



## Towards a Liveable Urban Climate

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# Towards a Liveable Urban Climate: Lessons from Stuttgart

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## Introduction

It has been known for centuries that the physical design of a city affects climatic variables - temperature, wind patterns, humidity, precipitation, air quality - which in turn have direct consequences for liveability. This paper considers how the climatic impacts of urban form can enhance or reduce the quality of

urban life, drawing valuable lessons from the experience of a city that deliberately studied the behaviour of its local weather systems and learned how to manage them through physical planning.

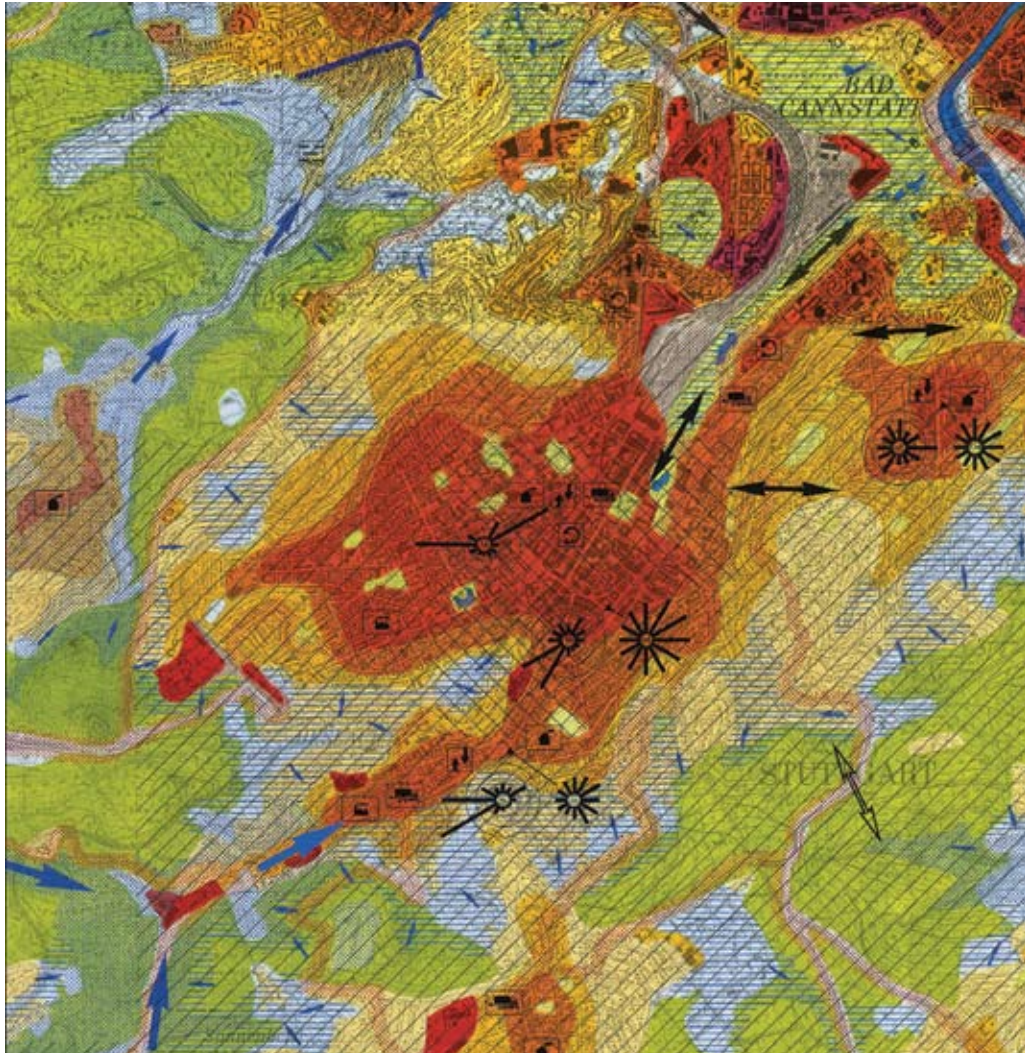


Figure 1: Climate Analysis Map of the City of Stuttgart. Source: Verband Region Stuttgart (2008)

## Urban Climatology and its Application

The history of design for a liveable urban climate has solid roots in practical precedents of traditional vernacular building typology, and a more elusive basis in abstract systems

such as Chinese geomantic *feng shue* or Greco-Roman wind theory. Some enigmatic principles of healthy ventilation set out more than two thousand years ago for the Emperor Augustus by the engineer Vitruvius in Book One of his treatise *De Architectura* continued to be invoked by nineteenth and early twentieth century planners, slim though their scientific basis was. After the First World War the Modern Movement put 'light and air', *Licht*

*und Luft*, at the centre of their rational design philosophy, orienting buildings towards the sun and arranging functional uses in accordance with 'prevailing wind'. Unfortunately the evidence basis remained sketchy, since designers had little empirical understanding of the complex nature of urban microclimates, and particularly of the impact of tall free-standing buildings on air turbulence and outdoor temperature.

Urban climatology was placed on a more solid scientific footing around the mid twentieth century, the seminal text being Albert Kratzer's *Stadtklima* published in 1937 and revised in 1956. Developing rapidly across the disciplines of applied meteorology and physical geography, the science appeared to hold great promise for climatically-informed town planning. Data-gathering was enhanced by new techniques such as vehicle-mounted ob-



Figure 2: above: Street canyon in Chicago. Source: Authors  
 Figure 3: right: A dense high-rise city block is not conducive to wind flow at street level. Source: Authors





servation points, high density weather stations on public buildings, balloon mounted sensors for monitoring city air-flow, radar, aerial photography and remote sensing of atmospheric conditions. The state of the art shifted from descriptive research to process analysis of energy exchanges and air circulation within the complex three-dimensional geometry of urban landscapes, using physical and then numerical models (Oke 1976).

Urban climatologists addressed anthropogenic variables that are perfectly familiar to town planners: street orientation, street width-to-height ratios, building height and spacing, architectural detail of street frontages, heat-reflectiveness (albedo) of building form and materials, the placing of street trees, parks and water-spaces, and the effects of vehicle movement (Givoni 1998; Erell 2011). The street canyon became an especially interesting point of intersection between climatology and design: this quintessential urban space can be represented as a rectangular trough with height and width dimensions composed of surface materials orientated at a particular angle, framing a sky view whose geometry determines sun access by day and loss of energy by night. Detailed studies have been done on its energy balances and air movement patterns and the optimal geometry of height, width and orientation (Oke, 1988). Digital modelling has brought a further level of sophistication, integrating design factors and climatic effects with biometeorological variables so human comfort levels can be estimated under different climate scenarios and design settings (Matzarakis et al. 1999). Urban climatology has come of age in recent years as a distinct scientific specialism with its own global network, the International Association for Urban Climate (IAUC)<sup>1</sup>.

Alas, whilst the science of urban climatology has progressed its practical application has not. Perhaps because of the rise of air-conditioning and motorisation, perhaps because of

the decline in pedestrianism or visible carbon pollution, city planning became less climate-aware in the decades after 1950. Planners addressed a dauntingly long and growing list of factors, but 'weather' was not generally one of them. With the honourable exceptions of German (and German-speaking) cities to which we return later in this chapter, wind-roses and rainfall distribution maps tended to disappear from planning documents. Climatic factors became little understood and weakly regulated. In the name of traffic flow streets were often widened and sidewalks narrowed to the detriment of outdoor air quality. Small city blocks were consolidated to allow the construction of large-scale climate controlled buildings, blocking air circulation or creating man-made wind tunnels. The higher heat absorption capacity of man-made materials, such as asphalt and cement, boosted urban heat island effects. The impervious surfaces of buildings, roads and parking lots accelerated storm-water run-off and flood risk. Tree removal deprived streets of pollution filters and exacerbated outdoor temperature extremes. Development pressure and architectural desire for visual impact combined in vertical building booms that too often turned daylight into shadow. Urban environmental management, where it occurred, was seen less as an urban design issue than a topic for microlevel building performance modification by architects, engineers and building services technicians (Bosselmann 1998; Doucet 2007; Schiller et al. 2006).

Scientists specialising in city weather patterns - urban climatologists - were well aware of adverse trends affecting outdoor liveability, as the writings of Tony Chandler (1976), Helmut Landsberg (1981), Arie Bitan (1984) and Baruch Givoni (1998) bear witness. Using the institutional networks of the World Meteorological Organisation, the United Nations Environment Programme, the International Society for Biometeorology, the International Federation for Housing and Planning and the

Confédération Internationale du Bâtiment the science community made persistent efforts in postwar decades to alert urban planners to anthropogenic climate change at the urban scale. Their climate awareness campaign met with little success (Hebbert & MacKillop 2011).

It is interesting to compare the disappointing record of knowledge transfer in urban-scale climatology with the impact of anthropogenic climate change at *the* global scale. The IPCC process and the UN Framework Convention on Climate Change have at last galvanised urban decision-makers. Climate change is the vogue topic in urban affairs. Most of the world's leading cities have adopted some form of action plan, and their example is energetically communicated through the policy networks of ICLEI's Cities for Climate Protection programme, the Climate Alliance, the Energies-Cités movement or the C40 group. Hardly a month goes by without a fresh urban initiative on carbon mitigation or adaptation to global warming, such as - at the moment of writing - UN-Habitat's Global Report for 2011 *Cities and Climate Change: Policy Directions* (UN-Habitat 2011) and 'ARC3', the First Assessment Report of the Urban Climate Change Research Network *Climate Change and Cities* (Rosenzweig et al. 2011).

The state-of-the art as summarised in these two substantial reports treats urban climate from a distinctive angle. The city is problematised as a factor in global emissions and as a site of vulnerability to climate change impacts. The time-frame extends up to ninety years in the future, an unusually remote horizon in urban planning. Climatic forecasts are downscaled from global circulation models via regional-scale models to a 'fine resolution' of pixels 12 kilometres square, an unusually coarse grain in urban planning. Attention is focussed on the catastrophic risks of inundation, drought, typhoons, or heat extremes, and the policy formulae are explicitly borrowed from the field of disaster preparedness planning.

Shagun Mehrotra and colleagues frame the entire issue in terms of an encounter between the two 'communities' of macro-scale climate modelling and disaster management (Rosenzweig 2011, p. 19). The knowledge community of urban climatology represented by the IAUC plays hardly any role.

Consequently the 'city climate' of the Urban Climate Change Research Network is a selective construct, focussed upon the exposure of cities to hazards that have a huge impact but a low frequency. It has little to say about the high-frequency and micro-scale climatic phenomena created within the anthropogenic environment of the city, such as the local circulations of regional winds, pollution and its dispersal on breezes, nocturnal cold air flows, variations in outdoor temperature and humidity, spatial patterns of sunshine and shade, shelter from wind and rain, and similar factors of significance for everyday liveability. These effects cannot be downscaled from a regional weather model, they are complex and require local observation and understanding. Patterns of urban wind circulation are typically diurnal, with breezes shifting direction between day and night, and intricate spatial distribution linked to topography, building form and landscape. Air ventilation and humidity directly affect human comfort and liveability within urban space. None of these factors are adequately considered in city climate analysis derived from model projections of extreme weather events.

So there is unfinished business here. While the challenge of global climate change has opened the door to city-level climatic awareness, city planners are still only beginning to factor in the full range of considerations that apply at the urban scale. The potential can be seen in the London Climate Change Mitigation and Adaptation Strategies (GLA 2010a, 2010b), which have benefited from the advisory role of the leading urban climatologist, and co-



Table 1: Causes of urban warming and examples of mitigation strategies. Grimmond 2007, p. 84

Urban heat island causes	Mitigation strategy
<p><i>Increased surface area</i>            Large vertical faces            Reduced sky view factor</p> <ul style="list-style-type: none"> <li>- Increased absorption of shortwave (solar) radiation</li> <li>- Decreased longwave (terrestrial) radiation loss</li> <li>- Decreased total turbulent heat transport</li> <li>- Reduced wind speeds</li> </ul> <p><i>Surface materials</i>  <i>Thermal characteristics</i></p> <ul style="list-style-type: none"> <li>- Higher heat capacities</li> <li>- Higher conductivities</li> <li>- Increased surface heat storage</li> </ul> <p><i>Moisture characteristics</i>            Urban areas have larger areas that are impervious</p> <ul style="list-style-type: none"> <li>- Shed water more rapidly – changes the hydrograph</li> <li>- Increased runoff with a more rapid peak</li> <li>- Decreased evapotranspiration (latent heat flux)</li> </ul> <p><i>Additional supply of energy – anthropogenic heat flux</i>            Electricity and combustion of fossil fuels: heating and cooling systems, machinery, vehicles.            3-D geometry of buildings – canyon geometry</p> <p><i>Air pollution</i>            Human activities lead to ejection of pollutants and dust into the atmosphere</p> <ul style="list-style-type: none"> <li>- Increased longwave radiation from the sky</li> <li>- Greater absorption and re-emission ('greenhouse effect')</li> </ul>	<p>High reflection building and road materials, high reflection paints for vehicles</p> <p>Spacing of buildings            Variability of building heights</p> <p>Reduce surface temperatures (changing albedo and emissivity)            Improved roof insulation</p> <p>Porous pavement</p> <p>Neighbourhood detention ponds and wetlands which collect stormwater            Increase greenspace fraction            Greenroofs, greenwalls</p> <p>Reduced solar loading internally, reduce need for active cooling (shades on windows, change materials)            District heating and cooling systems            Combined heat and power systems            High reflection paint on vehicles to reduce temperature</p> <p>District heating and cooling systems            Combined heat and power or cogeneration systems</p>

founder of IAUC, Professor Sue Grimmond (see Table 1). Even more significant exemplars are to be found in Germany. Here in the cradle of scientific urban climatology we find several cities which have maintained an active interest in atmospheric investigation for several decades and found means to factor it into design and regulation. The most important of these precedents is the city of Stuttgart.

### The example of Stuttgart, Germany

Stuttgart, the state capital of Baden-Württemberg, has a population of about 600,000, in a metropolitan region of some 2.6 million inhabitants. It is an industrial city whose vigorous manufacturing sector includes the Daimler, Porsche and Bosch plants as well as Hewlett-Packard and IBM. The city is located in the steep valley of the Neckar, a landscape

characterised by low wind speeds and weak air circulation. Consequently, air quality has been a long-standing concern. The city first established an Agency for Environmental Protection in 1938, including a municipal meteorologist to handle pollution-related aspects of its 1935 Urban Construction By-Law.

Climatically-aware design has an even longer history in the city. 'Unhindered access of light and air' was the chief design objective of the first workers suburb, *das Postdörfe* in 1868. The 1901 extension plan for the city included a technical appendix on the natural patterns of wind movement in the city valleys. During the Second World War the *Luftwaffe* exploited Stuttgart's topography, artificially generating fog to obstruct air bombers' view of target factories along the valley floor. A chance side-effect was to reveal longitudinal airflow conditions as the fog dissipated, resulting in



Figure 4: A topographical map of Stuttgart highlights the city's valley setting. Source: Landeshauptstadt Stuttgart

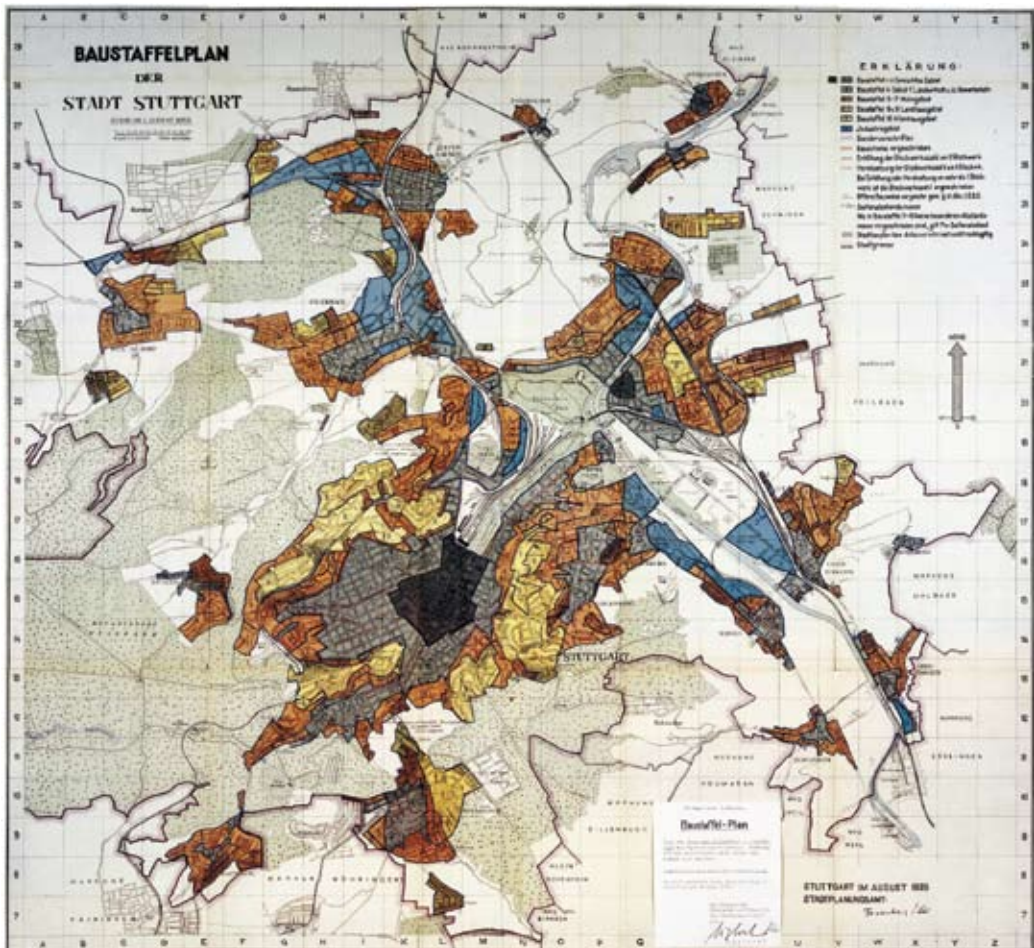


Figure 5: 1935 Urban Construction Bye-Law for the City of Stuttgart. Source: Landeshauptstadt Stuttgart

the identification of cold air drainage areas that came to be labelled as the city's fresh air swathes. The maintenance of these natural ventilators became a critical component of planning policy in Stuttgart, embodied in the city's post-war 1948 *General Binding Site Plan*. In 1953 the city adopted *Regulations for the Implementation of Functions in Climatology*, formalising the policy contribution of scientific evidence on meteorological and noise abatement issues.

With rising affluence and motorisation, air pollution remained prominent as a public health concern in the sixties, causing the city to initiate advanced monitoring systems for atmospheric carbon monoxide, sulphur dioxide, and dust precipitation. Stuttgart was a pioneer in streetside measurement of motor vehicle generated air pollution and thermographical measurement flights over the city. Its fine-grained urban heat island maps, *Data and Statements on Stuttgart's Urban Climate based*

on *Infrared-Thermography* (1978) were highly advanced for their time, as was the importance given to environmental management by planners and elected officials within the city. It caused Stuttgart to be profiled in a celebrated documentary film shown by the West German government at the first UN-Habitat conference in Vancouver in 1976,<sup>2</sup> which led in turn to its being featured as an exemplar of Vitruvian understanding of climatic comfort in Anne Whiston Spirn's seminal text of urban environmental management *The Granite Garden* (1984).

Today, the City of Stuttgart's urban climatology and environmental pollution unit of ten scientists remains outstanding in Germany and so the world. Its influence on planning issues extends to the publication of a 'climate atlas' for the wider metropolitan region in which it sits (Ministry of Economy Baden-Württemberg 2008). The *Klimaatlas* offers a written description of the city climate supported by analysis maps at a 1:20,000 scale, a scale that corresponds to that of the city's land use maps. The analysis maps identify 'climatopes' defined by daily variation in thermal energy, vertical roughness of the land, topographical position, and type of land use. Stuttgart identifies eleven climatopes: water, open land, forest, greenbelt, garden city, city periphery, city, core city, commercial, industry, and railway land. Each has a climatic role with planning implications. The dense climatopes of the city require mitigation, the leafy canopy areas of the forest climatope require protection, and spatial planning can help these complementary zones work as a single climatic system.

The *Klimaatlas* is intended as a knowledge transfer mechanism, bridging the elusive gap between urban climatology and public policy. Climatope analysis provides the basis for spatial planning recommendations. With pixels of up to 100 metres, the planning maps are not detailed enough to apply to the individual lot level, but they provide neighbourhood-level

guidance, and a basis for localised micro-climatic appraisal where necessary. The thrust of the policy is to protect vegetation and green spaces for their positive influence on the micro-climate, especially larger, connected green spaces; discourage development on valley sites with potential to hinder regional winds or disrupt local air circulation during weak wind conditions; protect the cold and fresh-air transport function of hillsides near built-up areas; conserve saddle-like topographies on lee slopes that act as air induction corridors; employ linear greenspaces as ventilation passages and induction corridors to support air exchange; prevent long-term convergence of built-up neighbourhoods, ensuring that urban extensions include nearby landscapes for fresh and cold air production, and ventilation corridors for distribution; and the siting of industrial and commercial enterprises in relation to local wind patterns (Ministry of Economy Baden-Württemberg 2008, p. 5.6):

Taken together these principles aim to make the urban environment more comfortable and liveable for residents. To help identify sensitive zones the maps differentiate broadly between open sites and settled areas, showing climatic sensitivity in relation to development. Open sites are classified by level of climatic activity: significant (high climatic sensitivity to a change in land use), less significant (low climatic sensitivity to a change in land use), or low (relatively no climatic sensitivity to a change in land use). Settled areas are commonly divided into four categories: those with small functions of relevance to climate, functions of relevance to climate, significant function of relevance to climate, and areas disadvantaged and in need of renewal to improve the urban climate. The maps also highlight streets with a traffic count of more than 15,000 vehicles per day, for which pollution forecasts should be undertaken for adjacent developments.



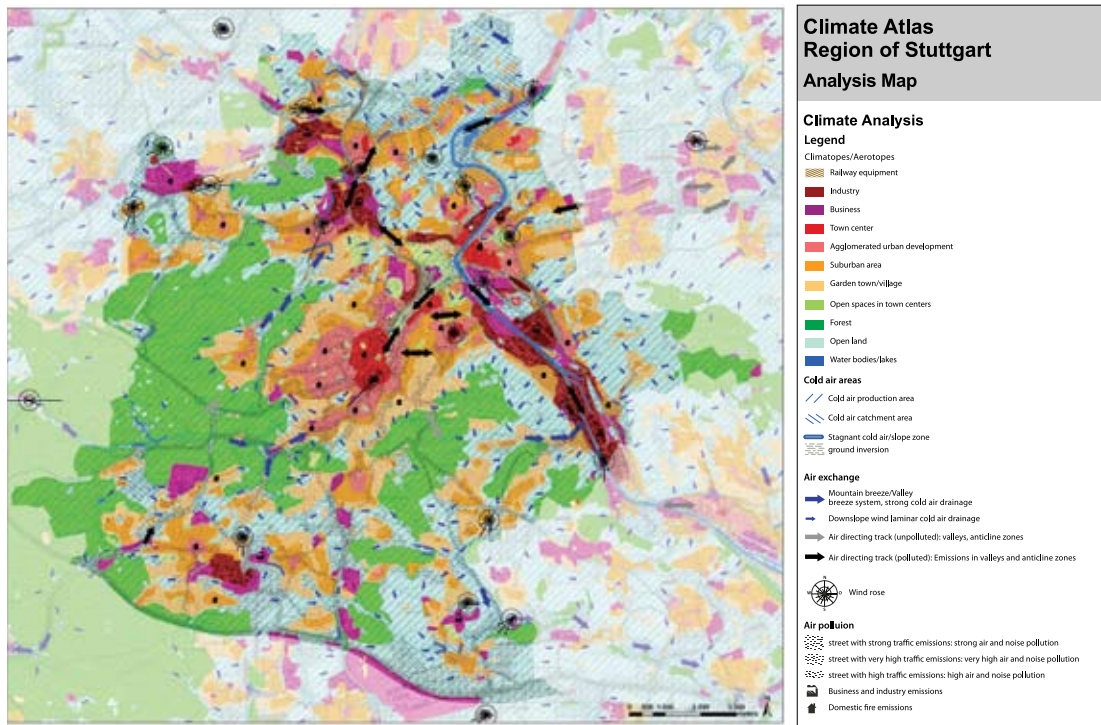


Figure 6: Climate Analysis Map for the Region of Stuttgart.  
Source: Verband Region Stuttgart (*Klimaatlas Region Stuttgart*, Ed.: Verband Region Stuttgart 2008)

Alongside the *Klimaatlas* the city's *Climate Booklet for Urban Development* offers detailed analysis of the climatic system with management recommendations based on the following principles of climate sensitive planning (Ministry of Economy Baden-Württemberg 2008, p. 6.0):

- Improvement of living conditions relative to climate comfort / bioclimate
- Improvement in ventilation of developments
- Support of fresh-air provision through local wind systems
- Reducing the release of air pollutants and greenhouse gases
- Reporting and proper evaluation of current or expected pollution
- Proper reaction to pollution situations by adjusting land use concepts

To achieve these liveability goals the climate booklet provides planning advice on four key themes: preservation and acquisition of green space; securing the local air exchange; air pollution control; and the use of urban climate studies to inform decisions. (Ministry of Economy Baden-Württemberg 2008, pp. 6.1 – 6.4)

Practical application of these principles translates into regulatory requirements for façade greening of buildings (including suggested criteria for the selection of plants) and the role of green roofs for the preservation and acquisition of green space. Local air exchange is promoted by guidelines on the optimal arrangement of buildings including restraints upon excessive height, green corridors that



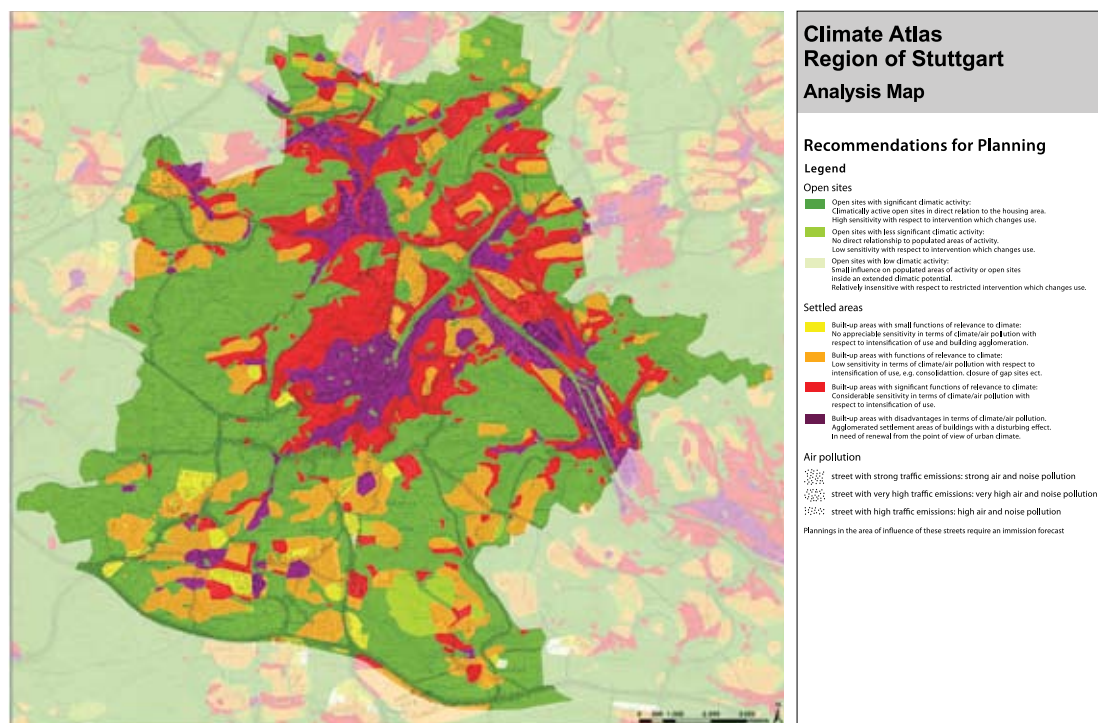


Figure 7: Planning Recommendation Map for the Region of Stuttgart.  
Source: Verband Region Stuttgart (*KlimaAtlas Region Stuttgart*, Ed.: Verband Region Stuttgart 2008)

act as ventilation zones, and the alignment of parks and streets to take advantage of airflows. Industrial and commercial development is tightly regulated to control air pollution and recommendations made for home heating systems. Measures to mitigate the harmful effects of highway pollution on residents include traffic calming schemes, the separation of intensive traffic uses from residential and recreation zones, noise protection barriers and dense plantings to mitigate exhaust pollution, and guidelines for street trees, broadly planted to allow for air flow (Ministry of Economy Baden-Württemberg 2008, pp. 6.1 – 6.4).

Stuttgart’s long and consistent attention to climatic factors takes on a new relevance in the era of global climate change. Climate projections for the Baden-Württemberg region in 2050 show an increase in temperature of 2 °Celsius in winter and 1.5 °C in summer, along with a 30% increase in the number of days with temperatures exceeding 25 °C and a doubling of days exceeding 30 °C. Further climate concerns related to precipitation are expected with reductions in rainfall by 10% in the summer and increases of up to 35% in winter. Thus long-standing efforts by the urban climatology and city planning departments to mitigate temperature extremes and manage climatic conditions will become all the more important in the future (Stuttgart 2010). The city already demonstrates the



Figure 8: A protected fresh air corridor in the City of Stuttgart. Source: Authors

political will and ability to use its mechanisms of building control and green-space protection to maintain fresh air corridors, drainage lands and natural air filtration sources. It has the technical capacity to promote low carbon development through passive design, using building orientation, shading and sunlight. Its monitoring and regulatory systems are already up and running. Stuttgart has the institutional capacity other cities crave.

### Learning from Stuttgart

The techniques developed in Stuttgart over decades have clear potential for application elsewhere. There is particular interest in the *KlimaAtlas* or urban climatic map, as a means of making the connections between urban micro-climate, development and liveability. Already in 1993 the technique was adopted as a good-practice blueprint by the German Institute of Engineers under National Guideline VDI-3787 *Environmental Meteorology Climate and Air Pollution Maps for Cities and Regions*. A recent review by Ren, Ng, and Katschner in the *International Journal of Climatology* finds worldwide applications, especially in European countries that suffered the effects of severe heat waves in 2003 and 2006, and Pacific Rim cities responding to the impact of the highly infectious SARS virus within dense, unventilated urban environments (Ren et al. 2010). The virtue of the technique is its combination of urban climatic analysis with planning recommendations. Ren, Ng and Katschner show how the spatial medium of cartography supported by geographical information systems facilitates the integration of three broad categories of data: analytical maps of climatic elements such as air temperature, atmospheric humidity, wind velocity and direction, precipitation, fog and mist, and air pollution; geographic terrain information derived from topographic, slope/valley, and soil type maps; and a third layer of data on land use, landscape, and buildings, with associated planning param-

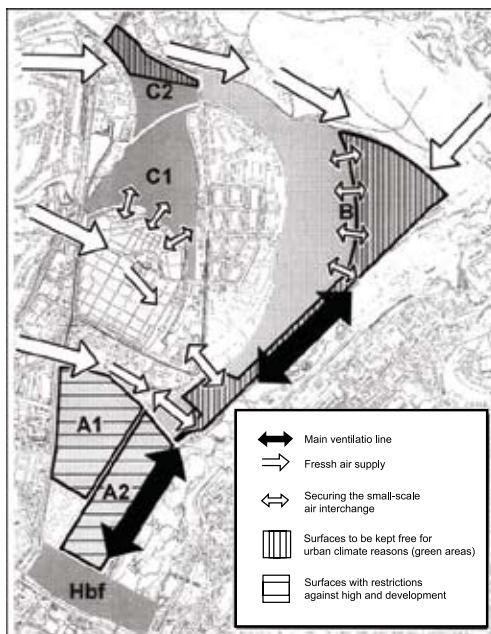


Figure 9: An example of the incorporation of climate conditions into detailed planning. Source: Amt für Umweltschutz der Landeshauptstadt Stuttgart

eters. This information is translated into the urban climatic analysis map where it can be interpreted into spatially specific recommendations - proactive, to improve and maintain desired micro-climates, and reactive, to deal with undesirable consequences of development. The methodology addresses precisely the urban-scale climatic issues that disaster managers and low energy designers tend to miss: how to reduce urban thermal loads; how to optimise existing urban ventilation paths and chart new air paths where needed; how to protect cold air production and drainage areas in the peri-urban landscape; and how to harness topography, land-sea breezes and the internal thermal circulation of the urban heat island. (Ren et al. 2010)

Equally, the *Klimaatlas* may provide a basis for distinguishing modes of planning response at the different spatial scales of building materials and surfaces; landscape and land use; building design and form; and zoning and urban morphology. Material and surface level interventions can be implemented through the use of building materials and pavements that are less energy absorbent, materials designed to cool roofs and building facades, porous paving and the planting of greenery. At the landscape/land use planning-level, interventions can be implemented through the creation of parks, open spaces, and green corridors that promote increased vegetation and cooler micro-climates and improved wind patterns, while street trees can be used to reduce air



Figure 10: Green roofs are a key component for mitigation of the urban heat island effect in city centres.  
Source: Authors

pollutants and reduce the temperature in the surrounding area. Building design-level interventions include stronger control over thermal exposure, better out-door provision for human shelter from sun and wind, and closer consideration of building heights in relation to street width. Urban planning/zoning-level interventions predominantly influence ventilation within the city through the provision of space for air paths, the proper division of land parcels, and the alignment of building lots and roads. Street orientation may also play an important role, depending on geographic location of the city in question.

The key benefit, and challenge, of urban climate mapping lies in the ability to translate complicated climate data into a spatial pattern that is comprehensible to non-experts and sufficiently robust to provide a basis for decision-making. It depends upon cross-disciplinary cooperation between urban climatologists and planners. Stuttgart was fortunate in having a well-established link between a municipal urban climatology unit and the municipal planning function. Few other cities have an in-house climatology team, or the support of a local public weather service; most rely on the more sporadic inputs of external partners, whether universities, research institutes or commercial consultants. Stuttgart and other German cities are also distinctive in the degree of public acceptance of restraint on private property for environmental purposes: the political culture recognizes the value of the urban climate as a public good, which is rare. Nevertheless, high-quality evidence can shift the boundaries of political possibility. For example, climate mapping has been successfully deployed by campaigners for public health and environmental justice in Hong Kong to demonstrate the harm caused to street-level ventilation by hyper-dense development. By linking three dimensional analysis of air movements, humidity and thermal loads to planning factors, the Hong Kong Urban Climatic Analysis Map has put outdoor micro-climates

onto the political agenda, causing planning codes to be revised and building volume to be restricted in areas of high climatic stress (Ng 2010; 2011). Despite the obvious differences between the two cities, Hong Kong has learned lessons from Stuttgart on why and how to make connections between urban climatology, planning and liveability.

## Conclusions

The configuration of a city's built and natural environments is a significant factor for carbon mitigation as well as for local adaptation to global warming's weather consequences. Ultimately urban weather cannot be modelled without detailed understanding of the urban landscape, and cities cannot plan for climate change without knowledge of atmospheric hazards and potentials. The need to resolve particular environmental issues in Stuttgart resulted in systematic application of urban climatological principles to exploit feedback effects in the built form and urban landscape. Technical capacity was developed over a span of decades and science-into-action mechanisms developed by trial and error. The *KlimaAtlas* proved its worth and this prototype urban climatic map has become widely imitated as cities around the world wake up to the importance of climate management in the 21st century context of global climate change.

The Stuttgart team make a very revealing comment in their 2010 report *Climate change - challenge facing urban climatology*. They observe that urban climatology and global climate adaptation/mitigation might seem like two sides of the same coin:

To the untrained observer, this combination of tasks might appear perfectly natural as a matter of course. However, in reality these two fields of activity involve com-

pletely different angles of approach which occasionally give rise to the need to draw attention to the differences between urban climatology and climate protection. It is the vast distinction in terms of scale - between regional and micro-climate on the one hand, and the global climate on the other - which clearly illustrates the difference between proactively protecting the climate along the lines of “think globally, act locally” and - as applied to urban climatology - making use of local climatic features to improve living conditions in the built-up urban landscape. (Stuttgart 2010, p. 13)

So we can take a double lesson from this case study. First it demonstrates the powerful contribution of micro-climatic observation and mapping, as in the *Klimaatlas*, towards urban strategy for carbon mitigation and climate change adaptation. And secondly it shows that climate-awareness is not just about GHG emissions and their disastrous consequences for the stratosphere. The scale of anthropogenic climate change which most affects liveability is closer to hand within the physical configuration of the built-up urban landscape, that is to say, the realm of city planning.

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## Endnotes

1. For more details on the IAUC, see [www.urban-climate.org](http://www.urban-climate.org) and <http://urban-climate.com/wp3/> newsletter for their quarterly Urban Climate News newsletter
2. The Stuttgart documentary film ‘Urban Climate and Development’ is available for viewing online at <http://www.sed.manchester.ac.uk/architecture/research/csud/workshop/media>



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