

# Chapter 10

## Pilot Actions in European Cities – Stuttgart

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**Abstract** The field of urban climatology has a long tradition in Stuttgart. It exists as discipline in Stuttgart since 1938. Stuttgart was the first city to establish its own Department of Climatology to research ways of improving the flow of fresh air into the city and to reduce thermal stress in most populated city districts. The specialist department of Urban Climatology, within the Environmental Protection Office, deals with tasks relating to environmental meteorology within the scope of air pollution control and also relating to urban and global climate protection. So in Stuttgart the urban heat island phenomenon (UHI) is studied for several decades, leading to a high level understanding of the UHI and the problems which it causes. The UHI causes an increase in air temperatures and thermal stress, that are identified as most negative impacts on human health and urban living. In the view of global climate change and the predicted temperature rise for the Stuttgart region of 1.5–2 K in this century, the negative impacts of UHI on human health and urban living will become more problematic in the future. According to the results of climate models the frequency of very hot days is expected to jump by nearly 30 % at the end of the century. The rising temperatures due to the global climate change in combination with the temperature shift as a result of the UHI will intensify the heat stress in

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urban areas, that leads to a significant increasing risk to human health, in particular to the very young and elderly. Not least due its importance for the human health and the quality of urban life in Stuttgart, the UHI is focussed by urban planners and is noticed by the future development of the city.

Within the pilot action study in Stuttgart several measure for reducing the UHI and the impacts on urban living and human health are analysed by the use of micro-scale and macro-scale simulations. With the help of these analysis realisable measure are selected. The most useful measures are implemented into a development outline plan for the redevelopment of the city district Stuttgart-West by the municipal urban planners.

**Keywords** Climate change • Urban climatology • Urban heat island (UHI) • Urban planning • Restructuring • Air ventilation • Thermal stress • Development outline plan • Green roofs • Heat warning system

## 10.1 The City of Stuttgart

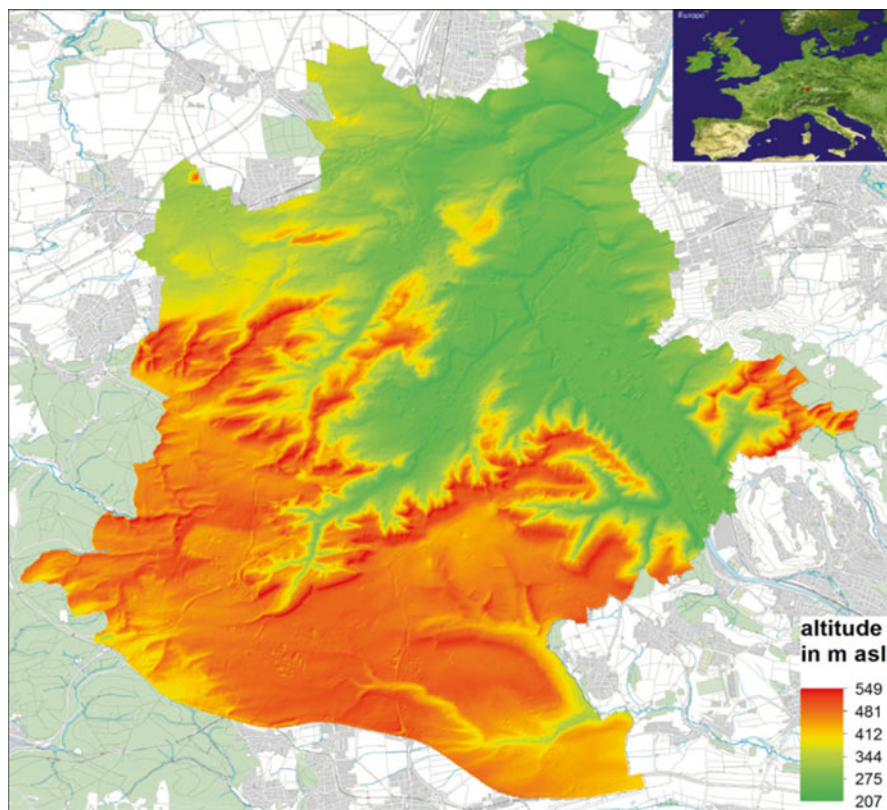
In the following chapter a short overview of the urban and climatic conditions in Stuttgart is given. Especially the basics of the complex topographic situation and the city structure, that influence strongly the urban climate in Stuttgart is described. Also the urban heat island phenomenon in Stuttgart is presented. More information can be found at the website: <http://www.stadtklima-stuttgart.de>

### 10.1.1 *Urban and Climatic Situation in Stuttgart*

Stuttgart is the capital of the state of Baden-Wuerttemberg located in south-western Germany. As the sixth-largest city in Germany, Stuttgart has a population of about 590.000 and is the centre of a densely populated area, the Greater Stuttgart Region, with a population of 2.6 million. Stuttgart covers an area of 207 km<sup>2</sup> thereof 49 % are settlements. The population density is about 5410 person/km<sup>2</sup>.

Stuttgart's area is characterised by a complex topographic situation with local distinctions (Fig. 10.1). It is one of the greenest cities in Germany. The land use distribution of Stuttgart is shown in Fig. 10.2. Greenery in the form of vineyards, forests, parks, etc. is prevalent throughout the city. In Stuttgart 39% of the surface area has been listed as protected green belt land or nature conservation area; a record in the whole of Germany. Despite this greenery populated, industrial and commercial areas are densely built-up. The city's location, building and topographical characteristics have a negative impact on urban climate and cause an intense urban heat island (City of Stuttgart 2010).

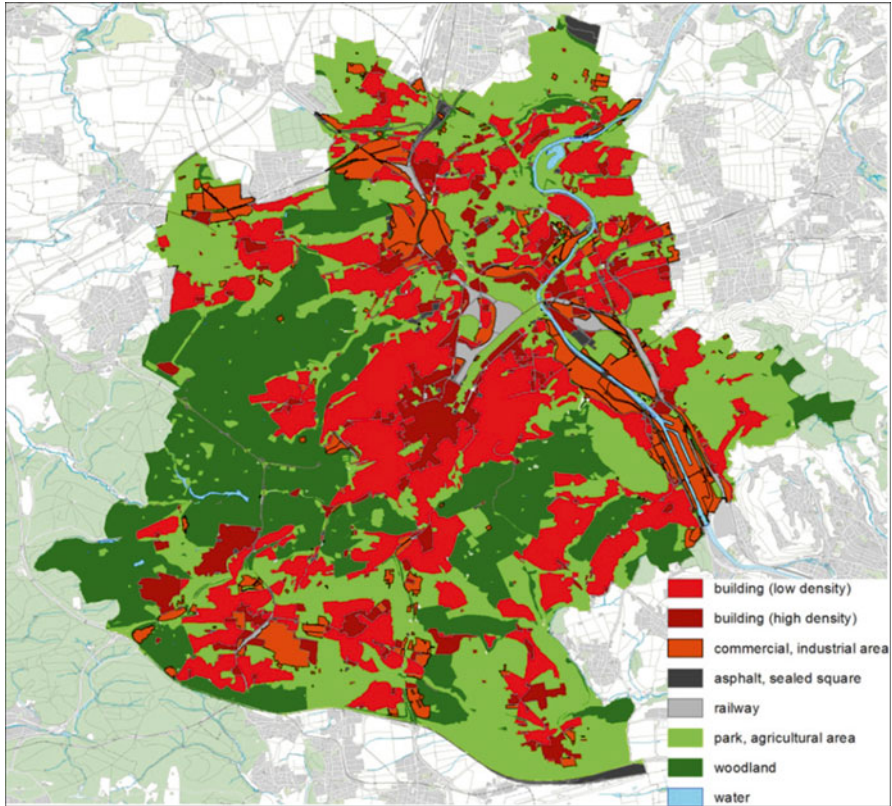
The city is located in a river valley (the Stuttgart basin), nestling between vineyards and thick woodland. Stuttgart's centre is situated close by, but not on the River Neckar in a Keuper sink. The city area is spread across a variety of hills and valleys.



**Fig. 10.1** Topographic map of Stuttgart's city area and Stuttgart's location within Europe

Steep hill slopes surround the city centre on three sides. The elevation ranges from 207 m above sea level by the Neckar River to 549 m on Bernhartshöhe hill. The complex terrain has a significant influence on all climatic elements like radiation, air temperature and wind, resulting in large climatic distinctions within the city area. Stuttgart's overall climate is mild with an average annual temperature of about 10 °C in the Stuttgart basin (city centre) and about 8 °C in the more elevated outskirts situated about 400 m asl. Figure 10.3 shows the annual mean temperature distribution in the city area). Besides the Upper Rhine Valley, Greater Stuttgart is one of the warmest regions in Germany. The month of July is the hottest month with an average temperature of 18.8 °C, while temperature in January averages 1.3 °C.

A major element of Stuttgart's climate is the light wind, that causes a lack of adequate air exchange. The light wind results not only of the city's position between two bights of the Keuper plains. The whole Neckar Valley is known for low wind speeds and very frequent lulls. This is the result of small air pressure differences common to Southern Germany and of Stuttgart's sheltered position between the Black Forest, the Swabian Alb, the Schurwald and the Swabian-Franconian Forest. Due to orographic conditions, it is impossible to indicate a consistent wind rose for the whole of Stuttgart. The sheltered position between the surrounding mountain

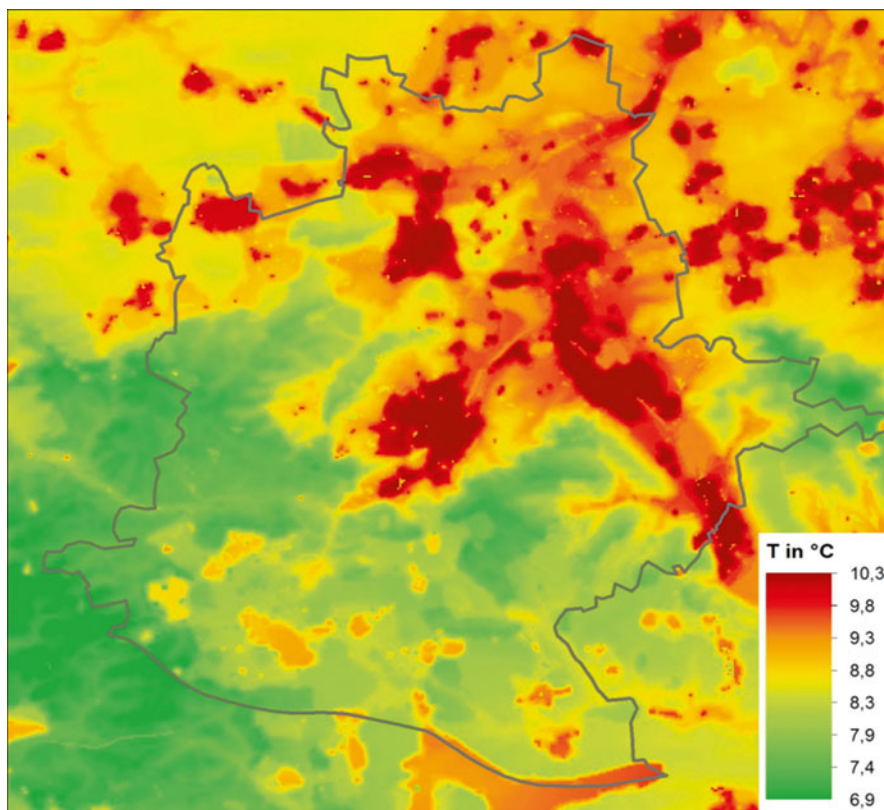


**Fig. 10.2** Land use map of Stuttgart

ranges leads to a frequent development of local wind systems, especially at the slopes and in the valleys. In addition, over large green areas in the surrounding and the city area especially at the higher altitudes, in the nighttime cold air is produced, that generates cold air streams. Even if these winds have no high wind speeds, they play a significant role for the ventilation and local fresh or cold air supply in some city districts. Preserving these local winds and streams is an important objective in the urban planning process in Stuttgart with focus on environmental and urban climate protection since decades. It becomes apparent that primarily cold air flows effectively reduce UHI caused thermal stress in nighttime.

### **10.1.2** *UHI in Stuttgart*

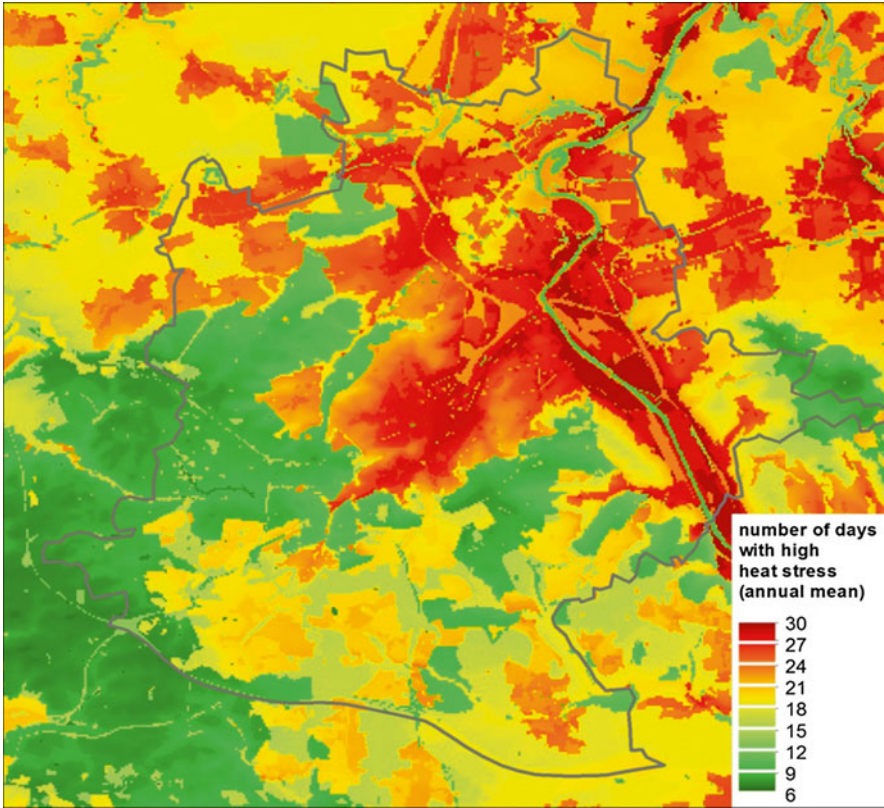
The lack of adequate air exchange in combination with high building density and a huge amount of sealed surfaces, especially in most populated and industrial city districts, facilitate the development of an intensive UHI. Quantifying the intensity of



**Fig. 10.3** Annual mean temperature in Stuttgart. The city area is marked with a *grey line*

UHI in Stuttgart is complicated, because of the differences in altitude, which influence the air temperature and overlay the temperature shift due to the UHI. However, the overall temperature raise due to the UHI phenomenon ( $\text{UHI}_{\text{Ta}}$ ) in Stuttgart is identified within several studies by 1–2 K in annual mean, but locally the  $\text{UHI}_{\text{Ta}}$  intensity can reach more than 5 K. The UHI phenomenon modifies the climate in Stuttgart. For example in the surrounding of Stuttgart, the Filder region, there are 28–32 summer days (days with more than 25 °C daily maximum temperature) as compared with 40–47 summer days in the Innercity region and the Stuttgart bight. The UHI turns Stuttgart's inner city into a region with high heat stress (about 32 days, Fig. 10.4) and only occasional cold stress.

For the longterm characterisation of UHI meteorological values such as temperature, solar radiation and humidity are measured continuously at about ten sites in the city area, operated by German Weather Service (DWD), municipality Stuttgart (MS), University Hohenheim (UnH) and the environmental protection agency of Baden-Württemberg (LUBW). In this study the UHI is analysed using air temperature and also the thermal index Physiologically Equivalent Temperature PET (Mayer



**Fig. 10.4** Annual number of days with high heat stress in Stuttgart. The city area is marked with a grey line

and Höppe 1987; Höppe 1993, 1999; Matzarakis et al. 1999) measured at the sites Schwabenzentrum (MS), Schnarrenberg (DWD), airport station Echterdingen (DWD) and at University Hohenheim (UnH). Average annual  $UHI_{Ta}$  intensity (based on air temperature) at Schwabenzentrum is 2 K and at Schnarrenberg 1.6 K. In the Neckar valley, the mean  $UHI_{Ta}$  is 0.9 K. At the suburb Hohenheim, the  $UHI_{Ta}$  of 0.3 K is not pronounced as the suburb is surrounded by agricultural areas and has a higher elevation as the rural reference station Echterdingen. The urban-rural differences in PET are higher with 4.1 K (3.1 K) between Schnarrenberg (Schwabenzentrum) and Echterdingen.

During summer, the  $UHI_{PET}$  ( $UHI_{Ta}$ ) is by 15.2% (8.1%) higher than 6 °C in the city center. However, a UHI between 0 and 6 °C is most frequent at the other measuring sites. The UHI effect is stronger and more frequent during summer than during winter, increasing the already existing heat load. The minimum  $UHI_{Ta}$  occurs in the late morning, whereupon the rural air temperature is often higher than the urban, especially during warm seasons. The  $UHI_{Ta}$  peaks at 6:00 p.m. in the winter and 9:00 p.m. during spring, summer and autumn at Schwabenzentrum. At Neckartal, the amplitude of the diurnal cycle is weaker and  $UHI_{Ta}$  is maximal in the

early morning. The monthly maximum  $\text{UHI}_{\text{Ta}}$  occurs in winter in the city center due to anthropogenic heat production. However, considering hourly averages, the maximum UHI is experienced in summer. It can be observed that air temperature differences are largest at nighttime, but the PET differences are highest at daytime. The urban heat island intensity was compared to the air pressure as well as flow patterns. The UHI is more pronounced during periods with anticyclonic weather situation (Ketterer and Matzarakis 2014a).

## 10.2 Pilot Action Study Stuttgart

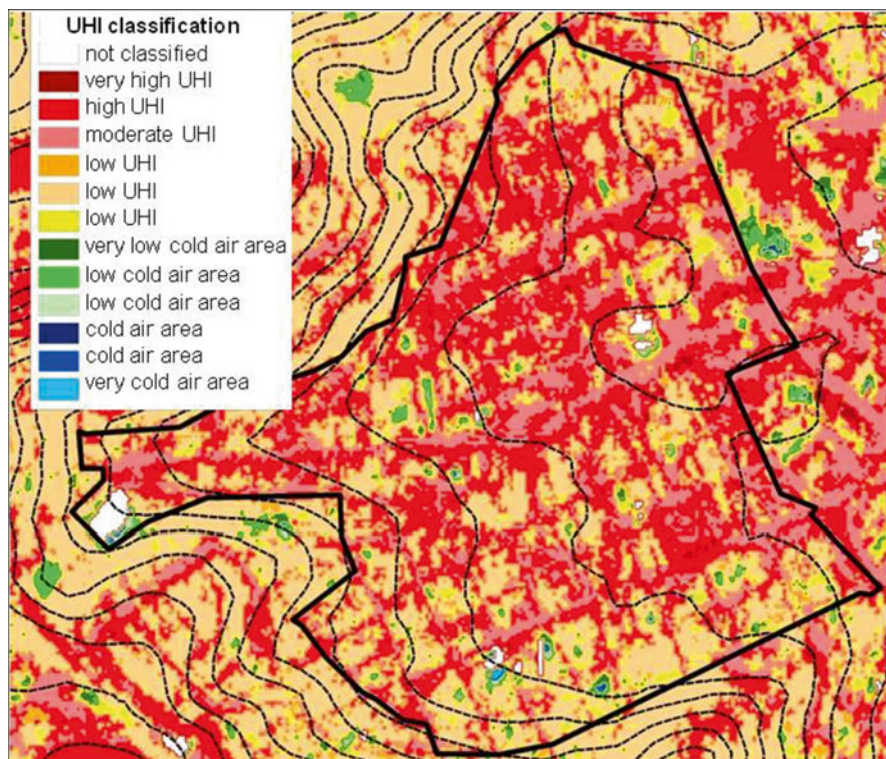
In this chapter the pilot action study in Stuttgart is presented. For the pilot action area the city district Stuttgart-West is chosen. The area was selected in view of a problematic climatic situation with high thermal stress caused by the structure of building. An important point for the selection of the area is an initiative launched by the municipal urban planners for restructuring the district in the next decades. Expected changes in urban living, the predicted increase in urban population, within the district existing brownfields and also the poor climatic situation are facts for a necessary restructuring of the district. The objective of the pilot action study is to find out realisable options for improving the local climatic situation in the district mainly due to better the air ventilation and the reduction of thermal stress. The results of these study should be integrated into a development outline plan of the district, which is under development by the municipal urban planners. In Stuttgart development outline plans are an established pathbreaking helpful urban planning tool for the sustainable future development and restructuring of single city districts weighting residential, economical, public, natural, environmental and climatical aspects. Reducing the negative impacts of the UHI on urban living will be a topic of the development outline plan. For the implementation into the development outline plan, first the UHI intensity and hotspots of high thermal stress in the district have to be known. As a second the effectivity of measures must be analysed to set up the most valuable ones. Within the pilot action study, the UHI intensity and its impacts on urban living is analysed using meteorological measurements and micro- and macro-scale simulation tools. Micro-scale simulation tools are also used to verify the local effectivity of thermal stress reducing measures. To estimate the potential of measures for a city wide reduction of the UHI intensity, macro-scale simulation tools are used.

### 10.2.1 Pilot Action Area

The pilot action area Stuttgart-West (valley floor) is located in a small valley close to the city centre in the western inner-city region (Fig. 10.5). The area is surrounded by steep hills at three sites (South, West and North). Stuttgart-West is the most densely populated district in Stuttgart and has a population of about 33,000 and a



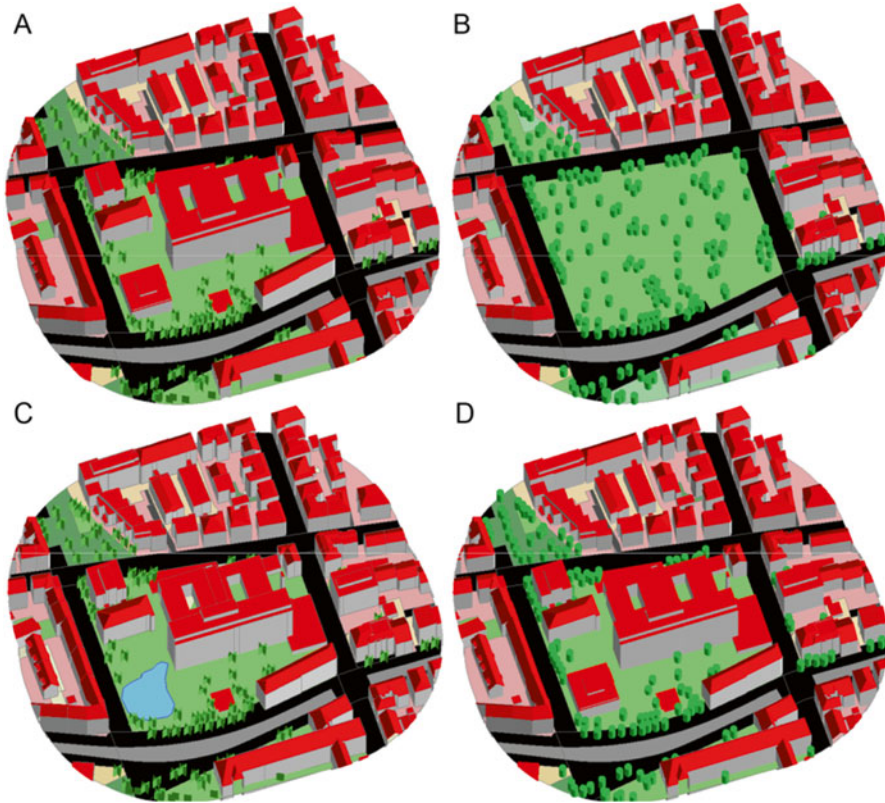




**Fig. 10.7** UHI classification in Stuttgart-West (*left*) and number of days with high thermal stress in Stuttgart-West (annual mean, *right*)

typical building structure in the district are blocks with additional buildings in the inner areas of the blocks (Fig. 10.6). These characteristics causes poor ventilation of the district and a high UHI intensity with increased thermal stress (Fig. 10.7). In addition the air pollution is on a high level. Due to these atmospheric conditions the pilot action area is less attractive for living with potential risks for human health.

The average  $\text{UHI}_{\text{Ta}}$  intensity is about 2 K, but can be many times higher on local hotspots depending on daytime and season. On hotspots an  $\text{UHI}_{\text{Ta}}$  intensity of more than 6 K is measured frequently. At the surrounding hill slopes local wind systems arise and at nighttime cold air flows are induced at the hill slopes. Because of the high building density in the valley floor, these local streams are blocked and mostly don't reach the inner district area. The pilot action area is the most thermally stressed area in Stuttgart. Based on case studies an optimized building structure for the pilot action area to reduce the thermal stress is developed.

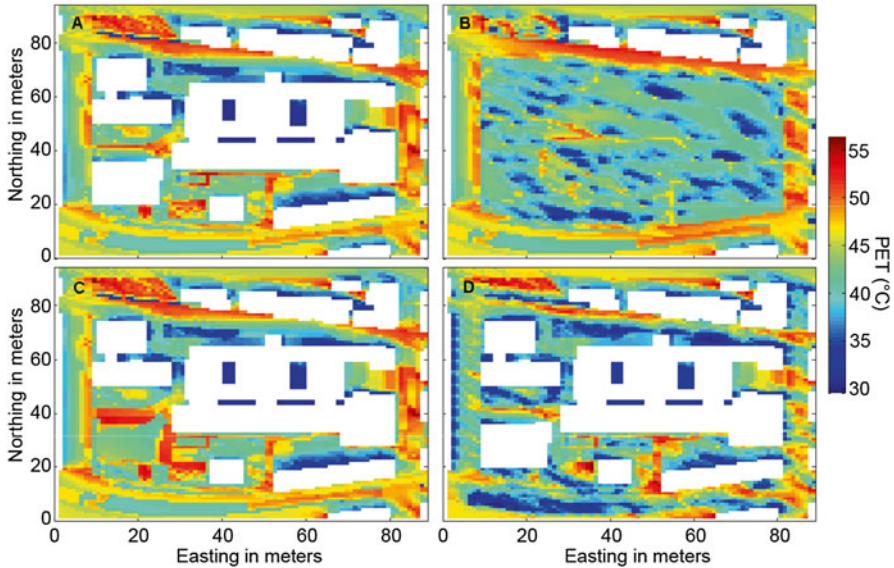


**Fig. 10.8** Different scenarios for the Olga Hospital site as input for the micro-climate simulations. *Panel A* depicts the current state of the Olga Hospital (also with green roofs for every building with flat roofs), *Panel B* the park scenario, in *Panel C* one building is replaced by a small pond (shallow water) and in *Panel D* the number of trees along the streets was increased

## 10.2.2 Case Study Olga Hospital (Stuttgart-West)

### 10.2.2.1 Quantification of Mitigation and Adaptation Possibilities

For the case study the area of the Olga Hospital in Stuttgart-West is chosen. The Olga Hospital is a hospital, that is not longer in use and should be redesigned into a residential area in the next years. The human thermal comfort conditions of the case study area and different scenarios (Figs. 10.8 and 10.9) were analyzed using micro-scale models RayMan (Matzarakis et al. 2007, 2010) and ENVI-met 3.5 (Bruse and Fleer 1998; Huttner 2012). The input parameters for the ENVI-met simulations are based on the measurements of the 24th July 2010 (wind speed  $2.6 \text{ ms}^{-1}$ , wind direction:  $250^\circ$ , no clouds, shortwave radiation adjustment factor 0.83, relative humidity and potential temperature were forced). So, these case studies are representative for hot summer days with a high amount of solar radiation. The average



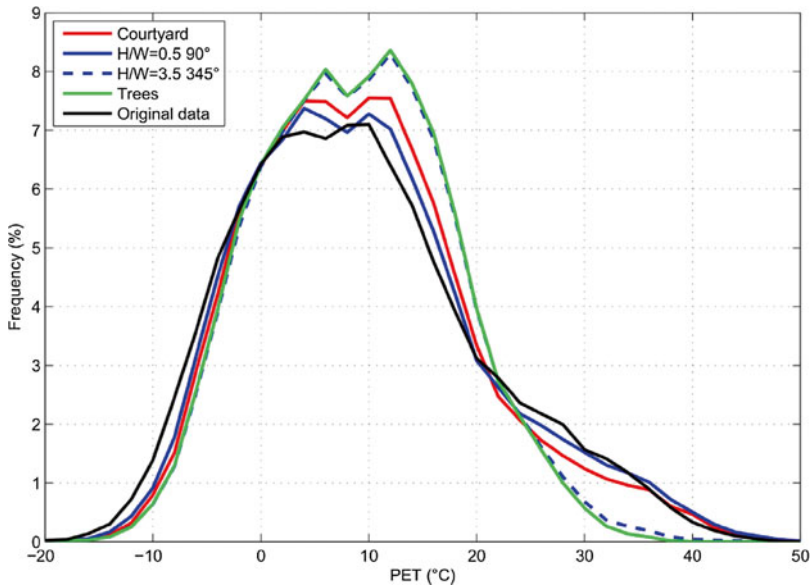
**Fig. 10.9** Physiologically Equivalent Temperature (PET) of different scenarios (see Fig. 10.8) of the Olga Hospital area. The basic meteorological variables were simulated by ENVI-met 3.5 and PET was calculated by TIC-ENVI-met (Ketterer and Matzarakis 2014b). Finally, the data were averaged from 10 a.m. to 4 p.m. for the height of 1.5 m above ground

mean radiant temperature in the whole area is 57 °C; ranging from 23.8 °C to 75.6 °C. The lowest mean radiant temperature was calculated in the shadow of trees in green areas. The mean radiant temperature is at least 3 K higher in the shadow of buildings and 45 K higher in sealed courtyards. The mean radiant temperature has the greatest influence on PET in the daytime on a sunny summer day. PET rises up to 58 °C above sealed surfaces with low albedo, high solar irradiation and low wind speed. In green areas, PET ranges between 18 and 28 °C in shaded, but does not exceed 35 °C in unshaded areas. Streets which are parallel to the wind direction (e. g. Bebel and Bismarck Street), featured lower PET ( $\Delta\text{PET} \leq 10$  K) than other streets (Senefelder Street). The difference in PET between sealed and non-sealed areas is at least 10 K (Ketterer et al. 2013).

## 10.2.2.2 Micro-scale Simulations

### 10.2.2.2.1 Surface Types

Thermal conditions over green areas, paved and water surfaces are quantified using ENVI-met simulations. PET rises up to 58 °C above paved, unshaded surfaces with low albedo. Above green areas, PET does not exceed 35 °C in unshaded areas and 25 °C in shaded areas. The difference between paved and green areas is at least



**Fig. 10.10** Frequency distribution of the Physiologically Equivalent Temperature (PET) for following different urban morphology: courtyards, street canyon with aspect (H/W) ratio of 0.5 and 3.5 and rotation of 90° (E–W) and 345° (NNE–SSW), under a group of trees and the original data of the measuring station Schwabenzentrum (city center) for the period 2000–2010

10 K. Considering the assessment scale of Matzarakis and Mayer (1996), the thermal stress can be reduced from strong heat stress above paved surfaces to light heat stress above green surfaces (Fig. 10.9).

The installation of a small pond has no significant impact on the spatial average of the studied Olga Hospital area, but a local impact on the air temperature. Air temperature is decreased due to the smaller Bowen ratio and enhanced latent heat flux. Additionally, water has a very high specific heat capacity. However, small and shallow water surfaces heat up relatively fast, so that they can have a warming effect during evenings and nights in mid-summer as well as in early autumn.

ENVI-met simulations of the current scenario with the Olga Hospital and for a scenario with a park were done for a calm, hot summer day and compared for 14 LST. The specially averaged PET value decreases by 2.6 K in the park scenario. The wind speed increases due to lower roughness in the lee (east) side of the park and decreases PET, too. The PET value was decreased by maximum 7.0 K and on average by 1.7 K in the street east of the park. On the streets in the north and south of the park, PET is 0.4 and 0.8 K lower than in the current state. A park with a continuous green area is 1–20 K PET colder than green areas on the built-up area. The more trees in a park, the cooler PET on a hot summer day and the smaller the diurnal amplitude of the temperature. However, the air temperature differences between different scenarios are below 2 °C (Ketterer et al. 2013; Ketterer and Matzarakis 2014b).

#### 10.2.2.2.2 Trees

PET in 1.5 m height was found to be around 10 K lower under trees compared to green areas and 25 K lower than over asphalt (Fig. 10.9). Therefore, shading by trees could reduce the frequency of daytime heat stress significantly (Fig. 10.10).

The increasing number of trees in the Olga Hospital area has no significant impact on the averaged air temperature during moderate warm conditions. However, during hot summer days it could reduce the air temperature in this area by 3.0 K (spatial average).

#### 10.2.2.2.3 Green Roofs

The effect of green roofs was quantified using ENVI-met and by changing all roofs of the hospital scenario into green roofs. The effect of green roofs on the local thermal conditions experienced by humans on street level are on a very low level ( $\Delta\text{PET} < 0.06$  K). The local air temperature differences on street level are even lower. However, green roofs significantly reduce the warming of urban roof surfaces in daytime. Inside green roofs the accumulation of heat is decreased, resulting in a lesser heat emission in nighttime. A large-scale revegetate of roofs is an effectively measure for the mitigation of UHI intensity especially in nighttime.

#### 10.2.2.2.4 Urban Morphology

The urban morphology is analyzed using RayMan Pro (Matzarakis et al. 2007, 2010). The morphology of street canyons influences solar access and radiation and therefore thermal comfort. The importance of solar access for city dwellers depends on the climate zone. While south of the Alps sun is considered as harmful, solar access is favored in northern cities such as Stuttgart. East-west oriented street canyons do not have solar access during winter months due to the low zenith angle of the sun. But during summer, the street canyon and especially the northern façade is illuminated during the whole day. Accordingly high is the frequency of heat stress in this E-W oriented street canyon. A N-S oriented street canyon is accessed by sunshine during the midday hours throughout the year (Ketterer and Matzarakis 2014b).

The daily maximum value of PET could be reduced by 10 K due to a changing H/W ratio from 0.5 to 3.5 and an orientation of  $120^\circ$  on a hot summer day. Throughout the year, the frequency of heat stress can be reduced by 477 h (4.3%). Additionally, the occurrence of thermal comfort conditions could be increased by 10%. However, a change in H/W ratio from 0.5 to 1 (2.5) could already reduce the frequency of heat stress by 192 (333) hours per year (Fig. 10.10).

#### 10.2.2.2.5 Courtyards

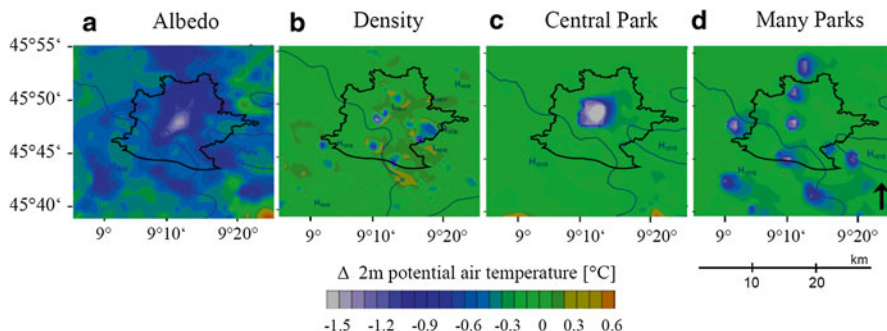
The micro-climate of courtyards was studied using the micro-climatic models RayMan and ENVI-met. The human thermal comfort conditions in two courtyards (Schlossstrasse and Senefelderstrasse) in the Olga Hospital area were compared to the conditions in street canyons (Breitscheidstrasse, Senefelderstrasse) and on a green area (Elisabethenstrasse – Hasenberstraße) over 11 years. Therefore, the micro-scale RayMan model employing fish-eye photos was used to describe long term conditions. In the courtyards, the frequency of heat stress ( $PET > 29.1$  °C) and thermal comfort is between 45.5 % and 51.6 % from May to September. Whereas the frequency of thermal comfort is between 3.6 % and 13.8 % higher in east-west and NNW – SSE oriented street canyons. Additionally, PET is also higher at night-time than during daytime due to the smaller sky view factor in courtyards. Multiple reflections can also increase PET in courtyards. Another factor is the low wind speed in these sheltered locations, triggering a further increase in PET. ENVI-met simulations for a hot summer day show that PET is up to 25 K higher over a paved courtyard compared to a park area covered with plants and grass.

### 10.2.3 Macro-scale Simulations

Specific urban planning strategies, like green roofs or facades and highly reflective materials are able to reduce the UHI. Taha (1997) demonstrated that increasing the albedo by 0.15 can reduce peak summertime temperatures for the urban area of Los Angeles by up to 1.5 °C. During the DESIREX Campaign 2008, Salamanca et al. (2012) stated that a higher albedo leads to about 5 % reduction in energy consumption through air conditioning during summertime periods for the area of Madrid. The regional energy saving effect of high-albedo roofs can also be found in Akbari et al. (1997) and on a more global perspective in Akbari et al. (2009).

In the course of the project UHI – Development and application of mitigation and adaptation strategies and measures for counteracting the global “UHI phenomenon” (3CE292P3) – CENTRAL Europe. (2011–2014), these kinds of scenarios are conducted for the urban area of Stuttgart. Due to its geographical location in a valley, the weak mountain – valley circulation leads to increasing potential for natural heat trapping in the urban region. Modelling work of the environmental agency of Stuttgart shows, that the area with more than 30 days/year heat stress is anticipated to increase from 6 % (1971–2000) up to 57 % (2071–2100). This reflects the calculations of the Intergovernmental Panel on Climate Change (IPCC) on global climate change.

The Karlsruhe Institute of Technology (KIT) conducts simulations using the numerical mesoscale Weather Research and Forecasting Model WRF Skamarock et al. (2005) on regional scale, coupled to urban parameterization schemes (Kusaka et al. 2001; Martilli et al. 2002). The results reflect the effects of certain urban planning strategies on near surface air temperature and on UHI intensity.



**Fig. 10.11** Difference in potential 2 m air temperature for the four scenarios: (a) changed albedo for roofs and walls, (b) modified proportion street width/building height and the two urban greening scenarios with one big park (c) and a number of smaller parks (d); projected time is August 13 2003 8:00 p.m

**Table 10.1** Impact on UHI formation expressed as the difference between mean urban and mean rural temperature, August 13 2003 8 p.m

Scenario	Control	Albedo	Many parks	Big park	Density	delta [°C]			
						Albedo	Many parks	Big park	Density
T mean urban [°C]	33.1	31.5	32.5	32.3	32.4	-1.60	-0.60	-0.80	-0.70
T max [°C]	34.3	31.9	33.5	33.3	33	-2.40	-0.80	-1.00	-1.30
<b>UHI; delta <math>\Theta</math></b>	<b>2.52</b>	<b>0.84</b>	<b>1.47</b>	<b>1.19</b>	<b>1.32</b>	<b>-1.68</b>	<b>-1.05</b>	<b>-1.33</b>	<b>-1.2</b>

The control run indicates ‘real’ conditions

Four case studies were applied representing different mitigation measures.

1. Increase of the reflectivity of roof and wall surfaces in the urban area (‘Albedo’)
2. Decreasing the building density by 20% by increasing the Sky View Factor (‘Density’)
3. Replacing urban surface by natural vegetation in the city center (‘Central Park’)
4. Replacement of single urban areas scattered around the city area (‘Many Parks’)

The difference in 2 m temperature between scenario- and base case (‘reality’) run reflects the efficiency of the mitigation procedure (Fig. 10.11). To refer to an extreme case scenario, a period during the European Heat Wave 2003 (August 11th–18th 2003) was chosen, where summertime temperatures exceeded the annual average.

Table 10.1 presents the mean and maximum urban temperature as well as the UHI, calculated from mean urban and mean rural temperature with regard to Aug 13 2003 8:00 p.m. The difference between Control run and Scenario is calculated for both temperature and UHI.

Referring to Table 10.1, a changing of the albedo of wall and roof surfaces has the strongest effect on temperature, causing a decrease of the UHI intensity by nearly 2 °C.

Both vegetation scenarios show a decrease of about 1–1.3 °C. With 1.2 temperature reduction, the effect is similar for the ‘Density’ case.

Because of insufficient observation data in the rural surrounding, it is difficult to retrieve the UHI intensity from measurements. The difference between air temperatures observed at ‘Stuttgart Schwabenzentrum’ (37.4 °C) and at Stuttgart Hohenheim in the near surrounding (33.1 °C) accounts for 4.3 °C, for August 13 18:00 UTC. Assuming a height dependent temperature decrease of 1 °C per 100 m between urban (250 m NN) and rural (400 m NN) location, the adapted observed UHI amounts to 3 °C. The second parameter in Table 10.1 describes the mean temperature for the whole modelling period for one single urban grid cell in the centre of the city, whereas all other parameters treat aerial statistics for one temporal snap-shot.

The above findings describe the climatological and meteorological background for the forthcoming mitigation and adaptation actions to reduce the urban heat islands and its impacts. Besides the modeling results it is now of great importance to find the best urban planning strategy for the specific urban area of interest, considering a mixture of different mitigation strategies. However, due to the coarse resolution it is difficult to directly apply the measures proposed by that study. Rather, these kinds of modelling studies can be used as a decision support and provide meteorological boundary conditions for high resolution street scale models.

### **10.3 Transferring the Findings of the Pilot Action Study to Urban Planning Process in Stuttgart**

The findings of the studies within the pilot action Stuttgart, have shown, that several measure can be effectively reduce the UHI intensity and the impacts on urban living and human health. However, reducing UHI intensity in a city, which is growing over the centuries, requires deep changes in the city and building structure. Changing a city to improve the urban climate is a hard and challenging transaction, which needs a sustainable future-oriented urban planning. Most of the measures for reducing UHI in a city are only effective by large-scale implementation, but changing a city due to urban planning are mostly concentrated on single buildings or small areas like existing brownfields. Additional difficulties are a low awareness for the problems caused by UHI by the public and political boards, existing national and international strategies for the future development of urban areas, which potential forces the UHI intensity (for example the European sustainable development strategy, which supports the development of more compact and more densed cities), a low number of free available areas to set up measures like parks, contrary interests of public, industry and economy and the ownership structure. Also, in Germany a legal basis for the consideration of UHI related aspects in the urban planning process is currently not available.



### ***10.3.1 Legal Basis for the Consideration of UHI Related Aspects Within the Urban Planning***

To date in Germany no independent “Urban Climate Protection Act” exists in its own right. Also planning measures for Urban Heat Island specific requirements are not directly regulated. Instead, these concerns have been integrated into the structure of existing environmental legislation. This is due to the circumstance that many of the classical disciplines of environmental protection or rather ecology simultaneously exercises positive repercussions for climate change and that a firm foothold can be provided for climate protection within the framework of existing legislation. Examples of this include the Federal Building Code (BauGB), the Federal Nature Conservation Act (BNatSchG) and a variety of regulations issued by the Federal Immission Control Act (BImSchG). Also rulings given by a series of laws and regulations such as the Energy Saving Act (EEG) and the Energy Saving Ordinance make a specific contribution to global climate protection, as well as the “Greenhouse Gas Emissions Trading Act” (TEHG).

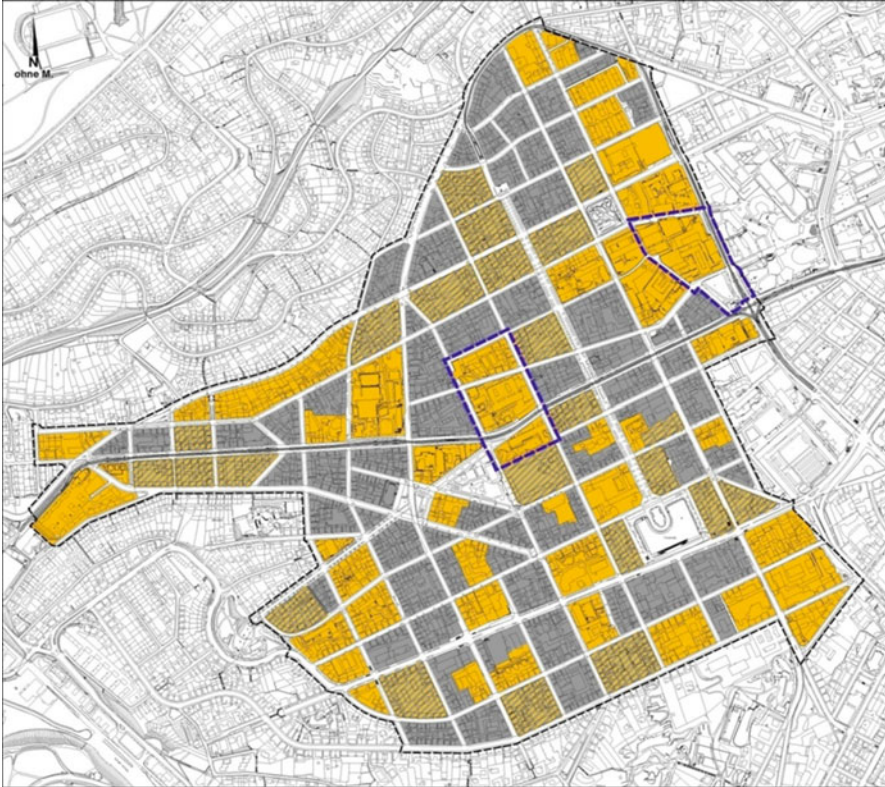
The German Building Code is the most powerful act in Germany for the municipal administration to arrange measures for urban planning in respect to environmental, nature, urban and global climate protection. The code offers differentiated possibilities for urban development that is urban and global climatically just.

### ***10.3.2 Development Outline Plan***

The development outline plan (DOP) constitutes a non-formalized level of spatial planning. It is not codified by the Federal Building Code and non-obligatory. In practice, however, the DOP proved to be a valuable and flexible tool to steer urban development within built up areas. It is an essential function of the DOP to define the municipality’s development and planning goals for those parts of the city that show tendencies of urban change. In practice, the planning intentions for public spaces and streets can be described more precisely than those for private building sites. This is why the DOP often also functions similarly to a local design plan. The DOP is not subject to legal regulations.

In Stuttgart development outline plans are used to set up the urban planning strategy for the sustainable future development and restructuring of single city districts weighting all aspects of urban living, economy and nature, environment and climate protection.

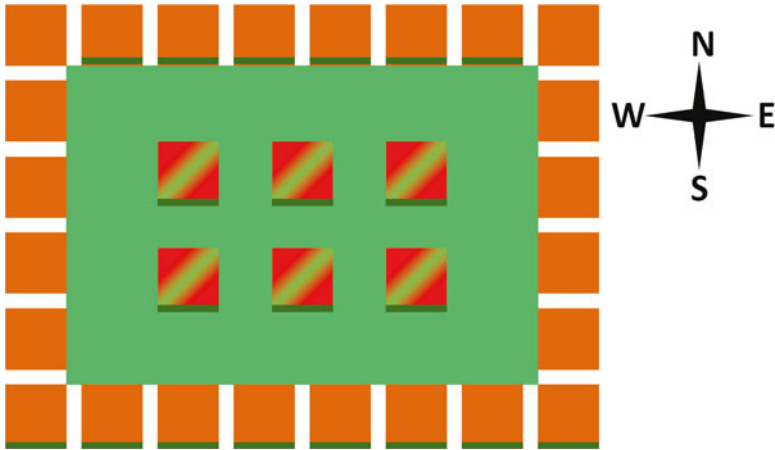
For the pilot action area Stuttgart-West a development outline plan is under progress by the municipal urban planning department. Within the development outline plan Stuttgart-West the strategy for the future development of the city district is ascertained. One aspect of this strategy is to improve the climatic situation and to reduce the negative impacts of the UHI inside the district. Based on the analysis simulation results, done within the pilot action study, hotspots of high thermal



**Fig. 10.12** Map based on the analysis of areas with high thermal stress. The *grey shaded blocks* are characterised by high thermal stress mainly due to a prevented ventilation of the inner area and due to high building density and unavailable greening. The *grey blocks* should be redesigned according the development outline plan. The purple surrounded blocks are currently under reconstruction

stressed areas in the district are identified. Also effective and realisable measure for reducing the thermal stress on the hotspots are chosen for the implementation into the development strategy and the development outline plan for the district.

Hotspots, which are high thermal stressed are located mostly in the inner region of the district (Fig. 10.12). These areas are characterised by a high building density with additional buildings inside the blocks, a high degree of sealing and a lack of greening. The high building density prevents a ventilation of the block inner area, which forces the accumulation of heat. For these blocks an optimised building structure (Fig. 10.13) for the potential reconstruction is developed based on the micro-scale simulation done in the pilot action study (Olga Hospital, see Chap. 2.2). These optimised building structure supports a better ventilation of the block and the thermal stress is reduced compared to the existing building structure due the greening of the block in form of greened courtyards, green roofs and green facades or the use of cool materials for roofs and facades. However, the optimised building structure is



**Fig. 10.13** Optimised building structure, which is offered to reduce the thermal stress inside the block. These building structure is part of the development outline plan is not obligatory for potential reconstruction of existing blocks, but gives a reference to improve the local climatic situation. Gaps between the buildings facilitate the ventilation of the inner area. The courtyard of the block (*green marked area*) is greened. Buildings inside the blocks (*red-green marked*) must be equipped with green roofs and the height of these buildings is limited. Buildings around the block (*orange marked*) should be equipped with green roofs, but it is not compulsory. Facades which are orientated to the south (*dark green marked*) have to be greened or designed with cool materials



**Fig. 10.14** Optimised design of street canyons in Stuttgart-West. *Green lines* marking street canyons, where the thermal stress is reduced due to facade greening of the use of cool materials for facades. *Green circles* marking possible positions for trees

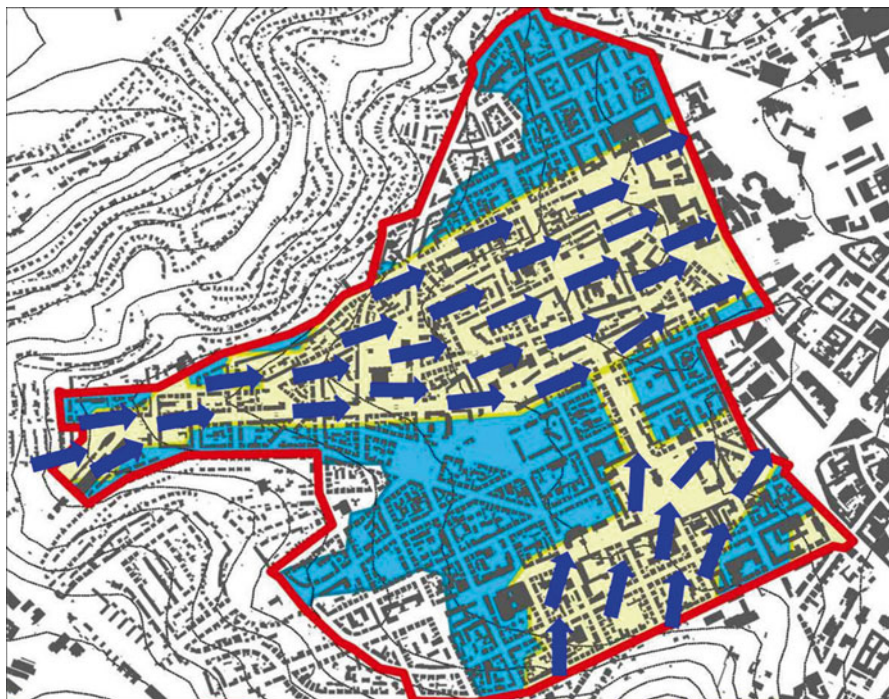


**Fig. 10.15** Possible creation of green connections (*green lines*) in Stuttgart-West

not obligatory for the redevelopment of a block, but gives a reference to improve the climatic situation. If the suggested building structure is absolutely the optimum has to be checked from case to case under consideration of the ambient conditions. But setting up green roofs on new buildings can only be prevented for a comprehensible reason. Green roofs on new buildings are a standard in Stuttgart.

Beside the optimised building structure also suggestions for the design of public spaces are offered (Figs. 10.14 and 10.15). The design of public spaces to reduce the thermal stress is relatively easy realisable, there no ownership structure must be respected. The measures offered for the design of public spaces mainly strive the improvement of the sojourn quality, due the reduction of thermal stress in street canyons, squares and parks. To reduce the thermal stress in street canyons, especially possible tree positions inside street canyons, which are orientated from east to west are identified and implemented into the development outline plan. Also for building facades along east to west orientated street canyons a design with cool materials and/or a facade greening is offered. The greening of existing brownfields mainly due to parks are also part of the development strategy of the district. The creation of connections between existing green areas (Fig. 10.14) are an utmost concern, which is considered within the strategy for the improvement of the climatic situation inside the district.

Also the ventilation of the district due to local wind systems and cold air streams is analysed (Fig. 10.16). To improve the ventilation of the district, reducing the



**Fig. 10.16** Major cold air streams in Stuttgart-West. The *yellow shaded areas* mark areas with restriction to buildings to reduce the obstruction of existing streams

obstruction of existing streams, due to the enlargement of the major stream axes (mostly street canyons) is implemented into to development outline plan for Stuttgart-West. For the enlargement of the stream axes in the concerned areas, a maximum building high, an optimal building axes orientation and the reinstatement of buildings are offered.

#### 10.4 Stuttgart’s Heat Warning System HITWIS

The increase in the number of days exposed to high temperatures and high humidity will result in heat stress for the population. This can pose a danger, particularly for the elderly and those in poor health. In the summer of 2003, the extreme conditions accounted for an estimated 2000 additional deaths. So it is necessary to inform and to warn respectively. Additionally a customized behaviour must be advised different target groups.

To improve the more or less existing heat warning system in Stuttgart HITWIS was constituted a working group “Heat waves/heat stress” including some parts of

the municipality (health care, urban climate, social welfare office etc.). This working group is well connected to external institutions like ambulance services, housing societies, social services etc..

The following measures are recommended and have been partly realised:

- Supply of a leaflet including recommendations for a more adapted behaviour in a heat case.
- Development of a special heat app(lication) (f.e. inclusive a drink reminder) for mobile devices running on different platforms.
- Distribution of the web-based heatwarning of the german weather service for Stuttgart.
- Publication of special thematic website within the Internet presence of the Municipality of Stuttgart.
- Organisation and operation of a heat phone to warn and inform elder and lone people.
- Composing of a heat city map including “Cooling Zones”, water posts etc..
- Public relations in different media (sensibilisation, reminding), high visibility events with small gifts, promotional articles f.e. folding fans
- Instructions for different target groups f.e. families, sportsmanlike people etc.
- using of electronic advertising panels displaying prepared warnings and hints before and during heat waves.

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## References

- Akbari, H., Bretz, S., Kurn, D. M., & Hanford, J. (1997). Peak power and cooling energy savings of high-albedo roofs. *Energy and Buildings*, 25(2), 117–126.
- Akbari, H., Menon, S., & Rosenfeld, A. (2009). Global cooling: Increasing world-wide urban albedos to offset CO<sub>2</sub>. *Climatic Change*, 94(3–4), 275–286.
- Bruse, M., & Fleer, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model: The challenge of awareness in developing societies. *Environmental Modelling and Software*, 13, 373–384.
- Höppe, P. (1993). Heat balance modelling. *Experientia*, 49, 741–746.
- 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.
- Huttner, S. (2012). *Further development and application of the 3D microclimate simulation ENVI-met*. Johannes Gutenberg-Universität Mainz.

- Ketterer, C., Ghasemi, I., Reuter, U., Rinke, R., Kapp, R., Bertram, A., & Matzarakis, A. (2013). Veränderung des thermischen Bioklimas durch stadtplanerische Umgestaltung. *Gefahrstoffe – Reinhaltung der Luft*, 73, 323–329.
- Ketterer, C., & Matzarakis, A. (2014a). Human-biometeorological assessment of heat stress reduction by replanning measures in Stuttgart, Germany. *Landscape and Urban Planning*, 122, 78–88.
- Ketterer, C., & Matzarakis, A. (2014b). Human-biometeorological assessment of the urban heat island in a city with complex topography – The case of Stuttgart, Germany. *Urban Climate*, 10, 573–584.
- Kusaka, H., Kondo, H., Kikegawa, Y., & Kimura, F. (2001). A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and slab models. Kluwer Academic Publishers; *Boundary-Layer Meteorology*, 101(3), 329–358.
- Martilli, A., Clappier, A., & Rotach, M. (2002). An urban surface exchange parameterisation for mesoscale models. Kluwer Academic Publishers; *Boundary-Layer Meteorology*, 104(2), 261–304.
- 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.
- 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.
- Mayer, H., & Höppe, P. R. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology*, 38, 43–49.
- Reuter, U., Hoffmann, U., & Kapp, R. (2010): City of Stuttgart. (2010). *Climate change – challenge facing urban climatology*. Publication series No. 3/2010. Available online at: <http://www.stadtklima-stuttgart.de>
- Salamanca, F., Martilli, A., & Yagüe, C. (2012). A numerical study of the urban heat island over Madrid during the DESIREX (2008) campaign with WRF and an evaluation of simple mitigation strategies. *International Journal of Climatology*, 32(15), 2372–2386.
- Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D.O., Barker, D. M., Wang, W., & Powers, J. G. (2005). A description of the advanced research WRF version 2. Available online at: <http://oi.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA487419>
- Taha, H. (1997). Urban climates and heat islands: Albedo, evaporation, and anthropogenic heat. *Energy and Buildings*, 25, 99–103. Available online at: [http://www.javeriana.edu.co/arquidis/educacion\\_continua/documents/Urbanclimates.pdf](http://www.javeriana.edu.co/arquidis/educacion_continua/documents/Urbanclimates.pdf)