Stuttgart: Combating heat island and poor air quality with green aeration corridors

Climate change impacts addressed	Poor air quality High temperatures
Spatial scale	Town or city
Response type	Regulations
Themes driving the initiative	Response to current climate Adaptation to future climate
Factors of success	Internal collaboration Sound evidence base

Summary

Stuttgart's location in a valley basin, its mild climate, low winds and surrounding industrial activity has made it susceptible to poor air quality since the 1970s. Development on the valley slopes have made the situation worse by preventing air from moving through the city, which contributes to the urban heat island effect. Consequently, Stuttgart has been planned to exploit the role of natural wind patterns and dense vegetation in reducing problems of overheating and air pollution. A Climate Atlas was developed for the Stuttgart region, presenting the distribution of temperature and cold air flows according to the city's topography and land use. Based on this information, a number of planning and zoning regulations are recommended which aim to preserve open space and increase the presence of vegetation in densely built-up areas. The planning recommendations build on the legislative framework of the German Building Code and other national, regional and locally developed regulations.

Case study location

Stuttgart is the capital of the German Land (federal state) of Baden-Würtemburg and has a population of approximately 600,000 (Figure 1). The city is located in the centre of an industrial region that is home to more than two million and is well-known for its high-tech industry [(1)].

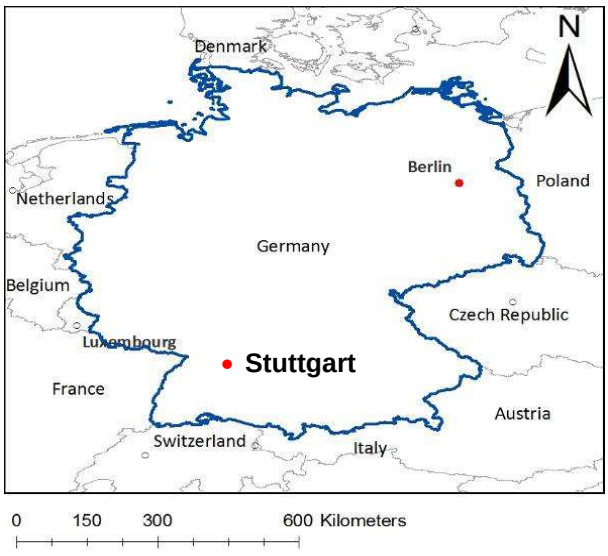

Figure 1. Location of Stuttgart in Germany

The city's location has a significant influence on its local climate with variables including radiation, temperature, humidity, precipitation and wind affected. Stuttgart sits in the wide Neckar basin formed by two river valleys, shielded by the steep hill slopes: Black Forest in the West, the Swabian Alb in the South, the Schurwald in the East and the Stromberg and Heuchelberg region in the Northwest. Stuttgart's centre is located at about 240m above sea level, while the surrounding hills reaching up to 500m a.s.l. The only opening to the Neckar Valley is in the Northeast along the Nesenbach valley, which narrows towards the southwest (Figure 2) [(2)].

Stuttgart has a mild, temperate climate with warm summers that are moderate enough to allow wine production on valley slopes. The mean summer temperature is 18ºC, mean winter temperature -1ºC. Wind speeds are generally low, which along with the urban heat island effect, contributes to

poor air quality. Stuttgart's climate is mostly affected by altitude; the urban core can have winters with no snow, while the surrounding hills can have up to 54 days of coverage (Figure 3) [(1)].

The future climate projections for 2071-2100 suggest a 2ºC increase of mean annual temperature [(3)]. The projections for heat waves are based on the assumption that the number of days with heat stress (when people's thermoregulation is impaired) will increase significantly. By 2100, 57% of the Greater Stuttgart region could have more than 30 days with heat stress (in the low lying areas even over 60 days) [(3)]. Therefore, a significantly higher percentage of people will be exposed to heat waves than at present [(4)].

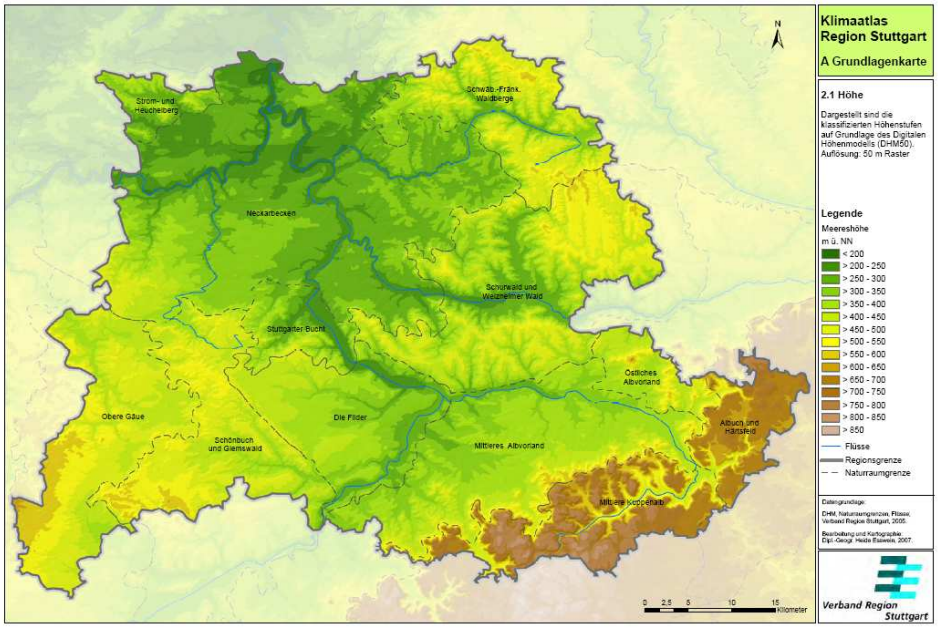

Figure 2. Topography of Stuttgart – green colours indicate lower locations, yellow and brown - higher [(3)]

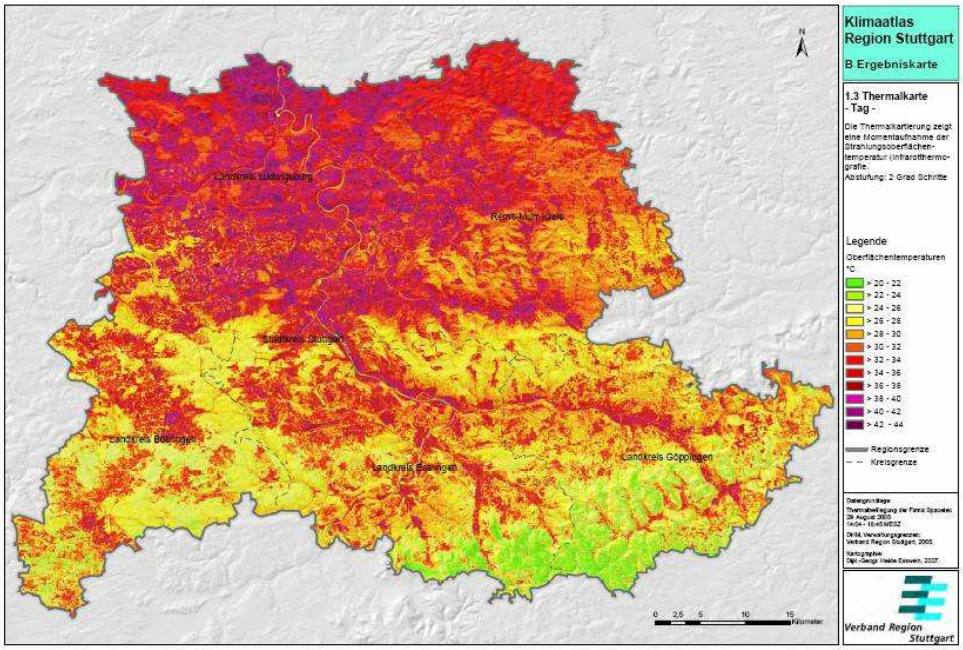

Figure 3. Day surface temperatures corresponding with the topography of the city: purple and red – high temperatures; green - low [(3)]

Development of the initiative

Key aims

The primary objective of the planning recommendations informed by the Climate Atlas 2008 for the region of Stuttgart is to facilitate air exchange in the city and enhance cool air flow from the hills towards the urban areas on the valley floor. This is to be achieved by specific measures aimed at the maintenance and enhancement of open spaces and provision of vegetation. The measures are targeted at locations that have an important role in air movement and air exchange across Stuttgart. In general, no development is allowed that would obstruct air-flow in key strategic areas, felling of trees over a certain size is banned, and green roofs, green facades and other solutions are promoted in densely developed areas.

Themes driving the initiative

History of research urban climatology
The importance of climatic conditions for human comfort in health has been recognised in Stuttgart since 1938, when the city council employed a meteorologist whose job was to analyse the climatic conditions in Stuttgart to understand the connection between climate and urban development [(5)]. In 1992 the first Climate Atlas was developed illustrating how landforms and structures affect the movement of air through the city, and identified the surrounding slopes, forests and agricultural areas as major sources of fresh air for the city. It was found that the air pollution problem resulted from increased urban growth onto valley slopes, which replaced vineyards and trees with built form [(1)], which was blocking the flow of fresh air into the city. These findings had a significant impact on city planning. The city established the Environmental Office which was given the task of assessing proposed developments and their effect on the local climate. The aim was to preserve the areas key to the improvement of the local climate by development control measures, and to improve the presence of vegetation across the city [(1)].

National and Land-level legislation:
The preservation of natural environment in urban areas is principally guided by the Federal Nature Conservation Act (BNatSchG) and by the Nature Conservation Act of the Land of Baden-Württemberg (NatSchG). The Federal Nature Conservation Act prohibits the modification or impairment of protected green spaces, or changing land use in these protected areas. Protected green spaces comprise: green zones in settlement areas, parks, cemeteries, significant gardens, single trees, lines of trees, avenues or groves in settled or unbuilt areas; and some plantings and protective wood outside forests. Preserving the history and culture of the region can also be a reason for protecting of green spaces.

German Building Code (BAUGESETZBUCH (BauGB) from 1960 is an important influence over urban development. The regulations were revised in 2004, and now require precautionary environmental protection in urban zoning and planning practices. § 1 (5) states that urban development planning has to be sustainable, integrating social, economic and ecological demands, and also assuming responsibility for future generations. Urban development plans must contribute to the creation of an environment that is fit for human beings, that protects natural resources, that contributes to climate protection, as well as preserving and developing the urban pattern and appearance of the landscape of towns and cities. According to § 1 (6) the following aspects have to be taken into account (amongst others) when establishing urban development plans: the presentation of landscape plans and green open space structure plans, as well as other plans concerning issues such as water rights, waste rights and pollution control rights; and the conservation of the best possible air quality [(6)].

Details of the initiative

The Climate Atlas

In 1987, the Section of Urban Climatology within the Office for Environmental Protection of the City of Stuttgart was tasked with a technical reworking of a climate analysis for the neighbourhood association of Stuttgart. An accompanying task force on "Climate" was established within the neighbourhood association of Stuttgart, whose job was to coordinate the scope, form and contents of the planned Climate Atlas. The purpose of the Atlas was to make available the basic materials required for a proper consideration of all climatic and air-related issues in Stuttgart during planning processes undertaken by the association and its participating towns and municipalities [(7)].

In 2008, the new Climate Atlas for the region of Stuttgart was published [(3)]. It covers the whole area of the region (3654 km²) and provides standardised climatic evaluations for all 179 towns and municipalities in the region and its 2.67 millions of inhabitants [(4)]. The Atlas comprises maps at scales of 1:100,000 and 1:20,000 (see Figures 2 and 3), which show regional wind patterns, flows of cold air, air pollution concentrations, and much other relevant information required to inform planners on what to do for urban climatic optimization in new projects and retrofits (Figure 4 and 5). The Climate Atlas provides technical support for decision making regarding land use planning.

The determination of the current climatic situation allows for the assessment of possible changes and significant effects of planning and development decisions on climatic variables. A key element of the Atlas is an area classification based on the role that different locations play in air exchange and cool air flow in the Stuttgart region. This is defined topography, development density and character, and provision of green space. The Atlas distinguishes eight categories of areas in this manner, and for each of them different planning measures and recommendations are provided (Table 1 and Figure 6) [(4)].

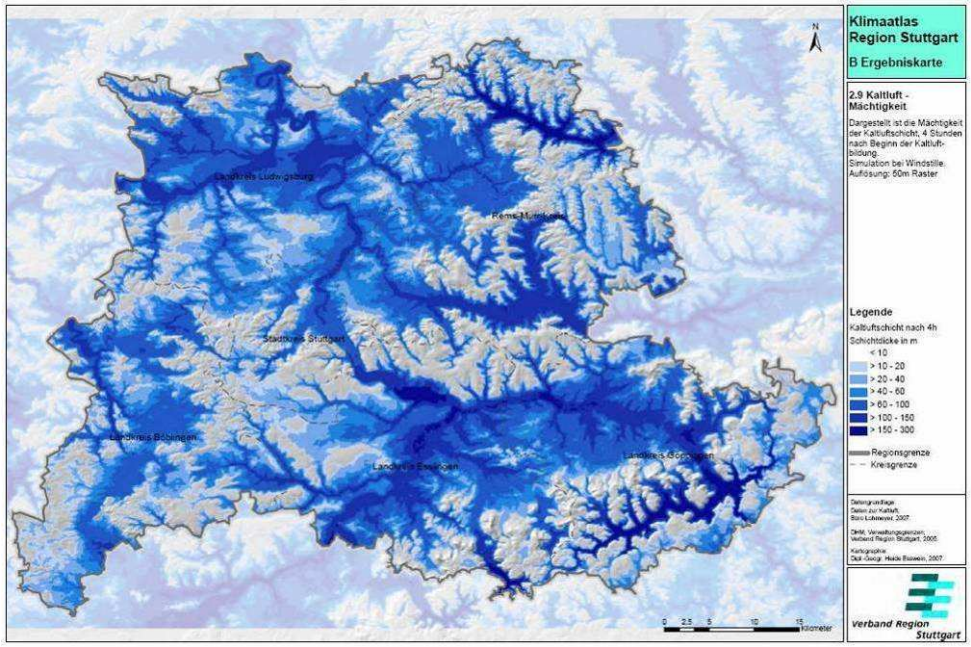

Figure 4. Intensity of cold air layers four hours after the beginning of cold air movement. The darker the blue, the thicker the layer of cold air [(3)]

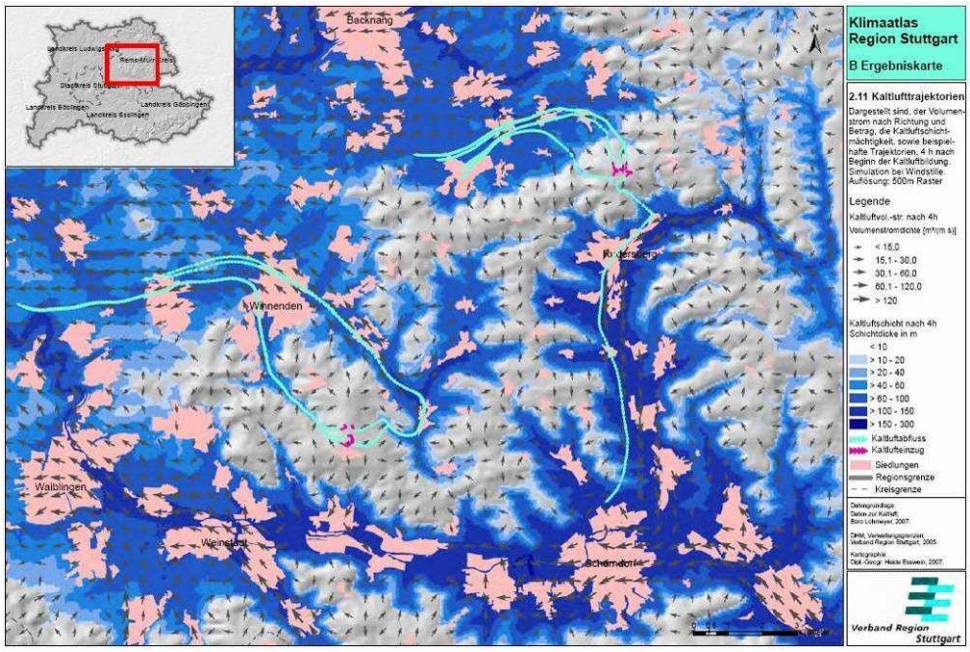

Figure 5 Direction of wind and intensity of cold air layers four hours after the beginning of cold air movement. The darker the blue, the thicker the layer of cold air. Light blue arrows indicate the direction of cold air flow; pink areas show settlements [3]

The Climate Booklet for Urban Development

In 1977, the City of Stuttgart published the first "Climate Booklet for Urban Development – Städtebauliche Klimafibel", which was then revised in 2008 and published online ("Climate Booklet for Urban Development Online – Städtebauliche Klimafibel Online") with support of the Ministry of Economy of the state of Baden-Württemberg. The booklet explains the characteristics of the local climate in Stuttgart and identifies the areas where particular planning and building regulations are needed to preserve or improve the air flow and generation of cool air in the city (based on the Stuttgart Climate Atlas).

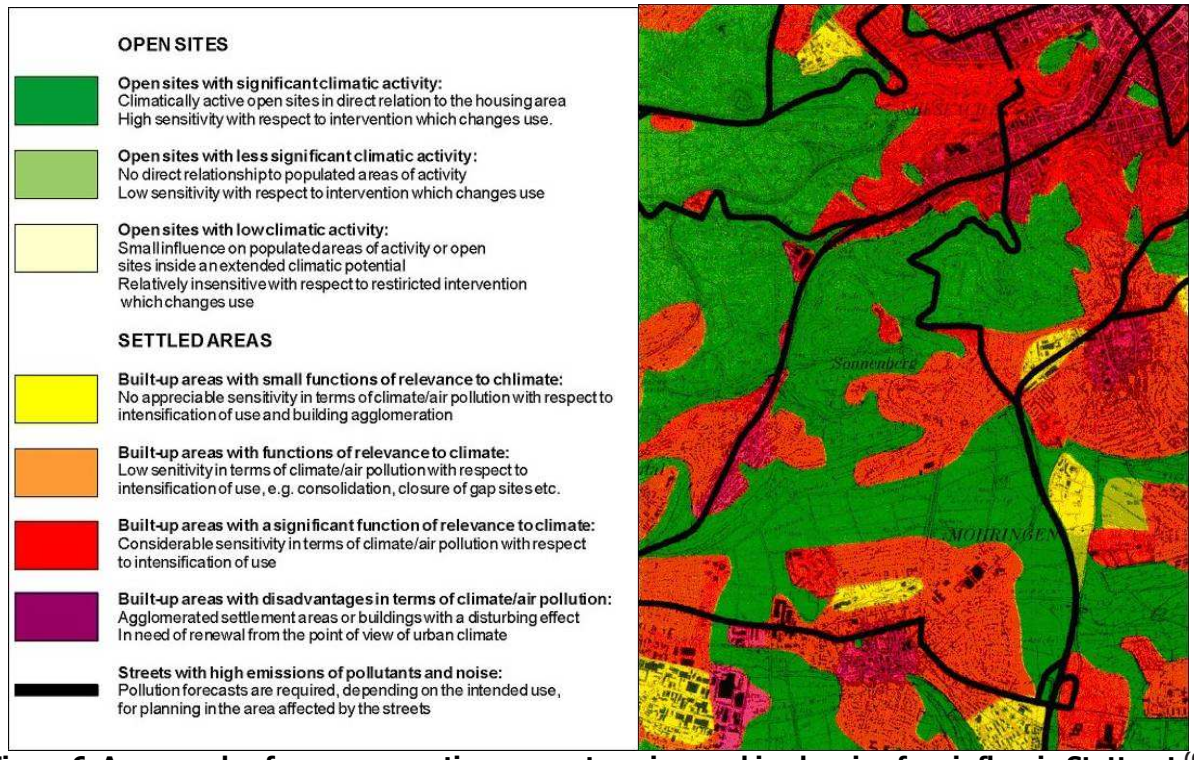

Figure 6. An example of a map presenting area categories used in planning for air flow in Stuttgart [6]

Table 1. Recommendations for development of different types of areas in Stuttgart [8]

Type of area	Characteristics of the area	Recommendations
Open Spaces with Important Climatic Activity	Direct relation to built-up areas (e.g. green spaces in the city); areas that lie upwind from built-up areas (undeveloped valleys, ridges, and gaps in terrain); large, connected open spaces near densely-settled areas. They are highly sensitive to changes in land use; construction of measures that hinder air exchange and soil sealing lead to significant impairments in climate function.	No large-scale construction or soil sealing permitted.
Open Spaces with Less Important Climatic Activity	No direct contact with developed areas or only minor role in cold air production (e.g. rocky or fallow lands); less sensitive to land use changes.	Large-scale development is permitted, as long as it does not substantially obstruct the regional air exchange and when climatically important local characteristics such as ridges, depressions or brooks are to taken into consideration during planning. To minimise the impairment of the climate function, preservation of green spaces and corridors, roof and façade greening, low building heights, and building orientation allowing air flows are recommended.
Open Spaces with Minor Climatic Activity	Lesser influence on developed areas; and relatively low importance for cold and fresh air production. Changes in land use are associated with only minor disturbances to climate. This category includes, for example, hilltops and large-scale, well-ventilated areas with level topography, distant from developed areas.	Development such as skyscrapers or large-scale commercial enterprises is possible in these areas. It should be ensured, however, that the ventilation conditions associated with the main wind direction remain unaltered. Also, no sensitive land uses should be planned in the vicinity of roads with heavy traffic to preserve air quality.
Developed Areas with Functions of Minor Climatic Relevance	Developed areas without high thermal or air-hygienic burdens that do not significantly impact neighbouring developed areas. No noteworthy climatic or air-quality sensitivity to intensifications of land use or expanded development (e.g. well-ventilated hilltops).	The existing ventilation conditions should remain intact and additional emissions should not bring negative effects on other developed areas. Roof and façade greening and the preservation of green spaces are recommended to prevent thermal problems.
Developed Areas with Functions of Climatic Relevance	Settlements of medium density with green spaces, which cool noticeably during the night and are relatively open to the wind; or well-ventilated dense development (e.g. hilltops). These areas do not produce intensive thermal or air-quality problems and do not impede air exchange. They have low climatic and air-quality sensitivity to land use changes.	The amount of developed land in the area should remain constant and soil sealing should be kept to a minimum. Soil sealing can be offset by the creation of green spaces as well as roof and façade greening.
Developed Areas with Functions of Significant Climatic Relevance	Sparsely-developed, areas with plenty green space and low building heights on the periphery of communities with nearly undisturbed air exchange; hillsides with development at their feet; areas with singular freestanding skyscrapers and green spaces; densely-developed areas whose climatic and air-hygienic footprint is not exceedingly high. The designated areas exhibit a substantial climatic and air-quality sensitivity to land use changes.	Further development and soil sealing measures would lead to negative effects on the climatic situation. Instead, an enlargement of the proportion of green space and the securing or expansion of ventilation spaces is recommended.
Developed Areas with Climatic and Air-Hygienic Disadvantages	Densely-developed areas that have significant climatic and air-quality problems. This category includes developed areas where air exchange is considerably hindered by buildings.	These areas require restructuring such as increasing the proportion of green space; minimizing the soil sealing; minimizing the level of emissions, especially traffic emissions; creation or expansion of greened ventilation corridors; removal or relocation of buildings disruptive to air flow where necessary.
Roads with High Air and Noise Pollution	Main traffic thoroughfares with a traffic count of more than 15,000 vehicles per day. The resultant high levels of air and noise pollution must be taken into consideration in planning.	Sensitive land uses (residential or recreational areas, agricultural land) should be planned only at sufficient distances from roads or with adequate protection measures.

In addition to responding to local climate characteristics, the following principles form the basis for the planning recommendations [6]:

- Areas of vegetation have an important effect on the local climate, due to cooling and shading, in particular by trees. Therefore, vegetation should be provided to surround developments and larger, connected green spaces should be created or maintained throughout developed areas to facilitate the air exchange.
- Valleys serve as air delivery corridors and should not be developed.
- Hillsides, and gullies and ridges on hillsides, should remain undeveloped, especially when development exists in valleys, since intensive cold- and fresh-air transport occurs here.
- Saddle-like topographies serve as air induction corridors and should not be developed.
- Urban sprawl is to be avoided.
- The development of commercial and industrial enterprises should ensure that the residential areas in the immediate vicinity do not suffer from heightened emissions of air pollutants.

Implementing the initiative

The Climate Atlas and the recommendations stemming from the climate maps included in the "Climate Booklet for Urban Development Online – Städtebauliche Klimafibel Online" [8] provide a uniform set of data to be used by the cities and municipalities in the Stuttgart Region, including Stuttgart, in their spatial planning and development control activities.

The main mechanism of implementation is the German Building Code, which provides a legislative basis for the solutions recommended by the Booklet. The Booklet lists the acts of law at the national and Land level which can be utilised in order to address issues relating to local climate. The regulations are divided according to different types of climate-amelioration mechanisms and different types of green infrastructure:

- Preservation and Acquisition of Green Space
  - Landscape and Open-Space Control Plan
  - Benchmarks for Describing "Green" Uses
  - Avoidance of Soil Capping; Green Spaces and Water
  - Roof Greening
  - Façade Greening
- Securing the Local Air Exchange
  - Cold Air Production
  - Fresh Air Supply
  - Green Corridors
  - Advantageous Forms of Development

The digital version of the Climate Atlas can also be used for the purposes of Strategic Environmental Assessment [4]. The greening of the city of Stuttgart is also supported by locally developed regulations. For example, Stuttgart protects all trees growing in the urban core with a trunk circumference of more than 80 cm at height of 1m with a tree preservation order. The conservation of these relatively big trees aims to revive the city's image, improve urban climate, and conserve habitats [7].

In the case of Stuttgart, the implementation of the recommendations in the Climate Atlas is carried out by the Office for Urban Planning and Urban Renewal, supported by the Office for Environmental Protection, which was also involved in the creation of the Climate Atlas 2008. The Office for Environmental Protection participate in the city planning process conducted by the Office for Urban Planning and Urban Renewal particularly through the provision of environmental information, consultation and producing environmental proposals. Their participation during the preparation of land use plans, framework plans for urban development and legally binding land-use plans is especially important. The Section of Urban Climatology within the Office for Environmental Protection evaluates the climatic implications of intended development and larger

buildings on the basis of meteorological measurements carried out since 1938, thermographic infrared measuring flights and increasingly on the basis of model calculations. This also includes the identification of climatic influences to which the intended development will be exposed. The Section aims to engage in early participation in building projects, early consultation with the Office for Urban Planning and also with architects and homeowners [7].

The planning recommendations stemming from the Climate Atlas are largely limited to structural changes of land use. This recognises that a change in the composition of vegetation exerts fewer climatic effects than large-scale soil capping measures and the erection of built structures for example. The planning recommendations are not specific to the level of individual parcels of land. As tolerances can range by up to 100 m, more detailed climatic analyses need to be carried out for specific site plans, especially in areas of high climatic and air quality sensitivity [6].

Sources of funding

The initiative was funded by the City of Stuttgart and the Verband Region Stuttgart. The funds were necessary to generate the climatic data around which the Climate Atlas is produced.

Stakeholder engagement

Collaboration with key stakeholders

The Climate Atlas 2008 was developed in close collaboration between the Verband Region Stuttgart (the association of regional cities and municipalities) and the City of Stuttgart. The Section of Urban Climatology within the Office for Environmental Protection of the city of Stuttgart contributed its specialist knowledge. The evaluation and processing of the data for the drawing up of the basic material for producing maps was undertaken by an external specialist consultant. Data from the State Institute for Environment, Measurements and Nature Conservation Baden-Württemberg (LUBW) and from the German Meteorological Service was also used during the process. The data was brought together by the Section of Urban Climatology [4].

Engaging the public

The City of Stuttgart emphasises the importance of public participation in greening strategies aimed at improving air quality and mitigation of the heat island effect. This is achieved through different strategies [7]:

- Since 1986, the City of Stuttgart has provided financial support to green about 60,000m^2 of roofs;
- Since 1992, a scheme has been in place for Stuttgart residents to adopt a tree. Today some 182 caretakers have adopted almost 500 trees. They are responsible for watering the tree, reporting pest attacks, removing the leaf litter and fallen branches, and protecting the tree from dog fouling.

Political buy-in

The Mayor of the City of Stuttgart supports the city greening initiatives aimed at improving of air quality and reducing in temperatures. Climate change adaptation and mitigation are both high on the political agenda locally, and the land use plan 2010 for Stuttgart envisages urban development under the slogan "urban – compact – green".

Can it have an impact?

In Stuttgart, over 39 per cent of Stuttgart's surface area has been put under the protection of nature conservation orders; a record in the whole of Germany [7]. As a result of greening actions, greenery covers more than 60 percent of the city [9]. Stuttgart contains 5,000 hectares of forests and woodland, 65,000 trees in parks and open spaces and 35,000 street trees. 300,000 m^2 of rooftops have been greened and 32 out of 245 kilometres of tram tracks have been grassed (as of 2007). In line with the city development vision, 60 hectares of greenfield land previously earmarked for development has been cut from the 2010 land development plan to protect existing green space [7].

However, the main success of the adaptation strategy based on preservation and enhancement of air exchange and cool air flows lies in targeted interventions such as a building ban in the hills around the town, and prevention of building projects that might obstruct the ventilation effect of nocturnal cold-air flows [10].

The success of the City of Stuttgart can be illustrated by the fact that several other German municipalities followed Stuttgart's lead developing a comprehensive environmental information database with the use of GIS. For example, the City of Berlin has built a comprehensive digital environment atlas of the city [10]. Also, the Stuttgart approach has been followed in other countries: the Stuttgart Climate Atlas methodology has been applied to Kobe City in Japan, where climatologists have worked with planners on measures to capture sea breezes by day and cold air drainage from the hills by night [11].

Key messages

- Compilation of detailed information about the area's topography, climate and land use allows for precise planning for different areas, which together aim to improve air quality and mitigate the urban heat island effect.

- The case demonstrates the advantages to a municipality of having in-house climatic research capacity to provide concrete knowledge of local conditions and remedies, as opposed to relying on an understanding derived from general principles. Cumulatively, over several decades, the city has used its planning and landscaping powers to engineer an entire system of urban wind circulation [10].

- Constructive use of existing regulations (e.g. the German Building Code) provides a mandate for the implementation of planning recommendations relating to local climate.

- Close collaboration between the Office for Environmental Protection (analysis of information, provision of recommendations) and the City Planning and Renewal team means that the recommended green infrastructure solutions are being implemented through spatial planning and development control.

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