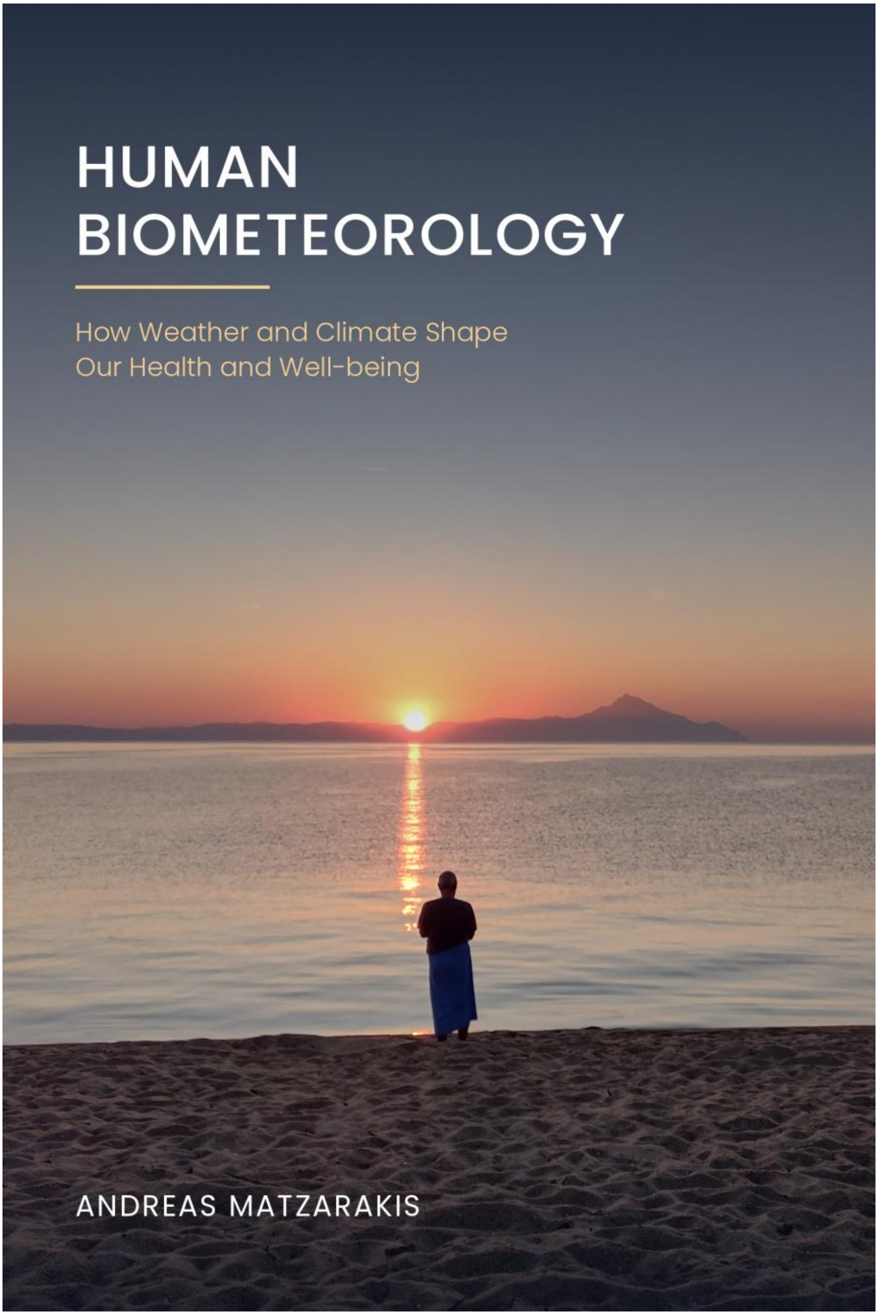
HUMAN BIOMETEOROLOGY

How Weather and Climate Shape Our Health and Well-being



ANDREAS MATZARAKIS

HUMAN BIOMETEOROLOGY

How Weather and Climate Shape Our Health and Well-being

Andreas Matzarakis

First edition 2026

Imprint

Human Biometeorology

How Weather and Climate Shape Our Health and Well-being

First edition 2026

Author: Prof. Dr. Andreas Matzarakis, Freiburg im Breisgau, Germany

Cover photograph: Irene Matzarakis. Sunrise over the Aegean Sea, with Mount Athos in the background, Greece.

Figures: drawings by the author, prepared with the support of artificial intelligence (Anthropic Claude). Concept, content and scientific review: Andreas Matzarakis.

Typesetting and production: the author

Author and publisher (self-published): Prof. Dr. Andreas Matzarakis, Im Rösslegarten 3, D-79189 Bad Krozingen, Germany

Chapters 1 to 49 in nine parts

ISBN: 978-3-00-088330-9

Bibliographic information of the German National Library: the Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; bibliographic data are available on the internet at https://portal.dnb.de.

Contact: andreas.matzarakis@meteo.uni-freiburg.de · www.matzarakis.de

Contents

Forty-nine chapters in nine parts.

APPENDIX

PART I

Foundations

Before we can ask what weather and climate do to people, five things need to be clear. What the atmosphere is. What separates weather from climate. Where this field came from. How the climates of the world are characterized. And along which paths the atmosphere actually reaches and reacts with us. Everything later in this book stands on these five chapters.

1 The atmosphere

A shell of a few kilometres. Everything we call life hangs on it.

Look at the Moon. A black sky, a blinding sun, an airless silence, and swings of hundreds of degrees between light and shadow. On Earth we smell the rain, we watch an evening sky turn red, we breathe without thinking about it. All of that comes from a thin veil of gases above our heads.

The atmosphere is much more than air. It is a shield, and on any clear night you can watch it working. A shooting star is dust burning up about eighty kilometres up, and this happens by the tonne, every day. Lower down, in the stratosphere, sits the ozone layer. It filters out the most dangerous part of the sun's ultraviolet radiation (UV) before it reaches the ground. Sunglasses for a whole planet.

The atmosphere also holds our heat. Water vapour and carbon dioxide let solar radiation in and slow down the heat that wants to escape into space. Without this natural greenhouse effect the Earth would average about minus eighteen degrees. With it we get plus fifteen. Thirty-three degrees of difference — our whole history sits inside it.

Our own room is small. About three quarters of the atmosphere's mass lies in the troposphere, its lowest layer — roughly twelve kilometres deep at our latitudes, less at the poles, more at the equator. That is where the weather happens and where we live. At three thousand metres the air is already noticeably thinner. Above eight thousand metres climbers speak of the death zone, and they are not exaggerating. Set against the size of the Earth, the layer that carries us is thinner than the skin of an apple.

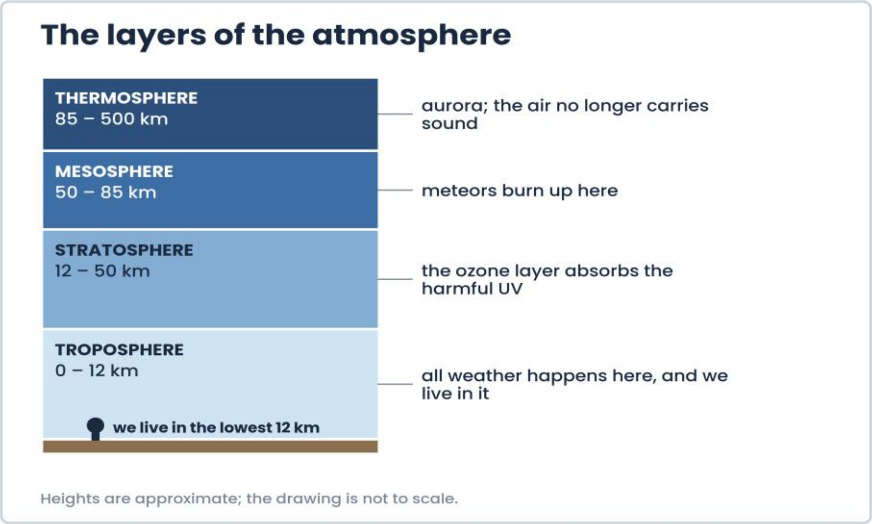


Figure 1: The layers of the atmosphere. Meteors burn up in the mesosphere, the ozone layer filters ultraviolet radiation in the stratosphere, and we live in the thin troposphere.

The word itself is Greek. Atmos is vapour, sphaira is sphere: the sphere of vapour. Aristotle wrote a whole book about it, the Meteorologica, and gave our subject its name in the process. Much of what he concluded was not correct. The instinct was right, and it lasted two thousand years: what happens over our heads is worth systematic attention.

We are, without noticing, heavy users of this thin layer. An adult breathes something like twelve thousand litres of air a day. Every one of those litres carries whatever is in it at the time, and the chapters on air pollutants later in this book belong to the same story as this one. And we do not even use the whole troposphere. Almost all of human life happens in the lowest few hundred metres of it, the layer that feels the ground directly, warms with it during the day and cools with it at night. That layer is where cities make their own climate.

There are no borders up there. A volcano in one hemisphere cools the summers of the other. Dust from the Sahara colours the sky over the Caribbean and, several times a year, over Greece. Gases released in one country warm all the rest. We share one room, and it is not a large one. I say this in every first lecture, because everything else in the subject follows from it.

The atmosphere's composition works like a thermostat. Nitrogen and oxygen make up ninety-nine per cent of the air and do almost nothing with heat radiation (Ahrens and Henson 2023). The work is done by the remainder: water vapour, carbon dioxide, methane, ozone. Change that small part and the setting changes. Carbon dioxide has risen from around 280 parts per million before industrialisation to more than 420 today (IPCC 2023). A small number with a large effect.

Table 1: What the air is made of, near the ground

Gas	Share	What it does for us
Nitrogen (N_2)	78 %	inert; provides pressure and volume
Oxygen (O_2)	21 %	breathing, combustion
Argon (Ar)	0.9 %	inert noble gas
Carbon dioxide (CO_2)	0.04 %	greenhouse gas; plant growth
Water vapour (H_2O)	0 to 4 % (variable)	greenhouse gas; clouds, rain, evaporation of sweat

The nitrogen, oxygen, argon and carbon dioxide figures describe the dry-air fraction; water vapour then adds on top of that, and how much depends entirely on the weather. One thing we notice only when it goes wrong is the pressure. At sea level the column of air above us presses down with about one kilogram on every square centimetre. We do not feel it, because we are built for it. Go up quickly and the body notices at once: the ears, the breathing, the sleep. The air pressure indoors is essentially the same as outdoors. Chapter 38 comes back to that.

In a changing climate. The composition of the air is no longer a constant of nature. The clearest sign that we are the cause is the pattern of the change itself. The troposphere is warming while the stratosphere above it cools. A stronger sun would warm both layers. A thicker blanket warms below and cools above, and that is what the measurements show.

GOOD TO KNOW

Nearly all weather happens below twelve kilometres. Almost all of your life happens in the lowest few hundred metres of that.

You breathe roughly twelve thousand litres of air a day. Air quality is not an abstract subject.

Keywords: Atmosphere · Troposphere · Stratosphere · Ozone layer · Greenhouse effect · Ultraviolet radiation

SOURCES

Ahrens, C. D., Henson, R. (2023): Meteorology Today. 13th edn. Cengage Learning, Boston.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

2 Weather, climate and climate change

Weather is the mood of a day. Climate is the character of a place.

Weather is what the atmosphere is doing now and over the next few days. Air temperature, rain, wind, clouds. Climate is the sum of all that weather over a long time, by international agreement thirty years (WMO 2017), with its averages, its swings, its extremes, and how often certain thresholds are crossed. We dress for the weather. We build a house for the climate.

Weather services put this into numbers with climate normals, at the moment the period 1991 to 2020. Against that yardstick a hot summer or a mild winter is judged. But averages can mislead. A human body has no interest in the mean of thirty years. What matters is how often the hard days come, how long they last, and whether the night brings any relief. The health risk sits in the variability and in the extremes, not in the average.

Climate change means that the whole pattern moves and stays moved. It is not only the middle that shifts. When the entire distribution slides towards the warm side, the rare becomes ordinary and the impossible becomes possible. A summer that used to be expected once in fifty years now arrives several times in a generation. The record of one decade becomes the normal of the next.

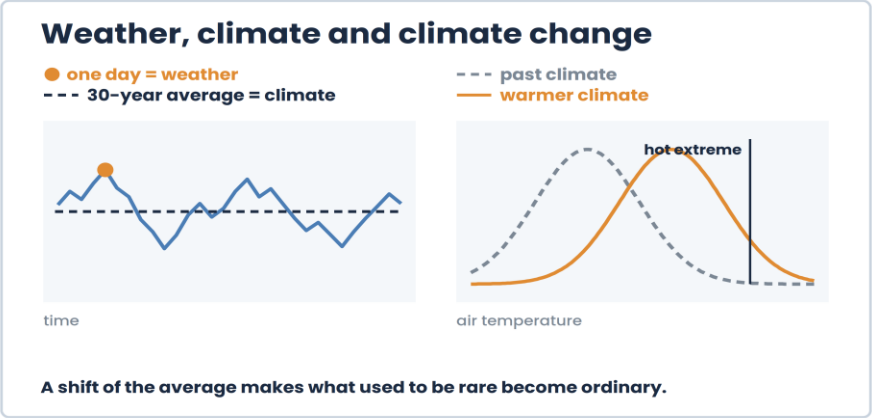


Figure 2: Left: a single day is weather, the thirty-year average is climate. Right: when the average shifts, hot extremes become far more frequent than the shift alone would suggest.

Natural causes have always been there. The sun, volcanoes, slow cycles in the orbit of the Earth. What is new is the fast change, and the source. Since industrialisation the greenhouse gases released by people have become the dominant driver (IPCC 2023), and they work much faster than the natural cycles they have joined.

The practical consequence is easy to say and hard to solve. Climate sets the frame for everything we build and organise. How houses are made. When the harvest comes. Which illnesses are common. How many nurses a hospital needs in August. Climate change moves that frame while the buildings, the habits and the institutions stay where they were put. Most of the health risk sits in exactly that gap, between the climate our infrastructure was designed for and the climate we now live in.

We looked at this for Freiburg some years ago (Matzarakis and Endler 2010): heat stress days rose while cold stress days fell, and only the rise made the newspapers. The tool that makes such a comparison possible is the thermal index — a measure of felt temperature, introduced in the next chapter: it turns a climate projection into a load on the body, in degrees a person can picture (Matzarakis and Amelung 2008).

Table 2: Three words that are often confused

Term	Time scale	What it describes
Weather	hours to days	the state of the atmosphere right now
Climate	30 years	the typical weather of a place, with its extremes
Climate change	decades to centuries	a lasting shift of that typical weather

In a changing climate. Even the word normal has a different meaning. The current normal period, 1991 to 2020, is clearly warmer than 1961 to 1990, which many of us still carry in our heads as the reference. When a forecast says above average today, it is measuring against an average that has itself been raised.

GOOD TO KNOW

One hot day is weather. Thirty years of them is climate.
When a forecast says “above average”, ask which average. The reference 1991 to 2020 is already warmer than the one most of us grew up with.

Keywords: Weather · Climate · Climate normal · Climate change · Extremes · Variability

SOURCES

WMO (2017): WMO Guidelines on the Calculation of Climate Normals. WMO-No. 1203, Geneva.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

Matzarakis, A., Endler, C. (2010): Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. International Journal of Biometeorology 54, 479–483.

Matzarakis, A., Amelung, B. (2008): Physiological Equivalent Temperature as indicator for impacts of climate change on thermal comfort of humans. In: Thomson, M. C. et al. (eds.): Seasonal Forecasts, Climatic Change and Human Health. Springer, Dordrecht, 161–172.

3 What is human biometeorology, from Hippocrates to UTCI

A young name for a very old question.

Around 400 BC a Greek physician advised his colleagues that on arriving in a strange town they should first look at its winds, its water and its seasons. The text is called Airs, Waters, Places and is attributed to Hippocrates (Hippocrates c. 400 BC). When I first read it I was surprised how modern it sounds. There were no instruments and no statistics, but the question is exactly ours: how does the place a person lives in shape their health? Similar traditions grew up on their own in Chinese, Indian and Arab medicine. The idea that air and season belong in a medical examination is one of the oldest in medicine.

For two thousand years the only answer was experience. That changed in the seventeenth century, when the thermometer and the barometer made the air properties measurable. From then on a feeling could become a number, and numbers can be compared between places and between years.

The nineteenth century turned the idea into a business. Spa towns and health resorts were built all over Europe on the conviction that a change of climate can heal. Sea air for the airways, mountain air for the lungs, sun for the skin. Some of it was fashion. Some of it was right, and it survives today as climate therapy.

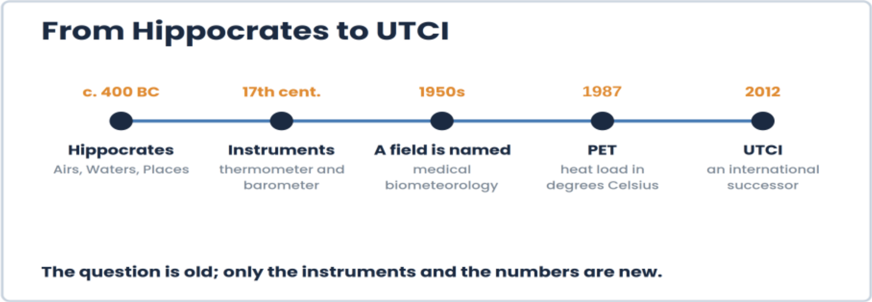


Figure 3: Five steps along a long road. The question stayed the same. The instruments and the numbers are new.

The name arrived in the twentieth century. Medical biometeorology was set out as a discipline of its own, and in 1956 the International Society of Biometeorology was founded. The division of labour has not changed since. Human biometeorology asks what today's weather does to us: heat load, circulation, sleep, airways, ultraviolet radiation, pollen. Bioclimatology asks the longer question, which risks a climate carries over decades and how those risks move when the climate moves.

The decisive practical step came late. Air temperature on its own says very little about what a body actually experiences. Thirty degrees in the shade with a breeze is not thirty degrees in full sun and still air. Thermal indices were built to put air temperature, air humidity, wind and radiation into one figure. The Physiologically Equivalent Temperature, PET, gives that figure in degrees Celsius, a unit everybody already understands (Mayer and Höppe 1987; Höppe 1999; Matzarakis et al. 1999). That was the whole point of it. None of it is read directly off an instrument — it is calculated, a point this book returns to often. The Universal Thermal Climate Index, UTCI, followed as an international updated index (Jendritzky et al. 2012), calculated from a model of human heat regulation that holds clothing and activity at fixed, standardised levels, not whatever a particular person happens to be wearing or doing.

What the field delivers today is service. Heat warnings, the ultraviolet index, pollen forecasts, advice for hospitals and care homes, bioclimatic maps for city planners. Behind every one of them stands the same old question, now with numbers attached.

Table 3: Two viewpoints on one concern

Feature	Human biometeorology	Human bioclimatology
Time scale	hours to days	years to decades
Focus	the weather of today	the climate of a region
Typical product	heat warning, pollen forecast	bioclimatic map, climate projection
Typical user	the public, doctors, employers	planners, policy, health authorities

In a changing climate. The field has quietly changed its job. For most of its history it described. It explained why a place felt the way it did. Today it is mostly asked to warn and to advise. How hot will it get, who is at risk, what should a city do. That move from description to service is the direct result of a climate that no longer sits still.

GOOD TO KNOW

If a value is given to you in degrees Celsius, someone has done you a favour. That was the whole point of PET.
Every warning you use — heat, ultraviolet, pollen — is applied biometeorology.

Keywords: Biometeorology · Bioclimatology · Hippocrates · Thermal index · PET · UTCI

SOURCES

Hippocrates: Airs, Waters, Places (c. 400 BC), in: Hippocratic Writings, various editions.

Mayer, H., Höppe, P. (1987): Thermal comfort of man in different urban environments. Theoretical and Applied Climatology 38, 43–49.

Höppe, P. (1999): The physiological equivalent temperature — a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology 43, 71–75.

Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84.

Jendritzky, G., de Dear, R., Havenith, G. (2012): UTCI — why another thermal index? International Journal of Biometeorology 56, 421–428.

4 Climate zones: where and how people live

People live from the Arctic to the desert, but not in equal numbers.

Starting in 1884, the climates of the world were sorted by a simple and clever criterion: what grows there. Vegetation adds up monthly air temperature and rainfall over the whole year, so plants make a reliable instrument. The result, known today as the Köppen–Geiger classification, with its five main groups of tropical, dry, temperate, continental and polar, is still in use. It has been refined many times and never replaced (Beck et al. 2018).

People are spread across these groups very unevenly, and not by chance. Deserts and polar regions are almost empty. Most of humanity lives in the tropics and in the temperate belt, where water is reliable and the thermal load is bearable for most of the year. Where a climate makes ordinary life expensive, in water, in energy or in effort, few people settle. Climate information of this kind can be prepared for a whole country and handed to the people who need it, from tourists to farmers (Zaninović and Matzarakis 2009; Brosy et al. 2014).

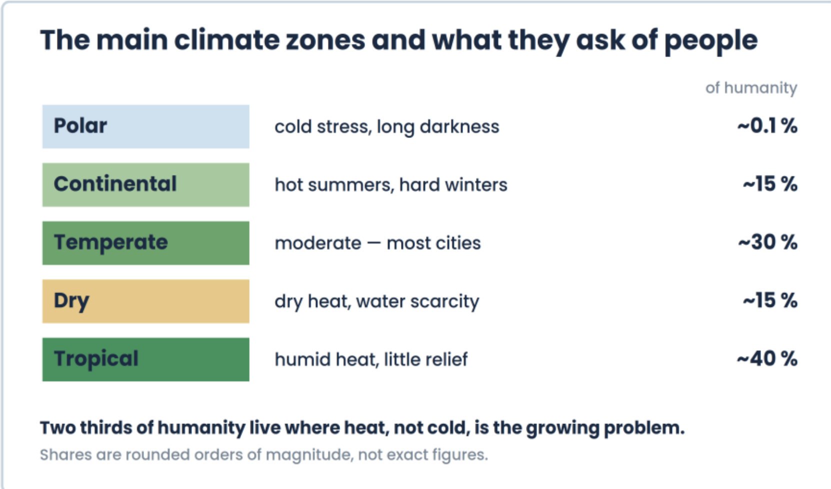


Figure 4: The five main climate zones, what each one asks of the human body, and roughly how much of humanity lives there.

Every zone puts a different question to the body. In the humid tropics the air already carries so much moisture that sweat evaporates poorly. The main cooling system of the body runs at a fraction of its capacity, and the night brings little relief. In dry zones the daytime heat is fiercer, but the air is dry, so sweating works and the nights cool off sharply. There the limit is water. The temperate belt is comfortable on average and changeable in practice, which is a stress of its own. Continental climates put hot summers and hard winters in the same place. Polar regions demand protection from cold and from months of darkness.

This is why the same number means different things in different places. Thirty-two degrees in Athens, dry, with a breeze off the sea, is an ordinary summer afternoon. Thirty-two degrees in Singapore, with the air almost saturated, is a serious heat load. Any assessment that uses air temperature alone will get one of those two badly wrong. That is exactly why the thermal indices of the previous chapter exist.

Traditional building shows how well people worked all this out long before there was a science of it. Thick walls, small windows and shaded courtyards in the Mediterranean and in North Africa store the coolness of the night for the day. Raised houses with wide openings and deep eaves in the humid tropics catch every breath of wind. Compact, well-insulated houses with small openings in the north keep the warmth in. Nobody calculated any of it. It was learned, over generations, and a good part of it is better adapted than what replaced it. Chapter 33 returns to this.

Table 4: What each zone asks of the body, and the traditional answer

Zone	Main demand on the body	Traditional answer
Tropical	humid heat, sweat evaporates poorly	open, raised, cross-ventilated houses
Dry	extreme daytime heat, water scarcity	thick walls, courtyards, narrow shaded streets
Temperate	changeable weather, moderate extremes	adaptable houses, seasonal clothing
Continental	hot summers and severe winters	heavy construction, heating and shading
Polar	cold stress, long darkness	compact, insulated dwellings, layered clothing

In a changing climate. The zones themselves are on the move, towards the poles and up the mountainsides. A place slowly acquires the summers of a region a few hundred kilometres to the south of it, while its buildings, its water supply and its habits still belong to the old zone. It is the mismatch, not the heat alone, that makes the transition hard.

GOOD TO KNOW

The same air temperature means very different things in Athens and in Singapore. Always ask about the humidity.
Before criticising an old building, ask what climate it was built against.

Keywords: Climate zones · Köppen classification · Humid heat · Dry heat · Settlement · Traditional building

SOURCES

Beck, H. E. et al. (2018): Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5, 180214.
Brosy, C., Zaninović, K., Matzarakis, A. (2014): Quantification of climate tourism potential of Croatia based on measured data and regional modeling. International Journal of Biometeorology 58, 1369–1381.
Zaninović, K., Matzarakis, A. (2009): The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. International Journal of Biometeorology 53, 369–374.

5 The atmospheric effect complexes

The atmosphere reaches us along three main paths, with two more that always travel alongside. Keeping them apart is what makes the whole subject manageable.

The atmosphere does not act on us as one single thing. It acts as heat, as radiation, and as something we breathe. These three are so different in how they work, how they are measured and what helps against them that human biometeorology has treated them separately for a long time. They are called the atmospheric effect complexes: the thermal, the actinic and the air pollution complex. Two further complexes are named alongside them, because they reach the same person in the same street: the biotropic complex, and noise and odours. That makes six effect complexes in total; noise and odours are combined into one shown complex in the table and figures that follow, because in practice they are assessed and managed together. The classification is old and sober. It has earned its place because it works in practice.

How each of these effects is assessed — which atmospheric quantity is measured, how it is turned into a rating, and how that rating reaches a decision — is what gives the field its shape; the reasoning behind the assessment is set out more fully elsewhere (Matzarakis 2020).

The thermal complex covers everything that decides whether the body can hold its temperature. Air temperature, air humidity, wind and radiation, always together. Not one of them decides on its own what we feel, and this complex is therefore assessed with combined indices, not with a thermometer (Matzarakis et al. 1999; VDI 3787 Part 2, 2022). Its public products are the heat and cold warnings. What helps is shade, ventilation, drinking, and doing the hard work at another hour.

The actinic complex is radiation that acts chemically rather than by warming. Ultraviolet radiation on the skin and the eyes, light on the daily rhythm and on mood. A cold bright day in the mountains carries almost no heat load and a considerable ultraviolet one. The two complexes can point in opposite directions on the same afternoon. Its product is the ultraviolet index (WHO 2002). What helps is clothing, shade and timing.

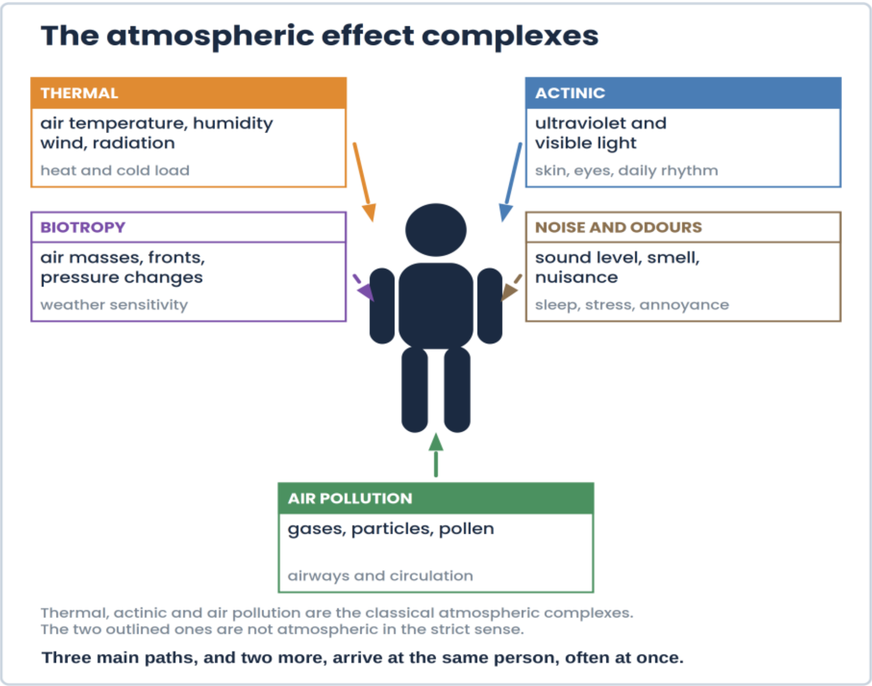


Figure 5: Three main paths from the atmosphere to the body, and two more that travel with them. They arrive at the same person, usually at the same time.

The air pollution complex is what we breathe. Gases such as nitrogen dioxide and ozone, particles from traffic, combustion, wildfires and deserts, and with them pollen. It is assessed with air quality indices and pollen forecasts. What helps here is different in kind from the other two. Mostly it means reducing what is emitted, because a single person can do rather little about the air in a street.

The biotropic complex is the one people ask about most and science answers most cautiously. It covers the passage of air masses and fronts, and with them the quick changes in air pressure, humidity and temperature that many people say they can feel in their joints, their head or their sleep. Roughly half the population in central Europe reports being weather sensitive (Höppe et al. 2002; Graw, Sommer and Matzarakis 2022). What the studies find is smaller and less specific than what people describe, and the honest position is to take the complaint seriously without promising a clean explanation for it. Chapter 28 comes back to this in full.

Noise and odours are the fifth. Sound level and smell are not atmospheric in the strict sense, but they travel through the same air, whose movement shapes how far they reach, and arrive in the same street, and they act on sleep, on concentration and on the sense of being at home in a place. A hot night with the window open is also a loud night. The remedies overlap with the other complexes more often than the responsible authorities do.

Keeping them apart is useful for a practical reason. Each needs its own measurements, its own assessment method, its own warning service, and in most countries its own responsible authority. Never forgetting that they belong together is useful for an equally practical reason. They interact. Strong sunlight drives the formation of ground-level ozone, and the same conditions that bring the sunshine usually bring the heat, so the worst heat days are often the worst air days as well. Warming lengthens the pollen season. Wind disperses pollutants and cools the body at the same time. A shaded green street is usually both cooler and cleaner.

In the end all of them arrive at one person. Nobody experiences five effect complexes. People experience one day, in one street, with one body. The division is a tool for those who study and manage the environment. It is not a description of what it feels like to stand in it.

Table 5: The five effect complexes at a glance

Complex	What it consists of	Public service	Protection
Thermal	air temperature, humidity, wind, radiation	heat and cold warnings	shade, ventilation, drinking, timing
Actinic	ultraviolet and visible radiation	ultraviolet index, UV warning	clothing, shade, avoid midday sun
Air pollution	gases, particles, pollen	air quality index, pollen forecast, ozone warning	lower emissions, ventilate wisely
Biotropic	air masses, fronts, pressure changes	general weather situation	sleep, routine, medical advice
Noise and odours	sound level, smell, nuisance	noise maps, complaints	quiet sides, distance, screening

In a changing climate. All of the complexes are moving in the same unhelpful direction at once. More heat and longer heat. A longer and stronger pollen season. More ozone episodes on hot days and more smoke from wildfires. They also coincide more often than they used to. A heatwave with high ozone and high pollen is not three separate problems. It is one bad week, and it is the combination that fills the emergency departments.

GOOD TO KNOW

Three questions on any summer day: how hot does it feel, how strong is the sun, what is in the air.
The worst days usually score badly on several of them at once.

Keywords: Effect complex · Thermal complex · Actinic complex · Air pollution complex · Biotropic complex · Weather sensitivity · Noise and odours · Warning services · Interaction

SOURCES

VDI 3787 Part 2 (2022): Environmental meteorology — Methods for human-biometeorological evaluation of the thermal component of the climate. VDI, Düsseldorf.
WHO (2002): Global Solar UV Index: A Practical Guide. World Health Organization, Geneva.
Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.
Höppe, P., von Mackensen, S., Nowak, D., Piel, E. (2002): Prävalenz von Wetterfühligkeit in Deutschland. Deutsche Medizinische Wochenschrift 127, 15–20.
Graw, K., Sommer, S., Matzarakis, A. (2022): The prevalence of weather sensitivity in Germany derived from population surveys. Atmosphere 13, 1865, 1–14.
Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84.

PART II

The Thermal Effect Complex

This is the part of the subject that touches everyone, every day. Heat and cold decide how we sleep, how we work, how the circulation copes and, in the end, how long some of us live. It is the most challenging and most important in the discussion about global warming and human health. Eight chapters: how the body exchanges heat with the air around it, how we put that exchange into a number, and then heat, humid heat, cold, the cold stimulus, adaptation, and work.

6 Body and atmosphere: the human energy balance

We do not feel temperature. We feel whether we are losing our warmth fast enough.

A human body is a small furnace that never goes out. At rest it produces about a hundred watts, roughly an old light bulb. Walking briskly it produces about three hundred, hard physical work five hundred and more. All of that heat has to leave the body, and it has to leave at exactly the rate at which it is made. If it leaves too slowly we overheat. Too fast and we cool down. The core temperature has almost no room to move, about two degrees in either direction before things become serious.

The heat leaves along four paths. It radiates from the skin to cooler surroundings. It is carried away by air moving over the skin. It goes out with every breath. And it evaporates, in sweat, which is, in practice, the only path that still works when the air is warmer than we are (radiative loss to a clear, cool sky can still help a little, but rarely enough on its own). At the same time heat comes in: from the sun, from warm walls and pavements, from the ground.

Add it up and you see why one instrument cannot answer the question. Four meteorological quantities decide the balance. Air temperature. Air humidity, which controls how well sweat evaporates. Wind, which controls the convection and also evaporation. And radiation, both from the sun and from the surfaces around us, which is summarised in the mean radiant temperature (VDI 3787 Part 2, 2022). Two more quantities are not meteorological at all: what the person is doing, and what they are wearing.

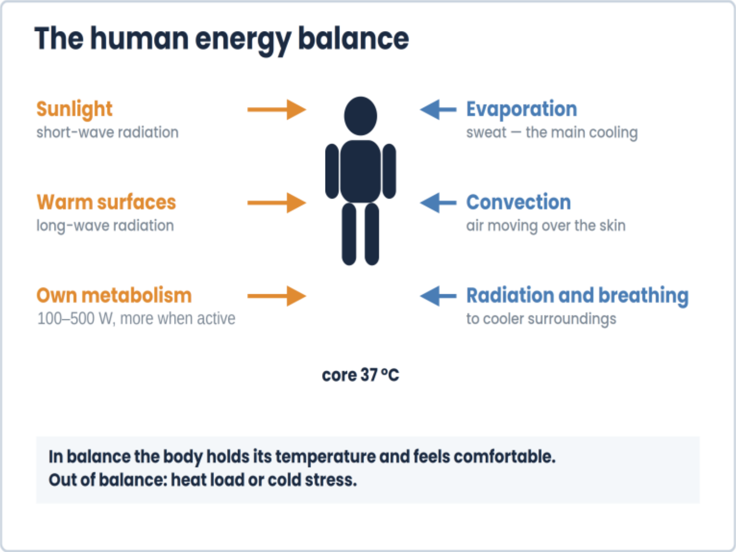


Figure 6: The human energy balance. What comes in must go out. Four meteorological quantities and two personal ones — activity and clothing — decide whether it does.

Students always ask me why we need four instruments where one seems to be enough. The honest answer is that the thermometer measures the air, and the air is not what we feel. On a still, sunny July afternoon in a paved square the mean radiant temperature can be twenty degrees above the air temperature. The thermometer in the shade knows nothing about it. Anyone standing there knows it immediately.

This is also why we built RayMan (Matzarakis et al. 2007, 2010). We built it because I was tired of telling planners that a proper radiation calculation needed a specialist and a workstation, when what they actually needed was an answer before their next meeting. The model takes the buildings, the trees and the sky that a person actually sees, works out the radiation arriving from each direction, and turns the whole balance into a single figure. It has been used in many parts of the world, and its main virtue is not precision. It is that a planner and a scientist like me can run it.

Table 6: The terms of the human energy balance

Term	Direction	What controls it
Metabolism	always a gain	activity, body size
Short-wave radiation	gain	sun, shade, reflecting surfaces
Long-wave radiation	gain or loss	temperature of walls, ground, sky
Convection	usually a loss	wind speed, air temperature
Evaporation	loss only	humidity, wind, sweat rate
Respiration	small loss	breathing rate, air temperature
Clothing	modifies all other terms	insulation (clo value), fit, colour, wind permeability

In a changing climate. In cities, more paved and built surface means the mean radiant temperature runs higher than in the surrounding countryside — an effect of urbanization as much as of a changing climate, and one that grows as cities grow. Chapter 31 covers it in full. Either way, the gap between what the thermometer says and what the body feels is widening, and warnings based on air temperature alone will understate the load more and more.

GOOD TO KNOW

Shade changes your heat balance more than a few degrees of air temperature ever will.

What you wear and what you are doing count as much as the weather does.

Keywords: Energy balance · Mean radiant temperature · Convection · Evaporation · Metabolism · RayMan

SOURCES

VDI 3787 Part 2 (2022): Environmental meteorology — Methods for human-biometeorological evaluation of the thermal component of the climate. VDI, Düsseldorf.

Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84.

Matzarakis, A., Rutz, F., Mayer, H. (2007): Modelling radiation fluxes in simple and complex environments: application of the RayMan model. International Journal of Biometeorology 51, 323–334.

Matzarakis, A., Rutz, F., Mayer, H. (2010): Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. International Journal of Biometeorology 54, 131–139.

7 Thermal comfort and how we measure it

A number only helps if people know what it means.

Thermal comfort is the state in which the energy balance closes without the body having to work at it. No sweating worth mentioning, no shivering, no need to move into the shade. Most people find it between eighteen and twenty-three degrees of physiologically equivalent temperature in central Europe — a range that shifts with climate and habit, as the Taiwan comparison below shows.

The problem was always how to say it. A heat balance can be calculated in watts, and watts mean nothing to a city councillor. So we looked for a unit that everybody already carries in their head. The Physiologically Equivalent Temperature, PET, is that attempt. It answers a simple question: in a standard room, with still air and no sun, at which air temperature would this person have the same skin temperature and the same core temperature as they have right now, out here? The answer is a number in degrees Celsius (Höppe 1999). Forty-two degrees PET needs no explanation.

I still remember calculating a PET value for a real street for the first time, rather than a test case on paper. It came out close to what I had felt walking to the measurement point ten minutes earlier, close enough that the coincidence itself was the argument. That was the moment the index stopped being an equation and became, for me, something worth building a career on.

One word deserves care here, because it is the source of most misunderstandings. Heat for humans cannot be measured. A thermometer measures air temperature. A globe thermometer measures a radiation effect. An anemometer measures wind. None of them measures the load on a human being, because that load is not a property of the air — it is what happens between the air and a body. It is calculated, from all those measurements together and from a model of how a body exchanges heat with its surroundings (VDI 3787 Part 2, 2022). Every thermal index in this book is the result of such a calculation. That is not a weakness to apologise for. It is the only honest way to put a number on something that only exists where the atmosphere meets a person.

The idea is older than our field. Indoor climate research had already put comfort into a formula in the early seventies, when Fanger derived the predicted mean vote from the heat balance of a person in a room (Fanger 1972). What human biometeorology had to add was the outdoors: the sun, the wind, and surfaces that are nothing like room temperature.

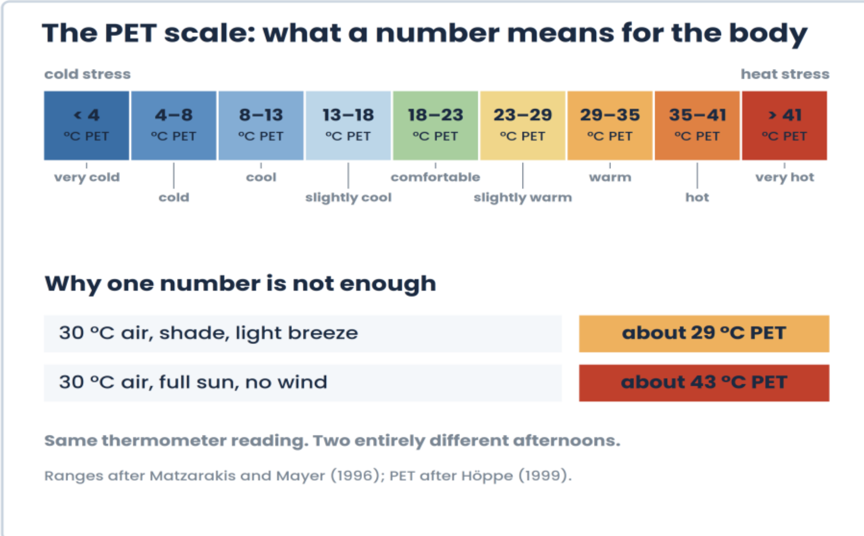


Figure 7: The PET scale, from extreme cold stress to extreme heat stress, and what the same air temperature can mean under different radiation and wind. (Matzarakis et al., 1999.)

The ranges in the table below came out in the mid-nineties (Matzarakis and Mayer 1996; Matzarakis et al. 1999). They are not laws of nature. They describe a standard person, lightly clothed, doing light work, and they should be read as a guide rather than a verdict. People in Athens and people in Helsinki do not draw the line in the same place (de Dear and Brager 1998).

The Universal Thermal Climate Index, UTCI, took a different route. It runs a model of human heat regulation, lets the clothing adapt as a real person would, and reports the result again in degrees Celsius. It was built by a large international group and is now the common language between weather services (Jendritzky et al. 2012). PET and UTCI usually agree on the direction and often disagree by a few degrees on the value. No scandal in that. They are two rulers, and both of them are honest about what they measure, or better what they quantify.

PET has a known weakness, and naming it does more good than hiding it. Its clothing and its handling of air humidity are fixed in a way that suits a temperate climate better than a tropical one, so in humid heat it reports less strain than a body actually carries. The modified PET, mPET, was built to repair exactly that. It uses a multi-node model of the body and lets the clothing adjust to the conditions, so humidity and clothing finally get the weight they deserve (Chen and Matzarakis 2018; Chen et al. 2020). Tested against two thousand questionnaires in hot and humid Taiwan, the comfortable range came out at roughly 26 to 30 °C — higher than the central European range, but consistent with it once local climate and habit are taken into account (Lin et al. 2019). For central Europe, PET and mPET stay near each other. For the humid tropics, and for the chapters on humid heat and on work that follow, mPET is the better ruler.

One warning, because I have seen it go wrong often. An index is a tool for comparing situations, not a promise about an individual. An older person on medication, a child, a construction worker and a tourist standing in the same square have the same PET and four different risks. Chapter 29 comes back to that.

Why two people feel the same weather differently. Stand two people in the same square at the same PET, and one is comfortable while the other is not. None of this is imagination. Age changes the margin: an older body sweats later and less, and its circulation has less reserve to spend on cooling. Health does the same: medication, heart and respiratory disease, and simply being unwell all narrow the range in which a person copes. Acclimatization matters as much as either, which is why the comfortable range measured in Athens sits higher than the one measured in Helsinki (de Dear and Brager 1998) — a body that has spent a summer in the heat genuinely needs less relief than one that has not. Clothing and activity are the two variables a person controls directly, and they can move the felt temperature by several degrees either way. And expectation plays its own quiet part: a day that feels merely warm in July can feel oppressive in May, before the body or the mind has adjusted to the season. None of this makes the index wrong. It makes the index what it always was, a description of the air, not a verdict on the person standing in it.

Table 7: PET ranges, thermal perception and physiological stress (Matzarakis et al., 1999)

PET	Thermal perception	Physiological stress
below 4 °C	very cold	extreme cold stress
4 to 8 °C	cold	strong cold stress
8 to 13 °C	cool	moderate cold stress
13 to 18 °C	slightly cool	slight cold stress
18 to 23 °C	comfortable	no thermal stress
23 to 29 °C	slightly warm	slight heat stress
29 to 35 °C	warm	moderate heat stress
35 to 41 °C	hot	strong heat stress
above 41 °C	very hot	extreme heat stress

In a changing climate. The whole distribution of PET days is sliding upwards. In Freiburg we found the days with strong heat stress rising by about five per cent of the year (Matzarakis and Endler 2010), while days with cold stress fell from sixteen per cent to under four. A city that plans only for the first number and forgets the second will get its heating and its cooling both wrong.

GOOD TO KNOW

Between 18 and 23 °C PET most people are comfortable. Above 35 °C PET, plan the day differently.

An index describes a situation, not a person. Your neighbour’s risk is not your risk.

Keywords: Thermal comfort · PET · UTCI · Thermal perception · Physiological stress · Thermal index

SOURCES

Höppe, P. (1999): The physiological equivalent temperature — a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology 43, 71–75.
VDI 3787 Part 2 (2022): Environmental meteorology — Methods for human-biometeorological evaluation of the thermal component of the climate. VDI, Düsseldorf.
Fanger, P. O. (1972): Thermal Comfort: Analysis and Applications in Environmental Engineering. McGraw-Hill, New York.
Matzarakis, A., Mayer, H. (1996): Another kind of environmental stress: thermal stress. WHO Collaborating Centre for Air Quality Management and Air Pollution Control, Newsletters 18, 7–10.
Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84.
de Dear, R., Brager, G. S. (1998): Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions 104, 145–167.
Jendritzky, G., de Dear, R., Havenith, G. (2012): UTCI — why another thermal index? International Journal of Biometeorology 56, 421–428.
Chen, Y.-C., Matzarakis, A. (2018): Modified physiologically equivalent temperature — basics and applications for western European climate. Theoretical and Applied Climatology 132, 1275–1289.
Chen, Y.-C., Chen, W.-N., Chou, C. C.-K., Matzarakis, A. (2020): Concepts and new implements for modified physiologically equivalent temperature. Atmosphere 11, 694.
Lin, T.-P., Yang, S.-R., Chen, Y.-C., Matzarakis, A. (2019): The potential of a modified physiologically equivalent temperature (mPET) based on local thermal comfort perception in hot and humid regions. Theoretical and Applied Climatology 135, 873–876.
Matzarakis, A., Endler, C. (2010): Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. International Journal of Biometeorology 54, 479–483.

8 Heat, and the nights that follow

The day is hard. The night decides.

Warmth is life. Without it nothing grows and nothing moves. But the body is a fine mechanic and it keeps its core near thirty-seven degrees. A few degrees above that and it is in trouble.

A word on the words. English lets us keep apart what German folds into one. Warmth is what a person feels — the sun on the skin, a room that is comfortable, the welcome side of things. Heat is the physical quantity and the hazard: the energy in the air and the load on the body, the thing we compute from the energy balance and warn about in summer. Thermal is the adjective for the field — thermal comfort, thermal index, thermal environment. The rule that keeps them straight is simple: warmth is felt, heat is calculated. We do not read heat off a thermometer; we work it out from the human energy balance and give the answer in degrees Celsius, so that anyone can understand it.

Under heat the body does two things. It widens the vessels of the skin, so warm blood reaches the surface and can give off heat. And it sweats, because evaporating water takes heat away with it. Both cost something. The circulation works harder, the fluid balance drains, and the heart of an old or sick person may not have the reserve for it.

My first heat study was Athens, July 1987. Air temperatures above forty degrees for days, a city that could not cool down, and around a thousand additional deaths (Matzarakis and Mayer 1991). I was young and I remember being shocked less by the numbers than by how ordinary the days looked from outside. Nobody drowns visibly in a heat wave. People simply stop coping, mostly alone, mostly indoors.

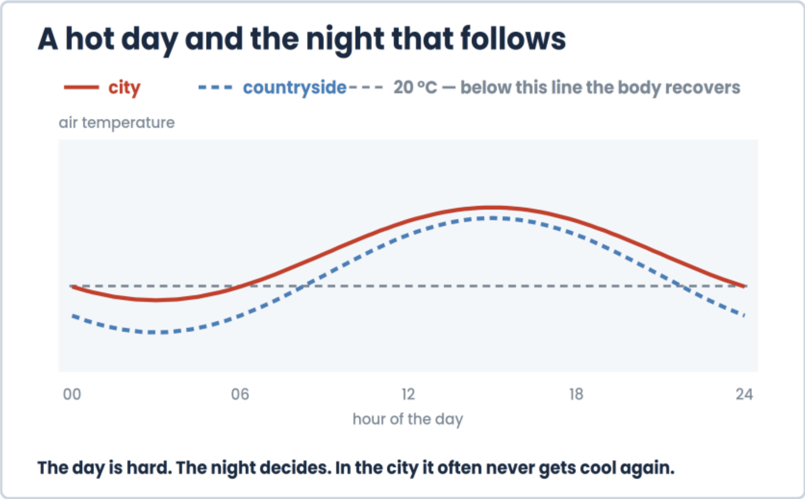


Figure 8: A hot day in the city and in the countryside. The daily maximum is similar. The night is not, and that is where the difference does its damage.

This is why a heat wave is defined by duration and not only by the peak. One hot afternoon is uncomfortable. Five hot days in a row with warm nights are dangerous, because the body never gets its recovery period. A night below twenty degrees allows the circulation to settle and sleep to work. Above that we speak of a tropical night, and in a dense city with stored heat in the walls those nights come in sequences.

Our work in Athens and in Vienna showed the same picture from two different climates (Matzarakis and Nastos 2011; Matzarakis et al. 2011). Mortality follows the heat with a lag of one to three days, it follows the thermal indices better than it follows air temperature, and it rises most steeply when the nights stop cooling. In Greece we also counted the tropical days over the second half of the last century (Nastos and Matzarakis 2008). They did not increase smoothly. They increased in steps, and the steps are getting closer together.

The good news is that almost everything that helps is simple. Drink before you are thirsty. Avoid the midday sun. Ventilate at night and shade by day, in that order, which is the opposite of what most people do. Light clothing. A cool room somewhere in the building. And a look in on the older neighbour, which has saved more lives than any technical measure.

Table 8: Words that get used for hot weather

Term	Definition	What it means for the body
Summer day	maximum ≥ 25 °C	pleasant for most people
Hot day	maximum ≥ 30 °C	load begins for sensitive groups
Tropical night	minimum ≥ 20 °C	no recovery; the critical measure
Heat wave	several hot days in sequence	the load accumulates
Strong heat stress	PET above 35 °C	shade and rest needed

In a changing climate. In most European cities, tropical nights are increasing faster than hot days. No number in this field is reported less often. The maximum air temperature makes the headline, and the minimum temperature fills the hospital.

GOOD TO KNOW
Ventilate at night, shade by day. Most people do it the other way round.
Watch the night minimum, not the day maximum. Above 20 °C the body gets no recovery.

Keywords: Heat · Heat wave · Tropical night · Thermoregulation · Heat-related mortality · Recovery

SOURCES

Winklmayr, C., Matthies-Wiesler, F., Muthers, S., Buchien, S., Kuch, B., an der Heiden, M., Mücke, H.-G. (2023): Heat in Germany: health risks and preventive measures. Journal of Health Monitoring 8(S4), 3–32.

Matzarakis, A., Mayer, H. (1991): The extreme heat wave in Athens in July 1987 from the point of view of human biometeorology. Atmospheric Environment 25, 203–211.

Matzarakis, A., Nastos, P. T. (2011): Human-biometeorological assessment of heat waves in Athens. Theoretical and Applied Climatology 105, 99–106.

Matzarakis, A., Muthers, S., Koch, E. (2011): Human biometeorological evaluation of heat-related mortality in Vienna. Theoretical and Applied Climatology 105, 1–10.

Nastos, P. T., Matzarakis, A. (2008): Variability of tropical days over Greece within the second half of the twentieth century. Theoretical and Applied Climatology 93, 75–89.

9 Humid heat and the limits of sweating

Sweat that runs off the skin has done nothing at all.

Once the air is warmer than the skin, radiation and convection stop helping. They start working against us and bring heat in. From that point the body has exactly one cooling system left, and it is evaporation. A litre of sweat that evaporates carries away well over half a kilowatt-hour of heat. The same litre running down the back and into the shirt carries away nothing.

Whether sweat evaporates depends on the air. Dry air takes it greedily. Humid air is already close to full and takes very little. This is the whole difference between a dry heat and a humid one, and it is far larger than most people expect. Thirty-five degrees at thirty per cent humidity is a hard but manageable afternoon. Thirty-five degrees at eighty per cent is a medical situation.

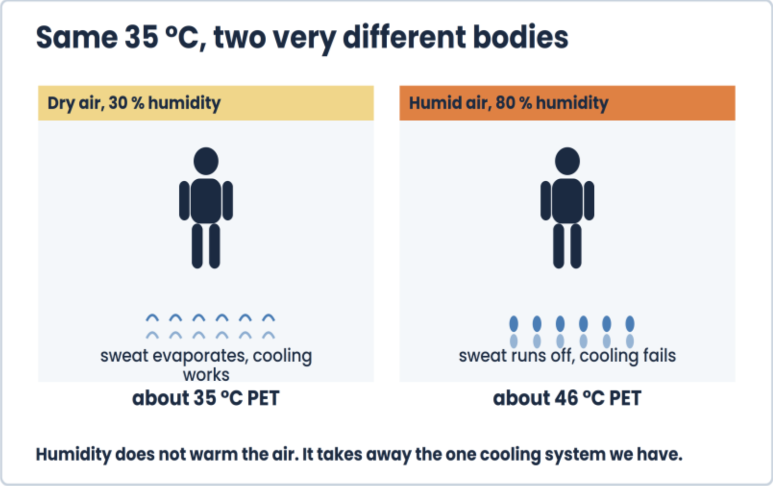


Figure 9: The same air temperature, two humidities. In dry air the sweat evaporates and cools. In humid air it runs off and the cooling fails.

Physiologists express the limit with the wet-bulb temperature, which is what a thermometer wrapped in a wet cloth shows. It is the lowest temperature that evaporation can reach under the given conditions. Above a wet-bulb temperature of about thirty-five degrees, a healthy resting person in the shade can no longer shed metabolic heat at all, however much they sweat and however much they drink. That is a theoretical survival limit, and it sits well above what the body can actually tolerate: chamber studies find young, healthy adults lose thermal balance at wet-bulb temperatures of only 25 to 28 °C in hot, dry air and 30 to 31 °C in warm, humid air (Vecellio et al. 2022). Even the theoretical limit itself was, until recently, thought never to occur on Earth (Sherwood and Huber 2010). It has now been measured for short periods in the Persian Gulf and in the Indus valley (Raymond, Matthews and Horton 2020).

Wet-bulb temperature measures only the evaporative half of the heat balance. It says nothing about the sun on a person's skin or the heat a working body produces itself — Chapter 6 covers those separately — so a shaded, resting body can sit near this limit while a body working in full sun crosses it at a far lower reading. This causes a genuine mix-up worth naming: wet-bulb temperature is not the wet-bulb globe temperature (WBGT), the heat-stress index most widely used in occupational health and sports safety guidance, rather than by national weather services generally. WBGT adds a black-globe reading for radiation to the wet-bulb and dry-bulb temperatures, bringing it closer to the full energy balance — which means a WBGT of thirty degrees and a wet-bulb temperature of thirty degrees describe different levels of stress, not the same one.

The practical point is far below that limit. Long before the theoretical threshold, work becomes impossible, sleep fails, and people with heart or kidney disease decompensate. Our mortality analyses in Vienna and in Athens both showed that indices which include air humidity track the deaths better than air temperature does (Matzarakis et al. 2011; Nastos and Matzarakis 2012). That is not a subtle statistical footnote — it is the reason humidity belongs in every heat warning.

A majority of humanity lives in climates where humid heat, not dry heat, is the challenge. Most of the research and most of the warning systems were built for the drier climates instead. That imbalance is slowly correcting itself, and it should.

Table 9**:** Thirty-five degrees, four humidities

Relative humidity	Wet-bulb temperature	Approximate mPET	Situation
20 %	about 20 °C	about 33 °C	hot, sweating works well
40 %	about 25 °C	about 37 °C	strong load, drink and rest
60 %	about 29 °C	about 42 °C	heavy work unsafe
80 %	about 32 °C	about 46 °C	dangerous even at rest

In a changing climate. Warmer air holds more water vapour, roughly seven per cent more for every degree. Humid heat therefore rises faster than dry heat, and it rises fastest in exactly those regions that are already humid and already crowded. Days that combine high air temperature with high air humidity are the fastest-growing category of dangerous weather anywhere.

GOOD TO KNOW

If your sweat is running instead of drying, the cooling has stopped. Slow down. A fan helps even in humid heat, by keeping some evaporation going. It is very hot, dry air above skin temperature where a fan can do more harm than good (Ebi et al. 2021).

Keywords: Humid heat · Evaporation · Wet-bulb temperature · Wet-bulb globe temperature · Sweating · Survival limit · Heat warning

SOURCES

Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., Jay, O. (2021): Hot weather and heat extremes: health risks. The Lancet 398, 698–708.
Sherwood, S. C., Huber, M. (2010): An adaptability limit to climate change due to heat stress. Proceedings of the National Academy of Sciences 107, 9552–9555.
Raymond, C., Matthews, T., Horton, R. M. (2020): The emergence of heat and humidity too severe for human tolerance. Science Advances 6(19), eaaw1838.
Vecellio, D. J., Wolf, S. T., Cottle, R. M., Kenney, W. L. (2022): Evaluating the 35°C wet-bulb temperature adaptability threshold for young, healthy subjects (PSU HEAT Project). Journal of Applied Physiology 132, 340–345.
Matzarakis, A., Muthers, S., Koch, E. (2011): Human biometeorological evaluation of heat-related mortality in Vienna. Theoretical and Applied Climatology 105, 1–10.
Nastos, P. T., Matzarakis, A. (2012): The effect of air temperature and human thermal indices on mortality in Athens, Greece. Theoretical and Applied Climatology 108, 591–599.

10 Cold, wind and wind chill

Cold is patient. It takes the warmth slowly, and it takes it from everyone.

Cold puts the body on the defensive. The vessels of the skin narrow so that warm blood stays in the core. The metabolism climbs. The muscles begin to shiver, which is simply a way of producing heat by doing useless work. In moderation all of this is invigorating and it trains the circulation. Medicine uses cold deliberately against pain and inflammation.

Too much of it turns dangerous. The body loses heat faster than it can make it, the core temperature falls, and thinking becomes slow before the person notices anything is wrong. That last point is what makes cold treacherous. Heat announces itself. Cold takes the judgement away before it takes the warmth.

Two things multiply the loss. Wind, because it strips away the thin layer of warmed air that clings to the skin, and moisture, because water conducts heat away roughly twenty times faster than air. Wet clothing in a breeze at five degrees can be more dangerous than dry clothing in still air at minus ten. This is what wind chill tries to express: what the same air temperature would feel like against exposed skin, referenced not to true calm but to the light, walking-pace breeze that modern wind chill indices use as their baseline.

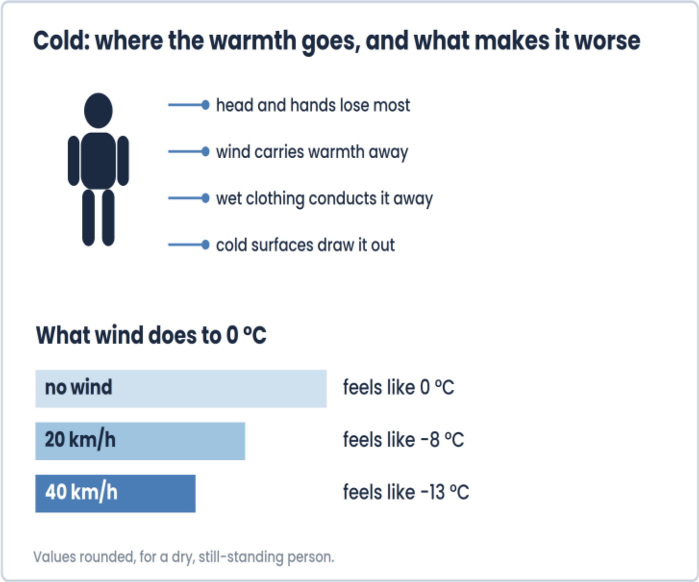


Figure 10: Where the warmth goes in the cold, and what wind does to a temperature of zero degrees.

The people at risk are the familiar ones and one that is often forgotten. Older people, whose circulation and whose sense of temperature both weaken. Infants, with a large surface for their volume. People with heart disease, because the heart has to pump against narrowed vessels. And people whose homes are cold, which in Europe is a far larger group than most health ministries admit.

That last point deserves its own sentence. In most countries more deaths are still attributed to cold than to heat, and a great many of them are linked to cold, poorly heated housing, spread quietly across the winter (WHO 2018). It is not a dramatic story and it gets very little attention. Our work in Athens on respiratory infections showed the same seasonal signature (Nastos and Matzarakis 2006): the airways suffer when cold, dry air meets a badly heated room.

Protection is old knowledge. Several thin layers rather than one thick one, because the air between them does the insulating. Cover the head and the hands. Keep moving. Stay dry. And check on the neighbour, in January as much as in August.

Table 10: Cold stress and what it asks for

PET	Cold stress	What is sensible
13 to 18 °C	slight	a jacket, nothing more
8 to 13 °C	moderate	layers, keep moving
4 to 8 °C	strong	cover head and hands, limit exposure
below 4 °C	extreme	short exposure only, watch for wind and wet

In a changing climate. Days with cold stress are becoming clearly fewer, and this is a real gain that is rarely counted. But the winter deaths do not fall in the same proportion, because most of them come from cold housing rather than from cold weather. A milder climate does not repair a badly insulated flat.

GOOD TO KNOW
Several thin layers beat one thick one. The trapped air does the insulating.
Wet and windy at plus five degrees can be harder on the body than dry and still at minus ten.

Keywords: Cold · Wind chill · Hypothermia · Cold stress · Indoor cold · Respiratory infections

SOURCES
Nastos, P. T., Matzarakis, A. (2006): Weather impacts on respiratory infections in Athens, Greece. International Journal of Biometeorology 50, 358–369.
WHO (2018): Housing and health guidelines. World Health Organization, Geneva.

11 The cold stimulus

A short cold shock can wake the body up. A long one can switch it off.

There is a long tradition behind this chapter. Cold water cures were part of European spa medicine for two centuries, sea bathing was prescribed by physicians long before it became a holiday, and the sauna followed by a cold plunge is older than any of it. The tradition was built on observation rather than on measurement, and a surprising amount of it has held up.

What happens is quick and well described. Within seconds the skin vessels close and blood is pulled into the core. Breathing deepens, the heart rate jumps, stress hormones are released. Within a minute or two the metabolism is running higher. When the stimulus stops, the vessels open again and a wave of warm, well-perfused blood returns to the skin. This is the pleasant part, the afterglow, and the part people become attached to.

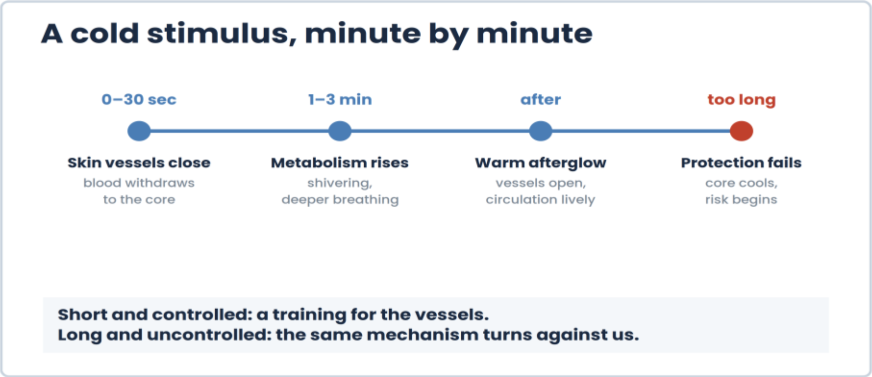


Figure 11: What a cold stimulus does, and where the useful part ends.

Repeated regularly, controlled cold seems to make the vessels more responsive and the response to the shock less violent over time. People report better mood and better sleep, and there is reasonable evidence for the mood effect. The claims about the immune system are weaker than the internet suggests, and the claims about weight loss and metabolism are weaker still. I would not discourage anyone. I would also not promise anything.

The risks are concentrated in the first thirty seconds. The gasp reflex on entering cold water has drowned strong swimmers (Tipton et al. 2017). The jump in blood pressure and heart rate is a genuine danger for people with coronary disease or high blood pressure, and it is exactly the group most likely to be told that cold showers are healthy. Anyone with a heart condition should ask a doctor before starting, not afterwards.

The sensible rule is the one the old spa physicians already used. Short, regular, and never to the point of shivering that will not stop. A cold stimulus is a dose, and like every dose it has a range in which it works and a range in which it harms.

Table 11: The dose makes the difference

Dose	What the body does	Effect
Seconds to 2 minutes	vessels close, metabolism rises	alerting, pleasant afterglow
Regular, over weeks	response becomes calmer	vessels train, mood often better
Long, uncontrolled	core temperature falls	shivering, confusion, danger
With heart disease	sharp rise in pressure and pulse	medical advice needed first

In a changing climate. As winters grow milder, the everyday cold stimulus that used to come free with the season is disappearing. People buy it back in the form of cold showers and ice baths. There is something worth noticing in that: we are recreating deliberately a stimulus that our grandparents could not have avoided.

GOOD TO KNOW

Short, regular, and stop before the shivering sets in.
With a heart condition or high blood pressure, ask a doctor before you start, not afterwards.

Keywords: Cold stimulus · Hardening · Circulation · Cold water immersion · Spa tradition · Dose

SOURCES

Tipton, M. J., Collier, N., Massey, H., Corbett, J., Harper, M. (2017): Cold water immersion: kill or cure? Experimental Physiology 102, 1335–1355.

12 Acclimatization, clothing and behaviour

The body is slow, the behaviour is fast, and the culture is stubborn.

People live from the Arctic to the desert because they can adjust on three different time scales at once, and the three do not compete. They cover for each other.

The body adjusts over days and weeks. Move someone from a cool climate into a hot one and within about a week they begin to sweat earlier in the exposure, within two weeks they sweat more and lose less salt in it, and the circulation stops labouring. Heat acclimatization is one of the most reliable effects in human physiology. It is also fragile. Two or three weeks back in a cool climate and most of it is gone. Cold acclimatization exists but is much weaker; in the cold we adapt mainly by what we wear and what we build.

Behaviour adjusts in minutes and does most of the daily work. Step into the shade. Move the hard job to seven in the morning. Drink. Open the window at night and close the shutters at ten. None of this requires a plan or a budget, and together these small decisions shift the thermal load by more than most technical measures.

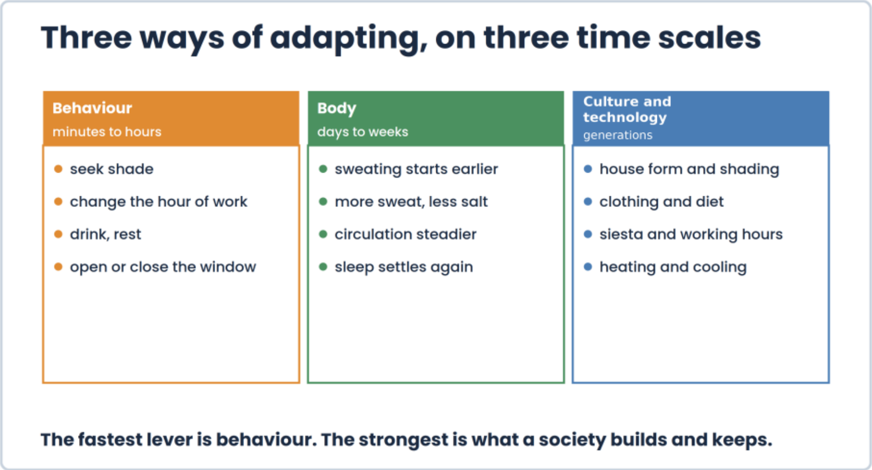


Figure 12: Three levers of adaptation on three time scales. They do not replace each other.

Clothing sits between the two. It is measured in clo, a unit of insulation that is really the heat resistance clothing offers: a light summer outfit is about half a clo, a business suit one, heavy winter clothing around two to two and a half — three or more is polar expedition wear, not an ordinary winter coat. Anyone who has ever gone outside dressed wrongly knows how much power sits in that one variable.

The third scale is the slowest and the one we tend to overlook because we grew up inside it. Building form, street width, courtyards, the siesta, when a country eats and when it works, what people drink in the afternoon. In Taiwan we measured what shade alone does to long-term outdoor comfort in a public space, and the answer was that a well-placed tree beats a great deal of technology (Lin et al. 2010). In Strasbourg during the heat wave of 2003 the differences between neighbouring streets were larger than the differences between years (Matzarakis et al. 2009).

The point of the chapter is a practical one. When a city or a hospital plans for heat, it should ask which of the three levers it is actually pulling. Most plans pull the slowest and the most expensive one first. The fastest one is usually free, and it needs information rather than money.

Table 12**:** Three levers of adaptation

Lever	Time scale	Examples	Limits
Behaviour	minutes to hours	shade, timing, drinking, ventilating	needs information and freedom to act
Body	days to weeks	earlier and richer sweating	lost again within weeks
Culture and technology	generations	building form, working hours, cooling	slow, costly, hard to reverse

In a changing climate. Acclimatization needs a stable season to work with. When heat arrives in early May, before anyone has adjusted, the same temperature does more damage than it would in August — a real physiological effect, not a statistical artefact. That does not make early heat waves the deadliest overall: the worst events on record, 2003 in Europe and 2010 in Russia, both struck at the height of summer, driven by extreme intensity and duration rather than by timing.

GOOD TO KNOW

Give yourself a week in a new climate before doing anything strenuous. The first heat wave of the year is the dangerous one, because nobody is adapted yet.

Keywords: Acclimatization · Clothing insulation · Adaptive comfort · Behaviour · Shading · Early heat waves

SOURCES

Lin, T.-P., Matzarakis, A., Hwang, R.-L. (2010): Shading effect on long-term outdoor thermal comfort. Building and Environment 45, 213–221.
Matzarakis, A., De Rocco, M., Najjar, G. (2009): Thermal bioclimate in Strasbourg — the 2003 heat wave. Theoretical and Applied Climatology 98, 209–220.

13 Heat at work and in sport

Heat does not ask what your job is.

Everything in the previous chapters assumed a person standing still. Now put them to work. Physical work multiplies the heat produced inside the body by three or four, and that heat has to leave through the same narrow channels as before. A bricklayer on a hot roof and a pensioner on a shaded balcony are exposed to the same weather and are in two entirely different situations.

The consequences are measurable and they are large. Work capacity falls long before anyone collapses. Concentration goes first, then accuracy, then speed, and accident rates climb well before the heat becomes officially dangerous (Kjellstrom et al. 2016). The International Labour Organization projects that heat stress will cost 2.2 per cent of total working hours worldwide by 2030, equivalent to some eighty million full-time jobs (ILO 2019). Most of that loss falls on agriculture and construction, and most of it falls on people who are paid by the hour or by the piece and therefore cannot afford to stop.

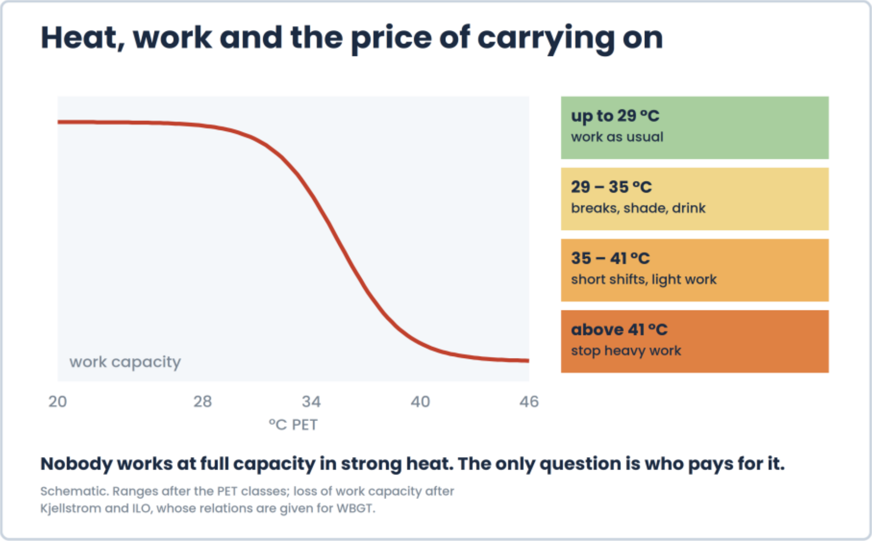


Figure 13: How work capacity falls with rising heat load, and what the different ranges call for.

The measures are unglamorous and they work. Shift the heavy work into the early morning. Build breaks into the schedule instead of leaving them to individual judgement, because a person paid by output will not take them. Provide shade at the workplace, not two hundred metres away. Provide water where the work is. Let new workers acclimatize over a week rather than throwing them straight onto the roof, which is when most heat incidents happen. And write the rules in terms of a thermal index rather than air temperature, or they will be wrong on exactly the days that matter.

Sport is the same physiology with a different social contract. Athletes are fit, acclimatized and monitored, and they still collapse, because competition removes the one protection that everybody else has: the freedom to slow down. The answers there are scheduling, shading of spectator areas, mandatory drinks breaks tied to a measured index, and a willingness to move or cancel an event. Amateur mass events deserve more attention than elite sport. The runner in the middle of the field is less fit, less monitored and more likely to ignore the warning signs.

The clearest case anyone can point to is a football tournament. When Qatar was awarded the 2022 World Cup, we looked at what a Doha summer actually does to the people who come to watch. The result was blunt. From May to September the conditions cause strong heat stress for visitors during the large majority of daylight hours, and the values run so high that the PET classes of 1996 had to be extended at the top end to describe them at all. November to February, by contrast, offers thermally comfortable conditions far more often (Matzarakis and Fröhlich 2015).

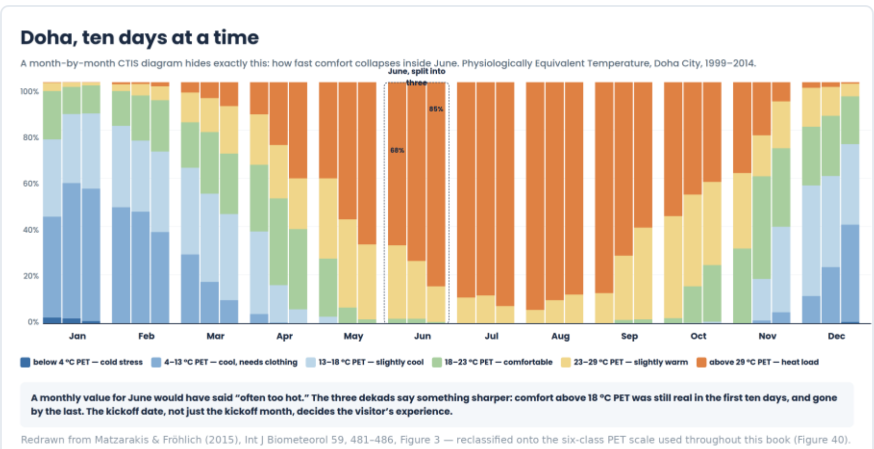


Figure 14: Doha, ten days at a time: PET frequency by dekad, redrawn from Matzarakis and Fröhlich (2015) on the extended PET scale of Figure 41.

Cooled stadiums were promised and they were built. But a tournament is not ninety minutes inside a stadium. It is training grounds, fan zones, queues, staff outdoors all day, and hundreds of thousands of visitors who are not acclimatized and who spend most of their time outside the stadium. In the end the calendar moved rather than the physiology. FIFA shifted the tournament out of the summer into November and December — the first World Cup moved to the Northern Hemisphere's winter (Argentina 1978 and South Africa 2010 had already fallen in a Southern Hemisphere winter, but as an accident of geography, not as a response to heat) — and the European leagues rearranged their seasons around it. Whether our paper caused that decision I cannot say; FIFA ran its own feasibility studies and reached the same months. What matters is the direction of the argument. For once an institution moved because the heat load on human beings could not be engineered away — and the same reasoning has since been applied to the Olympic Games (Matzarakis et al. 2019).

Underneath all of it sits a question about who carries the cost. The office worker gets air conditioning. The delivery rider gets a bottle of water and an app that keeps counting. Heat is not a great equaliser. It follows the same lines everything else follows.

Table 13**:** Heat load and sensible work practice

Heat load (PET)	Physical work	What should be organised
up to 29 °C	normal	water available, sun protection
29 to 35 °C	reduced	regular breaks in shade, drinking rhythm
35 to 41 °C	clearly limited	short shifts, light tasks, buddy system
above 41 °C	not advisable	postpone heavy work, medical standby

In a changing climate. The number of working hours lost to heat is projected to keep rising, and it rises fastest in the regions that can least afford it. This is the point where human biometeorology stops being a health topic and becomes an economic and a social one. A heat action plan that covers hospitals but not workplaces protects the people who are already the safest.

GOOD TO KNOW

Move the heavy work into the early morning. The heat load peaks in the afternoon, not at noon.

Breaks have to be scheduled. People paid by output will not take them on their own.

Keywords: Occupational heat · Work capacity · Work-rest cycles · Sport · Heat incidents · Social inequality

SOURCES

ILO (2019): Working on a warmer planet: the impact of heat stress on labour productivity and decent work. International Labour Organization, Geneva.

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016): Heat, human performance, and occupational health. Annual Review of Public Health 37, 97–112.

Matzarakis, A., Fröhlich, D., Bermon, S., Adami, P. E. (2019): Visualization of climate factors for sports events and activities — the Tokyo 2020 Olympic Games. Atmosphere 10, 572.

Matzarakis, A., Fröhlich, D. (2015): Sport events and climate for visitors—the case of FIFA World Cup in Qatar 2022. International Journal of Biometeorology 59(4), 481–486.

PART III

The Actinic Effect Complex

Radiation does not warm us only. A large part of what the sun does to a body happens chemically, in the skin, in the eyes and in the inner clock, and it happens quietly. The damage of a July afternoon shows up in the evening, or thirty years later. Five chapters on what the sun sends us, and on the part of it — the part we can neither see nor feel — that does the most lasting damage.

14 Sun, light and radiation

One sun, three entirely different jobs.

Everything that keeps this planet alive arrives as radiation from a star at a safe distance. It reaches the top of the atmosphere at about 1361 watts per square metre, and on average, over the year and across all sky conditions, roughly half of it makes it to the ground. What arrives is not one thing. It is a spectrum, and the body deals with each part of it differently (Matzarakis 2020).

About half the energy is infrared. We feel it immediately as warmth on the skin, and it belongs to the thermal complex of the previous part. Just under half is light, the narrow band our eyes evolved to use. And a few per cent is ultraviolet, which we cannot see or feel at all. That last point is the whole problem with ultraviolet radiation, and it fills the next two chapters.

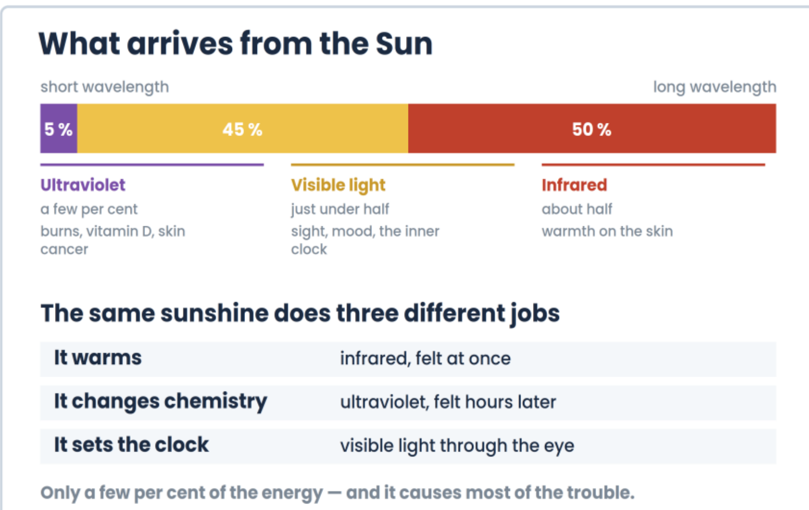


Figure 15: What arrives from the Sun, and the three different jobs it does on the human body.

Radiation reaches a person from every direction, not only from the sun. The sky sends down scattered radiation, walls and pavements send back what they reflected and what they stored, and the ground radiates upwards. On a summer afternoon in a paved square, the radiation coming from the surfaces around a person can exceed the radiation coming directly from the sun. Anyone who has stood between two south-facing house walls in August has measured this without instruments.

All of it together is summarised in the mean radiant temperature, and calculating it correctly for a real street with real trees and real buildings is one of the harder practical problems in this field. It is what RayMan was written for (Matzarakis et al. 2007, 2010). The model takes the sky that a person actually sees, works out what arrives from each direction, and hands back a number that a planner can use.

There is one comfort in all this: our exposure to two of the three — the infrared warmth and the ultraviolet dose — is largely within our own control, because we choose whether to stand in shade and we choose when to go out. Very little else in human biometeorology is that simple.

Table 14**:** The three parts of sunlight

Part of the spectrum	Share of the energy	What it does to us
Ultraviolet	a few per cent	sunburn, vitamin D, skin cancer, eye damage
Light	about 45 per cent	sight, mood, the daily rhythm
Infrared	about 50 per cent	warmth on the skin, part of the heat load

In a changing climate. Cloud cover is changing in many regions, and with it the radiation reaching the ground. Where the air has become cleaner, more sunlight arrives than fifty years ago — a welcome development for solar power and a less welcome one for skin. Cleaner air and more ultraviolet radiation are the same story told twice.

GOOD TO KNOW

The sun you feel is mostly infrared. The sun that damages you is ultraviolet, and you feel nothing at all.
On a bright day, half of what reaches you can come from walls, ground and sky rather than from the sun itself.

Keywords: Solar radiation · Spectrum · Infrared · Light · Mean radiant temperature · Reflection

SOURCES

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.
Matzarakis, A., Rutz, F., Mayer, H. (2007): Modelling radiation fluxes in simple and complex environments: application of the RayMan model. International Journal of Biometeorology 51, 323–334.
Matzarakis, A., Rutz, F., Mayer, H. (2010): Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. International Journal of Biometeorology 54, 131–139.

15 Ultraviolet radiation and the ozone layer

A gas twenty kilometres up decides how safe an afternoon is.

Ultraviolet radiation comes in three bands, and their fates are completely different. UVC is the most aggressive and never reaches us; the ozone layer stops it entirely. UVB is largely absorbed, about ninety per cent of it, and the remainder is what burns the skin and makes vitamin D. UVA passes almost freely, and it does its slower damage all year round and through window glass.

That the dangerous part is filtered at all is due to a thin gas high above us. Ozone in the stratosphere absorbs ultraviolet radiation and converts it to heat, which is also why the stratosphere warms with height instead of cooling. If you want a single example of how a trace gas decides the conditions for life, this is it: compressed to sea-level pressure, the ozone layer would form a shell only about three millimetres thick.

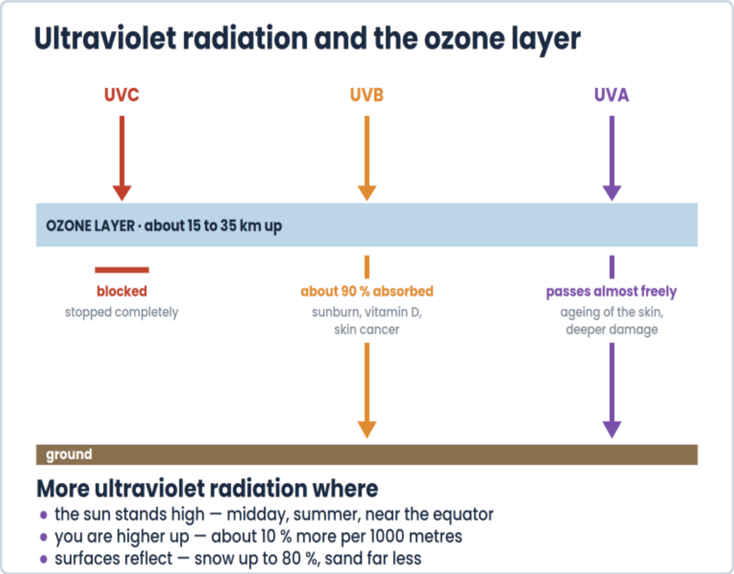


Figure 16: The three ultraviolet bands and what the ozone layer does with each of them.

In the nineteen-eighties it became clear that chlorofluorocarbons from spray cans, refrigerators and foam were destroying that layer, and a hole opened over Antarctica every spring of the southern hemisphere. The Montreal Protocol of 1987 set a schedule to phase the substances out. It is the most successful environmental agreement ever made, the layer is slowly recovering (WMO 2022), and that deserves remembering in a book that spends later chapters on problems we have not solved. We have done this once. It can be done.

How much ultraviolet radiation arrives on a given day depends on things a person can partly judge. The height of the sun matters most, and noon in June is not the same as four in the afternoon in September, and that is why the tropics get more of it than northern Europe ever does. Altitude adds roughly eight to ten per cent per thousand metres. Clouds reduce it, but thin cloud reduces it much less than it reduces the warmth, and that mismatch causes a great many sunburns.

All of it belongs in one picture, because these factors never act one at a time. Follow the radiation down. The sun's height sets how much atmosphere it has to cross, and with it the latitude and the season; about sixty per cent of a day's dose falls between ten and two. The ozone layer removes all UVC and most UVB. The remaining air absorbs and scatters, and every thousand metres of altitude therefore adds eight to ten per cent. Cloud takes away the warmth faster than the ultraviolet, so under a scattered sky roughly nine tenths still arrives and only a thick overcast brings it down to about a third — and that mismatch is what causes the sunburn nobody expected. What is left comes from the whole sky and not only from the sun, which is why shade is never total: under a tree or an umbrella up to half of it still reaches you.

Then the ground gives part of it back. Fresh snow throws up to eighty per cent of it straight back at a face, sea foam about a quarter, dry sand around fifteen per cent, grass almost nothing. A person on a glacier or a beach is lit from below as well as from above, and that is why sunscreen belongs under the chin. Water, finally, looks like protection and is not: half a metre down a swimmer is still in about forty per cent of the surface value, while the cool water removes every warning the skin would otherwise give. Add the reflection from the surface, and a day at the sea becomes one of the most reliable ways to burn (WHO 2002).

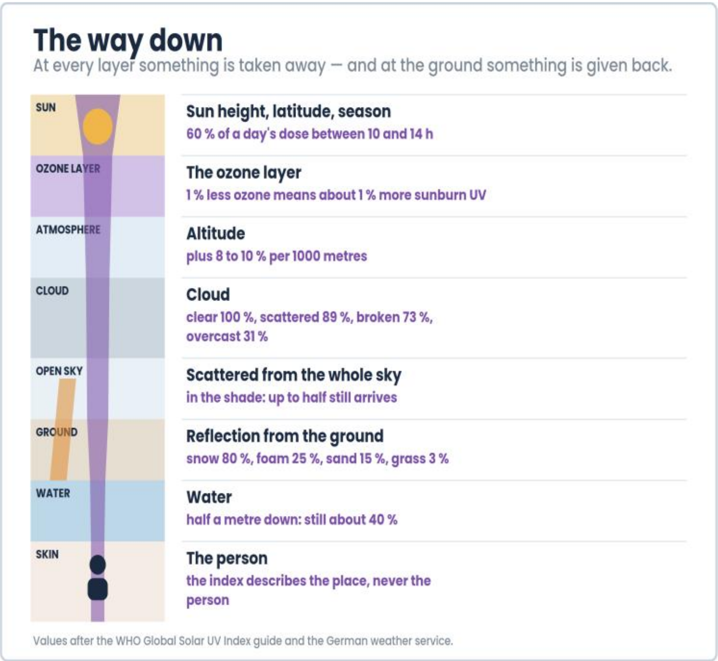


Figure 17: The way down. Every layer takes something away — sun height, ozone, altitude, cloud, the open sky — and the ground gives part of it back. What finally arrives is what the UV Index describes. (WHO 2002.)

Table 15: The three ultraviolet bands

Band	Reaches the ground	Effect on the body
UVC	no, absorbed completely	would be extremely damaging
UVB	about 10 per cent of it	sunburn, vitamin D, skin cancer
UVA	almost completely	ageing of the skin, deeper damage, passes glass

In a changing climate. Climate change and the ozone layer are two different problems that keep meeting. A cooler stratosphere, which is a fingerprint of greenhouse warming, helps ozone recover overall — except at the poles, where a colder polar lower stratosphere actually deepens the springtime ozone loss. But warmer weather changes behaviour too: people spend more time outdoors, more lightly dressed, earlier in the year. The dose of ultraviolet radiation a population receives is set as much by habits as by physics (Baldermann et al. 2023).

GOOD TO KNOW

Thin cloud takes away the warmth but leaves most of the ultraviolet radiation. Overcast days burn people who feel safe.

Snow, and to a lesser extent sand and water, reflect radiation upwards. Shade above you is not full protection.

Keywords: Ultraviolet radiation · UVA · UVB · Ozone layer · Montreal Protocol · Altitude effect

SOURCES

Baldermann, C., Laschewski, G., Grooß, J.-U. (2023): Impact of climate change on non-communicable diseases caused by altered UV radiation. Journal of Health Monitoring 8(S4), 57–75.

WHO (2002): Global Solar UV Index: A Practical Guide. World Health Organization, Geneva.

WMO (2022): Scientific Assessment of Ozone Depletion. World Meteorological Organization, Geneva.

16 Sunburn and the UV Index

The only injury we accept as the price of a nice afternoon.

Sunburn is not a burn in the ordinary sense. Nothing has been heated. Ultraviolet radiation has damaged the genetic material in the cells of the skin, and what we see hours later is the repair operation: blood flow up, inflammation, redness, pain. The delay is the treacherous part. By the time the skin tells us, the dose was taken four hours ago.

Most of it is repaired. A small part is not, and it accumulates over a lifetime. Sunburns in childhood count more heavily than sunburns later, and the shade of a beach umbrella at the age of six is worth more than any cream at forty. Skin cancer rates in fair-skinned populations have risen for decades. For melanoma, the more dangerous of the two, the pattern follows leisure habits — brief, intense exposure and sunburn — rather than working habits; the accumulated, chronic exposure that outdoor workers get instead drives the other common skin cancer, squamous cell carcinoma.

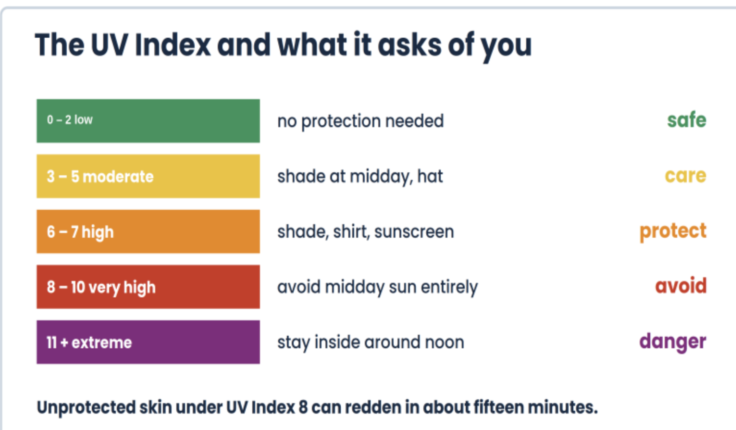


Figure 18: The UV Index, its five ranges and what each of them asks of you.

The UV Index was built to make this manageable (WHO 2002). It is a simple open scale beginning at zero, and it is deliberately not expressed in physical units. Above three, protection is worth thinking about. Above six it is necessary. Above eight, fair, untanned skin can redden in about a quarter of an hour, and the sensible response is to be somewhere else. In central Europe summer values reach seven or eight, in the Mediterranean nine or ten, in the mountains and the tropics higher still.

The protective measures are ranked, and the ranking matters because most people have it upside down. Shade first. Then clothing, a hat and sunglasses, because textile does not have to be reapplied and does not wash off. Sunscreen last, on what is left over. Sunscreen is the weakest of the three and the one people rely on most, largely because it is the easiest of the three to sell — a cream in a tube, rather than a habit of seeking shade or a wardrobe choice.

Table 16**:** What the UV Index means in practice

UV Index	Level	What to do
0 to 2	low	no protection needed
3 to 5	moderate	shade around midday, hat, sunglasses
6 to 7	high	shade, shirt, sunscreen on the rest
8 to 10	very high	avoid the midday hours outdoors
11 and above	extreme	stay indoors around noon

Knowing the UV Index for today is a forecasting problem. Knowing what a place normally offers is a climatological one, and it is the harder of the two, because ground stations that measure ultraviolet radiation are few and unevenly spread across Europe. We therefore built a UV Index climatology for Europe from satellite data instead: thirty-three years, 1983 to 2015, at a resolution of about five kilometres, from North Africa to well beyond the Baltic (Vitt et al. 2020). The monthly maps show in detail what most people only guess in outline — the strong gradient from south to north, the high values over the Alps and the Mediterranean, and month-by-month differences that matter to anyone planning a holiday, a building site or a school timetable. At several of the validation sites the annual mean UV Index has risen significantly, by one to four per cent per decade. This is destination-level detail, exactly what tourism and recreation planning requires.

What a national weather service then does with such numbers is a good example of this whole field at work. The German weather service issues three-day forecasts of the UV Index all year round and runs a warning service on top of them. The warnings do not only cover days with absolutely high values. They also cover spring days on which the value is high for the season, because stratospheric ozone can drop by more than a fifth for a few days in spring, and because skin that has not seen the sun since September is at its most vulnerable. The warnings go out by website, by newsletter and through the warning app, district by district (Deutscher Wetterdienst 2024).

The individual dose is another matter again, and this is where the honest limits of an index show. The UV Index describes the atmosphere above a place; it does not describe a person standing in it. Long-term series for Germany show pronounced regional differences and changes that do not all point in the same direction, and what a single person actually accumulates over a year depends far more on behaviour than on the trend in the radiation itself — on hours spent outdoors, on holidays taken at lower latitudes, on whether the work is in an office or on a roof (Laschewski and Matzarakis 2024). People who work outdoors can accumulate several times the population average. That is where prevention has to start, and it is why a forecast alone is never enough.

In a changing climate. The ultraviolet radiation itself is not rising dramatically. The exposure is. Warmer springs and longer summers move people outdoors for more weeks of the year, and they do it in April, when the skin has no tan and no habit of caution. The first warm weekend of the year reliably produces the first sunburns of the year.

GOOD TO KNOW

Order of protection: shade, then clothing, then sunscreen. Most people use exactly the reverse.

If your shadow is shorter than you are, the sun is high enough to burn you. It is the simplest rule there is.

Keywords: Sunburn · UV Index · Skin protection · Skin cancer · Shade · Sunscreen

SOURCES

WHO (2002): Global Solar UV Index: A Practical Guide. World Health Organization, Geneva.

Vitt, R., Laschewski, G., Bais, A. F., Diémoz, H., Fountoulakis, I., Siani, A. M., Matzarakis, A. (2020): UV-Index climatology for Europe based on satellite data. Atmosphere 11, 727.

Laschewski, G., Matzarakis, A. (2024): Langfristige Veränderung der UV-Strahlung und Auswirkungen auf die individuelle Strahlungsexposition von Menschen in Deutschland. Gefahrstoffe — Reinhaltung der Luft 84(7–8), 187–194.

Deutscher Wetterdienst (2024): UV-Index forecasts and UV warning service. www.dwd.de (accessed 2024).

17 Sun as medicine: vitamin D and heliotherapy

The same radiation that harms us is the one we cannot do without.

Before the antibiotic era, sunshine was a treatment. Tuberculosis patients were laid out on terraces in the Alps, children with rickets were sent to the sea, and whole sanatoria were built facing south for reasons that were, for once, correct. Heliotherapy was one of the few things medicine before antibiotics could offer that actually worked — because of vitamin D, we now understand, and because of what ultraviolet radiation does to some bacteria on the skin, even though vitamin D's fuller role in the body is still debated today.

The mechanism took until the twentieth century to explain. UVB striking the skin converts a cholesterol derivative into a precursor of vitamin D, which the liver and kidneys finish. Vitamin D governs the uptake of calcium and therefore bone, and it has further roles in the immune system that are still being argued about (Holick 2007). Food supplies very little of it. For most of humanity, the skin is the factory.

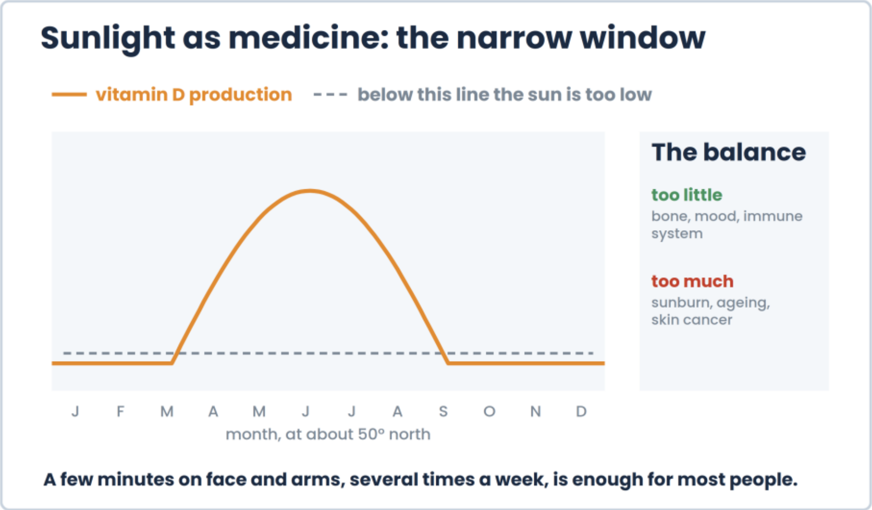


Figure 19: Vitamin D production through the year at middle latitudes, and the narrow window between too little and too much.

The catch is geometric. Vitamin D needs UVB, and UVB only arrives when the sun stands high enough. North of about forty degrees latitude there are months in winter when no amount of sunbathing produces any vitamin D at all, whatever the sky looks like. The body lives off what it stored in summer, and in many northern populations the store runs out in February.

So we sit between two errors. Too little sun costs bone strength, and probably mood and immune function. Too much costs ageing skin and, eventually, cancer. The honest answer is unglamorous and depends on the UV Index rather than the clock: a few minutes with face, hands and forearms uncovered and unprotected, two or three times a week, using only a fraction of the time it would take that skin to burn, is enough for most people in summer, whatever hour of day that falls in (Bundesamt für Strahlenschutz 2022). In winter at high latitudes the question is one for a doctor and a blood test rather than for a sun lounger.

Climate therapy kept the old tradition alive and gave it a proper basis. High-altitude and coastal resorts are still used for skin and airway conditions, and Chapter 38 comes back to them. What has changed is that we now dose the sun instead of prescribing it by the hour.

Table 17: Sunlight, the balance sheet

Too little sunlight	Too much sunlight
weak bones, in children rickets	sunburn, in the short term
low vitamin D in late winter	premature ageing of the skin
mood in the dark season	higher risk of skin cancer
possible effects on immunity	damage to the eyes over decades

In a changing climate. Milder winters do not help here at all. Vitamin D depends on the angle of the sun, and that does not change with the climate. A warm February is still a February. The one thing that does change is behaviour, and going outdoors more often in the cool season is the healthiest response to a milder winter that I know.

GOOD TO KNOW

In winter at northern latitudes, no sun angle means no vitamin D, however long you stay outside.

A few minutes with face, hands and forearms bare and unprotected, two or three times a week, covers most people in summer — the UV Index matters more than the time of day.

Keywords: Vitamin D · Heliotherapy · Rickets · Climate therapy · Latitude · Dosing the sun

SOURCES

Holick, M. F. (2007): Vitamin D deficiency. New England Journal of Medicine 357, 266–281.

Bundesamt für Strahlenschutz (2022): Joint recommendation on UV radiation and vitamin D. UV Protection Alliance, Munich.

18 Light, darkness and the inner clock

The body keeps time by daylight, and we have taken the daylight away.

Almost every process in the body runs on a daily rhythm. Body temperature, blood pressure, hormones, digestion, alertness, the way a medicine is absorbed. The clock that runs them sits in the brain, keeps a period of a little over twenty-four hours on its own, and is reset every morning chiefly by light entering the eye. Not by warmth, not by noise — those matter too, but only at the margins. By light, above all.

Two hormones make the rhythm visible. Melatonin rises in the evening when the light goes and tells the body it is night. Cortisol rises before waking and prepares the body for the day. Both are steered by what the eye sees, and both are surprisingly easy to push around.

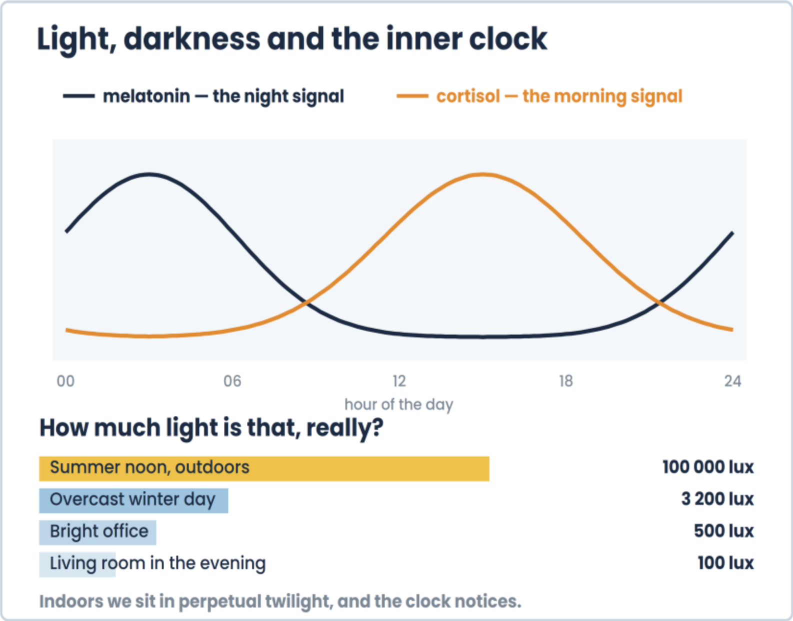


Figure 20: The daily rhythm of the two signal hormones, and how little light there actually is indoors.

The numbers in the lower half of that figure are the ones that surprise people. A bright office gives perhaps five hundred lux. An overcast winter day outdoors gives several thousand. Summer noon outdoors gives a hundred thousand. We have built a life in which the difference between our working day and our evening is a factor of five, when the difference the clock evolved with was a factor of a thousand. From the point of view of the inner clock, most of us live in permanent twilight, and then wonder why sleep is poor.

The consequences are best documented at the extremes. Shift workers, whose clocks are asked to do something they cannot, carry higher risks of metabolic and cardiovascular disease. Travellers crossing time zones lose about a day of adjustment per time zone (Roenneberg and Merrow 2016). And in the dark season at high latitudes a proportion of the population develops a seasonal depression that responds to bright light in the morning.

The remedy is cheap and it is the same one every time. Get real daylight into the eye in the first hours of the day, preferably outdoors, even under cloud. Keep the evening dim. The whole prescription, and it costs nothing.

Table 18**:** How much light, and what it does

Situation	Roughly	Effect on the clock
Living room in the evening	100 lux	still enough to delay melatonin; dimmer is better in the evening
Bright office	500 lux	far too little for a morning signal
Overcast day outdoors	3 000 lux	a real signal, even in winter
Summer noon outdoors	100 000 lux	the signal the clock was built for

In a changing climate. Warmer evenings keep people outdoors later and shift daily life towards the night, particularly in hot regions where the day is spent hiding from the sun. In a hot city the pleasant hours move to the middle of the night, and the clock and the working timetable end up pulling in opposite directions.

GOOD TO KNOW

Twenty minutes outdoors in the morning does more for the inner clock than an ordinary indoor lamp — though a proper light-therapy lamp, at clinical brightness and used as prescribed, can rival it.

It is not brightness in the evening that matters most, it is the absence of a strong morning signal.

Keywords: Circadian rhythm · Melatonin · Cortisol · Daylight · Shift work · Seasonal depression

SOURCES

Roenneberg, T., Merrow, M. (2016): The circadian clock and human health. Current Biology 26, R432–R443.

PART IV

The Air Pollution Effect Complex

This is the part of the atmosphere that we take inside us. An adult moves something like twelve thousand litres of air through the lungs every day, and whatever is in that air comes with it. Seven chapters: an overview, then particles, gases, ozone, the smoke and dust that arrive from other continents, the air in our own rooms, and pollen. Unlike heat and radiation, most of what follows is not natural. It was put there, which means it can be taken away again.

19 Air pollutants: an overview

Nothing in the air is optional. We breathe whatever is there.

Clean air is a recent idea and, in most of the world, still an aspiration. The World Health Organization estimates that air pollution contributes to millions of premature deaths every year, which puts it among the largest environmental health risks there are (WHO 2021; Landrigan et al. 2018). Most of those deaths are not dramatic. They are heart attacks, strokes, lung disease and lung cancer that came a few years early (Brunekreef and Holgate 2002).

The field sorts into two questions: what is in the air, and where did it come from. What is in the air divides into particles, which are matter suspended in it, and gases, which are part of it. Where it came from divides into what was emitted directly and what formed afterwards in the atmosphere. Ozone is the classic example of the second kind, and it behaves quite differently from the rest because of it.

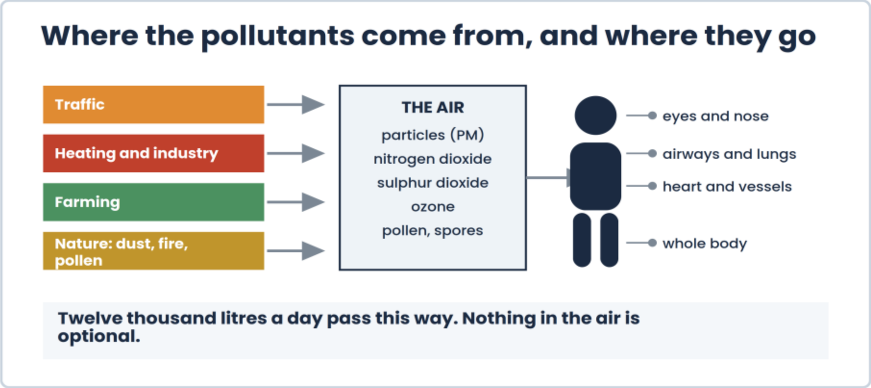


Figure 21: The main sources, what they put into the air, and where it arrives in the body.

The sources are familiar and they have shifted over time. In European cities of the nineteen-fifties the problem was coal smoke and sulphur dioxide, and the smogs of that era killed thousands in a few days. That problem was solved by regulation, which is worth stating plainly. Today the dominant urban sources are traffic, heating, industry and agriculture, and the pollutants that matter most are fine particles and nitrogen dioxide (European Environment Agency 2023).

One feature runs through the whole complex and it separates it from heat and radiation. An individual can do very little. You can choose a shaded street and you can choose a hat, but you cannot choose the air in the street you live on. Protection here is collective by nature, and that is why this part of the book has more to say about policy than the rest of it.

Table 19**:** The main pollutants at a glance

Pollutant	Chiefly from	Chiefly affects
Particles (PM10, PM2.5)	traffic, combustion, farming, dust	lungs, heart, vessels
Nitrogen dioxide	traffic and combustion	airways, asthma
Sulphur dioxide	coal and heavy fuel oil	airways
Ozone	traffic and industrial emissions, in strong sunlight	deep lungs, in summer
Pollen and spores	plants	allergies, airways

This table covers ambient, outdoor air. Carbon monoxide is missing from it for that reason — outdoors it is not too often a problem in modern cities, but indoors it is one of the more dangerous gases in the book, and Chapter 21 covers it in full.

In a changing climate. Heat alters the chemistry of the atmosphere and the behaviour of people at the same time. Hot, still, sunny days trap pollutants and manufacture ozone, so the worst air days and the worst hot days increasingly fall together (Breitner-Busch et al. 2023). The heat warning and the air quality warning are becoming one warning, and in most countries they are still issued by two different offices.

GOOD TO KNOW

On a hot, still, sunny afternoon, expect the air to be poor as well as hot. The two arrive together.

Ventilate a home in the early morning or late evening, when both the heat and the traffic pollution are lowest.

Keywords: Air pollution · Emissions · Particles · Gases · Secondary pollutants · Air quality index

SOURCES

Breitner-Busch, S., Mücke, H.-G., Schneider, A., Hertig, E. (2023): Impact of climate change on non-communicable diseases due to increased ambient air pollution. Journal of Health Monitoring 8(S4), 103–121.

Landrigan, P. J. et al. (2018): The Lancet Commission on pollution and health. The Lancet 391, 462–512.

Brunekreef, B., Holgate, S. T. (2002): Air pollution and health. The Lancet 360, 1233–1242.

WHO (2021): WHO Global Air Quality Guidelines. World Health Organization, Geneva.

European Environment Agency (2023): Europe's air quality status 2023. EEA, Copenhagen.

20 Particles: PM10, PM2.5 and ultrafine

The smaller a particle is, the further it travels inside us and the less we notice it.

Particulate matter is not one substance. It is everything solid or liquid small enough to stay suspended in the air: soot, brake and tyre abrasion, soil, sea salt, ammonium from farming, wood smoke, and droplets formed in the air out of gases. It is classified not by what it is but by how big it is, because size decides how deep it gets.

PM10 means particles below ten micrometres (µm), roughly a seventh of the width of a human hair — a category that includes the finer PM2.5 within it. The coarser part of PM10 reaches mainly the nose, the throat and the upper airways. PM2.5 itself, below two and a half micrometres, reaches the small airways and the alveoli and passes from there into the bloodstream. Ultrafine particles, below a tenth of a micrometre, can cross that barrier, and a small fraction has been found in organs far from the lungs.

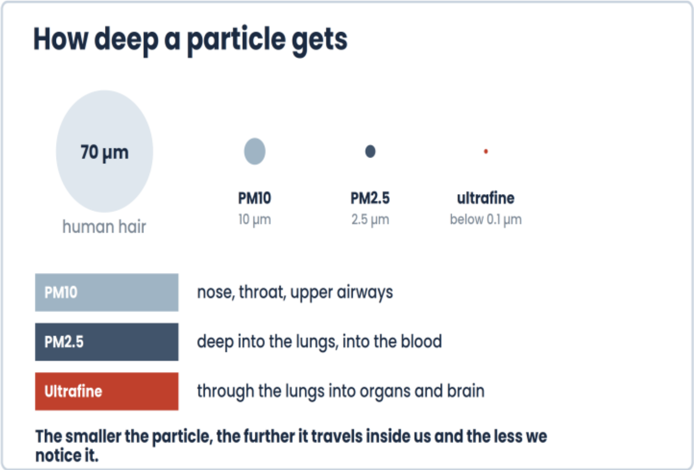


Figure 22: Particle sizes compared with a human hair, and how deep each fraction reaches.

The health effects follow that geometry. The coarse fraction irritates. The fine fraction inflames, and inflammation in the blood vessels is the mechanism behind the heart attacks and strokes that make up most of the mortality. Long-term exposure matters more than any single bad day, and that is what makes it hard to communicate: nobody notices the air that shortens their life (Pope and Dockery 2006).

The guideline values were tightened sharply in 2021, to five micrograms per cubic metre as an annual mean for PM2.5, and most European cities do not meet them (WHO 2021). That figure needs saying plainly. It does not mean those cities are catastrophic; it means the health evidence no longer supports the idea of a safe threshold. Below every level studied, less is still better.

What helps, in order of effect: fewer emissions, distance from the source, and timing. A cycle route one street back from a main road can halve the dose for no cost at all, and that is the kind of measure a city can actually deliver.

Table 20: The particle fractions

Fraction	Size	Reaches	Main sources
PM10	below 10 µm	nose, throat, upper airways	abrasion, soil, construction
PM2.5	below 2.5 µm	deep lung and bloodstream	combustion, traffic, wood smoke
Ultrafine	below 0.1 µm	organs beyond the lungs	engines, all combustion

In a changing climate. More wildfires mean more fine particles over larger areas, and warm, still weather keeps whatever is emitted close to the ground for longer. Both effects push in the same direction. At the same time the shift away from combustion for transport and heating is the single largest air quality improvement available to us, and it is the same measure that reduces greenhouse gases. That coincidence is the best argument climate policy has.

GOOD TO KNOW

One street back from the main road, the fine particle load is often half. Choose the route, not just the pace.

There is no known safe threshold for fine particles. Less is better all the way down.

Keywords: Particulate matter · PM10 · PM2.5 · Ultrafine particles · Inflammation · Guideline values

SOURCES

WHO (2021): WHO Global Air Quality Guidelines. World Health Organization, Geneva.

Pope, C. A., Dockery, D. W. (2006): Health effects of fine particulate air pollution: lines that connect. Journal of the Air and Waste Management Association 56, 709–742.

21 Gases: nitrogen dioxide, sulphur dioxide, carbon monoxide

Three gases, three different histories, and one of them is almost a solved problem.

A fourth gas, ozone, appears in the table and figure below for comparison — it gets a whole chapter of its own next, because unlike these three it is not emitted directly but manufactured in the air. Nitrogen dioxide is the signature pollutant of the modern city. It forms wherever something burns hot enough for the nitrogen of the air itself to react — mostly as nitric oxide at first, which then oxidises in the air to nitrogen dioxide — which in practice means engines and boilers as the ultimate source. It irritates the airways, worsens asthma, and it is a good tracer for traffic in general: where nitrogen dioxide is high, other combustion products are high too. Concentrations fall steeply within the first tens of metres from a road, which is the most useful practical fact in this chapter.

Sulphur dioxide is the one that has largely been dealt with, and the story is worth telling because it is a success. It comes from sulphur in coal and heavy fuel oil. It produced the killer smogs of London and the Ruhr, and it produced the acid rain that stripped the forests of central Europe in the nineteen-eighties. Desulphurisation of power stations and low-sulphur fuels reduced European emissions by more than ninety per cent within a generation (European Environment Agency 2023). Where coal is still burned without controls, the old problem is simply the current problem.

Figure 23: The four gases that matter most for health, where they come from and what they do.

Carbon monoxide is the quiet one. It is produced by incomplete combustion, it has no smell and no colour, and it binds to haemoglobin far more strongly than oxygen does, so it blocks the transport of oxygen through the blood. Outdoors it is not too often a problem in modern cities. Indoors it kills people every winter, from faulty heaters, blocked flues, charcoal grills brought inside and generators run in closed spaces. A detector costs very little and is one of the few pieces of technology in this book I would tell everybody to buy.

The pattern across all three is the same, and it is encouraging. Every one of them fell substantially where regulation was applied, and none of them fell where it was not. This is not a field where individual behaviour is decisive.

Table 21: The gases and their sources

Gas	Comes from	Effect	Trend in Europe
Nitrogen dioxide	engines, boilers	airways, asthma	falling slowly
Sulphur dioxide	coal, heavy fuel oil	airways, acid rain	largely solved
Carbon monoxide	incomplete combustion	blocks oxygen transport	outdoors low, indoors deadly
Ozone	formed in sunlight	deep lungs, summer	not falling

In a changing climate. The nitrogen oxides that drive ozone formation come from the same combustion that drives climate change, and sulphur dioxide has been cooling the planet slightly by making the air more reflective. Cleaning the air therefore unmasks a little of the warming that was already there. It is a real effect, it is not an argument against clean air, and better learned here than from somebody presenting it as one.

GOOD TO KNOW

Nitrogen dioxide falls steeply with distance from a road. A few tens of metres genuinely matter.

Never run a generator, charcoal grill or unvented heater in a closed room. Carbon monoxide gives no warning at all.

Keywords: Nitrogen dioxide · Sulphur dioxide · Carbon monoxide · Acid rain · Smog · Regulation

SOURCES

WHO (2021): WHO Global Air Quality Guidelines. World Health Organization, Geneva.

European Environment Agency (2023): Europe's air quality status 2023. EEA, Copenhagen.

22 Ground-level ozone, the summer pollutant

High up it protects us. Down here it burns the lungs. Same molecule.

One sentence has confused the public for forty years, and this chapter had better start by clearing it up. The ozone in the stratosphere that filters ultraviolet radiation and the ozone at street level that damages the lungs are the same substance in two places. We want a great deal of it fifteen kilometres up and none of it where we breathe.

Ground-level ozone is not emitted by anything. It is manufactured in the air, out of nitrogen oxides and volatile organic compounds, using sunlight as the energy source. That is why it has a rhythm nothing else has: it climbs through the morning, peaks in the middle of the afternoon around or shortly after the day's temperature peak, and collapses at night. It is a summer problem, a sunshine problem and a heat problem all at once.

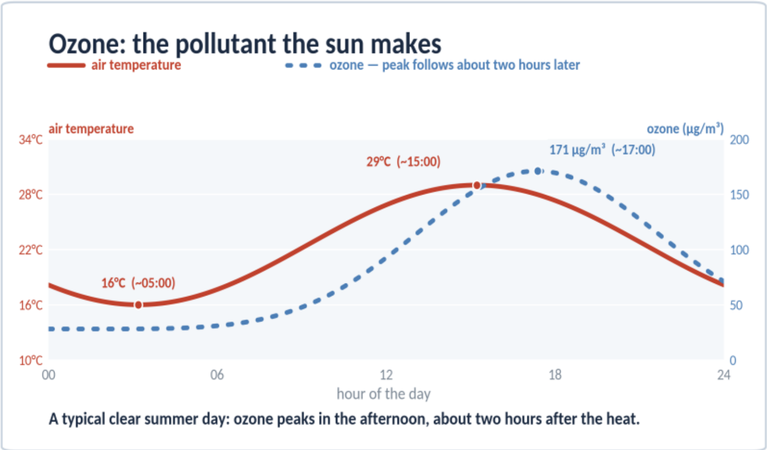


Figure 24: The daily course of ozone alongside air temperature. The peak comes in the afternoon, after the heat.

It has one property that surprises people. Concentrations are often higher in the suburbs and the countryside than in the middle of the city, because fresh traffic exhaust destroys ozone as fast as sunlight makes it. The polluted street has less ozone than the quiet village downwind of it. This is the single most counter-intuitive fact in air quality, and it means that clean-looking places are not automatically clean-breathing places.

Ozone attacks deep in the lung. It reduces lung function measurably within hours, provokes asthma, and there is good evidence for effects on mortality on high days. Children playing outdoors in the afternoon and adults exercising are the most exposed, simply because they move a great deal of air. Our heat wave analyses in Athens showed how tightly the two travel together: the days with the greatest thermal load are very often the days with the highest ozone (Matzarakis and Nastos 2011).

The practical advice is unusually specific. On a hot, sunny summer day, move the run, the football and the garden work to the morning. That single shift avoids most of the dose, and it avoids the worst of the heat as well.

Table 22: Ozone, above and below

	Stratospheric ozone	Ground-level ozone
Where	15 to 35 km up	the air we breathe
Origin	natural	traffic and industry emissions, plus a natural background
Role	filters ultraviolet radiation	damages the lungs
We want	as much as possible	as little as possible

In a changing climate. Ozone is the pollutant that climate change makes worse most directly. More heat and more sunshine mean more of it, even with unchanged emissions. It is one reason air quality in Europe has improved for particles and nitrogen dioxide over the last twenty years and has not improved in the same way for ozone.

GOOD TO KNOW

Ozone peaks in the afternoon. Exercise in the morning on hot, sunny days.
The countryside downwind of a city often has more ozone than the city centre. Green does not mean clean.

Keywords: Ozone · Photochemical smog · Nitrogen oxides · Lung function · Afternoon peak · Heat and ozone

SOURCES

Matzarakis, A., Nastos, P. T. (2011): Human-biometeorological assessment of heat waves in Athens. Theoretical and Applied Climatology 105, 99–106.
WHO (2022): WHO Ambient Air Quality Database, 2022 Update: Status Report. World Health Organization, Geneva.

23 Smoke and dust from far away

Some of the air you breathe today was somebody else's continent last week.

A few times a year, in the strongest episodes, the sky over Greece turns a strange yellow-orange, cars are covered in a fine reddish film, and the air smells of nothing in particular but tastes of dust. The material came from the Sahara, lifted by storms over the desert, carried across the Mediterranean at height and washed out by rain. The same thing happens with Gobi dust over eastern Asia and with Saharan dust over the Caribbean and the southern United States.

Desert dust is a natural phenomenon and it has always happened. It is also a genuine health burden. The particles are mostly coarse, so they load the upper airways rather than the bloodstream, but the concentrations during an episode can be many times the guideline value, and hospital admissions for asthma and other airway conditions rise measurably in affected regions (Middleton 2017).

Desert dust has a second face, and it is not a burden but a gift. The same Saharan plumes that dim the Caribbean sky carry phosphorus and iron, the very nutrients that are scarce in the old, weathered soils of the tropics. A large share of the dust that fertilises the Amazon was long thought to come from a single dried-out lake bed, the Bodélé Depression in Chad; satellite tracking now points instead to the El Djouf region, further west, as the larger contributor, since more of its dust survives the crossing without being rained or settled out (Yu et al. 2015, 2020). Either way, the phosphorus delivered is of the same order as the amount the forest loses each year to its rivers and rain. It is the lesson of this book in miniature: one and the same process is a health hazard in one place and the quiet condition for a forest in another, and only the distance and the receptor decide which.

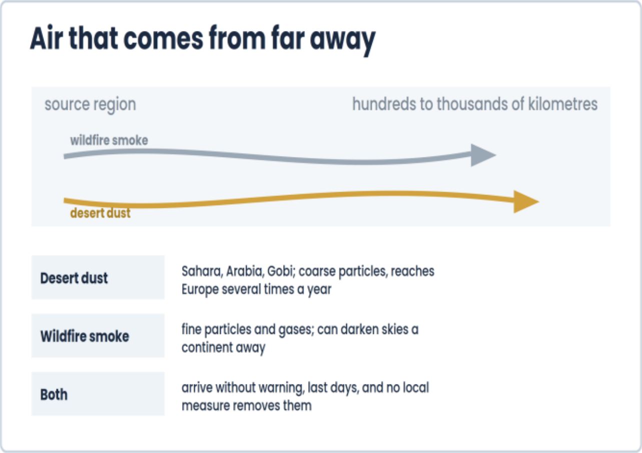


Figure 25: Dust and smoke travel for thousands of kilometres. No local measure removes them.

Wildfire smoke is the newer problem and the more serious one. Unlike dust it is dominated by fine and ultrafine particles, together with carbon monoxide and the ingredients of ozone, so it behaves like the worst of urban air rather than like coarse desert dust — it reaches deep into the lung and passes into the blood. It travels across continents; smoke from Canadian fires has closed schools in New York and been measured over Europe, and smoke from Siberian fires reaches the Arctic. The health effects of smoke exposure resemble those of urban fine particles: on smoke days emergency visits rise for asthma, heart disease and, some studies suggest, for stroke as well; pregnancies exposed to heavy smoke tend towards lower birth weights; and respiratory admissions climb in the days that follow (Reid et al. 2016). And the exposure is no longer rare: in fire-prone regions a few smoke weeks each summer can hand back much of the clean-air gain that thirty years of work at the tailpipe had won.

What makes both of these different from ordinary air pollution is that no local measure removes them. A city can reduce its own traffic and it cannot reduce the Sahara. That leaves only forecasting, warning and behaviour. Dust and smoke forecasts are now routine in several regions and they work, provided anyone is told about them.

The advice for an episode is old-fashioned and effective. Keep windows shut on the day, run any filtration you have, postpone outdoor sport, and pay particular attention to children, older people and anyone with asthma. A dust episode is usually over in a few days; a bad wildfire-smoke episode, as we saw above, can drag on for weeks.

Table 23**:** Dust and smoke compared

	Desert dust	Wildfire smoke
Particle size	mostly coarse	mostly fine and ultrafine
Also contains	minerals, sometimes microbes	carbon monoxide, ozone precursors
Reaches	upper airways	deep lung and bloodstream
Trend	variable, region-dependent	clearly increasing

In a changing climate. Fire seasons are lengthening and fire weather is becoming more frequent in the Mediterranean, in North America, in Australia and in Siberia (Butsch et al. 2023). Wildfire smoke is on its way to becoming one of the largest sources of fine particle exposure in the world, and unlike traffic emissions it cannot be regulated at the tailpipe. It has to be prevented in the landscape.

GOOD TO KNOW

During a dust or smoke episode: windows shut, outdoor sport postponed, filtration on if you have it.

These episodes are forecast several days ahead in many regions. Knowing they are coming is most of the protection.

Keywords: Desert dust · Saharan dust · Wildfire smoke · Long-range transport · Episodes · Forecasting

SOURCES

Butsch, C., Beckers, L.-M., Nilson, E., Frassl, M., Brennholt, N., Kwiatkowski, R., Söder, M. (2023): Health impacts of extreme weather events — cascading risks in a changing climate. Journal of Health Monitoring 8(S4), 33–56.

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., Elliott, C. T. (2016): Critical review of health impacts of wildfire smoke exposure. Environmental Health Perspectives 124, 1334–1343.

Middleton, N. J. (2017): Desert dust hazards: a global review. Aeolian Research 24, 53–63.

24 Indoor air, odours and air conditioning

We spend nine tenths of our lives indoors and measure almost none of it.

Every chapter so far has been about the air outside. That is where the monitoring stations are, where the regulations apply and where the research money goes. It is also where people spend roughly one tenth of their lives. The air that matters most for most of us is the air in our own rooms, and almost nobody measures it.

Indoor air starts as outdoor air and then has things added to it. Cooking, especially frying and open flames. Heating with wood or gas. Candles and tobacco. Cleaning agents, paints, new furniture and flooring, which release volatile organic compounds for months (WHO 2010). Damp and the mould that follows it, which is the single most consistent indoor risk for the airways (WHO 2009). And ourselves: carbon dioxide, water vapour and odour accumulate in an occupied room faster than most people expect. A stuffy meeting room is not an aesthetic complaint. It is a measurement.

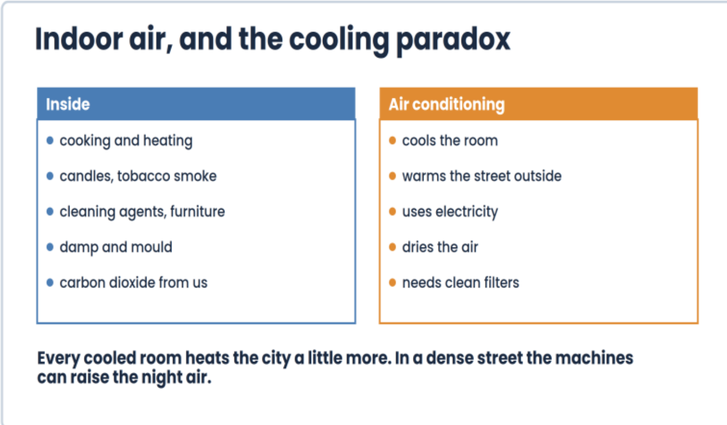


Figure 26: What is added to the air indoors, and the awkward arithmetic of air conditioning.

Odour deserves its own paragraph, because it is the one part of the air pollution complex that people notice immediately and that science treats with embarrassment. Smell is a warning system with no units. It is not a reliable guide to danger, since carbon monoxide has no smell and a strong cleaning product may be harmless, but it is a reliable guide to whether a room has been ventilated, and it drives behaviour more effectively than any number.

Which brings us to air conditioning, and to a genuine dilemma. A cooling machine does not destroy heat; it moves it, from the room to the street, and adds the waste heat of its own motor on top. In a dense district the machines of a whole block can raise the outdoor night air by one to two degrees (Salamanca et al. 2014). The people who benefit are inside. The people who pay are outside, and they are usually not the same people. Add the electricity, add the refrigerants, and the machine that protects an individual from heat is quietly making the city hotter for everyone else.

None of this argues against air conditioning. In a serious heat wave it saves lives, and a cool room for the vulnerable is a public health measure. It is an argument for the order in which things are done: shade and insulation and night ventilation first, and the machine for what those cannot handle. Chapter 36 comes back to this at the scale of a city.

Table 24: Indoor air: sources and remedies

Source	What it adds	What helps
Cooking and heating	particles, nitrogen dioxide	extractor hood, ventilate while cooking
Damp and mould	spores, allergens	find and fix the moisture, then ventilate
Furnishings and paint	volatile organic compounds	ventilate heavily for weeks after work
People	carbon dioxide, humidity, odour	short, wide-open airing several times a day
Air conditioning	dryness, filter problems	clean filters, shade the building first

In a changing climate. As summers lengthen, air conditioning is spreading fastest in exactly the regions with the least reliable electricity supply, and the peak demand for cooling now falls at the same hour as the peak heat load on people. Cooling that fails during a heat wave is worse than no cooling at all, because a building designed around the machine has no other defence.

GOOD TO KNOW

Short and wide open beats long and tilted. A few minutes of cross-ventilation exchanges the air of a room.

Shade and night ventilation first, the cooling machine for the remainder. In that order it costs a fraction as much.

Keywords: Indoor air · Ventilation · Mould · Volatile organic compounds · Odours · Air conditioning

SOURCES

WHO (2010): Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organization, Copenhagen.

WHO (2009): WHO Guidelines for Indoor Air Quality: Dampness and Mould. WHO Regional Office for Europe, Copenhagen.

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., Wang, M. (2014): Anthropogenic heating of the urban environment due to air conditioning. Journal of Geophysical Research: Atmospheres 119. https://doi.org/10.1002/2013JD021225

25 Pollen and allergies

A grain of pollen is harmless. The mistake is ours.

Pollen is a plant's way of reaching another plant, and the species that use the wind to do it produce it in absurd quantities, because the wind is a poor postman. A single birch catkin can release many millions of grains. None of it is toxic. Hay fever is an error of the immune system, which identifies a harmless protein as a threat and mounts a full defence against it: streaming eyes, blocked nose, sneezing, and in a proportion of sufferers, asthma.

Around a fifth to a quarter of the population of Europe is affected, and the proportion has risen through the last century for reasons that are still argued over. What is not argued over is that it is a serious condition rather than a seasonal nuisance. Untreated hay fever costs sleep, concentration and school and work performance, and in about a third of cases it progresses to allergic asthma.

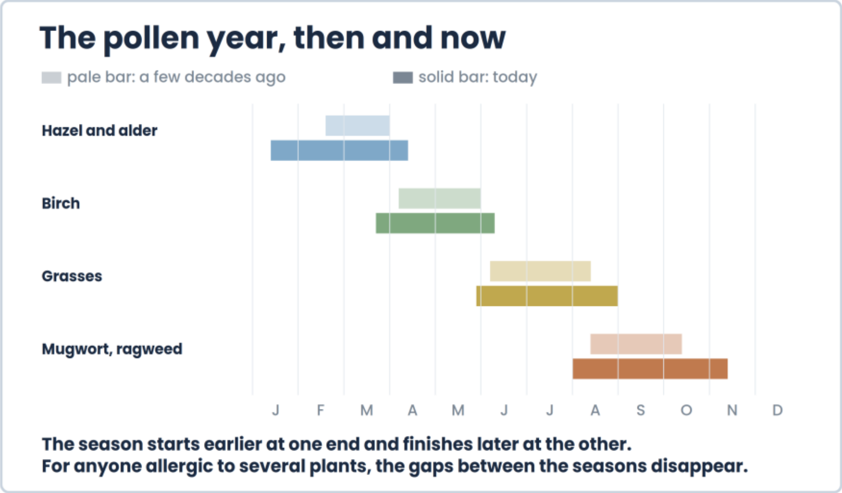


Figure 27: The pollen year at middle latitudes, and how the seasons have stretched at both ends.

The calendar is the practical heart of the subject. In central Europe hazel and alder come first, sometimes in January now. Birch follows in spring and is the most aggressive of the tree pollens. Grasses dominate early summer and affect the largest number of people. Mugwort and, increasingly, ragweed close the year in late summer. Anyone who knows which plant they react to can plan a holiday around it, which is the oldest and best piece of advice in this field.

Three things about the trend are now well established (Ziska et al. 2019). The season begins earlier, because warmth in late winter starts the trees. It ends later, because late-summer plants keep flowering. And the amount of pollen produced has increased, partly from warmth and partly because higher carbon dioxide makes many plants produce more of it. For someone allergic to several species, the consequence is not a longer season but the loss of the gaps between seasons.

Pollen forecasts exist in most European countries and they are one of the older services of applied biometeorology. They work best when they are specific enough to act on: which species, how strong, for how many days. A forecast that says merely "moderate" has told nobody anything.

Table 25**:** The pollen calendar in central Europe

Plant	Main season	Note
Hazel and alder	January to March	starting earlier decade by decade
Birch	March to May	the strongest of the tree pollens
Grasses	May to August	affects the largest number of people
Mugwort	July to September	often confused with ragweed
Ragweed	August to October	spreading northwards, highly allergenic

In a changing climate. The pollen season in Europe has lengthened by roughly two to four weeks over recent decades and the loads have risen with it. Ragweed, a late-summer plant with an unusually aggressive pollen, is expanding northwards as the frost-free season lengthens. Of all the health effects of a warming climate, this is the one the largest number of people will notice personally, and the one they will notice first.

GOOD TO KNOW

Know your species, not just your season. It turns a three-month misery into a three-week one you can plan around.

Air the bedroom in the evening in the countryside and early in the morning in the city. The pollen peaks differ.

Keywords: Pollen · Hay fever · Allergy · Pollen calendar · Ragweed · Pollen forecast

SOURCES

Bergmann, K.-C., Brehler, R., Endler, C., Höflich, C., Kespohl, S., Plaza, M., Raulf, M., Standl, M., Thamm, R., Traidl-Hoffmann, C., Werchan, B. (2023): Impact of climate change on allergic diseases in Germany. Journal of Health Monitoring 8(S4), 76–102.

Ziska, L. H. et al. (2019): Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere. Lancet Planetary Health 3, e124–e131.

PART V

Other Stimuli and Health

Not everything that reaches us through the atmosphere is heat, light or something we breathe. Sound arrives through the same air. Illness follows the seasons. Half the population says the weather can be felt in the body, and the studies find something smaller and less tidy than that. Insects that carry disease move north as the winters soften. And all of it lands unevenly: some people carry far more of the load than others. Five chapters on the stimuli that do not fit the three classical complexes, and on the people who feel them first.

26 Noise

Sound we did not choose. The body reacts to it long before we notice.

Noise is the one environmental stress that almost everybody can name and almost nobody can escape. It travels through the same air as everything else in this book, it follows the same weather — sound carries further on a still, cool night than on a warm, windy afternoon — and it acts on the body through a route that has nothing to do with the ear finding it unpleasant.

The ear evolved as an alarm system, and an alarm system cannot be switched off. A sudden sound raises the heart rate, tightens the vessels and releases stress hormones, and it does this whether a person is awake, asleep or long since used to the sound. That last point is the one that matters most and is believed least. Getting used to traffic noise means no longer noticing it. It does not mean the circulation has stopped reacting.

The consequences are now well documented. Long-term exposure to road traffic noise raises the risk of ischaemic heart disease (WHO 2018). It disturbs sleep, and disturbed sleep does the rest: blood pressure, metabolism, concentration, mood (Basner and McGuire 2018). Across western Europe the World Health Organization has estimated the loss at more than a million healthy life years every year, most of it from sleep disturbance and annoyance rather than from anything a doctor would diagnose as a noise injury (WHO 2011).

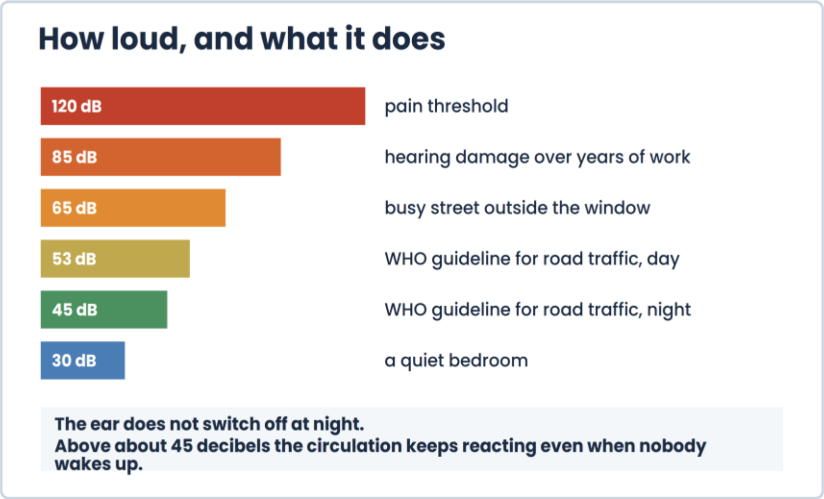


Figure 28: Sound levels, the guideline values, and what each level does to a person.

The guideline values are worth knowing, because they are unusually concrete for this field. For road traffic the World Health Organization recommends staying below 53 decibels over the day and below 45 decibels at night; for railways the night value is 44, for aircraft 40 (WHO 2018). Large numbers of Europeans live above those values, and most of them do not know it.

Where this book's other subjects meet noise is at the window. A hot night is a night with the window open, and an open window in a city street is a night at fifteen decibels more than a closed one. Anyone who plans a bedroom, a building or a street is therefore always planning heat and noise together, whether they mean to or not. The quiet side of a block is also the cooler side more often than not, and a room that can be ventilated towards a courtyard solves two problems at once.

Table 26: Where the noise comes from, and what actually helps

Source	What it does	What helps
Road traffic	the largest single source; sleep and heart	speed limits, quiet surfaces, distance
Railways	sharp events at night	rail grinding, barriers, timetable
Aircraft	worst for sleep, hardest to shield	night curfews, routing
Neighbours and leisure	annoyance more than illness	building acoustics, courtesy, hours

The remedy that works is the boring one. Noise falls fastest at the source and hardly at all at the ear: a quieter road surface, a lower speed limit or a rerouted flight path does more than any amount of individual effort. This is a planning subject, not a personal one, and that should be said plainly to anyone who has been advised to try earplugs.

In a changing climate. Warm nights are the link. As the number of nights above twenty degrees rises, the number of nights spent with the window open rises with them, and the noise that used to stop at the glass now comes in. Heat protection and noise protection have to be planned as one task, in the same building and by the same office. At present they almost never are.

GOOD TO KNOW

Getting used to a noise is not the same as no longer reacting to it. The circulation does not fully habituate.

If a bedroom faces a busy street, a quiet room on the courtyard side is worth more than any other single change.

Keywords: Noise · Sound level · Sleep disturbance · Annoyance · Night noise · Quiet side

SOURCES

WHO (2018): Environmental Noise Guidelines for the European Region. World Health Organization Regional Office for Europe, Copenhagen.
WHO (2011): Burden of Disease from Environmental Noise. World Health Organization Regional Office for Europe, Copenhagen.
Basner, M., McGuire, S. (2018): WHO environmental noise guidelines for the European region: a systematic review on environmental noise and effects on sleep. International Journal of Environmental Research and Public Health 15, 519.

27 Weather and illness

Some of this is measured in hundreds of thousands of deaths. It belongs apart from the rest.

This chapter and the next one belong together and are deliberately kept apart. Here we stay with what can be counted: deaths, hospital admissions, prescriptions, sick days, set against temperature and air pressure over years and across whole populations. The next chapter takes the phenomenon that people describe in themselves, where the evidence is thinner and the honest answer is a different one. Mixing the two damages both.

The single largest pattern is seasonal, and it is not the one most people expect. In temperate countries more people die in winter than in summer, and the excess is dominated by heart attack, stroke and respiratory infection. A large international analysis of more than seventy million deaths put the share attributable to non-optimal temperature at around seven per cent, and found that most of it came not from extreme cold but from ordinary, moderate cold — the long grey stretch rather than the record night (Gasparrini et al. 2015).

The mechanism is unglamorous. Cold constricts the vessels and raises blood pressure. Blood thickens slightly. The heart works against more resistance at the same time as the airways are meeting cold, dry air and whatever virus is going round indoors. None of this needs a dramatic temperature. It needs a season.

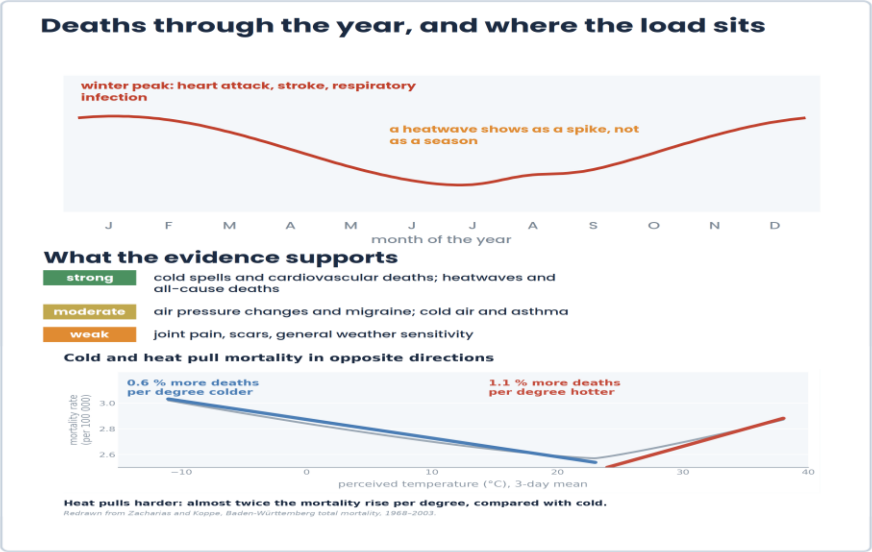


Figure 29: The seasonal course of deaths in a temperate country, and how strong the evidence is for the individual claims.

Heat behaves differently and shows up as a spike rather than a season. A heatwave raises deaths within one to three days, mostly among people who were already ill, and the effect is visible in the daily curve rather than in the annual one (Ebi et al. 2021). Thirty years of daily mortality data from south-west Germany showed both patterns in the same series, and showed that the thermal environment describes them better than air temperature alone (Laschewski and Jendritzky 2002).

Figure 29 has to be read with care, because a reader could take from it that heat is the lesser problem and stop there. It shows the temperate pattern, in which winter deaths outweigh summer ones. That is the wrong lesson for a warming climate. The relation between temperature and mortality is not a slope but a U: deaths are lowest in a comfortable middle band and rise on both sides, towards cold and towards heat. The cold arm is broader today, but the heat arm is the one that is growing — analyses of German mortality over recent decades show summer heat deaths rising as hot days multiply, even as better care and warmer homes ease the winter burden (Zacharias and Koppe 2015; Laschewski and Jendritzky 2002). Winter still dominates the count; heat dominates the trend. A heat action plan is written for the trend. For a comprehensive account of heatwaves — their causes, their consequences and the responses to them — see McGregor (2024).

Beyond these two the ground gets softer. Cold air and asthma: well supported. Air pressure changes and migraine: supported in several studies, with effects that are real but small. Joint pain in damp cold: reported by very many people, repeatedly investigated, and still without a convincing mechanism or a consistent result. Old scars aching before a front: no evidence at all beyond the reports themselves.

For practice, the useful move is to turn the seasonal pattern into something a person can act on. The winter risk belongs to the cardiovascular consultation, not to the weather forecast: blood pressure checked in the cold months, vaccination taken, the first cold snap of the season treated with more respect than the twentieth. The summer risk belongs to the heat warning (WHO Regional Office for Europe 2008), and Chapter 45 on heat action plans comes back to it.

Table 27: Weather and illness: what the evidence actually supports

Complaint	Weather situation	Strength of evidence
Heart attack, stroke	cold spells, the first cold of the season	strong
All-cause deaths	heatwaves, one to three days later	strong
Asthma, airways	cold dry air, inversions	strong
Migraine	falling pressure, föhn situations	moderate
Joint pain	damp cold	weak
Scars, amputations	approaching fronts	none beyond reports

In a changing climate. Warmer winters reduce the cold season, and that reduction is real: in temperate countries some analyses suggest it removes more deaths than the added heat causes, at least so far (Winklmayr et al. 2023). Saying so out loud is uncomfortable and necessary, because leaving it out invites the accusation of hiding it. Two things go with it. The balance reverses as warming continues, and it reverses first where it is already hot. And a death avoided in February and a death caused in August are not the same event in the same health system, in the same week, with the same warning.

GOOD TO KNOW

The first real cold snap of autumn carries more risk than a colder night in February. The body has not yet adjusted.

A heatwave shows in the death figures within one to three days. That is short enough for a warning to work.

Keywords: Seasonal mortality · Cold spell · Heatwave · Cardiovascular risk · Excess mortality · Attributable risk

SOURCES

Winklmayr, C., Matthies-Wiesler, F., Muthers, S., Buchien, S., Kuch, B., an der Heiden, M., Mücke, H.-G. (2023): Heat in Germany: health risks and preventive measures. Journal of Health Monitoring 8(S4), 3–32.
Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., Jay, O. (2021): Hot weather and heat extremes: health risks. The Lancet 398, 698–708.
Gasparrini, A. et al. (2015): Mortality risk attributable to high and low ambient temperature: a multicountry observational study. The Lancet 386, 369–375.
Laschewski, G., Jendritzky, G. (2002): Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. Climate Research 21, 91–103.
Zacharias, S., Koppe, C. (2015): Einfluss des Klimawandels auf die Biotropie des Wetters und die Gesundheit bzw. die Leistungsfähigkeit der Bevölkerung in Deutschland. UFOPLAN 3711 61 238, Umweltbundesamt, Dessau-Roßlau.
McGregor, G. (2024): Heatwaves: Causes, Consequences and Responses. Springer, Cham.
WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.

28 Weather sensitivity

About half the population says it can feel the weather. The measurements find less than that. Both statements are worth taking seriously.

Ask people in central Europe whether the weather affects how they feel and roughly one in two says yes. In a survey covering Germany and Canada the figure for Germany was around half, higher among women, higher among older people, and higher again among those who already had a chronic complaint (von Mackensen et al. 2005). Headache, tiredness, joint pain, sleep and mood were named most often, and the weather situations blamed were fronts, storms, föhn and heat.

That is a large number and it deserves a straight answer rather than a dismissal. The straight answer has two halves. The first: when the same question is investigated with diaries kept day by day and matched against measured weather, the effects that come out are consistently smaller and less specific than the questionnaires suggest (Dixon et al. 2019). The second: smaller is not zero, and unspecific is not imaginary.

Why the two numbers differ is not a mystery, and it is not an accusation against anybody. Memory works by fitting. A person who believes that föhn causes headache remembers the föhn days with headache and forgets the föhn days without one, and forgets equally the headaches on ordinary days. A headache has a dozen possible causes — sleep, alcohol, screen, stress, hormones — and only one of them is visible out of the window and available to everybody as an explanation. This is ordinary human reasoning, not a failing of the people who report it.

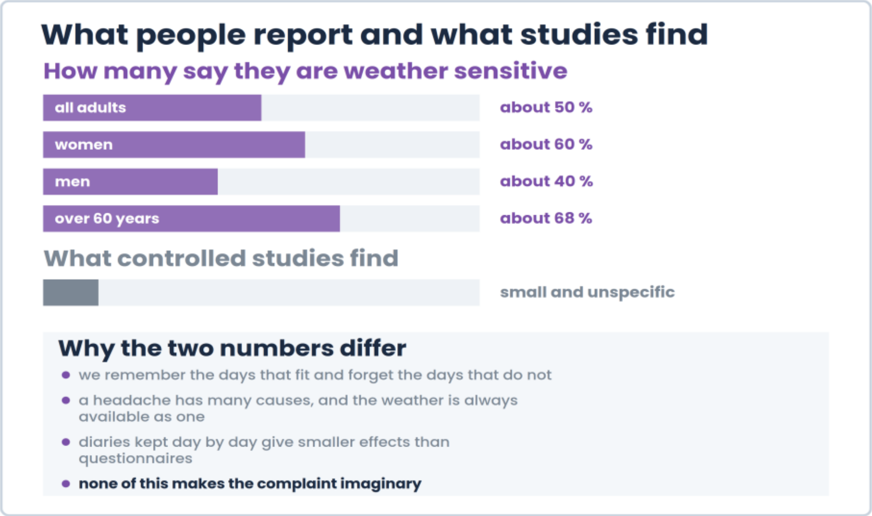


Figure 30: How many people describe themselves as weather sensitive, what controlled studies find, and why the two numbers differ.

The subject has a long history in this field, and the history explains some of the trouble. German-language biometeorology developed the idea of biotropy — the capacity of a weather situation to act on the organism — and built classifications of weather phases from it, which were issued for decades and are still remembered by many older readers. The intention was sound and the ambition ran ahead of the evidence. A classification that assigns a number to every day invites the belief that the number explains the day. When the effects turned out to be small, the whole subject took the damage, and the useful part went down with the overstated part.

The useful part is real. Rapid changes of air mass do change several quantities at once: temperature, humidity, pressure, wind, cloud, and with them light and activity. A body that regulates all of these is doing more work on such a day than on a settled one. Some people, particularly older people and those with a chronic condition, have less reserve for that work. It would be surprising if nothing happened. What is not established is a specific mechanism, a specific weather variable, or an effect large enough to justify a forecast that tells individuals how they will feel. None of this makes the weather the cause of the complaint. It is closer to a trigger: for somebody already close to their limit — through poor sleep, an existing condition, or simple fatigue — a demanding weather day can be the last small push, the drop that makes the glass overflow. The vulnerability was there beforehand; the weather only brings it to the surface.

Which weather does the most? The old German classifications tried to answer that, and although their specific claims did not survive, the ranking they pointed to is at least consistent with what people report today. The days that ask most are the days of rapid air-mass change: the passage of a front, a sharp fall in pressure, the arrival or collapse of föhn, and the transitions into and out of a heat wave. Settled high pressure asks least. A large population survey puts the same intuition in the modern language of air masses — reports cluster on change days rather than at any particular temperature (Graw, Sommer and Matzarakis 2022). The point is not to forecast one person's headache but to know that transition days, not extreme days, are when the vulnerable are most likely to feel the weather. The medical-meteorological forecast of Chapter 49 is built on exactly this.

Weather does not only take. The same sensitivity that makes a grey front feel heavy makes a clear morning after rain feel light, and that is not merely a figure of speech. Daylight lifts mood and sets the inner clock (Chapter 18: Light, darkness and the inner clock); a mild, sunny day draws people out to walk and to meet; a cool night after heat gives sleep back. In the language of this book, weather is a resource as often as a load, and a fair account of weather sensitivity has to include the good days with the bad.

One older strand deserves an honest word. German biometeorology long looked to air ions and to atmospheric electricity — the faint impulses sometimes called sferics — for a mechanism behind weather sensitivity. The idea is not absurd, but after decades of work no reliable effect on health has been shown, and it is better named and set aside than quietly implied.

So what should be said to somebody who suffers? Take the complaint seriously — it is a real experience and the person has usually been told otherwise by several people already. Suggest keeping a simple diary for a few weeks, because it costs nothing and it either finds a pattern worth acting on or it removes a worry. Look first for the causes that can actually be changed: sleep, fluid, medication timing, blood pressure, movement. And do not promise an explanation that does not exist. That is the honest advice entire, and it is more use than either denial or a weather-based diagnosis.

Table 28**:** Weather sensitivity: what is reported, and what is established

Reported	How often named	What is established
Headache, migraine	most often	moderate evidence for pressure change
Tiredness, sleep	very often	light and heat affect sleep, well established
Joint pain	very often	no consistent result
Mood	often	light in winter, well established
Scars, old injuries	often	no evidence

In a changing climate. Two things pull in opposite directions. Weather in a warming climate becomes more variable in some regions and less so in others, so there is no single answer to whether the trigger situations become more frequent. But the population that reports weather sensitivity most is the older population, and that population is growing quickly. The number of people who experience their days as weather-dependent will therefore rise even if the weather does not change at all.

GOOD TO KNOW

A diary kept for four weeks tells a person more about their own pattern than any classification of weather phases.

Feeling worse on a changeable day is common and real. It does not mean an illness has been found or missed.

Keywords: Weather sensitivity · Biotropy · Weather phases · Recall bias · Diary study · Front passage

SOURCES

Graw, K., Sommer, S., Matzarakis, A. (2022): The prevalence of weather sensitivity in Germany derived from population surveys. Atmosphere 13, 1865, 1–14.

Höppe, P., von Mackensen, S., Nowak, D., Piel, E. (2002): Prävalenz von Wetterfühligkeit in Deutschland. Deutsche Medizinische Wochenschrift 127, 15–20.

Zacharias, S., Koppe, C. (2015): Einfluss des Klimawandels auf die Biotropie des Wetters und die Gesundheit bzw. die Leistungsfähigkeit der Bevölkerung in Deutschland. UFOPLAN 3711 61 238, Umweltbundesamt, Dessau-Roßlau.

Bucher, K., Haase, C. (1993): Meteorotropy and medical-meteorological forecasts. Experientia 49, 759–768.

Dixon, W. G. et al. (2019): How the weather affects the pain of citizen scientists using a smartphone app. npj Digital Medicine 2, 105.

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.

von Mackensen, S., Hoeppe, P., Maarouf, A., Tourigny, P., Nowak, D. (2005): Prevalence of weather sensitivity in Germany and Canada. International Journal of Biometeorology 49, 156–166.

Höppe, P. (1997): Aspects of human biometeorology in past, present and future. International Journal of Biometeorology 40, 19–23.

Deutscher Wetterdienst: Biowetter and health-related weather information. www.dwd.de

29 Mosquitoes, ticks and a warming world

The climate does not make anybody ill. It decides where the carriers can live.

Some diseases do not come out of the air but out of an animal that lives in it. For these, the climate is not a stress on the human body at all. It is a condition of life for a tick or a mosquito, and it decides how far north, how far uphill and how many months of the year that animal can survive, feed and reproduce. Where the carrier can live, the disease becomes possible. Where it cannot, the disease is a travel diagnosis.

Ticks are the European case that concerns most people. The common tick becomes active at around seven degrees, which used to mean a season from April to October and now increasingly means February to November, with activity on mild days in between. The species has moved north through Scandinavia and uphill in the Alps, where it is now found well above a thousand metres in places that were considered free of it a generation ago. With it travel Lyme borreliosis, which is common and treatable, and tick-borne encephalitis, which is rarer, sometimes serious, and preventable by vaccination.

Figure 31: Two carriers whose range follows the warming, and what each of them asks of us.

Mosquitoes are the newer story in central Europe. The Asian tiger mosquito, which can carry dengue and chikungunya, established itself in southern Europe and has since settled in warm valleys further north, the upper Rhine among them. West Nile virus, carried by native mosquitoes and amplified in birds, has been transmitted within Germany since 2018 and appears in hot summers (Beermann et al. 2023). None of this is a tropical scenario. It is a slow northward shift of conditions that were already borderline. Sandflies, the carrier of leishmaniasis, remain confined for now to the warm, dry margins of southern Europe, but the same logic applies to them as to the others: where the climate becomes suitable further north, the sandfly moves first and the disease follows.

The biometeorological part of the subject is narrow and useful: which combination of temperature, rainfall and season allows a population to establish and a pathogen to complete its cycle. Warm nights matter more than hot days, because development continues at night. Standing water matters more than rainfall totals, because a bucket is a better breeding site than a river. And a mild winter matters most of all, because it decides how many survive to start the next season (Semenza and Suk 2018).

What follows is unusually practical for a field that often ends in recommendations to policy. Checking the skin after a walk removes most of the Lyme disease risk, because the bacteria that cause it need many hours in the skin before they transmit, and a tick removed within that window rarely passes them on. Tick-borne encephalitis works differently — the virus can transmit within minutes of the bite — which is exactly why vaccination, not skin-checking, is the real protection against it, and it is worthwhile where the risk maps say so (Beermann et al. 2023); those maps are updated every year. And emptying the standing water around a house once a week does more against tiger mosquitoes than any spraying programme, because that is where they breed.

Table 29**:** Carriers, conditions and countermeasures

Carrier	What it needs	What it brings	What works
Ticks	above about 7 °C, humidity, cover	Lyme disease, TBE	check the skin, vaccination
Tiger mosquito	warm nights, standing water	dengue, chikungunya	remove standing water
Native mosquitoes	hot summers, wetlands, birds	West Nile virus	surveillance, bite protection
Sandflies	warm dry summers, southern Europe	leishmaniasis	bite protection at dusk

In a changing climate. This is one of the clearest health signals of a warming climate, and one of the easiest to misuse. The signal is real: the season is longer, the range is larger, and the surveillance keeps finding things further north than the year before. The misuse is the leap to malaria returning to Berlin. Vector-borne disease depends on carrier, pathogen, host and a health system all at once, and in Europe the health system remains the strongest of the four.

GOOD TO KNOW

A tick removed within a few hours very rarely transmits Lyme disease. It can still transmit tick-borne encephalitis, though — the vaccine, not skin-checking, is what protects against that.

Empty every bucket, saucer and blocked gutter around the house once a week. That is where mosquitoes breed.

Keywords: Vector-borne disease · Ticks · Mosquitoes · Tick-borne encephalitis · West Nile virus · Range shift

SOURCES

Beermann, S., Dobler, G., Faber, M., Frank, C., Habedank, B., Hagedorn, P., Kampen, H., Kuhn, C., Nygren, T., Schmidt-Chanasit, J., Schmolz, E., Stark, K., Ulrich, R. G., Weiss, S., Wilking, H. (2023): Impact of climate change on vector- and rodent-borne infectious diseases. Journal of Health Monitoring 8(S3).

Semenza, J. C., Suk, J. E. (2018): Vector-borne diseases and climate change: a European perspective. FEMS Microbiology Letters 365, fnx244.

European Centre for Disease Prevention and Control: Vector maps and annual epidemiological reports. Stockholm.

Robert Koch-Institut: FSME-Risikogebiete in Deutschland. Epidemiologisches Bulletin, annual series, Berlin.

30 Who is most at risk: vulnerable groups

The same weather is not the same event for everybody. Knowing who carries it is where prevention starts.

Every chapter in this book has described an average person. There is no such person. The same thirty-five degree afternoon is a nuisance for one household and a medical emergency for the flat above it, and the difference between the two has less to do with the weather than with age, illness, medication, the building and whether anybody is going to knock on the door.

The useful way to think about it is that vulnerability is three things at once, and they multiply rather than add. Exposure is how much of the stress actually arrives: the flat under the roof, the street without trees, the shift that cannot be moved. Sensitivity is how much damage a given dose does: age, chronic illness, medication, pregnancy, very small children. Capacity to act is everything that turns knowledge into behaviour: money, mobility, language, information, and somebody who notices.

Age deserves its own paragraph because it is the strongest single demographic factor and the least understood. Older people sweat less and start later. The sense of thirst weakens, so the signal to drink arrives after the deficit. The heart has less reserve for the extra circulation that cooling demands (Bunker et al. 2016). And several of the most commonly prescribed drugs — diuretics, beta blockers, some antidepressants and drugs for Parkinson's disease — interfere directly with sweating, circulation or fluid balance (Hospers et al. 2024). A person can therefore be in serious difficulty while feeling neither thirsty nor especially hot.

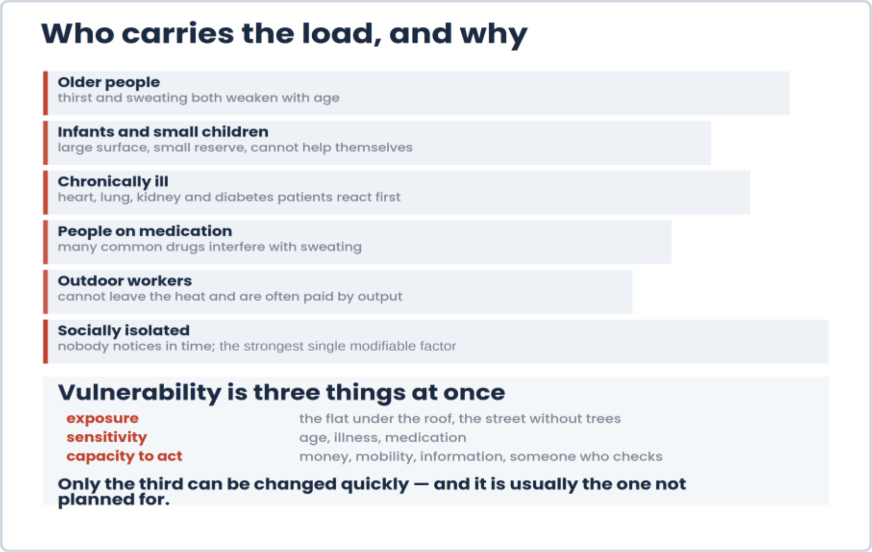


Figure 32: The groups that carry the load, and the three things that together make up vulnerability.

The factor that predicts death in a heatwave better than almost any other is not medical. Detailed investigations since the Chicago heatwave of 1995 and the European summer of 2003 have repeatedly found the same thing: people who lived alone, who had no regular visitor and who could not or would not open the door were the ones who died (Klinenberg 2002). Social isolation is the strongest single modifiable risk factor, and it is also the one that a neighbour can change in an afternoon.

Hence this chapter. Of the three components, exposure takes years to change, because it means buildings, trees and streets. Sensitivity cannot be changed much at all, because it means age and illness. Capacity to act can be changed within a single summer, with a list of who lives alone, a telephone call, a visit and a cool room in the building that is open to everybody. In practice, many heat action plans (WHO Regional Office for Europe 2008) lean on the fastest-moving part — warnings and phone calls — while the slower structural work on exposure gets far less investment; both matter, and this chapter is about the one that can start today.

One warning about the word itself. Vulnerable groups are not a category of people; they are a category of situations, and almost everybody enters one at some point — as an infant, as a patient after an operation, as a pregnant woman, as an outdoor worker in July, as an old person. A plan written as though vulnerability belonged to somebody else will protect nobody properly, including the person who wrote it.

Table 30**:** Vulnerable groups, the reason, and the measure that fits

Group	Why	What fits
People over 75	less sweating, weaker thirst, medication	daily contact, fluid plan, cool room
Infants, small children	large surface, no self-help	shade, never left in vehicles
Chronically ill	heart, lung, kidney, diabetes	medication review before summer
Outdoor workers	cannot leave the heat	shifted hours, breaks, water, shade
Socially isolated	nobody notices in time	visiting lists, telephone chains
Homeless people	no cool space at all, no water	open buildings, drinking fountains

In a changing climate. The number of people in the sensitive groups is rising for reasons that have nothing to do with the climate. Europe is ageing, more people live alone, and more people live with a chronic condition that is well controlled but leaves little reserve (Winklmayr et al. 2023). Even with no further warming at all, the same summer would cost more than it did thirty years ago. The two trends arrive together, and that is the argument for acting on the part that can be changed quickly.

GOOD TO KNOW

During a heatwave, telephone anybody you know who lives alone once a day. Evaluations since Chicago 1995 have been more sobering about phone-only outreach than this once sounded, but it costs nothing and it is a start.
Ask a doctor before summer whether any regular medication affects sweating or fluid balance. Many do.

Keywords: Vulnerability · Exposure · Sensitivity · Capacity to act · Social isolation · Heat action plan

SOURCES

Winklmayr, C., Matthies-Wiesler, F., Muthers, S., Buchien, S., Kuch, B., an der Heiden, M., Mücke, H.-G. (2023): Heat in Germany: health risks and preventive measures. Journal of Health Monitoring 8(S4), 3–32.
WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.
Bunker, A. et al. (2016): Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: a systematic review and meta-analysis. EBioMedicine 6, 258–268.
Hospers, L. et al. (2024): The effect of prescription and over-the-counter medications on core temperature in adults during heat stress: a systematic review and meta-analysis. eClinicalMedicine 77, 102886.
Klinenberg, E. (2002): Heat Wave. A Social Autopsy of Disaster in Chicago. University of Chicago Press, Chicago.

PART VI

Living in Cities

More than half of humanity lives in cities, and the share is still rising. A city is not simply a place where people happen to be; it is a climate of its own, built by accident out of stone, asphalt, geometry and engines. It is warmer than the land around it, especially at night. It is drier. It has less wind and more shadow, and the shadow falls in the wrong places. Six chapters: what a city does to the air, what happens inside a single street, what a park or a tree is actually worth, what a city does with its rainwater, what people built before there was a word for any of it, and what can be done now.

31 The urban heat island

A city builds its own climate, and it does most of it after dark.

Drive out of a large city on a clear, calm summer night with a thermometer and you will watch the air temperature fall. Not gradually, and not evenly: it drops at the edge of the dense quarters, it dips a little further over a park, and by the time the fields begin it can be several degrees lower than it was in the centre. That difference is the urban heat island, and it has been measured since Luke Howard did it in London two hundred years ago (Howard 1833), long before anybody had a theory for it.

My own path into this field ran through exactly this question. My habilitation in Freiburg was on the thermal component of urban climate, and the city itself was the laboratory: the same street measured on different nights, a park a few hundred metres away sitting several degrees cooler once the sun had gone down. The instruments have improved a great deal since then. The basic lesson from those first measurements has not: a city shows what it is really made of after dark, not at noon.

In the annual mean a central European city is about one to two degrees warmer than its surroundings, and almost all of that difference comes from the nights. On the nights that matter — clear sky, no wind, after a hot day — individual nights in a central European city can run more than seven degrees above the surroundings, and in very large cities differences above ten degrees have been measured (Matzarakis and Baumüller 2026). Those are exactly the nights on which the body most needs to recover, and the heat island is therefore a health subject, not only a curiosity of the temperature record.

Four things make it, and they are worth separating because they call for different remedies. Stone, brick and asphalt store heat during the day and release it all night, so a city cools far more slowly than a field. A narrow street sees only a strip of sky, so the long-wave radiation that carries heat away is caught by the wall opposite and sent back. There is little water and little vegetation, so almost nothing evaporates, and the energy that would have gone into evaporation goes into warming the air instead. And the city adds heat of its own, from engines, machines, cooling systems and bodies (Oke 1982; Erell et al. 2011).

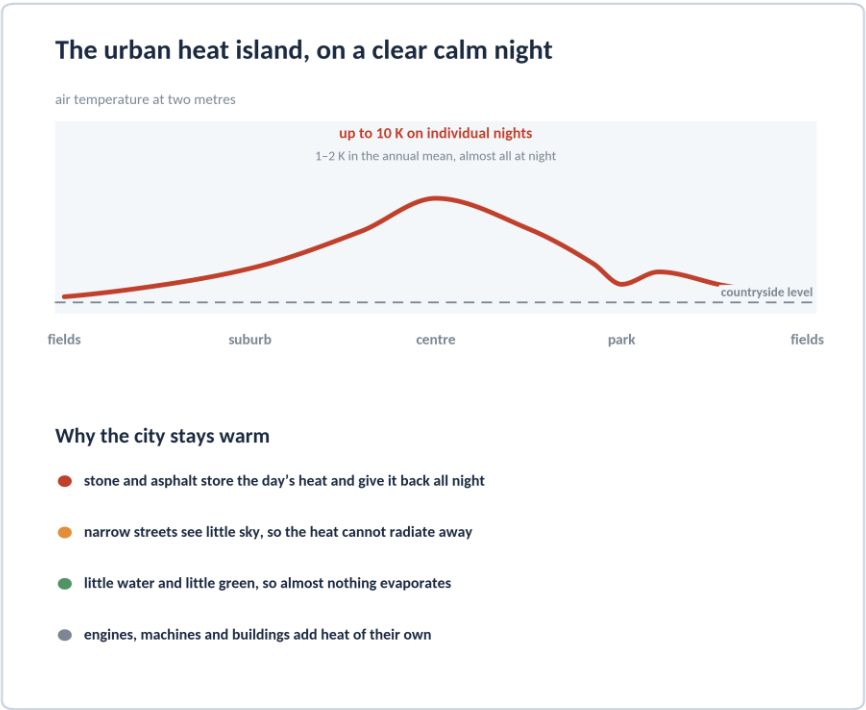


Figure 33**:** The temperature profile across a city on a clear, calm night, and the four reasons for it.

The daytime picture is different and often misunderstood, and the name deserves some pedantry. The English term is urban heat island, and the German translation that has taken hold —

urbane Hitzeinsel — is not correct, because it suggests a phenomenon that appears only during heat. What is meant is a general warming of the city relative to its surroundings, present all year, hot or not. Measurements in Stuttgart show almost no difference in the daily maximum air temperature between stations with different land uses, once elevation is accounted for — what decides the daytime reading is the ground cover below the station, not how high up the hill it sits. The urban heat island is a night phenomenon, and it is structural rather than extreme (Matzarakis and Baumüller 2026). During the day a dense city centre can be no warmer than the countryside in air temperature, and sometimes cooler, because the buildings shade the streets. What the body experiences is another matter entirely, because it is standing next to walls at fifty degrees. This is the first place where air temperature and human perception separate, and the next chapter is about the consequences.

The heat island also has a shape in time. It is weakest in the afternoon, strongest a few hours after sunset, and it persists until the morning. That timing matters for the people who live in the city: the night is when the circulation is supposed to recover from the day, and in a city centre it often does not get the chance. Nights above twenty degrees are among the best predictors of a severe heatwave's mortality toll, and cities manufacture them.

One more property deserves mention because it is easy to forget in a warming climate. In winter the same effect works in our favour: a city has fewer frost nights, less heating demand and less ice on the pavements. The heat island is not a fault to be abolished. It is an amplifier, and what has changed is that the summers it amplifies are getting hotter.

Table 31**:** What makes a city warm, and what can be done about it

Cause	How it works	What reduces it
Stored heat	stone and asphalt release at night	bright surfaces, less sealing
Street geometry	little sky visible, radiation trapped	wider spacing, open squares
Missing evaporation	no water, no plants, no cooling	trees, unsealed ground, water
Waste heat	engines, machines, cooling systems	efficiency, district solutions

In a changing climate. The heat island is not caused by climate change and it is not growing much on its own. What is growing is the climate underneath it. A city that used to add three degrees to a warm night still adds three degrees, but the warm night now starts higher, and that is what pushes whole quarters over the thresholds at which sleep and recovery fail. The two effects simply add, and only one of them can be worked on locally (Matzarakis and Endler 2010).

GOOD TO KNOW

The heat island is largest at night and smallest in the afternoon. It is a sleep problem before it is a daytime problem.

Nights above twenty degrees matter more for health than the maximum reached at midday.

Keywords: Urban heat island · Sky view factor · Stored heat · Waste heat · Tropical night · Urban climate

SOURCES

Howard, L. (1833): The Climate of London, Deduced from Meteorological Observations. Harvey and Darton, London.
Matzarakis, A., Baumüller, J. (2026): Stadtklima, Bioklima des Menschen und Klimaanpassung — einige Irrtümer und Fakten. Gefahrstoffe — Reinhaltung der Luft 96(5–6), 95–104.
Oke, T. R. (1982): The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society 108, 1–24.
Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.
Matzarakis, A., Endler, C. (2010): Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. International Journal of Biometeorology 54, 479–483.

32 Microclimate

The weather report gives one number for a whole city. The body meets a different one every few metres.

Stand on the sunny side of a square at three in the afternoon, walk fifty metres into the shade of a large tree, and the thermometer will hardly move. The body will disagree violently. This is the most useful single observation in urban biometeorology, and it is the reason the thermal indices of Part II exist at all.

The reason is radiation. Outdoors, the largest single term in the human heat balance is not the temperature of the air but the radiation arriving from the sun and from every surface in view. An asphalt surface in full sun reaches fifty or sixty degrees and radiates that heat at whatever stands on it. A wall that has been in the sun all afternoon does the same into the evening. Step out of that radiation and the load falls immediately, even though the air is unchanged.

Expressed in physiologically equivalent temperature, the differences within a single street are extraordinary. At thirty degrees air temperature, full sun over asphalt can produce well over forty degrees PET, the shade of a building something in the middle thirties, and the shade of a large tree with a little air movement below thirty. Nearly twenty degrees of difference in the perceived load, at a constant air temperature, inside a distance a person walks in a minute (Mayer and Höppe 1987). A lawn is often quoted as a fourth case, and it belongs with the others only if it is shaded — open grass at midday evaporates a little and shades nothing, so a person standing on it in full sun is in almost the same radiation field as on asphalt.

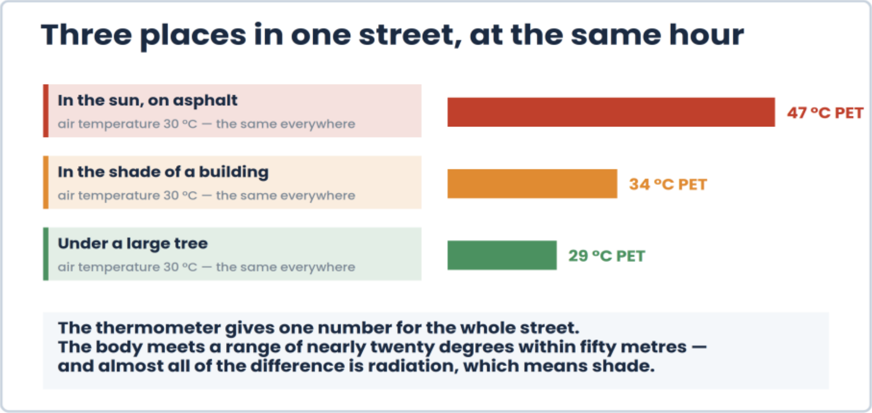


Figure 34: Three places in one street at the same hour: the same air temperature, very different loads on the body.

This is also why the tree beats everything else. A tree does two things at once: it removes the direct sun, which is the large term, and it evaporates, which cools the air a little (Lin, Matzarakis and Hwang 2010). A sunshade does only the first, and does it well. A lawn does only the second, and at midday that is almost nothing. If a city has money for one measure, the order is not in doubt.

Comparing such small-scale measures — trees, canopies, materials, water — calls for a common yardstick, and one has been proposed in the form of measure review frameworks, which rate each option against the same set of microclimatic and thermal criteria (Nouri et al. 2018; Matzarakis and Nouri 2026; Nouri and Matzarakis 2026).

The practical consequence is that a microclimate can be designed, and designed cheaply, once somebody looks at where the sun actually falls. A bus stop moved to the north side of the street. A row of trees along the western facade rather than the northern one. A playground that has shade at three in the afternoon rather than at ten in the morning. These decisions cost nothing extra at the planning stage and are almost impossible to correct afterwards.

Models exist to work this out in advance, and they have become ordinary tools of planning practice rather than research instruments. They compute the radiation arriving at a person from every direction in a given street geometry and turn it into an index a planner can read (Matzarakis et al. 2010). What they cannot do is decide where the bench should be. That is still a human judgement, and it is better made with a map of the shade than without one.

Table 32**:** The same afternoon in three places

Place	Air temperature	What the body feels
Asphalt, full sun	30 °C	about 47 °C PET — heat stress
Shade of a building	30 °C	about 34 °C PET — uncomfortable
Under a large tree	30 °C	about 29 °C PET — bearable

In a changing climate. As summers get hotter the differences within a street grow rather than shrink, because surfaces in full sun heat up faster than shaded ones. A city that is already unequal in shade becomes more unequal in heat load, and shade in most cities is not distributed by need. The quarters with the fewest trees are usually the quarters with the smallest flats, the oldest residents and the least air conditioning.

GOOD TO KNOW

Crossing to the shady side of a street can change the perceived load by more than ten degrees PET. It is the cheapest measure there is.
A tree beats a sunshade, and a sunshade beats a lawn, at least at midday.

Keywords: Microclimate · Mean radiant temperature · Shade · Surface temperature · Street canyon · PET

SOURCES

Matzarakis, A., Rutz, F., Mayer, H. (2010): Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. International Journal of Biometeorology 54, 131–139.
Mayer, H., Höppe, P. (1987): Thermal comfort of man in different urban environments. Theoretical and Applied Climatology 38, 43–49.
Lin, T.-P., Matzarakis, A., Hwang, R.-L. (2010): Shading effect on long-term outdoor thermal comfort. Building and Environment 45, 213–221.

33 Parks, green and water

Green cools. How much, and how far, is a question with surprisingly precise answers.

Every city that discusses heat arrives sooner or later at green space, and the discussion usually stops at the word. The word is where it should start, not where it should stop, because green things differ enormously in what they do, and the differences decide whether money is well spent.

A park is cooler than the built-up area around it, and the size of that cooling is routinely overstated. Reviews of the measurements report an average cooling of about one degree of air temperature, with two or three degrees seen only in the largest, densely treed parks (Bowler et al. 2010), but modelling for Dresden found that only green areas with a dense stand of trees reach a reduction of two degrees, and that the reduction applies inside the green area itself rather than to the quarter around it (Matzarakis and Baumüller 2026). Even large parks barely lower the air temperature of the surrounding streets. What they do change, strongly, is the thermal load on anybody standing inside them — which is a different quantity and the one that matters.

Once the right quantity is used the result stops being disappointing, for the reason the last chapter gave. Inside a wood or under a group of large trees, the radiation load falls far more than the air temperature does. Measured as PET, the difference between a sunlit square and a shaded park in the same city on the same afternoon is commonly fifteen to twenty degrees. The park is not a little cooler. It is a different climate.

Figure 35: A park, the temperature profile across it, and what different kinds of green are worth.

The tree itself deserves a page, because it is the single most effective measure in this part of the book and because the argument for it is usually made badly. A tree is not simply "green". It does a small number of specific things, it costs a small number of specific things, and a city that plants without understanding either ends up with dead trees and a disappointed council.

What it gives, in order of size. Shade first: it removes the direct sun from a person, which is the largest term in the outdoor heat balance and the reason the difference under a canopy can reach fifteen to twenty degrees of PET. Transpiration second: a large, well-supplied tree moves up to a few hundred litres of water into the air on a hot day, and that water takes its evaporative energy from the surroundings. Then the smaller ones, which are real but often overstated: the canopy intercepts particles, slows and stores rainwater, screens a little noise, and has measurable effects on recovery, sleep and stress that survive when the studies control for income and exercise (Twohig-Bennett and Jones 2018).

Figure 36: What a tree gives, what it asks for, and why the second column is a planning problem rather than an argument.

What it costs is the part that gets left out of the enthusiastic version, and leaving it out is why so many street trees fail. A tree needs root space, and a modern street with services under the pavement has least of it; a pit of two cubic metres produces a tree that never grows large enough to shade anything. It needs water in the summers when it is most wanted, and a tree under water stress closes its stomata and stops transpiring — the cooling switches off at the moment it is needed. In a narrow street canyon a dense canopy reduces the ventilation and can raise pollutant concentrations at street level. Some species emit biogenic volatile compounds that contribute to ozone formation on hot days, and some produce pollen that Chapter 25 was about. And it needs pruning, inspection, leaf clearance and occasional repair to the paving it has lifted — and, rarely, removal after it comes down entirely.

None of that is an argument against trees. Every item on the list is a planning and budget question with a known answer: structural soil under the pavement rather than a pit beside it, species chosen for the climate of 2050 rather than of 1980, spacing that leaves the canyon ventilated, and water in the first years and in dry summers. What it is an argument against is planting trees as a gesture and then being surprised.

Several claims about urban climate and urban vegetation circulate widely and do not survive contact with the measurements. They have been collected and corrected in one place (Matzarakis and Baumüller 2026), and the table below follows that account. Trees do little to measurably clean the air of gases; they intercept some particulate matter, and even that effect is modest and stays close to the tree. A green roof does very little for the person walking past at street level, however much it does for the building beneath it. A lawn is not a substitute for a canopy, because it evaporates and shades nothing. A fountain cools a few metres and not a quarter. And the urban heat island itself is not caused by climate change, though the two add. The pattern in all of these is the same: a real but small effect gets promoted into a solution, and the promotion eventually discredits the measure that actually works.

Table 33: Twelve claims about urban climate and climate adaptation, and what the measurements say

Often said	What the measurements show
Air temperature drives heat stress on the body	Wind, humidity and above all radiation matter as much or more. Official heat warnings therefore use thermal indices (PET, UTCI), not air temperature.
The city is a heat island	More precisely a night-time urban heat island: 1–2 °C warmer in the annual mean, almost entirely at night. Daily maxima are nearly the same as outside.
Forests are poor producers of cold air	Less efficient than meadows (about 4–8 against 8–15 m^3 per m^2 and hour) — but on slopes and in valleys they are important formation areas and drainage paths.
Enough green infrastructure can cool a city	The effect is always local. Even large parks barely lower the air temperature of the streets around them.
Trees noticeably lower air temperature	Hardly at all. What they do is cut the radiant load by shading — and that, not evaporation, is what decides thermal stress.
Green facades cool the urban atmosphere	Only in the immediate vicinity and for the building itself. The facade is 10–20 °C cooler; the street is not.
Green roofs cool the urban atmosphere	They cool the roof surface strongly, by up to 30–40 °C, and are barely measurable at street level.
Reflective surfaces reduce heat stress	They lower surface temperatures, but on walls they can raise the radiant load on people. City-wide air temperature effects are 0.1–0.5 K.
Air conditioning significantly heats the city	Mostly tenths of a degree. Cooling every flat in Stuttgart from 35 to 25 °C would warm the city by less than 1 K.
Water misting cools the urban atmosphere	The effect reaches 3 to 10 metres — but within that range it works well.
Rivers and ponds cool a city in summer	Locally, and mostly over the water itself. Well-watered grass often evaporates more than an open water surface, and at night water is the warmer of the two.
There is a lack of laws on climate adaptation	Numerous legal foundations already exist in Germany — the Climate Adaptation Act of 2024 and the Federal Building Code among them. The problem is applying them.

Water is the case where expectations and measurements diverge most. A pond, a canal or a fountain cools less than most people assume: open water evaporates, but a still surface warms through the day and gives that heat back at night, so a shallow urban pond can make the night warmer rather than cooler. Moving or sprayed water is better, because it evaporates far more per square metre, and being able to put hands and feet in it is better still, for reasons that have more to do with the body than with the air.

The most important point is a planning one rather than a biological one. A park cools its own quarter, and cool air also drains out of it at night along the streets, provided the streets are open enough to carry it. Blocking that path with a single building can undo the effect of the park it drains. This is why climate analysis maps, which show where the cool air is produced and where it flows, belong in the planning process rather than in a research report (Erell et al. 2011; VDI 3787 Part 1, 2015).

Table 34**:** What cools a city, and by how much

Element	Effect on air	Effect on the body
Large single tree	small, local	very large — it removes the sun
Park with trees	1 to 3 K inside; rarely reaching beyond its own edge	very large inside
Lawn without trees	small, mostly at night	little at midday
Green roof	helps the building, not the street	none at street level
Still water	small; can warm the night	small
Moving or sprayed water	local and short-lived	noticeable and immediate

In a changing climate. Warmer, drier summers put the cooling infrastructure under the same stress it is meant to relieve. Trees that were planted for a different climate suffer, and a stressed tree transpires less, which is precisely when its cooling is needed. Species choice, root space and summer watering are therefore not gardening details. They decide whether the measure still works in the decade it was planted for.

GOOD TO KNOW

Several small parks spread through a quarter usually help more people than one large park at the edge.

Keep the path that cool night air takes out of a park clear. One building in the wrong place can undo the park.

Keywords: Park cool island · Urban green · Evaporation · Cold air drainage · Climate analysis map · Tree canopy

SOURCES

Matzarakis, A., Baumüller, J. (2026): Stadtklima, Bioklima des Menschen und Klimaanpassung — einige Irrtümer und Fakten. Gefahrstoffe — Reinhaltung der Luft 96(5–6), 95–104.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., Pullin, A. S. (2010): Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning 97, 147–155.

Twohig-Bennett, C., Jones, A. (2018): The health benefits of the great outdoors: a systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research 166, 628–637.

VDI 3787 Part 1 (2015): Environmental meteorology — Climate and air pollution maps for cities and regions. VDI, Düsseldorf.

Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.

34 Sponge cities and the urban bioclimate

A city that keeps its rainwater has something to evaporate in July. The idea is no larger than that.

For a century, urban drainage had one goal: get the water away as fast as possible. Roofs, roads and yards were sealed, gutters led to pipes, pipes led to the river, and a heavy shower was gone from the city within the hour. It worked, in the sense that streets stopped flooding, and it produced two problems that only became visible later. Downstream, the flood peak arrived faster and higher. And in the city itself, nothing was left to evaporate.

That second consequence is the biometeorological one and it belongs in this book. Evaporation is one of the three ways a place can cool itself, alongside shade and ventilation (Erell et al. 2011). A sealed city has removed it almost entirely: the energy that would have gone into evaporating water goes into warming the air and the surfaces instead, which is one of the four causes of the heat island in Chapter 31. The water and the heat are the same problem seen from two sides, and for most of the twentieth century they were handled by two different offices.

The sponge city reverses the goal. Rain is held where it falls, in unsealed ground, in soil under the pavement, in swales and troughs, in substrate on roofs and in retention below ground, and it is released slowly — into the plants, into the air, and only then into the drain. The flood peak falls because the water leaves later. And the city keeps a reserve that its trees can draw on in August, which is precisely when the cooling is needed and precisely when a conventionally drained city has nothing left.

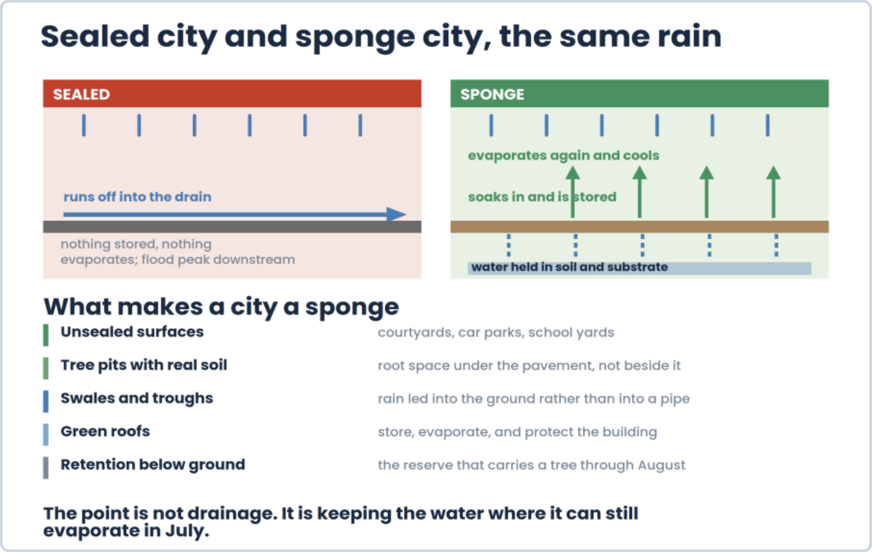


Figure 37: The same rain on a sealed and on an unsealed city, and the elements that make the difference.

The elements are unglamorous and most of them are cheap compared with what they replace. Unsealing courtyards, car parks and school yards. Tree pits built as continuous structural soil under the pavement rather than as isolated holes beside it, so that roots and water share the same volume. Swales and shallow troughs along streets that take the runoff from the road into the ground. Green roofs, which do little at street level but store a great deal and protect the building. And retention below ground, which is the reserve that carries a tree through a dry month (DWA-A 138 / DWA-M 102).

Table 35: What each element does for water, and what it does for the bioclimate

Element	For the water	For the bioclimate
Unsealed ground	infiltration, lower flood peak	evaporation, cooler surfaces
Structural soil under paving	stores the reserve	keeps trees transpiring in August
Swales and troughs	leads runoff into the ground	moisture near the surface
Green roofs	holds and delays rainfall	helps the building, little at street level
Underground retention	buffer for dry weeks	irrigation without drinking water
Open water	storage and delay	small cooling; can warm the night if shallow

Two cautions belong here, because the idea has become fashionable and fashionable ideas get oversold. The first: a sponge city is not a cooling measure on its own. Evaporation is the third lever, after shade and ventilation, and a well-watered treeless square is still a hot square. What the sponge does is make the first lever work — it keeps the trees alive and transpiring. The second: standing water in a warm city is also habitat, and Chapter 29 explained what breeds in it. Sponge elements have to drain within a day or two, which is a design requirement rather than an objection.

The strength of the approach, and the reason it earns a chapter, is that it joins two budgets that were previously separate. Flood protection is funded because floods are expensive and photogenic. Urban cooling is funded late and reluctantly because heat deaths are quiet. A measure that does both can be paid for out of the drainage budget and delivers the thermal benefit as a by-product — which, in the way cities actually decide things, matters more than any argument about either one alone.

In a changing climate. Both halves of the problem are moving in the same direction. Heavy rainfall is becoming more intense, which strengthens the case for retention, and summers are becoming drier and hotter, which strengthens the case for storage. The two used to be treated as opposite risks. In a warming climate they are the same infrastructure, and the city that builds it once solves both.

GOOD TO KNOW

Every square metre unsealed is a square metre that can evaporate in July and store water in October.

A tree pit of two cubic metres produces a small tree forever. Root space under the pavement is what decides the canopy.

Keywords: Sponge city · Infiltration · Retention · Structural soil · Evaporation · Flood peak

SOURCES

Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., Pullin, A. S. (2010): Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning 97, 147–155.

DWA-A 138 / DWA-M 102: Regelwerk zur Versickerung und Bewirtschaftung von Niederschlagswasser. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, Hennef.

35 Building with the climate: traditional wisdom

People solved this before they could measure it. The solutions are still standing.

Long before anybody could calculate a heat balance, people in every climate on earth worked out how to live in it, and they wrote the answer into their houses and their streets. The results were not designed in the modern sense. They were selected: forms that failed were not rebuilt, and forms that worked were copied for centuries. That is a slower method than calculation and a more reliable one, because it was tested against every summer rather than against a model (Olgyay 1963; Givoni 1998).

In hot dry climates the answer was mass and shade. Thick walls of stone or mud brick take most of a day to warm through, so the heat of the afternoon arrives inside around midnight, when the outside has cooled and the windows can be opened. Streets were kept narrow so that the buildings shaded each other. Courtyards held shade, a tree and often water, and cool air collected in them overnight and sank into the rooms. In Persia and the Gulf, wind catchers on the roof pulled the moving air of the upper level down into the house, sometimes over water on the way.

In hot humid climates the answer was the opposite, and this is the point that gets lost when solutions travel. Where the air is already close to saturation, mass is useless because there is no cool night to store, and evaporation is useless because sweat will not evaporate anyway. What is left is air movement. So the houses became light, open and raised on stilts, with wide openings on both sides for cross ventilation and deep overhanging roofs to keep the sun and the rain off the openings. A large share of humanity lives in this second kind of climate, and most of the advice written in Europe was written for the first (Erell et al. 2011).

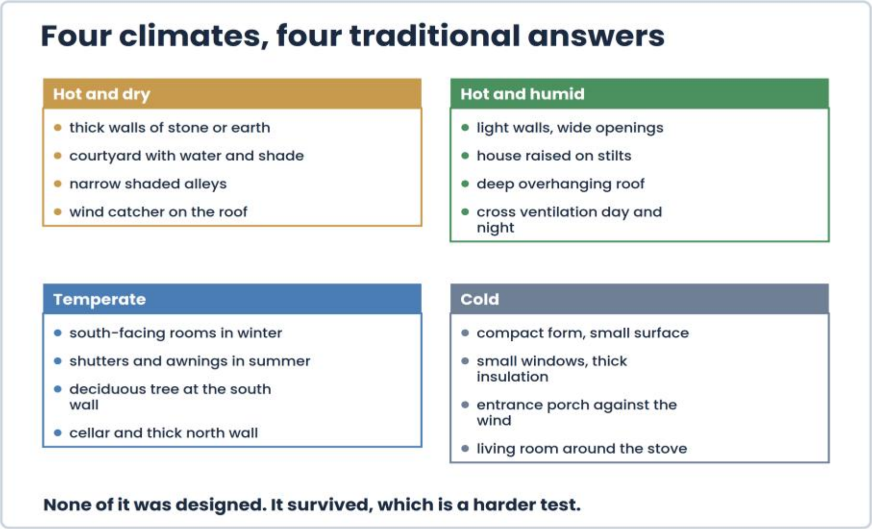


Figure 38: Four climates and the answers that were built for them, long before any of it was measured.

Temperate Europe developed a third set of solutions, less visible because it looks like ordinary building. Rooms that are used in the day face the sun in winter. Shutters, awnings and deep reveals keep the same sun out in summer. A deciduous tree at the south wall shades in August and lets the light through in February, which is a piece of engineering with no moving parts. The cellar was cool, the north wall was thick, and the stove stood where the family sat. Cold climates went further in the same direction: a compact, near-cubic form that keeps surface area to a minimum, small windows to limit heat loss, and a porch or air-lock entrance so the warmed indoor air does not empty out through the door every time someone comes in.

Two habits deserve separate mention, because both are usually dismissed as folklore. The siesta is a thermal measure: it moves work and movement out of the hours in which the load is highest, and it is the same measure that occupational medicine now recommends for outdoor work in heat. And night ventilation — closing everything by day and opening it after dark — is exactly the correct strategy in a dry climate with heavy walls, and exactly the wrong one where the nights stay humid and warm.

The point of the chapter is not nostalgia. Much of the old building stock was dark, damp and cramped, and nobody should want it back as it was. The point is that the principles are still correct and are cheap, and that they were abandoned not because they stopped working but because mechanical cooling made it possible to ignore them. A glass tower in Dubai and a glass tower in Hamburg are the same building, and neither of them is a response to anything.

Table 36**:** Climate, traditional answer, and the modern equivalent

Climate	Traditional answer	Same idea today
Hot and dry	thick walls, courtyard, narrow alleys	thermal mass, night ventilation, shading
Hot and humid	stilts, wide openings, deep roof	cross ventilation, overhangs, light structure
Temperate	south rooms, shutters, deciduous tree	solar orientation, external shading
Cold	compact form, small windows, porch	compactness, insulation, air-lock entrance

In a changing climate. Traditional forms were tuned to the climate a place used to have, and that climate is moving. A house built for the summers of 1900 in central Europe is not automatically right for those of 2050, and heavy walls without night ventilation become a trap when the nights stop cooling.

The principles survive the change; the specific solutions have to be checked against the climate the building will actually stand in.

GOOD TO KNOW

Night ventilation works where the night is cool and dry. Where the night stays warm and humid it does nothing, and can make things worse.

A deciduous tree on the south side shades in summer and lets the winter sun through. Nothing mechanical does both.

Keywords: Traditional building · Thermal mass · Courtyard · Wind catcher · Cross ventilation · Night ventilation

SOURCES

Olgyay, V. (1963): Design with Climate. Bioclimatic Approach to Architectural Regionalism. Princeton University Press, Princeton.

Givoni, B. (1998): Climate Considerations in Building and Urban Design. Van Nostrand Reinhold, New York.

Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.

36 Cooling cities: planning and practice

Everything in this part comes together here, in the order in which it actually works.

A city that wants to be cooler has a long list of options and a short list of things that genuinely change what a body feels. The order matters more than the list, and it follows directly from the heat balance: shade first, then air movement, then evaporation. Radiation is the largest term outdoors, so removing the sun from a person does more than cooling the air by a degree ever will (Erell et al. 2011).

Working with colleagues from Vienna to Taipei to Thessaloniki has taught me the same lesson from a dozen different angles. The physics of the energy balance travels perfectly across borders. The answer to what a city should actually do about it never does. A shading rule that works in a Mediterranean square needs rethinking in a humid subtropical one, and the reverse is just as true, which is exactly why the modified index in Chapter 7 had to be tested against real people in Taiwan before anyone could trust it there.

Shade means trees before anything else, because a tree shades and evaporates at the same time and costs almost nothing to run. Where a tree cannot stand — over a tram stop, along a narrow lane with services under the pavement — built shade does most of the same job for the person beneath it. What matters is the hour: shade at three in the afternoon on the western side is worth more than shade at ten in the morning anywhere.

Air movement is the part that is decided long before anyone thinks about heat. Cool air forms over fields, parks and water at night and drains down into the built-up area along valleys and open streets. Those paths can be mapped, and in Germany they routinely are, through climate analysis maps that show where the cool air is produced and where it flows (VDI 3787 Part 1, 2015). Building across one of them removes a benefit that no later measure can replace, and this therefore belongs in the land use plan, not in a summer campaign.

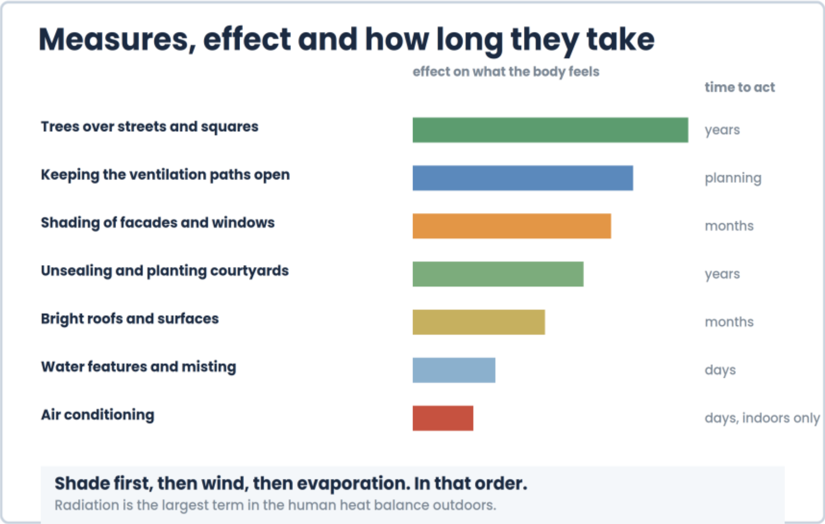


Figure 39: Measures ranked by what they do for the body, and by how long they take to arrive.

Surfaces come next and need a caution rather than an endorsement. A bright roof reflects rather than stores, which lowers its own surface temperature by twenty to forty degrees and helps the building beneath it; city-wide the effect on air temperature is between a tenth and half a kelvin. For a person in the street it can be worse than neutral, because a bright facade reflects short-wave radiation back at passers-by and raises the mean radiant temperature — the quantity that decides thermal stress. Reflective roofs are worth having, especially on industrial buildings, and reflective walls at eye level are not (Matzarakis and Baumüller 2026). Unsealing a courtyard, a car park or a school yard helps twice: it lets water in, and it lets evaporation out. And every square metre that stops storing heat is a square metre that stops releasing it at two in the morning.

Air conditioning has to be discussed honestly rather than dismissed. Inside a hospital, a care home or a room where a vulnerable person is trying to survive a heatwave, it saves lives and no amount of urban design substitutes for it. What it also does is move heat from inside to outside — but the size of that effect is regularly overstated. In a dense quarter the waste heat raises the local air temperature by tenths of a degree, and a calculation for Stuttgart found that cooling every flat in the city from thirty-five to twenty-five degrees would warm the outside air by less than one kelvin; the increases of one to two degrees that get quoted come from the immediate surroundings of very large building complexes in Asian megacities (Matzarakis and Baumüller 2026). The genuine costs of air conditioning lie elsewhere and are underrated: electricity, noise from the outdoor units, and refrigerants with a high greenhouse potential. In an ageing European population it will be indispensable for health protection, and the sensible position is to demand that it sits in a well-insulated, shaded building and runs on renewable electricity.

One objection turns up in every discussion and is worth answering here, because it stops projects before they start: that the law does not require any of this. In Germany it does. Climate adaptation has been anchored in the Federal Building Code since 2011, the Climate Adaptation Act of 2024 sets binding aims, responsibilities and minimum requirements and obliges municipalities to draw up local adaptation plans, and further requirements sit in the spatial planning, nature conservation, water and environmental assessment acts, supported by a long series of technical guidelines. The difficulty is not a missing law.

It is the consistent application of the ones that exist, and that is a question of priorities, staff and nerve rather than of legislation (Matzarakis and Baumüller 2026).

None of this is decided by argument. It is decided by a map, and the maps deserve a section of their own, because they are the instrument through which this field actually enters planning — and because they are routinely misread.

The German tradition here is older than the climate debate. Stuttgart, a city in a basin with almost no natural ventilation, began mapping its cold air in the nineteen-thirties and has run a municipal climate office ever since; the regional climate atlas that grew out of that work shows where cold air forms on the slopes at night, along which valleys it drains, and which building plots would block it (Verband Region Stuttgart 2008). Freiburg, in a valley opening towards the Rhine, has the same problem in a different geometry, and the same instrument: the cold air that comes down the Dreisam valley in the evening is the reason parts of the old city cool down at all (Matzarakis and Endler 2010).

Figure 40: The four scales of urban climate mapping, and the four ways the maps get misread.

The maps come at different scales and answer different questions, and mixing them up is the commonest error. A regional climate analysis at 1 : 50 000 shows where cold air is produced and where it flows; it cannot say anything about a courtyard. An urban climate map divides the city into climatopes — quarters that behave alike thermally — at 1 : 10 000 to 1 : 25 000. A planning advice map turns that into statements a planning office can act on: where building is sensitive, where a ventilation path must stay open, where a green area has to be kept. And below all of them sit the micro-scale models that answer what a person feels in one particular street.

Producing these maps has become far easier and, in one respect, far harder. Easier, because high resolution data on buildings, vegetation and surfaces are now available for whole cities, and because the analysis can be automated: linking urban morphology and green infrastructure to the atmospheric conditions of a neighbourhood is now a computation rather than a field campaign (Gangwisch et al. 2023). Harder, because a micro-scale model run for a whole city over a whole climate period used to be impossible; the way around it has been to train a neural network on a limited number of model runs and let it produce the long-term thermal comfort field for the entire city as a computational shortcut, which was done for Freiburg (Briegel et al. 2023).

Four misreadings recur often enough to need naming. A colour on a map is a class, not a measurement at a particular address, and a plot at the edge of a class is not the same as one in the middle of it. Most published maps show air temperature or cold air volume, not what a body feels, and Chapter 32 explained how far apart those are. The scale decides the question, so a city map cannot settle an argument about a single street. And a map has a date: one produced in the nineteen-nineties describes a climate that no longer exists. Its temperature classes have aged along with it, but the ventilation path has not, because that follows the topography, and the topography does not move.

What makes the German examples worth citing is not the cartography but what followed it. In Stuttgart the maps became binding input to the land use plan, and building on the ventilation paths was refused — repeatedly, against pressure, over decades. Between a map and a measure, that is the difference.

The last point is about who does this. Nothing in this chapter is done by a meteorologist. It is done by planners, engineers, foresters, housing companies and city councils, and it is done years before the heatwave that it will be judged by. The task of this field is to give them numbers they can use — a map of the shade, a map of the cool air, an index of what a place asks of the human body — and then to be present in the room where the plan is decided. That is the service, and the reason for writing any of this down. And a specific comment on it, if you don't work together or cooperate explicitly you don't gain.

Table 37**:** What to do, what it is worth, and how long it takes

Measure	Effect on the body	Time until it works
Trees over streets and squares	very large	years, so start now
Keeping ventilation paths open	large, city-wide	decided in the land use plan
Shading facades and windows	large indoors	months
Unsealing courtyards and yards	moderate, and helps at night	years
Bright roofs and surfaces	helps the building; can raise the radiant load felt in the street	months
Drinking water and cool rooms	large for those at risk	days
Air conditioning	decisive indoors, negative outdoors	days

In a changing climate. Everything in this chapter has to be planned for a climate that will not stand still. A tree planted today will do its most important work in twenty or thirty years, in summers hotter than any in the record, and it has to be chosen for those summers rather than for the ones we remember. That is uncomfortable for a profession used to planting what has always grown well, and it is the single decision in this chapter with the longest reach.

GOOD TO KNOW

Shade first, then wind, then evaporation. In that order, and the order is not a matter of taste.
A tree planted this year does its real work in twenty. That is an argument for starting, not for waiting.

Keywords: Cooling cities · Shade · Ventilation path · Unsealing · Albedo · Heat planning

SOURCES

Gangwisch, M., Saha, S., Matzarakis, A. (2023): Spatial neighborhood analysis linking urban morphology and green infrastructure to atmospheric conditions in Karlsruhe, Germany. Urban Climate 51, 101624.
Briegel, F., Makansi, O., Brox, T., Matzarakis, A., Christen, A. (2023): Modelling long-term thermal comfort conditions in urban environments using a deep convolutional encoder-decoder as a computational shortcut. Urban Climate 47, 101359.
Verband Region Stuttgart (2008): Klimaatlas Region Stuttgart. Verband Region Stuttgart, Stuttgart.
Matzarakis, A., Baumüller, J. (2026): Stadtklima, Bioklima des Menschen und Klimaanpassung — einige Irrtümer und Fakten. Gefahrstoffe — Reinhaltung der Luft 96(5–6), 95–104.
Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.
VDI 3787 Part 1 (2015): Environmental meteorology — Climate and air pollution maps for cities and regions. VDI, Düsseldorf.
Matzarakis, A., Endler, C. (2010): Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. International Journal of Biometeorology 54, 479–483.
Matzarakis, A., Nouri, A. S. (2026): Thermal Comfort Models for Outdoor Spaces. In: Eslamian, S., Eslamian, F. A. (eds.): Encyclopedia of Smart and Green Cities. Springer, Singapore, 1–12. https://doi.org/10.1007/978-981-96-1800-2_105-1
Nouri, A. S., Matzarakis, A. (2026): Urban Microclimates and Comfort. In: Eslamian, S., Eslamian, F. A. (eds.): Encyclopedia of Smart and Green Cities. Springer, Singapore, 1–10. https://doi.org/10.1007/978-981-96-1800-2_213-1
Nouri, A. S., Costa, J. P., Santamouris, M., Matzarakis, A. (2018): Approaches to Outdoor Thermal Comfort Thresholds through Public Space Design: A Review. Atmosphere 9(3), 108. https://doi.org/10.3390/atmos9030108

PART VII

Climate as a Resource

Almost everything so far has been about load: heat, cold, radiation, particles, noise. That is the half of the subject that gets funded. It is not all of it. Climate is also something people seek out. They travel for it, they are sent to it by a doctor, they build whole towns on it. Four chapters on the side of the ledger where weather does good — what a healthy climate is, how it has been used as treatment for two hundred years, what happens to the body in thin air, and why the tourist season of half of Europe is quietly moving.

37 Healthy weather and healthy climate

A healthy climate is not a mild one. It is one that offers both a stimulus and a way to recover.

Ask once what good weather would be. The question sounds naive and it is not, because a field that only measures harm ends up implying that the ideal condition is no weather at all — a room at twenty-two degrees, no sun, no wind, forever. Nobody who has lived in such a room would call it healthy.

In the language of Part II, the comfortable range runs from roughly eighteen to twenty-three degrees of physiologically equivalent temperature, with the range from thirteen to twenty-nine still acceptable for most people doing most things (Matzarakis, Mayer and Iziomon 1999; VDI 3787 Part 2, 2022). But comfort is a poor definition of health. A body that is never asked to regulate loses the ability to do it well: the vessels react more slowly, sweating starts later, and the first hot day of the summer becomes an event rather than a nuisance (Matzarakis 2020). This is the reasoning behind the cold stimulus in Chapter 11 and behind the whole tradition of climate therapy in the next chapter.

So the honest definition is a double one. A healthy climate offers stimulus — changes of temperature, moving air, daylight, reasons to be outdoors — and it offers recovery, above all a night that cools. Its dangerous variants are the two ends: a climate with no stimulus at all, which is what air conditioning and office life produce, and a climate with stimulus and no recovery, which is what a tropical night in a city centre produces.

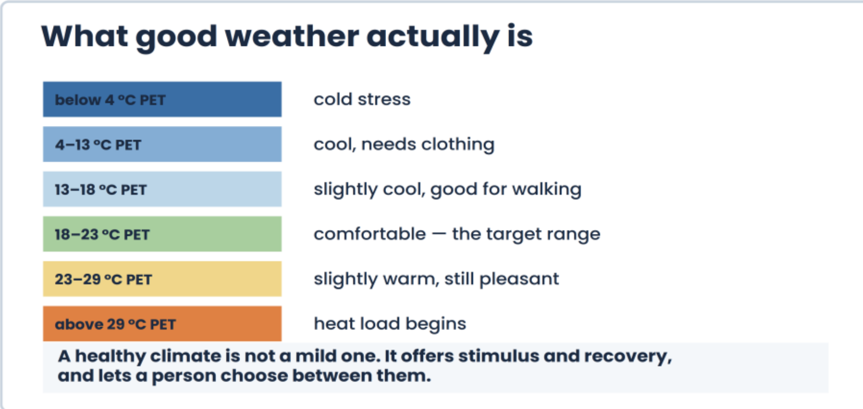


Figure 41: The thermal scale, read from the other direction: not where the danger starts, but where the good conditions are.

Daylight belongs here too, and it is the most underrated of the resources. Twenty minutes outdoors on an overcast winter day can deliver more light to the eye than hours spent in a bright office, and because the inner clock responds to timing and threshold rather than simply adding up lux over the day, even that comparison undersells the difference, as Chapter 18 described. It is free, it works in almost any weather, and no supplement replaces it.

Two old sayings survive because they are broadly right. There is no bad weather, only unsuitable clothing — true for the thermal complex, and false for the actinic one, where clothing helps but the sun still reaches skin and eyes. And air does you good — true, if the air is clean, and that was the subject of Part IV. Both sayings are worth repeating with their conditions attached, because people act on sayings far more than on studies.

The practical version of this chapter is short. Go outside daily and at a time when the load is moderate rather than extreme. Let the body meet cool air, warm air, wind and rain in reasonable doses. Protect the night: cool bedroom, dark, quiet. And treat the weather as something to be used rather than only survived — that is what the next three chapters are about.

Table 38**:** Climate as a load and as a resource

Element	As a load	As a resource
Heat	heat stress, sleepless nights	warmth, outdoor life, movement
Cold	cold stress, cardiovascular risk	training for the vessels, clear air
Sun	sunburn, skin cancer	vitamin D, mood, the inner clock
Wind	cold stress, discomfort	cooling, ventilation, clean air
Changeable weather	burden for the sensitive	stimulus for a healthy regulation

In a changing climate. A warming climate does not simply increase the load; it also moves the resource. Comfortable hours shift out of midsummer into spring and autumn, mild winters make outdoor movement possible in months that used to prevent it, and tropical nights remove the recovery that the whole balance depends on. The gain and the loss are not symmetrical, and the loss falls on the people with the least reserve.

GOOD TO KNOW
Twenty minutes outdoors on a grey winter morning does more for the inner clock than a bright room all day.
A body that never meets cool air handles heat worse. Regulation is a capacity, and capacities are trained.

Keywords: Healthy climate · Stimulus and recovery · Comfort range · Daylight · Climate as resource · Regulation

SOURCES

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.

VDI 3787 Part 2 (2022): Environmental meteorology — Methods for human-biometeorological evaluation of the thermal component of the climate. VDI, Düsseldorf.

Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84.

38 Climate therapy: mountains, sea and health resorts

For two hundred years, doctors have prescribed places. The reasoning is better than its reputation.

Long before there were thermal indices there were spa towns, and the logic behind them was biometeorological even though nobody used the word (Matzarakis 2020). A place was thought to have a climate with a particular effect, patients were sent there for a defined period, and the treatment consisted of controlled exposure to that climate: walking at a prescribed pace, resting in the open air, bathing, breathing. In German-speaking Europe this became an organised system with legal definitions, and towns still carry the titles — Heilklimatischer Kurort, Seeheilbad — as a matter of certification rather than advertising (Deutscher Heilbäderverband and Deutscher Tourismusverband 2005).

The mountain climate works through three things at once. The air is cooler, which raises the thermal stimulus and makes exertion easier. It is cleaner, with fewer particles and less nitrogen dioxide away from the traffic — though ozone itself is often higher there, since it is the traffic-borne nitric oxide near the road that would otherwise scavenge it. And above roughly fifteen hundred metres it is genuinely poor in allergens: the house dust mite does not thrive there, and the pollen season is shorter and later. That combination is why high-altitude clinics were built for asthma and for atopic skin disease, and why they still work for some patients when nothing else has.

The sea climate works differently. It is a strong stimulus climate: steady wind, a large cold stimulus, strong light with reflection from water and sand, and a salt aerosol that is measurably present in the first few hundred metres inland. It is also remarkably even — the sea removes the extremes of temperature in both directions. The classical prescription of walking along the waterline is not folklore: it delivers wind, aerosol, light and movement in one dose, and the coast does the dosing without the patient having to think about it.

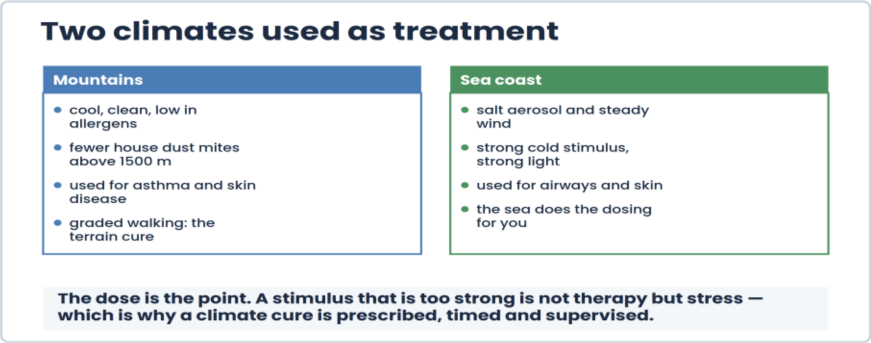


Figure 42: The two classical therapeutic climates and what each of them actually delivers.

The third element of the tradition is the terrain cure — walking on marked paths of graded difficulty, with the effort prescribed rather than chosen. It is cardiac rehabilitation using a landscape instead of a machine, and anecdotally people are more likely to keep it up after they leave than with most other forms of exercise prescription, though rigorous adherence data are scarce.

How good is the evidence? Mixed, and this book had better say so. The strongest results are for high-altitude treatment of asthma and atopic dermatitis, where the mechanism is concrete and the improvements are documented. Beyond that, much of what a climate cure delivers — three weeks of movement, sleep, daylight, no work and no traffic — would help wherever it happened. None of that argues against the cure. It argues for being honest about which part of the effect comes from the climate and which from everything else, and the honest version is more persuasive than the overstated one.

What survives from the tradition is a principle worth keeping: the dose. A stimulus that is too strong is not therapy but stress, and an elderly patient sent to a strong coastal climate in March can be harmed by it. Prescribing a place means prescribing a season, a duration and an intensity, which the old system did and a weekend booked online does not.

Table 39**:** Therapeutic climates, their effects and their limits

Climate	Main effect	Used for	Caution
High mountain	cool, clean, allergen-poor	asthma, atopic skin disease	cardiac patients, altitude
Low mountain	moderate stimulus, forest air	recovery, cardiovascular training	few, if any
Sea coast	wind, aerosol, light, cold stimulus	airways, skin, recovery	strong stimulus in winter
Spa and mineral springs	water, heat, routine	musculoskeletal complaints	heat load in summer

In a changing climate. The resorts are affected by the same warming as everywhere else, and some are losing the property they were certified for. Low mountain resorts see fewer cool nights, coastal resorts see summer conditions that are a load rather than a stimulus, and the season for a genuine cure moves out of July. The certification systems were written for a stationary climate and will have to be rewritten for a moving one.

GOOD TO KNOW

Above about 1500 metres the house dust mite largely disappears. For some patients that alone is the effect.

The dose matters more than the place. A strong stimulus climate can harm a frail patient in the wrong season.

Keywords: Climate therapy · Health resort · Terrain cure · Stimulus climate · High altitude clinic · Sea climate

SOURCES

Deutscher Heilbäderverband, Deutscher Tourismusverband (2005): Begriffsbestimmungen — Qualitätsstandards für die Prädikatisierung von Kurorten, Erholungsorten und Heilbrunnen. Bonn.

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.

39 Mountain air and altitude sickness

The air does not get thinner in composition. There is simply less of it pressing down.

One misunderstanding is worth removing at the start. The air at four thousand metres contains the same twenty-one per cent oxygen as the air at sea level. What has fallen is the pressure, and with it the partial pressure of oxygen — the force that drives oxygen across the lung into the blood. At five thousand five hundred metres that force is roughly half of what it is at the coast, and every step the body takes to compensate follows from that single fact.

The compensation begins within minutes. Breathing deepens and quickens, and people feel short of breath at a lower level of exertion than they are used to. The heart rate rises. Over days the kidneys excrete bicarbonate to let the breathing stay elevated, plasma volume falls, and the hormonal signal that drives red-cell production rises within hours — though it takes one to two weeks before that shows up as a measurable increase in red cell count. That is acclimatization, and it is genuinely effective — but it works on a timescale of days, while a cable car works on a timescale of minutes. Almost every case of altitude sickness is a mismatch between those two clocks.

Acute mountain sickness usually starts six to twelve hours after arriving too high: headache first, then loss of appetite, nausea, poor sleep, a general feeling of having a bad hangover without having earned it. It is common above two thousand five hundred metres and it is usually harmless if it is respected. The two dangerous forms are the ones that follow when it is not: fluid in the lungs, which presents as breathlessness at rest and a cough, and fluid in the brain, which presents as confusion and an unsteady walk. Both are emergencies and both are treated the same way — go down (Bärtsch and Swenson 2013).

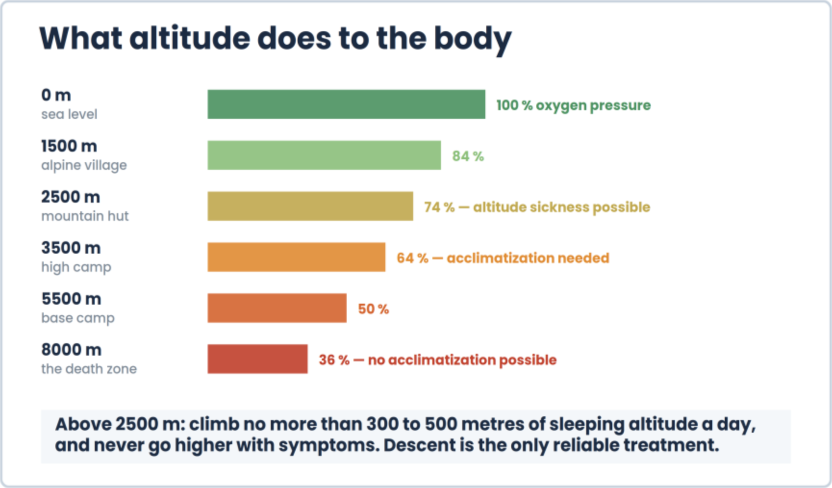


Figure 43: Oxygen pressure with altitude, and what each level asks of the body.

The prevention rules are old, simple and widely ignored. Above two thousand five hundred metres, increase the sleeping altitude by no more than three hundred to five hundred metres a day, with a rest day every three or four days. Climb high and sleep low. Never go higher with symptoms, and never leave somebody with symptoms alone. Drink, but do not overdrink; dehydration and altitude sickness feel similar and are not the same thing. And a slow ascent beats every drug available (Luks et al. 2019).

Our understanding of all this is remarkably recent. The mountains were feared for centuries and the symptoms were blamed on bad air, on vapours from the rock, on the mountain itself. Almost all of the eight-thousand-metre summits were reached in the nineteen-fifties, and the region above them was named the death zone precisely because no acclimatization is possible there: at that height the body deteriorates continuously no matter how long it stays. There is no adapting to it, only visiting it briefly.

The other side of altitude is the therapeutic one from the last chapter. Moderate height — fifteen hundred to two thousand metres — offers cooler air, cleaner air, fewer allergens and just enough hypoxic stimulus to be a mild training rather than a stress. In that range the mountain clinics were built, and it is a long way below the range in which mountains become dangerous.

Table 40**:** Altitude, symptoms and what to do

Altitude	What happens	What to do
up to 1500 m	no effect for most people	nothing
1500–2500 m	mild, useful stimulus; therapeutic range	enjoy it
2500–3500 m	acute mountain sickness common	300–500 m sleeping-altitude gain a day, rest days
3500–5500 m	acclimatization essential	300–500 m a day, climb high sleep low
above 5500 m	deterioration outpaces adaptation	limit time, plan the descent
above 8000 m	the death zone	no acclimatization is possible

In a changing climate. Warming reaches the mountains faster than the lowlands, and it changes the risks rather than removing them. Permafrost thaws and rockfall increases, glaciers retreat and route conditions change from year to year, and the season in which a high route is safe moves. The oxygen pressure is unchanged; almost everything else about a mountain is not.

GOOD TO KNOW

Headache six to twelve hours after arriving high is altitude sickness until proved otherwise. Do not go higher.
Descent treats every form of altitude illness. Supplemental oxygen, a portable hyperbaric bag or dexamethasone can buy time when descent is not immediately possible, but none of them is a substitute for going down.

Keywords: Altitude · Partial pressure · Acclimatization · Acute mountain sickness · Death zone · High altitude therapy

SOURCES

Bärtsch, P., Swenson, E. R. (2013): Acute high-altitude illnesses. New England Journal of Medicine 368, 2294–2302.
Luks, A. M. et al. (2019): Wilderness Medical Society clinical practice guidelines for the prevention and treatment of acute altitude illness. Wilderness & Environmental Medicine 30(4S), S3–S18.

40 Travel, tourism and climate

For most destinations the climate is the product. It is also the part nobody controls.

Tourism is among the largest economic activities that depend directly on the weather — agriculture is the obvious other one — and it is one of the few fields where biometeorology has been asked for numbers rather than warnings. A visitor does not want to know the mean July temperature. They want to know how many days in July are good for walking around a city, how many are too hot to be outside at midday, how likely rain is, and whether the sea is warm enough to swim in.

Answering that requires the thermal index rather than air temperature, because a visitor walks, carries things and stands in the sun. It also requires more than the thermal component: sunshine and rain matter to the experience, wind matters on a coast, and the aesthetic facets — a clear view, a dry evening — matter more than a strict physiological account would suggest. The approaches that work in practice put these facets side by side rather than compressing them into a single score, so that a traveller can see for themselves what a month offers (de Freitas et al. 2008; Matzarakis 2006).

Presented that way, the climate of a destination becomes a calendar rather than an average. For much of the Mediterranean the calendar now says something the tourist industry has not fully absorbed: the best months for being outside are April to June and September to October, while July and August have moved into a range that is a load rather than a pleasure for anybody walking a city in the afternoon.

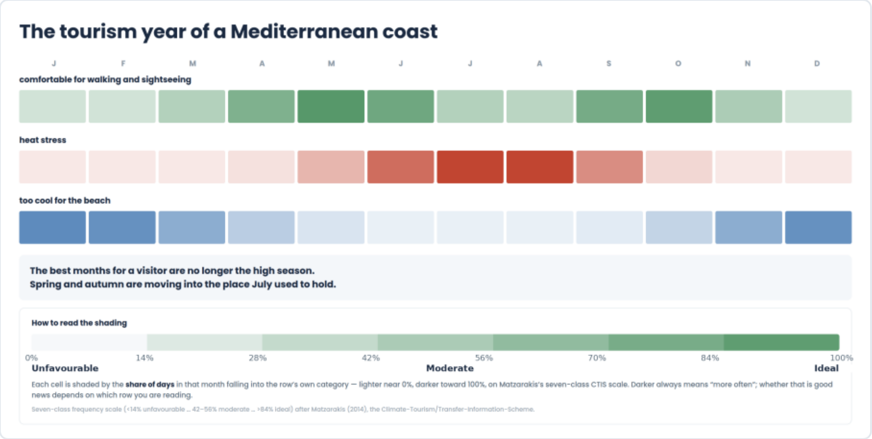


Figure 44: The tourism year of a Mediterranean coast, read as what a visitor can comfortably do.

There is a way of presenting this that has been used for twenty years and is worth describing, because it solves the problem that every single-number tourism index runs into. The climate-tourism or transfer information scheme, CTIS, keeps the facets apart and shows each of them as a frequency, month by month or ten-day period by ten-day period: how often the conditions are thermally acceptable, how often there is heat stress, how often cold stress, how often it is sunny, how often it rains, how often it is sultry, how often the wind is uncomfortable. One diagram, one place, the whole year (Matzarakis 2007, 2014).

The scheme has been applied to destinations from Taiwan to the Mediterranean and developed further since (Lin and Matzarakis 2008; Matzarakis 2014), and the results usually surprise the local tourist office rather than the residents.

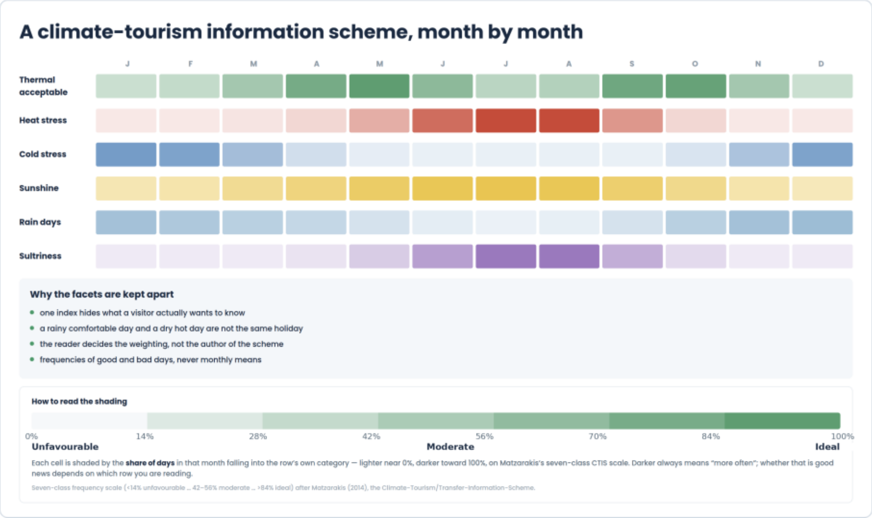


Figure 45: A climate-tourism information scheme: each facet shown separately as a frequency, month by month, for one destination.

The examples above use monthly resolution, because that is what most published climate normals give. The scheme itself does not require it: the same facets can be split into ten-day periods whenever conditions change fast within a month. Chapter 13 works through exactly that case for Doha, where the difference between the first and the last ten days of June turns out to be most of the story.

The reason for keeping the facets apart is not methodological fussiness. A single index has to decide in advance how a rainy comfortable day compares with a dry hot one, and that weighting belongs to the traveller and not to the author of the scheme. A hiker, a beach visitor, a cyclist and a person with a heart condition read the same diagram and reach different conclusions from it, and that is the point. And frequencies rather than means are what a visitor actually needs: eighteen days out of thirty suitable for walking is information, a mean July temperature of twenty-seven degrees is not.

For the Croatian coast the diagrams show a broad spring and autumn shoulder that the marketing had ignored (Brosy et al. 2014); for Freiburg and the Black Forest they show how much of the summer advantage lies in the evenings; for destinations in the eastern Mediterranean they show the midsummer hollow that this chapter opened with. The same scheme has been used for planning sporting events, which is where the Doha analysis in Chapter 13 came from.

What makes it useful in practice is that it can be produced from data a national weather service already holds, and that it can be handed to somebody who is not a meteorologist. A bioclimatic leaflet built on it — one page, one place, the facets and a short text — has turned out to be a better transfer instrument than any journal article on the same data (Zaninović and Matzarakis 2009). Hence the word transfer in the name.

The consequences are already visible. Northern European destinations gain summers that are genuinely pleasant. Alpine winter tourism loses snow reliability fastest at low altitudes, where snowmaking can no longer fully compensate; mid-altitude resorts buy more time with it, but at a rising cost. And the Mediterranean faces a shift of season rather than a loss of season — which is economically harder, because a hotel, an airline schedule and a school holiday calendar are all built around July and August.

For the individual traveller the advice is simpler and worth giving plainly. Check the thermal conditions rather than the temperature. Expect the middle of the day in a southern summer to be unusable for sightseeing, and plan around it as local people always have. Remember that acclimatization takes a week, which is longer than most holidays, so the first days abroad are the risky ones. And remember that a traveller carries their own vulnerabilities with them: age, medication, heart and lung conditions do not stay at home.

One more point belongs in a book about people. Tourism is also one of the larger contributors to the emissions that drive the changes described in the next part, and the destinations that suffer earliest are rarely the ones whose residents fly. That tension does not resolve neatly, and pretending otherwise would be dishonest in a chapter that is otherwise about pleasure.

Table 41**:** What a visitor actually needs to know

Facet	What it answers	How it is given
Thermal	can I walk around comfortably	PET or UTCI by month and hour
Aesthetic	will it be sunny, clear, pleasant	sunshine hours, cloud, visibility
Physical	rain, wind, sea temperature	frequencies, not averages
Risk	heat, UV, storms, air quality	warnings and index values

In a changing climate. The comfortable season is moving in most of Europe: earlier in spring, later in autumn, and hollowed out in midsummer around the Mediterranean. Winter sports at low altitude are the clearest loss. For destinations this is a planning question with a decade of lead time, and for the biometeorological side it is one of the few places where our numbers are asked for before the damage rather than after it.

GOOD TO KNOW

In a southern summer, plan the day as residents do: outdoors early and late, indoors from noon to four.

Acclimatization takes about a week. On a ten-day holiday the first days are the dangerous ones.

Keywords: Climate tourism · CTIS · Seasonality · Destination climate · Thermal facet · Season shift

SOURCES

Matzarakis, A. (2007): Assessment method for climate and tourism based on daily data. In: Matzarakis, A., de Freitas, C. R., Scott, D. (eds.): Developments in Tourism Climatology, 52–58. Commission on Climate, Tourism and Recreation, Freiburg.

Matzarakis, A. (2014): Transfer of climate data for tourism applications — the Climate-Tourism/Transfer-Information-Scheme. Sustainable Environment Research 24, 273–280.

de Freitas, C. R., Scott, D., McBoyle, G. (2008): A second generation climate index for tourism. International Journal of Biometeorology 52, 399–407.

Matzarakis, A. (2006): Weather- and climate-related information for tourism. Tourism and Hospitality Planning & Development 3, 99–115.

Lin, T.-P., Matzarakis, A. (2008): Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. International Journal of Biometeorology 52, 281–290.

Zaninović, K., Matzarakis, A. (2009): The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. International Journal of Biometeorology 53, 369–374.

Brosy, C., Zaninović, K., Matzarakis, A. (2014): Quantification of climate tourism potential of Croatia based on measured data and regional modeling. International Journal of Biometeorology 58, 1369–1381.

PART VIII

Climate Change and Action

Climate change has run through every chapter of this book in the paragraphs headed 'In a changing climate'. This part puts it in one place and asks the questions that follow. How does a warming climate actually reach a human being? What do the extremes do, and why do they do it in cascades? What can be avoided, what can only be adapted to, and where does adaptation stop? And finally, the one instrument that turns all of this into something that reaches a person on the day it matters: the heat action plan.

41 Climate change and human health

The climate does not make anybody ill — no more than weather does, and for the same reason: both are triggers rather than causes, working through a vulnerability that was already there, as Chapter 27 explained. What climate changes is the conditions under which everything else does harm.

Written as a list of dangers, this chapter would be accurate and useless. What helps more is to separate the paths by which a warming climate arrives at a human body, because the paths call for different responses and are handled by different people.

The direct path is the one everybody pictures: heat and heatwaves, and to a smaller and shrinking degree cold, together with floods, storms and wildfires. It is the path with the clearest numbers, and it is not the largest.

The environmental path runs through everything Parts III and IV described. Heat manufactures ozone on hot sunny days. It lengthens the pollen season at both ends and changes what grows where. It moves ticks north and uphill and lets mosquitoes overwinter that could not before. None of these is a new disease; each is an old one arriving in a new place or for more of the year.

The societal path is larger than either and gets least attention in a book like this. Heat reduces the capacity to work, and where work is paid by output that is a loss of income before it is a loss of health. Harvests fail, water supplies fall, prices rise, and people move. The health effects of all of that are real and they arrive through economics rather than through physiology. And the fourth path runs through the mind, which Chapter 48 comes back to.

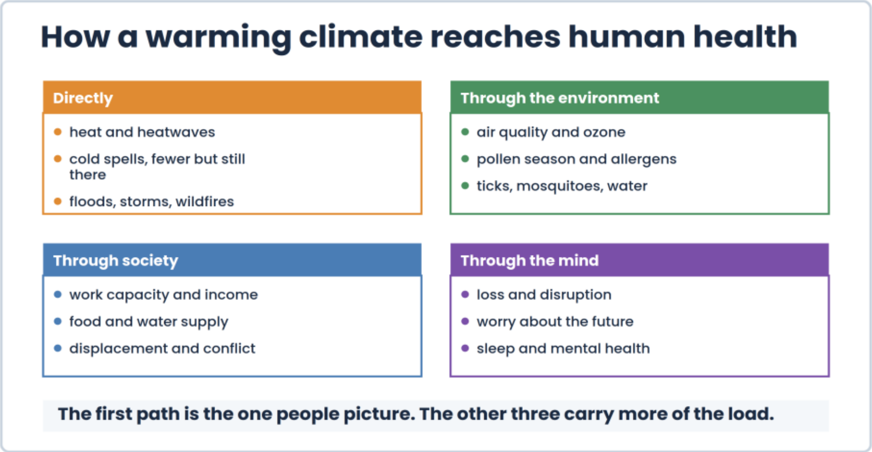


Figure 46: The four paths by which a warming climate reaches human health.

Two honest qualifications belong here. The first: in temperate countries, the raw count still runs one way — warmer winters remove more cold-related deaths than the added heat causes, at least so far (Hertig et al. 2023) — and that is a count, not a verdict. Saying so is not a concession to anybody; leaving it out invites the accusation of hiding it, and the argument is stronger with it in. The balance reverses as warming continues, it reverses first where it is already hot, and a death avoided in February is not interchangeable with a death caused in August in the same overloaded hospital.

The second: attribution has become far more precise than it was. It is now possible to say how much more likely a particular heatwave was made by warming, and increasingly how many deaths in a given summer are attributable to it (Vicedo-Cabrera et al. 2021). That changes the conversation from a general worry into an account with numbers, which is what public health has always needed in order to act.

For Germany the picture is now documented in one place, in the status report on climate change and health published as a series of reviews (Hertig et al. 2023). For the world, the annual Lancet

Countdown tracks indicators year by year. Neither is light reading, and both are the right thing to point a doubtful colleague towards.

Table 42: The paths, the mechanism and who acts

Path	Mechanism	Who can act
Direct	heat, cold, floods, storms, fire	weather service, health system, planning
Environmental	ozone, pollen, vectors, water	environment agencies, surveillance
Societal	work, food, water, displacement	economic and social policy
Mental	loss, disruption, worry	health care, schools, communities

In a changing climate. This whole chapter is the changing climate, so the question turns around: what is not changing? The physiology. A human body regulates heat exactly as it did ten thousand years ago, with the same margins and the same failure points. Everything that is new is on the other side of the skin, which is also where every remedy has to be applied.

GOOD TO KNOW

The direct effects are the visible ones. The effects through air, allergens, vectors and economics carry more of the load.

Warmer winters really do remove cold deaths. That is true, it is temporary, and it does not balance the accounts.

Keywords: Climate change and health · Direct effects · Attribution · Status report · Pathways · Lancet Countdown

SOURCES

Hertig, E., Hunger, I., Kaspar-Ott, I., Matzarakis, A., Niemann, H., Schulte-Droesch, L., Voss, M. (2023): Climate change and public health in Germany — an introduction to the German status report on climate change and health 2023. Journal of Health Monitoring 8(S3), 6–32.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

Vicedo-Cabrera, A. M. et al. (2021): The burden of heat-related mortality attributable to recent human-induced climate change. Nature Climate Change 11, 492–500.

Romanello, M., di Napoli, C., Green, C. et al. (2023): The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. The Lancet 402, 2346–2394. https://doi.org/10.1016/S0140-6736(23)01859-7

42 Extremes: heatwaves, cold spells, floods, storms

An extreme event is rarely one event. It is a first day and then a chain of consequences.

Extremes matter out of proportion to their frequency, and for a simple reason: systems built for the ordinary fail at the edges. A hospital copes with the usual number of admissions. A power grid copes with the usual demand. A person copes with the usual night. The extreme is the condition under which each of those margins runs out at the same time.

The five kinds behave differently enough to be worth separating. A heatwave shows in the death figures within one to three days, mostly among people who were already ill, and its effect is concentrated and visible (Ebi et al. 2021). A cold spell acts more slowly, over one to three weeks; its own toll is smaller than a heatwave's, but it is a poor guide to the real cold burden, which comes mostly from ordinary, moderate cold rather than from spells like this one, as Chapter 27 explained. A flood injures during the event and then causes infection, mould and displacement for months. A storm injures during the hours it lasts and then removes power, heating and communication for days. A wildfire injures directly only rarely, but its smoke reaches lungs hundreds of kilometres away and for longer than the fire itself burns.

What all four share is the cascade, and it is the part that planning consistently underestimates (Butsch et al. 2023). The heatwave does not stop when the temperature falls: the hospital is still full, the staff are exhausted, and the next event arrives into a system with no reserve. The flood does not stop when the water leaves:

the house cannot be dried, then it cannot be heated, and the health effect appears in the winter that follows.

Figure 47: The extremes, their timescales and the health effects that follow them.

Compound events deserve their own name because they are becoming the normal case rather than the exception. A heatwave with high ozone and high pollen is one week for the person breathing it and three warnings from three different offices. Drought followed by heavy rain gives flooding on ground that cannot absorb water. Heat and drought together give wildfires, and wildfire smoke is an air quality event a continent away, as Chapter 23 described.

The practical lesson from every review of every major event is the same and it is not about meteorology. In the Chicago heatwave of 1995 — laid bare in forensic detail by a study of who actually died and why (Klinenberg 2002) — and again in the European summer of 2003, the people who died were disproportionately those who lived alone, in top-floor flats, without air movement and without a visitor. The forecast was correct in both cases. What failed was the last mile between a warning and a person, which is the subject of Chapter 45.

One thing has improved markedly, and it should be said, because little else in this part is encouraging. Early warning for storms and floods now works in most of Europe, lead times have lengthened, and deaths from storms have fallen substantially over decades even as the events have not. That happened because somebody built the chain from measurement to warning to action. The same chain can be built for heat, and in most countries it has only been half built.

Table 43**:** Extremes, their course and the cascade that follows

Event	Health effect	Timescale	What follows
Heatwave	deaths, admissions, work loss	1–3 days	exhausted system, no reserve
Cold spell	cardiovascular, respiratory	1–3 weeks	winter infections, fuel poverty
Flood	injury, drowning, infection	hours to days	mould, displacement, mental health
Storm	injury, power loss	hours	cold homes, care interrupted
Wildfire	smoke, particles, evacuation	days to weeks	air quality far downwind

In a changing climate. Extremes are where the change is most visible, because a small shift of the average moves a great many days across a threshold. What used to be a once-in-fifty-years summer becomes a once-in-five-years summer (IPCC 2023), and the plans, the buildings and the health services were all designed against the old number. Compound events are becoming more common, and the warning systems built for single extremes are not built to catch them.

GOOD TO KNOW

The days after an extreme carry a large part of the health effect. Plans that end when the warning ends are half plans.

Storm and flood warning saves lives and has done for decades. Heat warning can do the same and is usually only half built.

Keywords: Extreme events · Heatwave · Cold spell · Flood · Compound events · Cascading risk

SOURCES

Butsch, C., Beckers, L.-M., Nilson, E., Frassl, M., Brennholt, N., Kwiatkowski, R., Söder, M. (2023): Health impacts of extreme weather events — cascading risks in a changing climate. Journal of Health Monitoring 8(S4), 33–56.

Ebi, K. L. et al. (2021): Hot weather and heat extremes: health risks. The Lancet 398, 698–708.

Klinenberg, E. (2002): Heat Wave. A Social Autopsy of Disaster in Chicago. University of Chicago Press, Chicago.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

43 Mitigation

Most of what reduces emissions also makes somebody healthier this year. That argument is the one to make.

Mitigation means reducing the emissions that cause the warming, and it sits slightly outside the usual territory of this book. It belongs here for one reason: almost every serious mitigation measure has a health benefit that arrives immediately, locally, and for the people who take it. Those benefits are large enough to justify the measures on their own, which means the argument does not have to rest on a promise about the year 2050.

Transport is the clearest case. Replacing short car journeys with walking and cycling reduces emissions, and it also reduces heart disease, obesity, diabetes, particles, nitrogen dioxide, noise and road deaths — pollution alone accounts for a large share of preventable death worldwide (Landrigan et al. 2018). Every one of those effects lands in the same city within a few years. The health benefit of the movement alone is larger than the benefit of the cleaner air, and both are larger than the climate benefit measured over the same period.

Diet is the second. Shifting towards more plants and less meat reduces emissions substantially and reduces cardiovascular disease and some cancers. Housing is the third: a well-insulated, well-ventilated home uses less energy, is warmer in winter — which matters more than it sounds, given what Chapter 27 said about winter deaths — and is cooler in summer if it is built with shading rather than only with insulation.

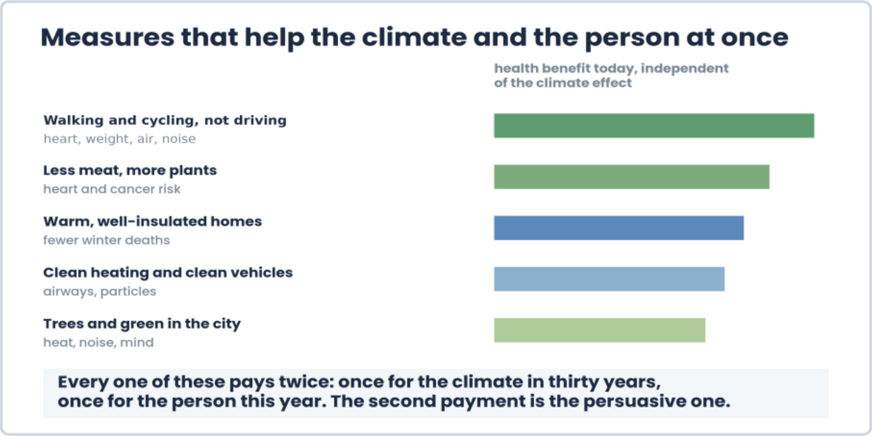


Figure 48: Measures that reduce emissions and improve health at the same time.

This double benefit has a name in the literature, the co-benefit, and it is one of the more useful ideas that health has contributed to climate policy (Haines and Ebi 2019). It changes who the argument is addressed to. A city council that will not act on emissions will often act on air quality, road safety or the cost of heating, and the measure is the same measure.

The traps have to be named too. Not every measure is a co-benefit: biomass heating reduces emissions and worsens particle pollution, and dense building without shade reduces energy use per person and creates heat islands. Insulating a home without ventilating it produces damp and indoor pollutants, which Chapter 24 described. A measure has to be checked for its health effect rather than assumed to have a good one.

And a limit has to be stated. Co-benefits are an argument for doing the easy and popular part of mitigation. They do not cover the difficult part, which is industrial and structural and has no obvious local health payoff. Presenting mitigation as a health programme is honest as far as it goes and stops well short of what is required.

Table 44**:** Mitigation measures and their health effect

Measure	Climate effect	Health effect, and when
Walking and cycling	large in cities	heart, weight, air, noise — immediate
Fewer animal products	large	cardiovascular, some cancers — years
Insulation and ventilation	large	fewer winter deaths — immediate
Clean heating	large	particles and NO2 — immediate
Urban green	small	heat, noise, mind — years
Biomass heating	moderate	worse particles — a trap, not a benefit

In a changing climate. The window in which mitigation determines the size of the problem is closing (IPCC 2023), and the remaining warming decides how much of the next chapter is needed. This is the one place in the book where the honest sentence is uncomfortable: everything that is not avoided now has to be adapted to later, by somebody with fewer options.

GOOD TO KNOW

The health benefit of walking instead of driving is larger than the benefit of the cleaner air, and both arrive this year.

Not every green measure is healthy. Insulation without ventilation, and biomass heating, both make indoor air worse.

Keywords: Mitigation · Co-benefits · Active travel · Diet · Insulation · Maladaptation

SOURCES

Haines, A., Ebi, K. (2019): The imperative for climate action to protect health. New England Journal of Medicine 380, 263–273.

Landrigan, P. J. et al. (2018): The Lancet Commission on pollution and health. The Lancet 391, 462–512.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

44 Adaptation

Adaptation is what is left when prevention is late. It works, it costs, and it has a ceiling.

Adaptation covers everything done to reduce the harm from a climate that is already changing (IPCC 2023). It runs on four timescales, and confusing them is the commonest failure in the field. Behaviour changes in minutes and costs nothing and helps least. Warning and care systems take months to years and can reach exactly the people who need them. Buildings take years to decades. Cities and infrastructure take decades and do the most.

The mistake almost every heat programme makes is to put the largest effort into the fastest lever. Leaflets advising people to drink water are cheap, visible and easy to fund, and they are the weakest measure available: the people who most need them are the least likely to read them or to be able to act on them. Meanwhile the tree that would shade the same street takes twenty years to grow and is therefore always something for next year's budget.

Adaptation also has the awkward property that it can be done badly in ways that make things worse. Air conditioning is the standard example, and Chapter 36 gave the reason: it cools the room and heats the street, it costs energy that may itself be emitting, and it fails precisely in a power cut during a heatwave, which is when it is needed. That does not make it wrong — inside a hospital or a care home it saves lives. It makes it wrong as the default answer for a whole city.

Figure 49: The four timescales of adaptation, and the point at which adaptation stops working.

The ceiling is real and it can be stated physically. Above a wet-bulb temperature of roughly thirty-five degrees, a human body cannot shed heat to the air at all, no matter what it does or wears, as Chapter 9 explained (Sherwood and Huber 2010) — though Chapter 9 also showed that even young, healthy adults lose thermal balance well before that theoretical point (Vecellio et al. 2022), and the practical ceiling sits lower still for older people and anyone whose capacity to sweat or raise cardiac output is already reduced. No behaviour, no building and no clothing helps an unprotected person in those conditions; only mechanical cooling does, which means only electricity does. Regions that reach that threshold regularly are not adapting to a difficult climate. They are becoming dependent on a machine.

There are softer limits well below that. Adaptation costs money, and the people most exposed have least of it. It requires functioning institutions, which the places under most pressure often lack. And it is limited by what a society will accept: a siesta is an excellent adaptation and a European working culture has spent fifty years abolishing it.

The constructive version is the one worth ending on. The measures that work are known, they are listed in Chapter 36 and Chapter 45 (WHO Regional Office for Europe 2008), and they are almost all boring: shade, ventilation paths, warning systems, visiting lists, cool rooms, medication reviews before summer. None of it requires new science. It requires somebody to be responsible for it before the summer rather than during it.

Table 45**:** Adaptation by timescale

Level	Timescale	Examples	Limits
Behaviour	minutes to days	shade, timing, fluids, clothing	reaches those who can act
Warning and care	months to years	heat warning, visiting lists, cool rooms	needs institutions
Buildings	years to decades	shading, insulation, night ventilation	cost, ownership
Cities	decades	trees, ventilation paths, unsealing	planning, land, patience

In a changing climate. Every year of delayed mitigation raises the amount of adaptation required, and adaptation is the more expensive and less certain of the two. It is also the one that has to be paid for locally, by the places least responsible for the problem. That is the fairness argument entire, and one sentence is better than an evasion.

GOOD TO KNOW

Put the effort where the lever is longest. Leaflets are the cheapest measure and the weakest.

Air conditioning is a medical device indoors and a collective problem outdoors. Both statements are true at once.

Keywords: Adaptation · Timescales · Maladaptation · Limits to adaptation · Wet-bulb limit · Responsibility

SOURCES

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.

Sherwood, S. C., Huber, M. (2010): An adaptability limit to climate change due to heat stress. Proceedings of the National Academy of Sciences 107, 9552–9555.

Vecellio, D. J., Wolf, S. T., Cottle, R. M., Kenney, W. L. (2022): Evaluating the 35°C wet-bulb temperature adaptability threshold for young, healthy subjects (PSU HEAT Project). Journal of Applied Physiology 132, 340–345.

45 Heat action plans and early warnings

This is where everything the book has assembled finally has to leave the page and knock on somebody's door.

A heat action plan is the instrument that connects everything in this book: a measured atmosphere, a calculated index, a threshold that reflects what a body can take, a warning, an institution that acts on it, and finally somebody who knocks on a door. It is the clearest example there is of the field doing what it exists for, and it is also where most of the failures are.

The chain begins with the forecast. What is forecast is not air temperature but a measure of the load on the body, because Chapter 7 explained why temperature alone will get it wrong. Thresholds are then set regionally, because a population acclimatizes to its own climate: thirty-two degrees in Hamburg is a different event from thirty-two degrees in Athens, and a single European threshold would over-warn in the south and under-warn in the north.

The warning goes to authorities, care institutions, the media and increasingly to individual phones. Then comes the part that decides whether any of it worked. Hospitals and care homes change staffing and fluid routines. Schools change timetables. Cities open cool rooms and drinking fountains. Employers shift shifts. And somebody with a list telephones or visits the people who live alone.

Figure 50**:** The chain from forecast to front door, and the step at which most plans stop.

The German experience is instructive because it was built after a failure. The summer of 2003 cost Europe tens of thousands of lives, and heat warning systems followed across the continent. Germany's national system has run since then, and national recommendations for producing local heat action plans were published in 2017 (Bund/Länder-Arbeitsgruppe GAK 2017). What is still uneven, twenty years later, is the implementation at municipal level — the part that involves the last two steps of the chain.

So much for the honest summary of where the field stands. The meteorology works. The indices work. The warnings are issued, on time and to the right regions. What is frequently missing is a named person in a municipality who is responsible for what happens when the warning arrives, and a list of who lives alone in which building. Those are not scientific problems, and they are the ones that decide the death figures.

The measures that belong in a plan are unglamorous and well established (WHO Regional Office for Europe 2008; Winklmayr et al. 2023): identify the people at risk before the summer, review medication with them, open cool public rooms and say where they are, provide drinking water in the open, shift outdoor work, prepare hospitals and care homes, organise contact for those living alone, and once the season is over, review what worked and what did not. Add to that the long-term measures of Chapter 36, because a plan that only reacts will need to react every year in a city that gets hotter every decade.

Table 46: What belongs in a heat action plan

Element	Who does it	When
Forecast and threshold	weather service	continuously
Warning and communication	weather service, authorities, media	1–2 days ahead
Identify those at risk	municipality, care services, doctors	before summer
Medication review	general practitioners, pharmacies	spring
Cool rooms, water, shade	municipality	before and during
Contact for those alone	neighbours, services, volunteers	during
Long-term measures	planning, housing, forestry	years ahead
Surveillance and evaluation	municipality, weather service	after summer

In a changing climate. Thresholds set on twenty-year-old data are already out of date, and a plan that triggers a few times a decade is being asked to work several times a summer. Warning systems will therefore have to shift from an exceptional response to a routine seasonal one — which is harder, because exceptional responses attract effort and routine ones do not.

GOOD TO KNOW

During a heat warning, telephone anybody you know who lives alone. It is the measure with the best evidence behind it.
A warning that nobody has been made responsible for acting on is a measurement, not a protection.

Keywords: Heat action plan · Heat warning · Threshold · Early warning · Municipality · Preparedness

SOURCES

WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.

Bund/Länder-Arbeitsgruppe GAK (2017): Handlungsempfehlungen für die Erstellung von Hitzeaktionsplänen zum Schutz der menschlichen Gesundheit. Bundesgesundheitsblatt 60, 662–672.

Winklmayr, C., Matthies-Wiesler, F., Muthers, S., Buchien, S., Kuch, B., an der Heiden, M., Mücke, H.-G. (2023): Heat in Germany: health risks and preventive measures. Journal of Health Monitoring 8(S4), 3–32.

PART IX

Information and Outlook

Four chapters to close with. The first is practical: where the numbers in this book come from, how to find them yourself, and how to tell a reliable source from a confident one. The second looks outward: how a finding actually reaches the people who need it, through journalists and broadcasters rather than through journals. The third is the chapter this field usually leaves to somebody else — what to do with the feeling that follows from knowing all of it. And the fourth returns to something very concrete: the Biowetter, the daily bulletin that puts everything in this book to work, one region and one day at a time.

46 Where to find reliable information

Everything in this book can be checked. Hence the trouble taken to write down where it came from.

A book like this is a starting point and it goes out of date. The measurements continue, the guidelines are revised, and the maps are redrawn every few years. What lasts longer than any chapter is knowing where to look, so this chapter names the places and says what each of them is good for.

The national weather service is the first address for anything about today and tomorrow, and it is better than most people realise. Beyond the forecast it issues warnings for heat, UV, storms and pollen, publishes climate data going back a century or more, and in several countries runs an explicitly health-related service. It is publicly funded, its data are free, and it has no interest in exaggerating.

For the assessed state of the science there are two institutions and they do different things. The World Health Organization publishes numeric guideline values for air quality and noise — statements of what a level does to health and what a safe level would be (WHO 2021) — and, for ultraviolet radiation, a communication index rather than a guideline number, and for heat, general guidance rather than a single safe threshold. The Intergovernmental Panel on Climate Change does not do research; it assesses what the research collectively says, which is why its reports are conservative and why they are the reference when somebody asks what is actually known (IPCC 2023).

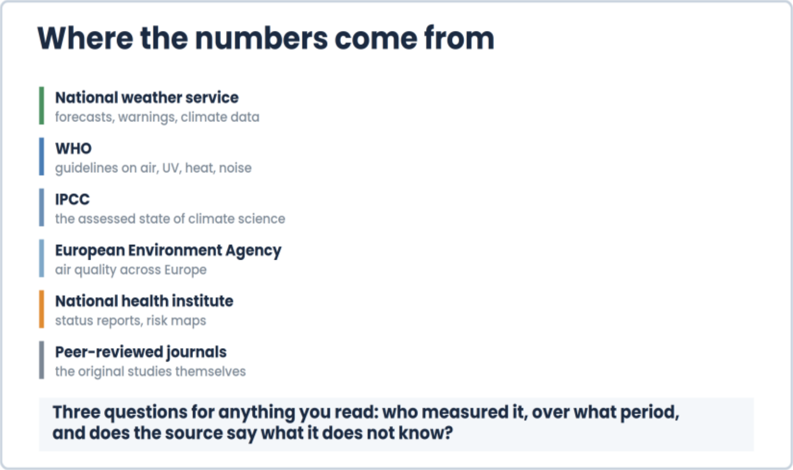


Figure 51: Where the numbers in this book come from, and what each source is good for.

For a specific country the national public health institute is usually the best single source, because it puts the international science together with local data. Germany's status report on climate change and health, cited throughout Part VIII, is a good example (Hertig et al. 2023): fourteen review articles by more than ninety authors, published in a journal that is freely available in German and English. Most countries have an equivalent. Find it once and keep the address.

Reading the sources themselves is easier than it used to be. A great deal is open access, and the abstract and the conclusions of a paper are usually comprehensible to anybody who has read this far. Three questions do most of the work of judging what you find. Who measured it, and over what period — a single hot summer is not a trend. What is being compared with what — a risk that doubles from very small to slightly less small is still small. And does the source say what it does not know? Sources that admit their limits are usually the ones worth believing.

Two warnings. First, an authoritative tone is not authority: the most confident statements about weather and health are usually the least supported, which Chapter 28 illustrated at length. Second, be careful with a search engine on a health question, because what ranks highest is what is optimised, not what is right — and an AI-generated summary at the top of the results inherits that same bias, dressed up as a direct answer. Going straight to a named institution takes ten seconds longer and saves a great deal.

Table 47**:** Sources, and what to use each one for

Source	Use it for	Note
National weather service	forecast, warnings, climate data	free, public, no interest in drama
World Health Organization	guideline values for air and noise; a UV index; general heat guidance	what a level does to health
IPCC	the assessed state of climate science	conservative by construction
European Environment Agency	air quality across Europe	comparable between countries
National health institute	country-specific risks and reports	links science to local data
Journals	the original studies	read the abstract and the limitations

In a changing climate. Information itself is changing: warnings arrive by app rather than by radio, forecasts are personalised, and models produce far more detail than they used to. That is an improvement and it carries a risk, because a personalised number looks more certain than it is. The underlying uncertainty has not shrunk as fast as the resolution has grown.

GOOD TO KNOW

Ask three things of anything you read: who measured it, over what period, and does it say what it does not know.

For a health question, go to a named institution rather than to a search engine. It takes ten seconds longer.

Keywords: Sources · Weather service · Guidelines · Assessment reports · Open access · Judging evidence

SOURCES

WHO (2021): WHO Global Air Quality Guidelines. World Health Organization, Geneva.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

Hertig, E., Hunger, I., Kaspar-Ott, I., Matzarakis, A., Niemann, H., Schulte-Droesch, L., Voss, M. (2023): Climate change and public health in Germany — an introduction to the German status report on climate change and health 2023. Journal of Health Monitoring 8(S3), 6–32.

47 Talking about it: biometeorology in the media

A finding that stays in a journal protects nobody. Getting it out is part of the work, not a distraction from it.

This field produces a peculiar kind of knowledge. It is not secret, it is not difficult in principle, and it is useless unless somebody who is not a scientist acts on it (Matzarakis 2020). A heat warning only works if it reaches a person; a UV Index only works if somebody understands what an eight means; a climate analysis map only works if a planning committee reads it (Zaninović and Matzarakis 2009). Every chapter of this book therefore ends somewhere outside the laboratory, and the route out runs through the media.

That route is worth taking seriously, because the alternative is not silence but somebody else filling the space. Not all of the claims collected in Chapter 33 deserved equal confidence. That a single street tree noticeably cools a whole neighbourhood, and that a green roof cools the street below it, both ran further than the evidence supports; that air conditioning quietly heats the city around it turned out to be true. None of the three came from nowhere — they came from confident statements by people with an interest, repeated until they sounded like consensus — but only some of them needed correcting, and correcting them afterwards is far harder than saying the right thing first.

Figure 52: The chain from a finding to a reader, and the point at which most of it is lost.

What a journalist needs is genuinely different from what a reviewer needs, and treating that as a defect is the commonest mistake scientists make. A journalist needs a person, a place and a number, in a sentence short enough to survive editing. Anything qualified into safety will be cut or replaced. Guidance written specifically for this handoff exists and is worth using rather than reinventing each time (West et al. 2023). The useful discipline is therefore to prepare one sentence in advance that is both true and quotable — the number and what it does to a body, together — and to be willing to repeat it unchanged as often as necessary.

Table 48**:** What each side needs, and where the two can meet

The scientist needs	The journalist needs	What works for both
Every qualification stated	One clear sentence	The main finding first, one qualification after
The method to be visible	A person and a place	A concrete example that carries the method
No overstatement	A reason to publish today	A number tied to something the reader remembers
The uncertainty acknowledged	Not to sound unsure	Say the uncertainty once, plainly, then stop
To be cited correctly	A short, usable quote	Offer the quote yourself, in writing

In practice this means being available, and being available repeatedly, over years, to the same outlets. Greek television and news sites such as CNN Greece, the Cypriot press through outlets like Philenews, and the German print and broadcast media have all carried this material — heat and health, the UV Index, urban climate, weather sensitivity, forest fires and the summer they arrive in. What makes those appearances useful is not any single one of them. It is that after the tenth time, the editorial desk knows who to call before the heatwave rather than during it, and the framing of the story shifts from a spectacle to a health warning that arrives in time.

There are traps, and they should be said out loud. Being quoted on everything erodes the authority that made the first call worth making, so declining questions outside the field is part of doing it well. A dramatic number will always travel further than a careful one, which is a reason to choose the number carefully rather than to refuse to give one. Corrections almost never catch up with the original, so it is better to spend the effort before publication than after. And a sentence given in one language rarely survives translation into another — a point that anybody working across German, English and Greek learns early.

The reward for all of it is specific and worth stating. A heat action plan is adopted because a city councillor read something (WHO Regional Office for Europe 2008). A grandmother drinks more because her grandson saw a broadcast. A school moves sports day to the morning because a head teacher heard a number and remembered it. None of these appears in a citation index, and all of them are what this field is for.

In a changing climate. Communication itself is changing faster than the science. Warnings arrive through apps, health advice arrives through social media, and a heatwave now generates more text in a day than a research group produces in a year. Two things follow. The competence to communicate has to be taught rather than left to talent. And an institution that stays silent is not neutral; the space it leaves is filled by whoever speaks.

GOOD TO KNOW

Prepare one true, quotable sentence before the interview. It will be the only part that survives.

Being reachable before an event matters more than being right after it.

Keywords: Science communication · Media · Heat warning · Public understanding · Transfer · Press

SOURCES

West, M., Arrighi, J., Jones, H., Keith, L., Knowlton, K., Kolli, R. K., Matzarakis, A., Lee, J., Ren, C., Tan, A., Tiwari, A. (2023): Reporting on Heatwaves and the Health Impacts of Heat. Guidance Note for the Media. Global Heat Health Information Network (GHHIN) 1, 1–6.

Zaninović, K., Matzarakis, A. (2009): The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. International Journal of Biometeorology 53, 369–374.

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283.

WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.

48 Climate anxiety: from worry to action

Worrying about this is not a disorder. It is an accurate reading of the situation. The question is what happens next.

A book that spends forty-seven chapters describing what the atmosphere does to people owes the reader a chapter about what that knowledge does to the reader. A large international survey of young people found that most were worried about climate change and a substantial share said the worry affected their daily functioning — sleep, concentration, plans for the future (Hickman et al. 2021). A parallel scoping review for Germany found the same direct and indirect impacts, the same vulnerable groups, and some early evidence on what builds resilience (Gebhardt et al. 2023). Those numbers are often reported as though they described an illness. They do not. They describe people responding correctly to a correct description of a real situation.

That distinction matters. Clinicians generally reserve the word "disorder" for worry that is out of proportion to the threat, or that stops somebody functioning — and climate worry, grounded as it is in an accurate reading of a real situation, is usually neither. When it does tip into the kind that gets in the way of daily life, that deserves proper professional help, the same as any other cause of it would. But the answer to worry about the climate is not to make somebody stop worrying. It is to move the worry into a form that a person can carry.

What turns worry into paralysis follows a fairly consistent pattern in the research, and it has three parts. The problem is presented as global, which makes any individual contribution look pointless. It is presented as certain and imminent, which removes the sense that anything is still open. And it is carried alone, which is the part that does most of the damage.

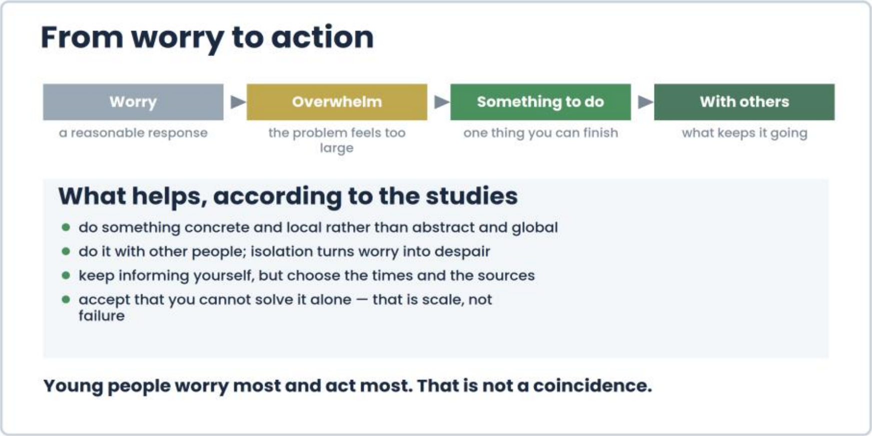


Figure 53: The path from worry to something a person can carry, and what the studies say helps.

Each of the three has a counterpart. Something concrete and local beats something abstract and global: a street with trees, a school without air conditioning that nonetheless stays usable, a neighbour on the visiting list during a heatwave. Something unfinished beats something finished, because a task that ends leaves nothing to return to. And doing it with other people beats doing it alone — one of the more consistent findings across this research.

For the people who work in this field there is a version of the same problem, and it is rarely discussed. Spending a career measuring damage is a specific kind of burden, and it is made heavier by the gap between what the measurements say and what gets done about them. The remedy is the same as for everybody else, and it is why this book keeps returning to the practical: a heat action plan that works in one town is worth more, psychologically as well as actually, than another paper describing the problem.

So the point this chapter leaves you with is deliberately small. Nobody solves this. The atmosphere is not a problem that gets closed. What a person can do is understand how it acts on the human body — which is what the previous forty-seven chapters were for — and then use that understanding somewhere close by, on somebody who needs it, this summer. It is a modest conclusion, honestly presented as one. It is all this field has ever been able to offer, and it has been enough to move a good deal.

Table 49**:** What helps, and what does not

Helps	Does not help
Something concrete, local and finishable	resolving to care more
Doing it together with others	carrying it alone
Choosing when and where to inform yourself	constant exposure to bad news
Accepting the scale of the problem	believing it depends on you
Professional help when functioning is affected	being told the worry is irrational

In a changing climate. This chapter is the one explicitly about the changing climate's toll on people, so the thought that closes it belongs here. Everything described in this book will be described differently in twenty years, because the conditions will have moved. What will not have moved is the human body in the middle of it, and the fact that somebody has to look after it. That job does not get finished either, and it has never been a reason not to start.

GOOD TO KNOW

Worrying about this is proportionate. What helps is not less worry but somewhere to put it.
One concrete thing, close by, done with other people. Everything the research finds points the same way.

Keywords: Climate anxiety · Eco-anxiety · Agency · Coping · Collective action · Mental health

SOURCES

Hickman, C. et al. (2021): Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health 5, e863–e873.
Gebhardt, N., van Bronswijk, K., Bunz, M., Müller, T., Niessen, P., Nikendei, C. (2023): Scoping review of climate change and mental health in Germany — direct and indirect impacts, vulnerable groups, resilience factors. Journal of Health Monitoring 8(S4), 122–149.

49 The Biowetter: the medical-meteorological forecast

Chapter 28 asked whether the weather really does something to us, and found a real but modest signal. This chapter follows that signal into practice: the forecast built to say, one region and one day at a time, when it might.

Alongside the ordinary weather forecast, the Deutscher Wetterdienst issues a second, quieter one: the Biowetter, or medical-meteorological forecast. It translates the coming one to three days of weather into a plain statement of which weather-related complaints are more or less likely, region by region — not a diagnosis for one person, but a bulletin for a population. A short public version goes out with the daily weather; a more detailed one reaches physicians, pharmacies and clinics.

Figure 54: The Biowetter production chain, from national data to the physician's desk

The idea is older than the current service, and had to survive its own early ambition. German medical meteorology spent much of the twentieth century classifying the weather into named phases and assigning each one a physiological load, on the assumption that a number could stand in for how a day would feel (Chapter 28: Weather sensitivity). The classifications were issued for decades, and the ambition ran ahead of what could be shown. Along the way the field also explored physical mechanisms such as air ions and atmospheric electricity — sferics — as a possible cause; none of them delivered a reliable explanation (Chapter 28: Weather sensitivity). When the specific claims did not hold up, the field had to rebuild on narrower ground: not a load number for every day, but a forecast for the days that are actually different.

What is different, and what the modern service is built around, are the transition days: a front passing through, a sharp fall in pressure, the arrival or collapse of föhn, the start or end of a heat wave. National survey and clinical data put the familiar complaint categories — headache and migraine, joint pain, sleep, circulation, mood — against these situations and show where a real, if modest, signal sits and where it does not (Graw, Sommer and Matzarakis 2022). The forecast is built from that evidence rather than from the phase system it replaced, and it is issued region by region, because a transition that unsettles Hamburg is not the one that reaches Munich two days later.

Table 50: Weather situations and the complaints they raise

Weather situation	What changes	Complaints most often reported
Frontal passage	Rapid shifts in pressure and temperature	Headache and migraine, joint pain
Sharp pressure fall	Barometric pressure drops quickly	Headache and migraine, sleep
Föhn onset	A warm, dry downslope wind arrives	Headache and migraine, mood
Föhn collapse	Wind and temperature reverse sharply	Circulation, mood
Heat wave onset	Heat and humidity load rises	Circulation, sleep
Heat wave end	Heat eases, pressure often falls	Headache and migraine, joint pain
Settled high pressure, outside a heat wave	Little day-to-day change	Complaints least likely

What it is not is a prediction of one person's headache. About half of respondents describe themselves as weather sensitive, considerably more than controlled studies confirm (von Mackensen et al. 2005; Chapter 28), and a forecast that promised to name the affected days for an individual would be repeating the old overreach in a new form. What it offers instead is more modest and more honest: a flagged day means that more people than usual are likely to notice something, and that is enough to be useful — time to check blood pressure, take medication on schedule, or simply expect to feel it.

Biowetter — or, more precisely, the biosynoptic weather forecast, or medical-meteorological forecast — can be seen as the umbrella under which several more targeted forecasts sit, built on the same production system but answering narrower questions: the heat warning (Chapter 45: Heat action plans and early warnings) for the one risk that is acute and clearly established, the UV Index (Chapter 16: Sunburn and the UV Index) for planning sun exposure, and the pollen forecast (Chapter 25: Pollen and allergies) for allergy sufferers. Each has its own trigger and its own evidence behind it. Keeping them distinct, rather than folding everything into a single number, is what separates today's service from the phase system it grew out of.

In a changing climate. As heat becomes the growing risk (Chapter 27: Weather and illness), the acute and well-founded part of the medical-meteorological forecast — the heat warning — matters more with each decade, while the diffuse air-mass part stays what it was. A forecast that keeps the two apart, and is honest about which is which, is the one worth trusting.

GOOD TO KNOW

The Biowetter forecasts the situation, not your symptom.
Transition days — fronts, pressure falls, föhn, the edges of a heat wave — ask most of the body; settled high pressure asks least, outside a heat wave.
On a flagged day: check blood pressure, take medication on time, postpone heavy exertion, keep cool.

Keywords: Biowetter · Medical-meteorological forecast · Air masses · Heat warning · UV Index · Pollen forecast · Service

SOURCES
von Mackensen, S., Höppe, P., Maarouf, A., Tourigny, P., Nowak, D. (2005): Prevalence of weather sensitivity in Germany and Canada. International Journal of Biometeorology 49, 156–166.
Graw, K., Sommer, S., Matzarakis, A. (2022): The prevalence of weather sensitivity in Germany derived from population surveys. Atmosphere 13, 1865, 1–14.
Matzarakis, A. (2026): Hitzewarnungen und Hitzeaktionspläne. GGW — Gesundheit und Gesellschaft Wissenschaft 26(3), 15–22.
Deutscher Wetterdienst: Biowetter and health forecasts. www.dwd.de

Ten Lessons from Human Biometeorology

Forty-nine chapters, one idea running through all of them: the atmosphere only matters once it reaches a body.

This book has moved through forty-nine chapters and a great many numbers. If a reader keeps only the numbers, the book has not done its job. What follows is the distillation: ten lessons that hold across heat and cold, sun and pollution, city and mountain, and that are worth carrying out of these pages into an ordinary day.

1. Warmth is felt; heat is calculated. The load on the body is not a property of the air alone. It comes from air temperature, radiation, wind and humidity together, which is why a single thermometer never tells the whole story (Chapters 6 and 7).

2. The night decides more than the day. A hot afternoon is uncomfortable. A hot night is dangerous, because it is when the body is supposed to recover and, in a warming climate and a dense city, increasingly does not get the chance (Chapters 8 and 31).

3. An index describes a situation, not a person. The same PET, the same UV Index, the same air quality reading carries a different risk for a child, an older adult on medication, and someone in good health standing in the same spot (Chapters 7 and 30).

4. Cold deserves the same respect as heat. Wind, damp and inadequate clothing take lives quietly, without the headlines a heatwave gets, and the same energy balance that explains heat stress explains cold stress (Chapters 10 to 13).

5. Cities build their own climate, mostly after dark and mostly by accident. Stone, narrow streets and lost vegetation store the day's heat and give it back all night. Understanding that is the first step to designing a city on purpose rather than by accident (Chapters 31 to 34).

6. Shade and shelter before technology. A tree, an orientation, a shutter closed at the right hour, usually outperform the newest mechanical solution, and cost far less to run (Chapters 35 and 36).

7. Weather sensitivity is real, but it is rarely the whole story. For most people it is a trigger for a vulnerability that was already there, sleep debt, an existing condition, simple fatigue, rather than a cause acting on its own (Chapter 28).

8. Sun, light and air quality sit on the same balance sheet as heat. Protecting against one hazard while ignoring the others solves only part of the problem; a shaded, well-ventilated, low-pollution place is protective on every axis at once (Chapters 14 to 26).

9. Climate change is shifting distributions, not only adding rare extremes. More hot days, fewer cold ones, more tropical nights: the shift is gradual, it is everywhere, and it quietly changes what design standards, health planning and daily habit all need to assume (Chapters 41 to 44).

10. None of this matters until it reaches a decision. A number is only useful once somebody can act on it. Translating the atmosphere into a warning, a building, a habit or a look in on the neighbour is as much a part of this science as the physics behind it, and it is the part this book has tried hardest to serve (Chapters 45 to 49).

Take the ten together and they say one thing twice over: the atmosphere is not something that happens to us. It is something we can understand, anticipate, and, in almost every case, do something about.

Test Yourself

A quiz, five real-world scenarios, and a short weather-sensitivity check.

Every chapter ends with a Keywords line and a SOURCES box, but a book is read once and a fact fades. This appendix is meant to be used after finishing the book, or dipped into part by part — to check what stuck, to think a few situations through the way the book's own reasoning would, and to see how many of the terms come back on their own.

Quick quiz

Sixteen questions, one from most parts of the book, in reading order. The chapter reference after each question is where to check an answer, not a hint.

1. Which two atmospheric layers matter most for daily weather and for UV protection? (Ch. 1)

a) The mesosphere and thermosphere
b) The ionosphere and the exosphere
c) The troposphere and the stratosphere

2. Along how many paths does heat leave the human body, and which one is the only path that still works once the air is warmer than the skin? (Ch. 6)

a) Four paths; evaporation
b) Two paths; radiation
c) One path; convection

3. Why is humid heat more dangerous than dry heat at the same temperature? (Ch. 9)

a) Humid air is physically heavier on the chest

b) Sweat cannot evaporate well in humid air, so the body's main cooling path fails

c) Humidity raises blood pressure directly

4. What actually causes sunburn? (Ch. 16)

a) Heat absorbed by the skin

b) Damage to the genetic material in skin cells from ultraviolet radiation

c) Dehydration of the outer skin layer

5. What is the main cue that resets the body's inner clock each day? (Ch. 18)

a) Ambient temperature

b) Background noise

c) Daylight entering the eye

6. Why is ground-level ozone called “the summer pollutant”? (Ch. 22)

a) It is manufactured in the air from nitrogen oxides and volatile organic compounds, using sunlight as energy

b) It is emitted directly by summer traffic

c) It only forms above 30°C

7. Why do diary studies of weather sensitivity find smaller effects than surveys do? (Ch. 28)

a) Memory fits: people recall the weather days that match a symptom and forget the ones that don't

b) Diaries are less accurate than memory

c) Weather does not affect health at all

8. According to the book, what three things multiply to produce vulnerability to a weather hazard? (Ch. 30)

a) Age, income and nationality

b) Temperature, humidity and wind

c) Exposure, sensitivity and capacity to act

9. What are the main contributors to the urban heat island? (Ch. 31)

a) Higher altitude and thinner air in cities

b) Stored heat in building materials, blocked long-wave radiation, little evaporation, and waste heat

c) Stronger sunlight over paved surfaces

10. In cooling a street, what does the book say should come first? (Ch. 36)

a) Shade, before air movement or evaporation

b) Air conditioning

c) White paint on every surface

11. What is the main risk factor for acute mountain sickness? (Ch. 39)

a) Cold temperature alone

b) Wind speed at altitude

c) Ascending faster than the body's days-long acclimatization can keep up with

12. What does attribution science try to establish? (Ch. 41)

a) The exact year climate change began

b) How much more likely or severe climate change made a specific event

c) Which country is legally responsible for an event

13. What is the key difference between mitigation and adaptation? (Ch. 43/44)

a) They mean the same thing in practice

b) Mitigation is for cities, adaptation is for rural areas only

c) Mitigation reduces the emissions causing warming; adaptation reduces the harm from a climate that is already changing

14. Reviews of the 1995 Chicago and 2003 European heatwaves found that forecasts were correct. What failed? (Ch. 44/45)

a) The measuring instruments

b) The last mile between an issued warning and an isolated person

c) The choice of temperature threshold

15. According to the book's media chapter, what should a scientist prepare in advance for a journalist? (Ch. 47)

a) One sentence that is both true and quotable, ready to repeat unchanged

b) A ten-page technical brief with every caveat

c) A list of limitations to state before any finding

16. What is the key difference between what WHO and the IPCC each publish? (Ch. 46)

a) They publish the same kind of document

b) WHO covers only climate change, the IPCC only air quality

c) WHO states what a level does to health and what is safe; the IPCC assesses and summarises existing climate research rather than producing new research

Scenario challenges

Five short situations. Choose first, then read what the book's own chapters would suggest.

1. A clear day, UV Index 9

You are planning a five-hour hike, starting at eleven in the morning, on a clear day with a forecast UV Index of 9. What is your first move?

a) Apply sunscreen and set off — sunscreen is the strongest protection

b) Plan the route to use shade at midday, and treat clothing, hat and sunglasses as the main protection, with sunscreen for what is left uncovered

c) Ignore it — UV only matters above 35°C

> **WHAT THE BOOK SUGGESTS**
> Order of protection: shade, then clothing, then sunscreen. Above eight, unprotected skin can burn in about fifteen minutes (Ch. 16).

2. A heat warning, three days out

A heat warning is issued for the coming weekend. You know an elderly neighbour who lives alone on a top floor. What matters most?

a) Assuming the warning itself will reach and help her

b) Physically checking on her and making sure the warning actually changes what she does that day

c) Waiting until the temperature is already high before acting

> **WHAT THE BOOK SUGGESTS**
> The Chicago 1995 and European 2003 reviews found the forecasts were correct; what failed was the last mile between the warning and an isolated person (Ch. 44/45).

3. A sudden cold snap with wind

Temperatures are around freezing with a strong wind. Which single piece of advice matters most for time spent outdoors?

a) Wind chill describes how fast exposed skin loses heat — cover skin and block the wind, not just add a layer

b) Wind makes no real difference below freezing

c) Only the air temperature needs to be considered

> **WHAT THE BOOK SUGGESTS**
> Wind chill is about the rate of heat loss from exposed skin, not a different air temperature — wind-proof, covered skin matters as much as insulation (Ch. 10).

4. Redesigning a shadeless square

A city has budget for one summer intervention on a paved, treeless square. Which option does the book's own priority order favour?

a) Painting the pavement white

b) Planting trees or installing shade structures, because shade removes the largest heat term outdoors

c) Installing more benches

> **WHAT THE BOOK SUGGESTS**
> Shade first, then air movement, then evaporation — because radiation is the largest term in the outdoor heat balance (Ch. 36).

5. A fast ascent to altitude

A cable car takes you from valley floor to 3,000 metres in twenty minutes for a hike. What is the main risk to plan for?

a) Acute mountain sickness, because acclimatization takes days while the cable car takes minutes

b) Sunburn only
c) Hypothermia only

> **WHAT THE BOOK SUGGESTS**
> Almost every case of altitude sickness is a mismatch between the days-long clock of acclimatization and a much faster ascent (Ch. 39).

How weather-sensitive are you?

About half the population in central Europe says the weather affects how they feel — but diary studies, which check the claim day by day against measured weather, consistently find smaller and less specific effects than surveys suggest (Chapter 28: Weather sensitivity). This short check does not diagnose anything; it is a starting point for noticing your own pattern, the way Chapter 28 describes.

For statements 1–8, score: 0 = never · 1 = rarely · 2 = sometimes · 3 = often. Statements 9 and 10 are not scored — they check your own answers rather than add another symptom.

1. I notice a change in my mood on days with strong wind, thunderstorms or a Föhn wind.

2. I get headaches that I associate with a change in the weather.

3. I feel more tired than usual before or during a spell of unsettled weather.

4. Joint or old-injury pain seems worse to me on damp or cold days.

5. My sleep is worse on hot, humid nights.

6. I feel low or restless on long grey, overcast stretches.

7. I have mentioned a weather-related symptom to family or a doctor.

8. I can usually tell what the weather is doing without looking outside.

9. (Not scored.) A symptom I blame on the weather has, on reflection, also happened on ordinary days too — recognising that is the recall bias Chapter 28 describes, not a sign of weather sensitivity.

10. (Not scored.) I would keep a diary for a few weeks if I were curious whether this holds up.

READING YOUR SCORE

0–6: little evidence of a consistent pattern — plausible, since diary studies usually find less than people expect.
7–14: a moderate pattern, worth a two-week diary before drawing conclusions.
15–24: a strong pattern — worth mentioning to a doctor if a specific symptom is severe, since a dozen ordinary causes can look identical to a weather effect (Chapter 28: Weather sensitivity). This is a self-reflection tool, not a medical or diagnostic instrument.

Answer key

Quiz:

1c · 2a · 3b · 4b · 5c · 6a · 7a · 8c · 9b · 10a · 11c · 12b · 13c · 14b · 15a · 16c

For climate adaptation practitioners

A short summary for readers who plan for cities rather than for individuals — six points that recur across the chapters above.

FOR CLIMATE ADAPTATION PRACTITIONERS

Heat risk is an energy balance, not a temperature. Radiation dominates outdoors, so shade beats every other single measure (Ch. 6, 36).

The urban heat island is a night problem with four distinct causes — stored heat, blocked long-wave radiation, little evaporation, waste heat — each needing a different fix (Ch. 31).

Vulnerability multiplies rather than adds: exposure × sensitivity × capacity to act. Target the person most at risk, not the average day (Ch. 30).

Warnings usually fail at the last mile, not at the forecast. Chicago 1995 and Europe 2003 both had correct forecasts (Ch. 44, 45).

Adaptation runs on four timescales, from behaviour to urban form. The fastest, cheapest lever is usually the weakest one (Ch. 44).

Mitigation pays back immediately through local health co-benefits — the argument that works when the climate case alone does not (Ch. 43).

List of Figures

List of Tables

References

All sources listed in the chapter boxes, in alphabetical order.

Ahrens, C. D., Henson, R. (2023): Meteorology Today. 13th edn. Cengage Learning, Boston.

Baldermann, C., Laschewski, G., Grooß, J.-U. (2023): Impact of climate change on non-communicable diseases caused by altered UV radiation. Journal of Health Monitoring 8(S4), 57–75. https://doi.org/10.25646/11653

Basner, M., McGuire, S. (2018): WHO environmental noise guidelines for the European region: a systematic review on environmental noise and effects on sleep. International Journal of Environmental Research and Public Health 15, 519. https://doi.org/10.3390/ijerph15030519

Beck, H. E. et al. (2018): Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5, 180214. https://doi.org/10.1038/sdata.2018.214

Beermann, S., Dobler, G., Faber, M., Frank, C., Habedank, B., Hagedorn, P., Kampen, H., Kuhn, C., Nygren, T., Schmidt-Chanasit, J., Schmolz, E., Stark, K., Ulrich, R. G., Weiss, S., Wilking, H. (2023): Impact of climate change on vector- and rodent-borne infectious diseases. Journal of Health Monitoring 8(S3). https://doi.org/10.25646/11401

Bergmann, K.-C., Brehler, R., Endler, C., Höflich, C., Kespohl, S., Plaza, M., Raulf, M., Standl, M., Thamm, R., Traidl-Hoffmann, C., Werchan, B. (2023): Impact of climate change on allergic diseases in Germany. Journal of Health Monitoring 8(S4), 76–102. https://doi.org/10.25646/11654

Bowler, D. E., Buyung-Ali, L., Knight, T. M., Pullin, A. S. (2010): Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning 97, 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Breitner-Busch, S., Mücke, H.-G., Schneider, A., Hertig, E. (2023): Impact of climate change on non-communicable diseases due to increased ambient air pollution. Journal of Health Monitoring 8(S4), 103–121. https://doi.org/10.25646/11655.2

Briegel, F., Makansi, O., Brox, T., Matzarakis, A., Christen, A. (2023): Modelling long-term thermal comfort conditions in urban environments using a deep convolutional encoder-decoder as a computational shortcut. Urban Climate 47, 101359. https://doi.org/10.1016/j.uclim.2022.101359

Brosy, C., Zaninović, K., Matzarakis, A. (2014): Quantification of climate tourism potential of Croatia based on measured data and regional modeling. International Journal of Biometeorology 58, 1369–1381. https://doi.org/10.1007/s00484-013-0738-8

Brunekreef, B., Holgate, S. T. (2002): Air pollution and health. The Lancet 360, 1233–1242. https://doi.org/10.1016/S0140-6736(02)11274-8

Bucher, K., Haase, C. (1993): Meteorotropy and medical-meteorological forecasts. Experientia 49, 759–768. https://doi.org/10.1007/BF01923545

Bund/Länder-Arbeitsgruppe GAK (2017): Handlungsempfehlungen für die Erstellung von Hitzeaktionsplänen zum Schutz der menschlichen Gesundheit. Bundesgesundheitsblatt 60, 662–672. https://doi.org/10.1007/s00103-017-2554-5

Bundesamt für Strahlenschutz (2022): Joint recommendation on UV radiation and vitamin D. UV Protection Alliance, Munich.

Bunker, A. et al. (2016): Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: a systematic review and meta-analysis. EBioMedicine 6, 258–268. https://doi.org/10.1016/j.ebiom.2016.02.034

Butsch, C., Beckers, L.-M., Nilson, E., Frassl, M., Brennholt, N., Kwiatkowski, R., Söder, M. (2023): Health impacts of extreme weather events — cascading risks in a changing climate. Journal of Health Monitoring 8(S4), 33–56. https://doi.org/10.25646/11652

Bärtsch, P., Swenson, E. R. (2013): Acute high-altitude illnesses. New England Journal of Medicine 368, 2294–2302. https://doi.org/10.1056/NEJMcp1214870

Chen, Y.-C., Chen, W.-N., Chou, C. C.-K., Matzarakis, A. (2020): Concepts and new implements for modified physiologically equivalent temperature. Atmosphere 11, 694.

Chen, Y.-C., Matzarakis, A. (2018): Modified physiologically equivalent temperature — basics and applications for western European climate. Theoretical and Applied Climatology 132, 1275–1289.

de Dear, R., Brager, G. S. (1998): Developing an adaptive model of thermal comfort and preference. ASHRAE Transactions 104, 145–167.

de Freitas, C. R., Scott, D., McBoyle, G. (2008): A second generation climate index for tourism. International Journal of Biometeorology 52, 399–407. https://doi.org/10.1007/s00484-007-0134-3

Deutscher Heilbäderverband, Deutscher Tourismusverband (2005): Begriffsbestimmungen — Qualitätsstandards für die Prädikatisierung von Kurorten, Erholungsorten und Heilbrunnen. Bonn.

Deutscher Wetterdienst: Biowetter and health-related weather information. www.dwd.de

Deutscher Wetterdienst: UV-Index forecasts and UV warning service. www.dwd.de

Dixon, W. G. et al. (2019): How the weather affects the pain of citizen scientists using a smartphone app. npj Digital Medicine 2, 105. https://doi.org/10.1038/s41746-019-0180-3

DWA-A 138 / DWA-M 102: Regelwerk zur Versickerung und Bewirtschaftung von Niederschlagswasser. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall, Hennef.

Ebi, K. L. et al. (2021): Hot weather and heat extremes: health risks. The Lancet 398, 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3

Ebi, K. L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., Jay, O. (2021): Hot weather and heat extremes: health risks. The Lancet 398, 698–708.

Erell, E., Pearlmutter, D., Williamson, T. (2011): Urban Microclimate. Designing the Spaces Between Buildings. Earthscan, London.

European Centre for Disease Prevention and Control: Vector maps and annual epidemiological reports. Stockholm.

European Environment Agency: Air quality in Europe. Annual report series, Copenhagen.

Fanger, P. O. (1972): Thermal Comfort: Analysis and Applications in Environmental Engineering. McGraw-Hill, New York.

Gangwisch, M., Saha, S., Matzarakis, A. (2023): Spatial neighborhood analysis linking urban morphology and green infrastructure to atmospheric conditions in Karlsruhe, Germany. Urban Climate 51, 101624. https://doi.org/10.1016/j.uclim.2023.101624

Gasparrini, A. et al. (2015): Mortality risk attributable to high and low ambient temperature: a multicountry observational study. The Lancet 386, 369–375. https://doi.org/10.1016/S0140-6736(14)62114-0

Gebhardt, N., van Bronswijk, K., Bunz, M., Müller, T., Niessen, P., Nikendei, C. (2023): Scoping review of climate change and mental health in Germany — direct and indirect impacts, vulnerable groups, resilience factors. Journal of Health Monitoring 8(S4), 122–149. https://doi.org/10.25646/11656

Givoni, B. (1998): Climate Considerations in Building and Urban Design. Van Nostrand Reinhold, New York.

Graw, K., Sommer, S., Matzarakis, A. (2022): The prevalence of weather sensitivity in Germany derived from population surveys. Atmosphere 13, 1865, 1–14. https://doi.org/10.3390/atmos13111865

Haines, A., Ebi, K. (2019): The imperative for climate action to protect health. New England Journal of Medicine 380, 263–273. https://doi.org/10.1056/NEJMra1807873

Havenith, G. (2001): Individualized model of human thermoregulation for the simulation of heat stress response. Journal of Applied Physiology 90, 1943–1954. https://doi.org/10.1152/jappl.2001.90.5.1943

Hertig, E., Hunger, I., Kaspar-Ott, I., Matzarakis, A., Niemann, H., Schulte-Droesch, L., Voss, M. (2023): Climate change and public health in Germany — an introduction to the German status report on climate change and health 2023. Journal of Health Monitoring 8(S3), 6–32. https://doi.org/10.25646/11400

Hickman, C. et al. (2021): Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health 5, e863–e873. https://doi.org/10.1016/S2542-5196(21)00278-3

Hippocrates: Airs, Waters, Places (c. 400 BC), in: Hippocratic Writings, various editions.

Holick, M. F. (2007): Vitamin D deficiency. New England Journal of Medicine 357, 266–281. https://doi.org/10.1056/NEJMra070553

Hospers, L. et al. (2024): The effect of prescription and over-the-counter medications on core temperature in adults during heat stress: a systematic review and meta-analysis. eClinicalMedicine 77, 102886.

Howard, L. (1833): The Climate of London, Deduced from Meteorological Observations. Harvey and Darton, London.

Höppe, P. (1997): Aspects of human biometeorology in past, present and future. International Journal of Biometeorology 40, 19–23. https://doi.org/10.1007/BF02439406

Höppe, P. (1999): The physiological equivalent temperature — a universal index for the biometeorological assessment of the thermal environment. International Journal of Biometeorology 43, 71–75. https://doi.org/10.1007/s004840050118

Höppe, P., von Mackensen, S., Nowak, D., Piel, E. (2002): Prävalenz von Wetterfühligkeit in Deutschland. Deutsche Medizinische Wochenschrift 127, 15–20. https://doi.org/10.1055/s-2002-19429

ILO (2019): Working on a warmer planet: the impact of heat stress on labour productivity and decent work. International Labour Organization, Geneva.

IPCC (2023): Climate Change 2023 — Synthesis Report. Geneva.

Jendritzky, G., de Dear, R., Havenith, G. (2012): UTCI — why another thermal index? International Journal of Biometeorology 56, 421–428. https://doi.org/10.1007/s00484-011-0513-7

Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016): Heat, human performance, and occupational health. Annual Review of Public Health 37, 97–112. https://doi.org/10.1146/annurev-publhealth-032315-021740

Klinenberg, E. (2002): Heat Wave. A Social Autopsy of Disaster in Chicago. University of Chicago Press, Chicago.

Landrigan, P. J. et al. (2018): The Lancet Commission on pollution and health. The Lancet 391, 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

Laschewski, G., Jendritzky, G. (2002): Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. Climate Research 21, 91–103. https://doi.org/10.3354/cr021091

Laschewski, G., Matzarakis, A. (2024): Langfristige Veränderung der UV-Strahlung und Auswirkungen auf die individuelle Strahlungsexposition von Menschen in Deutschland. Gefahrstoffe — Reinhaltung der Luft 84(7–8), 187–194.

Lin, T.-P., Matzarakis, A. (2008): Tourism climate and thermal comfort in Sun Moon Lake, Taiwan. International Journal of Biometeorology 52, 281–290.

Lin, T.-P., Matzarakis, A., Hwang, R.-L. (2010): Shading effect on long-term outdoor thermal comfort. Building and Environment 45, 213–221. https://doi.org/10.1016/j.buildenv.2009.06.002

Lin, T.-P., Yang, S.-R., Chen, Y.-C., Matzarakis, A. (2019): The potential of a modified physiologically equivalent temperature (mPET) based on local thermal comfort perception in hot and humid regions. Theoretical and Applied Climatology 135, 873–876.

Luks, A. M. et al. (2019): Wilderness Medical Society clinical practice guidelines for the prevention and treatment of acute altitude illness. Wilderness & Environmental Medicine 30(4S), S3–S18. https://doi.org/10.1016/j.wem.2019.04.006

Matzarakis, A. (2006): Weather- and climate-related information for tourism. Tourism and Hospitality Planning & Development 3, 99–115. https://doi.org/10.1080/14790530600938279

Matzarakis, A. (2007): Assessment method for climate and tourism based on daily data. In: Matzarakis, A., de Freitas, C. R., Scott, D. (eds.): Developments in Tourism Climatology, 52–58. Commission on Climate, Tourism and Recreation, Freiburg.

Matzarakis, A. (2014): Transfer of climate data for tourism applications — the Climate-Tourism/Transfer-Information-Scheme. Sustainable Environment Research 24, 273–280.

Matzarakis, A. (2020): A note on the assessment of the effect of atmospheric factors and components on humans. Atmosphere 11, 1283. https://doi.org/10.3390/atmos11121283

Matzarakis, A. (2026): Hitzewarnungen und Hitzeaktionspläne. GGW — Gesundheit und Gesellschaft Wissenschaft 26(3), 15–22.

Matzarakis, A., Amelung, B. (2008): Physiological Equivalent Temperature as indicator for impacts of climate change on thermal comfort of humans. In: Thomson, M. C. et al. (eds.): Seasonal Forecasts, Climatic Change and Human Health. Springer, Dordrecht, 161–172.

Matzarakis, A., Baumüller, J. (2026): Stadtklima, Bioklima des Menschen und Klimaanpassung — einige Irrtümer und Fakten. Gefahrstoffe — Reinhaltung der Luft 96(5–6), 95–104. https://doi.org/10.37544/0949-8036-2026-05-06-91

Matzarakis, A., De Rocco, M., Najjar, G. (2009): Thermal bioclimate in Strasbourg — the 2003 heat wave. Theoretical and Applied Climatology 98, 209–220. https://doi.org/10.1007/s00704-009-0102-4

Matzarakis, A., Endler, C. (2010): Climate change and thermal bioclimate in cities: impacts and options for adaptation in Freiburg, Germany. International Journal of Biometeorology 54, 479–483. https://doi.org/10.1007/s00484-009-0296-2

Matzarakis, A., Fröhlich, D. (2015): Sport events and climate for visitors—the case of FIFA World Cup in Qatar 2022. International Journal of Biometeorology 59(4), 481–486. https://doi.org/10.1007/s00484-014-0886-5

Matzarakis, A., Fröhlich, D., Bermon, S., Adami, P. E. (2019): Visualization of climate factors for sports events and activities — the Tokyo 2020 Olympic Games. Atmosphere 10, 572.

Matzarakis, A., Mayer, H. (1991): The extreme heat wave in Athens in July 1987 from the point of view of human biometeorology. Atmospheric Environment 25, 203–211. https://doi.org/10.1016/0957-1272(91)90055-J

Matzarakis, A., Mayer, H. (1996): Another kind of environmental stress: thermal stress. WHO Collaborating Centre for Air Quality Management and Air Pollution Control, Newsletters 18, 7–10.

Matzarakis, A., Mayer, H., Iziomon, M. G. (1999): Applications of a universal thermal index: physiological equivalent temperature. International Journal of Biometeorology 43, 76–84. https://doi.org/10.1007/s004840050119

Matzarakis, A., Muthers, S., Koch, E. (2011): Human biometeorological evaluation of heat-related mortality in Vienna. Theoretical and Applied Climatology 105, 1–10. https://doi.org/10.1007/s00704-010-0372-x

Matzarakis, A., Nastos, P. T. (2011): Human-biometeorological assessment of heat waves in Athens. Theoretical and Applied Climatology 105, 99–106. https://doi.org/10.1007/s00704-010-0379-3

Matzarakis, A., Nouri, A. S. (2026): Thermal Comfort Models for Outdoor Spaces. In: Eslamian, S., Eslamian, F. A. (eds.): Encyclopedia of Smart and Green Cities. Springer, Singapore, 1–12. https://doi.org/10.1007/978-981-96-1800-2_105-1

Matzarakis, A., Rutz, F., Mayer, H. (2007): Modelling radiation fluxes in simple and complex environments: application of the RayMan model. International Journal of Biometeorology 51, 323–334. https://doi.org/10.1007/s00484-006-0061-8

Matzarakis, A., Rutz, F., Mayer, H. (2010): Modelling radiation fluxes in simple and complex environments: basics of the RayMan model. International Journal of Biometeorology 54, 131–139. https://doi.org/10.1007/s00484-009-0261-0

Mayer, H., Höppe, P. (1987): Thermal comfort of man in different urban environments. Theoretical and Applied Climatology 38, 43–49. https://doi.org/10.1007/BF00866252

McGregor, G. R. (2024): Heatwaves: Causes, Consequences and Responses. Biometeorology, vol. 6. Springer, Cham.

Middleton, N. J. (2017): Desert dust hazards: a global review. Aeolian Research 24, 53–63. https://doi.org/10.1016/j.aeolia.2016.12.001

Nastos, P. T., Matzarakis, A. (2006): Weather impacts on respiratory infections in Athens, Greece. International Journal of Biometeorology 50, 358–369. https://doi.org/10.1007/s00484-006-0031-1

Nastos, P. T., Matzarakis, A. (2008): Variability of tropical days over Greece within the second half of the twentieth century. Theoretical and Applied Climatology 93, 75–89. https://doi.org/10.1007/s00704-007-0325-1

Nastos, P. T., Matzarakis, A. (2012): The effect of air temperature and human thermal indices on mortality in Athens, Greece. Theoretical and Applied Climatology 108, 591–599. https://doi.org/10.1007/s00704-011-0555-0

Nouri, A. S., Costa, J. P., Santamouris, M., Matzarakis, A. (2018): Approaches to Outdoor Thermal Comfort Thresholds through Public Space Design: A Review. Atmosphere 9(3), 108. https://doi.org/10.3390/atmos9030108

Nouri, A. S., Matzarakis, A. (2026): Urban Microclimates and Comfort. In: Eslamian, S., Eslamian, F. A. (eds.): Encyclopedia of Smart and Green Cities. Springer, Singapore, 1–10. https://doi.org/10.1007/978-981-96-1800-2_213-1

Oke, T. R. (1982): The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society 108, 1–24. https://doi.org/10.1002/qj.49710845502

Olgyay, V. (1963): Design with Climate. Bioclimatic Approach to Architectural Regionalism. Princeton University Press, Princeton.

Pope, C. A., Dockery, D. W. (2006): Health effects of fine particulate air pollution: lines that connect. Journal of the Air and Waste Management Association 56, 709–742. https://doi.org/10.1080/10473289.2006.10464485

Raymond, C., Matthews, T., Horton, R. M. (2020): The emergence of heat and humidity too severe for human tolerance. Science Advances 6(19), eaaw1838.

Reid, C. E., Brauer, M., Johnston, F. H., Jerrett, M., Balmes, J. R., Elliott, C. T. (2016): Critical review of health impacts of wildfire smoke exposure. Environmental Health Perspectives 124, 1334–1343. https://doi.org/10.1289/ehp.1409277

Robert Koch-Institut: FSME-Risikogebiete in Deutschland. Epidemiologisches Bulletin, annual series, Berlin.

Roenneberg, T., Merrow, M. (2016): The circadian clock and human health. Current Biology 26, R432–R443. https://doi.org/10.1016/j.cub.2016.04.011

Romanello, M., di Napoli, C., Green, C. et al. (2023): The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms. The Lancet 402, 2346–2394. https://doi.org/10.1016/S0140-6736(23)01859-7

Salamanca, F., Georgescu, M., Mahalov, A., Moustaoui, M., Wang, M. (2014): Anthropogenic heating of the urban environment due to air conditioning. Journal of Geophysical Research: Atmospheres 119. https://doi.org/10.1002/2013JD021225

Semenza, J. C., Suk, J. E. (2018): Vector-borne diseases and climate change: a European perspective. FEMS Microbiology Letters 365, fnx244. https://doi.org/10.1093/femsle/fnx244

Sherwood, S. C., Huber, M. (2010): An adaptability limit to climate change due to heat stress. Proceedings of the National Academy of Sciences 107, 9552–9555. https://doi.org/10.1073/pnas.0913352107

Tipton, M. J., Collier, N., Massey, H., Corbett, J., Harper, M. (2017): Cold water immersion: kill or cure? Experimental Physiology 102, 1335–1355. https://doi.org/10.1113/EP086283

Twohig-Bennett, C., Jones, A. (2018): The health benefits of the great outdoors: a systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research 166, 628–637.

VDI 3787 Part 1: Environmental meteorology — Climate and air pollution maps for cities and regions. VDI, Düsseldorf.

VDI 3787 Part 2 (2022): Environmental meteorology — Methods for human-biometeorological evaluation of the thermal component of the climate. VDI, Düsseldorf.

Vecellio, D. J., Wolf, S. T., Cottle, R. M., Kenney, W. L. (2022): Evaluating the 35°C wet-bulb temperature adaptability threshold for young, healthy subjects (PSU HEAT Project). Journal of Applied Physiology 132, 340–345.

Verband Region Stuttgart (2008): Klimaatlas Region Stuttgart. Verband Region Stuttgart, Stuttgart.

Vicedo-Cabrera, A. M. et al. (2021): The burden of heat-related mortality attributable to recent human-induced climate change. Nature Climate Change 11, 492–500.

Vitt, R., Laschewski, G., Bais, A. F., Diémoz, H., Fountoulakis, I., Siani, A. M., Matzarakis, A. (2020): UV-Index climatology for Europe based on satellite data. Atmosphere 11, 727. https://doi.org/10.3390/atmos11070727

von Mackensen, S., Hoeppe, P., Maarouf, A., Tourigny, P., Nowak, D. (2005): Prevalence of weather sensitivity in Germany and Canada. International Journal of Biometeorology 49, 156–166. https://doi.org/10.1007/s00484-004-0226-2

West, M., Arrighi, J., Jones, H., Keith, L., Knowlton, K., Kolli, R. K., Matzarakis, A., Lee, J., Ren, C., Tan, A., Tiwari, A. (2023): Reporting on Heatwaves and the Health Impacts of Heat. Guidance Note for the Media. Global Heat Health Information Network (GHHIN) 1, 1–6.

WHO (2002): Global Solar UV Index: A Practical Guide. World Health Organization, Geneva.

WHO (2009): WHO Guidelines for Indoor Air Quality: Dampness and Mould. WHO Regional Office for Europe, Copenhagen.

WHO (2010): Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organization, Copenhagen.

WHO (2011): Burden of Disease from Environmental Noise. World Health Organization Regional Office for Europe, Copenhagen.

WHO (2018): Environmental Noise Guidelines for the European Region. World Health Organization Regional Office for Europe, Copenhagen.

WHO (2018): Housing and health guidelines. World Health Organization, Geneva.

WHO (2021): WHO Global Air Quality Guidelines. World Health Organization, Geneva.

WHO (2022): WHO Ambient Air Quality Database, 2022 Update: Status Report. World Health Organization, Geneva.

WHO Regional Office for Europe (2008): Heat–Health Action Plans. Guidance. Copenhagen.

Winklmayr, C., Matthies-Wiesler, F., Muthers, S., Buchien, S., Kuch, B., an der Heiden, M., Mücke, H.-G. (2023): Heat in Germany: health risks and preventive measures. Journal of Health Monitoring 8(S4), 3–32. https://doi.org/10.25646/11651

WMO (2017): WMO Guidelines on the Calculation of Climate Normals. WMO-No. 1203, Geneva.

WMO (2022): Scientific Assessment of Ozone Depletion. World Meteorological Organization, Geneva.

Zacharias, S., Koppe, C. (2015): Einfluss des Klimawandels auf die Biotropie des Wetters und die Gesundheit bzw. die Leistungsfähigkeit der Bevölkerung in Deutschland. UFOPLAN 3711 61 238, Umweltbundesamt, Dessau-Roßlau.

Zaninović, K., Matzarakis, A. (2009): The bioclimatological leaflet as a means conveying climatological information to tourists and the tourism industry. International Journal of Biometeorology 53, 369–374. https://doi.org/10.1007/s00484-009-0219-2

Ziska, L. H. et al. (2019): Temperature-related changes in airborne allergenic pollen abundance and seasonality across the northern hemisphere. Lancet Planetary Health 3, e124–e131. https://doi.org/10.1016/S2542-5196(19)30015-4

Index

Dedication and acknowledgements

This book grew out of many years of work in meteorology, applied climatology, human biometeorology and climate impact research. Working with colleagues and friends from all over the world has been the engine behind it, and most of what is in these pages came out of that collaboration in one way or another.

It also rests on my lecture course in human biometeorology at the Albert-Ludwigs-University of Freiburg, and on the questions that the students in it have asked over the years. Several chapters exist because someone in the third row would not accept a simple answer.

It is dedicated to my wife and to my family in Greece.

A closing word

This book could not cover every topic, and it could not go deep everywhere. That was never the aim. The aim was to show how closely our well-being is bound up with weather and climate, and that protection is often possible with very simple means.

If a reader takes only three things away from it, let them be these. Shade before technology. The night matters more than the day. And look in on the neighbour, in August as much as in January.

The author

Andreas Matzarakis, born in Greece in 1960, studied meteorology at the Ludwig-Maximilians-University in Munich. In 1995 he took his doctorate at the Aristotle University of Thessaloniki, on the bioclimate of Greece. From 1995 to 2001 he was a research assistant at the Albert-Ludwigs-University of Freiburg, where he gained his habilitation on the thermal component of urban climate.

From 2001 to 2015 he worked in Freiburg, and in 2006 he was appointed extraordinary professor there. From 2015 to 2024 he headed the Research Centre for Human Biometeorology of the German Meteorological Service in Freiburg. Since April 2024 he has been back at the University of Freiburg. He is also an external member of the University Council of the Democritus University of Thrace in Greece, the region he comes from.

His research covers human biometeorology, urban climatology, tourism climatology and climate impact research. The thermal indices and models discussed in this book, among them mPET and the RayMan model, came out of that work and out of the collaborations behind it.