# MOOC Zero-Energy Design

## Course Reader Module 2

TU Delft

This reader provides additional information for the Massive Open Online Course (MOOC) Zero Energy Design.

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## Content

# 1
# Climate zones

# 1. Climate zones

If we look at the world climate, the Köppen climate classification is most widely used climate classification systems. The Köppen climate classification scheme divides climates into five main climate groups: tropical, dry, temperate, continental and polar. (fig. 1.1)

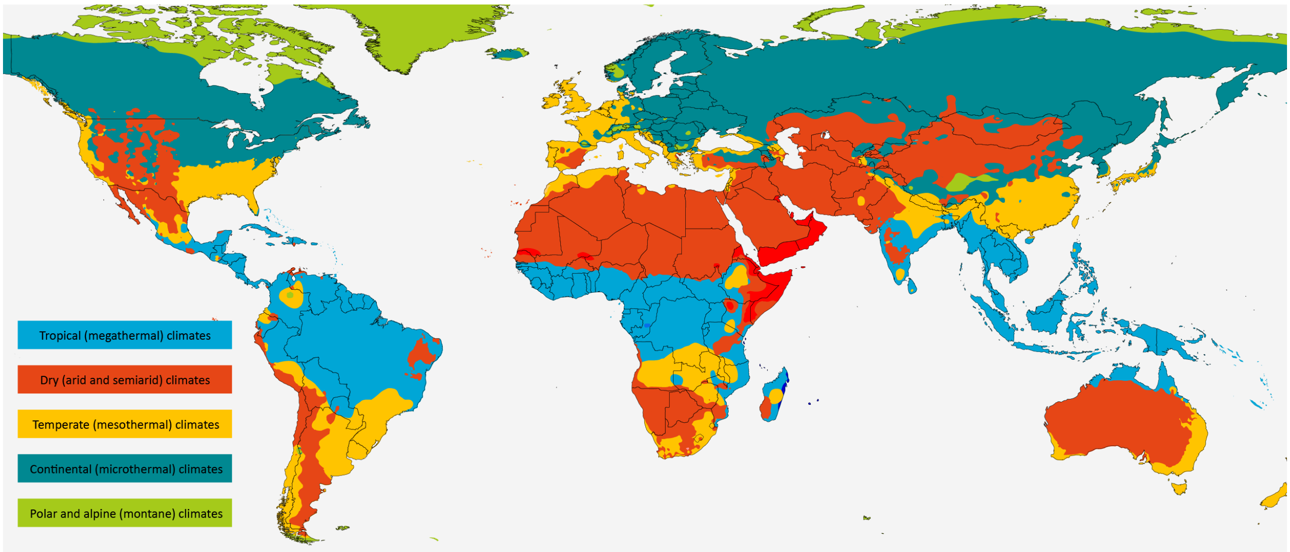


Fig 1.1: Koppen climate classification (main five climate regions)

This climate classification is useful as a starting point for climatic design of a building, where different environmental aspects come into play:

**Temperature** The annual mean temperature, but also the diurnal differences in temperature of the given climate zone define the requirements for the design. For example a large diurnal temperature difference allows for effective use of thermal mass in buildings.

**Humidity** Both the absolute and the relative humidity are important to understand what you can do with heating and cooling. For example evaporative cooling is optimal in warm climates with a low relative humidity and is therefore mostly applied in dry climates (deserts).

**Sun** Understanding the course of the sun, as well as the solar intensity allows for clever designing. Sun-exposed facades often cause overheating, where the latitude determines which façades are most exposed.

**Wind** Climate roses tell you the prevailing wind direction.

**Precipitation** Data about the amount and patterns of precipitation throughout the year can be used to assess the possibilities for rainwater storage and use for toilet flushing or evaporative cooling for example.

**Soil** The underground and its geology define the possibilities, for example the use of underground heat storage.

**Surroundings** Mountains, trees and buildings can cast shadows onto your building, and there may be different local energy potentials you can utilise.

Use of the Köppen climate classification might be a good starting point to analyse the advantages and disadvantages of the building site. As stated before there are five main groups.

**A-Tropical** Temperature is at least 18 degrees Celsius in the coldest month, there is a wet and relatively dry season and the average humidity is high.
**B-Dry** Climates with little to no rainfall (evaporation and transpiration exceed precipitation), clear temperature difference between summer and winter and large diurnal temperature differences.
**C-Temperate** Average temperature of 10 degrees Celsius (April to September) and higher than -3 degrees Celsius in the fall/winter months. All year round precipitation.
**D-Continental** Average temperature above 10 degrees Celsius (April to September) and colder than -3 Celsius in fall/winter. Resembles the temperate climate, but is more extreme in summer and winter.
**E-Polar** Coldest climate with in the warmest months an average temperature lower than 10 degrees Celsius. Large temperature difference between winter and summer. Only a limited amount of precipitation.

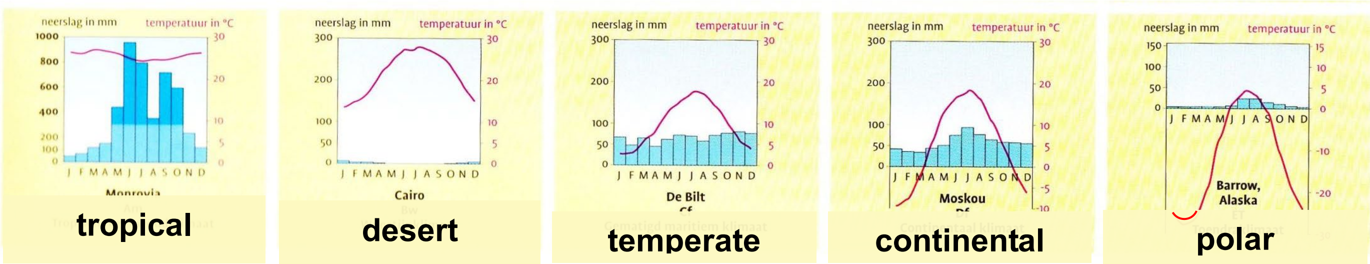


Fig 1.2: Koppen climate classification (main five climate regions). Source KNMI
Blue: precipitation, mm per month / red: temperature, degrees Celsius

Examples of appropriate climatic design are the narrow streets you see in dry climates to provide for shading, houses with a lot of mass that temper diurnal differences, white plastered housing to reflect solar radiation. And so each climate has optimal designing solutions. There are online tools to help you with climatic design strategies, a good example is the free program called Climate Consultant, developed by UCLA, which gives design advices based on the location you select (fig. 1.3.).

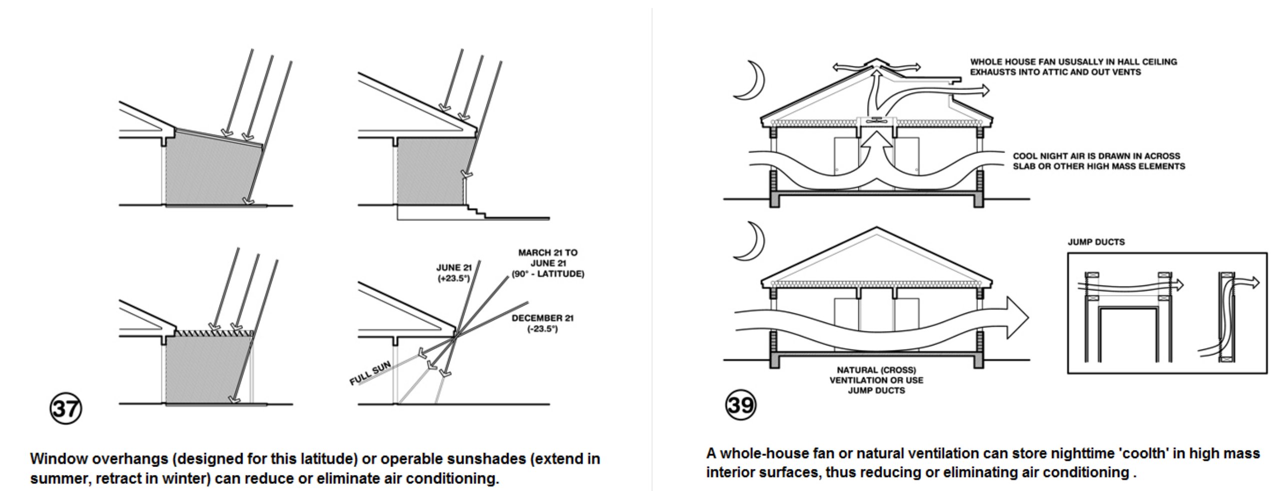


Fig 1.3: Examples of design improvements given by the program Climate Consultant.

# 2.

# History of climatic design

# 2. History of climatic design

Ever since there are settlements people make the place where they live as comfortable as possible. Over the centuries, different systems have been developed, these can be summarized by 4 topics: shelter, heating, light/view, and cooling.

## 2.1. Shelter

### Caves

The use of caves as a shelter starts with the hunter-gatherers from the Stone Age, with few resources or skills available and the need for places to shelter, caves were good places to live. The temperature in a cave is almost constant, because of the large rock mass: a large mass takes a long time to absorb and release heat. The bigger the mass, the greater the temperature delay.

The first Western European cave dwellers lived in southern France and Spain, where the average annual temperature is 14-16°C. According to research (Huynen et al., 2011)[1], the lowest mortality (number of deaths) occurs at around 15°C. We do not know if this statistic also applies to our distant ancestors, the cave dwellers, but it could explain why these regions were first inhabited by the Neanderthal and later the early modern man. Even in later times there are still houses carved out of soft rock, to make a home with a reasonably comfortable, stable indoor climate. Especially in climates with a strongly varying temperature - such as deserts, with extreme differences between day and night - cave houses offer a relatively comfortable indoor climate.

### Shelter from wind

With increasing dexterity, man could shape his shelter more and more, giving himself the possibility to stay in other places than caves. The most simple alternative was probably formed by standing branches, whether or not covered with leaves or sods. (fig. 2.1)

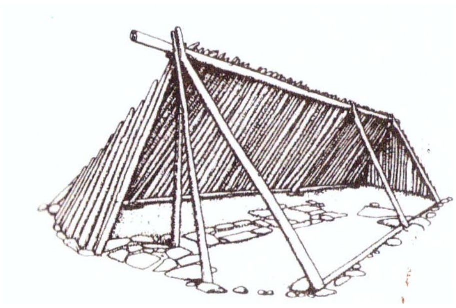

Fig. 2.1: Primitive shelter

With these forms of shelter, especially wind nuisance could be prevented. This can sometimes still be seen in more recent examples of buildings, such as the sheepfolds on Texel, of which the sloping roof section is oriented towards the west, the most common wind direction.

Tents offered an even more advanced form of shelter. In the beginning they consisted of branches, mammoth teeth or whale bones, covered with animal skins. The advantage of a tent was that it could be made in any desired shape and could be moved. The disadvantage was that the temperature in the tent could rise high when the sun was shining, while in the winter it could not keep the heat inside.

Fig. 2.2: Stone dwellings

When the hunter-gatherers became farmers and settled in a permanent place for a longer period of time, it became possible to build with heavier materials. Stones took over the role of the mass in caves. (fig. 2.2) But also buildings made of wood offered more stabilization in the indoor climate than tent constructions.

[1] 1. Huynen M.M., Martens P., Schram D., Weijenberg M.P. & Kunst A.E.,'The impact of heat waves and cold spells on mortality rates in the Dutch population', in: Environmental Health Perspectives, Vol. 109 No. 5, 2001 (463-470)

### Shelter from rain

In rainy areas, in addition to the shelter from wind and cold, shelter from water was also an important point of attention: a waterproof roof was an absolute prerequisite for a comfortable indoor climate in these regions. Because rain drainage is easier with an inclined than with a flat roof, sloping roofs were created, covered with branches, plagues, reeds and later with roof tiles.

Although it is not common in modern architecture, in regions like in the Netherlands a sloping roof is the logical consequence of the climate. Bituminous roofing has been able to waterproof flat roofs, but sloping roofs traditionally remain a logical solution. In other countries precipitation has led to other expressions, which partly depend on the local availability of materials. For example, building with (coniferous) wood in Japan is a tradition, which makes it useful to make sloping roof overhangs to protect from rain and to protect the wood. (fig. 2.3.)

Fig. 2.3: The Seirin-ji temple in Tokyo: Traditional Japanese architecture, is a result of climatologic conditions.

## 2.2. Heating

### Solar heat

Rich Romans already had greenhouses for tropical plants and thus understood the principle of passive solar energy. A Roman heliocaminus was a room in a bathhouse that was warmed up by the sun: the north side was closed, the south side open.

The Roman architect Vitruvius designed a sauna with an opening in the roof and below it a bronze dome. Because of the solar heat, this dome became warm. By moving the dome up and down, the temperature in the room could be regulated.

### Heating with fire

Through the control of the fire, man could keep himself warm in cold climates or during cold nights with a fire. The efficiency of a fire is about 10-15 percent. Our ancestors already made fire in the aforementioned caves, but also in tents and huts.

Not much has changed for millennia: even now fire is at the basis of building heating. However the way in which the heat is generated with fire and delivered to the indoor environment has changed considerably over the years.

In the Roman period a hypocaust was used. Hot air was fed from a heating point (an oven) through hollow floors and walls, so that the room was evenly heated. Especially bath houses and villas of wealthy Romans were heated with this system. After the fall of the Roman empire, the hypocaust disappeared, which meant a huge decline in technology.

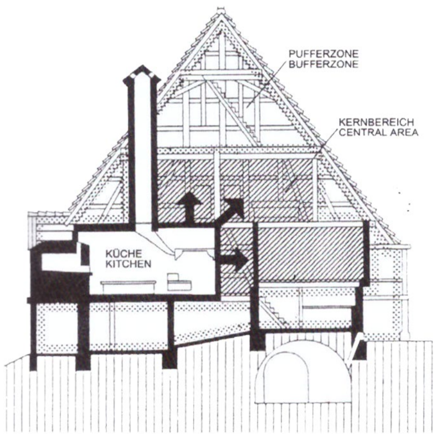


Fig. 2.4: Traditional European middle-age architecture with central kitchen fireplace.

Until the twelfth century, a central fire was often used in the wooden and stone houses. In doing so, smoke was discharged through the roof, through a high window or sometimes simply through cracks. Due to the smoke development, the living conditions in these houses

were usually unhealthy, and the sparks caused fire frequently. The exhaust of warm smoke air also caused cold drafts from the outside. Later the fires were placed on the façade to facilitate the air supply.
Despite the disadvantages, this heating principle has been applied until fairly recently. In South Germany the method of an open fire without a chimney was used until the beginning of the twentieth century. This was not because the return is much higher than the mentioned 10-15 percent, but because the smoke in the house made sure that woodworms did not stand a chance! In warmer climates more local heaters were installed instead of fires in the rooms, for example in the form of Spanish *braseros* and Japanese *hibachi's*; these are a kind of hot pans or barbecues.

Chimneys were created in the twelfth century, first horizontally on the façade, then vertically through the roof. The fire was made in appropriate fireplaces with chimneys above it. This development was continued - especially in colder regions of Europe - towards the kitchen fireplace, which was placed in the centre of the building and thus heated the entire building. The chimney discharged the smoke. (fig. 1.7.)

## Stoves

From 1685, stoves and fireplaces were created on the façade. The stove sucked air from the room under the fireplace; it was fed upwards and warmed up behind the stove, after which the warm air curled into the room. Fresh air to stir up the fire was taken from the outside of the stove; at the top there was a chimney that drained the smoke.

At the beginning of the nineteenth century air heating arose, mainly used in non-residential buildings. In the basement there was a firebox with many compact pipes through which steam was guided. Cold air from outside was led through these ducts, which therefore warmed up and was led to the rooms via large ducts. The warm air was led in at the bottom of the room and discharged at the top to the outside. Air humidification could also be used with this system. The rooms were not only heated but also ventilated.
Due to the natural draft upwards, the air could not be transported horizontally over a long distance, therefore several fireplaces had to be made in large buildings. In addition, combustion gases also entered the rooms, which led to unhealthy situations. Because of this a switch was made to the aforementioned central heating by water or steam.

## Further, and back to the Romans

In 1890, the first control equipment of central heating systems was created: thermostat controls that operated according to the principle that materials expand or shrink due to temperature differences. In 1892 the electric heater was created.

The previously introduced hypocaust of the Romans only in the early twentieth century continued with more modern wall or floor heating. This was used, among other things, in the famous Open Air School of Johannes Duiker in Amsterdam (fig 2.5).

In the 1940s and 1950s, wall and floor heating was increasingly used in the United States, in other countries such as the Netherlands, the large-scale application started later.

Fig. 2.5. Open Air School Amsterdam, Johannes Duiker

### District heating

Heating by means of steam was later even more centralized. Because of the high temperature steam could be transported further than hot water, this resulted in the possibility for a steam power station for a city or district. Later this steam was also used to generate electricity. Ultimately, this electricity production became the primary function, with the residual heat only being discovered again in the second half of the twentieth century as a source for district heating.

### Compactness

To burn wood or coal in an economical way, compact building became important. That trend had already started with the central kitchen fireplace, around which other rooms were situated. It was quickly discovered that high rooms are more difficult to heat than low ones, simply because hot air rises. Compact buildings were thus better kept warm, which was reflected in the difference between castles and country houses in cold regions on the one hand versus Mediterranean countries on the other hand.

### Insulation

Thermal insulation was already known as a principle since people started wearing clothes. This was later introduced in buildings. From the first century BC window openings in buildings were closed with translucent materials (mica, glass, selenite) that let in and hold solar heat.

For a long time the principle of insulation was not commonly used in Western Europe, probably because fuels were readily available. Only in colder regions such as Scandinavia and the Low Countries sods were used as a basic  layer of insulation.

It was learned from experience that houses were better warm with an insulating buffer zone. In farms in cold regions, that zone was formed for a long time (and sometimes still) by the hayloft, which lay like a thick insulation blanket on the living room, as well as the animal stables that were built against the living area. These stables were not only a buffer zone, but also provided active heating by natural heaters: the animals.

In the Netherlands architect Jón Kristinsson was the first to introduce insulation material in the cavity of a façade. That was at the end of the 1960s. The principle of thermal insulation has taken off since the oil crisis of 1973.

## 2.3. Light & Sight

### Daylight

From the moment our distant ancestors sought shelter in closed buildings, the demand for daylighting came up. Because of the climate, the construction (thick, heavy walls) and for the sake of safety, windows were usually quite small until the early Middle Ages. Initially these were open windows without glass, which could possibly be closed with a hatch. Already with the Pantheon in Rome (from the second century AD) the importance of a high window becomes clear: the oculus, despite its small size - compared with the construction around it - has a high light output in the dome-shaped space beneath it.

The Romanesque architecture was heavy and massive, with little room for windows, but with the advent of Gothic architecture in the twelfth century, constructions became lighter and windows could become larger and larger. Those windows were filled with glass in lead strips, or stained glass.

### The glass window

Glass, a material obtained by mixing and melting a proper proportion of sand, soda and lime, has been used in a first version in Mesopotamia for the manufacture of beads, 5000 years BC. The Egyptians and Greeks improved the technique and invented new applications. In the Roman times, glass became a mass product. Glass sheets could be made by allowing molten glass to flow out onto a stone table. Probably these were not large at first, but in the city of Pompeii, buried by volcanic ash in the year 79, a glass window was found in a bronze window with a size of about 540x720 mm. Around 200 AD, glass could be made of even larger dimensions: 0.5 / 0.75 * 1.5 m. In those days, even double glazing was used.

In the Middle Ages flat glass was made by cutting blown cylinders and rolling them flat or by swinging a blown bulb into a flat disc, from which small squares were then cut. Both forms of glass had a rather irregular surface, but openings could in any case be fitted with windows, which provided comfort, light and (distorted) visibility. Later the production techniques for flat glass have been further optimized with pull and floating techniques. In the eighteenth century the entry of daylight was improved by thinner glass and larger glass surfaces.

Nowadays we can give all kinds of properties to glass: with vapour-deposited coatings we can influence daylight and sun light, make mirror glass and optically select light, so that UV light or heat radiation is reflected.

Equipped with such a heat-reflective coating and whether or not filled with noble gas, with double or triple glazing, the insulation value is significantly improved compared to a single sheet of clear glass.

## Glass architecture

With the development of cast-iron structures, the use of glass panes really took off in the nineteenth century. Large glass roofs in atria, galleries and greenhouses became increasingly common, culminating in the Crystal Palace, built in 1851 at Hyde Park in London. This famous building inspired the construction of the Dutch counterpart, the Paleis voor Volksvlijt in Amsterdam, opened in 1864. Unfortunately, both masterpieces were burned down, the Paleis voor Volksvlijt in 1929 and Crystal Palace in 1936.

Fig. 2.6 Paleis voor Volksvlijt Amsterdam

Large glass windows were also increasingly used in non-residential buildings and dwellings, with modernism (the New Building) bringing the breakthrough to complete glass facades. The aforementioned Openluchtschool from Duiker was an example of this. Het Glaspaleis in Heerlen, a department store designed by Frits Peutz, was ahead of his time (1935) an unprecedentedly transparent building.

The highlight of glass architecture is probably the Post Tower in Bonn from 2002. Architect Helmut Jahn also used glass interior walls and even a few glass floors in addition to a full glass façade (fig 2.8)

Fig 2.8. Post Tower Bonn

### Disadvantages of glass for the climate
With the use of large glass facades, optimal transparency, view and daylighting were guaranteed, but disadvantages also became apparent, such as undesired heating by the sun and unpleasant cold drafts due to lack of heating on the façade, and consequently a much greater use of energy.

Especially the occurrence of unwanted solar irradiation is increasingly a point of attention with the increased glass percentage in the façade. Overhangs, slats and louvres can obstruct the sun from a certain angle. Around the equator, the use of downward facing windows is also an option. Where such architectural measures are insufficient to maintain internal heating within comfort limits, mechanical cooling is inevitable.

## 2.4. Cooling
In the past the cooling of buildings has always been a point of attention in warmer countries. Narrow streets, compact houses and whitewashed façades and roofs were simple measures to prevent heating of the construction and the interior.

### Ice
The history of more active cooling goes far back. Already around 2000 BC, Persians tombs were cooled with ice. But also in homes they made use of ice, the first 'ice houses'.

Around 1660, ice houses were created in Western Europe. An insulated room was filled with ice and served as a refrigerator. These ice houses were often under the ground. A drainage from the lowest point produced melt water and condensation. The was sometimes taken from colder locations and transported by boat around the world, but usually simply from a nearby pond made for this purpose.

Fig 2.9. $18^{th}$ century ice house

## Evaporative cooling

By carrying warm air along water, this water evaporates, whereby the water extracts heat from the environment. This is called evaporative cooling, an adiabatic process. According to this principle, a certain substance or building mass (stone) can be cooled by constantly keeping it humid and passing air along it. This principle is well known to soldiers, who have kept their water bottle cool with a wet cloth for years.

## Mechanical cooling

By building compactly and high insulation standards, the need to cope with undesirable high temperatures also arose in colder regions such as Northern Europe. Mechanical cooling could provide this need. In the second half of the nineteenth century, the circular process of evaporation, compression and condensation was developed. In the beginning ammonia (NH), sulfur dioxide ($SO_2$) and methyl chloride ($CH_3Cl$) were the most used media, but because of their toxicity they were replaced by chlorofluorocarbons (CFCs). These very stable non-toxic cold media, however, turned out to affect the ozone layer of our planet, after which the 1987 Montreal protocol decided to discontinue the use of these media.