NOTES ON EUROPEAN CLIMATE AND DESIGN

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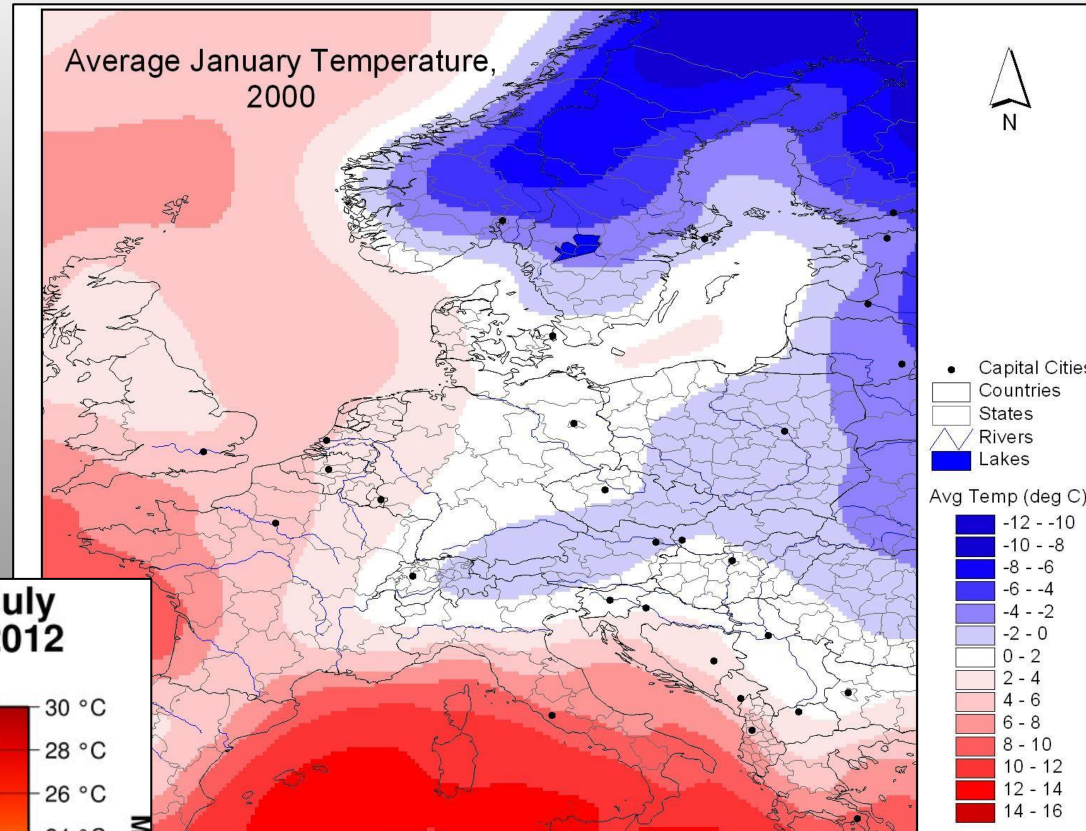
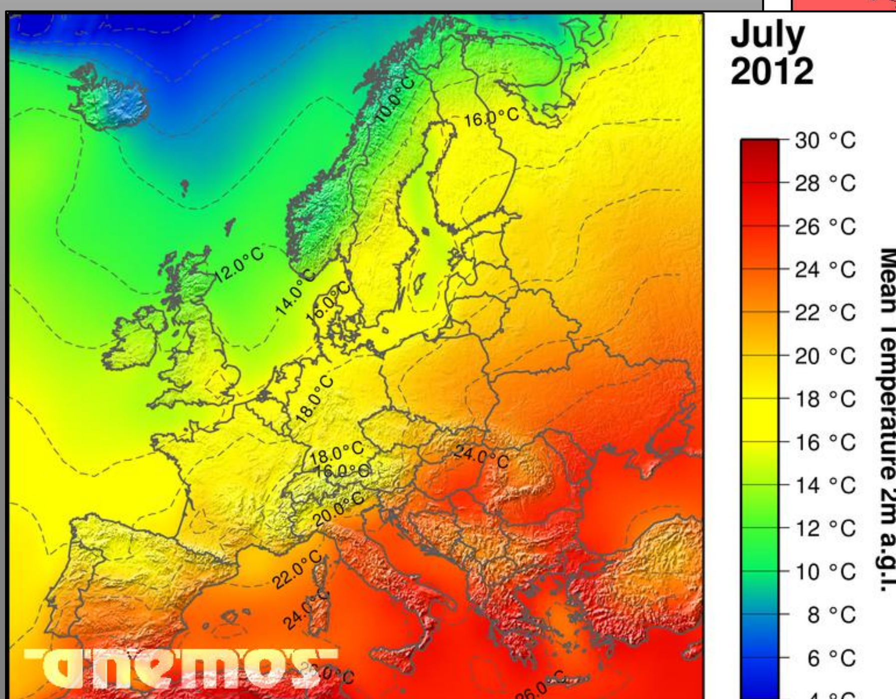
Aalto University, 17.09.2014

Studying climate in Europe, to develope building design criteria, is an involved task.

This is due to the latitude span, inhomogeneous morphology, cold/hot waves, Gulf Stream etc.





While the Summer is easier to model, the Winter is problematic, since these diversities emerge strongly.

Modelling the building design for the Winter is a rather demanding challenge.

EUROPE

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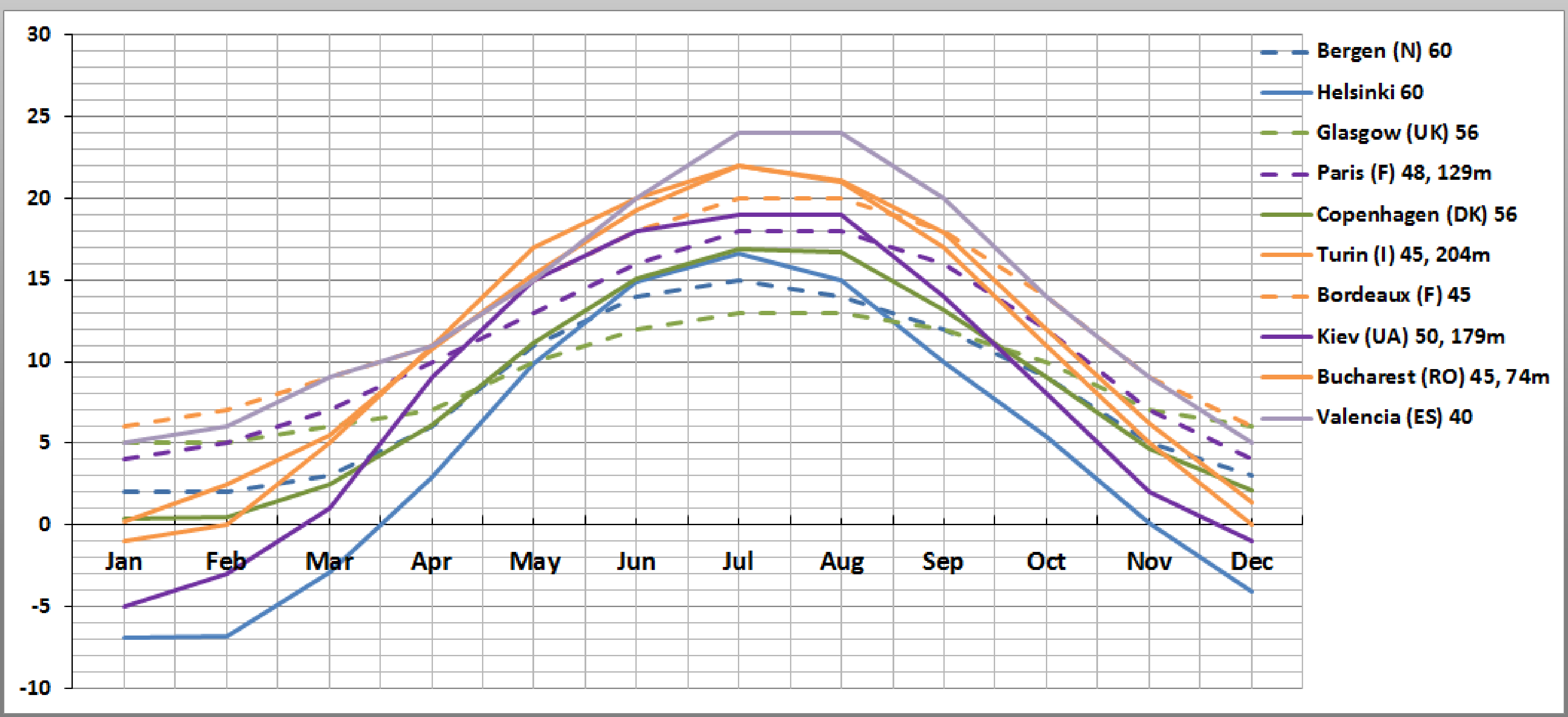
European temperatures change not only with latitude. Especially during winter, we can roughly distinguish between the East (more continental) and the West (more oceanic/Atlantic).

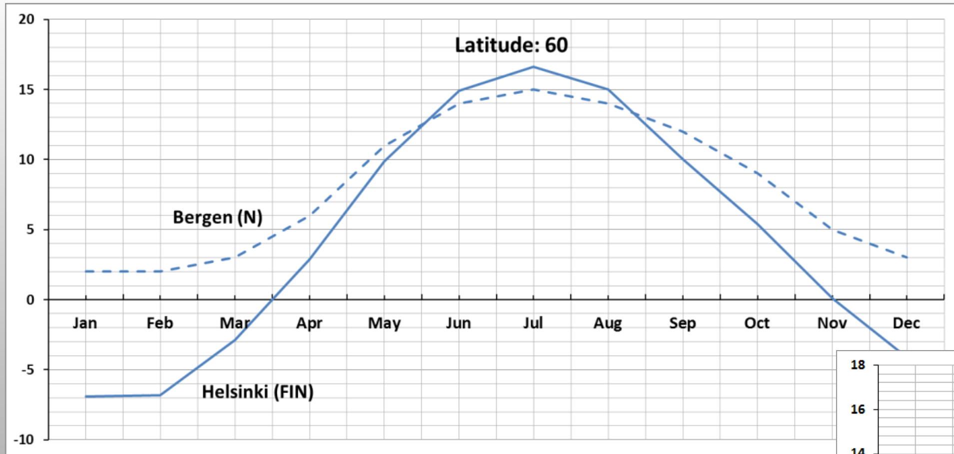
Below we see the average monthly temperatures of some European cities (1961-1990), together with their latitude and elevation.

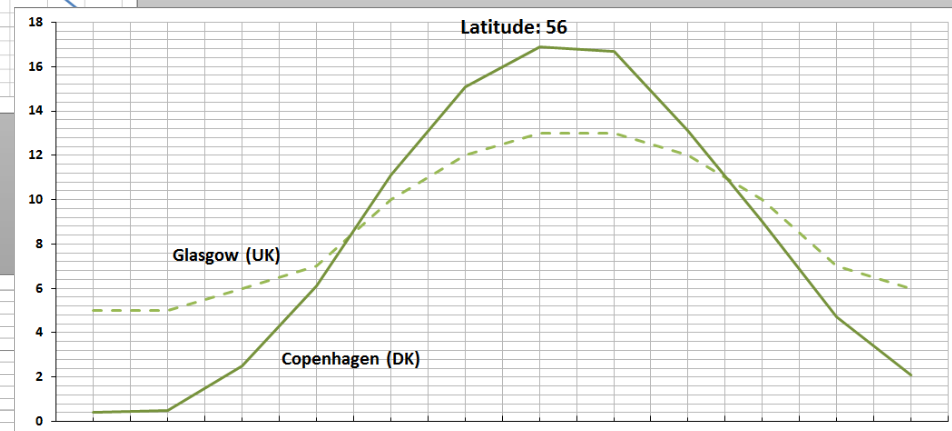


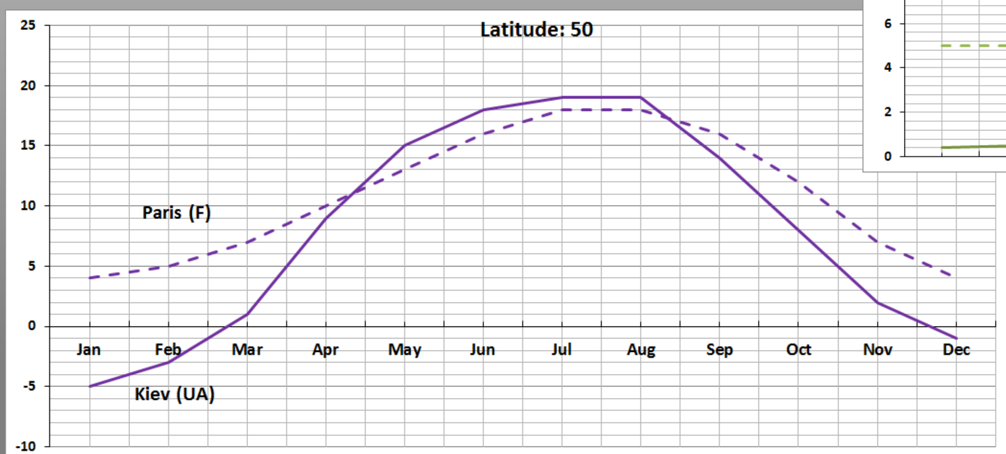
<u>Solid line</u>: *continental* (or semi-continental) climate, mediterranean for Valencia.

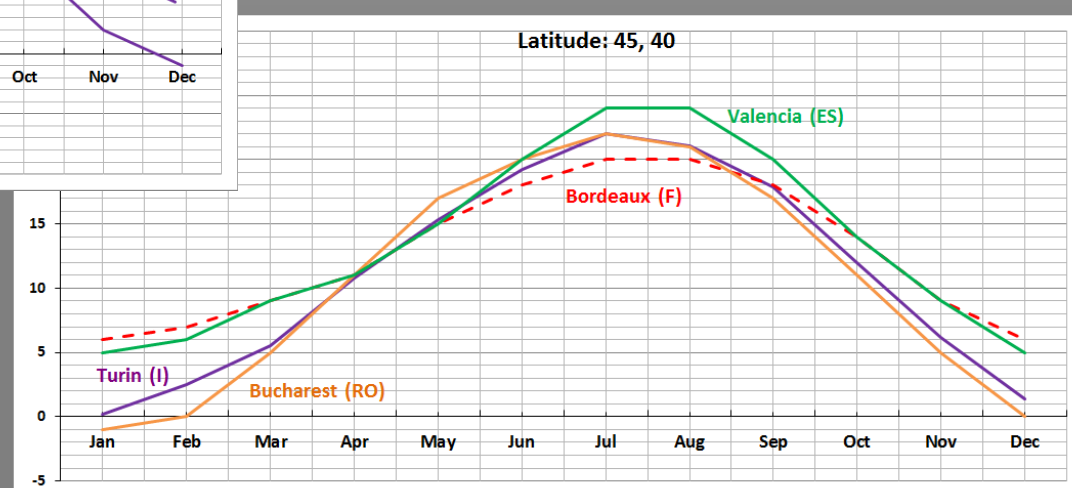
<u>Dashed line</u>: *oceanic* climate

Continental (solid line) vs Oceanic (dashed line)

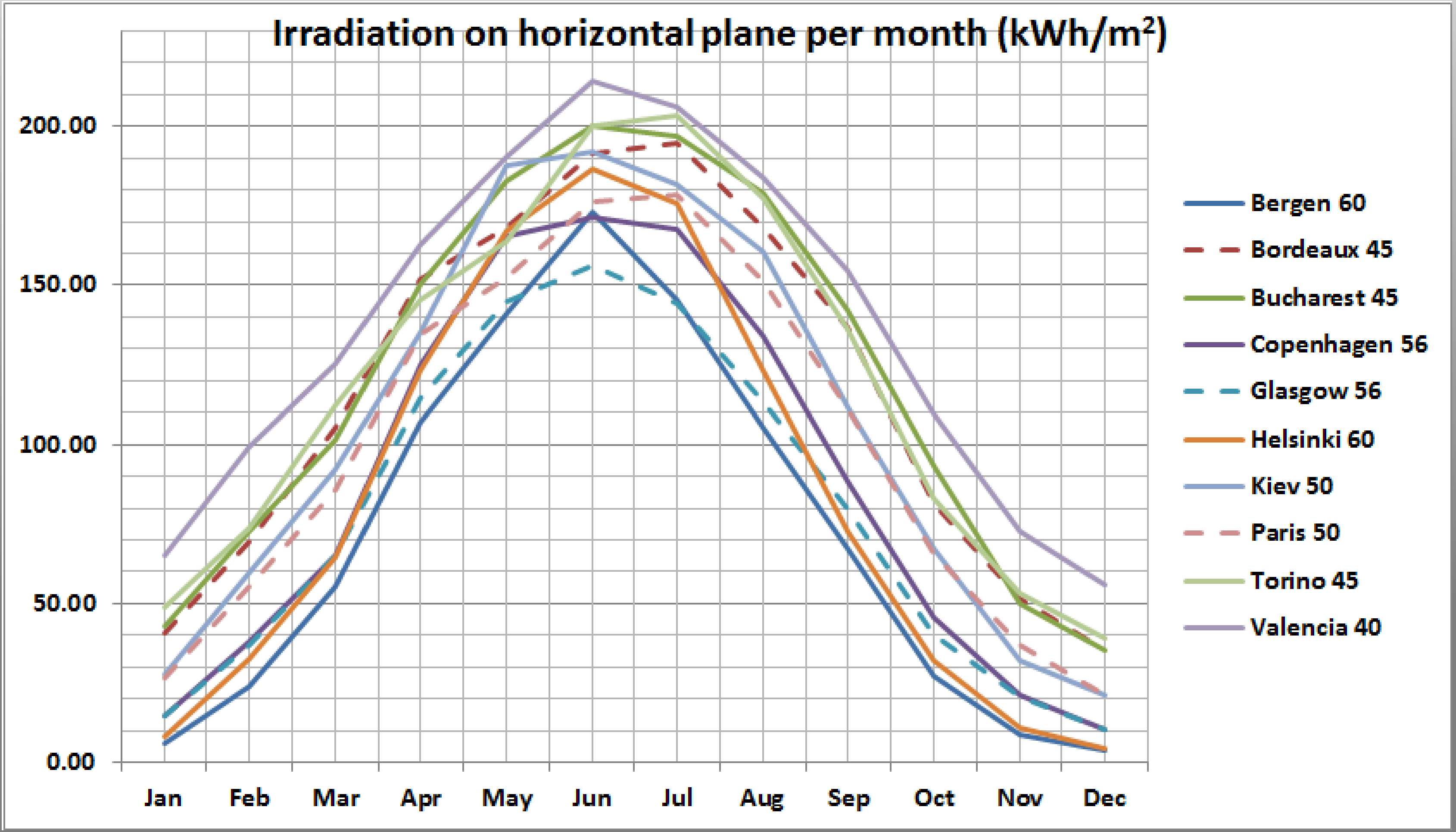


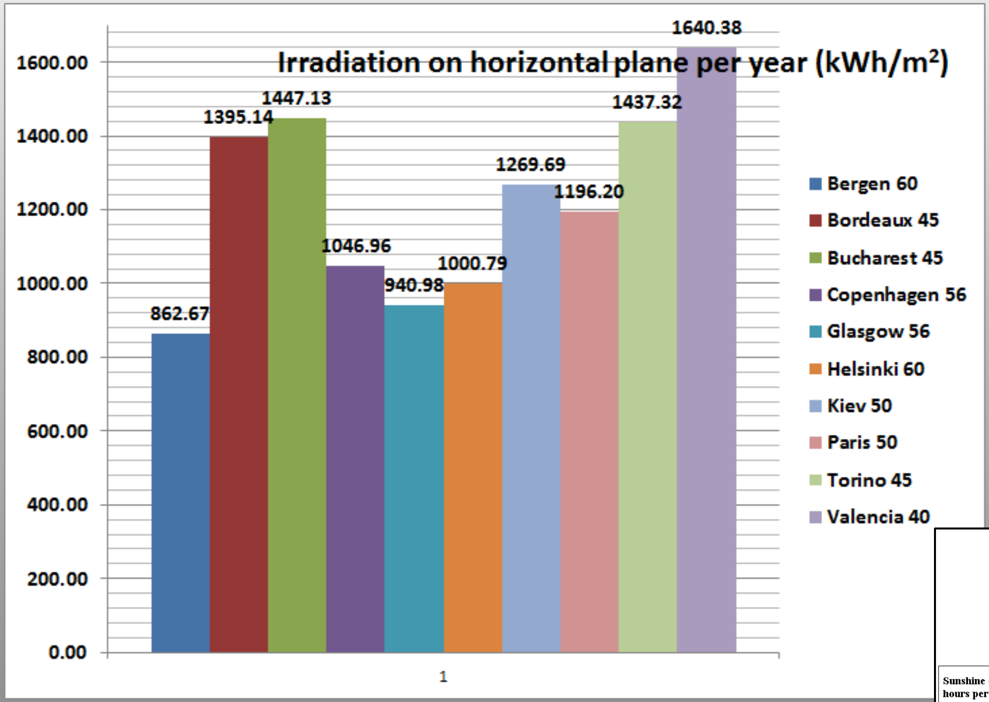




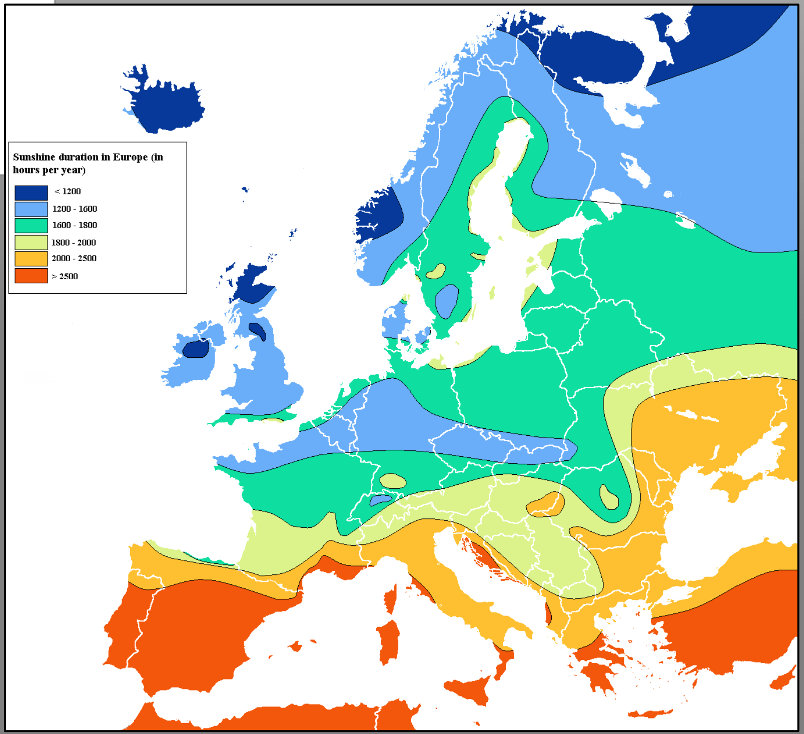


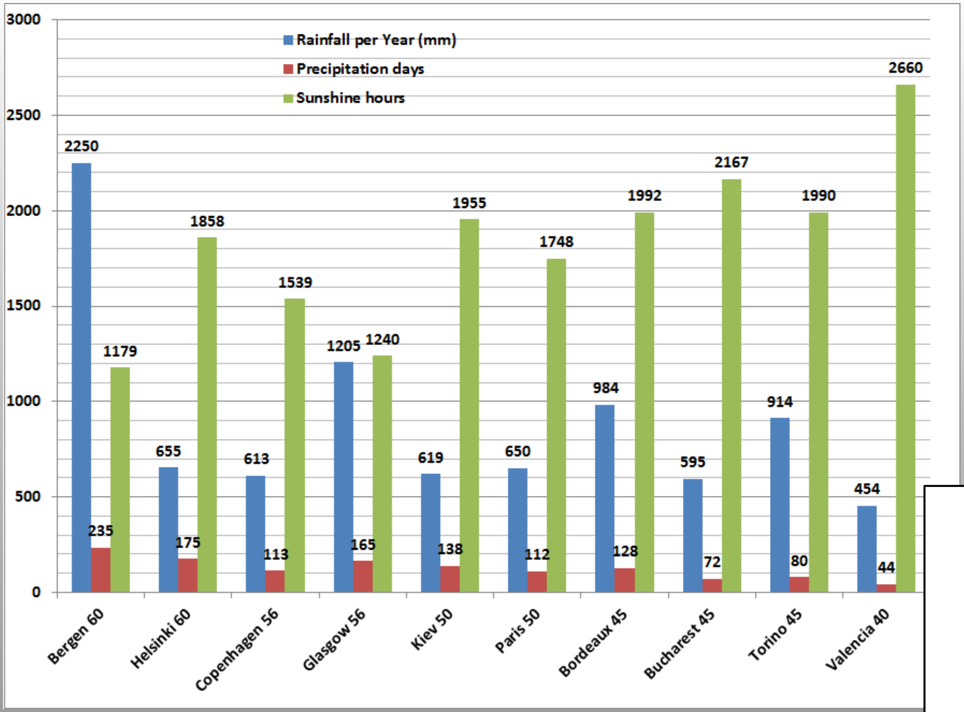
The <u>sunshine effect</u> is a direct consequence of the latitude during autumn and winter. In spring and summer, more sunshine hours in the North and cloudy sky alter this difference.



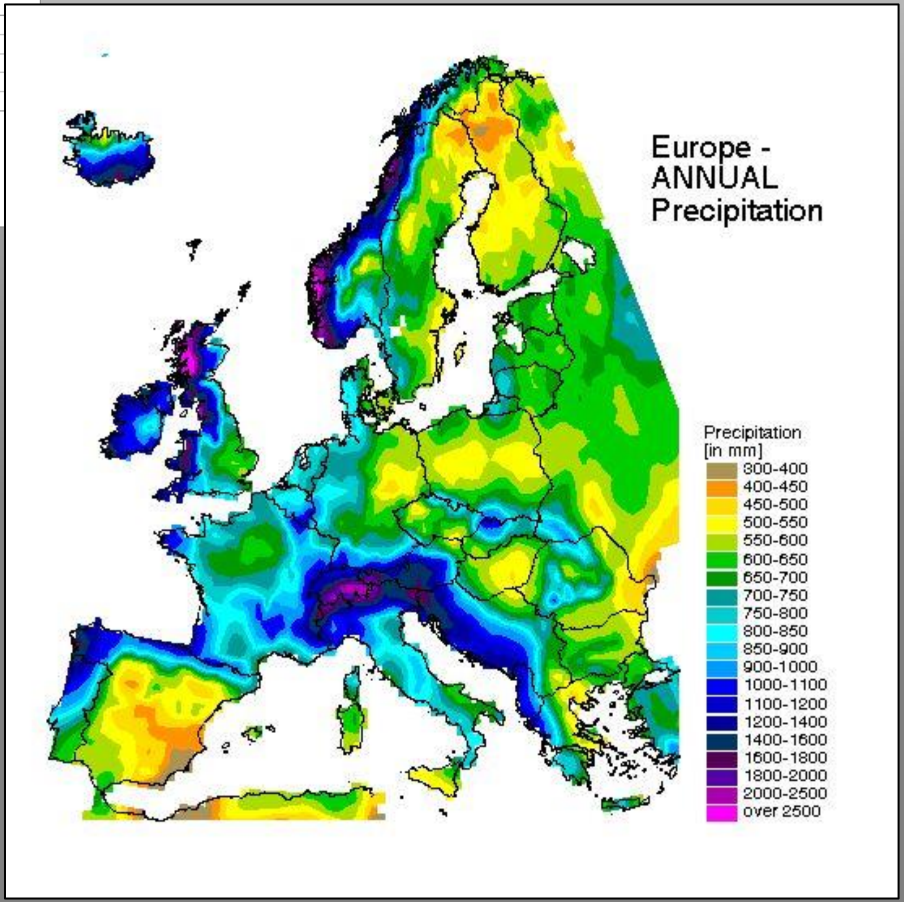


The irradiation data distinguish clearly between the oceanic and continental climates, at all latitudes.



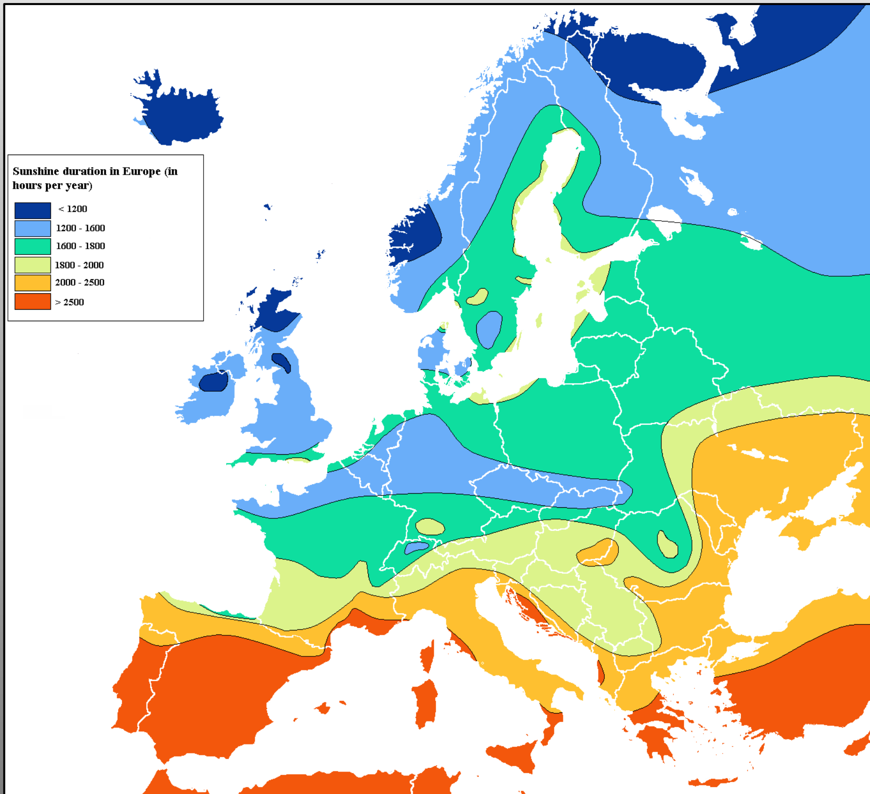


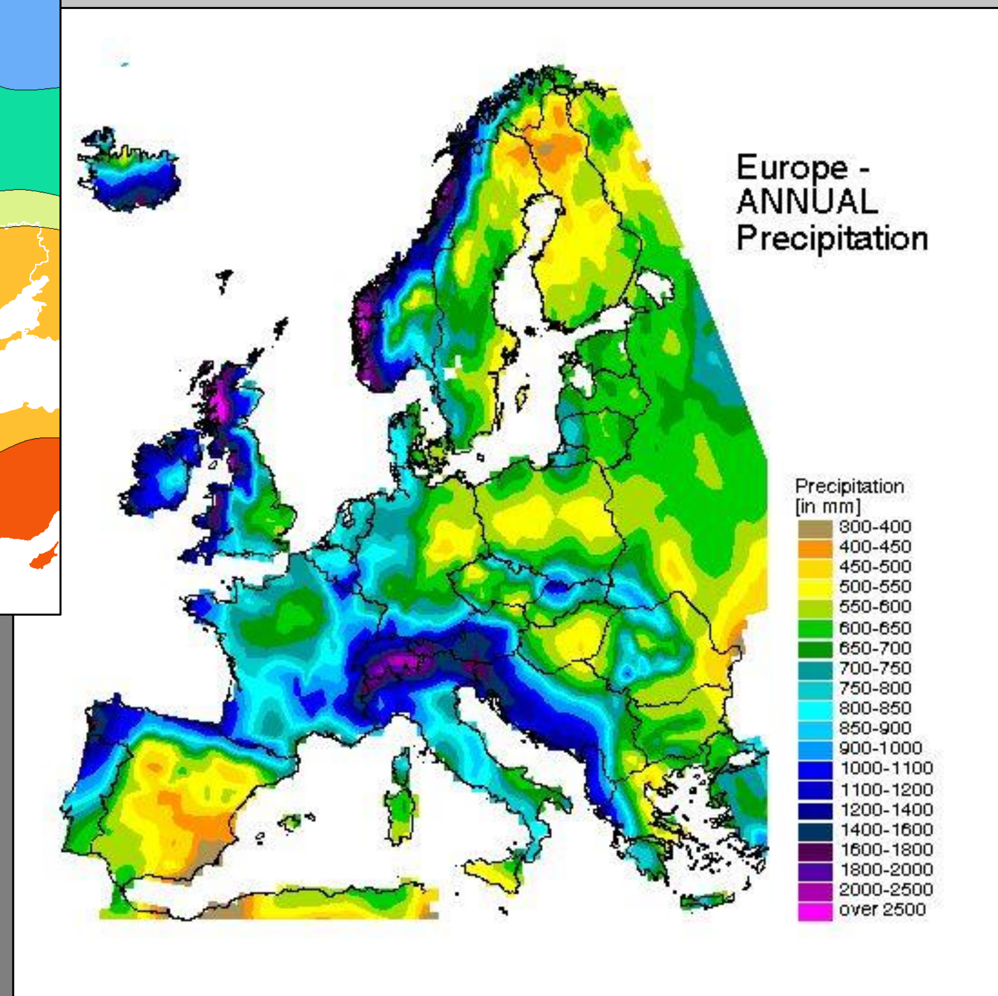
Rain data show a very variegated profile for Europe.



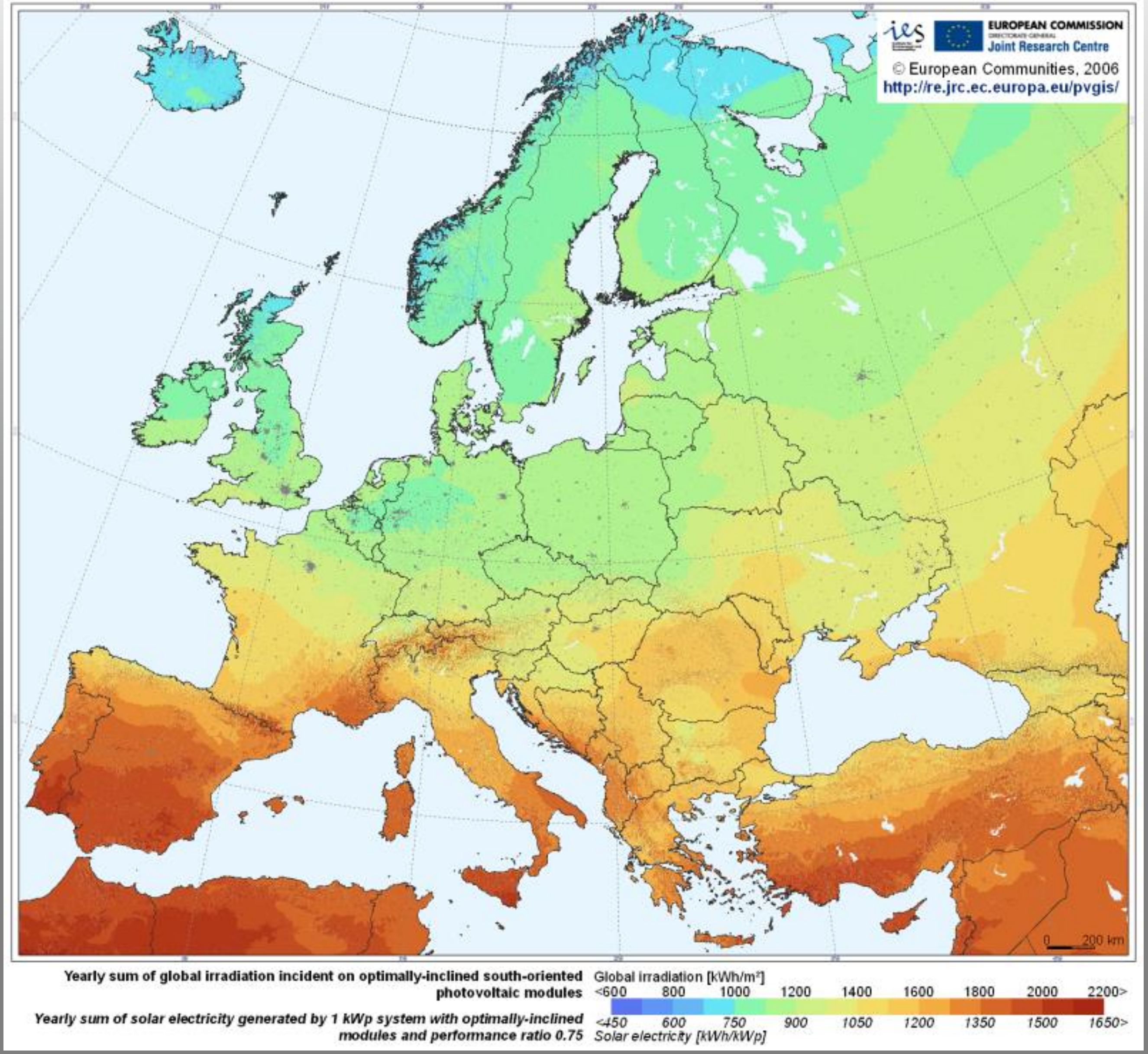
They separate quite clearly the East (more continental) from the West (more oceanic). The role of mountain chains is crucial.

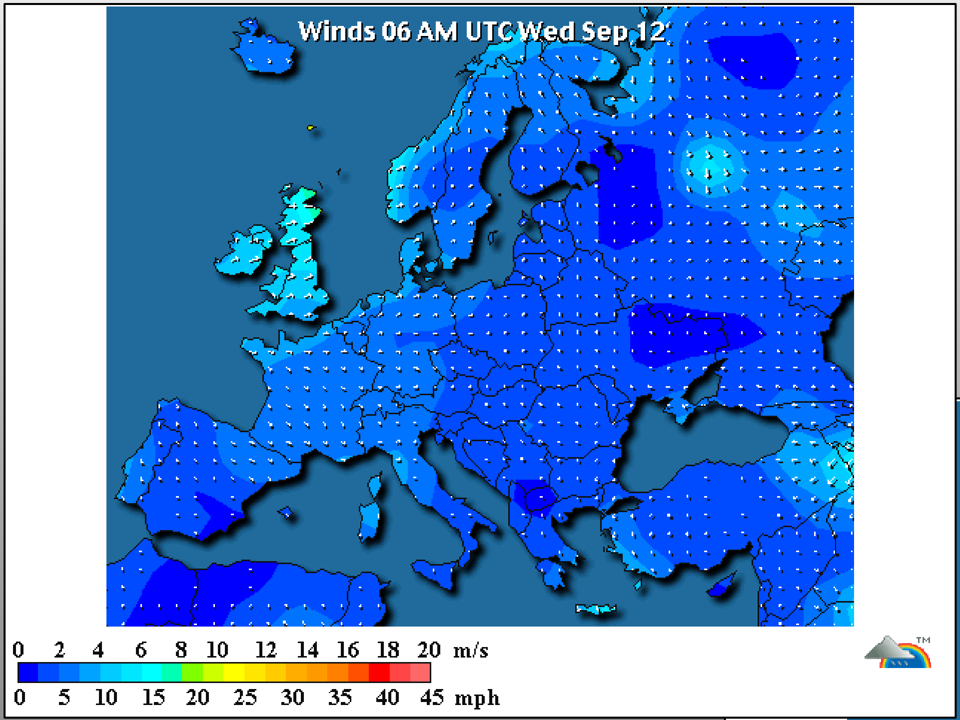
All in all, latitude, precipitations and sunshine effect are concurring parameters for the study of the European climate and design.



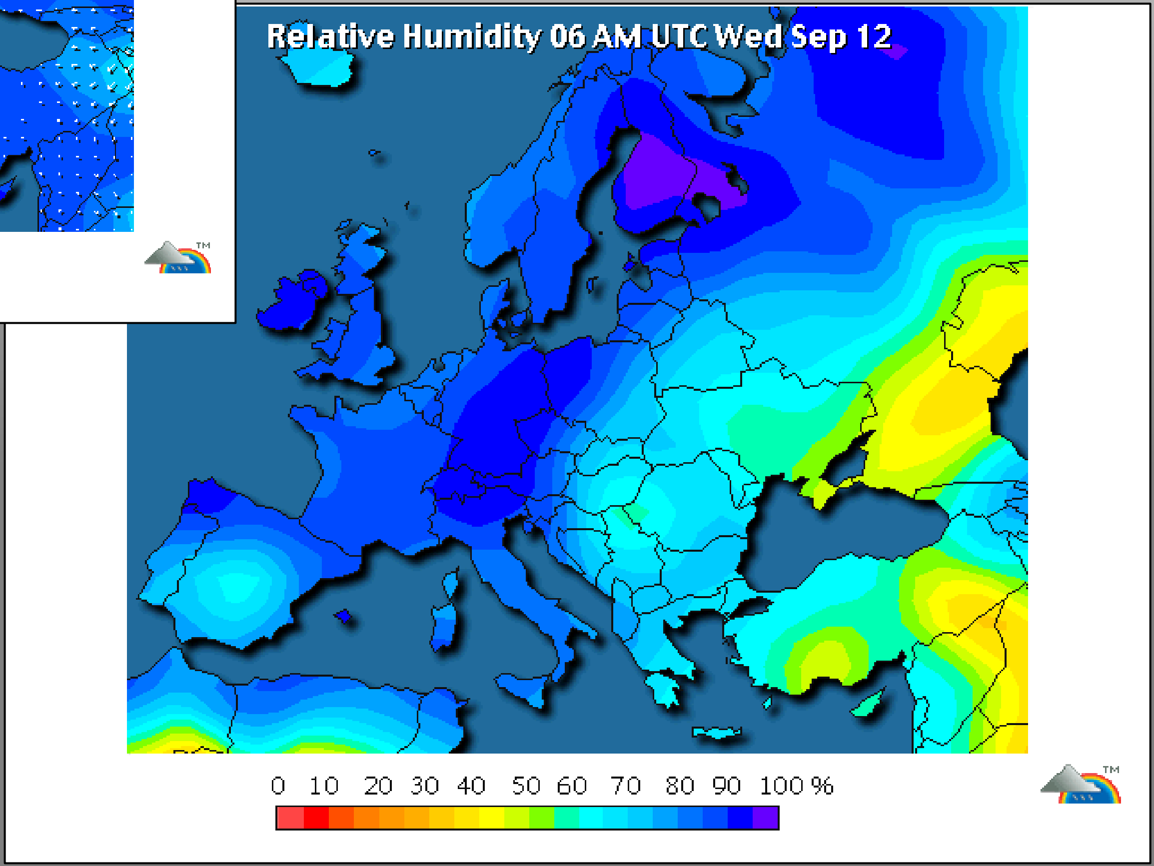


Photovoltaic Solar Electricity Potential in European Countries





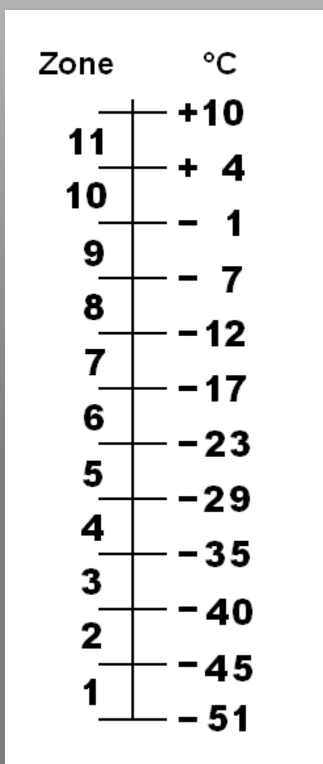
Regarding building design, the wind effect and relative humidity are especially important.

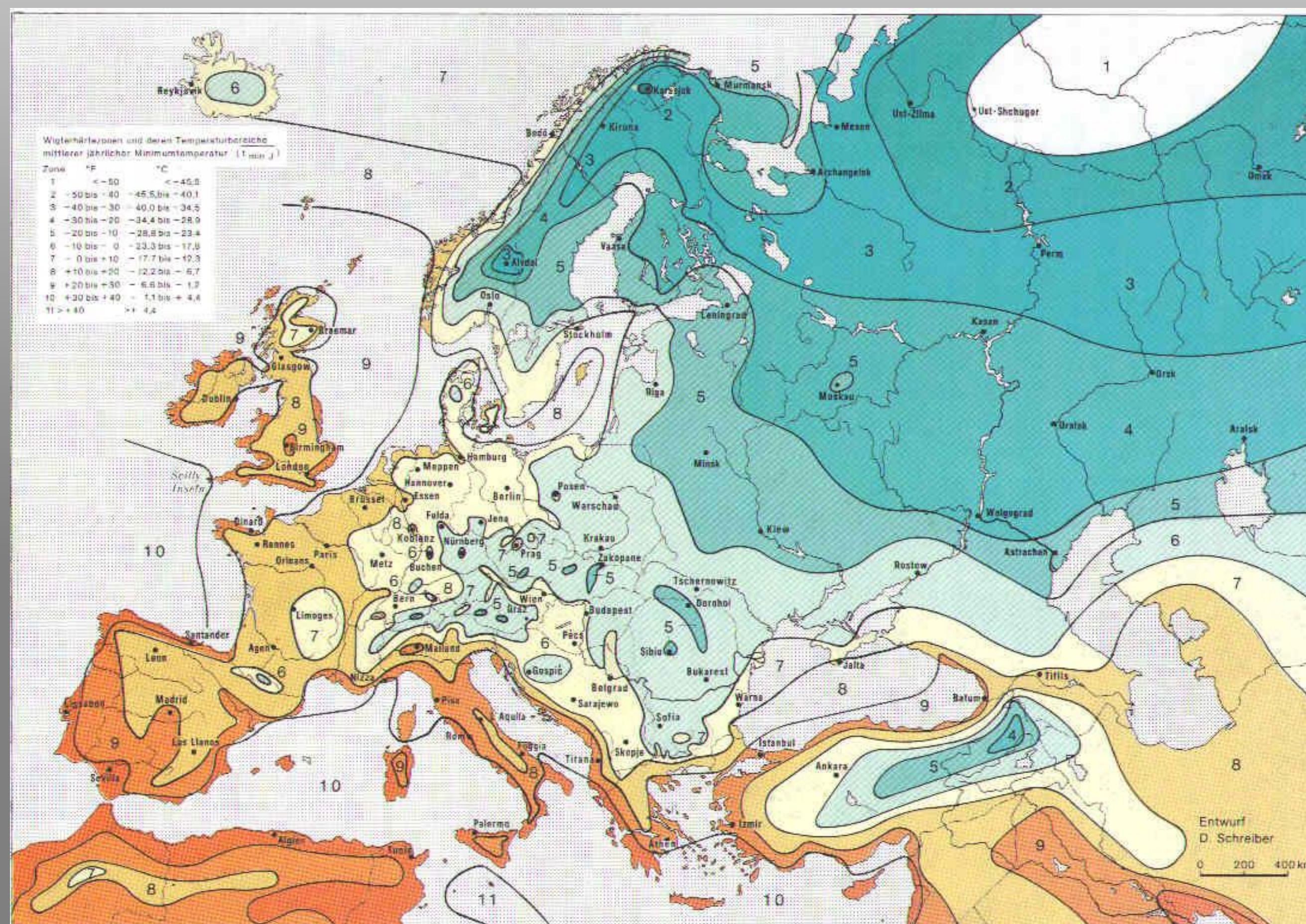


Let's now see how these climatic issues are dealt with, by introducing a number of suitable parameters.

Hardiness zones

A <u>hardiness zone</u> is a geographically defined area in which a specific category of plant life is capable of growing, as defined by climatic conditions, including its ability to <u>withstand the minimum temperatures</u> of the zone.



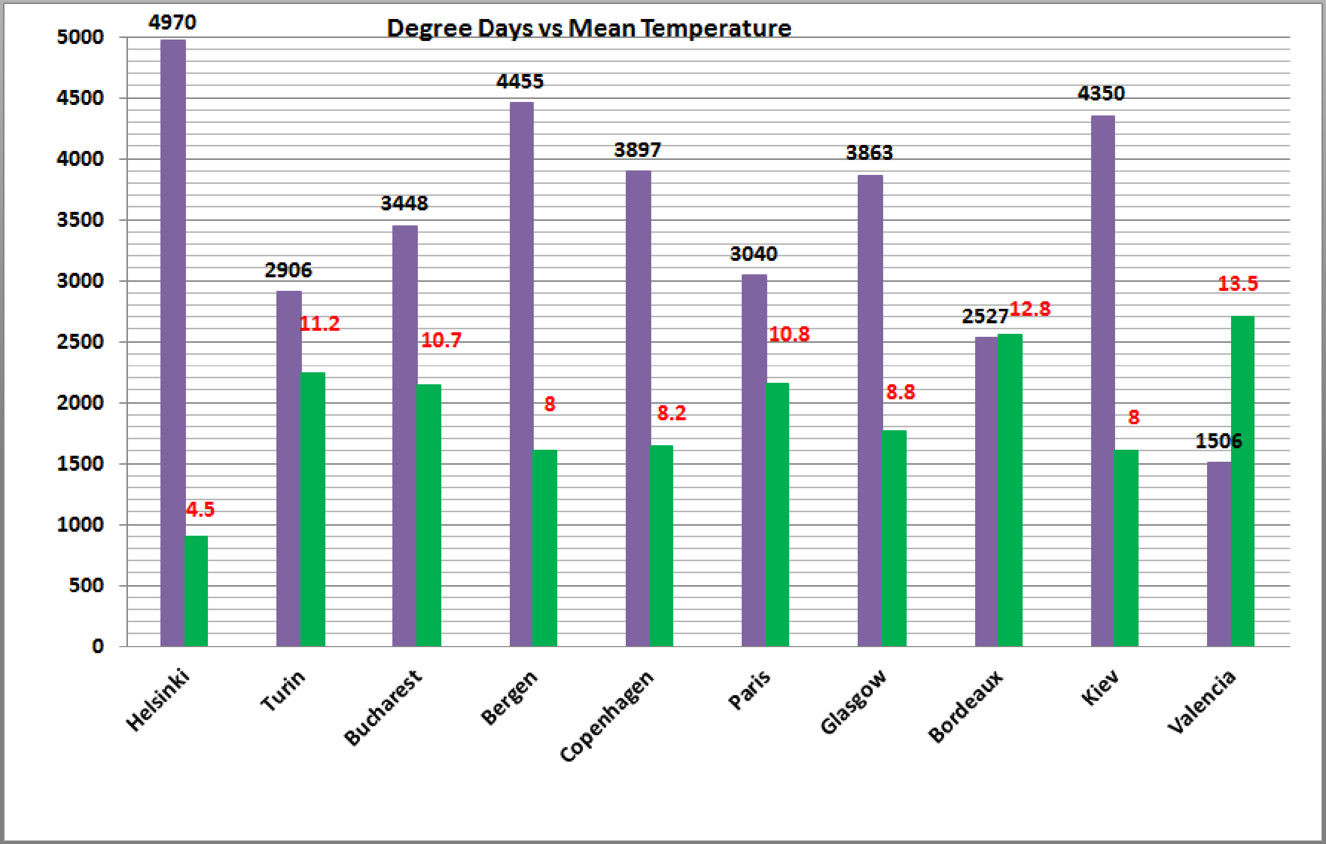


(Heating) degree days

Heating degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature T_e was below a certain level (the <u>base temperature</u> T_b):

$$HDD = \Sigma_e (T\_b - T\_e)$$

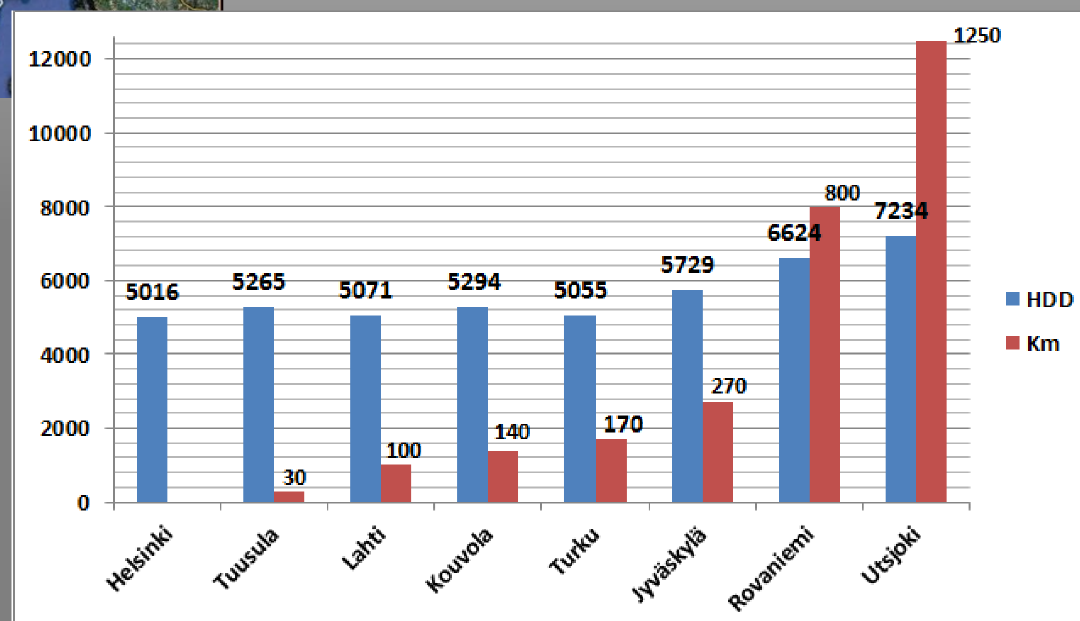
The below plot refers to 12 months, with T_b = 20C.



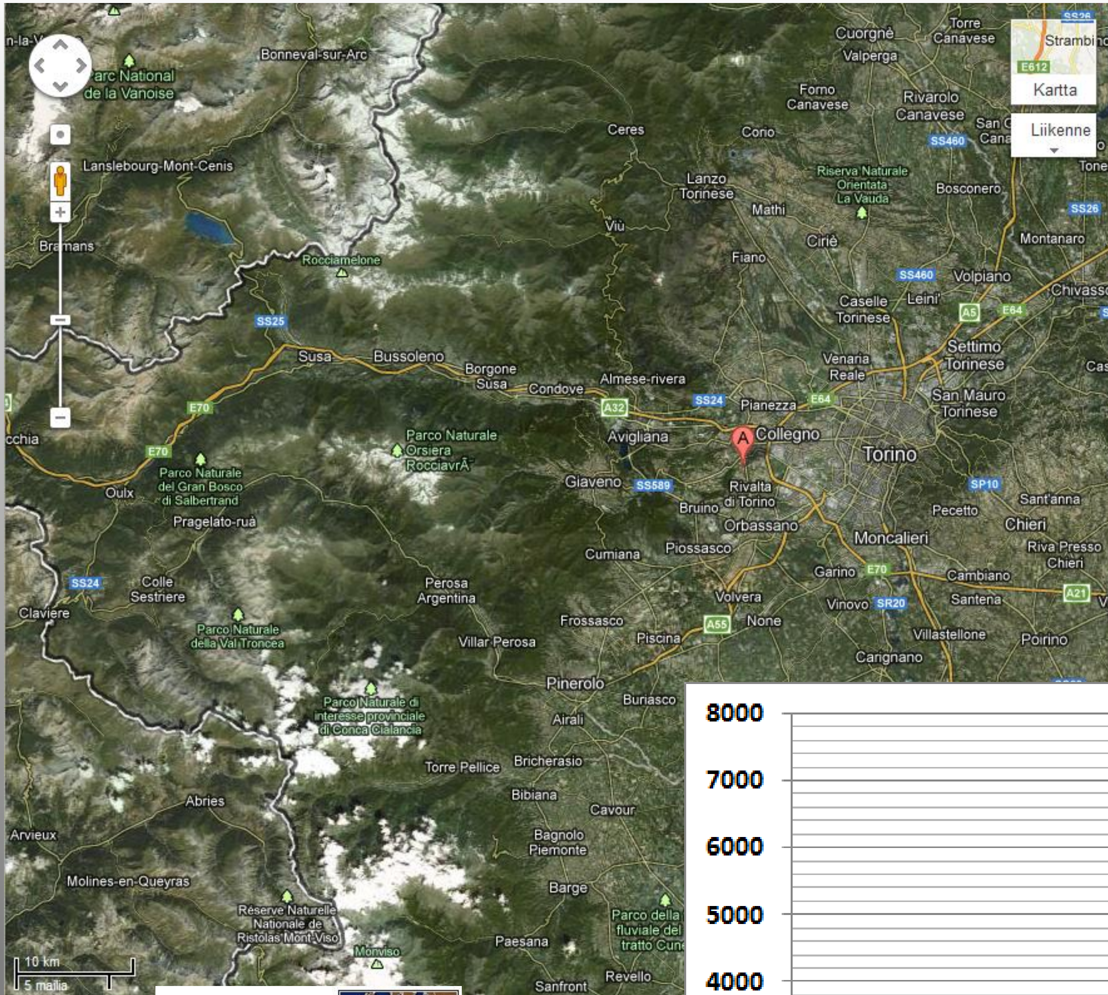
GLOBALLY VS LOCALLY

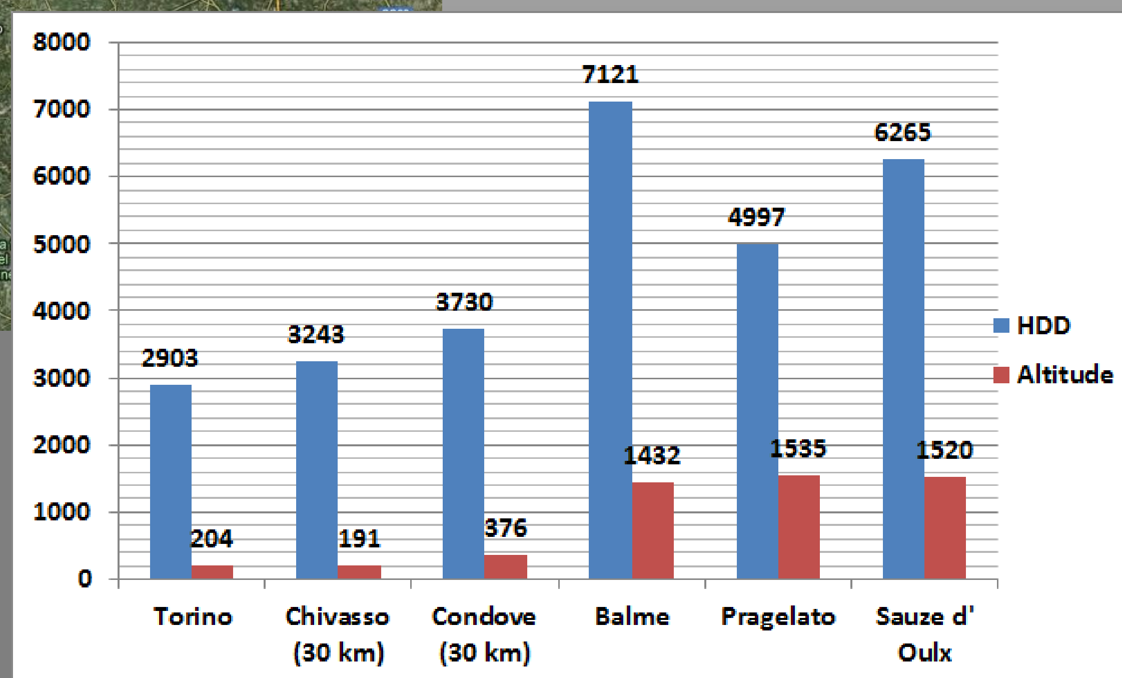
It is not always possible to generalize climate -> boundary conditions for a certain region. The morphology of the area is crucial: <u>a few km might or might not matter</u>.

The rather uniform landscape of Finland results in <u>small differences</u>, in comparison with the distance (notice anyway the case of Tuusula).
Tampere has 5300 HDD.



In areas with a complex <u>morphology</u>, several elements concur to the HDD picture.
Altitude, air mass flows, sunshine hours etc. lead to <u>important differences</u> even within a few Km.
Balme is located at only 45 Km from Turin.





Outside design temperature

The outside design temperature is the coldest outside temperature expected for a normal season on a statistical basis.

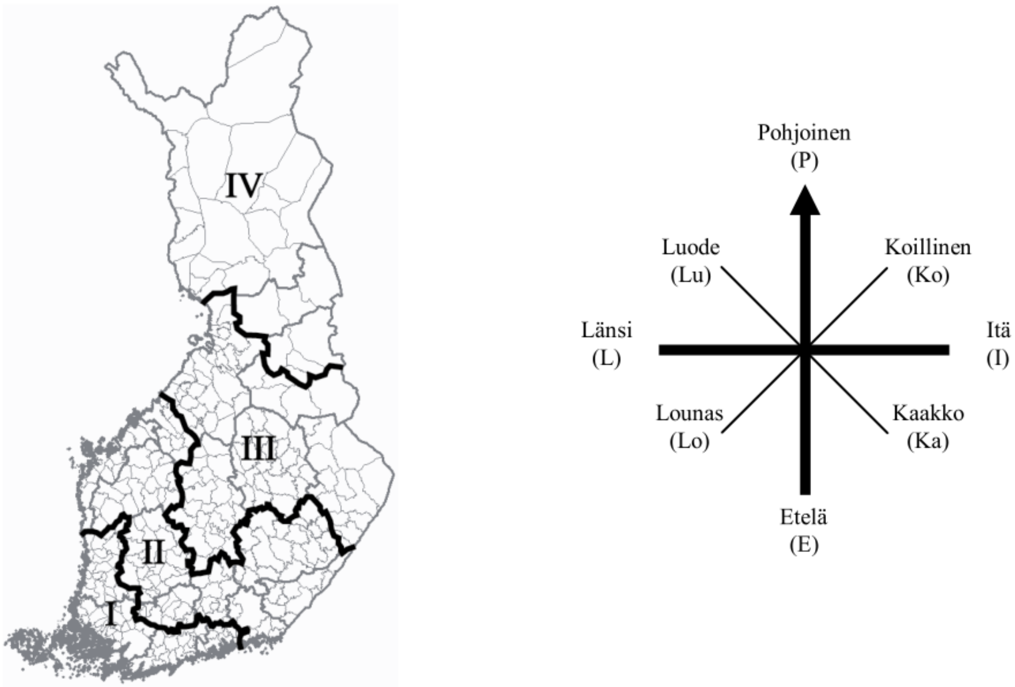
This is defined by the lowest running two-day mean temperature, measured ten times over twenty-years (probability of 0.14%).

There is no uniform definition: the USA tends to use 1% or 0.4% design temperatures.

Helsinki and Southwestern Finland give -26 C, Rovaniemi -38 C.

The ODT contributes to define the climatic zones country by country.

It provides a sound basis for sizing heating systems.



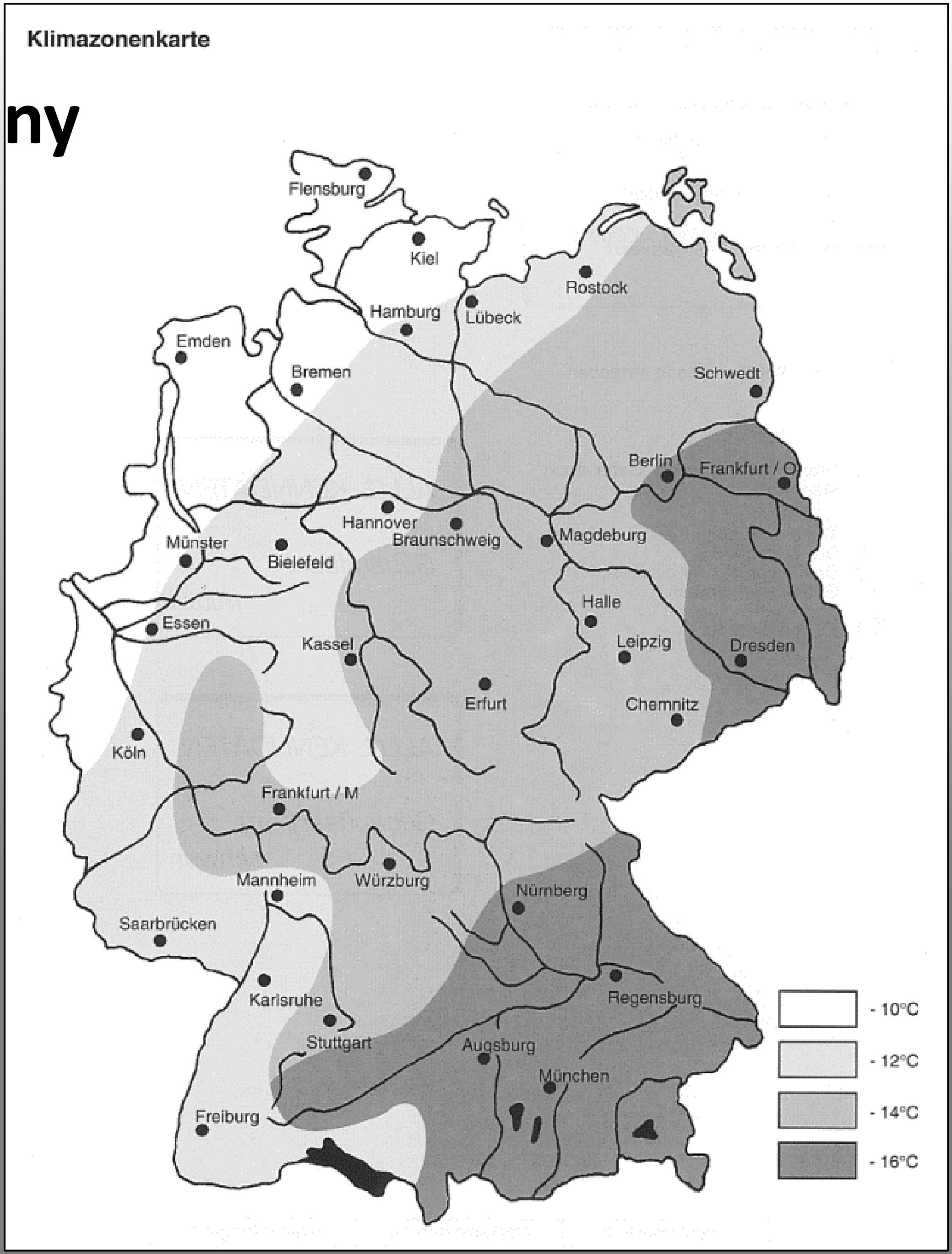
Kuva L2.1. Säävyöhykkeet.

Taulukko L2.1.	*Mitoittavat ja keskimääräiset ulkoilman lämpötilat eri säävyöhykkeillä.*	
Säävyöhyke	Mitoittava ulkoilman lämpötila, °C	Vuoden keskimääräinen ulkoilman lämpötila, °C
I	-26	5,3
II	-29	4,6
III	-32	3,2
IV	-38	-0,4

Climate zones - Germany

Four climate zones, based on the outside design temperatures, like in Finland.
These are again defined by the lowest running two-day mean temperature, measured ten times over twenty-years (probability of 0.14%).

Notice the distinction between East and West.

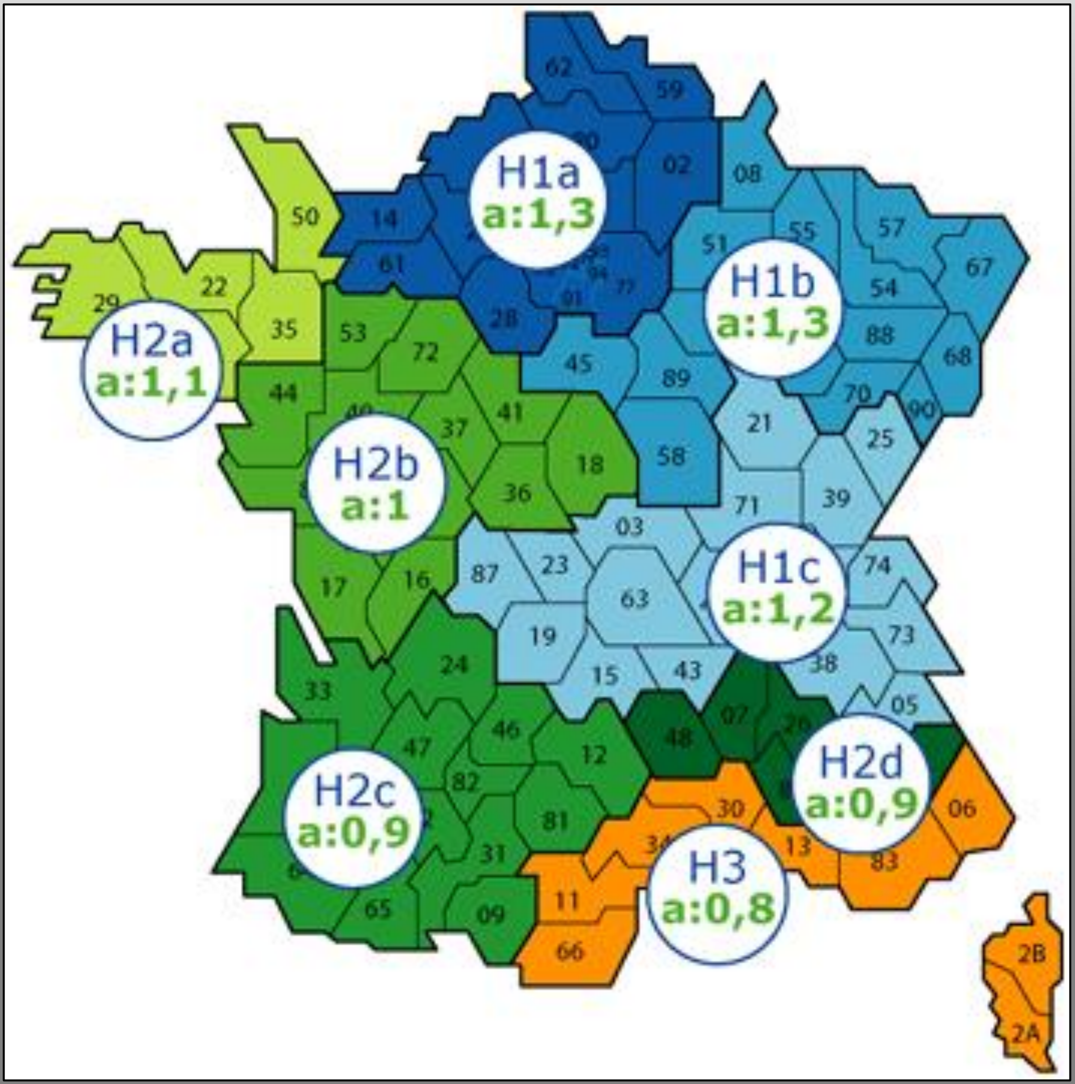


Climate zones - France

Eight climate zones (resulting from extended area and complex morphology).
These are H1, H2, H3 (heating) and a, b, c, d (cooling).

Also the *coefficient of rigid climate* is introduced, from 0.8 to 1.3. It is augmented by 0.1 if the altitude is between 400 and 800 m, by 0.2 if the altitude is higher than 800 m.

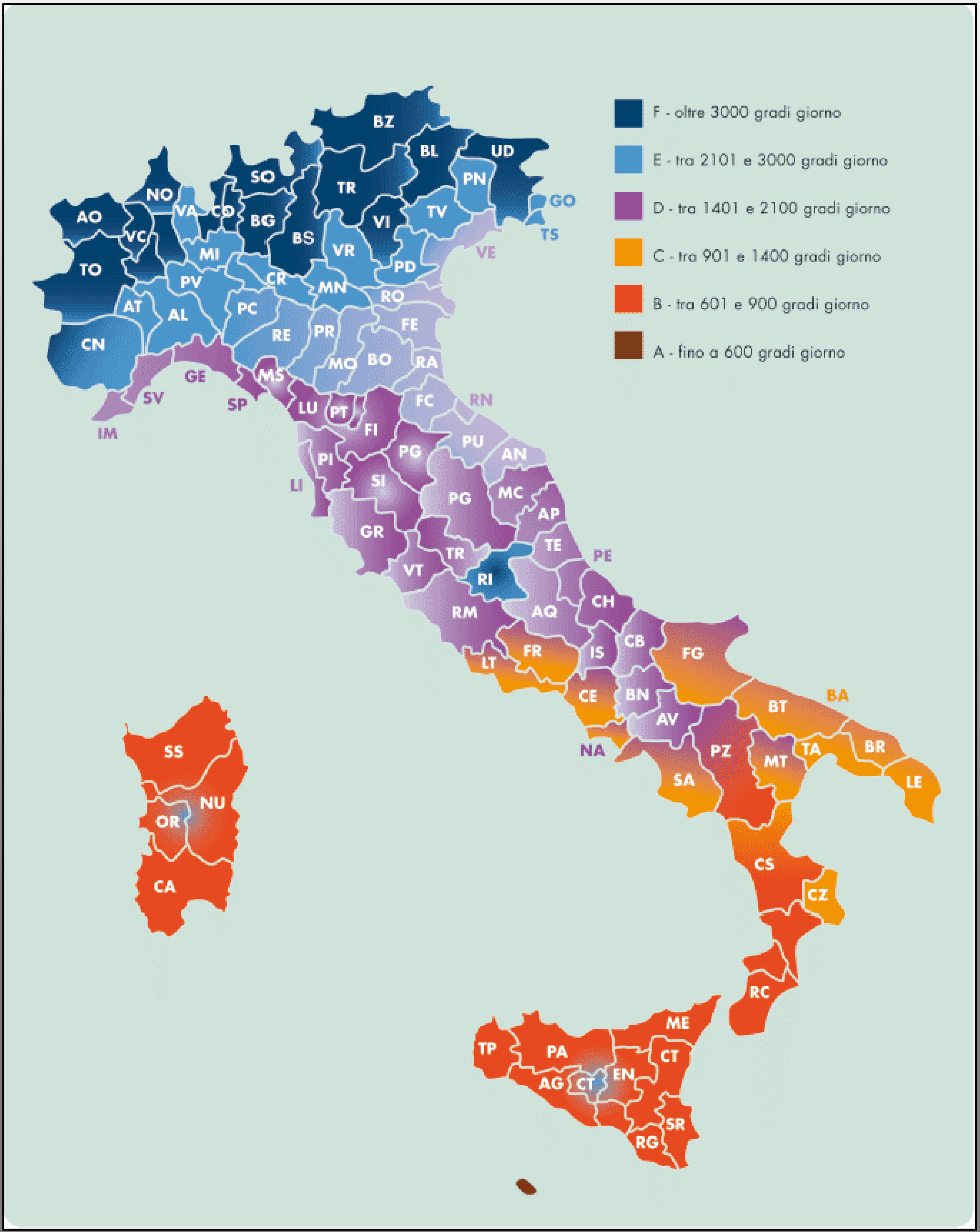
These parameters are used to compute the basic energetic consumption.



Climate zones - Italy

In Italy there are 6 climatic zones, reflecting the complex morphology and the latitude span.

These are defined by the heating degree days (HDD) with base temperature 20C.
The lowest zone A is for HDD<600, the highest is F, where HDD>3000.



Precipitation and wind-driven rain

In humid climates, rain is the largest moisture load buildings have to cope with.

Studying how rain determines moisture->mould in a building structure is non-trivial:
Wind Driven Rain = horizontal component of the rain vector.
Precipitation = vertical component.
For wind velocities beyond 5 m/s, WDR surpasses Precipitation.

The Wind Driven Rain intensity on a facade depends on:

- Horizontal rain fall intensity
- Raindrop size distribution
- Building volumes vs wind direction
- Building geometry
- Building orientation
- Position and local details

Buildings in open neighbourhoods may catch 40 times more WDR than buildings in a closed neighbourhood

Example

Wind Driven Rain measured between 05/1972 and 11/1972 in Munich, Germany:

West, middle 3rd floor - 29 kg/m2
West, middle 9th floor - 55 kg/m2
West, middle 16th floor - 65 kg/m2
Roof edge nord – 115 kg/m2
Roof edge south – 130 kg/m2

Precipitation and wind-driven rain

The formula used to describe wind driven rain intensity on a building enclosure is:

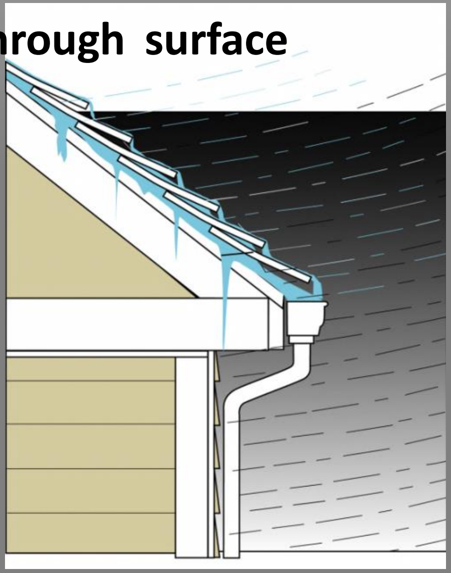
$$g_{r,\mathrm{V}} = (0.2\, C_r\, v_{\mathrm{W}} \cos\vartheta\,)\, g_{r,h} \qquad [\mathrm{kg}/(\mathrm{m}^2\mathrm{s})]$$

where 0.25< C_r <2 is the WDR factor (a function of type of precipitation, surrounding environment...); v_{W} the wind speed [m/s]; $g_{r,h}$ is the average precipitation intensity [kg/(m^2s)]. ϑ is the wind angle with the normal on the surface.
The product ($0.2\, C_r\, v_{\mathrm{W}} \cos\vartheta$) is called the catch ratio (as a fraction of measurement in open field). The catch ratio is measured as being highest at corners.

Rain is problematic as it penetrates into the envelope's layers.
The indoor finish gets wet -> water vapour released inside through surface drying -> heat absorption -> evaporative cooling:

$$\theta_i = \theta_e + \frac{\phi_H - l_b\, g_{\mathrm{vd}}\, A}{U\,A + 0.34\, n\, V}$$

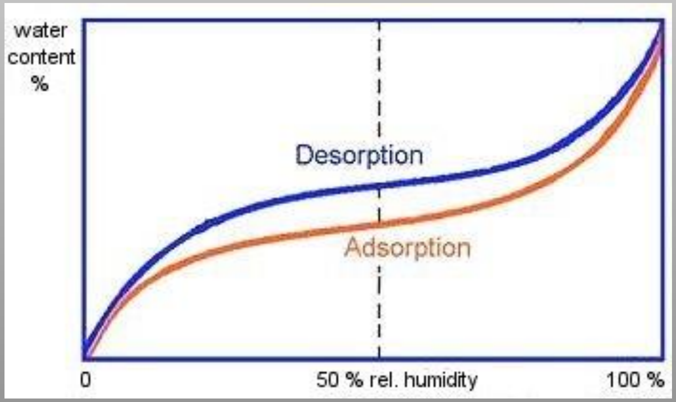
Here l_b=latent evaporation heat, g_{vd}=drying flow rate, ϕ_H=mean heating power needed in a room of volume V with n exposed walls.
If the drying increases the water vapour pressure inside -> mould and surface condensation.



Hygroscopic moisture

Namely, the moisture content in a material in equilibrium with RH in the surroundings. The sorption curve of a material is S-shaped. Hysteresis between adsorption and desorption: the desorption curve gives higher moisture content for a same relative humidity.

Too high or too low RH => problems: timber, textiles, paper shrink when RH < 30% .
Too high RH <=> mould attack and dust mite overpopulation.



What is the acceptable lower limit of the monthly mean temperature factor inside the envelope, to avoid mould? The modelling is made in two steps:

1) Compute the monthly mean saturation pressure using indoors vapour pressure p_i . Then transpose it into a dew point temperature θ_d:

$$p_{sat,si} = \frac{p_i}{0.8} \qquad p_{sat,si} \rightarrow \theta_d(p_{sat,si})$$

2) The acceptable lower limit for the monthly mean temperature factor inside is

$$f_{h_i} \geq \frac{\theta_d(p_{sat,si}) - \theta_e}{\theta_i - \theta_e}$$

Avoiding mould

Main factors determining mould growth:

- **Outside temperature and Relative Humidity (RH)**
- **Thermal insulation of the building overall and of each envelope part**
- **Presence of thermal bridges**
- **Amount of water vapour released indoors $G_{v,P}$**
- **Heating**
- **Ventilation**

No visible mould on internal surfaces ⬄ monthly mean RH at surface < 80%.

This is given by

$$\phi_s = 100 \frac{p_i}{p_{sat,s}} = \frac{100}{p_{sat,s}} \left(p_e + \frac{462\, T_i\, G_{v,P}}{\dot{V}_a} \right)$$

therefore it is inversely proportional to the monthly av. ventilation rate $\dot{V}_a$.

The higher the temperature, the less the ventilation which is demanded.
Moreover: external temperature is higher -> more water vapour is released.
⇒ In cool climates avoiding mould is not a matter of ventilation only.
In warm and humid climates drying the ventilation air is the only way to avoid mould.

Performance arrays for building physics

Performance metrics were proposed by energy committees at level 1, the building, and at level 2, the building components.

For building physics:

Level 1, the building:
Heat, air, moisture – Thermal comfort in winter and summer, moisture tolerance (mould, dust-mites, surface condensation), indoor air quality, energy efficiency.
Sound – Acoustical comfort, room acoustics, overall sound insulation.

Level 2, the building components:
Heat, air, moisture – Air tightness, venting.
Thermal insulation: thermal transmittance U of doors and windows, mean U of the envelope, thermal bridging.
Transient response: dynamic thermal resistance, solar transmittance...
Moisture tolerance: Building moisture and dry-ability, rain-tightness, rising damp, hygroscopic loading, surface & interstitial condensation.
Acoustics – Sound attenuation factor and sound insulation, sound absorption...

Ventilation requirements

Standardization bodies impose ventilation requirements for everyday use. For instance, for non-residential buildings, the European standard EN 13779 defines 4 classes according to the ventilation flow per person in l/s (dm3/s). For non-smoking buildings these are:

IDA 1 : 15 l/s
IDA 2 : 10-15 l/s
IDA 3 : 6-10 l/s
IDA 4 : < 6 l/s

For residential buildings instead, the Finnish standard 2012 is in figure.

The Belgian standard has similar values, which are however given per square meter.

Tila / käyttötarkoitus	Ulkoilma-virta (dm³/s)/hlö	Ulkoilma-virta (dm³/s)/m²	Poistoilma-virta dm³/s	Äänitaso $L_{A,eq,T}$ / $L_{A,max}$ dB	Ilman nopeus talvi m/s	Huom!
Asuintilat:	6					
Asuinhuoneet		0,5		**28 / 33 ***	0,20	*C1 määräys
Keittiö		#S	8 #A	**33 / 38 ***	0,20	*C1 määräys
- käyttöajan tehostus		#S	25	33 / 38	0,20	
Vaatehuone, varasto		#S	3	33 / 38		
Kylpyhuone		#S	10 #B	38 / 43	0,20	
- käyttöajan tehostus		#S	15	38 / 43	0,20	
WC		#S	7 #B	33 / 38		
- käyttöajan tehostus		#S	10	33 / 38		
Kodinhoitohuone		#S	8	33 / 38	0,30	
- käyttöajan tehostus		#S	15	33 / 38	0,30	
Huoneistosauna		2 #C	2/m² #C	33 / 38		
Yhteistilat:						
Porrashuone		0,5 1/h	0,5 1/h	38 / 43		
Varastot		0,35	0,35 /m²	43 / 48		
Kylmäkellari (myös asunto-kylmiö, jos pinta-ala > 4m²)		0,2	0,2 / m²	43 / 48		
Pukuhuone		2	2 / m²	33 / 38	0,20	
Pesuhuone		3	3 / m²	43 / 48	0,20	
Saunan löylyhuone		2	2 / m²	33 / 38		
Talopesula		1	1 / m²	43 / 48		
Kuivaushuone		2 #D	2 / m² #D	43 / 48		
Askarteluhuone, kerhohuone		1 #E	1 / m² #E	33 / 38	0,20	

Net energy demand in buildings: heating

The parameters influencing the annual Net Energy Demand (NED) for heating are:

- **Outside climate**

NED increases with lower temperature, higher wind speed, more precipitation.
NED decreases with more *insolation*.

- **Building use**

NED increases with inside temperature, higher ventilation.
NED decreases with higher internal gains.

- **Building design**

NED increases with larger protected volume, depends on the orientation and solar and thermal transmittance U of the loss surfaces (typically, windows).

We can however modify the climate quite sensibly:
Cities are warmer, less sunny and less windy than rural regions.
Open landscapes transform into less windy region by planting trees.
Broadleaf trees let the sun through in winter and protect from the sun in summer etc.
In moderate climates, the impact of the inside temperature is large on the NED: 1C of difference results in 10-15% heating demand!

Energy ranking of residential buildings

Regarding energy efficiency, <u>seven distinct ranks</u> are considered:

G) <u>Insulated building</u>: the only requirement is the average thermal transmittance U at the envelope and maximum U of the envelope parts.

F) <u>Energy efficient building</u>: the objective is good thermal insulation, correct ventilation and optimal use of solar and internal gains. A net energy demand calculation is required, max consumption allowed: 60 MJ/(m3.a) .

E) <u>Low energy building</u>: Normalised energy consumption for heating, cooling, air conditioning, domestic hot water, lighting. Calculations based on EPDB-legislation in EU.

D) <u>Passive building</u>: Comparable to low energy buildings, but with higher restrictions. e.g. the maximum consumption allowed is lowered to 18 MJ/(m3.a). Stricter bounds on U and ventilation are also imposed.

C) <u>Zero energy building</u>: produces as much energy as it is consumed for heating, cooling, domestic hot water, by lowering the energy consumption as much as possible and producing the same amount by photovoltaics.

B) <u>Energy plus building</u>: produces more primary energy than used for heating, cooling, domestic hot water and household.

A) <u>Energy autarkic building</u>: does not depend on fossil fuels and electricity, producing its own energy from biomass, PV-panels, wind turbines, heat storage etc.

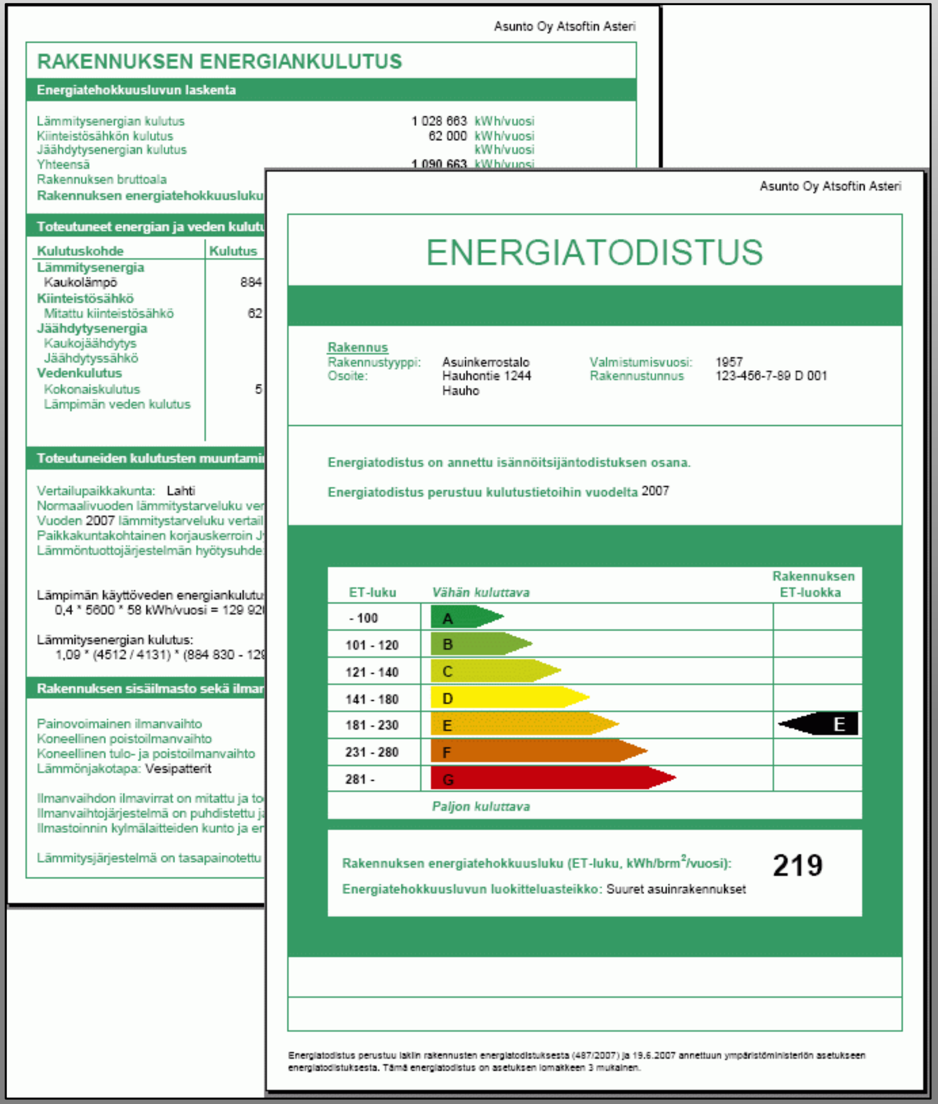
Energy performance certificate

An **assessor** visits the property, examines key items and inputs the observations into a software program.

-> **calculation** of energy efficiency.

-> **single number** for the rating of energy efficiency.

The RAK building in Otaniemi is ranked E-class, according to the 2010 rating for educational buildings. (ET-luku 280).



Summary of these notes

- Building structures must be designed according to the surrounding climate.

- It is very difficult to model the climate on a large scale, due to local differences which prevent generalizations. Each case must be studied carefully.

- Latitude, precipitations, wind speed and sunshine effect are crucial factors for design considerations.
Parameters like Heating Degree Days (HDD), outside design temperature and climatic zones help in simplifying this task.

- Each country (together with the European Union) sets construction and operational standards, in order to lower the energetic consumption of buildings and to enhance their durability.

- Building physics provides with numerous tools for addressing crucial problems such as energy waste, mould, frost damage and related issues.

- The course RAK-43.3410 will address the problem solving task and provide with a comprehensive description of the theory and applications of a large number of these tools.

DATA SOURCES

Weather data:

http://www.weather-and-climate.com/

http://www.ncdc.noaa.gov/cdo-web/search#t=firstTabLink

(excellent for hourly and daily values)

http://www.theweathernetwork.com/statistics/C00438/fixx0002

Dewpoint calculator:
http://www.decatur.de/javascript/dew/index.html

Even http://en.wikipedia.org/wiki/Helsinki**! (climate section)**

Calculation of degree days:

http://www.degreedays.net/

Design values and methodology:

Hugo Hens, ”Applied building physics – Boundary conditions, building performance and material properties”. Ernst&Sohn