

# History of urban climatology

## 1. Medical roots of urban climatology

During the years of deprivation following World War I, tuberculosis was rife and established itself as the single most widespread disease among the population. Attempts to systematically combat not only tuberculosis but also rickets – another widespread disorder affecting particularly children due to vitamin D deficiency – clearly highlighted the link between poor nutrition and susceptibility to disease, and also the impact of habitation conditions and general living circumstances. The call for “light, air and sun” which resulted from this realization became synonymous with demand for healthy living conditions, which were hailed as an important remedy in tackling the spread of these diseases.

Demands for better illumination, ventilation and exposure to sunlight provided a platform for local and environmental hygiene to become established disciplines. Their legal foundations were set in stone by the third implementing regulation on the Health System Standardization Act dated July 3, 1934 (the “Creation, maintenance and restoration of healthy living and working conditions”).

## 2. Meteorological roots of urban climatology

The comparatively recent geophysical science of meteorology deals with the physical aspects of the atmosphere and atmospheric phenomena. The formerly restrictive interpretation of the term was taken to mean the “science of weather and weather forecasting”.

The ranks of the meteorological disciplines were joined by the new field of urban climatology in 1937, driven by a book published during the same year by Pater Albert Kratzer entitled “The Urban Climate”. For the first time, this book highlighted the influence which urban planning and construction can exert on air and climate quality. Urban climatology is based on applying meteorological precepts, working methods and findings to the environment in built-up areas, including the influence of air pollution. It rapidly became evident that because urban climatology essentially deals with the microclimate in cities, it cannot be studied using the regular measurement networks used to monitor global weather and climate conditions. As a result, urban climatology is reliant on additional microscale information.

## 3. Where the field of urban climatology began

In 1938, Stuttgart City Council decided to appoint a meteorological graduate to perform studies of the climate conditions and their relationship to urban development. Previously to this in 1935, a new local building statute had been passed which divided the urban area into 10 building sectors with defined regulations governing spacing, density and utilization.

The creation of “urban climatology” as a field of study needs to be placed in context, particularly against the background of the complex topographical situation of the City of Stuttgart and the lack of adequate air exchange which prevailed here. Thermal stress and sensitivity to the effects of heat are common in combination with the mild climate of a wine-growing region. Stuttgart’s second handicap in respect of climate and air hygiene is due to its lack of wind, namely the episodic rise in air pollution.

The new urban discipline was assigned to the Chemical Investigation Agency which had already been in existence since 1869. By today’s standards, the instruments available for the study of air hygiene were rudimentary and primarily took into account dust pollution. Experience in the measurement of harmful gases originated primarily from the fields of occupational safety and medicine, and from the mining industry (ventilation and “weather protection” in the mines, combating “black lung”, general explosion prevention). Some of the expertise gained in the field of gas distribution had originated from experiences with combat gas used in the First World War.

The Urban Meteorologist was appointed on the outbreak of war in 1939 to organize civil air defence measures. One of the motivations behind implementing these measures was the idea that creating artificial fog could prevent attacking air raid squadrons from gaining a clear sighting of the city as a bombing target – a concept which would only be effective until the comprehensive introduction of radar during the latter years of the war.

The synthetic fog was released from a large number of different points selected on aspects of wind climate. This gave rise to findings about air flow conditions and the possibilities for ventilation and aeration of the different valley settlements. It was discovered that the synthetically produced fog clouds dissipated more quickly than intended in certain areas, while in other districts of the city they tended to remain in situ for long periods. This circumstance was accurately linked to the ventilation effect of many of the downhill flows of cold air existing close to the ground in the city district, which in otherwise calm weather conditions occur in the form of nightly downslope winds, in some cases as strong mountain winds. Their topologically-related guiding and flow channels in the landscape were recognized from an early stage as the city’s fresh air corridors.

This involuntary large-scale urban climatology study exerted a considerable impact on urban planning, as it generated awareness that fresh air corridors of major significance to the urban climate should be taken into consideration in any future urban planning projects, both with a view to maintaining and where possible further enhancing their function. No such comparatively enlightening experiment was performed again until August 1996, this time through the release of tracer gas (see section 5).

#### **4. Development of the Section of Urban Climatology in the period immediately following World War I**

The bomb devastation left in post-war Stuttgart provided no shortage of opportunity to consider issues of urban planning, both within the framework of reconstruction and also as regards the issue of redesigning the city.

The observations of ventilation channels described above were considered of such significance for the issue of air pollution control that the meteorologist Karl Schwalb was

commissioned to take part in the process of devising a general urban development plan for the city in 1948.

In keeping with the generally shared view of the times that a future-oriented city was one designed to accommodate the needs of the automobile, from the meteorological standpoint the concept of building wide inner-city roadways met with unanimous approval. From the viewpoint of through ventilation, this decision was undoubtedly the right one, although the disruptive effect of the major arteries created by Theodor-Heuss-Straße, Hauptstätter Straße and Konrad-Adenauer-Straße cutting through the city centre carrying an enormous volume of traffic centre was underestimated.

Air hygiene-related issues came to assume a growing importance. In Stuttgart – as everywhere else – this growing degree of interest originated from a meteorological issue: the significance of fresh air corridors for air purification and the consequences to be drawn for the field of urban planning.

Alongside a list of climatic and air hygiene-related investigations and measurements to be performed, the instructions issued relating to the execution of tasks in the field of climatology in 1953 also included advising the Mayoral Office, the specialist agencies and district authorities on questions of meteorological and climatological relevance, and also in aspects of noise abatement. The latter represented an additional pioneering field in the activities of the Climatological Section.

## **5. Further development as a field of environmental protection**

Systematic measurements of air pollution in Stuttgart have been performed since as long ago as 1965. Initially, these encompassed the components sulphur dioxide (SO<sub>2</sub>) and dust fallout, which at the time were considered the key substances in terms of air pollution, and which were also relatively easily verifiable using simple technology. Consequently in terms of sulphur dioxide and dust fallout, a comparatively thorough fund of knowledge has been inherited on the basis of long-term measurements.

1974 saw the commissioning of a carbon monoxide (CO) measurement station on Charlottenplatz as an add-on to the continued sulphur measurements (City Hall and Staf-flenbergstraße) and the dust fallout measurement (between 39 and 62 measurement points). The CO measurement series undertaken from Charlottenplatz (Jan. 1974 to Aug. 1976) marked the beginning of an increasing focus on vehicle-related air pollution. The evaluation arising from this measurement series resulted in probably one of the first ever systematic reports on what was now set to become the single most important source group for urban air pollution.

In the early seventies, the use of infrared thermography for urban climatology investigations was researched and implemented in practice for the first time as part of the planning process for the development known as the “Löwentorzentrum”.

On the basis of experience gained during this process, comprehensive infrared thermographic measurement flights were commissioned over the entire urban area. However, for various reasons the execution of these measurements failed to live up to expectation, permitting only an inadequate evaluation.

A repeated attempt to complete infrared thermographic measurement flights in 1976 proved more successful, and permitted the anticipated evaluation to be completed according to plan. This work was published in 1978 in a series entitled “Contributions to Urban Development” whose title translates as “Data and Statements on the Urban Climate of Stuttgart on the Basis of Infrared Thermography”. This publication made a significant contribution towards the 1990 Land Use Plan which was then in the preparation stage.

During the early seventies, the term “environmental protection” became an ever more familiar part of the language. The German Federal Environment Office came into being and important additions were made to environmental legislation. The German Immission Control Act came into force in 1974. Alongside plant-specific regulations, this also sets out district-related regulations, and in Article 50 formulates a significant principle of environmental protection as it relates to urban planning.

At the same time, interest in questions of urban climatology was also on the increase. January 1, 1977 saw the validation of a new draft of the Federal Construction Act, article 1 of which sets out the objectives and principles of construction management planning, which include consideration of environmental concerns, ruling that the natural basis for human existence, in particular the soil, climate and air, be maintained and safeguarded. This raised “air and climate” to the status of planning factors.

The planning procedure for the 1990 Land Use Plan involved numerous statements and expertises in connection with controversial land-use areas. A municipal administrative body existed at that time in the form of the Stuttgart Regional Federation. Its mission was to establish a combined Land Use Plan for the area covered by the Federation (the city of Stuttgart and surrounding municipalities). The considerable effort involved in achieving a consensus was rewarded by the publication of a carefully considered Land Use Planning document which paid due attention to the concerns of the neighbouring communities.

Prohibitions on the combustion of solid fuels – for each of which different reasons were initially given – became increasingly common in connection with the urban development plans for the city. Banning the combustion of solid fuels meant that, with one exception, Stuttgart was spared the fuel combustion-related smog events which were a typical occurrence in the seventies. The various bans on the combustion of solid fuels were merged in 1991 into a statute applicable across the whole urban area on the restricted use of air-polluting fuels. This statute was repealed without replacement by a decree of the Municipal Council on March 18, 2004.

A first “multiple-component air measurement station” was successfully established to measure sulphur dioxide, carbon monoxide, dust content and dust fallout as well as wind direction and wind speed in 1997 over a period of one year. In cooperation with the University of Stuttgart, for the first time it was also possible to measure total nitrogen oxides (NO<sub>x</sub>). A technical extension to the “multiple component measurement station” was completed in 1979, allowing the Chemical Investigation Agency to commission the first installation of its kind in Stuttgart with facility for complete electronic data acquisition. 1980 saw procurement of the first computer for data evaluation. The space required to install this ground-breaking equipment took up a dedicated workroom – to achieve a computing capacity which is exceeded today by any standard PC or notebook!

In 1981, four immission measurement stations were run in Stuttgart by State Environmental Protection Agency (LfU). In June 1981, the city set up its own identical measurement station in addition to the existing installations, so increasing the number of modern measurement stations in operation to five.

January 1982 was recorded as a period with a prolonged low-exchange weather situation which resulted in a considerable increase in air pollution. In Stuttgart, an excessively high smog index value moved the Ministry of Labour, Health and Social Order responsible at the time to issue a smog alert (advance warning). This was the first and also the last time that the Smog Act with its total of three smog alert stages has ever had to be invoked. The Climatological Section benefitted from this event to the extent that it triggered the approval of funding for additional measurement equipment including an air measurement aircraft.

The then Head of the Climatological Section, Professor Dr. Baumüller, was invited in November 1984 by the UN World Meteorological Organization (WMO) to take part in a Conference on "Urban Climatology and its Applications" in Mexico, lecturing on "Integration of Climatology in the Municipal Administration and Urban Planning of the City of Stuttgart". Even at this early juncture, the conference was staged within the framework of a Global Climate Program. This marked the beginning of many guest lecture trips and international scientific contacts, in particular to Japan, with a number of return visits from wide-ranging different delegations from the fields of science, politics and administration. This exchange of ideas drew impending global climate correlations and local solution possibilities sharply into focus.

The LfU carried out the first full-coverage emission measurement and an immission measurement program in the Stuttgart study area in 1985/1986. The results of the mobile measurement points provided the basis for the Immission Register which encompasses 139 assessment areas (of 1 km<sup>2</sup> each) throughout the State Capital. This allowed the spatial distribution of pollution over the Stuttgart urban area to be comprehensively assessed.

When the Meteorological Office moved from its location in the Stuttgart city centre in 1985, a new measurement point on the site was planned by the Climatological Section which would allow it to continue to gather meteorological air hygiene data in the city centre. Since January 1, 1986, half-hourly mean values of the most important air data have been transmitted to the Climatological Section online. Since 1997, the current data can also be accessed by the general public over the Internet.

1988 brought important changes with the foundation of the "Environmental Protection Office". The new office was formed by merging different functions and departments previously under the supervision other municipal offices with various environmental responsibilities. As part of these restructuring measures, the Chemical Investigation Agency was dissolved and integrated into the "Environmental Protection Office". The Climatological Section became the somewhat less ambiguously named "Section of Urban Climatology".

1988 saw the start of important work on continuation of the Land Use Plan (FNP) for the target year 2010. At this time, the Stuttgart Regional Federation was still in existence, whose pioneering and progressive approach to cooperation was regrettably no longer

pursued after the formation of the Regional Association of Stuttgart. The proposal that the Section of Urban Climatology be commissioned with supervision of this work was approved by the neighbouring communities. Against the backdrop of certain differences of opinion in the different communities in respect of domination by the State Capital in questions relating to building land allocation close to boundaries, this step must be seen as a special vote of confidence in the work of this Stuttgart Institution.

To produce the Climate Atlas – the working title given to the climate study – a new series of thermographic measurement flights was undertaken. These produced data and picture material in a previously unattainable standard of quality, both in terms of the spatial resolution and also of largely successful distortion correction, which impacted very positively on the evaluation of the picture material.

During the period from May 1988 to April 1989, a temporary measurement network was maintained. The data from temperature, humidity and wind measurements collected at 12 different stations was fed into a newly developed regional climate model. For this purpose, the measurement locations took into account different altitudes, different topographical situations (valley locations, hillside locations and hilltops) as well as different forms of land use. For the first time, the results achieved permitted comprehensive climate overview maps to be produced of the territory of the associated municipalities. Added to these were coordinated climate analysis maps and what was considered the somewhat controversial undertaking of compiling so-called planning indication maps which took an unabashedly critical view of individual Land Use Plans put forward by the municipalities. Contrary to some of the fears expressed, these planning indications were actually received very positively by the municipalities as a useful working tool. The Stuttgart Municipal Council adopted a resolution that the results of the climate study should be taken into consideration in future planning.

In 1990, the legal outline conditions surrounding immission control in the assessment of air pollutant immissions were amended. Based on the scope offered by this change for traffic planning, traffic guidance and traffic restricting measures, an initial Air Pollution Control Plan was issued for Stuttgart by the responsible Ministry of the Environment. A special feature of this Air Pollution Control Plan was the design for a system of speed restrictions for different road types within the city known as the “Stuttgart Speed Pyramid”. However, the clearly evident reducing impact this measure had on air hygiene was called into question for reasons of traffic management, with the result that a diluted form of the speed limit was brought into effect for the subsequent Air Pollution Control Plan. The “Mettools II” conference staged in 1993 in Stuttgart by the Environmental Meteorology Working Committee (AKUMET) of the German Meteorological Society came up with the idea of familiarizing conference-goers to the topographic and climatographical circumstances of Stuttgart in the form of an urban climatological tour of the city. The tour, for which an accompanying brochure was designed, proved an enormous success among the specialist conference-goers. Particularly groups of visitors from countries of the Far East demonstrate a high degree of interest in the problem areas of air pollution control. There is an unmistakable tendency for the emerging industrial nations of the Far East to consider intact environmental conditions as an important economic location factor.

Although the impact of small-scale air exchange processes is basically understood, to allow this phenomenon to be quantified in Stuttgart, a city-wide tracer gas experiment was staged in 1996. The discharge point was in Southern Stuttgart in the cold air intake

area of the Nesenbachtal valley. The dispersion of the gas was successfully traced during the measurement night as far as the most distant part of the railway station site to the North. The mapping of the dispersion paths and speeds as well as the spot sampling of gas concentrations was integrated into the image of the large-volume night-time “Kaltental” mountain wind. It was possible to show, contrary to prior assumption, that this local wind system is capable of extending across the area of the Stuttgart-West district, with an important role played by the saddle-shaped terrain between Hasenberg and Karlshöhe.

The measurement campaign was repeated in 1997. On this occasion, the tracer gas experiment was substantially extended, now allowing three different gases to be discharged simultaneously. The discharge points took into account the flow conditions in the Stuttgart-Nord district, in which major urban development plans were in prospect in the run-up to “Stuttgart 21”. This test also fulfilled every expectation and permitted the preparation of quantifiable statements to provide concrete evidence where previously only verbal argumentation was possible.

## **6. Development in the last two centuries**

With the city’s accession to the Climate Alliance in 1995, the work of the Section of Urban Climatology was extended to include the new field of global climate protection. In this context, a resolution was adopted to develop a climate protection program (KLIKS) for Stuttgart. The aim of the program is to prevent a further increase of the CO<sub>2</sub> emissions which threaten our climate and which are caused to a large degree by the combustion of fossil fuels. KLIKS consequently contains action scenarios for saving energy in every aspect of urban life which require constant updating and reevaluation. The city was honoured with the “Climate Star” of the climate Alliance of European cities in 2004 for the big efforts in global climate protection.

The year 1996 is associated with not one but two major projects or rather on-going tasks for the Section of Urban Climatology:

1996 saw the launch of the “Noise Abatement in Vaihingen” pilot project, and with it a whole new field of operations for the department, based on the statutory stipulation of the former Article 47 a of the Federal Immission Control Act. As a result, noise abatement plans were drawn up for Vaihingen (May 2000), Zuffenhausen (November 2003) and Bad Cannstatt (2009) and approved by the Municipal Council. With the EU Environmental Noise Directive in 2002, the legal foundation for this work underwent a shift. Following the preparation and publication of a series of noise maps in 2007, the noise abatement plan drawn up for the whole of the city was passed by the Municipal Council in November 2009. The legal stipulations require the different stages of noise abatement planning (noise maps, action plans) to be updated in each case after five years. The noise maps were updated in 2012. The action plan will be updated 2014.

The plans drawn up for the “Stuttgart 21” railway and urban planning project in 1996 required the commissioning and management of wide-ranging different urban climatological and noise control studies. The reports of external experts were published in a dedicated publication series by the Environmental Protection Office entitled “Analyses on the Environment – Stuttgart 21”. The Section of Urban Climatology had already been involved in the advance planning for “Stuttgart 21” within the framework of a feasibility

study by providing its assessment of the initial architectural designs. When bids were invited for the submission of outline plans, the department compiled an information folder providing information on the urban climatological framework conditions and the key urban climatological points to be observed in the planning. This initiative proved highly successful in the interests of urban climatology, as the majority of design bids submitted made clearly verifiable efforts to take the urban climatological specifications into account.

For the first time, a digital wind field simulation was calculated for the entire urban area of Stuttgart on the basis of an aerodynamic wind field model, with the additional integration of a cold air flow model. The application scope for these model calculations proved so versatile that they were taken as the basis of an "Urban climate information system" in 1997. This information system was also given the equally pioneering name of "Urban climate21". Through the integration of additional system components, this system has continuously evolved to its present-day development status (5<sup>th</sup> version, 2008).

The advent of the new century saw the implementation of major changes in the field of air pollution control. As a result of the new EU Directive on Air Quality, a number of binding stipulations were defined on the evaluation and monitoring of air quality and on limiting values for sulphur dioxide, nitrogen dioxide and nitrogen oxide, particulate and lead in the air. As a result, a whole new set of regulations on air pollution control based on substantially lower limiting levels came into being.

An air pollution control / action plan set up in December 2005 by the District Administration of Stuttgart encompasses a total of 36 individual measures. The action plan is set to continue in 2010 with the reintroduction of an (extended) prohibition on HGV transit traffic and step-by-step advance implementation of driving bans in the environmental zone, new speed restrictions and traffic continuation. The coordination of the measures in the city is done by the section of Urban Climatology.

Since the hot summer 2003 measures to adapt to the inevitable part of global climate change got more and more important. With the guidance of the section of Urban Climatology KLIMAKS, the climate adaptation Strategy Stuttgart was elaborated 2012.

Stuttgarts long tradition, taking into account urban climatology in urban planning (= adaptation to climate) was honoured 2011 with the title "Klimawandelanpassungspionier" (= pioneer in adapting to climate change).

The Section of Urban Climatology is also engaged in projects of the EU, for example the project UHI, to explore more and more the urban heat island. In a project, granted by the district of Baden-Württemberg, (HITWIS) heat warning in Stuttgart shall be optimized.

Still in the year 2013, the year of the 75<sup>th</sup> anniversary, an urban climate-viewer will be developed in cooperation with the office for survey. So many data of Urban Climate will be available for the public in GIS-based maps in the internet.

The international contacts concerning urban climatology in Stuttgart increased during all the time. There are contacts to many European countries, but also to Japan, Korea, Brasil, Hong Kong. In 2012 a book was published on urban climatology in Chinese language with a contribution of the Section of Urban Climatology.