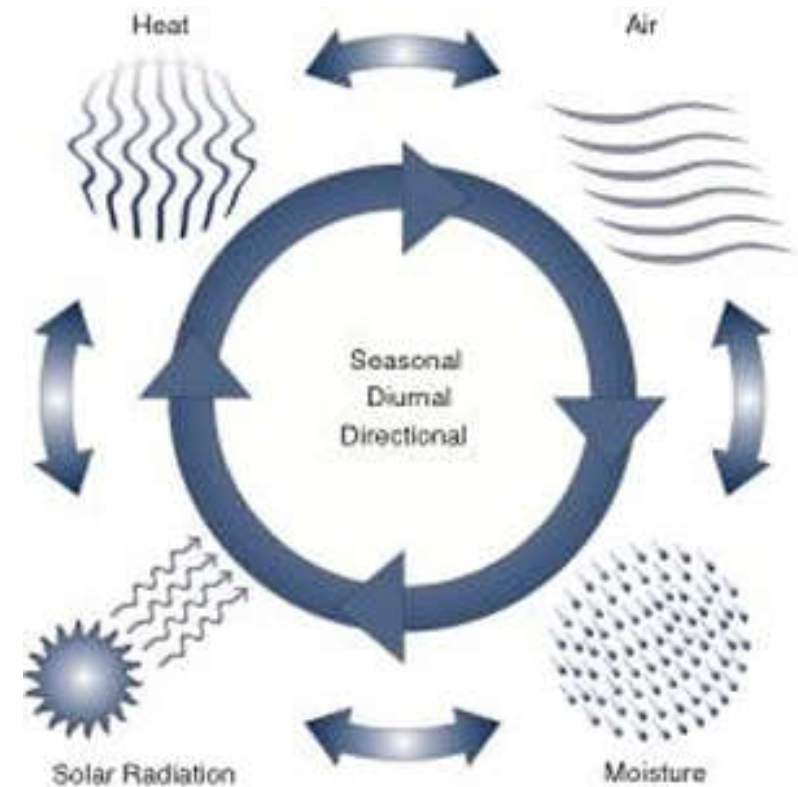
E-mail: cmhui@hku.hk

Aug 2022

Contents



- Basic principles
- Micro & urban climate
- Weather data
- The Sun
- Wind properties
- Humid air & climate analysis





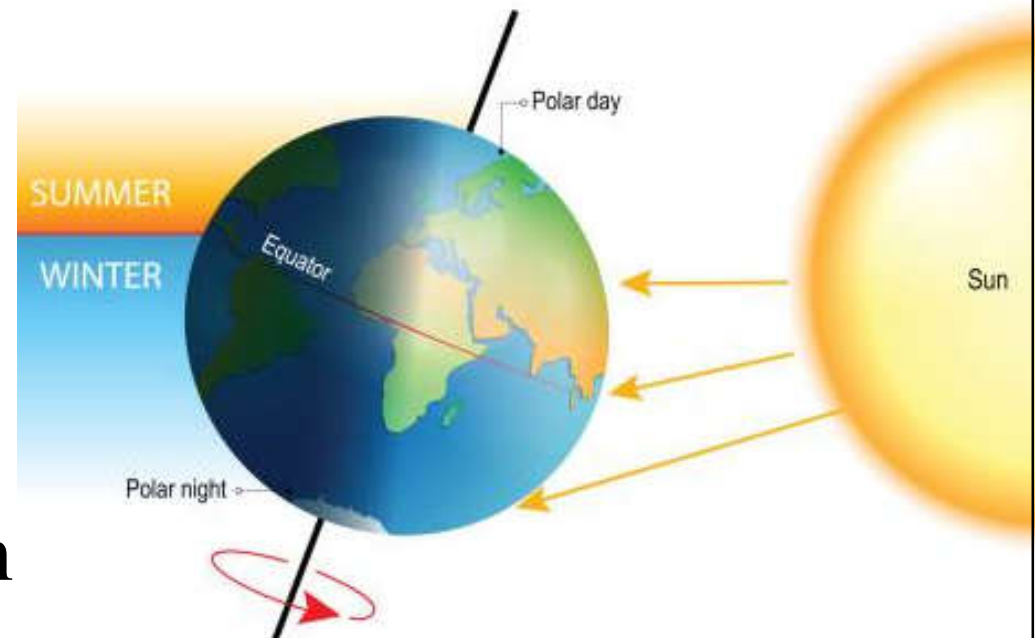
Basic principles

- **The Earth's atmosphere** is a particular environment which produces ever-changing effects of sunshine & clouds, pressure & wind, temperature & humidity, and precipitation in the form of rain, hail & snow
 - When these short-term variations of **weather** are observed at one place and considered over a period of time they form a **climate**
 - The climate varies from place to place on Earth and creates a variety of environments

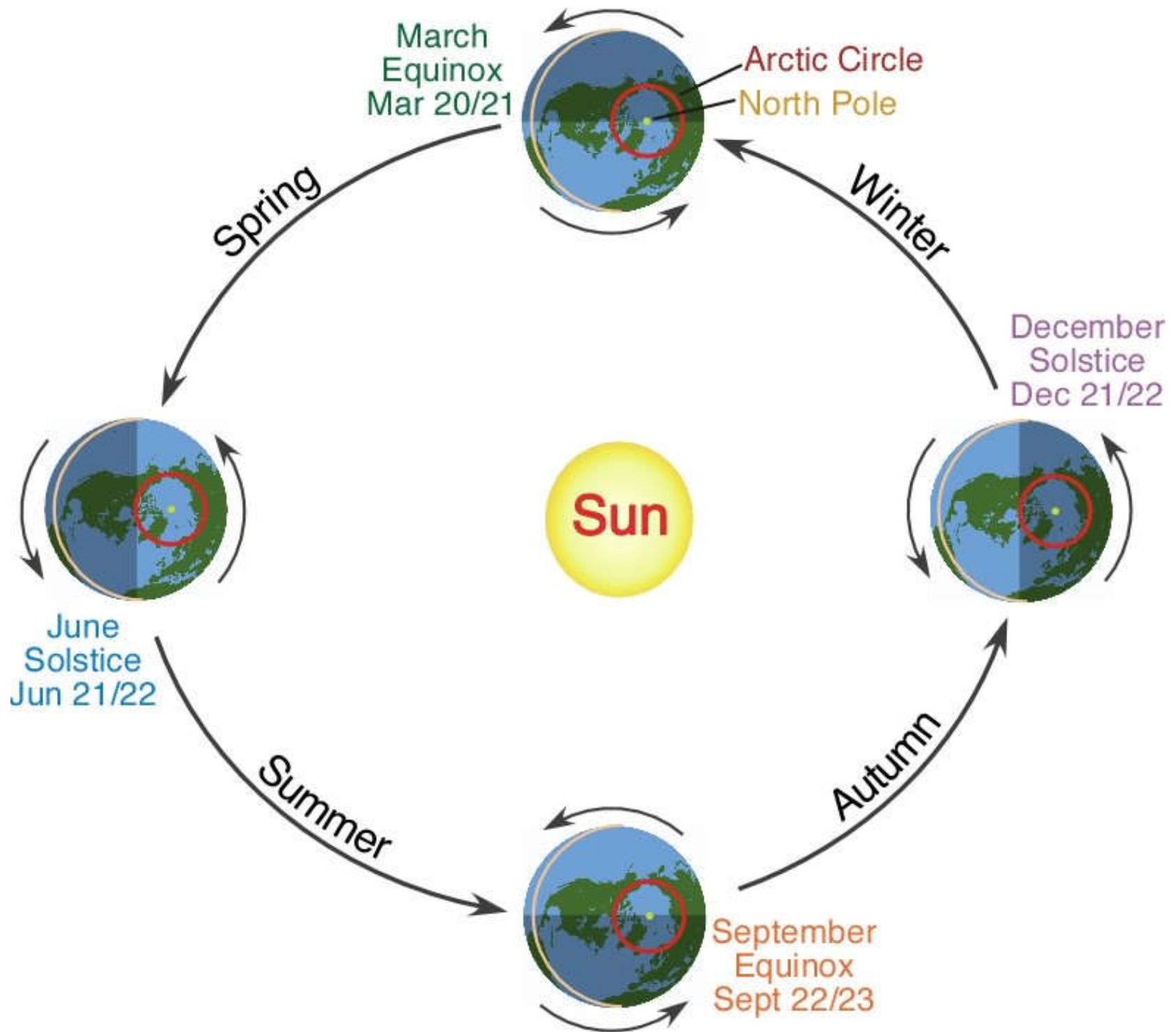


Basic principles

- Directly or indirectly, climate has an influence on all human activities
- The underlying climate of a region can be linked to certain factors:
 - Geographical latitude
 - Season of the year
 - Altitude & topography
 - Effects of water
 - Atmospheric circulation



Sun-Earth relationship and the seasons





Basic principles

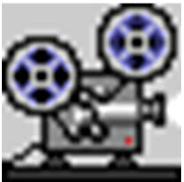
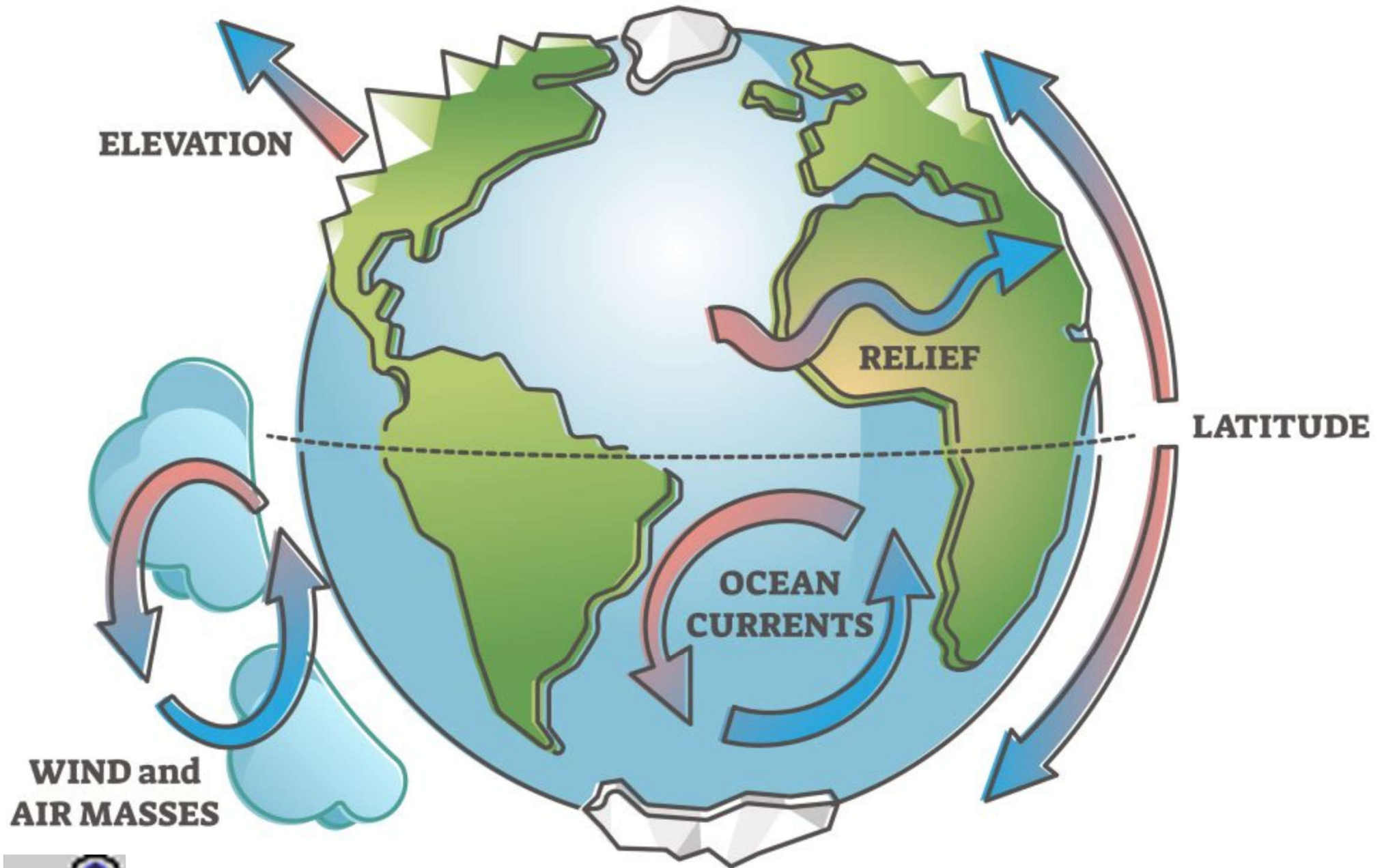
- **Climate** (from Greek Klima) is defined as certain conditions of temperature, dryness, wind, light, etc. of a region
 - Determined by both natural & man-made factors
 - Natural elements: atmosphere, geosphere, hydrosphere & biosphere
 - Human factors: land use & consumption of natural resources
- Gives a general picture of weather conditions



Basic principles

- Factors that influence climate
 - Latitude (the amount of solar energy received)
 - Altitude (atmospheric temperature)
 - Distance from the sea (moderation by sea water)
 - Air pressure and wind system
 - Relief (mountains act as a climatic barrier)
 - Ocean currents (warm & cold currents)
- Human activities may also affect local climate

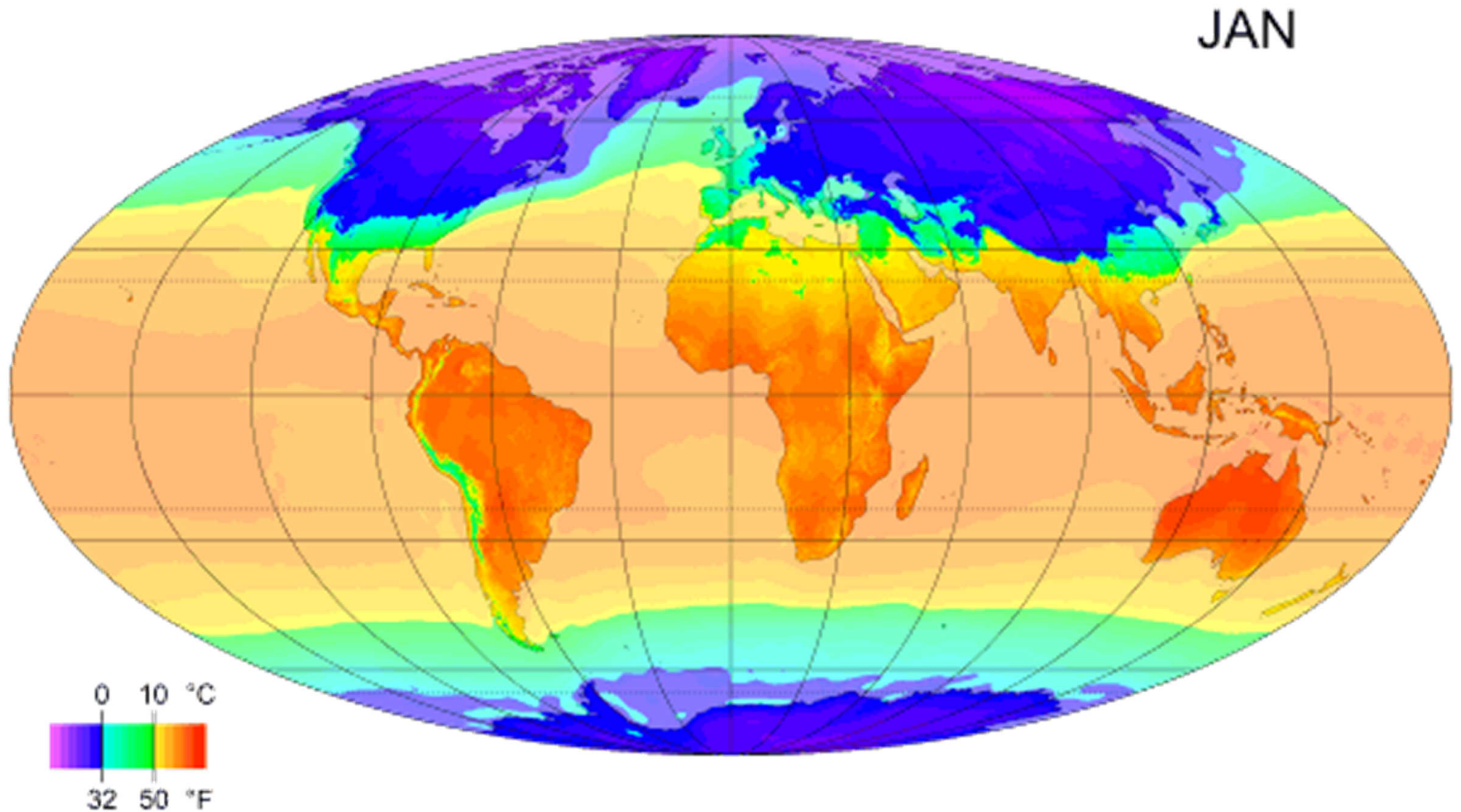
Factors that influence climate



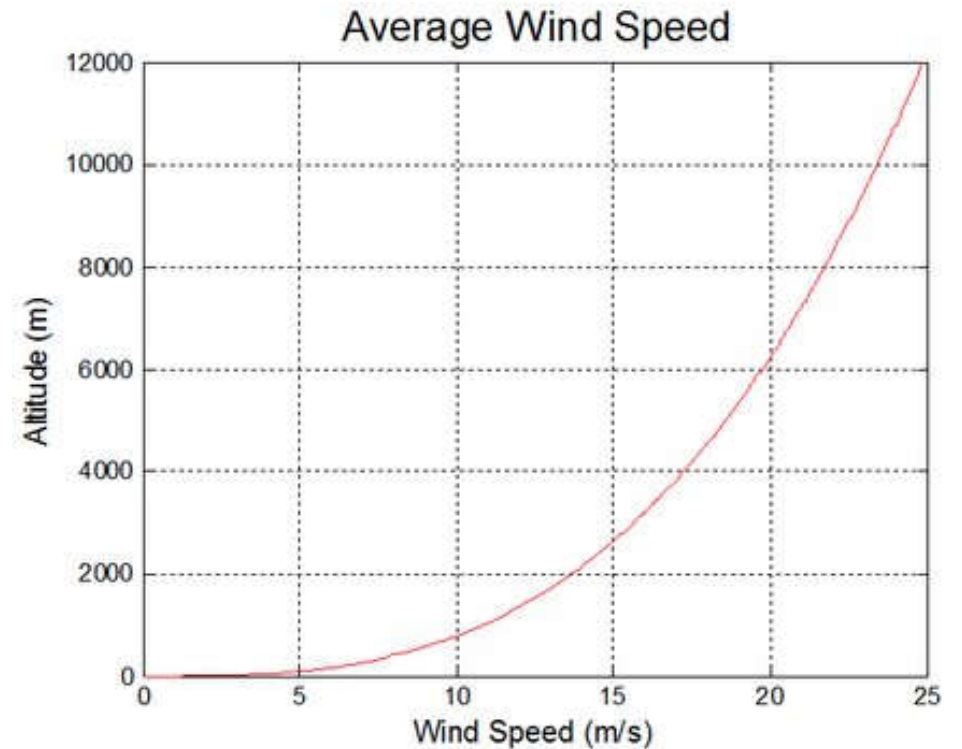
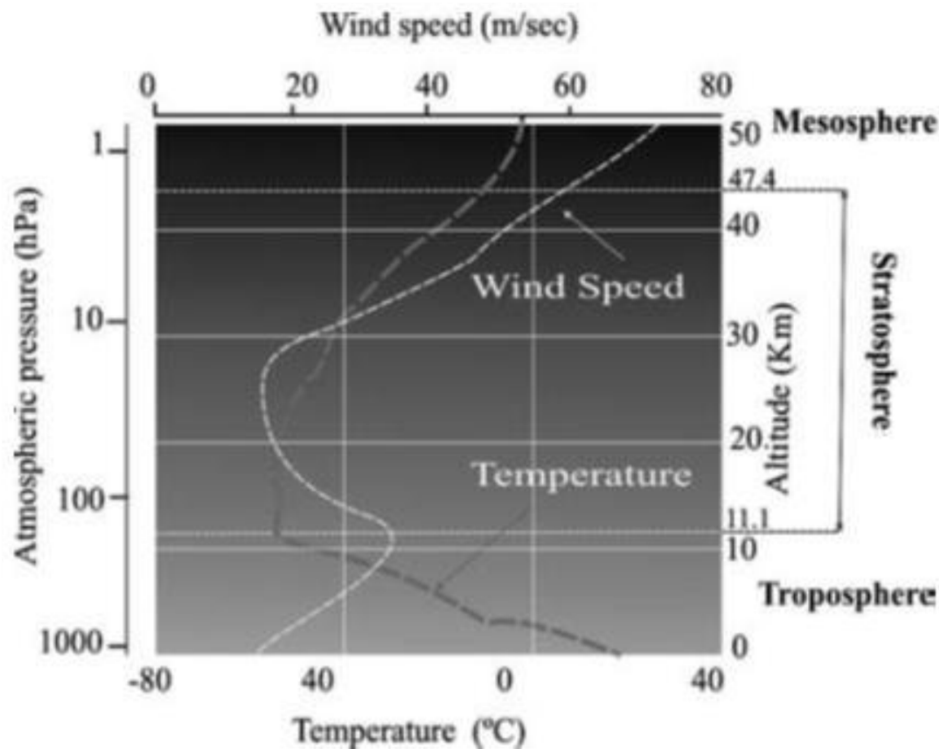
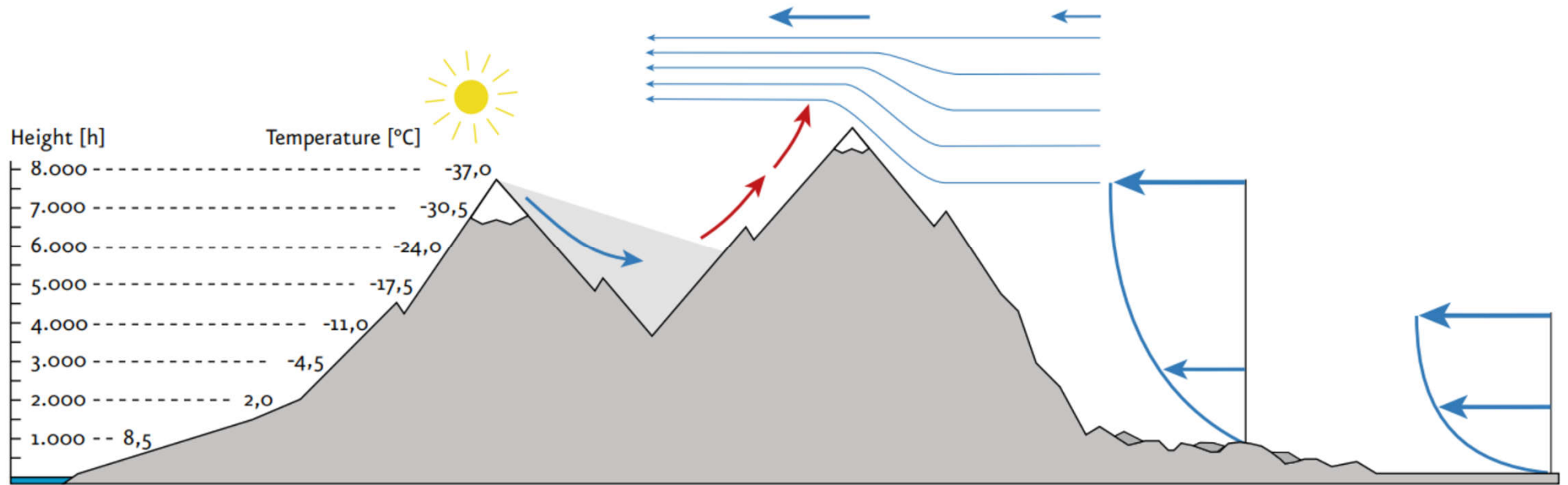
Video: Why does Climate vary around the world? (6:09) <https://youtu.be/BJGRAfapg0E>

(Source: <https://nittygrittyscience.com/textbooks/weather-climate/section-4-factors-that-influence-climate/>)

How climate varies with location and season



Influence of altitude on the temperature and the wind system





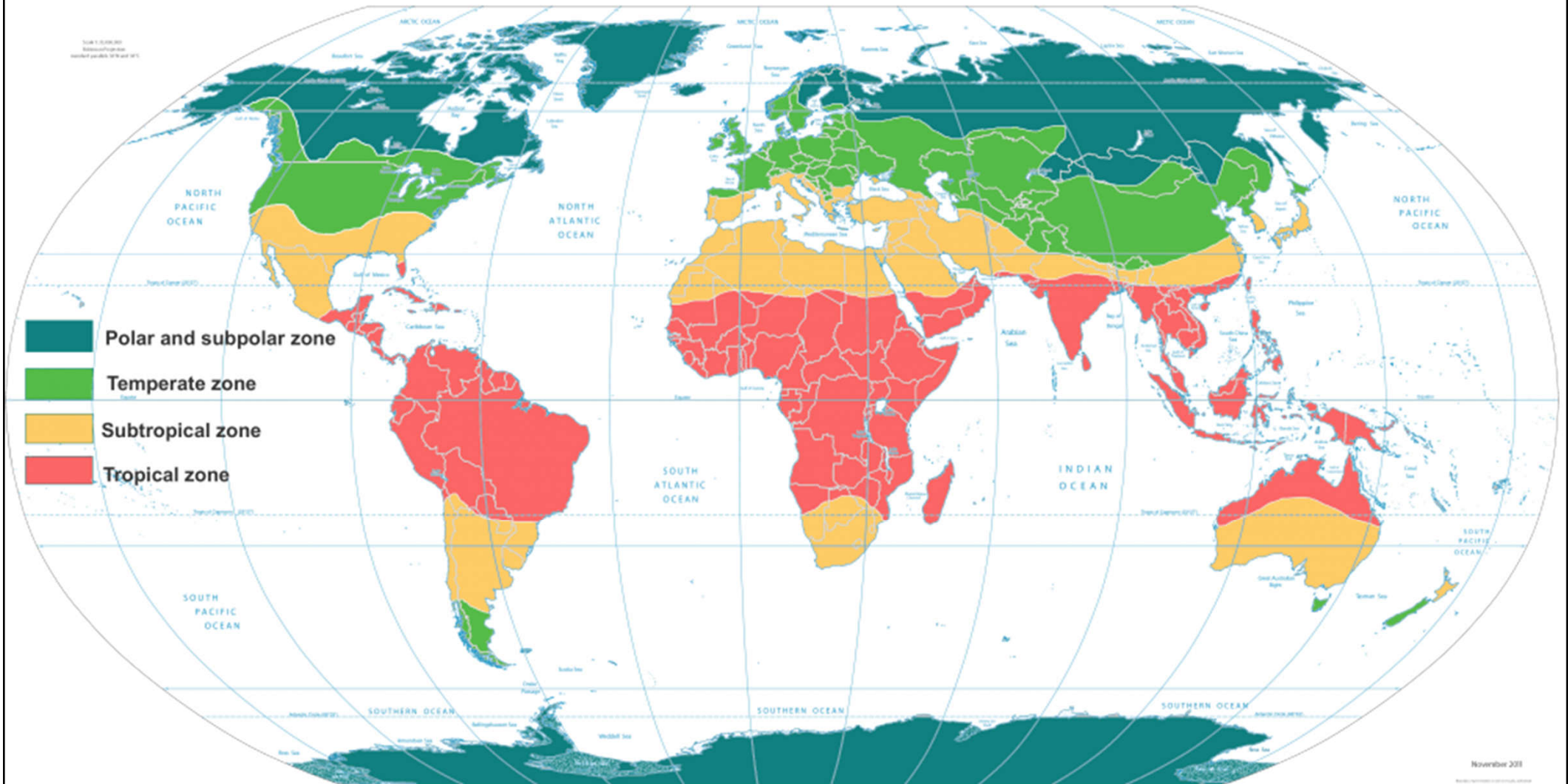
Basic principles

- Köppen Climate Classification System

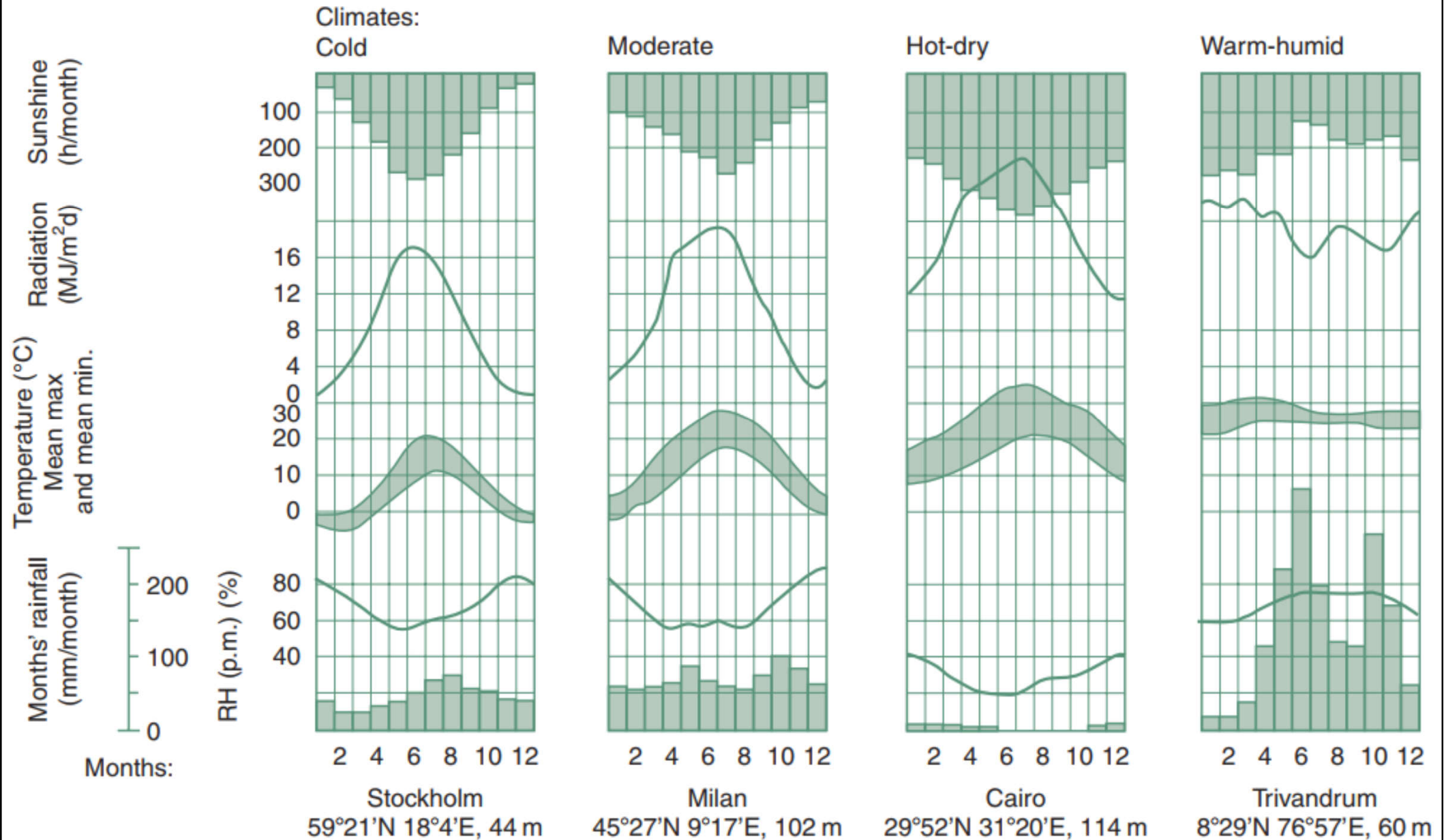
https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification

- A - Tropical moist climates: all months have average temperatures above 18° Celsius
- B - Dry climates: with deficient precipitation during most of the year
- C - Moist mid-latitude climates with mild winters
- D - Moist mid-latitude climates with cold winters
- E - Polar climates: with extremely cold winters and summers

Climates of the earth in different geographical locations

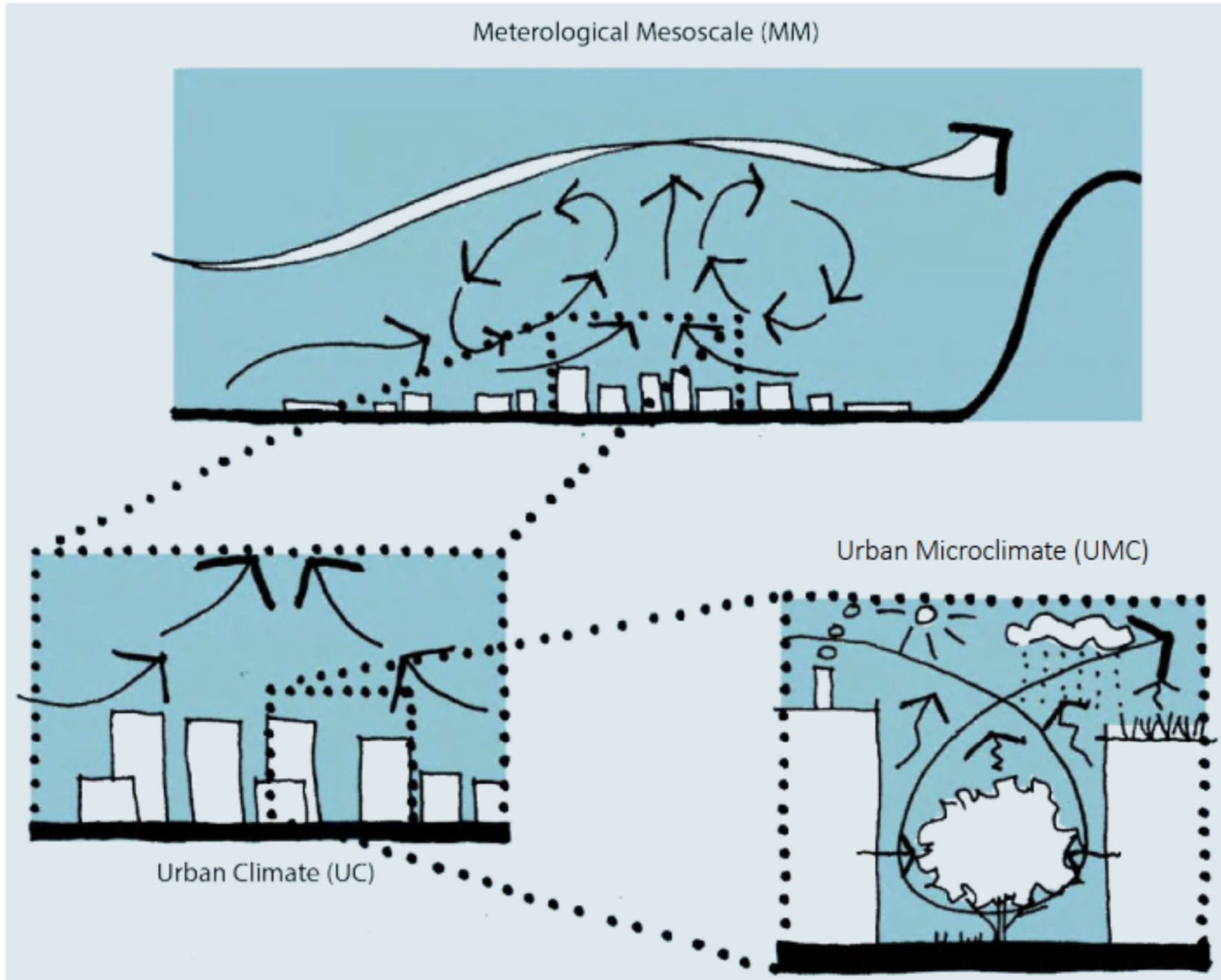


Composite (simplified) climate graphs for the four basic types



(Source: Szokolay S. V., 2008. *Introduction to Architectural Science: the Basis of Sustainable Design*, Second edition.)

Different scales in climatic studies

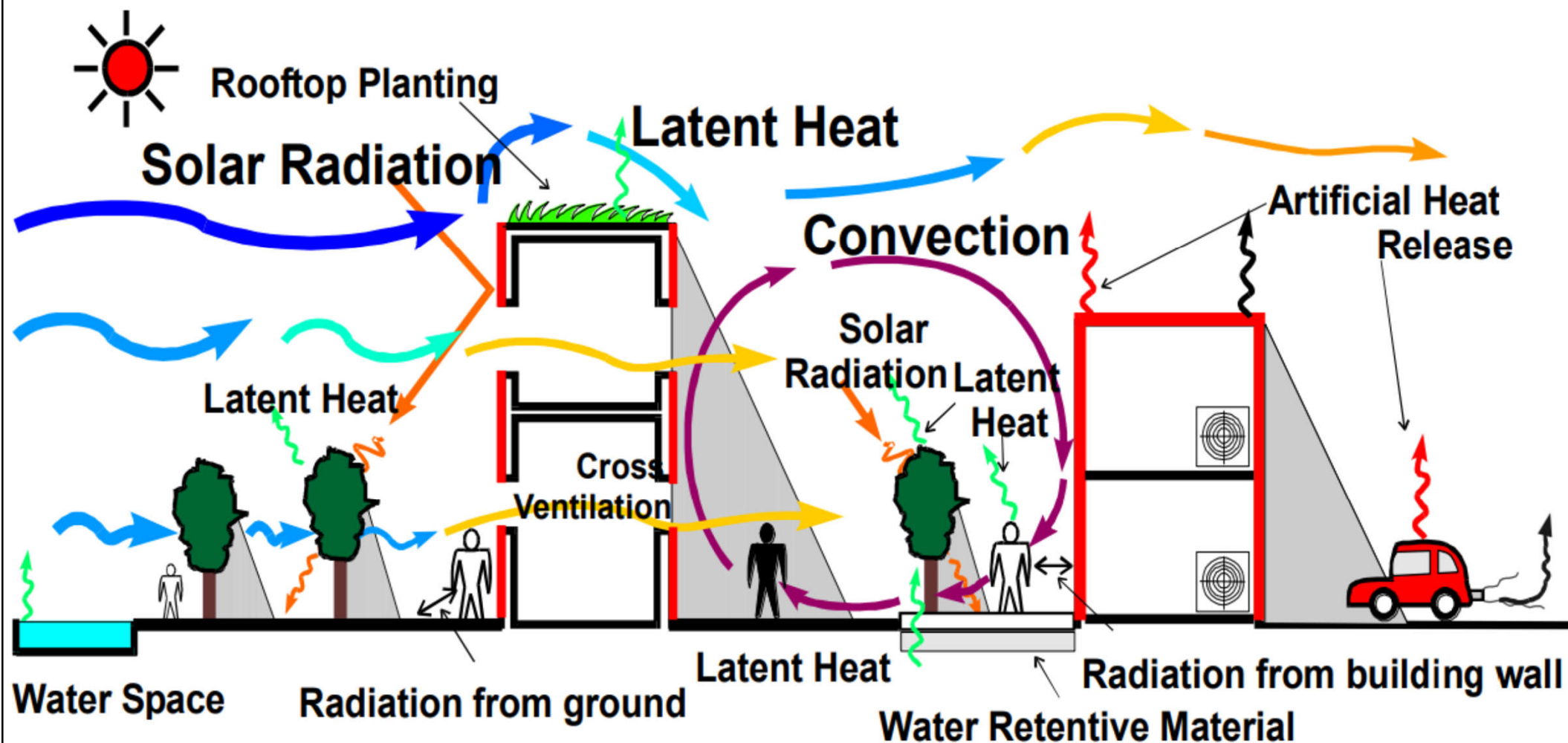


Micro & urban climate

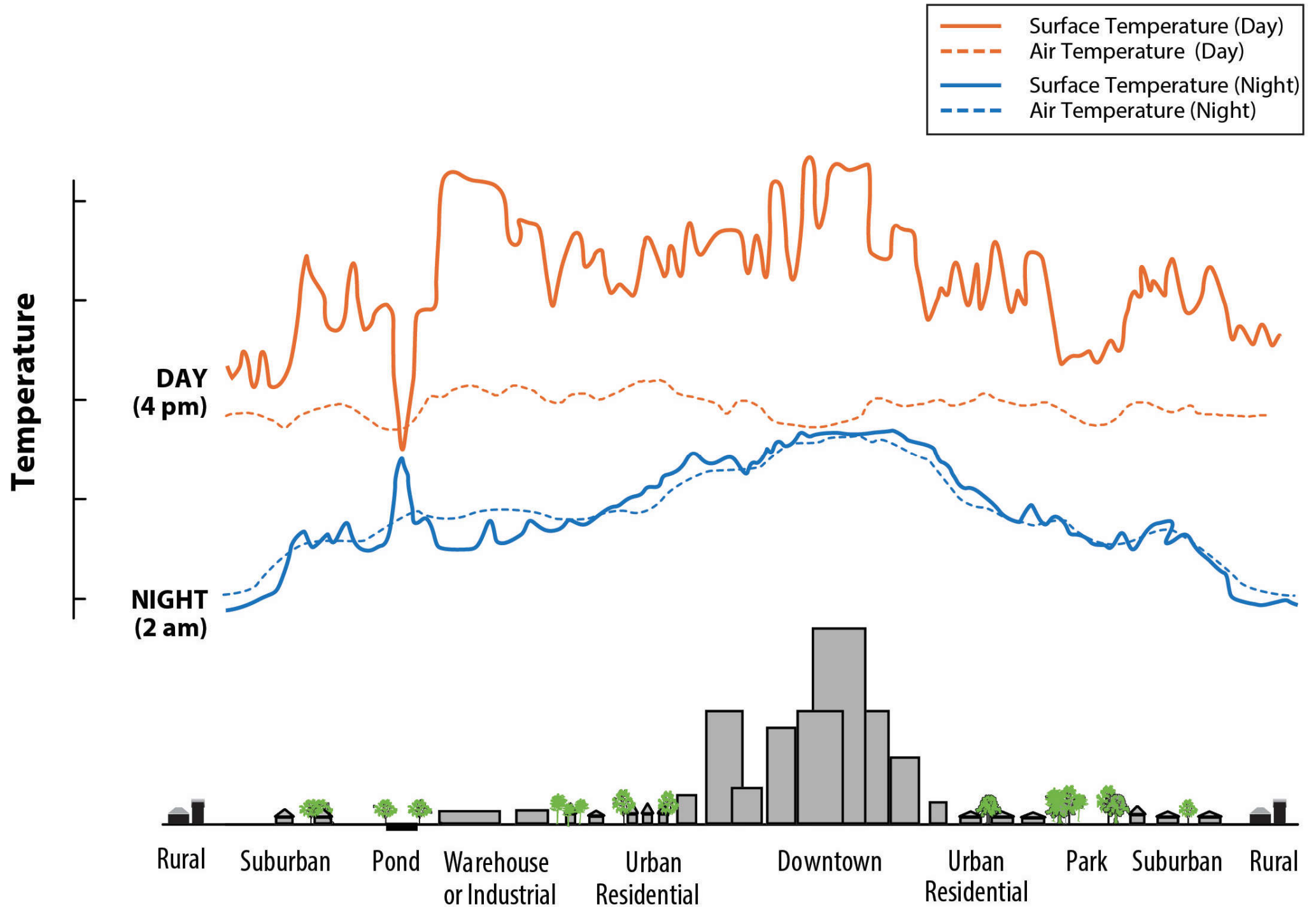


- Micro-climate 微氣候
 - The climate of a site or location
 - Small scale patterns of climate resulting from the influence of topography, urban forms, water bodies, vegetation, sun path, etc.
 - Microclimate scale may be at the level of:
 - A settlement (urban or rural)
 - Neighbourhood & cluster
 - Street or buffer space in between buildings
 - Within the building itself

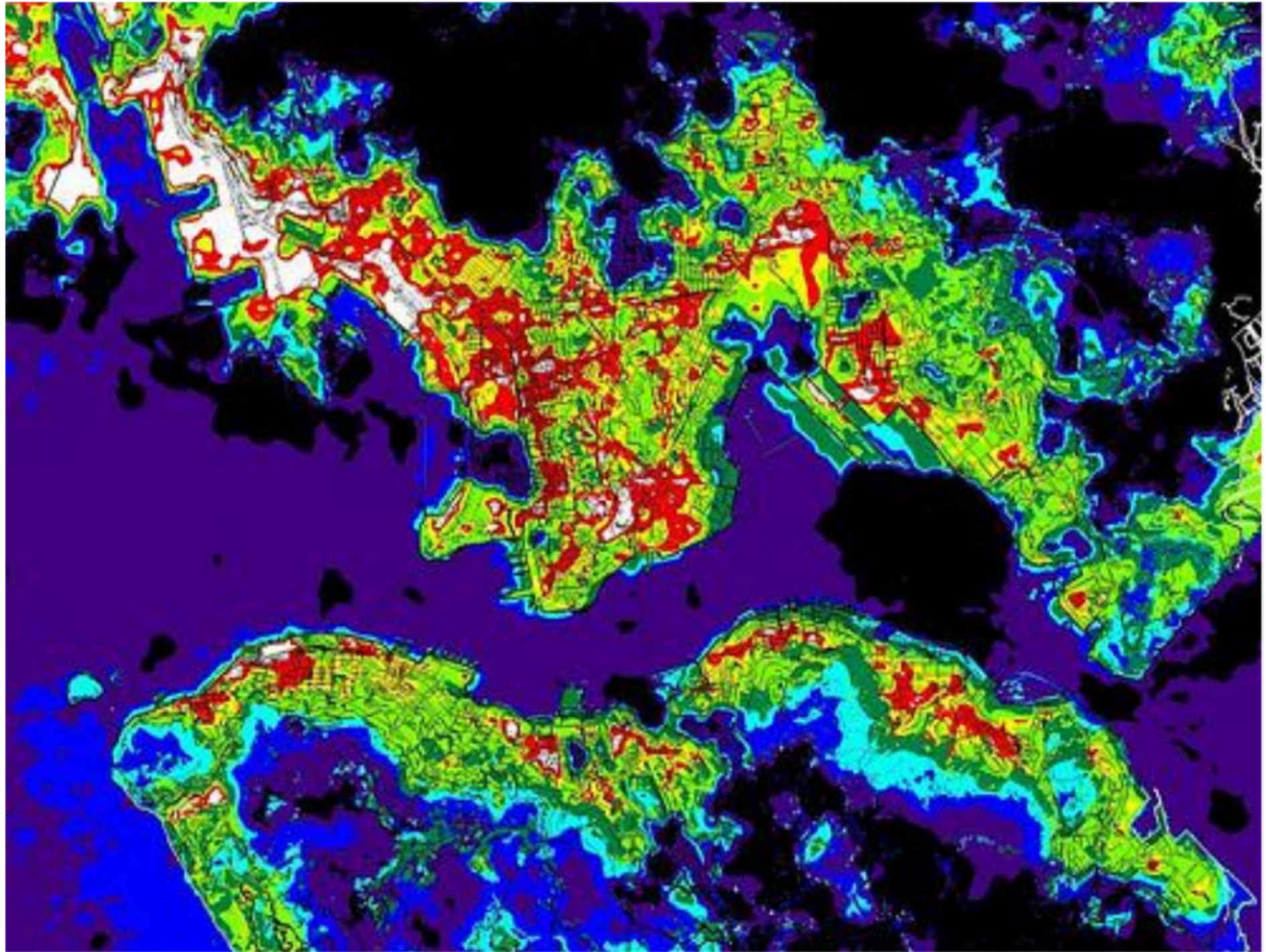
The urban thermal environment needs a balanced understanding of air temperature, solar and surface radiation & wind



Urban heat island effect

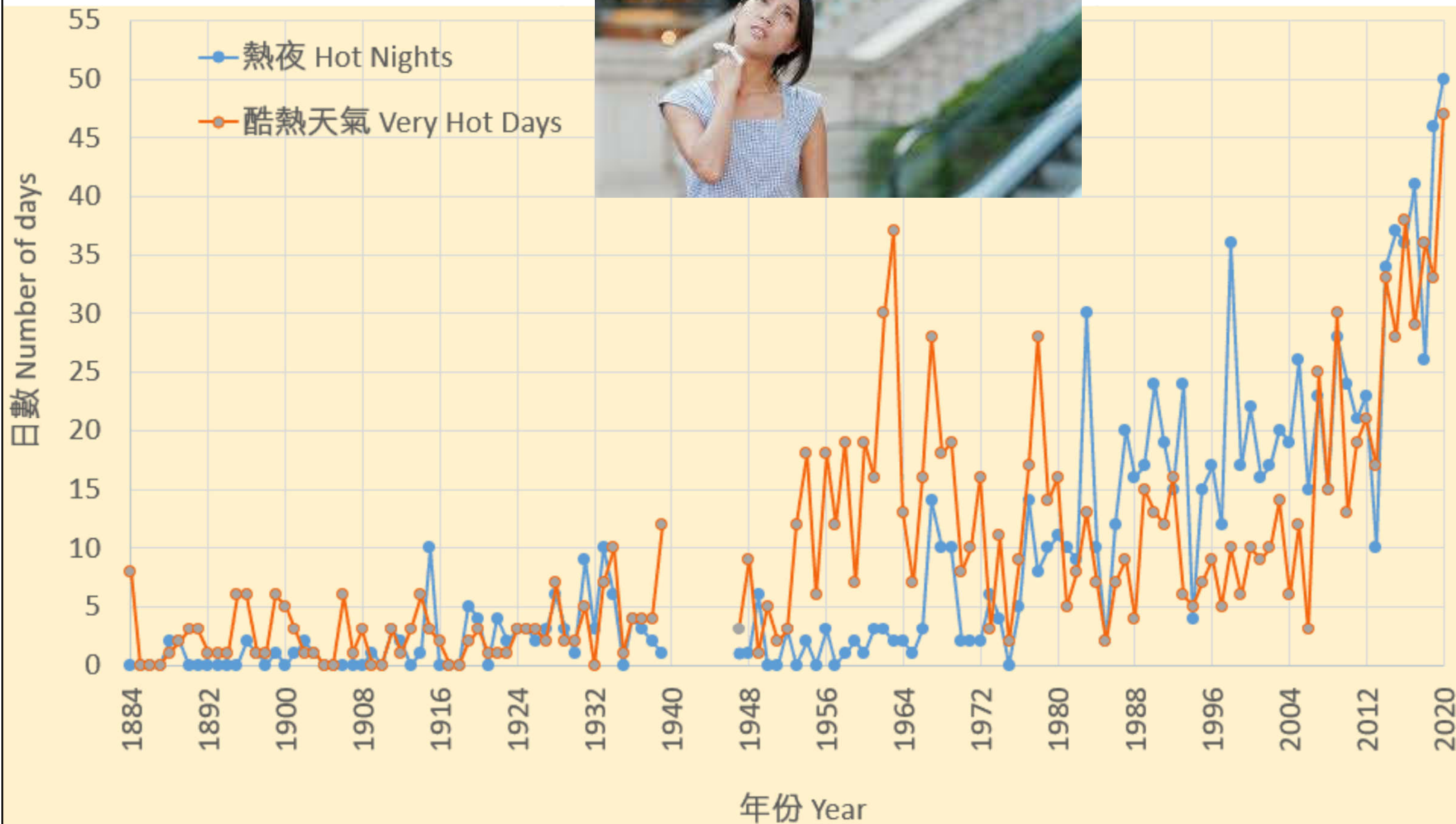


Urban temperatures in Kowloon and Hong Kong Island



(Source: https://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/)

Number of days of hot nights and very hot days in Hong Kong 香港的酷熱日數和熱夜數目



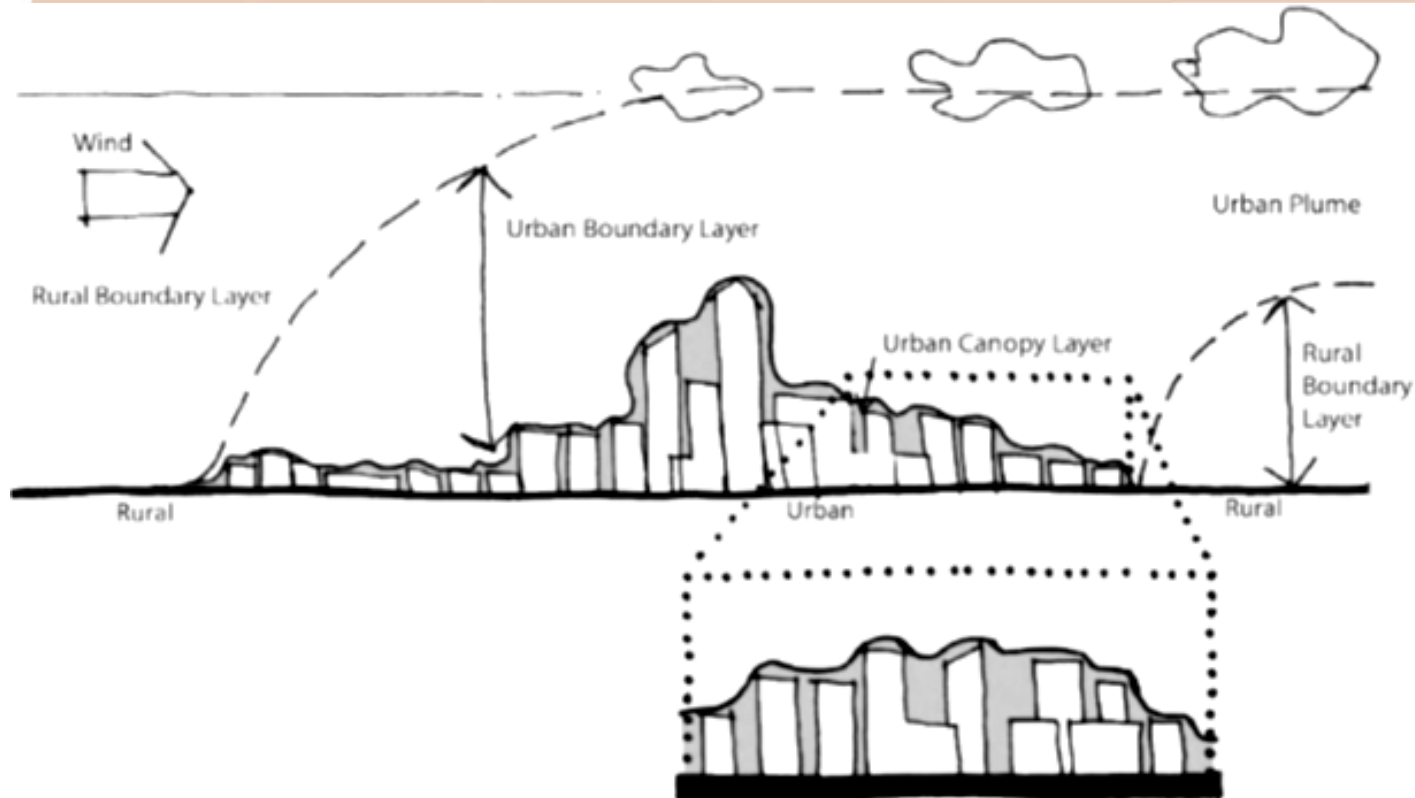
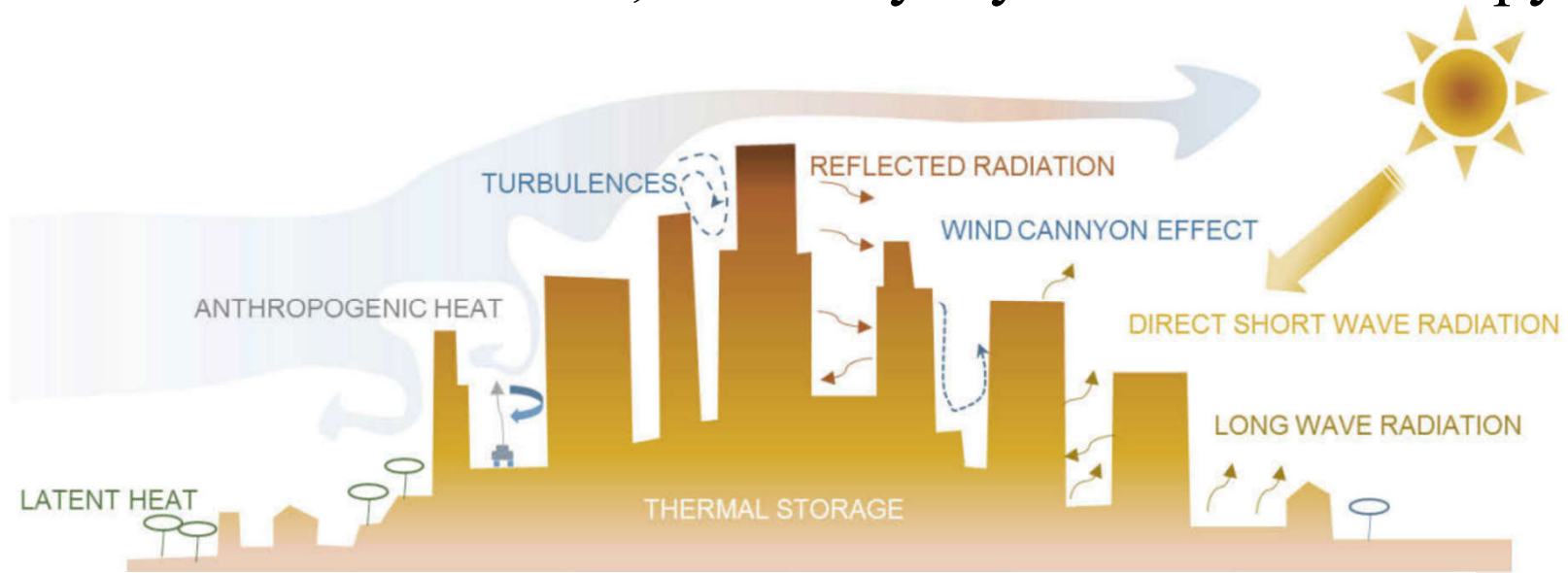
(Source: https://openday.hko.gov.hk/en/ocw/the_weather.html)

Micro & urban climate

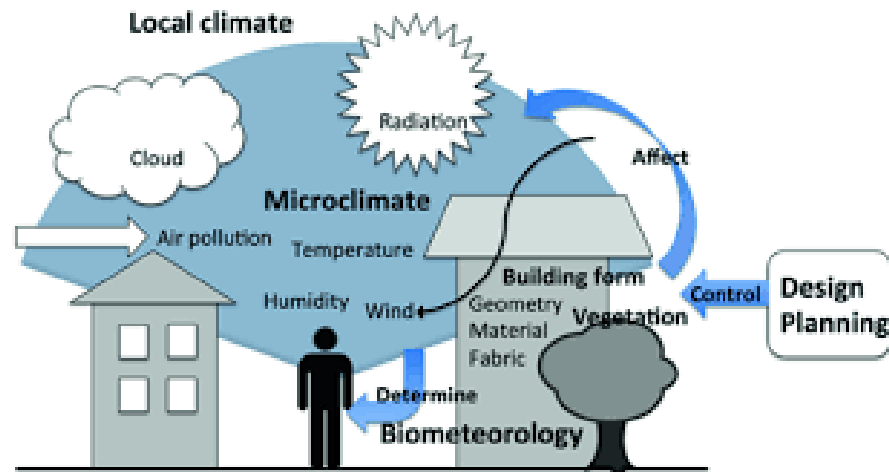
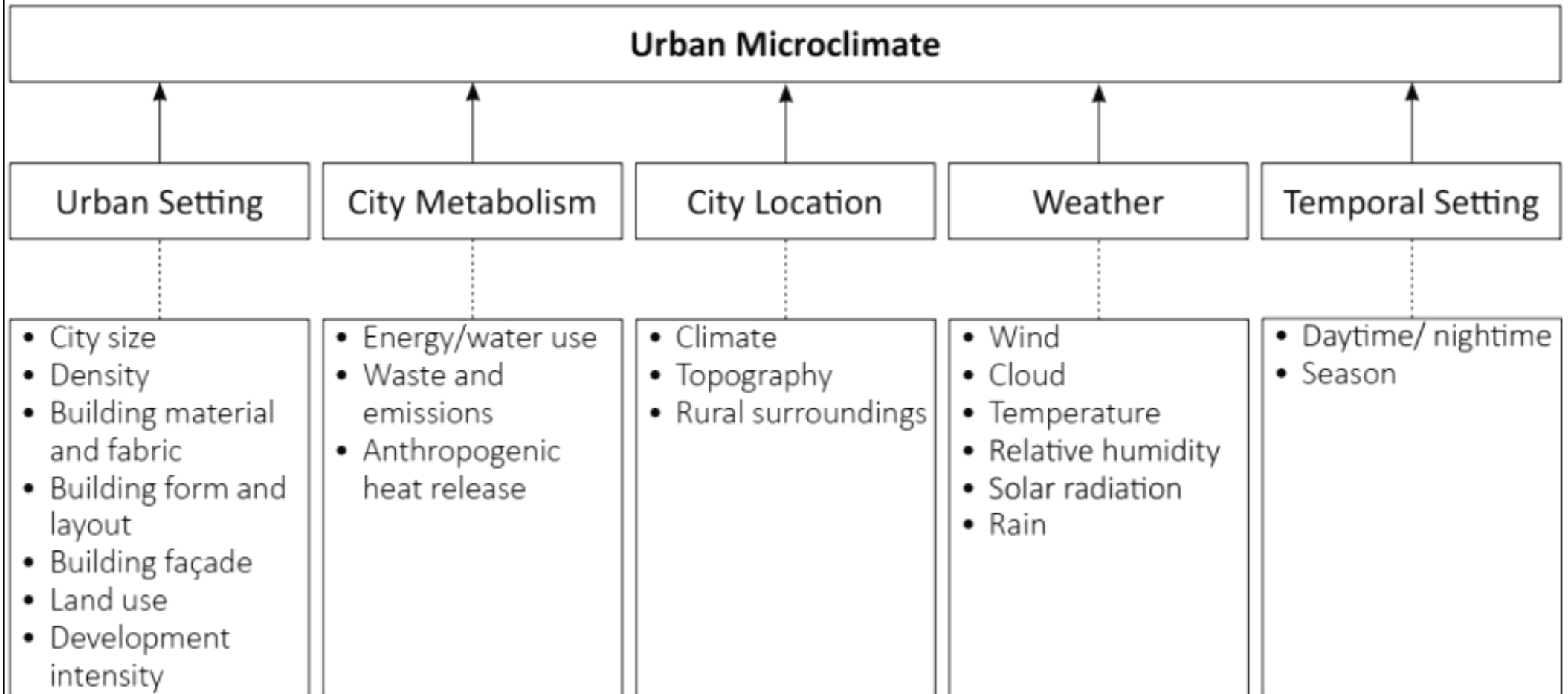


- City/Urban climate 都市氣候
 - Determined by a mixture of natural & anthropogenic factors
 - Natural factors include geographical position, terrain, altitude & any natural, undeveloped areas
 - Anthropogenic factors include the nature & density of the city's development, the heat storage capacity of building components and the degree of surface sealing, and industrial, household & traffic emissions

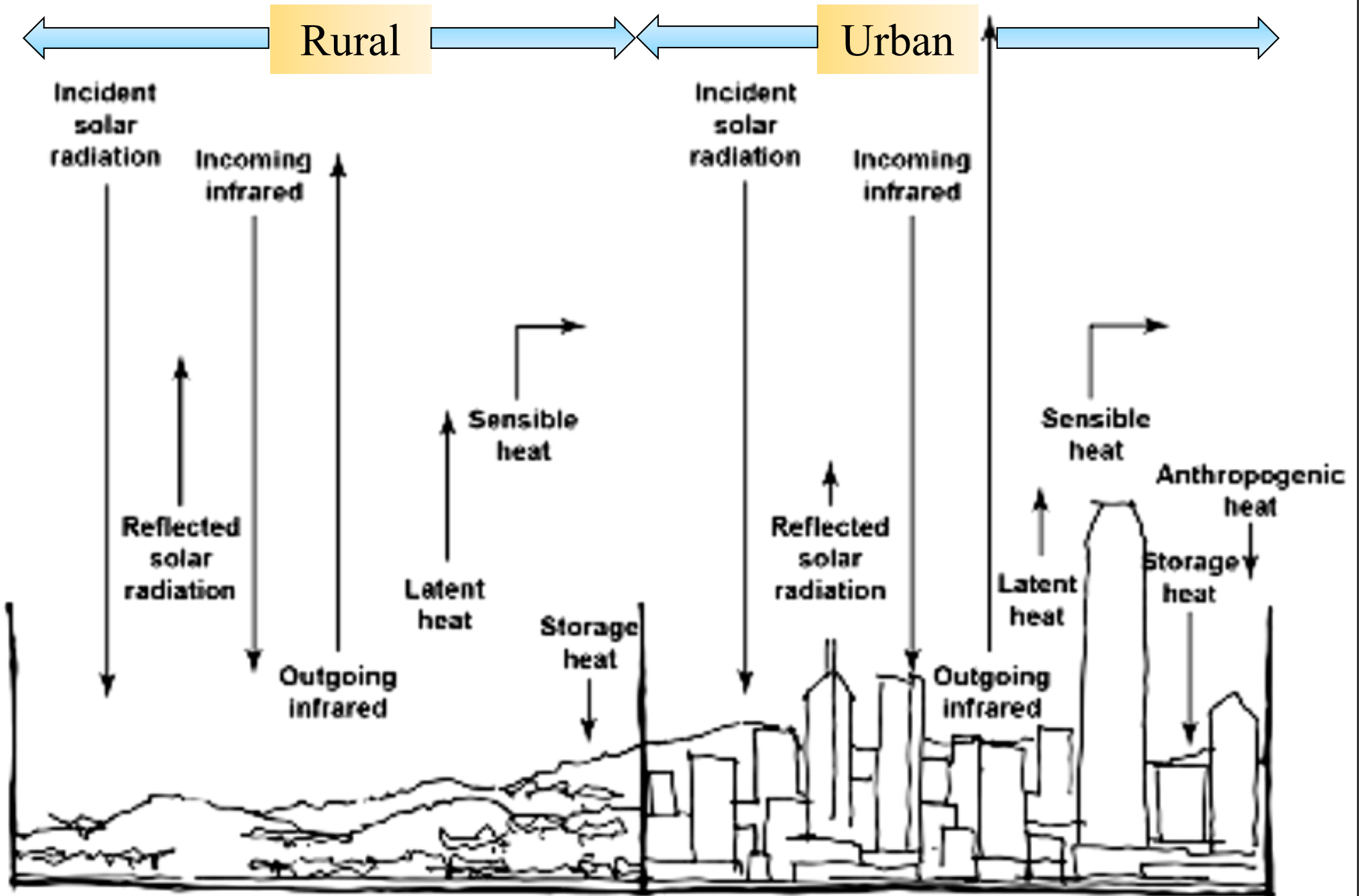
Urban microclimate factors, boundary layers & urban canopy layer



Factors influencing the urban microclimate

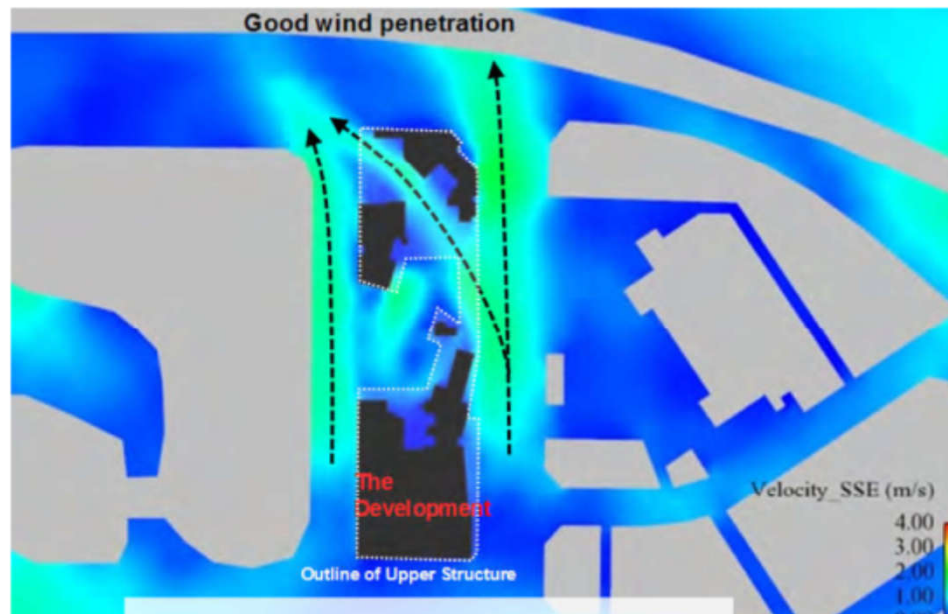


A comparison of energy balances in typical rural and urban settings

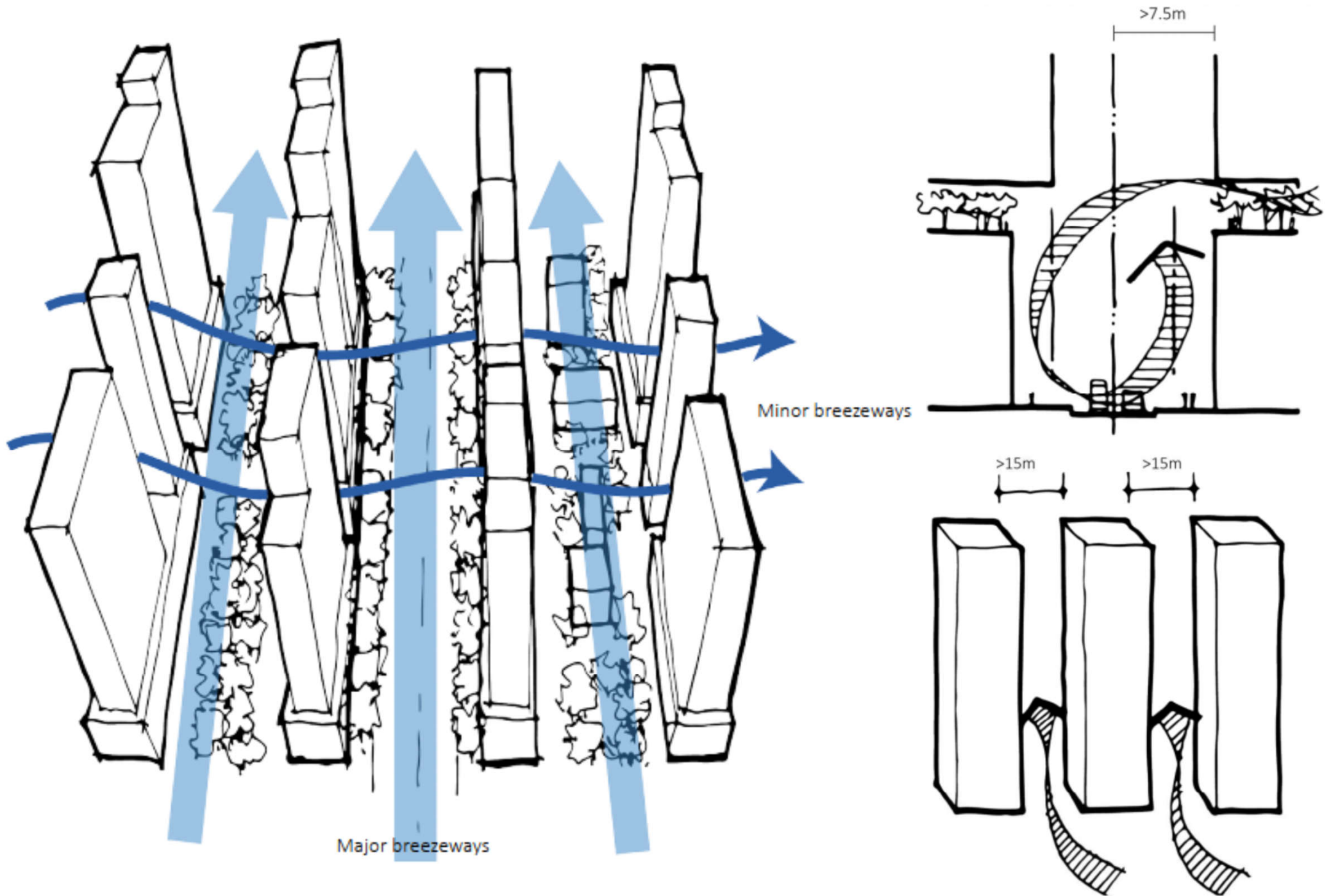


Urban microclimate design strategies

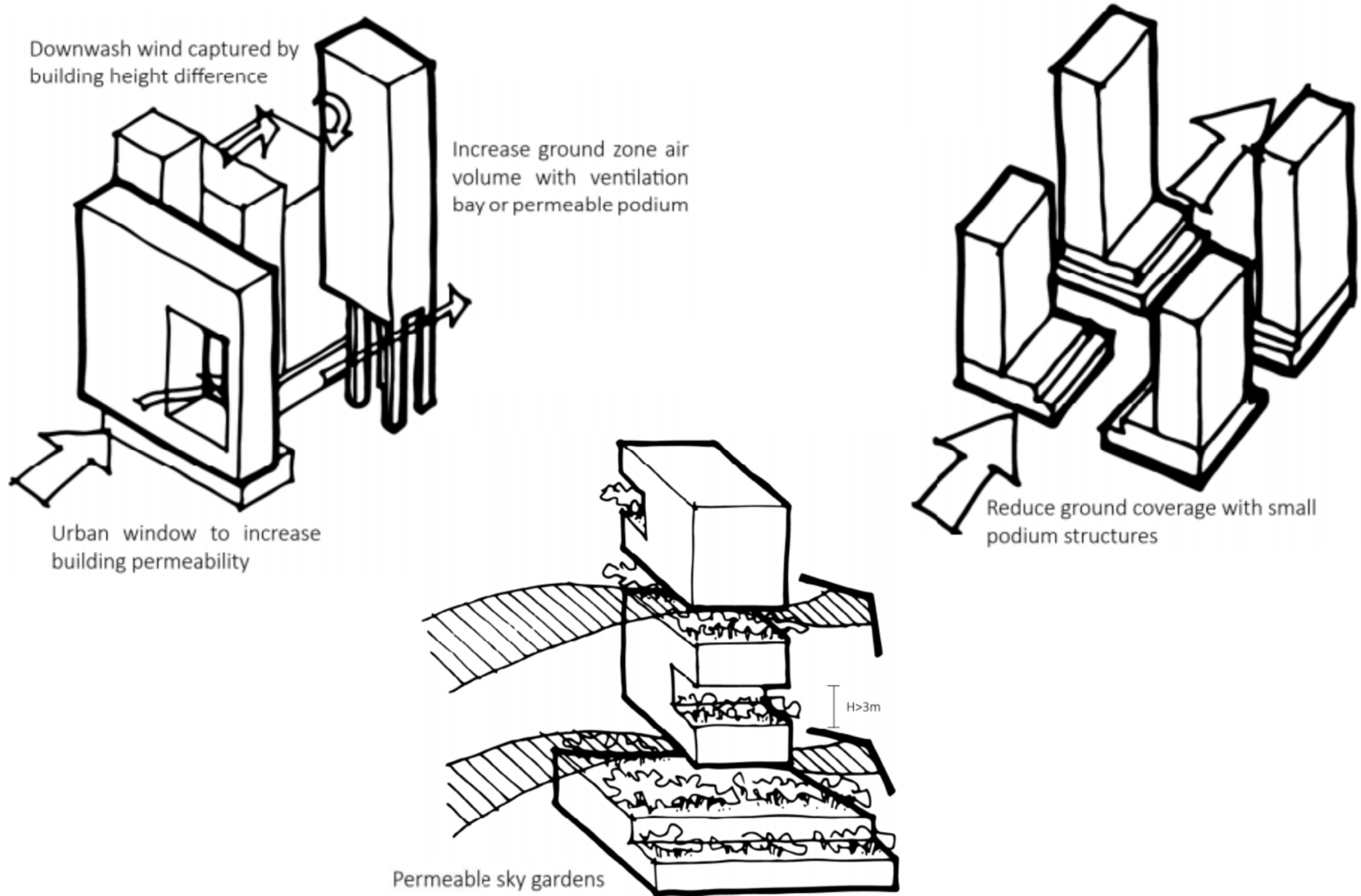
Wind	<ul style="list-style-type: none">• Increase ventilation with site planning• Increase ventilation with building design
Thermal radiation	<ul style="list-style-type: none">• Reduce direct solar radiation• Reduce surface temperature
Temperature	<ul style="list-style-type: none">• Increase evaporative cooling• Reduce heat accumulation• Reduce heat release
Precipitation	<ul style="list-style-type: none">• Provide rain protection



Increase ventilation with site planning (major & minor breezeways)



Increase ventilation with building design



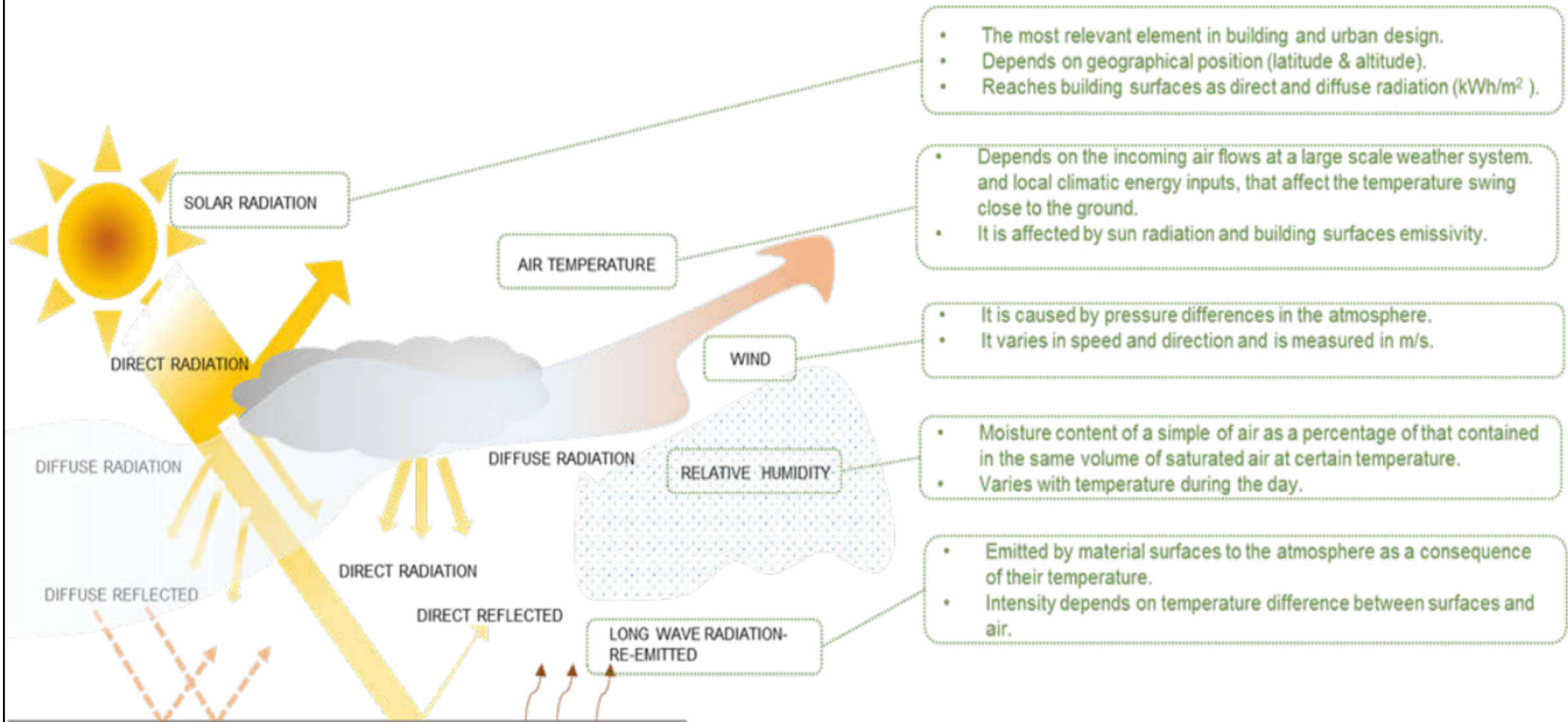


Weather data

- **Weather** is the sum total of the atmospheric conditions at a place or in an area in terms of weather parameters at a particular time
 - 1. Temperature
 - 2. Wind
 - 3. Humidity
 - 4. Precipitation (rainfall)
- A day to day or hour to hour phenomenon



Climate parameters: solar radiation, air temperature, wind, relative humidity, long wave radiation re-emitted

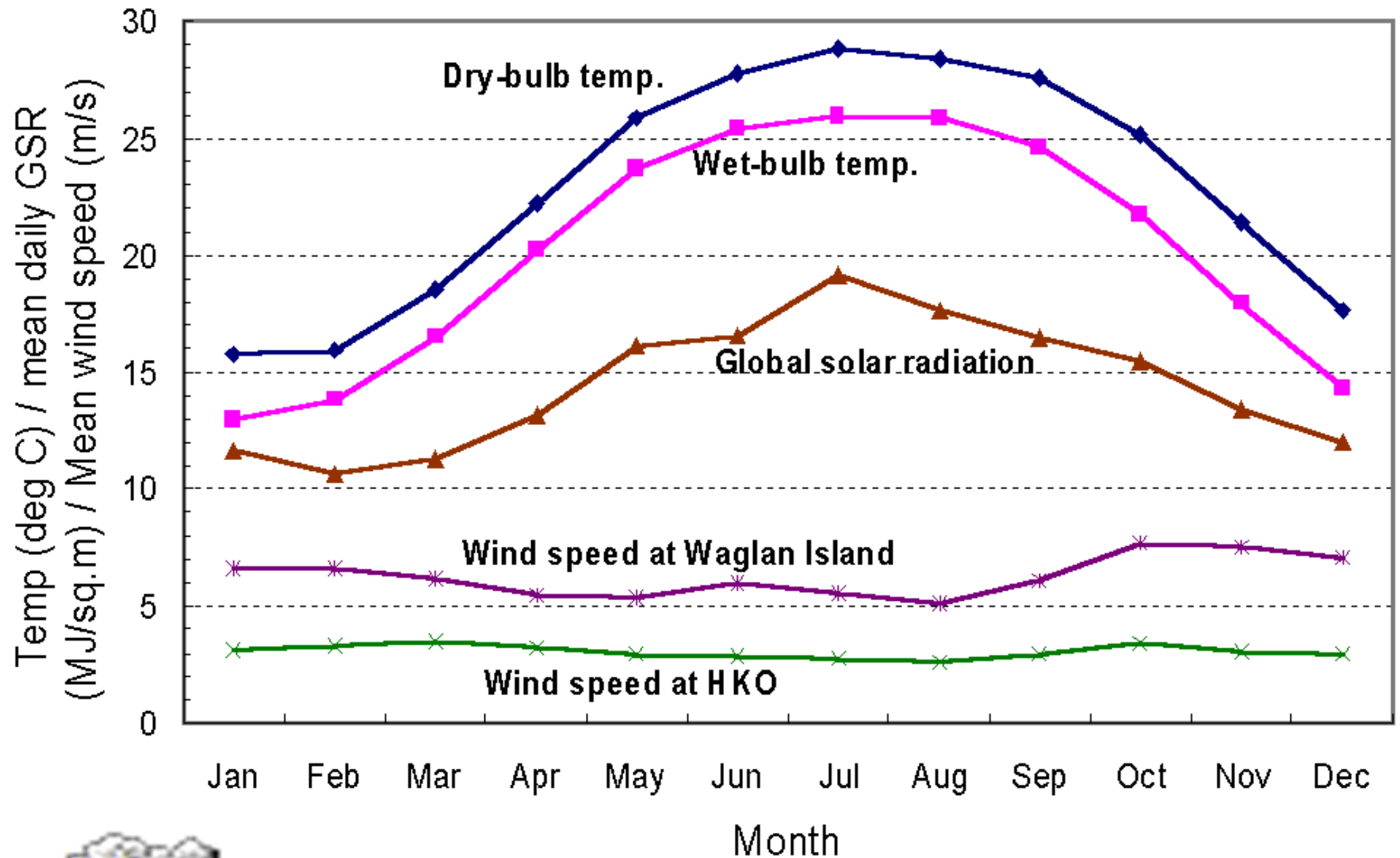




Weather data

- Common types of weather data
 - Temperature (dry bulb, wet bulb) ($^{\circ}\text{C}$)
 - Humidity (relative humidity, %RH)
 - Solar radiation (kW/hr)
 - Sunshine duration (hr)
 - Cloud cover (%)
 - Atmospheric pressure (kPa)
 - Wind speed (m/s) & direction
 - Precipitation (mm)

Major climatic elements of Hong Kong



MONTHLY DIURNAL AVERAGES
ASHRAE Standard 55

LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

HOURLY AVERAGES

TEMPERATURE: (degrees C)

- DRY BULB MEAN
- WET BULB MEAN
- █ DRY BULB (all hours)

COMFORT ZONE

- SUMMER
- WINTER

(At 50% Relative Humidity)

RADIATION: (Wh/sq.m)

- █ GLOBAL HORIZ
- █ DIRECT NORMAL
- █ DIFFUSE

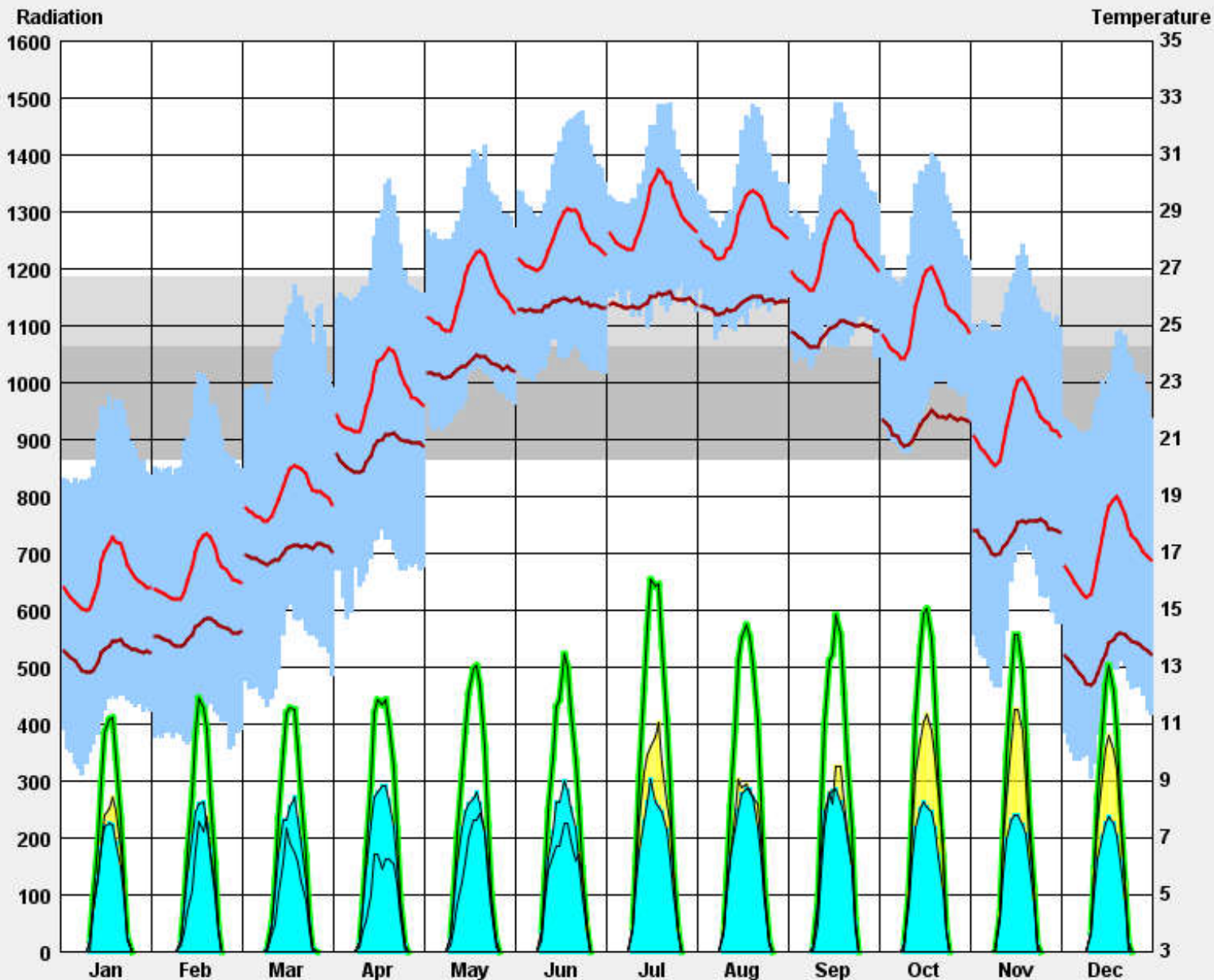
Display Dry Bulb Temp

(all hours)

TEMPERATURE RANGE:

-10 to 40 °C

Fit to Data

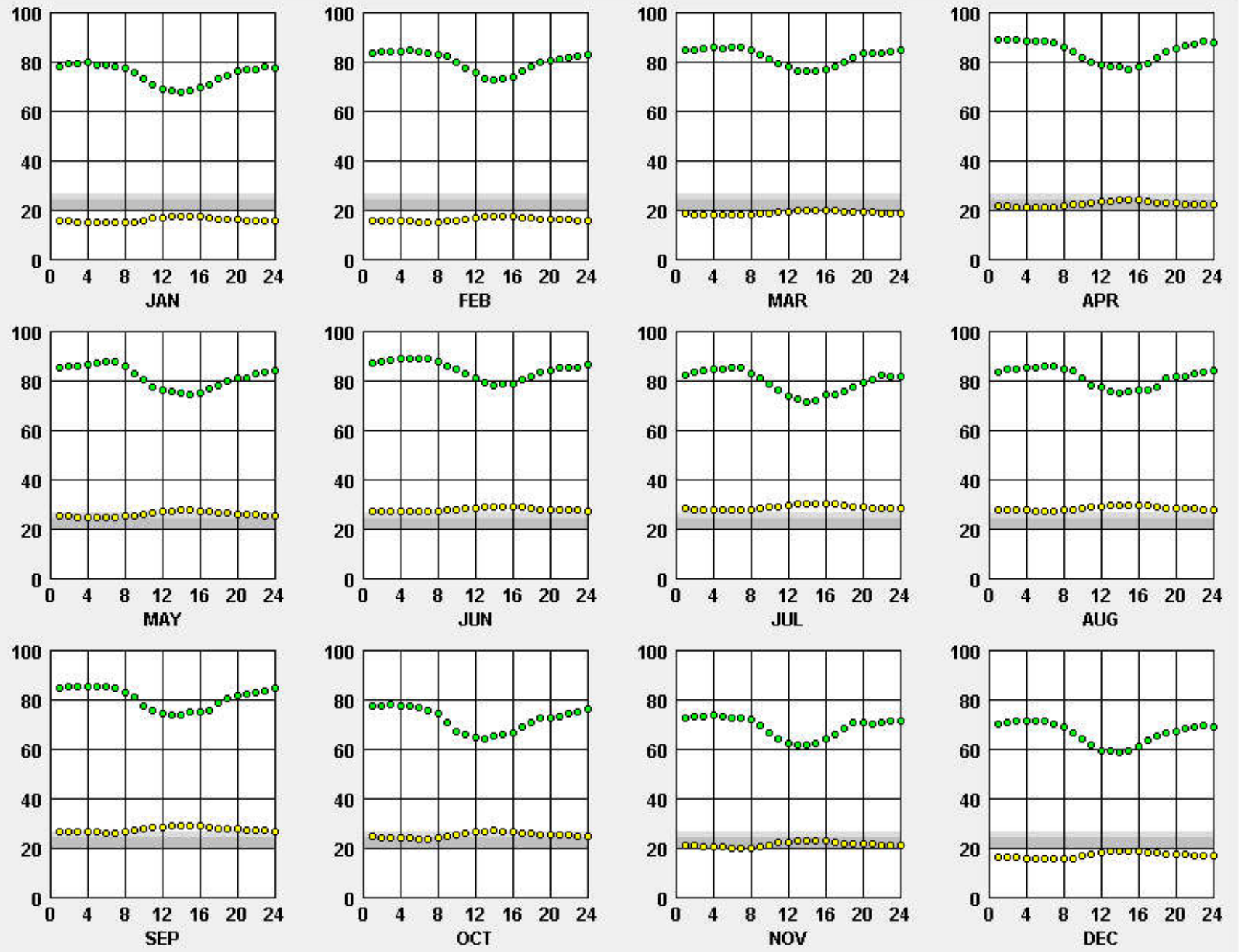


DRY BULB X RELATIVE HUMIDITY
ASHRAE Standard 55

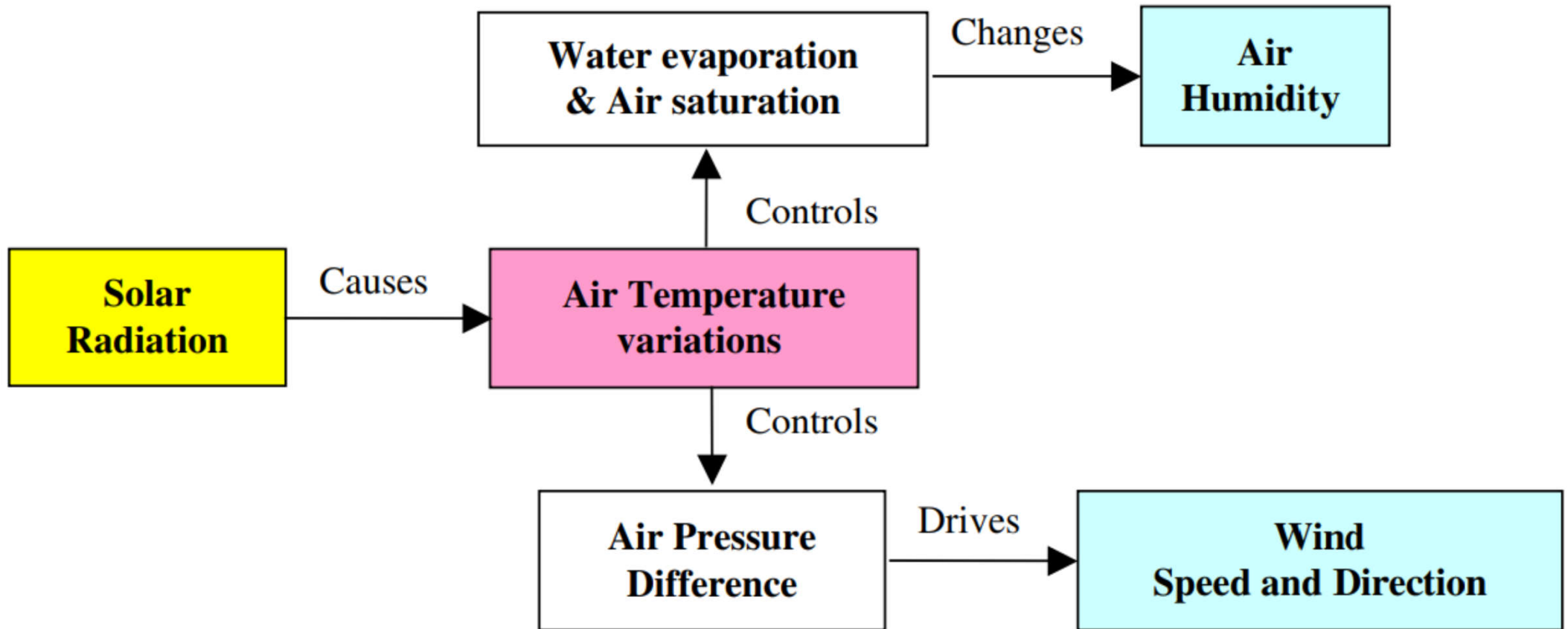
LOCATION: HONG KONG, SAR, CHN
Latitude/Longitude: 22.32° North, 114.17° East, **Time Zone from Greenwich** 8
Data Source: CityUHK-45007 450070 WMO Station Number, **Elevation** 65 m

LEGEND

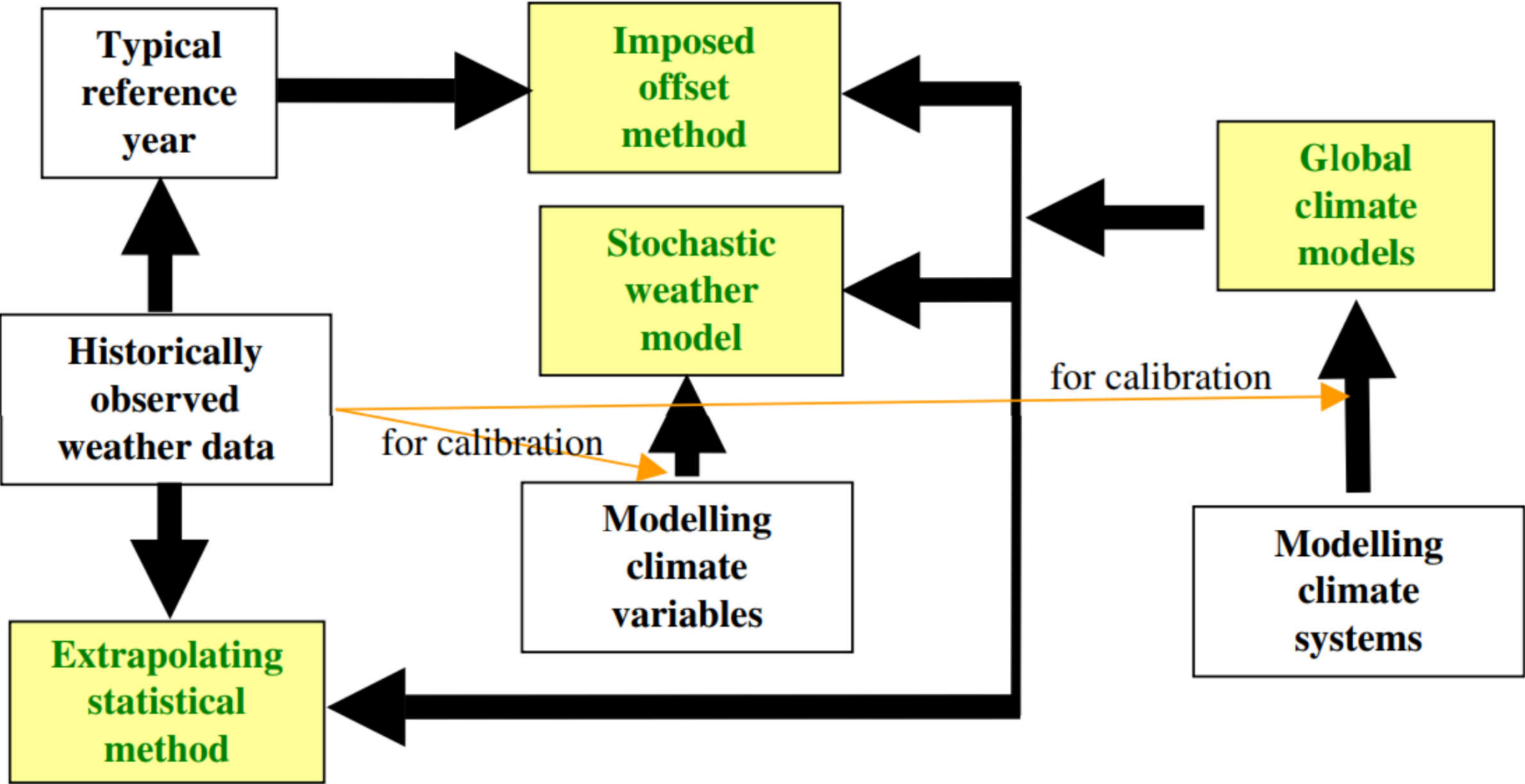
- Dry Bulb ○
- Humidity ●
- Comfort Zone
- Summer ☐
- Winter ☐
- At 50%
- Relative Humidity



Relationship between different weather variables



Statistical methods, weather and climate models

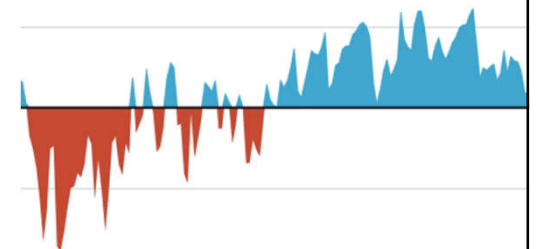


(Source: Guan L., 2009. Preparation of future weather data to study the impact of climate change on buildings, *Building and Environment*, 44 (4) 793-800. <https://doi.org/10.1016/j.buildenv.2008.05.021>)

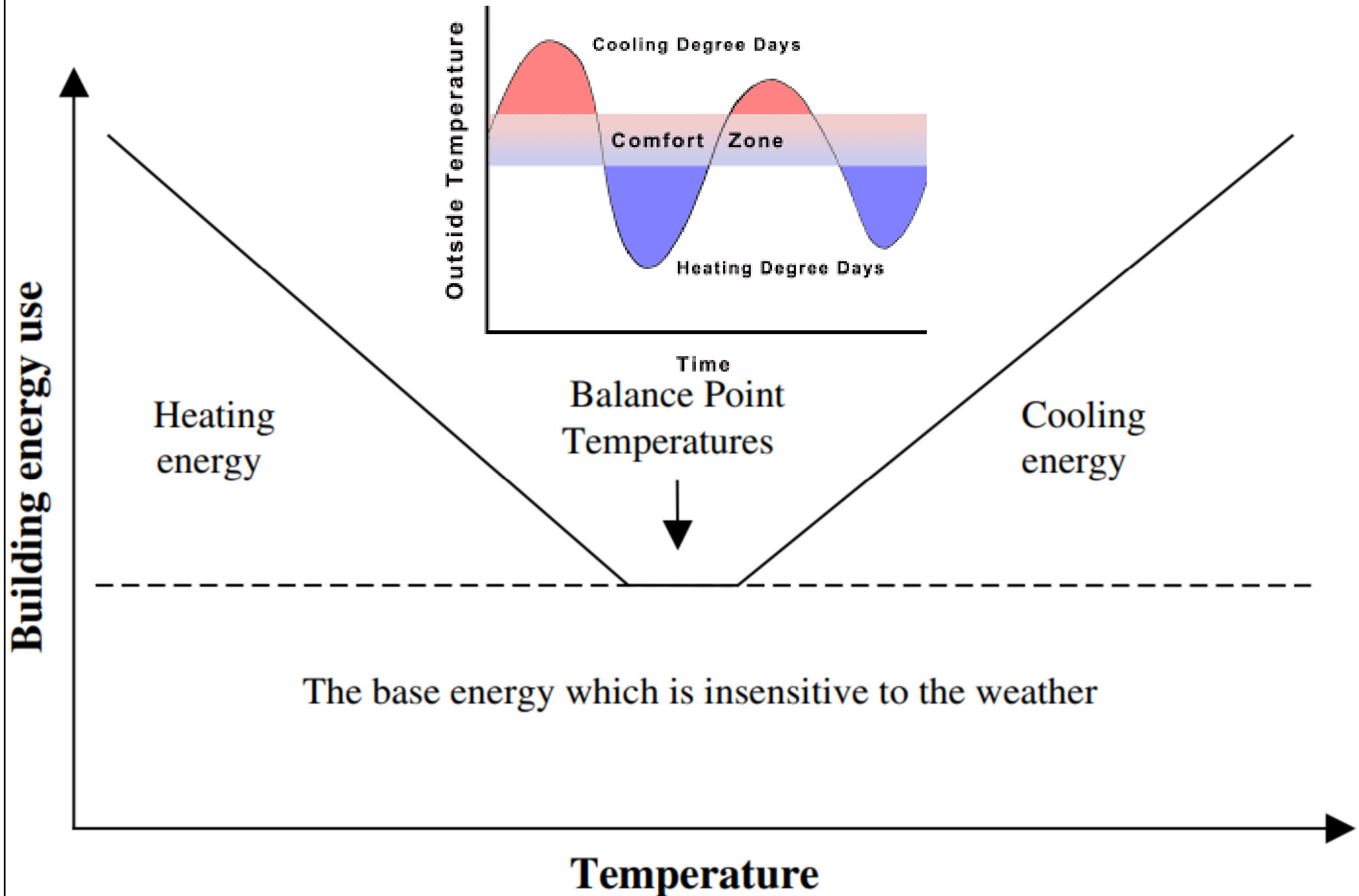


Weather data

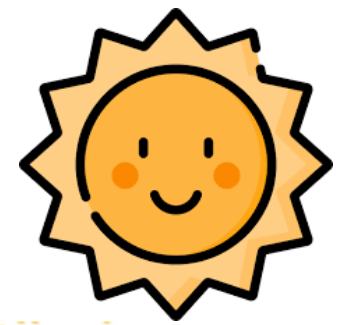
- Derived data
 - Degree-days (DD): cumulative temperature deficit below/above a set base temperature (T_b)
 - Heating degree-days (HDD) - heating requirements
 - Cooling degree-days (CDD) - cooling requirements
 - $HDD = \Sigma(18 - T_{av})$ (from day 1 to 365), $T_b = 18^\circ\text{C}$
 - $CDD = \Sigma(T_{av} - 26)$ (from day 1 to 365), $T_b = 26^\circ\text{C}$
 - Degree-hours (DH): on a hourly basis
 - $HDH = \Sigma(18 - T_h)$ (from hour 1 to 8760)
 - $CDH = \Sigma(T_h - 26)$ (from hour 1 to 8760)



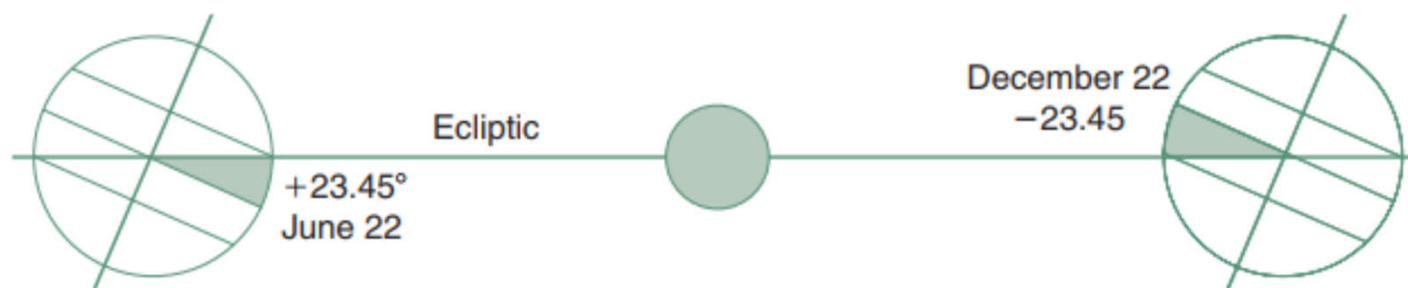
Relationship between building energy use and the outdoor temperature



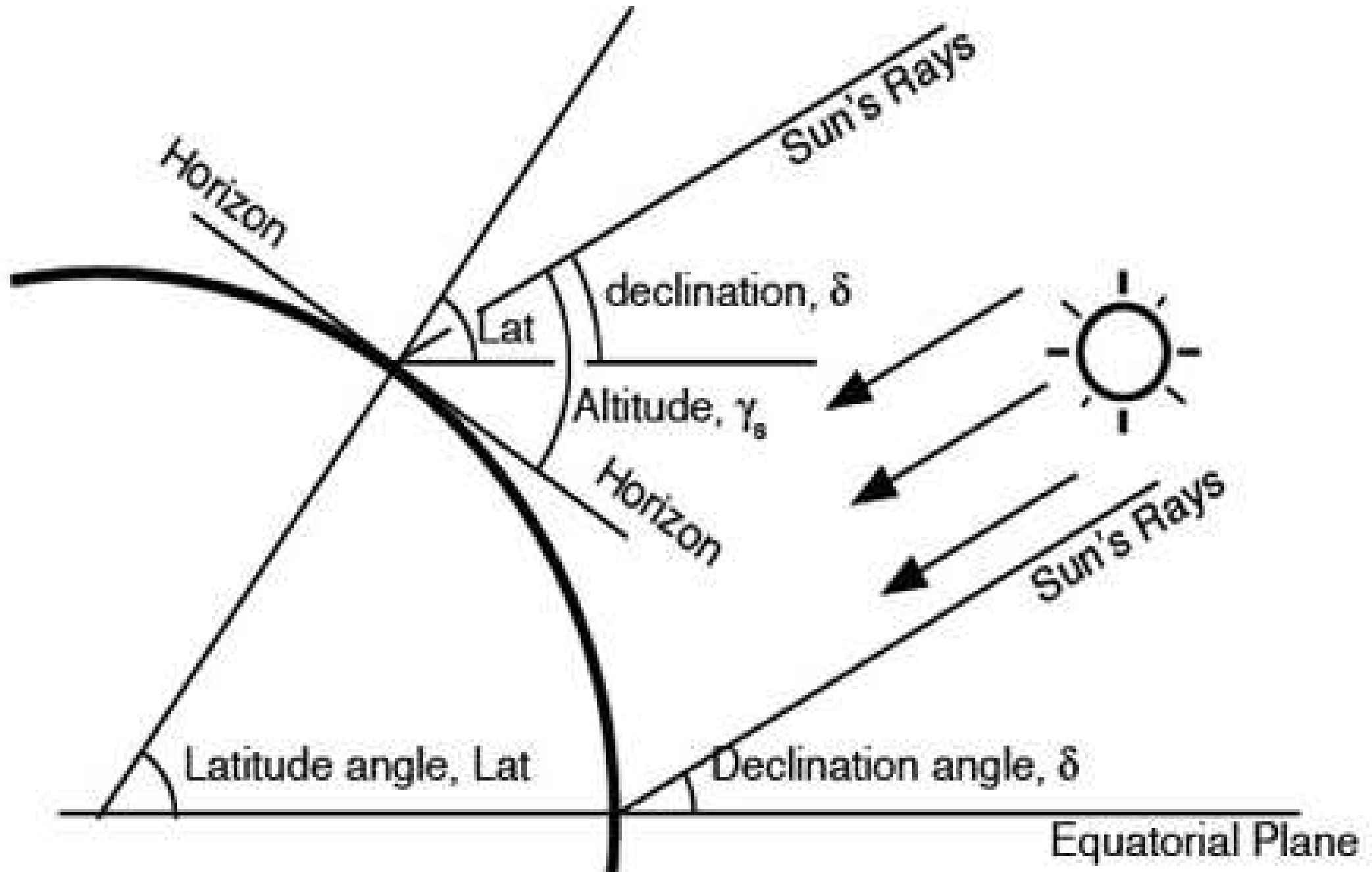
The Sun



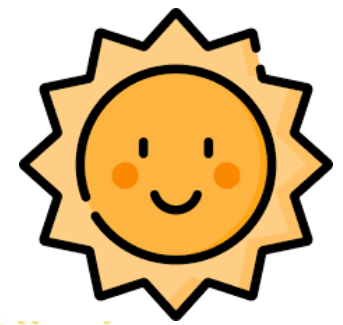
- The climate of the earth is driven by the energy input from the sun
- Two essential aspects for building designers:
 - Solar geometry: the apparent movement of the sun
 - Solar radiation: the energy flow from the sun & how to handle it (exclude it or make use of it)
- Declination (DEC) angle: $\pm 23.45^\circ$



Solar geometry at a point on the earth's surface relative to the tangential visual horizon

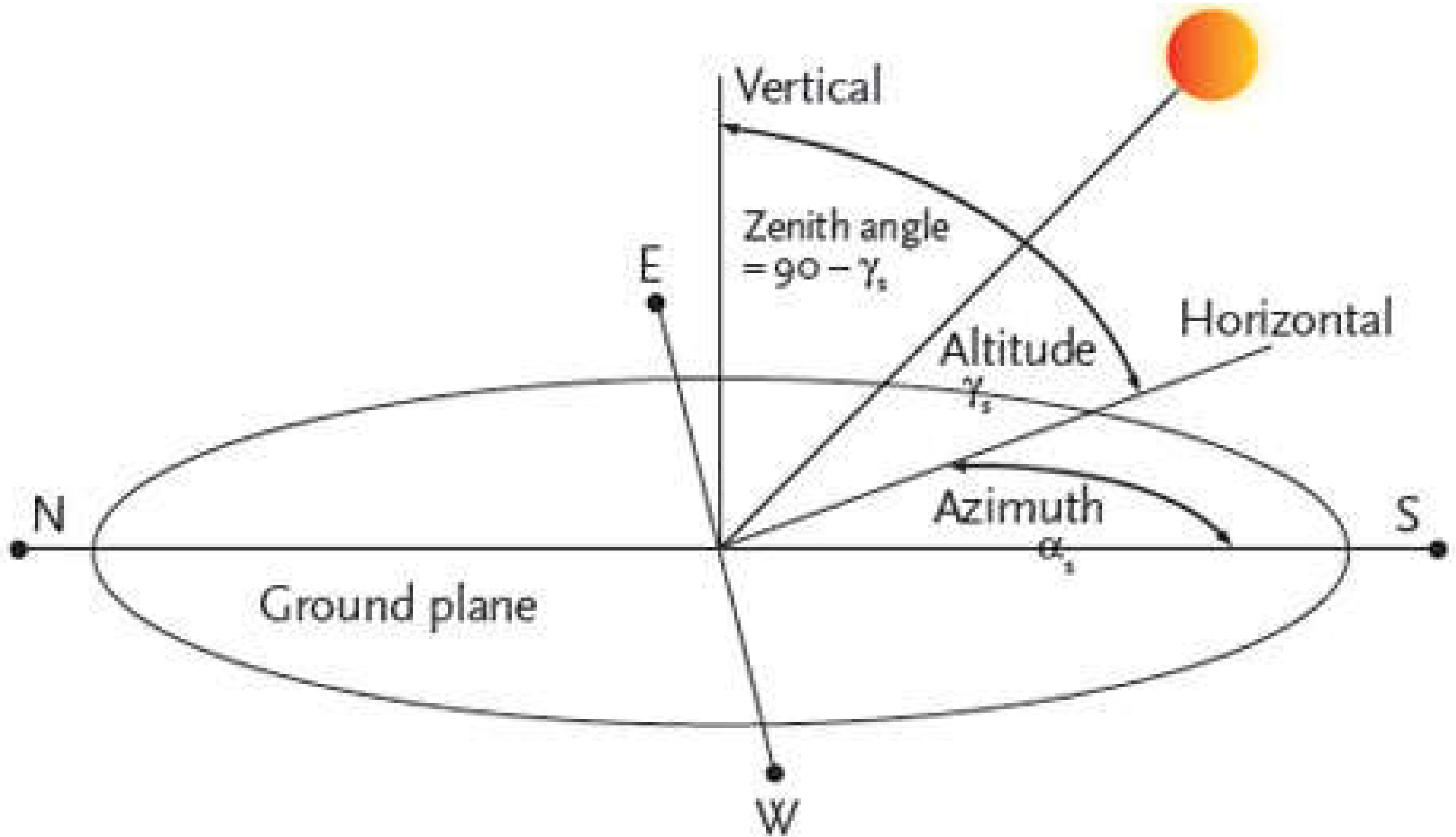


The Sun



- Solar geometry
 - The altitude (ALT / α): measured upwards from the horizon, 90° being the zenith
 - The azimuth (AZI / γ): measured in the horizontal plane from north (0°), through east (90°), south (180°) and west (270°) to north (360°)
- The Tropic of Cancer ($LAT = + 23.45^\circ$) and the Tropic of Capricorn ($LAT = - 23.45^\circ$)

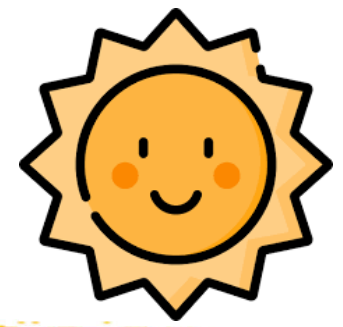
The relative position of the sun to a point on the earth's surface



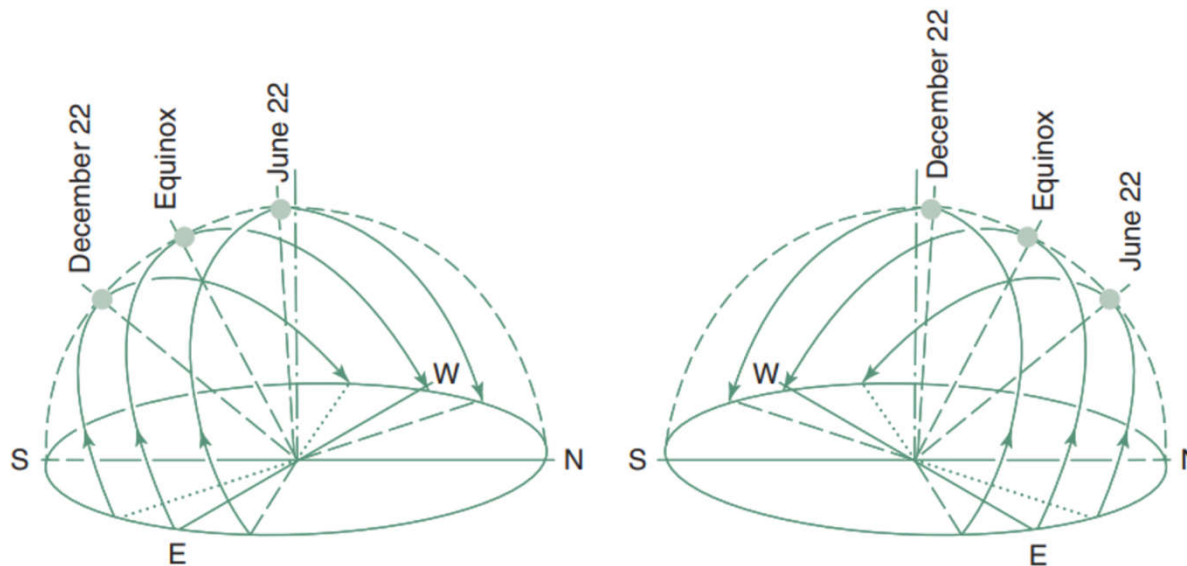
Video: Intro to Solar Orientation [Solar Schoolhouse] (10:50) <https://youtu.be/OR8EQ0DWpPw>

(Source: <https://www.cibsejournal.com/cpd/modules/2013-07/>)

The Sun



- In the northern hemisphere, it travels through south in a clockwise direction but in the southern hemisphere (for an observer facing the equator) it travels through the north in an anticlockwise direction, to set at due west



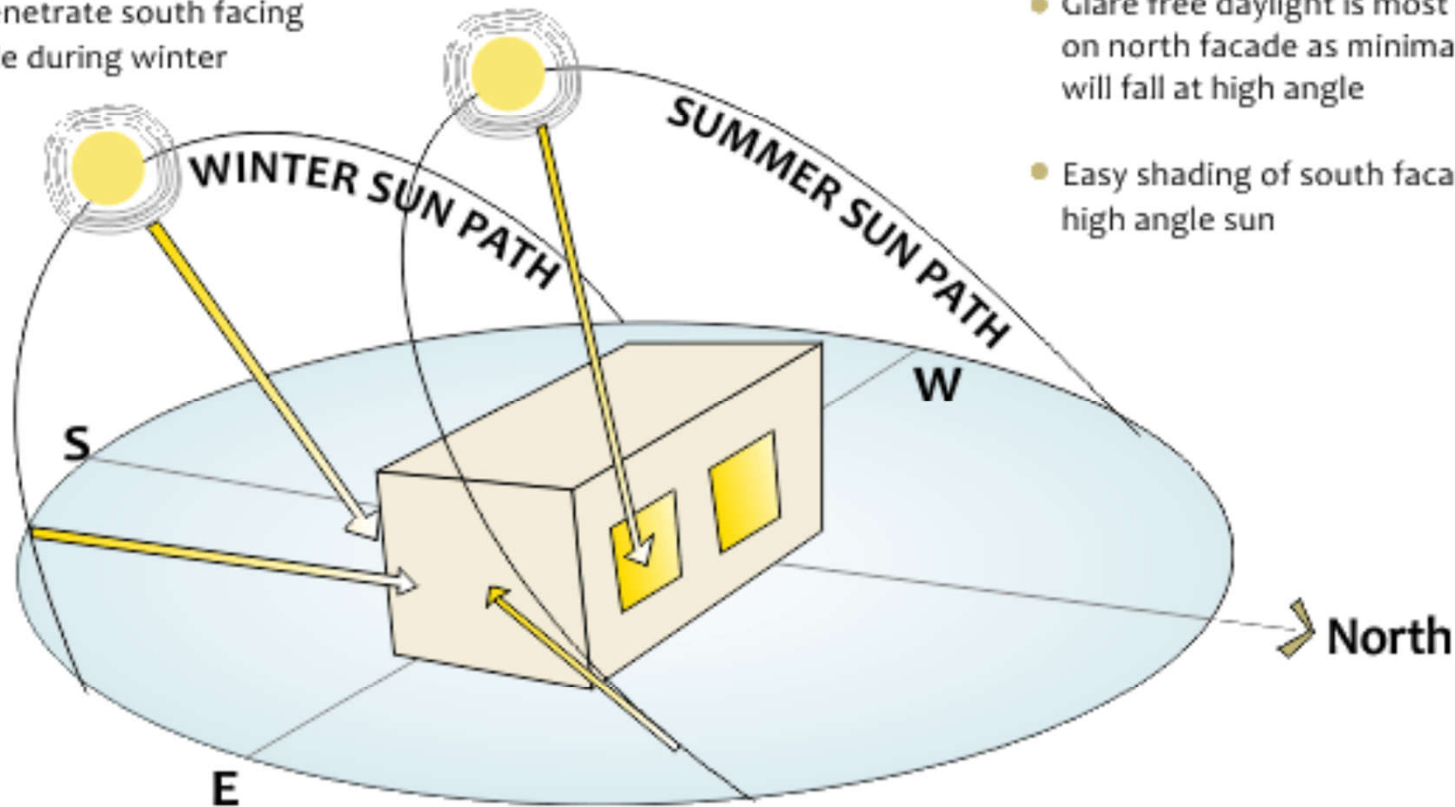
Sun's position in summer and winter

WINTER SUN

- Sun path at a low angle, south to E-W axis
- Solar radiation will penetrate south facing facades at a low angle during winter

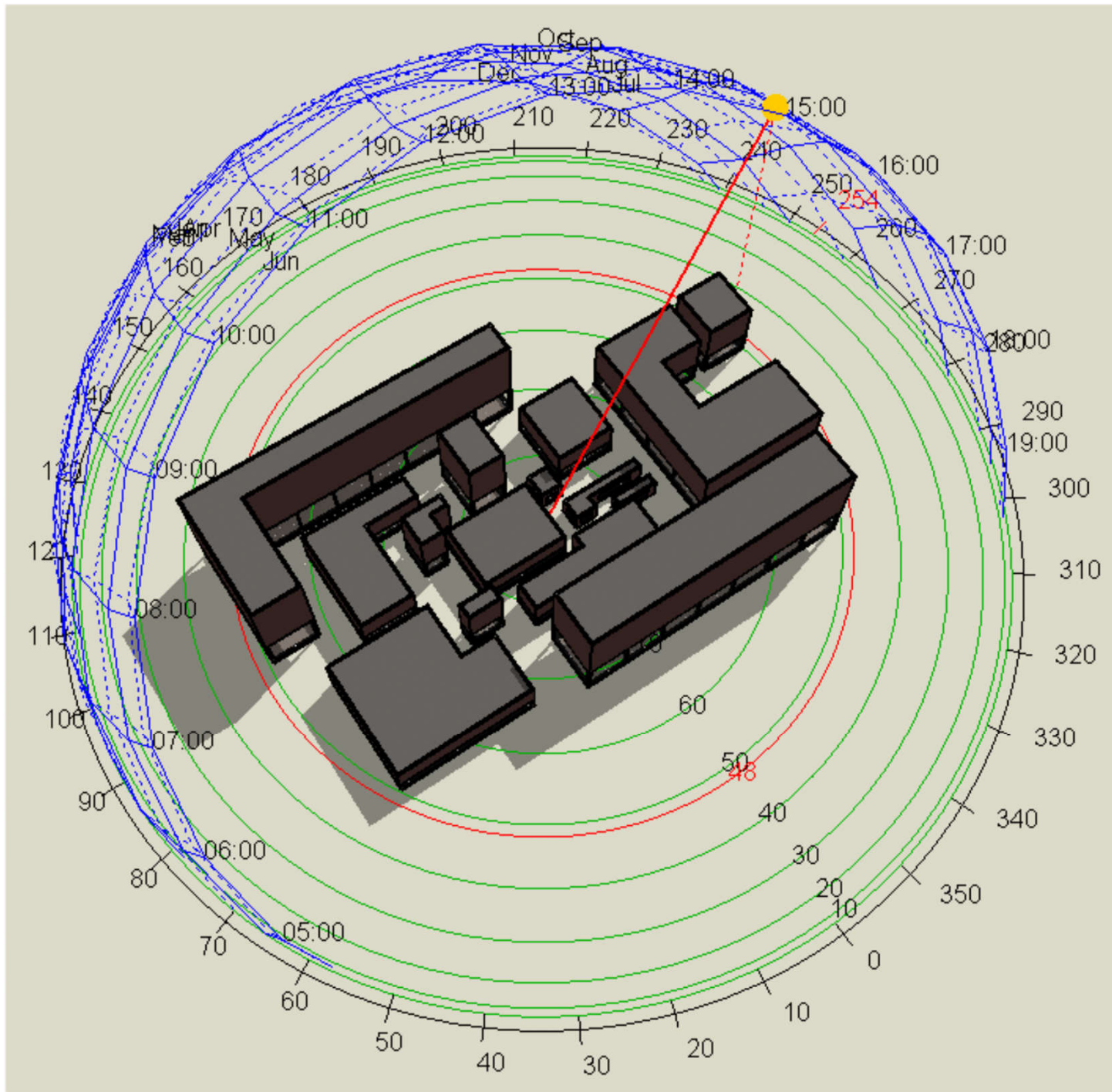
SUMMER SUN

- Sun path at a high angle sun, north to E-W axis
- Glare free daylight is most easily available on north facade as minimal solar radiation will fall at high angle
- Easy shading of south facade from high angle sun

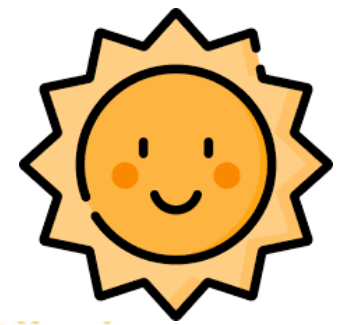


East and west facades continue to receive uniform, strong solar radiation at a low angle through the year.

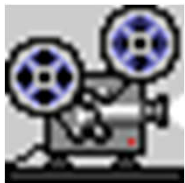
Analysis of solar position by simulation



The Sun

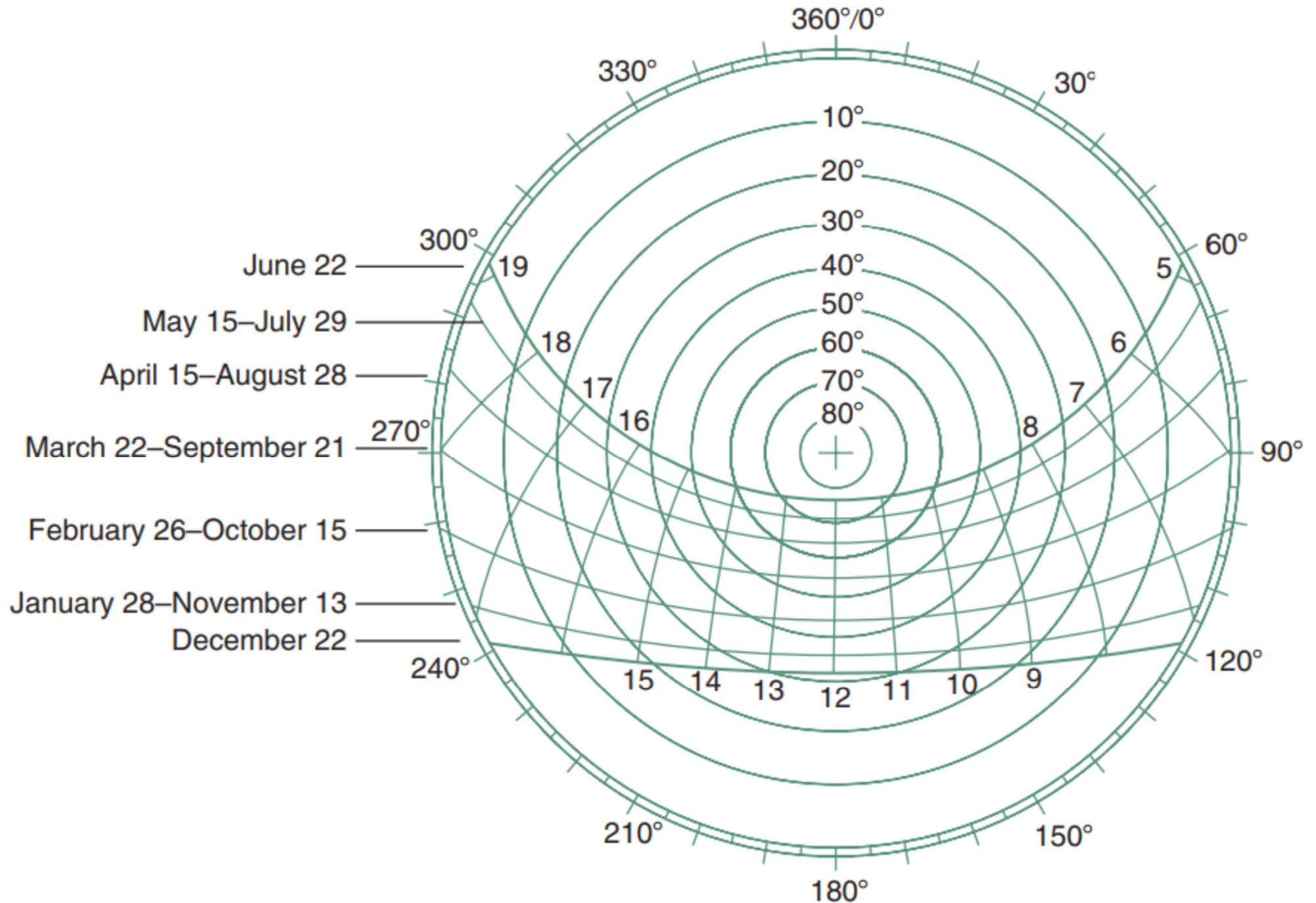


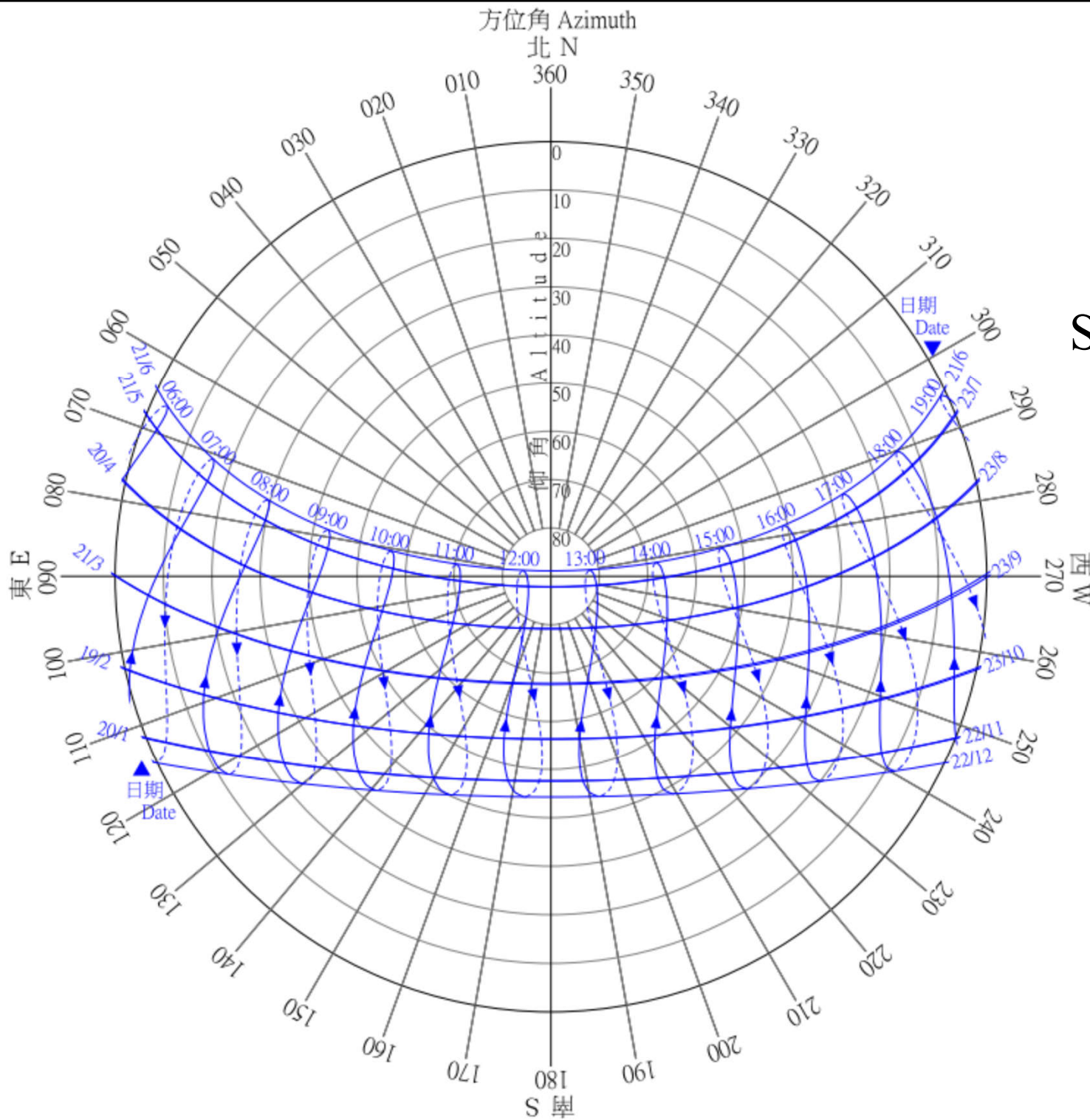
- Sun path diagrams or solar charts
 - Can indicate how the sun will impact the site & building throughout the year
 - Stereographic sun path diagrams to read the solar azimuth & altitude for a given location
 - Sun-path analysis predicts the daylight experience at any building plot, helping us to design & orientate a building to make the most of sunlight & solar gains



Video: Reading Sun Path Diagrams (4:55) https://youtu.be/_0B26Am5lRw

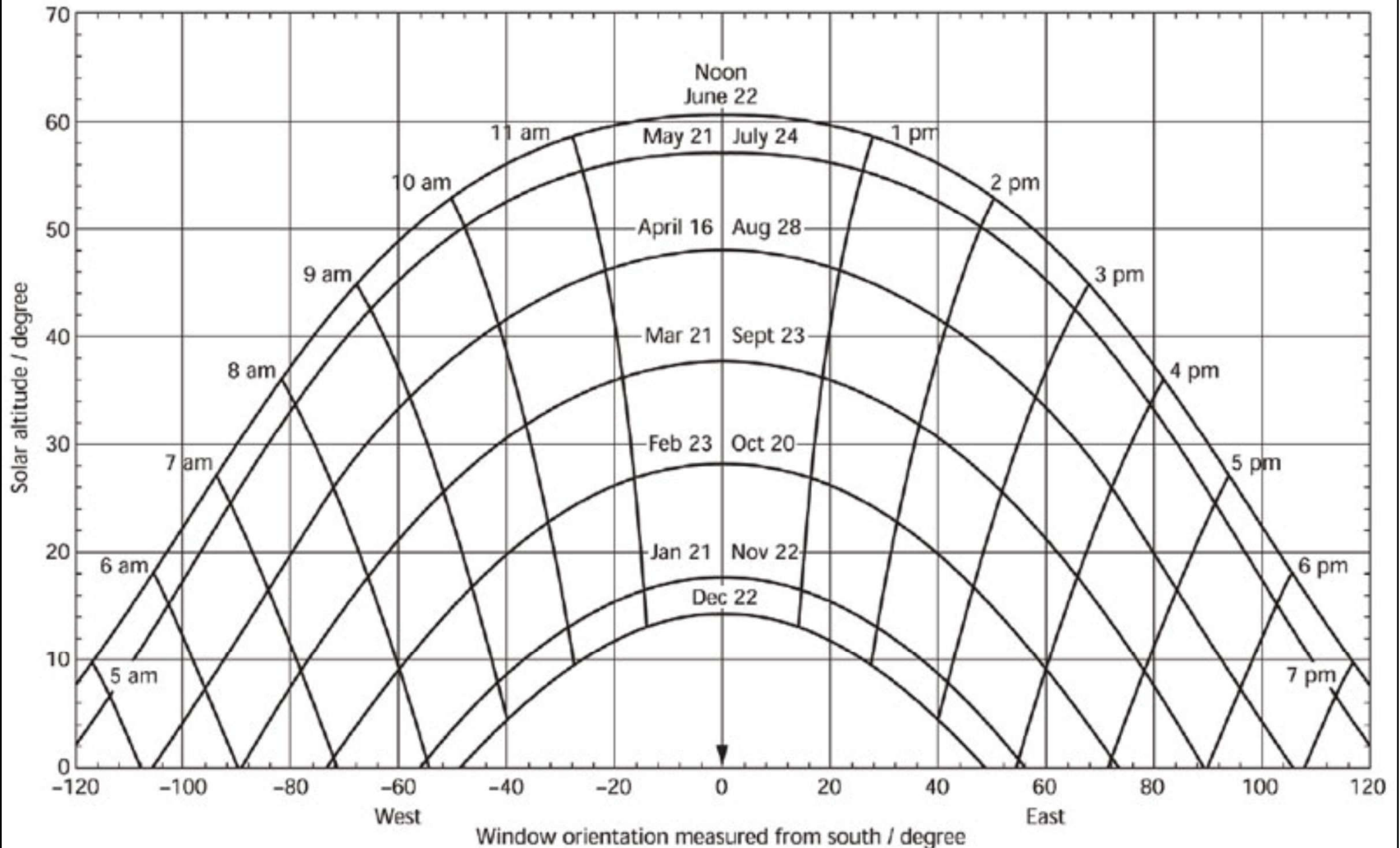
A stereographic sun-path diagram for latitude 36° (e.g. Tokyo)



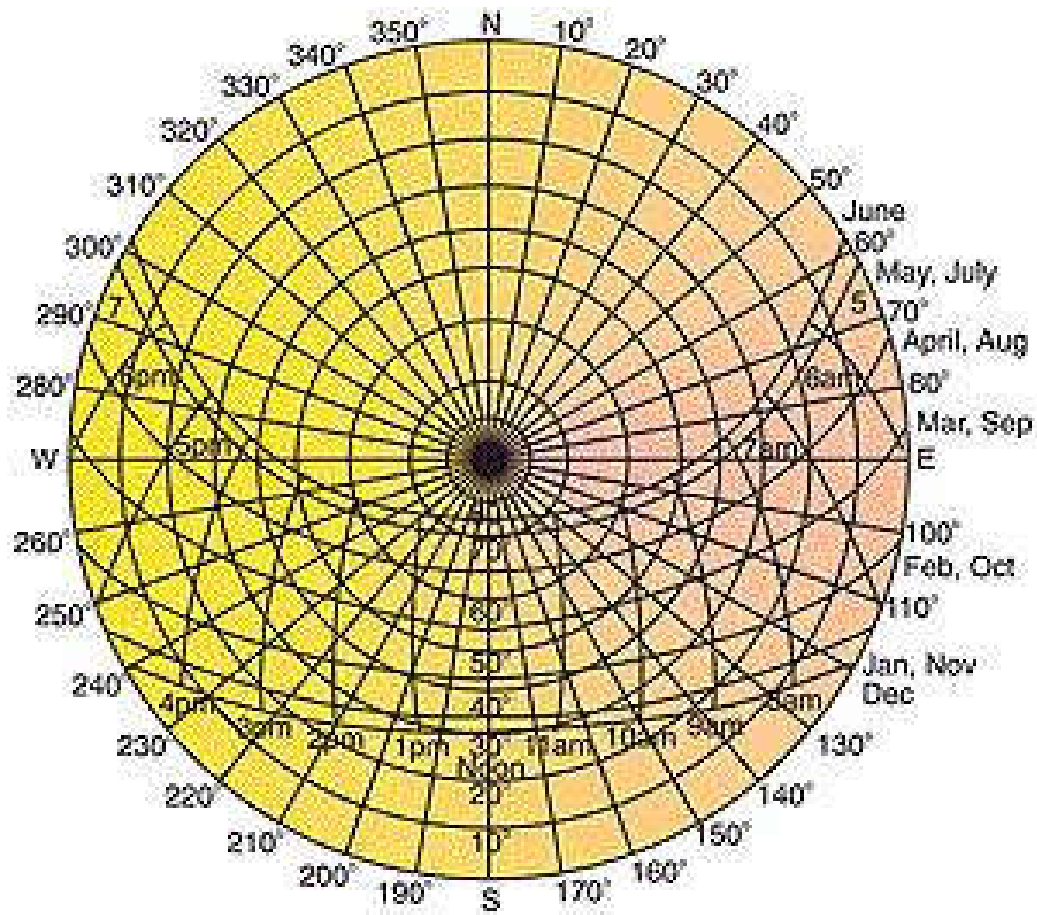


Sun path diagram for Hong Kong

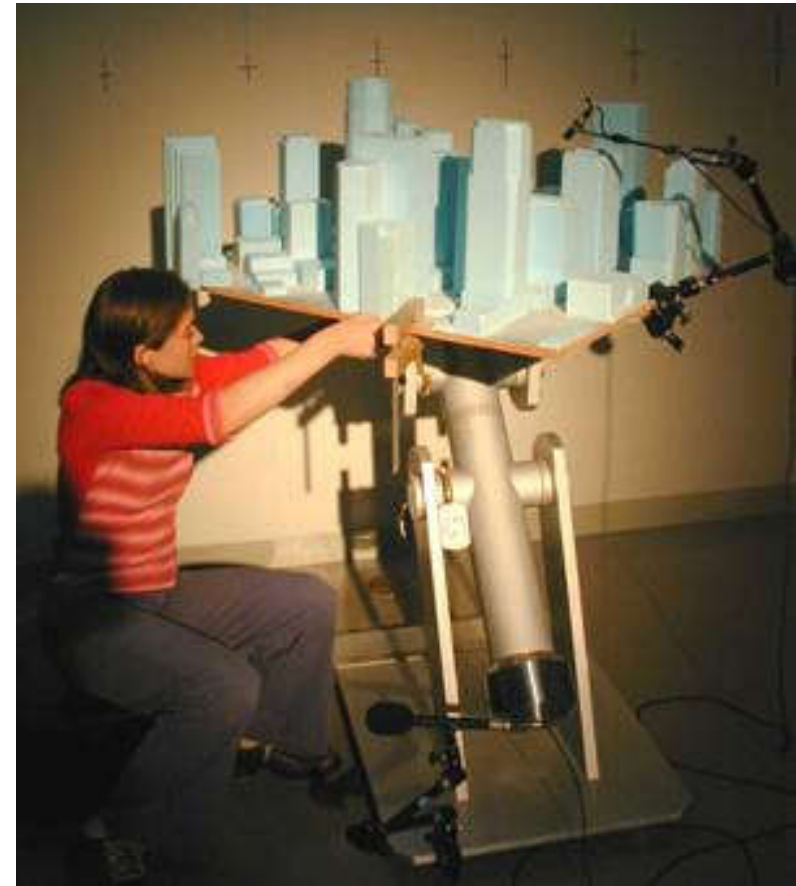
Example sun-path diagram for 52°N latitude related to local apparent time (suntime)



Daylighting design and analysis tools

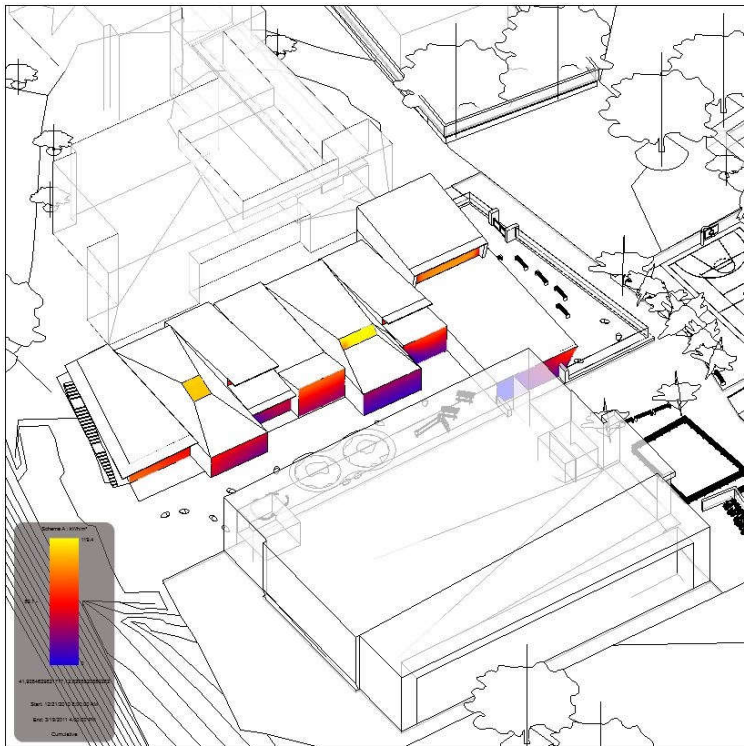
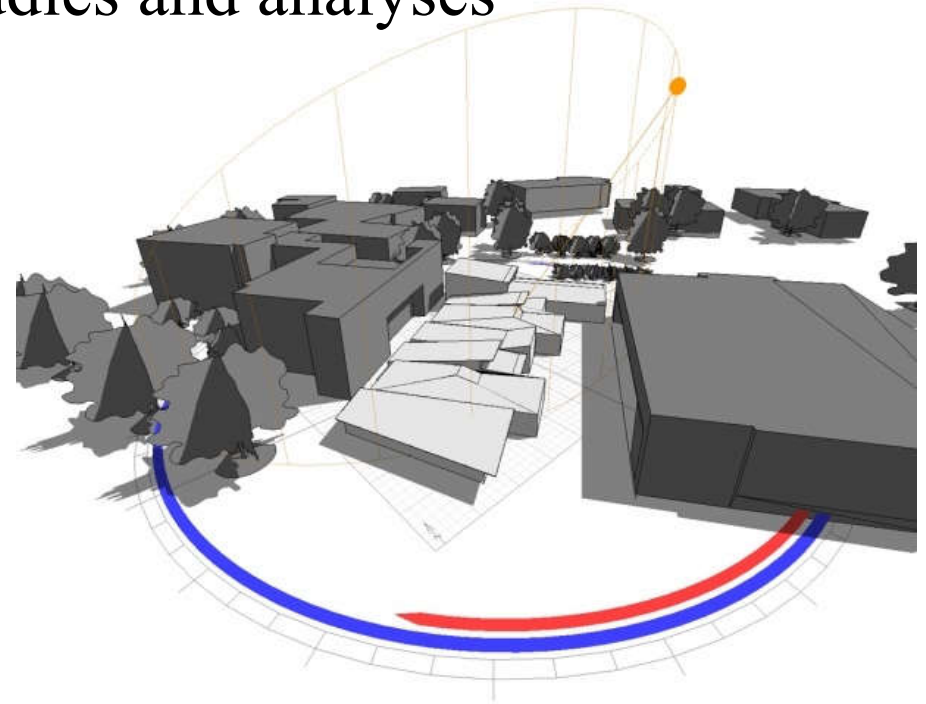
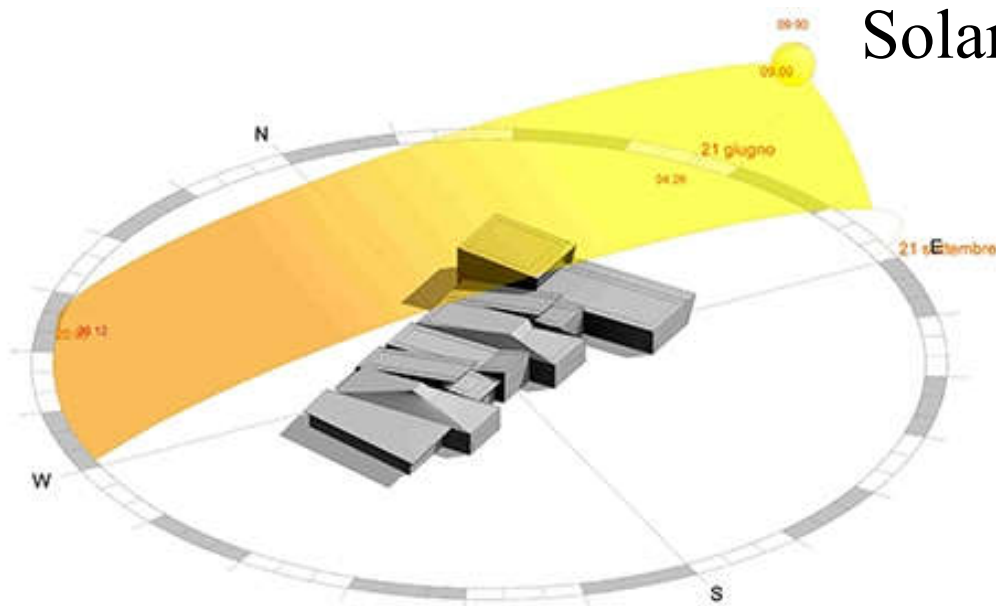


Sunpath diagram



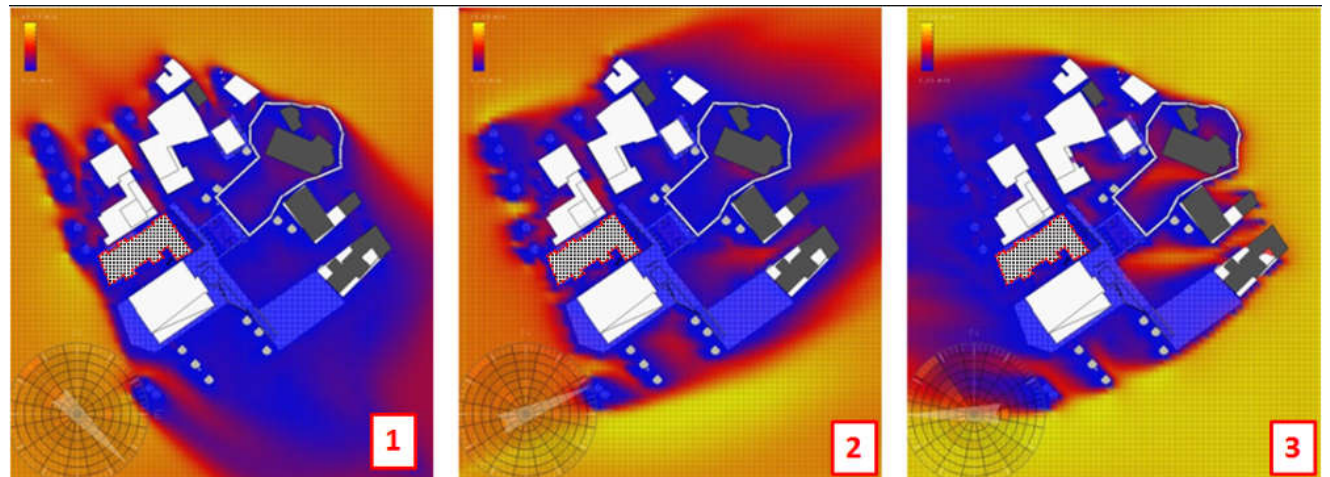
Heliodon studies

Solar studies and analyses



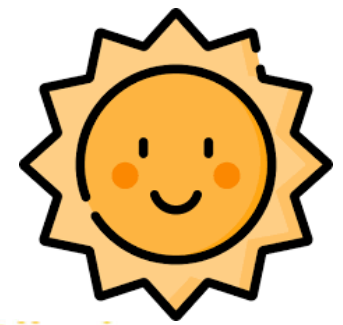
Solar insolation

(Source: Autodesk)



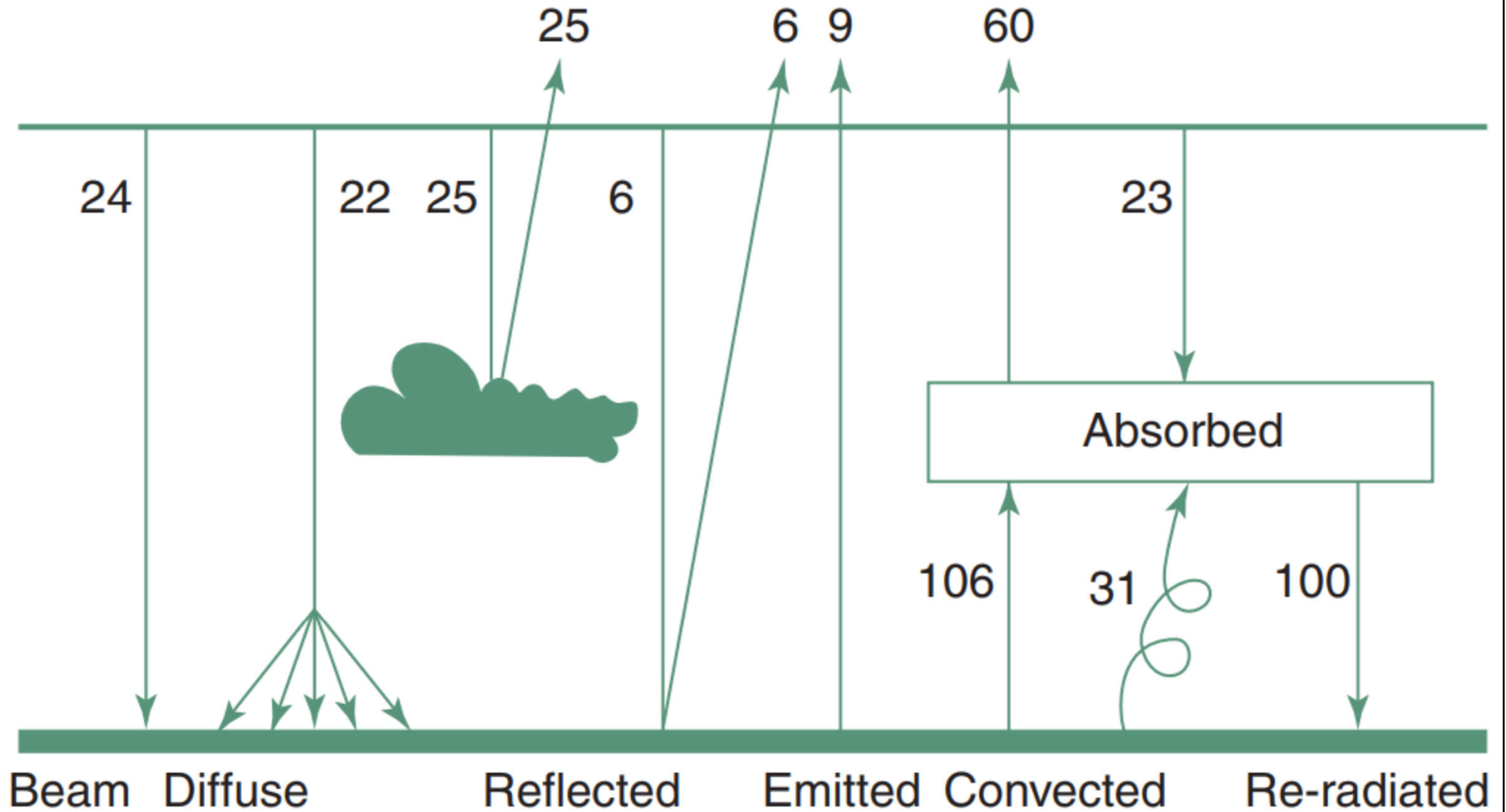
Wind tunnel analysis

The Sun

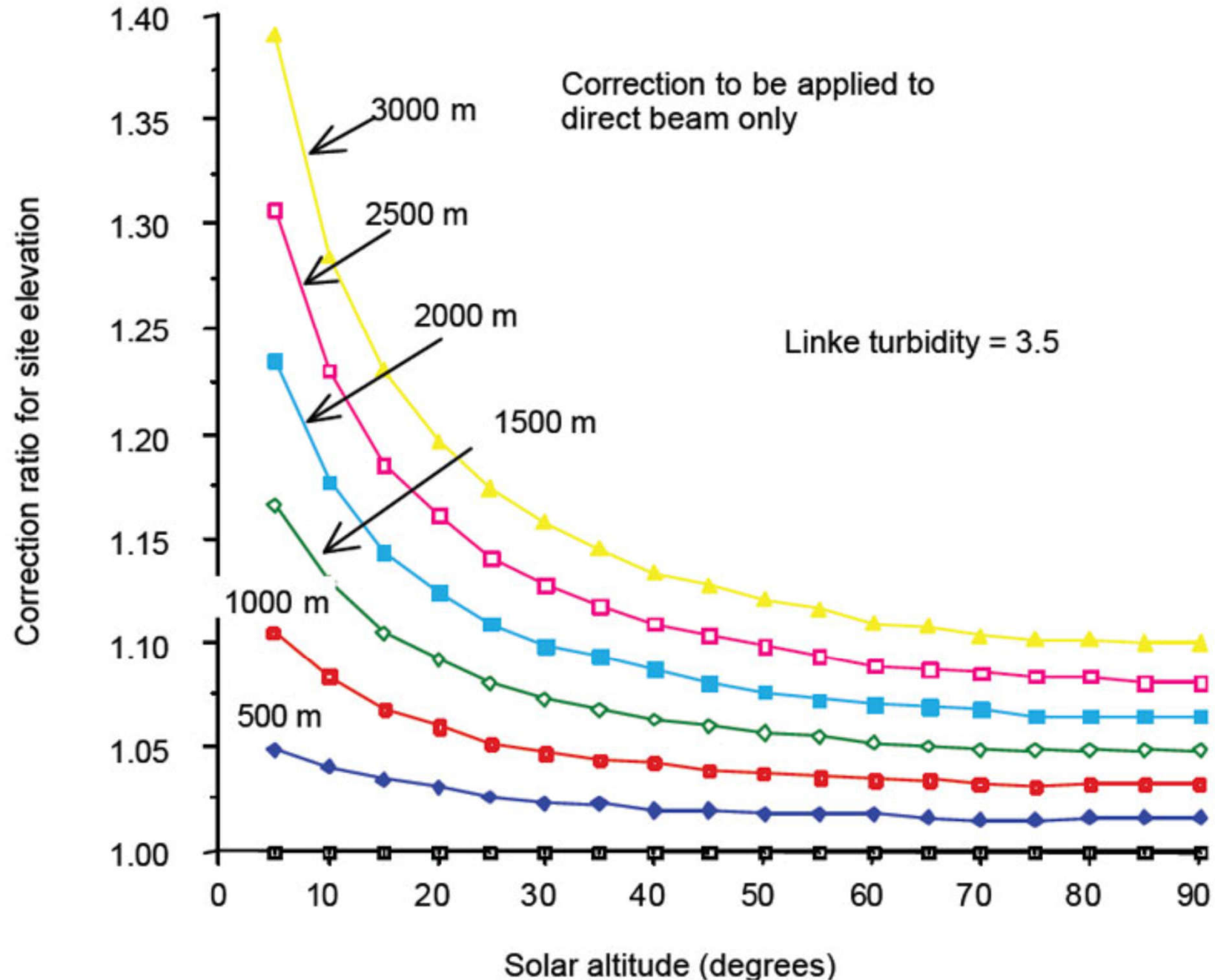


- Solar radiation (irradiation)
 - Irradiance (W/m^2): intensity which means instantaneous flux or energy flow density
 - Irradiation (Wh/m^2 or J/m^2): an energy quantity integrated over a specific period of time (hour, day, month or year)
- Horizontal global solar radiation (GSR)
 - Direct (Beam) and diffuse components
 - Effects of cloud/sky conditions & site elevation

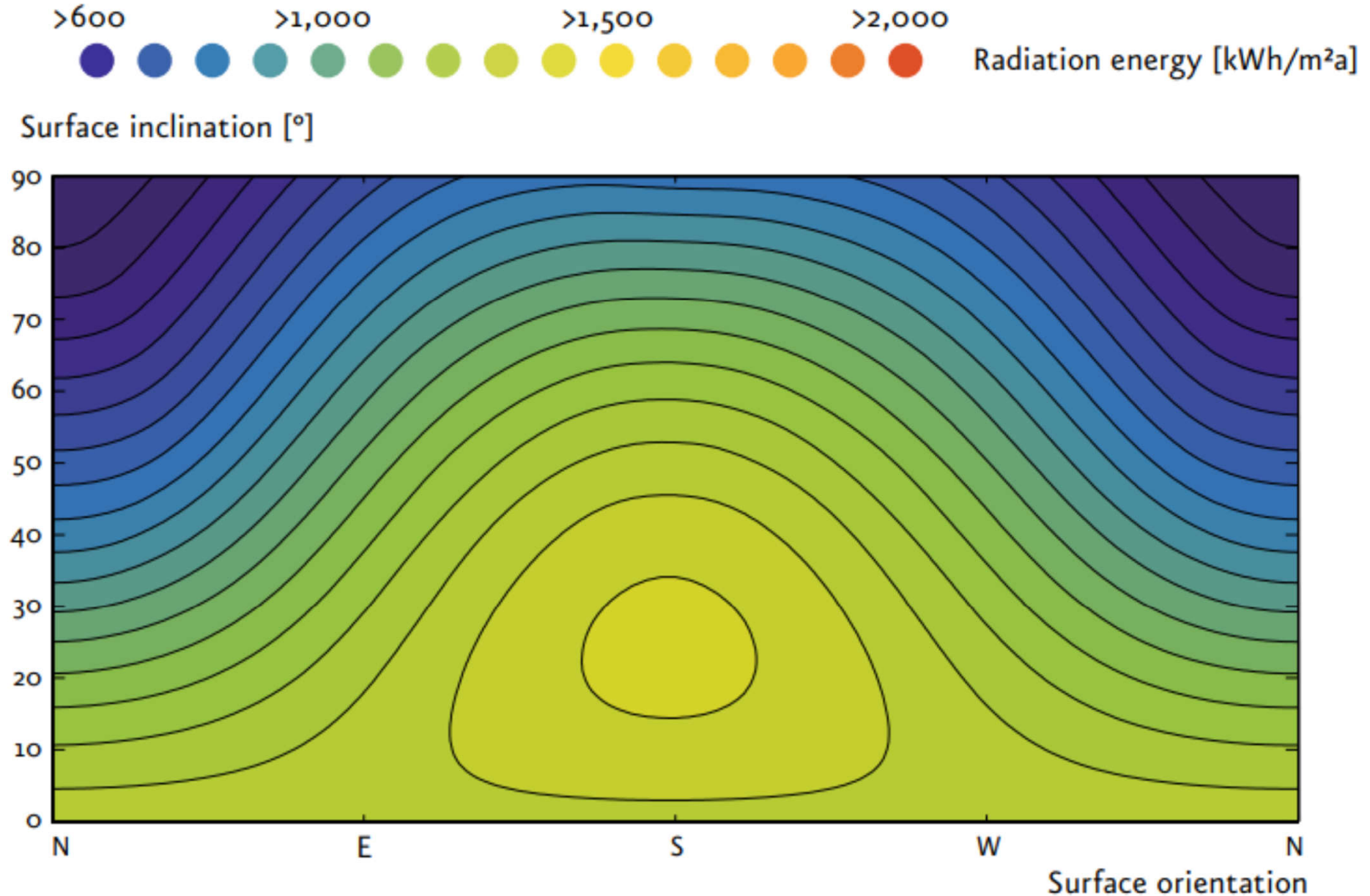
Radiation balance in the atmosphere



Effect of site elevation on the predicted beam irradiance expressed as a ratio to the sea level beam irradiance at different solar altitude angles



Radiation energy in kWh/m² correlated with orientation and angle of inclination, to be used for evaluating the alignment of solar power systems in Shanghai

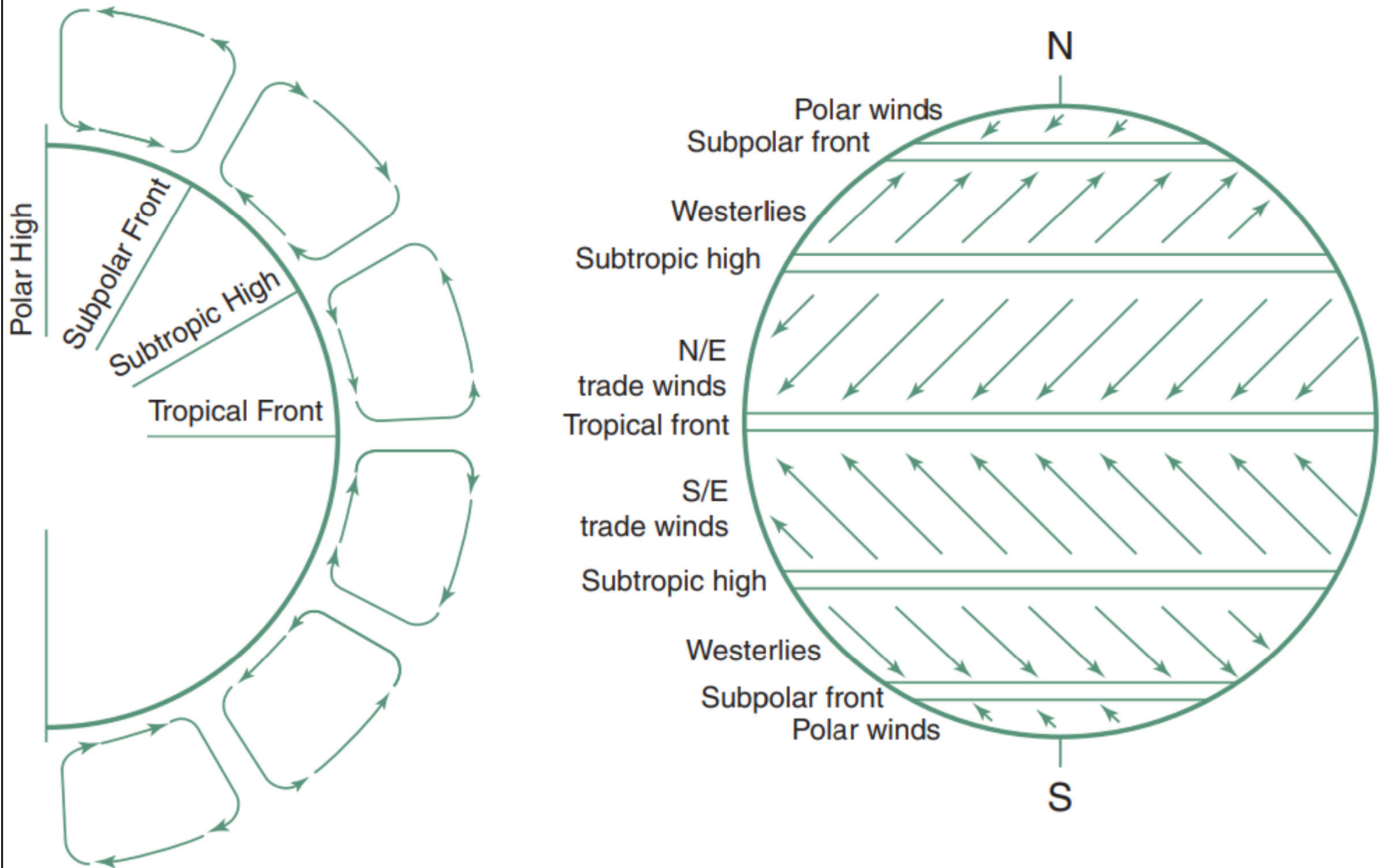


Wind properties

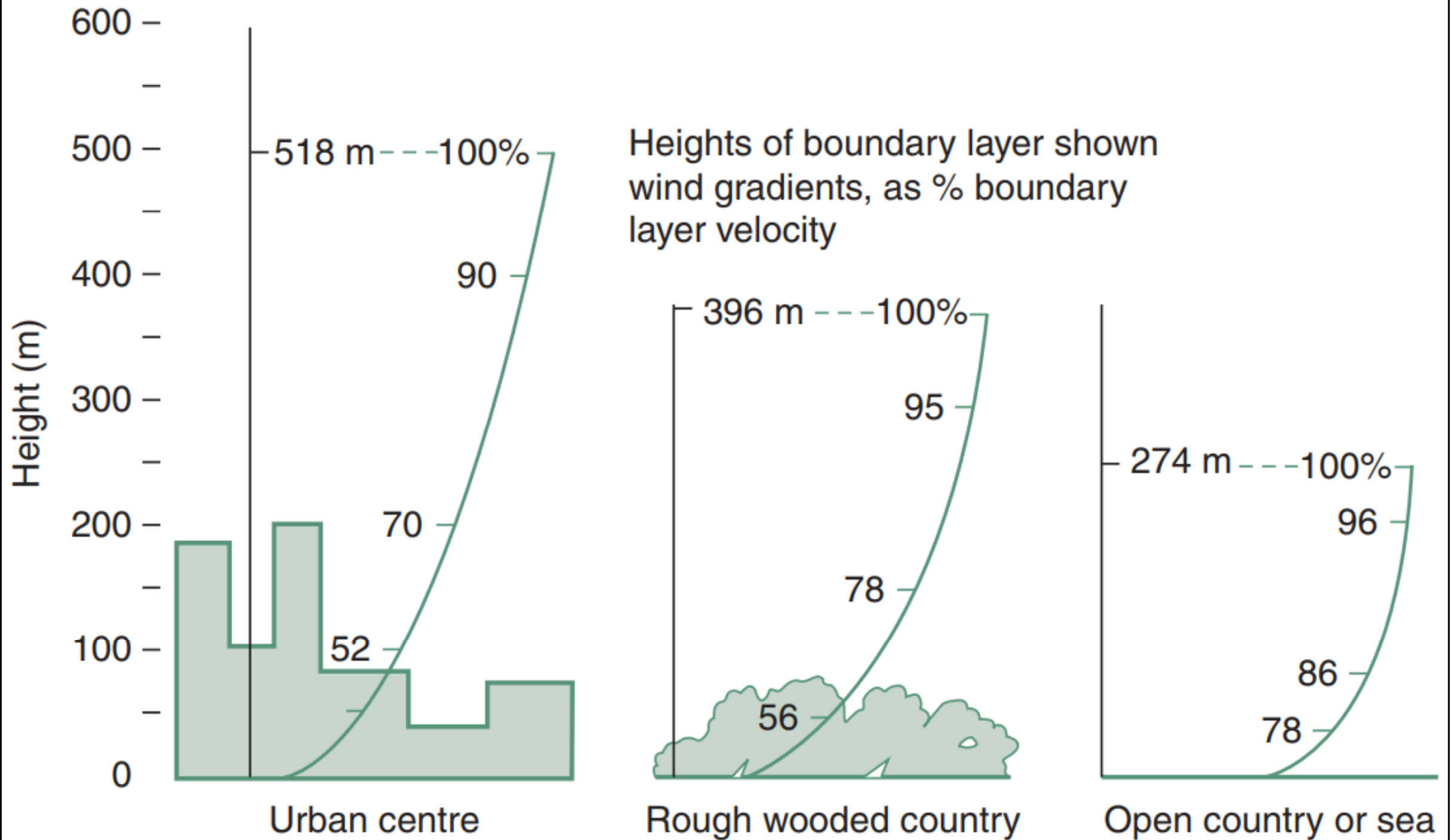


- Wind & atmospheric air circulation
 - At points of strong heating the air rises and at a (relatively) cold location it sinks
 - The movement of air masses and of moisture-bearing clouds is driven by temperature differentials, but strongly influenced by the Coriolis force
 - Small differences in local heating (which may be due to topography and ground cover) can have significant effects on air movements and influence the swirling patterns of low and high pressure (cyclonic and anticyclonic) zones

The global wind pattern

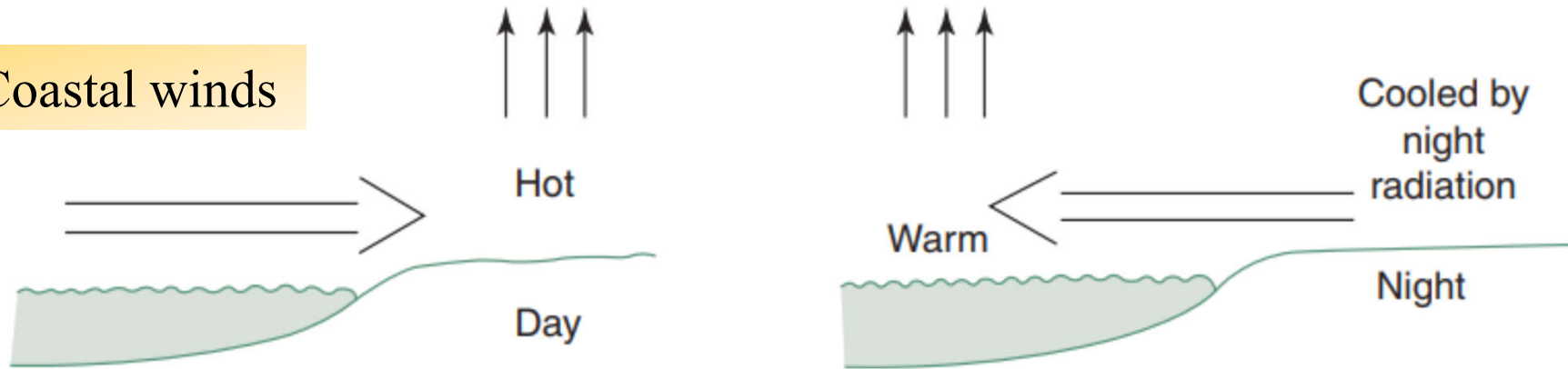


Wind velocity profiles

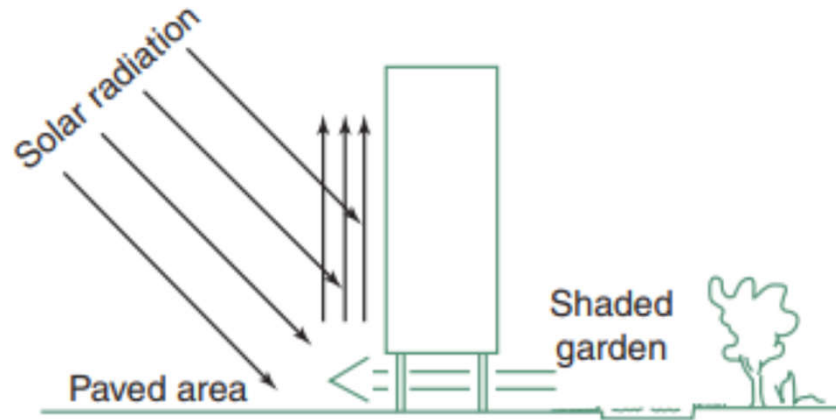


Wind & rainfall properties on building site

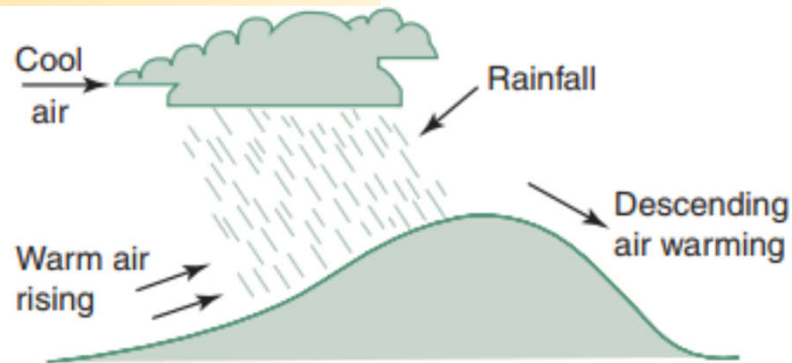
Coastal winds



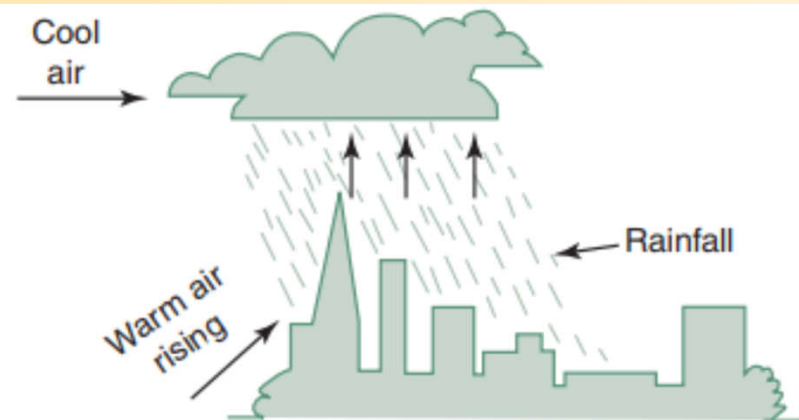
Local wind at one building



Rainfall on hills

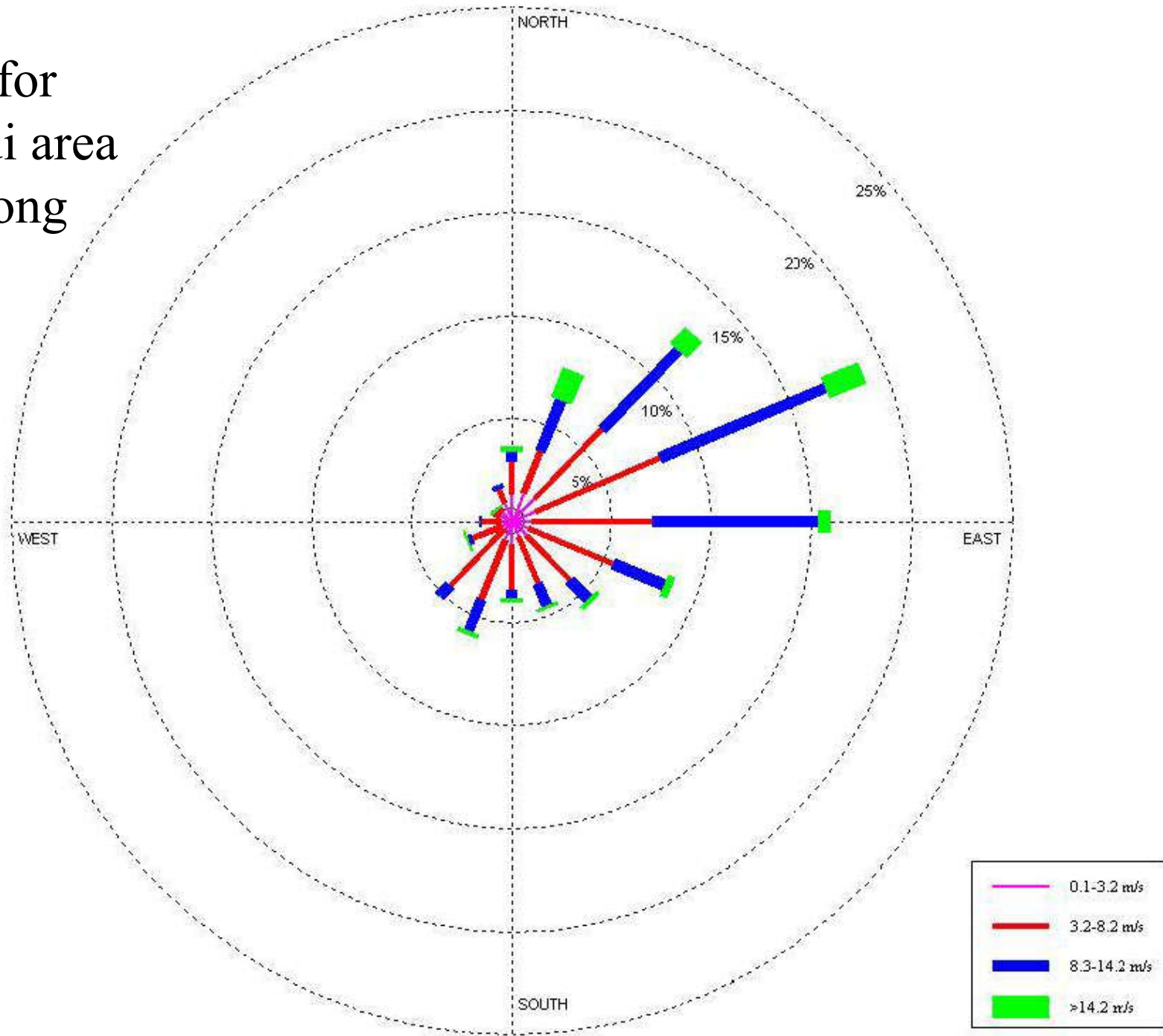


Urban heat island effect on rainfall



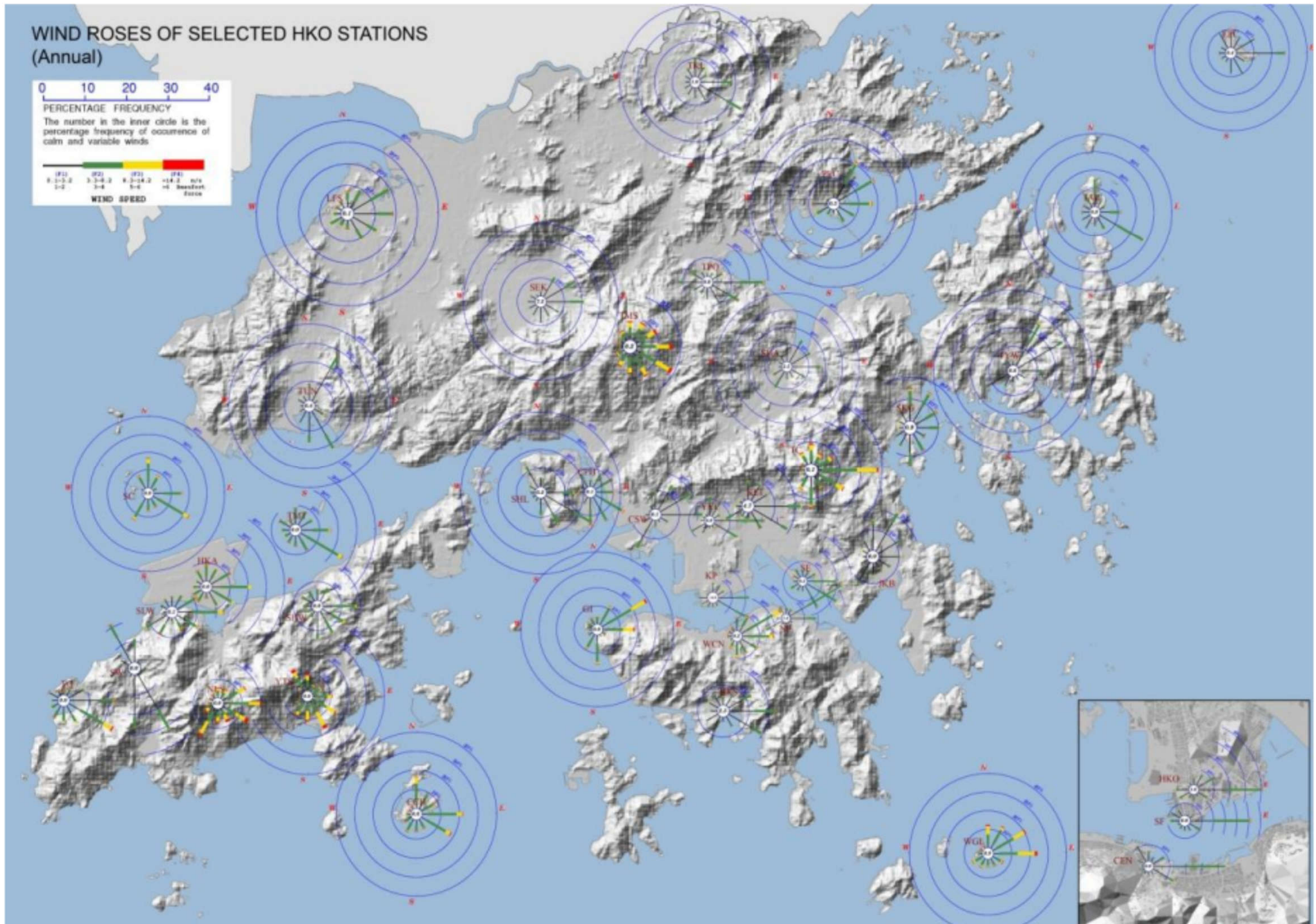
Square:(27,26) Windrose in 16 Directions

Wind rose for Tsimshatsui area in Hong Kong



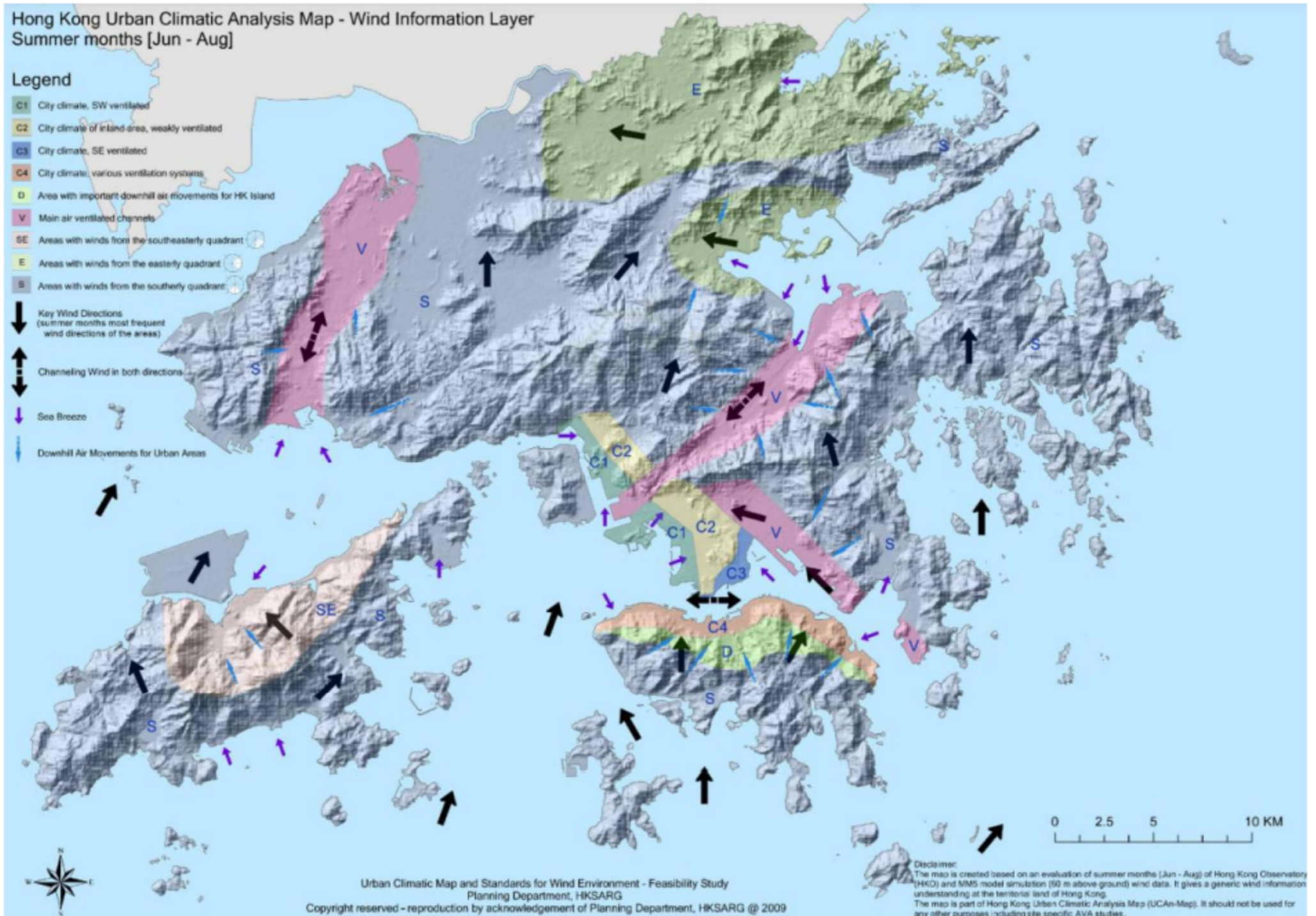
(Source: www.pland.gov.hk)

Wind roses of selected weather stations in Hong Kong



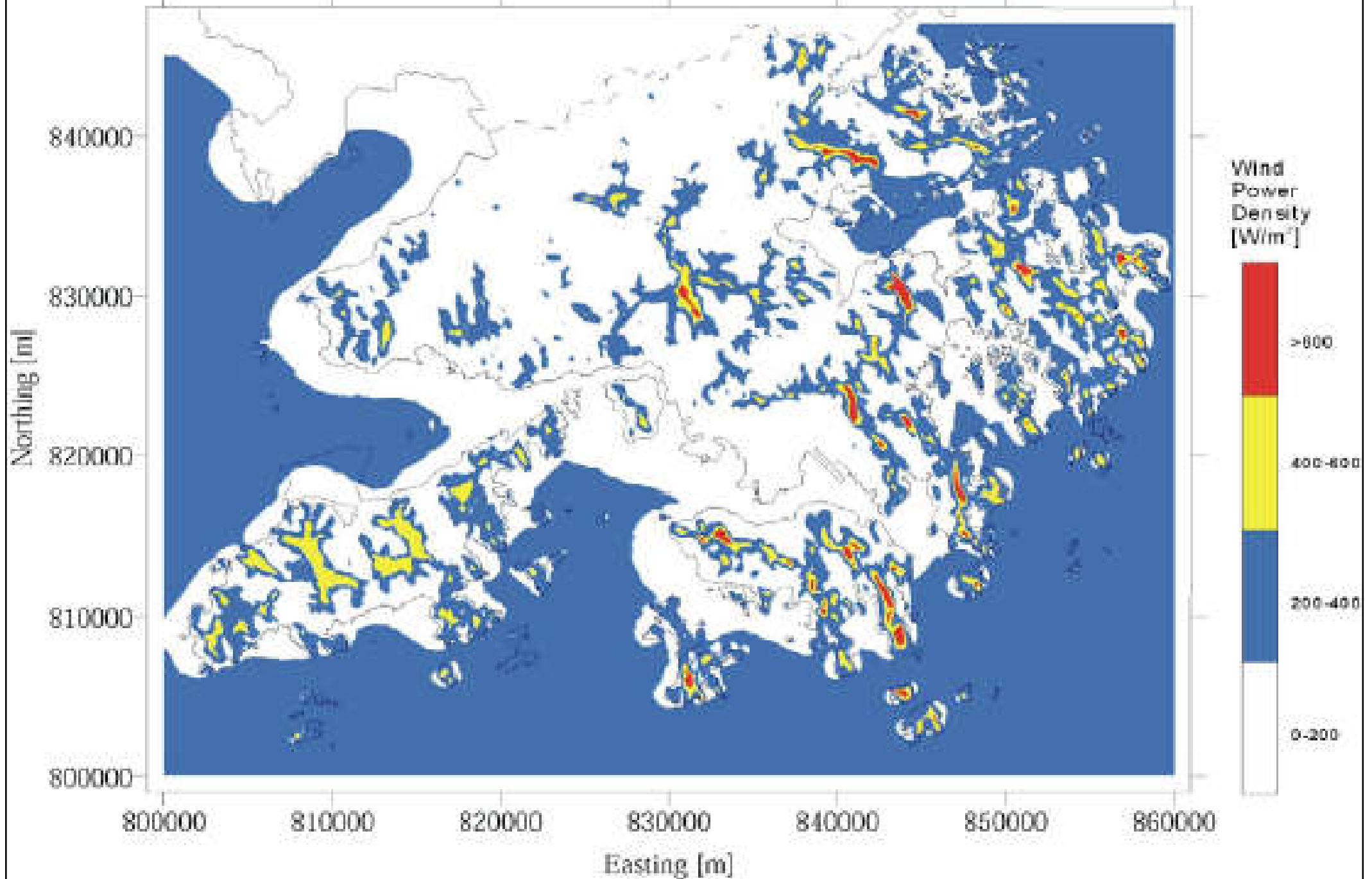
(Source: https://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/)

Wind information layer of Hong Kong in the summer months (Jun-Aug)



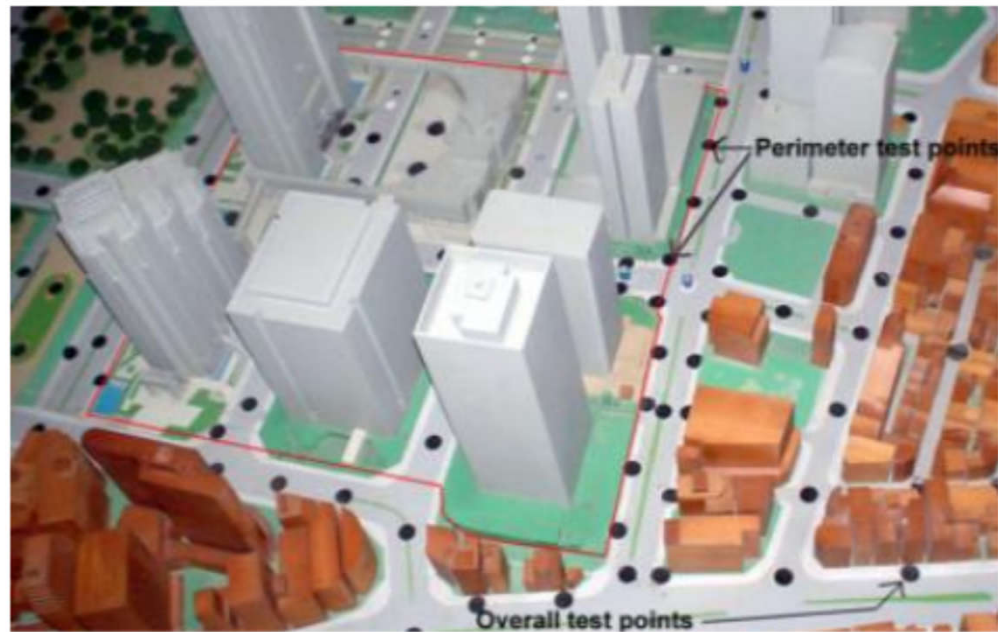
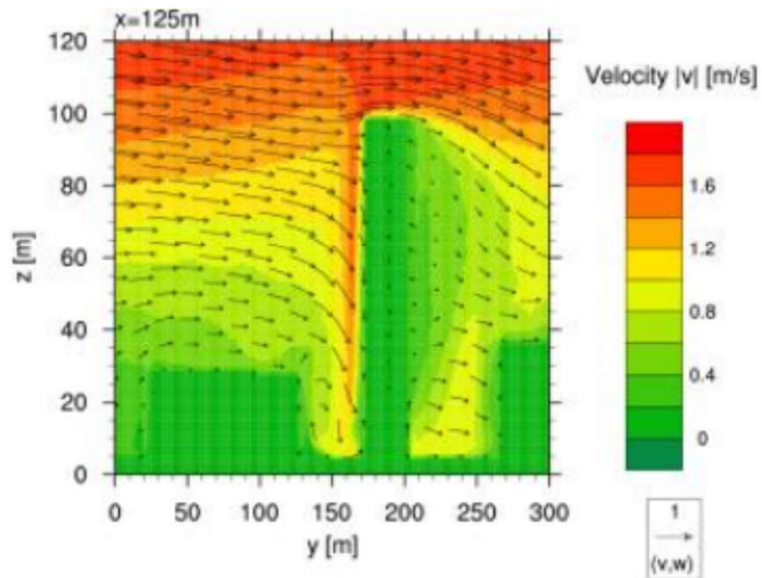
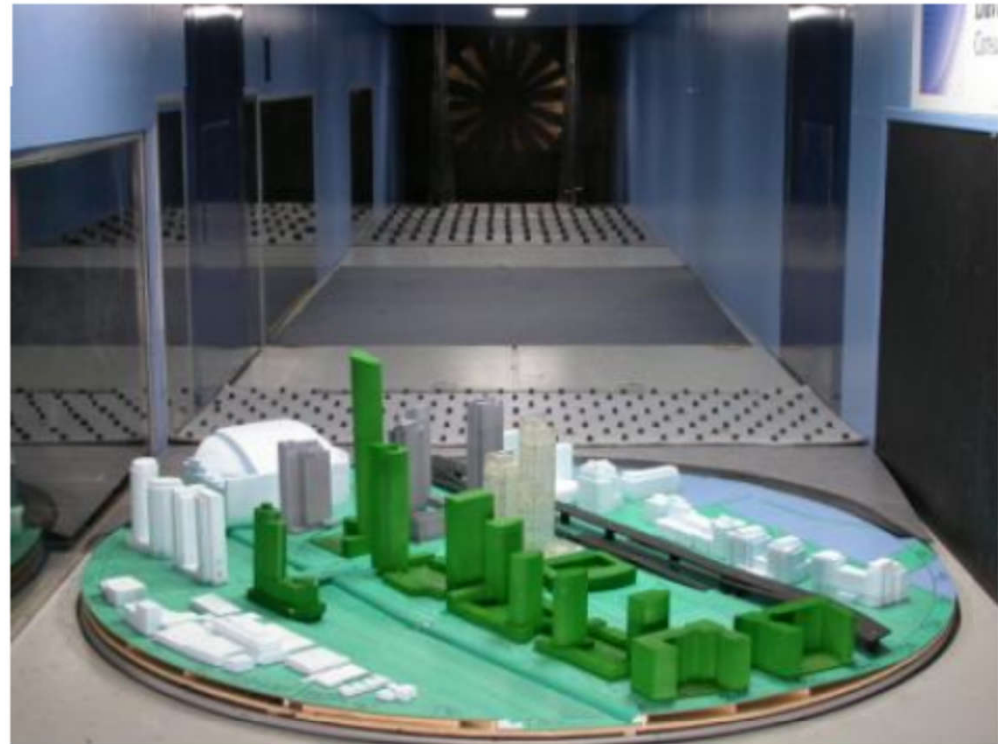
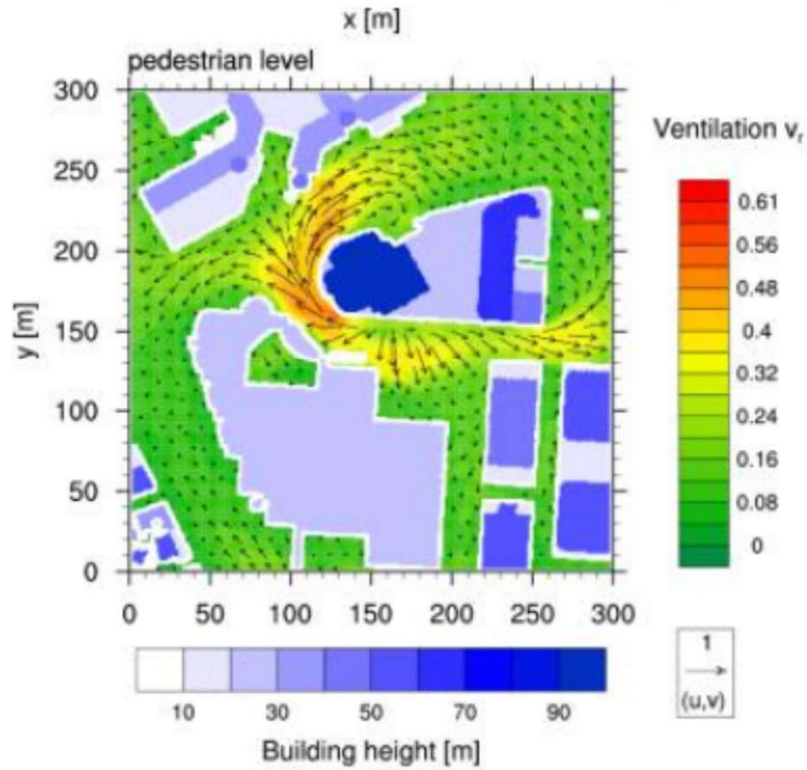
(Source: https://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/)

Wind power density over the region of Hong Kong (from EMSD)



(See also: Wind Resource Maps 風力資源圖 https://re.emsd.gov.hk/english/wind/gwind/gwind_images.html)

Wind tunnel analysis of urban climate in Hong Kong



Humid air & climate analysis

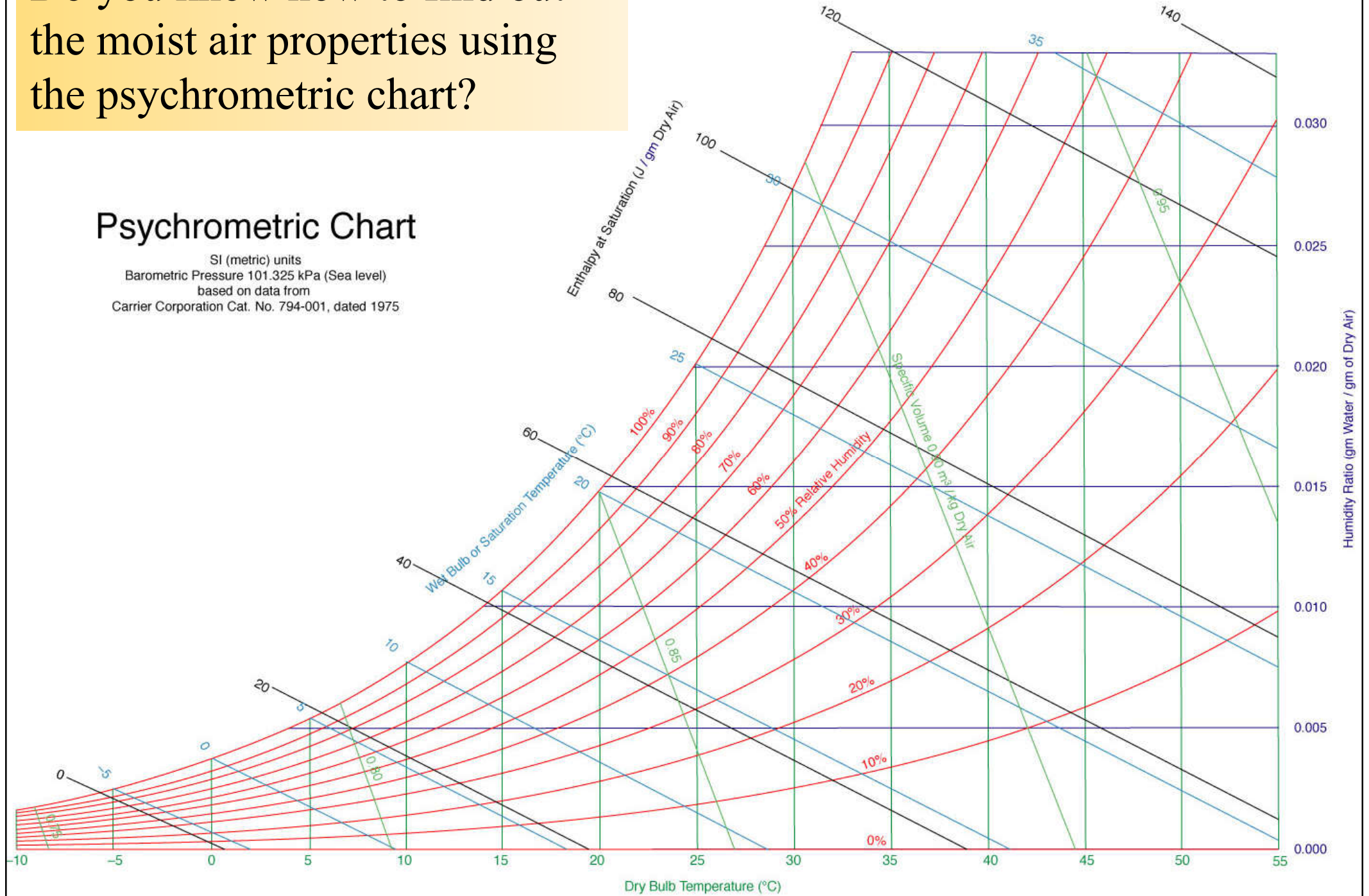


- Psychrometry (測濕學)
 - The measurement or study of the thermodynamic properties of **moist air** (dry air + water vapour)
 - The Greek term psuchron (ψυχρόν) meaning "cold" and metron (μέτρον) meaning "means of measurement"
 - Moist air properties:
 - Ideal gas laws: Dalton's law of partial pressures
 - Standard atmospheric pressure = 101.325 kPa
 - Saturated vapour pressure: Max. pressure of water vapour that can occur at any given temperature

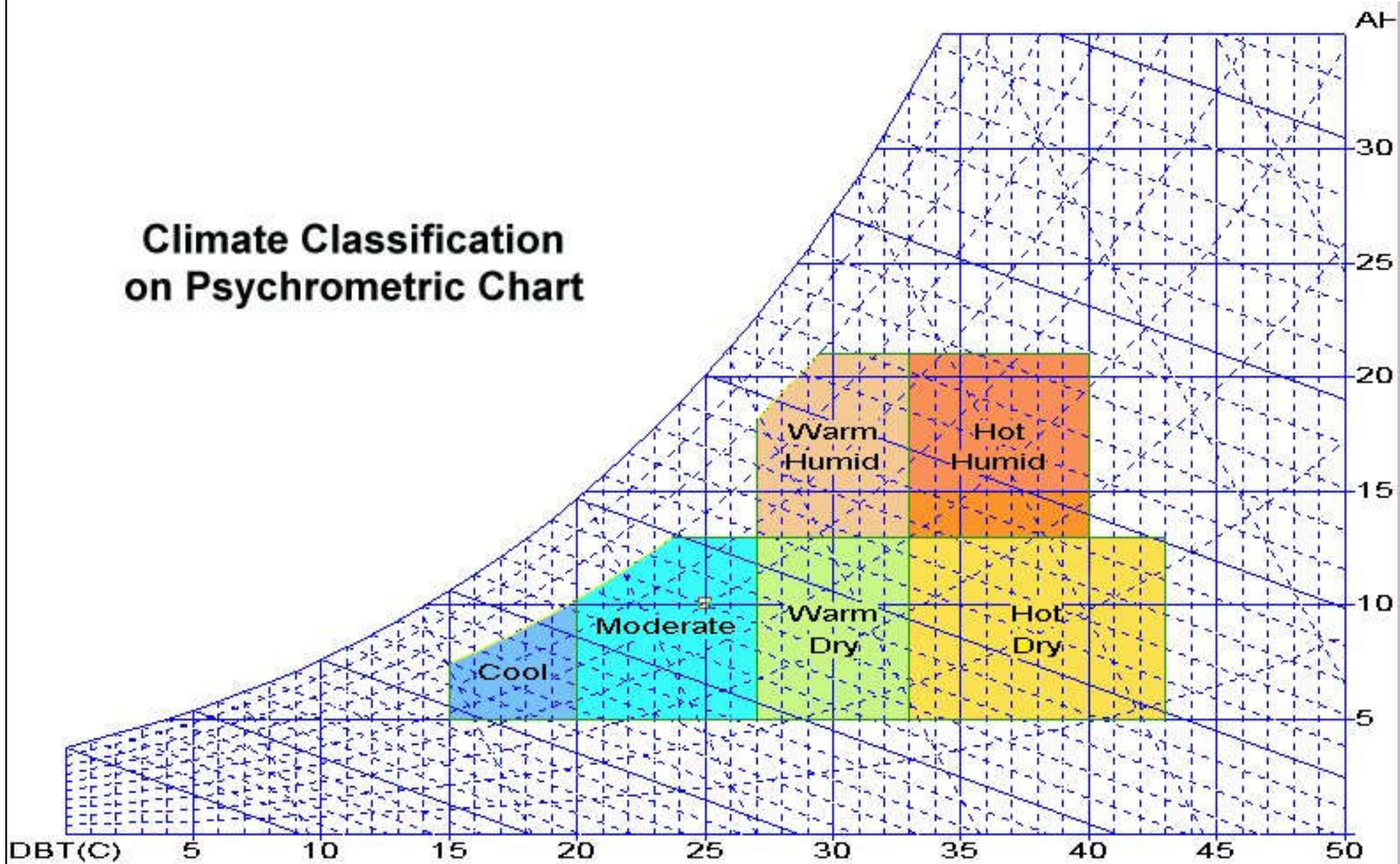
Do you know how to find out the moist air properties using the psychrometric chart?

Psychrometric Chart

SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975

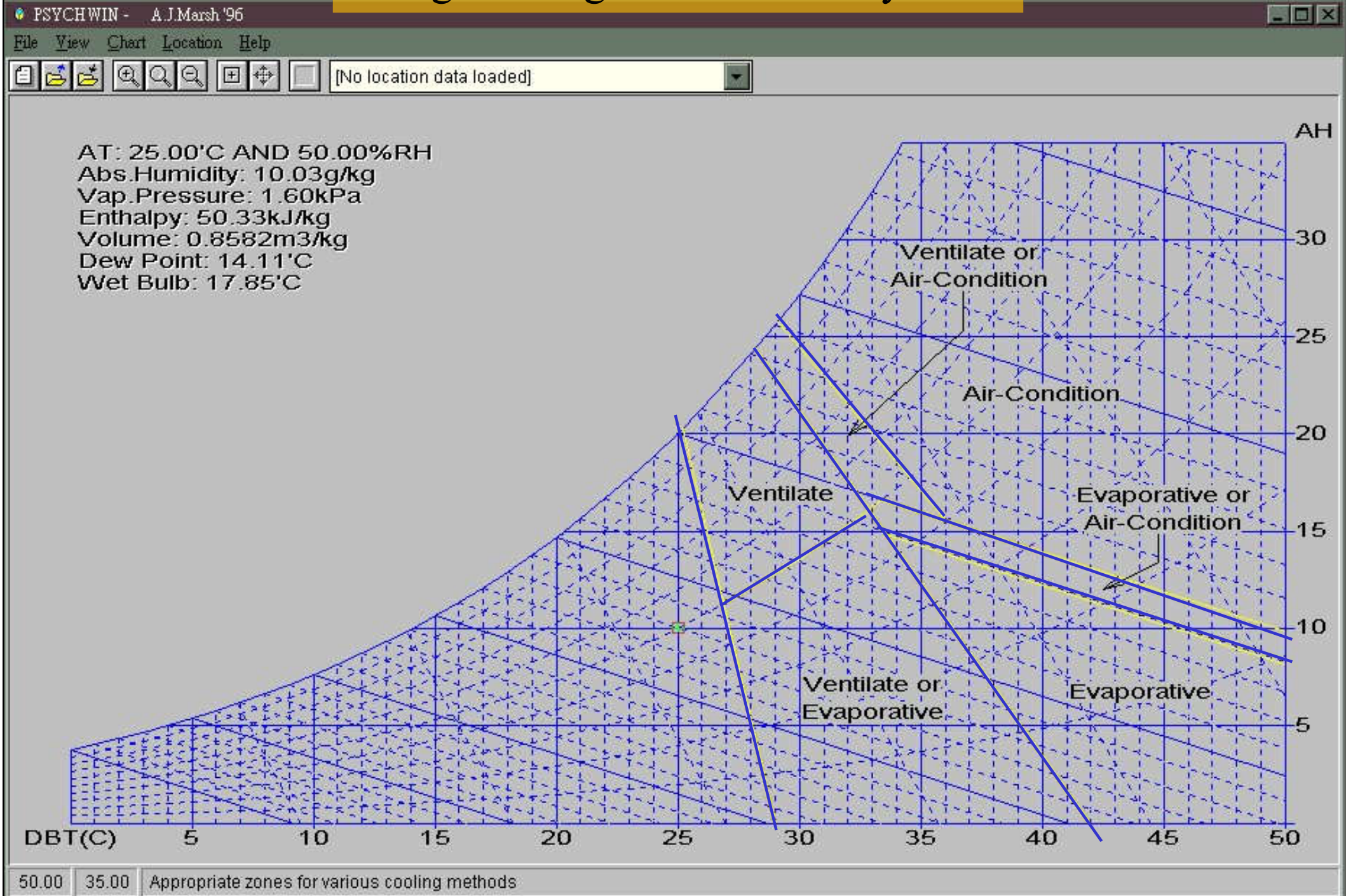


Climate Classification on Psychrometric Chart



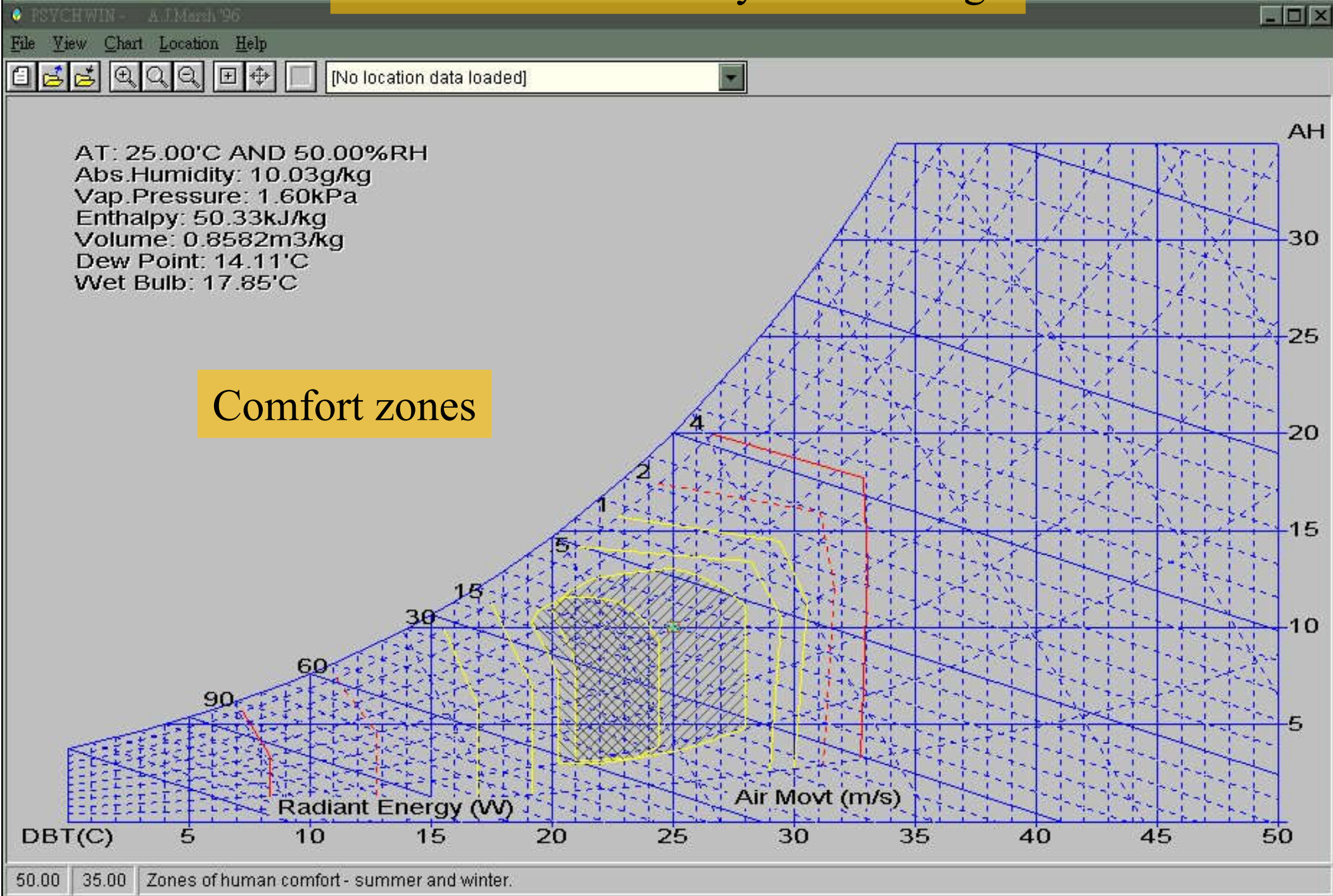
(Source: ArchiSci Software - PSYCHWIN)

Design strategies for HVAC systems



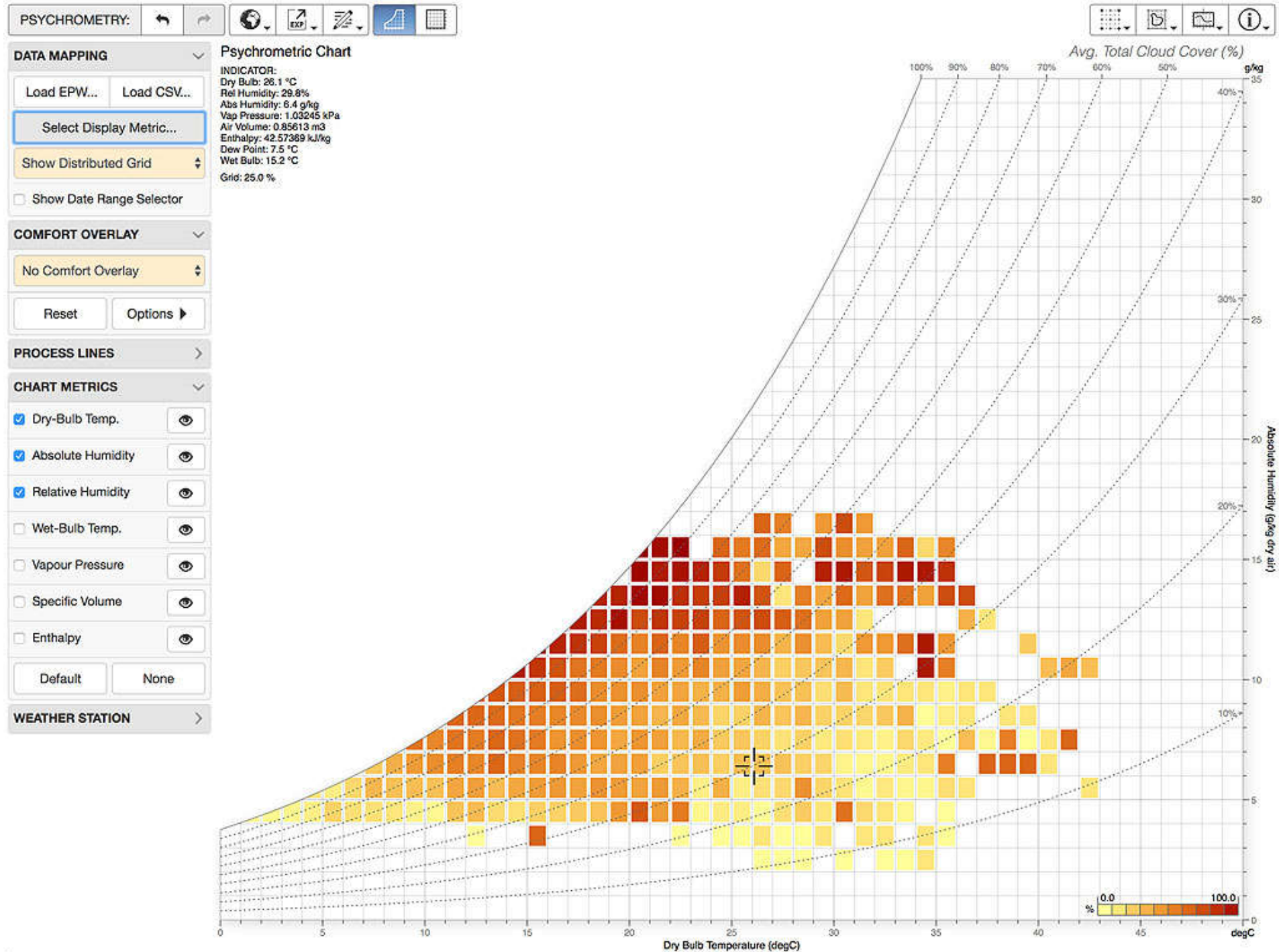
(Source: ArchiSci Software - PSYCHWIN)

Thermal comfort analysis and design



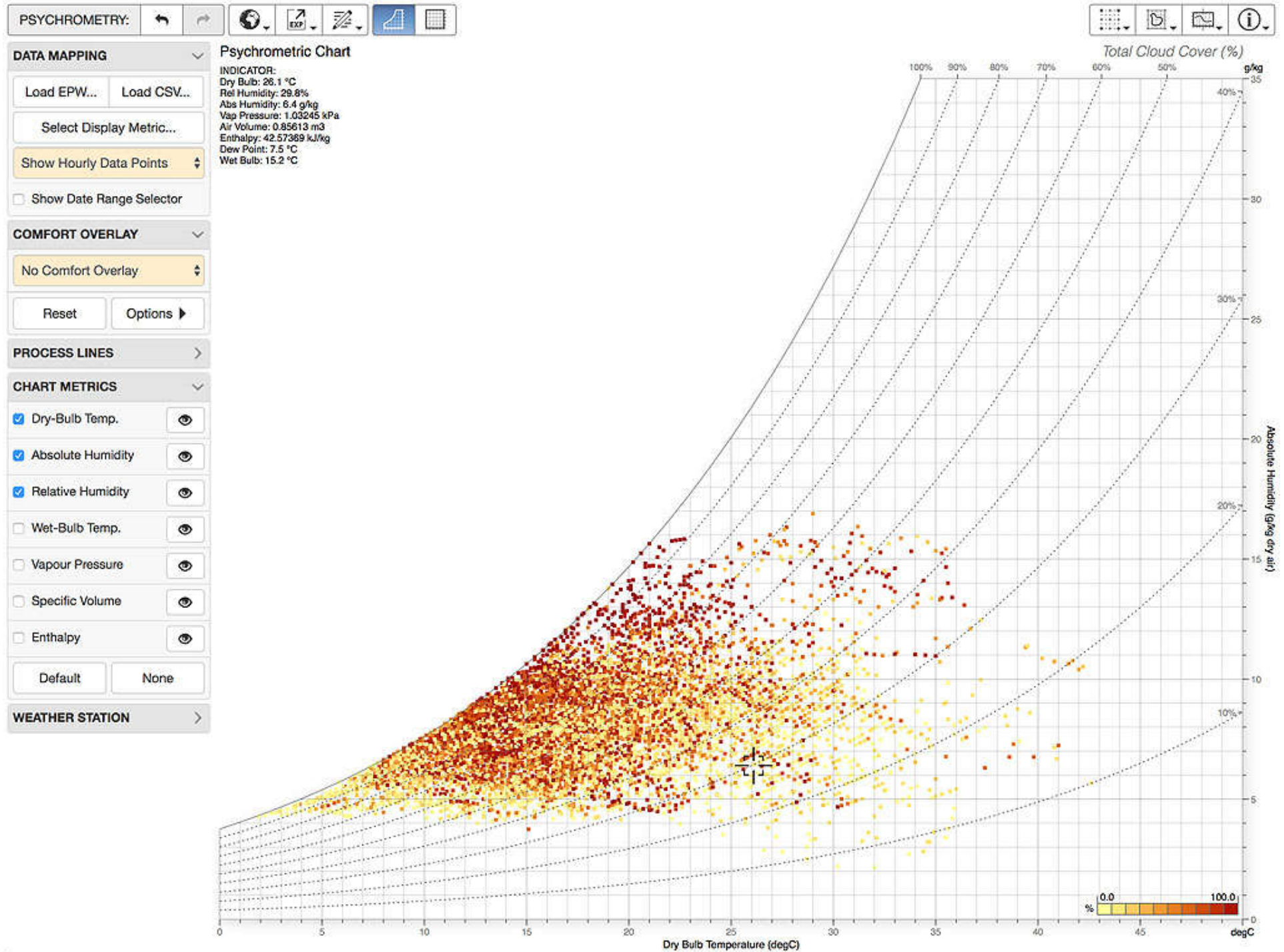
(Source: ArchiSci Software - PSYCHWIN)

Hourly climatic data as a distributed grid



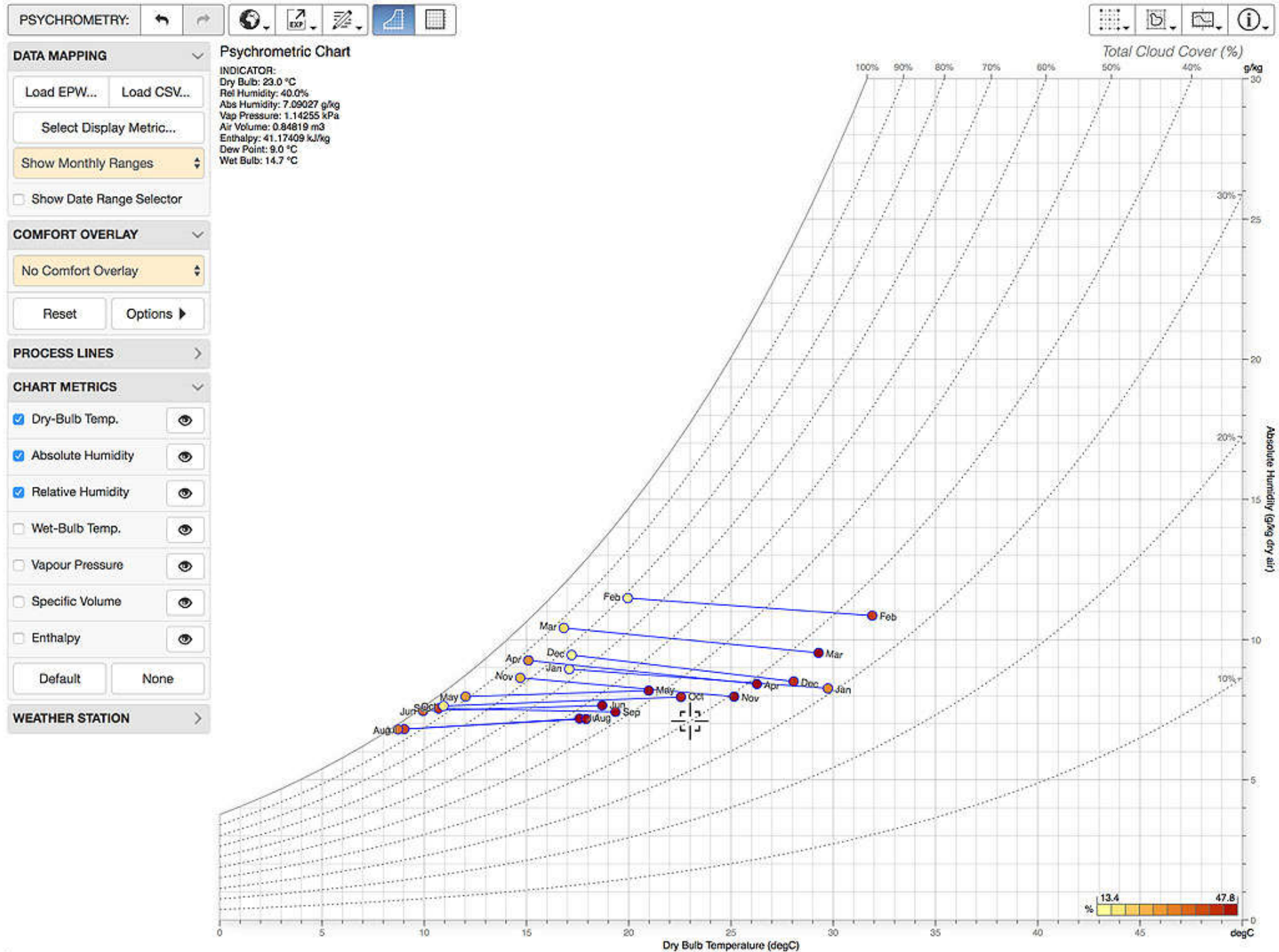
(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Climatic data as individual hourly data points



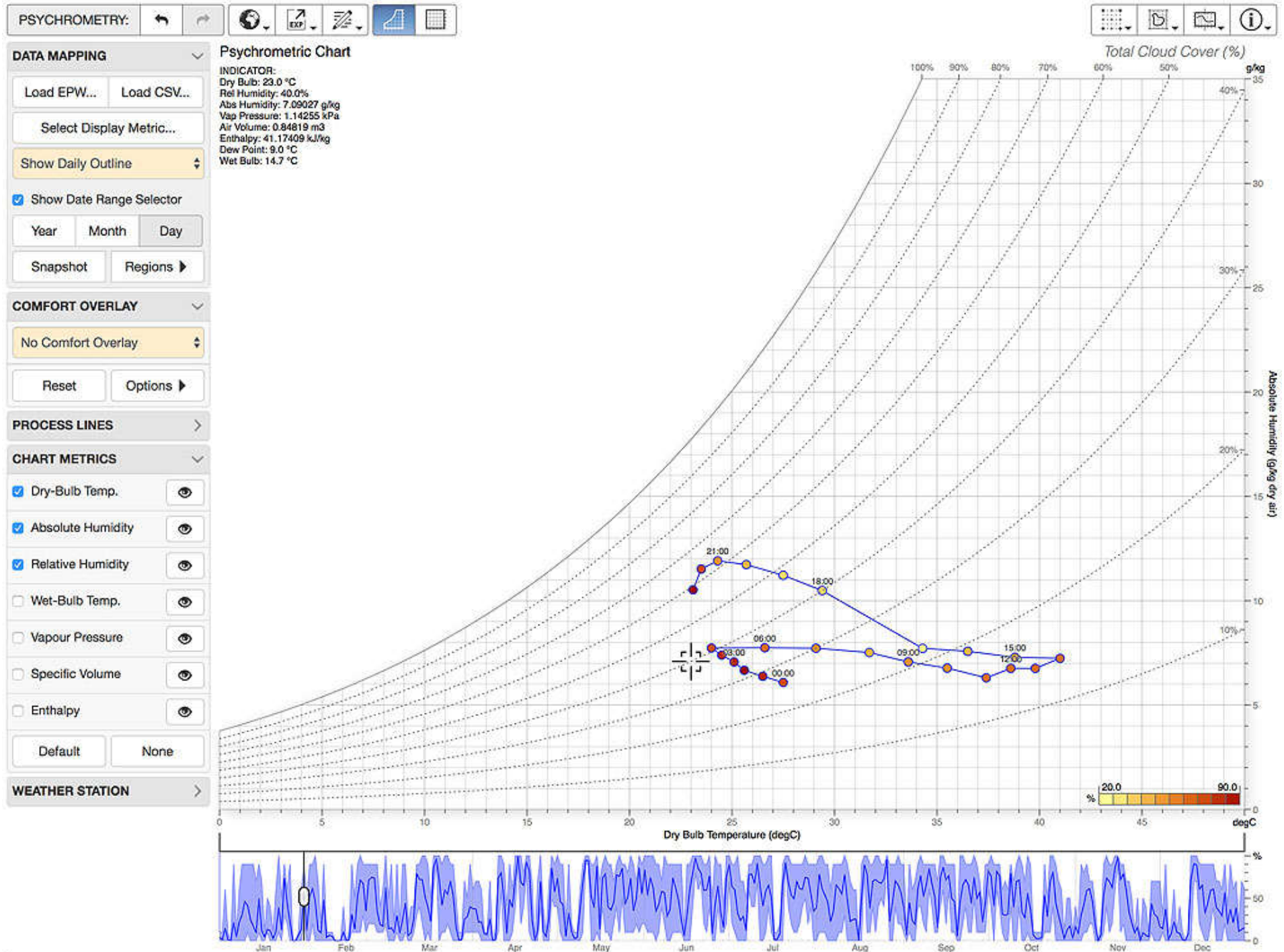
(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Climatic data as monthly mean average min/max lines

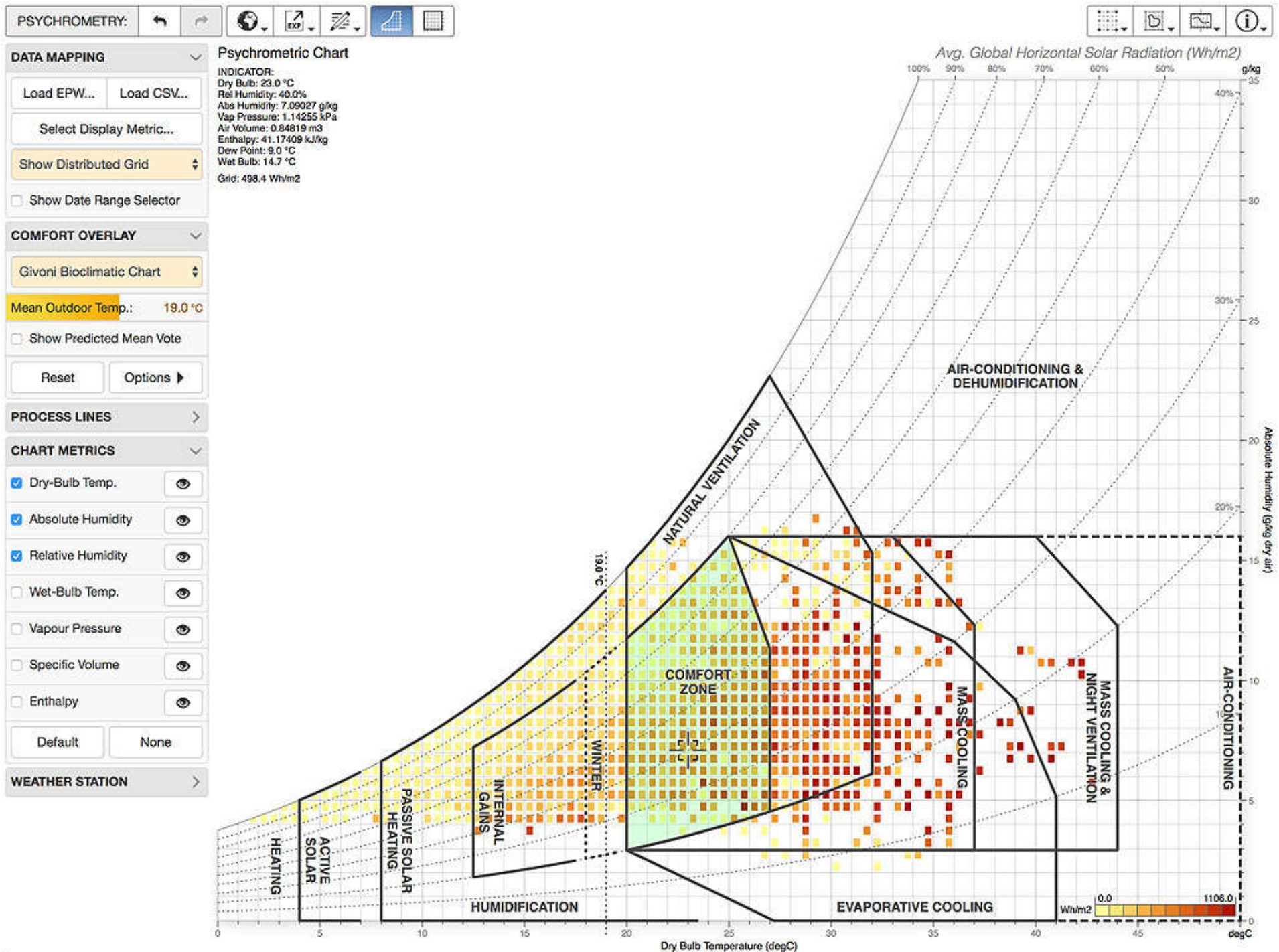


(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Climatic data as track conditions over the course of a day

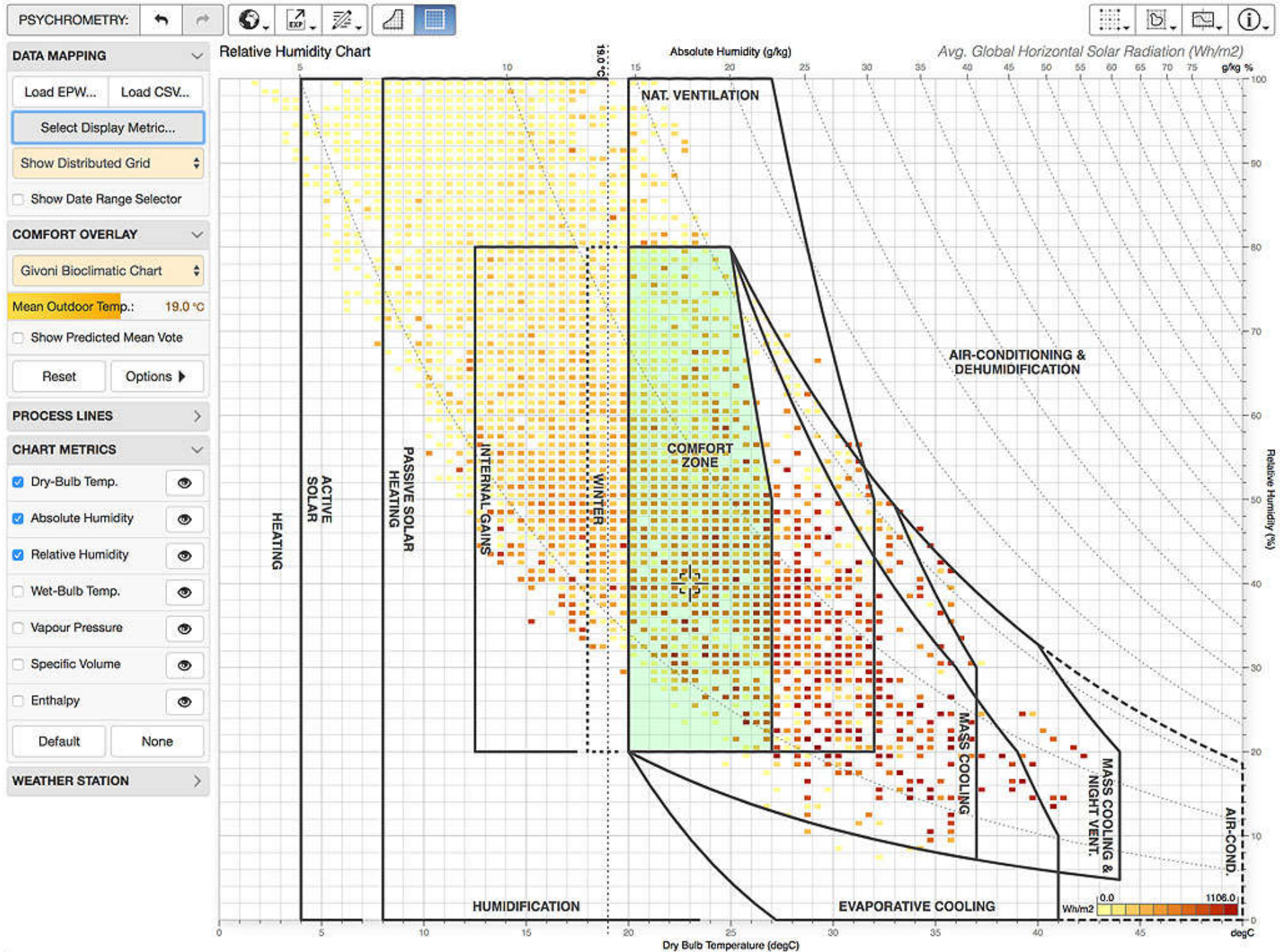


Bioclimatic analysis using a psychrometric chart

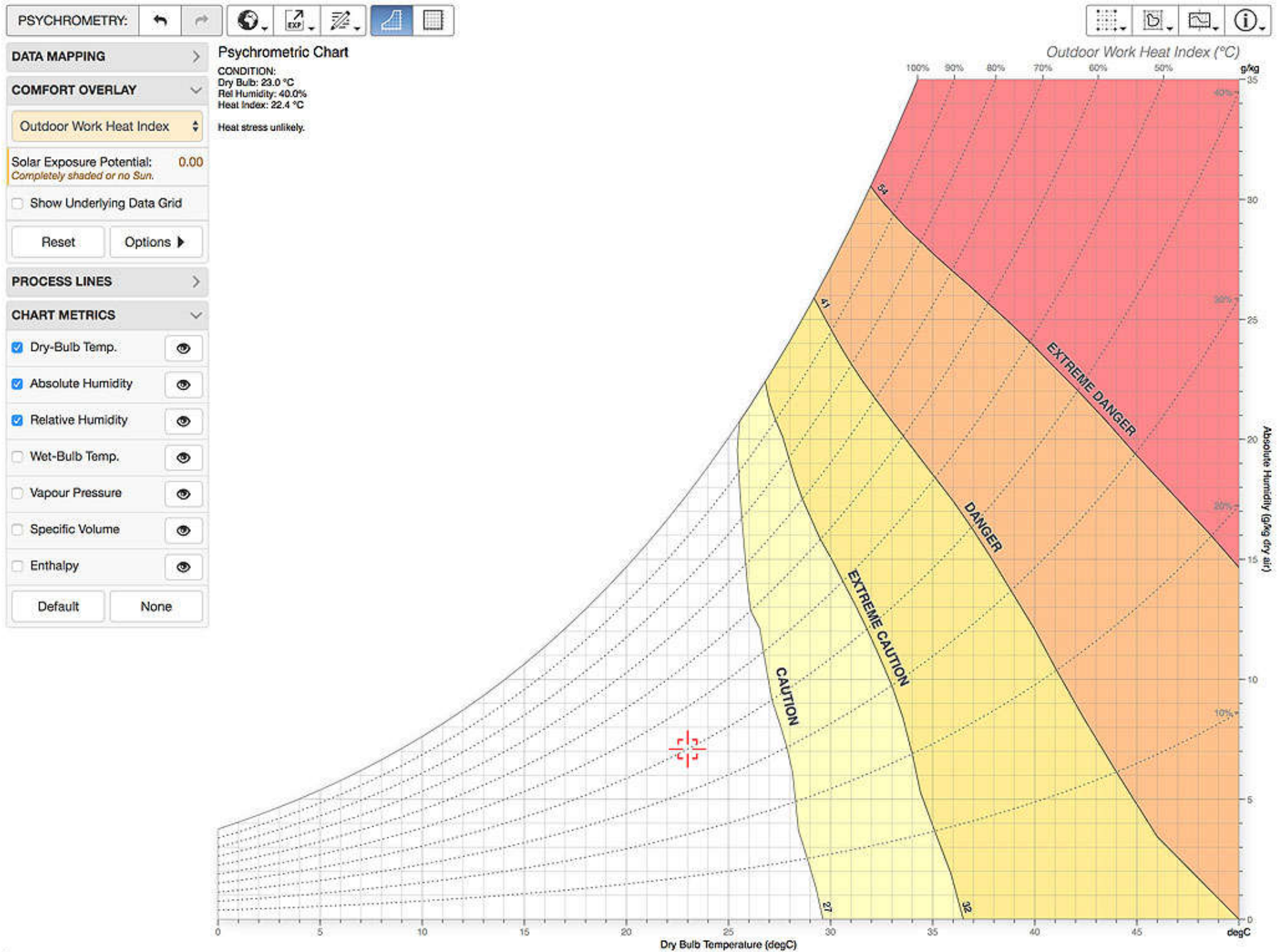


(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Bioclimatic analysis using a relative humidity chart

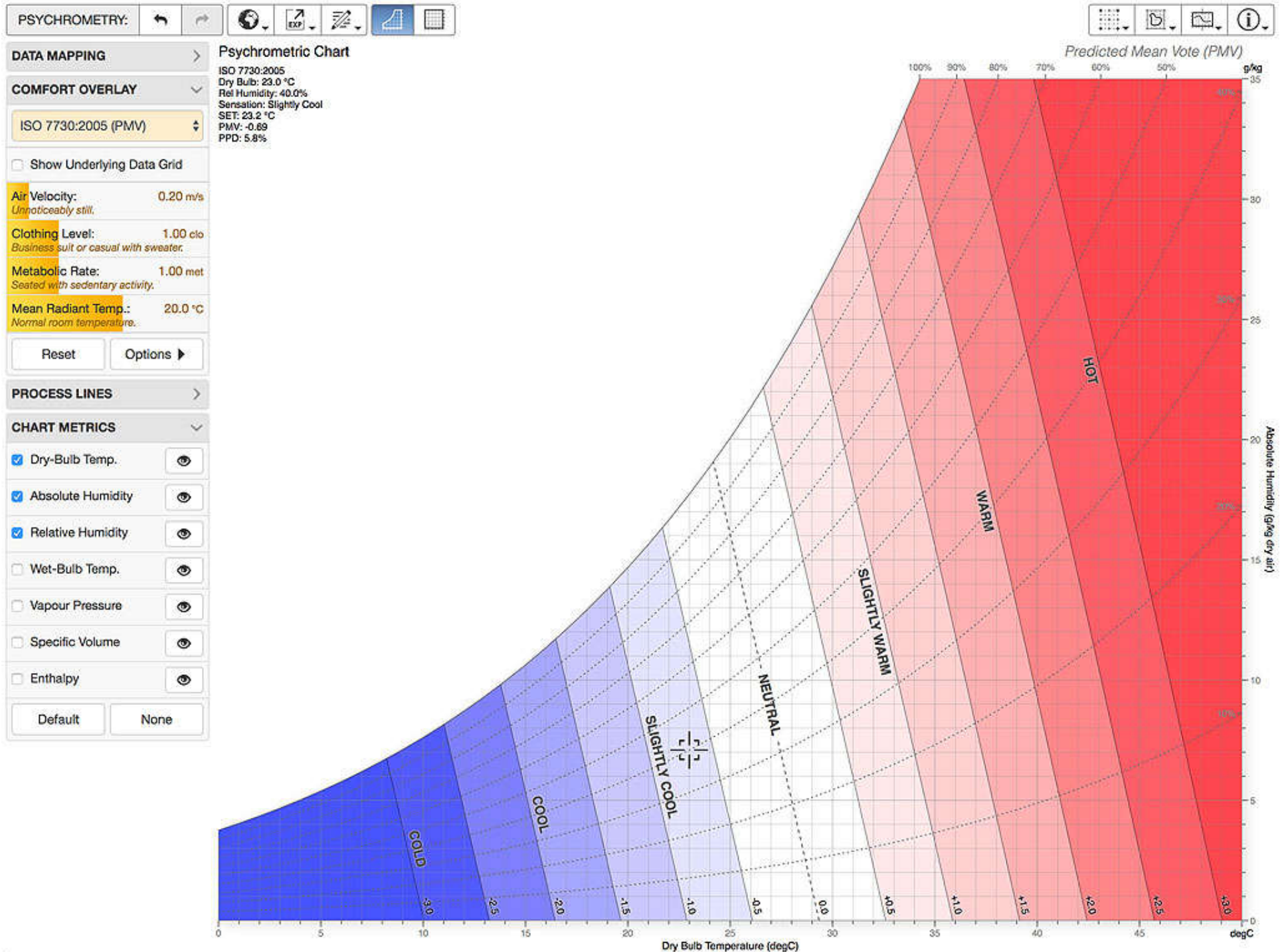


Heat index contours mapped over the psychrometric chart



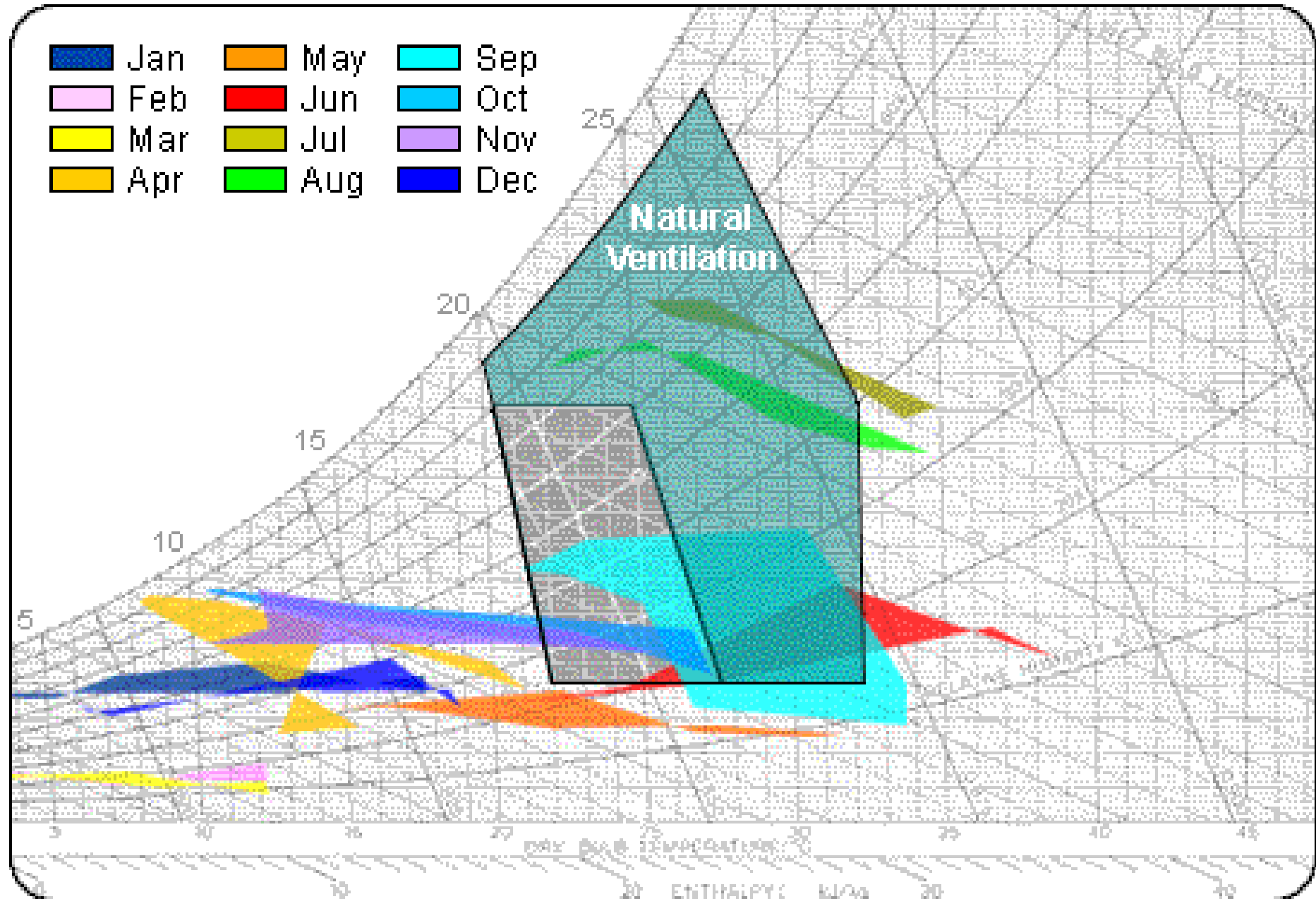
(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Thermal comfort predicted mean vote (PMV) contours



(Source: <http://andrewmarsh.com/software/psychro-chart-web/>)

Analysis of external climate on cooling & ventilation strategies



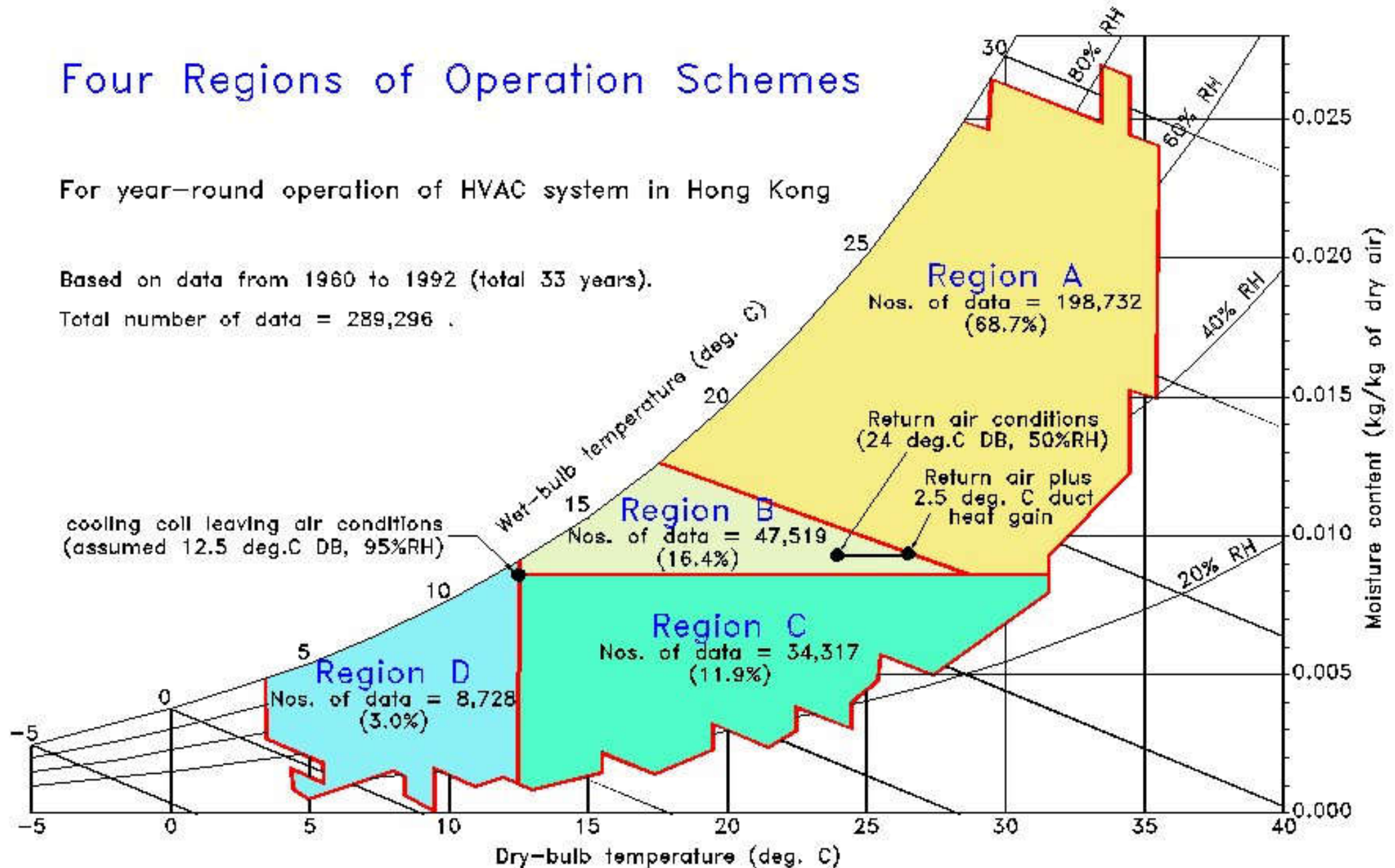
Analysis of HVAC operation strategy

Four Regions of Operation Schemes

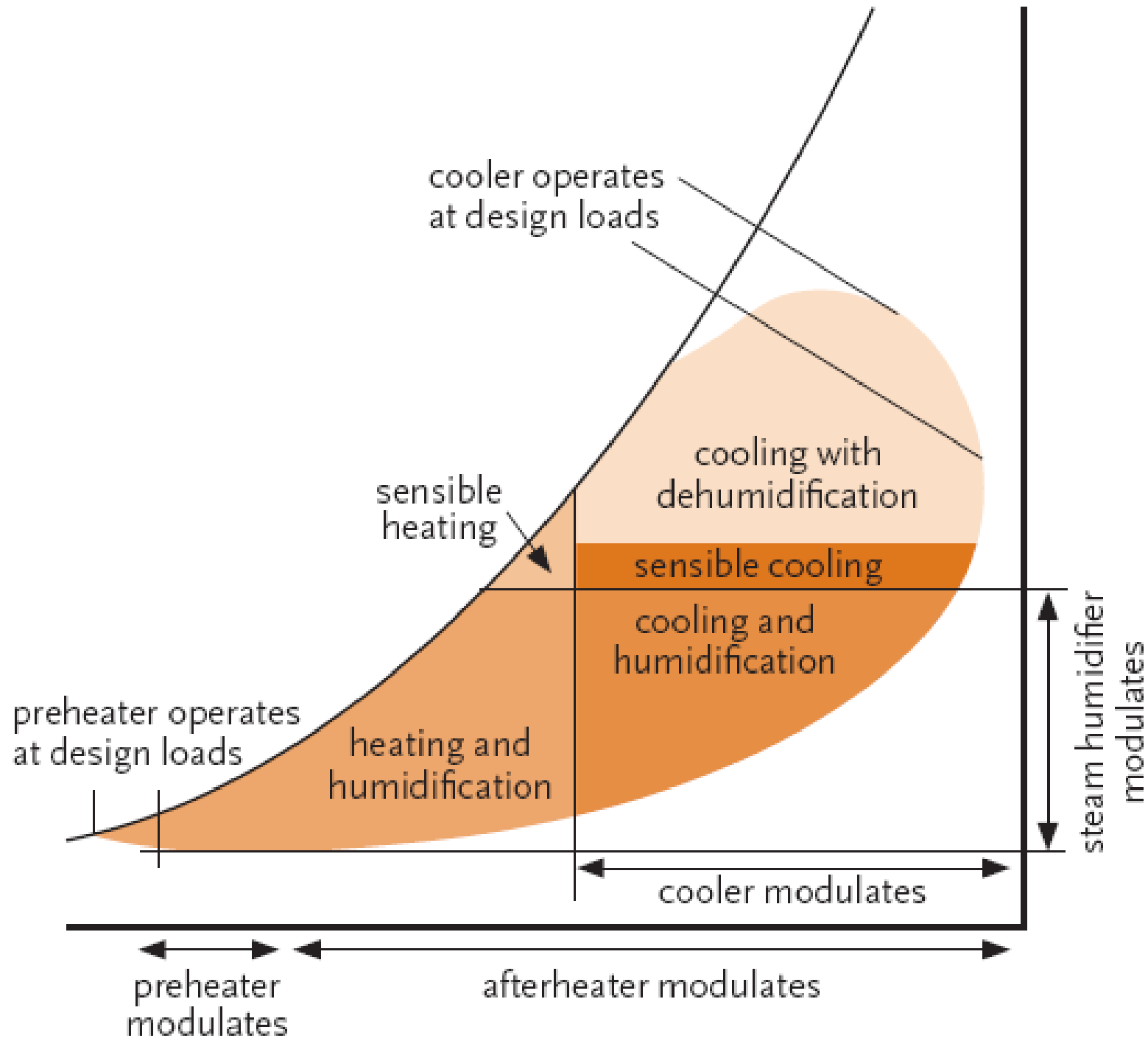
For year-round operation of HVAC system in Hong Kong

Based on data from 1960 to 1992 (total 33 years).

Total number of data = 289,296 .



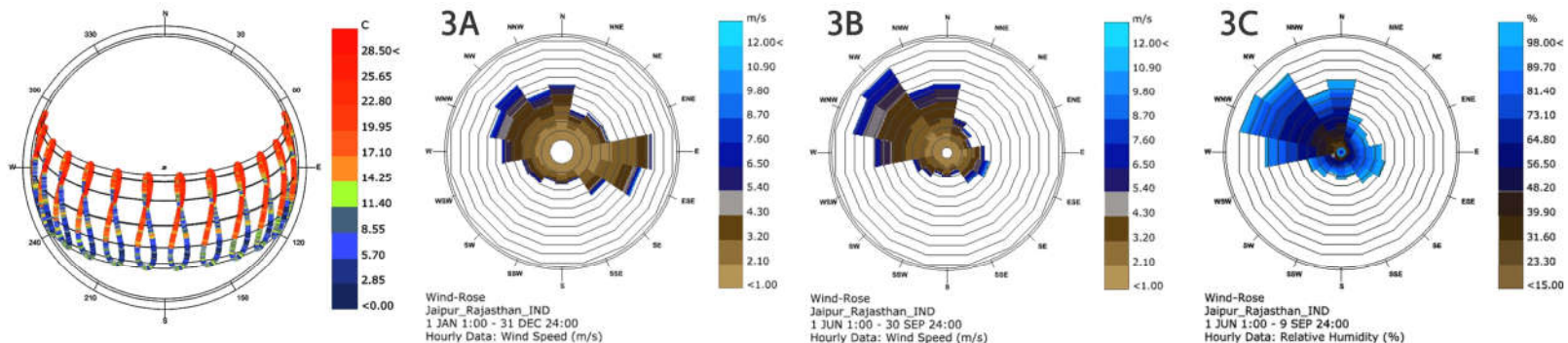
All-year-round operating regime based on outdoor conditions

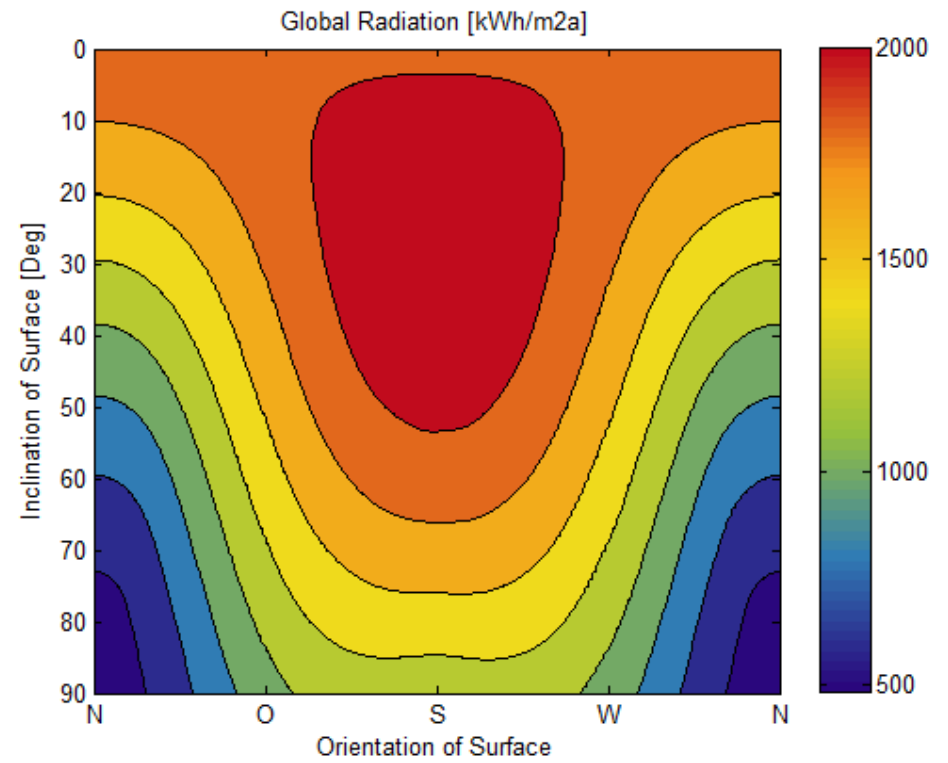
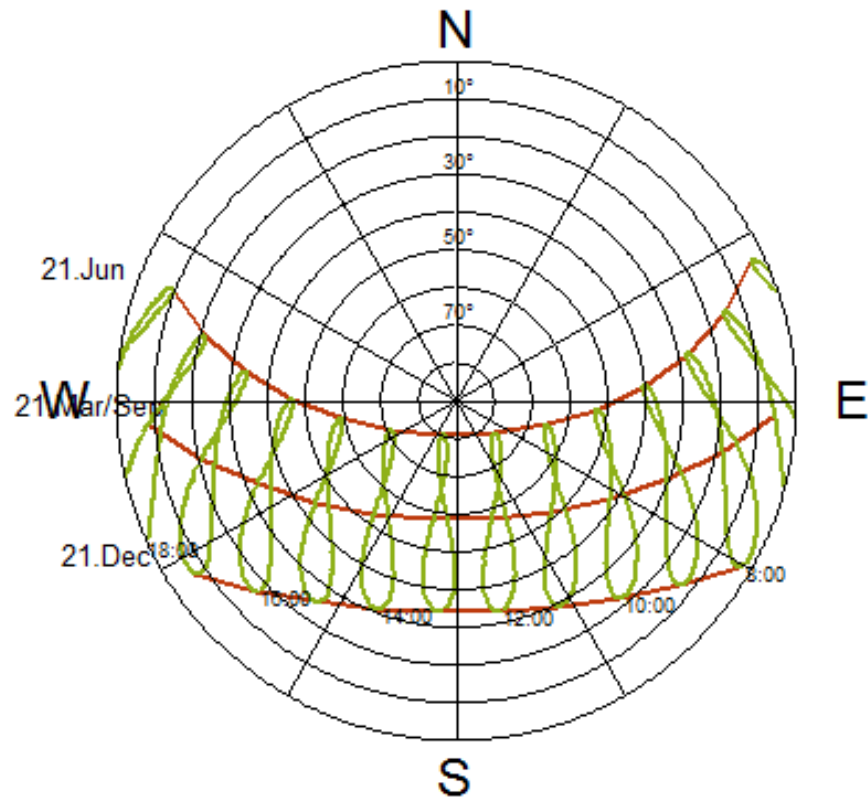
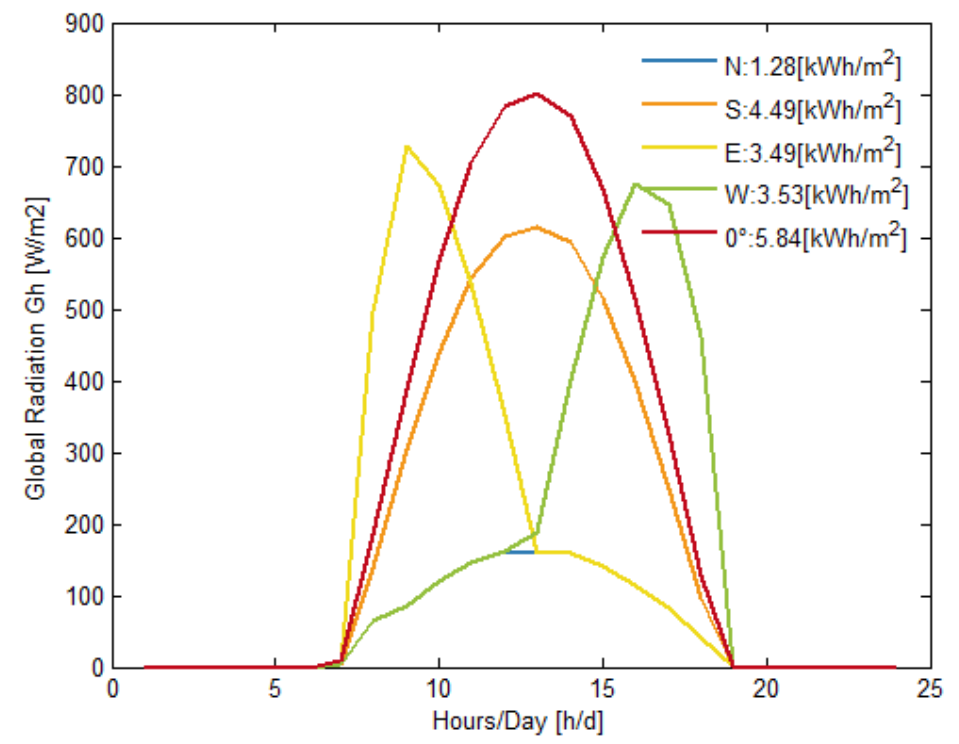
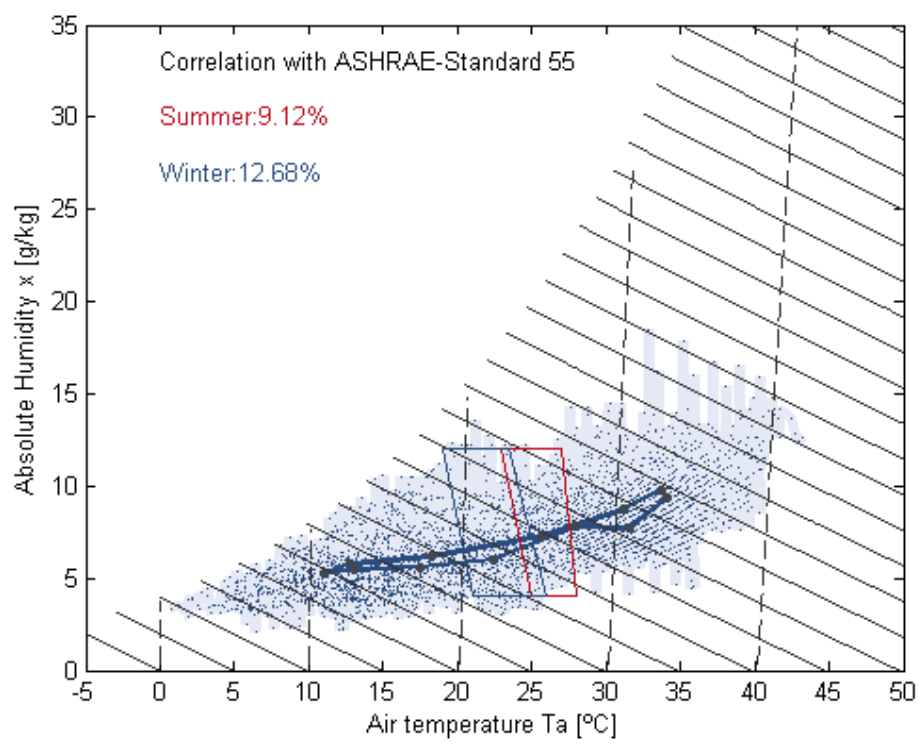


Humid air & climate analysis

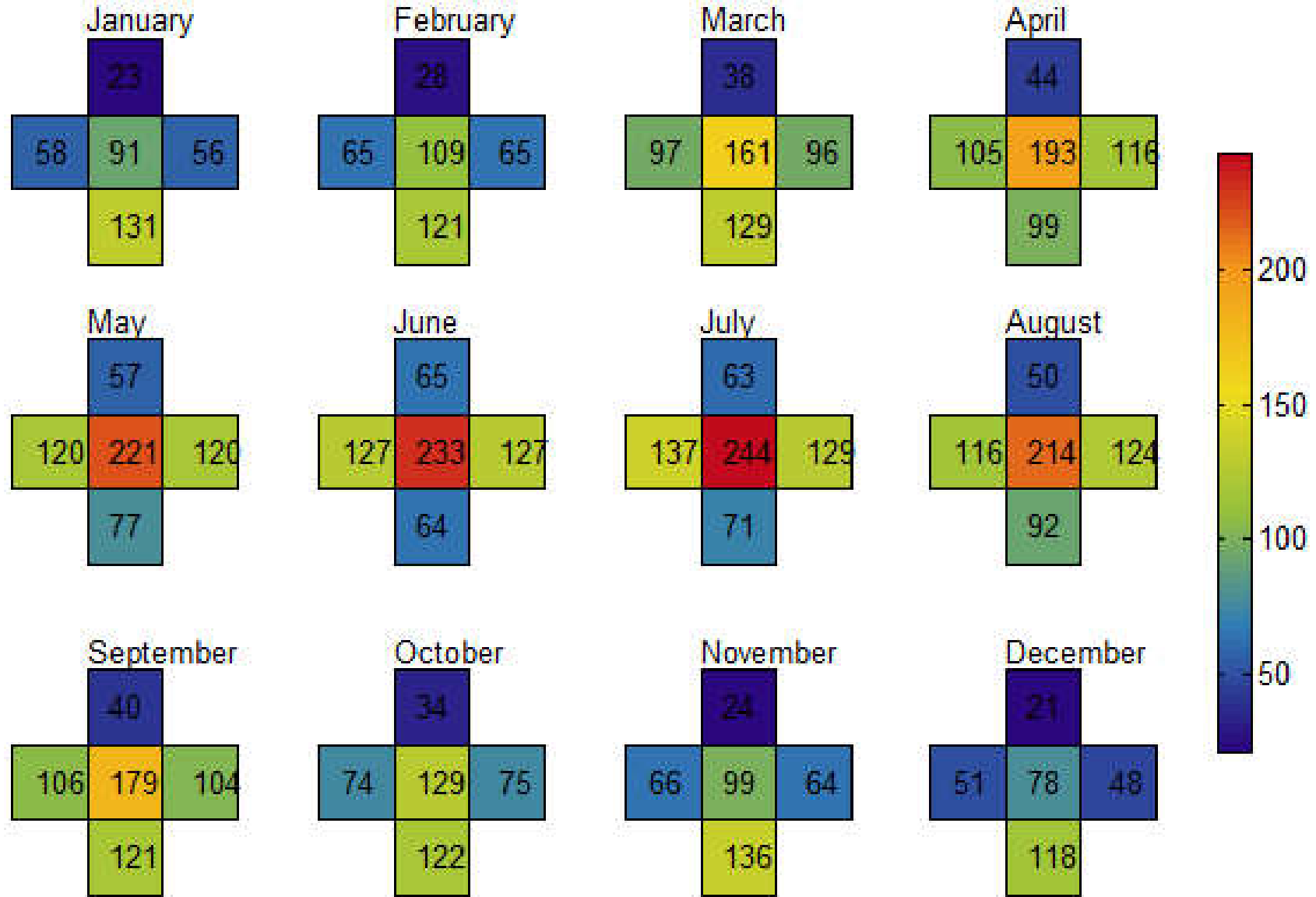
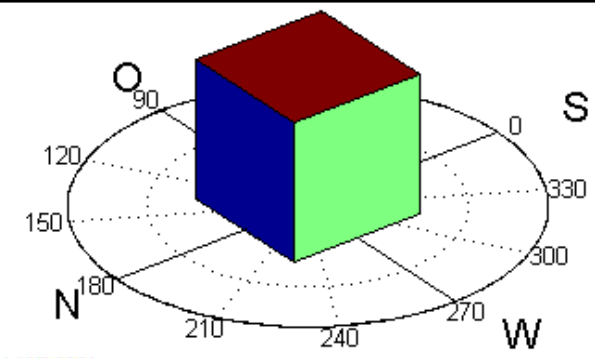


- Climate can influence building design and dictate what passive design strategies are most suitable and effective for the building site
 - Climate refers to the average atmospheric conditions over a long period of time
 - Weather refers to the daily temperatures and atmospheric conditions



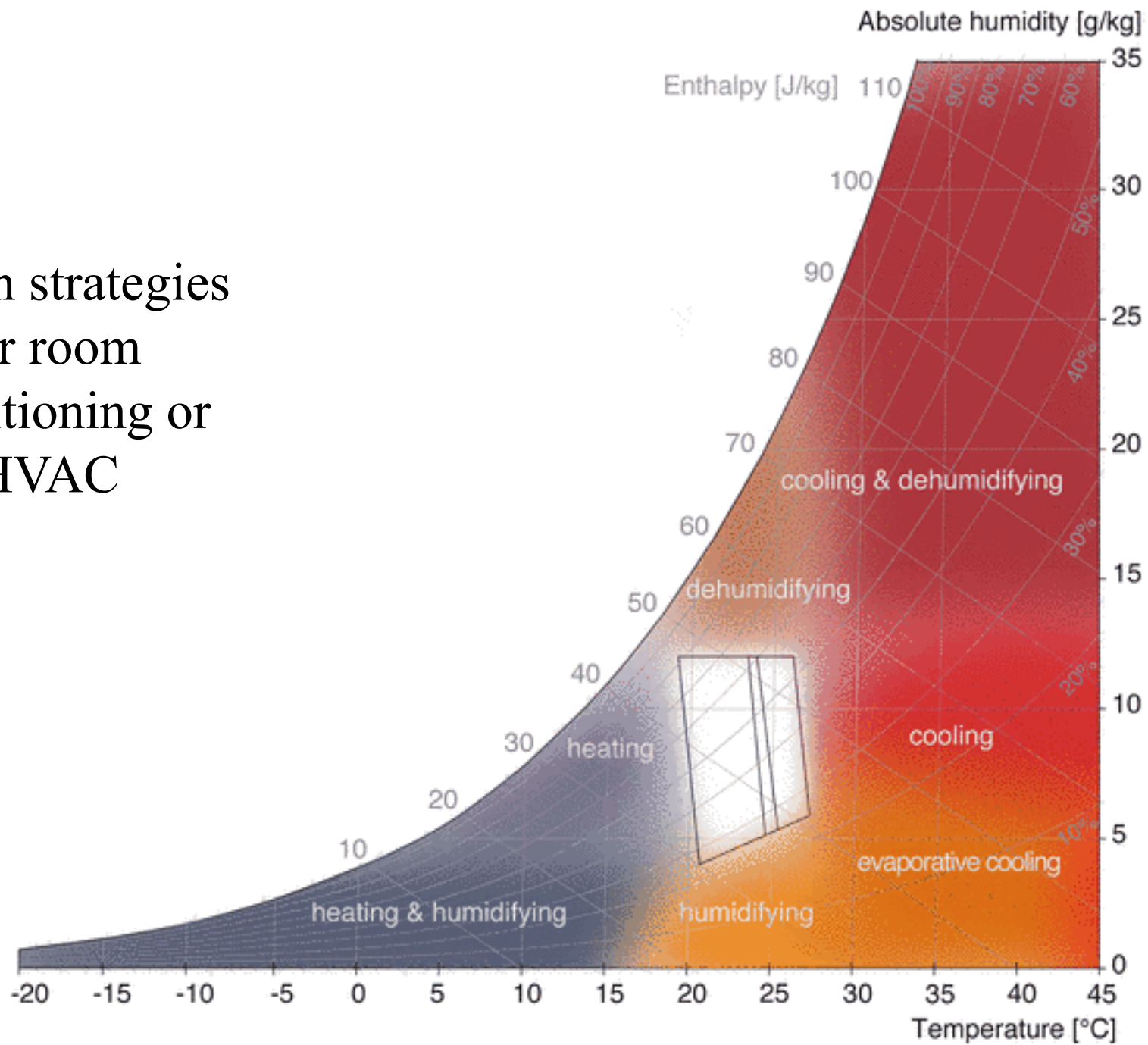


Solar radiation analysis (façade month)

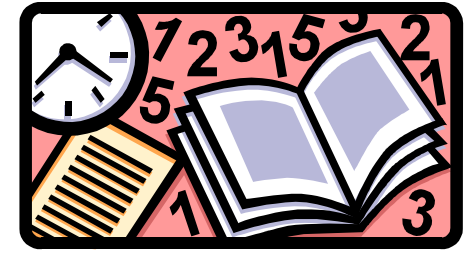


Global Radiation [kWh/m²*Month]

Design strategies for room conditioning or HVAC



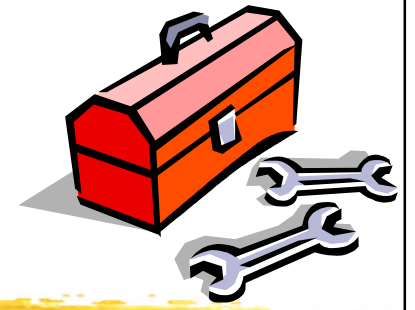
Room conditioning according to the outdoor climate shown in psychrometric chart
(cf. Olgay, 1963)



Further Reading

- Climate - CLEAR (Comfortable Low Energy ARchitecture) <https://www.new-learn.info/packages/clear/thermal/climate/>
- Interactive Sun Path Diagram 互動版太陽路徑圖
 - https://www.hko.gov.hk/en/gts/astronomy/SunPathDay3_ue.htm
- Hong Kong Solar Irradiation Map 香港太陽輻照圖
 - <https://solarmap.emsd.gov.hk/>
- Wind Resource Maps 風力資源圖
 - https://re.emsd.gov.hk/english/wind/gwind/gwind_images.html

Useful Tools



- ClimateTool <http://www.climate-tool.com>
- Software by Andrew Marsh <http://andrewmarsh.com/software/>
 - Psychrometric Chart <http://andrewmarsh.com/software/psychro-chart-web/>,
<https://drajmarsh.bitbucket.io/psychro-chart2d.html>
 - Weather Data <http://andrewmarsh.com/software/weather-data-web/>,
<https://drajmarsh.bitbucket.io/weather-data.html>
 - 2D Sun-Path <http://andrewmarsh.com/software/sunpath2d-web/>,
<https://drajmarsh.bitbucket.io/sunpath2d.html>
 - 3D Sun-Path <http://andrewmarsh.com/software/sunpath3d-web/>,
<https://drajmarsh.bitbucket.io/shading-box.html>
 - Dynamic Daylighting <http://andrewmarsh.com/software/daylight-box-web/>,
<https://drajmarsh.bitbucket.io/daylight-box.html>
 - Dynamic Overshadowing <http://andrewmarsh.com/software/shading-box-web/>,
<https://drajmarsh.bitbucket.io/shading-box.html>